Appendix B

Technical Study Reports

Technical Report for the Downstream American Eel Passage Assessment

Lowell Hydroelectric Project (FERC No. 2790)

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Table of Contents

List of Tables

List of Figures

1 Introduction

A radio-telemetry assessment of the downstream passage success for adult silver-phase American eels (*Anguilla rostrata*) was conducted in support of the relicensing for the Lowell Hydroelectric Project (Lowell or Project), Federal Energy Regulatory Commission (FERC) No. 2790, as identified in the Revised Study Plan (RSP) submitted by Boott Hydropower, LLC (Boott) on January 28, 2019. The approach and methodology described in the RSP for the downstream eel passage study was approved with modifications by the FERC in its Study Plan Determination (SPD) letter dated March 13, 2019. In their SPD, FERC staff commented on several points related to the original resource agency study requests and the eel passage study proposed by Boott as part of the PSP.

- Resource agency request for a HI-Z balloon tag turbine survival assessment.
  - *FERC recommended no HI-Z balloon tag assessment be conducted during 2019. Information from the radio-telemetry and desktop analyses should provide adequate estimates of passage route survival. In the event these findings are inconclusive FERC would consider additional study requests.*
- Resource agency request for eel releases to start in mid-September.
  - *FERC recommended that Boott should initiate eel releases as early in the fall season as the commercial collection and associated bacterial and viral screening process prior to import allows.*
- Resource agency request for release of 10 dead tagged eels in conjunction with each upstream release of live tagged eels.
  - *FERC recommended Boott release two dead tagged eels in conjunction with each upstream release of live tagged eels.*
- Resource agency request for two years of radio-telemetry data collection.
  - *FERC noted there was no indication at the time of issuance for the SPD that a second study year was warranted. If the first study year failed to meet study objectives and provide the necessary information for assessing project effects then stakeholders will have an opportunity to file a request to modify the study to collect additional information.*

In accordance with 18 C.F.R. § 5.15(c), Boott filed their Initial Study Report (ISR) with FERC on February 25, 2020. As described in the ISR, data analyses were in progress and scheduled for completion during 2020. On June 12, 2020 FERC issued a Revised Process Plan and Schedule and Determination on Requests for Study Modifications for the Lowell Hydroelectric Project (Revised PPS). In accordance with the Revised PPS, Boott filed their Revised ISR with FERC on September 30, 2020, which contained a full report for the Downstream American Eel Passage

Assessment. Boott held a revised ISR meeting on October 15, 2020 and representatives from FERC, U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Massachusetts Division of Fisheries and Wildlife (MADFW), Massachusetts Division of Marine Fisheries (MDMF), and the New Hampshire Fish and Game Department (NHFGD) had the opportunity to provide comments. Subsequent to the September 30, 2020 ISR meeting, the MADFW (November 25, 2020), NMFS (November 30, 2020), and MDMF (November 30, 2020) submitted written comments on the ISR to FERC. A summary of comments received and the corresponding responses is provided in Appendix E of this report. Where noted, the body of the report has been updated to reflect the content of those comments.

This final technical report provides a description of the objectives, methodologies and results of the 2019 radio-telemetry assessment to evaluate the downstream passage of adult silver eels at the Lowell Project. In addition to the radio-tagged silver-phase eels marked as part of this evaluation, an additional eel passage study was conducted outside of the Licensing efforts for Lowell to assess downstream movement at the Merrimack River Project (FERC No. 1893). Adult eels tagged as part of the upstream project were also monitored as they moved through the Lowell Project area. Findings for those individuals have been included in this report.

2 Objectives

The goal of this study was to determine the Lowell Project's impact on the outmigration of adult silver-phase American eels.

Specific objectives included:

- Quantification of the movement rates and relative proportion of eels passing via various routes at the project (i.e., turbines, downstream bypass, and spill); and
- Evaluation of mortality of eels passed via each potential route.

3 Project Description and Study Area

The Lowell Project is located at River Mile (RM) 41 on the Merrimack River in the City of Lowell in Middlesex County, Massachusetts, with an impoundment extending approximately 23 miles upstream into Hillsborough County, New Hampshire. The existing Lowell Project consists of: (1) a 1,093-foot-long, 15-foot-high masonry gravity dam (Pawtucket dam) that includes a 982.5-foot-long spillway with a crest elevation of 87.2 feet National Geodetic Vertical Datum 1929 (NGVD 29) topped by 5-foot-high pneumatically-operated crest gates deployed in five independently-operable zones; (2) a 720-acre impoundment with a normal maximum water surface elevation of 92.2 feet NGVD 29; (3) a 5.5-mile-long canal system which includes several small dams and gatehouses; (4) a powerhouse (E.L. Field) which uses water from the Northern Canal and contains two turbine-generator units with a total installed capacity of 15.0 megawatts (MW); (5) a 440-foot-long tailrace channel; (6) four powerhouses (Assets, Bridge Street, Hamilton, and John Street) housed in nineteenth century mill buildings along the Northern and Pawtucket Canal System containing 15 turbine-generator units with a total installed capacity of approximately 5.1 MW; (7) a 4.5-mile long, 13.8-kilovolt transmission line connecting the powerhouses to the regional distribution grid; (8) upstream and downstream fish passage facilities including a fish elevator and downstream fish bypass at the E.L. Field powerhouse, and a vertical-slot fish ladder at the Pawtucket dam; and (9) appurtenant facilities. At the normal pond elevation of 92.2 feet NGVD 1929 (crest of the pneumatic flashboards), the surface area of the impoundment encompasses an area of approximately 720 acres. The gross storage capacity between the normal surface elevation of 92.2 feet and the minimum pond level of 87.2 feet is approximately 3,600 acre-feet. The Project operates essentially in a run-of-river (ROR) mode using automatic pond level control, and has no usable storage capacity.

The study area for the downstream eel passage assessment included the mainstem Merrimack River from the upper extent of the Project's impoundment located approximately 23 river miles upstream from the Pawtucket Dam in Litchfield, New Hampshire, to the Lawrence Hydroelectric Project (FERC No. 2800), located approximately 11 river miles downstream of the Pawtucket Dam (Figure 3-1). The Upper Pawtucket Canal and Guard Locks facility were also considered as part of the study area.

Figure 3–1. Merrimack River study reach considered during the fall 2019 adult silver-phase American eel downstream passage assessment.

4 Methods

Downstream passage of adult American eels through the Lowell Project reach was evaluated via radio-telemetry during the fall of 2019. Following the release of radio-tagged individuals into the Merrimack River upstream of the Lowell impoundment, their movements were monitored using a series of stationary radio-telemetry receivers in place at the Project as well as at several additional stationary monitoring stations installed at bank-side locations upstream and downstream of the Project to inform on general movements, distribution among available passage routes and Project passage success.

4.1 Radio Telemetry Equipment

Movements of radio-tagged individuals during the 2019 study were recorded via a series of stationary radio-telemetry receivers. Radio-telemetry equipment used during the evaluation of downstream passage at Lowell included Orion receivers, manufactured by Sigma Eight, as well as SRX receivers manufactured by Lotek Wireless. Each receiver was paired with either an aerial or underwater antenna (dropper antenna). Aerial antennas (four or six element Yagi) were utilized to detect radio-tagged individuals within the larger, more open sections of river, such as within the tailrace or at locations downriver of Lowell. Dropper antennas were fixed at downstream passage locations (e.g., downstream bypass). Dropper antennas were custom built by stripping the shielded ends of RG-58 coaxial cables.

All eels radio-tagged during 2019 were equipped with a Sigma Eight TX-PSC-I-450 radio transmitter (149.320, 149.340 or 149.360 MHz, pulse rate = 2.0 seconds). The TX-PSC-I-450 transmitters measured approximately 12 x 12 x 46 mm, weighed 8.5 g and had an estimated battery life of 357 days when set at a 2.0 second burst rate. Each transmitter was coded to emit a unique identifying signal so that individual eels could be identified by a receiver.

4.2 Monitoring Stations

The RSP identified a total of twelve monitoring stations to be set up at Lowell for the downstream eel passage assessment. Each of the twelve monitoring locations identified in the RSP were installed as described and each location consisted of a data-logging receiver, antenna, power source, and were configured to receive transmitter signals from a designated area continuously throughout the study period. During installation of each station, range testing was conducted to configure the antennas and receivers in a manner which maximized detection efficiencies at each location. The operation of the radio telemetry receivers was initially established during installation, then confirmed throughout the study period by using beacon tags. A number of beacon tags were stationed at strategic locations within the detection range of either multiple or single antennas, and they emitted signals at programmed time intervals. These signals were detected and logged by the receivers and used to record the functionality of the system throughout the study period.

The locations of monitoring stations installed for the 2019 Lowell eel passage study are outlined here and presented in Figures 4-1 through 4-3.

Monitoring Station 19: This station was installed at the upper end of the Project impoundment and detected eels following their initial movement downstream from the release location and upon entry into the project area. Station 19 consisted of a single Lotek SRX receiver and aerial antenna oriented perpendicular to the river channel.

Monitoring Station 21: This station consisted of a single Lotek SRX radio-receiver and an aerial antenna and was installed and calibrated in a manner to provide detection information for radio-tagged eels as they approached the upstream face of Pawtucket Dam. Detections at this location were used to inform on arrival of eels immediately upstream of the project.

Monitoring Station 25: Station 25 consisted of a single Orion radio-receiver and aerial antenna installed and calibrated to provide coverage of the upstream side of the Pawtucket Gatehouse. This station informed on radio-tagged eels which had approached the upstream side of the Pawtucket Gatehouse.

Monitoring Station 27: Station 27 consisted of a single Lotek radio-receiver and aerial antenna installed and calibrated to provide coverage of the downstream side of the Pawtucket Gatehouse. This station informed on radio-tagged eels which had successfully passed through the Pawtucket Gatehouse and entered the Northern Canal.

Monitoring Station 29: Station 29 consisted of a single Lotek SRX radio-receiver and aerial antenna installed and calibrated to provide detection information for radio-tagged eels that passed through the Pawtucket Gatehouse, entered the E.L. Field Powerhouse forebay (i.e., the Northern Canal) and were in the vicinity of the entrance to the downstream bypass and intake racks.

Monitoring Station 31: This station consisted of a single Orion radio-receiver and underwater drop antenna installed and calibrated to provide detection information for radio-tagged eels exiting the forebay via the downstream bypass.

Monitoring Station 33: Station 33 consisted of a single Lotek SRX radio-receiver and aerial antenna installed to monitor across the bypassed reach at a point downstream of where the surge gate enters from the power canal and upstream of the downstream bypass discharge. Detections at this location were used to confirm the downstream passage of individuals using the spillway or surge gate.

Monitoring Station 35: This station consisted of a single Lotek SRX radio-receiver and aerial antenna installed at a location overlooking the E.L. Field Powerhouse tailrace. Detections at this location were used to confirm downstream passage of individuals via the Project turbine units.

Monitoring Station 37: This station was installed at a point along the mainstem of the Merrimack River downstream of both the E.L. Field Powerhouse tailrace and the confluence with the Concord River. Station 37 consisted of a single Lotek SRX receiver and aerial antenna oriented perpendicular to the river channel. Station 37 was installed at the Lowell Waste Water Treatment Plant, approximately 2.1 miles downstream of the tailrace.

Monitoring Station 39: Station 39 was installed at a commercial business near the midpoint between the Lowell and Lawrence projects and consisted of a single Lotek SRX receiver and aerial antenna oriented perpendicular to the river channel. Station 39 was located approximately 6.0 miles downstream of the tailrace.

Monitoring Station 40: This station consisted of a single Lotek SRX radio-receiver and an aerial antenna and was installed and calibrated in a manner to provide detection information for radio-tagged eels as they approached the upstream face of Essex Dam (approximately 10.75 miles downstream of the Lowell tailrace).

Monitoring Station 23: This station was installed to detect eels which entered the downtown canal system via the Pawtucket Canal rather than pass the Project via one of the mainstem passage routes. The entrance to the Pawtucket Canal sits at a point upstream of the Pawtucket Dam and the Northern Canal. Station 23 was installed at the Guard Locks, approximately 1,700 feet downstream from the entrance to the canal. The monitoring zone for Station 23 was directed downstream to ensure detections recorded at that location were of individuals which had definitively entered the downtown canal system.

4.3 Tagging and Release Procedures

Silver-phase American eels were purchased from a commercial eel trapper operating on the St. Croix River in Maine. Eels were transported by truck from the St. Croix area to holding tanks installed at Garvins Falls Dam (Merrimack River Project, Bow, NH) on October 3, 2019. The total number of eels available for purchase from the St. Croix River was slightly less than the number required to achieve the study sample size described in the FERC-approved RSP. An additional twelve silver eels were provided by the New Hampshire Fish and Game Department (NHFGD) following their collection in a sampling weir being operated on the Soucook River. NHFGD staff maintained Soucook River eels at the Nashua Fish Hatchery until Normandeau staff transported them to the holding tanks at Garvins Falls on October 21.

All eels were held for a minimum of 24 hours prior to tagging. Individuals were visually examined and if they appeared healthy were anesthetized in a clove oil and ethanol solution (Figure 4-4). Eels were held and visually monitored in the anesthesia bath for approximately 10–15 min prior to tagging. Once sedated, eels were removed from the bath and placed on a clean, wet towel. The total length (TL) and eye diameter (horizontal and vertical; nearest 0.1 mm) were measured. Although the capture method virtually guarantees sample specimens are migratory, a previously described correlation between eye size, body length and gonad development was used to confirm whether individuals were mature and likely to be active outmigrants (Pankhurst 1982). This eye index relationship (I) was described using the formula:

$$I = [(A+B/4)2\pi/L]*100$$

where A = horizontal eye diameter, B = vertical eye diameter, and L = total body length. Silver-phase American eels typically have an eye index between 6.0 and 13.5, with a bronze coloration along the lateral line that separates the dark, silver back from the white belly. Eels meeting these characteristics were selected for surgical tagging. In short, an incision was made off center on the ventral surface of the individual and of an adequate length to insert the transmitter into the body cavity. A hollow needle was inserted into the incision and was pushed through the body wall just off of the ventral mid-line and at a point posterior to the incision. The antenna was fed through the needle and gently pulled so that the transmitter entered the body cavity. The needle was then fully pulled through the body wall and removed from the antenna. The transmitter was positioned by pulling the antenna so that it lay directly under the incision. The incision was closed with two or three interrupted sutures (chromic gut with a 4-0 cutting needle) evenly spaced across the incision. A small amount of an antibacterial ointment was applied to the incision site to prevent infection.

Following tagging, each individual was transferred to an acclimation tank supplied with ambient river water for an additional 24-h observation period to allow eels to recover from surgery. Following the recovery period, eels were assessed for normal behavior prior to release and were then trucked to the car-top boat launch located adjacent to the Northeast Delta Dental Stadium in Manchester, NH and upstream of the Lowell Project impoundment[1]. Radio-tagged individuals were carefully netted from the truck tank and were released from the shoreline. A total of five separate release groups, each comprising 20 radio-tagged eels were released during the 2019 study. The date and time of each release was recorded.

4.4 Data Collection

4.4.1 Stationary Telemetry Data

Receiver downloads occurred three to four times weekly during the period from the initial tag and release event until the end of November, 2019. Backup copies of all telemetry data were made prior to receiver initialization. Field tests at the time of download to ensure data integrity and receiver performance included confirmation of file integrity, confirmation that the last record was consistent with the downloaded data (beacon tags were critical to this step), and lastly, confirmation that the receiver was operational upon restart and actively collecting data post download. Within a data file, transmitter detections were stored as a single event (i.e., single data line). Each event included the date and time of detection, frequency, ID code, and signal strength.

4.4.2 Manual Telemetry Data

To provide supplemental detection information to the stationary receiver data set, manual tracking was conducted on a number of occasions from the time of initial release through the end of November, 2019. Manual effort was exerted in the vicinity of the Lowell Project (i.e., tailrace and headpond immediately upstream of Pawtucket Dam) on most dates when stationary telemetry equipment was checked. In addition, a number of boat or truck-based

[1] Normandeau Associates simultaneously conducted an additional downstream adult eel passage study at the Merrimack River Project (FERC No. 1893) during fall 2019. A total of 60 eels were radio-tagged during that assessment and were also monitored for passage at Lowell. Results from that group of eels at Lowell and points downriver have been incorporated into this report.

efforts were conducted to look for radio-tagged eels within the Lowell impoundment and the reach of the Merrimack downstream to Lawrence.

4.4.3 Operational and Environmental Data

Merrimack River water temperature was recorded via a continuously operating logger installed within the Lowell intake canal. Hourly records for operations data were provided by Boott for the 2019 evaluation period and included:

- Headpond elevation (ft);
- Power canal elevation (ft);
- Headpond-power canal differential (ft);
- Tailrace elevation (ft);
- Head differential for E.L. Field turbines (ft);
- Total inflow (cfs);
- Unit 1 discharge (cfs) and output (KW);
- Unit 2 discharge (cfs) and output (KW);
- Downstream bypass discharge (cfs);
- Upstream fishway discharge (cfs);
- Downtown canal flow (cfs); and
- Spill flow through the bypassed reach.

4.4.4 Downstream Drift Assessment

A total of ten freshly dead adult silver-phase eels were radio-tagged and released downstream of Lowell during the 2019 study period. Two individuals were released on each date that a group of live test eels was released upstream of the Lowell impoundment. Dead, radio-tagged eels were released directly into the discharge of an active turbine unit at the E.L. Field powerhouse. The downstream progression of these known mortalities was recorded via both the stationary receivers as well as during manual tracking events.

4.5 Data Analysis

The tagging, telemetry and Project operations data sets collected as part of this effort were examined and used to evaluate a number of metrics related to downstream passage success and movement through the Project area.

4.5.1 Downstream Movement and Passage Route Selection

A complete record of all valid stationary receiver detections for each radio-tagged adult American eel was generated. The pattern and timing of detections in these individual records were reviewed, and a route of passage as well as project arrival and passage times were assigned to each radio-tagged individual. In the instance that a downstream route could not be clearly determined from the collected data, the passage event for that particular fish was classified as ‘unknown’.

Where data were available, impoundment duration and project residence times were calculated. Values for impoundment duration were calculated as the duration of time from detection at Station 19 until detection at Station 21. Upstream project residence time was defined as the duration of time from the initial detection at Station 21 until the determined time of downstream passage. Time spent immediately upstream of the dam was further evaluated using initial detection times for eels at Monitoring Stations 25 and 27 to provide an understanding of passage times associated with moving through the Pawtucket Gatehouse and entering into the Northern Canal approach to the E.L. Field powerhouse.

4.5.2 Parameter Estimates for Evaluation of Downstream Passage

Downstream passage success at the Project was estimated for adult American eels using a standard Cormack-Jolly-Seber (CJS) model run for the set of individual encounter histories (i.e., the series of detection/no detection through the linear sequence of receivers from upstream to downstream; Lebreton et al. 1992). This approach provided a series of reach-specific "survival" or passage success estimates for:

- Monitoring Station 19 to Monitoring Station 21 (i.e., impoundment duration);
- Monitoring Station 21 (i.e., upstream approach) to downstream passage;
- Downstream passage to Monitoring Station 37 (i.e., first downstream receiver); and
- Monitoring Station 37 (i.e., first downstream receiver) to Monitoring Station 39 (i.e., second downstream receiver)

Standard error and confidence bounds for each estimate were generated. The joint probability of three reach survival estimates (i.e., (Lowell to Station 37)*(Station 37 to Station 39)*(Station 39 to Lawrence)) was used as the estimate of total passage survival for the Project. This approach resulted in a mortality estimate that included both background mortality (i.e., natural mortality such as predation) and mortality due to Project effects in the reach extending from Lowell downstream to Lawrence. Thus, the results presented in this report reflect a minimum estimate of survival attributable to Project effects for adult silver eels.

To evaluate passage success using the CJS models, a suite of candidate models were developed in Program MARK (White and Burnham 1999) based on whether survival (i.e., passage success), recapture (i.e., detection), or both vary or are constant among stations. Models developed during this study included:

- *Phi(t)p(t)*: survival and recapture may vary between receiver stations;
- *Phi(t)p(.)*: survival may vary between stations; recapture is constant between stations;
- *Phi(.)p(t)*: survival is constant between stations; recapture may vary between stations;
- *Phi(.)p(.)*: survival and recapture are constant between stations;

Where;

- *Phi* = probability of survival
- *p* = probability of detection
- *(t)* = parameter varies
- *(.)* = parameter is constant

To evaluate the fit of the CJS model, goodness of fit testing was conducted for the "starting model" (i.e., the fully parameterized model) using the function RELEASE within Program MARK. Akaike's Information Criterion (AIC) was used to rank the models as to how well they fit the observed mark-recapture data (Lebreton et al. 1992). Lower AIC values denote a more explanatory yet parsimonious fit than higher AIC values. Assuming the assumptions of the model with the lowest AIC value were reasonable with regards to this study, that model was selected for the purposes of generating passage effectiveness estimates.

Models were prepared which evaluated downstream passage success of adult eels at Lowell as follows:

- All eels – based on detection at Station 37, Station 39 and Lawrence;
- Garvins Falls release group – based on detection at Station 37, Station 39, and Lawrence;
- Lowell Project release group – based on detection at Station 37, Station 39, and Lawrence;
- All eels – adjusted for median "travel time" for freshly dead eels released in Lowell tailrace to reach Lawrence (i.e., test eels with downstream travel times in excess of median drift duration manually adjusted to reflect a mortality at the Project); and
- All eels – by downstream passage route.

4.5.3 Time to Event Analysis

4.5.3.1 Cox Proportional Hazard Model

Utilizing available methodology for quantifying fish passage performance (Castro-Santos and Perry 2012), multi-variate Cox proportional hazard models were developed to assess the impact of various operational and environmental variables on the rate of passage success. Operational and environmental variables considered as part of this analysis included:

- Merrimack River water temperature (^{o}C);
- Head differential (ft) at the Pawtucket Gatehouse (i.e., headpond vs. Northern Canal);
- Bypassed reach spill flow (cfs);
- E.L. Field turbine discharge (cfs);
- Merrimack River inflow (cfs); and
- E.L. Field head differential (ft) (i.e., Northern Canal vs. tailwater).

This assessment on the rate of passage success focused on approach events at (1) the Pawtucket Gatehouse (i.e., Station 25), and (2) at the E.L. Field Powerhouse (i.e., Station 29).

Regression models for the time to event analyses were constructed using the *coxph*() function from the package "*survival*" in R (R Core Team 2020) and were used to evaluate the rate of passage success and identify operational hazards at sites which contained a physical barrier or a structure through which tagged individuals would have to navigate (i.e., the Pawtucket Gatehouse and E.L. Field Powerhouse).

The Cox proportional hazard regression can be described as a hazard function to evaluate the proportionate risk at time (t) such that

$$h(t) = h_0(t) \times exp(b_1x_1 + b_2x_2 + \ldots + b_ix_i)$$

where $h(t)$ represents that hazard at a given time point which is equal to the initial or baseline hazard at time 0:00 ($h_0(t)$) multiplied by e (the base of the natural logarithm) to the power of the additive relationship between each covariate (x_i) multiplied by its associated coefficient (b_i).

From the above equation, the relative impact of an operational parameter on the rate of passage success is represented by its associated coefficient. The hazard ratio of a given operational parameter is calculated by exponentiating the coefficient of a given parameter, which represents that multiplicative impact of that parameter. It is important to note that exponentiating these coefficients makes the value relative to a value of 1 (e^0), which represents a baseline of no hazard. For example, if the hazard ratio is greater than 1, e.g., 1.5, that will be interpreted as that covariate increasing the risk of passage failure by a factor of 1.5. Alternatively stated, a hazard ratio of 1.5 indicates that the associated covariate increases the risk by 50% as it is 0.5 greater than 1. In contrast, a hazard ratio below 1, e.g., 0.75, indicates that the associated covariate reduces the risk of passage failure by a factor of 0.75, or 25%. In short, a hazard ratio >1 indicates an increase in the risk of passage failure, a hazard ratio of 1 indicates no significant directional effect on passage, and a hazard ratio <1 indicates a reduction in the risk of passage failure.

4.5.3.2 Model Evaluation and Selection

As is the case with any statistical model, the type of model selected makes inherent assumptions about the nature of the data being modelled. The primary assumption of a Cox proportional hazard model is that the hazards are proportional. However, this assumption is not always appropriate for the data. As a result, the *cox.zph()* function was used during this assessment to assess the validity of the proportional hazard assumption. This function assessed scaled Schoenfield residuals to evaluate whether Cox regression residuals of each covariate in addition to the model as a whole are independent of time. In the event that the Schoenfield residuals are not independent of time, it can be said that the assumption of proportional hazards is violated and a Cox proportional hazards model may be misrepresentative of the true relationships between the selected covariates and passage success.

4.5.3.3 Event Definition

To evaluate the impact of operational parameters on passage success, instances of passage success and failure required definition and represent the 'events' (or passage attempts) in this analysis. Ostensibly, the transmitters deployed during this study should transmit a signal that when within range of a particular receiver will be detected every 2.0 seconds. However, various sources of outside noise or areas of poor coverage due to structures, etc. introduce variation into the frequency of detection for a unique transmitters signals. Given that different site locations and receiver types are subject to varying degrees of ambient noise, the duration between successive detections was calculated for each tagged individual at each receiver location. A threshold interval for determining continued presence of a transmitter within the detection zone of a specific receiver was identified as the 95th percentile of the observed set of interval durations. This value was calculated at 14.4 seconds for Station 25 and 32.4 seconds for Station 29. These two threshold values were then used to delineate when each event was started and completed for a tagged individual. The departure of a radio-tagged individual from the detection zone of a particular receiver was determined when the time interval between successive detections exceeded the specific threshold interval for that zone.

From this, a passage failure event (assigned a value of 0) was defined as any duration where all detections lay within the 95th percentile of durations for all individuals at that site. Passage failure represents events in which a tagged individual enters the field of detection at a given site without passing to the next site (i.e., moving downstream) in the system. A passage success event (assigned a status of 1) was defined using the final instance of detection for a tagged individual at a singular site where that tagged individual was next detected at a downstream receiver (i.e., successfully passed). Passage success/failure (1/0) was used as the status coinciding with time in the Cox proportional hazard models. After defining passage events for every individual, the time duration for the regression was defined as the duration from one event to the next.

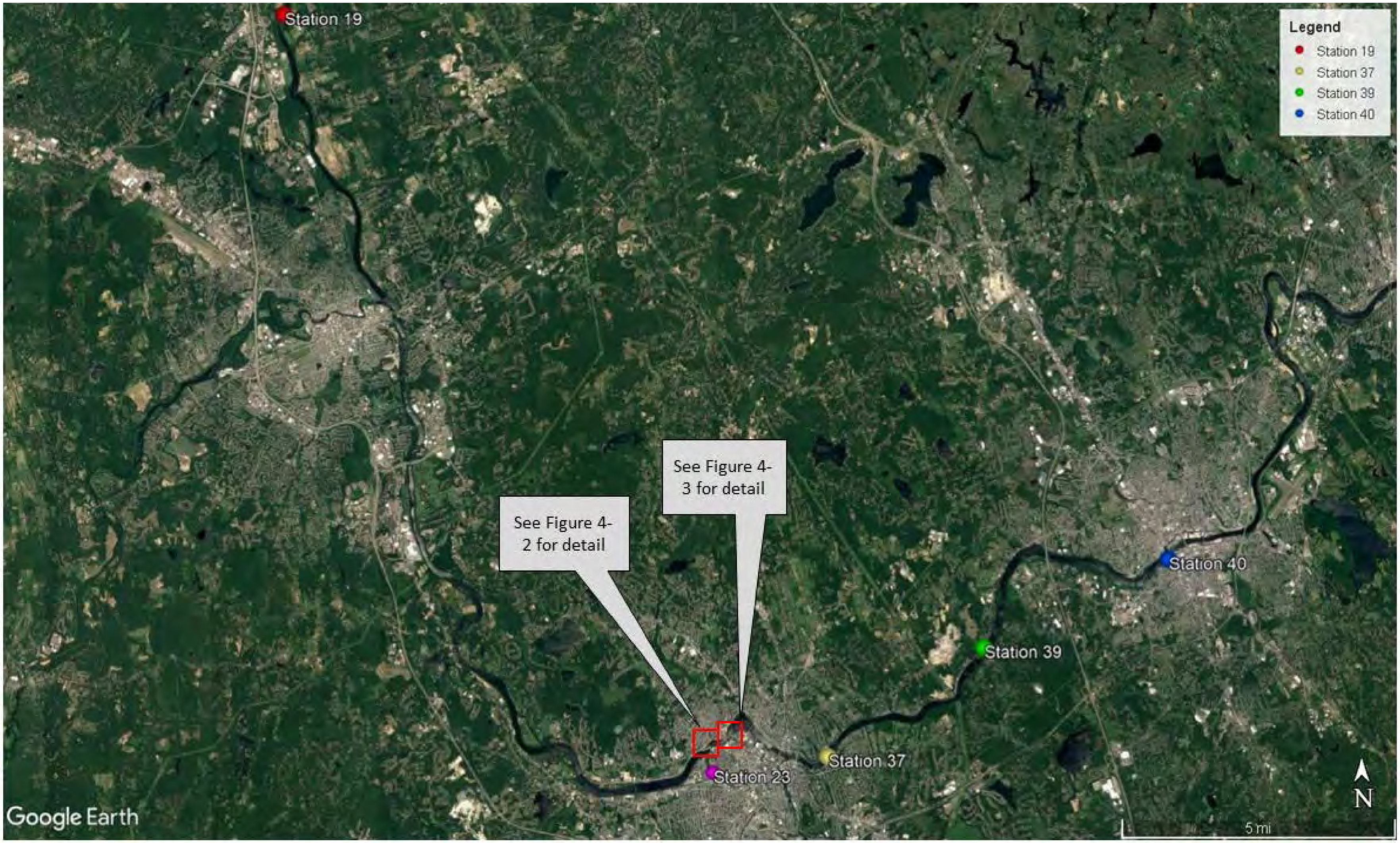

Figure 4–1. Locations of remote stationary radio-telemetry receivers installed during the 2019 adult American eel downstream passage assessment at Lowell.

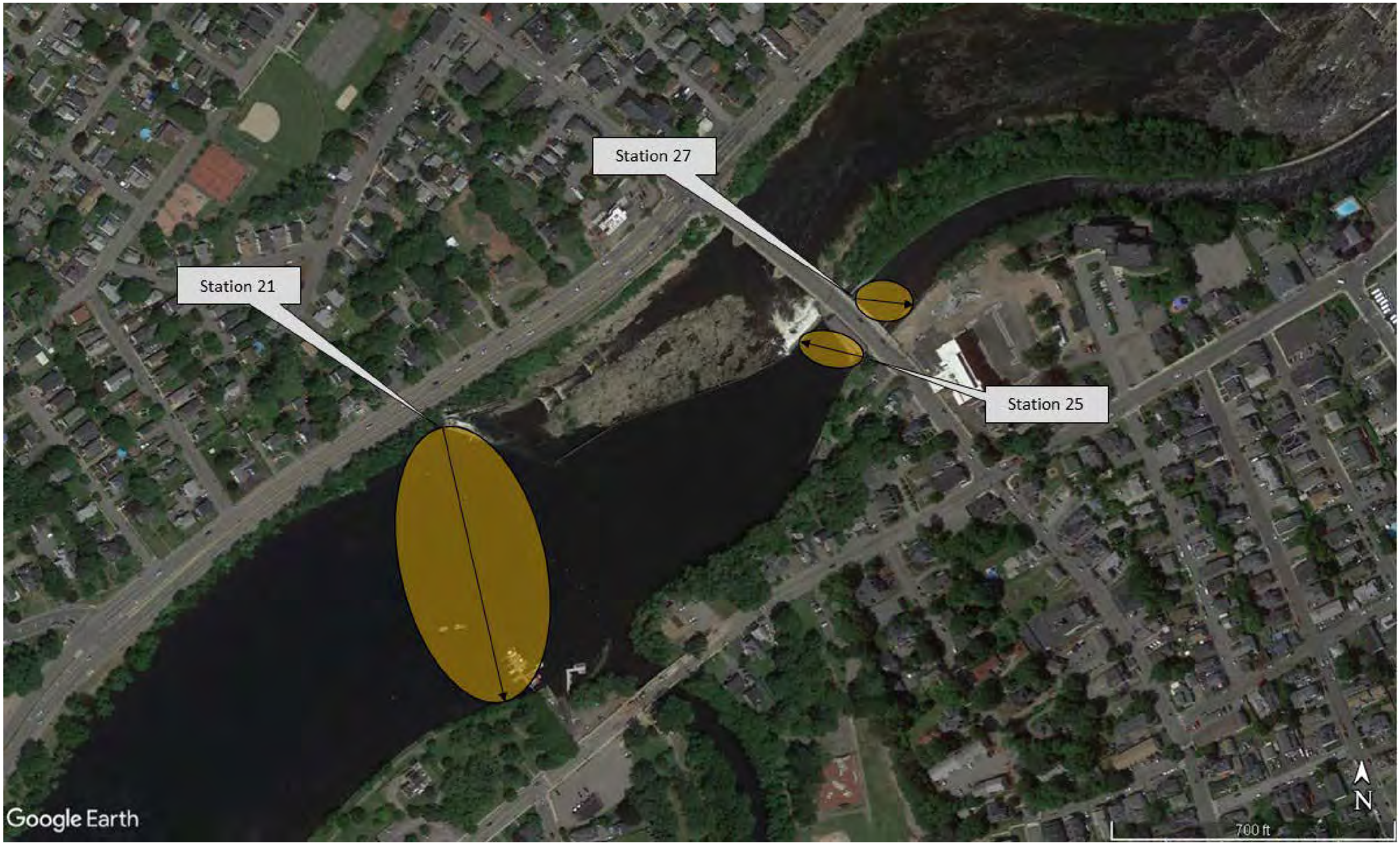

Figure 4–2. Locations and approximate detection areas for stationary radio-telemetry receivers installed upstream of Pawtucket Dam and at the Northern Gatehouse during the 2019 adult American eel downstream passage assessment at Lowell.

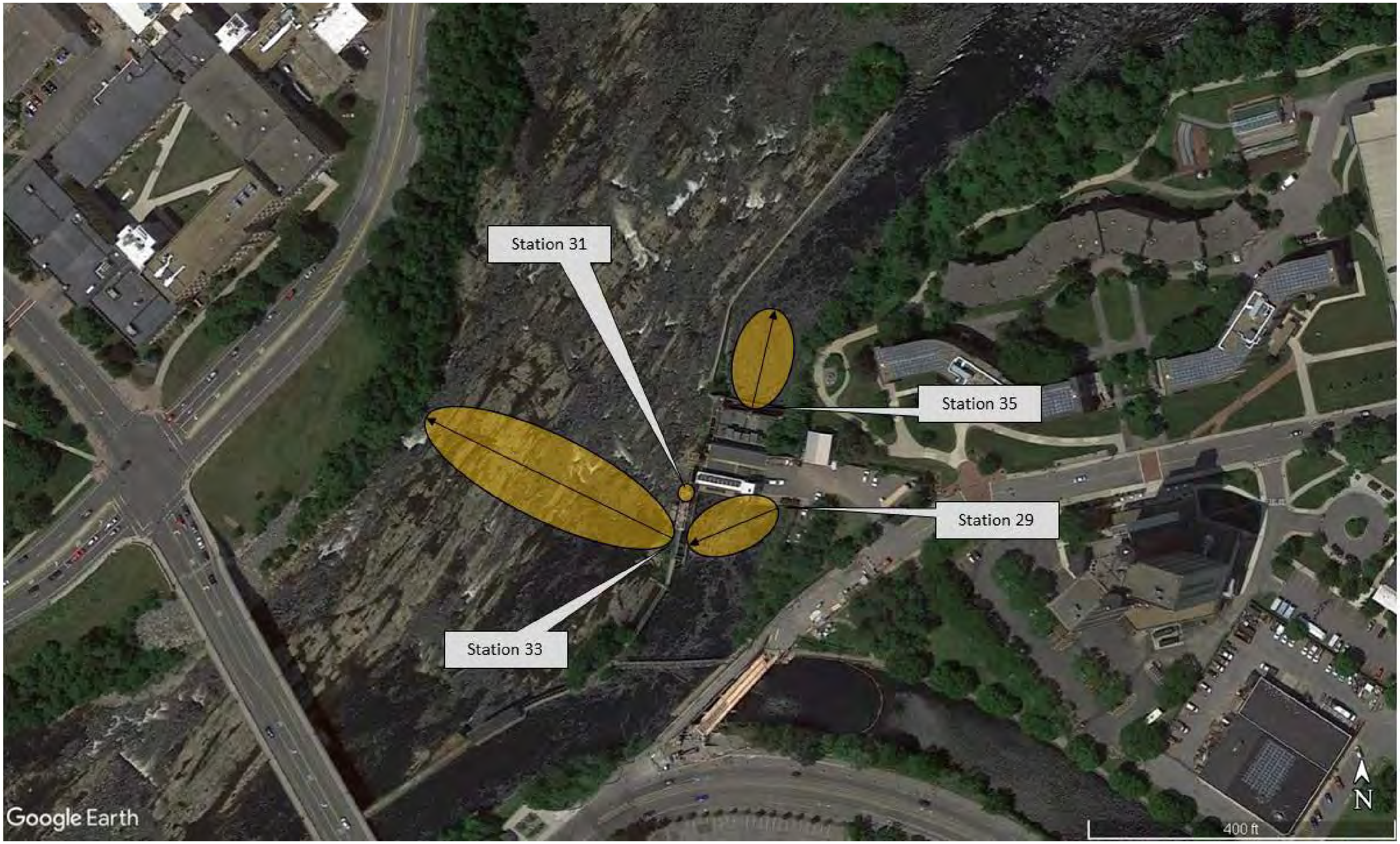

Figure 4–3. Locations and approximate detection areas for stationary radio-telemetry receivers installed in the vicinity of the E.L. Field Powerhouse during the 2019 adult American eel downstream passage assessment at Lowell.

Figure 4–4. Tagging process for silver-phase American eels.

5 Results

5.1 Merrimack River Conditions and Lowell Project Operations

Figure 5-1 presents the Merrimack River flow and water temperature for the period of time from the first eel release on October 9 until the end of the monitoring period on November 31, 2019. Water temperatures at Lowell ranged from 16°C at the onset of the study to 2°C on November 30. Total river flow values represent the reported inflow at the Lowell Project. Merrimack River flow at Lowell ranged between 1,089 and 12,995 cfs during the nearly two month fall study period. Figure 5-2 presents the monthly flow duration curves prepared for Lowell during the development of the Preliminary Application Document. The median flow condition at the Project is approximately 3,600 cfs during October and 6,500 cfs during November. Merrimack River conditions have a ~20% probability during October and a ~38% probability during November to exceed the ~8,000 cfs capacity of the E.L. Field powerhouse.

Table 5-1 summarizes the percentage of inflow records from the 2019 study period categorized by volume (to the nearest 1,000 cfs) as well as the percentage of time that each volume category is historically exceeded[2]. To help characterize the 2019 passage season, monthly exceedance probabilities less than 0.35 were classified as “high” flow conditions, 0.35 to 0.65 were classified as “normal” flow conditions, and greater than 0.65 were classified as “low” flow conditions. Inflows at the Project for the period October 9 through 31 were representative of high flow conditions (i.e., those with a probability of exceedance of less than 0.35) for 35% of the period, normal flow conditions (i.e., those with a probability of exceedance of 0.35-0.65) for 29% of the time and low flow conditions (i.e., those with a probability of exceedance of greater than 0.65) for 36% of the time. For the month of November, inflows were representative of high flow conditions 26% of the time, normal flow conditions 15% of the time and low flow conditions 59% of the time.

Flow duration information for the months of October and November (combined) is presented in Figure 5-3. The median flow condition during the two month period is near 5,000 cfs. When characterized using the flow condition criteria above, inflows at the Project for the period October 9 through November 30 were representative of high flow conditions (i.e., those with a probability of exceedance of less than 0.35) for 19% of the period, normal flow conditions (i.e., those with a probability of exceedance of 0.35-0.65) for 56% of the time and low flow conditions (i.e., those with a probability of exceedance of greater than 0.65) for 24% of the time (Table 5-1).

Figure 5-4 summarizes the allocation of water among the E.L. Field powerhouse, bypassed reach, downstream fishway, and downtown canal system at Lowell. Turbine units were in operation at the E.L. Field powerhouse for the duration of the study period with Unit 1 in operation throughout the study and Unit 2 coming online at 0900 on October 16. The

[2] Estimates of monthly exceedance estimated from monthly flow duration curves provided in Appendix H of the PAD.

downstream bypass was operated throughout the study period, passing approximately 132 cfs (i.e., 2% of the nameplate capacity of the E.L. Field turbine units; 6,600 cfs). Two major spill events, associated with increases in river flows, occurred during the monitoring period. The first major spill event occurred from approximately October 29 to November 5 and the second occurred towards the end of the passage season (~November 25). Flows to the downstream canal system represented between 15-20% of the 2,000 cfs capacity during October and between 20-57% of the 2,000 cfs capacity during November. Due to overriding safety concerns, Boott limited operation of the turbine units within the downtown canal system during the study period. To the extent possible, Boott's operations staff attempted to operate the canal system as if there were canal units available, by opening gates when river flows exceeded the hydraulic capacity of the E.L. Field turbines (7,000 to 8,000 cfs). As a result, flows through the downtown canal system were largely restricted to passage via open gates. The Licensee manually recorded gate and unit settings during the study period within the downtown canal system. A breakdown of those values and related discharge estimates are provided in Appendix A.

Table 5–1. Frequency of occurrence of river inflow at Lowell (to nearest 1,000 cfs) during 2019 adult American eel passage assessment and corresponding percentage of time flows are historically exceeded.

River Flow (nearest 1k)	October 9-30, 2019		November 1-30, 2019		Oct 9 - Nov 30, 2019	
	Percentage of Month	Percentage of Month Historically Exceeded	Percentage of Month	Percentage of Month Historically Exceeded	Percentage of Period	Percentage of Period Historically Exceeded
1000	16.1%	90	-	> 95	7.0%	>95
2000	19.4%	85	-	> 95	8.4%	90
3000	6.0%	60	10.7%	88	8.6%	76
4000	22.6%	45	25.1%	78	24.0%	63
5000	12.7%	34	23.6%	66	18.9%	50
6000	9.4%	27	5.5%	55	7.2%	42
7000	6.2%	23	6.5%	45	6.4%	35
8000	4.2%	19	2.8%	38	3.4%	29
9000	3.1%	16	2.8%	30	2.9%	24
10000	0.4%	14	5.4%	25	3.2%	21
11000	-	<5	9.8%	5	5.6%	5
12000	-	<5	5.4%	<5	3.1%	LT 5
13000	-	<5	2.4%	<5	1.3%	LT 5

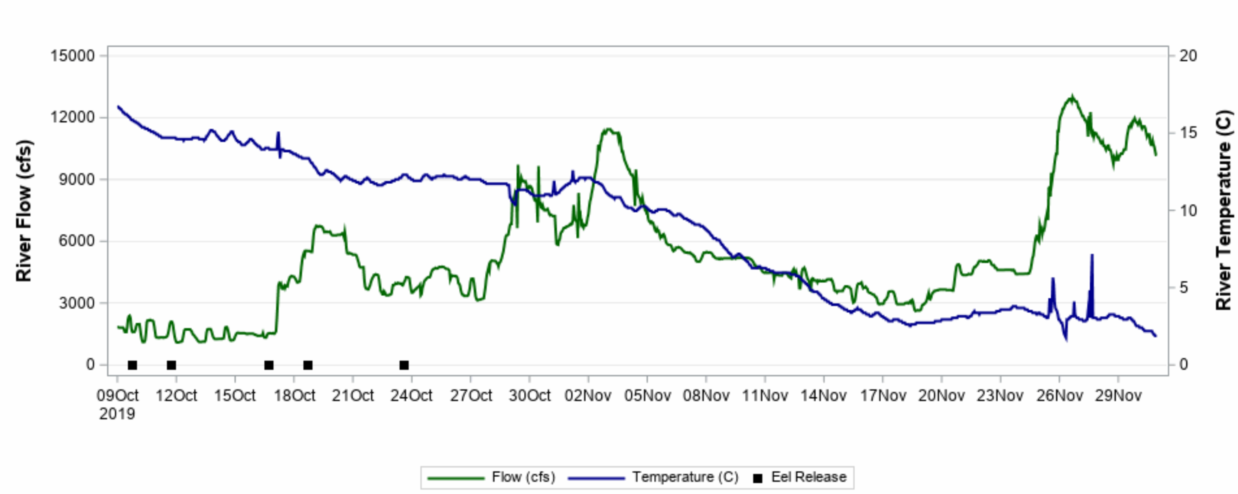

Figure 5–1. Merrimack River flow and water temperature at Lowell for the period October 9 to November 30, 2019.

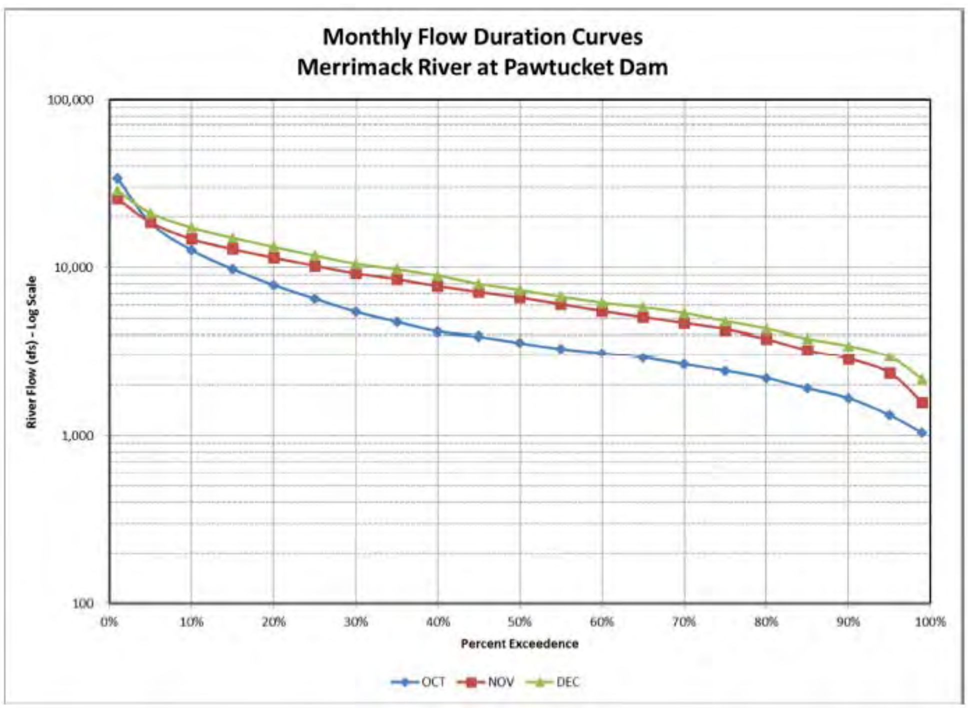

Figure 5–2. Flow duration curves for the months of October, November and December at the Lowell hydroelectric project.

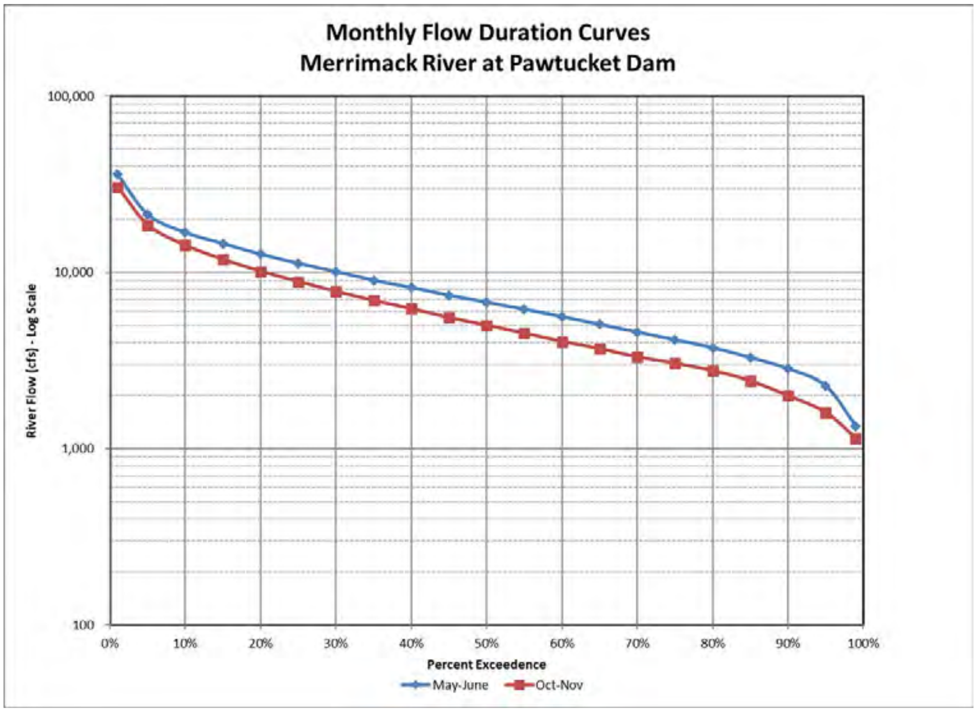

Figure 5–3. Flow duration curves for the two month period of October-November at the Lowell hydroelectric project.

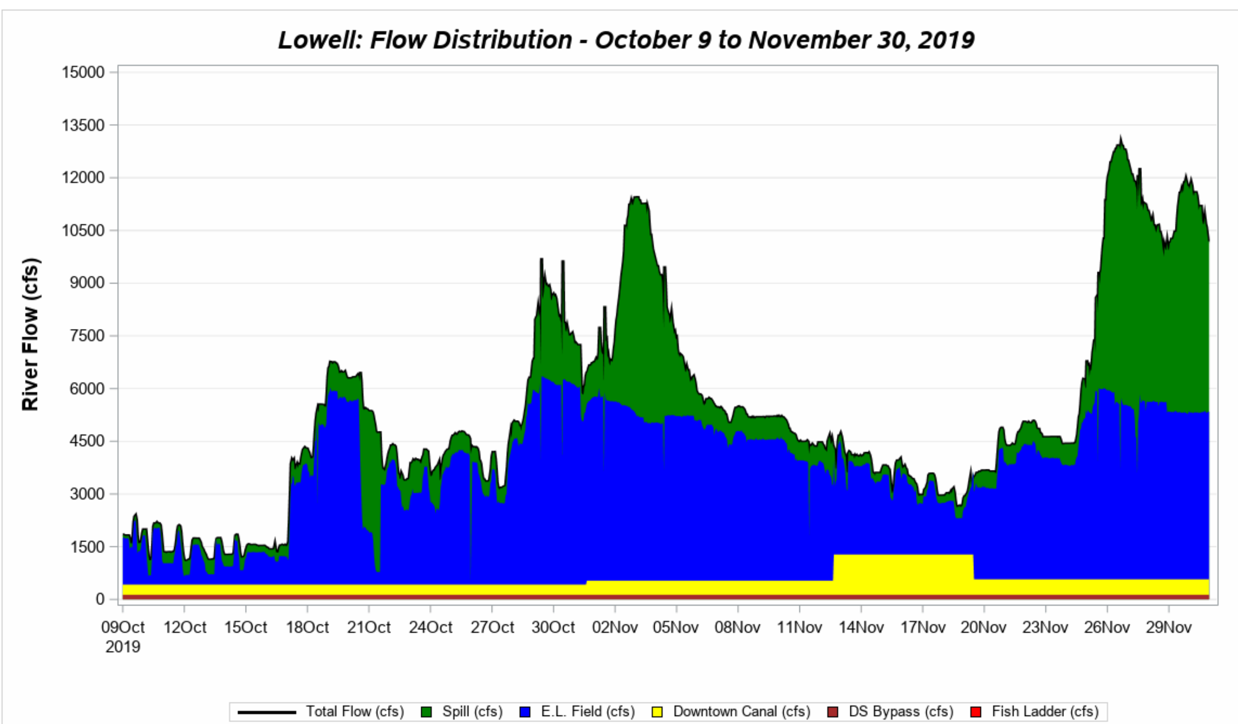

Figure 5–4. Total, spill, E.L. Field, downstream bypass and downstream canal system flow (cfs) for the period October 9 to November 30, 2019.

5.2 Monitoring Station Functionality

Radio-tagged adult American eels were released into the Merrimack River beginning in early October, 2019. The RSP called for continuous monitoring at each stationary receiver location through the end of November. Figure 5-5 provides an overview of the continuity of monitoring at each of the twelve stationary receiver locations during the fall period. The majority of the radio-telemetry monitoring stations installed to evaluate passage at Lowell during the fall study operated without issue for the full period.

Interruptions in continuous coverage were observed at three locations during the latter part of the study when lessened levels of daylight led to reduced efficiency of solar panel charge. These locations included Station 19 (upstream end of the Lowell impoundment) from 2000 on November 10 to 1400 on November 12, Station 27 (downstream side of the Pawtucket Gatehouse) from 0830 to 1030 on November 12, and Station 37 (first receiver downstream of Lowell) from 0200 to 1300 on November 5. Potential impacts to the study results from these three outages were likely limited. A single radio-tagged eel which approached the Pawtucket Dam after 2000 on November 10 lacked a detection at Station 19 and may have passed during the outage at that location preventing calculation of an impoundment residence duration for that individual. The outage at Station 27 was extremely short in duration and there were no radio-tagged eels detected upstream of the gatehouse that went undetected at that location prior to initial detection in the E.L. Field forebay. No radio-tagged eels passing downstream of Lowell on November 5 (or preceding two dates) went undetected at Station 37.

The aerial antenna at Station 25 (upstream side of the Pawtucket Gatehouse was removed by Boott operations staff to facilitate the installation of a crane to remove the in-river debris load from the upstream side of the gatehouse structure on November 21. A single radio-tagged eel did approach on November 22 and the outage at that station prevented a determination of the time to pass through the Pawtucket Gatehouse for that individual.

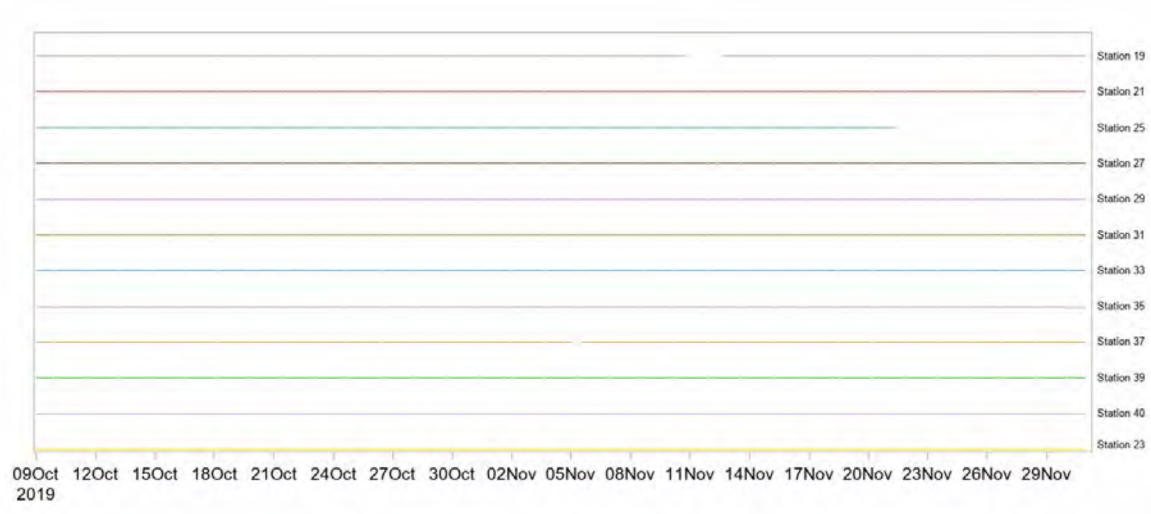

Figure 5–5. Operational coverage for telemetry receivers at Lowell during the adult silver eel downstream passage assessment, October 9 to November 30, 2019.

5.3 Downstream Drift Assessment

A total of ten freshly dead, radio-tagged American eels were released from the back deck of the E.L. Field powerhouse and directly into the upper portion of the discharge from an active turbine unit during the 2019 evaluation period. Freshly-dead eels were released intact and would be representative of an individual which did not suffer a physical strike which may result in partial or full severing of the body. Two individuals were released in the tailrace on each date where a group of radio-tagged eels were released upstream of the Project impoundment in Manchester, NH. Table 5-2 provides a summary of the release schedule and date-time of first detection for the drift eels to arrive at monitoring stations downstream of Lowell (Stations 37, 39, and 40).

Of the ten freshly dead, radio-tagged eels released at Lowell, seven were eventually detected at Station 40 (located at Lawrence, 10.75 miles downstream of the Lowell tailrace). The median duration to drift from the Lowell tailrace downstream to Lawrence was 216.4 hours (range = 59.4-538.9 hours). Three freshly dead eels did not drift the full distance from the tailrace to Station 40 at Lawrence. Of those individuals, two moved away from the Lowell tailrace but were not detected at Station 37 (2.1 miles downstream of Lowell). The third individual drifted from the Lowell tailrace to Station 37 over a period of 247.8 hours.

5.4 Eel Tagging and Releases

Eels were tagged and released upstream of the Project starting on October 9 and ending on October 23. Monitoring coverage at Lowell provided detection information on radio-tagged individuals released upstream of Lowell as part of this relicensing study (n = 102) as well as individuals released as part of a separate study conducted upstream at Garvins Falls Dam (Merrimack River Project, FERC No. 1893; n = 60) in Bow, NH. Table 5-3 provides a summary of the release dates and number of individuals for the 2019 passage assessment. A total of 162 live, radio-tagged adult eels were released over a span of two weeks and were potentially available for evaluation of downstream passage at Lowell. The majority of those individuals originated from the St. Croix River whereas the rest were captured locally (Soucook River; n = 10).[3] Eels tagged and released at locations upstream of Lowell as part of the 2019 passage evaluation ranged in length from 646 to 1,032 mm with the highest contribution of individuals to the 800-849 mm length class (Figure 5-6). The mean length of radio-tagged individuals released upstream of Garvins Falls (mean = 828 mm; range = 646-999 mm) was similar to that for eels released upstream of the Lowell impoundment (mean = 823 mm; range = 679-1,032 mm). The majority of eye index values recorded (98%) were within the literature reported range (6.0-13.5) for outmigrating eels. A full listing of tagging and biocharacteristics information for eels released during 2019 is provided in Appendix B.

[3] See Appendix D for a comparison of passage metrics for the October 23 release group comprised of eels originating from the Soucook River (n = 10) and St. Croix River (n = 12).

5.5 Impoundment Passage

Radio-tagged eels released upstream of the Lowell impoundment and upstream of Garvins Falls Dam were initially detected at Monitoring Station 19, located at the upstream extent of the Lowell impoundment (~ 23 miles from the Pawtucket Dam). The duration of time for radio-tagged individuals to move through the Lowell impoundment and arrive at the Pawtucket Dam (as indicated by detection at Station 21) ranged from 12.5 hours to 16.4 days (Table 5-4; Figure 5-7. The median duration of time spent in the Lowell impoundment was 2.1 days and did not appear to differ for eels originally released upstream of the Lowell impoundment or upstream of Garvins Falls.

5.6 Project Arrival and Upstream Residence Duration

Releases of radio-tagged eels were initiated on October 9 at locations upstream of the Project boundary and upstream of Garvins Falls Dam. Figure 5-8 presents the distribution of arrival dates for radio-tagged eels at the Pawtucket Dam as indicated by detection at Station 21. Initial detections for eels were recorded over a range of dates from October 13 through November 22 with just over fifty percent of individuals initially detected between the dates of October 24 and 30.

The duration of time radio-tagged individuals were present upstream of the Pawtucket Dam was determined for all individuals which approached and eventually passed downstream and was calculated as the duration of time from initial detection at Station 21 until confirmed downstream passage via one of the available routes. When all individuals are considered, upstream residence duration prior to downstream passage ranged between 0.2 hours to 16.5 days (Table 5-5; Figure 5-9). The median duration of time spent immediately upstream of the dam structure was 0.4 hours and did not appear to differ for eels originally released upstream of the Lowell impoundment or upstream of Garvins Falls. Of the radio-tagged eels which approached Pawtucket Dam, 94% passed in fewer than 24 hours after initial detection. Eight radio-tagged adult eels took greater than 24 hours to pass downstream following their initial detection at Station 21.

Outmigrating adult eels encountering the Pawtucket Dam can (1) pass through the Pawtucket Gatehouse and enter the power canal, (2) pass downstream over Pawtucket Dam via spill, or (3) enter the Pawtucket Canal and navigate downstream via the downtown canal system. During the 2019 evaluation there were no detections of radio-tagged eels at Monitoring Station 23 indicating individuals passed downstream of Lowell in the mainstem Merrimack rather than entering the downtown canal system. The majority of radio-tagged eels were determined to have passed through the Pawtucket Gatehouse and entered the Northern Canal to approach the E.L. Field powerhouse. The duration of time to pass through the Pawtucket Gatehouse was determined based on the initial detection for each individual eel at Stations 25 and 27 which independently monitored the upstream and downstream sides of that structure. The median duration of time for radio-tagged eels to approach and pass through the Pawtucket Gatehouse was 0.1 hours (range <0.1 hours to 3.9 days; Table 5-6). The vast majority (95%) of radio-tagged eels passing through the Pawtucket Gatehouse did so in 30 minutes or less.

Similar to observations at the Pawtucket Gatehouse, radio-tagged eels which entered the Northern Canal and passed downstream of E.L. Field powerhouse did so relatively quickly. Of those individuals, 94% were resident in the power canal upstream of E.L. Field for 3 hours or less. The median residence duration in the Northern Canal was 0.2 hours (range = 0.1 hours to 22.1 days; Table 5-7). Seven radio-tagged individuals were present in the Northern Canal for 36 hours or greater prior to downstream passage.

5.7 Downstream Passage

A total of 162 radio-tagged eels were released at points upstream of the Lowell Project during the fall of 2019. Of that total, 147 were determined to have approached the Pawtucket Dam and were available for the evaluation of downstream passage route (Table 5-8). The majority of radio-tagged individuals passed through the Pawtucket Gatehouse and approached the E.L. Field powerhouse. Most individuals (92.5%) passed downstream of Lowell via the E.L. Field turbine units. Use of the downstream bypass was limited to two individuals (1.4% of those approaching the Pawtucket Dam). Use of the bypassed reach was limited to four individuals, representing 2.8% of radio-tagged eels which approached the Pawtucket Dam.

Radio-tagged silver eels were observed passing downstream of Lowell between the dates of October 13 and November 22 (Figure 5-10). Downstream passage of radio-tagged eels at Lowell peaked during the last part of October with 81% of all downstream passage events at the Project occurring on or before October 31. Figure 5-11 presents the timing distribution of downstream passage events for silver eels at Lowell. The majority of individuals passed downstream at dusk (hours 1800 – 2200) with a peak in the number of downstream passage events during the hour of 2000 (20%).

For each of the 142 individuals which were confirmed to have passed downstream of Lowell via a known passage route (i.e., turbine, downstream bypass, or spill) the hourly record of Project operations (Section 5.1) at the time of passage was reviewed. The discharge at the selected route was identified and contrasted with the cumulative discharge for all non-selected routes at the time of downstream passage (Table 5-9). The majority of radio-tagged eels passing downstream at Lowell did so via the E.L. Field turbine units. The median discharge through the two E.L. Field turbine units at the time of passage for those individuals was 4,122 cfs. When examined by passage route, the median percentage of passage route flow at each known downstream passage route represented 78% of project flow for turbine passed eels, 2% of project flow for downstream bypass passed eels and 41% of project flow for spill passed eels. Passage via the downstream route with the greatest proportion of flow at the time of passage occurred 87% of the time. A listing of route discharge at the time of downstream passage for each eel is provided in Appendix F.

5.8 Downstream Transit

Three monitoring stations were installed downstream of Lowell for the purpose of detecting radio-tagged adult eels following passage at the Project. Those receivers were located approximately 2.1 (Monitoring Station 37), 6.0 (Monitoring Station 39), and 10.75 (Monitoring

Station 40) miles downstream of the project. The minimum, maximum, and quartile transit times through those three reaches are presented in Table 5-10. The median transit time durations for tagged adult eels moving downstream of Lowell were 2.1, 15.0, and 21.8 hours for the 2.1 mile, 3.9 mile and 4.75 mile-long downstream reaches, respectively.

Table 5-11 and Figure 5-12 present the minimum, maximum and quartile transit times for radio-tagged silver eels to cover the reach from immediately downstream of Lowell to the upstream face of the Essex Dam in Lawrence (i.e., Station 40). The median travel time for radio-tagged eels to approach Lawrence following downstream passage at Lowell was 2.3 days (range = 6.7 hours to 38.2 days). Figure 5-13 presents the distribution of observed downstream transit rates for radio-tagged eels moving from Lowell to Lawrence. Reference lines for the 25, 50, and 75% quartiles observed for the freshly-dead drift eels are included (5.7, 9.0, and 19.0 days, respectively; Table 5-2). Of the live-radio-tagged eels which passed downstream of Lowell and were subsequently detected at Lawrence, 85% did so in less time than the 25th percentile of occurrence for the dead drift eels, 91% did so in less time than the 50th percentile (median) of occurrence for the dead drift eels, and 99% did so in less time than the 75th percentile of occurrence for the dead drift eels.

5.9 Passage Survival

The CJS model *Phi(t)p(t)* provided the best fit for the observed mark-recapture data associated with downstream movements of radio-tagged silver-phase American eels approaching and passing at Lowell during 2019 (Table 5-12). The detection efficiency for telemetry receivers recording passage of adult eels at monitoring stations at Lowell and Lawrence as well as the remote riverside locations ranged from 1.000 to 0.839 (Table 5-13). The relatively poor detection efficiency rate (0.839) was estimated for Station 37 (first receiver downstream of Lowell). It is suspected that background interference in the vicinity of the Waste Water Treatment Plant property may have led to the lower than desired detection rate. However, detection was 100% for eels at Station 39 and Lawrence.

The reach-specific survival estimates for the Merrimack River from the upstream extent of the Lowell impoundment to detection immediately upstream of Lawrence are presented in Table 5-14. There was no mortality associated with passage for adult radio-tagged eels moving downstream through the Lowell impoundment. Passage success for downstream adult American eels at Lowell was calculated as the joint probability of the three reach-specific survival estimates which encompasses the full section of the Merrimack River from Lowell downstream to Lawrence (i.e., Lowell to Station 37, Station 37 to Station 39, and Station 39 to Lawrence). This resulted in an estimated downstream passage survival for silver-phase American eels at Lowell of 75.5% (75% CI = 71.4%-79.6%). Estimates of downstream passage for eels released upstream of Garvins Falls (75.6%; 75% CI = 68.8%-82.2%) and immediately upstream of the Lowell impoundment (75.5%; 75% CI = 70.5%-80.4%) did not differ.

Encounter histories for all radio-tagged eels which approached and passed downstream of Lowell were evaluated relative to the calculated downstream transit durations for freshly dead eels released into the Lowell tailrace. Individual test eels with a transit duration from Lowell to

Lawrence in excess of the median duration required to drift the 10.75 mile reach were manually adjusted to reflect mortality at the Lowell Project. When those individuals are adjusted, the estimate of overall project passage survival at Lowell is 68.7% (75% CI = 64.5%-72.9%).

Radio-tagged eels which approached and passed downstream at Lowell during the 2019 evaluation did so primarily via the E.L. Field turbine units (Table 5-8) and the number of individuals (n = 136) permitted the generation of a route-specific passage survival rate (75.0%; 75% CI = 70.6%-79.4%). The limited number of radio-tagged eels passing the Project via spill (n = 4) or via the downstream bypass system (n = 2) were all determined to have successfully approached the Lawrence Project following downstream passage at Lowell.

5.10 Time to Event Analysis

A total of 144 Pawtucket Gatehouse and 61 E.L. Field Powerhouse forebay events were defined based on recorded detections of adult American eels during the 2019 study to evaluate the impact of operational parameters on passage success. The median event duration recorded for a radio-tagged adult eel was 1.6 minutes for individuals in the detection field of Station 25 immediately upstream of the Pawtucket Gatehouse and 29 seconds for individuals in the detection field of Station 29 covering the area immediately upstream of the intakes to the downstream bypass and turbine units at the E.L. Field Powerhouse.

5.10.1 Pawtucket Gatehouse

Results of the Cox proportional hazard model for the Pawtucket Gatehouse can be found in Table 5-15 and illustrated in Figure 5-14. Model results suggest a statistically significant and negative relationship between water temperature and passage success at the Pawtucket Gatehouse wherein a decrease in temperature leads to a 22% increase in the probability of passage failure (i.e., the probability of successfully passing downstream through the Pawtucket Gatehouse decreases as the water temperature decreases (presumably later in the season)). For this model, inflow data was split into three bins based on volume: 1080-5060 cfs (i.e., low), 5060-9030 cfs (i.e., mid), and 9030-13,000 cfs (i.e., high). The low inflow condition was used as a reference for comparison with mid and high inflow conditions, as illustrated in Figure 5-14. Although the model suggests an insignificant, negative relationship between inflow values from 1080-5060 cfs and passage success, a statistically significant, positive relationship was found between passage success and high inflow values ranging from 9030-13,000 cfs. This indicates inflow values classified as “high” reduced the probability of passage failure by 33% (i.e., likelihood of successful passage at the Pawtucket Gatehouse increases with rising inflow). Similarly, spill data was split into three bins: 0-3040 cfs (i.e., low), 3040-6070 cfs (i.e., mid), and 6070-9120 cfs (i.e., high) and the low spill flow category was used as reference for comparison with mid and high spill conditions (Figure 5-14). Mid-levels of spill flow were found to be significantly correlated with passage success. The probability of passage failure for adult eels at the Pawtucket Gatehouse decreases by 79% when spill is between 2080 and 6070 cfs. Additionally, it should be noted that Table 5-16 demonstrates the Pawtucket Gatehouse model meets the criteria necessary to accept the assumption that hazards are proportional, as all covariates were found to be independent of time.

5.10.2 E.L. Field Powerhouse Forebay

Results of the Cox proportional hazards model for E.L. Field forebay events suggest a statistically significant, negative relationship between both water temperature and the forebay-tailrace head differential versus passage success, increasing the probability of passage failure by 26% and 58%, respectively (Table 5-17). In order to make sure the data met the assumption of proportional hazards and ensure the use of an appropriate modelling framework, spill was maintained as a continuous variable and inflow was split into three bins (1080-5060 cfs (i.e., low), 5060-9030 cfs (i.e., mid), and 9030-13,000 cfs (i.e., high; Table 5-17). However, neither spill nor inflow were found to be significant variables with neither exhibiting a measurable impact on passage success out of the E.L. Field Powerhouse forebay. Model results indicate the combined turbine discharge (cfs) exhibited a negative, statistically significant impact on passage success, which was also classified into three bins: 592-1980 cfs (i.e., low generation), 1980-3950 cfs (i.e., mid generation), and 3950-5930 cfs (i.e., high generation). As illustrated in Figure 5-15, the low generation category was used as a reference for comparison to the mid and high generation conditions. Results suggest a strong, statistically significant interaction for the rate of passage failure under the mid and high generation conditions with an increase in the observed rate of passage failure for those two conditions relative to the low generation condition. Table 5-18 demonstrates that the E.L. Field Powerhouse forebay model meets the criteria necessary to accept the assumption that hazards are proportional, as all covariates were found to be independent of time.

5.11 Manual Tracking

In addition to the continuous monitoring provided by the 12 stationary receivers installed throughout the Project area for the duration from early October through November 2019, a total of 116 manual detections representing 66 individuals were recorded between October 21 and November 25. Appendix C contains a listing of manual detections identified to the nearest 0.25 mile and classified as “Transit” for eels which were detected at stationary receivers downstream of their manually determined position or “Stationary” for eels which were not detected again at stationary receivers downstream of their manually determined position(s). A total of 39 individuals were located a single time within the Lowell impoundment with the majority (38 or 39) representing an individual which exhibited continued downstream movement following manual detection. A total of 10 individuals were manually detected within the Merrimack River downstream of Lowell and upstream of Station 37. The majority of those individuals (8 of 10) represented stationary individuals which were not detected at any of the downstream stationary receivers (i.e., Stations 37, 39, or 40). Similarly, a total of 18 individuals were manually detected within the Merrimack River between Stations 37 and 39. The majority of those individuals (11 of 18) represented stationary individuals which were not detected at additional downstream stationary receivers (i.e., Stations 39, or 40). Five radio-tagged eels were each detected on a single occasion in the reach between Station 39 and immediately upstream of Lawrence (Station 40).

Table 5–2. Summary of the downstream drift distance and duration for freshly dead, radio-tagged silver eels released in the Lowell tailrace during the downstream passage assessment, October 9 to November 30, 2019.

Release Date	River Condition (cfs)		Frequency (ID)	Total Length (mm)	Station 37 Arrival		Station 39 Arrival		Station 40 Arrival		Drift Duration	
	Inflow	ELF Discharge			Date	Time	Date	Time	Date	Time	Hours	Days
9-Oct	1830	1265	149.320 (80)	806	-	-	17-Oct	22:01	18-Oct	2:29	198.8	8.3
			149.320 (81)	761	-	-	-	-	-	-	-	-
11-Oct	1515	824	149.320 (82)	726	14-Oct	4:12	15-Oct	3:47	1-Nov	18:44	503.4	21.0
			149.320 (83)	775	22-Oct	3:08	-	-	-	-	-	-
16-Oct	1454	780	149.320 (84)	807	27-Oct	20:06	8-Nov	1:19	8-Nov	5:35	538.9	22.5
			149.320 (85)	802	-	-	23-Oct	23:20	25-Oct	19:06	216.4	9.0
18-Oct	4938	3932	149.320 (86)	806	-	-	-	-	-	-	-	-
			149.320 (87)	932	20-Oct	5:56	2-Nov	19:29	4-Nov	18:28	407.0	17.0
23-Oct	3981	2795	149.320 (88)	958	24-Oct	3:58	25-Oct	2:29	26-Oct	18:44	72.6	3.0
			149.320 (89)	751	25-Oct	3:46	25-Oct	23:18	26-Oct	5:33	59.4	2.5

Table 5–3. Release date and location for radio-tagged silver eels upstream of Lowell during the downstream passage assessment, October 9 to November 30, 2019.

Release Date	Release Location	No. of Individuals
9-Oct	Upstream of Garvins Falls	20
9-Oct	Upstream of Lowell Impoundment	20
11-Oct	Upstream of Garvins Falls	20
11-Oct	Upstream of Lowell Impoundment	20
15-Oct	Upstream of Garvins Falls	20
16-Oct	Upstream of Lowell Impoundment	20
18-Oct	Upstream of Lowell Impoundment	20
23-Oct	Upstream of Lowell Impoundment	22

Table 5–4. Minimum, maximum, and quartile values of impoundment duration (hours) for radio-tagged eels released upstream of the Lowell project boundary and upstream of Garvins Falls Dam during the fall 2019 downstream passage assessment.

Release Location	Release Date	Impoundment Duration (hours)				
		Minimum	Maximum	Q25	Q50 (Median)	Q75
Garvins Falls	9-Oct	21.2	393.9	28.2	49.2	82.4
Garvins Falls	11-Oct	24.6	242.6	28.9	51.2	72.5
Garvins Falls	15-Oct	19.7	266.9	24.6	50.4	126.3
Garvins Falls	All	19.7	393.9	28.6	50.7	74.9
Lowell	9-Oct	12.5	239.3	47.8	68.9	131.8
Lowell	11-Oct	13.7	335.6	27.4	63.7	101.1
Lowell	16-Oct	21.8	287.7	46.0	68.1	137.0
Lowell	18-Oct	23.3	240.9	29.4	51.8	94.0
Lowell	23-Oct	23.2	71.8	26.7	29.0	51.5
Lowell	All	12.5	335.6	29.0	51.7	107.5
All		12.5	393.9	28.8	51.3	95.3

Table 5–5. Minimum, maximum, and quartile values of upstream residence duration (hours) for radio-tagged eels released upstream of the Lowell project boundary and upstream of Garvins Falls Dam during the fall 2019 downstream passage assessment.

Release Location	Release Date	Upstream Residence Duration (hours)*				
		Minimum	Maximum	Q25	Q50 (Median)	Q75
Garvins Falls	9-Oct	0.3	24.1	0.3	0.4	1.7
Garvins Falls	11-Oct	0.2	17.1	0.3	0.3	0.5
Garvins Falls	15-Oct	0.2	17.5	0.3	0.5	1.4
Garvins Falls	All	0.2	24.1	0.3	0.4	1.3
Lowell	9-Oct	0.2	395.4	0.3	0.4	1.3
Lowell	11-Oct	0.2	47.7	0.3	0.4	1.3
Lowell	16-Oct	0.2	0.5	0.2	0.3	0.4
Lowell	18-Oct	0.3	113.9	0.3	0.4	0.5
Lowell	23-Oct	0.2	165.3	0.3	0.4	1.5
Lowell	All	0.2	395.4	0.3	0.4	0.6
All		0.2	395.4	0.3	0.4	0.7

*Upstream residence duration = duration from arrival at Pawtucket Dam until confirmed downstream passage

Table 5–6. Minimum, maximum, and quartile values of time to pass the Pawtucket Gatehouse and enter Northern Canal (hours) for radio-tagged eels released upstream of the Lowell project boundary and upstream of Garvins Falls Dam during the fall 2019 downstream passage assessment.

Release Location	Release Date	Pawtucket Gatehouse Passage (hours)				
		Minimum	Maximum	Q25	Q50 (Median)	Q75
Garvins Falls	9-Oct	<0.1	23.0	0.1	0.1	0.3
Garvins Falls	11-Oct	<0.1	36.8	0.1	0.1	0.1
Garvins Falls	15-Oct	<0.1	0.5	0.1	0.1	0.1
Garvins Falls	All	<0.1	36.8	0.1	0.1	0.1
Lowell	9-Oct	<0.1	10.2	0.1	0.1	0.1
Lowell	11-Oct	<0.1	0.2	0.1	0.1	0.1
Lowell	16-Oct	<0.1	0.2	<0.1	0.1	0.1
Lowell	18-Oct	<0.1	0.2	0.1	0.1	0.1
Lowell	23-Oct	<0.1	93.5	0.1	0.1	0.1
Lowell	All	<0.1	93.5	0.1	0.1	0.1
All		<0.1	93.5	0.1	0.1	0.1

Table 5–7. Minimum, maximum, and quartile values of Northern Canal residence duration (hours) for radio-tagged eels released upstream of the Lowell project boundary and upstream of Garvins Falls Dam during the fall 2019 downstream passage assessment.

Release Location	Release Date	Northern Canal Residence (hours)				
		Minimum	Maximum	Q25	Q50 (Median)	Q75
Garvins Falls	9-Oct	0.2	1.0	0.2	0.2	0.7
Garvins Falls	11-Oct	0.1	3.1	0.2	0.2	0.3
Garvins Falls	15-Oct	0.1	0.5	0.1	0.2	0.3
Garvins Falls	All	0.1	3.1	0.2	0.2	0.3
Lowell	9-Oct	0.1	530.5	0.1	0.2	0.3
Lowell	11-Oct	0.1	47.6	0.2	0.2	0.5
Lowell	16-Oct	0.1	0.3	0.1	0.2	0.3
Lowell	18-Oct	0.1	113.7	0.2	0.2	0.3
Lowell	23-Oct	0.1	165.1	0.2	0.2	0.3
Lowell	All	0.1	530.5	0.2	0.2	0.3
All		0.1	530.5	0.2	0.2	0.3

Table 5–8. Downstream passage route selection for radio-tagged eels released upstream of the Lowell project boundary and upstream of Garvins Falls Dam during the fall 2019 downstream passage assessment.

Release Location	Release Date	Lowell Downstream Passage Route					
		No Detect	No Pass	Unknown	Turbine	Spill	Bypass
Garvins Falls	9-Oct	7	0	1	11	1	0
Garvins Falls	11-Oct	2	1	0	15	1	1
Garvins Falls	15-Oct	6	0	0	13	1	0
Garvins Falls	All	15	1	1	39	3	1
Lowell	9-Oct	0	0	1	19	0	0
Lowell	11-Oct	0	0	0	19	0	1
Lowell	16-Oct	0	0	1	18	1	0
Lowell	18-Oct	0	0	0	20	0	0
Lowell	23-Oct	0	0	1	21	0	0
Lowell	All	0	0	3	97	1	1
All		15	1	4	136	4	2
Percent Utilization			0.7%	2.7%	92.5%	2.7%	1.4%

Table 5–9. Quartile conditions of project discharge at the time of downstream passage for radio-tagged eels at the known route of passage and the cumulative sum of discharge at non-passage routes.

Passage Route	No. Using Route	Quartile	Route Discharge		Non-Route Discharge	
			cfs	%	cfs	%
Turbines	136	Q25	3353	67%	922.8	19%
		Q50	4122	78%	1169	22%
		Q75	5356	81%	2616	33%
Downstream Bypass	2	Q25	132	2%	1386	91%
		Q50	132	2%	1386	91%
		Q75	132	2%	1386	91%
Spill	4	Q25	2092	28%	3257	47%
		Q50	3031	41%	4355	59%
		Q75	3794	53%	5079	72%

Table 5–10. Minimum, maximum, and quartile values of travel time (hours) through three separate downstream reaches for radio-tagged eels released upstream of the Lowell project boundary and upstream of Garvins Falls Dam during the fall 2019 downstream passage assessment.

Downstream Reach	Release Location	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Downstream of Lowell to Station 37 (2.1 miles)	Garvins Falls	9-Oct	0.8	425.8	2.0	13.5	164.8
	Garvins Falls	11-Oct	0.8	667.7	1.1	1.4	6.8
	Garvins Falls	15-Oct	0.7	517.8	1.3	3.5	88.2
	Garvins Falls	All	0.7	667.7	1.1	2.6	29.0
	Lowell	9-Oct	0.7	23.9	0.9	2.2	10.3
	Lowell	11-Oct	0.7	453.6	1.0	1.2	3.2
	Lowell	16-Oct	0.7	237.6	1.7	2.7	3.9
	Lowell	18-Oct	0.7	44.1	1.0	1.9	7.5
	Lowell	23-Oct	0.7	600.5	1.1	1.6	14.3
	Lowell	All	0.7	600.5	1.1	2.0	10.3
	All		0.7	667.7	1.1	2.1	14.3
Station 37 to Station 39 (3.9 miles)	Garvins Falls	9-Oct	2.2	12.6	2.5	2.8	5.1
	Garvins Falls	11-Oct	1.4	86.7	2.0	3.4	67.2
	Garvins Falls	15-Oct	2.4	499.5	14.8	16.4	51.9
	Garvins Falls	All	1.4	499.5	2.5	9.1	41.5
	Lowell	9-Oct	1.8	324.9	17.7	37.3	66.7
	Lowell	11-Oct	1.4	187.3	2.2	19.9	108.4
	Lowell	16-Oct	2.1	69.4	15.5	18.6	20.6
	Lowell	18-Oct	1.9	381.0	2.3	3.0	15.1
	Lowell	23-Oct	1.7	190.8	2.3	2.8	32.5
	Lowell	All	1.4	381.0	2.5	16.6	38.5
	All		1.4	499.5	2.5	15.0	39.8
Station 39 to Lawrence (Station 40; 4.75 miles)	Garvins Falls	9-Oct	3.7	91.3	5.2	21.8	39.3
	Garvins Falls	11-Oct	3.7	89.2	7.9	16.3	23.4
	Garvins Falls	15-Oct	2.8	270.3	21.4	52.8	70.9
	Garvins Falls	All	2.8	270.3	7.9	21.6	56.2
	Lowell	9-Oct	3.0	182.3	3.8	23.5	70.0
	Lowell	11-Oct	3.1	119.4	3.4	4.5	21.9
	Lowell	16-Oct	3.5	114.4	4.7	27.3	47.6
	Lowell	18-Oct	3.7	113.1	19.1	23.5	57.8
	Lowell	23-Oct	3.3	356.2	4.5	20.4	46.0
	Lowell	All	3.0	356.2	4.5	22.1	47.1
	All		2.8	356.2	4.7	21.8	48.1

Table 5–11. Minimum, maximum, and quartile values for downstream travel duration from Lowell to Lawrence (hours) for radio-tagged eels released upstream of the Lowell project boundary and upstream of Garvins Falls Dam during the fall 2019 downstream passage assessment.

Release Location	Release Date	Downstream Travel: Lowell to Lawrence (hours)				
		Minimum	Maximum	Q25	Q50 (Median)	Q75
Garvins Falls	9-Oct	19.4	431.7	38.5	55.6	97.6
Garvins Falls	11-Oct	7.7	169.8	20.7	27.7	80.7
Garvins Falls	15-Oct	19.9	917.2	52.4	78.9	176.9
Garvins Falls	All	7.7	917.2	27.7	63.0	97.6
Lowell	9-Oct	10.9	427.5	38.9	70.6	165.3
Lowell	11-Oct	7.1	415.5	32.3	45.9	125.2
Lowell	16-Oct	8.2	146.8	33.6	57.7	87.0
Lowell	18-Oct	6.7	399.2	25.2	42.2	80.0
Lowell	23-Oct	21.1	359.8	41.9	60.9	97.6
Lowell	All	6.7	427.5	33.6	50.2	96.7
All		6.7	917.2	28.0	56.3	97.1

Table 5–12. CJS model selection criteria for survival of adult American eels at Lowell during the fall 2019 downstream passage assessment.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Parameters	Deviance
Phi(t)p(t)	657.65	0.00	1.00	1.00	8	11.92
Phi(.)p(t)	714.22	56.57	0.00	0.00	5	74.59
Phi(t)p(.)	719.99	62.34	0.00	0.00	6	78.33
Phi(.)p(.)	800.54	142.89	0.00	0.00	2	166.96

Where *phi* = survival; *p* = detection probability; t = parameter is allowed to vary with time; and "." = parameter is fixed with time.
AIC = Akaike's Information Criterion – comparison value among set of evaluated survival models

Table 5–13. Detection efficiency estimates (p) for monitoring locations installed to detect radio-tagged adult American eels approaching and passing Lowell during the fall 2019 downstream passage assessment.

Location	S	SE	95% CI	
Station 19	0.952	0.018	0.903	0.977
Lowell	1.000	0.000	-	-
Station 37	0.839	0.035	0.759	0.896
Station 39	1.000	0.000	-	-
Lawrence	1.000	0.000	-	-

Table 5–14. Reach-specific survival probability estimates (*phi)*, standard errors, and likelihood 75% and 95% confidence intervals for radio-tagged adult American eels approaching and passing Lowell during the fall 2019 downstream passage assessment.

Reach	Reach Length (mile)	*Phi*	SE	95% CI		75% CI	
Lowell Impoundment	23.0	1.000	0.000	-	-	-	-
Lowell to Station 37	2.1	0.900	0.029	0.828	0.944	0.861	0.928
Station 37 to Station 39	3.9	0.847	0.034	0.767	0.903	0.803	0.882
Station 39 to Lawrence	4.8	0.991	0.009	0.939	0.999	0.972	0.997
Lawrence to Station 45	2.1	0.903	0.039	0.795	0.957	0.848	0.939

Table 5–15. Results of the Cox proportional hazards model for adult American eel passage through Pawtucket Gatehouse. Significance is determined by p < 0.05.

Pawtucket Gatehouse										
Model: Time to Event ~ Temperature + Inflow + Spill										
Model Parameter	*b*	se	z	P-value	Significance	e^{b}	e^{-b}	Lower .95	Upper .95	Percent Change
Temp	0.2	0.07	2.86	0	Significant	1.22	0.82	1.06	1.4	↑ 22%
Inflow 5060-9030 cfs	0.04	0.31	0.14	0.89	Insignificant	1.05	0.96	0.56	1.94	↑ 5%
Inflow 9030-13,000 cfs	-0.27	0.79	-0.34	0.74	Insignificant	0.77	1.31	0.16	3.62	↓ 33%
Spill 3040-6070 cfs	-1.56	0.41	-3.86	0	Significant	0.21	4.78	0.09	0.46	↓ 79%
Spill 6070-9120 cfs	1.22	0.91	1.33	0.18	Insignificant	3.37	0.3	0.56	20.16	↑ 237%
Canal Height Diff.	-0.09	0.12	-0.75	0.45	Insignificant	0.91	1.09	0.72	1.16	↓ 9%

Significance is determined by p < 0.05.

Table 5–16. Output of the Schoenfield residual test for time independence of covariates in Cox proportional hazard model of Pawtucket Gatehouse passage events.

Variable	Chi-squared	df	P-Value
Temperature (°C)	3.35	1	0.067
Inflow (cfs)	1.34	2	0.512
Spill (cfs)	1.3	2	0.521
Gatehouse Differential (ft)	2.35	1	0.125
Full Model	11.88	6	0.065

Note: p < 0.05 indicates a violation of the proportional hazard assumption.

Table 5–17. Results of the Cox proportional hazards model for adult American eel passage through E.L. Field Powerhouse forebay.

Forebay										
Model: Time to Event ~ Temperature + Combined Turbine cfs + Spill + Inflow + ELF Head										
Model Parameter	*b*	se	z	P-value	Significance	e^b	e^{-b}	Lower .95	Upper .95	Percent Change
Temp	0.23	0.08	2.96	0	Significant	1.26	0.79	1.08	1.47	↑ 26%
Inflow 5060-9030 cfs	0.76	0.89	0.85	0.39	Insignificant	2.14	0.47	0.37	12.25	↑ 114%
Inflow 9030-13,000 cfs	-1.3	1.56	-0.84	0.4	Insignificant	0.27	3.68	0.01	5.78	↓ 73%
Spill cfs	0	0	2.19	0.03	No Hazard	1	1	1	1	0
Turbine CFS 1980-3950 cfs	2.26	0.73	3.09	0	Significant	9.56	0.1	2.28	39.98	↑ 856%
Turbine CFS 3950-5930 cfs	4.69	0.97	4.82	0	Significant	109	0.01	16.15	735.5	↑ 10798%
E.L. Field Powerhouse Head	0.46	0.18	2.47	0.01	Significant	1.58	0.63	1.1	2.27	↑ 58%

Significance is determined by $p < 0.05$.

Table 5–18. Output of the Schoenfield Residual test for time independence of covariates in Cox proportional hazard model of E.L. Field Powerhouse forebay events.

Variable	Chi-squared	df	P-Value
Temperature (°C)	0.0689	1	0.79
Inflow (cfs)	2.7546	2	0.25
Spill (cfs)	1.6921	1	0.19
Turbine Discharge (cfs)	1.3068	2	0.52
ELF Head Differential (ft)	0.099	1	0.75
Full Model	9.2518	7	0.24

Note: $p < 0.05$ indicates a violation of the proportional hazard assumption.

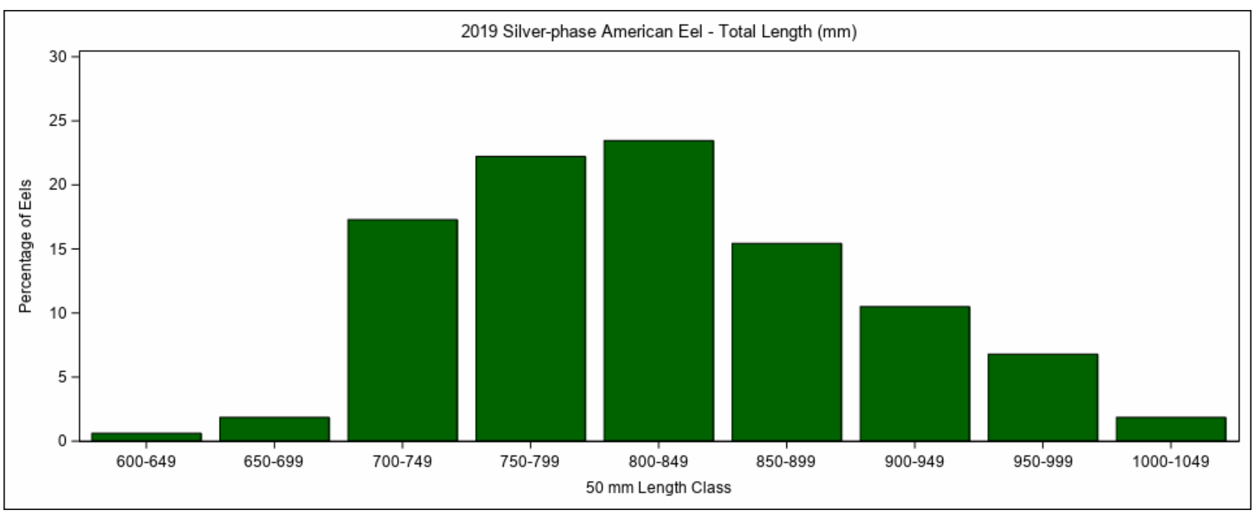

Figure 5–6. Length frequency distribution of adult American eels radio-tagged and released upstream of Lowell during 2019.

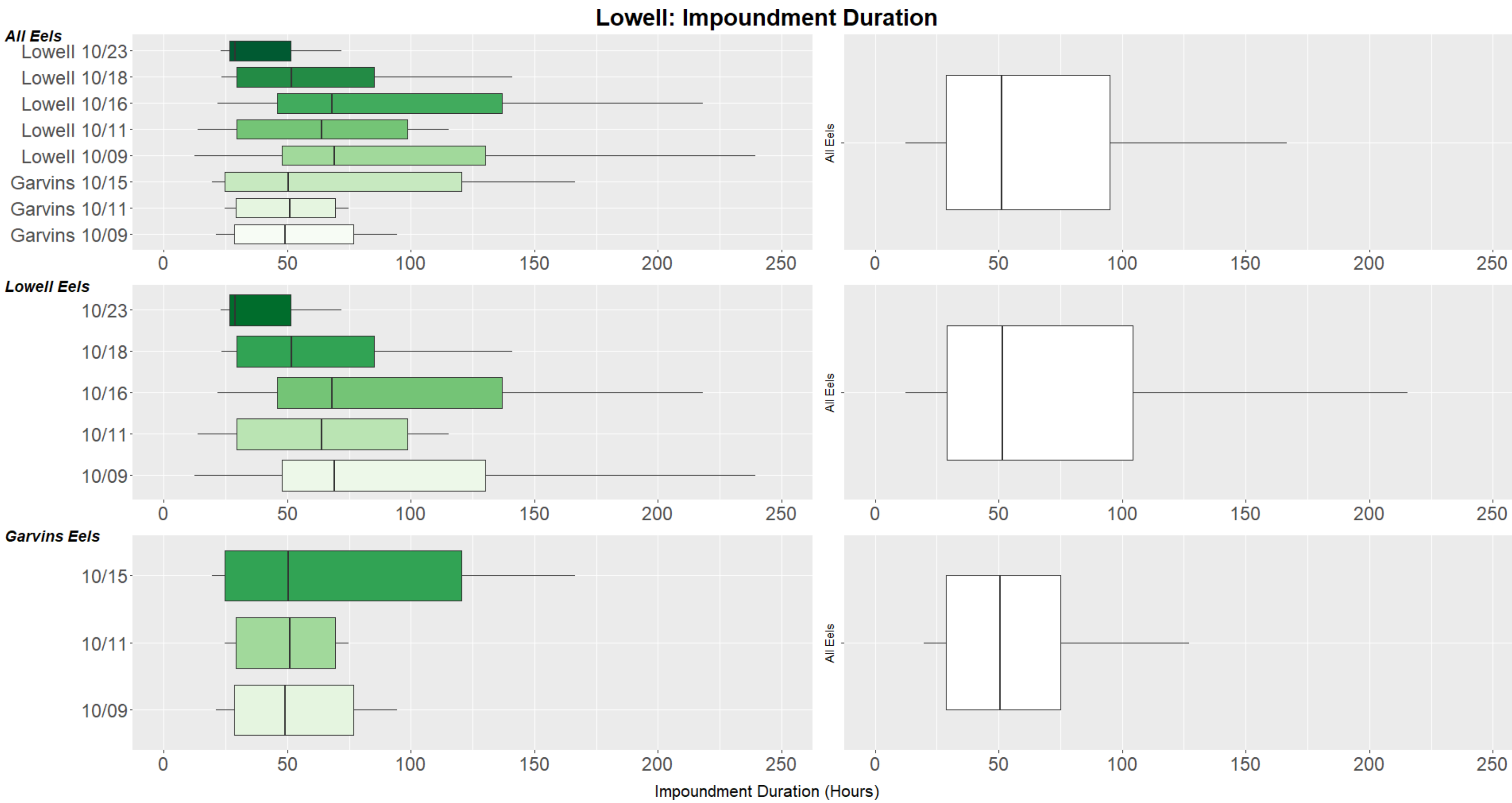

Figure 5–7. Boxplot of the Lowell impoundment duration for all radio-tagged eels (top panel), radio-tagged eels released upstream of Project boundary (middle panel) and upstream of Garvins Falls Dam (bottom panel).[4]

[4] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

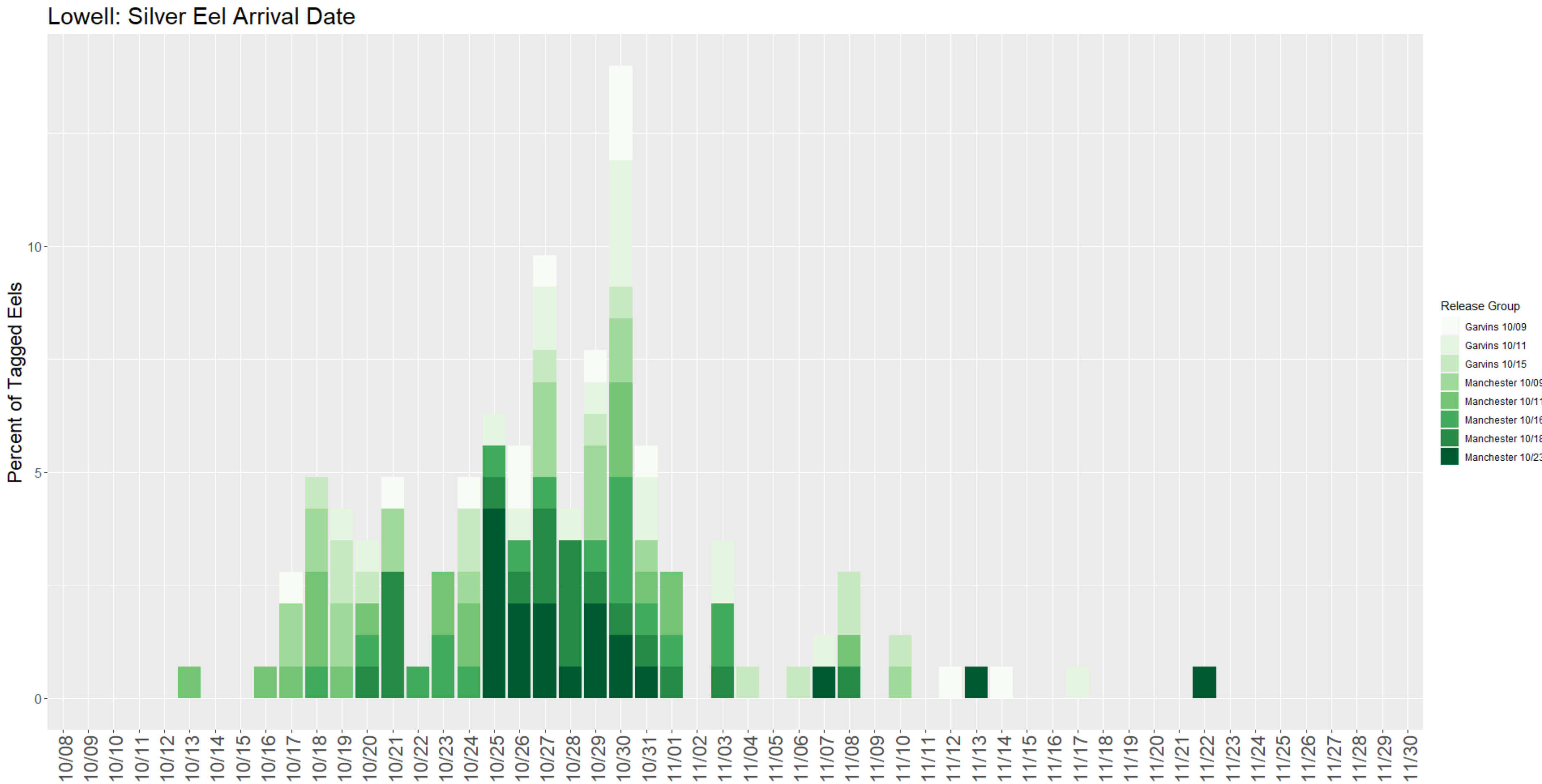

Figure 5–8. Distribution of Pawtucket Dam arrival dates for radio-tagged eels originally released upstream of the Project boundary (Manchester) and upstream of Garvins Falls Dam (Garvins Falls).

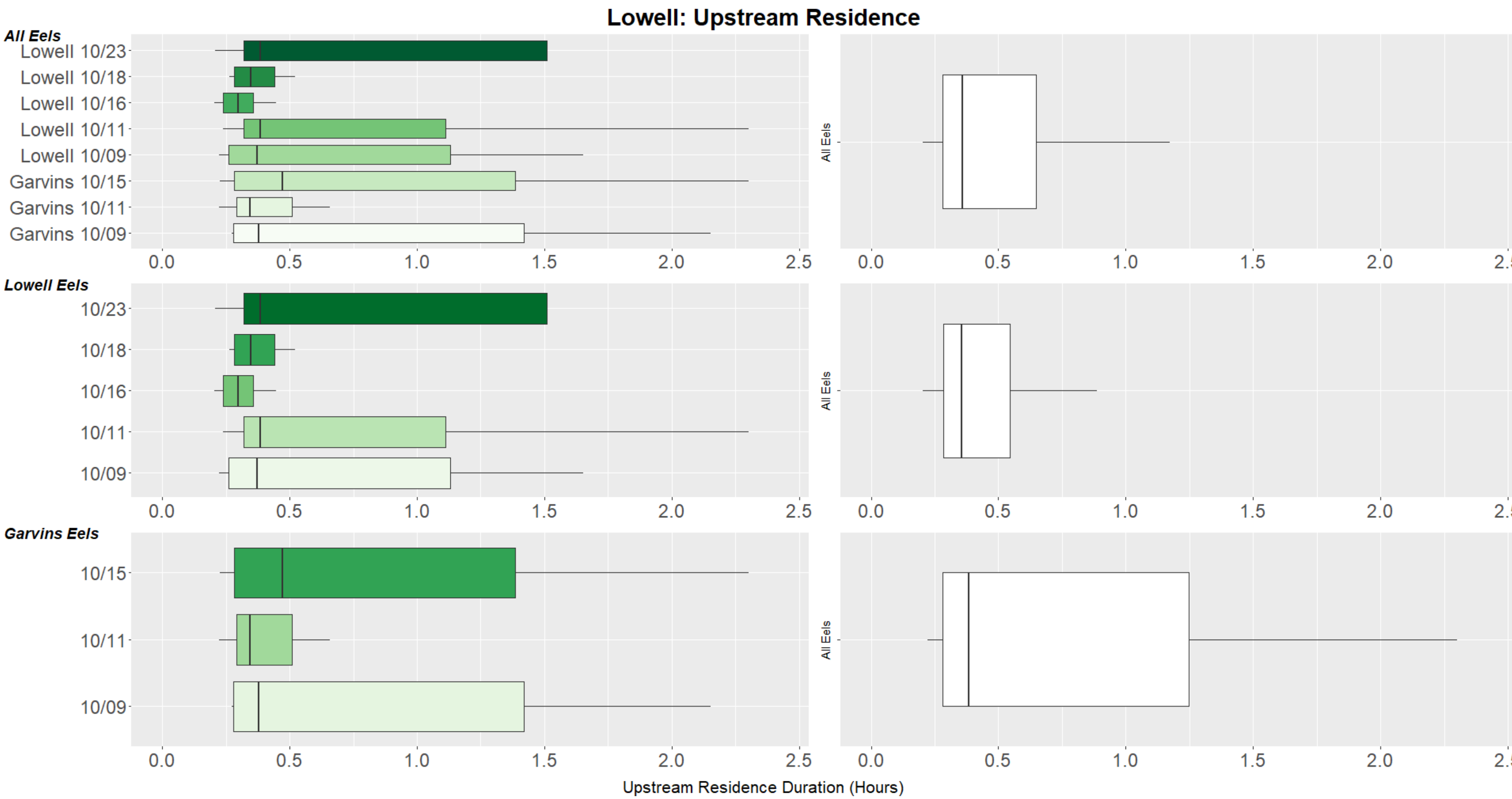

Figure 5–9. Boxplot of the residence duration upstream of Lowell for all radio-tagged eels (top panel), radio-tagged eels released upstream of Project boundary (middle panel) and upstream of Garvins Falls Dam (bottom panel).[5]

[5] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

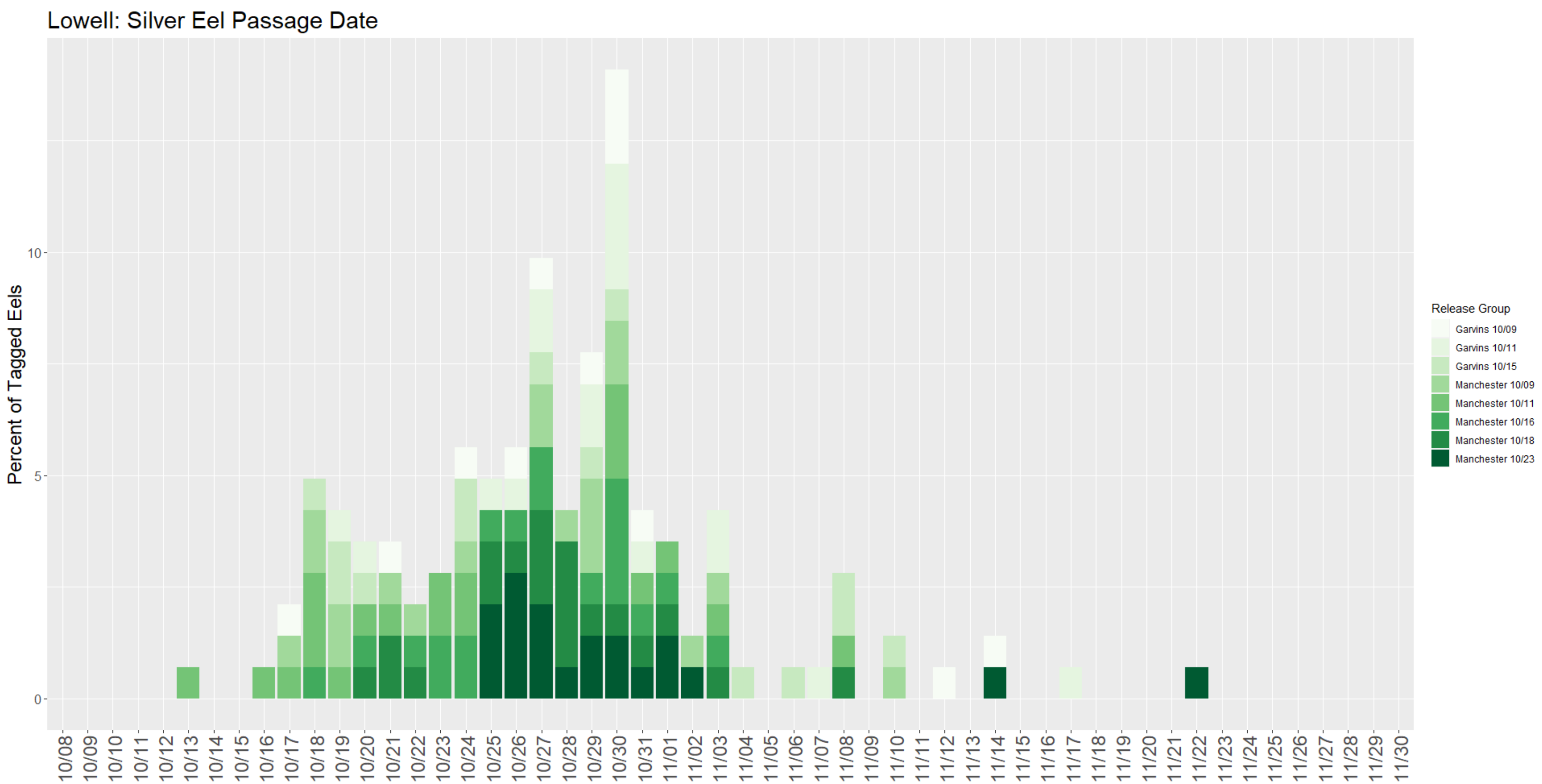

Figure 5–10. Distribution of Pawtucket Dam downstream passage dates for radio-tagged eels originally released upstream of the Project boundary (Manchester) and upstream of Garvins Falls Dam (Garvins Falls).

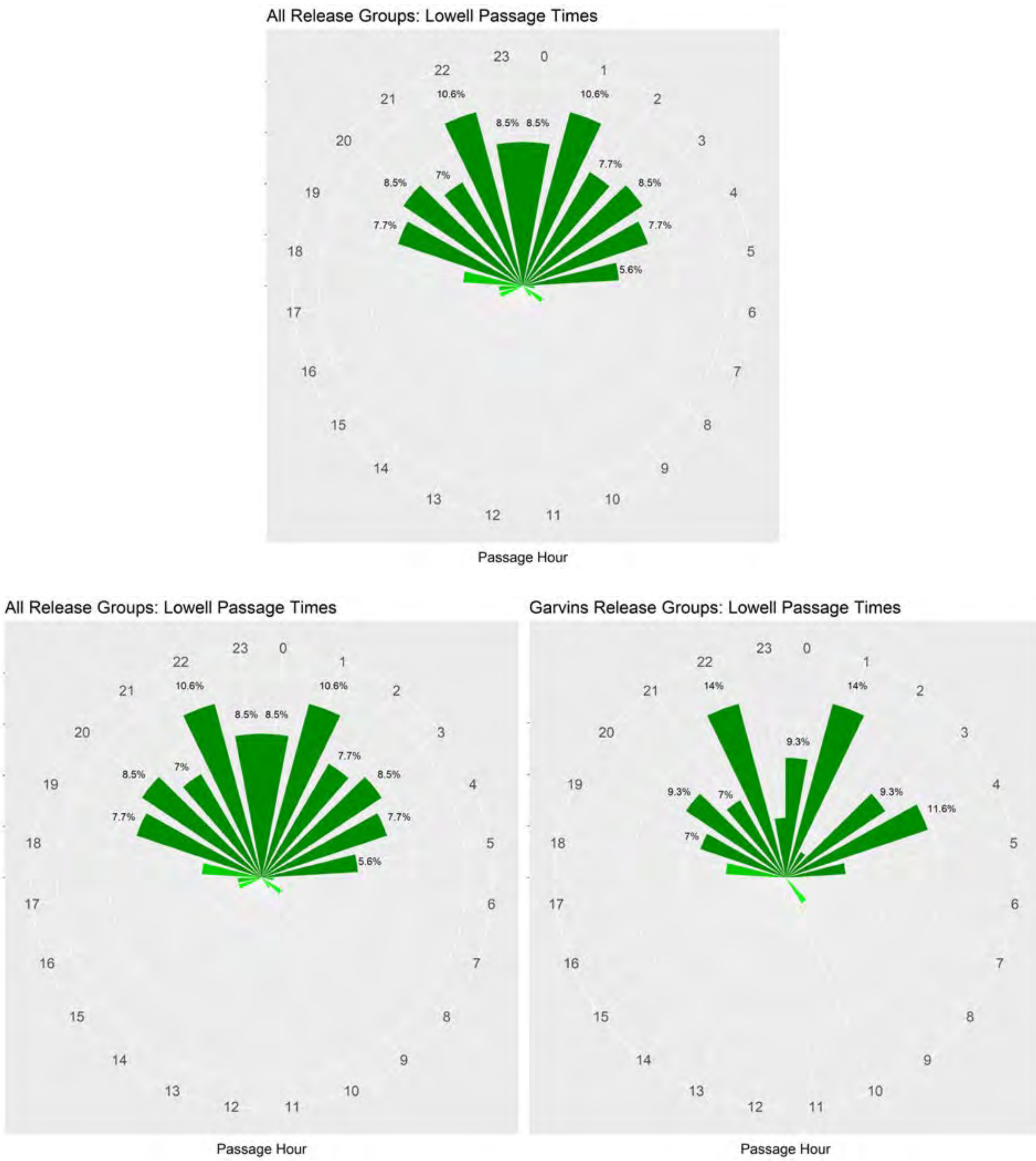

Figure 5–11. Distribution of downstream passage time for all radio-tagged silver eels (top), individuals released upstream of the Lowell Project boundary (bottom left) and upstream of Garvins Falls (bottom right)[6].

[6] Color shaded to represent light conditions: dark green corresponds to overnight hours, moderate green to crepuscular hours, and bright hours correspond to daylight hours.

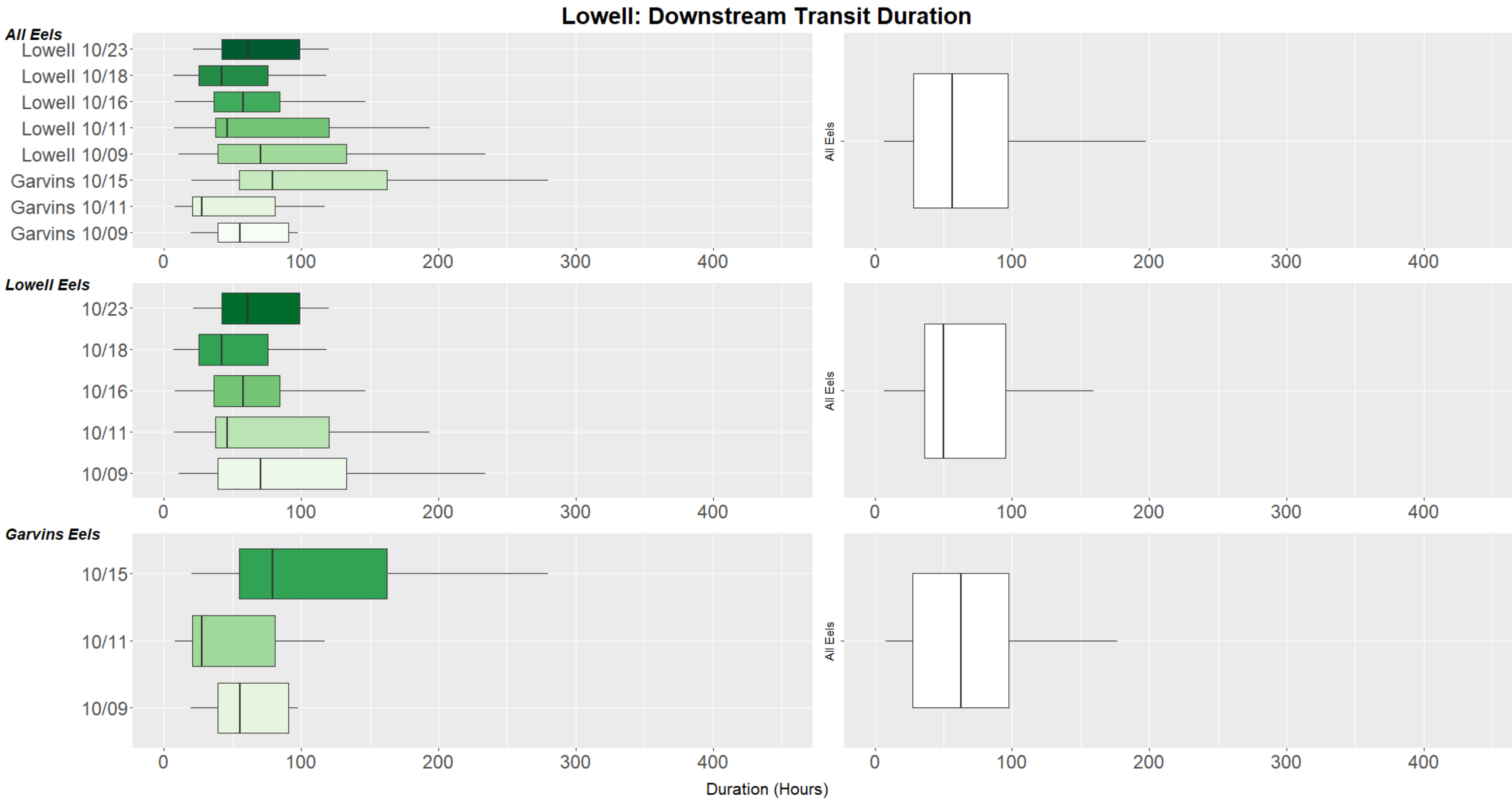

Figure 5–12. Boxplot of the downstream transit duration from Lowell to Lawrence for all radio-tagged eels (top panel), radio-tagged eels released upstream of Project boundary (middle panel) and upstream of Garvins Falls Dam (bottom panel).[7]

[7] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

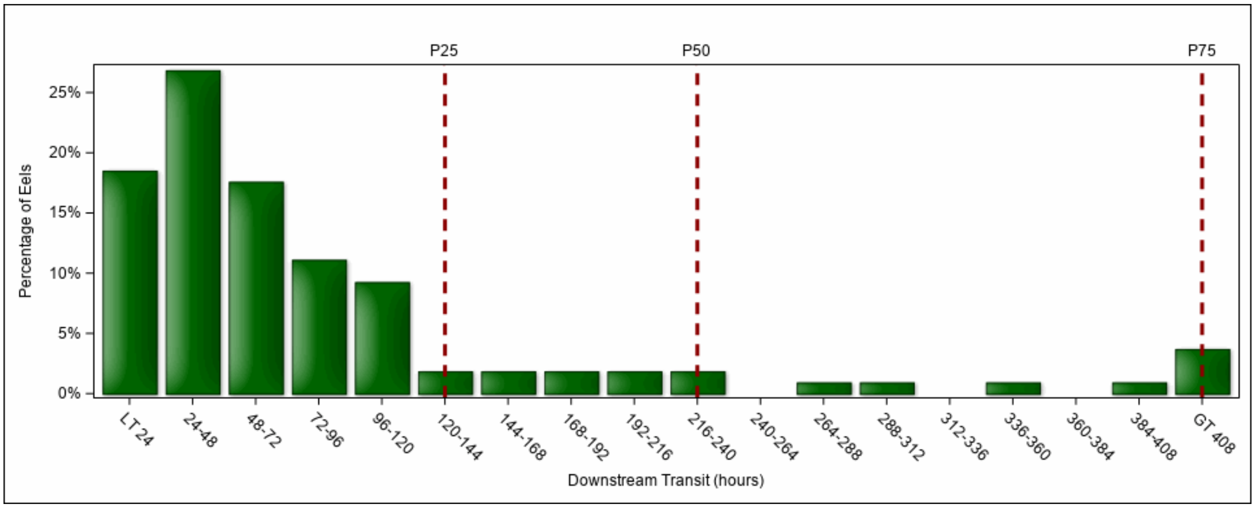

Figure 5–13. Distribution of downstream transit duration from Lowell to Lawrence for radio-tagged silver eels released upstream of the Lowell Project boundary and Garvins Falls. Vertical lines represent the 25th, 50th, and 75th percentiles for downstream transit durations from Lowell to Lawrence for freshly-dead drift eels.

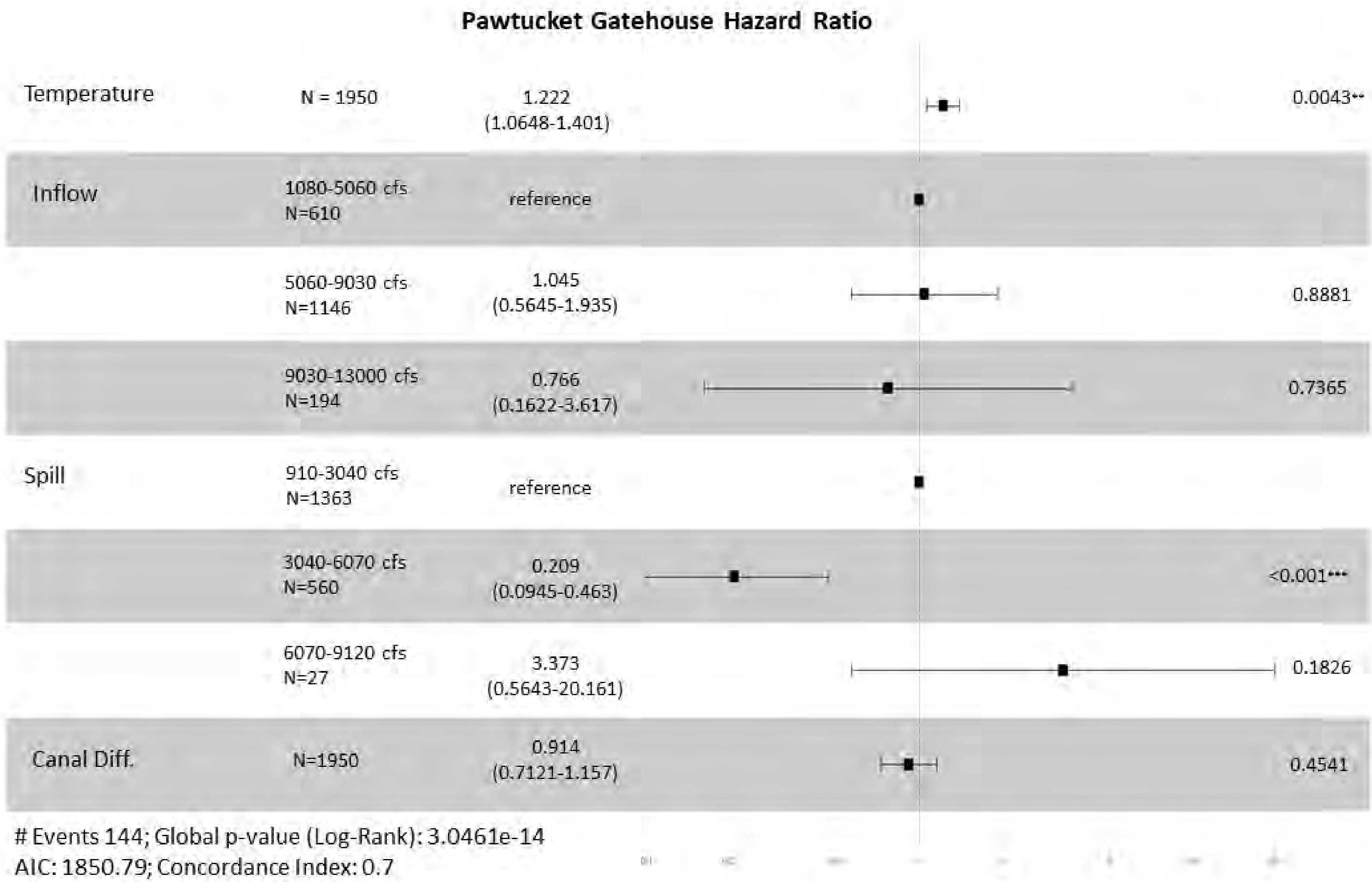

Figure 5–14. Cox proportional hazards model results for passage success of radio-tagged adult American eels at the Pawtucket Gatehouse.

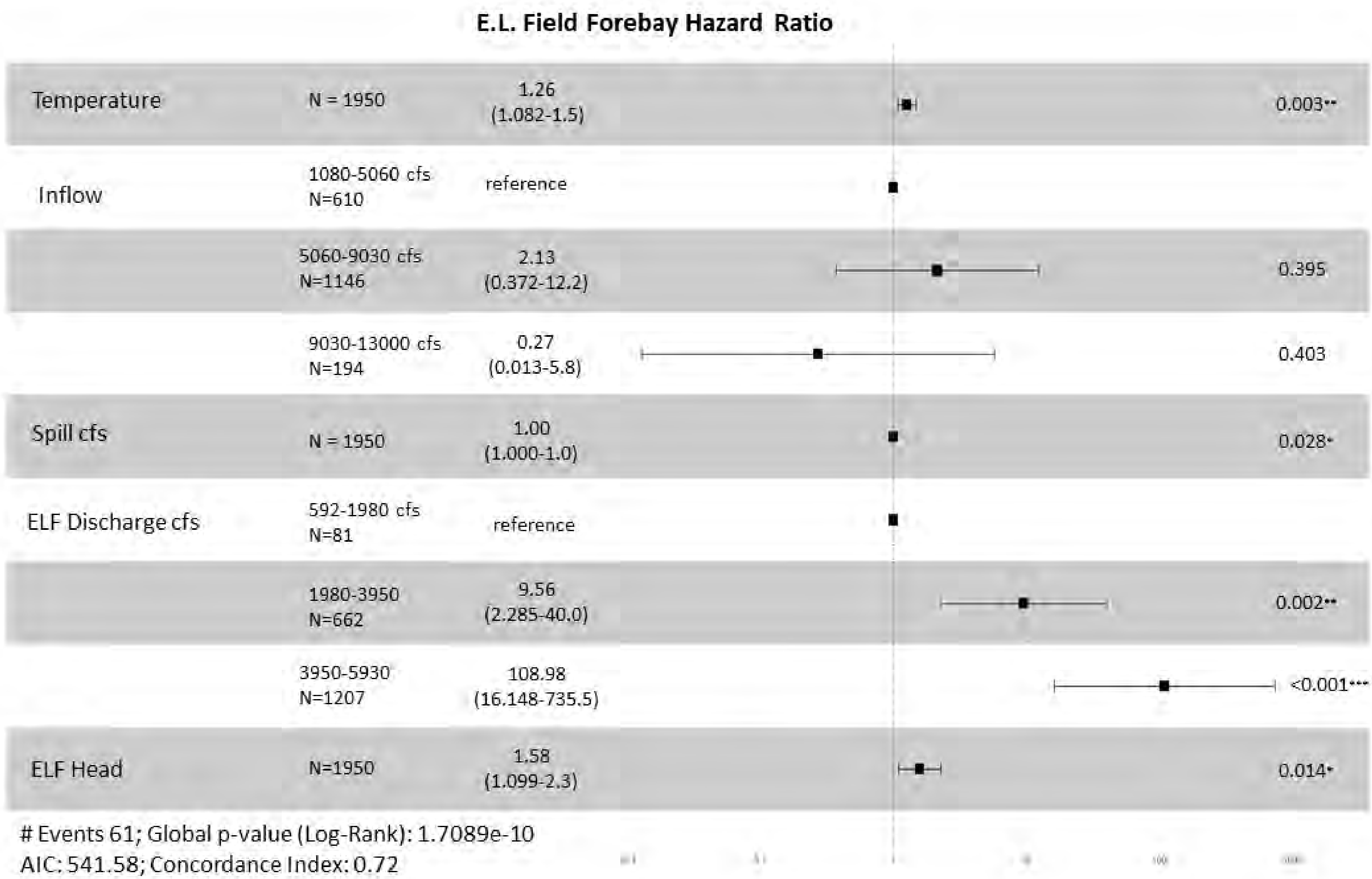

Figure 5–15. Cox proportional hazards model results for passage success of radio-tagged adult American eels at the E.L. Field Powerhouse forebay.

6 Summary

An evaluation of the potential impacts on the outmigration of adult silver-phase American eels was conducted in support of the FERC relicensing of the Lowell Project on the Merrimack River. Downstream passage effectiveness was evaluated using radio-telemetry during the 2019 fall migration season (October 9 to November 30, 2019). Monitoring of outmigrating adult American eels focused on the evaluation of movement through the Project impoundment, residence time immediately upstream of the Pawtucket Dam and prior to passage, passage route utilization and estimation of downstream passage survival at the Project.

A total of 102 adult silver eels were tagged and released at a shoreline location approximately 11 miles upstream of the upper end of the Lowell Project impoundment. Their subsequent downstream arrival and passage at the Project was monitored via a series of fixed-location telemetry receivers within the Lowell Project area. Arrival and downstream passage information was also monitored for 60 radio-tagged individuals released upstream of the Garvins Falls Dam as part of a separate study. The majority of individuals (152 of the 162) were obtained from a commercial vendor operating on the St. Croix River, Maine. The New Hampshire Fish and Game Department provided an additional 12 adult eels collected by a weir in the Soucook River, ten of which were also radio-tagged and released upstream of the Lowell impoundment. All 162 individuals were surgically radio-tagged and were released into the Merrimack over a range of release dates between October 9 and 23.

Radio-tagged eels moved through the 23 mile long Project impoundment in a median duration of 2.1 days. Upon initial detection at the Pawtucket Dam, the median duration of time spent immediately upstream of the dam structure was 0.4 hours with 94% passing downstream within the first 24 hours of their initial detection. Closer examination of the total residence time for radio-tagged eels indicated that the 95% of individuals passing through the Pawtucket Gatehouse did so in 30 minutes or less and upon entry into the Northern Canal the median residence duration prior to downstream passage was 0.2 hours.

Outmigrating adult eels encountering the Pawtucket Dam can (1) pass through the Pawtucket Gatehouse and enter the power canal, (2) pass downstream over Pawtucket Dam via spill, or (3) enter the Pawtucket Canal and navigate downstream via the downtown canal system. Individuals which enter the Northern Canal can pass downstream via one of the two turbine units at the E.L. Field Powerhouse, utilize the downstream bypass, or pass via the surge gate (operated only in the event of a station trip). During the 2019 evaluation there was no use of the downtown canal system. The majority of radio-tagged individuals passed through the Pawtucket Gatehouse and approached the E.L. Field powerhouse with 92.5% eventually passing downstream via the turbine units. Use of the existing downstream bypass system was limited to only two individuals. Downstream passage at the Project peaked during late October with all passage events completed by October 31. The majority of downstream passage events occurred during the evening and overnight hours.

Downstream passage survival was estimated for all radio-tagged eels from the point of initial detection upstream of the Pawtucket Dam downstream to Lawrence. This resulted in an estimated downstream passage survival for silver-phase American eel at Lowell of 75.5% (75% CI = 71.4%-79.6%). This estimate of downstream passage survival for adult eels at the Project includes any background (i.e., natural) or tagging-related mortality for the species in the reach from approach to the Pawtucket Dam to Lawrence. As a result, this estimate should be viewed as a minimum estimate of total project survival (i.e., due solely to project effects) for adult eels at the Project. Due to the limited distribution of downstream passage route selection, route-specific estimates of passage were developed for only individuals using turbine units at the E.L. Field powerhouse (n = 136; 75.0% survival; 75% CI = 70.6%-79.4%). The limited number of radio-tagged eels passing the Project via spill or the downstream bypass system were all determined to have successfully approached the Lawrence Project following downstream passage at Lowell.

7 Variances from FERC-Approved Study Plan

The FERC-approved RSP indicated that a total of 100 radio-tagged silver-phase American eels would be released just upstream of upper boundary of the Project impoundment. The availability of two additional transmitters and test eels resulted in a total of 102 radio-tagged individuals released upstream of Lowell. To further enhance the sample size for evaluation of downstream passage, Boott also monitored the passage of radio-tagged silver-phase adult eels released further upstream in the Merrimack River. This resulted in an additional 45 individuals which approached Lowell and were available for analysis. There were no additional variances from the FERC-approved study plan.

8 References

Castro-Santos, T. and R. Perry. 2012. Time-to-event analysis as a framework for quantifying fish passage performance. Pages 427-452 *in* N.S. Adams, J.W. Beeman, and J.H. Eiler, editors. Telemetry techniques: a user guide for fisheries research. American Fisheries Society, Bethesda, Maryland.

Lebreton, J.D., K.P. Burnham, J. Clobert, and D.R. Anderson. 1992. Modeling survival and testing biological hypotheses using marked animals: a unified approach with case studies. Ecological Mongraphs 62: 67-118

R Core Team. 2020. R: A Language and Environment for Statistical Computing. Vienna, Austria.

White, G.C., and K.P. Burnham. 1999 Program MARK: Survival estimation from populations of marked animals. Bird Study 46: 120-139.

9 Appendices

Appendix A. Estimated weekly discharge values (cfs) for the Guard Locks, Swamp Locks, Hamilton Station, Section 8 Station, John Street Station, Boott Gate and Lower Locks.

BOOTT HYDROPOWER DOWNTOWN OPERATIONS: ESTIMATED FLOWS

Date	10/10/2019	10/17/2019	10/23/2019	10/31/2019	11/7/2019	11/12/2019	11/13/2019	11/19/2019
Time	900	1100	900	1445	1000	1530	1600	1200

Guard Locks								
Gate 1	197	197	197	246	246	529	529	246
Gate 2	128	128	128	0	0	0	0	0
Gate 3	0	0	0	0	0	0	0	0
Gate 4	0	0	0	0	0	176	176	0
Gate 5	0	0	0	197	197	441	441	246
Total	325	325	325	443	443	1145	1145	493

Swamp Locks								
Gate 1	0	0	0	0	0	0	0	0
Gate 2	252	252	252	252	252	492	492	252
Bayboards opened	0	0	0	0	0	0	0	0
Total	252	252	252	252	252	492	492	252

Hamilton								
Unit 1	26	13	13	13	13	100	109	0
Unit 2	13	13	13	13	13	158	127	0
Unit 3	20	20	20	20	20	0	0	0
Unit 4	10	10	10	10	10	127	127	0
Unit 5	17	17	17	17	17	14	14	0
Hamilton Wasteway	0	0	0	0	0	0	0	0
Total	86	73	73	73	73	399	377	0

Section 8								
Unit 1	0	0	0	0	0	0	0	0
Unit 2	0	0	0	0	0	133	133	0
Unit 3	75	75	75	75	75	0	0	0
Total	75	75	75	75	75	133	133	0

John St.								
Unit 3	0	0	0	0	0	0	0	0
Unit 4	0	0	0	0	0	0	0	0
Unit 5	0	0	0	0	0	0	0	0
Unit 6	0	0	0	0	0	236	0	0
Total	0	0	0	0	0	236	0	0

Boott Gate								
Gate	0	0	0	0	0	0	399	0
Bayboards opened	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	399	0

Lower Locks								
Gate	120	120	120	120	120	120	120	120
Bayboards opened	0	0	0	0	0	0	0	0
Total	120	120	120	120	120	120	120	120

Appendix B. Silver eel source, release, and biocharacteristics information for the 2019 downstream passage assessment at Lowell.

Frequency	ID	Source Location	Release		Total Length (mm)	Eye Measurements		
			Location	Date		Horizontal (mm)	Vertical (mm)	Index
149.340	10	St. Croix	Garvins	10/9/2019	815	10.2	10.2	10.0
149.340	11	St. Croix	Garvins	10/9/2019	842	10.2	10.1	9.5
149.340	12	St. Croix	Garvins	10/9/2019	764	9.5	9.2	9.0
149.340	13	St. Croix	Garvins	10/9/2019	744	9.9	10.0	10.5
149.340	14	St. Croix	Garvins	10/9/2019	723	8.8	9.0	8.6
149.340	15	St. Croix	Garvins	10/9/2019	720	9.5	9.3	9.6
149.340	16	St. Croix	Garvins	10/9/2019	821	9.9	9.7	9.1
149.340	17	St. Croix	Garvins	10/9/2019	874	11.2	10.9	11.0
149.340	18	St. Croix	Garvins	10/9/2019	892	10.0	10.0	8.8
149.340	19	St. Croix	Garvins	10/9/2019	824	9.7	9.8	9.1
149.360	20	St. Croix	Garvins	10/9/2019	807	9.5	9.1	8.4
149.360	21	St. Croix	Garvins	10/9/2019	838	10.4	10.2	9.9
149.360	22	St. Croix	Garvins	10/9/2019	817	9.2	9.0	7.9
149.360	23	St. Croix	Garvins	10/9/2019	912	10.0	9.9	8.5
149.360	24	St. Croix	Garvins	10/9/2019	919	10.1	10.1	8.7
149.360	25	St. Croix	Garvins	10/9/2019	975	10.2	10.2	8.4
149.360	26	St. Croix	Garvins	10/9/2019	917	10.0	10.0	8.6
149.360	27	St. Croix	Garvins	10/9/2019	806	9.2	9.3	8.4
149.360	28	St. Croix	Garvins	10/9/2019	883	9.9	9.9	8.7
149.360	29	St. Croix	Garvins	10/9/2019	946	10.5	10.1	8.8
149.340	90	St. Croix	Lowell	10/9/2019	727	.	.	.
149.340	91	St. Croix	Lowell	10/9/2019	734	11.0	8.0	9.7
149.340	92	St. Croix	Lowell	10/9/2019	883	10.5	9.0	8.5
149.340	93	St. Croix	Lowell	10/9/2019	896	12.0	10.0	10.6
149.340	94	St. Croix	Lowell	10/9/2019	709	9.0	7.0	7.1
149.340	95	St. Croix	Lowell	10/9/2019	901	12.2	9.8	10.5
149.340	96	St. Croix	Lowell	10/9/2019	811	9.5	8.1	7.5
149.340	97	St. Croix	Lowell	10/9/2019	814	9.8	8.7	8.3
149.340	98	St. Croix	Lowell	10/9/2019	742	7.5	6.8	5.4
149.340	99	St. Croix	Lowell	10/9/2019	901	11.6	10.9	11.0
149.360	100	St. Croix	Lowell	10/9/2019	853	11.2	9.5	9.9
149.360	101	St. Croix	Lowell	10/9/2019	956	10.2	9.8	8.2
149.360	102	St. Croix	Lowell	10/9/2019	995	10.0	9.5	7.5
149.360	103	St. Croix	Lowell	10/9/2019	988	10.0	9.2	7.3
149.360	104	St. Croix	Lowell	10/9/2019	803	10.0	9.1	8.9
149.360	105	St. Croix	Lowell	10/9/2019	1019	11.1	10.0	8.6
149.360	106	St. Croix	Lowell	10/9/2019	865	10.8	9.9	9.7
149.360	107	St. Croix	Lowell	10/9/2019	1032	11.6	10.0	8.9
149.360	108	St. Croix	Lowell	10/9/2019	796	7.9	7.5	5.9
149.360	109	St. Croix	Lowell	10/9/2019	815	9.8	8.9	8.4

Frequency	ID	Source Location	Release		Total Length (mm)	Eye Measurements		
			Location	Date		Horizontal (mm)	Vertical (mm)	Index
149.340	30	St. Croix	Garvins	10/11/2019	742	8.3	8.1	7.1
149.340	31	St. Croix	Garvins	10/11/2019	711	9.8	9.0	9.8
149.340	32	St. Croix	Garvins	10/11/2019	808	10.8	10.2	10.7
149.340	33	St. Croix	Garvins	10/11/2019	765	9.3	9.3	8.8
149.340	34	St. Croix	Garvins	10/11/2019	793	10.0	9.9	9.8
149.340	35	St. Croix	Garvins	10/11/2019	740	9.7	9.3	9.5
149.340	36	St. Croix	Garvins	10/11/2019	842	11.3	10.8	11.3
149.340	37	St. Croix	Garvins	10/11/2019	758	8.7	8.8	7.9
149.340	38	St. Croix	Garvins	10/11/2019	791	9.9	10.0	9.8
149.340	39	St. Croix	Garvins	10/11/2019	797	9.0	8.4	7.5
149.360	40	St. Croix	Garvins	10/11/2019	884	10.6	9.9	9.3
149.360	41	St. Croix	Garvins	10/11/2019	873	10.1	10.0	9.0
149.360	42	St. Croix	Garvins	10/11/2019	734	8.9	8.6	8.2
149.360	43	St. Croix	Garvins	10/11/2019	782	8.9	9.0	8.0
149.360	44	St. Croix	Garvins	10/11/2019	646	7.9	7.8	7.5
149.360	45	St. Croix	Garvins	10/11/2019	757	9.9	9.5	9.7
149.360	46	St. Croix	Garvins	10/11/2019	843	10.4	10.0	9.7
149.360	47	St. Croix	Garvins	10/11/2019	798	10.1	10.0	10.0
149.360	48	St. Croix	Garvins	10/11/2019	806	9.2	9.0	8.1
149.360	49	St. Croix	Garvins	10/11/2019	816	10.2	9.8	9.6
149.340	110	St. Croix	Lowell	10/11/2019	875	11.0	9.8	9.7
149.340	111	St. Croix	Lowell	10/11/2019	724	9.5	8.5	8.8
149.340	112	St. Croix	Lowell	10/11/2019	845	11.1	10.0	10.3
149.340	113	St. Croix	Lowell	10/11/2019	876	10.1	9.2	8.3
149.340	114	St. Croix	Lowell	10/11/2019	804	11.0	9.8	10.6
149.340	115	St. Croix	Lowell	10/11/2019	816	10.3	9.8	9.7
149.340	116	St. Croix	Lowell	10/11/2019	793	9.1	8.8	7.9
149.340	117	St. Croix	Lowell	10/11/2019	969	10.6	9.5	8.2
149.340	118	St. Croix	Lowell	10/11/2019	751	9.0	7.9	7.5
149.340	119	St. Croix	Lowell	10/11/2019	706	7.1	6.0	4.8
149.360	120	St. Croix	Lowell	10/11/2019	902	10.2	9.8	8.7
149.360	121	St. Croix	Lowell	10/11/2019	749	10.2	8.1	8.8
149.360	122	St. Croix	Lowell	10/11/2019	787	8.0	7.2	5.8
149.360	123	St. Croix	Lowell	10/11/2019	808	9.9	9.0	8.7
149.360	124	St. Croix	Lowell	10/11/2019	894	10.7	9.6	9.1
149.360	125	St. Croix	Lowell	10/11/2019	854	10.3	9.6	9.1
149.360	126	St. Croix	Lowell	10/11/2019	911	13.0	10.2	11.6
149.360	127	St. Croix	Lowell	10/11/2019	890	10.3	9.5	8.6
149.360	128	St. Croix	Lowell	10/11/2019	932	12.0	10.1	10.3
149.360	129	St. Croix	Lowell	10/11/2019	934	10.4	9.3	8.2
149.340	50	St. Croix	Garvins	10/15/2019	795	10.7	9.5	10.1
149.340	51	St. Croix	Garvins	10/15/2019	928	10.1	10.1	8.6
149.340	52	St. Croix	Garvins	10/15/2019	894	9.8	8.6	7.4
149.340	53	St. Croix	Garvins	10/15/2019	810	10.9	9.8	10.4

Frequency	ID	Source Location	Release		Total Length (mm)	Eye Measurements		
			Location	Date		Horizontal (mm)	Vertical (mm)	Index
149.340	54	St. Croix	Garvins	10/15/2019	884	10.2	9.6	8.7
149.340	55	St. Croix	Garvins	10/15/2019	775	10.0	8.8	9.0
149.340	56	St. Croix	Garvins	10/15/2019	941	10.2	9.7	8.3
149.340	57	St. Croix	Garvins	10/15/2019	995	13.4	12.2	12.9
149.340	58	St. Croix	Garvins	10/15/2019	741	9.2	8.7	8.5
149.340	59	St. Croix	Garvins	10/15/2019	829	10.3	8.9	8.7
149.360	60	St. Croix	Garvins	10/15/2019	834	10.5	9.1	9.0
149.360	61	St. Croix	Garvins	10/15/2019	802	9.4	8.8	8.1
149.360	62	St. Croix	Garvins	10/15/2019	728	8.6	7.9	7.3
149.360	63	St. Croix	Garvins	10/15/2019	999	12.8	11.0	11.1
149.360	64	St. Croix	Garvins	10/15/2019	972	11.0	10.1	9.0
149.360	65	St. Croix	Garvins	10/15/2019	766	8.0	7.4	6.1
149.360	66	St. Croix	Garvins	10/15/2019	798	9.2	8.3	7.5
149.360	67	St. Croix	Garvins	10/15/2019	996	12.3	11.3	11.0
149.360	68	St. Croix	Garvins	10/15/2019	845	11.0	9.9	10.1
149.360	69	St. Croix	Garvins	10/15/2019	824	9.3	8.0	7.1
149.340	130	St. Croix	Lowell	10/16/2019	1025	11.5	9.2	8.2
149.340	131	St. Croix	Lowell	10/16/2019	842	10.0	9.1	8.5
149.340	132	St. Croix	Lowell	10/16/2019	889	11.0	9.9	9.6
149.340	133	St. Croix	Lowell	10/16/2019	751	8.8	7.6	7.0
149.340	134	St. Croix	Lowell	10/16/2019	812	9.1	7.6	6.7
149.340	135	St. Croix	Lowell	10/16/2019	716	8.3	7.3	6.7
149.340	136	St. Croix	Lowell	10/16/2019	830	9.7	8.8	8.1
149.340	137	St. Croix	Lowell	10/16/2019	857	10.0	9.1	8.4
149.340	138	St. Croix	Lowell	10/16/2019	777	10.3	8.9	9.3
149.340	139	St. Croix	Lowell	10/16/2019	762	9.0	7.8	7.3
149.360	140	St. Croix	Lowell	10/16/2019	691	7.8	6.9	6.1
149.360	141	St. Croix	Lowell	10/16/2019	702	9.2	7.3	7.6
149.360	142	St. Croix	Lowell	10/16/2019	969	11.1	9.9	8.9
149.360	143	St. Croix	Lowell	10/16/2019	819	11.5	9.4	10.5
149.360	144	St. Croix	Lowell	10/16/2019	721	9.1	8.2	8.2
149.360	145	St. Croix	Lowell	10/16/2019	820	10.0	9.0	8.6
149.360	146	St. Croix	Lowell	10/16/2019	956	10.1	9.0	7.5
149.360	147	St. Croix	Lowell	10/16/2019	823	9.9	8.3	7.9
149.360	148	St. Croix	Lowell	10/16/2019	886	10.4	9.1	8.4
149.360	149	St. Croix	Lowell	10/16/2019	794	9.0	7.8	7.0
149.340	70	St. Croix	Lowell	10/18/2019	791	8.9	7.2	6.4
149.340	71	St. Croix	Lowell	10/18/2019	836	9.4	8.1	7.2
149.340	72	St. Croix	Lowell	10/18/2019	767	9.8	8.7	8.8
149.340	73	St. Croix	Lowell	10/18/2019	890	11.0	9.9	9.6
149.340	74	St. Croix	Lowell	10/18/2019	729	10.3	8.6	9.6
149.340	75	St. Croix	Lowell	10/18/2019	909	11.8	10.6	10.8
149.340	76	St. Croix	Lowell	10/18/2019	782	9.5	8.1	7.8
149.340	77	St. Croix	Lowell	10/18/2019	811	10.5	9.2	9.4

Frequency	ID	Source Location	Release		Total Length (mm)	Eye Measurements		
			Location	Date		Horizontal (mm)	Vertical (mm)	Index
149.340	78	St. Croix	Lowell	10/18/2019	879	10.6	9.2	8.8
149.340	79	St. Croix	Lowell	10/18/2019	705	9.1	7.3	7.5
149.360	80	St. Croix	Lowell	10/18/2019	891	10.6	9.2	8.6
149.360	81	St. Croix	Lowell	10/18/2019	730	8.9	7.8	7.5
149.360	82	St. Croix	Lowell	10/18/2019	815	9.2	8.3	7.4
149.360	83	St. Croix	Lowell	10/18/2019	732	9.0	8.1	7.8
149.360	84	St. Croix	Lowell	10/18/2019	796	9.1	8.0	7.2
149.360	85	St. Croix	Lowell	10/18/2019	938	11.1	9.1	8.5
149.360	86	St. Croix	Lowell	10/18/2019	679	8.7	7.6	7.7
149.360	87	St. Croix	Lowell	10/18/2019	939	10.6	9.0	8.0
149.360	88	St. Croix	Lowell	10/18/2019	790	10.7	8.9	9.5
149.360	89	St. Croix	Lowell	10/18/2019	853	9.9	8.2	7.5
149.340	150	St. Croix	Lowell	10/23/2019	933	11.5	10.3	10.0
149.340	151	St. Croix	Lowell	10/23/2019	756	9.8	8.5	8.7
149.340	152	St. Croix	Lowell	10/23/2019	757	10.0	8.5	8.9
149.340	153	St. Croix	Lowell	10/23/2019	708	10.8	10.0	12.0
149.340	154	St. Croix	Lowell	10/23/2019	898	10.2	9.8	8.7
149.340	155	St. Croix	Lowell	10/23/2019	709	10.0	9.5	10.5
149.340	156	St. Croix	Lowell	10/23/2019	813	11.0	10.6	11.3
149.340	157	St. Croix	Lowell	10/23/2019	752	9.8	8.5	8.7
149.340	158	St. Croix	Lowell	10/23/2019	942	10.5	10.5	9.2
149.340	159	St. Croix	Lowell	10/23/2019	719	9.3	8.0	8.2
149.360	160	Soucook	Lowell	10/23/2019	750	8.0	8.5	7.1
149.360	161	Soucook	Lowell	10/23/2019	693	9.1	9.0	9.3
149.360	162	Soucook	Lowell	10/23/2019	758	10.0	9.7	10.1
149.360	163	Soucook	Lowell	10/23/2019	862	8.9	9.1	7.4
149.360	164	Soucook	Lowell	10/23/2019	734	9.0	9.6	9.3
149.360	165	Soucook	Lowell	10/23/2019	760	9.1	9.6	9.0
149.360	166	Soucook	Lowell	10/23/2019	836	8.8	9.2	7.6
149.360	167	Soucook	Lowell	10/23/2019	792	8.8	9.0	7.9
149.360	168	Soucook	Lowell	10/23/2019	773	9.8	9.2	9.2
149.360	169	Soucook	Lowell	10/23/2019	774	9.1	9.0	8.3
149.360	170	St. Croix	Lowell	10/23/2019	750	8.3	9.0	7.8
149.340	171	St. Croix	Lowell	10/23/2019	747	9.0	9.0	8.5

Appendix C. Listing of manual tracking detections within the Lowell Project area.

River mile demarcations for reaches defined by stationary receivers:

Reach	River Mile	
	Upper End	Lower End
Station 19-Station 21	61.5	41.75
Station 35-Station 37	41.75	39.25
Station 37-Station 39	39.25	35.25
Station 39-Station 40	35.25	30.25

Date	Frequency	ID	RM	Location	Type
10/21/2019	149.340	74	42	Station 19-Station 21	Transit
10/28/2019	149.340	156	42	Station 19-Station 21	Transit
10/24/2019	149.360	21	42.5	Station 19-Station 21	Transit
10/24/2019	149.360	80	43.75	Station 19-Station 21	Transit
10/24/2019	149.340	139	44	Station 19-Station 21	Transit
11/6/2019	149.360	64	44.25	Station 19-Station 21	Transit
10/24/2019	149.340	58	44.5	Station 19-Station 21	Transit
10/24/2019	149.340	116	45.25	Station 19-Station 21	Transit
10/24/2019	149.360	101	47.75	Station 19-Station 21	Transit
11/6/2019	149.360	46	48	Station 19-Station 21	Transit
10/24/2019	149.340	53	49	Station 19-Station 21	Transit
10/24/2019	149.360	23	49.25	Station 19-Station 21	Transit
10/24/2019	149.360	142	49.25	Station 19-Station 21	Transit
10/24/2019	149.340	138	49.75	Station 19-Station 21	Transit
11/21/2019	149.340	159	49.75	Station 19-Station 21	Transit
10/24/2019	149.340	35	50.5	Station 19-Station 21	Transit
11/6/2019	149.360	89	50.5	Station 19-Station 21	Transit
10/24/2019	149.340	77	51.25	Station 19-Station 21	Transit
10/24/2019	149.340	95	51.25	Station 19-Station 21	Transit
11/6/2019	149.360	120	51.25	Station 19-Station 21	Transit
11/6/2019	149.340	17	51.5	Station 19-Station 21	Transit
11/6/2019	149.340	59	51.5	Station 19-Station 21	Transit
10/24/2019	149.360	41	52	Station 19-Station 21	Transit
11/6/2019	149.340	158	52.5	Station 19-Station 21	Transit
10/24/2019	149.360	83	52.75	Station 19-Station 21	Transit
11/6/2019	149.360	47	53	Station 19-Station 21	Transit
10/24/2019	149.360	147	53.25	Station 19-Station 21	Transit
10/24/2019	149.340	78	53.5	Station 19-Station 21	Transit
10/24/2019	149.360	166	53.5	Station 19-Station 21	Transit
10/24/2019	149.340	79	53.75	Station 19-Station 21	Transit
10/24/2019	149.360	105	54.25	Station 19-Station 21	Transit
10/24/2019	149.360	162	55.25	Station 19-Station 21	Transit
10/24/2019	149.360	20	55.5	Station 19-Station 21	Transit
10/24/2019	149.340	24	56.25	Station 19-Station 21	Stationary
10/24/2019	149.340	156	56.25	Station 19-Station 21	Transit

Date	Frequency	ID	RM	Location	Type
10/24/2019	149.340	171	56.25	Station 19-Station 21	Transit
10/24/2019	149.360	69	57.5	Station 19-Station 21	Transit
10/24/2019	149.360	165	59	Station 19-Station 21	Transit
10/24/2019	149.340	118	60.5	Station 19-Station 21	Transit
10/24/2019	149.340	10	61.25	Station 19-Station 21	Transit
11/11/2019	149.360	81	39.25	Station 35-Station 37	Stationary
11/18/2019	149.360	81	39.25	Station 35-Station 37	Stationary
11/25/2019	149.360	81	39.25	Station 35-Station 37	Stationary
11/25/2019	149.360	120	40.25	Station 35-Station 37	Transit
11/25/2019	149.340	171	40.25	Station 35-Station 37	Transit
11/11/2019	149.340	171	40.5	Station 35-Station 37	Transit
11/18/2019	149.360	120	40.75	Station 35-Station 37	Transit
11/18/2019	149.340	171	40.75	Station 35-Station 37	Transit
11/11/2019	149.340	55	41	Station 35-Station 37	Stationary
11/11/2019	149.360	102	41	Station 35-Station 37	Stationary
11/11/2019	149.340	131	41	Station 35-Station 37	Stationary
11/18/2019	149.340	55	41.25	Station 35-Station 37	Stationary
11/25/2019	149.340	55	41.25	Station 35-Station 37	Stationary
11/18/2019	149.360	80	41.25	Station 35-Station 37	Stationary
11/18/2019	149.360	102	41.25	Station 35-Station 37	Stationary
11/25/2019	149.360	102	41.25	Station 35-Station 37	Stationary
11/18/2019	149.360	108	41.25	Station 35-Station 37	Stationary
11/25/2019	149.360	108	41.25	Station 35-Station 37	Stationary
11/25/2019	149.340	131	41.25	Station 35-Station 37	Stationary
10/28/2019	149.340	35	41.5	Station 35-Station 37	Stationary
11/11/2019	149.340	35	41.5	Station 35-Station 37	Stationary
11/14/2019	149.360	132	41.5	Station 35-Station 37	Stationary
11/5/2019	149.360	103	35.25	Station 37-Station 39	Transit
11/5/2019	149.360	66	36.25	Station 37-Station 39	Transit
11/11/2019	149.340	154	36.25	Station 37-Station 39	Stationary
11/25/2019	149.360	164	36.25	Station 37-Station 39	Stationary
11/5/2019	149.340	154	36.5	Station 37-Station 39	Stationary
11/11/2019	149.360	164	36.5	Station 37-Station 39	Stationary
11/18/2019	149.360	164	36.5	Station 37-Station 39	Stationary
11/5/2019	149.360	65	36.75	Station 37-Station 39	Transit
11/5/2019	149.340	117	36.75	Station 37-Station 39	Stationary
11/11/2019	149.340	117	36.75	Station 37-Station 39	Stationary
11/18/2019	149.340	117	36.75	Station 37-Station 39	Stationary
11/25/2019	149.340	117	36.75	Station 37-Station 39	Stationary
11/5/2019	149.340	130	36.75	Station 37-Station 39	Stationary
11/5/2019	149.360	148	36.75	Station 37-Station 39	Stationary
11/11/2019	149.360	148	36.75	Station 37-Station 39	Stationary
11/25/2019	149.360	148	36.75	Station 37-Station 39	Stationary
11/5/2019	149.360	128	37	Station 37-Station 39	Transit
11/5/2019	149.360	164	37.5	Station 37-Station 39	Stationary
11/5/2019	149.340	155	37.75	Station 37-Station 39	Transit
11/5/2019	149.340	99	38	Station 37-Station 39	Stationary

Date	Frequency	ID	RM	Location	Type
11/5/2019	149.340	114	38	Station 37-Station 39	Transit
11/5/2019	149.360	22	38.25	Station 37-Station 39	Stationary
11/11/2019	149.360	22	38.25	Station 37-Station 39	Stationary
11/11/2019	149.340	93	38.25	Station 37-Station 39	Stationary
11/18/2019	149.340	93	38.25	Station 37-Station 39	Stationary
11/25/2019	149.340	93	38.25	Station 37-Station 39	Stationary
11/11/2019	149.340	99	38.25	Station 37-Station 39	Stationary
11/14/2019	149.340	99	38.25	Station 37-Station 39	Stationary
11/18/2019	149.340	99	38.25	Station 37-Station 39	Stationary
11/25/2019	149.340	99	38.25	Station 37-Station 39	Stationary
11/5/2019	149.340	33	38.5	Station 37-Station 39	Stationary
11/11/2019	149.340	33	38.5	Station 37-Station 39	Stationary
11/14/2019	149.360	33	38.5	Station 37-Station 39	Stationary
11/18/2019	149.340	33	38.5	Station 37-Station 39	Stationary
11/5/2019	149.360	145	38.5	Station 37-Station 39	Stationary
11/11/2019	149.360	145	38.5	Station 37-Station 39	Stationary
11/18/2019	149.360	145	38.5	Station 37-Station 39	Stationary
11/25/2019	149.360	145	38.5	Station 37-Station 39	Stationary
11/25/2019	149.340	33	39	Station 37-Station 39	Stationary
11/5/2019	149.360	41	39	Station 37-Station 39	Stationary
11/11/2019	149.360	41	39	Station 37-Station 39	Stationary
11/14/2019	149.360	41	39	Station 37-Station 39	Stationary
11/18/2019	149.360	41	39	Station 37-Station 39	Stationary
11/25/2019	149.360	41	39	Station 37-Station 39	Stationary
11/5/2019	149.360	144	39	Station 37-Station 39	Transit
11/11/2019	149.360	144	39	Station 37-Station 39	Stationary
11/14/2019	149.360	144	39	Station 37-Station 39	Stationary
11/18/2019	149.360	144	39	Station 37-Station 39	Stationary
11/25/2019	149.360	144	39	Station 37-Station 39	Stationary
11/5/2019	149.340	52	33.25	Station 39-Station 40	Stationary
11/5/2019	149.340	92	33.25	Station 39-Station 40	Transit
11/5/2019	149.360	85	34	Station 39-Station 40	Stationary
11/5/2019	149.340	90	34.5	Station 39-Station 40	Transit
11/18/2019	149.360	66	35	Station 39-Station 40	Transit

Appendix D. October 23, 2019 eel release: Soucook and St. Croix River eels.

The October 23, 2019 release of radio-tagged eels upstream of the Lowell impoundment was comprised of 10 individuals originating from the Soucook River in New Hampshire and 12 individuals originating from the St. Croix River, Maine. Table D-1 provides a comparison of the range of values for movement indices evaluated during this study and between the two groups. For most metrics the median duration did not appear to differ between the two groups. The median duration to pass downstream through the Lowell impoundment was nearly twice as long for eels originating in the St. Croix River. However, the minimum duration to do so was nearly the same for eels from both locations.

With regard to passage at Lowell there was no differentiation in passage route usage. All ten eels originating in the Soucook River and eleven of the twelve[8] eels originating in the St. Croix River passed downstream via the turbine units. Based on downriver detections, 83% of the eels originating in the St. Croix River and 80% of the eels originating in the Soucook River reached the Essex Dam in Lawrence.

Table D-1. Minimum, maximum, and quartile values for the suite of movement metrics assessed for radio-tagged eels originating from the Soucook and St. Croix Rivers and released upstream of the Lowell project boundary on October 23, 2019.

Movement Metric	Origin	Value				
		Min	Max	P25	Median	P75
Impoundment Duration (hrs)	Soucook	23.2	51.5	23.4	26.7	26.8
	St. Croix	25.4	71.8	29.0	49.9	66.0
Upstream Residence Duration (hrs)	Soucook	0.3	94.4	0.3	0.5	22.6
	St. Croix	0.2	165.3	0.3	0.4	1.5
Pawtucket Gatehouse Passage (hrs)	Soucook	<0.1	93.5	0.1	0.1	0.2
	St. Croix	<0.1	0.2	0.1	0.1	0.1
Northern Canal Residence (hrs)	Soucook	0.1	38.6	0.2	0.3	0.4
	St. Croix	0.1	165.1	0.2	0.2	0.3
Downstream Travel: Lowell to Lawrence (hrs)	Soucook	41.9	359.8	47.0	57.6	102.8
	St. Croix	21.1	196.7	26.1	60.9	97.6

[8] Passage route for one individual was left as unknown.

Appendix E. Responses to September 30, 2020 Revised ISR meeting comments.

Comment No.	Agency	Comment	Response
1	FERC	In Section 5.1 of the Revised ISR report it was stated that "Due to overriding safety concerns, Boott limited operation of the turbine units within the downtown canal system during the study period." Can Boott provide better definition of the referenced safety concerns? Is the operation of gates to provide flows through the downtown canal system a normal occurrence when units are offline?	Boott decided to cease operation of the downtown units due electrical hazard concerns for all of the units, in combination with mechanical and other issues with several of the units. The cost to return the units to safe, reliable service was deemed to be economically infeasible relative to the limited amount of generation historically gained from these units. When the downtown units are offline, Boott only operates the canal gates to the extent necessary to manage canal water levels.
2	FERC	In Section 5.1 of the Revised ISR report it was stated that "Flows to the downstream canal system represented between 15-20% of the 2,000 cfs capacity during October and between 20-57% of the 2,000 cfs capacity during November." Can Boott add language to the report to summarize historic canal flows?	Historically, the downtown units have only been operated when there is river flow in excess of the hydraulic capacity of the E.L. Field Powerhouse's two units, typically during spring runoff (March - May). Boott has never directly measured canal flows, and can only estimate flows using the generation records for the downtown units, which are metered separately from the E.L. Field units. For example, for the period 1998 – 2007, estimated average monthly canal flows used for generation were approximately 575 cfs, 800 cfs and 550 cfs for March, April and May respectively. Maximum generation flows for these months were

			approximately 1,500 to 1,600 cfs. Average and maximum generation flows during the eel outmigration period were approximately 90 cfs and 1,200 cfs respectively during October, and 115 and 900 cfs respectively during November.
3	FERC	Can Boott provide a Microsoft Excel file of station operations for the study period to allow for calculation of flow proportions by passage route?	Hourly operations records have been provided in Appendix G and include values for headpond elevation, forebay elevation, tailrace elevation, inflow, Unit 1 discharge, Unit 2 discharge, downstream bypass discharge, upstream fishway flow, downtown canal flow, and spill flow. The reported station operations at the time of downstream passage for each radio-tagged fish were identified. Section 5.7 of the final report has been modified to include a summary of the proportional volume of discharge through the selected passage route relative to non-selected routes (e.g., if a fish passed downstream via the turbines values reported for that individual would include the volume of water passing through the turbines vs. the volume of water passing downstream via alternative routes (i.e., downstream bypass or spill).
4	FERC	Can you provide a summary of the number of events defined for eels in the proportional hazards analysis?	Section 5.10 provides the requested number of events. A total of 144 Pawtucket Gatehouse and 61 E.L. Field Powerhouse forebay events were defined based on recorded detections of adult American eels during the 2019 study to evaluate the impact of operational parameters on passage success.

5	USFWS	In Section 5.1 of the Revised ISR report it was stated that "The downstream bypass was operated throughout the study period, passing approximately 130 cfs." Can you confirm the discharge through that facility when operated in the full open position?	The downstream bypass facility at E.L. Field was designed to pass up to 2% of the E.L. Field nameplate capacity of 6,600 cfs, or 132 cfs. That value has been corrected where referenced in the final report.
6	USFWS	Were approach velocities at the intake racks calculated for this evaluation?	Approach velocities were not calculated specific to observed passage conditions for radio-tagged silver eels. Discussion of the approach velocities expected at the E.L. Field Powerhouse is provided in the *Fish Passage Survival Study.*
7	NMFS	Is it possible to incorporate light incidence into the hourly passage plots (Revised ISR report Figure 5-10)?	Figure 5-10 of the final report has been updated to reflect diurnal, nocturnal or crepuscular passage events.
8	NMFS	Table 5-1 in Section 5-1 summarizes the percentage of inflow records from the 2019 study period categorized by volume as well as the percentage of time that each volume category is historically exceeded for the months of October and November. Is it possible to consider the study months of October and November as a whole to classify the full study period by flow condition?	Section 5-1 has been updated to include an examination of Merrimack River conditions during the full October 9 – November 30, 2019 study period relative to flow exceedance probabilities.
9	MDFW and NMFS	In their Revised ISR comment letters both MDFW and NMFS commented: *The goal of the juvenile alosine and American eel downstream passage assessments was to determine the Lowell Project's impact on the outmigration of juvenile alosine and adult American eel. The specific objectives included*	As stated in the DLA, Boott has elected to decommission the downtown canal units, and to remove the units and associated canal infrastructure from the new license.

		assessing rates and delay to migration for alosine and evaluation of route specific mortality for American eel. Operation of turbine units in the downtown canal system did not occur during the study for safety reasons. This lack of operation significantly affects the study results and our ability to assess project related impacts. However, it is our understanding that the canal units will be decommissioned, as stated by CRP during a conference call with us and the US Fish and Wildlife Service on November 16, 2020. Decommissioning of the canal units should be confirmed in the Draft License Application. If confirmed, then additional evaluation of project impacts related to the canals are not necessary. However, is there is a change in this decision and the downtown canal units are part of the proposed action within the Draft License Application, then the agencies intend to request a second year of study once the canal units are fully operational to determine post-spawned adult alosine and American eel downstream migration route selection, passage efficiency, and residence duration associated with the power canal under various operational conditions, including a range of spill conditions.	

Appendix F. Project inflow and discharge by potential passage route at the time of downstream passage for radio-tagged silver eels at Lowell.

		Passage			Reported cfs				
Frequency	ID	Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
149.340	113	10/13/2019	21:47:35	Turbine	1298	541	132	335	290
149.360	121	10/16/2019	23:22:18	Bypass	1518	792	132	304	290
149.340	96	10/17/2019	5:30:23	Turbine	3966	2886	132	658	290
149.360	25	10/17/2019	20:02:26	Turbine	4289	3416	132	451	290
149.360	122	10/17/2019	21:24:17	Turbine	4319	3414	132	483	290
149.340	119	10/18/2019	2:15:38	Turbine	4165	3248	132	495	290
149.360	129	10/18/2019	5:31:18	Turbine	4023	3073	132	527	290
149.360	100	10/18/2019	8:10:29	Turbine	4333	3640	132	271	290
149.340	93	10/18/2019	20:27:26	Turbine	5490	4457	132	611	290
149.360	124	10/18/2019	21:31:19	Turbine	5485	4554	132	509	290
149.360	66	10/18/2019	22:19:52	Turbine	5485	4554	132	509	290
149.360	140	10/18/2019	23:20:56	Turbine	5860	5091	132	348	290
149.340	52	10/19/2019	1:21:12	Turbine	6585	5448	132	715	290
149.340	56	10/19/2019	1:43:40	Turbine	6620	5493	132	705	290
149.340	39	10/19/2019	20:03:10	Turbine	6475	5326	132	728	290
149.360	102	10/19/2019	20:36:49	Turbine	6385	5294	132	669	290
149.360	123	10/19/2019	22:12:44	Turbine	6315	5209	132	683	290
149.360	107	10/19/2019	23:24:53	Turbine	6285	5203	132	660	290
149.340	51	10/20/2019	1:11:07	Turbine	6285	5226	132	637	290
149.360	85	10/20/2019	3:31:16	Turbine	6285	5210	132	653	290
149.360	149	10/20/2019	21:45:44	Spill	5405	1540	132	3443	290
149.360	45	10/20/2019	22:12:19	Turbine	5405	1540	132	3443	290
149.360	125	10/20/2019	23:51:04	Turbine	5345	1494	132	3430	290
149.340	75	10/21/2019	0:52:02	Turbine	5350	1472	132	3456	290
149.340	110	10/21/2019	2:02:10	Turbine	5350	1500	132	3429	290
149.360	26	10/21/2019	3:21:09	Turbine	5350	1485	132	3443	290
149.360	86	10/21/2019	21:00:51	Turbine	3860	3214	132	224	290

Frequency	ID	Passage			Reported cfs				
		Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
149.340	98	10/21/2019	21:15:58	Turbine	3860	3214	132	224	290
149.360	103	10/22/2019	0:19:40	Turbine	4225	3556	132	247	290
149.360	84	10/22/2019	0:25:22	Turbine	4225	3556	132	247	290
149.340	135	10/22/2019	0:36:31	Turbine	4285	3423	132	440	290
149.360	126	10/23/2019	1:44:58	Turbine	3870	2560	132	888	290
149.340	115	10/23/2019	2:42:26	Turbine	3900	2733	132	746	290
149.360	141	10/23/2019	19:19:33	Turbine	4255	3356	132	477	290
149.360	148	10/23/2019	23:35:43	Turbine	3510	2337	132	751	290
149.340	91	10/24/2019	2:27:30	Turbine	3540	2319	132	799	290
149.360	127	10/24/2019	2:31:29	Turbine	3630	2290	132	918	290
149.340	55	10/24/2019	4:54:09	Turbine	3660	2205	132	1033	290
149.360	21	10/24/2019	19:01:24	Turbine	4225	3330	132	473	290
149.340	139	10/24/2019	19:59:18	Turbine	4255	3322	132	512	290
149.340	58	10/24/2019	20:33:01	Turbine	4259	3342	132	495	290
149.360	142	10/24/2019	22:11:30	Turbine	4259	3336	132	500	290
149.340	116	10/24/2019	22:14:29	Turbine	4259	3336	132	500	290
149.360	164	10/25/2019	1:02:28	Turbine	4589	3659	132	508	290
149.340	138	10/25/2019	1:06:12	Turbine	4589	3659	132	508	290
149.340	35	10/25/2019	1:26:24	Turbine	4589	3659	132	508	290
149.360	166	10/25/2019	2:27:12	Turbine	4649	3736	132	491	290
149.340	78	10/25/2019	4:01:13	Turbine	4679	3733	132	524	290
149.340	74	10/25/2019	19:15:26	Turbine	4661	3721	132	518	290
149.360	168	10/25/2019	22:38:59	Turbine	4135	0	132	3713	290
149.360	167	10/26/2019	1:59:38	Turbine	4317	3485	132	409	290
149.360	23	10/26/2019	3:02:40	Turbine	4322	3496	132	404	290
149.360	80	10/26/2019	3:51:21	Turbine	4326	3468	132	436	290
149.360	165	10/26/2019	4:20:42	Turbine	4326	3468	132	436	290
149.360	169	10/26/2019	4:33:48	Turbine	4301	3479	132	400	290
149.360	162	10/26/2019	18:26:54	Turbine	3347	2526	132	399	290

Frequency	ID	Passage			Reported cfs				
		Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
149.340	136	10/26/2019	22:54:25	Turbine	3716	2935	132	359	290
149.360	44	10/26/2019	23:16:14	Turbine	3716	2935	132	359	290
149.340	73	10/27/2019	3:26:52	Turbine	4184	3260	132	501	290
149.360	147	10/27/2019	3:57:01	Turbine	3994	3121	132	451	290
149.340	152	10/27/2019	5:55:37	Turbine	3338	2302	132	615	290
149.360	105	10/27/2019	17:02:43	Turbine	3500	2557	132	521	290
149.340	153	10/27/2019	17:52:56	Turbine	3755	3039	132	294	290
149.360	20	10/27/2019	19:11:55	Turbine	4155	3414	132	320	290
149.340	79	10/27/2019	20:25:58	Turbine	4425	3570	132	433	290
149.340	33	10/27/2019	21:10:22	Turbine	4575	3686	132	466	290
149.360	101	10/27/2019	22:12:33	Turbine	4744	3794	132	528	290
149.360	146	10/27/2019	22:40:24	Turbine	4597	3901	132	274	290
149.340	53	10/27/2019	22:43:09	Turbine	4597	3901	132	274	290
149.360	41	10/27/2019	22:58:17	Turbine	4597	3901	132	274	290
149.340	157	10/27/2019	23:30:50	Turbine	4995	4058	132	515	290
149.360	83	10/27/2019	23:33:59	Turbine	4995	4058	132	515	290
149.340	95	10/28/2019	0:06:52	Turbine	4995	4058	132	515	290
149.340	77	10/28/2019	0:54:09	Turbine	5035	4092	132	521	290
149.360	88	10/28/2019	1:19:58	Turbine	5035	4092	132	521	290
149.340	76	10/28/2019	2:08:33	Turbine	5070	4152	132	495	290
149.360	163	10/28/2019	20:24:43	Turbine	6299	5150	132	728	290
149.340	72	10/28/2019	20:44:31	Turbine	6294	5141	132	731	290
149.340	30	10/29/2019	0:24:35	Bypass	6774	5536	132	816	290
149.340	70	10/29/2019	1:05:58	Turbine	6838	5542	132	874	290
149.340	90	10/29/2019	4:31:11	Turbine	8062	5446	132	2194	290
149.340	19	10/29/2019	4:47:24	Turbine	8062	5446	132	2194	290
149.340	97	10/29/2019	5:06:06	Turbine	8062	5446	132	2194	290
149.360	40	10/29/2019	5:31:28	Turbine	8266	5453	132	2391	290
149.360	145	10/29/2019	18:11:28	Turbine	8877	5838	132	2617	290

Frequency	ID	Passage			Reported cfs				
		Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
149.360	170	10/29/2019	19:50:25	Turbine	8802	5820	132	2561	290
149.360	60	10/29/2019	21:03:17	Turbine	8512	5787	132	2303	290
149.360	108	10/29/2019	23:13:53	Turbine	8646	5776	132	2448	290
149.340	154	10/29/2019	23:36:59	Turbine	8680	5759	132	2499	290
149.360	144	10/30/2019	0:20:53	Turbine	8680	5759	132	2499	290
149.360	22	10/30/2019	0:27:20	Turbine	8680	5759	132	2499	290
149.360	69	10/30/2019	0:29:51	Turbine	8680	5759	132	2499	290
149.340	36	10/30/2019	0:38:42	Turbine	8610	5728	132	2460	290
149.340	15	10/30/2019	1:28:12	Turbine	8610	5728	132	2460	290
149.360	43	10/30/2019	1:32:03	Turbine	8634	5694	132	2518	290
149.360	82	10/30/2019	1:38:07	Turbine	8634	5694	132	2518	290
149.340	133	10/30/2019	3:06:26	Turbine	8558	5693	132	2443	290
149.340	112	10/30/2019	3:34:50	Turbine	8368	5674	132	2272	290
149.360	48	10/30/2019	3:36:31	Turbine	8368	5674	132	2272	290
149.340	131	10/30/2019	3:42:42	Turbine	8368	5674	132	2272	290
149.360	160	10/30/2019	3:47:59	Turbine	8368	5674	132	2272	290
149.340	11	10/30/2019	3:55:05	Turbine	8368	5674	132	2272	290
149.340	94	10/30/2019	5:27:46	Turbine	8193	5679	132	2092	290
149.340	137	10/30/2019	16:29:17	Turbine	7749	5777	132	1550	290
149.340	150	10/30/2019	18:33:49	Turbine	7509	5770	132	1317	290
149.340	99	10/30/2019	20:11:40	Turbine	7503	5753	132	1329	290
149.340	117	10/30/2019	21:53:19	Turbine	7573	5707	132	1444	290
149.340	31	10/30/2019	22:14:58	Turbine	7573	5707	132	1444	290
149.340	114	10/30/2019	22:35:11	Turbine	7473	5715	132	1336	290
149.340	118	10/31/2019	2:25:17	Turbine	7297	5645	132	1230	290
149.340	71	10/31/2019	5:22:39	Turbine	7227	5600	132	1205	290
149.340	132	10/31/2019	16:55:20	Turbine	6580	5118	132	931	400
149.340	155	10/31/2019	19:51:20	Turbine	6650	5167	132	951	400
149.340	12	10/31/2019	20:08:19	Turbine	6650	5167	132	951	400

Frequency	ID	Passage			Reported cfs				
		Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
149.360	42	10/31/2019	21:51:40	Turbine	6714	5217	132	966	400
149.340	156	11/1/2019	2:46:31	Turbine	6807	5224	132	1051	400
149.340	171	11/1/2019	4:21:38	Turbine	6837	5241	132	1064	400
149.360	128	11/1/2019	8:36:03	Turbine	6984	5237	132	1215	400
149.360	143	11/1/2019	19:43:59	Turbine	6773	5087	132	1154	400
149.360	81	11/1/2019	20:19:48	Turbine	6773	5087	132	1154	400
149.360	161	11/2/2019	20:34:03	Turbine	11229	4855	132	5842	400
149.360	104	11/2/2019	23:53:46	Turbine	11429	4754	132	6143	400
149.360	109	11/3/2019	0:32:27	Turbine	11435	4712	132	6192	400
149.340	37	11/3/2019	2:28:04	Turbine	11435	4671	132	6232	400
149.340	134	11/3/2019	4:22:50	Turbine	11435	4706	132	6198	400
149.340	111	11/3/2019	6:15:36	Turbine	11341	4666	132	6143	400
149.340	38	11/3/2019	22:21:04	Spill	9866	4489	132	4845	400
149.360	87	11/3/2019	22:47:38	Turbine	9766	4491	132	4743	400
149.360	65	11/4/2019	19:49:23	Spill	7870	4719	132	2619	400
149.340	50	11/6/2019	4:22:12	Turbine	5823	4568	132	723	400
149.360	46	11/7/2019	18:32:50	Turbine	5152	4021	132	599	400
149.360	89	11/8/2019	1:51:29	Turbine	5483	4261	132	691	400
149.360	120	11/8/2019	2:58:43	Turbine	5453	4243	132	678	400
149.360	64	11/8/2019	4:43:08	Turbine	5458	4288	132	637	400
149.340	59	11/8/2019	4:59:43	Turbine	5458	4288	132	637	400
149.360	106	11/10/2019	19:00:04	Turbine	4704	3597	132	575	400
149.340	57	11/10/2019	23:17:20	Turbine	4499	3426	132	541	400
149.340	16	11/12/2019	9:08:30	Spill	4201	3157	132	512	400
149.340	151	11/14/2019	1:00:49	Turbine	4059	2524	132	259	1145
149.340	17	11/14/2019	18:19:03	Turbine	3590	2003	132	310	1145
149.360	47	11/17/2019	5:22:47	Turbine	3179	1665	132	237	1145
149.340	159	11/22/2019	19:12:08	Turbine	4725	3529	132	625	440

Appendix G. Reported hourly operations information for the Lowell Project for the duration of the 2019 fall telemetry studies

Report Appendix G available as Microsoft Excel data listing.

Technical Report
for the
Upstream and Downstream Adult Alosine Passage Assessment

Lowell Hydroelectric Project (FERC No. 2790)

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Table of Contents

List of Tables

List of Figures

1 Introduction

A radio-telemetry assessment of the upstream and downstream passage success for adult alewife (*Alosa pseudoharengus*) and American shad (*Alosa sapidissima*) was conducted in support of the relicensing for the Lowell Hydroelectric Project (Lowell or Project), Federal Energy Regulatory Commission (FERC) No. 2790, as identified in the Revised Study Plan (RSP) submitted by Boott Hydropower, LLC (Boott) on January 28, 2019. The approach and methodology described in the RSP for the adult alosine telemetry study was approved with modifications by the FERC in its Study Plan Determination (SPD) letter dated March 13, 2019. In their SPD, FERC staff commented on several points related to the original resource agency study requests and the adult alosine passage study proposed by Boott as part of the PSP.

- Resource agency request for a HI-Z balloon tag turbine survival assessment.
    - FERC recommended no HI-Z balloon tag assessment be conducted during 2019. Information from the radio-telemetry and desktop analyses should provide adequate estimates of project survival. In the event these findings are inconclusive FERC would consider additional study requests.
- Resource agency request to increase the number of dual-tagged (i.e., PIT and radio transmitters) from 150 alewives to 200 alewives and from 180 American shad to 200 American shad.
    - FERC indicated there was no evidence that the originally proposed sample sizes of 150 dual-tagged alewives and 180 dual tagged American shad would be insufficient to meet the goals of the study.
- Resource agency request to release tagged alewives and American shad intended to evaluate upstream passage at Lowell at the Lawrence Project rather than transport by truck to a point further upstream.
    - FERC recommended fish be released at a point further upstream to reduce the potential for fallback downstream of Lawrence immediately following tagging and release.
- Resource agency request for one group of herring to be released after May 20 due to likelihood of blueback herring present at that point in the season.
    - FERC recommended at least one release event occur after May 20.
- Resource agency request to add additional monitoring stations into the bypassed reach to help assess passage effectiveness through the existing concrete weirs.

  - FERC recommended that the spatial layout of the monitoring stations as described in the RSP should provide sufficient information to assess passage through that reach.

- Resource agency request to add an additional stationary receiver along the eastern wall of the E.L. Field tailrace to provide data redundancy.
  - FERC recommended placement of an additional stationary receiver along the eastern wall of the E.L. Field tailrace.

- Resource agency requested that Boott either (1) adjust the detection zone of RSP Station M7 further downstream or (2) add an additional station to ensure detection of fish as they approach the confluence of the bypassed reach and tailrace.
  - FERC recommended that the proposed location for Station M7 described in the RSP be installed in a manner which adequately covered the bypassed reach and tailrace confluence area.

On June 12, 2020 FERC issued a Revised Process Plan and Schedule and Determination on Requests for Study Modifications for the Lowell Hydroelectric Project (Revised PPS). In accordance with the Revised PPS, Boott filed their Revised ISR with FERC on September 30, 2020, which contained a mostly completed report for the Upstream and Downstream Adult Alosine Passage Assessment. Boott held a revised ISR meeting on October 15, 2020 and representatives from FERC, U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Massachusetts Division of Fisheries and Wildlife (MADFW), Massachusetts Division of Marine Fisheries (MDMF), and the New Hampshire Fish and Game Department (NHFGD) had the opportunity to provide comments. A summary of comments received during the October 15 Revised ISR meeting and the corresponding responses are provided in Appendix B of this report. In addition, additional information gaps identified in Section 7.0 of the Revised ISR have been completed into this Updated Study Report. This final technical report describes the objectives, methodologies and results of the 2020 radio-telemetry assessment to evaluate the upstream and downstream passage of adult alosines at the Lowell Project.

It is important to note that the timing of this field study (April – June 2020) coincided with the rapid onset of the COVID-19 pandemic throughout the United States and that both the States of New Hampshire and Massachusetts were operating under a “stay-at-home” order during that time. Every effort was made to conduct this evaluation as described in the RSP and as approved by FERC in their SPD while still maintaining the health and safety of all Normandeau project staff and Boott operations staff.

2 Objectives

The goal of this study was to assess the behavior, approach routes, passage success, survival, and residence duration of adult American shad and alewives as they encounter the Lowell Project during their upstream and downstream migrations to determine if Project operations negatively impact their survival and production.

Specific objectives focused on upstream passage included:

- Determining route selection and behavior of upstream migrating shad and alewives at the Project under varied operational conditions, including a range of spill conditions;
- Assessing the nearfield attraction to, and entrance efficiency of, the fish lift with the river-side entrance open;
- Evaluating residence or fallback associated with the Pawtucket Gatehouse at the upstream end of the Northern Canal;
- Assessing the nearfield attraction to, and entrance efficiency of, the Pawtucket Dam ladder;
- Evaluating the internal efficiency of the Pawtucket Dam ladder;
- Collection of ladder and lift efficiency data, to include rates of approach to fishway entrances, entry into fishways, and passage under varied operational conditions, including a range of spill conditions; and
- To assess the effects of Project operations on the timing, orientation, routes and migration rates of shad and alewives.

Specific objectives focused on downstream passage included:

- Determining the proportion of post-spawned adults that select the downtown canal system or E.L. Field power canal as a downstream passage route;
- Determining post-spawned adult downstream migration route selection, passage efficiency, and residence duration associated with the power canal under various operational conditions, including a range of spill conditions;
- Comparing rates and measures of residence duration and movement among Project areas and routes utilized (e.g., spill at dam versus power canal); and
- Evaluating mortality of adult alosines passed via each potential route.

3 Project Description and Study Area

The Lowell Project is located at River Mile (RM) 41 on the Merrimack River in the City of Lowell in Middlesex County, Massachusetts, with an impoundment extending approximately 23 miles upstream into Hillsborough County, New Hampshire. The existing Lowell Project consists of: (1) a 1,093-foot-long, 15-foot-high masonry gravity dam (Pawtucket dam) that includes a 982.5-foot-long spillway with a crest elevation of 87.2 feet National Geodetic Vertical Datum 1929 (NGVD 29) topped by 5-foot-high pneumatically-operated crest gates deployed in five independently-operable zones; (2) a 720-acre impoundment with a normal maximum water surface elevation of 92.2 feet NGVD 29; (3) a 5.5-mile-long canal system which includes several small dams and gatehouses; (4) a powerhouse (E.L. Field) which uses water from the Northern Canal and contains two turbine-generator units with a total installed capacity of 15.0 megawatts (MW); (5) a 440-foot-long tailrace channel; (6) four powerhouses (Assets, Bridge Street, Hamilton, and John Street) housed in nineteenth century mill buildings along the Northern and Pawtucket Canal System containing 15 turbine-generator units with a total installed capacity of approximately 5.1 MW; (7) a 4.5-mile long, 13.8-kilovolt transmission line connecting the powerhouses to the regional distribution grid; (8) upstream and downstream fish passage facilities including a fish elevator and downstream fish bypass at the E.L. Field powerhouse, and a vertical-slot fish ladder at the Pawtucket dam; and (9) appurtenant facilities. At the normal pond elevation of 92.2 feet NGVD 1929 (crest of the pneumatic flashboards), the surface area of the impoundment encompasses an area of approximately 720 acres. The gross storage capacity between the normal surface elevation of 92.2 feet and the minimum pond level of 87.2 feet is approximately 3,600 acre-feet. The Project operates essentially in a run-of-river (ROR) mode using automatic pond level control, and has no usable storage capacity.

The study area for the upstream and downstream adult alosine passage assessment included the mainstem Merrimack River from the upper extent of the Project's impoundment located approximately 23 river miles upstream from the Pawtucket Dam in Litchfield, New Hampshire, to the Lawrence Hydroelectric Project (FERC No. 2800), located approximately 11 river miles downstream of the Pawtucket Dam (Figure 3-1). The Project's downtown canal system and the Hamilton, Assets, Bridge Street and John Street Power Stations were also considered as part of the study area.

Figure 3–1. Merrimack River study reach considered during the spring 2020 adult alosine upstream and downstream passage assessment.

4 Methods

The upstream and downstream passage of adult alewives and American shad at the Lowell Project was evaluated using radio-telemetry during the spring of 2020. Following the release of radio-tagged individuals into the Merrimack River both upstream and downstream of the Lowell facility, their movements were monitored using a series of stationary radio-telemetry receivers in place at the Project as well as at several additional stationary monitoring receivers installed at bank-side locations upstream and downstream of the Project to inform on general movements, distribution among available passage routes and Project passage success.

4.1 Telemetry Equipment

Movements of radio-tagged individuals during the 2020 study were recorded via a series of stationary PIT[1] and radio-telemetry receivers. Telemetry equipment used during the evaluation of adult alosine passage at Lowell included Orion radio-telemetry receivers, manufactured by Sigma Eight, as well as SRX radio receivers manufactured by Lotek Wireless. Each radio-telemetry receiver was paired with either an aerial or underwater antenna (dropper antenna). Aerial antennas (four or six element Yagi) were utilized to detect radio-tagged individuals within the larger, more open sections of river, such as within the tailrace or at locations downriver of Lowell. Dropper antennas were fixed at downstream passage locations (e.g., downstream bypass). Dropper antennas were custom built by stripping the shielded ends of RG-58 coaxial cables.

Adult American shad and alewives were tagged using transmitters manufactured by Sigma-Eight (model TX-PSC-I-80 or TX-PSC-I-80D) and operating on one of five unique frequencies (149.440, 149.460, 149.480, 149.760, or 149.800 MHz). The TX-PSC-I-80 transmitters measured approximately 10 x 10 x 27 mm, weighed 4.2 g, and had an estimated battery life of 64 days when set at a 2.0 second burst rate. The TX-PSC-I-80D transmitters measured approximately 10 x 10 x 22 mm, weighed 3.3 g and had an estimated battery life of 64 days when set at a 2.0 second burst rate. Each transmitter was coded to emit a unique identifying signal so that individual shad and alewives could be identified by a receiver.

A series of PIT receivers were installed to complement the radio-telemetry array and were placed at locations intended to allow for precise tracking of shad and herring within the Project fishways. The PIT receivers and tags used during 2020 were half-duplex (HDX) and were manufactured by Oregon RFID. Each antenna loop was customized per monitoring site specifics, and equipped with a set of capacitors to properly tune the antenna loop inductance. The HDX PIT tags were encoded by the manufacturer and read only with a 64 bit unique ID. Each cylindrical PIT tag measured 3.65 mm in diameter, 32 mm long, and weighed 0.8g.

[1] Passive Integrated Transponder

4.2 Monitoring Stations

The RSP identified monitoring stations to be set up at Lowell for the spring 2020 adult alosine passage assessment. Each monitoring location identified in the RSP was installed and consisted of a data-logging receiver, antenna, and power source[2]. Receivers were configured to receive transmitter signals from a designated area continuously throughout the study period. During installation of each station, range testing was conducted to configure the antennas and receivers in a manner which maximized detection efficiencies at each location. The operation of receivers was initially established during installation, then confirmed throughout the study period by using beacon tags. A number of beacon tags were stationed at strategic locations within the detection range of either multiple or single antennas, and they emitted signals at programmed time intervals. These signals were detected and logged by the receivers and used to record the functionality of the system throughout the study period.

The locations of monitoring stations installed for the 2020 Lowell adult alosine passage study are outlined here and presented in Figures 4-1 through 4-4.

Monitoring Station 04: Station 04 was installed within the Lowell Project impoundment and was intended to detect radio-tagged adult alosines (1) originally released downstream of Lowell and following successful passage via the fish lift or ladder at the Project, or (2) during their initial movement downstream and away from the upstream release location. Station 04 consisted of a single Lotek SRX radio-receiver and aerial antenna oriented perpendicular to the river channel. It was located approximately 2.1 miles upstream of the Pawtucket Gatehouse and approximately 5.1 miles downstream of the upper release location.

Monitoring Station 05: This station consisted of a single Lotek SRX radio-receiver and an aerial antenna calibrated to provide detection information for radio-tagged alosines (1) originally released downstream of Lowell and following successful passage via the fish lift or ladder at the Project, or (2) originally released upstream as they approached the upstream face of Pawtucket Dam.

Monitoring Station 06: Station 06 consisted of a single Orion radio-receiver and aerial antenna. It was calibrated to provide coverage of the upstream side of the Pawtucket Gatehouse and to inform on (1) radio-tagged alosines originally released downstream of Lowell which had ascended the Project fish lift and successfully exited the Northern Canal via the Pawtucket Gatehouse, or (2) radio-tagged alosines which following a period of residence upstream of the Project had approached the upstream side of the Pawtucket Gatehouse.

Monitoring Station 07: Station 07 consisted of a single Orion radio-receiver and aerial antenna calibrated to provide coverage of the downstream side of the Pawtucket Gatehouse. Station 07 was installed to inform on (1) radio-tagged adult alosines originally released downstream which

[2] Note that three stations identified in the RSP were either modified or eliminated due to logistical issues identified during install, as discussed below. RSP Station M20 was eliminated and replaced with Station M21. RSP Stations C3 and C7 were changed from PIT to radio-telemetry receivers as noted during the ISR meeting in March, 2020.

had ascended the Project fish lift and approached the Pawtucket Gatehouse in an attempt to exit the Northern Canal, or (2) radio-tagged adult alosines which following a period of residence upstream of the Project had successfully passed through the Pawtucket Gatehouse and entered the Northern Canal.

Monitoring Station 08: Station 08 consisted of a single Lotek SRX radio-receiver and aerial antenna installed to provide detection information for radio-tagged adult alosines which were (1) successfully ascended via the fish lift following release downstream, or (2) following a period of residence upstream of the Project had successfully passed through the Pawtucket Gatehouse, entered the Northern Canal and forebay and were in the vicinity of the entrances to the downstream bypass and E.L. Field turbine intake racks.

Monitoring Station 09: Station 09 consisted of a single Orion radio-receiver and underwater drop antenna. It was installed and calibrated to provide detection information for radio-tagged adult alosines which following a period of residence upstream of the Project had successfully passed through the Pawtucket Gatehouse, entered the Northern Canal and forebay, and passed downstream via the downstream bypass.

Monitoring Station 10: This station consisted of a single Lotek SRX radio-receiver and aerial antenna and was installed at a location overlooking the Project tailrace. Detections at this location were used to identify radio-tagged adult alosines which were (1) originally released downstream and subsequently ascended into the Project tailrace and were within the nearfield area of the upstream fish lift, or (2) passed downstream through the turbine units at the E.L. Field Powerhouse following a period of residence upstream of the Pawtucket Dam and within the Northern Canal upstream of the intakes. As stated in the SPD, the installation of an additional stationary receiver along the eastern wall of the E.L. Field tailrace to provide data redundancy was recommended. During the spring installation period, the installation of an additional receiver along the eastern tailrace wall was not conducted due to a lack of safe access during spring flow conditions. Detections from the receiver installed on the backside of the E.L. Field Powerhouse were used for determining presence in the Lowell tailrace.

Monitoring Station 11: Station 11 consisted of a single Lotek SRX radio-receiver and aerial antenna and was installed to scan across the bypassed reach at a point downstream of where the surge gate enters from the power canal and upstream from the downstream bypass. Detections at this location were used to (1) confirm the downstream passage of radio-tagged adult alosines which following a period of residence upstream of the Project passed downstream using the spillway or surge gate, or (2) identify radio-tagged adult alosines released at Lawrence which had initiated an ascent upstream into the bypassed reach. The detection field for Station 11 was centered at a point in the bypassed reach approximately 15% of the distance upstream from the downstream confluence with the tailrace (when considering the full length of the bypassed reach from the entrance to the Pawtucket Dam fish ladder downstream to the confluence with the tailrace).

Monitoring Station 12: Station 12 consisted of a single Lotek SRX radio-receiver and aerial antenna installed to scan across the bypassed reach at a location near to the midpoint of that section. Detections at this location were used to identify radio-tagged adult alosines which had ascended upstream within the bypassed reach. The detection field for Station 12 was centered at a point in the bypassed reach approximately 53% of the distance upstream from the downstream confluence with the tailrace (when considering the full length of the bypassed reach from the entrance to the Pawtucket Dam fish ladder downstream to the confluence with the tailrace).

Monitoring Station 13: Station 13 consist of a single Lotek SRX radio-receiver and aerial antenna installed to scan the upper section of the bypassed reach in close proximity to the entrance to the upstream fishway. Detections at this location were used to identify radio-tagged adult alosines which have ascended the full length of the bypassed reach, were upstream of the concrete weirs and within the nearfield area of the upstream fishway.

Monitoring Stations 14/15: Stations 14 and 15 each consisted of a single half-duplex PIT reader and antenna installed at the first weir upstream from the entrance to the Project fish ladder. These two readers provided fine scale detection information for PIT-tagged adult alosines which had ascended the Project bypassed reach and entered the upstream fishway. The use of two independent PIT readers at this location permitted the install of a pair of smaller loop antennas to monitor each of the two slot openings rather than a single large antenna to try to monitor the full cross section of the fish ladder.

Monitoring Station 16**:** Station 16 was not described in the RSP but was added as a supplement to Stations 14 and 15 during the installation of stationary receivers prior to the spring 2020 study. Station 16 consisted of a single Orion radio-telemetry receiver coupled to an underwater drop antenna positioned inside of the entrance to the Pawtucket Dam fish ladder. This receiver was intended to provide redundant detection information for dual-tagged adult alosines in fish ladder entrance. The drop antenna was positioned upstream of the entrance weir and immediately downstream of the first concrete weir within the lower leg of the fishway.

Monitoring Stations 17/18: Stations 17 and 18 each consisted of a single half-duplex PIT reader and antenna installed at the first weir upstream from the turn pool within the Project fish ladder. These two readers provided fine scale detection information for PIT-tagged adult alosines which had ascended the lower leg of the fishway and were beginning their ascent through the upper leg. Similar to Stations 14/15, the use of two independent PIT readers at this location permitted the install of a pair of smaller loop antennas to monitor each of the two slot openings rather than a single large antenna to try to monitor the full cross section of the fish ladder.

Monitoring Station 19: Station 19 consisted of a single half-duplex PIT reader and antenna. The antenna was installed at the upstream side of the window crowder just downstream from the exit gate at the top of the Pawtucket Dam fish ladder. Installation of the antenna at this position allowed for the usage of a smaller loop antenna than would be required to attempt to monitor the full cross section of the fish ladder. Station 19 was intended to provide fine scale detection information for PIT-tagged adult alosines which had ascended the Project bypassed reach, entered and successfully navigated the upstream fishway structure.

Monitoring Station 20: Station 20 consisted of a single half-duplex PIT reader and antenna installed to provide detection information for adult alosines which had entered the Lowell fish lift via the river-side entrance. Site conditions prior to the 2020 lift operational season were characterized by high tailwater elevations which prevented the dewatering of the lower entrance flume. As a result, options for installation of the single antenna in the lift entrance were limited. The antenna frame was sized to slide into an existing slot in the wall of the entrance flume just upstream of the riverside entrance weir and was of a size to span the full cross section of the fish lift entrance flume. The watered conditions in the exit flume eliminated the ability to move the antenna frame back and forth within the entrance flume to position at the “sweet spot” for detection range. Construction of two smaller antennas to cover the entrance was not considered due to concerns with a vertical pipe at the center of the entrance flume water column and the potential impact on upstream migrants.

Monitoring Station 21: Station 21 was not described in the RSP but was added during the installation of stationary receivers prior to the spring 2020 study, as a supplement for Monitoring Station 20. Station 21 consisted of a single Orion radio-telemetry receiver coupled to an underwater drop antenna positioned inside of the entrance to the E.L. Field fish lift. This receiver was intended to provide redundant detection information for dual-tagged adult alosines in the lift entrance. The drop antenna was positioned midway between the entrance weir the fish crowder when in its “fishing” position.

Monitoring Stations 22/23: Stations 22 and 23 each consisted of a single half-duplex PIT reader and antenna installed at the upstream end of E.L. Field fish lift exit flume. These two readers provided detection information for PIT-tagged adult alosines which had ascended upstream via the lift and were exiting into the Northern Canal. A pair of independent PIT readers were installed at this location rather than a single large antenna to monitor the full cross section of exit flume to maximize detection probability. Antennas were positioned side by side in the exit flume. During installation the exit flume was dewatered and project staff were able to move the antennas to multiple locations within the channel to identify the location where background interference was minimal.

Monitoring Station 24: Station 24 was installed at a point just downstream of the convergence of flow from the bypassed reach and E.L. Field powerhouse tailrace channel and consisted of a Lotek SRX receiver and aerial antenna. This station provided detection information for radio-tagged adult alosines (1) released at the Lawrence Project as they approach the Lowell Project, and (2) following downstream passage or a period of residence within the tailrace or bypassed reach at the Lowell Project.

Monitoring Station 25: This station was installed at a point along the mainstem of the Merrimack River downstream of both the E.L. Field Powerhouse tailrace and the confluence with the Concord River. Station 25 consisted of a single Lotek SRX receiver and aerial antenna oriented perpendicular to the river channel. This station provided detection information for radio-tagged adult alosines released (1) at the Lawrence Project as they approach the Lowell Project, and (2) following downstream passage or a period of residence within the tailrace or bypassed reach at the Lowell Project. Station 25 was installed at the Lowell Waste Water Treatment Plant, approximately 2.1 miles downstream of the tailrace.

Monitoring Station 26: Station 26 was installed at a commercial business near the midpoint between the Lowell and Lawrence projects and consisted of a single Lotek SRX receiver and aerial antenna oriented perpendicular to the river channel. This station provided detection information for radio-tagged adult alosines released (1) at the Lawrence Project as they approach the Lowell Project, and (2) following downstream passage or a period of residence within the tailrace or bypassed reach at the Lowell Project. Station 26 was located approximately 6.0 miles downstream of the tailrace.

Monitoring Station 27: This station consisted of a single Lotek SRX radio-receiver and an aerial antenna and was installed and calibrated in a manner to provide detection information for radio-tagged adult alosines as they approached the upstream face of Essex Dam (approximately 10.75 miles downstream of the Lowell tailrace).

Monitoring Stations 04 through 27 were installed and maintained throughout the duration of the spring 2020 adult alosine study to inform on the upstream and downstream passage of tagged alewives and American shad at Lowell and within the mainstem of the Merrimack River. An additional seven receivers were described in the RSP and were installed at locations within the Pawtucket Canal system (or "downtown canal" system) as part of this study. Outmigrating adult alosines can potentially enter the Pawtucket Canal system, the entrance of which sits at a point upstream of the Pawtucket Dam and the Northern Canal.

Outmigrating adult alosines entering the Pawtucket Canal first encounter the Guard Locks at a point approximately 1,700 ft downstream from the confluence with the mainstem Merrimack River. Following passage by the Guard Locks, radio-tagged adult alosines are free to move downstream through the Pawtucket Canal until flow diverges and continued passage is possible into either the Western, Merrimack, or Hamilton Canals or the individual can continue downstream in the Pawtucket Canal (via the Swamp Locks). The Western and Merrimack Canals are no longer in use and are essentially deadwater areas and the Assets Power Station (located on the Merrimack Canal) is non-functional and is planned to be eliminated from the new project license. Individuals passing into the Hamilton Canal subsequently enter the Lower Pawtucket Canal via the turbine intakes at the Hamilton Power Station or through the Hamilton Wasteway. From the lower Pawtucket Canal individuals enter into the Eastern Canal. From the Eastern Canal fish can pass into the Concord River via the Bridge Street Power Station or into the Merrimack River via the John Street Power Station or Boott Gate. The Lower Locks is rarely used to pass flow from the Eastern Canal other than for lockage. Monitoring Stations installed and operated within the downtown canal system during the 2020 adult alosine study consisted of:

Monitoring Station 28: Station 28 was installed to detect outmigrating radio-tagged adult alosines which entered the Pawtucket Canal system rather than pass the Lowell Project via one of the mainstem passage routes. The entrance to the Pawtucket Canal sits at a point upstream of the Pawtucket Dam and the Northern Canal. Station 28 was located at the Guard Locks, approximately 1,700 ft downstream from the entrance to the canal. The monitoring zone for Station 28 was focused downstream of the Guard Locks facility to ensure any detections recorded at that location were of fish which had definitively entered the Pawtucket Canal system. Monitoring Station 28 consisted of a single Orion receiver and aerial antenna.

Monitoring Station 29: Station 29 was installed to detect radio-tagged adult alosines which have moved from the Pawtucket Canal to the Hamilton Canal and reached the Hamilton Power Station. It consisted of a single Orion receiver and antenna coverage at the Hamilton Power Station intake area upstream of the intake for Hamilton Unit 1.

Monitoring Station 30: As described in the RSP, Station 30 was to consist of a single half-duplex PIT reader and antenna and installed at the Hamilton Wasteway located at the downstream end of the Hamilton Canal. During the initial site reconnaissance it was determined that the installation of a PIT antenna was not feasible at this site due to the potential flow volume and the size of the opening and as a result coverage of this route was modified to a single Orion receiver and aerial antenna.

Monitoring Station 31: This station was installed to detect radio-tagged adult alosines which had entered the Eastern Canal and reached the Bridge Street Power Station (a.k.a. "Section 8"). It consisted of a single Lotek receiver and antenna coverage of the Bridge Street Power Station discharge area. Adult alosines successfully passing here had the potential to be subsequently detected downstream at Monitoring Stations 25, 26, and 27.

Monitoring Station 32: Station 32 was installed to detect radio-tagged adult alosines which had entered the Eastern Canal and reached the John Street Power Station. It consisted of a single Orion receiver and antenna coverage at the John Street Power Station intake area.

Monitoring Station 33: Station 33 consisted of a single Orion radio receiver and antenna coverage of the John Street Power Station discharge. Adult alosines successfully passing here had the potential to be subsequently detected downstream at Monitoring Stations 25, 26, and 27.

Monitoring Station 34: As described in the RSP, Station 34 was to consist of a single half-duplex PIT reader and antenna installed at the sluice gate located at Boott Dam. During the initial site reconnaissance it was determined that the installation of a PIT antenna was not feasible at this site due to the potential flow volume and the size of the opening and as a result coverage of this route was modified to a single Orion receiver and aerial antenna. This location provided coverage to detect any fish departing the Eastern Canal for the Merrimack River during periods of gate operation to flush debris from the lower canal system.

4.3 Tagging and Release Procedures

The majority of adult American shad and alewives were collected for tagging at the Essex Dam fish lift at the Lawrence Hydroelectric Project[3]. Following collection methodology from a previous evaluation of shad movement in the lower Merrimack River (Sprankle, 2005), adult alosines were collected from a net pen placed in the exit flume of the lift which received fish directly from the hopper bucket. Following capture in the net pen, fish were dip-netted out and visually assessed to ascertain their suitability for tagging. Any individuals exhibiting excessive scale loss or other signs of significant stress were not considered for tagging and were released directly into the fish lift exit flume. Individuals deemed acceptable for tagging were quickly measured (total length, nearest mm), and gender was determined (when possible) by gently expressing eggs or milt from running-ripe fish. Radio transmitters were inserted gastrically. To facilitate gastric implantation, transmitters were affixed to a flexible tube with their trailing antenna running through the hollow center. The transmitter and leading edge of the flexible tube were pushed through the mouth and down to the stomach. Once in place, the tube was removed leaving the transmitter antenna trailing from the mouth. PIT tags were implanted into the peritoneal cavity through a small incision on the ventral side of the fish. Adult alosines during this study were either tagged with a radio transmitter (i.e., “radio-tagged”), a PIT tag (i.e., “PIT-tagged”) or both a radio and PIT tag (i.e., “dual-tagged”).

4.3.1 Upstream Release Procedures

Dual and PIT-tagged adult alosines intended to assess upstream passage effectiveness were released over six dates for alewives and five dates for American shad. All dual and PIT-tagged adult alosines were released directly into the exit flume of the upstream fishway at Lawrence following tagging.

4.3.2 Downstream Release Procedures

Radio-tagged adult alosines intended to assess downstream passage effectiveness were released over four dates for alewives and three dates for American shad. All radio-tagged adult alosines were trucked upstream and released into the Merrimack River at the Tyngsboro Riverfront Park, approximately 7.25 miles upstream of the dam. As described in the RSP, a total of 100 adult alewives and 100 adult American shad were to be radio-tagged and released upstream of the Pawtucket Dam for the purposes of evaluating downstream passage. The RSP had described an additional 50 adult alewives and 50 adult American shad which were to be radio-tagged and released directly into the downtown canal system downstream of the Guard Locks to assess passage through those facilities. Due to overriding safety concerns, Boott had ceased operation of the turbine units within the downtown canal system prior to the study

[3] Note that a subset of adult river herring required for the downstream passage evaluation were collected at Amoskeag fishways. Boott consulted with the resource agencies prior to tagging fish from Amoskeag. Additional details are provided in Section 5.6.

period. Following consultation with the resource agencies, Boott elected to reallocate the transmitters originally purchased for the downtown canal assessment to increase the number of individuals evaluated for downstream passage at the Pawtucket Dam and E.L. Field Powerhouse.

Concurrent with the upstream and downstream adult alosine passage assessment at Lowell, Normandeau Associates simultaneously conducted a separate adult alosine effectiveness study at the Mine Falls Project (FERC No. 3442) on the Nashua River, a tributary to the Merrimack River with a confluence 13.5 miles upstream of the Pawtucket Dam and within the Lowell Project impoundment. Mine Falls is the second dam on the Nashua River, sitting at river mile 5.2, approximately 4.0 miles upstream of the Jackson Mills Project. A total of 100 radio-tagged adult river herring were released upstream of Mine Falls (to be referenced as “Pepperell”) and 100 radio-tagged adult river herring were released downstream of Mine Falls (to be referenced as “Mine Falls”). The portion of individuals from those two release groups which were determined to have approached the Pawtucket Dam (based on stationary receiver detections) have been included in this report as part of the assessment of downstream passage.

4.4 Data Collection

4.4.1 Stationary Telemetry Data

Receiver downloads occurred three to four times weekly during the period from the initial tag and release event until the end of June, 2020. Backup copies of all telemetry data were made prior to receiver initialization. Field tests at the time of download to ensure data integrity and receiver performance included confirmation of file integrity, confirmation that the last record was consistent with the downloaded data (beacon tags were critical to this step), and lastly, confirmation that the receiver was operational upon restart and actively collecting data post download. Within a data file, transmitter detections were stored as a single event (i.e., single data line). Each event included the date and time of detection, frequency, ID code, and signal strength.

4.4.2 Manual Telemetry Data

To provide supplemental detection information to the stationary receiver data set, manual tracking was conducted on a number of occasions from the time of initial release through the end of June, 2020. Manual effort was exerted in the vicinity of the Lowell Project (i.e., tailrace and headpond immediately upstream of Pawtucket Dam) on most dates when stationary telemetry equipment was checked. In addition, a number of boat or truck-based efforts were conducted to look for radio-tagged alosines within the Lowell impoundment and the reach of the Merrimack downstream to Lawrence.

4.4.3 Operational and Environmental Data

Hourly records for operations data were provided by Boott for the 2020 evaluation period and included:

- Headpond elevation (ft);

- Power canal elevation (ft);
- Headpond-power canal differential (ft);
- Tailrace elevation (ft);
- Head differential for E.L. Field turbines (ft);
- Total inflow (cfs);
- E.L. Field discharge (cfs);
- Downstream bypass facility discharge (cfs);
- Upstream fishway discharge (cfs);
- Downtown canal flow (cfs); and
- Spill flow through the bypassed reach.

4.4.4 Downstream Drift Assessment

Ten freshly dead adult alewives and ten American shad were radio-tagged and released downstream of Lowell during the 2020 study period. Two individuals were released on each date that a group of live test fish was released upstream of the Pawtucket Dam. Dead, radio-tagged adult alosines were released directly into the discharge of an active turbine unit at the E.L. Field powerhouse. The downstream progression of these known mortalities was recorded by the downstream stationary receivers.

4.5 Data Analysis – Upstream Passage

4.5.1 Fish Movement and Project Area Usage

The tagging, telemetry and Project operations data sets collected as part of this effort were examined and used to evaluate a number of metrics related to upstream passage success and movement through the Project area. These metrics included:

Approach Duration: This value was calculated as the duration of time from release into the Merrimack River at the Lawrence fish lift facility until the initial detection at Monitoring Station 24, the convergence area of the Pawtucket Dam bypassed reach and the E.L. Field tailrace discharge. The duration and rates of upstream ascent for tagged adult alosines from the Lawrence fish lift were further broken down to the discrete sections as bounded by Monitoring Stations 27 to 26, 26 to 25, and 25 to 24. This value was calculated for only dual-tagged individuals.

Time at Large: This value was calculated as the duration of time from the initial detection at Monitoring Station 24 until (1) upstream passage at the Project fish lift or fish ladder, or (2) movement downstream and permanently away from the project area. Final departure times were determined by the last detection at the lift or ladder structures for fish passing upstream or the last detection at Monitoring Station 24 for fish failing to pass and departing downstream. This value was calculated for only dual-tagged individuals.

Foray Events: Foray events were defined for dual-tagged individuals which moved from the convergence area (i.e., the detection zone of Station 24) upstream towards the fish lift or fish ladder as evidenced by detections on one or more receivers along those two routes leading towards possible upstream passage into the headpond above the Pawtucket Dam. Each event was initiated by a detection at either Station 10 (i.e., E.L. Field tailrace and access to the fish lift) or Station 11 (i.e., the Pawtucket Dam bypassed reach and access to the fish ladder). The duration and magnitude (i.e., most upstream station) of each foray was determined. For individuals which initiated a foray in the direction of the fish lift, each unique event could potentially encompass a sequence of detections at:

- Station 10 – E.L. Field tailrace;
- Stations 20/21 – fish lift entrance;
- Stations 22/23 – fish lift exit flume;
- Station 08 – E.L. Field forebay;
- Station 07 – downstream side of the Pawtucket Gatehouse;
- Station 06 – upstream side of the Pawtucket Gatehouse;
- Station 05 – Merrimack River immediately upstream of the Pawtucket Dam; and
- Station 04 – Merrimack River approximately 2.0 miles upstream of the Pawtucket Dam.

For individuals which initiated a foray in the direction of the fish ladder, each unique event could potentially encompass a sequence of detections at:

- Station 11 – lower portion of the Pawtucket Dam bypassed reach;
- Stations 12 – mid-point of the Pawtucket Dam bypassed reach;
- Stations 13 – upstream end of the Pawtucket Dam bypassed reach;
- Station 14/15/16 – fish ladder entrance;
- Station 17/18 – fish ladder turn pool;
- Station 19 – fish ladder exit;
- Station 05 – Merrimack River immediately upstream of the Pawtucket Dam; and
- Station 04 – Merrimack River approximately 2.0 miles upstream of the Pawtucket Dam.

Entrance Events: The total number of unique entrance events within each defined foray event for a dual-tagged adult alosines approaching either the lift or fish ladder was determined. This process relied on the ability to identify the breaks in the detection time series for a particular individual to indicate when that fish was or was not present in the vicinity of an entrance receiver. Initial attempts to determine the appropriate threshold interval for coverage of the two entrances (i.e., lift or ladder), the intervals between all successive detections at those two locations were calculated by individual and foray event. A threshold interval for determining continued presence was identified as the 97th percentile of the observed set of interval durations. However, due to overlap in receiver coverage, tagged individuals had the opportunity to be detected by both the entrance receiver and the adjacent receiver above or below. This resulted in entrance detection intervals that were heavily inflated by rapid, alternating detections between sites skewing the 97th percentile threshold and overestimating the number of entrance events. To remove the impact of double coverage and alternating site detections and more accurately capture unique entrance events, an individual needed to exhibit at least three successive detections at either entrance before moving up or downstream in order to be considered an entry event. It should be noted that the receivers at the lift and ladder entrances do not provide directional data. As a result, the reported number of "entrance events" calculated for an individual does not necessarily represent the precise number of individual entries at each structure. However, it does provide some insight into how often a tagged fish was in the vicinity of the entrance (either entering or exiting the structure).

4.5.2 Parameter Estimates for Evaluation of Upstream Passage Effectiveness

Upstream passage effectiveness for adult herring and shad at the Project fish lift and fish ladder was estimated using a standard Cormack-Jolly-Seber (CJS) model run for the set of individual encounter histories developed for each dual-tagged individual which was determined to have initiated a foray towards either passage facility. For dual-tagged individuals this approach provided a series of reach-specific "survival" or passage success estimates at the fish lift for:

- Station 10 to Stations 20/21 (tailrace to lift entrance);
- Stations 20/21 to Stations 22/23 (lift entrance to lift exit);
- Stations 22/23 to Station 08 (lift exit to E.L. Field forebay);
- Station 08 to Station 07 (E.L. Field forebay to downstream of Pawtucket Gatehouse); and
- Station 07 to Station 06 (downstream to upstream of Pawtucket Gatehouse).

This approach provided a series of reach-specific "survival" or passage success estimates at the fish ladder for:

- Station 11 to Station 12 (lower to middle of Pawtucket Dam bypassed reach);
- Station 12 to Station 13 (middle to upper Pawtucket Dam bypassed reach);
- Station 13 to Stations 14/15/16 (upper Pawtucket Dam bypassed reach to ladder entrance);
- Stations 14/15/16 to Stations 17/18 (ladder entrance to turn pool); and
- Stations 17/18 to Station 19 (ladder turn pool to exit).

Standard error and confidence bounds for each estimate were generated and those reach-specific estimates or the product of adjacent reach-specific estimates were used to evaluate upstream passage success. At the fish lift, nearfield effectiveness was estimated as the probability of a fish detected at Station 10 (E.L. Field tailrace) to move to Stations 20/21 (fish lift entrance). Internal effectiveness was estimated as the probability of a fish detected at the lift entrance to move to the lift exit (i.e., from Stations 20/21 to Stations 22/23). Total effectiveness for the Lowell fish lift was estimated as the joint probability to move from the E.L. Field tailrace to the lift exit (i.e., (Stn10 to Stn20/21)*(Stn20/21 to Stn22/23)). Additionally, the probability of successful departure from the Northern Canal (i.e., passage upstream and through the Pawtucket Gatehouse) was estimated as the probability to move from Station 07 to Station 06.

At the fish ladder, nearfield effectiveness was estimated as the probability of a fish detected at Station 13 (upper Pawtucket Dam bypassed reach) to move to Stations 14/15/16 (fish ladder entrance). Internal effectiveness was estimated as the joint probability of a fish detected at the ladder entrance to move to the ladder exit (i.e., (Stn14/15/16 to Stn17/18)*(Stn17/18 to Stn19)). Total effectiveness for the Lowell fish ladder was estimated as the joint probability to move from the upper Pawtucket Dam bypassed reach to the ladder exit (i.e., (Stn13 to Stn14/15/16)*(Stn14/15/16 to Stn17/18)*(Stn17/18 to Stn19)).

To evaluate upstream passage effectiveness using the CJS models, a suite of candidate models were developed in Program MARK (White and Burnham 1999) based on whether survival (i.e., passage success), recapture (i.e., detection), or both vary or are constant among stations. Models developed during this study included:

- Phi(t)p(t): survival and recapture may vary between receiver stations;
- Phi(t)p(.): survival may vary between stations; recapture is constant between stations;
- Phi(.)p(t): survival is constant between stations; recapture may vary between stations;
- Phi(.)p(.): survival and recapture are constant between stations;

Where;

- Phi = probability of survival
- p = probability of detection
- (t) = parameter varies
- (.) = parameter is constant

To evaluate the fit of the CJS model, goodness of fit testing was conducted for the "starting model" (i.e., the fully parameterized model) using the function RELEASE within Program MARK. Akaike's Information Criterion (AIC) was used to rank the models as to how well they fit the observed mark-recapture data. Lower AIC values denote a more explanatory yet parsimonious fit than higher AIC values. The model with the lowest AIC value was selected for the purposes of generating passage effectiveness estimates.

4.5.3 Time to Event Analysis

4.5.3.1 Cox Proportional Hazard Model

Utilizing available methodology for quantifying fish passage performance (Castro-Santos and Perry 2012), multi-variate Cox proportional hazard models were developed to assess the impact of various operational and environmental variables on the rate of passage success. Operational variables considered as part of this analysis included:

- Bypassed reach spill flow (i.e., the sum of the Pawtucket Dam fish ladder and inflatable section overflow) (cfs);
- Spill flow (cfs);
- Merrimack River inflow (cfs); and
- Release date.

This assessment on the rate of passage success focused on upstream passage events directed towards the (1) E.L. Field fish lift, and (2) Pawtucket Dam fish ladder.

Regression models for the time to event analyses were constructed using the *coxph*() function from the package "*survival*" in R (R Core Team 2020) and were used to evaluate the rate of passage success and identify operational hazards at sites which contained a physical barrier or a structure through which tagged individuals would have to navigate upstream of the dam through one of the two possible routes.

The Cox proportional hazard regression can be described as a hazard function to evaluate the proportionate risk at time (t) such that

$$h(t) = h_0(t) \times exp(b_1x_1 + b_2x_2 + \ldots + b_ix_i)$$

where $h(t)$ represents that hazard at a given time point which is equal to the initial or baseline hazard at time 0:00 ($h_0\ (t)$) multiplied by e (the base of the natural logarithm) to the power of the additive relationship between each covariate (x_i) multiplied by its associated coefficient (b_i).

From the above equation, the relative impact of an operational parameter on the rate of passage success is represented by its associated coefficient. The hazard ratio of a given operational parameter is calculated by exponentiating the coefficient of a given parameter, which represents that multiplicative impact of that parameter. It is important to note that exponentiating these coefficients makes the value relative to a value of 1 (e^0), which represents a baseline of no hazard. For example, if the hazard ratio is greater than 1, e.g., 1.5, that will be interpreted as that covariate increasing the risk of passage failure by a factor of 1.5. Alternatively stated, a hazard ratio of 1.5 indicates that the associated covariate increases the risk by 50% as it is 0.5 greater than 1. In contrast, a hazard ratio below 1, e.g., 0.75, indicates that the associated covariate reduces the risk of passage failure by a factor of 0.75, or 25%. In short, a hazard ratio >1 indicates an increase in the risk of passage failure, a hazard ratio of 1 indicates no significant directional effect on passage, and a hazard ratio <1 indicates a reduction in the risk of passage failure.

4.5.3.2 Model Evaluation and Selection

As is the case with any statistical model, the type of model selected makes inherent assumptions about the nature of the data being modelled. The primary assumption of a Cox proportional hazard model is that the hazards are proportional. However, this assumption is not always appropriate for the data. As a result, the *cox.zph()* function was used during this assessment to assess the validity of the proportional hazard assumption. This function assessed scaled Schoenfield residuals to evaluate whether Cox regression residuals of each covariate in addition to the model as a whole are independent of time. In the event that the Schoenfield residuals are not independent of time, it can be said that the assumption of proportional hazards is violated and a Cox proportional hazards model may be misrepresentative of the true relationships between the selected covariates and passage success.

4.5.3.3 Event Definition

The multi-variate Cox proportional hazard models constructed to assess the impact of various operational and environmental variables on the rate of upstream passage success for adult alewives and American shad incorporated the series of upstream foray events defined for each radio-tagged adult alosine using the methodology described above in Section 4.5.1.

4.6 Data Analysis – Downstream Passage

A complete record of all valid stationary receiver detections for each radio-tagged adult alosine was generated. The pattern and timing of detections in these individual records were reviewed, and a route of passage as well as project arrival and passage times were assigned to each radio-tagged individual. In the instance that a downstream route could not be clearly determined from the collected data, the passage event for that particular fish was classified as 'unknown'.

Where data were available, the approach duration and project residence times were calculated. Values for approach duration were calculated as the duration of time from release until detection at Station 05. Upstream project residence time was defined as the duration of time from the initial detection at Station 05 until the determined time of downstream passage. Time spent immediately upstream of the dam was further evaluated using initial detection times for adult alosines at Monitoring Stations 06 and 07 to provide an understanding of passage times associated with moving through the Pawtucket Gatehouse and entering into the Northern Canal approach to the E.L. Field powerhouse.

4.6.1 Parameter Estimates for Evaluation of Downstream Passage

Downstream passage success at the Project was estimated for adult alosines using a standard Cormack-Jolly-Seber (CJS) model run for the set of individual encounter histories (i.e., the series of detection/no detection through the linear sequence of receivers from upstream to downstream). This approach provided a series of reach-specific "survival" or passage success estimates for:

- Monitoring Station 04 to Monitoring Station 05 (i.e., lower impoundment);
- Monitoring Station 05 (i.e., upstream approach) to downstream passage;
- Downstream passage to Monitoring Station 25 (i.e., first downstream receiver);
- Monitoring Station 25 (i.e., first downstream receiver) to Monitoring Station 26 (i.e., second downstream receiver); and
- Station 26 to Lawrence.

Standard error and confidence bounds for each estimate were generated. The joint probability of three reach survival estimates (i.e., (Lowell to Station 25)*(Station 25 to Station 26)*(Station 26 to Lawrence)) was used as the estimate of total passage survival for the Project. This approach resulted in a mortality estimate that included both background mortality (i.e., natural mortality such as predation) and mortality due to Project effects in the reach extending from Lowell downstream to Lawrence. Thus, the results presented in this report reflect a minimum estimate of survival attributable to Project effects for adult alosines.

To evaluate passage success using the CJS models, a suite of candidate models were developed in Program MARK based on whether survival (i.e., passage success), recapture (i.e., detection), or both vary or are constant among stations. Models developed during this study included:

- *Phi(t)p(t)*: survival and recapture may vary between receiver stations;

- *Phi(t)p(.)*: survival may vary between stations; recapture is constant between stations;
- *Phi(.)p(t)*: survival is constant between stations; recapture may vary between stations;
- *Phi(.)p(.)*: survival and recapture are constant between stations;

Where;

- *Phi* = probability of survival
- *p* = probability of detection
- *(t)* = parameter varies
- *(.)* = parameter is constant

To evaluate the fit of the CJS model, goodness of fit testing was conducted for the "starting model" (i.e., the fully parameterized model) using the function RELEASE within Program MARK. Akaike's Information Criterion (AIC) was used to rank the models as to how well they fit the observed mark-recapture data. Lower AIC values denote a more explanatory yet parsimonious fit than higher AIC values. The model with the lowest AIC value was selected for the purposes of generating passage effectiveness estimates.

Models were prepared which evaluated downstream passage success of adult alosines at Lowell as follows:

- All adult alewives– based on detection at Station 37, Station 39 and Lawrence;
- Adult alewives originally released at Tyngsborough – based on detection at Station 25, Station 26 and Station 27 (i.e., Lawrence);
- Adult alewives originally released at Mine Falls or Pepperell – based on detection at Station 25, Station 26 and Station 27 (i.e., Lawrence);
- Route-specific adult alewives (turbine or downstream bypass) – based on detection at Station 25, Station 26 and Station 27 (i.e., Lawrence);
- All adult alewives– adjusted for median "travel time" for freshly dead adult alosines released in Lowell tailrace to reach Lawrence (i.e., test fish with downstream travel times in excess of median drift duration manually adjusted to reflect a mortality at the Project);
- All adult shad – based on detection at Station 25, Station 26 and Station 27 (i.e., Lawrence);
- Route-specific adult shad (turbine, downstream bypass, or spill) – based on detection at Station 25, Station 26 and Station 27 (i.e., Lawrence); and

- All adult shad– adjusted for median "travel time" for freshly dead adult alosines released in Lowell tailrace to reach Lawrence (i.e., test fish with downstream travel times in excess of median drift duration manually adjusted to reflect a mortality at the Project).

4.6.2 Time to Event Analysis – Downstream Passage

4.6.2.1 Cox Proportional Hazard Model

Utilizing available methodology for quantifying fish passage performance (Castro-Santos and Perry 2012), multi-variate Cox proportional hazard models were developed to assess the impact of various operational and environmental variables on the rate of downstream passage success for adult river herring and American shad. Operational variables considered as part of this analysis included:

- Merrimack River inflow (cfs);
- Spill flow (cfs);
- Downstream bypass facility flow (cfs);
- Release location (alewives only); and
- Release date.

This assessment on the rate of passage success focused on approach events at (1) the Pawtucket Gatehouse (i.e., Station 06), and (2) at the E.L. Field Powerhouse (i.e., Station 08).

Regression models for the time to event analyses were constructed using the *coxph*() function from the package "*survival*" in R (R Core Team 2020) and were used to evaluate the rate of passage success and identify operational hazards at sites which contained a physical barrier or a structure through which tagged individuals would have to navigate (i.e., the Pawtucket Gatehouse and E.L. Field Powerhouse).

The Cox proportional hazard regression can be described as a hazard function to evaluate the proportionate risk at time (t) such that

$$h(t) = h_0(t) \times exp(b_1x_1 + b_2x_2 + \ldots + b_ix_i)$$

where $h(t)$ represents that hazard at a given time point which is equal to the initial or baseline hazard at time 0:00 ($h_0(t)$) multiplied by e (the base of the natural logarithm) to the power of the additive relationship between each covariate (x_i) multiplied by its associated coefficient (b_i).

From the above equation, the relative impact of an operational parameter on the rate of passage success is represented by its associated coefficient. The hazard ratio of a given operational parameter is calculated by exponentiating the coefficient of a given parameter, which represents the multiplicative impact of that parameter. It is important to note that exponentiating these coefficients makes the value relative to a value of 1 (e^0), which represents a baseline of no hazard. For example, if the hazard ratio is greater than 1, e.g., 1.5, that will be interpreted as that covariate increasing the risk of passage failure by a factor of 1.5. Alternatively stated, a hazard ratio of 1.5 indicates that the associated covariate increases the risk by 50% as it is 0.5 greater than 1. In contrast, a hazard ratio below 1, e.g., 0.75, indicates that the associated covariate reduces the risk of passage failure by a factor of 0.75, or 25%. In short, a hazard ratio >1 indicates an increase in the risk of passage failure, a hazard ratio of 1 indicates no significant directional effect on passage, and a hazard ratio <1 indicates a reduction in the risk of passage failure.

4.6.2.2 Model Evaluation and Selection

As is the case with any statistical model, the type of model selected makes inherent assumptions about the nature of the data being modelled. The primary assumption of a Cox proportional hazard model is that the hazards are proportional. However, this assumption is not always appropriate for the data. As a result, the *cox.zph()* function was used during this assessment to assess the validity of the proportional hazard assumption. This function assessed scaled Schoenfield residuals to evaluate whether Cox regression residuals of each covariate in addition to the model as a whole are independent of time. In the event that the Schoenfield residuals are not independent of time, it can be said that the assumption of proportional hazards is violated and a Cox proportional hazards model may be misrepresentative of the true relationships between the selected covariates and passage success.

4.6.2.3 Event Definition

To evaluate the impact of operational parameters on passage success, instances of passage success and failure required definition and represent the 'events' (or passage attempts) in this analysis. Ostensibly, the transmitters deployed during this study should transmit a signal that when within range of a particular receiver will be detected every 2.0 seconds. However, various sources of outside noise or areas of poor coverage due to structures, etc. introduce variation into the frequency of detection for a unique transmitters signals. Given that different site locations and receiver types are subject to varying degrees of ambient noise, the duration between successive detections was calculated for each tagged individual at each receiver location. A threshold interval for determining continued presence of a transmitter within the detection zone of a specific receiver was identified as the 95th percentile of the observed set of interval durations. This value was calculated at 3.42 minutes for Station 6 and 5.64 minutes for Station 29. These two threshold values were then used to delineate when each event was started and completed for a tagged individual. The departure of a radio-tagged individual from the detection zone of a particular receiver was determined when the time interval between successive detections exceeded the specific threshold interval for that zone. In addition, if an individual was observed having left the field of detection and was subsequently detected at another site before returning, this was considered as an event regardless of whether or not the fish returned to the field of detection within the limits of the 95th percentile threshold.

From this, a passage failure event (assigned a value of 0) was defined as any duration where all detections lay within the 95th percentile of durations for all individuals at that site. Passage failure represents events in which a tagged individual enters the field of detection at a given site without passing to the next site (i.e., moving downstream) in the system. A passage success event (assigned a status of 1) was defined using the final instance of detection for a tagged individual at a singular site where that tagged individual was next detected at a downstream receiver (i.e., successfully passed). Passage success/failure (1/0) was used as the status coinciding with time in the Cox proportional hazard models. After defining passage events for every individual, the time duration for the regression was defined as the duration from one event to the next.

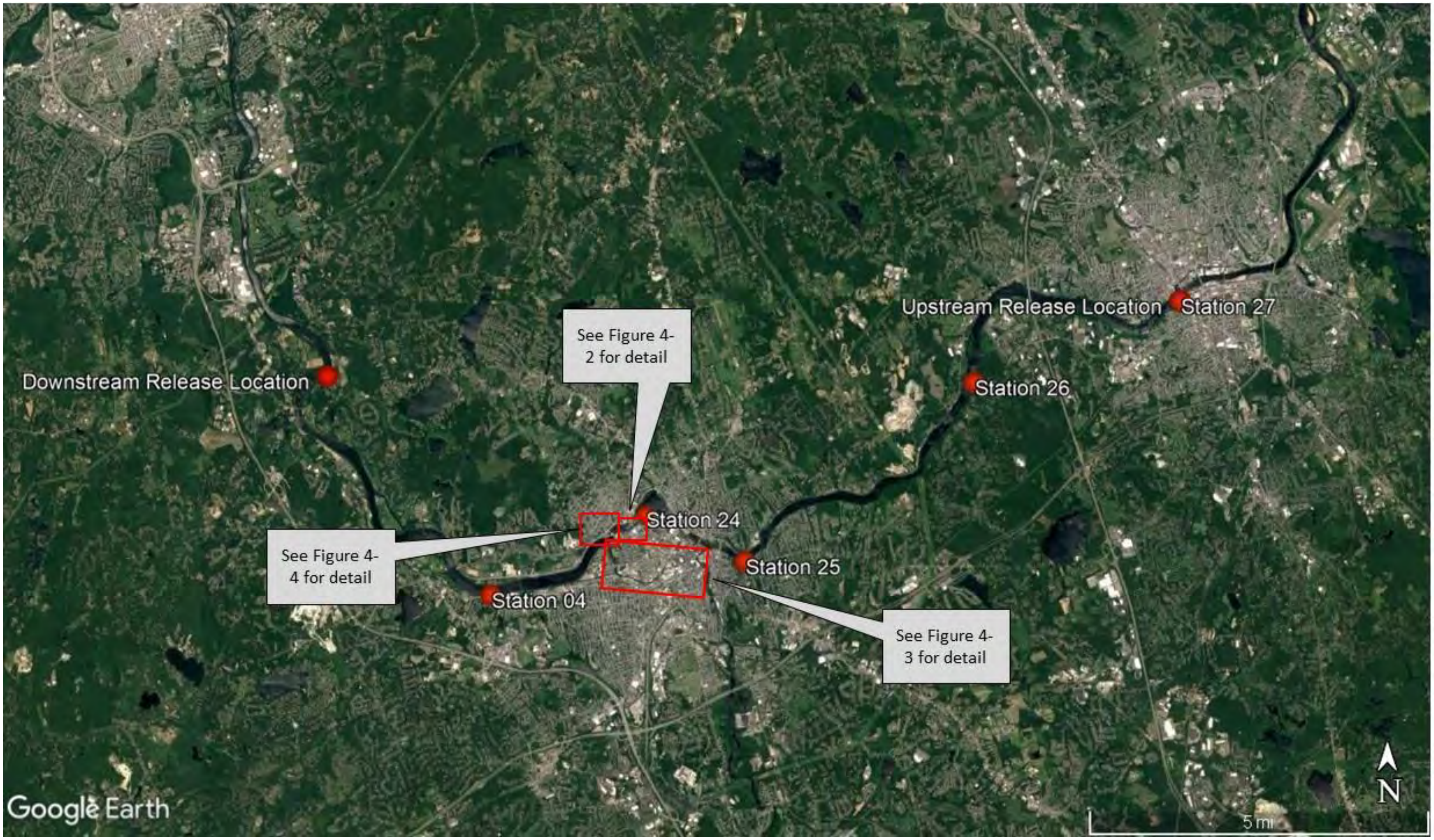

Figure 4–1. Locations of remote stationary radio-telemetry receivers installed during the 2020 adult alosine passage assessment at Lowell.

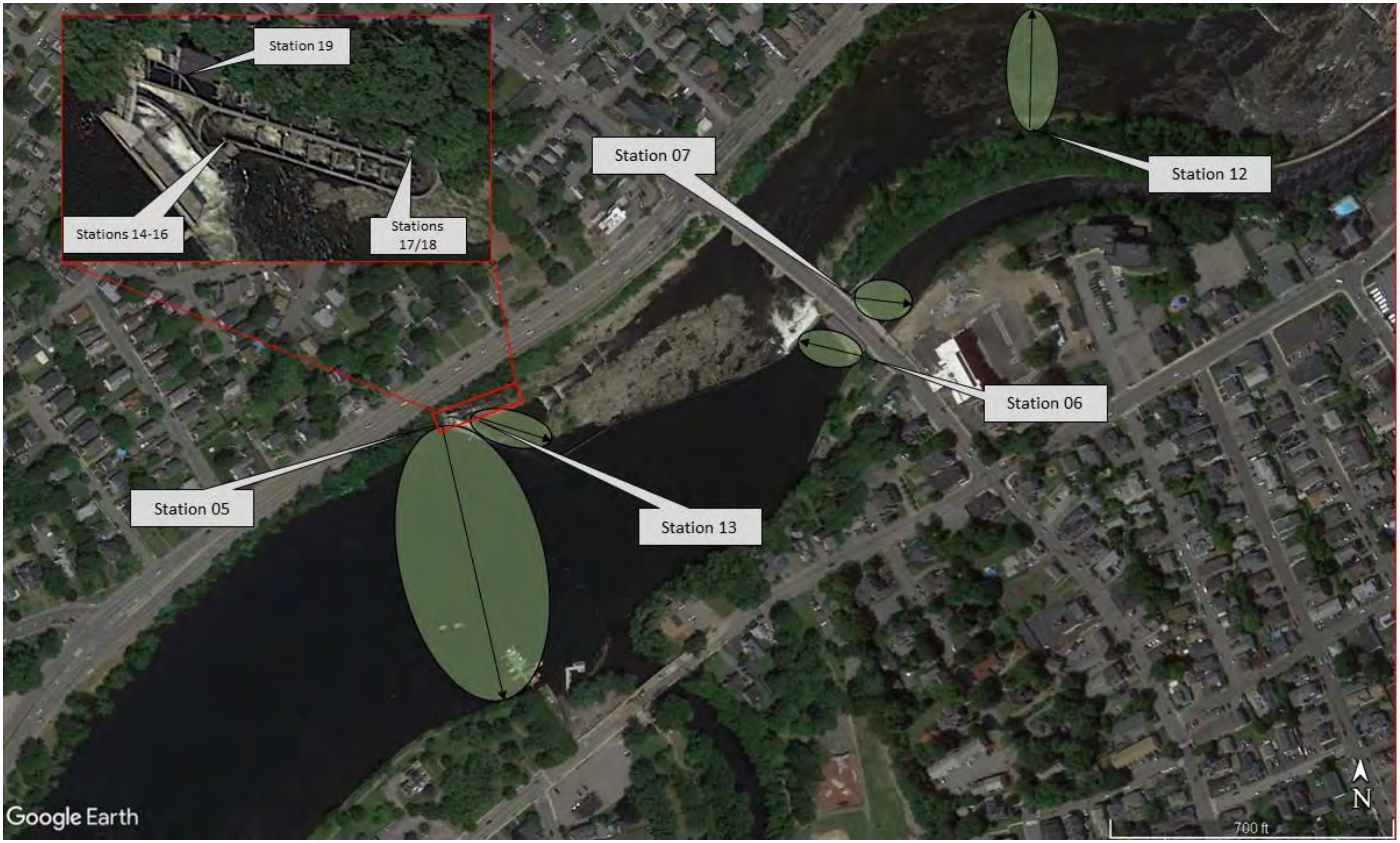

Figure 4–2. Locations and approximate detection areas for stationary radio-telemetry receivers installed upstream of Pawtucket Dam, fish ladder and Northern Gatehouse during the 2020 adult alosine passage assessment at Lowell.

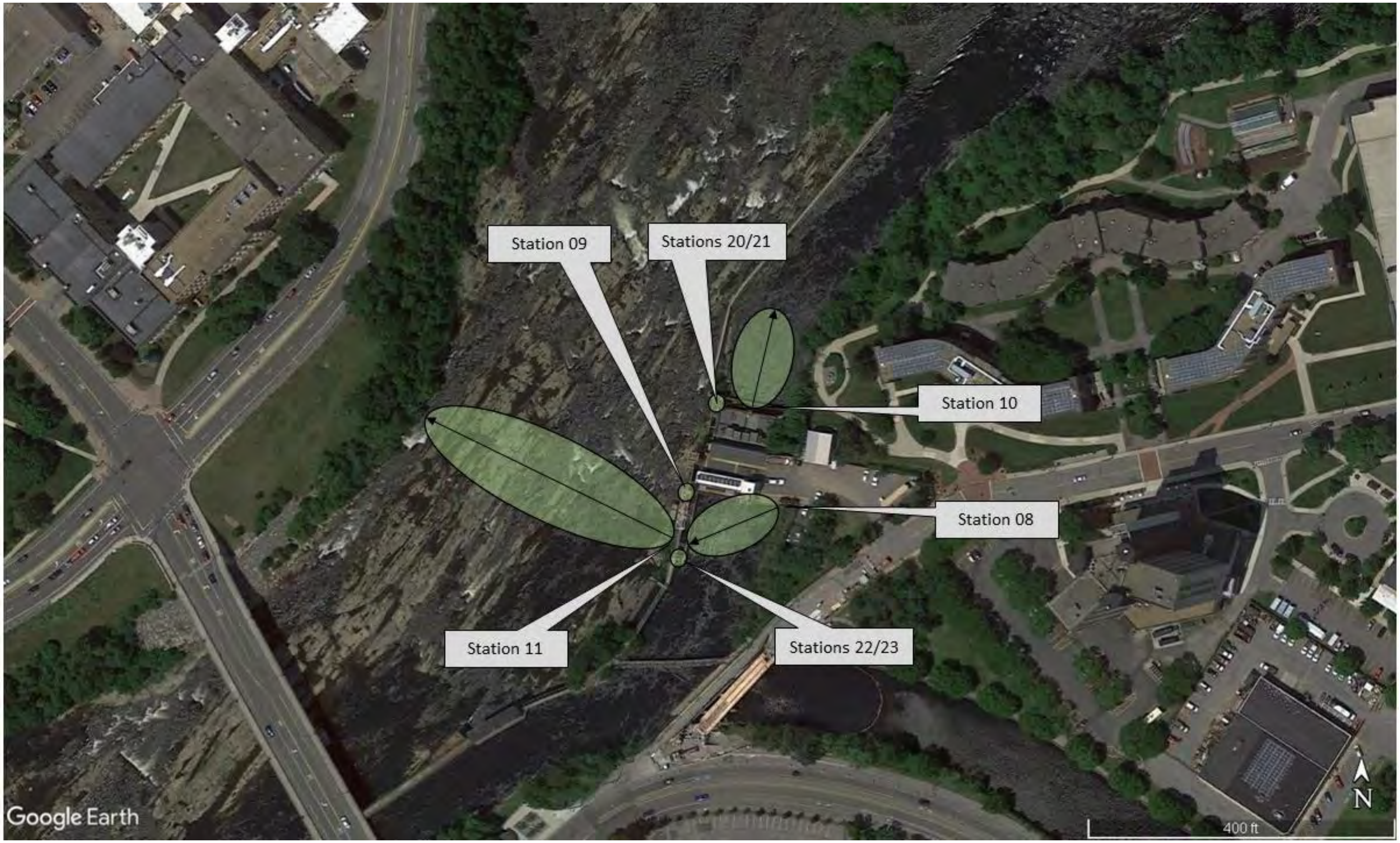

Figure 4–3. Locations and approximate detection areas for stationary radio-telemetry receivers installed in the vicinity of the E.L. Field Powerhouse during the 2020 adult alosine passage assessment at Lowell.

Figure 4–4. Locations and approximate detection areas for stationary radio-telemetry receivers installed within the downtown canal system during the 2020 adult alosine passage assessment at Lowell.

5 Results

5.1 Merrimack River Conditions and Lowell Project Operations

Daily water temperature at Lowell ranged from 8.0-21.1 °C over the course of the monitoring period. Figure 5-1 presents the Merrimack River inflow as recorded at the Lowell Project for the period of time from the first release of tagged adult alosines at Lawrence on May 7 until the end of the monitoring period on June 30, 2020. Merrimack River flow at Lowell ranged between 1,150 and 13,200 cfs during the nearly two month spring study period. Figure 5-2 presents the monthly flow duration curves prepared for the Lowell Project during the development of the Preliminary Application Document. The median flow condition at the Project is approximately 8,900 cfs during May and 4,900 cfs during June. Merrimack River conditions have a ~72% probability during May and a ~35% probability during June to exceed the ~6,600 cfs capacity of the E.L. Field powerhouse.

Table 5-1 summarizes the percentage of inflow records from the 2019 study period categorized by volume (to the nearest 1,000 cfs) as well as the percentage of time that each volume category is historically exceeded[4]. To help characterize the 2020 passage season, monthly exceedance probabilities less than 0.35 were classified as "high" flow conditions, 0.35 to 0.65 were classified as "normal" flow conditions, and greater than 0.65 were classified as "low" flow conditions. Inflows at the Project for the period May 7 through 31 were representative of high flow conditions (i.e., those with a probability of exceedance of less than 0.35) for 6% of the period, normal flow conditions (i.e., those with a probability of exceedance of 0.35-0.65) for 59% of the time and low flow conditions (i.e., those with a probability of exceedance of greater than 0.65) for 35% of the time. For the month of June, inflows were representative of normal flow conditions 7% of the time and low flow conditions 93% of the time.

Flow duration information for the months of May and June (combined) is presented in Figure 5-3. The median flow condition during the two month period is near 6,700 cfs. When characterized using the flow condition criteria above, inflows at the Project for the period May 7 through June 30, 2020 were representative of high flow conditions (i.e., those with a probability of exceedance of less than 0.35) for 7% of the period, normal flow conditions (i.e., those with a probability of exceedance of 0.35-0.65) for 36% of the time and low flow conditions (i.e., those with a probability of exceedance of greater than 0.65) for 57% of the time (Table 5-1).

Figure 5-4 summarizes the allocation of water among the E.L. Field powerhouse, bypassed reach, E.L. Field fish passage facility, Pawtucket Dam fish ladder and the downtown canal system at Lowell. Turbine units were in operation at the E.L. Field powerhouse for the duration of the study period with a brief exception on June 11. The E.L. Field fish passage facilities were

[4] Estimates of monthly exceedance estimated from monthly flow duration curves provided in Appendix H of the PAD.

operated throughout the study period, passing approximately 100 cfs between the hours of approximately 0600 to 1500 and 132 cfs from approximately 1500 to 0600. Two major spill events, associated with increases in river flows, occurred during the early portion of the monitoring period. Peaks for these two high flow events occurred on May 7 and May 18. Outside of those two periods of increased discharge, flows through the bypassed reach during the 2020 monitoring period were comprised of the ~500 cfs of water constituting the attraction and conveyance flow associated with the Pawtucket Dam fish ladder as well as incidental spill flow passing over the spillway. Incidental spill flows in excess of 500 cfs were present until May 21 after which incidental spill was reduced to near zero through the month of June (Figure 5-4).

Flows to the downstream canal system represented between 27-26% of the 2,000 cfs capacity during May and 27% of the 2,000 cfs capacity during June. Due to overriding safety concerns, Boott ceased operation of the turbine units within the downtown canal system prior to the study period. To the extent possible, Boott's operations staff attempted to operate the canal system as if there were canal units available, by opening gates when river flows exceeded the hydraulic capacity of the E.L. Field turbines (6,600 cfs). As a result, flows through the downtown canal system were limited to passage via open gates. Manual gate manipulations during the study period were limited to two dates. A summary of the downtown canal gate operations and discharge is provided in Table 5-2.

Hourly operations records are provided in Appendix C and include values for forebay elevation, tailrace elevation, inflow, E.L. Field turbine discharge, downstream bypass discharge, upstream fishway flow, downtown canal flow, and spill flow.

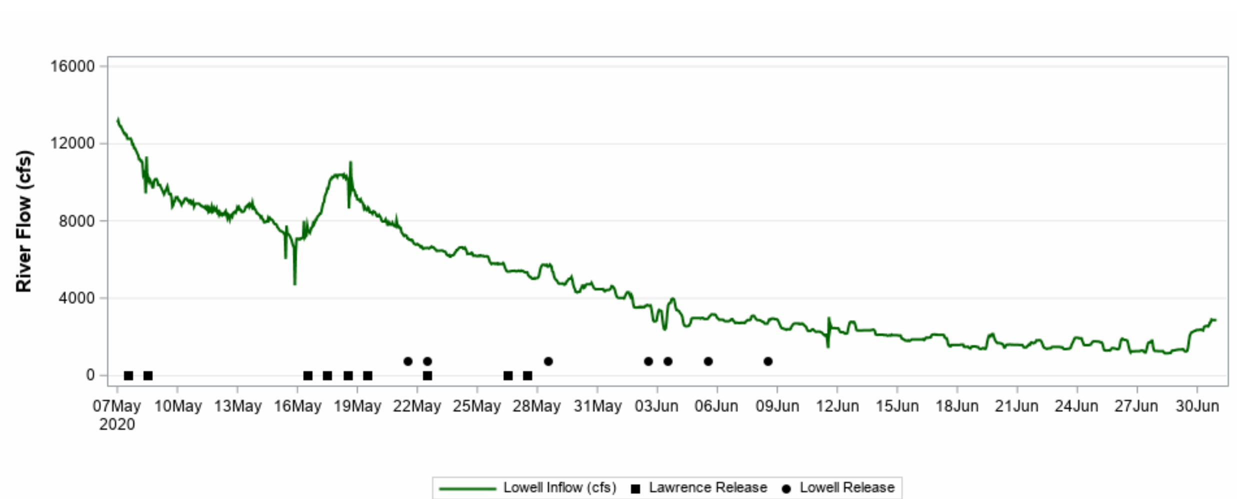

Figure 5–1. Merrimack River flow at Lowell for the period May 7 to June 30, 2020.

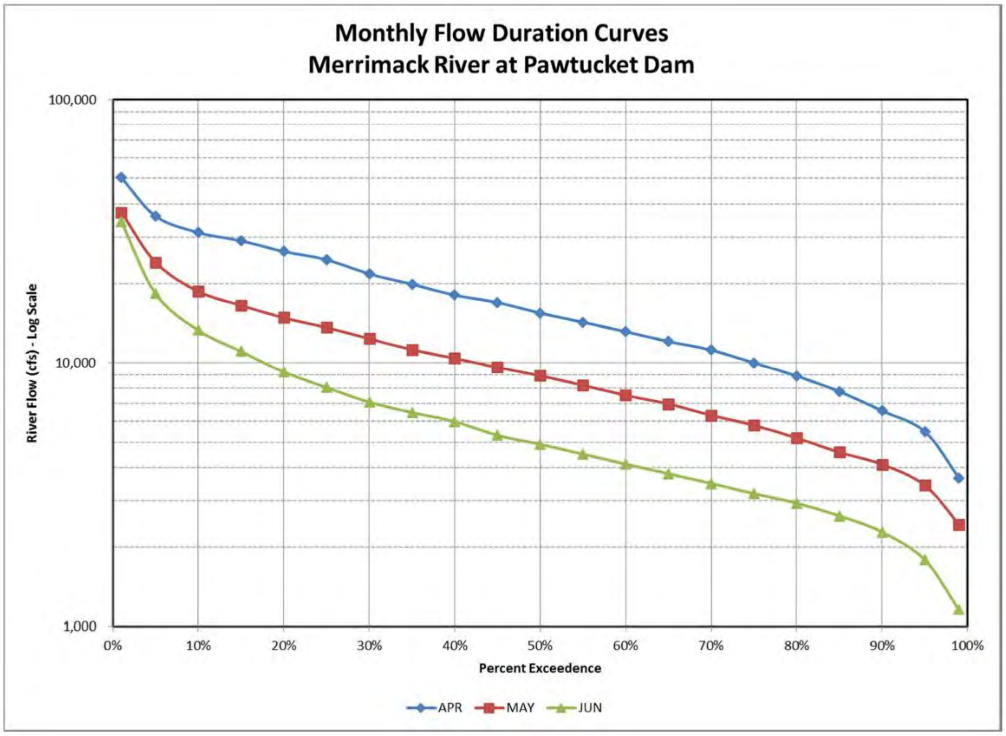

Figure 5–2. Flow duration curves for the months of April, May, and June at the Lowell hydroelectric project.

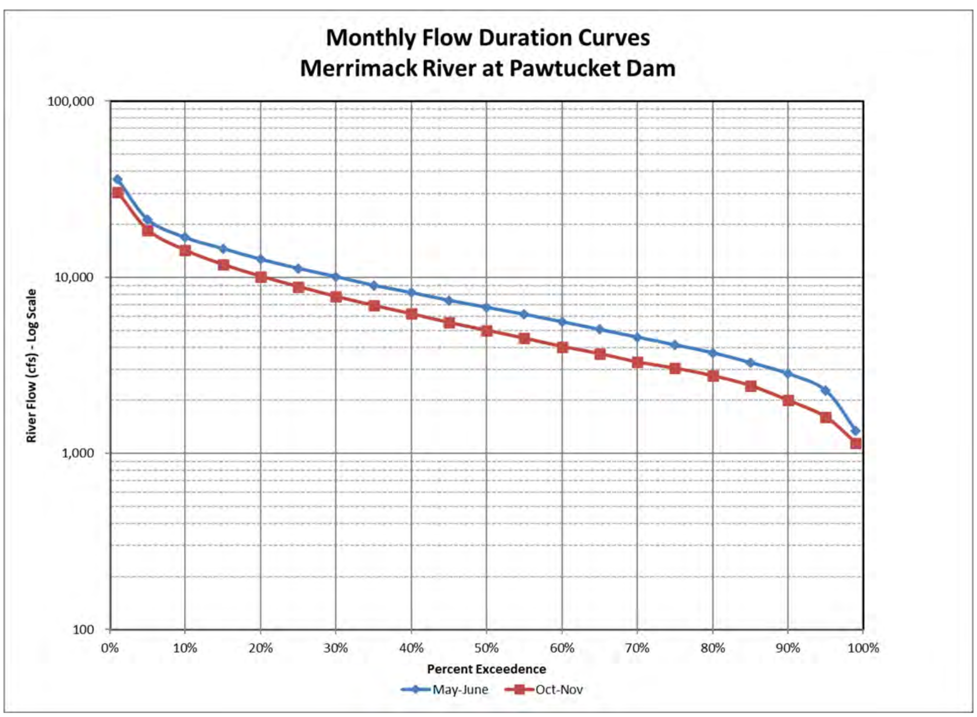

Figure 5–3. Flow duration curves for the two month period of October-November at the Lowell hydroelectric project.

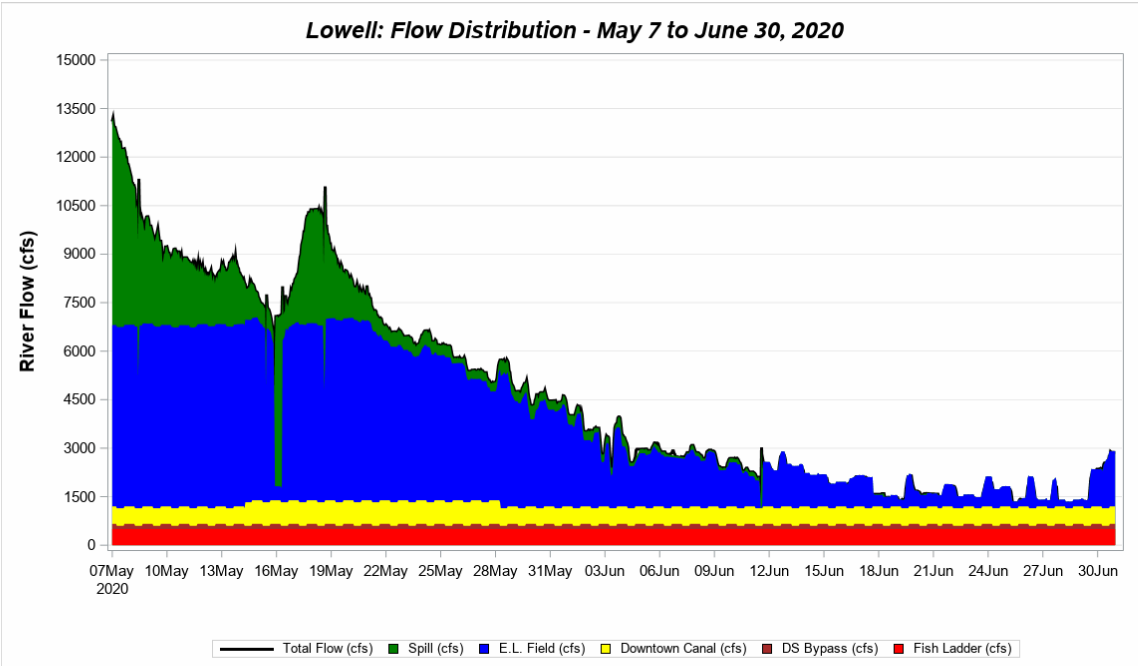

Figure 5–4. Total, spill, E.L. Field, fish ladder, downstream bypass and downtown canal system flow (cfs) for the period May 7 to June 30, 2020.

Table 5–1. Frequency of occurrence of river inflow at Lowell (to nearest 1,000 cfs) during 2020 adult alosine passage assessment and corresponding percentage of time flows are historically exceeded.

River Flow (nearest 1k)	May 7-31, 2020		June 1-30, 2020		May 7-June 30, 2020	
	Percentage of Month	Percentage of Month Historically Exceeded	Percentage of Month	Percentage of Month Historically Exceeded	Percentage of Period	Percentage of Period Historically Exceeded
1000	0.0%	100	20.6%	99	11.2%	99
2000	0.0%	100	46.4%	94	25.3%	96
3000	0.0%	96	26.0%	80	14.2%	88
4000	5.2%	90	7.1%	62	6.2%	76
5000	15.0%	82	-	-	6.8%	65
6000	14.8%	74	-	-	6.7%	56
7000	13.7%	65	-	-	6.2%	48
8000	18.5%	56	-	-	8.4%	41
9000	17.7%	48	-	-	8.0%	35
10000	9.5%	42	-	-	4.3%	30
11000	1.7%	9	-	-	0.8%	6
12000	2.3%	6	-	-	1.1%	LT5
13000	1.7%	LT 5	-	-	0.8%	LT5

Table 5–2. Summary of downtown canal gate settings and estimated discharge values during the spring 2020 adult alosine telemetry study at Lowell.

Date	Gate	Setting	Estimated Discharge (cfs)
7-May	Guard Locks	open	542
	Swamp Locks Deep Gate	open	542
	Hamilton Wasteway	closed	0
	Lower Locks Gates	open	542
	Boott Gate	closed	0
14-May	Guard Locks	open	729
	Swamp Locks Deep Gate	open	0
	Hamilton Wasteway	open	729
	Lower Locks Gates	open	542
	Boott Gate	open	190
28-May	Guard Locks	open	542
	Swamp Locks Deep Gate	open	542
	Hamilton Wasteway	closed	0
	Lower Locks Gates	open	542
	Boott Gate	closed	0

5.2 Monitoring Station Functionality

Radio-tagged adult alosines were released into the Merrimack River beginning in early May, and the RSP called for continuous monitoring at each stationary receiver location through the end of June, 2020. An overview of system continuity for stationary receivers along the mainstem of the Merrimack and at the E.L. Field Powerhouse is provided in Figure 5-5, for receivers associated with the fish lift and ladder is provided in Figure 5-6, and for receivers positioned at locations in the downtown power canal in Figure 5-7. The majority of the radio-telemetry monitoring stations installed to evaluate passage at Lowell during the spring study operated without issue for the full period.

Interruptions in continuous coverage were observed at two locations among the mainstem and E.L. Field receivers. Station 05 (approach area immediately upstream of Pawtucket Dam) was offline from 1000 on June 4 to 1000 on June 8 due to an internal error in the receiver. To adjust for this outage detection data recorded at Station 06 was reviewed and was used as an approximate for "first detection" of outmigrants approaching the Pawtucket Dam during this period. Station 24 (convergence area of the tailrace and bypassed reach) was offline for three periods during the latter part of May (1500 on May 19 – 1100 on May 20, 1200 on May 20 – 0900 on May 22, and 1300 on May 26 – 1000 on May 27). All components at Station 24 were evaluated after the second interruption (with no obvious cause). The receiver was replaced with a new unit on May 27 and operated without issue for the remainder of the study. To adjust for this outage, detection data from Stations 10 and 11 were used as a surrogate to represent "first detection" downstream of the Project for dual-tagged fish migrating upstream.

Neither outage had an impact on the ability to estimate effectiveness of the upstream fishway facilities or downstream passage survival for adult alosines.

All radio and PIT-readers installed in the E.L. Field fish lift and Pawtucket Dam fish ladder operated without issue for the duration of the study. Over the course of the study there were several minor outages at receiver stations related to the generating units within the downtown canal system. As there was no generation at any of the downtown canal turbine units over the course of the study the overall impact of these short duration outages had no impact on study results.

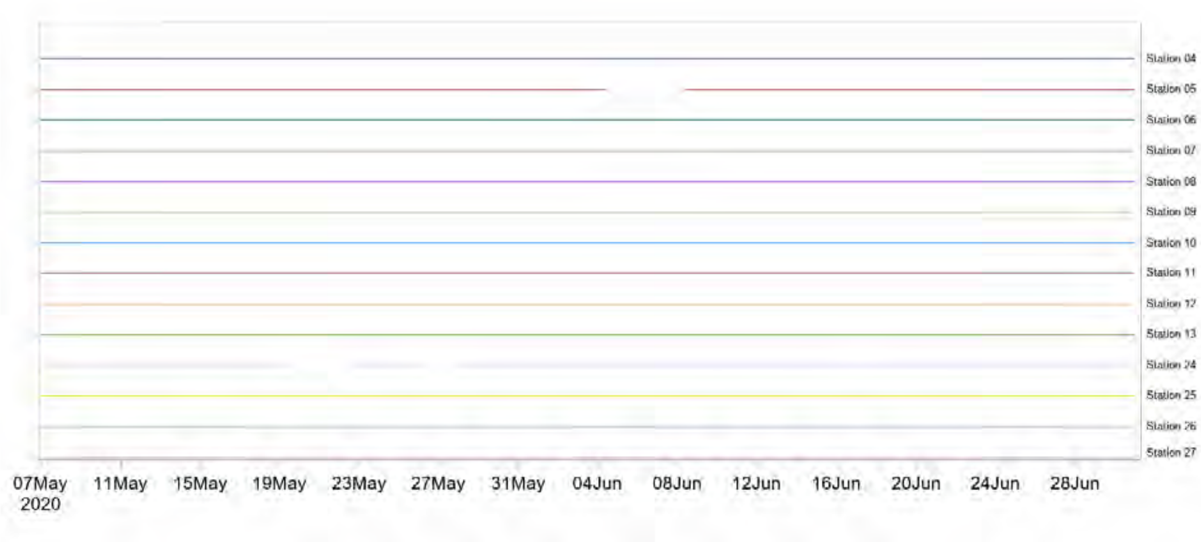

Figure 5–5. Operational coverage for telemetry receivers along the mainstem Merrimack River and vicinity of the E.L. Field Powerhouse during the adult alosine passage assessment, May 7 to June 30, 2020.

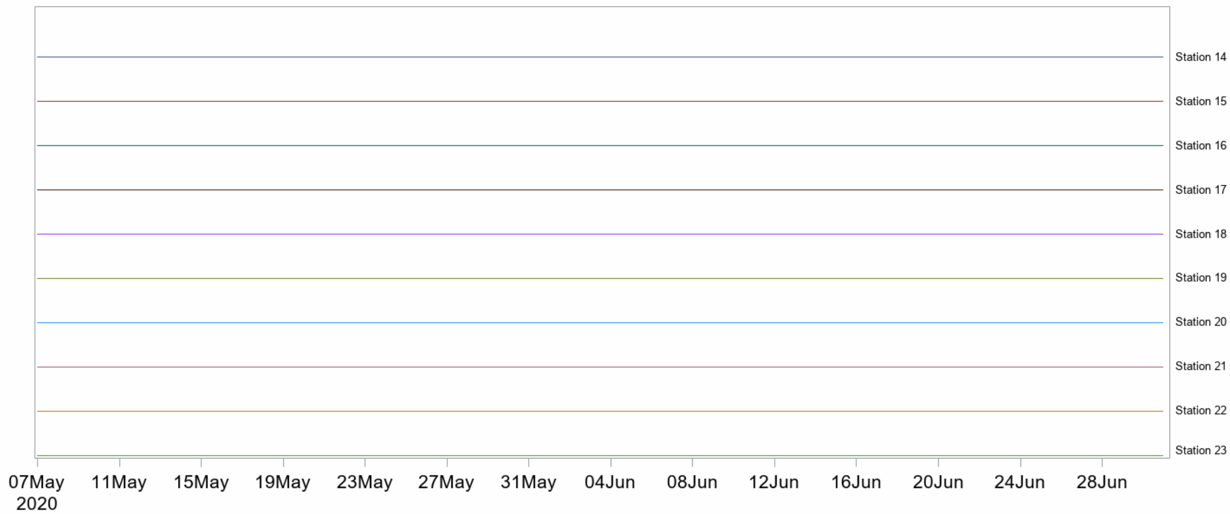

Figure 5–6. Operational coverage for telemetry receivers at the E.L. Field fish lift and Pawtucket Dam fish ladder during the adult alosine passage assessment, May 7 to June 30, 2020.

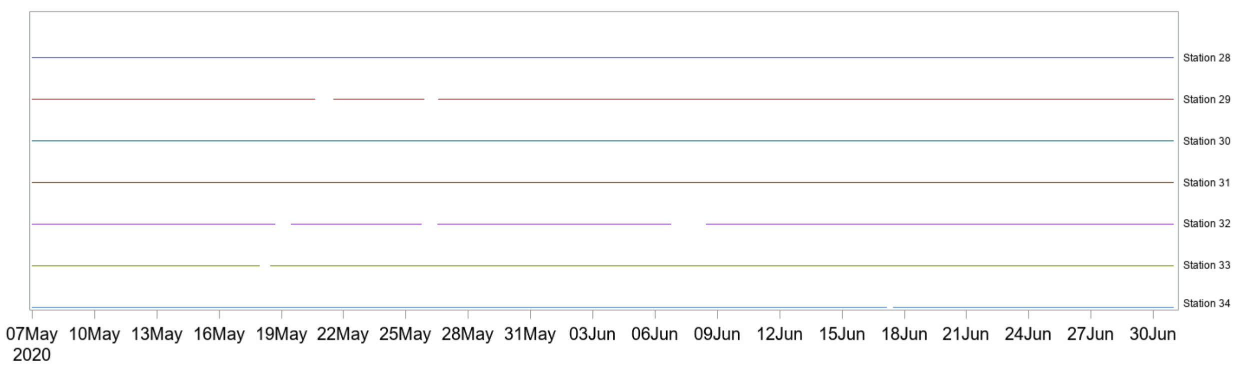

Figure 5–7. Operational coverage for telemetry receivers within the downtown canal system at the Lowell Project during the adult alosine passage assessment, May 7 to June 30, 2020.

5.3 Downstream Drift Assessment

Freshly dead, radio-tagged adult alewives (n = 10) and American shad (n =10) were released directly into the discharge of an active turbine unit at the Lowell Project during the 2020 downstream passage assessment. A total of two individuals were released in the tailrace on each date when 20 live radio-tagged adult alewives or American shad were released upstream of the Project. Table 5-3 provides a summary of the body size, tag information, release schedule and flow conditions at the time of release. These individuals were radio-tagged using a unique frequency (149.360 MHz) and a set of independent receivers were positioned at Monitoring Stations 25, 26, and 27 to scan for the approach and passage of these fish. There were no detections for any of the 20 drift individuals at Stations 25 (2.1 miles), 26 (6.0 miles) or 27 (10.75 miles) downstream of the Lowell tailrace.

Table 5–3. Summary of tagging and release information for the downstream drift assessment of adult alewives and American shad released in the Lowell tailrace during the downstream passage assessment, May 7 to June 30, 2020.

<table>
<tr><th rowspan="2">Species</th><th rowspan="2">Release Date</th><th colspan="2">River Condition (cfs)</th><th rowspan="2">Frequency (ID)</th><th rowspan="2">Total Length (mm)</th></tr>
<tr><th>Inflow</th><th>ELF Discharge</th></tr>
<tr><td rowspan="10">River Herring</td><td rowspan="6">21-May</td><td rowspan="6">7027</td><td rowspan="6">5127</td><td>149.360(10)</td><td>294</td></tr>
<tr><td>149.360(11)</td><td>303</td></tr>
<tr><td>149.360(12)</td><td>313</td></tr>
<tr><td>149.360(13)</td><td>328</td></tr>
<tr><td>149.360(14)</td><td>305</td></tr>
<tr><td>149.360(15)</td><td>306</td></tr>
<tr><td rowspan="2">22-May</td><td rowspan="2">6594</td><td rowspan="2">4808</td><td>149.360(16)</td><td>283</td></tr>
<tr><td>149.360(17)</td><td>250</td></tr>
<tr><td rowspan="2">28-May</td><td rowspan="2">5730</td><td rowspan="2">4188</td><td>149.360(18)</td><td>300</td></tr>
<tr><td>149.360(19)</td><td>296</td></tr>
<tr><td rowspan="10">Shad</td><td rowspan="5">3-Jun</td><td rowspan="5">3278</td><td rowspan="5">2069</td><td>149.360(190)</td><td>452</td></tr>
<tr><td>149.360(191)</td><td>475</td></tr>
<tr><td>149.360(192)</td><td>438</td></tr>
<tr><td>149.360(193)</td><td>472</td></tr>
<tr><td>149.360(194)</td><td>438</td></tr>
<tr><td rowspan="5">5-Jun</td><td rowspan="5">2927</td><td rowspan="5">1699</td><td>149.360(30)</td><td>464</td></tr>
<tr><td>149.360(31)</td><td>499</td></tr>
<tr><td>149.360(32)</td><td>451</td></tr>
<tr><td>149.360(33)</td><td>487</td></tr>
<tr><td>149.360(34)</td><td>506</td></tr>
</table>

5.4 Upstream Passage Effectiveness – Adult Alewives

A total of 354 adult alewives were tagged following collection at the Lawrence fish lift during May 2020 and were released for the purposes of evaluating upstream passage at Lowell (Table 5-4). Tagging was conducted over a total of six dates starting on May 7 and ending on May 19. Annual returns for river herring at Lawrence commenced on April 22 and ended on June 15 with significant daily peaks on May 17 and May 28 (Figure 5-8). Looking retrospectively, tagging dates carried out during the 2020 study were conducted during the 5th to 40th percentiles of the annual return. Of the fish tagged, 150 individuals carried both a PIT and radio-transmitter[5] and 204 carried only a PIT tag. Adult alewives tagged for evaluation of upstream passage at Lowell had a sex ratio of nearly 1:1 (51% male, 48% female; 1% undetermined). Total length of individuals tagged ranged from 260-335 mm (mean = 302 mm). A full listing of tagged individuals released at Lawrence during the spring of 2020 is provided in Appendix A.

5.4.1 Post-Release Movements

Adult alewives released downstream of Lowell were free to (1) move upstream and enter into the monitored section of the Merrimack River immediately downstream of the Project, (2) utilize the section of the Merrimack River between Lawrence and Lowell, or (3) fail to move upstream and depart the study reach to downstream of Lawrence. Each dual-tagged individual was classified into a unique post-release movement category based on their pattern of detections among the various monitoring stations. Individuals that were determined to have moved upstream to the project (based on detection at Monitoring Station 24) were classified as "Approached". Individuals that were limited to detections at the monitoring stations downstream of Lowell (i.e., Stations 25 and 26) were classified as "Lower River." Individuals that moved downstream immediately following release (as indicated by a lack of detections at any receivers upstream of Station 27 were classified as "Fallback").

As presented in Table 5-5, the majority of dual-tagged adult alewives were determined to have successfully moved upstream and into the area immediately downstream of the Lowell Project following their release. Of the 150 dual-tagged alewives released, 85% (128 of the 150) were determined to have approached Lowell. A total of 16 dual-tagged adult alewives (11% of all dual-tagged individuals) partially ascended the reach between Lowell and Lawrence but failed to approach the Project. Of those individuals, 50% ascended as far upstream as Station 26 and 50% ascended as far upstream as Station 25. Six dual-tagged individuals were undetected at any of the monitoring stations upstream of Lawrence following their release into the river.

5.4.2 Approach Duration and Time at Large

Adult alewives dual-tagged and released at Lawrence approached Lowell over a range of dates from May 7 (i.e., the first date of downstream releases) until May 23 (Figure 5-9). The median approach duration for dual-tagged adult alewives (i.e., the duration of time from release at Lawrence until initial detection at Station 24) was 19.6 hours (range = 7.7 hours to 11.9 days;

[5] All alewives that were tagged with a radio-tag and a PIT transmitter are referred to as "dual-tagged" in this report.

Table 5-6). When examined by release date, the median approach duration to Lowell was lowest for adult alewives released on May 16 and 17 and highest for those released on May 7 and 8 (Figure 5-10). The minimum, maximum, and quartile transit times through defined sections of the Merrimack River between the release location at Lawrence and the approach receiver (i.e., Station 24) at Lowell are provided in Table 5-7. Transit times calculated using the first detections for each dual-tagged fish at Stations 26, 25, and 24 resulted in median swim times of 5.9 hours from Lawrence to Station 26 (approximately 4.75 miles), 3.5 hours from Station 26 to Station 25 (approximately 3.9 miles) and 2.9 hours from Station 25 to Station 24 (approximately 2.0 miles). Table 5-8 provides the minimum, maximum, and quartile transit times through defined sections of the Merrimack River between the release location at Lawrence and Station 24 as a rate (i.e., miles per hour (mph)).

The duration of time at large following the initial detection at Station 24 for each dual-tagged individual ranged from 1.2 hours to 18.6 days (median = 1.9 days; Table 5-9). For an individual herring, the calculated value for time at large represented time from initial Station 24 detection until either (1) upstream passage out of the study area at the E.L. Field fish lift or the Pawtucket Dam fish ladder, or (2) the final movement downstream and away from the project area. When examined by eventual passage fate (i.e., passed or failed), the median duration of time at large for adult herring successfully passing upstream was less than one half that observed for adult herring which failed to pass upstream (1.7 days vs. 3.9 days, respectively).

5.4.3 Foray and Entrance Events

The full time series of recorded detections for each dual-tagged adult alewife was reviewed and each unique foray upstream towards either the E.L. Field fish lift or Pawtucket Dam fish ladder was identified based on the approach described in Section 4.5. Of the 128 dual-tagged alewives which were determined to have approached Lowell (based on detection at a minimum of Station 24) 95% (121 of the 128) made at least one upstream foray towards either the fish lift or ladder during their time at large in the Project area. Of those dual-tagged alewives, 82 individuals made one or more foray event towards the fish lift and 86 individuals made one or more foray towards the fish ladder. Fifty of the 128 dual-tagged adult alewives were determined to have made at least one foray in the direction of both the fish lift and fish ladder during their time at large in the project area.

5.4.3.1 E.L. Field Fish Lift

The 82 dual-tagged adult alewives determined to have approached the E.L. Field fish lift produced a combined total of 134 unique foray events. When considered on an individual basis, the number of unique lift forays ranged between one and five (mean = 1.6 events). Figure 5-11 summarizes the upstream magnitude for the full set of observed foray events at the fish lift for dual-tagged adult alewives. Approximately 66% of the set of upstream foray events towards the E.L. Field fish lift resulted in detection of the dual-tagged alewife at the lift entrance. Approximately 23% of upstream foray events resulted in dual-tagged adult alewives reaching the downstream side of the Pawtucket Gatehouse. Finally, 17% of the total number of 134 upstream forays in the direction of the E.L. Field fish lift resulting in dual-tagged alewives reached the upstream side of the Pawtucket Gatehouse.

Table 5-10 provides the minimum, maximum and quartile transit times for dual-tagged adult alewives moving upstream during fish lift forays. Upon entering the tailrace detection zone, the median duration of time to locate the fish lift entrance was 0.7 hours (range <0.1 hours to 13.4 hours). The median time to move from the entrance to the exit of the upstream fish lift was 10.4 hours and may be a function of a number of influences including timing of the lift schedule. Upon entering the E.L. Field Power Canal dual-tagged adult alewives proceed quickly upstream to the downstream face of the Pawtucket Gatehouse (median duration = 0.7 hours). The median duration of time for dual-tagged adult alewives to pass the Pawtucket Gatehouse was 25.7 hours (range 0.8 hours to 5.0 days).

Dual-tagged adult alewives were free to be detected at the E.L. Field fish lift entrance multiple times within a single foray event. As noted earlier, approximately 66% of upstream foray events resulted in detection at the fish lift entrance on at least one occasion. The total number of these entrance events were defined for each unique foray event and ranged from one to five (mean = 1.6; Table 5-11). Fish lift entrances were recorded over a range of dates from May 8 through May 30, 2020 (Figure 5-12). The percentage of entrance events peaked during mid-May (approximately May 17 through May 21). The diel distribution of entrance events at the E.L. Field fish lift is presented in Figure 5-13 and indicated dual-tagged alewives initially approached the lift entrance throughout the day with peaks during morning, midday, and late afternoon.

5.4.3.2 Pawtucket Dam Fish Ladder

The 86 dual-tagged adult alewives determined to have approached the Pawtucket Dam fish ladder produced a combined total of 105 unique foray events. When considered on an individual basis, the number of unique fish ladder forays ranged between one and three (mean = 1.2 events). Figure 5-14 summarizes the upstream magnitude for the full set of observed foray events at the fish ladder for dual-tagged adult alewives. The majority of upstream foray events terminated between the lower and upper bypassed reach detection locations (i.e., Stations 11 and 13) with approximately 55% of upstream foray events resulting in detection of the dual-tagged alewife at the upstream end of the bypassed reach. Upon reaching the upstream end of the bypassed reach, the rate of foray failure decreased. Finally, 41% of the total number of 105 upstream forays in the direction of the Pawtucket Dam fish ladder resulted in dual-tagged alewives reaching the ladder exit.

Table 5-12 provides the minimum, maximum and quartile transit times for dual-tagged adult alewives moving upstream during fish ladder forays. Following detection at the lower bypassed reach receiver, the median duration of time to ascend the bypassed reach was 23.6 hours (range = 2.7 hours to 11.7 days). Upon detection at the upper end of the bypassed reach the median duration of time to locate the fish lift entrance was 4.0 hours. Time from initial detection at the fish ladder entrance until exit at the top of the structure ranged from 0.8 hours to 2.0 days (median = 2.9 hours). The median time for dual-tagged adult alewives to transit the lower leg of the fish ladder was 2.1 hours and to transit the upper leg of the fish ladder was 1.1 hours.

Quartile ranges (i.e., P25 to P75) for the mean discharge through the bypass reach during each of the 105 adult alewife foray events were determined using hourly operations data provided by Boott. When examined by upstream magnitude, these ranges overlapped for conditions present for foray events reaching the lower bypassed reach receiver (1,944-3,372 cfs), the middle bypass receiver (954-2,563 cfs), and the upper bypass receiver (2,020-2,176 cfs). The quartile range of mean discharge through the bypass reach for adult herring which successfully passed upstream via the Pawtucket Dam fish ladder was 1,509-3-251 cfs (median = 2,478 cfs).

Dual-tagged adult alewives were free to be detected at the Pawtucket Dam fish ladder entrance multiple times within a single foray event. Approximately 51% of upstream foray events resulted in detection at the fish ladder entrance on at least one occasion. The total number of these entrance events were defined for each unique foray event and ranged from one to three (mean = 1.2; Table 5-13). The average number of entrance detections during a single foray was higher for the earlier release groups of dual-tagged adult alewives. Fish ladder entrances for dual-tagged adult alewives were recorded over a range of dates from May 7 through May 23, 2020 (Figure 5-15). Similar to the fish lift, the percentage of entrance events peaked during mid-May (approximately May 17 through May 21). The diel distribution of entrance events at the Pawtucket Dam fish ladder is presented in Figure 5-16 and indicated dual-tagged alewives initially approached the ladder entrance during the mid-morning, through afternoon hours.

5.4.4 PIT-Tagged Individuals

5.4.4.1 E.L. Field Fish Lift

Limitations detailed for the installation of Monitoring Station 20 in Section 4.2 precluded effective monitoring of PIT-tagged fish at that location. As a result, detection potential for the 204 PIT-tagged adult alewives at the E.L. Field fish lift was limited to the upper exit flume (Stations 22 and 23). PIT-tagged adult alewives were detected at the upper exit flume over a range of dates from May 10 through June 14, 2020 (Figure 5-17). The majority of PIT detections for tagged adult alewives at the lift entrance occurred between 0800 and 1800 with a pronounced peak at 1500 (Figure 5-18). Of the possible 204 PIT-tagged adult alewives, 88 (43%) were determined to have been present in the E.L. Field fish lift exit flume over the course of the study (Table 5-14).

5.4.4.2 Pawtucket Dam Fish Ladder

A total of 204 PIT-tagged adult alewives were released at Lawrence (Table 5-4) and 101 (49.5%) of those individuals were detected at the PIT reader stations installed within the Pawtucket Dam fish ladder (Table 5-15). PIT-tagged adult alewives were detected at the entrance to the Pawtucket Dam fish ladder over a range of dates from May 9 to May 27, 2020 (Figure 5-19). The majority of PIT detections for tagged adult alewives at the fish ladder entrance occurred between 0900 and 1800 (Figure 5-20). Of the 101 PIT-tagged adult alewives detected at the entrance reader, 94% (95 of the 101) were subsequently detected at the turn pool reader and 68% of those (65 of the 95) were subsequently detected at the exit reader. Table 5-16 provides the transit durations for PIT-tagged adult alewives based on initial detections at the entrance, turn pool and exit readers. The median duration to transit the lower leg of the fish ladder was 1.6 hours and to transit the upper leg of the fish ladder was 1.2 hours. The median duration for a PIT-tagged alewife to move from the Pawtucket Dam fish ladder entrance to the exit was 3.8 hours.

5.4.5 Upstream Passage Effectiveness – Lowell Fish Lift

The CJS model *Phi*(t)*p*(t) provided the best fit for the observed mark-recapture data associated with upstream movements of dual-tagged adult alewives approaching the E.L. Field fish lift (Table 5-17). Specific passage success estimates at Lowell ranged between 0.527- 1.0 among discretely monitored river sections from the tailrace to the point upstream of the Pawtucket Gatehouse (Table 5-18). The detection efficiency for receivers associated with upstream passage of dual-tagged adult alewives at the fish lift ranged from 0.724-1.0 (Table 5-19). The lowest detection value was associated with the two PIT readers positioned in the exit flume of the upstream fishway.

As defined in Section 4.5.2, the specific passage success estimates obtained from the CJS model for dual-tagged adult alewives approaching the E.L. field fish lift were used to estimate (1) near field attraction, (2) fish lift internal efficiency, and (3) overall fish lift effectiveness. As stated earlier the nearfield attraction rate is the probability of an adult herring to move from the nearfield/tailrace region into the downstream entrance of the lift, the internal efficiency is the probability of an adult herring to move from the lift entrance to the lift exit and the overall efficiency is the probability of an adult herring to move from the tailrace/nearfield region to the upstream exit from the fish lift. Upstream passage effectiveness estimates for dual-tagged adult alewives at the Lowell fish lift during 2020 are as follows:

- Nearfield attraction effectiveness:
    - 83.3% (75% CI = 77.4-88.0%)
- Fish lift internal efficiency:
    - 52.7% (75% CI = 45.0-60.3%)
- Overall fish lift effectiveness:
    - 43.9% (75% CI = 39.3-51.4%)

5.4.6 Upstream Passage Effectiveness – Lowell Fish Ladder

The CJS model *Phi*(t)*p*(t) provided the best fit for the observed mark-recapture data associated with upstream movements of dual-tagged adult alewives approaching the Pawtucket Dam fish ladder (Table 5-20). Specific passage success estimates at Lowell ranged between 0.722-0.930 among discretely monitored river sections from Station 11 in the lower bypassed reach to the exit of the fish ladder upstream of the Pawtucket Dam (Table 5-21). The detection efficiency for receivers associated with upstream passage of dual-tagged adult alewives at the fish ladder ranged from 0.905-1.0 (Table 5-22).

As defined in Section 4.5.2, the specific passage success estimates obtained from the CJS model for dual-tagged adult alewives approaching the Pawtucket Dam fish ladder were used to estimate (1) near field attraction, (2) fish ladder internal efficiency, and (3) overall fish ladder effectiveness. As stated earlier the nearfield attraction rate is the probability of an adult herring to move from the nearfield/upper bypass region into the downstream entrance of the ladder, the internal efficiency is the probability of an adult herring to move from the ladder entrance to the ladder exit and the overall efficiency is the probability of an adult herring to move from the nearfield/upper bypass region to the upstream exit from the fish ladder. Upstream passage effectiveness estimates for dual-tagged adult alewives at the Pawtucket Dam fish ladder during 2020 are as follows:

- Nearfield attraction effectiveness:
    - 93.0% (75% CI = 87.9-96.0%)
- Fish ladder internal efficiency:
    - 81.3% (75% CI = 75.1-87.5%)
- Overall fish ladder effectiveness:
    - 75.6% (75% CI = 69.2-82.2%)

The CJS model prepared for the assessment of upstream passage effectiveness of the Pawtucket Dam fish ladder also generated an effectiveness estimate for passage of adult alewife through the series of concrete weirs installed in the reach between the ladder entrance and the School Street Bridge. That reach was bracketed by Monitoring Stations 12 and 13 and passage effectiveness for adult alewives through that section was estimated at 91.8% (75% CI = 86.8-95.0%) (Table 5-21).

Table 5–4. Summary of tagging and release information for adult alewives released at Lawrence during the Lowell upstream passage assessment, May 7 to June 30, 2020.

Date	Type	Number
7-May	Dual	25
	PIT	34
8-May	Dual	25
	PIT	34
16-May	Dual	14
	PIT	-
17-May	Dual	36
	PIT	68
18-May	Dual	25
	PIT	34
19-May	Dual	25
	PIT	34
Total	Dual	150
	PIT	204

Table 5–5. Summary of post-release movement for adult alewives tagged and released downstream of Lowell during spring 2020.

Post-release Movement	Release Group						
	7-May	8-May	16-May	17-May	18-May	19-May	All
Approach	20	21	12	30	22	23	128
Downstream							0
Station 26	2	2	1	3	0	0	8
Station 25	2	2	0	2	1	1	8
Fallback	1	0	1	1	2	1	6
Total	25	25	14	36	25	25	150

Table 5–6. Minimum, maximum, and quartile values of approach duration (hours) for dual-tagged adult alewives released downstream of Lowell during the spring 2020 upstream passage assessment.

Alewife - Approach Duration (hrs)					
Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
7-May	8.3	286.1	12.5	27.5	39.4
8-May	12.4	223.7	20.2	28.1	29.9
16-May	8.9	31.1	10.0	10.4	12.9
17-May	7.7	48.5	9.0	11.2	22.2
18-May	9.3	55.9	10.6	16.1	22.0
19-May	11.1	78.5	18.8	24.1	28.6
All	**7.7**	**286.1**	**11.0**	**19.6**	**28.6**

Table 5–7. Minimum, maximum, and quartile values of upstream transit durations (hours) for dual-tagged adult alewives released downstream of Lowell during the spring 2020 upstream passage assessment.

Alewife - Upstream Transit Times (hrs)						
Downstream Reach	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Lawrence to Station 26 (4.75 miles)	7-May	3.3	36.6	5.3	8.25	14.6
	8-May	3.9	8.6	5.6	6.6	7.1
	16-May	4.1	14	5.25	5.7	7.4
	17-May	3.1	74.9	4.4	5.4	6.1
	18-May	3.7	13.5	4.5	5.45	7.3
	19-May	5.5	25.5	5.8	5.9	6.4
	All	**3.1**	**74.9**	**4.7**	**5.9**	**7.1**
Station 26 to Station 25 (3.9 miles)	7-May	2.9	139.7	3.4	4.7	25.9
	8-May	3.8	27.3	7	19.5	21.1
	16-May	2.6	11.7	2.6	2.6	3.1
	17-May	2.4	40.7	2.7	3.2	12.4
	18-May	2.6	13.8	3.2	3.65	8.9
	19-May	2.1	6.1	2.2	2.6	3.4
	All	**2.1**	**139.7**	**2.7**	**3.5**	**11.7**
Station 25 to Station 24 (2.0 miles)	7-May	1.9	186.3	2.4	4	13.3
	8-May	2	12.4	2.65	2.95	7.3
	16-May	2.1	11.7	2.15	2.2	2.4
	17-May	1.4	13.3	1.6	2.1	3.8
	18-May	1.9	97	2.4	2.9	6.2
	19-May	14.5	70.4	15.4	16.2	47
	All	**1.4**	**186.3**	**2.2**	**2.9**	**8.4**

Table 5–8. Minimum, maximum, and quartile values of upstream transit rates (mph) for dual-tagged adult alewives released downstream of Lowell during the spring 2020 upstream passage assessment.

Alewife - Upstream Transit Rates (mph)						
Downstream Reach	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Lawrence to Station 26 (4.75 miles)	7-May	0.13	1.44	0.33	0.58	0.90
	8-May	0.55	1.22	0.67	0.72	0.85
	16-May	0.34	1.16	0.64	0.83	0.91
	17-May	0.06	1.53	0.78	0.88	1.08
	18-May	0.35	1.28	0.65	0.87	1.06
	19-May	0.19	0.86	0.74	0.81	0.82
	All	**0.06**	**1.53**	**0.67**	**0.81**	**1.01**
Station 26 to Station 25 (3.9 miles)	7-May	0.03	1.34	0.15	0.83	1.15
	8-May	0.14	1.03	0.18	0.20	0.56
	16-May	0.33	1.50	1.26	1.50	1.50
	17-May	0.10	1.63	0.31	1.22	1.44
	18-May	0.28	1.50	0.44	1.07	1.22
	19-May	0.64	1.86	1.15	1.50	1.77
	All	**0.03**	**1.86**	**0.33**	**1.11**	**1.44**
Station 25 to Station 24 (2.0 miles)	7-May	0.01	1.05	0.15	0.50	0.83
	8-May	0.16	1.00	0.27	0.68	0.76
	16-May	0.17	0.95	0.84	0.91	0.93
	17-May	0.15	1.43	0.53	0.95	1.25
	18-May	0.02	1.05	0.32	0.69	0.83
	19-May	0.03	0.14	0.04	0.12	0.13
	All	**0.01**	**1.43**	**0.24**	**0.69**	**0.91**

Table 5–9. Minimum, maximum, and quartile values of time at large (hours) for dual-tagged adult alewives released downstream of Lowell during the spring 2020 upstream passage assessment.

Alewife - Time at Large (hrs)					
Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
7-May	16.0	333.6	91.6	171.3	234.9
8-May	3.1	411.4	43.7	161.9	206.6
16-May	20.2	97.9	38.8	46.6	67.5
17-May	1.2	192.5	22.4	41.6	54.7
18-May	12.1	445.6	28.8	58.4	83.3
19-May	2.0	148.5	6.0	26.2	39.5
All	**1.2**	**445.6**	**23.1**	**46.9**	**134.9**
Fate	**Minimum**	**Maximum**	**Q25**	**Q50 (Median)**	**Q75**
Failed	1.2	445.6	22.5	94.8	181.1
Passed	2.1	254.8	24.4	41.5	67.4

Table 5–10. Minimum, maximum, and quartile values of transit durations (hours) for dual-tagged adult alewives during fish lift forays recorded during the spring 2020 upstream passage assessment.

Alewife - Fish Lift Foray Durations (hrs)					
Lift Foray Segment	Minimum	Maximum	Q25	Q50 (Median)	Q75
Tailrace to Entrance	<0.1	13.4	0.4	0.7	1.7
Entrance to Exit	0.2	46.9	1.5	10.4	19.1
Exit to Forebay	<0.1	<0.1	<0.1	<0.1	<0.1
Forebay to Pawtucket Gatehouse	0.2	1.5	0.5	0.7	0.8
Pawtucket Gatehouse to Upstream	0.8	120.2	4.9	25.7	47.4

Table 5–11. Minimum, maximum, and mean number of fish lift entrance events per upstream foray for dual-tagged adult alewives recorded during the spring 2020 upstream passage assessment.

Alewife - Number of Lift Entrance Detection Events			
Release Date	Minimum	Maximum	Mean
7-May	1	2	1.3
8-May	1	3	1.4
16-May	1	2	1.1
17-May	1	2	1.2
18-May	1	2	1.2
19-May	1	2	1.1
All	**1**	**3**	**1.2**

Table 5–12. Minimum, maximum, and quartile values of transit durations (hours) for radio-tagged adult alewives during fish ladder forays recorded during the spring 2020 upstream passage assessment.

Alewife - Fish Ladder Foray Durations (hrs)					
Ladder Foray Segment	Minimum	Maximum	Q25	Q50 (Median)	Q75
Lower Bypass to Mid Bypass	0.8	236.3	3.2	10.0	16.9
Mid Bypass to Upper Bypass	0.5	30.4	1.0	2.1	9.6
Lower Bypass to Upper Bypass	2.7	281.9	16.3	23.6	35.9
Upper Bypass to Entrance	0.3	258.7	1.0	4.0	19.0
Entrance to Turn Pool	0.3	102.4	1.3	2.1	4.1
Turn Pool to Exit	0.2	47.4	0.6	1.1	3.2
Entrance to Exit	0.8	49.1	2.2	2.9	14.7

Table 5–13. Minimum, maximum, and mean number of fish lift entrance events per upstream foray for dual-tagged adult alewives recorded during the spring 2020 upstream passage assessment.

Alewife - Number of Ladder Entrance Detection Events			
Release Date	Minimum	Maximum	Mean
7-May	1	5	2.6
8-May	1	5	2.1
16-May	1	3	1.6
17-May	1	3	1.6
18-May	1	4	1.4
19-May	1	2	1.1
All	**1**	**5**	**1.6**

Table 5–14. Number of PIT-tagged adult alewives released at Lawrence and recorded at in the exit channel of the E.L. Field Powerhouse fish lift during the spring 2020 upstream passage assessment.

Alewife - PIT Reader Counts	
Release Date	Fish Lift Exit
7-May	12
8-May	13
16-May	46
17-May	17
18-May	0
All	**88**

Table 5–15. Number of PIT-tagged adult alewives released at Lawrence and recorded at in the entrance, turn pool and exit of the Pawtucket Dam fish ladder during the spring 2020 upstream passage assessment.

Alewife - PIT Reader Counts			
Release Date	Entrance	Turn Pool	Exit
7-May	18	17	7
8-May	18	16	5
16-May	51	48	41
17-May	13	13	12
18-May	1	1	0
All	**101**	**95**	**65**

Table 5–16. Minimum, maximum, and quartile values for PIT-tagged adult alewives moving within the Pawtucket Dam fish ladder during the spring 2020 upstream passage assessment.

PIT-Tagged Alewife - Fish Ladder Durations (hours)					
Ladder Foray Segment	Minimum	Maximum	Q25	Q50 (Median)	Q75
Entrance to Turn Pool	0.2	196	0.8	1.6	4.9
Turn Pool to Exit	0.2	56	0.7	1.2	2.9
Entrance to Exit*	0.4	69.4	1.9	3.8	17.1

*Entrance to Exit duration calculated for individuals which ascended full length of ladder. Entrance to turn pool durations include individuals which may have ascended only as far upstream as the turn pool (i.e., did not pass full length of structure)

Table 5–17. CJS model selection criteria for upstream passage effectiveness of the E.L. Field fish lift for adult alewives at Lowell during spring 2020.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Parameters	Deviance
Phi(t)p(t)	375.79	0.00	1.00	1.00	10	37.83
Phi(t)p(.)	466.96	91.18	0.00	0.00	6	137.30
Phi(.)p(t)	478.19	102.40	0.00	0.00	8	144.40
Phi(.)p(.)	589.86	214.07	0.00	0.00	2	268.35

Table 5–18. Passage success probability estimates (*Phi)*, standard errors, and likelihood 75 and 95% confidence intervals for dual-tagged adult alewives approaching the E.L. Field fish lift during 2020.

Reach	*Phi*	SE	95% CI		75% CI	
Tailrace to Entrance	0.833	0.046	0.724	0.905	0.774	0.880
Entrance to Exit	0.527	0.067	0.396	0.654	0.450	0.603
Exit to Forebay	1.000	0.000	-	-	-	-
Forebay to Pawtucket Gatehouse	1.000	0.000	-	-	-	-
Pawtucket Gatehouse to Upstream	0.793	0.075	0.610	0.904	0.694	0.867

Table 5–19. Detection efficiency estimates (*p)*, for monitoring stations installed to detect dual-tagged adult alewives approaching the E.L. Field fish lift during 2020.

Location	S	SE	95% CI	
Station 21	1.000	0.000	-	-
Station 22/23	0.724	0.083	0.538	0.856
Station 08	0.828	0.070	0.647	0.926
Station 07	1.000	0.000	-	-
Station 06	1.000	0.000	-	-

Table 5–20. CJS model selection criteria for upstream passage effectiveness of the Pawtucket Dam fish ladder for adult alewives at Lowell during spring 2020.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Parameters	Deviance
Phi(t)p(t)	502.57	0.00	1.00	1.00	13	59.49
Phi(t)p(.)	520.06	17.49	0.00	0.00	7	89.34
Phi(.)p(t)	578.38	75.81	0.00	0.00	8	145.61
Phi(.)p(.)	648.23	145.66	0.00	0.00	2	227.65

Table 5–21. Passage success probability estimates (*Phi)*, standard errors, and likelihood 75 and 95% confidence intervals for dual-tagged adult alewives approaching the Pawtucket Dam fish ladder during 2020.

Reach	*Phi*	SE	95% CI		75% CI	
Lower Bypass to Mid Bypass	0.722	0.048	0.618	0.806	0.663	0.774
Mid Bypass to Upper Bypass	0.918	0.035	0.818	0.965	0.868	0.950
Upper Bypass to Entrance	0.930	0.034	0.827	0.973	0.879	0.960
Entrance to Turn Pool	0.913	0.041	0.793	0.966	0.853	0.950
Turn Pool to Exit	0.891	0.047	0.760	0.955	0.824	0.935

Table 5–22. Detection efficiency estimates (*p)*, for monitoring stations installed to detect dual-tagged adult alewives approaching the Pawtucket Dam fish ladder during 2020.

Location	S	SE	95% CI	
Station 11	1.000	0.000	1.000	1.000
Station 12	0.982	0.017	0.886	0.998
Station 13	1.000	0.000	1.000	1.000
Station 14/15/16	1.000	0.000	1.000	1.000
Station 17/18	0.930	0.039	0.805	0.977
Station 19	0.905	0.045	0.772	0.964

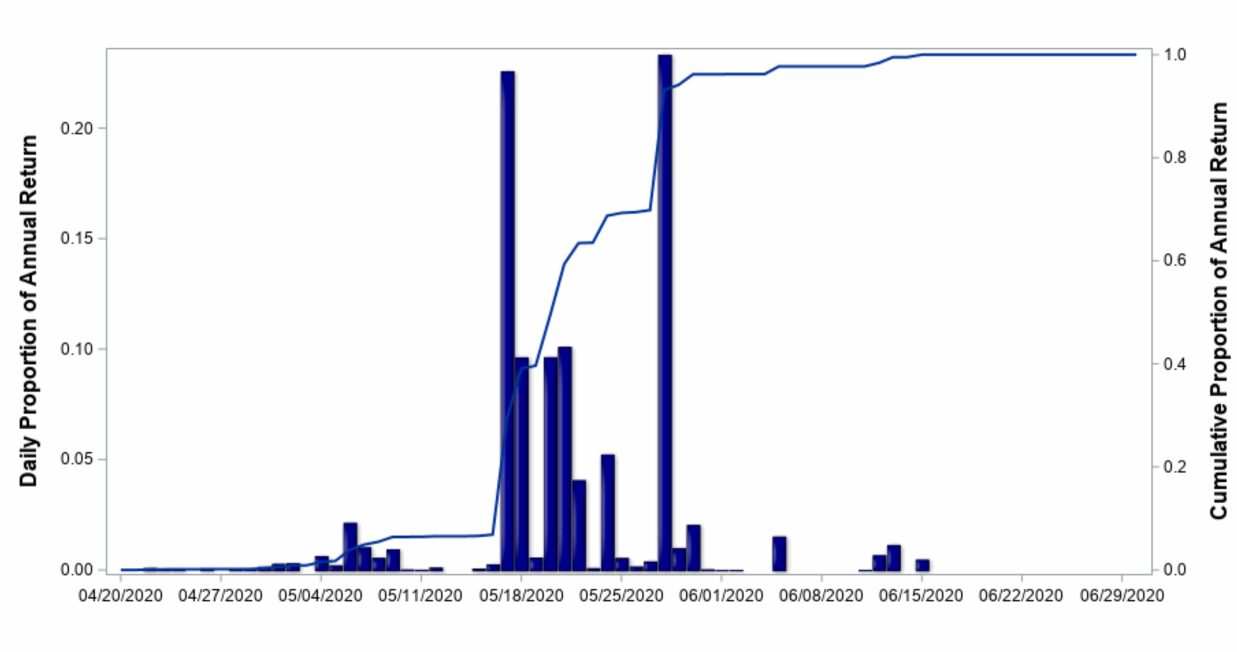

Figure 5–8. Daily (bars) and cumulative (line) percentage of adult river herring returns at the Lawrence fishway as enumerated by Salmonsoft recording for the 2020 passage season.

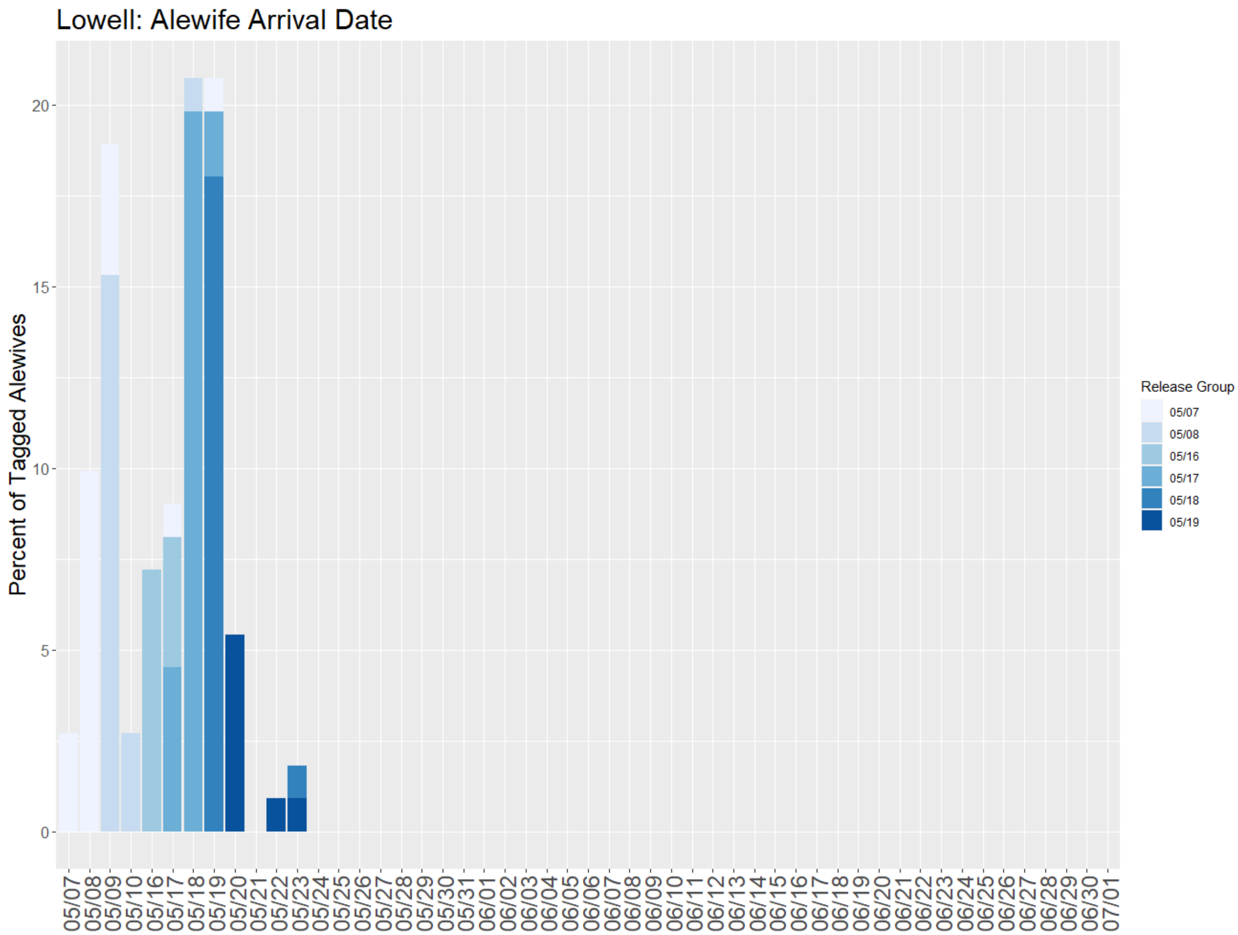

Figure 5–9. Distribution of arrival dates for dual-tagged adult alewives originally released downstream of Lowell at the Lawrence Project as part of the spring 2020 upstream passage assessment.

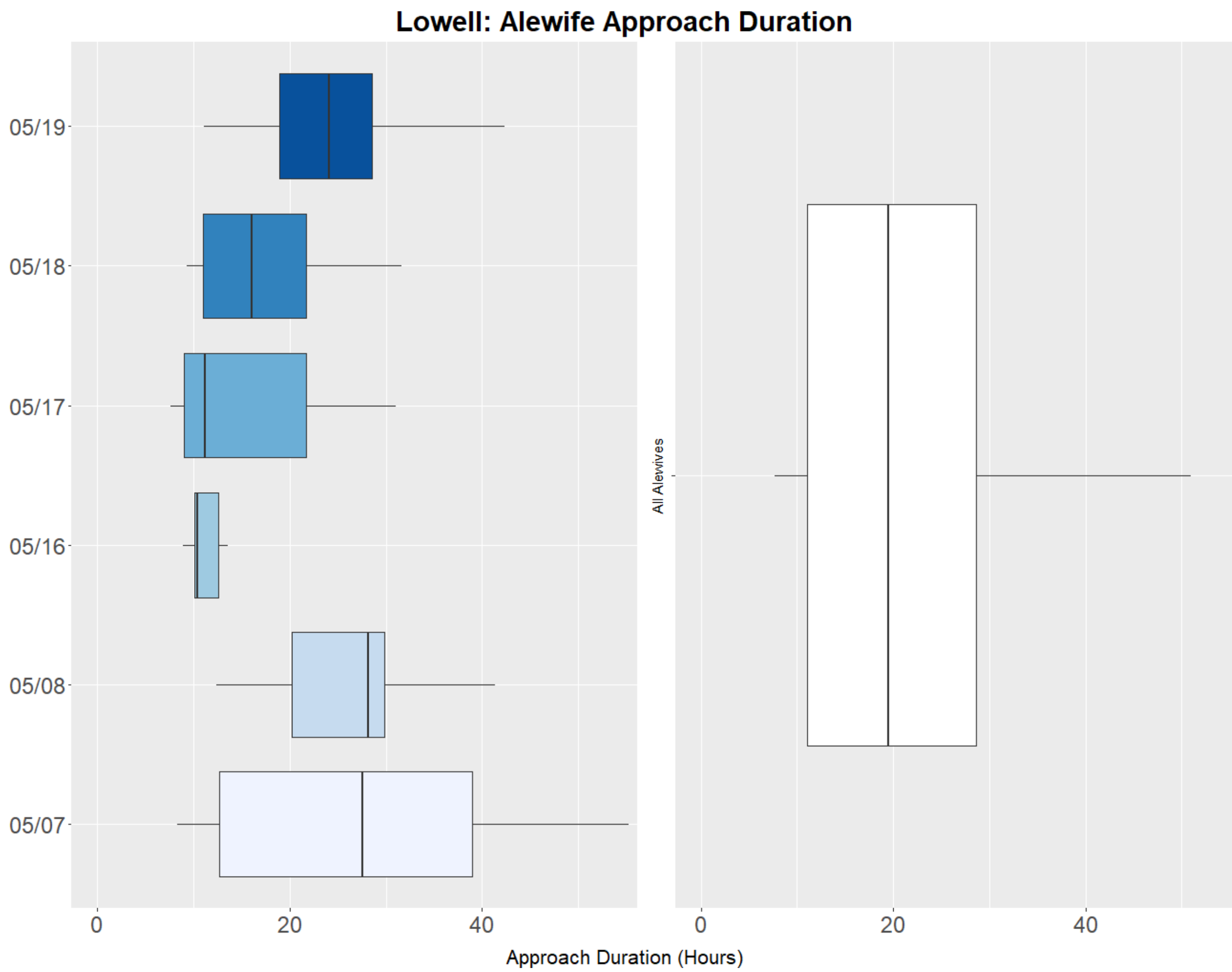

Figure 5–10. Boxplot of the approach duration for all dual-tagged adult alewives released downstream of Lowell during the spring 2020 upstream passage assessment. [6]

[6] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

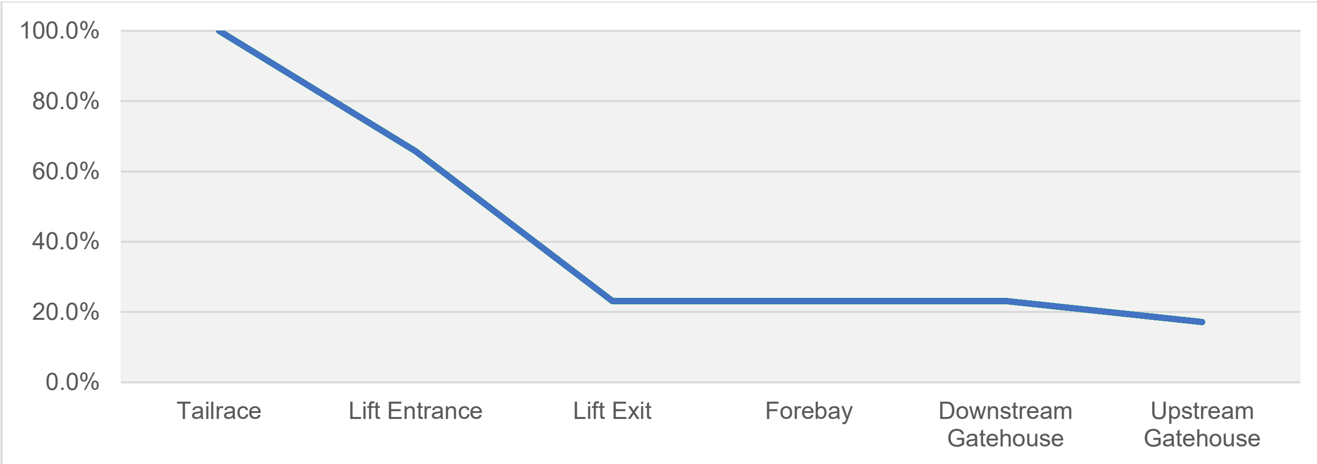

Figure 5–11. Magnitude of upstream progress for dual-tagged adult alewife forays at the E.L. Field fish lift during the spring 2020 upstream passage assessment.

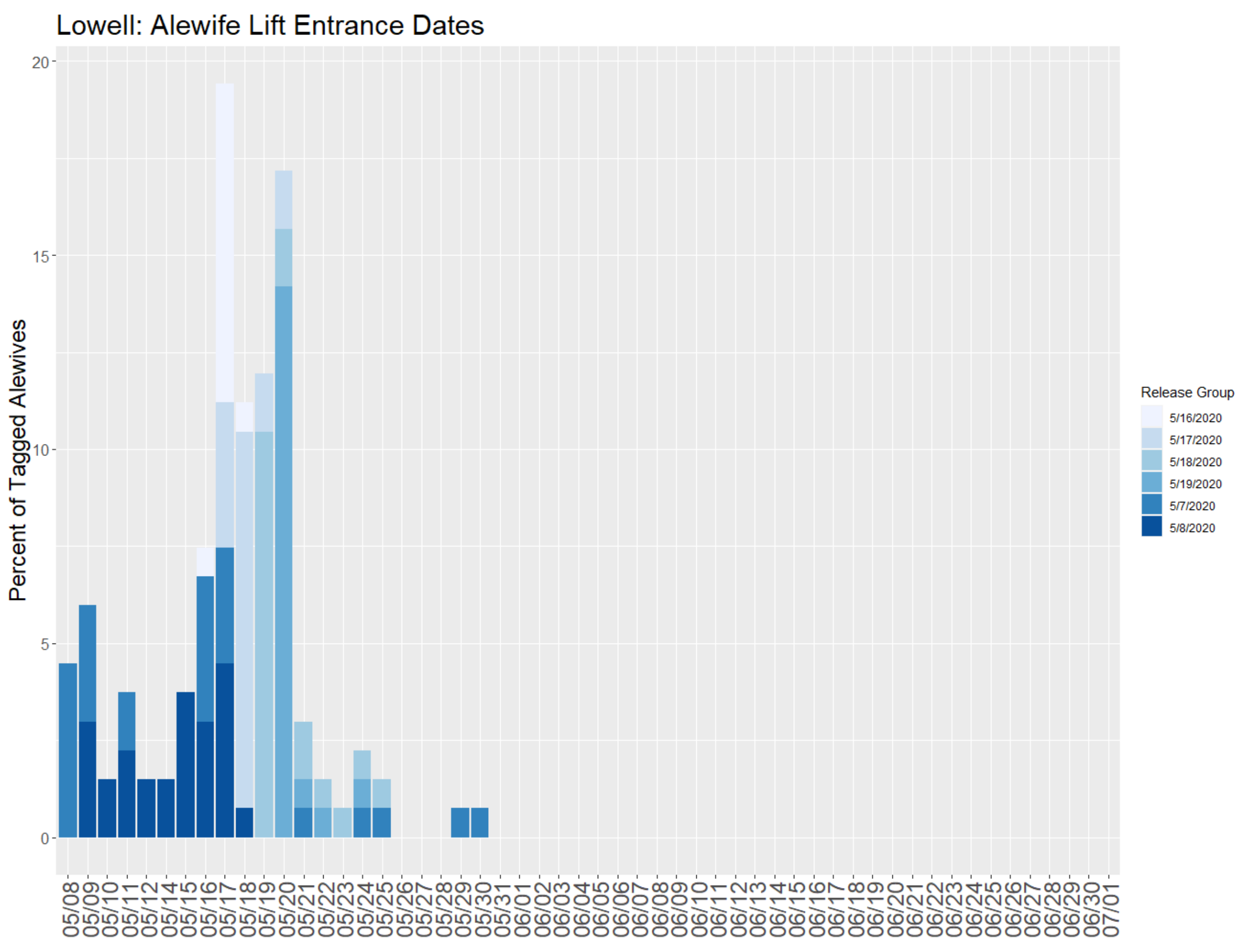

Figure 5–12. Distribution of entrance dates for dual-tagged adult alewives at the E.L. Field fish lift during the spring 2020 upstream passage assessment.

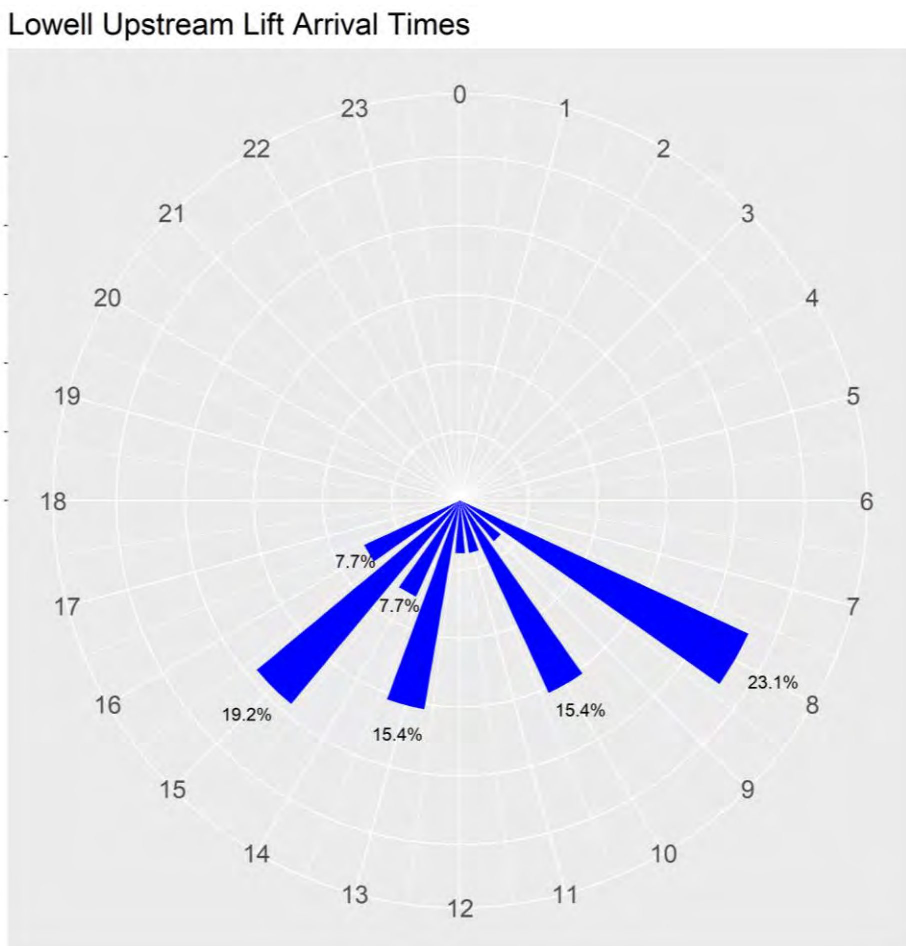

Figure 5–13. Distribution of entrance times for dual-tagged adult alewives at the E.L. Field fish lift during the spring 2020 upstream passage assessment.

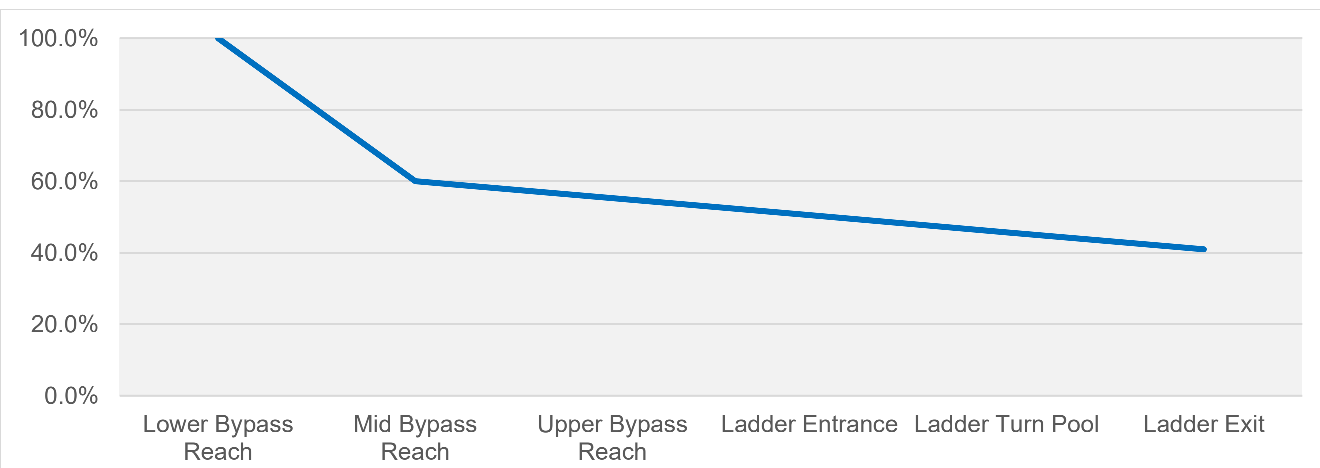

Figure 5–14. Magnitude of upstream progress for dual-tagged adult alewife forays at the Pawtucket Dam fish ladder during the spring 2020 upstream passage assessment.

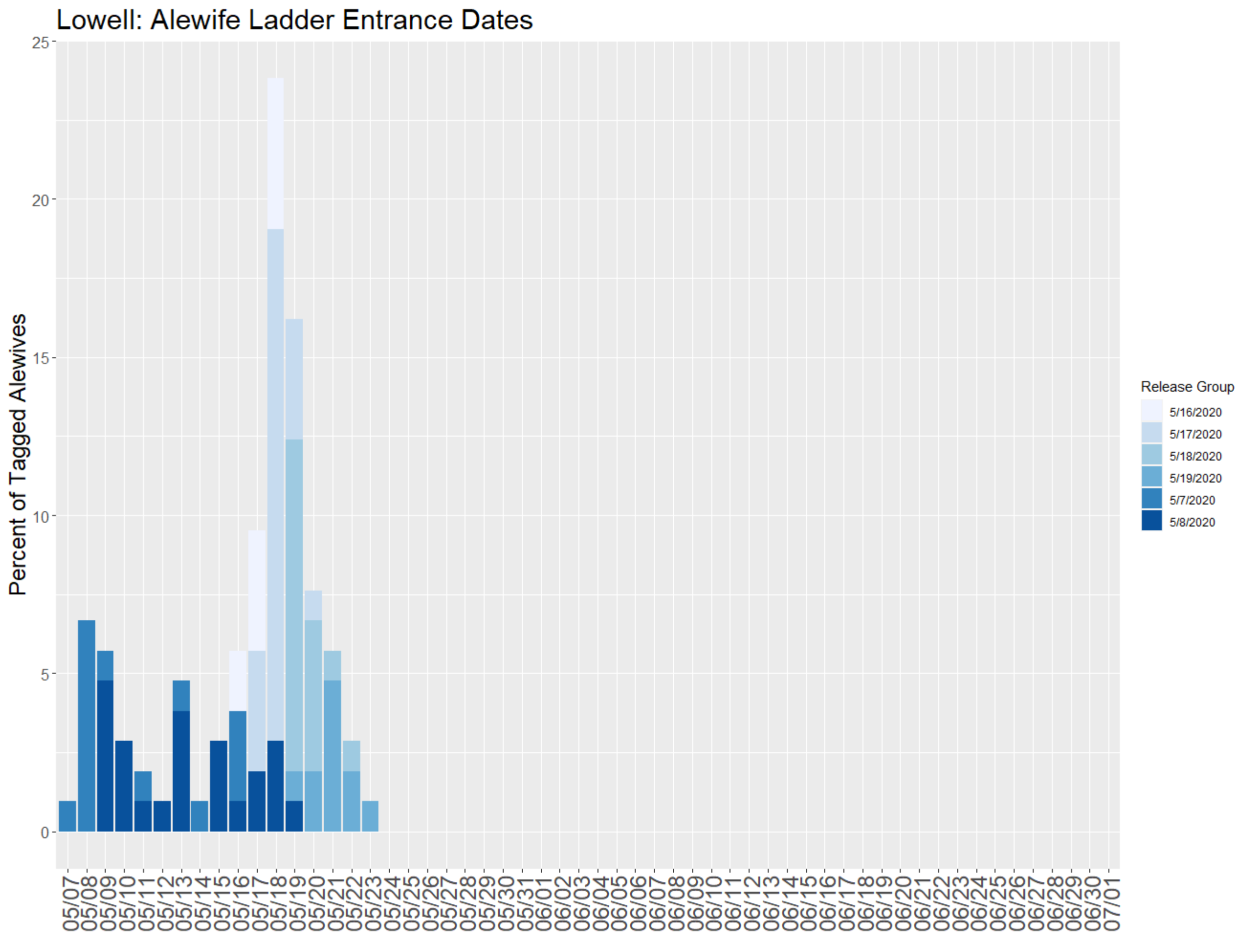

Figure 5–15. Distribution of entrance dates for dual-tagged adult alewives at the Pawtucket Dam fish ladder during the spring 2020 upstream passage assessment.

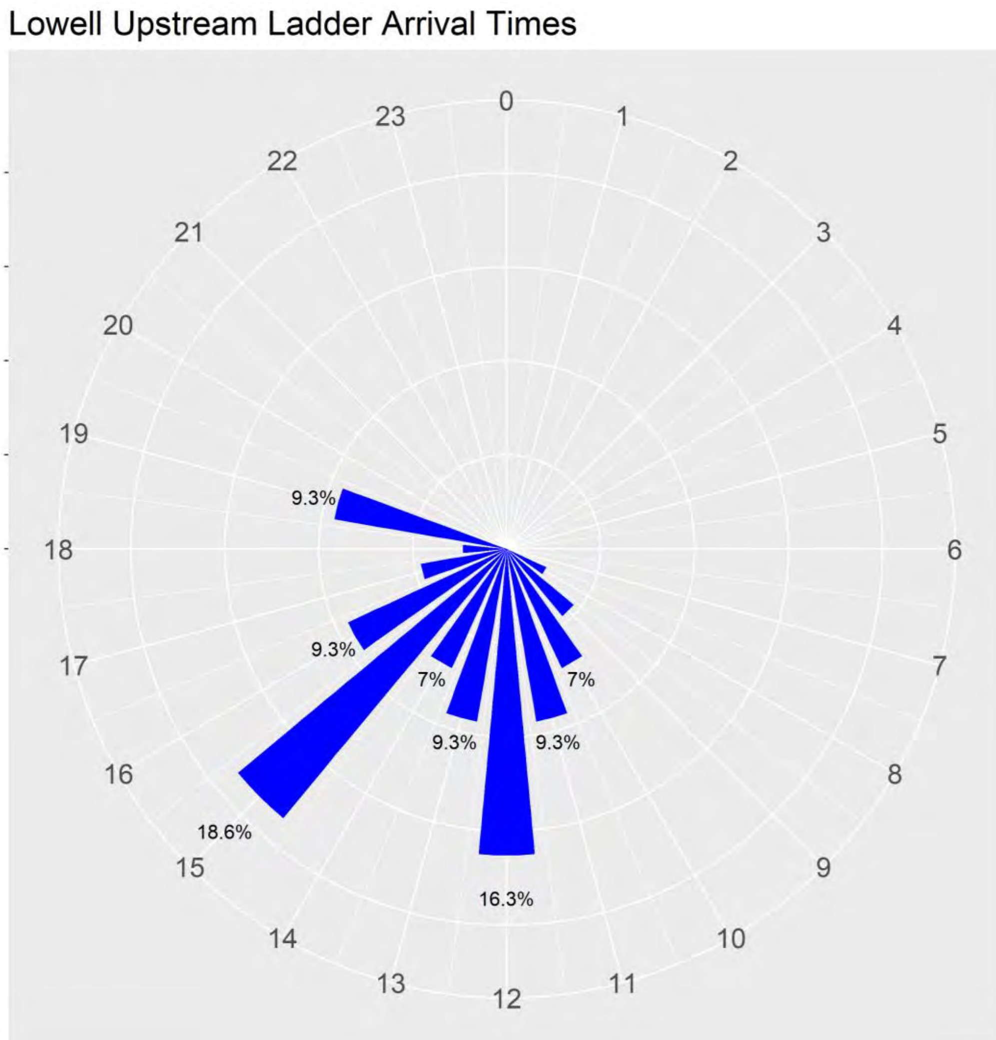

Figure 5–16. Distribution of entrance times for dual-tagged adult alewives at the Pawtucket Dam fish ladder during the spring 2020 upstream passage assessment.

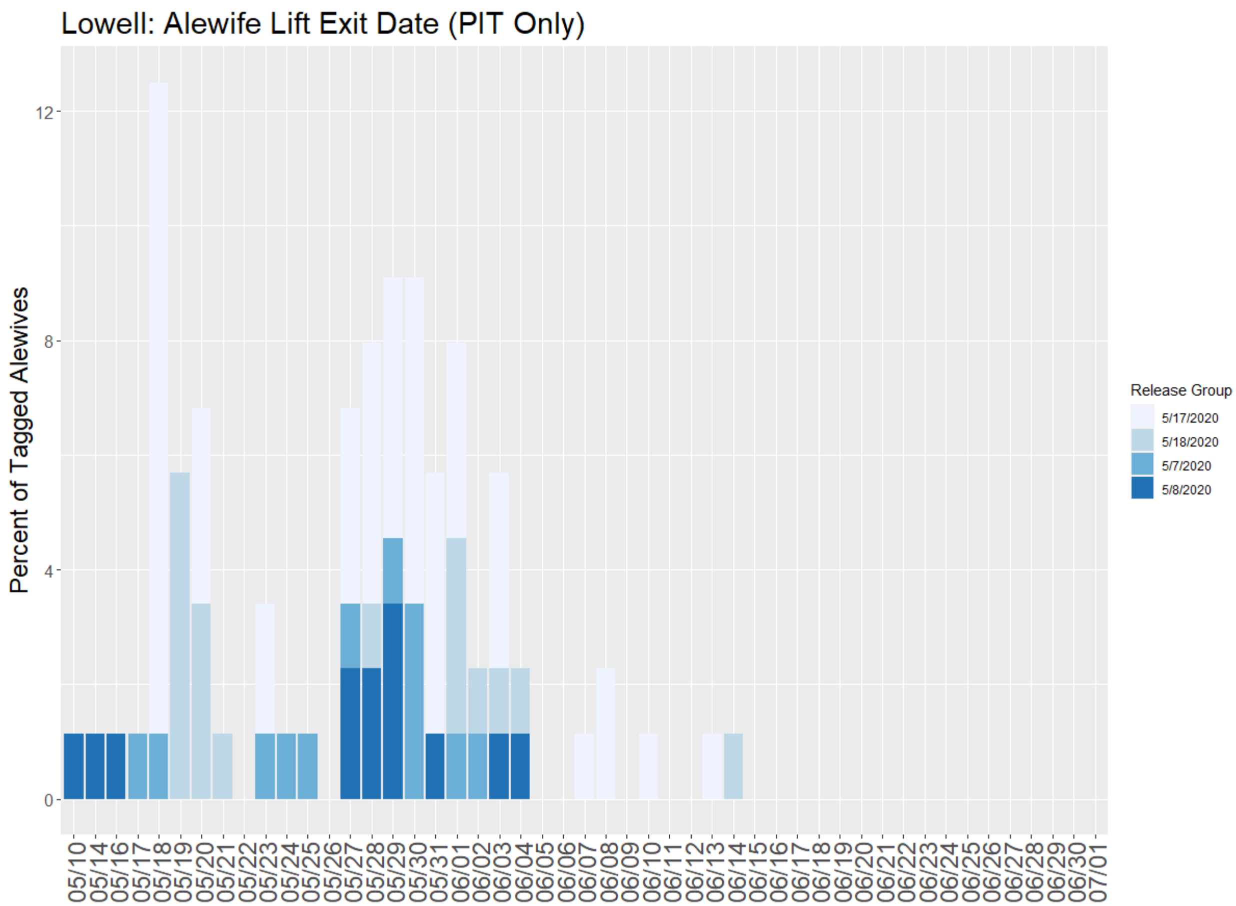

Figure 5–17. Distribution of exit flume dates for PIT-tagged adult alewives at the E.L Field Powerhouse fish lift during the spring 2020 upstream passage assessment.

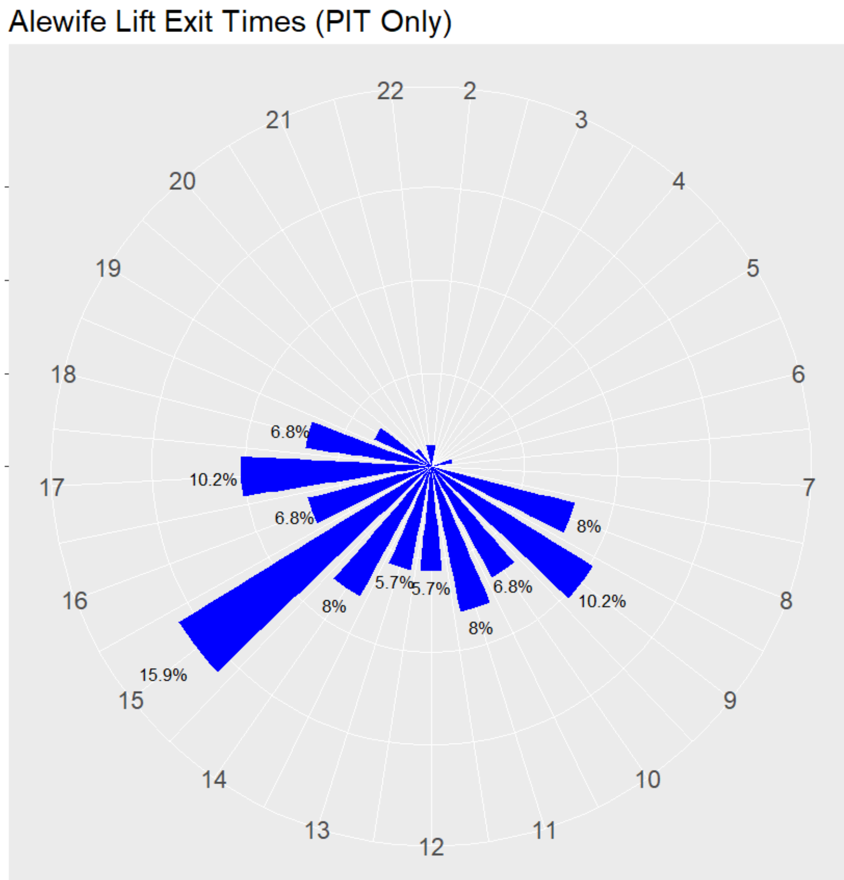

Figure 5–18. Distribution of entrance times for PIT-tagged adult alewives at the E.L Field Powerhouse fish lift during the spring 2020 upstream passage assessment.

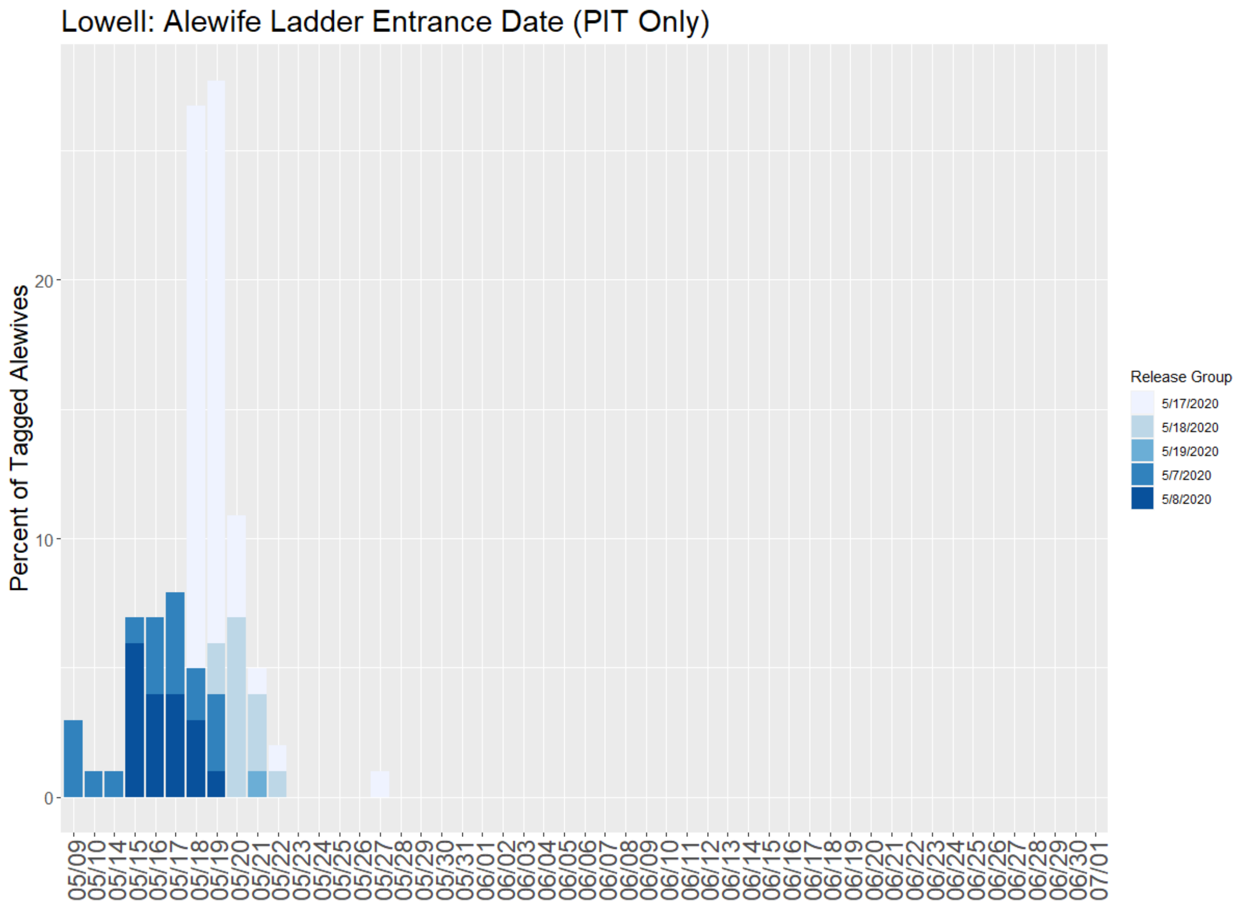

Figure 5–19. Distribution of entrance dates for PIT-tagged adult alewives at the Pawtucket Dam fish ladder during the spring 2020 upstream passage assessment.

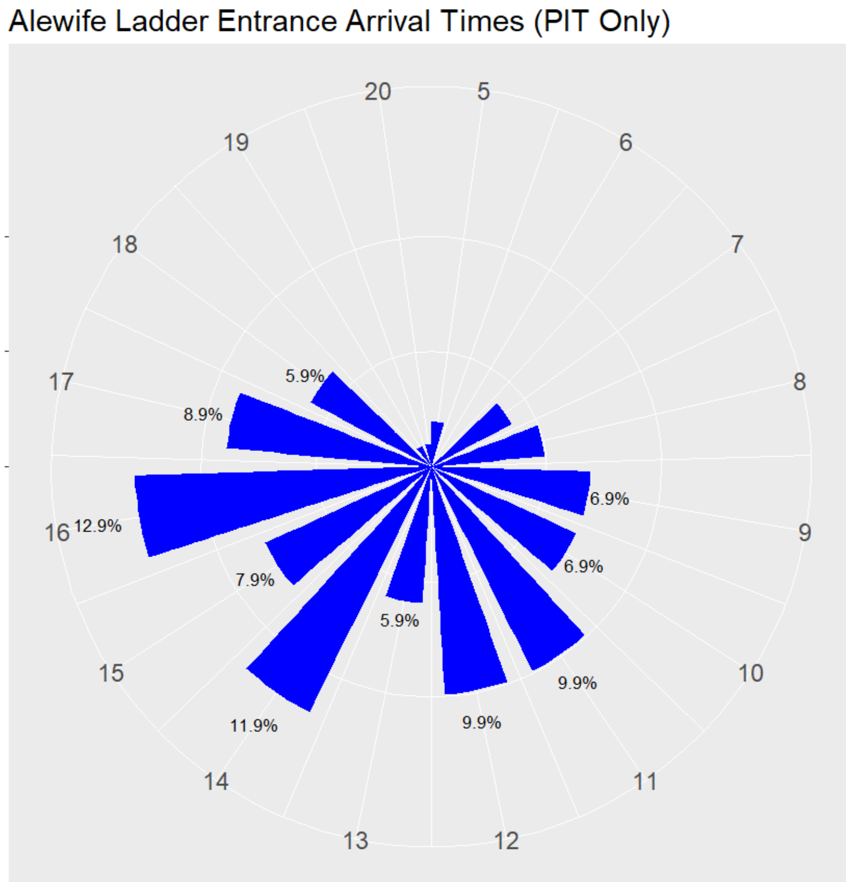

Figure 5–20. Distribution of entrance times for PIT-tagged adult alewives at the Pawtucket Dam fish ladder during the spring 2020 upstream passage assessment.

5.5 Upstream Passage Effectiveness – Adult American Shad

A total of 384 adult American shad were tagged following collection at the Lawrence fish lift during May 2020 and were released for the purposes of evaluating upstream passage at Lowell (Table 5-23). Tagging was conducted over a total of five dates starting on May 16 and ending on May 27. Annual returns for American shad at Lawrence commenced on May 5 and ended on June 25 with the peak daily returns occurring during the last week of May (Figure 5-21). Looking retrospectively, tagging dates carried out during the 2020 study were conducted during the 2nd to 32nd percentiles of the annual return. Of the adult shad tagged, 180 individuals carried both a PIT and radio-transmitter and 204 carried only a PIT tag[7]. Adult American shad tagged for evaluation of upstream passage at Lowell were 73% male, 21% female, and 6% undetermined. Total length of individuals tagged ranged from 400-573 mm (mean = 480 mm).

5.5.1 Post-Release Movements

Similar to adult alewives, the American shad tagged and released downstream of Lowell were free to (1) move upstream and enter into the monitored section of the Merrimack River immediately downstream of the Project, (2) utilize the section of the Merrimack River between Lawrence and Lowell, or (3) fail to move upstream and depart the study reach to downstream of Lawrence. Each dual-tagged individual was classified into a unique post-release movement category based on their pattern of detections among the various monitoring stations. Individuals which were determined to have moved upstream to the project (based on detection at Monitoring Station 24) were classified as “Approached”. Individuals which were limited to detections at the monitoring stations downstream of Lowell (i.e., Stations 25 and 26) were classified as “Lower River”. Individuals which moved downstream immediately following release (as indicated by a lack of detections at any receivers upstream of Station 27 were classified as “Fallback”).

As presented in Table 5-24, nearly 40% of dual-tagged adult shad (70 out of 180 individuals) were determined to have successfully moved upstream and into the area immediately downstream of the Lowell Project following their release. The percentage of dual-tagged shad to ascend upstream to the Project was consistent between the sexes (39% of dual-tagged males and 39% of dual-tagged females). The majority of individuals (47% of all dual-tagged individuals) partially ascended the reach between Lowell and Lawrence but failed to approach the Project. Of those individuals, 48% ascended as far upstream as Station 26 (4.75 miles upstream of Lawrence) and 52% ascended as far upstream as Station 25 (8.7 miles upstream of Lawrence). Twenty-five dual-tagged individuals (14% of the total) were undetected at any of the monitoring stations upstream of Lawrence following their release into the river. A portion of a tagged group of adult shad exhibiting fallback behavior immediately following handling and tagging is not unexpected.

[7] All shad that were tagged with a radio-tag and a PIT transmitter are referred to as “dual-tagged” in this report.

5.5.2 Approach Duration and Time at Large

Adult American shad dual-tagged and released at Lawrence approached Lowell over a range of dates from May 17 until June 6 (Figure 5-22). The median approach duration for dual-tagged adult shad (i.e., the duration of time from release at Lawrence until initial detection at Station 24) was 2.7 days (range = 8.4 hours to 29.3 days; Table 5-25). When examined by release date, the median approach duration to Lowell was lowest for adult shad released on May 22 and 26 and highest for those released on May 18 (Figure 5-23). The minimum, maximum, and quartile transit times through defined sections of the Merrimack River between the release location at Lawrence and the approach receiver (i.e., Station 24) at Lowell are provided in Table 5-26. Transit times calculated using the first detections for each dual-tagged fish at Stations 26, 25, and 24 resulted in median swim times of 14.0 hours from Lawrence to Station 26 (approximately 4.75 miles), 23.4 hours from Station 26 to Station 25 (approximately 3.9 miles) and 22.3 hours from Station 25 to Station 24 (approximately 2.0 miles). Table 5-27 provides the minimum, maximum, and quartile transit times through defined sections of the Merrimack River between the release location at Lawrence and Station 24 as a rate (i.e., miles per hour (mph)).

The duration of time at large following the initial detection at Station 24 for each dual-tagged American shad ranged from 0.3 hours to 24.1 days (median = 2.1 days; Table 5-28). For an individual adult shad, the calculated value for time at large represented time from initial Station 24 detection until either (1) upstream passage out of the study area at the E.L. Field fish lift or the Pawtucket Dam fish ladder, or (2) the final movement downstream and away from the project area. When examined by eventual passage fate (i.e., passed or failed), the median duration of time at large for adult American shad successfully passing upstream was nearly equal to that observed for adult shad which failed to pass upstream (2.3 days vs. 1.9 days, respectively).

5.5.3 Foray and Entrance Events

The full time series of recorded detections for each dual-tagged adult American shad was reviewed and each unique foray upstream towards either the E.L. Field fish lift or Pawtucket Dam fish ladder was identified based on the approach described in Section 4.5. Of the 70 dual-tagged shad which were determined to have approached Lowell (based on detection at a minimum of Station 24) 63% (44 of the 70) made at least one upstream foray towards either the fish lift or ladder during their time at large in the Project area. Of those dual-tagged shad, 43 individuals made one or more foray event towards the fish lift and only a single individual made a foray towards the fish ladder.

5.5.3.1 E.L. Field Fish Lift

The 43 dual-tagged adult shad determined to have approached the E.L. Field fish lift produced a combined total of 201 unique foray events. When considered on an individual basis, the number of unique lift forays ranged between one and 20 (mean = 4.7 events). Figure 5-24 summarizes the upstream magnitude for the full set of observed foray events at the fish lift for dual-tagged adult American shad. Approximately 37% of the set of upstream foray events towards the E.L. Field fish lift resulted in detection of the dual-tagged shad at the lift entrance.

Approximately 6% of upstream foray events resulted in dual-tagged adult American shad reaching the downstream side of the Pawtucket Gatehouse. Finally, 3% of the total number of 201 upstream forays in the direction of the E.L. Field fish lift resulted in dual-tagged shad reaching the upstream side of the Pawtucket Gatehouse.

Table 5-29 provides the minimum, maximum and quartile transit times for dual-tagged adult American shad moving upstream during fish lift forays. Upon entering the tailrace detection zone, the median duration of time to locate the fish lift entrance was 1.1 hours (range 0.1 hours to 1.8 days). Upon entering the E.L. Field Power Canal dual-tagged adult shad proceeded quickly upstream to the downstream face of the Pawtucket Gatehouse (median duration = 0.8 hours). The median duration of time for dual-tagged adult shad to pass the Pawtucket Gatehouse was 5.4 days (range 3.3 days to 9.0 days).

Dual-tagged adult shad were free to be detected at the E.L. Field fish lift entrance multiple times within a single foray event. As noted earlier, approximately 37% of upstream foray events resulted in detection at the fish lift entrance on at least one occasion. The total number of these entrance events were defined for each unique foray event and ranged from one to twenty (mean = 4.6; Table 5-30). Fish lift entrances were recorded over a range of dates from May 18 through June 15, 2020 (Figure 5-25). The percentage of entrance events peaked during late-May (approximately May 28 through May 30). The diel distribution of entrance events at the E.L. Field fish lift is presented in Figure 5-26 and indicated dual-tagged shad present at the lift entrance peaked during the mid-morning and early afternoon hours.

5.5.3.2 Pawtucket Dam Fish Ladder

Foray events for dual-tagged adult American shad up the Lowell bypassed reach and towards the Pawtucket Dam fish ladder were limited to a single event. A dual-tagged shad from the May 16 release group was detected at Station 11 in the lower bypassed reach on May 17th. It did not enter the fish ladder.

5.5.4 PIT-Tagged Individuals

5.5.4.1 E.L. Field Fish Lift

Limitations detailed for the installation of Monitoring Station 20 in Section 4.2 precluded effective monitoring of PIT-tagged fish at that location. As a result, detection potential for the 204 PIT-tagged adult American shad at the E.L. Field fish lift was limited to the upper exit flume (Stations 21 and 22). PIT-tagged adult shad were detected at the upper exit flume over a range of dates from May 19 through June 14, 2020 (Figure 5-27). Of the possible 204 PIT-tagged adult shad, 16 (8%) were determined to have been present in the E.L. Field fish lift exit flume over the course of the study.

5.5.4.2 Pawtucket Dam Fish Ladder

Detections at PIT readers within the Pawtucket Dam fish ladder for the 204 PIT-tagged adult shad released at Lawrence were limited to just two individuals. One PIT-tagged adult shad released at Lawrence on May 18 was detected at the fish ladder entrance on May 24 and ascended as far upstream as the turn pool (travel time = 0.8 hours). A second individual (released at Lawrence on May 26) was detected at the fish ladder entrance reader on June 11 but was not subsequently detected at the turn pool or the ladder exit.

5.5.5 Upstream Passage Effectiveness – Lowell Fish Lift

The CJS model *Phi*(t)*p*(t) provided the best fit for the observed mark-recapture data associated with upstream movements of dual-tagged adult American shad approaching the E.L. Field fish lift (Table 5-31). Specific passage success estimates at Lowell ranged between 0.451- 1.0 among discretely monitored river sections from the tailrace to the point upstream of the Pawtucket Gatehouse (Table 5-32). The detection efficiency for receivers associated with upstream passage of dual-tagged adult American shad at the fish lift ranged from 0.612-1.0 (Table 5-33). Similar to that observed for dual-tagged adult alewives, the lowest detection value was associated with the two PIT readers positioned in the exit flume of the upstream fishway.

As defined in Section 4.5.2, the specific passage success estimates obtained from the CJS model for dual-tagged adult shad approaching the E.L. field fish lift were used to estimate (1) near field attraction, (2) fish lift internal efficiency, and (3) overall fish lift effectiveness. As stated earlier the nearfield attraction rate is the probability of an adult shad to move from the nearfield/tailrace region into the downstream entrance of the lift, the internal efficiency is the probability of an adult shad to move from the lift entrance to the lift exit and the overall efficiency is the probability of an adult shad to move from the tailrace/nearfield region to the upstream exit from the fish lift. Upstream passage effectiveness estimates for dual-tagged adult shad at the Lowell fish lift during 2020 are as follows:

- Nearfield attraction effectiveness:
    - 67.4% (75% CI = 58.8-75.1%)
- Fish lift internal efficiency:
    - 45.1% (75% CI = 34.8-55.8%)
- Overall fish lift effectiveness:
    - 30.4% (75% CI = 22.1-39.5%)

5.5.6 Upstream Passage Effectiveness – Lowell Fish Ladder

Limited number of returns for dual-tagged American shad (see Section 5.5.3.2) prevented the usage of a CJS model to evaluate upstream passage effectiveness of the Pawtucket Dam fish ladder for that species during spring, 2020.

Table 5–23. Summary of tagging and release information for adult American shad released at Lawrence during the Lowell upstream passage assessment, May 7 to June 30, 2020.

Date	Type	Number
16-May	Dual	30
	PIT	20
18-May	Dual	30
	PIT	48
22-May	Dual	30
	PIT	34
26-May	Dual	59
	PIT	68
27-May	Dual	31
	PIT	34
Total	Dual	180
	PIT	204

Table 5–24. Summary of post-release movement for adult American shad tagged and released downstream of Lowell during spring 2020.

Post-release Movement	Release Group					
	16-May	18-May	22-May	26-May	27-May	All
Approach	16	13	10	18	13	70
Downstream						0
Station 26	4	7	6	17	7	41
Station 25	5	8	11	14	6	44
Fallback	5	2	3	10	5	25
Total	30	30	30	59	31	180

Table 5–25. Minimum, maximum, and quartile values of approach duration (hours) for dual-tagged adult American shad released downstream of Lowell during the spring 2020 upstream passage assessment.

Shad - Approach Duration (hrs)					
Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
16-May	31.0	703.2	46.7	64.5	163.3
18-May	8.4	223.8	76.1	111.9	123.8
22-May	10.5	85.4	27.1	40.0	67.7
26-May	28.4	288.3	31.1	41.7	70.1
27-May	18.6	186.4	43.0	70.5	82.7
All	**8.4**	**703.2**	**37.7**	**64.5**	**94.5**

Table 5–26. Minimum, maximum, and quartile values of upstream transit durations (hours) for dual-tagged adult American shad released downstream of Lowell during the spring 2020 upstream passage assessment.

Shad - Upstream Transit Times (hr)						
Downstream Reach	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Lawrence to Station 26 (4.75 miles)	16-May	3.8	141.0	5.5	8.5	17.9
	18-May	4.5	220.1	7.9	10.3	27.6
	22-May	3.8	239.7	4.5	9.4	67.8
	26-May	2.2	194.4	7.8	15.0	26.2
	27-May	5.8	225.4	9.7	16.3	27.7
	All	**2.2**	**239.7**	**7.4**	**14.0**	**27.6**
Station 26 to Station 25 (3.9 miles)	16-May	4.1	49.1	15.6	20.7	34.7
	18-May	2.1	37.6	2.5	23.1	27.2
	22-May	2.1	138.4	13.4	18.2	74.7
	26-May	11.3	480.2	18.2	27.2	50.2
	27-May	5.0	235.6	7.2	25.9	32.1
	All	**2.1**	**480.2**	**15.2**	**23.4**	**37.3**
Station 25 to Station 24 (2.0 miles)	16-May	2.3	166.6	14.6	36.4	61.0
	18-May	1.8	194.7	49.4	88.5	94.0
	22-May	2.7	54.9	4.0	7.9	24.9
	26-May	2.3	197.9	8.6	11.3	21.2
	27-May	2.0	99.2	3.2	13.2	75.4
	All	**1.8**	**197.9**	**5.9**	**22.3**	**75.4**

Table 5–27. Minimum, maximum, and quartile values of upstream transit rates (mph) for dual-tagged adult American shad released downstream of Lowell during the spring 2020 upstream passage assessment.

Shad - Upstream Transit Rates (mph)						
Downstream Reach	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Lawrence to Station 26 (4.75 miles)	16-May	0.03	1.25	0.27	0.56	0.86
	18-May	0.02	1.06	0.17	0.47	0.60
	22-May	0.02	1.25	0.07	0.51	1.06
	26-May	0.02	2.16	0.18	0.32	0.61
	27-May	0.02	0.82	0.17	0.30	0.50
	All	**0.02**	**2.16**	**0.17**	**0.34**	**0.64**
Station 26 to Station 25 (3.9 miles)	16-May	0.08	0.95	0.11	0.19	0.25
	18-May	0.10	1.86	0.14	0.17	1.56
	22-May	0.03	1.86	0.06	0.22	0.30
	26-May	0.01	0.35	0.08	0.14	0.21
	27-May	0.02	0.78	0.12	0.15	0.54
	All	**0.01**	**1.86**	**0.10**	**0.17**	**0.26**
Station 25 to Station 24 (2.0 miles)	16-May	0.01	0.87	0.03	0.05	0.14
	18-May	0.01	1.11	0.02	0.02	0.04
	22-May	0.04	0.74	0.08	0.25	0.50
	26-May	0.01	0.87	0.09	0.18	0.23
	27-May	0.02	1.00	0.03	0.15	0.63
	All	**0.01**	**1.11**	**0.03**	**0.09**	**0.34**

Table 5–28. Minimum, maximum, and quartile values of time at large (hours) for dual-tagged adult American shad released downstream of Lowell during the spring 2020 upstream passage assessment.

Shad - Time at Large (hrs)					
Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
16-May	1.3	578.2	43.5	190.6	260.1
18-May	0.9	424.6	31.8	76.6	312.1
22-May	97.0	499.5	121.3	184.1	243.9
26-May	0.3	49.7	12.2	31.0	45.1
27-May	0.5	145.6	9.7	43.2	58.6
All	**0.3**	**578.2**	**24.0**	**49.7**	**165.5**
Fate	**Minimum**	**Maximum**	**Q25**	**Q50 (Median)**	**Q75**
Failed	0.3	578.2	11.8	46.8	215.3
Passed	28.5	424.6	43.9	54.5	136.4

Table 5–29. Minimum, maximum, and quartile values of transit durations (hours) for dual-tagged adult American shad during fish lift forays recorded during the spring 2020 upstream passage assessment.

Shad - Fish Lift Foray Durations (hr)					
Lift Foray Segment	Minimum	Maximum	Q25	Q50 (Median)	Q75
Tailrace to Entrance	0.1	43.6	0.6	1.1	1.8
Entrance to Exit	1.0	23.5	1.2	2.4	11.5
Exit to Forebay	<0.1	0.4	<0.1	<0.1	0.1
Forebay to Pawtucket Gatehouse	0.3	1.5	0.5	0.8	1.1
Pawtucket Gatehouse to Upstream	79.7	216.2	80.6	129.5	197.6

Table 5–30. Minimum, maximum, and mean number of fish lift entrance events per upstream foray for dual-tagged adult American shad recorded during the spring 2020 upstream passage assessment.

Shad - Number of Lift Entrance Detection Events			
Release Date	Minimum	Maximum	Mean
16-May	1	20	5.6
18-May	1	10	4.8
22-May	1	10	3.9
26-May	1	9	3.4
27-May	1	18	5.2
All	**1**	**20**	**4.6**

Table 5–31. CJS model selection criteria for upstream passage effectiveness of the E.L. Field fish lift for adult American shad at Lowell during spring 2020.

Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Parameters	Deviance
Phi(t)p(t)	254.77	0.00	1.00	1.00	10	32.13
Phi(t)p(.)	315.05	60.28	0.00	0.00	5	103.05
Phi(.)p(t)	336.50	81.73	0.00	0.00	7	120.30
Phi(.)p(.)	410.43	155.66	0.00	0.00	2	204.63

Table 5–32. Passage success probability estimates (*Phi)*, standard errors, and likelihood 75 and 95% confidence intervals for dual-tagged adult American shad approaching the E.L. Field fish lift during 2020.

Reach	*Phi*	SE	95% CI		75% CI	
Tailrace to Entrance	0.674	0.071	0.523	0.797	0.588	0.751
Entrance to Exit	0.451	0.093	0.282	0.631	0.348	0.558
Exit to Forebay	1.000	0.000	-	-	-	-
Forebay to Pawtucket Gatehouse	0.918	0.078	0.594	0.989	0.773	0.974
Pawtucket Gatehouse to Upstream	0.500	0.144	0.244	0.756	0.340	0.660

Table 5–33. Detection efficiency estimates (*p*), for monitoring stations installed to detect dual-tagged adult American shad approaching the E.L. Field fish lift during 2020.

Location	S	SE	95% CI	
Station 21	1.000	0.000	1.000	1.000
Station 22/23	0.612	0.135	0.341	0.828
Station 08	0.842	0.102	0.541	0.960
Station 07	1.000	0.000	1.000	1.000
Station 06	0.833	0.152	0.369	0.977

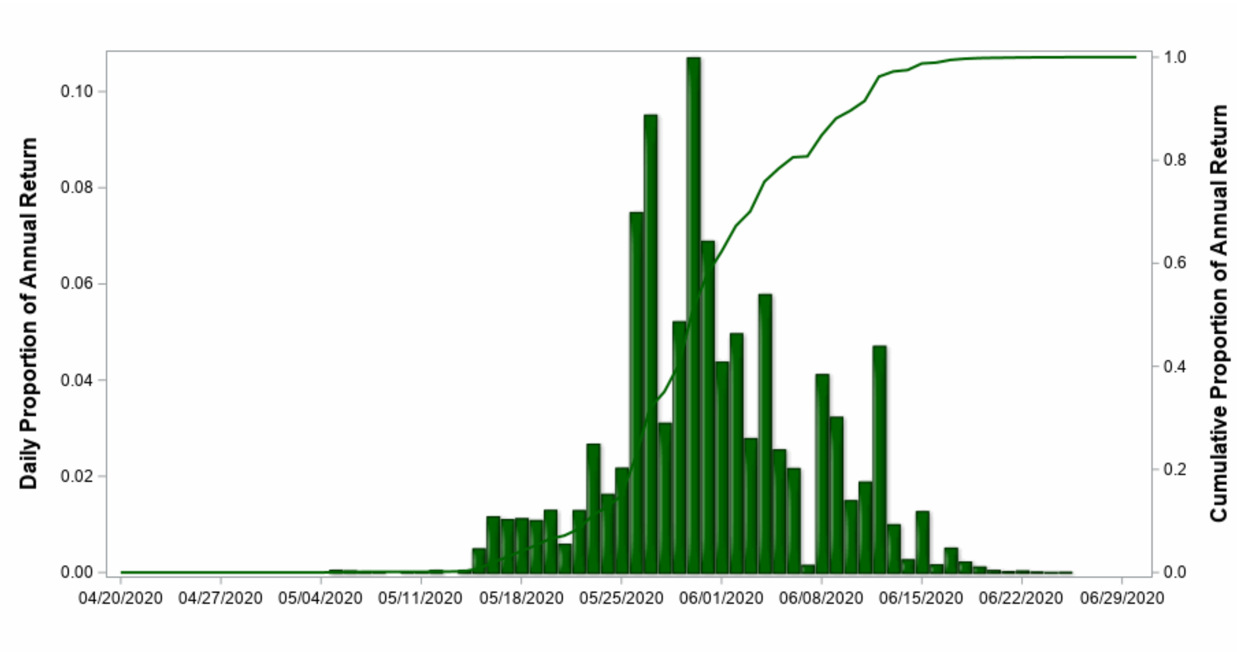

Figure 5–21. Daily (bars) and cumulative (line) proportion of annual adult American shad returns at the Lawrence fishway as enumerated by Salmonsoft recording for the 2020 passage season.

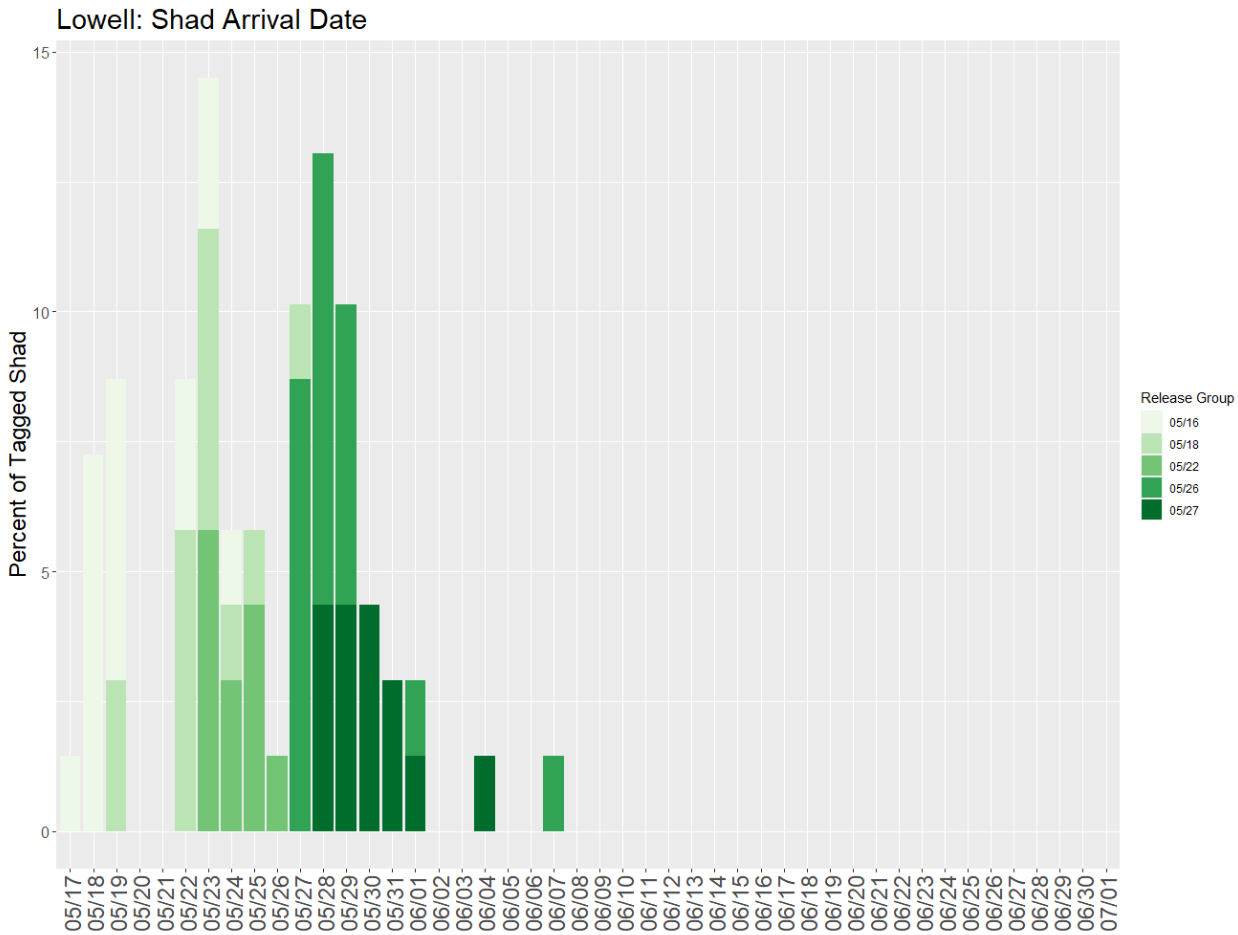

Figure 5–22. Distribution of arrival dates for dual-tagged adult American shad originally released downstream of Lowell at the Lawrence Project as part of the spring 2020 upstream passage assessment.

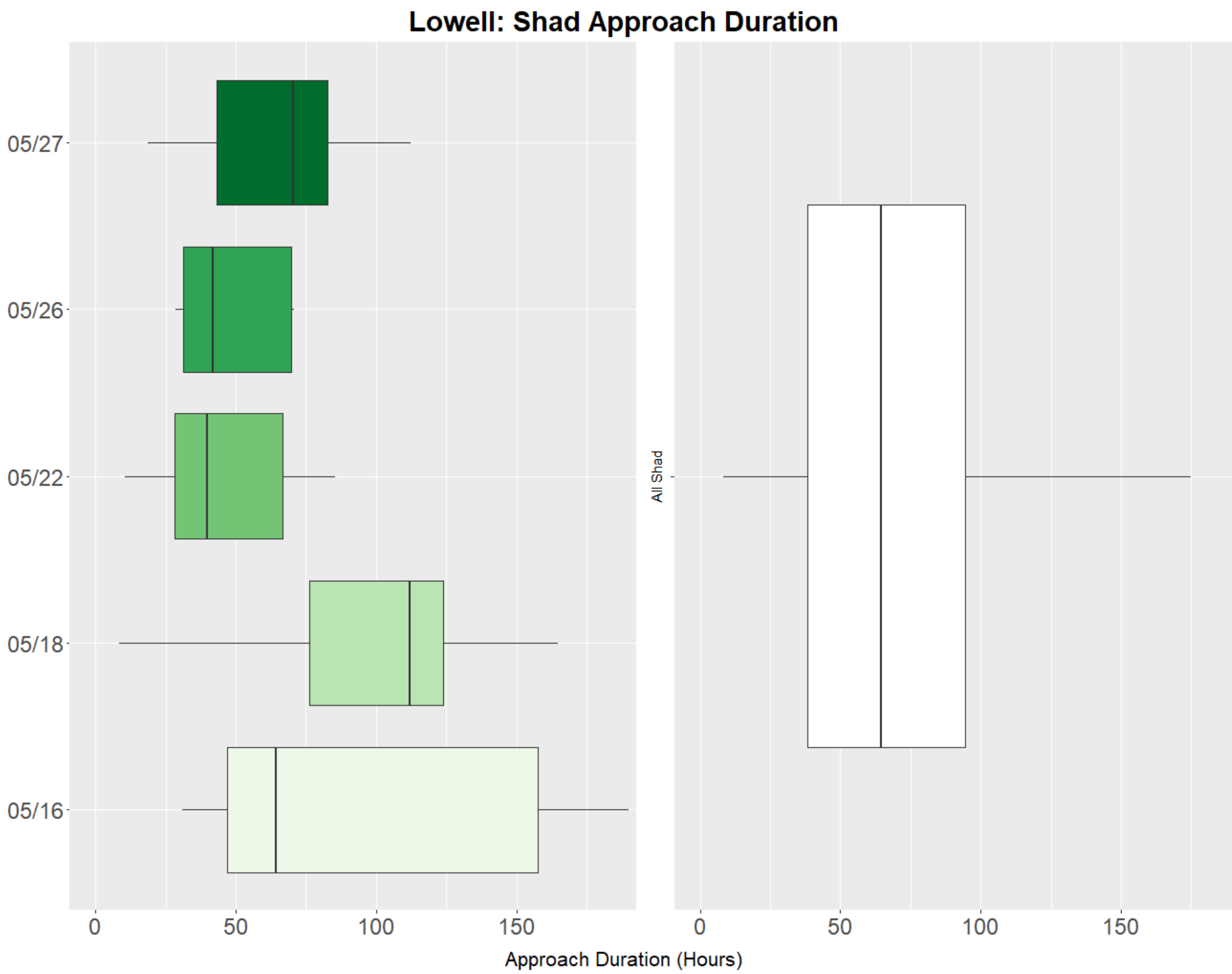

Figure 5–23. Boxplot of the approach duration for all dual-tagged adult American shad released downstream of Lowell during the spring 2020 upstream passage assessment. [8]

[8] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

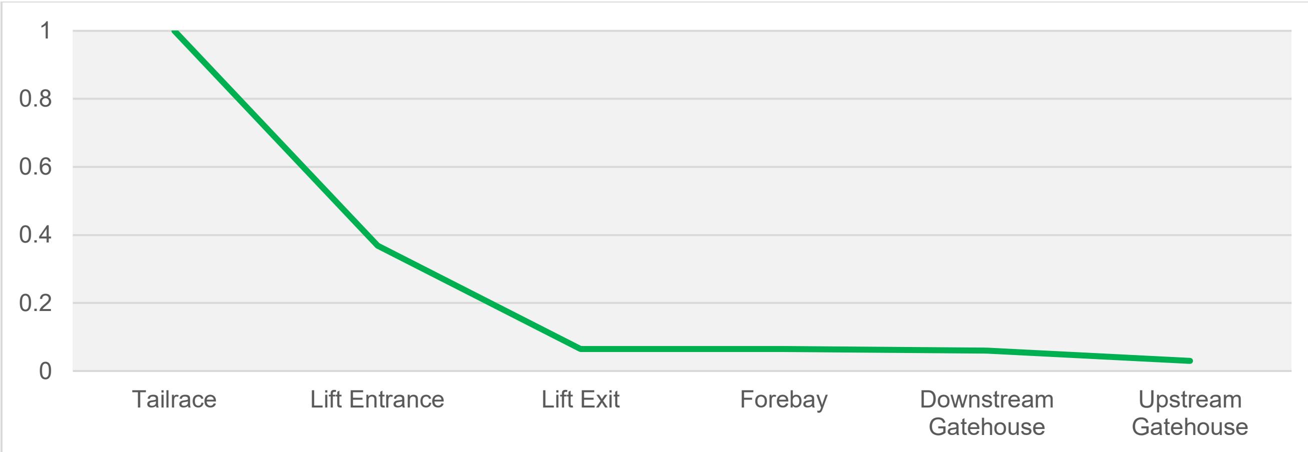

Figure 5–24. Magnitude of upstream progress for dual-tagged adult American shad forays at the E.L. Field fish lift during the spring 2020 upstream passage assessment.

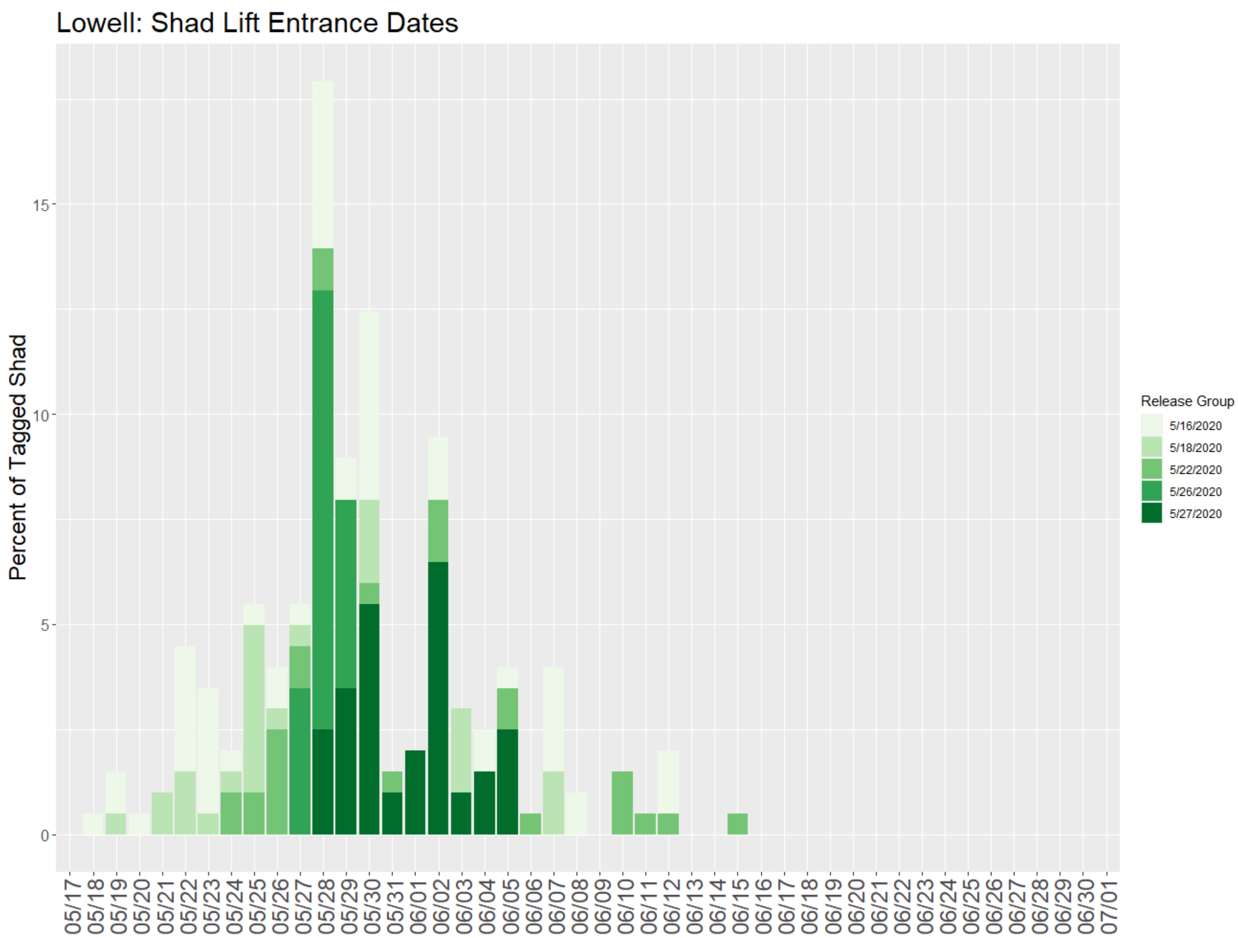

Figure 5–25. Distribution of entrance dates for dual-tagged adult American shad at the E.L. Field fish lift during the spring 2020 upstream passage assessment.

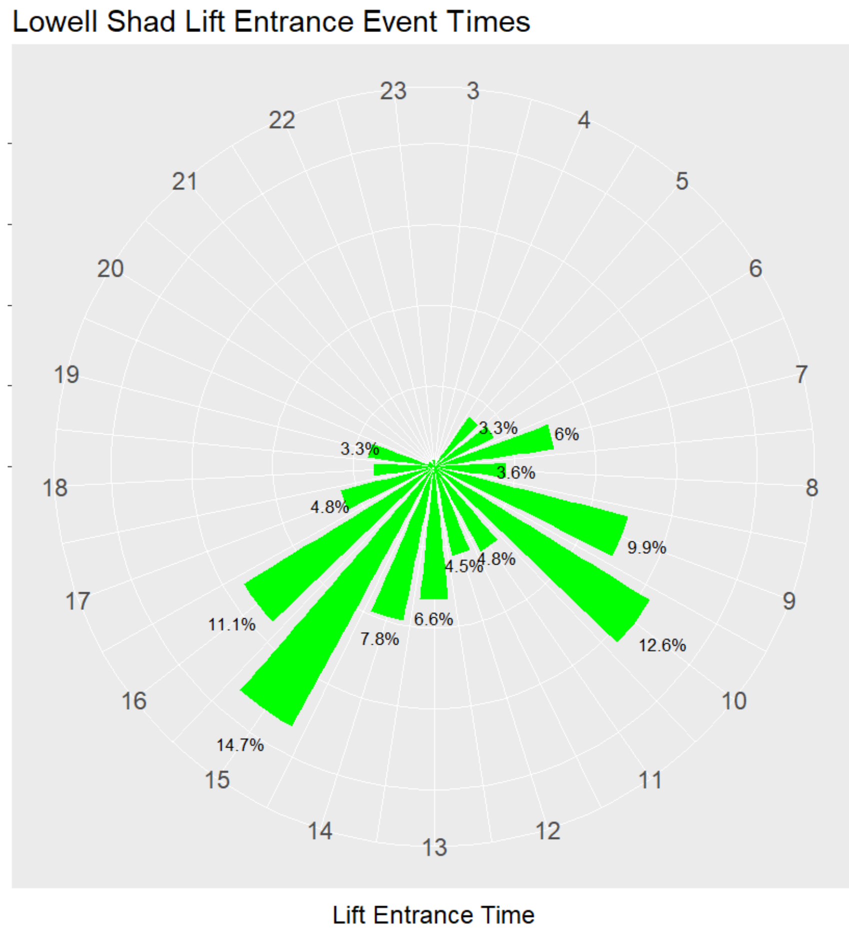

Figure 5–26. Distribution of entrance times for dual-tagged adult American shad at the E.L. Field fish lift during the spring 2020 upstream passage assessment.

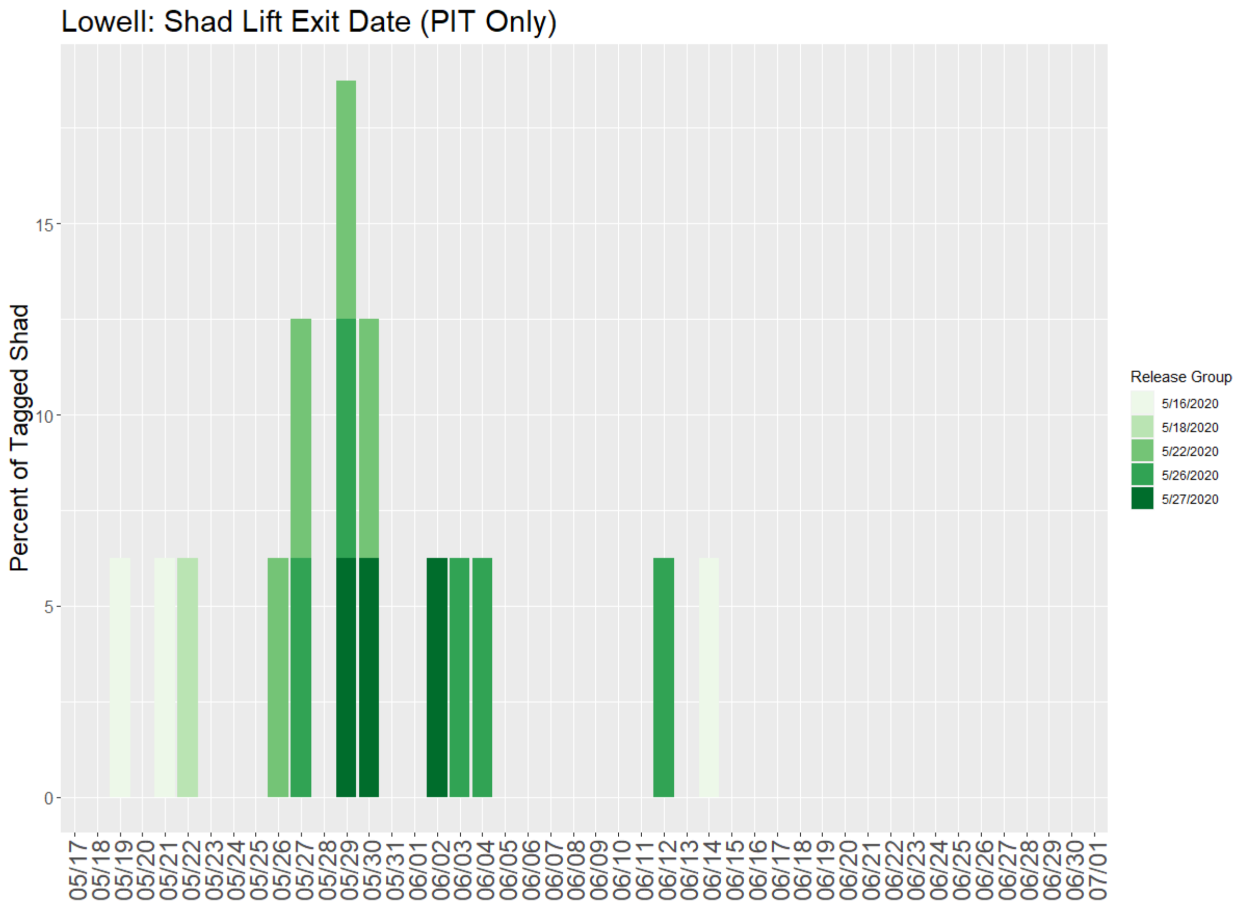

Figure 5–27. Distribution of exit flume dates for PIT-tagged adult American shad at the E.L Field Powerhouse fish lift during the spring 2020 upstream passage assessment.

5.6 Downstream Passage Effectiveness – Adult Alewives

A total of 150 adult alewives were radio-tagged and released during late-May and early-June 2020 for the purposes of evaluating downstream passage at Lowell (Table 5-34). Tagging was conducted on a total of four dates starting on May 21 and ending on June 2. Due to observations of reduced daily returns of river herring to the Lawrence Project over the days following the second release group (May 22) adult herring for the last two releases were obtained at the Amoskeag fishway located upstream of the Lowell Project in Manchester, NH[9]. Adult alewives tagged for evaluation of downstream passage at Lowell were comprised of 43% female, 56% male and 1% undetermined. Total length of individuals tagged ranged from 220-330 mm (mean = 294 mm). The mean body length for fish obtained at Lawrence and Amoskeag was similar (295 mm and 292 mm, respectively). A full listing of tagged individuals released upstream of Lowell during the spring of 2020 is provided in Appendix A.

As initially described in Section 4.3.2, a total of 200 radio-tagged adult alewives were released at two locations within the Nashua River, a tributary to the Merrimack River upstream of Lowell. The Pepperell release group consisted of 100 radio-tagged individuals released upstream of Mine Falls and subsequently moved downstream of both Mine Falls and Jackson Mills Dams. The Mine Falls release group consisted of 100 radio-tagged individuals released downstream of Mine Falls and subsequently moved downstream of Jackson Mills (and potentially Mine Falls, dependent on volitional upstream passage there) prior to arrival at Lowell. The subset of radio-tagged adult herring originating in the Nashua River and approaching Lowell (n = 93) has been incorporated into this overall review of downstream passage at the Project.

5.6.1 Project Arrival and Upstream Residence Duration

Releases of radio-tagged adult alewives were initiated upstream of Lowell at the Tyngsborough Riverfront Park on May 21 and concluded on June 2, 2020. Adult herring releases in the Nashua River occurred between the dates of May 17 to 19 for the Mine Falls group and between the dates of May 21 and 28 for the Pepperell release group. Figure 5-28 presents the distribution of arrival dates for those individual radio-tagged herring at the Pawtucket Dam as indicated by detection at Stations 05 and 06. When individuals from all upstream release locations are considered, initial detections for radio-tagged alewives were recorded over a range of dates from May 18 through June 10 with peaks in arrivals on May 30 and June 3, 2020. Radio-tagged individuals released at Mine Falls and Tyngsborough represented the majority of fish arriving through the second half of May and into early June. Later arriving outmigrants recorded approaching Lowell were originally released in the upper Nashua River at Pepperell. The duration of time from release until arrival at Lowell (i.e., the approach duration) ranged from 6.7 hours to 13.4 days (median = 2.4 days) for alewives released at Tyngsborough, from 12.3

[9] See Appendix F for a brief comparison of passage metrics for the adult river herring release groups at Tyngsborough which originated from tagging collections at the Lawrence (n = 80) and Amoskeag Dam (n = 70) fish passage facilities.

hours to 29.3 days (median = 10.3 days) for fish released at Pepperell, and from 3.0 days to 21.4 days (median = 11.4 days) for fish released at Mine Falls (Table 5-35).

The duration of time radio-tagged individuals were present upstream of the Pawtucket Dam was determined for all individuals which approached and eventually passed downstream and was calculated as the duration of time from initial detection immediately upstream of the dam until confirmed downstream passage via one of the available routes. When all individuals are considered, the upstream residence duration prior to downstream passage ranged between 0.4 hours to 8.9 days (Table 5-36; Figure 5-29). The median duration of time spent immediately upstream of the dam structure was 1.8 days and did not appear to differ greatly by release location for radio-tagged adult alewives released at any of the three locations upstream of Lowell (Tyngsborough = 2.0 days; Mine Falls = 1.6 days; and Pepperell = 1.5 days). Of the radio-tagged alewives which approached Pawtucket Dam, 26% passed in less than 24 hours and 78% passed in less than 96 hours after initial detection.

Outmigrating adult alosines encountering the Pawtucket Dam can (1) pass through the Pawtucket Gatehouse and enter the power canal, (2) pass downstream over Pawtucket Dam via spill, or (3) enter the Pawtucket Canal and navigate downstream via the downtown canal system. During the 2020 evaluation only four radio-tagged adult alewives were detected at Monitoring Station 28 indicating those individuals passed downstream through the downtown canal system rather than remaining in the mainstem Merrimack. The majority of radio-tagged alewives were determined to have passed through the Pawtucket Gatehouse and entered the Northern Canal to approach the E.L. Field powerhouse. The duration of time to pass through the Pawtucket Gatehouse was determined based on the initial detection for each individual adult at Stations 06 and 07 which independently monitored the upstream and downstream sides of that structure. The median duration of time for radio-tagged adult alewives to initially encounter and then pass through the Pawtucket Gatehouse was 1.7 hours (range <0.1 hours to 4.1 days; Table 5-37). The quartile ranges (25th to 75th percentiles) did not vary when examined among release groups (0.2-15.3 hours for herring originating at Tyngsborough; 0.1-10.1 hours for fish originating at Mine Falls; and 0.8-13.2 hours for fish originating at Pepperell). The majority (65%) of radio-tagged adult alewives passing through the Pawtucket Gatehouse did so in four hours or less following their initial detection at the structure.

Radio-tagged adult alewives released upstream of Lowell at Tyngsborough and which entered the Northern Canal and passed downstream of E.L. Field powerhouse did so relatively quickly. Of those individuals, 84% were resident in the power canal upstream of E.L. Field for 12 hours or less and the median residence duration in the Northern Canal was 0.5 hours (range = 0.2 hours to 1.8 days; Table 5-38). Adult river herring tagged and released at locations in the Nashua River demonstrated longer residence periods within the Northern Canal prior to downstream passage at Lowell. The quartile ranges (25th to 75th percentiles) for adult herring originally released at Pepperell ranged from 14.5-43.6 hours and for adult herring originally released at Mine Falls ranged from 4.7-69.6 hours (Table 5-38). When all individuals are considered, 20% of adult river herring were present in the Northern Canal for greater than 24 hours prior to downstream passage.

5.6.2 Downstream Passage

A total of 350 radio-tagged adult alewives were released at locations upstream of Lowell during the spring of 2020. Of that total, 124 of the 150 released upstream at Tyngsborough as part of this evaluation were determined to have approached the Pawtucket Dam and were available for the evaluation of downstream passage route (Table 5-39). An additional 93 radio-tagged adult river herring released upstream at Mine Falls (n = 50) and Pepperell (n=43) also approached Lowell and were included in the downstream analysis. The majority of radio-tagged individuals passed through the Pawtucket Gatehouse and approached the E.L. Field powerhouse (92% of approaching fish). Most individuals passed downstream of Lowell via the E.L. Field turbine units (47% of radio-tagged alewives) or utilized the downstream bypass (45% of radio-tagged alewives). Use of the bypassed reach (i.e., spill) was limited to a single individual.

Four radio-tagged adult alewives (2% of all fish approaching Pawtucket Dam) utilized the downtown canal system for downstream passage. The first of two individuals originally released at Tyngsborough and entering the downtown canal system moved through the Pawtucket Canal (i.e., Guard Locks and Swamp Locks) to the Eastern Canal. It was detected at Station 32 in the intake area of the John St. Station prior to passing downstream via the Boott Dam and subsequent detection downstream at Lawrence. Transit time from initial detection at the Guard Locks (Station 28) to passage at Boott Dam was 9.6 hours. The second individual moved through the Pawtucket Canal to Hamilton Canal and passed via the Hamilton Wasteway. It was detected at Station 32 in the intake area of the John St. Station prior to arrival at the receiver monitoring Boott Dam (i.e., Station 34). This individual exited the downtown canal system approximately 16.1 hours following initial detection at the Guard Locks. A single adult river herring originally released at Mine Falls entered the downtown canal system moved through the Pawtucket Canal to Hamilton Canal and passed via the Hamilton Wasteway. It was detected at Station 32 in the intake area of the John St. Station prior to arrival at the receiver monitoring Boott Dam (i.e., Station 34). Transit time from initial detection at the Guard Locks (Station 28) to passage at Boott Dam was 3.1 hours. This individual was subsequently detected downstream at Lawrence (Station 27). The fourth tagged adult river herring documented passing downstream via the downtown canal system was originally released at Pepperell. This individual moved through the Pawtucket Canal (i.e., Guard Locks and Swamp Locks) to the Eastern Canal. It was detected at Station 32 in the intake area of the John St. Station prior to initial detection at the Boott Dam sluice gate 51.9 hours after entering at the Guard Locks. This individual was likely a mortality as it remained stationary in the detection field of Station 34 for over two weeks following initial detection.

The single individual which passed Lowell via spill was initially detected at Station 06 (i.e., immediately upstream of the Pawtucket Gatehouse) but did not pass that structure and enter the Northern Canal.

Radio-tagged adult alewives were observed passing downstream of Lowell between the dates of May 18 through June 19 (Figure 5-30). Downstream passage of radio-tagged adult alosines at Lowell peaked during the early part of June with a peak of downstream passage events occurring between June 3 and June 6, 2020. Figure 5-31 presents the timing distribution of downstream passage events for radio-tagged adult alewives at Lowell. The majority of individuals passed downstream during the mid-afternoon through early evening hours (i.e., 1400-1900).

For each of the 205 individuals which were confirmed to have passed downstream of Lowell via a known passage route (i.e., turbine, downstream bypass, spill or downtown canal) the hourly record of Project operations (Section 5.1) at the time of passage was reviewed. The discharge at the selected route was identified and contrasted with the cumulative discharge for all non-selected routes at the time of downstream passage (Table 5-40). A total of 47% of radio-tagged adult river herring passing downstream at Lowell did so via the E.L. Field turbine units. The median discharge through the two E.L. Field turbine units at the time of passage for those individuals was 1,853 cfs. When examined by passage route, the median percentage of passage route flow at each known downstream passage route represented 58% of project flow for turbine passed alewives, 4% of project flow for downstream bypass passed alewives, 23% of project flow for spill passed alewives, and 20% of project flow for individuals using the downtown canal system. A listing of route discharge at the time of downstream passage for each adult herring is provided in Appendix D.

5.6.3 Downstream Transit

Three monitoring stations were installed downstream of Lowell for the purpose of detecting radio-tagged adult alosines following passage at the Project during the spring of 2020. Those receivers were located approximately 2.1 (Monitoring Station 25), 6.0 (Monitoring Station 26), and 10.75 (Monitoring Station 27) miles downstream of the project. The minimum, maximum, and quartile transit times through those three reaches are presented in Table 5-41. The median transit time durations for all tagged adult alewives moving downstream of Lowell were 4.7, 2.7, and 17.9 hours for the 2.1 mile, 3.9 mile and 4.75 mile downstream reaches, respectively. When examined by release location the median downstream transit durations were comparable among groups for each reach, ranging from 4.0 to 5.0 hours for adult herring from Lowell to Station 25, 2.6 to 3.3 hours for adult herring from Station 25 to Station 26, and 15.4 to 19.0 hours for adult herring from Station 26 to Essex Dam in Lawrence. Table 5-42 provides the minimum, maximum, and quartile transit times through defined sections of the Merrimack River between Lowell and Lawrence as a rate (i.e., miles per hour (mph)).

Table 5-43 and Figure 5-32 present the minimum, maximum and quartile transit times for radio-tagged adult alewives to cover the full reach from immediately downstream of Lowell to the upstream face of the Essex Dam in Lawrence (i.e., Station 27). The median travel time for those individuals to approach Lawrence following downstream passage at Lowell was 1.1 days (range = 8.0 hours to 7.7 days).

5.6.4 Passage Survival

The CJS model *Phi(t)p(t)* provided the best fit for the observed mark-recapture data associated with downstream movements of all radio-tagged adult alewives approaching and passing at Lowell during 2020 (Table 5-44). The detection efficiency for telemetry receivers recording passage of adult herring for monitoring stations at Lowell and downstream of Lowell ranged from 1.000 to 0.853 (Table 5-45). The reach-specific survival estimates for the Merrimack River from the Lowell impoundment receiver to detection immediately upstream of Lawrence for (1) all adult alewives, (2) adult alewives released at Tyngsborough, (3) adult alewives released in the Nashua River, (4) turbine-passed adult alewives, and (5) downstream bypass passed adult alewives are presented in Table 5-46. Passage success for downstream passage of adult alewives at Lowell was calculated as the joint probability of the three reach-specific survival estimates which encompasses the full section of the Merrimack River from Lowell downstream to Lawrence (i.e., Lowell to Station 25, Station 25 to Station 26, and Station 26 to Lawrence). This resulted in an estimated downstream passage survival for all adult alewives at Lowell of 80.1% (75% CI = 76.7%-83.6%). No adjustments were made to encounter histories for adult alewives passing Lowell to reflect the duration of time to detection at Lawrence following downstream passage since there were no documented events for radio-tagged “drift” alewives at the downstream receiver stations indicating that the magnitude of downstream travel for that species following dead release into the tailrace was negligible. When examined by release location, downstream passage survival was estimated for adult herring released at Tyngsborough at 76.1% (75% CI = 71.5%-80.5%) and for adult herring released in the Nashua River at 86.2% (75% CI = 81.3%-91.0%).

Radio-tagged adult alewives which approached and passed downstream at Lowell during the 2020 evaluation did so via a variety or passage routes (Table 5-39). Individual CJS models were run for the subset of individuals utilizing the E.L. Field turbine units and downstream bypass facility for downstream passage and produced estimates of 73.9% (75% CI = 68.8%-79.1%) and 87.8% (75% CI = 81.8%-91.5%), respectively. . The single adult alewife passing Lowell via spill and three of the four passing Lowell via the downtown canal system were also subsequently detected at Lawrence.

Table 5–34. Summary of tagging and release information for adult alewives released upstream of Lowell during the spring 2020 downstream passage assessment.

Date	Source	Type	Number
21-May	Lawrence	Radio	60
22-May	Lawrence	Radio	20
28-May	Amoskeag	Radio	20
2-Jun	Amoskeag	Radio	50
Total		Radio	150

Table 5–35. Minimum, maximum, and quartile values of approach duration (hours) for radio-tagged alewives released upstream of Lowell during the spring 2020 adult alosine passage assessment.

Alewife - Approach Duration (hrs)						
Release Location	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Tyngsborough	21-May	6.7	323.6	154.4	181.0	233.1
	22-May	58.5	299.4	124.8	147.9	228.5
	28-May	11.8	155.1	28.1	37.8	52.5
	2-Jun	11.5	75.9	28.2	32.7	38.3
	All	**6.7**	**323.6**	**32.7**	**58.5**	**176.8**
Mine Falls	17-May	57.3	350.6	118.1	198.5	285.7
	18-May	12.3	702.6	204.3	239.4	292.4
	19-May	111.8	439.0	203.5	277.3	390.6
	All	**12.3**	**702.6**	**199.5**	**248.3**	**306.6**
Pepperell	21-May	197.2	481.5	379.5	397.4	440.5
	22-May	169.2	439.5	240.3	354.2	400.6
	28-May	72.6	513.7	130.2	173.9	235.1
	All	**72.6**	**513.7**	**174.7**	**274.7**	**397.4**
	All	**6.7**	**702.6**	**46.7**	**175.0**	**261.4**

Table 5–36. Minimum, maximum, and quartile values of upstream residence duration (hours) for radio-tagged alewives released upstream of Lowell during the spring 2020 adult alosine passage assessment.

Alewife - Upstream Residence (hrs)						
Release Location	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Tyngsborough	21-May	0.8	198.6	22.3	44.3	88.5
	22-May	16.0	210.1	37.7	51.5	78.7
	28-May	0.7	181.7	55.0	77.5	103.7
	2-Jun	2.1	134.4	22.7	42.6	71.8
	All	**0.7**	**210.1**	**25.3**	**48.2**	**88.6**
Mine Falls	17-May	0.9	114.9	4.7	10.1	39.3
	18-May	0.4	215.6	16.3	42.6	102.2
	19-May	0.8	164.6	25.5	39.7	90.3
	All	**0.4**	**215.6**	**15.7**	**38.3**	**100.2**
Pepperell	21-May	6.5	98.4	16.7	37.1	51.6
	22-May	6.0	69.0	28.6	36.1	37.9
	28-May	2.4	134.0	24.5	37.5	60.2
	All	**2.4**	**134.0**	**22.8**	**36.2**	**54.2**
	All	**0.4**	**215.6**	**23.0**	**44.0**	**87.1**

Table 5–37. Minimum, maximum, and quartile values of time to pass the Pawtucket Gatehouse and enter Northern Canal (hours) for radio-tagged alewives released upstream of Lowell during the spring 2020 adult alosine passage assessment.

Alewife - Pawtucket Gatehouse Passage (hrs)						
Release Location	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Tyngsborough	21-May	<0.1	99.3	0.2	0.5	7.3
	22-May	0.1	9.9	0.2	0.8	3.8
	28-May	<0.1	94.2	0.4	2.2	16.8
	2-Jun	<0.1	65.6	0.6	2.6	25.1
	All	**<0.1**	**99.3**	**0.2**	**1.8**	**15.3**
Mine Falls	17-May	<0.1	28.2	0.0	0.1	10.4
	18-May	<0.1	46.1	0.2	1.0	7.6
	19-May	<0.1	27.6	0.3	1.5	11.1
	All	**<0.1**	**46.1**	**0.1**	**0.8**	**10.1**
Pepperell	21-May	0.3	47.4	0.8	1.0	2.2
	22-May	0.1	21.7	0.3	0.8	6.9
	28-May	0.1	95.9	1.4	2.6	18.0
	All	**0.1**	**95.9**	**0.8**	**1.9**	**13.2**
	All	**<0.1**	**99.3**	**0.2**	**1.7**	**14.6**

Table 5–38. Minimum, maximum, and quartile values of Northern Canal residence duration (hours) for radio-tagged alewives released upstream of Lowell during the spring 2020 adult alosine passage assessment.

Alewife - Northern Canal Residence (hrs)						
Release Location	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Tyngsborough	21-May	0.2	38.2	0.3	0.4	6.1
	22-May	0.2	27.2	0.3	0.4	0.5
	28-May	0.2	33.3	0.3	0.5	3.7
	2-Jun	0.2	42.3	0.4	0.7	5.7
	All	**0.2**	**42.3**	**0.3**	**0.5**	**5.1**
Mine Falls	17-May	0.6	86.1	3.0	9.2	39.1
	18-May	0.2	213.4	13.3	28.8	86.6
	19-May	0.5	117.5	4.7	22.6	66.6
	All	**0.2**	**213.4**	**4.7**	**22.5**	**69.6**
Pepperell	21-May	1.0	95.5	2.2	19.1	46.0
	22-May	1.0	44.9	9.5	23.5	30.1
	28-May	1.6	133.1	18.9	21.7	42.1
	All	**1.0**	**133.1**	**14.5**	**22.3**	**43.6**
	All	**0.2**	**213.4**	**0.4**	**2.8**	**21.4**

Table 5–39. Downstream passage route selection for radio-tagged alewives released upstream of Lowell during the spring 2020 adult alosine passage assessment.

Alewife - Lowell Downstream Passage Route							
Release Location	Release Date	No Detect	No Pass	Downtown	Turbine	Spill	Bypass
Tyngsborough	21-May	16	0	0	24	1	19
	22-May	7	0	0	7	0	6
	28-May	0	0	0	11	0	9
	2-Jun	3	1	2	22	0	22
	All	**26**	**1**	**2**	**64**	**1**	**56**
% of Total Detected			1%	2%	52%	1%	45%
Mine Falls	17-May	13	1	0	4	0	2
	18-May	18	3	0	9	0	10
	19-May	19	2	1	11	0	7
	All	**50**	**6**	**1**	**24**	**0**	**19**
% of Total Detected			12%	2%	48%	0%	38%
Pepperell	21-May	28	1	0	3	0	8
	22-May	9	3	0	2	0	5
	28-May	20	1	1	10	0	9
	All	**57**	**5**	**1**	**15**	**0**	**22**
% of Total Detected			12%	2%	35%	0%	51%
All		**133**	**12**	**4**	**103**	**1**	**97**
% of Total Detected			6%	2%	47%	0%	45%

Table 5–40. Quartile conditions of project discharge at the time of downstream passage for radio-tagged adult river herring at the known route of passage and the cumulative sum of discharge at non-passage routes.

Passage Route	No. Using Route	Quartile	Route Discharge		Non-Route Discharge	
			cfs	%	cfs	%
Turbines	103	Q25	1414	51%	1259	32%
		Q50	1853	58%	1352	42%
		Q75	3203	68%	1526	49%
Downstream Bypass	97	Q25	132	3%	2706	95%
		Q50	132	4%	2953	96%
		Q75	132	5%	3928	97%
Spill	1	-	683	23%	2283	77%
Downtown Canal	4	Q25	542	17%	2010	79%
		Q50	542	20%	2202	80%
		Q75	589	21%	2873	83%

Table 5–41. Minimum, maximum, and quartile values of travel time (hours) through three separate downstream reaches for radio-tagged alewives following downstream passage at Lowell during the spring 2020 adult alosine passage assessment.

Alewife - Downstream Transit Duration (hrs)							
Downstream Reach	Release Location	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Downstream of Lowell to Station 25 (2.1 miles)	Tyngsborough	21-May	1.1	50.8	3.2	5.2	11.7
		22-May	2.6	17.0	4.5	6.2	10.0
		28-May	1.7	18.7	3.8	5.5	9.3
		2-Jun	1.5	28.5	2.6	4.6	6.9
		All	**1.1**	**50.8**	**3.0**	**5.0**	**8.8**
	Mine Falls	17-May	1.4	5.9	2.1	3.3	4.5
		18-May	1.1	16.5	3.7	4.9	6.2
		19-May	1.1	18.1	2.7	4.5	9.7
		All	**1.1**	**18.1**	**2.6**	**4.7**	**6.4**
	Pepperell	21-May	2.0	7.0	2.7	3.2	4.3
		22-May	0.5	7.6	2.3	3.9	4.3
		28-May	2.1	9.9	3.3	5.0	5.8
		All	**0.5**	**9.9**	**2.9**	**4.0**	**5.3**
	All		**0.5**	**50.8**	**2.9**	**4.7**	**7.1**
Station 25 to Station 26 (3.9 miles)	Tyngsborough	21-May	1.7	4.2	1.9	2.2	2.9
		22-May	1.8	4.5	2.0	2.1	2.4
		28-May	1.9	16.5	2.3	2.7	3.2
		2-Jun	2.2	13.7	2.6	3.0	3.9
		All	**1.7**	**16.5**	**2.1**	**2.6**	**3.1**
	Mine Falls	17-May	1.9	22.1	3.2	7.1	15.7
		18-May	1.8	18.1	2.1	2.6	3.1
		19-May	1.8	20.7	2.1	2.4	3.4
		All	**1.8**	**22.1**	**2.1**	**2.9**	**3.7**
	Pepperell	21-May	2.1	7.9	2.4	2.5	4.1
		22-May	2.5	4.6	2.8	3.3	4.0
		28-May	1.9	19.4	2.3	3.5	5.4
		All	**1.9**	**19.4**	**2.4**	**3.3**	**4.4**
	All		**1.7**	**22.1**	**2.1**	**2.7**	**3.5**
Station 26 to Lawrence (Station 27; 4.75 miles)	Tyngsborough	21-May	2.6	138.9	14.6	19.0	21.0
		22-May	4.5	8.5	5.2	5.8	7.2
		28-May	13.4	51.5	17.8	19.6	21.4
		2-Jun	4.1	68.2	17.0	18.7	20.4
		All	**2.6**	**138.9**	**16.3**	**19.0**	**21.0**
	Mine Falls	17-May	2.9	70.5	8.1	18.8	32.7
		18-May	13.5	20.7	16.2	17.0	19.2
		19-May	3.6	21.9	4.6	13.9	16.4
		All	**2.9**	**70.5**	**13.3**	**16.4**	**19.2**
	Pepperell	21-May	2.9	23.7	10.8	14.0	16.7
		22-May	3.4	17.6	5.9	13.0	16.2
		28-May	12.7	19.4	15.4	17.9	19.2
		All	**2.9**	**23.7**	**12.9**	**15.4**	**17.9**
	All		**2.6**	**138.9**	**13.7**	**17.9**	**19.9**

Table 5–42. Minimum, maximum, and quartile values of rate of travel (mph) through three separate downstream reaches for radio-tagged alewives following downstream passage at Lowell during the spring 2020 adult alosine passage assessment.

Alewife - Downstream Transit Rate (mph)							
Downstream Reach	Release Location	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Downstream of Lowell to Station 25 (2.1 miles)	Tyngsborough	21-May	0.0	1.9	0.7	0.4	0.2
		22-May	0.1	0.8	0.5	0.3	0.2
		28-May	0.1	1.2	0.6	0.4	0.2
		2-Jun	0.1	1.4	0.8	0.5	0.3
		All	**0.0**	**1.9**	**0.7**	**0.4**	**0.2**
	Mine Falls	17-May	0.4	1.5	1.0	0.6	0.5
		18-May	0.1	1.8	0.6	0.4	0.3
		19-May	0.1	1.9	0.8	0.5	0.2
		All	**0.1**	**1.9**	**0.8**	**0.4**	**0.3**
	Pepperell	21-May	0.3	1.1	0.8	0.7	0.5
		22-May	0.3	4.2	0.9	0.5	0.5
		28-May	0.2	1.0	0.6	0.4	0.4
		All	**0.2**	**4.2**	**0.7**	**0.5**	**0.4**
	All		**0.0**	**4.2**	**0.7**	**0.4**	**0.3**
Station 25 to Station 26 (3.9 miles)	Tyngsborough	21-May	0.9	2.3	2.1	1.8	1.3
		22-May	0.9	2.2	2.0	1.9	1.6
		28-May	0.2	2.1	1.7	1.4	1.2
		2-Jun	0.3	1.8	1.5	1.3	1.0
		All	**0.2**	**2.3**	**1.9**	**1.5**	**1.3**
	Mine Falls	17-May	0.2	2.1	1.2	0.6	0.2
		18-May	0.2	2.2	1.8	1.5	1.3
		19-May	0.2	2.1	1.8	1.6	1.2
		All	**0.2**	**2.2**	**1.8**	**1.3**	**1.1**
	Pepperell	21-May	0.5	1.9	1.6	1.5	1.0
		22-May	0.9	1.6	1.4	1.2	1.0
		28-May	0.2	2.0	1.7	1.1	0.7
		All	**0.2**	**2.0**	**1.6**	**1.2**	**0.9**
	All		**0.2**	**2.3**	**1.9**	**1.4**	**1.1**
Station 26 to Lawrence (Station 27; 4.75 miles)	Tyngsborough	21-May	0.0	1.8	0.3	0.3	0.2
		22-May	0.6	1.1	0.9	0.8	0.7
		28-May	0.1	0.4	0.3	0.2	0.2
		2-Jun	0.1	1.2	0.3	0.3	0.2
		All	**0.0**	**1.8**	**0.3**	**0.3**	**0.2**
	Mine Falls	17-May	0.1	1.6	0.6	0.3	0.1
		18-May	0.2	0.4	0.3	0.3	0.2
		19-May	0.2	1.3	1.0	0.3	0.3
		All	**0.1**	**1.6**	**0.4**	**0.3**	**0.2**
	Pepperell	21-May	0.2	1.6	0.4	0.3	0.3
		22-May	0.3	1.4	0.8	0.4	0.3
		28-May	0.2	0.4	0.3	0.3	0.2
		All	**0.2**	**1.6**	**0.4**	**0.3**	**0.3**
	All		**0.0**	**1.8**	**0.3**	**0.3**	**0.2**

Table 5–43. Minimum, maximum, and quartile values for downstream travel duration from Lowell to Lawrence (hours) for radio-tagged alewives released upstream of Lowell during the spring 2020 adult alosine passage assessment.

Alewife - Downstream Travel: Lowell to Lawrence (hrs)						
Release Location	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Tyngsborough	21-May	8.0	143.4	23.9	26.4	29.3
	22-May	15.0	23.4	15.2	15.3	19.4
	28-May	21.1	61.6	26.3	28.5	37.5
	2-Jun	10.6	184.6	23.9	26.2	34.0
	All	**8.0**	**184.6**	**23.8**	**26.6**	**32.4**
Mine Falls	17-May	10.6	94.6	23.8	26.7	44.6
	18-May	20.4	43.6	24.1	24.4	26.2
	19-May	16.0	37.3	21.9	24.0	27.0
	All	**10.6**	**94.6**	**23.0**	**24.4**	**27.3**
Pepperell	21-May	8.2	36.1	18.4	22.4	30.3
	22-May	9.7	28.7	12.2	20.9	23.1
	28-May	22.0	29.2	24.1	25.8	28.5
	All	**8.2**	**36.1**	**21.6**	**23.7**	**28.6**
	All	**8.0**	**184.6**	**22.8**	**25.8**	**30.3**

Table 5–44. CJS model selection criteria for survival of alewives at Lowell during the spring 2020 adult alosine passage assessment.

Scenario	Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Parameters	Deviance
All Herring	*Phi(t)p(t)*	1496.93	0.00	1.00	1.00	11	31.11
	Phi(t)p(.)	1548.03	51.10	0.00	0.00	8	88.29
	Phi(.)p(t)	1687.72	190.79	0.00	0.00	7	230.01
	Phi(.)p(.)	1864.79	367.86	0.00	0.00	2	417.15
Tyngsborough Herring	*Phi(t)p(t)*	671.00	0.00	1.00	1.00	11	23.25
	Phi(t)p(.)	698.84	27.84	0.00	0.00	7	59.29
	Phi(.)p(t)	722.83	51.83	0.00	0.00	8	81.24
	Phi(.)p(.)	868.37	197.37	0.00	0.00	2	238.95
Nashua River Herring	*Phi(t)p(t)*	760.23	0.00	1.00	1.00	11	22.76
	Phi(t)p(.)	782.43	22.20	0.00	0.00	8	51.15
	Phi(.)p(t)	911.48	151.25	0.00	0.00	7	182.25
	Phi(.)p(.)	966.21	205.97	0.00	0.00	2	247.13
Turbine Passed	*Phi(t)p(t)*	492.78	0.00	1.00	1.00	9	27.38
	Phi(t)p(.)	526.12	33.34	0.00	0.00	5	68.92
	Phi(.)p(t)	557.04	64.26	0.00	0.00	7	95.75
	Phi(.)p(.)	670.78	178.00	0.00	0.00	2	219.66
Bypass Passed	*Phi(t)p(t)*	375.05	0.00	1.00	1.00	7	13.37
	Phi(.)p(t)	398.24	23.19	0.00	0.00	6	38.61
	Phi(t)p(.)	399.51	24.47	0.00	0.00	5	41.92
	Phi(.)p(.)	590.82	215.77	0.00	0.00	2	239.31

Where *phi* = survival; *p* = detection probability; t = parameter is allowed to vary with time; and "." = parameter is fixed with time.

Table 5–45. Detection efficiency estimates (p) for monitoring locations installed to detect radio-tagged alewives at Lowell during the spring 2020 adult alosine passage assessment.

Location	S	SE	95% CI	
Station 04	0.963	0.013	0.927	0.981
Lowell	0.961	0.014	0.924	0.980
Station 25	1.000	0.000	-	-
Station 26	0.975	0.012	0.936	0.991
Station 27	0.853	0.030	0.785	0.902

Table 5–46. Reach-specific survival probability estimates (*phi)*, standard errors, and likelihood 75% and 95% confidence intervals for radio-tagged alewives at Lowell during the spring 2020 adult alosine passage assessment.

Scenario	Reach	*Phi*	SE	95% CI		75% CI	
All Herring	*Station 04 to Project*	0.983	0.009	0.950	0.994	0.968	0.991
	Project to Passage	0.952	0.015	0.913	0.974	0.931	0.966
	Passage to Station 25	0.835	0.026	0.778	0.880	0.803	0.863
	Station 25 to Station 26	0.959	0.020	0.898	0.984	0.930	0.976
	Station 26 to Lawrence	1.000	0.000	-	-	-	-
Tyngsborough Herring	*Station 04 to Project*	0.976	0.014	0.929	0.992	0.955	0.988
	Project to Passage	0.992	0.008	0.944	0.999	0.974	0.997
	Passage to Station 25	0.782	0.037	0.700	0.846	0.736	0.822
	Station 25 to Station 26	0.973	0.022	0.872	0.995	0.931	0.990
	Station 26 to Lawrence	1.000	0.000	-	-	-	-
Nashua River Herring	*Station 04 to Project*	0.995	0.012	0.677	1.000	0.930	1.000
	Project to Passage	0.895	0.033	0.811	0.945	0.851	0.928
	Passage to Station 25	0.916	0.031	0.832	0.960	0.873	0.945
	Station 25 to Station 26	0.941	0.034	0.828	0.981	0.888	0.970
	Station 26 to Lawrence	1.000	0.000	-	-	-	-
Turbine Herring	*Station 04 to Project*	1.000	0.000	-	-	-	-
	Project to Passage	1.000	0.000	-	-	-	-
	Passage to Station 25	0.778	0.041	0.688	0.849	0.727	0.822
	Station 25 to Station 26	0.950	0.033	0.831	0.986	0.896	0.977
	Station 26 to Lawrence	1.000	0.000	-	-	-	-
Bypass Herring	*Station 04 to Project*	1.000	0.000	-	-	-	-
	Project to Passage	1.000	0.000	-	-	-	-
	Passage to Station 25	0.908	0.030	0.832	0.952	0.868	0.937
	Station 25 to Station 26	0.967	0.024	0.871	0.992	0.926	0.986
	Station 26 to Lawrence	1.000	0.000	1.000	1.000	1.000	1.000

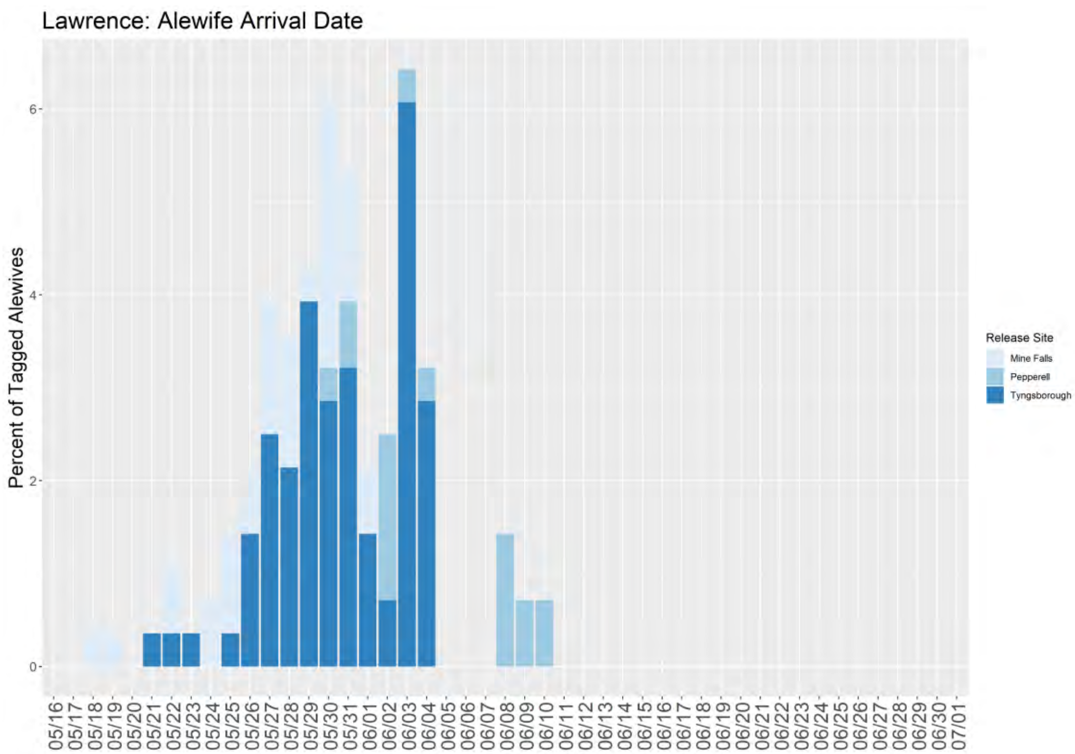

Figure 5–28. Distribution of Pawtucket Dam arrival dates for radio-tagged alewives at Lowell (by release location) during the spring 2020 adult alosine passage assessment.

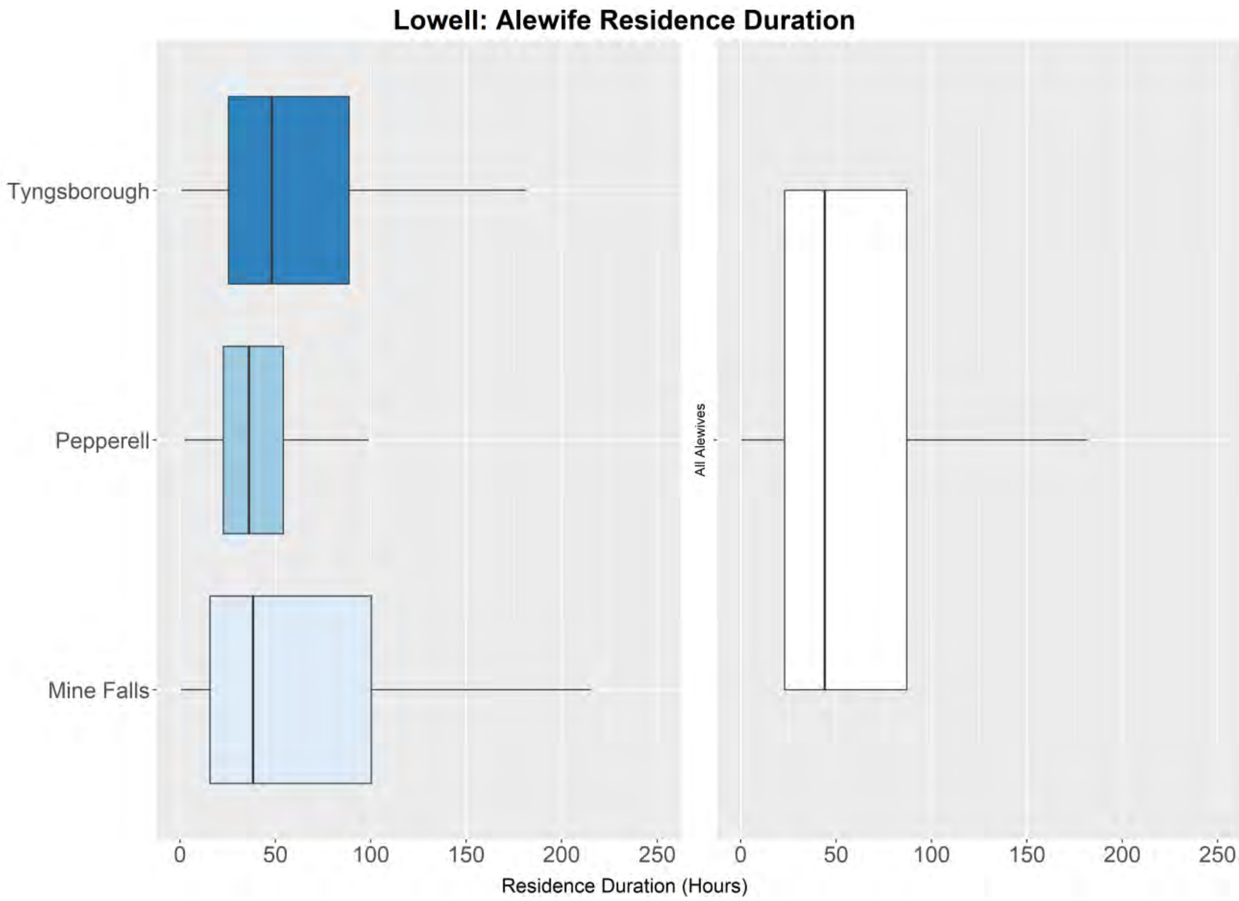

Figure 5–29. Boxplot of the Lowell upstream residence duration for radio-tagged alewives at Lowell (by release location) during the spring 2020 adult alosine passage assessment. [10]

[10] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

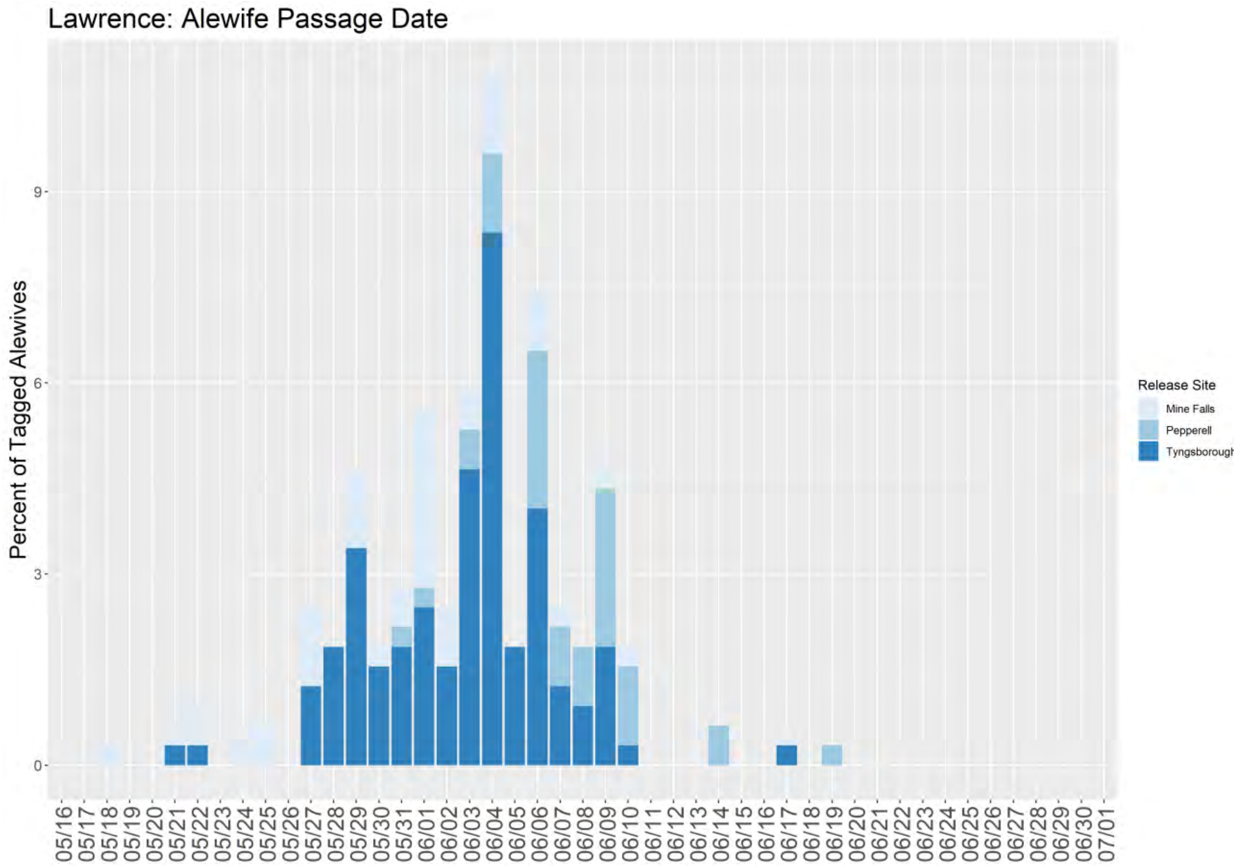

Figure 5–30. Distribution of Pawtucket Dam downstream passage dates for radio-tagged alewives at Lowell (by release location) during the spring 2020 adult alosine passage assessment.

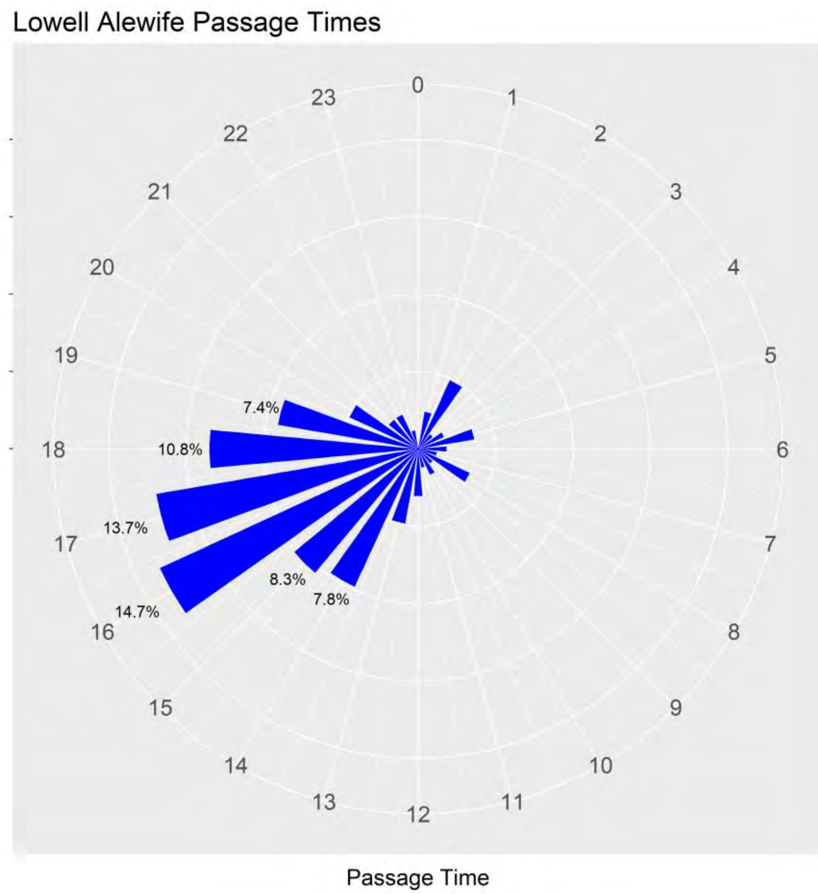

Figure 5–31. Distribution of downstream passage time for all radio-tagged alewives at Lowell during the spring 2020 adult alosine passage assessment.

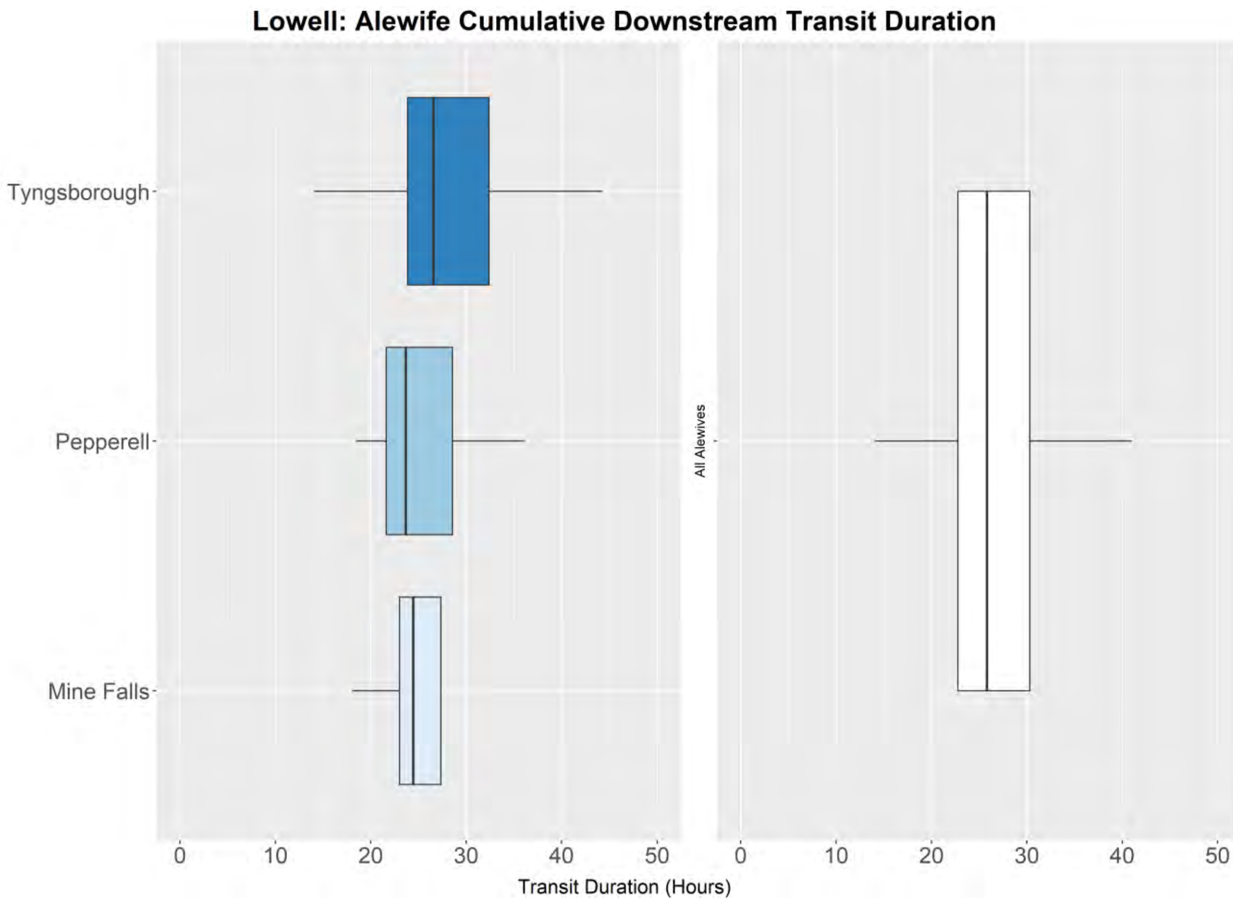

Figure 5–32. Boxplot of the downstream transit duration from Lowell to Lawrence for all radio-tagged alewives at Lowell (by release location) during the spring 2020 adult alosine passage assessment. [11]

[11] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

5.7 Downstream Passage Effectiveness – Adult American Shad

A total of 150 adult American shad were radio-tagged and released during early-June 2020 for the purposes of evaluating downstream passage at Lowell (Table 5-47). Tagging was conducted on a total of three dates (June 3, 5, and 8). The New Hampshire Fish and Game Department provided a tank truck to assist with moving radio-tagged shad from the Lawrence lift to the release location upstream of Lowell. Adult shad tagged for evaluation of downstream passage at Lowell were comprised of 37% female, 58% male and 5% undetermined. Total length of individuals tagged ranged from 385-556 mm (mean = 482 mm). A full listing of tagged individuals released upstream of Lowell during the spring of 2020 is provided in Appendix A.

5.7.1 Project Arrival and Upstream Residence Duration

Releases of radio-tagged adult American shad were initiated upstream of Lowell at the Tyngsborough Riverfront Park on June 3, 2020. Figure 5-33 presents the distribution of arrival dates for those individuals at the Pawtucket Dam as indicated by detection at Stations 05 and 06. Initial detections for radio-tagged shad were recorded over a range of dates from June 4 through June 27 with nearly 70% of those fish arriving on or before June 15, 2020. The duration of time from release until arrival at Lowell (i.e., the approach duration) ranged from 13.0 hours to 20.0 days (median = 6.8 days; Table 5-48).

The duration of time radio-tagged individuals were present upstream of the Pawtucket Dam was determined for all individuals which approached and eventually passed downstream and was calculated as the duration of time from their initial detection immediately upstream of the dam until confirmed downstream passage via one of the available routes. When all individuals are considered, the upstream residence duration prior to downstream passage ranged between 0.4 hours to 19.1 days (Table 5-49; Figure 5-34). The median duration of time spent immediately upstream of the dam structure for a radio-tagged adult shad was 3.9 days. Of the radio-tagged adult shad which approached Pawtucket Dam, 30% passed in fewer than 24 hours and 51% passed in fewer than 96 hours after initial detection.

Outmigrating adult alosines encountering the Pawtucket Dam can (1) pass through the Pawtucket Gatehouse and enter the power canal, (2) pass downstream over Pawtucket Dam via spill, or (3) enter the Pawtucket Canal and navigate downstream via the downtown canal system. During the 2020 evaluation there were no radio-tagged adult shad detected at the Guard Locks (Station 28) and determined to have utilized the downtown canal system. The majority of radio-tagged adult shad were determined to have passed through the Pawtucket Gatehouse and entered the Northern Canal to approach the E.L. Field powerhouse. The duration of time to pass through the Pawtucket Gatehouse was determined based on the initial detection for each individual adult at Stations 06 and 07 which independently monitored the upstream and downstream sides of that structure. The median duration of time for radio-tagged adult shad to initially encounter and then pass through the Pawtucket Gatehouse was 2.1 hours (range <0.1 hours to 5.9 days; Table 5-50). The majority (75%) of radio-tagged adult shad passing through the Pawtucket Gatehouse did so in 12 hours or less following their initial detection at the structure.

Radio-tagged adult shad which entered the Northern Canal and passed downstream of E.L. Field powerhouse did so relatively quickly. Of those individuals, 78% were resident in the power canal upstream of E.L. Field for 12 hours or less. The median residence duration in the Northern Canal was 4.4 hours (range = 0.5 hours to 3.0 days; Table 5-51). Five radio-tagged individuals were present in the Northern Canal for greater than 24 hours prior to downstream passage.

5.7.2 Downstream Passage

A total of 150 radio-tagged adult American shad were released upstream of Lowell during the spring of 2020. Of that total, 118 were determined to have approached the Pawtucket Dam and were available for the evaluation of downstream passage route (Table 5-52). Over half of the radio-tagged shad passed through the Pawtucket Gatehouse, approached the E.L. Field powerhouse, and passed downstream via the E.L. Field turbine units (26% of radio-tagged shad) or utilized the downstream bypass (28% of radio-tagged shad). Use of the bypassed reach (i.e., spill or usage of the attraction water gate associated with the upstream fish ladder) was observed for 38% of the radio-tagged adult shad which approached the Project. Of the 45 radio-tagged adult shad which were determined to have passed downstream via the bypassed reach, 89% were initially detected in the area immediately upstream of the Pawtucket Gatehouse prior to downstream passage. Of those same 45 individuals, 9% were determined to have entered and exited the Northern Canal via the Pawtucket Gatehouse prior to their eventual passage downstream via the bypassed reach.

Radio-tagged adult shad were observed passing downstream of Lowell between the dates of June 5 through June 27 (Figure 5-35). Downstream passage of radio-tagged adult shad at Lowell peaked during mid-June with over half of all passage events occurring between June 16 and June 20, 2020. Figure 5-36 presents the timing distribution of downstream passage events for radio-tagged adult shad at Lowell. The majority of individuals passed downstream during the late morning, afternoon and early evening hours (i.e., 1000-2000).

For each of the 109 individuals which were confirmed to have passed downstream of Lowell via a known passage route (i.e., turbine, downstream bypass, or spill) the hourly record of Project operations (Section 5.1) at the time of passage was reviewed. The discharge at the selected route was identified and contrasted with the cumulative discharge for all non-selected routes at the time of downstream passage (Table 5-53). A total of 28% of radio-tagged adult shad passing downstream at Lowell did so via the E.L. Field turbine units. The median discharge through the two E.L. Field turbine units at the time of passage for those individuals was 967 cfs. When examined by passage route, the median percentage of passage route flow at each known downstream passage route represented 46% of project flow for turbine passed shad, 6% of project flow for downstream bypass passed shad, and 33% of project flow for spill passed shad. A listing of route discharge at the time of downstream passage for each adult American shad is provided in Appendix D.

5.7.3 Downstream Transit

Three monitoring stations were installed downstream of Lowell for the purpose of detecting radio-tagged adult alosines following passage at the Project during the spring of 2020. Those receivers were located approximately 2.1 (Monitoring Station 25), 6.0 (Monitoring Station 26), and 10.75 (Monitoring Station 27) miles downstream of the project. The minimum, maximum, and quartile transit times through those three reaches are presented in Table 5-54. The median transit time durations for tagged adult shad moving downstream of Lowell were 6.4, 1.9, and 5.9 hours for the 2.1 mile, 3.9 mile and 4.75 mile downstream reaches, respectively. Table 5-55 provides the minimum, maximum, and quartile transit times through defined sections of the Merrimack River between Lowell and Lawrence as a rate (i.e., miles per hour (mph)).

Table 5-56 and Figure 5-37 present the minimum, maximum and quartile transit times for radio-tagged adult shad to cover the full reach from immediately downstream of Lowell to the upstream face of the Essex Dam in Lawrence (i.e., Station 27). The median travel time for those fish to approach Lawrence following downstream passage at Lowell was 18.5 hours (range = 6.9 hours to 5.6 days).

5.7.4 Passage Survival

The CJS model *Phi(t)p(t)* provided the best fit for the observed mark-recapture data associated with downstream movements of radio-tagged adult American shad approaching and passing at Lowell during 2020 (Table 5-57). The detection efficiency for telemetry receivers recording passage of adult shad for monitoring stations at and downstream of Lowell ranged from 0.987 to 0.859 (Table 5-58). The reach-specific survival estimates for the Merrimack River from the Lowell impoundment receiver to detection immediately upstream of Lawrence are presented in Table 5-59. Passage success for downstream passage of adult shad at Lowell was calculated as the joint probability of the three reach-specific survival estimates which encompasses the full section of the Merrimack River from Lowell downstream to Lawrence (i.e., Lowell to Station 25, Station 25 to Station 26, and Station 26 to Lawrence). This resulted in an estimated downstream passage survival for adult shad at Lowell of 70.0% (75% CI = 64.5%-74.6%). No adjustments were made to encounter histories for shad passing Lowell to reflect the duration of time to detection at Lawrence following downstream passage since there were no documented events for radio-tagged “drift” shad at the downstream receiver stations indicating that the magnitude of downstream travel for that species following dead release into the tailrace was negligible.

Radio-tagged adult shad which approached and passed downstream at Lowell during the 2020 evaluation did so via a variety or passage routes (Table 5-52). Sample sizes for adult shad passing downstream via the turbines, downstream bypass facility or spill through the bypassed reach were sufficient to generate an estimate of downstream passage survival via the CJS model approach. When examined by passage route downstream passage for adult American shad was estimated at:

- E.L. Field Turbines: adult American shad passage success = 35.5% (75% CI = 25.8%-45.2%);

- Downstream bypass facility: adult American shad passage success = 82.6% (75% CI = 75.7%-90.9%); and
- Spill: adult American shad passage success = 89.2% (75% CI = 82.6%-93.8%).

Table 5–47. Summary of tagging and release information for adult American shad released upstream of Lowell during the spring 2020 downstream passage assessment.

Date	Source	Type	Number
3-Jun	Lawrence	Radio	50
5-Jun	Lawrence	Radio	50
8-Jun	Amoskeag	Radio	50
Total		Radio	150

Table 5–48. Minimum, maximum, and quartile values of approach duration (hours) for radio-tagged American shad released upstream of Lowell during the spring 2020 adult alosine passage assessment.

American Shad - Approach Duration (hrs)					
Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
3-Jun	13.0	410.7	53.4	155.1	243.8
5-Jun	16.1	480.5	54.6	155.5	312.6
8-Jun	31.6	455.4	46.9	163.3	262.1
All	**13.0**	**480.5**	**53.4**	**163.3**	**266.6**

Table 5–49. Minimum, maximum, and quartile values of upstream residence duration (hours) for radio-tagged American shad released upstream of Lowell during the spring 2020 adult alosine passage assessment.

American Shad - Upstream Residence (hrs)					
Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
3-Jun	3.1	349.3	39.6	126.5	250.8
5-Jun	0.4	459.3	17.6	133.5	236.7
8-Jun	1.6	239.5	5.6	20.8	140.1
All	**0.4**	**459.3**	**14.6**	**92.8**	**213.2**

Table 5–50. Minimum, maximum, and quartile values of time to pass the Pawtucket Gatehouse and enter Northern Canal (hours) for radio-tagged American shad released upstream of Lowell during the spring 2020 adult alosine passage assessment.

American Shad - Pawtucket Gatehouse Passage (hrs)					
Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
3-Jun	<0.1	141.7	0.5	2.9	14.9
5-Jun	0.1	50.1	0.4	1.5	7.6
8-Jun	0.5	95.3	0.8	2.4	30.5
All	**<0.1**	**141.7**	**0.5**	**2.1**	**11.7**

Table 5–51. Minimum, maximum, and quartile values of Northern Canal residence duration (hours) for radio-tagged American shad released upstream of Lowell during the spring 2020 adult alosine passage assessment.

American Shad - Northern Canal Residence (hrs)					
Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
3-Jun	0.5	73.0	1.5	4.5	9.5
5-Jun	0.7	37.5	1.8	5.8	10.2
8-Jun	0.6	44.9	1.4	3.8	12.7
All	**0.5**	**73.0**	**1.7**	**4.4**	**10.6**

Table 5–52. Downstream passage route selection for radio-tagged American shad released upstream of Lowell during the spring 2020 adult alosine passage assessment.

Release Date	American Shad - Lowell Downstream Passage Route					
	No Detect	No Pass	Downtown	Turbine	Spill	Bypass
3-Jun	9	3	0	15	10	13
5-Jun	7	3	0	10	15	15
8-Jun	16	3	0	6	20	5
All	32	9	0	31	45	33
% of Total Detected		8%	0%	26%	38%	28%

Table 5–53. Quartile conditions of project discharge at the time of downstream passage for radio-tagged adult American shad at the known route of passage and the cumulative sum of discharge at non-passage routes.

Passage Route	No. Using Route	Quartile	Route Discharge		Non-Route Discharge	
			cfs	%	cfs	%
Turbines	31	Q25	418	27%	1104	49%
		Q50	967	46%	1154	54%
		Q75	1272	51%	1222	73%
Spill	45	Q25	500	29%	934	64%
		Q50	500	33%	1023	67%
		Q75	528	36%	1212	71%
Downstream Bypass	33	Q25	132	6%	1453	92%
		Q50	132	6%	1942	94%
		Q75	132	8%	1982	94%

Table 5–54. Minimum, maximum, and quartile values of travel time (hours) through three separate downstream reaches for radio-tagged American shad following downstream passage at Lowell during the spring 2020 adult alosine passage assessment.

American Shad - Downstream Transit Duration (hrs)						
Downstream Reach	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Downstream of Lowell to Station 37 (2.1 miles)	21-May	2.0	267.5	3.8	5.6	14.2
	22-May	1.5	71.2	4.6	6.3	20.1
	28-May	2.1	54.8	3.6	6.9	27.0
	All	**1.5**	**267.5**	**3.7**	**6.4**	**19.3**
Station 37 to Station 39 (3.9 miles)	21-May	1.3	9.1	1.5	1.8	2.6
	22-May	1.4	11.2	1.8	2.4	4.1
	28-May	1.3	28.9	1.5	1.7	2.0
	All	**1.3**	**28.9**	**1.6**	**1.9**	**3.0**
Station 39 to Lawrence (Station 40; 4.75 miles)	21-May	1.7	119.3	3.2	5.7	11.5
	22-May	1.7	41.2	2.9	5.7	9.4
	28-May	2.8	24.5	3.4	8.4	14.4
	All	**1.7**	**119.3**	**3.3**	**5.9**	**11.5**

Table 5–55. Minimum, maximum, and quartile values of rate of travel (mph) through three separate downstream reaches for radio-tagged American shad following downstream passage at Lowell during the spring 2020 adult alosine passage assessment.

American Shad - Downstream Transit Rate (mph)						
Downstream Reach	Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
Downstream of Lowell to Station 37 (2.1 miles)	21-May	0.20	1.38	0.69	1.00	1.20
	22-May	0.16	1.29	0.44	0.75	1.00
	28-May	0.06	1.38	0.90	1.06	1.20
	All	**0.06**	**1.38**	**0.60**	**0.95**	**1.13**
Station 37 to Station 39 (3.9 miles)	21-May	0.43	3.00	1.50	2.17	2.60
	22-May	0.35	2.79	0.95	1.63	2.17
	28-May	0.13	3.00	1.95	2.29	2.60
	All	**0.13**	**3.00**	**1.30**	**2.05**	**2.44**
Station 39 to Lawrence (Station 40; 4.75 miles)	21-May	0.04	2.79	0.41	0.83	1.49
	22-May	0.12	2.79	0.51	0.83	1.64
	28-May	0.19	1.70	0.33	0.57	1.40
	All	**0.04**	**2.79**	**0.41**	**0.81**	**1.46**

Table 5–56. Minimum, maximum, and quartile values for downstream travel duration from Lowell to Lawrence (hours) for radio-tagged American shad released upstream of Lowell during the spring 2020 adult alosine passage assessment.

American Shad - Downstream Travel: Lowell to Lawrence (hrs)					
Release Date	Minimum	Maximum	Q25	Q50 (Median)	Q75
3-Jun	7.5	135.1	11.9	16.8	27.4
5-Jun	9.1	55.6	11.1	18.9	33.7
8-Jun	6.9	53.8	10.5	19.4	37.7
All	**6.9**	**135.1**	**11.1**	**18.5**	**32.6**

Table 5–57. CJS model selection criteria for survival of American shad at Lowell during the spring 2020 adult alosine passage assessment.

Scenario	Model	AICc	Delta AICc	AICc Weight	Model Likelihood	No. Parameters	Deviance
All Shad	*Phi(t)p(t)*	700.94	0.00	0.99	1.00	13	36.10
	Phi(t)p(.)	710.68	9.74	0.01	0.01	8	56.15
	Phi(.)p(t)	733.58	32.64	0.00	0.00	8	79.06
	Phi(.)p(.)	740.85	39.91	0.00	0.00	2	98.51
Turbine Passed	*Phi(t)p(t)*	86.36	0.00	0.99	1.00	4	1.38
	Phi(t)p(.)	96.46	10.11	0.01	0.01	4	11.49
	Phi(.)p(t)	145.28	58.92	0.00	0.00	4	60.30
	Phi(.)p(.)	152.16	65.80	0.00	0.00	2	71.37
Bypass Passed	*Phi(t)p(t)*	95.27	0.00	0.96	1.00	6	0.42
	Phi(.)p(t)	102.54	7.27	0.03	0.03	4	11.90
	Phi(t)p(.)	104.57	9.30	0.01	0.01	5	11.84
	Phi(.)p(.)	109.90	14.63	0.00	0.00	2	23.40
Spill Passed	*Phi(t)p(t)*	202.02	0.00	0.97	1.00	8	13.90
	Phi(.)p(t)	210.16	8.14	0.02	0.02	7	24.16
	Phi(t)p(.)	210.16	8.14	0.02	0.02	4	30.42
	Phi(.)p(.)	218.28	16.26	0.00	0.00	2	42.64

Where *phi* = survival; *p* = detection probability; t = parameter is allowed to vary with time; and "." = parameter is fixed with time.

Table 5–58. Detection efficiency estimates (p) for monitoring locations installed to detect radio-tagged American shad at Lowell during the spring 2020 adult alosine passage assessment.

Location	S	SE	95% CI	
Station 04	0.966	0.017	0.914	0.987
Lowell	0.965	0.020	0.896	0.989
Station 25	0.987	0.013	0.916	0.998
Station 26	0.859	0.039	0.763	0.920
Station 27	0.897	0.037	0.799	0.950

Table 5–59. Reach-specific survival probability estimates (*phi)*, standard errors, and likelihood 75% and 95% confidence intervals for radio-tagged American shad at Lowell during the spring 2020 adult alosine passage assessment.

Scenario	Reach	*Phi*	SE	95% CI		75% CI	
All Shad	*Station 04 to Project*	0.951	0.02	0.894	0.978	0.923	0.97
	Project to Passage	0.948	0.023	0.881	0.979	0.915	0.969
	Passage to Station 25	0.753	0.041	0.663	0.825	0.702	0.797
	Station 25 to Station 26	0.931	0.028	0.851	0.969	0.89	0.957
	Station 26 to Lawrence	1.000	0.016	-	-	-	-
Turbine Shad	*Station 04 to Project*	1.000	0.000	-	-	-	-
	Project to Passage	1.000	0.000	-	-	-	-
	Passage to Station 25	0.452	0.089	0.289	0.626	0.352	0.555
	Station 25 to Station 26	0.786	0.110	0.506	0.929	0.634	0.886
	Station 26 to Lawrence	1.000	0.000	-	-	-	-
Bypass Shad	*Station 04 to Project*	1.000	0.000	-	-	-	-
	Project to Passage	1.000	0.000	-	-	-	-
	Passage to Station 25	0.879	0.057	0.718	0.954	0.797	0.930
	Station 25 to Station 26	0.967	0.034	0.785	0.996	0.896	0.990
	Station 26 to Lawrence	0.973	0.038	0.687	0.998	0.874	0.995
Spill Shad	*Station 04 to Project*	1.000	0.000	-	-	-	-
	Project to Passage	1.000	0.000	-	-	-	-
	Passage to Station 25	0.934	0.037	0.812	0.979	0.876	0.966
	Station 25 to Station 26	0.954	0.034	0.820	0.990	0.895	0.981
	Station 26 to Lawrence	1.000	0.000	-	-	-	-

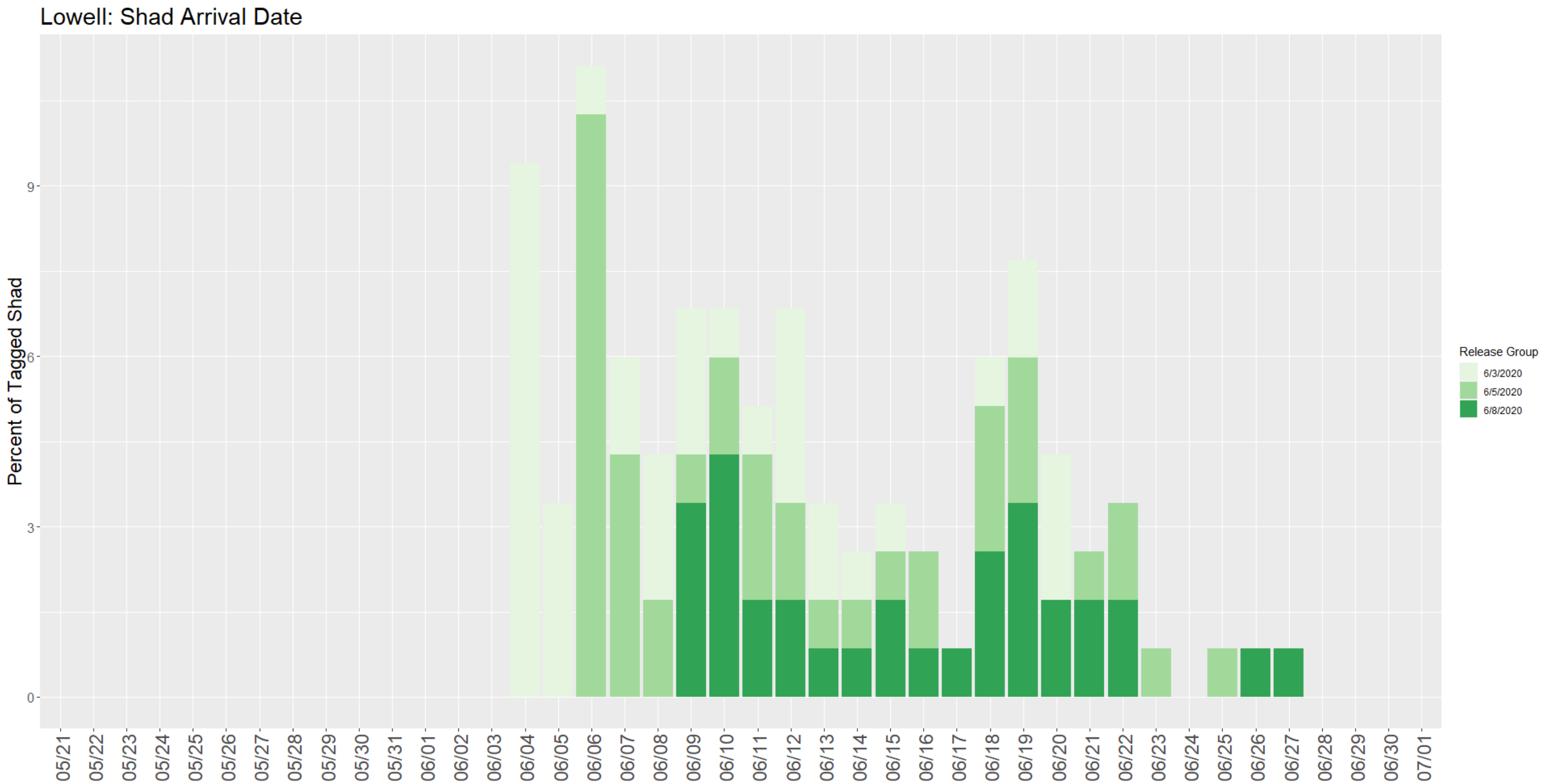

Figure 5–33. Distribution of Pawtucket Dam arrival dates for radio-tagged American shad at Lowell during the spring 2020 adult alosine passage assessment.

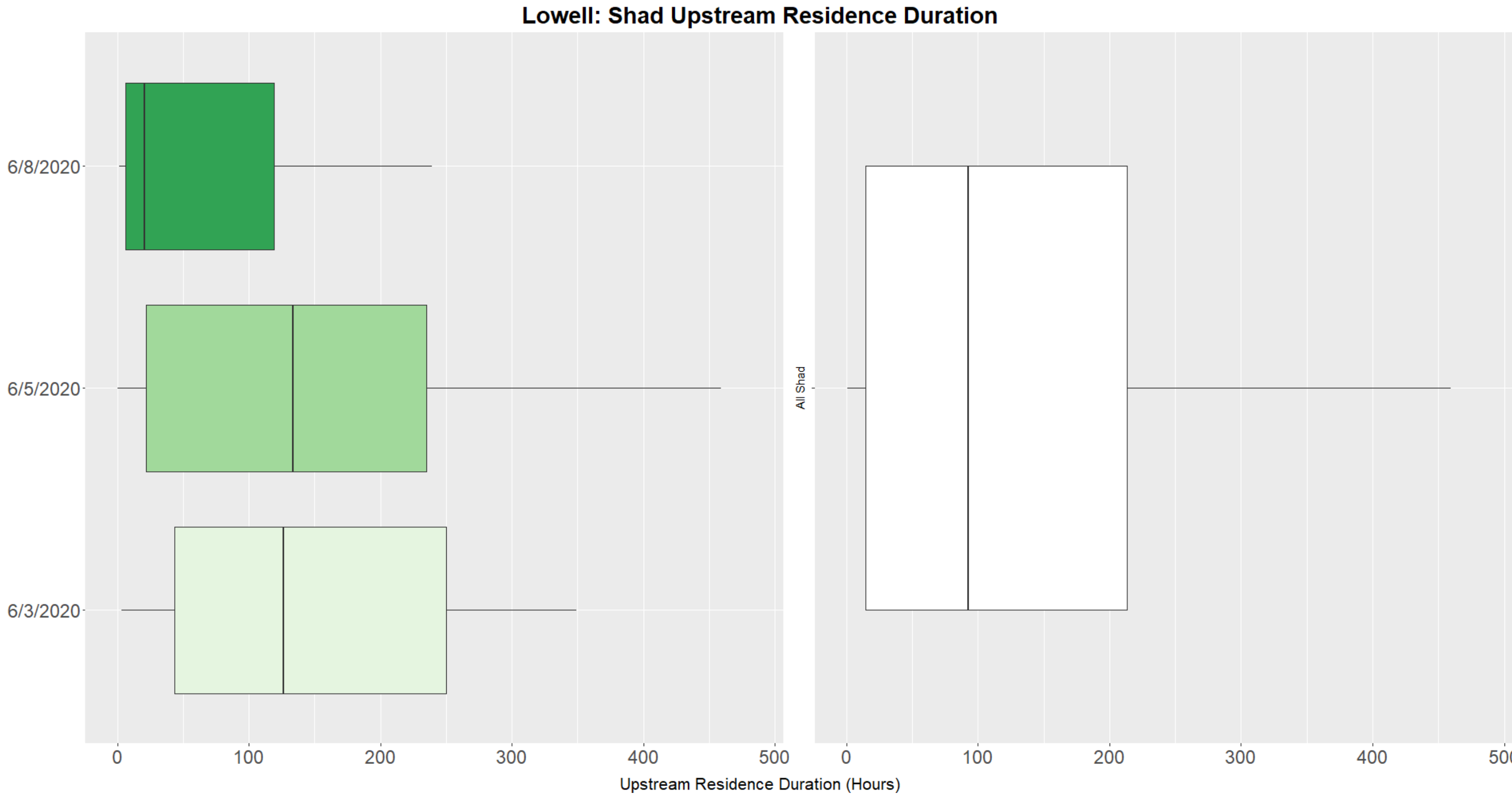

Figure 5–34. Boxplot of the Lowell upstream residence duration for radio-tagged American shad at Lowell during the spring 2020 adult alosine passage assessment. [12]

[12] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

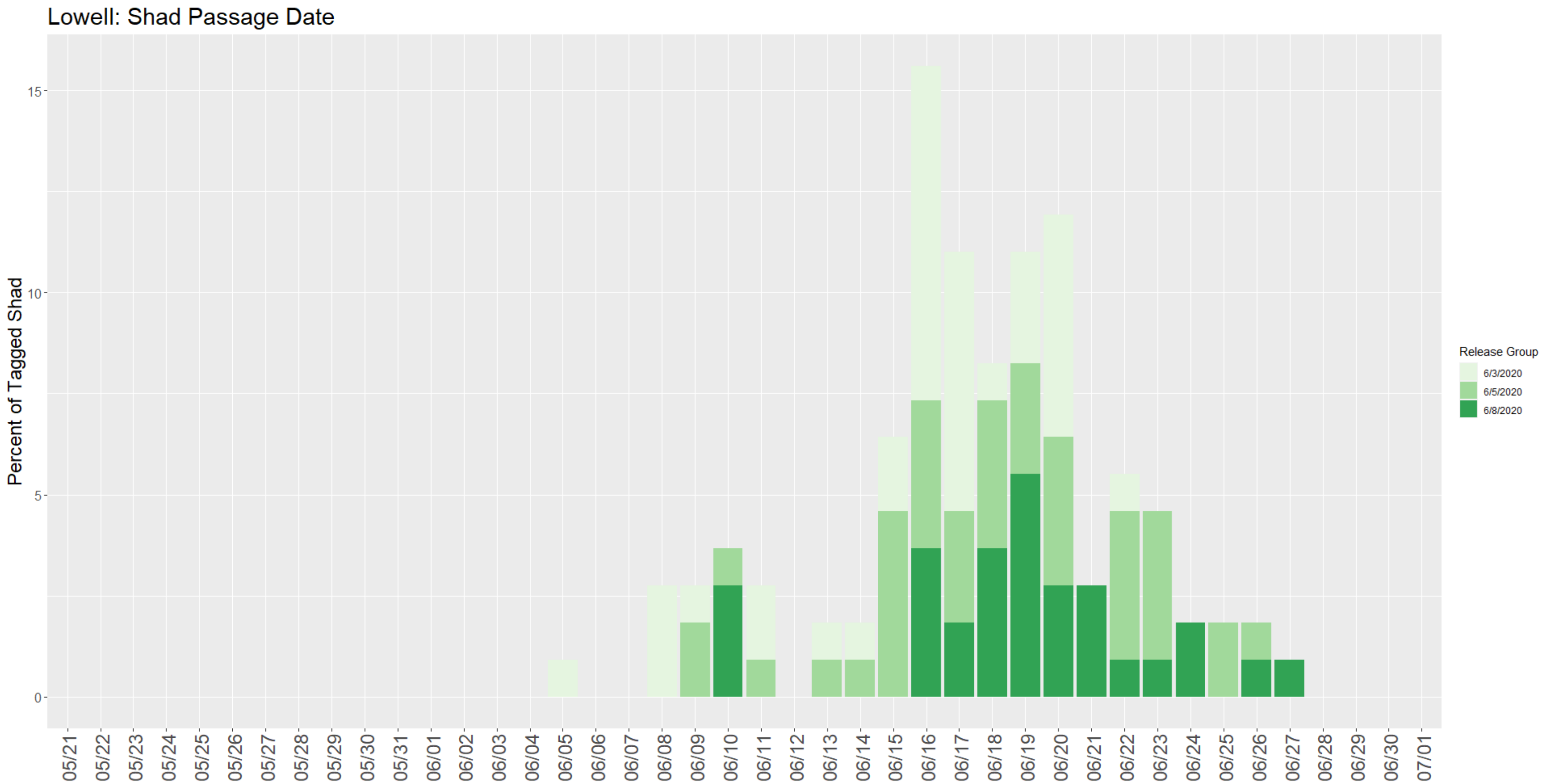

Figure 5–35. Distribution of Pawtucket Dam downstream passage dates for radio-tagged American shad at Lowell during the spring 2020 adult alosine passage assessment.

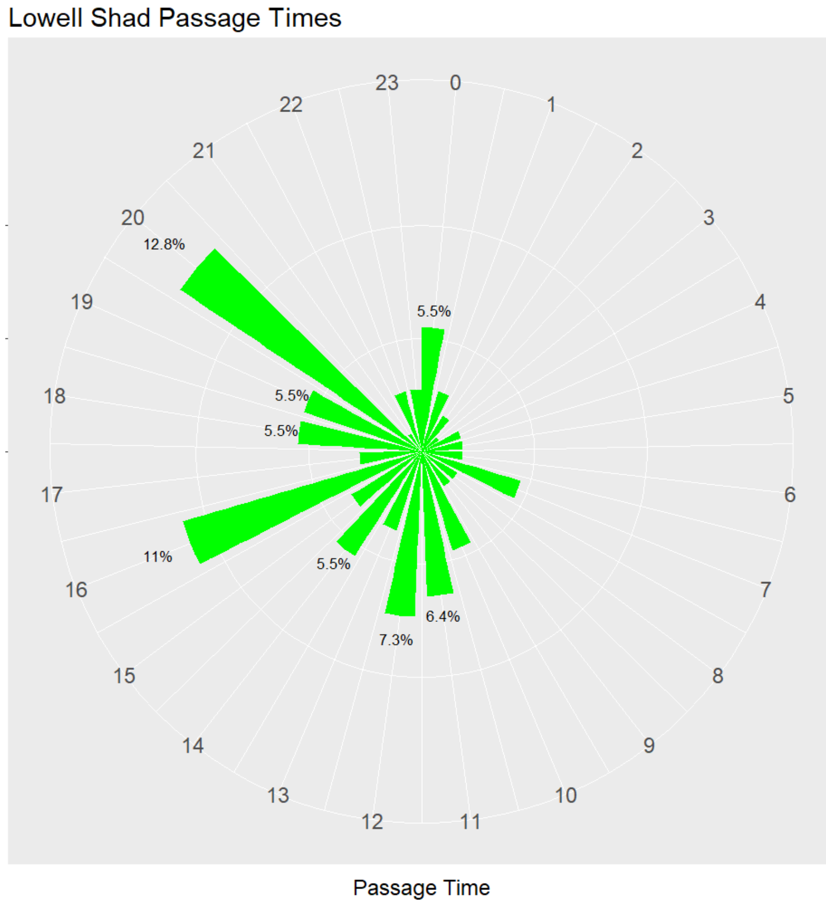

Figure 5–36. Distribution of downstream passage time for all radio-tagged American shad at Lowell during the spring 2020 adult alosine passage assessment.

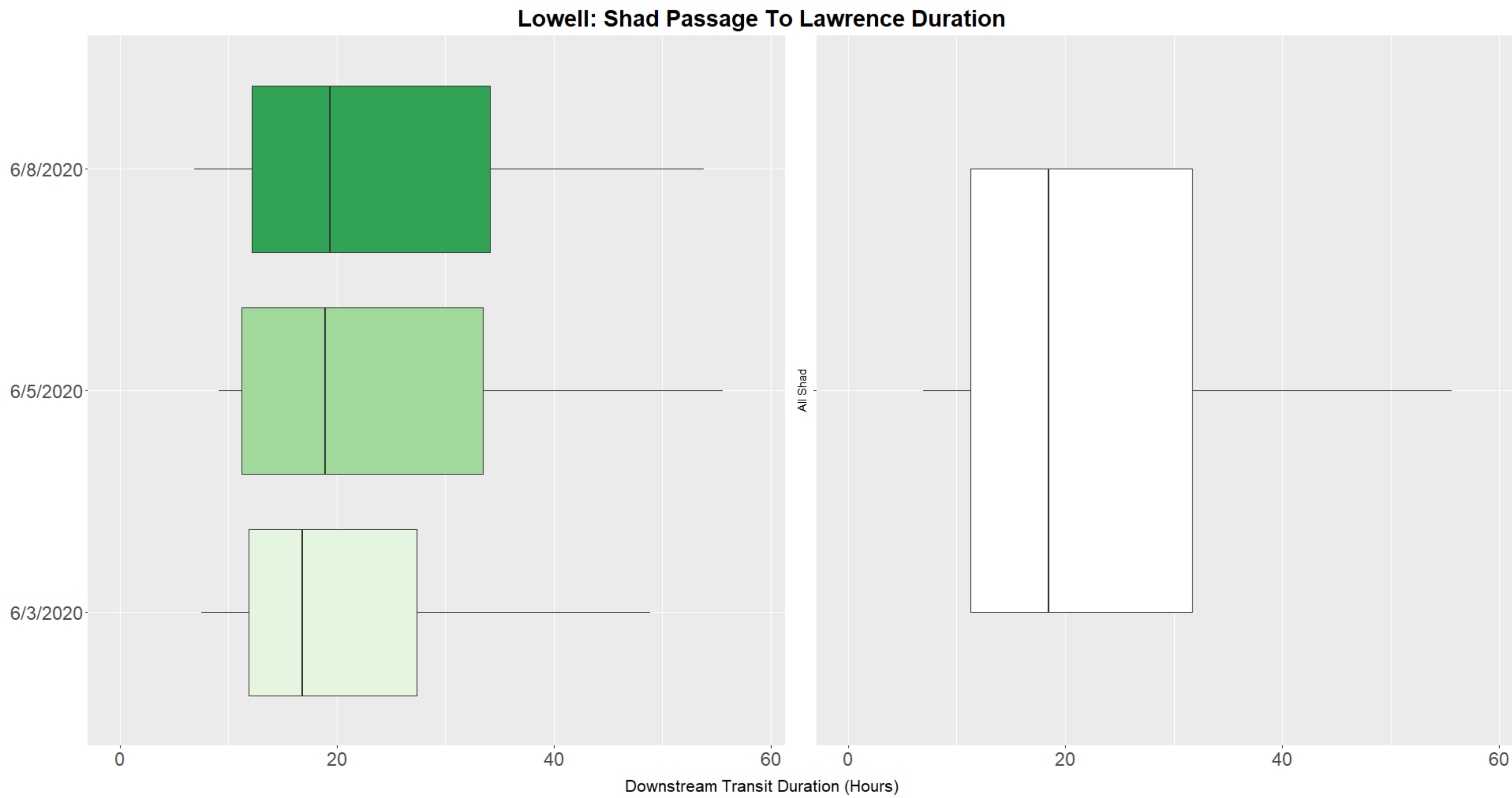

Figure 5–37. Boxplot of the downstream transit duration from Lowell to Lawrence for all radio-tagged American shad at Lowell during the spring 2020 adult alosine passage assessment.[13]

[13] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

5.8 Time to Event Analysis

5.8.1 Adult Alewives – Downstream

A total of 1,508 Pawtucket Gatehouse and 22,051 E.L. Field Powerhouse forebay events were defined based on recorded detections of radio-tagged adult alewives during the 2020 study to evaluate the impact of operational parameters on passage success. The median event duration recorded for a radio-tagged individual was 3.4 minutes for individuals in the detection field of Station 06 immediately upstream of the Pawtucket Gatehouse and 5.6 minutes for individuals in the detection field of Station 08 covering the area immediately upstream of the E.L. Field intake structure.

5.8.1.1 Pawtucket Gatehouse

Results of the adult alewife Cox proportional hazard model for the Pawtucket Gatehouse were found to be unreliable as all variables failed to obey the assumption that covariates are independent of time and that hazards are proportional (Table 5-60). In an effort to identify any existing correlations between passage success/failure or delay and the operational parameters available, a generalized additive model (GAM) with a Tweedie-distribution and generalized linear model (GLM) with a binomial distribution were built from the package '*mgcv*' in the Program R (R Core Team 2020). These model types permitted flexible parameterization of the error structure and offered an alternative method for exploring the relationships in question under a different suite of model assumptions.

GLMs were constructed as a means of understanding whether event success was correlated with inflow, spill, release location, or release date. The GLM model suggested a statistically significant positive correlation between downstream adult herring passage success and inflow with successful downstream passage events occurring most frequently when inflow is greater than 6000 cfs (Figure 5-38). Additionally, there was a statistically significant negative relationship between release location and downstream adult herring passage success indicating that individuals released in the Nashua River at the Mine Falls release site were less likely to pass downstream of Lowell successfully than either the Tyngsborough or Pepperell release groups (Figure 5-39).

GAMs were built in an attempt to understand which covariates exhibited a significant impact on the duration of each event (i.e. which covariates were responsible for causing delay in successful downstream passage for adult river herring at the Pawtucket Gatehouse). Release date, release location, inflow, bypass flow, and event type (i.e., pass or fail) were included in the GAM as a covariate to assess whether passage success or failure significantly impacted the duration of an event. Although results of this model agreed with that of the GLM, suggesting event duration was positively correlated with inflow and negatively correlated with passage success (i.e. successful passage reduced event duration) these results were considered weak as only 10.7% of the deviance in the data was explained by the model.

Table 5–60. Output of the Schoenfield residual test for time independence of covariates in Cox proportional hazard model for adult river herring Pawtucket Gatehouse downstream passage events.

Variable	Chi-squared	df	P-Value
Release Location	7.00	2	0.03
Release Date	36.32	2	0.07
Inflow (cfs)	47.98	5	<0.01
Spill (cfs)	2.41	1	<0.01
Full Model	85.47	10	<0.01

Note: $p < 0.05$ indicates a violation of the proportional hazard assumption.

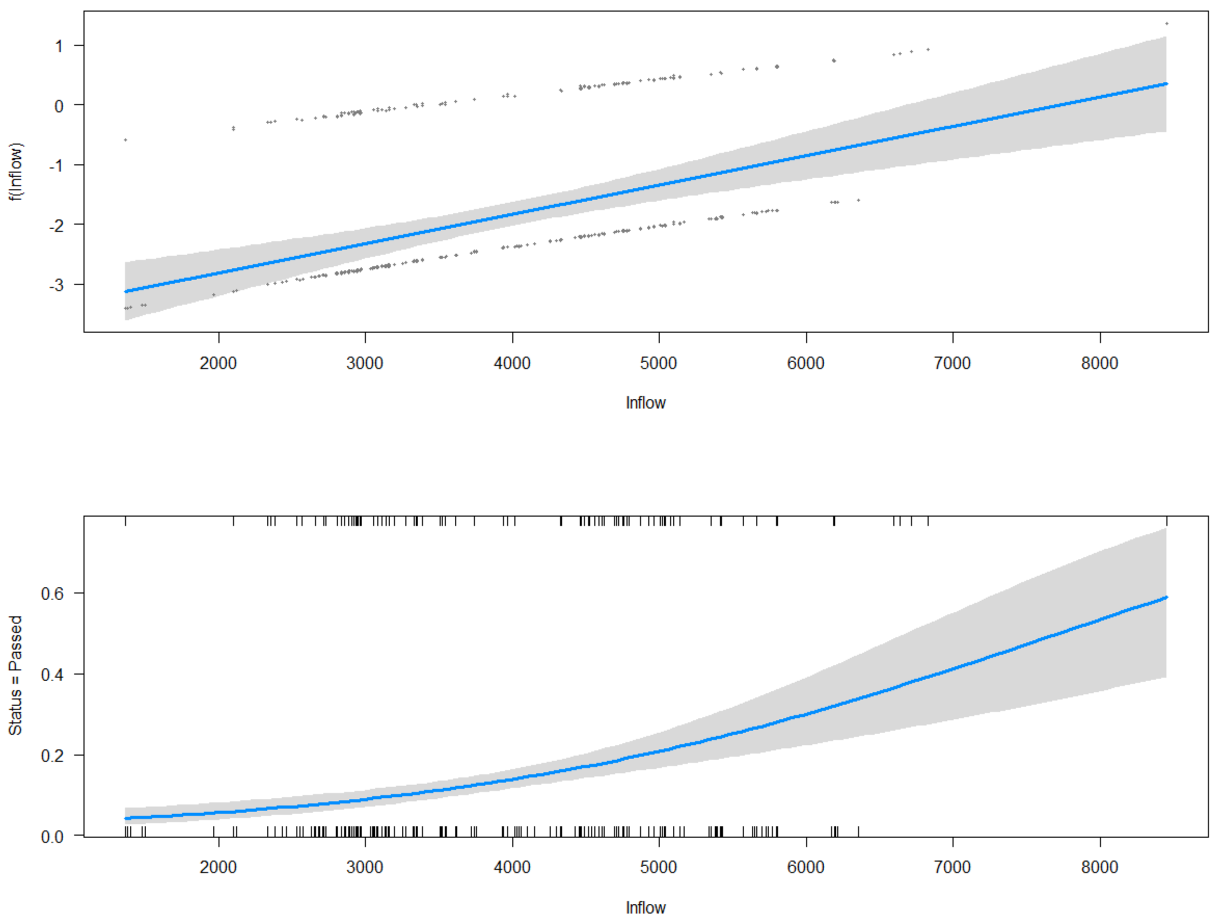

Figure 5–38. Results of the binomial GLM illustrating the relationship between inflow and the probability of passage success for adult river herring at the Pawtucket Gatehouse.

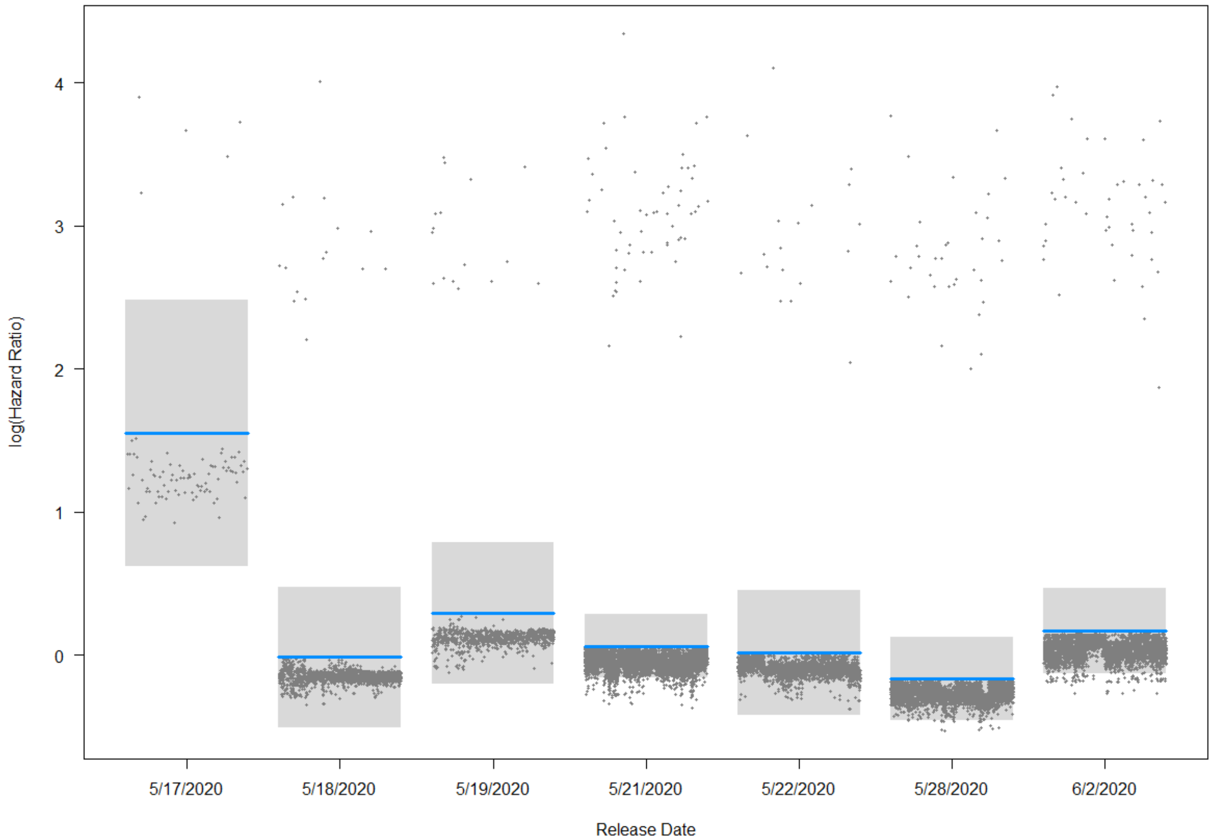

Figure 5–39. Results of the binomial GLM illustrating the relationship between release date and the probability of passage success for adult river herring at the Pawtucket Gatehouse.

5.8.1.2 E.L. Field Powerhouse Forebay

Similar to the results for the downstream adult river herring Pawtucket gatehouse model, release location and bypass flow failed to meet the assumptions of the Cox proportional hazard model for adult river herring downstream passage at the E.L. Field Powerhouse (Table 5-61). As a result, these covariates were excluded from consideration in the model. Inflow and release date were the only two covariates to pass the test of proportional hazards and were the only two covariates included in the model (Table 5-62). Results of the Cox proportional hazard model for downstream passage of adult river herring at the E.L. Field Powerhouse indicate a significant relationship between passage success and inflow, however this impact was marginal with inflow causing <1% decrease in the hazard ratio. Release date was significantly correlated with downstream adult river herring passage success at the E.L. Field Powerhouse, with an overall decrease in hazard ratio with later release dates (i.e., increased residence duration and lowered passage success during the latter part of the downstream migration window).

Table 5–61. Output of the Schoenfield residual test for time independence of covariates in Cox proportional hazard model for adult river herring E.L. Field Powerhouse downstream passage events.

Variable	Chi-squared	df	P-Value
Inflow (cfs)	0.87	1	0.35
Release Date	8.24	6	0.22
Full Model	8.27	7	0.31

Note: $p < 0.05$ indicates a violation of the proportional hazard assumption.

Table 5–62. Results of the Cox proportional hazards model for adult alewife downstream passage at the E.L. Field Powerhouse.

E.L. Field Powerhouse										
Model: Time to Event ~ Inflow + Release Date										
Model Parameter	*b*	se	z	P-value	Significance	e^b	e^{-b}	Lower .95	Upper .95	Percent Change
Inflow	<-0.01	0.00	-2.32	0.02	Significant	1.00	1.00	1.00	1.00	No Change
Release – May 18	<-0.01	0.52	-3.00	<0.01	Significant	0.21	4.77	0.08	0.58	↓ 79%
Release – May 19	<-0.01	0.53	-2.37	0.17	Significant	0.28	3.51	0.10	0.80	↓ 72%
Release – May 21	<-0.01	0.48	-3.10	<0.01	Significant	0.23	4.43	0.09	0.58	↓ 77%
Release – May 22	<-0.01	0.52	-2.96	<0.01	Significant	0.22	4.64	0.08	0.60	↓78
Release – May 28	<-0.01	0.50	-3.45	<0.01	Significant	0.18	5.55	0.07	0.48	↓ 82%
Release – June 2	<-0.01	0.51	-2.69	<0.01	Significant	0.25	3.98	0.09	0.69	↓ 75%

Significance is determined by $p < 0.05$.

5.8.2 Adult American Shad – Downstream

A total of 8,219 Pawtucket Gatehouse and 30,028 E.L. Field Powerhouse forebay events were defined based on recorded detections of radio-tagged adult American shad during the 2020 study to evaluate the impact of operational parameters on passage success. The median event duration recorded for a radio-tagged shad was 54.8 seconds for individuals in the detection field of Station 06 immediately upstream of the Pawtucket Gatehouse and 2.1 minutes for individuals in the detection field of Station 08 covering the area immediately upstream of the E.L. Field intake structure.

5.8.2.1 Pawtucket Gatehouse

Results of the Cox proportional hazard model for the Pawtucket Gatehouse showed no significant relationships between event durations and operational parameters (Table 5-63; Table 5-64). Only release date exhibited a statistically significant correlation, with tagged adult American shad released on June 8 exhibiting significantly higher hazard ratios than tagged adult American shad released on June 6. Inflow was not included in this model as it was not independent of time and failed to meet the criteria of the model assumptions.

5.8.2.2 E.L. Field Powerhouse Forebay

Results of the Cox proportional hazards model for the E.L. Field Powerhouse indicated statistically significant relationships between passage success and inflow, release date, and downstream bypass flow (Table 5-65). Inflow was determined to have a minor negative impact on downstream shad passage success at the E.L. Field Powerhouse, decreasing the likelihood of hazards occurring by approximately 1% as inflow increases (Table 5-66). On the contrary, release date and discharge through the downstream bypass exhibited positive correlations. The hazard probability for tagged adult American shad released on June 8 was higher than that for tagged adult American shad released on June 6. No variables were excluded from this model as they all met the time-independent assumptions of the Cox proportional hazards model.

Table 5–63. Output of the Schoenfield residual test for time independence of covariates in Cox proportional hazard model for adult American shad Pawtucket Gatehouse downstream passage events.

Variable	Chi-squared	df	P-Value
Release Date	2.06	2	0.36
Spill (cfs)	<0.01	1	0.97
Full Model	2.15	3	0.54

Note: $p < 0.05$ indicates a violation of the proportional hazard assumption.

Table 5–64. Results of the Cox proportional hazards model for adult American shad downstream passage at the Pawtucket Gatehouse.

Pawtucket Gatehouse										
Model: Time to Event ~ Release Date + Spill										
Model Parameter	*b*	se	z	P-value	Significance	e^b	e^{-b}	Lower .95	Upper .95	Percent Change
Release – June 5	0.03	1.03	0.25	0.11	Insignificant	1.03	0.97	0.63	1.67	↑ 3%
Release – June 8	0.64	1.90	0.26	2.49	Significant	1.90	0.53	1.15	3.15	↑ 90%
Spill (cfs)	<0.01	1.00	<0.01	0.96	Insignificant	1.00	1.00	1.00	1.00	No Change

Significance is determined by $p < 0.05$.

Table 5–65. Output of the Schoenfield residual test for time independence of covariates in Cox proportional hazard model for adult American shad E.L. Field Powerhouse downstream passage events.

Variable	Chi-squared	df	P-Value
Inflow (cfs)	0.01	1	0.93
Release Date	0.87	2	0.65
Bypass (cfs)	0.26	1	0.61
Full Model	1.25	4	0.87

Note: $p < 0.05$ indicates a violation of the proportional hazard assumption.

Table 5–66. Results of the Cox proportional hazards model for adult American shad downstream passage at the E.L. Field Powerhouse.

E.L. Field Powerhouse										
Model: Time to Event ~ Inflow + Release Date + Bypass Flow										
Model Parameter	*b*	se	z	P-value	Significance	e^b	e^{-b}	Lower .95	Upper .95	Percent Change
Inflow (cfs)	<0.01	1.00	<0.01	-3.78	Significant	1.00	1.00	1.00	1.00	No Change
Release – June 5	0.11	1.12	0.29	0.38	Insignificant	1.12	0.89	0.63	1.98	↑ 12%
Release – June 8	1.07	2.90	0.37	2.86	Significant	2.90	0.34	1.40	6.03	↑ 190%
Bypass (cfs)	0.03	1.03	0.01	5.08	Significant	1.03	0.97	1.02	1.04	↑ 3%

Significance is determined by $p < 0.05$.

5.8.3 Adult Alewives – Upstream

A total of 239 upstream foray events were defined based on recorded detections of adult alewives during the 2020 study to evaluate the impact of operational parameters on passage success. A description of the upstream magnitude and duration of those events is provided in Sections 5.4.3 for adult alewives.

Results of the Cox proportional hazard model were limited as the set of operations related parameters failed to meet the assumption they were independent of time and as a result were not included in the model (Table 5-67). The final adult alewife model assessed the hazards to passage success as a function of path selection (i.e., Pawtucket Dam fish ladder or the E.L. Field fish lift) and release date (Table 5-68). Results of the Cox proportional hazard model indicated a marginally significant relationship between path selection and hazard ratio in addition to a significant relationship between release date and hazard ratio. Based on these outputs, adult river herring utilizing the Pawtucket Dam fish ladder are less likely to experience passage failure than those using the E.L. Field fish lift. Foray attempts directed towards the E.L. Field fish lift increased the hazard (or probability of failure) by 62%. With regards to release date, adult alewives released during the beginning of the study were more likely to pass successfully than fish released during the latter part of the evaluation. No release date was found to negatively impact the hazard.

In an effort elucidate any existing correlations between passage success/failure or delay and the operational parameters available, a generalized additive model (GAM) with a Tweedie-distribution and generalized linear model (GLM) with a binomial distribution were built from the package '*mgcv*' in the Program R (R Core Team 2020). These model types allow for flexible parameterization of the error structure and offer an alternative method for exploring the relationships in question under a different suite of model assumptions.

GLMs were constructed as a means of understanding whether event success was correlated with turbine discharge, spill, release date, or path selection. Results of this model indicated a statistically significant negative correlation between passage successes and E.L. Field fish lift attempts with successful passage events occurring most frequently at the Pawtucket Dam fish ladder (Figure 5-40). This reaffirms the results of the Cox model, which suggests that adult alewives attempting to utilize the E.L. Field fish lift are more likely to incur a hazard (i.e., fail).

No statistically significant relationships were identified between upstream passage success and operational parameters (i.e., total bypass reach flow, spill flow, or inflow).

GAMs were built in an attempt to understand which covariates exhibited a significant impact on the duration of each event (i.e. which covariates are responsible for causing delay in upstream passage attempts for adult alewives). In addition to release date, turbine discharge, and route selection, event type (i.e., success/failure) was included in the GAM as a covariate to assess whether passage success or failure significantly impacted the duration of an event. Results of this model agreed with that of the GLM, suggesting event duration was negatively correlated with adult alewife attempts at the E.L. Field fish lift and positively correlated with passage success (i.e. adult alewives attempting to use the E.L. Field fish lift had longer event durations, but successful passage reduced event duration). In addition, results of the adult alewife GAM suggested that event durations are significantly and negatively correlated with increasing spill such that increasing spill decreases event durations. However, given that spill was not found to be a significant factor impacting passage success, it can be inferred that the shorter durations are the result of fish exiting the system during periods of high spill flow. This does not suggest that increasing spill will increase passage efficiency.

Table 5–67. Output of the Schoenfield residual test for time independence of covariates in Cox proportional hazard model for adult alewife upstream passage events.

Variable	Chi-squared	df	P-Value
Path	1.82	1	0.18
Release Date	2.53	5	0.77
Full Model	3.65	6	0.72

Note: $p < 0.05$ indicates a violation of the proportional hazard assumption.

Table 5–68. Results of the Cox proportional hazards model for adult alewife upstream passage.

Upstream Passage										
Model: Time to Event ~ Path + Release Date										
Model Parameter	*b*	se	z	P-value	Significance	e^b	e^{-b}	Lower .95	Upper .95	Percent Change
Path	0.49	1.63	1.76	0.08	Insignificant	1.63	0.61	0.95	2.80	↑ 63%
Release – May 8	-1.71	0.18	-2.83	<0.01	Significant	0.18	5.54	0.06	0.59	↓ 81%
Release – May 7	-1.48	0.23	-2.78	0.01	Significant	0.23	4.39	0.08	0.65	↓ 77%
Release – May 17	-0.33	0.72	-0.81	0.42	Insignificant	0.72	1.39	0.33	1.59	↓ 28%
Release – May 18	-1.25	0.29	-2.81	<0.01	Significant	0.29	3.48	0.12	0.69	↓ 31%
Release – May 19	-0.59	0.55	-1.37	0.17	Insignificant	0.55	1.81	0.24	1.29	↓ 45%

Significance is determined by $p < 0.05$.

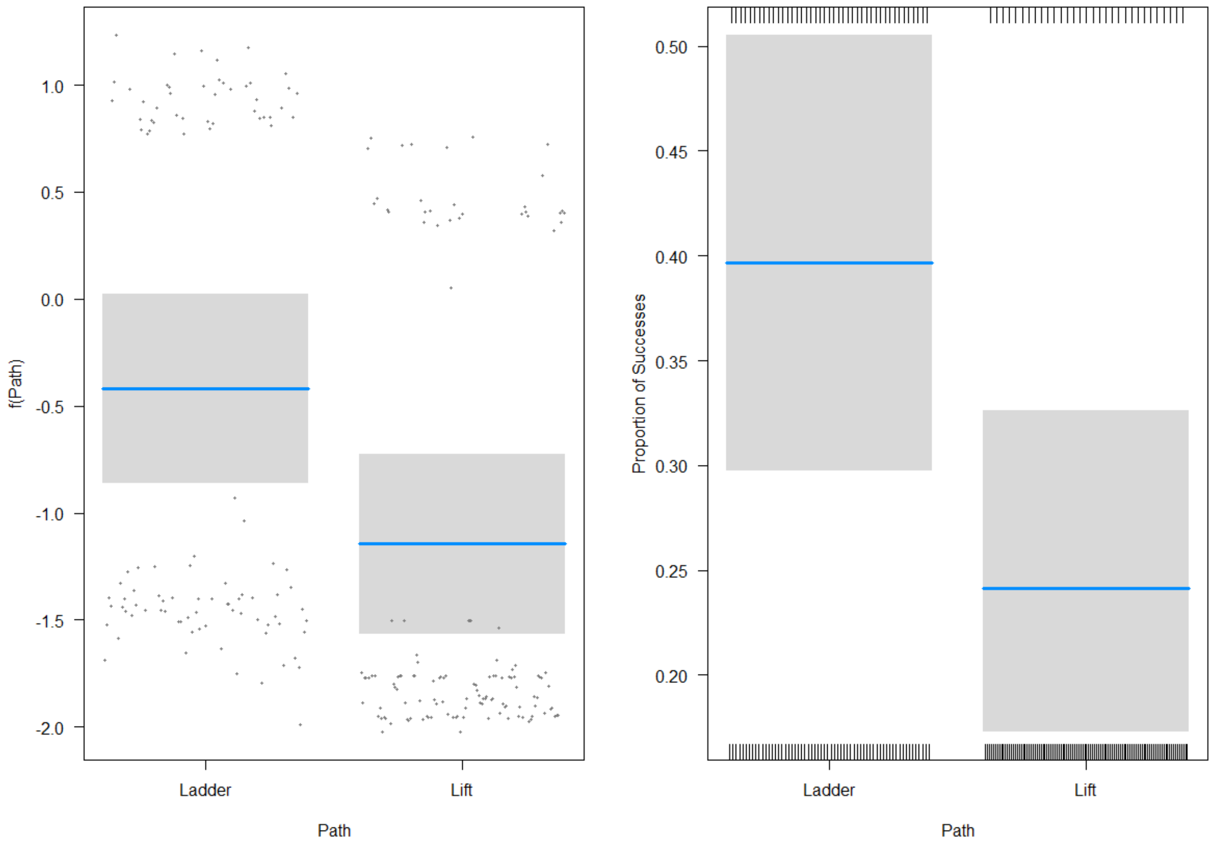

Figure 5–40. Results of the binomial GLM illustrating the relationship between passage route selection and the probability of passage success for adult river herring at the E.L. Field Powerhouse fish lift or Pawtucket Dam fish ladder.

5.8.4 Adult American Shad – Upstream

A total of 202 upstream foray events were defined based on recorded detections of American shad during the 2020 study to evaluate the impact of operational parameters on passage success. Of those 202 events, 201 were identified as forays directed towards the E.L. Field fish lift and 1 was identified as a foray directed towards the Pawtucket Dam fish ladder. A description of the upstream magnitude and duration of those events is provided in Sections 5.5.3 for adult American shad.

A meaningful Cox proportional hazard model was unable to be built to represent upstream passage for adult American shad at Lowell. The full set of variables failed to meet the assumption that they are independent of time (Table 5-69). In lieu of that, a GAM with a Tweedie-distribution and GLM with a binomial distribution were assembled to evaluate upstream passage for adult American shad at Lowell.

GLMs were constructed as a means of understanding whether turbine discharge, spill, or event duration had statistically significant impacts on the probability of passage success (i.e., event = 1). Results of this model indicate a statistically significant positive correlation between passage successes and event duration with most successful passage events occurring after 1 hour (4000 seconds; Figure 5-41). No statistically significant relationships were identified between passage success and operational parameters (i.e., i.e., total bypass reach flow, spill flow, or inflow). Due to the limited observations of dual-tagged adult shad ascending the bypassed reach in an attempt to reach the Pawtucket Dam fish ladder, path selection was not included in this model.

GAMs were built in an attempt to understand which covariates exhibited a significant impact on the duration of each event (i.e. which covariates are responsible for causing delay in upstream passage attempts). In addition to turbine discharge and spill flow, event type (i.e., success/failure) was included in the GAM as a covariate to assess whether passage success or failure significantly impacted the duration of an event. Results of this model suggested statistically significant correlations between several covariate and event duration. Covariates with the heaviest influence on event duration were passage success (event = 1) and turbine discharge. In both instances, event duration was positively correlated, suggesting that shad exhibiting a longer event duration are more likely to successfully pass and that event duration increases with turbine discharge. With regard to spill flow, results of this model suggest that event durations are significantly and negatively correlated with increasing spill such that increasing spill decreases event durations (Figure 5-42). However, given that spill was not found to be a significant factor impacting passage success, it can be inferred that the shorter durations are the result of fish exiting the system during periods of high spill flow. This does not suggest that increasing spill will increase passage efficiency.

Table 5–69. Output of the Schoenfield residual test for time independence of covariates in Cox proportional hazard model for adult American shad upstream passage events.

Variable	Chi-squared	df	P-Value
ELF (cfs)	4.75	1.00	0.03
Spill (cfs)	6.49	1.00	0.01
Full Model	6.49	2.00	0.04

Note: $p < 0.05$ indicates a violation of the proportional hazard assumption.

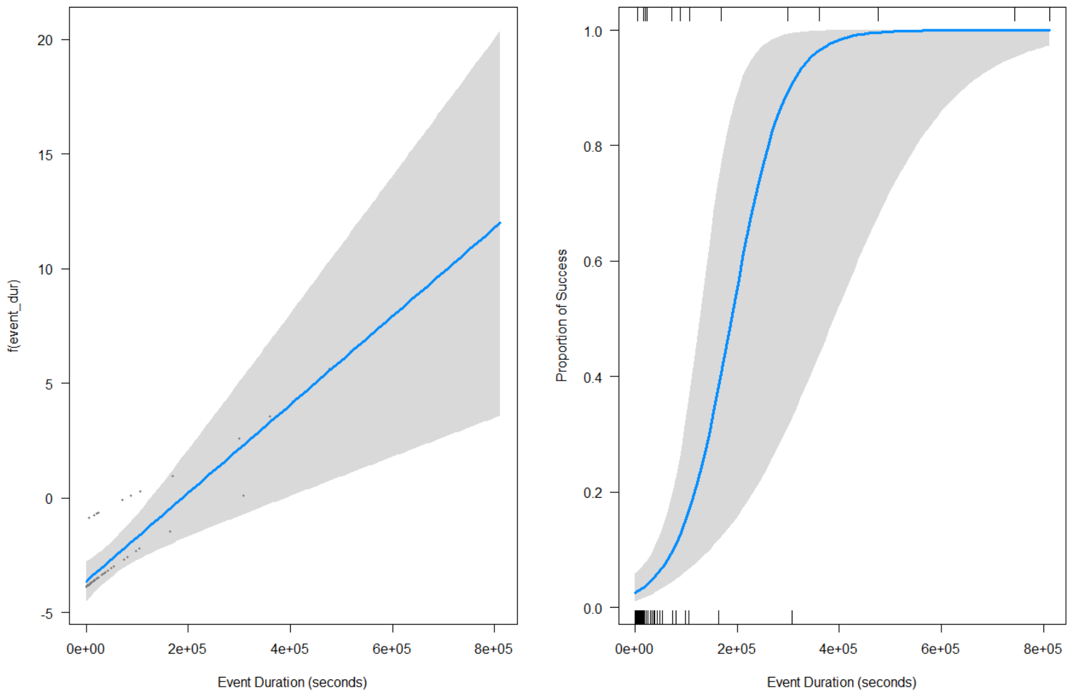

Figure 5–41. Results of the binomial GLM illustrating the relationship between event duration and the probability of passage success for adult American shad at the E.L. Field Powerhouse fish lift or Pawtucket Dam fish ladder.

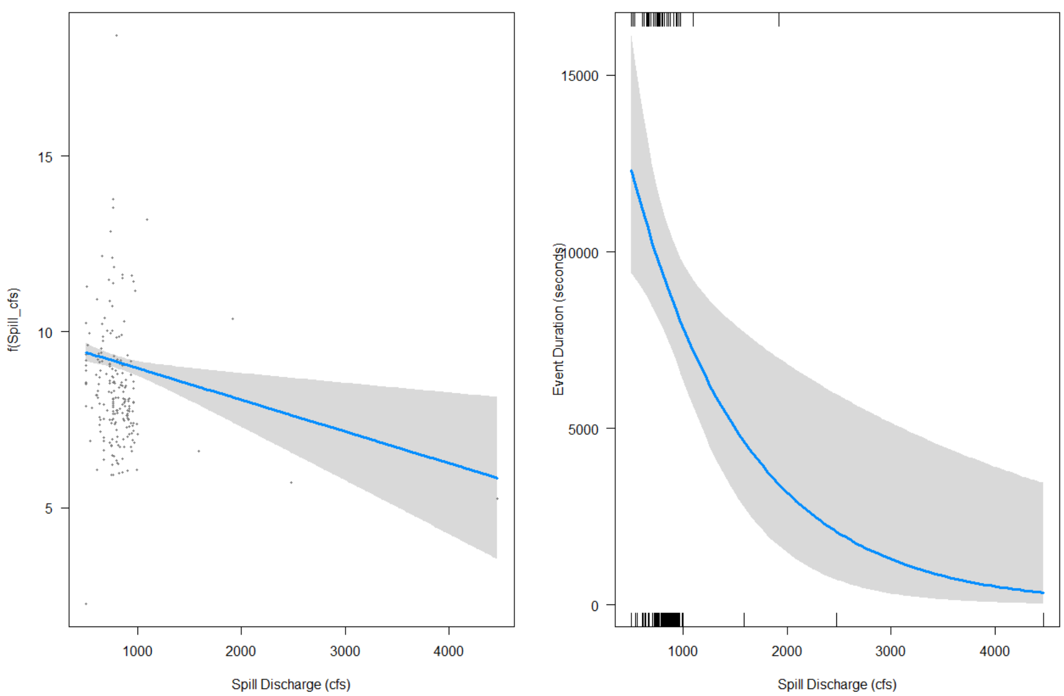

Figure 5–42. Results of the Tweedie GAM illustrating the relationship between event duration and spill discharge for adult American shad at Lowell.

5.9 Manual Tracking

In addition to the continuous monitoring provided by the set of stationary receivers installed throughout the Project area for the duration from early May through June 2020, a total of 99 manual detections representing 67 individuals (20 alewives and 47 American shad) were recorded between May 29 and July 2. Appendix E contains a listing of manual detections identified to the nearest 0.25 mile and classified as “Transit” for tagged fish which were subsequently detected at stationary receivers downstream of their manually determined position or “Final” for tagged alosines which were detected within the section of river bounded by the receiver station(s) at which their final stationary detection was recorded (e.g., manual detection of a fish immediately upstream of Essex Dam with stationary detections at Stations 26 and 27 would be classified as “Final” for that reach). Manual detections classified as “Transit” were predominantly recorded for individuals in the upper sections of the study area (i.e., upstream of Station 04 (17 observations) or between Stations 04 and 05 (9 observations)). Manual detections classified as “Final” were mostly recorded in the reach between Stations 26 and 27 which represented the bottom of the study reach at Essex Dam (44 observations). Manual detections were classified as “Final” for an additional 12 observations recorded upstream of Station 04 for individuals which failed to approach Pawtucket Dam.

6 Summary

An evaluation of the upstream and downstream passage effectiveness for adult alewives and American shad was conducted in support of the FERC relicensing of the Lowell Hydroelectric Project. Fish passage effectiveness was evaluated using telemetry during the 2020 spring passage season (May through June). Merrimack River conditions during the spring 2020 passage assessment were considered as normal or low for the majority of May and low for most of the month of June. The E.L. Field fish passage facilities (i.e., upstream fish lift and downstream fish bypass) were operated throughout the study period and those turbine units were in operation for the duration of the study period. Two major spill events, associated with increases in river flows, occurred during the early portion of the monitoring period (May 7 and May 18). Outside of those two periods of increased discharge, flows through the bypassed reach during the 2020 monitoring period were comprised of the ~500 cfs of water constituting the attraction and conveyance flow associated with the Pawtucket Dam fish ladder as well as incidental spill flow passing over the spillway. Incidental spill flows in excess of 500 cfs were present until May 21 after which incidental spill was reduced to near zero through the month of June. Flows to the downstream canal system were limited during both months as Boott suspended operation of the generating units in that system prior to the onset of the study due to overriding safety concerns.

6.1 Adult Alewife

A total of 504 adult alewives were radio and/or PIT-tagged over a range of dates from May 7 through June 2, 2020. Of that total, 354 (150 dual-tagged and 204 PIT-tagged) were tagged and released at the Lawrence Project (FERC No. 2800) fish lift facility and were evaluated for upstream passage at Lowell. The remaining 150 radio-tagged adult alewives were sourced from either the fish passage facility at Lawrence or the upstream fish ladder at Amoskeag Dam in

Manchester, NH (FERC No. 1893) and were released upstream of Lowell at the Tyngsborough Riverfront Park for the evaluation of downstream passage. An additional set of radio-tagged adult alewives released as part of a concurrent fish passage study on the Nashua River were also monitored for downstream passage at Lowell. Of the dual-tagged adult alewives released downstream of the Project, 85% were determined to have approached Lowell and were available to assess passage effectiveness of either E.L. Field powerhouse fish lift or the Pawtucket Dam fish ladder. Of the 150 radio-tagged adult alewives released upstream of Lowell, 83% approached the Pawtucket Dam and were available to evaluate downstream passage at the Project. The downstream passage analysis for adult alewives at Lowell was supplemented with information from an additional 93 individuals which approached Pawtucket Dam following release in the Nashua River.

Releases of dual-tagged alewives downstream of the Project occurred over six dates between May 7 and May 19, 2020 and individuals were observed approaching the Lowell Project as early as the initial date of release through May 23. The duration of time for fish to move upstream from the release location at Lawrence to Lowell was around one day for most dual-tagged adult alewives (median = 19.6 hours; 75th percentile = 28.6 hours). Following arrival downstream of the Project, 95% of dual-tagged adult alewives made at least one foray upstream towards either the fish lift or ladder. When examined by structure 64% of dual-tagged alewives made at least one foray in the direction of the fish lift, 67% in the direction of the fish ladder, and 39% in the direction of the fish lift and fish ladder.

The 82 dual-tagged adult alewives determined to have approached the E.L. Field fish lift produced a combined total of 134 unique foray events. Approximately 66% of the set of upstream foray events towards the E.L. Field fish lift resulted in detection of the dual-tagged alewife at the lift entrance and the median duration of time to locate the fish lift entrance was 0.7 hours. Fish lift entrances were recorded over a range of dates from May 8 through May 30 and peaked during mid-May. Upstream effectiveness of the E.L. Field fish lift was assessed using a CJS model and for an individual adult alewife which entered the tailrace channel estimated the probability of locating the entrance (i.e., the nearfield attraction) at 83.3%. The overall effectiveness of the E.L. Field fish lift for adult alewife passage during 2020 was estimated at 43.9% (75% CI = 39.3-51.4%). Following upstream passage at the lift, dual-tagged adult alewives proceed quickly upstream to the downstream face of the Pawtucket Gatehouse (median duration = 0.7 hours). The median duration of time for dual-tagged adult alewives to pass the Pawtucket Gatehouse was 25.7 hours.

A total of 86 adult alewives made at least one foray in the direction of the Pawtucket Dam fish ladder during their time at large in the Project area. Of the 105 total forays towards the fish ladder, 51% resulted in at least one detection at the ladder entrance and the median duration of time to locate the entrance once an individual had arrived at the upper end of the bypassed reach was 4.0 hours. Fish lift entrances were recorded for dual-tagged adult alewives over a range of dates from May 7 through May 23 and peaked during mid-May. Additional observations of PIT-tag only adult alewife entrances into the fish ladder occurred over a comparable range of dates (May 9 to May 27). Upstream effectiveness of the Pawtucket Dam fish ladder was assessed using a CJS model and for an individual adult alewife which ascended to the upper end of the bypassed reach the probability of locating the entrance (i.e., the nearfield attraction) was 93.0%. The overall effectiveness of the Pawtucket Dam fish ladder for adult alewife passage during 2020 was estimated at 75.6% (75% CI = 69.2-82.2%). The median duration of time from initial detection at the fish ladder entrance until exit at the top of the structure for dual-tagged adult alewives was 2.9 hours (lower leg median duration = 2.1 hours; upper leg median duration = 1.1 hours). Supplemental data collected for the PIT-tag only adult alewives which entered the Pawtucket Dam fish ladder corresponded with observations for the dual-tagged fish (median ladder passage duration = 3.8 hours; lower leg passage = 1.6 hours; upper leg passage = 1.2 hours).

Outmigration of radio-tagged adult alewives was observed over a range of dates from May 21 to June 17 with a peak number of events occurring between June 3 and 6. The median upstream residence time prior to downstream passage was 1.8 days with 78% of those individuals passing downstream within 96 hours of arrival. The majority of individuals passed downstream of Lowell via the E.L. Field turbine units (47% of radio-tagged alewives) or utilized the downstream bypass (45% of radio-tagged alewives). Downstream passage survival was calculated as the joint probability of the three reach-specific survival estimates which encompasses the full section of the Merrimack River from Lowell downstream to Lawrence and resulted in an estimated downstream passage survival for adult alewives at Lowell of 80.1% (75% CI = 76.7%-83.6%). This estimate of downstream passage survival for adult alewives at Lowell includes background mortality (i.e., natural mortality) for the species in the downstream reach, along with any tagging-related mortalities or tag regurgitations. As a result, this estimate should be viewed as a minimum estimate of total project survival (i.e., due solely to project effects) for adult alewives at the Project. Downstream passage survival for adult alewives utilizing the E.L. Field turbine units and downstream bypass facility was 73.9% (75% CI = 68.8%-79.1%) and 87.8% (75% CI = 81.8%-91.5%), respectively.

6.2 Adult American Shad

A total of 534 adult American shad were radio and/or PIT-tagged over a range of dates from May 16 through June 8, 2020. Of that total, 384 (180 dual-tagged and 204 PIT-tagged) were tagged and released at the Lawrence fish lift facility and were evaluated for upstream passage at Lowell. The remaining 150 radio-tagged adult American shad were collected from the fish passage facility at Lawrence and were released upstream of Lowell at the Tyngsborough Riverfront Park for the evaluation of downstream passage. Of the dual-tagged adult American shad released downstream of the Project, 40% were determined to have approached Lowell and were available to assess passage effectiveness of either E.L. Field powerhouse fish lift or the Pawtucket Dam fish ladder. An additional 47% of the dual-tagged shad exhibited upstream movement following tagging and release at Lawrence but did not move the full length of the Merrimack River reach between the two Projects. Of the 150 radio-tagged adult shad released upstream of Lowell, 79% approached the Pawtucket Dam and were available to evaluate downstream passage at the Project.

Releases of dual-tagged American shad downstream of the Project occurred over five dates between May 16 and May 27, 2020 and individuals were observed approaching the Lowell Project between May 17 and June 6. The median duration of time for shad to move upstream from the release location at Lawrence to Lowell was 64.5 hours (2.7 days). Following arrival downstream of the Project, 63% of dual-tagged adult American shad made at least one foray upstream towards either the fish lift or ladder. The vast majority those shad made one or more forays in the direction of the fish lift. Only a single dual-tagged shad was determined to have initiated an upstream ascent into the bypassed reach and in the direction of the fish ladder.

The 43 dual-tagged adult American shad determined to have approached the E.L. Field fish lift produced a combined total of 201 unique foray events. Approximately 37% of the set of upstream foray events towards the E.L. Field fish lift resulted in detection of the dual-tagged shad at the lift entrance and the median duration of time to locate the fish lift entrance was 1.1 hours. Fish lift entrances were recorded over a range of dates from May 18 through June 15 and peaked during late-May. Upstream effectiveness of the E.L. Field fish lift was assessed using a CJS model and for an individual adult shad which entered the tailrace channel estimated the probability of locating the entrance (i.e., the nearfield attraction) at 67.4%. The overall effectiveness of the E.L. Field fish lift for adult American shad passage during 2020 was estimated at 30.4% (75% CI = 22.1-39.5%). Following upstream passage at the lift, dual-tagged adult shad proceed quickly upstream to the downstream face of the Pawtucket Gatehouse (median duration = 0.8 hours). The median duration of time for dual-tagged adult shad to pass the Pawtucket Gatehouse was 5.4 days.

Upstream movement of dual-tagged shad within the Lowell bypassed reach was limited to a single individual which was detected only at the lowermost receiver within that reach. There were no detections of any dual-tagged adult American shad at the Pawtucket Dam fish ladder during the 2020 study. Similarly, detections of PIT-tagged adult shad were also very limited during the 2020 study period. Of the 204 PIT-tagged adult shad released at Lawrence during the onset of the study only two individuals were determined to have entered the fish ladder.

Outmigration of radio-tagged adult American shad was observed over a range of dates from June 4 to June 27 with a peak number of events occurring on or before June 15. The median upstream residence time prior to downstream passage was 3.9 days with 51% of individuals passing downstream in less than 96 hours after their arrival. The majority of individuals passed downstream of Lowell via the E.L. Field turbine units (26%), the downstream bypass (28%) or utilized the bypassed reach (38% of radio-tagged shad). Downstream passage survival was calculated as the joint probability of the three reach-specific survival estimates which encompasses the full section of the Merrimack River from Lowell downstream to Lawrence and resulted in an estimated downstream passage survival for adult shad at Lowell of 70.0% (75% CI = 64.5%-74.6%). This estimate of downstream passage survival for adult shad at Lowell includes background mortality (i.e., natural mortality) for the species in the downstream reach, along with any tagging-related mortalities or tag regurgitations. As a result, this estimate should be viewed as a minimum estimate of total project survival (i.e., due solely to project effects) for adult American shad at the Project. Downstream passage survival for adult American shad utilizing the E.L. Field turbine units, downstream bypass facility or spill was 35.5% (75% CI = 25.8%-45.2%), 82.6% (75% CI = 75.7%-90.9%), and 89.2% (75% CI = 82.6%-93.8%), respectively.

7 Variances from FERC-Approved Study Plan

The timing of this field study (April – June 2020) coincided with the rapid onset of the COVID-19 pandemic throughout the United States and during the course of this evaluation both the States of New Hampshire and Massachusetts were operating under a “stay-at-home” order. Every effort was made to conduct this evaluation as described in the FERC-approved RSP while still maintaining the health and safety of all Normandeau project staff and Boott operations staff.

Variances from the RSP included:

- Monitoring Station M20 was described in the RSP as a PIT-reader to be installed at the hopper discharge of the E.L. Field fish lift. Range testing conducted following installation of this antenna indicated significant background interference at that location reducing the read range of the antenna to near zero. As a result that unit was moved further upstream to allow for a pair of readers to provide coverage of the fish lift exit flume.

- Monitoring Stations C3 and C7 were described in the RSP as PIT-readers. Following initial site reconnaissance it was determined by Normandeau field staff that the intended detection area was not suitable for a PIT antenna. As a result those two locations were instead monitored using a Sigma-Eight Orion radio telemetry receiver. This change in equipment was noted during the March 2020 ISR meeting held in Lowell, MA.

- As Boott was not operating the downtown canal units due to safety concerns, the 100 radio-tagged adult alewife and shad (50 each) proposed in the RSP for release into the downtown canal system to assess outmigration through those facilities were instead placed in the river upstream of Lowell to increase the sample size for the downstream passage assessment. Boott consulted with both USFWS and NHFGD prior to making this modification.

- Due to uncertainty in returns of adult river herring at Lawrence towards the tail end of the monitoring period, Boott relied on the use of 70 adult alewives collected at the Amoskeag trap and truck facility in Manchester, NH. These individuals were radio-tagged and the released into the river upstream of Lowell to evaluate downstream passage of that species. Boott consulted with both USFWS and NHFGD prior to making this modification.

- In their SPD and based on resource agency comments, FERC recommended placement of an additional stationary receiver along the eastern wall of the E.L. Field tailrace. Boott and Normandeau staff evaluated the eastern tailrace wall during the site installation process and access to that reach was deemed unsafe. The study proceeded with a single tailrace receiver which operated without issue for the duration of the study period.

- In their SPD, FERC recommended fish be released at a point further upstream to reduce the potential for fallback downstream of Lawrence immediately following tagging and release. Adult alosines collected for upstream passage from the Lawrence fish lift were released directly into the exit flume of that facility following tagging. This change was made due to the lack of early season tank truck assistance to move American shad upstream as well as the closure of the public boat access upstream of Lawrence by the City due to the ongoing COVID situation.

- The evaluation of the E.L. Field fish lift as part of the spring 2020 adult alosine passage evaluation was conducted under the same tailrace channel geometry as previous evaluations. As discussed during consultation with the resource agencies prior to the 2020 study, Boott could not guarantee that the planned tailrace ledge modifications could be completed in time to avoid interference with fish lift operations and this study.

8 References

Castro-Santos, T. and R. Perry. 2012. Time-to-event analysis as a framework for quantifying fish passage performance. Pages 427-452 *in* N.S. Adams, J.W. Beeman, and J.H. Eiler, editors. Telemetry techniques: a user guide for fisheries research. American Fisheries Society, Bethesda, Maryland.

R Core Team. 2020. R: A Language and Environment for Statistical Computing. Vienna, Austria.

White, G.C., and K.P. Burnham. 1999 Program MARK: Survival estimation from populations of marked animals. Bird Study 46: 120-139.

9 Appendices

Appendix A. Tagging and release information for adult alosines for the spring 2020 passage assessment at Lowell.

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	F	295	5/7/2020	Dual	149.440	10	900_230000237305	Lawrence	US
Alewife	M	310	5/7/2020	Dual	149.440	11	900_230000237304	Lawrence	US
Alewife	F	298	5/7/2020	Dual	149.440	12	900_230000237303	Lawrence	US
Alewife	F	319	5/7/2020	Dual	149.440	13	900_230000237302	Lawrence	US
Alewife	F	296	5/7/2020	Dual	149.440	14	900_230000237301	Lawrence	US
Alewife	F	315	5/7/2020	Dual	149.460	40	900_230000237310	Lawrence	US
Alewife	M	292	5/7/2020	Dual	149.460	41	900_230000237309	Lawrence	US
Alewife	M	298	5/7/2020	Dual	149.460	42	900_230000237308	Lawrence	US
Alewife	M	305	5/7/2020	Dual	149.460	43	900_230000237307	Lawrence	US
Alewife	F	314	5/7/2020	Dual	149.460	44	900_230000237306	Lawrence	US
Alewife	M	303	5/7/2020	Dual	149.480	70	900_230000237315	Lawrence	US
Alewife	M	280	5/7/2020	Dual	149.480	71	900_230000237314	Lawrence	US
Alewife	F	311	5/7/2020	Dual	149.480	72	900_230000237313	Lawrence	US
Alewife	M	297	5/7/2020	Dual	149.480	73	900_230000237312	Lawrence	US
Alewife	F	304	5/7/2020	Dual	149.480	74	900_230000237311	Lawrence	US
Alewife	F	319	5/7/2020	Dual	149.760	100	900_230000237320	Lawrence	US
Alewife	F	314	5/7/2020	Dual	149.760	101	900_230000237319	Lawrence	US
Alewife	F	315	5/7/2020	Dual	149.760	102	900_230000237318	Lawrence	US
Alewife	M	305	5/7/2020	Dual	149.760	103	900_230000237317	Lawrence	US
Alewife	F	305	5/7/2020	Dual	149.760	104	900_230000237316	Lawrence	US
Alewife	M	295	5/7/2020	Dual	149.800	130	900_230000237325	Lawrence	US
Alewife	F	330	5/7/2020	Dual	149.800	131	900_230000237324	Lawrence	US
Alewife	M	310	5/7/2020	Dual	149.800	132	900_230000237323	Lawrence	US
Alewife	F	294	5/7/2020	Dual	149.800	133	900_230000237322	Lawrence	US
Alewife	F	295	5/7/2020	Dual	149.800	134	900_230000237321	Lawrence	US
Alewife	F	285	5/7/2020	PIT	-	-	900_230000237328	Lawrence	US
Alewife	M	285	5/7/2020	PIT	-	-	900_230000237356	Lawrence	US
Alewife	M	288	5/7/2020	PIT	-	-	900_230000237348	Lawrence	US
Alewife	M	290	5/7/2020	PIT	-	-	900_230000237329	Lawrence	US
Alewife	F	290	5/7/2020	PIT	-	-	900_230000237330	Lawrence	US
Alewife	M	290	5/7/2020	PIT	-	-	900_230000237331	Lawrence	US
Alewife	M	292	5/7/2020	PIT	-	-	900_230000237341	Lawrence	US
Alewife	M	295	5/7/2020	PIT	-	-	900_230000237353	Lawrence	US
Alewife	M	295	5/7/2020	PIT	-	-	900_230000237359	Lawrence	US
Alewife	M	296	5/7/2020	PIT	-	-	900_230000237354	Lawrence	US
Alewife	F	297	5/7/2020	PIT	-	-	900_230000237334	Lawrence	US
Alewife	M	297	5/7/2020	PIT	-	-	900_230000237347	Lawrence	US
Alewife	M	299	5/7/2020	PIT	-	-	900_230000237333	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	F	299	5/7/2020	PIT	-	-	900_230000237339	Lawrence	US
Alewife	M	300	5/7/2020	PIT	-	-	900_230000237326	Lawrence	US
Alewife	F	300	5/7/2020	PIT	-	-	900_230000237332	Lawrence	US
Alewife	M	300	5/7/2020	PIT	-	-	900_230000237346	Lawrence	US
Alewife	M	300	5/7/2020	PIT	-	-	900_230000237352	Lawrence	US
Alewife	M	303	5/7/2020	PIT	-	-	900_230000237345	Lawrence	US
Alewife	M	303	5/7/2020	PIT	-	-	900_230000237351	Lawrence	US
Alewife	M	304	5/7/2020	PIT	-	-	900_230000237335	Lawrence	US
Alewife	M	304	5/7/2020	PIT	-	-	900_230000237343	Lawrence	US
Alewife	F	305	5/7/2020	PIT	-	-	900_230000237357	Lawrence	US
Alewife	F	308	5/7/2020	PIT	-	-	900_230000237355	Lawrence	US
Alewife	M	310	5/7/2020	PIT	-	-	900_230000237349	Lawrence	US
Alewife	M	312	5/7/2020	PIT	-	-	900_230000237336	Lawrence	US
Alewife	F	312	5/7/2020	PIT	-	-	900_230000237344	Lawrence	US
Alewife	F	313	5/7/2020	PIT	-	-	900_230000237340	Lawrence	US
Alewife	F	314	5/7/2020	PIT	-	-	900_230000237337	Lawrence	US
Alewife	F	314	5/7/2020	PIT	-	-	900_230000237338	Lawrence	US
Alewife	U	315	5/7/2020	PIT	-	-	900_230000237342	Lawrence	US
Alewife	U	316	5/7/2020	PIT	-	-	900_230000237358	Lawrence	US
Alewife	F	319	5/7/2020	PIT	-	-	900_230000237350	Lawrence	US
Alewife	F	330	5/7/2020	PIT	-	-	900_230000237327	Lawrence	US
Alewife	M	294	5/8/2020	Dual	149.440	16	900_230000237419	Lawrence	US
Alewife	M	303	5/8/2020	Dual	149.440	17	900_230000237418	Lawrence	US
Alewife	M	300	5/8/2020	Dual	149.440	18	900_230000237417	Lawrence	US
Alewife	F	335	5/8/2020	Dual	149.440	19	900_230000237416	Lawrence	US
Alewife	F	314	5/8/2020	Dual	149.440	20	900_230000237415	Lawrence	US
Alewife	M	290	5/8/2020	Dual	149.460	46	900_230000237424	Lawrence	US
Alewife	F	311	5/8/2020	Dual	149.460	47	900_230000237423	Lawrence	US
Alewife	M	301	5/8/2020	Dual	149.460	48	900_230000237422	Lawrence	US
Alewife	M	304	5/8/2020	Dual	149.460	49	900_230000237421	Lawrence	US
Alewife	M	289	5/8/2020	Dual	149.460	50	900_230000237420	Lawrence	US
Alewife	M	282	5/8/2020	Dual	149.480	76	900_230000237429	Lawrence	US
Alewife	M	301	5/8/2020	Dual	149.480	77	900_230000237428	Lawrence	US
Alewife	M	314	5/8/2020	Dual	149.480	78	900_230000237427	Lawrence	US
Alewife	M	285	5/8/2020	Dual	149.480	79	900_230000237426	Lawrence	US
Alewife	M	284	5/8/2020	Dual	149.480	80	900_230000237425	Lawrence	US
Alewife	U	320	5/8/2020	Dual	149.760	106	900_230000237434	Lawrence	US
Alewife	M	304	5/8/2020	Dual	149.760	107	900_230000237433	Lawrence	US
Alewife	M	293	5/8/2020	Dual	149.760	108	900_230000237432	Lawrence	US
Alewife	M	290	5/8/2020	Dual	149.760	109	900_230000237431	Lawrence	US
Alewife	F	289	5/8/2020	Dual	149.760	110	900_230000237430	Lawrence	US
Alewife	M	304	5/8/2020	Dual	149.800	136	900_230000237439	Lawrence	US
Alewife	F	315	5/8/2020	Dual	149.800	137	900_230000237438	Lawrence	US
Alewife	M	306	5/8/2020	Dual	149.800	138	900_230000237437	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	F	325	5/8/2020	Dual	149.800	139	900_230000237436	Lawrence	US
Alewife	M	294	5/8/2020	Dual	149.800	140	900_230000237435	Lawrence	US
Alewife	M	280	5/8/2020	PIT	-	-	900_230000237406	Lawrence	US
Alewife	M	285	5/8/2020	PIT	-	-	900_230000237403	Lawrence	US
Alewife	M	287	5/8/2020	PIT	-	-	900_230000237413	Lawrence	US
Alewife	M	290	5/8/2020	PIT	-	-	900_230000237404	Lawrence	US
Alewife	M	290	5/8/2020	PIT	-	-	900_230000237412	Lawrence	US
Alewife	M	291	5/8/2020	PIT	-	-	900_230000237440	Lawrence	US
Alewife	M	292	5/8/2020	PIT	-	-	900_230000237391	Lawrence	US
Alewife	M	292	5/8/2020	PIT	-	-	900_230000237407	Lawrence	US
Alewife	M	294	5/8/2020	PIT	-	-	900_230000237443	Lawrence	US
Alewife	M	295	5/8/2020	PIT	-	-	900_230000237393	Lawrence	US
Alewife	M	295	5/8/2020	PIT	-	-	900_230000237397	Lawrence	US
Alewife	M	295	5/8/2020	PIT	-	-	900_230000237398	Lawrence	US
Alewife	M	297	5/8/2020	PIT	-	-	900_230000237441	Lawrence	US
Alewife	U	298	5/8/2020	PIT	-	-	900_230000237445	Lawrence	US
Alewife	F	300	5/8/2020	PIT	-	-	900_230000237405	Lawrence	US
Alewife	M	300	5/8/2020	PIT	-	-	900_230000237410	Lawrence	US
Alewife	M	302	5/8/2020	PIT	-	-	900_230000237411	Lawrence	US
Alewife	M	302	5/8/2020	PIT	-	-	900_230000237448	Lawrence	US
Alewife	F	304	5/8/2020	PIT	-	-	900_230000237442	Lawrence	US
Alewife	F	305	5/8/2020	PIT	-	-	900_230000237402	Lawrence	US
Alewife	F	305	5/8/2020	PIT	-	-	900_230000237408	Lawrence	US
Alewife	U	305	5/8/2020	PIT	-	-	900_230000237447	Lawrence	US
Alewife	F	307	5/8/2020	PIT	-	-	900_230000237444	Lawrence	US
Alewife	M	308	5/8/2020	PIT	-	-	900_230000237399	Lawrence	US
Alewife	F	308	5/8/2020	PIT	-	-	900_230000237446	Lawrence	US
Alewife	M	310	5/8/2020	PIT	-	-	900_230000237390	Lawrence	US
Alewife	F	310	5/8/2020	PIT	-	-	900_230000237400	Lawrence	US
Alewife	M	310	5/8/2020	PIT	-	-	900_230000237409	Lawrence	US
Alewife	F	314	5/8/2020	PIT	-	-	900_230000237394	Lawrence	US
Alewife	F	314	5/8/2020	PIT	-	-	900_230000237396	Lawrence	US
Alewife	F	314	5/8/2020	PIT	-	-	900_230000237414	Lawrence	US
Alewife	F	315	5/8/2020	PIT	-	-	900_230000237401	Lawrence	US
Alewife	F	317	5/8/2020	PIT	-	-	900_230000237395	Lawrence	US
Alewife	M	318	5/8/2020	PIT	-	-	900_230000237392	Lawrence	US
Alewife	F	321	5/16/2020	Dual	149.440	22	900_230000237461	Lawrence	US
Alewife	M	313	5/16/2020	Dual	149.440	23	900_230000237463	Lawrence	US
Alewife	F	302	5/16/2020	Dual	149.440	24	900_230000237465	Lawrence	US
Alewife	M	304	5/16/2020	Dual	149.440	25	900_230000237467	Lawrence	US
Alewife	F	316	5/16/2020	Dual	149.440	26	900_230000237469	Lawrence	US
Alewife	F	325	5/16/2020	Dual	149.460	52	900_230000237478	Lawrence	US
Alewife	F	321	5/16/2020	Dual	149.460	53	900_230000237477	Lawrence	US
Alewife	F	312	5/16/2020	Dual	149.460	54	900_230000237475	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	M	295	5/16/2020	Dual	149.460	55	900_230000237471	Lawrence	US
Alewife	M	305	5/16/2020	Dual	149.800	142	900_230000237449	Lawrence	US
Alewife	M	315	5/16/2020	Dual	149.800	143	900_230000237456	Lawrence	US
Alewife	M	303	5/16/2020	Dual	149.800	144	900_230000237454	Lawrence	US
Alewife	F	309	5/16/2020	Dual	149.800	145	900_230000237452	Lawrence	US
Alewife	F	325	5/16/2020	Dual	149.800	146	900_230000237450	Lawrence	US
Alewife	F	304	5/17/2020	Dual	149.440	28	900_230000237677	Lawrence	US
Alewife	M	275	5/17/2020	Dual	149.440	29	900_230000237676	Lawrence	US
Alewife	M	290	5/17/2020	Dual	149.440	30	900_230000237675	Lawrence	US
Alewife	F	310	5/17/2020	Dual	149.440	31	900_230000237674	Lawrence	US
Alewife	F	295	5/17/2020	Dual	149.440	32	900_230000237673	Lawrence	US
Alewife	F	305	5/17/2020	Dual	149.460	56	900_230000237613	Lawrence	US
Alewife	F	300	5/17/2020	Dual	149.460	58	900_230000237683	Lawrence	US
Alewife	F	310	5/17/2020	Dual	149.460	59	900_230000237682	Lawrence	US
Alewife	F	292	5/17/2020	Dual	149.460	60	900_230000237681	Lawrence	US
Alewife	F	290	5/17/2020	Dual	149.460	61	900_230000237680	Lawrence	US
Alewife	M	310	5/17/2020	Dual	149.460	62	900_230000237678	Lawrence	US
Alewife	M	300	5/17/2020	Dual	149.480	82	900_230000237618	Lawrence	US
Alewife	F	304	5/17/2020	Dual	149.480	83	900_230000237617	Lawrence	US
Alewife	F	308	5/17/2020	Dual	149.480	84	900_230000237616	Lawrence	US
Alewife	F	310	5/17/2020	Dual	149.480	85	900_230000237615	Lawrence	US
Alewife	F	310	5/17/2020	Dual	149.480	86	900_230000237614	Lawrence	US
Alewife	F	310	5/17/2020	Dual	149.480	88	900_230000237688	Lawrence	US
Alewife	F	310	5/17/2020	Dual	149.480	89	900_230000237687	Lawrence	US
Alewife	F	297	5/17/2020	Dual	149.480	90	900_230000237686	Lawrence	US
Alewife	M	290	5/17/2020	Dual	149.480	91	900_230000237685	Lawrence	US
Alewife	M	300	5/17/2020	Dual	149.480	92	900_230000237684	Lawrence	US
Alewife	F	295	5/17/2020	Dual	149.760	112	900_230000237624	Lawrence	US
Alewife	F	315	5/17/2020	Dual	149.760	113	900_230000237623	Lawrence	US
Alewife	F	310	5/17/2020	Dual	149.760	114	900_230000237622	Lawrence	US
Alewife	F	293	5/17/2020	Dual	149.760	115	900_230000237620	Lawrence	US
Alewife	M	275	5/17/2020	Dual	149.760	116	900_230000237619	Lawrence	US
Alewife	F	310	5/17/2020	Dual	149.760	118	900_230000237693	Lawrence	US
Alewife	F	315	5/17/2020	Dual	149.760	119	900_230000237692	Lawrence	US
Alewife	F	318	5/17/2020	Dual	149.760	120	900_230000237691	Lawrence	US
Alewife	F	295	5/17/2020	Dual	149.760	121	900_230000237690	Lawrence	US
Alewife	F	315	5/17/2020	Dual	149.760	122	900_230000237689	Lawrence	US
Alewife	F	300	5/17/2020	Dual	149.800	148	900_230000237699	Lawrence	US
Alewife	M	295	5/17/2020	Dual	149.800	149	900_230000237698	Lawrence	US
Alewife	F	295	5/17/2020	Dual	149.800	150	900_230000237696	Lawrence	US
Alewife	F	310	5/17/2020	Dual	149.800	151	900_230000237695	Lawrence	US
Alewife	M	290	5/17/2020	Dual	149.800	152	900_230000237694	Lawrence	US
Alewife	M	260	5/17/2020	PIT	-	-	900_230000237743	Lawrence	US
Alewife	F	274	5/17/2020	PIT	-	-	900_230000237745	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	M	275	5/17/2020	PIT	-	-	900_230000237736	Lawrence	US
Alewife	M	280	5/17/2020	PIT	-	-	900_230000237775	Lawrence	US
Alewife	M	281	5/17/2020	PIT	-	-	900_230000237766	Lawrence	US
Alewife	M	281	5/17/2020	PIT	-	-	900_230000237752	Lawrence	US
Alewife	M	285	5/17/2020	PIT	-	-	900_230000237625	Lawrence	US
Alewife	F	285	5/17/2020	PIT	-	-	900_230000237636	Lawrence	US
Alewife	M	286	5/17/2020	PIT	-	-	900_230000237733	Lawrence	US
Alewife	F	288	5/17/2020	PIT	-	-	900_230000237774	Lawrence	US
Alewife	M	288	5/17/2020	PIT	-	-	900_230000237738	Lawrence	US
Alewife	M	290	5/17/2020	PIT	-	-	900_230000237627	Lawrence	US
Alewife	M	290	5/17/2020	PIT	-	-	900_230000237631	Lawrence	US
Alewife	M	290	5/17/2020	PIT	-	-	900_230000237634	Lawrence	US
Alewife	F	290	5/17/2020	PIT	-	-	900_230000237773	Lawrence	US
Alewife	M	291	5/17/2020	PIT	-	-	900_230000237754	Lawrence	US
Alewife	M	292	5/17/2020	PIT	-	-	900_230000237744	Lawrence	US
Alewife	M	292	5/17/2020	PIT	-	-	900_230000237759	Lawrence	US
Alewife	M	293	5/17/2020	PIT	-	-	900_230000237750	Lawrence	US
Alewife	M	293	5/17/2020	PIT	-	-	900_230000237751	Lawrence	US
Alewife	M	294	5/17/2020	PIT	-	-	900_230000237735	Lawrence	US
Alewife	M	295	5/17/2020	PIT	-	-	900_230000237621	Lawrence	US
Alewife	F	295	5/17/2020	PIT	-	-	900_230000237628	Lawrence	US
Alewife	F	295	5/17/2020	PIT	-	-	900_230000237635	Lawrence	US
Alewife	M	295	5/17/2020	PIT	-	-	900_230000237742	Lawrence	US
Alewife	F	295	5/17/2020	PIT	-	-	900_230000237753	Lawrence	US
Alewife	F	296	5/17/2020	PIT	-	-	900_230000237768	Lawrence	US
Alewife	M	296	5/17/2020	PIT	-	-	900_230000237758	Lawrence	US
Alewife	F	299	5/17/2020	PIT	-	-	900_230000237771	Lawrence	US
Alewife	M	300	5/17/2020	PIT	-	-	900_230000237633	Lawrence	US
Alewife	F	300	5/17/2020	PIT	-	-	900_230000237637	Lawrence	US
Alewife	M	300	5/17/2020	PIT	-	-	900_230000237641	Lawrence	US
Alewife	F	300	5/17/2020	PIT	-	-	900_230000237642	Lawrence	US
Alewife	F	300	5/17/2020	PIT	-	-	900_230000237769	Lawrence	US
Alewife	U	300	5/17/2020	PIT	-	-	900_230000237679	Lawrence	US
Alewife	F	301	5/17/2020	PIT	-	-	900_230000237764	Lawrence	US
Alewife	M	302	5/17/2020	PIT	-	-	900_230000237737	Lawrence	US
Alewife	M	302	5/17/2020	PIT	-	-	900_230000237747	Lawrence	US
Alewife	F	303	5/17/2020	PIT	-	-	900_230000237740	Lawrence	US
Alewife	F	304	5/17/2020	PIT	-	-	900_230000237772	Lawrence	US
Alewife	F	304	5/17/2020	PIT	-	-	900_230000237749	Lawrence	US
Alewife	F	305	5/17/2020	PIT	-	-	900_230000237629	Lawrence	US
Alewife	M	305	5/17/2020	PIT	-	-	900_230000237638	Lawrence	US
Alewife	M	305	5/17/2020	PIT	-	-	900_230000237730	Lawrence	US
Alewife	M	305	5/17/2020	PIT	-	-	900_230000237732	Lawrence	US
Alewife	F	305	5/17/2020	PIT	-	-	900_230000237741	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	M	305	5/17/2020	PIT	-	-	900_230000237746	Lawrence	US
Alewife	F	305	5/17/2020	PIT	-	-	900_230000237756	Lawrence	US
Alewife	M	305	5/17/2020	PIT	-	-	900_230000237757	Lawrence	US
Alewife	M	306	5/17/2020	PIT	-	-	900_230000237734	Lawrence	US
Alewife	F	307	5/17/2020	PIT	-	-	900_230000237762	Lawrence	US
Alewife	F	308	5/17/2020	PIT	-	-	900_230000237739	Lawrence	US
Alewife	M	309	5/17/2020	PIT	-	-	900_230000237767	Lawrence	US
Alewife	F	310	5/17/2020	PIT	-	-	900_230000237630	Lawrence	US
Alewife	F	310	5/17/2020	PIT	-	-	900_230000237765	Lawrence	US
Alewife	M	310	5/17/2020	PIT	-	-	900_230000237770	Lawrence	US
Alewife	M	310	5/17/2020	PIT	-	-	900_230000237697	Lawrence	US
Alewife	F	310	5/17/2020	PIT	-	-	900_230000237731	Lawrence	US
Alewife	F	312	5/17/2020	PIT	-	-	900_230000237640	Lawrence	US
Alewife	F	312	5/17/2020	PIT	-	-	900_230000237776	Lawrence	US
Alewife	M	314	5/17/2020	PIT	-	-	900_230000237763	Lawrence	US
Alewife	F	315	5/17/2020	PIT	-	-	900_230000237632	Lawrence	US
Alewife	F	315	5/17/2020	PIT	-	-	900_230000237755	Lawrence	US
Alewife	F	316	5/17/2020	PIT	-	-	900_230000237748	Lawrence	US
Alewife	F	319	5/17/2020	PIT	-	-	900_230000237760	Lawrence	US
Alewife	F	320	5/17/2020	PIT	-	-	900_230000237626	Lawrence	US
Alewife	F	324	5/17/2020	PIT	-	-	900_230000237761	Lawrence	US
Alewife	F	330	5/17/2020	PIT	-	-	900_230000237639	Lawrence	US
Alewife	F	282	5/18/2020	Dual	149.440	34	900_230000237815	Lawrence	US
Alewife	M	306	5/18/2020	Dual	149.440	35	900_230000237812	Lawrence	US
Alewife	M	290	5/18/2020	Dual	149.440	36	900_230000237811	Lawrence	US
Alewife	M	274	5/18/2020	Dual	149.440	37	900_230000237809	Lawrence	US
Alewife	F	306	5/18/2020	Dual	149.440	38	900_230000237807	Lawrence	US
Alewife	M	306	5/18/2020	Dual	149.460	64	900_230000237846	Lawrence	US
Alewife	F	295	5/18/2020	Dual	149.460	65	900_230000237821	Lawrence	US
Alewife	F	315	5/18/2020	Dual	149.460	66	900_230000237819	Lawrence	US
Alewife	M	305	5/18/2020	Dual	149.460	67	900_230000237818	Lawrence	US
Alewife	M	287	5/18/2020	Dual	149.460	68	900_230000237816	Lawrence	US
Alewife	F	307	5/18/2020	Dual	149.480	94	900_230000237858	Lawrence	US
Alewife	F	294	5/18/2020	Dual	149.480	95	900_230000237859	Lawrence	US
Alewife	F	323	5/18/2020	Dual	149.480	96	900_230000237860	Lawrence	US
Alewife	M	291	5/18/2020	Dual	149.480	97	900_230000237861	Lawrence	US
Alewife	F	280	5/18/2020	Dual	149.480	98	900_230000237862	Lawrence	US
Alewife	F	318	5/18/2020	Dual	149.760	124	900_230000237863	Lawrence	US
Alewife	M	281	5/18/2020	Dual	149.760	125	900_230000237864	Lawrence	US
Alewife	M	287	5/18/2020	Dual	149.760	126	900_230000237865	Lawrence	US
Alewife	M	269	5/18/2020	Dual	149.760	127	900_230000237866	Lawrence	US
Alewife	F	318	5/18/2020	Dual	149.760	128	900_230000237504	Lawrence	US
Alewife	M	286	5/18/2020	Dual	149.800	154	900_230000237505	Lawrence	US
Alewife	F	306	5/18/2020	Dual	149.800	155	900_230000237506	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	F	319	5/18/2020	Dual	149.800	156	900_230000237507	Lawrence	US
Alewife	F	286	5/18/2020	Dual	149.800	157	900_230000237508	Lawrence	US
Alewife	F	304	5/18/2020	Dual	149.800	158	900_230000237509	Lawrence	US
Alewife	F	262	5/18/2020	PIT	-	-	900_230000237534	Lawrence	US
Alewife	F	285	5/18/2020	PIT	-	-	900_230000237535	Lawrence	US
Alewife	M	286	5/18/2020	PIT	-	-	900_230000237517	Lawrence	US
Alewife	M	286	5/18/2020	PIT	-	-	900_230000237527	Lawrence	US
Alewife	M	287	5/18/2020	PIT	-	-	900_230000237538	Lawrence	US
Alewife	M	291	5/18/2020	PIT	-	-	900_230000237511	Lawrence	US
Alewife	M	291	5/18/2020	PIT	-	-	900_230000237536	Lawrence	US
Alewife	M	291	5/18/2020	PIT	-	-	900_230000237540	Lawrence	US
Alewife	F	292	5/18/2020	PIT	-	-	900_230000237514	Lawrence	US
Alewife	M	295	5/18/2020	PIT	-	-	900_230000237526	Lawrence	US
Alewife	M	296	5/18/2020	PIT	-	-	900_230000237524	Lawrence	US
Alewife	M	298	5/18/2020	PIT	-	-	900_230000237519	Lawrence	US
Alewife	M	299	5/18/2020	PIT	-	-	900_230000237541	Lawrence	US
Alewife	F	300	5/18/2020	PIT	-	-	900_230000237510	Lawrence	US
Alewife	F	303	5/18/2020	PIT	-	-	900_230000237539	Lawrence	US
Alewife	F	304	5/18/2020	PIT	-	-	900_230000237542	Lawrence	US
Alewife	F	305	5/18/2020	PIT	-	-	900_230000237521	Lawrence	US
Alewife	M	305	5/18/2020	PIT	-	-	900_230000237522	Lawrence	US
Alewife	M	305	5/18/2020	PIT	-	-	900_230000237531	Lawrence	US
Alewife	M	305	5/18/2020	PIT	-	-	900_230000237537	Lawrence	US
Alewife	F	307	5/18/2020	PIT	-	-	900_230000237530	Lawrence	US
Alewife	M	308	5/18/2020	PIT	-	-	900_230000237516	Lawrence	US
Alewife	M	308	5/18/2020	PIT	-	-	900_230000237543	Lawrence	US
Alewife	F	310	5/18/2020	PIT	-	-	900_230000237523	Lawrence	US
Alewife	F	310	5/18/2020	PIT	-	-	900_230000237525	Lawrence	US
Alewife	F	311	5/18/2020	PIT	-	-	900_230000237512	Lawrence	US
Alewife	F	312	5/18/2020	PIT	-	-	900_230000237515	Lawrence	US
Alewife	F	314	5/18/2020	PIT	-	-	900_230000237518	Lawrence	US
Alewife	F	315	5/18/2020	PIT	-	-	900_230000237532	Lawrence	US
Alewife	F	316	5/18/2020	PIT	-	-	900_230000237513	Lawrence	US
Alewife	F	316	5/18/2020	PIT	-	-	900_230000237529	Lawrence	US
Alewife	F	317	5/18/2020	PIT	-	-	900_230000237528	Lawrence	US
Alewife	F	319	5/18/2020	PIT	-	-	900_230000237520	Lawrence	US
Alewife	F	326	5/18/2020	PIT	-	-	900_230000237533	Lawrence	US
Alewife	M	295	5/19/2020	Dual	149.440	40	900_230000237955	Lawrence	US
Alewife	F	297	5/19/2020	Dual	149.440	41	900_230000237956	Lawrence	US
Alewife	F	312	5/19/2020	Dual	149.440	42	900_230000237957	Lawrence	US
Alewife	F	301	5/19/2020	Dual	149.440	43	900_230000237958	Lawrence	US
Alewife	F	314	5/19/2020	Dual	149.440	44	900_230000237959	Lawrence	US
Alewife	M	304	5/19/2020	Dual	149.460	70	900_230000237960	Lawrence	US
Alewife	F	310	5/19/2020	Dual	149.460	71	900_230000237961	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	F	316	5/19/2020	Dual	149.460	72	900_230000237962	Lawrence	US
Alewife	F	314	5/19/2020	Dual	149.460	73	900_230000237963	Lawrence	US
Alewife	M	312	5/19/2020	Dual	149.460	74	900_230000237964	Lawrence	US
Alewife	F	305	5/19/2020	Dual	149.480	100	900_230000237965	Lawrence	US
Alewife	M	299	5/19/2020	Dual	149.480	101	900_230000237966	Lawrence	US
Alewife	M	295	5/19/2020	Dual	149.480	102	900_230000237967	Lawrence	US
Alewife	M	308	5/19/2020	Dual	149.480	103	900_230000237968	Lawrence	US
Alewife	F	305	5/19/2020	Dual	149.480	104	900_230000237969	Lawrence	US
Alewife	M	307	5/19/2020	Dual	149.760	130	900_230000237970	Lawrence	US
Alewife	F	309	5/19/2020	Dual	149.760	131	900_230000237971	Lawrence	US
Alewife	F	320	5/19/2020	Dual	149.760	132	900_230000237972	Lawrence	US
Alewife	F	310	5/19/2020	Dual	149.760	133	900_230000237973	Lawrence	US
Alewife	F	324	5/19/2020	Dual	149.760	134	900_230000237974	Lawrence	US
Alewife	M	287	5/19/2020	Dual	149.800	160	900_230000237975	Lawrence	US
Alewife	M	305	5/19/2020	Dual	149.800	161	900_230000237976	Lawrence	US
Alewife	F	313	5/19/2020	Dual	149.800	162	900_230000237977	Lawrence	US
Alewife	F	302	5/19/2020	Dual	149.800	163	900_230000237978	Lawrence	US
Alewife	M	307	5/19/2020	Dual	149.800	164	900_230000237979	Lawrence	US
Alewife	M	285	5/19/2020	PIT	-	-	900_230000237921	Lawrence	US
Alewife	F	287	5/19/2020	PIT	-	-	900_23000023865	Lawrence	US
Alewife	M	288	5/19/2020	PIT	-	-	900_23000023855	Lawrence	US
Alewife	M	289	5/19/2020	PIT	-	-	900_23000023843	Lawrence	US
Alewife	M	289	5/19/2020	PIT	-	-	900_23000023849	Lawrence	US
Alewife	M	290	5/19/2020	PIT	-	-	900_23000023862	Lawrence	US
Alewife	F	291	5/19/2020	PIT	-	-	900_23000023848	Lawrence	US
Alewife	M	291	5/19/2020	PIT	-	-	900_23000023859	Lawrence	US
Alewife	M	292	5/19/2020	PIT	-	-	900_23000023844	Lawrence	US
Alewife	M	294	5/19/2020	PIT	-	-	900_23000023860	Lawrence	US
Alewife	F	295	5/19/2020	PIT	-	-	900_23000023866	Lawrence	US
Alewife	M	295	5/19/2020	PIT	-	-	900_23000023870	Lawrence	US
Alewife	F	296	5/19/2020	PIT	-	-	900_23000023840	Lawrence	US
Alewife	M	296	5/19/2020	PIT	-	-	900_23000023851	Lawrence	US
Alewife	F	296	5/19/2020	PIT	-	-	900_23000023854	Lawrence	US
Alewife	M	296	5/19/2020	PIT	-	-	900_23000023857	Lawrence	US
Alewife	F	298	5/19/2020	PIT	-	-	900_23000023856	Lawrence	US
Alewife	F	300	5/19/2020	PIT	-	-	900_23000023867	Lawrence	US
Alewife	M	302	5/19/2020	PIT	-	-	900_23000023864	Lawrence	US
Alewife	M	303	5/19/2020	PIT	-	-	900_23000023861	Lawrence	US
Alewife	F	304	5/19/2020	PIT	-	-	900_23000023852	Lawrence	US
Alewife	M	305	5/19/2020	PIT	-	-	900_23000023846	Lawrence	US
Alewife	M	306	5/19/2020	PIT	-	-	900_23000023847	Lawrence	US
Alewife	F	307	5/19/2020	PIT	-	-	900_23000023863	Lawrence	US
Alewife	M	311	5/19/2020	PIT	-	-	900_23000023842	Lawrence	US
Alewife	M	312	5/19/2020	PIT	-	-	900_23000023872	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	F	315	5/19/2020	PIT	-	-	900_23000023853	Lawrence	US
Alewife	F	316	5/19/2020	PIT	-	-	900_23000023850	Lawrence	US
Alewife	F	316	5/19/2020	PIT	-	-	900_23000023868	Lawrence	US
Alewife	F	320	5/19/2020	PIT	-	-	900_23000023869	Lawrence	US
Alewife	F	321	5/19/2020	PIT	-	-	900_23000023845	Lawrence	US
Alewife	F	321	5/19/2020	PIT	-	-	900_23000023858	Lawrence	US
Alewife	F	325	5/19/2020	PIT	-	-	900_23000023841	Lawrence	US
Alewife	F	330	5/19/2020	PIT	-	-	900_23000023871	Lawrence	US
Alewife	M	289	5/21/2020	Radio	149.440	158	-	Lawrence	DS
Alewife	M	287	5/21/2020	Radio	149.440	159	-	Lawrence	DS
Alewife	M	271	5/21/2020	Radio	149.440	160	-	Lawrence	DS
Alewife	M	299	5/21/2020	Radio	149.440	161	-	Lawrence	DS
Alewife	M	304	5/21/2020	Radio	149.440	162	-	Lawrence	DS
Alewife	M	295	5/21/2020	Radio	149.440	163	-	Lawrence	DS
Alewife	F	307	5/21/2020	Radio	149.440	164	-	Lawrence	DS
Alewife	M	273	5/21/2020	Radio	149.440	165	-	Lawrence	DS
Alewife	F	313	5/21/2020	Radio	149.440	166	-	Lawrence	DS
Alewife	F	220	5/21/2020	Radio	149.440	167	-	Lawrence	DS
Alewife	M	298	5/21/2020	Radio	149.440	168	-	Lawrence	DS
Alewife	M	298	5/21/2020	Radio	149.440	169	-	Lawrence	DS
Alewife	M	301	5/21/2020	Radio	149.460	76	-	Lawrence	DS
Alewife	M	295	5/21/2020	Radio	149.460	77	-	Lawrence	DS
Alewife	M	293	5/21/2020	Radio	149.460	78	-	Lawrence	DS
Alewife	M	267	5/21/2020	Radio	149.460	79	-	Lawrence	DS
Alewife	F	290	5/21/2020	Radio	149.460	80	-	Lawrence	DS
Alewife	F	294	5/21/2020	Radio	149.460	81	-	Lawrence	DS
Alewife	M	306	5/21/2020	Radio	149.460	82	-	Lawrence	DS
Alewife	M	285	5/21/2020	Radio	149.460	83	-	Lawrence	DS
Alewife	M	295	5/21/2020	Radio	149.460	84	-	Lawrence	DS
Alewife	F	261	5/21/2020	Radio	149.460	85	-	Lawrence	DS
Alewife	F	292	5/21/2020	Radio	149.460	86	-	Lawrence	DS
Alewife	M	270	5/21/2020	Radio	149.460	87	-	Lawrence	DS
Alewife	M	288	5/21/2020	Radio	149.480	106	-	Lawrence	DS
Alewife	M	298	5/21/2020	Radio	149.480	107	-	Lawrence	DS
Alewife	M	302	5/21/2020	Radio	149.480	108	-	Lawrence	DS
Alewife	F	314	5/21/2020	Radio	149.480	109	-	Lawrence	DS
Alewife	M	287	5/21/2020	Radio	149.480	110	-	Lawrence	DS
Alewife	M	293	5/21/2020	Radio	149.480	111	-	Lawrence	DS
Alewife	F	310	5/21/2020	Radio	149.480	112	-	Lawrence	DS
Alewife	M	294	5/21/2020	Radio	149.480	113	-	Lawrence	DS
Alewife	M	304	5/21/2020	Radio	149.480	114	-	Lawrence	DS
Alewife	M	315	5/21/2020	Radio	149.480	115	-	Lawrence	DS
Alewife	M	282	5/21/2020	Radio	149.480	116	-	Lawrence	DS
Alewife	F	321	5/21/2020	Radio	149.480	117	-	Lawrence	DS

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	M	309	5/21/2020	Radio	149.760	180	-	Lawrence	DS
Alewife	F	289	5/21/2020	Radio	149.760	181	-	Lawrence	DS
Alewife	M	308	5/21/2020	Radio	149.760	182	-	Lawrence	DS
Alewife	F	282	5/21/2020	Radio	149.760	183	-	Lawrence	DS
Alewife	F	298	5/21/2020	Radio	149.760	184	-	Lawrence	DS
Alewife	M	297	5/21/2020	Radio	149.760	185	-	Lawrence	DS
Alewife	M	295	5/21/2020	Radio	149.760	186	-	Lawrence	DS
Alewife	F	304	5/21/2020	Radio	149.760	187	-	Lawrence	DS
Alewife	M	260	5/21/2020	Radio	149.760	188	-	Lawrence	DS
Alewife	M	305	5/21/2020	Radio	149.760	189	-	Lawrence	DS
Alewife	F	330	5/21/2020	Radio	149.760	190	-	Lawrence	DS
Alewife	F	308	5/21/2020	Radio	149.760	191	-	Lawrence	DS
Alewife	F	305	5/21/2020	Radio	149.800	41	-	Lawrence	DS
Alewife	F	304	5/21/2020	Radio	149.800	42	-	Lawrence	DS
Alewife	M	297	5/21/2020	Radio	149.800	43	-	Lawrence	DS
Alewife	M	304	5/21/2020	Radio	149.800	44	-	Lawrence	DS
Alewife	F	296	5/21/2020	Radio	149.800	45	-	Lawrence	DS
Alewife	F	308	5/21/2020	Radio	149.800	46	-	Lawrence	DS
Alewife	M	286	5/21/2020	Radio	149.800	47	-	Lawrence	DS
Alewife	M	314	5/21/2020	Radio	149.800	48	-	Lawrence	DS
Alewife	F	320	5/21/2020	Radio	149.800	49	-	Lawrence	DS
Alewife	F	310	5/21/2020	Radio	149.800	50	-	Lawrence	DS
Alewife	F	309	5/21/2020	Radio	149.800	51	-	Lawrence	DS
Alewife	F	323	5/21/2020	Radio	149.800	52	-	Lawrence	DS
Alewife	M	277	5/22/2020	Radio	149.440	170	-	Lawrence	DS
Alewife	M	265	5/22/2020	Radio	149.440	171	-	Lawrence	DS
Alewife	M	290	5/22/2020	Radio	149.440	172	-	Lawrence	DS
Alewife	M	299	5/22/2020	Radio	149.440	173	-	Lawrence	DS
Alewife	M	278	5/22/2020	Radio	149.460	88	-	Lawrence	DS
Alewife	M	283	5/22/2020	Radio	149.460	89	-	Lawrence	DS
Alewife	M	284	5/22/2020	Radio	149.460	90	-	Lawrence	DS
Alewife	F	314	5/22/2020	Radio	149.460	91	-	Lawrence	DS
Alewife	F	295	5/22/2020	Radio	149.480	118	-	Lawrence	DS
Alewife	M	275	5/22/2020	Radio	149.480	119	-	Lawrence	DS
Alewife	M	291	5/22/2020	Radio	149.480	120	-	Lawrence	DS
Alewife	M	288	5/22/2020	Radio	149.480	121	-	Lawrence	DS
Alewife	M	282	5/22/2020	Radio	149.760	192	-	Lawrence	DS
Alewife	F	316	5/22/2020	Radio	149.760	194	-	Lawrence	DS
Alewife	F	294	5/22/2020	Radio	149.760	195	-	Lawrence	DS
Alewife	M	295	5/22/2020	Radio	149.760	193	-	Lawrence	DS
Alewife	F	318	5/22/2020	Radio	149.800	53	-	Lawrence	DS
Alewife	M	282	5/22/2020	Radio	149.800	54	-	Lawrence	DS
Alewife	M	296	5/22/2020	Radio	149.800	55	-	Lawrence	DS
Alewife	F	304	5/22/2020	Radio	149.800	56	-	Lawrence	DS

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	F	310	5/28/2020	Radio	149.440	174	-	Amoskeag	DS
Alewife	M	268	5/28/2020	Radio	149.440	175	-	Amoskeag	DS
Alewife	M	291	5/28/2020	Radio	149.440	176	-	Amoskeag	DS
Alewife	M	302	5/28/2020	Radio	149.440	177	-	Amoskeag	DS
Alewife	F	293	5/28/2020	Radio	149.460	92	-	Amoskeag	DS
Alewife	F	298	5/28/2020	Radio	149.460	93	-	Amoskeag	DS
Alewife	M	282	5/28/2020	Radio	149.460	94	-	Amoskeag	DS
Alewife	M	286	5/28/2020	Radio	149.460	95	-	Amoskeag	DS
Alewife	F	314	5/28/2020	Radio	149.480	122	-	Amoskeag	DS
Alewife	M	277	5/28/2020	Radio	149.480	123	-	Amoskeag	DS
Alewife	M	302	5/28/2020	Radio	149.480	124	-	Amoskeag	DS
Alewife	M	273	5/28/2020	Radio	149.480	125	-	Amoskeag	DS
Alewife	M	285	5/28/2020	Radio	149.760	196	-	Amoskeag	DS
Alewife	M	297	5/28/2020	Radio	149.760	197	-	Amoskeag	DS
Alewife	F	290	5/28/2020	Radio	149.760	198	-	Amoskeag	DS
Alewife	M	271	5/28/2020	Radio	149.760	199	-	Amoskeag	DS
Alewife	M	295	5/28/2020	Radio	149.800	57	-	Amoskeag	DS
Alewife	M	292	5/28/2020	Radio	149.800	58	-	Amoskeag	DS
Alewife	M	294	5/28/2020	Radio	149.800	59	-	Amoskeag	DS
Alewife	M	299	5/28/2020	Radio	149.800	60	-	Amoskeag	DS
Alewife	U	283	6/2/2020	Radio	149.440	55	-	Amoskeag	DS
Alewife	F	291	6/2/2020	Radio	149.440	56	-	Amoskeag	DS
Alewife	M	306	6/2/2020	Radio	149.440	57	-	Amoskeag	DS
Alewife	F	283	6/2/2020	Radio	149.440	58	-	Amoskeag	DS
Alewife	M	283	6/2/2020	Radio	149.440	59	-	Amoskeag	DS
Alewife	U	295	6/2/2020	Radio	149.440	60	-	Amoskeag	DS
Alewife	M	280	6/2/2020	Radio	149.440	61	-	Amoskeag	DS
Alewife	F	293	6/2/2020	Radio	149.440	62	-	Amoskeag	DS
Alewife	F	291	6/2/2020	Radio	149.440	63	-	Amoskeag	DS
Alewife	F	310	6/2/2020	Radio	149.440	64	-	Amoskeag	DS
Alewife	F	271	6/2/2020	Radio	149.460	141	-	Amoskeag	DS
Alewife	M	292	6/2/2020	Radio	149.460	142	-	Amoskeag	DS
Alewife	F	315	6/2/2020	Radio	149.460	143	-	Amoskeag	DS
Alewife	F	301	6/2/2020	Radio	149.460	144	-	Amoskeag	DS
Alewife	F	305	6/2/2020	Radio	149.460	145	-	Amoskeag	DS
Alewife	F	286	6/2/2020	Radio	149.460	146	-	Amoskeag	DS
Alewife	F	306	6/2/2020	Radio	149.460	147	-	Amoskeag	DS
Alewife	F	293	6/2/2020	Radio	149.460	148	-	Amoskeag	DS
Alewife	M	274	6/2/2020	Radio	149.460	149	-	Amoskeag	DS
Alewife	M	284	6/2/2020	Radio	149.460	150	-	Amoskeag	DS
Alewife	M	264	6/2/2020	Radio	149.480	127	-	Amoskeag	DS
Alewife	F	295	6/2/2020	Radio	149.480	128	-	Amoskeag	DS
Alewife	F	303	6/2/2020	Radio	149.480	129	-	Amoskeag	DS
Alewife	F	298	6/2/2020	Radio	149.480	130	-	Amoskeag	DS

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Alewife	F	310	6/2/2020	Radio	149.480	131	-	Amoskeag	DS
Alewife	M	282	6/2/2020	Radio	149.480	132	-	Amoskeag	DS
Alewife	F	296	6/2/2020	Radio	149.480	133	-	Amoskeag	DS
Alewife	M	275	6/2/2020	Radio	149.480	134	-	Amoskeag	DS
Alewife	F	293	6/2/2020	Radio	149.480	135	-	Amoskeag	DS
Alewife	F	317	6/2/2020	Radio	149.480	136	-	Amoskeag	DS
Alewife	F	302	6/2/2020	Radio	149.760	83	-	Amoskeag	DS
Alewife	F	316	6/2/2020	Radio	149.760	84	-	Amoskeag	DS
Alewife	F	293	6/2/2020	Radio	149.760	85	-	Amoskeag	DS
Alewife	M	294	6/2/2020	Radio	149.760	86	-	Amoskeag	DS
Alewife	F	320	6/2/2020	Radio	149.760	87	-	Amoskeag	DS
Alewife	F	293	6/2/2020	Radio	149.760	88	-	Amoskeag	DS
Alewife	M	274	6/2/2020	Radio	149.760	89	-	Amoskeag	DS
Alewife	M	286	6/2/2020	Radio	149.760	90	-	Amoskeag	DS
Alewife	F	323	6/2/2020	Radio	149.760	91	-	Amoskeag	DS
Alewife	M	279	6/2/2020	Radio	149.760	92	-	Amoskeag	DS
Alewife	M	264	6/2/2020	Radio	149.800	166	-	Amoskeag	DS
Alewife	F	289	6/2/2020	Radio	149.800	167	-	Amoskeag	DS
Alewife	M	286	6/2/2020	Radio	149.800	168	-	Amoskeag	DS
Alewife	M	287	6/2/2020	Radio	149.800	169	-	Amoskeag	DS
Alewife	M	255	6/2/2020	Radio	149.800	170	-	Amoskeag	DS
Alewife	F	298	6/2/2020	Radio	149.800	173	-	Amoskeag	DS
Alewife	M	276	6/2/2020	Radio	149.800	174	-	Amoskeag	DS
Alewife	M	292	6/2/2020	Radio	149.800	175	-	Amoskeag	DS
Alewife	F	310	6/2/2020	Radio	149.800	176	-	Amoskeag	DS
Alewife	F	306	6/2/2020	Radio	149.800	177	-	Amoskeag	DS
Shad	M	492	5/16/2020	Dual	149.440	121	900_230000237479	Lawrence	US
Shad	M	429	5/16/2020	Dual	149.440	122	900_230000237460	Lawrence	US
Shad	F	533	5/16/2020	Dual	149.440	123	900_230000237462	Lawrence	US
Shad	M	500	5/16/2020	Dual	149.440	124	900_230000237464	Lawrence	US
Shad	F	527	5/16/2020	Dual	149.440	125	900_230000237466	Lawrence	US
Shad	M	482	5/16/2020	Dual	149.440	126	900_230000237468	Lawrence	US
Shad	M	471	5/16/2020	Dual	149.460	156	900_230000237476	Lawrence	US
Shad	M	475	5/16/2020	Dual	149.460	157	900_230000237474	Lawrence	US
Shad	M	466	5/16/2020	Dual	149.460	158	900_230000237473	Lawrence	US
Shad	M	510	5/16/2020	Dual	149.460	159	900_230000237472	Lawrence	US
Shad	M	487	5/16/2020	Dual	149.460	160	900_230000237470	Lawrence	US
Shad	M	467	5/16/2020	Dual	149.460	161	900_230000237488	Lawrence	US
Shad	M	475	5/16/2020	Dual	149.480	10	900_230000237487	Lawrence	US
Shad	M	490	5/16/2020	Dual	149.480	11	900_230000237486	Lawrence	US
Shad	M	445	5/16/2020	Dual	149.480	12	900_230000237485	Lawrence	US
Shad	M	500	5/16/2020	Dual	149.480	13	900_230000237484	Lawrence	US
Shad	M	474	5/16/2020	Dual	149.480	14	900_230000237483	Lawrence	US
Shad	M	495	5/16/2020	Dual	149.480	15	900_230000237482	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	M	456	5/16/2020	Dual	149.760	46	900_230000237481	Lawrence	US
Shad	F	480	5/16/2020	Dual	149.760	47	900_230000237480	Lawrence	US
Shad	M	467	5/16/2020	Dual	149.760	48	900_230000237499	Lawrence	US
Shad	F	493	5/16/2020	Dual	149.760	49	900_230000237498	Lawrence	US
Shad	M	482	5/16/2020	Dual	149.760	50	900_230000237497	Lawrence	US
Shad	M	525	5/16/2020	Dual	149.760	51	900_230000237496	Lawrence	US
Shad	M	457	5/16/2020	Dual	149.800	83	900_230000237459	Lawrence	US
Shad	M	494	5/16/2020	Dual	149.800	84	900_230000237458	Lawrence	US
Shad	M	492	5/16/2020	Dual	149.800	85	900_230000237457	Lawrence	US
Shad	M	501	5/16/2020	Dual	149.800	86	900_230000237455	Lawrence	US
Shad	M	497	5/16/2020	Dual	149.800	87	900_230000237453	Lawrence	US
Shad	M	484	5/16/2020	Dual	149.800	88	900_230000237451	Lawrence	US
Shad	M	400	5/16/2020	PIT	-	-	900_230000237606	Lawrence	US
Shad	M	426	5/16/2020	PIT	-	-	900_230000237607	Lawrence	US
Shad	M	441	5/16/2020	PIT	-	-	900_230000237491	Lawrence	US
Shad	M	441	5/16/2020	PIT	-	-	900_230000237605	Lawrence	US
Shad	M	452	5/16/2020	PIT	-	-	900_230000237495	Lawrence	US
Shad	M	452	5/16/2020	PIT	-	-	900_230000237611	Lawrence	US
Shad	M	455	5/16/2020	PIT	-	-	900_230000237494	Lawrence	US
Shad	M	465	5/16/2020	PIT	-	-	900_230000237600	Lawrence	US
Shad	M	468	5/16/2020	PIT	-	-	900_230000237610	Lawrence	US
Shad	M	469	5/16/2020	PIT	-	-	900_230000237612	Lawrence	US
Shad	M	472	5/16/2020	PIT	-	-	900_230000237490	Lawrence	US
Shad	M	474	5/16/2020	PIT	-	-	900_230000237601	Lawrence	US
Shad	M	485	5/16/2020	PIT	-	-	900_230000237604	Lawrence	US
Shad	M	490	5/16/2020	PIT	-	-	900_230000237603	Lawrence	US
Shad	M	491	5/16/2020	PIT	-	-	900_230000237608	Lawrence	US
Shad	F	502	5/16/2020	PIT	-	-	900_230000237493	Lawrence	US
Shad	F	510	5/16/2020	PIT	-	-	900_230000237489	Lawrence	US
Shad	F	511	5/16/2020	PIT	-	-	900_230000237492	Lawrence	US
Shad	F	532	5/16/2020	PIT	-	-	900_230000237309	Lawrence	US
Shad	F	545	5/16/2020	PIT	-	-	900_230000237602	Lawrence	US
Shad	M	472	5/18/2020	Dual	149.440	127	900_230000237820	Lawrence	US
Shad	M	432	5/18/2020	Dual	149.440	128	900_230000237817	Lawrence	US
Shad	U	535	5/18/2020	Dual	149.440	129	900_230000237814	Lawrence	US
Shad	M	462	5/18/2020	Dual	149.440	130	900_230000237813	Lawrence	US
Shad	U	497	5/18/2020	Dual	149.440	131	900_230000237810	Lawrence	US
Shad	F	545	5/18/2020	Dual	149.440	132	900_230000237808	Lawrence	US
Shad	F	470	5/18/2020	Dual	149.460	162	900_230000237827	Lawrence	US
Shad	M	440	5/18/2020	Dual	149.460	163	900_230000237826	Lawrence	US
Shad	M	505	5/18/2020	Dual	149.460	164	900_230000237825	Lawrence	US
Shad	F	533	5/18/2020	Dual	149.460	165	900_230000237824	Lawrence	US
Shad	M	480	5/18/2020	Dual	149.460	166	900_230000237823	Lawrence	US
Shad	M	470	5/18/2020	Dual	149.460	167	900_230000237822	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	U	445	5/18/2020	Dual	149.480	16	900_230000237833	Lawrence	US
Shad	F	520	5/18/2020	Dual	149.480	17	900_230000237832	Lawrence	US
Shad	M	473	5/18/2020	Dual	149.480	18	900_230000237831	Lawrence	US
Shad	M	467	5/18/2020	Dual	149.480	19	900_230000237830	Lawrence	US
Shad	M	520	5/18/2020	Dual	149.480	20	900_230000237829	Lawrence	US
Shad	F	515	5/18/2020	Dual	149.480	21	900_230000237828	Lawrence	US
Shad	M	468	5/18/2020	Dual	149.760	52	900_230000237838	Lawrence	US
Shad	M	455	5/18/2020	Dual	149.760	53	900_230000237837	Lawrence	US
Shad	M	460	5/18/2020	Dual	149.760	54	900_230000237836	Lawrence	US
Shad	M	483	5/18/2020	Dual	149.760	55	900_230000237835	Lawrence	US
Shad	M	445	5/18/2020	Dual	149.760	56	900_230000237834	Lawrence	US
Shad	F	515	5/18/2020	Dual	149.760	57	900_230000237839	Lawrence	US
Shad	M	453	5/18/2020	Dual	149.800	89	900_230000237845	Lawrence	US
Shad	M	461	5/18/2020	Dual	149.800	90	900_230000237844	Lawrence	US
Shad	M	466	5/18/2020	Dual	149.800	91	900_230000237843	Lawrence	US
Shad	M	483	5/18/2020	Dual	149.800	92	900_230000237842	Lawrence	US
Shad	F	558	5/18/2020	Dual	149.800	93	900_230000237841	Lawrence	US
Shad	M	486	5/18/2020	Dual	149.800	94	900_230000237840	Lawrence	US
Shad	M	404	5/18/2020	PIT	-	-	900_230000237887	Lawrence	US
Shad	M	413	5/18/2020	PIT	-	-	900_230000237849	Lawrence	US
Shad	M	418	5/18/2020	PIT	-	-	900_230000237503	Lawrence	US
Shad	M	429	5/18/2020	PIT	-	-	900_230000237882	Lawrence	US
Shad	M	433	5/18/2020	PIT	-	-	900_230000237502	Lawrence	US
Shad	M	445	5/18/2020	PIT	-	-	900_230000237878	Lawrence	US
Shad	M	445	5/18/2020	PIT	-	-	900_230000237886	Lawrence	US
Shad	M	447	5/18/2020	PIT	-	-	900_230000237501	Lawrence	US
Shad	M	449	5/18/2020	PIT	-	-	900_230000237897	Lawrence	US
Shad	U	450	5/18/2020	PIT	-	-	900_230000237884	Lawrence	US
Shad	M	451	5/18/2020	PIT	-	-	900_230000237891	Lawrence	US
Shad	M	452	5/18/2020	PIT	-	-	900_230000237890	Lawrence	US
Shad	M	453	5/18/2020	PIT	-	-	900_230000237894	Lawrence	US
Shad	M	455	5/18/2020	PIT	-	-	900_230000237888	Lawrence	US
Shad	M	456	5/18/2020	PIT	-	-	900_230000237867	Lawrence	US
Shad	M	456	5/18/2020	PIT	-	-	900_230000237880	Lawrence	US
Shad	M	457	5/18/2020	PIT	-	-	900_230000237500	Lawrence	US
Shad	M	458	5/18/2020	PIT	-	-	900_230000237881	Lawrence	US
Shad	M	462	5/18/2020	PIT	-	-	900_230000237879	Lawrence	US
Shad	M	465	5/18/2020	PIT	-	-	900_230000237868	Lawrence	US
Shad	M	467	5/18/2020	PIT	-	-	900_230000237893	Lawrence	US
Shad	F	468	5/18/2020	PIT	-	-	900_230000237870	Lawrence	US
Shad	M	469	5/18/2020	PIT	-	-	900_230000237885	Lawrence	US
Shad	M	470	5/18/2020	PIT	-	-	900_230000237852	Lawrence	US
Shad	M	472	5/18/2020	PIT	-	-	900_230000237895	Lawrence	US
Shad	M	474	5/18/2020	PIT	-	-	900_230000237856	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	M	480	5/18/2020	PIT	-	-	900_230000237877	Lawrence	US
Shad	M	481	5/18/2020	PIT	-	-	900_230000237899	Lawrence	US
Shad	M	485	5/18/2020	PIT	-	-	900_230000237874	Lawrence	US
Shad	F	490	5/18/2020	PIT	-	-	900_230000237853	Lawrence	US
Shad	M	493	5/18/2020	PIT	-	-	900_230000237847	Lawrence	US
Shad	M	493	5/18/2020	PIT	-	-	900_230000237855	Lawrence	US
Shad	M	493	5/18/2020	PIT	-	-	900_230000237876	Lawrence	US
Shad	F	494	5/18/2020	PIT	-	-	900_230000237898	Lawrence	US
Shad	F	495	5/18/2020	PIT	-	-	900_230000237851	Lawrence	US
Shad	F	498	5/18/2020	PIT	-	-	900_230000237883	Lawrence	US
Shad	M	499	5/18/2020	PIT	-	-	900_230000237892	Lawrence	US
Shad	F	500	5/18/2020	PIT	-	-	900_230000237875	Lawrence	US
Shad	M	505	5/18/2020	PIT	-	-	900_230000237896	Lawrence	US
Shad	F	510	5/18/2020	PIT	-	-	900_230000237872	Lawrence	US
Shad	M	511	5/18/2020	PIT	-	-	900_230000237871	Lawrence	US
Shad	M	518	5/18/2020	PIT	-	-	900_230000237889	Lawrence	US
Shad	F	521	5/18/2020	PIT	-	-	900_230000237850	Lawrence	US
Shad	M	527	5/18/2020	PIT	-	-	900_230000237869	Lawrence	US
Shad	F	530	5/18/2020	PIT	-	-	900_230000237854	Lawrence	US
Shad	M	535	5/18/2020	PIT	-	-	900_230000237848	Lawrence	US
Shad	M	540	5/18/2020	PIT	-	-	900_230000237873	Lawrence	US
Shad	M	466	5/18/2020	PIT			900_230000237857	Lawrence	US
Shad	F	573	5/22/2020	Dual	149.440	133	900_23000023879	Lawrence	US
Shad	F	543	5/22/2020	Dual	149.440	134	900_23000023878	Lawrence	US
Shad	M	453	5/22/2020	Dual	149.440	135	900_23000023877	Lawrence	US
Shad	M	445	5/22/2020	Dual	149.440	136	900_23000023876	Lawrence	US
Shad	M	509	5/22/2020	Dual	149.440	137	900_23000023875	Lawrence	US
Shad	M	510	5/22/2020	Dual	149.440	138	900_23000023874	Lawrence	US
Shad	F	504	5/22/2020	Dual	149.460	168	900_23000023885	Lawrence	US
Shad	U	482	5/22/2020	Dual	149.460	169	900_23000023884	Lawrence	US
Shad	F	457	5/22/2020	Dual	149.460	170	900_23000023883	Lawrence	US
Shad	M	470	5/22/2020	Dual	149.460	171	900_23000023882	Lawrence	US
Shad	M	469	5/22/2020	Dual	149.460	172	900_23000023881	Lawrence	US
Shad	F	540	5/22/2020	Dual	149.460	173	900_23000023880	Lawrence	US
Shad	M	538	5/22/2020	Dual	149.480	22	900_23000023892	Lawrence	US
Shad	M	467	5/22/2020	Dual	149.480	23	900_23000023891	Lawrence	US
Shad	F	531	5/22/2020	Dual	149.480	24	900_23000023890	Lawrence	US
Shad	M	485	5/22/2020	Dual	149.480	25	900_23000023888	Lawrence	US
Shad	M	468	5/22/2020	Dual	149.480	26	900_23000023887	Lawrence	US
Shad	F	511	5/22/2020	Dual	149.480	27	900_23000023886	Lawrence	US
Shad	M	448	5/22/2020	Dual	149.760	58	900_23000023899	Lawrence	US
Shad	M	493	5/22/2020	Dual	149.760	59	900_23000023898	Lawrence	US
Shad	M	480	5/22/2020	Dual	149.760	60	900_23000023897	Lawrence	US
Shad	M	460	5/22/2020	Dual	149.760	61	900_23000023896	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	M	428	5/22/2020	Dual	149.760	62	900_23000023895	Lawrence	US
Shad	M	480	5/22/2020	Dual	149.760	63	900_23000023893	Lawrence	US
Shad	M	467	5/22/2020	Dual	149.800	95	900_230000238100	Lawrence	US
Shad	M	478	5/22/2020	Dual	149.800	96	900_230000238101	Lawrence	US
Shad	M	448	5/22/2020	Dual	149.800	97	900_230000238103	Lawrence	US
Shad	M	486	5/22/2020	Dual	149.800	98	900_230000238104	Lawrence	US
Shad	F	475	5/22/2020	Dual	149.800	99	900_230000238105	Lawrence	US
Shad	M	495	5/22/2020	Dual	149.800	100	900_230000238106	Lawrence	US
Shad	M	423	5/22/2020	PIT	-	-	900_230000238113	Lawrence	US
Shad	M	433	5/22/2020	PIT	-	-	900_230000238122	Lawrence	US
Shad	M	434	5/22/2020	PIT	-	-	900_230000238129	Lawrence	US
Shad	M	440	5/22/2020	PIT	-	-	900_230000238110	Lawrence	US
Shad	M	447	5/22/2020	PIT	-	-	900_230000238109	Lawrence	US
Shad	M	448	5/22/2020	PIT	-	-	900_23000023873	Lawrence	US
Shad	M	453	5/22/2020	PIT	-	-	900_230000238128	Lawrence	US
Shad	M	453	5/22/2020	PIT	-	-	900_230000238131	Lawrence	US
Shad	M	454	5/22/2020	PIT	-	-	900_230000238134	Lawrence	US
Shad	M	455	5/22/2020	PIT	-	-	900_23000023889	Lawrence	US
Shad	M	456	5/22/2020	PIT	-	-	900_230000238119	Lawrence	US
Shad	M	457	5/22/2020	PIT	-	-	900_230000238125	Lawrence	US
Shad	M	457	5/22/2020	PIT	-	-	900_230000238133	Lawrence	US
Shad	M	465	5/22/2020	PIT	-	-	900_230000238117	Lawrence	US
Shad	M	468	5/22/2020	PIT	-	-	900_230000238116	Lawrence	US
Shad	M	468	5/22/2020	PIT	-	-	900_230000238121	Lawrence	US
Shad	M	468	5/22/2020	PIT	-	-	900_230000238132	Lawrence	US
Shad	M	470	5/22/2020	PIT	-	-	900_230000238124	Lawrence	US
Shad	M	470	5/22/2020	PIT	-	-	900_230000238127	Lawrence	US
Shad	M	475	5/22/2020	PIT	-	-	900_230000238107	Lawrence	US
Shad	M	478	5/22/2020	PIT	-	-	900_230000238123	Lawrence	US
Shad	M	482	5/22/2020	PIT	-	-	900_230000238112	Lawrence	US
Shad	M	482	5/22/2020	PIT	-	-	900_230000238130	Lawrence	US
Shad	M	483	5/22/2020	PIT	-	-	900_230000238120	Lawrence	US
Shad	M	487	5/22/2020	PIT	-	-	900_230000238136	Lawrence	US
Shad	M	506	5/22/2020	PIT	-	-	900_230000238118	Lawrence	US
Shad	M	513	5/22/2020	PIT	-	-	900_230000238108	Lawrence	US
Shad	M	520	5/22/2020	PIT	-	-	900_230000238102	Lawrence	US
Shad	F	520	5/22/2020	PIT	-	-	900_230000238126	Lawrence	US
Shad	M	525	5/22/2020	PIT	-	-	900_230000238111	Lawrence	US
Shad	F	531	5/22/2020	PIT	-	-	900_23000023894	Lawrence	US
Shad	M	532	5/22/2020	PIT	-	-	900_230000238114	Lawrence	US
Shad	M	554	5/22/2020	PIT	-	-	900_230000238115	Lawrence	US
Shad	M	560	5/22/2020	PIT	-	-	900_230000238135	Lawrence	US
Shad	M	482	5/26/2020	Dual	149.440	145	900_230000238137	Lawrence	US
Shad	M	484	5/26/2020	Dual	149.440	146	900_230000238138	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	M	450	5/26/2020	Dual	149.440	147	900_230000238139	Lawrence	US
Shad	M	465	5/26/2020	Dual	149.440	148	900_230000238140	Lawrence	US
Shad	F	510	5/26/2020	Dual	149.440	149	900_230000238141	Lawrence	US
Shad	M	484	5/26/2020	Dual	149.440	150	900_230000238142	Lawrence	US
Shad	M	498	5/26/2020	Dual	149.440	151	900_230000238205	Lawrence	US
Shad	M	478	5/26/2020	Dual	149.440	152	900_230000238204	Lawrence	US
Shad	M	462	5/26/2020	Dual	149.440	153	900_230000238203	Lawrence	US
Shad	F	525	5/26/2020	Dual	149.440	154	900_230000238202	Lawrence	US
Shad	M	462	5/26/2020	Dual	149.440	155	900_230000238201	Lawrence	US
Shad	M	478	5/26/2020	Dual	149.440	156	900_230000238200	Lawrence	US
Shad	M	492	5/26/2020	Dual	149.460	180	900_230000238143	Lawrence	US
Shad	F	536	5/26/2020	Dual	149.460	181	900_230000238144	Lawrence	US
Shad	F	535	5/26/2020	Dual	149.460	182	900_230000238145	Lawrence	US
Shad	F	495	5/26/2020	Dual	149.460	183	900_230000238146	Lawrence	US
Shad	M	440	5/26/2020	Dual	149.460	184	900_230000238147	Lawrence	US
Shad	M	461	5/26/2020	Dual	149.460	185	900_230000238148	Lawrence	US
Shad	M	468	5/26/2020	Dual	149.460	186	900_230000238211	Lawrence	US
Shad	M	444	5/26/2020	Dual	149.460	187	900_230000238210	Lawrence	US
Shad	F	496	5/26/2020	Dual	149.460	188	900_230000238209	Lawrence	US
Shad	M	456	5/26/2020	Dual	149.460	189	900_230000238208	Lawrence	US
Shad	M	452	5/26/2020	Dual	149.460	190	900_230000238207	Lawrence	US
Shad	M	458	5/26/2020	Dual	149.460	191	900_230000238206	Lawrence	US
Shad	M	478	5/26/2020	Dual	149.480	34	900_230000238149	Lawrence	US
Shad	M	444	5/26/2020	Dual	149.480	35	900_230000238150	Lawrence	US
Shad	M	445	5/26/2020	Dual	149.480	36	900_230000238152	Lawrence	US
Shad	M	460	5/26/2020	Dual	149.480	37	900_230000238153	Lawrence	US
Shad	F	549	5/26/2020	Dual	149.480	38	900_230000238154	Lawrence	US
Shad	F	532	5/26/2020	Dual	149.480	39	900_230000238155	Lawrence	US
Shad	M	438	5/26/2020	Dual	149.480	40	900_230000238217	Lawrence	US
Shad	M	485	5/26/2020	Dual	149.480	41	900_230000238216	Lawrence	US
Shad	M	433	5/26/2020	Dual	149.480	42	900_230000238215	Lawrence	US
Shad	F	520	5/26/2020	Dual	149.480	43	900_230000238214	Lawrence	US
Shad	M	485	5/26/2020	Dual	149.480	44	900_230000238213	Lawrence	US
Shad	M	533	5/26/2020	Dual	149.480	45	900_230000238212	Lawrence	US
Shad	M	467	5/26/2020	Dual	149.760	70	900_230000238156	Lawrence	US
Shad	F	540	5/26/2020	Dual	149.760	71	900_230000238157	Lawrence	US
Shad	M	480	5/26/2020	Dual	149.760	72	900_230000238158	Lawrence	US
Shad	M	536	5/26/2020	Dual	149.760	74	900_230000238159	Lawrence	US
Shad	M	478	5/26/2020	Dual	149.760	75	900_230000238160	Lawrence	US
Shad	M	463	5/26/2020	Dual	149.760	76	900_230000238223	Lawrence	US
Shad	M	476	5/26/2020	Dual	149.760	77	900_230000238222	Lawrence	US
Shad	F	559	5/26/2020	Dual	149.760	78	900_230000238221	Lawrence	US
Shad	M	450	5/26/2020	Dual	149.760	79	900_230000238220	Lawrence	US
Shad	M	475	5/26/2020	Dual	149.760	80	900_230000238219	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	F	505	5/26/2020	Dual	149.760	81	900_230000238218	Lawrence	US
Shad	M	451	5/26/2020	Dual	149.800	107	900_230000238161	Lawrence	US
Shad	M	477	5/26/2020	Dual	149.800	110	900_230000238164	Lawrence	US
Shad	M	469	5/26/2020	Dual	149.800	111	900_230000238165	Lawrence	US
Shad	M	450	5/26/2020	Dual	149.800	112	900_230000238166	Lawrence	US
Shad	F	501	5/26/2020	Dual	149.800	113	900_230000238229	Lawrence	US
Shad	M	492	5/26/2020	Dual	149.800	114	900_230000238228	Lawrence	US
Shad	M	480	5/26/2020	Dual	149.800	115	900_230000238227	Lawrence	US
Shad	M	492	5/26/2020	Dual	149.800	116	900_230000238226	Lawrence	US
Shad	M	441	5/26/2020	Dual	149.800	117	900_230000238225	Lawrence	US
Shad	M	462	5/26/2020	Dual	149.800	118	900_230000238224	Lawrence	US
Shad	M	475	5/26/2020	Dual	149.800	708	900_230000238162	Lawrence	US
Shad	U	475	5/26/2020	Dual	149.800	709	900_230000238163	Lawrence	US
Shad	M	430	5/26/2020	PIT	-	-	900_230000238246	Lawrence	US
Shad	M	435	5/26/2020	PIT	-	-	900_230000238176	Lawrence	US
Shad	M	438	5/26/2020	PIT	-	-	900_230000238232	Lawrence	US
Shad	M	440	5/26/2020	PIT	-	-	900_230000238234	Lawrence	US
Shad	M	441	5/26/2020	PIT	-	-	900_230000238187	Lawrence	US
Shad	M	450	5/26/2020	PIT	-	-	900_230000238241	Lawrence	US
Shad	U	455	5/26/2020	PIT	-	-	900_230000238235	Lawrence	US
Shad	M	455	5/26/2020	PIT	-	-	900_230000238253	Lawrence	US
Shad	M	456	5/26/2020	PIT	-	-	900_230000238189	Lawrence	US
Shad	M	457	5/26/2020	PIT	-	-	900_230000238182	Lawrence	US
Shad	M	457	5/26/2020	PIT	-	-	900_230000238259	Lawrence	US
Shad	M	460	5/26/2020	PIT	-	-	900_230000238172	Lawrence	US
Shad	U	460	5/26/2020	PIT	-	-	900_230000238180	Lawrence	US
Shad	U	460	5/26/2020	PIT	-	-	900_230000238240	Lawrence	US
Shad	M	460	5/26/2020	PIT	-	-	900_230000238257	Lawrence	US
Shad	M	461	5/26/2020	PIT	-	-	900_230000238258	Lawrence	US
Shad	M	462	5/26/2020	PIT	-	-	900_230000238186	Lawrence	US
Shad	M	463	5/26/2020	PIT	-	-	900_230000238195	Lawrence	US
Shad	M	463	5/26/2020	PIT	-	-	900_230000238254	Lawrence	US
Shad	F	464	5/26/2020	PIT	-	-	900_230000238247	Lawrence	US
Shad	M	465	5/26/2020	PIT	-	-	900_230000238173	Lawrence	US
Shad	F	465	5/26/2020	PIT	-	-	900_230000238190	Lawrence	US
Shad	M	465	5/26/2020	PIT	-	-	900_230000238196	Lawrence	US
Shad	M	465	5/26/2020	PIT	-	-	900_230000238249	Lawrence	US
Shad	M	465	5/26/2020	PIT	-	-	900_230000238255	Lawrence	US
Shad	M	466	5/26/2020	PIT	-	-	900_230000238250	Lawrence	US
Shad	U	467	5/26/2020	PIT	-	-	900_230000238239	Lawrence	US
Shad	M	470	5/26/2020	PIT	-	-	900_230000238233	Lawrence	US
Shad	M	472	5/26/2020	PIT	-	-	900_230000238260	Lawrence	US
Shad	M	473	5/26/2020	PIT	-	-	900_230000238245	Lawrence	US
Shad	M	474	5/26/2020	PIT	-	-	900_230000238178	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	M	474	5/26/2020	PIT	-	-	900_230000238236	Lawrence	US
Shad	M	475	5/26/2020	PIT	-	-	900_230000238177	Lawrence	US
Shad	M	477	5/26/2020	PIT	-	-	900_230000238151	Lawrence	US
Shad	M	477	5/26/2020	PIT	-	-	900_230000238168	Lawrence	US
Shad	U	477	5/26/2020	PIT	-	-	900_230000238185	Lawrence	US
Shad	M	477	5/26/2020	PIT	-	-	900_230000238248	Lawrence	US
Shad	M	478	5/26/2020	PIT	-	-	900_230000238192	Lawrence	US
Shad	M	479	5/26/2020	PIT	-	-	900_230000238181	Lawrence	US
Shad	M	480	5/26/2020	PIT	-	-	900_230000238238	Lawrence	US
Shad	M	481	5/26/2020	PIT	-	-	900_230000238263	Lawrence	US
Shad	M	482	5/26/2020	PIT	-	-	900_230000238243	Lawrence	US
Shad	M	484	5/26/2020	PIT	-	-	900_230000238194	Lawrence	US
Shad	M	485	5/26/2020	PIT	-	-	900_230000238174	Lawrence	US
Shad	M	485	5/26/2020	PIT	-	-	900_230000238184	Lawrence	US
Shad	M	485	5/26/2020	PIT	-	-	900_230000238256	Lawrence	US
Shad	U	487	5/26/2020	PIT	-	-	900_230000238198	Lawrence	US
Shad	F	489	5/26/2020	PIT	-	-	900_230000238197	Lawrence	US
Shad	F	490	5/26/2020	PIT	-	-	900_230000238231	Lawrence	US
Shad	F	490	5/26/2020	PIT	-	-	900_230000238242	Lawrence	US
Shad	M	490	5/26/2020	PIT	-	-	900_230000238262	Lawrence	US
Shad	F	492	5/26/2020	PIT	-	-	900_230000238244	Lawrence	US
Shad	F	498	5/26/2020	PIT	-	-	900_230000238167	Lawrence	US
Shad	U	498	5/26/2020	PIT	-	-	900_230000238170	Lawrence	US
Shad	F	500	5/26/2020	PIT	-	-	900_230000238199	Lawrence	US
Shad	F	504	5/26/2020	PIT	-	-	900_230000238191	Lawrence	US
Shad	M	504	5/26/2020	PIT	-	-	900_230000238230	Lawrence	US
Shad	U	507	5/26/2020	PIT	-	-	900_230000238183	Lawrence	US
Shad	F	510	5/26/2020	PIT	-	-	900_230000238175	Lawrence	US
Shad	U	512	5/26/2020	PIT	-	-	900_230000238193	Lawrence	US
Shad	F	513	5/26/2020	PIT	-	-	900_230000238237	Lawrence	US
Shad	U	515	5/26/2020	PIT	-	-	900_230000238169	Lawrence	US
Shad	F	515	5/26/2020	PIT	-	-	900_230000238261	Lawrence	US
Shad	F	518	5/26/2020	PIT	-	-	900_230000238188	Lawrence	US
Shad	F	518	5/26/2020	PIT	-	-	900_230000238251	Lawrence	US
Shad	F	518	5/26/2020	PIT	-	-	900_230000238252	Lawrence	US
Shad	F	520	5/26/2020	PIT	-	-	900_230000238179	Lawrence	US
Shad	F	536	5/26/2020	PIT	-	-	900_230000238171	Lawrence	US
Shad	F	503	5/27/2020	Dual	149.440	139	900_230000238269	Lawrence	US
Shad	M	469	5/27/2020	Dual	149.440	140	900_230000238268	Lawrence	US
Shad	M	483	5/27/2020	Dual	149.440	141	900_230000238267	Lawrence	US
Shad	M	470	5/27/2020	Dual	149.440	142	900_230000238266	Lawrence	US
Shad	M	519	5/27/2020	Dual	149.440	143	900_230000238265	Lawrence	US
Shad	U	482	5/27/2020	Dual	149.440	144	900_230000238264	Lawrence	US
Shad	U	516	5/27/2020	Dual	149.460	174	900_230000238275	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	M	464	5/27/2020	Dual	149.460	175	900_230000238274	Lawrence	US
Shad	F	522	5/27/2020	Dual	149.460	176	900_230000238273	Lawrence	US
Shad	M	443	5/27/2020	Dual	149.460	177	900_230000238272	Lawrence	US
Shad	M	483	5/27/2020	Dual	149.460	178	900_230000238271	Lawrence	US
Shad	M	480	5/27/2020	Dual	149.460	179	900_230000238270	Lawrence	US
Shad	M	460	5/27/2020	Dual	149.480	28	900_230000238281	Lawrence	US
Shad	M	466	5/27/2020	Dual	149.480	29	900_230000238280	Lawrence	US
Shad	M	469	5/27/2020	Dual	149.480	30	900_230000238279	Lawrence	US
Shad	M	444	5/27/2020	Dual	149.480	31	900_230000238278	Lawrence	US
Shad	F	500	5/27/2020	Dual	149.480	32	900_230000238277	Lawrence	US
Shad	M	492	5/27/2020	Dual	149.480	33	900_230000238276	Lawrence	US
Shad	M	472	5/27/2020	Dual	149.760	64	900_230000238287	Lawrence	US
Shad	U	504	5/27/2020	Dual	149.760	65	900_230000238286	Lawrence	US
Shad	M	471	5/27/2020	Dual	149.760	66	900_230000238285	Lawrence	US
Shad	F	509	5/27/2020	Dual	149.760	67	900_230000238284	Lawrence	US
Shad	M	440	5/27/2020	Dual	149.760	68	900_230000238283	Lawrence	US
Shad	M	485	5/27/2020	Dual	149.760	69	900_230000238282	Lawrence	US
Shad	M	467	5/27/2020	Dual	149.760	73	900_230000238294	Lawrence	US
Shad	F	533	5/27/2020	Dual	149.800	101	900_230000238293	Lawrence	US
Shad	F	542	5/27/2020	Dual	149.800	102	900_230000238292	Lawrence	US
Shad	M	463	5/27/2020	Dual	149.800	103	900_230000238291	Lawrence	US
Shad	M	488	5/27/2020	Dual	149.800	104	900_230000238290	Lawrence	US
Shad	M	413	5/27/2020	Dual	149.800	105	900_230000238289	Lawrence	US
Shad	M	480	5/27/2020	Dual	149.800	106	900_230000238288	Lawrence	US
Shad	M	460	5/27/2020	PIT	-	-	900_230000238312	Lawrence	US
Shad	M	410	5/27/2020	PIT	-	-	900_230000238311	Lawrence	US
Shad	M	419	5/27/2020	PIT	-	-	900_230000238307	Lawrence	US
Shad	M	420	5/27/2020	PIT	-	-	900_230000238303	Lawrence	US
Shad	M	420	5/27/2020	PIT	-	-	900_230000238323	Lawrence	US
Shad	M	434	5/27/2020	PIT	-	-	900_230000238316	Lawrence	US
Shad	M	438	5/27/2020	PIT	-	-	900_230000238327	Lawrence	US
Shad	M	440	5/27/2020	PIT	-	-	900_230000238325	Lawrence	US
Shad	M	456	5/27/2020	PIT	-	-	900_230000238317	Lawrence	US
Shad	M	458	5/27/2020	PIT	-	-	900_230000238309	Lawrence	US
Shad	M	460	5/27/2020	PIT	-	-	900_230000238295	Lawrence	US
Shad	M	462	5/27/2020	PIT	-	-	900_230000238308	Lawrence	US
Shad	F	471	5/27/2020	PIT	-	-	900_230000238320	Lawrence	US
Shad	M	472	5/27/2020	PIT	-	-	900_230000238296	Lawrence	US
Shad	M	474	5/27/2020	PIT	-	-	900_230000238299	Lawrence	US
Shad	M	476	5/27/2020	PIT	-	-	900_230000238313	Lawrence	US
Shad	M	477	5/27/2020	PIT	-	-	900_230000238298	Lawrence	US
Shad	M	480	5/27/2020	PIT	-	-	900_230000238301	Lawrence	US
Shad	M	480	5/27/2020	PIT	-	-	900_230000238310	Lawrence	US
Shad	M	480	5/27/2020	PIT	-	-	900_230000238322	Lawrence	US

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	F	482	5/27/2020	PIT	-	-	900_230000238314	Lawrence	US
Shad	U	489	5/27/2020	PIT	-	-	900_230000238321	Lawrence	US
Shad	F	490	5/27/2020	PIT	-	-	900_230000238328	Lawrence	US
Shad	F	491	5/27/2020	PIT	-	-	900_230000238305	Lawrence	US
Shad	M	495	5/27/2020	PIT	-	-	900_230000238300	Lawrence	US
Shad	F	500	5/27/2020	PIT	-	-	900_230000238319	Lawrence	US
Shad	U	500	5/27/2020	PIT	-	-	900_230000238326	Lawrence	US
Shad	F	504	5/27/2020	PIT	-	-	900_230000238318	Lawrence	US
Shad	U	506	5/27/2020	PIT	-	-	900_230000238315	Lawrence	US
Shad	F	506	5/27/2020	PIT	-	-	900_230000238324	Lawrence	US
Shad	M	510	5/27/2020	PIT	-	-	900_230000238302	Lawrence	US
Shad	F	510	5/27/2020	PIT	-	-	900_230000238306	Lawrence	US
Shad	M	519	5/27/2020	PIT	-	-	900_230000238297	Lawrence	US
Shad	F	540	5/27/2020	PIT	-	-	900_230000238304	Lawrence	US
Shad	M	494	6/3/2020	Radio	149.440	77	-	Lawrence	DS
Shad	F	504	6/3/2020	Radio	149.440	78	-	Lawrence	DS
Shad	M	460	6/3/2020	Radio	149.440	79	-	Lawrence	DS
Shad	F	497	6/3/2020	Radio	149.440	80	-	Lawrence	DS
Shad	F	508	6/3/2020	Radio	149.440	81	-	Lawrence	DS
Shad	M	472	6/3/2020	Radio	149.440	82	-	Lawrence	DS
Shad	M	436	6/3/2020	Radio	149.440	83	-	Lawrence	DS
Shad	F	512	6/3/2020	Radio	149.440	84	-	Lawrence	DS
Shad	M	442	6/3/2020	Radio	149.440	87	-	Lawrence	DS
Shad	F	500	6/3/2020	Radio	149.440	88	-	Lawrence	DS
Shad	M	422	6/3/2020	Radio	149.460	97	-	Lawrence	DS
Shad	M	411	6/3/2020	Radio	149.460	98	-	Lawrence	DS
Shad	F	490	6/3/2020	Radio	149.460	99	-	Lawrence	DS
Shad	M	448	6/3/2020	Radio	149.460	100	-	Lawrence	DS
Shad	F	551	6/3/2020	Radio	149.460	101	-	Lawrence	DS
Shad	F	497	6/3/2020	Radio	149.460	102	-	Lawrence	DS
Shad	F	505	6/3/2020	Radio	149.460	103	-	Lawrence	DS
Shad	M	446	6/3/2020	Radio	149.460	104	-	Lawrence	DS
Shad	M	493	6/3/2020	Radio	149.460	107	-	Lawrence	DS
Shad	F	490	6/3/2020	Radio	149.460	108	-	Lawrence	DS
Shad	M	463	6/3/2020	Radio	149.480	161	-	Lawrence	DS
Shad	M	466	6/3/2020	Radio	149.480	162	-	Lawrence	DS
Shad	U	463	6/3/2020	Radio	149.480	163	-	Lawrence	DS
Shad	F	542	6/3/2020	Radio	149.480	164	-	Lawrence	DS
Shad	F	503	6/3/2020	Radio	149.480	165	-	Lawrence	DS
Shad	F	445	6/3/2020	Radio	149.480	166	-	Lawrence	DS
Shad	M	476	6/3/2020	Radio	149.480	167	-	Lawrence	DS
Shad	F	505	6/3/2020	Radio	149.480	168	-	Lawrence	DS
Shad	M	500	6/3/2020	Radio	149.480	171	-	Lawrence	DS
Shad	M	413	6/3/2020	Radio	149.480	172	-	Lawrence	DS

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	M	436	6/3/2020	Radio	149.760	25	-	Lawrence	DS
Shad	F	521	6/3/2020	Radio	149.760	26	-	Lawrence	DS
Shad	M	485	6/3/2020	Radio	149.760	27	-	Lawrence	DS
Shad	M	453	6/3/2020	Radio	149.760	28	-	Lawrence	DS
Shad	M	440	6/3/2020	Radio	149.760	29	-	Lawrence	DS
Shad	U	498	6/3/2020	Radio	149.760	30	-	Lawrence	DS
Shad	M	435	6/3/2020	Radio	149.760	31	-	Lawrence	DS
Shad	M	459	6/3/2020	Radio	149.760	35	-	Lawrence	DS
Shad	M	455	6/3/2020	Radio	149.760	36	-	Lawrence	DS
Shad	F	550	6/3/2020	Radio	149.760	132	-	Lawrence	DS
Shad	M	455	6/3/2020	Radio	149.800	20	-	Lawrence	DS
Shad	M	422	6/3/2020	Radio	149.800	21	-	Lawrence	DS
Shad	U	510	6/3/2020	Radio	149.800	22	-	Lawrence	DS
Shad	F	470	6/3/2020	Radio	149.800	23	-	Lawrence	DS
Shad	F	506	6/3/2020	Radio	149.800	24	-	Lawrence	DS
Shad	M	444	6/3/2020	Radio	149.800	25	-	Lawrence	DS
Shad	M	445	6/3/2020	Radio	149.800	26	-	Lawrence	DS
Shad	F	495	6/3/2020	Radio	149.800	27	-	Lawrence	DS
Shad	M	482	6/3/2020	Radio	149.800	30	-	Lawrence	DS
Shad	M	521	6/3/2020	Radio	149.800	31	-	Lawrence	DS
Shad	M	500	6/5/2020	Radio	149.440	85	-	Lawrence	DS
Shad	M	422	6/5/2020	Radio	149.440	86	-	Lawrence	DS
Shad	M	493	6/5/2020	Radio	149.440	89	-	Lawrence	DS
Shad	M	425	6/5/2020	Radio	149.440	90	-	Lawrence	DS
Shad	M	488	6/5/2020	Radio	149.440	91	-	Lawrence	DS
Shad	M	481	6/5/2020	Radio	149.440	92	-	Lawrence	DS
Shad	M	500	6/5/2020	Radio	149.440	93	-	Lawrence	DS
Shad	M	425	6/5/2020	Radio	149.440	94	-	Lawrence	DS
Shad	M	445	6/5/2020	Radio	149.440	95	-	Lawrence	DS
Shad	F	527	6/5/2020	Radio	149.440	96	-	Lawrence	DS
Shad	F	494	6/5/2020	Radio	149.460	105	-	Lawrence	DS
Shad	M	490	6/5/2020	Radio	149.460	106	-	Lawrence	DS
Shad	M	444	6/5/2020	Radio	149.460	109	-	Lawrence	DS
Shad	M	502	6/5/2020	Radio	149.460	110	-	Lawrence	DS
Shad	M	443	6/5/2020	Radio	149.460	111	-	Lawrence	DS
Shad	F	530	6/5/2020	Radio	149.460	112	-	Lawrence	DS
Shad	M	471	6/5/2020	Radio	149.460	113	-	Lawrence	DS
Shad	M	393	6/5/2020	Radio	149.460	114	-	Lawrence	DS
Shad	M	465	6/5/2020	Radio	149.460	115	-	Lawrence	DS
Shad	F	501	6/5/2020	Radio	149.460	116	-	Lawrence	DS
Shad	U	481	6/5/2020	Radio	149.480	169	-	Lawrence	DS
Shad	M	413	6/5/2020	Radio	149.480	170	-	Lawrence	DS
Shad	F	528	6/5/2020	Radio	149.480	173	-	Lawrence	DS
Shad	M	520	6/5/2020	Radio	149.480	174	-	Lawrence	DS

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	F	459	6/5/2020	Radio	149.480	175	-	Lawrence	DS
Shad	U	502	6/5/2020	Radio	149.480	176	-	Lawrence	DS
Shad	M	437	6/5/2020	Radio	149.480	177	-	Lawrence	DS
Shad	M	481	6/5/2020	Radio	149.480	178	-	Lawrence	DS
Shad	M	472	6/5/2020	Radio	149.480	179	-	Lawrence	DS
Shad	F	530	6/5/2020	Radio	149.480	180	-	Lawrence	DS
Shad	M	490	6/5/2020	Radio	149.760	33	-	Lawrence	DS
Shad	M	465	6/5/2020	Radio	149.760	34	-	Lawrence	DS
Shad	M	457	6/5/2020	Radio	149.760	37	-	Lawrence	DS
Shad	M	385	6/5/2020	Radio	149.760	38	-	Lawrence	DS
Shad	M	500	6/5/2020	Radio	149.760	40	-	Lawrence	DS
Shad	M	475	6/5/2020	Radio	149.760	41	-	Lawrence	DS
Shad	M	508	6/5/2020	Radio	149.760	42	-	Lawrence	DS
Shad	M	482	6/5/2020	Radio	149.760	43	-	Lawrence	DS
Shad	M	475	6/5/2020	Radio	149.760	44	-	Lawrence	DS
Shad	F	505	6/5/2020	Radio	149.760	59	-	Lawrence	DS
Shad	M	475	6/5/2020	Radio	149.800	28	-	Lawrence	DS
Shad	M	468	6/5/2020	Radio	149.800	29	-	Lawrence	DS
Shad	M	492	6/5/2020	Radio	149.800	32	-	Lawrence	DS
Shad	U	526	6/5/2020	Radio	149.800	33	-	Lawrence	DS
Shad	F	470	6/5/2020	Radio	149.800	34	-	Lawrence	DS
Shad	F	486	6/5/2020	Radio	149.800	35	-	Lawrence	DS
Shad	F	508	6/5/2020	Radio	149.800	36	-	Lawrence	DS
Shad	F	545	6/5/2020	Radio	149.800	37	-	Lawrence	DS
Shad	M	460	6/5/2020	Radio	149.800	38	-	Lawrence	DS
Shad	M	432	6/5/2020	Radio	149.800	39	-	Lawrence	DS
Shad	F	530	6/8/2020	Radio	149.440	65	-	Lawrence	DS
Shad	F	481	6/8/2020	Radio	149.440	66	-	Lawrence	DS
Shad	F	532	6/8/2020	Radio	149.440	67	-	Lawrence	DS
Shad	F	518	6/8/2020	Radio	149.440	68	-	Lawrence	DS
Shad	F	490	6/8/2020	Radio	149.440	69	-	Lawrence	DS
Shad	M	496	6/8/2020	Radio	149.440	70	-	Lawrence	DS
Shad	M	452	6/8/2020	Radio	149.440	71	-	Lawrence	DS
Shad	M	476	6/8/2020	Radio	149.440	72	-	Lawrence	DS
Shad	F	538	6/8/2020	Radio	149.440	73	-	Lawrence	DS
Shad	F	530	6/8/2020	Radio	149.440	74	-	Lawrence	DS
Shad	F	505	6/8/2020	Radio	149.440	75	-	Lawrence	DS
Shad	M	393	6/8/2020	Radio	149.440	76	-	Lawrence	DS
Shad	F	525	6/8/2020	Radio	149.460	30	-	Lawrence	DS
Shad	M	450	6/8/2020	Radio	149.460	31	-	Lawrence	DS
Shad	F	552	6/8/2020	Radio	149.460	32	-	Lawrence	DS
Shad	M	452	6/8/2020	Radio	149.460	33	-	Lawrence	DS
Shad	F	556	6/8/2020	Radio	149.460	34	-	Lawrence	DS
Shad	F	553	6/8/2020	Radio	149.460	35	-	Lawrence	DS

Species	Gender	Total Length (mm)	Release Date	Type	Frequency	ID	PIT ID	Collection Location	US_DS
Shad	F	519	6/8/2020	Radio	149.460	36	-	Lawrence	DS
Shad	M	505	6/8/2020	Radio	149.460	37	-	Lawrence	DS
Shad	M	460	6/8/2020	Radio	149.460	38	-	Lawrence	DS
Shad	M	450	6/8/2020	Radio	149.460	39	-	Lawrence	DS
Shad	F	497	6/8/2020	Radio	149.460	117	-	Lawrence	DS
Shad	F	506	6/8/2020	Radio	149.460	118	-	Lawrence	DS
Shad	M	440	6/8/2020	Radio	149.480	181	-	Lawrence	DS
Shad	F	522	6/8/2020	Radio	149.480	182	-	Lawrence	DS
Shad	F	495	6/8/2020	Radio	149.480	183	-	Lawrence	DS
Shad	F	545	6/8/2020	Radio	149.480	184	-	Lawrence	DS
Shad	F	550	6/8/2020	Radio	149.480	185	-	Lawrence	DS
Shad	U	525	6/8/2020	Radio	149.480	186	-	Lawrence	DS
Shad	M	470	6/8/2020	Radio	149.480	187	-	Lawrence	DS
Shad	F	535	6/8/2020	Radio	149.480	188	-	Lawrence	DS
Shad	M	442	6/8/2020	Radio	149.480	189	-	Lawrence	DS
Shad	F	505	6/8/2020	Radio	149.480	190	-	Lawrence	DS
Shad	M	450	6/8/2020	Radio	149.480	191	-	Lawrence	DS
Shad	F	545	6/8/2020	Radio	149.480	192	-	Lawrence	DS
Shad	F	516	6/8/2020	Radio	149.760	14	-	Lawrence	DS
Shad	M	475	6/8/2020	Radio	149.760	15	-	Lawrence	DS
Shad	M	473	6/8/2020	Radio	149.760	16	-	Lawrence	DS
Shad	M	463	6/8/2020	Radio	149.760	17	-	Lawrence	DS
Shad	M	432	6/8/2020	Radio	149.760	18	-	Lawrence	DS
Shad	F	502	6/8/2020	Radio	149.760	19	-	Lawrence	DS
Shad	M	462	6/8/2020	Radio	149.760	20	-	Lawrence	DS
Shad	M	482	6/8/2020	Radio	149.760	21	-	Lawrence	DS
Shad	F	540	6/8/2020	Radio	149.760	22	-	Lawrence	DS
Shad	M	440	6/8/2020	Radio	149.760	23	-	Lawrence	DS
Shad	M	470	6/8/2020	Radio	149.760	24	-	Lawrence	DS
Shad	M	438	6/8/2020	Radio	149.800	119	-	Lawrence	DS
Shad	M	468	6/8/2020	Radio	149.800	120	-	Lawrence	DS
Shad	M	470	6/8/2020	Radio	149.800	121	-	Lawrence	DS

Appendix B. Responses to September 30, 2020 Revised ISR meeting comments.

Comment No.	Agency	Comment	Response
1	USFWS	In Section 5.4.6 (Upstream Passage Effectiveness – Lowell Fish Ladder) please better identify the success rate corresponding with passage of adult river herring through the weir section of the bypass reach.	Clarifying language has been added to Section 5.4.6 of the final report.
2	MDMF	For circle plots showing the hourly distributions of arrival or passage times can you confirm that source data for those plots are based on individual events and are not the sum or all detections (which may skew results towards one or more hours based on continued detection of an individual(s)).	Circle plots in the final report have been reviewed and are based on individual events, not the sum of all detections.
3	FERC	Will the updated revised study report contain CJS model estimates of downstream passage survival by passage route?	Sections 5.6.4 and 5.7.4 contain route-specific downstream passage survival estimates for adult river herring and American shad.
4	MDFW	Can a section be added which provides a comparison of downstream passage metrics for adult river herring originating at Lawrence versus those originating at Amoskeag?	Appendix F has a summary of passage metrics for adult river herring released upstream of Lowell at Tyngsborough and originating at either Lawrence or Amoskeag.

Appendix C. Reported hourly operations information for the Lowell Project for the duration of the 2020 spring telemetry study.

Report Appendix C available as Microsoft Excel data listing.

Appendix D. Project inflow and discharge by potential passage route at the time of downstream passage for radio-tagged adult alosines at Lowell.

Adult Alewives:

ID_Frequency	Release Location	Passage			Reported cfs					
		Date	Time	Route	Inflow	Turbine	Bypass	Ladder	Downtown	Spill
104 149.44	Mine Falls	5/18/2020	22:31:40	Turbine	9311	5625	132	500	729	2325
121 149.46	Mine Falls	5/21/2020	19:58:43	Turbine	6824	4979	132	500	729	484
188 149.76	Tyngsborough	5/21/2020	21:01:31	Turbine	6801	4943	132	500	729	497
85 149.46	Tyngsborough	5/22/2020	3:29:07	Turbine	6714	4900	132	500	729	453
183 149.8	Mine Falls	5/22/2020	15:50:19	Bypass	6630	4808	132	500	729	461
141 149.48	Mine Falls	5/22/2020	23:02:10	Turbine	6450	4638	132	500	729	451
154 149.48	Mine Falls	5/24/2020	2:30:34	Turbine	6625	4804	132	500	729	460
144 149.48	Mine Falls	5/24/2020	19:44:54	Turbine	6194	4483	132	500	729	350
116 149.44	Mine Falls	5/25/2020	8:19:42	Turbine	6163	4484	100	500	729	350
162 149.76	Mine Falls	5/25/2020	22:14:29	Turbine	5800	4240	132	500	729	199
112 149.44	Mine Falls	5/27/2020	0:06:52	Turbine	5393	3747	132	500	729	285
182 149.76	Tyngsborough	5/27/2020	3:10:24	Turbine	5393	3747	132	500	729	285
158 149.44	Tyngsborough	5/27/2020	5:52:46	Turbine	5398	3752	100	500	729	317
164 149.76	Mine Falls	5/27/2020	5:53:25	Turbine	5398	3752	100	500	729	317
148 149.48	Mine Falls	5/27/2020	10:20:41	Turbine	5334	3747	100	500	729	258
119 149.48	Tyngsborough	5/27/2020	16:43:06	Bypass	5034	3388	132	500	729	285
111 149.48	Tyngsborough	5/27/2020	17:52:17	Turbine	5004	3356	132	500	729	287
195 149.8	Mine Falls	5/27/2020	22:44:12	Downtown	5039	3364	132	500	729	314
191 149.76	Tyngsborough	5/28/2020	0:32:54	Turbine	5074	3412	132	500	729	301
108 149.48	Tyngsborough	5/28/2020	4:46:38	Turbine	5660	4020	132	500	729	279
186 149.76	Tyngsborough	5/28/2020	5:19:41	Turbine	5660	4020	132	500	729	279
80 149.46	Tyngsborough	5/28/2020	6:22:48	Turbine	5725	4096	100	500	729	300
87 149.46	Tyngsborough	5/28/2020	6:38:05	Turbine	5725	4082	100	500	542	501
91 149.46	Tyngsborough	5/28/2020	8:01:20	Turbine	5730	4109	100	500	542	479
183 149.76	Tyngsborough	5/29/2020	2:17:00	Bypass	4750	3259	132	500	542	317
493 149.76	Tyngsborough	5/29/2020	2:17:00	Bypass	4750	3259	132	500	542	317
122 149.48	Tyngsborough	5/29/2020	2:41:07	Bypass	4750	3248	132	500	542	328
173 149.44	Tyngsborough	5/29/2020	5:27:02	Turbine	4755	3249	132	500	542	332
43 149.8	Tyngsborough	5/29/2020	14:18:13	Bypass	5005	3529	100	500	542	334
168 149.44	Tyngsborough	5/29/2020	15:52:43	Bypass	5010	3537	132	500	542	299
111 149.44	Mine Falls	5/29/2020	15:55:25	Bypass	5010	3537	132	500	542	299
170 149.76	Mine Falls	5/29/2020	15:58:29	Bypass	5010	3537	132	500	542	299
54 149.8	Tyngsborough	5/29/2020	17:16:43	Turbine	5095	3484	132	500	542	437
110 149.44	Mine Falls	5/29/2020	17:26:05	Bypass	5095	3484	132	500	542	437
107 149.48	Tyngsborough	5/29/2020	17:51:59	Turbine	4950	3282	132	500	542	494
47 149.8	Tyngsborough	5/29/2020	18:07:53	Bypass	4950	3282	132	500	542	494
46 149.8	Tyngsborough	5/29/2020	18:09:54	Turbine	4950	3282	132	500	542	494
175 149.76	Mine Falls	5/29/2020	18:52:42	Turbine	4710	3105	132	500	542	431
160 149.44	Tyngsborough	5/29/2020	19:12:42	Bypass	4710	3105	132	500	542	431
125 149.48	Tyngsborough	5/30/2020	15:45:37	Turbine	4724	3316	132	500	542	234
138 149.46	Mine Falls	5/30/2020	15:57:25	Bypass	4724	3316	132	500	542	234
169 149.44	Tyngsborough	5/30/2020	16:11:55	Bypass	4724	3316	132	500	542	234
171 149.44	Tyngsborough	5/30/2020	16:22:25	Bypass	4724	3316	132	500	542	234
172 149.44	Tyngsborough	5/30/2020	18:38:17	Turbine	4609	3157	132	500	542	278
94 149.46	Tyngsborough	5/30/2020	20:07:50	Turbine	4519	3073	132	500	542	272
159 149.44	Tyngsborough	5/31/2020	5:36:37	Turbine	4468	2991	100	500	542	335

ID_Frequency	Release Location	Passage			Reported cfs					
		Date	Time	Route	Inflow	Turbine	Bypass	Ladder	Downtown	Spill
157 149.48	Mine Falls	5/31/2020	8:26:08	Turbine	4383	2995	100	500	542	246
172 149.76	Mine Falls	5/31/2020	12:22:12	Turbine	4422	3032	100	500	542	248
161 149.44	Tyngsborough	5/31/2020	14:55:25	Turbine	4456	3104	100	500	542	210
113 149.48	Tyngsborough	5/31/2020	15:24:57	Turbine	4456	3104	100	500	542	210
180 149.44	Pepperell	5/31/2020	15:59:24	Bypass	4486	3142	132	500	542	170
116 149.48	Tyngsborough	5/31/2020	16:52:53	Bypass	4624	3152	132	500	542	298
123 149.48	Tyngsborough	5/31/2020	17:40:25	Turbine	4620	3152	132	500	542	294
109 149.48	Tyngsborough	5/31/2020	17:50:58	Turbine	4620	3152	132	500	542	294
175 149.44	Tyngsborough	6/1/2020	1:35:28	Bypass	4013	2524	132	500	542	315
160 149.76	Mine Falls	6/1/2020	2:40:36	Turbine	4013	2521	132	500	542	318
163 149.44	Tyngsborough	6/1/2020	7:56:37	Turbine	3987	2540	100	500	542	305
171 149.76	Mine Falls	6/1/2020	8:21:44	Turbine	3987	2540	100	500	542	305
146 149.76	Pepperell	6/1/2020	11:58:34	Bypass	4311	2930	100	500	542	239
83 149.46	Tyngsborough	6/1/2020	12:10:38	Turbine	4311	2930	100	500	542	239
198 149.76	Tyngsborough	6/1/2020	13:48:30	Bypass	4296	2924	100	500	542	230
197 149.8	Mine Falls	6/1/2020	14:25:13	Turbine	4296	2924	100	500	542	230
187 149.8	Mine Falls	6/1/2020	16:02:38	Turbine	4060	2905	132	500	542	28
150 149.48	Mine Falls	6/1/2020	16:07:08	Bypass	4060	2905	132	500	542	28
150 149.48	Mine Falls	6/1/2020	16:07:08	Bypass	4060	2905	132	500	542	28
187 149.76	Tyngsborough	6/1/2020	16:09:41	Bypass	4060	2905	132	500	542	28
143 149.48	Mine Falls	6/1/2020	16:23:07	Bypass	4060	2905	132	500	542	28
196 149.76	Tyngsborough	6/1/2020	16:23:26	Bypass	4060	2905	132	500	542	28
145 149.48	Mine Falls	6/1/2020	17:13:25	Turbine	4150	2689	132	500	542	287
42 149.8	Tyngsborough	6/1/2020	17:23:49	Bypass	4150	2689	132	500	542	287
189 149.76	Tyngsborough	6/1/2020	18:26:26	Bypass	4030	2501	132	500	542	355
128 149.46	Mine Falls	6/1/2020	21:34:18	Turbine	3514	2041	132	500	542	299
178 149.76	Mine Falls	6/2/2020	0:12:32	Bypass	3514	2043	132	500	542	297
95 149.46	Tyngsborough	6/2/2020	13:42:16	Turbine	3616	2340	100	500	542	134
167 149.76	Mine Falls	6/2/2020	17:08:55	Bypass	3410	2005	132	500	542	231
176 149.44	Tyngsborough	6/2/2020	17:35:20	Bypass	3160	1727	132	500	542	259
118 149.48	Tyngsborough	6/2/2020	17:39:07	Bypass	3160	1727	132	500	542	259
199 149.8	Mine Falls	6/2/2020	17:41:46	Bypass	3160	1727	132	500	542	259
197 149.76	Tyngsborough	6/2/2020	17:50:08	Bypass	3160	1727	132	500	542	259
77 149.46	Tyngsborough	6/2/2020	17:59:07	Bypass	3160	1727	132	500	542	259
57 149.8	Tyngsborough	6/3/2020	1:06:08	Turbine	3274	1865	132	500	542	235
58 149.8	Tyngsborough	6/3/2020	2:29:45	Bypass	3384	1960	132	500	542	250
190 149.76	Tyngsborough	6/3/2020	8:50:43	Bypass	2378	1023	100	500	542	213
177 149.44	Tyngsborough	6/3/2020	9:33:31	Turbine	2428	1084	100	500	542	202
184 149.76	Tyngsborough	6/3/2020	9:37:45	Turbine	2428	1084	100	500	542	202
199 149.76	Tyngsborough	6/3/2020	15:42:16	Turbine	3757	2449	132	500	542	134
64 149.44	Tyngsborough	6/3/2020	16:10:18	Turbine	3757	2449	132	500	542	134
25 149.46	Pepperell	6/3/2020	16:13:24	Bypass	3757	2449	132	500	542	134
50 149.8	Tyngsborough	6/3/2020	16:35:36	Bypass	3937	2438	132	500	542	325
189 149.8	Mine Falls	6/3/2020	16:36:00	Bypass	3937	2438	132	500	542	325
185 149.8	Mine Falls	6/3/2020	16:36:11	Bypass	3937	2438	132	500	542	325
82 149.46	Tyngsborough	6/3/2020	17:05:55	Bypass	3937	2438	132	500	542	325
181 149.76	Tyngsborough	6/3/2020	17:06:41	Bypass	3937	2438	132	500	542	325
106 149.48	Tyngsborough	6/3/2020	17:07:57	Bypass	3937	2438	132	500	542	325
165 149.44	Tyngsborough	6/3/2020	17:22:54	Bypass	3937	2438	132	500	542	325
59 149.8	Tyngsborough	6/3/2020	19:08:44	Turbine	3967	2439	132	500	542	354
112 149.48	Tyngsborough	6/3/2020	19:10:18	Bypass	3967	2439	132	500	542	354

ID_Frequency	Release Location	Passage			Reported cfs					
		Date	Time	Route	Inflow	Turbine	Bypass	Ladder	Downtown	Spill
134 149.48	Tyngsborough	6/3/2020	19:14:05	Bypass	3967	2439	132	500	542	354
76 149.8	Pepperell	6/3/2020	20:59:10	Turbine	3743	2219	132	500	542	350
173 149.76	Mine Falls	6/4/2020	2:50:07	Bypass	3252	1798	132	500	542	280
57 149.44	Tyngsborough	6/4/2020	2:50:40	Bypass	3252	1798	132	500	542	280
191 149.8	Mine Falls	6/4/2020	4:27:43	Turbine	3196	1731	132	500	542	291
136 149.48	Tyngsborough	6/4/2020	10:21:46	Turbine	2548	1300	100	500	542	106
192 149.76	Tyngsborough	6/4/2020	10:53:31	Turbine	2548	1304	100	500	542	102
53 149.8	Tyngsborough	6/4/2020	11:02:47	Turbine	2548	1304	100	500	542	102
62 149.44	Tyngsborough	6/4/2020	12:51:17	Bypass	2552	1304	100	500	542	106
129 149.48	Tyngsborough	6/4/2020	12:51:39	Bypass	2552	1304	100	500	542	106
166 149.44	Tyngsborough	6/4/2020	12:56:59	Turbine	2552	1304	100	500	542	106
77 149.8	Pepperell	6/4/2020	13:06:00	Turbine	2552	1304	100	500	542	106
148 149.46	Tyngsborough	6/4/2020	13:14:44	Downtown	2552	1304	100	500	542	106
148 149.76	Pepperell	6/4/2020	13:22:59	Downtown	2552	1304	100	500	542	106
195 149.76	Tyngsborough	6/4/2020	13:57:47	Bypass	2572	1302	100	500	542	128
56 149.8	Tyngsborough	6/4/2020	14:38:25	Turbine	2656	1365	100	500	542	149
150 149.76	Pepperell	6/4/2020	14:39:36	Turbine	2656	1365	100	500	542	149
63 149.44	Tyngsborough	6/4/2020	14:53:04	Turbine	2656	1365	100	500	542	149
185 149.76	Tyngsborough	6/4/2020	15:01:48	Turbine	2656	1365	100	500	542	149
130 149.48	Tyngsborough	6/4/2020	15:10:57	Turbine	2656	1365	100	500	542	149
196 149.44	Pepperell	6/4/2020	15:27:35	Turbine	2656	1365	100	500	542	149
85 149.76	Tyngsborough	6/4/2020	16:46:59	Downtown	2936	1462	132	500	542	300
114 149.48	Tyngsborough	6/4/2020	16:47:07	Turbine	2936	1462	132	500	542	300
60 149.8	Tyngsborough	6/4/2020	16:54:56	Turbine	2936	1462	132	500	542	300
124 149.48	Tyngsborough	6/4/2020	16:56:33	Bypass	2936	1462	132	500	542	300
149 149.46	Tyngsborough	6/4/2020	17:15:39	Bypass	2936	1462	132	500	542	300
65 149.48	Pepperell	6/4/2020	17:18:36	Bypass	2936	1462	132	500	542	300
194 149.8	Mine Falls	6/4/2020	17:25:03	Bypass	2936	1462	132	500	542	300
132 149.48	Tyngsborough	6/4/2020	17:55:15	Bypass	2966	1593	132	500	542	199
141 149.46	Tyngsborough	6/4/2020	18:08:33	Bypass	2966	1593	132	500	542	199
167 149.8	Tyngsborough	6/4/2020	18:36:53	Bypass	2966	1559	132	500	542	233
166 149.8	Tyngsborough	6/4/2020	19:16:26	Bypass	2966	1559	132	500	542	233
174 149.8	Tyngsborough	6/4/2020	19:28:56	Bypass	2966	1559	132	500	542	233
44 149.8	Tyngsborough	6/4/2020	19:44:30	Spill	2966	1609	132	500	542	183
150 149.46	Tyngsborough	6/4/2020	20:14:18	Turbine	2966	1609	132	500	542	183
192 149.8	Mine Falls	6/4/2020	21:11:52	Turbine	2966	1609	132	500	542	183
127 149.48	Tyngsborough	6/4/2020	21:20:50	Turbine	2966	1609	132	500	542	183
89 149.76	Tyngsborough	6/4/2020	22:19:13	Turbine	2966	1642	132	500	542	150
61 149.44	Tyngsborough	6/5/2020	0:49:28	Turbine	2969	1643	132	500	542	152
56 149.44	Tyngsborough	6/5/2020	1:46:00	Turbine	2969	1639	132	500	542	156
87 149.76	Tyngsborough	6/5/2020	15:48:40	Turbine	3112	1854	132	500	542	84
84 149.76	Tyngsborough	6/5/2020	17:54:19	Turbine	3162	1853	132	500	542	135
92 149.76	Tyngsborough	6/5/2020	20:07:30	Bypass	3138	1678	132	500	542	286
145 149.46	Tyngsborough	6/5/2020	20:48:31	Turbine	3155	1667	132	500	542	314
128 149.48	Tyngsborough	6/6/2020	6:26:03	Turbine	2885	1589	100	500	542	154
173 149.8	Tyngsborough	6/6/2020	14:08:20	Turbine	2808	1606	100	500	542	60
55 149.44	Tyngsborough	6/6/2020	14:12:46	Bypass	2808	1606	100	500	542	60
60 149.44	Tyngsborough	6/6/2020	14:17:40	Turbine	2808	1606	100	500	542	60
133 149.48	Tyngsborough	6/6/2020	14:36:09	Turbine	2838	1605	100	500	542	91
93 149.46	Tyngsborough	6/6/2020	14:48:12	Turbine	2838	1605	100	500	542	91
52 149.8	Tyngsborough	6/6/2020	14:52:19	Turbine	2838	1605	100	500	542	91

ID_Frequency	Release Location	Passage			Reported cfs					
		Date	Time	Route	Inflow	Turbine	Bypass	Ladder	Downtown	Spill
92 149.46	Tyngsborough	6/6/2020	15:50:28	Turbine	2858	1639	132	500	542	45
152 149.76	Pepperell	6/6/2020	16:20:51	Bypass	2858	1639	132	500	542	45
198 149.8	Mine Falls	6/6/2020	16:34:41	Bypass	2918	1638	132	500	542	106
90 149.76	Tyngsborough	6/6/2020	16:44:57	Bypass	2918	1638	132	500	542	106
21 149.46	Pepperell	6/6/2020	16:53:51	Turbine	2918	1638	132	500	542	106
179 149.76	Mine Falls	6/6/2020	17:31:35	Turbine	2918	1638	132	500	542	106
59 149.48	Pepperell	6/6/2020	18:22:50	Turbine	2918	1638	132	500	542	106
169 149.8	Tyngsborough	6/6/2020	18:40:04	Bypass	2838	1638	132	500	542	28
66 149.48	Pepperell	6/6/2020	18:59:04	Bypass	2838	1638	132	500	542	28
135 149.48	Tyngsborough	6/6/2020	18:59:19	Bypass	2838	1638	132	500	542	28
86 149.76	Tyngsborough	6/6/2020	18:59:49	Bypass	2838	1638	132	500	542	28
141 149.76	Pepperell	6/6/2020	19:08:40	Bypass	2838	1638	132	500	542	28
50 149.48	Pepperell	6/6/2020	19:09:22	Bypass	2838	1638	132	500	542	28
186 149.44	Pepperell	6/6/2020	19:09:34	Bypass	2838	1638	132	500	542	28
83 149.76	Tyngsborough	6/6/2020	19:10:49	Turbine	2838	1638	132	500	542	28
153 149.76	Pepperell	6/6/2020	19:28:57	Turbine	2838	1638	132	500	542	28
118 149.44	Mine Falls	6/6/2020	20:09:25	Bypass	2808	1634	132	500	542	28
174 149.44	Tyngsborough	6/7/2020	16:00:26	Bypass	2895	1714	132	500	542	28
81 149.8	Pepperell	6/7/2020	16:03:57	Bypass	2895	1714	132	500	542	28
164 149.44	Tyngsborough	6/7/2020	16:08:41	Bypass	2895	1714	132	500	542	28
168 149.76	Mine Falls	6/7/2020	17:48:31	Bypass	3085	1748	132	500	542	163
91 149.76	Tyngsborough	6/7/2020	17:49:33	Bypass	3085	1748	132	500	542	163
194 149.76	Tyngsborough	6/7/2020	18:09:30	Bypass	3085	1748	132	500	542	163
142 149.76	Pepperell	6/7/2020	18:15:05	Bypass	3085	1748	132	500	542	163
55 149.48	Pepperell	6/7/2020	18:54:59	Bypass	3085	1751	132	500	542	160
198 149.44	Pepperell	6/8/2020	1:14:45	Bypass	2862	1555	132	500	542	133
115 149.48	Tyngsborough	6/8/2020	5:33:39	Turbine	2778	1463	100	500	542	173
176 149.8	Tyngsborough	6/8/2020	7:40:22	Turbine	2728	1468	100	500	542	118
188 149.44	Pepperell	6/8/2020	18:22:13	Bypass	2938	1699	132	500	542	65
168 149.8	Tyngsborough	6/8/2020	18:41:51	Bypass	2938	1694	132	500	542	70
60 149.48	Pepperell	6/8/2020	23:28:47	Turbine	2912	1667	132	500	542	71
119 149.44	Mine Falls	6/9/2020	13:56:39	Turbine	2392	1179	100	500	542	71
79 149.8	Pepperell	6/9/2020	14:03:44	Turbine	2392	1179	100	500	542	71
143 149.46	Tyngsborough	6/9/2020	14:24:47	Turbine	2392	1179	100	500	542	71
64 149.48	Pepperell	6/9/2020	15:10:00	Turbine	2382	1180	100	500	542	60
175 149.8	Tyngsborough	6/9/2020	15:55:19	Bypass	2412	1203	132	500	542	35
58 149.44	Tyngsborough	6/9/2020	15:59:11	Turbine	2412	1203	132	500	542	35
56 149.48	Pepperell	6/9/2020	16:18:35	Bypass	2412	1203	132	500	542	35
131 149.48	Tyngsborough	6/9/2020	16:19:03	Bypass	2412	1203	132	500	542	35
143 149.76	Pepperell	6/9/2020	16:22:27	Bypass	2412	1203	132	500	542	35
149 149.76	Pepperell	6/9/2020	17:00:41	Turbine	2532	1213	132	500	542	145
197 149.44	Pepperell	6/9/2020	17:05:12	Bypass	2532	1213	132	500	542	145
137 149.76	Pepperell	6/9/2020	18:30:43	Bypass	2652	1336	132	500	542	142
170 149.8	Tyngsborough	6/9/2020	18:30:49	Turbine	2652	1336	132	500	542	142
147 149.46	Tyngsborough	6/9/2020	18:40:17	Bypass	2652	1336	132	500	542	142
53 149.48	Pepperell	6/9/2020	18:49:54	Turbine	2652	1336	132	500	542	142
176 149.76	Mine Falls	6/10/2020	13:13:32	Turbine	2299	1086	100	500	542	71
47 149.48	Pepperell	6/10/2020	13:50:16	Turbine	2299	1084	100	500	542	73
140 149.76	Pepperell	6/10/2020	14:07:03	Turbine	2299	1084	100	500	542	73
57 149.48	Pepperell	6/10/2020	14:48:27	Turbine	2302	1083	100	500	542	77
146 149.46	Tyngsborough	6/10/2020	16:11:38	Bypass	2302	1086	132	500	542	42

ID_Frequency	Release Location	Passage			Reported cfs					
		Date	Time	Route	Inflow	Turbine	Bypass	Ladder	Downtown	Spill
144 149.76	Pepperell	6/10/2020	18:47:50	Bypass	2385	1065	132	500	542	146
69 149.8	Pepperell	6/14/2020	19:51:14	Bypass	2082	984	132	500	542	28
154 149.76	Pepperell	6/14/2020	20:29:04	Bypass	2082	984	132	500	542	28
59 149.44	Tyngsborough	6/17/2020	8:01:09	Turbine	2083	966	100	500	542	0
165 149.76	Mine Falls	6/17/2020	20:13:17	Bypass	1576	353	132	500	542	49
195 149.44	Pepperell	6/19/2020	4:28:20	Bypass	1368	210	132	500	542	28

Adult American Shad:

ID_Frequency	Release Location	Passage			Reported cfs					
		Date	Time	Route	Inflow	Turbine	Bypass	Ladder	Downtown	Spill
87 149.44	Tyngsborough	6/5/2020	16:02:37	Turbine	3112	1854	132	500	542	84
81 149.44	Tyngsborough	6/8/2020	7:18:07	Turbine	2778	1468	100	500	542	168
82 149.44	Tyngsborough	6/8/2020	17:00:07	Turbine	2938	1696	132	500	542	68
21 149.8	Tyngsborough	6/8/2020	20:46:18	Turbine	2908	1672	132	500	542	62
27 149.8	Tyngsborough	6/9/2020	10:37:38	Turbine	2362	1168	100	500	542	52
38 149.76	Tyngsborough	6/9/2020	15:58:49	Turbine	2412	1203	132	500	542	35
32 149.8	Tyngsborough	6/9/2020	20:40:30	Bypass	2685	1362	132	500	542	149
30 149.46	Tyngsborough	6/10/2020	5:20:10	Turbine	2655	1361	132	500	542	120
74 149.44	Tyngsborough	6/10/2020	11:10:52	Turbine	2469	1234	100	500	542	93
119 149.8	Tyngsborough	6/10/2020	20:05:58	Turbine	2335	1023	132	500	542	138
113 149.46	Tyngsborough	6/10/2020	22:26:57	Bypass	2262	925	132	500	542	163
40 149.76	Tyngsborough	6/11/2020	13:14:48	Spill	1414	-22	100	500	542	294
107 149.46	Tyngsborough	6/11/2020	14:27:24	Spill	3022	-21	100	500	542	1901
29 149.76	Tyngsborough	6/11/2020	16:47:51	Turbine	2471	1373	132	500	542	28
171 149.48	Tyngsborough	6/13/2020	1:15:31	Turbine	2329	1311	132	500	542	28
176 149.48	Tyngsborough	6/13/2020	7:59:26	Turbine	2332	1309	100	500	542	0
97 149.46	Tyngsborough	6/14/2020	3:08:46	Turbine	2105	1032	132	500	542	28
38 149.8	Tyngsborough	6/14/2020	20:48:56	Bypass	2082	989	132	500	542	28
90 149.44	Tyngsborough	6/15/2020	0:01:17	Bypass	2082	988	132	500	542	28
94 149.44	Tyngsborough	6/15/2020	0:06:56	Bypass	2082	988	132	500	542	28
103 149.46	Tyngsborough	6/15/2020	1:12:32	Turbine	2062	989	132	500	542	28
33 149.8	Tyngsborough	6/15/2020	2:05:42	Turbine	2062	986	132	500	542	28
105 149.46	Tyngsborough	6/15/2020	4:04:08	Bypass	2062	951	132	500	542	28
92 149.44	Tyngsborough	6/15/2020	20:47:30	Bypass	1861	758	132	500	542	28
26 149.8	Tyngsborough	6/15/2020	23:59:51	Turbine	1861	758	132	500	542	28
22 149.8	Tyngsborough	6/16/2020	0:48:03	Bypass	1861	759	132	500	542	28
163 149.48	Tyngsborough	6/16/2020	1:30:30	Bypass	1861	758	132	500	542	28
179 149.48	Tyngsborough	6/16/2020	5:58:44	Turbine	1861	751	100	500	542	0
168 149.48	Tyngsborough	6/16/2020	7:23:00	Spill	1881	757	100	500	542	0
41 149.76	Tyngsborough	6/16/2020	10:03:40	Turbine	1941	925	100	500	542	0
186 149.48	Tyngsborough	6/16/2020	16:52:52	Bypass	2074	947	132	500	542	28
180 149.48	Tyngsborough	6/16/2020	16:53:03	Bypass	2074	947	132	500	542	28
192 149.48	Tyngsborough	6/16/2020	18:02:25	Turbine	2114	925	132	500	542	28
166 149.48	Tyngsborough	6/16/2020	18:28:00	Bypass	2114	925	132	500	542	28
116 149.46	Tyngsborough	6/16/2020	18:48:22	Bypass	2117	925	132	500	542	28
27 149.76	Tyngsborough	6/16/2020	19:55:28	Bypass	2120	963	132	500	542	28
38 149.46	Tyngsborough	6/16/2020	20:11:12	Bypass	2120	963	132	500	542	28
31 149.76	Tyngsborough	6/16/2020	20:30:14	Bypass	2120	963	132	500	542	28

ID_Frequency	Release Location	Passage			Reported cfs					
		Date	Time	Route	Inflow	Turbine	Bypass	Ladder	Downtown	Spill
20 149.76	Tyngsborough	6/16/2020	20:48:22	Bypass	2120	963	132	500	542	28
28 149.76	Tyngsborough	6/16/2020	20:48:52	Bypass	2120	963	132	500	542	28
84 149.44	Tyngsborough	6/16/2020	22:12:23	Bypass	2100	963	132	500	542	28
30 149.76	Tyngsborough	6/16/2020	23:57:49	Turbine	2100	964	132	500	542	28
111 149.46	Tyngsborough	6/17/2020	0:58:42	Bypass	2100	964	132	500	542	28
83 149.44	Tyngsborough	6/17/2020	2:30:36	Bypass	2100	965	132	500	542	28
15 149.76	Tyngsborough	6/17/2020	4:54:15	Turbine	2100	966	132	500	542	28
181 149.48	Tyngsborough	6/17/2020	6:56:28	Turbine	2103	967	100	500	542	0
164 149.48	Tyngsborough	6/17/2020	11:58:23	Spill	1823	965	100	500	542	0
108 149.46	Tyngsborough	6/17/2020	16:44:06	Turbine	1576	422	132	500	542	28
162 149.48	Tyngsborough	6/17/2020	16:56:37	Bypass	1576	422	132	500	542	28
30 149.8	Tyngsborough	6/17/2020	18:18:52	Bypass	1576	364	132	500	542	38
31 149.8	Tyngsborough	6/17/2020	19:11:55	Bypass	1576	355	132	500	542	47
78 149.44	Tyngsborough	6/17/2020	20:43:11	Bypass	1576	357	132	500	542	45
109 149.46	Tyngsborough	6/17/2020	21:53:18	Bypass	1576	353	132	500	542	49
96 149.44	Tyngsborough	6/17/2020	23:44:06	Bypass	1576	354	132	500	542	48
165 149.48	Tyngsborough	6/18/2020	6:47:19	Turbine	1594	352	100	500	542	100
110 149.46	Tyngsborough	6/18/2020	12:26:46	Spill	1484	357	100	500	542	0
33 149.76	Tyngsborough	6/18/2020	12:43:53	Spill	1484	359	100	500	542	0
32 149.46	Tyngsborough	6/18/2020	13:02:34	Spill	1484	359	100	500	542	0
187 149.48	Tyngsborough	6/18/2020	14:25:05	Spill	1434	355	100	500	542	0
34 149.46	Tyngsborough	6/18/2020	15:36:47	Spill	1401	353	132	500	542	28
112 149.46	Tyngsborough	6/18/2020	20:14:43	Spill	1501	345	132	500	542	28
65 149.44	Tyngsborough	6/18/2020	20:36:09	Spill	1498	347	132	500	542	28
173 149.48	Tyngsborough	6/18/2020	22:16:18	Turbine	1498	349	132	500	542	28
36 149.76	Tyngsborough	6/19/2020	7:27:17	Turbine	1418	254	100	500	542	22
167 149.48	Tyngsborough	6/19/2020	7:44:08	Spill	1401	256	100	500	542	3
121 149.8	Tyngsborough	6/19/2020	11:05:41	Spill	1501	469	100	500	542	0
190 149.48	Tyngsborough	6/19/2020	11:49:20	Spill	1761	817	100	500	542	0
93 149.44	Tyngsborough	6/19/2020	12:39:12	Spill	1941	986	100	500	542	0
37 149.76	Tyngsborough	6/19/2020	12:47:07	Spill	1941	986	100	500	542	0
25 149.8	Tyngsborough	6/19/2020	12:55:25	Spill	1941	986	100	500	542	0
23 149.76	Tyngsborough	6/19/2020	13:07:21	Spill	1941	986	100	500	542	0
43 149.76	Tyngsborough	6/19/2020	15:41:56	Spill	2014	1006	132	500	542	28
191 149.48	Tyngsborough	6/19/2020	16:32:54	Spill	2124	1001	132	500	542	28
37 149.46	Tyngsborough	6/19/2020	16:56:34	Spill	2124	1001	132	500	542	28
24 149.76	Tyngsborough	6/19/2020	19:13:38	Spill	2141	984	132	500	542	28
169 149.48	Tyngsborough	6/20/2020	0:22:53	Bypass	1675	484	132	500	542	28
19 149.76	Tyngsborough	6/20/2020	9:24:47	Spill	1445	417	100	500	542	0
35 149.76	Tyngsborough	6/20/2020	9:55:28	Spill	1525	411	100	500	542	0
29 149.8	Tyngsborough	6/20/2020	10:01:22	Turbine	1525	411	100	500	542	0
77 149.44	Tyngsborough	6/20/2020	11:04:43	Turbine	1585	413	100	500	542	30
42 149.76	Tyngsborough	6/20/2020	11:18:33	Turbine	1585	413	100	500	542	30
104 149.46	Tyngsborough	6/20/2020	11:29:22	Spill	1585	413	100	500	542	30
114 149.46	Tyngsborough	6/20/2020	14:49:20	Turbine	1598	411	100	500	542	45
76 149.44	Tyngsborough	6/20/2020	16:55:56	Bypass	1585	409	132	500	542	28
20 149.8	Tyngsborough	6/20/2020	17:35:30	Spill	1595	411	132	500	542	28
80 149.44	Tyngsborough	6/20/2020	18:09:00	Spill	1595	411	132	500	542	28
172 149.48	Tyngsborough	6/20/2020	18:44:21	Spill	1585	410	132	500	542	28
120 149.8	Tyngsborough	6/20/2020	20:13:24	Spill	1585	413	132	500	542	28
70 149.44	Tyngsborough	6/21/2020	8:51:38	Spill	1448	397	100	500	542	0

ID_Frequency	Release Location	Passage			Reported cfs					
		Date	Time	Route	Inflow	Turbine	Bypass	Ladder	Downtown	Spill
36 149.46	Tyngsborough	6/21/2020	12:46:38	Spill	1551	549	132	500	542	28
73 149.44	Tyngsborough	6/21/2020	16:16:48	Spill	1681	689	132	500	542	28
91 149.44	Tyngsborough	6/22/2020	12:57:46	Spill	1397	369	100	500	542	0
72 149.44	Tyngsborough	6/22/2020	14:20:45	Spill	1397	370	100	500	542	0
170 149.48	Tyngsborough	6/22/2020	14:29:07	Spill	1397	370	100	500	542	0
26 149.76	Tyngsborough	6/22/2020	16:49:58	Bypass	1457	367	132	500	542	28
177 149.48	Tyngsborough	6/22/2020	19:29:05	Bypass	1477	365	132	500	542	28
39 149.8	Tyngsborough	6/22/2020	20:18:59	Spill	1477	367	132	500	542	28
44 149.76	Tyngsborough	6/23/2020	0:32:21	Turbine	1472	367	132	500	542	28
28 149.8	Tyngsborough	6/23/2020	10:49:18	Spill	1367	343	100	500	542	0
31 149.46	Tyngsborough	6/23/2020	10:54:54	Spill	1367	343	100	500	542	0
34 149.76	Tyngsborough	6/23/2020	17:39:39	Spill	1660	596	132	500	542	28
86 149.44	Tyngsborough	6/23/2020	19:09:11	Bypass	1747	723	132	500	542	28
21 149.76	Tyngsborough	6/24/2020	8:04:48	Spill	1575	593	100	500	542	0
16 149.76	Tyngsborough	6/24/2020	16:15:28	Bypass	1590	586	132	500	542	28
89 149.44	Tyngsborough	6/25/2020	15:06:58	Spill	1286	209	100	500	542	0
115 149.46	Tyngsborough	6/25/2020	19:22:42	Spill	1419	206	132	500	542	39
35 149.46	Tyngsborough	6/26/2020	12:51:56	Spill	1639	778	100	500	542	0
95 149.44	Tyngsborough	6/26/2020	14:15:52	Spill	1439	517	100	500	542	0
71 149.44	Tyngsborough	6/27/2020	13:57:17	Spill	1712	879	100	500	542	0

Appendix E. Listing of manual tracking detections within the Lowell Project area.

River mile demarcations for reaches defined by stationary receivers:

Reach	River Mile	
	Upper End	Lower End
Top of Impoundment-Station 04	61.5	43.85
Station 04-Station 05	43.85	41.75
Station 10-Station 25	41.75	39.25
Station 25-Station 26	39.25	35.25
Station 26-Station 27	35.25	30.25

Date	Species	Release Location	Frequency	ID	RM	Location	Type	Note
5/29/2020	Alewife	Tyngsborough	149.480	108	30.75	Station 26-Station 27	Final	via boat
6/4/2020	Alewife	Tyngsborough	149.460	93	42.75	Station 04-Station 05	Transit	via truck
6/4/2020	Alewife	Mine Falls	149.760	162	30.25	Station 26-Station 27	Final	via truck
6/4/2020	Alewife	Mine Falls	149.760	164	30.25	Station 26-Station 27	Final	via truck
6/4/2020	Alewife	Tyngsborough	149.800	46	30.25	Station 26-Station 27	Final	via truck
6/4/2020	American Shad	Tyngsborough	149.440	82	44.25	US of Station 04	Transit	via truck
6/4/2020	American Shad	Tyngsborough	149.440	84	47.75	US of Station 04	Transit	via truck
6/4/2020	American Shad	Tyngsborough	149.440	87	44.25	US of Station 04	Transit	via truck
6/4/2020	American Shad	Tyngsborough	149.460	100	49.25	US of Station 04	Final	via truck
6/4/2020	American Shad	Tyngsborough	149.480	166	44.25	US of Station 04	Transit	via truck
6/4/2020	American Shad	Tyngsborough	149.760	30	47.75	US of Station 04	Transit	via truck
6/4/2020	American Shad	Tyngsborough	149.760	36	44.25	US of Station 04	Transit	via truck
6/4/2020	American Shad	Tyngsborough	149.800	21	47.75	US of Station 04	Transit	via truck
6/4/2020	American Shad	Tyngsborough	149.800	30	47.75	US of Station 04	Transit	via truck
6/9/2020	Alewife	Tyngsborough	149.460	92	30.25	Station 26-Station 27	Final	via truck
6/10/2020	Alewife	Tyngsborough	149.440	177	30.25	Station 26-Station 27	Final	via truck
6/11/2020	Alewife	Tyngsborough	149.480	150	30.25	Station 26-Station 27	Final	via truck
6/11/2020	American Shad	Tyngsborough	149.760	29	30.25	Station 26-Station 27	Final	via truck
6/12/2020	American Shad	Tyngsborough	149.440	66	48.5	US of Station 04	Final	via boat
6/12/2020	American Shad	Tyngsborough	149.440	77	49.25	US of Station 04	Transit	via boat
6/12/2020	American Shad	Tyngsborough	149.440	94	48.5	US of Station 04	Transit	via boat
6/12/2020	American Shad	Tyngsborough	149.460	100	49.25	US of Station 04	Final	via boat
6/12/2020	American Shad	Tyngsborough	149.460	117	48.5	US of Station 04	Transit	via boat
6/12/2020	American Shad	Tyngsborough	149.480	181	44.25	US of Station 04	Transit	via boat
6/12/2020	American Shad	Tyngsborough	149.480	183	49.25	US of Station 04	Final	via boat
6/12/2020	American Shad	Tyngsborough	149.760	20	44.25	US of Station 04	Transit	via boat
6/12/2020	American Shad	Tyngsborough	149.760	21	44.75	US of Station 04	Transit	via boat
6/12/2020	American Shad	Tyngsborough	149.800	121	49.5	US of Station 04	Transit	via boat
6/12/2020	American Shad	Tyngsborough	149.440	83	41.5	Station 10-Station 25	Transit	via truck
6/12/2020	American Shad	Tyngsborough	149.460	111	41.75	Station 04-Station 05	Transit	via truck
6/12/2020	American Shad	Tyngsborough	149.760	15	41.75	Station 04-Station 05	Transit	via truck
6/12/2020	American Shad	Tyngsborough	149.760	38	41.75	Station 04-Station 05	Transit	via truck

Date	Species	Release Location	Frequency	ID	RM	Location	Type	Note
6/12/2020	American Shad	Tyngsborough	149.760	41	41.75	Station 04-Station 05	Transit	via truck
6/12/2020	American Shad	Tyngsborough	149.800	22	41.75	Station 04-Station 05	Transit	via truck
6/12/2020	American Shad	Tyngsborough	149.800	31	41.75	Station 04-Station 05	Transit	via truck
6/15/2020	Alewife	Pepperell	149.440	196	30.25	Station 26-Station 27	Final	via truck
6/15/2020	American Shad	Tyngsborough	149.440	75	47.25	US of Station 04	Final	via truck
6/15/2020	American Shad	Tyngsborough	149.460	33	42	Station 04-Station 05	Final	via truck
6/16/2020	American Shad	Tyngsborough	149.480	162	41.5	Station 10-Station 25	Transit	via truck
6/17/2020	Alewife	Pepperell	149.440	196	30.25	Station 26-Station 27	Final	via truck
6/17/2020	Alewife	Mine Falls	149.760	164	30.25	Station 26-Station 27	Final	via truck
6/17/2020	American Shad	Tyngsborough	149.480	163	30.25	Station 26-Station 27	Final	via truck
6/17/2020	American Shad	Tyngsborough	149.760	31	30.25	Station 26-Station 27	Final	via truck
6/18/2020	Alewife	Mine Falls	149.440	111	30.25	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Pepperell	149.440	196	30.25	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Tyngsborough	149.460	150	32.5	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Tyngsborough	149.480	135	31	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Pepperell	149.760	141	30.25	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Pepperell	149.760	143	30.25	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Pepperell	149.760	148	30.25	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Mine Falls	149.760	160	39	Station 25-Station 26	Final	via boat
6/18/2020	Alewife	Mine Falls	149.760	164	30.25	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Mine Falls	149.760	179	30.25	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Tyngsborough	149.760	197	30.25	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Tyngsborough	149.800	53	32.5	Station 26-Station 27	Final	via boat
6/18/2020	Alewife	Tyngsborough	149.440	56	33.75	Station 26-Station 27	Final	via boat
6/18/2020	American Shad	Tyngsborough	149.440	78	30.25	Station 26-Station 27	Transit	via boat
6/18/2020	American Shad	Tyngsborough	149.460	103	39	Station 25-Station 26	Final	via boat
6/18/2020	American Shad	Tyngsborough	149.460	111	30.25	Station 26-Station 27	Transit	via boat
6/18/2020	American Shad	Tyngsborough	149.480	180	30.25	Station 26-Station 27	Final	via boat
6/18/2020	American Shad	Tyngsborough	149.760	29	34.5	Station 26-Station 27	Final	via boat
6/18/2020	American Shad	Tyngsborough	149.800	30	34	Station 26-Station 27	Final	via boat
6/19/2020	Alewife	Pepperell	149.440	196	30.25	Station 26-Station 27	Final	via truck
6/19/2020	Alewife	Pepperell	149.760	141	30.25	Station 26-Station 27	Final	via truck
6/19/2020	Alewife	Mine Falls	149.760	164	30.25	Station 26-Station 27	Final	via truck
6/19/2020	American Shad	Tyngsborough	149.440	70	45.5	US of Station 04	Transit	via truck
6/19/2020	American Shad	Tyngsborough	149.440	75	47.25	US of Station 04	Final	via truck
6/19/2020	American Shad	Tyngsborough	149.460	108	30.25	Station 26-Station 27	Transit	via truck
6/19/2020	American Shad	Tyngsborough	149.460	111	30.25	Station 26-Station 27	Transit	via truck
6/19/2020	American Shad	Tyngsborough	149.480	183	49	US of Station 04	Final	via truck
6/19/2020	American Shad	Tyngsborough	149.480	184	48.25	US of Station 04	Final	via truck
6/19/2020	American Shad	Tyngsborough	149.480	191	48.25	US of Station 04	Transit	via truck
6/22/2020	American Shad	Tyngsborough	149.440	86	41.75	Station 04-Station 05	Transit	via truck
6/22/2020	American Shad	Tyngsborough	149.480	174	41.75	Station 04-Station 05	Final	via truck
6/22/2020	American Shad	Tyngsborough	149.480	177	41.5	Station 10-Station 25	Transit	via truck
6/22/2020	American Shad	Tyngsborough	149.760	16	41.75	Station 04-Station 05	Transit	via truck
6/22/2020	American Shad	Tyngsborough	149.760	38	41.5	Station 10-Station 25	Final	via truck

Date	Species	Release Location	Frequency	ID	RM	Location	Type	Note
6/23/2020	Alewife	Pepperell	149.440	196	30.25	Station 26-Station 27	Final	via truck
6/24/2020	Alewife	Pepperell	149.760	147	42.25	Station 04-Station 05	Final	via truck
6/24/2020	American Shad	Tyngsborough	149.440	75	47.25	US of Station 04	Final	via truck
6/24/2020	American Shad	Tyngsborough	149.460	31	41.5	Station 10-Station 25	Transit	via truck
6/24/2020	American Shad	Tyngsborough	149.460	101	41.75	Station 04-Station 05	Final	via truck
6/24/2020	American Shad	Tyngsborough	149.480	184	47.75	US of Station 04	Final	via truck
6/24/2020	American Shad	Tyngsborough	149.760	26	30.5	Station 26-Station 27	Final	via truck
6/24/2020	American Shad	Tyngsborough	149.760	38	41.25	Station 10-Station 25	Final	via truck
6/24/2020	American Shad	Tyngsborough	149.760	44	41.25	Station 10-Station 25	Final	via truck
6/24/2020	American Shad	Tyngsborough	149.800	22	41.25	Station 10-Station 25	Final	via truck
6/26/2020	American Shad	Tyngsborough	149.440	75	47.25	US of Station 04	Final	via boat
6/26/2020	American Shad	Tyngsborough	149.480	184	48	US of Station 04	Final	via truck
7/2/2020	Alewife	Tyngsborough	149.440	56	33.75	Station 26-Station 27	Final	via boat
7/2/2020	Alewife	Mine Falls	149.440	111	30.25	Station 26-Station 27	Final	via boat
7/2/2020	Alewife	Tyngsborough	149.460	150	32.25	Station 26-Station 27	Final	via boat
7/2/2020	Alewife	Tyngsborough	149.480	135	31	Station 26-Station 27	Final	via boat
7/2/2020	Alewife	Mine Falls	149.760	160	39	Station 25-Station 26	Final	via boat
7/2/2020	Alewife	Mine Falls	149.760	164	30.25	Station 26-Station 27	Final	via boat
7/2/2020	Alewife	Tyngsborough	149.760	197	30.25	Station 26-Station 27	Final	via boat
7/2/2020	American Shad	Tyngsborough	149.460	103	39	Station 25-Station 26	Final	via boat
7/2/2020	American Shad	Tyngsborough	149.760	20	38.75	Station 25-Station 26	Final	via boat
7/2/2020	American Shad	Tyngsborough	149.800	30	34.5	Station 26-Station 27	Final	via boat

Appendix F. Tyngsborough adult river herring releases – comparison of individuals originating at Lawrence vs. Amoskeag Dam.

Adult river herring radio-tagged and released into the mainstem Merrimack River in Tyngsborough for the assessment of downstream passage at Lowell originated at Lawrence (May 21 and May 22 releases; n = 80 fish) and at Amoskeag Dam (May 28 and June 2 releases; n = 70 fish). Table F-1 provides a comparison of the range of values for movement indices evaluated during this study and between the two groups. Based on comparison of the quartile values, observations for most metrics did not appear to differ between the two groups. The approach duration (i.e., time to pass from Station 04 to approach at the dam (Station 05)) was longer for individuals collected at Lawrence. Fish collected at the fish lift at Lawrence were likely pre-spawn individuals and may have moved upstream following release versus the fish collected at Amoskeag which showed a more directed downstream approach following their release at Tyngsborough. Residence in the Lowell project area did not appear to vary for the release groups originating at Lawrence or Amoskeag Dams. Similarly, the period of time to move downstream from Lowell to Lawrence did not vary greatly among the defined downstream reaches based on the quartile ranges for passage from Lowell to Station 25, Station 25 to Station 26 and Station 26 to detection at Lawrence. With regards to passage at Lowell, the majority of radio-tagged adult river herring originating at Lawrence and Amoskeag passing downstream did so via the turbines or downstream bypass facility (Figure F-1).

Table F-1. Minimum, maximum, and quartile values for the suite of movement metrics assessed for radio-tagged adult river herring originating at Lawrence and Amoskeag and released upstream of Lowell in Tyngsborough.

Movement Metric	Origin	Value				
		Min	Max	P25	Median	P75
Approach Duration (hrs)	Lawrence	6.7	323.6	135.2	179.1	234.1
	Amoskeag	11.5	155.1	27.6	33.6	40.5
Upstream Residence Duration (hrs)	Lawrence	0.8	210.1	25	44.7	88.5
	Amoskeag	0.7	181.7	26.1	49.4	90.2
Pawtucket Gatehouse Passage (hrs)	Lawrence	0	99.3	0.2	0.5	6.1
	Amoskeag	0	94.2	0.6	2.6	20.8
Northern Canal Residence (hrs)	Lawrence	0.2	38.2	0.3	0.4	2.2
	Amoskeag	0.2	42.3	0.4	0.7	5.6
Downstream Travel: Lowell to Station 25 (hrs)	Lawrence	1.1	50.8	3.4	5.3	11.6
	Amoskeag	1.5	28.5	2.9	4.8	7.6
Downstream Travel: Station 25 to Station 26 (hrs)	Lawrence	1.7	4.5	1.9	2.2	2.9
	Amoskeag	1.9	16.5	2.4	2.8	3.7
Downstream Travel: Station 26 to Station 27 (hrs)	Lawrence	2.6	138.9	10.7	18.8	21.0
	Amoskeag	4.1	68.2	17.6	19.4	21.1

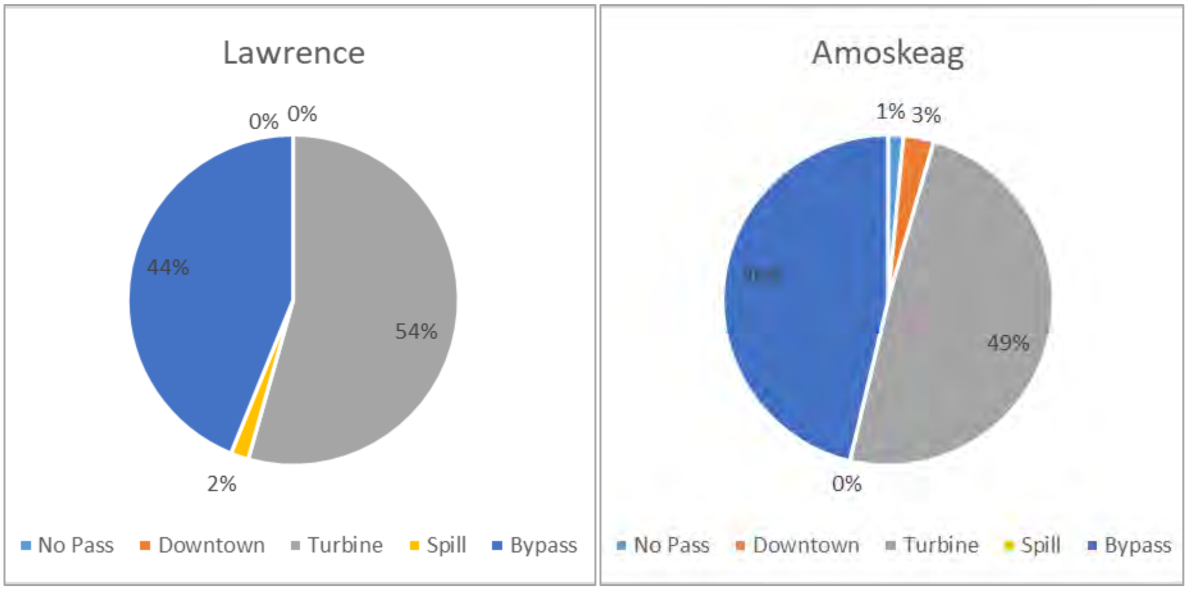

Figure F-1. Downstream passage route distribution observed at Lowell for radio-tagged adult river herring originating at Lawrence (left panel) and Amoskeag (right panel) and released upstream of Lowell in Tyngsborough.

Technical Report for the Fish Assemblage Study

Lowell Hydroelectric Project (FERC No. 2790)

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Table of Contents

List of Tables

1 Introduction

A survey of the resident fish community was conducted in support of the relicensing for the Lowell Hydroelectric Project (Lowell or Project), Federal Energy Regulatory Commission (FERC) No. 2790, as identified in the Revised Study Plan (RSP) submitted by Boott Hydropower, LLC (Boott) on January 28, 2019. The approach and methodology described in the RSP for the fish community study was approved by FERC in its Study Plan Determination letter dated March 13, 2019.

In accordance with 18 C.F.R. § 5.15(c), Boott filed their Initial Study Report (ISR) with FERC on February 25, 2020. As described in the ISR, data analyses were in progress and scheduled for completion during 2020. On June 12, 2020 FERC issued a Revised Process Plan and Schedule and Determination on Requests for Study Modifications for the Lowell Hydroelectric Project (Revised PPS). In accordance with the Revised PPS, Boott filed their Revised ISR with FERC on September 30, 2020, which contained a full report for the Fish Assemblage Study. Boott held a revised ISR meeting on October 15, 2020 and a summary of the study results was presented to representatives from FERC, U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Massachusetts Division of Fisheries and Wildlife (MADFW), Massachusetts Division of Marine Fisheries (MDMF), and the New Hampshire Fish and Game Department (NHFGD). No significant comments on the Fish Assemblage Study were received.

This final technical report provides a description of the objectives, methodologies and results of the 2019 field sampling intended to describe the fish community within the Lowell Project area.

2 Objectives

The goal of this study was to characterize the fish assemblage in areas affected by the Lowell Project, specifically the impoundment and bypassed reach.

Specific objectives included:

- Field sampling to describe the fish assemblage structure, distribution, and abundance within the Project affected area along spatial and temporal gradients; and
- A comparison of historical records of fish species occurrence in the Project area to results of this study.

3 Project Description and Study Area

The Lowell Project is located at River Mile (RM) 41 on the Merrimack River in the City of Lowell in Middlesex County, Massachusetts, with an impoundment extending approximately 23 miles upstream into Hillsborough County, New Hampshire. The existing Lowell Project consists of: (1) a 1,093-foot-long, 15-foot-high masonry gravity dam (Pawtucket dam) that includes a 982.5-foot-long spillway with a crest elevation of 87.2 feet National Geodetic Vertical Datum 1929 (NGVD 29) topped by 5-foot-high pneumatically-operated crest gates deployed in five independently-operable zones; (2) a 720-acre impoundment with a normal maximum water surface elevation of 92.2 feet NGVD 29; (3) a 5.5-mile-long canal system which includes several small dams and gatehouses; (4) a powerhouse (E.L. Field) which uses water from the Northern Canal and contains two turbine-generator units with a total installed capacity of 15.0 megawatts (MW); (5) a 440-foot-long tailrace channel; (6) four powerhouses (Assets, Bridge Street, Hamilton, and John Street) housed in nineteenth century mill buildings along the Northern and Pawtucket Canal System containing 15 turbine-generator units with a total installed capacity of approximately 5.1 MW; (7) a 4.5-mile long, 13.8-kilovolt transmission line connecting the powerhouses to the regional distribution grid; (8) upstream and downstream fish passage facilities including a fish elevator and downstream fish bypass at the E.L. Field powerhouse, and a vertical-slot fish ladder at the Pawtucket dam; and (9) appurtenant facilities. At the normal pond elevation of 92.2 feet NGVD 1929 (crest of the pneumatic flashboards), the surface area of the impoundment encompasses an area of approximately 720 acres. The gross storage capacity between the normal surface elevation of 92.2 feet and the minimum pond level of 87.2 feet is approximately 3,600 acre-feet. The Project operates essentially in a run-of-river (ROR) mode using automatic pond level control, and has no usable storage capacity.

The study area for this fish community survey included the mainstem Merrimack River from the Pawtucket Dam to the upper extent of the Project's impoundment located approximately 23 river miles upstream, and the Project's 0.7-mile-long bypassed reach.

4 Methods

4.1 Lowell Impoundment

The 23-mile-long (37 kilometer) impoundment was stratified based on mesohabitat characteristics. Each stratum was delineated in 547-yard (500-meter) segments using Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS). Sampling locations were randomly selected and weighted proportional to mesohabitat type frequency (e.g., if 50 percent of a particular geographic reach was shallow, riffle habitat, then 50 percent of the total number of sampling locations for that geographic reach were randomly placed within that habitat type). As long as habitat was accessible, efforts were made to ensure that a minimum of three sampling locations were placed within each strata (i.e., habitat type). A total of twelve, 547-yard (500-meter) segments were randomly selected within the reach so that approximately 16% of the impoundment was sampled. The stratified-random site selection process was repeated for each of three seasonal surveys (spring, summer, and fall).

Following selection of the twelve, 500-meter sample units, boat electrofish sampling took place during the nighttime hours (as defined by daily sunset/sunrise times). A single bank (east or west) was randomly selected for each sample unit. Prior to the start of sampling, settings on the electrofishing unit were adjusted by a trained crew member to ensure that approximately 4.0 amps of pulsed DC current was being generated. After recording the start time, boat electrofish sampling consisted of a single shoreline pass starting at the upstream end of each 500m transect and proceeded downstream. Effort was made by the boat driver to follow the shoreline contour and probe the sampling anodes into habitat areas (i.e., overhanging vegetation, submerged aquatic vegetation, woody debris, etc.). The boat driver maintained the boat in near-shore littoral habitat (< 10-feet deep) where the sampling field would be most effective. A pair of netters stood on the bow of the sampling vessel and placed all stunned fish into an onboard live well for processing. Once the sample transect was finished, the driver recorded the completion time and duration of the sampling effort.

An experimental gill net was set concurrent with boat electrofishing in each 500-m sample unit. Gill nets were fished within all sample units containing adequate water depths and flow conditions to allow for proper performance of the nets, specifically deep and mid-channel microhabitats. Experimental gillnets were eight feet deep and were constructed of four 25-ft panels of increasing mesh size (1.0, 2.0, 3.0, and 4.0-inch stretch mesh). Gillnets were set during nighttime hours (as defined by daily sunset/sunrise times) when fish species are most susceptible to the gear due to the reduced visual avoidance. Gillnets were deployed perpendicular to the shoreline in areas where water depths were greater than the net height and capture area was maximized. Nets were set and fished for an approximate four-hour period prior to retrieval to minimize netting mortality. Net set coordinates and the date and time of each set and pull were recorded.

To supplement experimental gill net sampling in deeper habitats (> 10 ft) where electrofishing is not effective and small fish and eels are not susceptible to gillnets, a pair of standard minnow traps were deployed. The traps were 2.5 feet long galvanized wire mesh (0.25 square inch) cylinders with two entry fykes. Traps were baited and anchored to remain on station for the duration of their soak time. For each sample unit, two traps were fished simultaneously with gillnets for an approximate four-hour period. Trap set coordinates and the date and time of each set and pull were recorded.

All fish collected from the impoundment were identified to the lowest possible taxonomic classification (preferably to species), enumerated, measured to total length (to the nearest mm), and weighed (to the nearest g). If large numbers of small fish (i.e., YOY or small cyprinid species) were captured, length and weight information was collected from the first 25 individuals within the sample and the remaining individuals were grouped, enumerated, and batch weighed.

For each 500-m sample unit, the sampling crews visually evaluated habitat within the reach. The dominant substrate (organics, sand/silt/clay, cobble/gravel, boulder, or ledge), proportion of transect with submerged aquatic vegetation (i.e., 0-25%, 5-50%, 50-75%, or 75-100%), and the proportion of transect with overhanging vegetative cover (i.e., 0-25%, 5-50%, 50-75%, or 75-100%) was recorded. To get a sense of relative water depth for the Merrimack River at each sampling transect, a series of nine measurements were collected. River depths were recorded at the quarter points (i.e., 25, 50, and 75%) of three cross sections placed at the upstream extent, downstream extent, and midpoint of each sample unit. A representative water velocity (ft/s) was recorded at the midpoint of the middle cross-section of each habitat unit. Following documentation of sample unit habitat and characteristics, a representative water quality measurement was collected at approximately one meter of depth. Water temperature (^{o}C), dissolved oxygen (mg/L) conductivity (µs/cm), pH, and turbidity (ntu) were recorded.

4.2 Lowell Bypassed Reach

Delineation of sample units was scaled for the shorter, less accessible bypassed reach. Each stratum was delineated in 55-yard (50-meter) segments using ArcGIS. Sampling locations were randomly selected and weighted proportional to mesohabitat type frequency. As long as habitat was available, effort was made to ensure that at least one sampling location was placed within each strata (i.e., habitat type) within the bypassed reach. A total of three segments were randomly selected within the bypassed reach during each of three seasonal surveys (spring, summer, fall). Due to safety and gear limitations, sampling was not conducted in (1) the reach from the Pawtucket Dam downstream to the School Street Bridge, and (2) the lowermost section of the bypass channel downstream of the Northern Canal surge gate. Sampling was limited to periods of minimum flow in the bypassed reach.

Backpack electrofish sampling was conducted within the Lowell bypassed reach. Halltech Aquatic Research Model HT2000B/MK5, battery-powered backpack electrofishers with ring probes and rattail cathodes were used to sample within the bypassed reach. Sampling was conducted by anchoring a fine mesh seine at the downstream end of a 50-m sample unit. A pair of backpack electrofishing units and four technicians moved in a downstream direction towards the seine while actively netting stunned individuals and kicking the substrate to drive additional stunned individuals towards the collection net. Backpack electrofish sampling was conducted during daylight hours. The backpack units were set at 550 volts at 100 Hertz (Hz). The start time, end time and duration of sampling were recorded for each sample unit. Specifics related to habitat and effort were the same as described above for impoundment sampling.

5 Results

5.1 Lowell Impoundment

5.1.1 Habitat Evaluation and Sample Unit Selection

A pair of biologists boated the stretch of the Merrimack River from the Pawtucket Dam upstream 23.0 miles to the uppermost extent of the Project area on May 18, 2019. Changes in mesohabitat type were visually identified and their locations recorded. Following importation of those habitat break points into ArcGIS, the 23.0 miles of the Merrimack River upstream of Lowell impoundment was subdivided into a total of 74 547-yard (500-meter) segments. The majority of those (78%) were classified as impoundment habitat. Lesser amounts of the overall reach were classified as run (7%) and pool (15%). The spatial distribution of mesohabitat types and 500-m segments for the 23.0 miles upstream of Lowell is provided in Appendix A.

Table 5-1 provides a listing of the habitat units upstream of the Pawtucket Dam that were randomly selected for sampling during the spring, summer, and fall periods of 2019. A total of twelve, 500-m segments were selected per season. During the spring season, a total of six impoundment, three run and three pool habitat units were sampled. River conditions (i.e., water depth) prevented effective sampling within some of the run habitat at the uppermost end of the Project area during the summer and fall sampling periods. As a result, seven impoundment, two run, and three pool habitat units were sampled during those seasons.

5.1.2 Sampling Effort

Fish community data were collected from a total of 36, 500-m sample units during the spring, summer, and fall of 2019 (12 sites per season). Effort expended at a sample unit during each of the three seasons consisted of (1) a 500-m shoreline boat electrofish sample, (2) a four hour experimental gill net set, and (3) a four hour baited minnow trap set. Fish community sampling in the Lowell impoundment occurred on June 24-26 (spring), August 19-21 (summer) and October 28-30 (fall). Tables 5-2 through 5-4 provide a summary of boat electrofish, gill net and minnow trap sampling in the Lowell impoundment. Impoundment sample units selected by season are presented visually in Appendix A.

5.1.3 Species Richness and Composition

A total of 1,847 individuals representing twenty-two fish species were collected from the Lowell impoundment during 2019 when all sampling seasons and sample units are considered (Table 5-5). The total impoundment catch represents all individuals collected and identified during boat electrofish and gill net sampling. There were no fish collected via minnow trap during the 2019 survey. Table 5-6 provides a summary of the impoundment community composition by season (electrofish and gill net). Spottail shiner (23.0%), redbreast sunfish (20.5%) and smallmouth bass (12.3%) were the three most numerically abundant species within the Lowell impoundment during the 2019 sampling. When examined by species, spottail shiner were most abundant during the spring (27.6% of seasonal catch) and fall (33.9% of seasonal catch) whereas redbreast sunfish were most abundant during the summer period (27.1% of seasonal catch).

Total catch and community composition from sampling units upstream of Pawtucket Dam and classified as impoundment, pool and run mesohabitat types are presented in Table 5-7. Centrarchid species were the most abundant within impoundment habitat with redbreast sunfish (24.2%), pumpkinseed (14.2%), and smallmouth bass (12.5%) representing the three most abundantly sampled species. Spottail shiner were the most abundantly sampled fish species in the pool (28.4%) and run (46.3%) habitat areas.

The majority of catch in the impoundment was observed during boat electrofishing efforts (Table 5-8). A total of 1,792 individuals representing 20 fish species were collected. Spottail shiner, redbreast sunfish, and smallmouth bass were the most frequently observed species within the impoundment electrofish catch. Total boat electrofish catch within the impoundment was fairly even across seasons (high of 677 individuals during the summer to a low of 543 individuals during the fall). A total of 55 individuals representing 15 species were recorded during gill net sampling in the Lowell impoundment. Yellow bullhead was the most frequently encountered species during gill net sampling and the majority of catch was recorded during the summer season.

5.1.4 Relative Abundance

Relative abundance, the number of fish captured with known sampling effort and indexed as catch per unit of effort (CPUE), was calculated on a species-specific basis. CPUE values were standardized to a fixed unit of time or distance using the following equations:

For time (i.e., fish per hour): CPUE for taxon j in sample i = (catch ji / duration i) * 60 min

Where: duration is expressed in minutes

For distance (i.e., fish per 100 m): CPUE for taxon j in sample i = (catch ji / length i) * 100m

Where: length is expressed in meters

Prior to the calculation of any CPUE values the data set was "zero filled" for each fish species, such that each species collected in the study was represented in every sample. CPUE values were calculated for each fish species by season and gear.

Catch rates were highest for spottail shiner, redbreast sunfish and smallmouth bass captured by boat electrofish sampling in the 23.0 mile reach upstream of Pawtucket Dam during the 2019 sampling (Table 5-9). Values for fish per unit of effort were highest for spottail shiner and smallmouth bass during the spring sampling event, redbreast sunfish and spottail shiner during the summer sampling event and fallfish and alewife during the fall sampling event. Table 5-10 provides CPUE rates for fish collected during gill net sampling in the upstream reach during 2019. The CPUE rate for yellow bullhead was the highest for fish collected in the experimental gill nets. A listing of CPUE rates for all species by season and mesohabitat type is provided in Appendix B.

5.1.5 Biocharacteristics

Length frequency distributions for fish species where 25 or more individuals were collected and measured during the impoundment sampling are presented in Appendix E. The observed range for fish sizes recorded for species observed in both the boat electrofish and gill net catch from the Lowell impoundment fall within the expected bounds for those species in the northeastern U.S. (Table 5-11). A full listing of catch data is provided in Appendix F.

5.1.6 Habitat and Water Quality Characteristics

Tables 5-12 and 5-13 provide summaries of habitat and water quality information recorded for each of the 36, 500-m sample units surveyed during the spring, summer and fall seasons. Dominant substrate, presence of submerged aquatic vegetation (SAV), and presence of general cover were consistent among all sample units regardless of mesohabitat classification (i.e., pool, run or impoundment). Sampled areas upstream of Pawtucket Dam were characterized by sand-silt-clay sediments, presence of SAV over 0-25% of the sample area and the presence of general cover over 0-25% of the sample area. Mean water depth (as sampled at quarter points of the river channel at the upper, middle, and lower points of each transect) trended towards shallower at the upper end of the reach upstream of Pawtucket Dam in areas classified as pool and run and deeper at the lower end in areas classified as impoundment.

Water temperature was relatively consistent among sample units with a ± 1-2°C range in values within each season. The average Merrimack River water temperature was 21.5°C during the spring sampling, 25.6°C during the summer sampling, and 10.8°C during the fall sampling. Dissolved oxygen was measured at 8.1 mg/L or greater at all stations upstream of Pawtucket

Dam regardless of season. Conductivity averaged 114 µs/cm during the spring sampling, 181 µs/cm during the summer sampling, and 117 µs/cm during the fall sampling. In general, conductivity increased with proximity to the Pawtucket Dam. River pH was consistent across seasons ranging from 6.5-7.5. The average turbidity reading was higher during the spring sampling (2.6 NTU) than was observed during the summer or fall periods (1.8 and 1.6 NTUs, respectively).

Table 5–1. Sample unit habitat type and location for the spring, summer and fall Lowell impoundment fish community survey

Season	Sample Unit	Mesohabitat Type	Upstream		Downstream		Efish Bank
			Latitude	Longitude	Latitude	Longitude	
Spring	LIMP_002	Run	42.88173	-71.47036	42.87818	-71.47409	W
	LIMP_004	Run	42.87414	-71.47563	42.87073	-71.47963	E
	LIMP_005	Pool	42.87073	-71.47963	42.86747	-71.48384	W
	LIMP_012	Pool	42.84162	-71.48371	42.83729	-71.48473	E
	LIMP_015	Pool	42.82889	-71.48038	42.82455	-71.47880	E
	LIMP_016	Run	42.82455	-71.47880	42.82055	-71.47999	W
	LIMP_017	Impoundment	42.82055	-71.47999	42.81789	-71.47512	W
	LIMP_021	Impoundment	42.80479	-71.47225	42.80101	-71.46898	W
	LIMP_027	Impoundment	42.78203	-71.45706	42.77753	-71.45706	W
	LIMP_049	Impoundment	42.69368	-71.42215	42.69125	-71.41704	W
	LIMP_050	Impoundment	42.69125	-71.41704	42.68765	-71.41352	W
	LIMP_069	Impoundment	42.63767	-71.36403	42.63851	-71.35805	W
Summer	LIMP_001	Run	42.88500	-71.46616	42.88173	-71.47036	W
	LIMP_002	Run	42.88173	-71.47036	42.87818	-71.47409	W
	LIMP_006	Pool	42.86747	-71.48384	42.86341	-71.48632	E
	LIMP_011	Pool	42.84596	-71.48228	42.84162	-71.48371	E
	LIMP_014	Pool	42.83315	-71.48236	42.82889	-71.48038	W
	LIMP_020	Impoundment	42.80909	-71.47339	42.80479	-71.47225	E
	LIMP_021	Impoundment	42.80479	-71.47225	42.80101	-71.46898	E
	LIMP_042	Impoundment	42.72045	-71.43789	42.71597	-71.43723	W
	LIMP_045	Impoundment	42.70703	-71.43625	42.70288	-71.43394	W
	LIMP_056	Impoundment	42.67057	-71.41675	42.66851	-71.41135	E
	LIMP_065	Impoundment	42.64835	-71.37998	42.64423	-71.37771	E
	LIMP_068	Impoundment	42.63777	-71.37011	42.63767	-71.36403	E
Fall	LIMP_002	Run	42.88173	-71.47036	42.87818	-71.47409	E
	LIMP_003	Run	42.87818	-71.47409	42.87414	-71.47563	W
	LIMP_005	Pool	42.87073	-71.47963	42.86747	-71.48384	W
	LIMP_011	Pool	42.84596	-71.48228	42.84162	-71.48371	E
	LIMP_015	Pool	42.82889	-71.48038	42.82455	-71.47880	W
	LIMP_023	Impoundment	42.79761	-71.46500	42.79481	-71.46027	W
	LIMP_037	Impoundment	42.74124	-71.43966	42.73705	-71.43771	E
	LIMP_044	Impoundment	42.71149	-71.43696	42.70703	-71.43625	W
	LIMP_058	Impoundment	42.66630	-71.40605	42.66252	-71.40286	W
	LIMP_060	Impoundment	42.65840	-71.40047	42.65406	-71.39903	W
	LIMP_061	Impoundment	42.65406	-71.39903	42.64990	-71.39711	E
	LIMP_067	Impoundment	42.64024	-71.37510	42.63777	-71.37011	E

Table 5–2. Impoundment boat electrofish effort for the spring, summer and fall Lowell impoundment fish community survey

Season	Sample Unit	Sample			No. Amps	No. Netters	No. Runs
		Date	Time	Duration (Sec)			
Spring	LIMP_002	6/24/2019	21:01	753	4	2	1
	LIMP_004	6/24/2019	22:04	956	4	2	1
	LIMP_005	6/24/2019	23:29	741	4	2	1
	LIMP_012	6/25/2019	0:37	782	4	2	1
	LIMP_015	6/26/2019	22:31	907	4	2	1
	LIMP_016	6/26/2019	21:49	968	4	2	1
	LIMP_017	6/26/2019	21:01	1001	4	2	1
	LIMP_021	6/26/2019	23:30	833	4	2	1
	LIMP_027	6/26/2019	1:25	888	4	2	1
	LIMP_049	6/25/2019	23:56	909	4	2	1
	LIMP_050	6/25/2019	22:42	842	4	2	1
	LIMP_069	6/25/2019	21:26	837	4	2	1
Summer	LIMP_001	8/19/2019	20:38	851	4	2	1
	LIMP_002	8/19/2019	21:44	722	4	2	1
	LIMP_006	8/19/2019	22:54	775	4	2	1
	LIMP_011	8/20/2019	0:02	959	4	2	1
	LIMP_014	8/21/2019	22:02	837	4	2	1
	LIMP_020	8/21/2019	20:56	841	4	2	1
	LIMP_021	8/21/2019	20:20	729	4	2	1
	LIMP_042	8/21/2019	0:17	903	4	2	1
	LIMP_045	8/20/2019	23:32	852	4	2	1
	LIMP_056	8/20/2019	22:22	815	4	2	1
	LIMP_065	8/20/2019	21:35	881	4	2	1
	LIMP_068	8/20/2019	20:21	812	4	2	1
Fall	LIMP_002	10/29/2019	16:54	839	4	2	1
	LIMP_003	10/29/2019	18:02	834	4	2	1
	LIMP_005	10/29/2019	20:02	814	4	2	1
	LIMP_011	10/29/2019	21:11	939	4	2	1
	LIMP_015	10/29/2019	21:48	842	4	2	1
	LIMP_023	10/29/2019	22:45	946	4	2	1
	LIMP_037	10/30/2019	18:39	835	4	2	1
	LIMP_044	10/30/2019	17:45	942	4	2	1
	LIMP_058	10/28/2019	17:54	900	4	2	1
	LIMP_060	10/28/2019	18:24	1140	4	2	1
	LIMP_061	10/28/2019	19:00	1080	4	2	1
	LIMP_067	10/28/2019	20:00	1140	4	2	1

Table 5–3. Impoundment experimental gill net effort for the spring, summer and fall Lowell impoundment fish community survey

Season	Sample Unit	Sample			Set Location	
		Date	Time	Duration (hr)	Latitude	Longitude
Spring	LIMP_002	6/24/2019	20:49	4.3	42.87818	71.47409
	LIMP_004	6/24/2019	21:02	4.3	42.87054	71.47924
	LIMP_005	6/24/2019	21:09	4.6	42.86747	71.48384
	LIMP_012	6/24/2019	21:30	4.7	42.83729	71.48472
	LIMP_015	6/26/2019	21:02	4.1	42.82588	71.47865
	LIMP_016	6/26/2019	21:14	4.2	42.82069	71.47828
	LIMP_017	6/26/2019	21:24	4.3	42.81857	71.47600
	LIMP_021	6/26/2019	21:35	4.4	42.80157	71.46944
	LIMP_027	6/25/2019	22:22	4.2	42.77752	71.45763
	LIMP_049	6/25/2019	21:55	4.1	42.69118	71.41750
	LIMP_050	6/25/2019	21:47	4.0	42.68747	71.41373
	LIMP_069	6/25/2019	21:18	4.1	42.63792	71.35815
Summer	LIMP_001	8/19/2019	20:33	4.7	42.88173	71.47036
	LIMP_002	8/19/2019	21:04	4.5	42.87818	71.47409
	LIMP_006	8/19/2019	21:30	4.4	42.86341	71.48632
	LIMP_011	8/19/2019	21:54	4.5	42.84162	71.48371
	LIMP_014	8/21/2019	20:20	4.1	42.82890	71.48038
	LIMP_020	8/21/2019	19:52	5.2	42.80479	71.47225
	LIMP_021	8/21/2019	19:44	5.6	42.80101	71.46984
	LIMP_042	8/20/2019	21:58	5.7	42.71597	71.43723
	LIMP_045	8/20/2019	21:42	5.6	42.70288	71.43394
	LIMP_056	8/20/2019	21:10	5.6	42.66851	71.41135
	LIMP_065	8/20/2019	20:39	5.7	42.64423	71.37771
	LIMP_068	8/20/2019	20:18	5.4	42.63767	71.36403
Fall	LIMP_002	10/29/2019	17:50	4.2	42.87818	71.47409
	LIMP_003	10/29/2019	18:06	4.3	42.87414	71.47563
	LIMP_005	10/29/2019	18:15	4.7	42.86747	71.48384
	LIMP_011	10/29/2019	18:35	5.0	42.84162	71.48371
	LIMP_015	10/29/2019	18:50	5.3	42.82455	71.47880
	LIMP_023	10/30/2019	17:41	4.0	42.79481	71.46027
	LIMP_037	10/30/2019	18:01	4.2	42.73705	71.43771
	LIMP_044	10/30/2019	18:16	4.5	42.70703	71.43625
	LIMP_058	10/28/2019	17:48	4.0	42.66252	71.40286
	LIMP_060	10/28/2019	18:06	4.1	42.65406	71.39903
	LIMP_061	10/28/2019	18:13	4.2	42.64990	71.39711
	LIMP_067	10/28/2019	18:29	4.3	42.63777	71.37011

Table 5–4. Impoundment minnow trap effort for the spring, summer and fall Lowell impoundment fish community survey

Season	Sample Unit	Sample			Set Location	
		Date	Time	Duration (hr)	Latitude	Longitude
Spring	LIMP_002	6/24/2019	23:05	1.9	42.87818	71.47409
	LIMP_004	6/24/2019	22:29	3.1	42.87073	71.47963
	LIMP_005	6/24/2019	22:11	3.6	42.86747	71.48384
	LIMP_012	6/24/2019	21:30	4.8	42.83729	71.48472
	LIMP_015	6/25/2019	22:23	4.0	42.77731	71.45747
	LIMP_016	6/25/2019	21:56	4.1	42.69115	71.41727
	LIMP_017	6/25/2019	21:48	4.0	42.68721	71.41364
	LIMP_021	6/25/2019	21:22	4.0	42.63770	71.35809
	LIMP_027	6/26/2019	21:02	4.1	42.82511	71.47849
	LIMP_049	6/26/2019	21:15	4.2	42.82085	71.47791
	LIMP_050	6/26/2019	21:26	4.1	42.81836	71.47588
	LIMP_069	6/26/2019	21:36	4.2	42.80159	71.46933
Summer	LIMP_001	8/19/2019	22:42	2.8	42.88173	71.47036
	LIMP_002	8/19/2019	22:36	3.0	42.87818	71.47409
	LIMP_006	8/19/2019	22:20	3.7	42.86341	71.48632
	LIMP_011	8/19/2019	21:59	4.4	42.84162	71.48371
	LIMP_014	8/21/2019	20:22	4.0	42.82890	71.48038
	LIMP_020	8/21/2019	19:53	5.1	42.80479	71.47225
	LIMP_021	8/21/2019	19:46	5.5	42.80101	71.46984
	LIMP_042	8/20/2019	22:04	5.5	42.71597	71.43723
	LIMP_045	8/20/2019	21:45	5.5	42.70288	71.43394
	LIMP_056	8/20/2019	21:13	5.6	42.66851	71.41135
	LIMP_065	8/20/2019	22:48	3.5	42.64423	71.37771
	LIMP_068	8/20/2019	20:22	2.3	42.63767	71.36403
Fall	LIMP_002	10/29/2019	17:52	4.1	42.87818	71.47409
	LIMP_003	10/29/2019	18:07	4.2	42.87414	71.47563
	LIMP_005	10/29/2019	18:17	4.7	42.86747	71.48384
	LIMP_011	10/29/2019	18:37	5.0	42.84162	71.48371
	LIMP_015	10/29/2019	18:52	5.2	42.82455	71.47880
	LIMP_023	10/30/2019	17:42	4.0	42.79481	71.46027
	LIMP_037	10/30/2019	18:02	4.2	42.73705	71.43771
	LIMP_044	10/30/2019	18:18	4.4	42.70703	71.43625
	LIMP_058	10/28/2019	17:50	4.2	42.66252	71.40286
	LIMP_060	10/28/2019	18:04	4.2	42.65406	71.39903
	LIMP_061	10/28/2019	18:15	4.1	42.64990	71.39711
	LIMP_067	10/28/2019	18:31	4.2	42.63777	71.37011

Table 5–5. Number of fish captured upstream of Pawtucket Dam by boat electrofishing and experimental gill net during the spring, summer and fall sampling, 2019

Common Name	Spring	Summer	Fall	2019
	N	N	N	N
Alewife	0	21	92	113
American Eel	6	10	1	17
Black Crappie	2	2	1	5
Bluegill	24	77	21	122
Channel Catfish	0	1	0	1
Common Carp	1	3	1	5
Fallfish	34	34	75	143
Golden Shiner	1	5	7	13
Largemouth Bass	2	32	7	41
Lepomis spp.	1	3	0	4
Margined Madtom	3	5	1	9
Pumpkinseed	10	126	19	155
Redbreast Sunfish	137	196	45	378
Rock Bass	3	2	2	7
Sea Lamprey	7	6	8	21
Smallmouth Bass	127	50	50	227
Spottail Shiner	160	79	185	424
Tessellated Darter	14	14	3	31
Walleye	0	1	0	1
White Perch	0	1	0	1
White Sucker	24	9	22	55
Yellow Bullhead	7	42	5	54
Yellow Perch	16	3	1	20
Total	**579**	**722**	**546**	**1847**

Table 5–6. Percent composition of fish captured upstream of Pawtucket Dam by boat electrofishing and experimental gill net during the spring, summer and fall sampling, 2019

Common Name	Spring	Summer	Fall	2019
	Pct.	Pct.	Pct.	Pct.
Alewife	<0.1	2.9	16.8	6.1
American Eel	1.0	1.4	0.2	0.9
Black Crappie	0.3	0.3	0.2	0.3
Bluegill	4.1	10.7	3.8	6.6
Channel Catfish	<0.1	0.1	<0.1	0.1
Common Carp	0.2	0.4	0.2	0.3
Fallfish	5.9	4.7	13.7	7.7
Golden Shiner	0.2	0.7	1.3	0.7
Largemouth Bass	0.3	4.4	1.3	2.2
Lepomis spp.	0.2	0.4	<0.1	0.2
Margined Madtom	0.5	0.7	0.2	0.5
Pumpkinseed	1.7	17.5	3.5	8.4
Redbreast Sunfish	23.7	27.1	8.2	20.5
Rock Bass	0.5	0.3	0.4	0.4
Sea Lamprey	1.2	0.8	1.5	1.1
Smallmouth Bass	21.9	6.9	9.2	12.3
Spottail Shiner	27.6	10.9	33.9	23.0
Tessellated Darter	2.4	1.9	0.5	1.7
Walleye	<0.1	0.1	<0.1	0.1
White Perch	<0.1	0.1	<0.1	0.1
White Sucker	4.1	1.2	4.0	3.0
Yellow Bullhead	1.2	5.8	0.9	2.9
Yellow Perch	2.8	0.4	0.2	1.1

Table 5–7. Number and percent composition of fish captured upstream of Pawtucket Dam by boat electrofishing and experimental gill net within impoundment, pool and run mesohabitat areas, 2019

Common Name	Impoundment		Pool		Run	
	N	Pct.	N	Pct.	N	Pct.
Alewife	104	9.9	4	1.3	5	1.0
American Eel	11	1.0	1	0.3	5	1.0
Black Crappie	1	0.1	3	1.0	1	0.2
Bluegill	87	8.2	28	9.0	7	1.5
Channel Catfish	1	0.1	0	0.0	0	0.0
Common Carp	4	0.4	0	0.0	1	0.2
Fallfish	66	6.3	37	11.9	40	8.3
Golden Shiner	3	0.3	6	1.9	4	0.8
Largemouth Bass	22	2.1	15	4.8	4	0.8
Lepomis spp.	2	0.2	1	0.3	1	0.2
Margined Madtom	6	0.6	2	0.6	1	0.2
Pumpkinseed	150	14.2	3	1.0	2	0.4
Redbreast Sunfish	255	24.2	39	12.6	84	17.4
Rock Bass	3	0.3	2	0.6	2	0.4
Sea Lamprey	11	1.0	5	1.6	5	1.0
Smallmouth Bass	132	12.5	35	11.3	60	12.4
Spottail Shiner	113	10.7	88	28.4	223	46.3
Tessellated Darter	14	1.3	11	3.5	6	1.2
Walleye	1	0.1	0	0.0	0	0.0
White Perch	1	0.1	0	0.0	0	0.0
White Sucker	21	2.0	12	3.9	22	4.6
Yellow Bullhead	42	4.0	6	1.9	6	1.2
Yellow Perch	5	0.5	12	3.9	3	0.6
Total	**1055**	**100.0**	**310**	**100.0**	**482**	**100.0**

Table 5–8. Number of fish captured upstream of Pawtucket Dam by boat electrofishing or experimental gill net during spring, summer, and fall, 2019

Common Name	Boat Efish				Gill Net			
	Spring	Summer	Fall	Total	Spring	Summer	Fall	Total
Alewife	0	19	92	111	0	2	0	2
American Eel	6	10	1	17	0	0	0	0
Black Crappie	2	2	1	5	0	0	0	0
Bluegill	23	77	21	121	1	0	0	1
Channel Catfish	0	0	0	0	0	1	0	1
Common Carp	1	2	1	4	0	1	0	1
Fallfish	33	32	75	140	1	2	0	3
Golden Shiner	1	4	7	12	0	1	0	1
Largemouth Bass	2	32	7	41	0	0	0	0
Lepomis spp.	1	3	0	4	0	0	0	0
Margined Madtom	2	5	1	8	1	0	0	1
Pumpkinseed	10	125	19	154	0	1	0	1
Redbreast Sunfish	137	191	45	373	0	5	0	5
Rock Bass	3	2	2	7	0	0	0	0
Sea Lamprey	7	6	8	21	0	0	0	0
Smallmouth Bass	126	46	50	222	1	4	0	5
Spottail Shiner	159	79	184	422	1	0	1	2
Tessellated Darter	14	14	3	31	0	0	0	0
Walleye	0	0	0	0	0	1	0	1
White Perch	0	1	0	1	0	0	0	0
White Sucker	22	7	22	51	2	2	0	4
Yellow Bullhead	7	19	3	29	0	23	2	25
Yellow Perch	16	1	1	18	0	2	0	2
Total	**572**	**677**	**543**	**1792**	**7**	**45**	**3**	**55**

Table 5–9. Catch per unit of effort for fish captured upstream of Pawtucket Dam by boat electrofishing during spring, summer, and fall, 2019

Common Name	Spring		Summer		Fall		Total	
	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m
Alewife	0.00	0.00	1.39	0.06	10.15	0.61	3.85	0.23
American Eel	0.53	0.03	2.17	0.09	<0.01	<0.01	0.90	0.04
Black Crappie	0.53	0.02	0.23	0.01	0.31	0.01	0.36	0.02
Bluegill	3.04	0.14	9.13	0.43	3.15	0.15	5.11	0.24
Common Carp	0.07	<0.01	0.76	0.03	0.13	0.01	0.32	0.01
Fallfish	7.27	0.34	6.43	0.28	14.09	0.65	9.26	0.43
Golden Shiner	0.06	<0.01	0.75	0.03	1.66	0.07	0.82	0.04
Largemouth Bass	0.34	0.02	4.28	0.20	1.43	0.06	2.02	0.09
Lepomis spp.	0.07	<0.01	0.92	0.04	0.00	0.00	0.33	0.01
Margined Madtom	0.37	0.02	1.06	0.05	0.12	0.01	0.52	0.02
Pumpkinseed	0.80	0.04	9.60	0.44	2.13	0.13	4.18	0.20
Redbreast Sunfish	22.79	1.05	35.24	1.55	5.52	0.29	21.18	0.96
Rock Bass	1.19	0.05	0.24	0.01	0.10	0.01	0.51	0.02
Sea Lamprey	1.63	0.08	0.42	0.02	1.20	0.06	1.08	0.06
Smallmouth Bass	25.51	1.16	9.26	0.42	5.58	0.29	13.45	0.62
Spottail Shiner	35.29	1.55	25.94	1.12	8.30	0.37	23.17	1.01
Tessellated Darter	3.02	0.14	1.56	0.07	0.12	0.01	1.57	0.07
White Perch	0.00	0.00	0.08	0.00	0.00	0.00	0.03	0.00
White Sucker	4.19	0.21	1.27	0.06	2.46	0.12	2.64	0.13
Yellow Bullhead	0.90	0.05	2.00	0.09	0.52	0.03	1.14	0.05
Yellow Perch	4.66	0.20	0.21	0.01	<0.01	<0.01	1.62	0.07

Table 5–10. Catch per unit of effort for fish captured upstream of Pawtucket Dam by experimental gill net during spring, summer, and fall, 2019

Common Name	Spring	Summer	Fall	Total
	Fish/hr	Fish/hr	Fish/hr	Fish/hr
Alewife	<0.01	0.01	0.00	0.00
Bluegill	0.02	<0.01	<0.01	0.01
Channel Catfish	<0.01	0.00	<0.01	<0.01
Common Carp	<0.01	0.00	<0.01	<0.01
Fallfish	0.00	0.01	<0.01	0.01
Golden Shiner	<0.01	0.03	<0.01	0.01
Margined Madtom	0.00	<0.01	<0.01	<0.01
Pumpkinseed	<0.01	0.00	<0.01	<0.01
Redbreast Sunfish	<0.01	0.02	<0.01	0.01
Smallmouth Bass	0.00	0.01	<0.01	0.01
Spottail Shiner	0.03	<0.01	0.02	0.02
Walleye	<0.01	0.00	<0.01	<0.01
White Sucker	0.02	0.01	<0.01	0.01
Yellow Bullhead	<0.01	0.08	0.04	0.04
Yellow Perch	<0.01	0.01	<0.01	<0.01

Table 5–11. Minimum, mean, and maximum total length (mm) and weight (g) for fish captured upstream of Pawtucket Dam by boat electrofish and experimental gill net sampling during spring, summer, and fall, 2019

Sampling Gear	Common Name	No. Individuals	Total Length (mm)			Total Weight (g)		
			Min.	Mean	Max.	Min.	Mean	Max.
Boat Electrofish	Alewife	111	59	69	104	1	4	102
	American Eel	17	225	459	670	20	236	535
	Black Crappie	5	84	133	155	8	36	49
	Bluegill	121	47	110	220	1	38	255
	Common Carp	4	429	662	793	1350	4813	6500
	Fallfish	140	55	127	310	2	28	335
	Golden Shiner	12	80	120	208	6	23	73
	Largemouth Bass	41	57	141	382	2	108	900
	Margined Madtom	8	82	102	138	4	9	23
	Pumpkinseed	154	57	97	150	3	27	685
	Redbreast Sunfish	373	38	113	190	1	35	160
	Rock Bass	7	121	157	189	41	86	140
	Sea Lamprey	21	90	127	174	1	4	8
	Smallmouth Bass	222	64	158	494	3	93	1450
	Spottail Shiner	422	49	93	126	1	11	840
	Tessellated Darter	31	39	65	80	1	3	5
	White Perch	1	69	69	69	5	5	5
	White Sucker	51	84	310	520	7	600	1800
	Yellow Bullhead	29	104	183	297	15	95	310
	Yellow Perch	18	80	156	287	5	75	325
Gill Net	Alewife	2	101	101	101	11	12	12
	Bluegill	1	136	136	136	52	52	52
	Channel Catfish	1	296	296	296	290	290	290
	Common Carp	1	552	552	552	2400	2400	2400
	Fallfish	3	219	299	354	120	353	540
	Golden Shiner	1	95	95	95	9	9	9
	Margined Madtom	1	114	114	114	14	14	14
	Pumpkinseed	1	173	173	173	115	115	115
	Redbreast Sunfish	5	131	150	180	45	63	99
	Smallmouth Bass	5	178	217	270	80	132	240
	Spottail Shiner	2	110	118	125	15	18	20
	Walleye	1	630	630	630	2800	2800	2800
	White Sucker	4	358	398	430	550	788	950
	Yellow Bullhead	25	160	202	254	49	122	240
	Yellow Perch	2	178	223	268	70	175	280

Table 5–12. Physical habitat measurements recorded for sample units upstream of Pawtucket Dam during spring, summer, and fall, 2019

Season	Mesohabitat Type	Sample Unit	Habitat Parameter			
			Dominant Substrate	Pct. SAV	Pct. Cover	Mean Depth (ft)
Spring	Run	LIMP-002	Sand-Silt-Clay	0-25%	0-25%	16.3
	Run	LIMP-004	Sand-Silt-Clay	0-25%	0-25%	9.7
	Pool	LIMP-005	Sand-Silt-Clay	0-25%	0-25%	9.4
	Pool	LIMP-012	Sand-Silt-Clay	0-25%	0-25%	9.6
	Pool	LIMP-015	Sand-Silt-Clay	0-25%	0-25%	8.8
	Run	LIMP-016	Sand-Silt-Clay	0-25%	0-25%	6.4
	Impoundment	LIMP-017	Sand-Silt-Clay	0-25%	0-25%	8.4
	Impoundment	LIMP-021	Sand-Silt-Clay	0-25%	0-25%	11.6
	Impoundment	LIMP-027	Sand-Silt-Clay	0-25%	0-25%	6.8
	Impoundment	LIMP-049	Sand-Silt-Clay	0-25%	0-25%	14.6
	Impoundment	LIMP-050	Sand-Silt-Clay	0-25%	0-25%	12.6
	Impoundment	LIMP-069	Sand-Silt-Clay	0-25%	0-25%	16.1
Summer	Run	LIMP-001	Sand-Silt-Clay	0-25%	0-25%	11.0
	Run	LIMP-002	Sand-Silt-Clay	0-25%	0-25%	16.3
	Pool	LIMP-006	Sand-Silt-Clay	25-50%	0-25%	6.9
	Pool	LIMP-011	Sand-Silt-Clay	0-25%	0-25%	8.5
	Pool	LIMP-014	Sand-Silt-Clay	0-25%	0-25%	5.9
	Impoundment	LIMP-020	Sand-Silt-Clay	0-25%	0-25%	8.7
	Impoundment	LIMP-021	Sand-Silt-Clay	0-25%	0-25%	11.6
	Impoundment	LIMP-042	Sand-Silt-Clay	0-25%	0-25%	13.7
	Impoundment	LIMP-045	Sand-Silt-Clay	0-25%	0-25%	17.3
	Impoundment	LIMP-056	Sand-Silt-Clay	0-25%	0-25%	19.2
	Impoundment	LIMP-065	Sand-Silt-Clay	0-25%	0-25%	17.4
	Impoundment	LIMP-068	-	-	-	17.0
Fall	Run	LIMP-002	Sand-Silt-Clay	0-25%	0-25%	16.3
	Run	LIMP-003	Sand-Silt-Clay	0-25%	0-25%	6.4
	Pool	LIMP-005	Sand-Silt-Clay	0-25%	0-25%	9.4
	Pool	LIMP-011	Sand-Silt-Clay	0-25%	0-25%	8.5
	Pool	LIMP-015	Sand-Silt-Clay	0-25%	0-25%	8.8
	Impoundment	LIMP-023	Sand-Silt-Clay	0-25%	0-25%	9.7
	Impoundment	LIMP-037	Sand-Silt-Clay	0-25%	0-25%	14.8
	Impoundment	LIMP-044	Sand-Silt-Clay	0-25%	0-25%	19.8
	Impoundment	LIMP-058	Sand-Silt-Clay	0-25%	0-25%	13.4
	Impoundment	LIMP-060	Sand-Silt-Clay	0-25%	0-25%	14.7
	Impoundment	LIMP-061	Sand-Silt-Clay	0-25%	0-25%	17.4
	Impoundment	LIMP-067	Sand-Silt-Clay	0-25%	0-25%	14.3

Table 5–13. Water quality parameters recorded upstream of Pawtucket Dam during spring, summer, and fall, 2019

Season	Mesohabitat Type	Sample Unit	Water Quality Parameter				
			Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (µs/cm)	pH	Turbidity (NTU)
Spring	Run	LIMP-002	21.6	8.8	98.0	7.4	1.6
	Run	LIMP-004	21.4	8.7	100.0	6.6	2.5
	Pool	LIMP-005	21.5	8.8	97.0	6.6	2.2
	Pool	LIMP-012	21.6	8.9	99.0	6.7	2.4
	Pool	LIMP-015	22.1	8.7	114.0	6.5	3.1
	Run	LIMP-016	22.0	9.0	112.0	6.5	3.7
	Impoundment	LIMP-017	22.0	8.8	114.0	6.6	2.2
	Impoundment	LIMP-021	21.9	8.7	120.0	6.6	3.2
	Impoundment	LIMP-027	20.8	8.6	115.0	6.7	2.5
	Impoundment	LIMP-049	20.6	8.5	133.0	6.6	2.7
	Impoundment	LIMP-050	20.7	8.5	131.0	6.6	3.5
	Impoundment	LIMP-069	21.2	8.4	139.0	6.6	2.0
Summer	Run	LIMP-001	26.0	8.3	169.0	7.5	1.9
	Run	LIMP-002	26.0	8.3	169.0	7.5	1.9
	Pool	LIMP-006	25.9	8.3	166.0	7.5	1.9
	Pool	LIMP-011	25.5	8.1	171.0	7.3	1.9
	Pool	LIMP-014	25.2	8.1	169.0	7.0	1.8
	Impoundment	LIMP-020	25.4	8.2	176.0	6.8	1.8
	Impoundment	LIMP-021	25.4	8.3	180.0	6.8	1.8
	Impoundment	LIMP-042	25.8	8.4	191.0	6.9	1.7
	Impoundment	LIMP-045	25.7	8.4	187.0	6.7	1.6
	Impoundment	LIMP-056	25.7	8.8	199.0	6.9	1.6
	Impoundment	LIMP-065	25.7	8.6	195.0	6.9	1.6
	Impoundment	LIMP-068	25.4	8.4	195.0	6.9	1.5
Fall	Run	LIMP-002	10.3	11.1	91.0	6.5	2.2
	Run	LIMP-003	10.4	11.1	91.0	6.6	2.1
	Pool	LIMP-005	10.4	11.1	92.0	6.7	2.0
	Pool	LIMP-011	10.5	11.1	95.0	6.9	2.0
	Pool	LIMP-015	10.5	11.0	96.0	7.4	1.9
	Impoundment	LIMP-023	10.8	10.9	96.0	6.9	2.2
	Impoundment	LIMP-037	11.0	10.8	125.0	7.0	1.8
	Impoundment	LIMP-044	10.9	10.6	123.0	7.1	1.9
	Impoundment	LIMP-058	11.2	10.1	145.0	7.2	0.9
	Impoundment	LIMP-060	11.2	10.1	146.0	7.2	1.0
	Impoundment	LIMP-061	11.3	10.0	152.0	7.2	0.9
	Impoundment	LIMP-067	11.5	9.8	151.0	7.3	0.8

5.2 Lowell Bypassed Reach

5.2.1 Habitat Evaluation and Sample Unit Selection

Changes in general habitat types within the Lowell bypassed reach were visually identified and marked in ArcGIS. The approximately 0.75 mile reach downstream of Pawtucket Dam was subdivided into a total of 23, 55-yard (50-meter) segments. The bypassed reach was subdivided into habitat classifications associated with the upper chute (i.e., the area between Pawtucket Dam and School Street Bridge), pooled section immediately downstream of the School Street Bridge, ledge channel area in the vicinity of the University Avenue Bridge, and the lower bypassed reach downstream of the power canal surge gate. Site conditions were considered inappropriate or unsafe for sampling in the upper chute reach and downstream of the spill gate. As a result back pack electrofish sampling in the bypassed reach occurred within the two middle reaches. Sampling locations were randomly selected on a seasonal basis. The spatial distribution of habitat classifications and 50-m segments within the 0.75 mile bypassed reach is provided in Appendix C.

Table 5-14 provides a listing of the habitat units downstream of the Pawtucket Dam and within the Lowell bypassed reach that were randomly selected for sampling during the spring, summer, and fall periods of 2019. A total of three, 50-m segments were selected per season.

5.2.2 Sampling Effort

Fish community data were collected from a total of 12, 50-m sample units during the spring, summer, and fall of 2019 (12 sites per season). Effort expended at a sample unit during each of the three seasons consisted of an approximately 50-m back pack electrofish sample. Fish community sampling in the Lowell bypassed reach occurred on June 28 (spring), August 27 (summer) and October 21 (fall). Table 5-15 provides a summary of the back pack electrofish sampling in the Lowell bypassed reach. Bypassed reach sample units selected by season are presented visually in Appendix C.

5.2.3 Species Richness and Composition

A total of 526 individuals representing fourteen fish species were collected during back pack electrofishing efforts within the Lowell bypassed reach during 2019 when all sampling seasons and sample units are considered (Table 5-16). Table 5-17 provides a summary of the bypassed reach community composition by season. Fallfish (39.9%), smallmouth bass (20.3%) and spottail shiner (16.7%) were the three most numerically abundant species within the Lowell bypassed reach during the 2019 sampling. When examined by species, spottail shiner were most abundant during the spring (48.8%), fallfish during the summer (55.0%) and fallfish during the fall (39.9%).

Total catch and community composition from sampling units within the pooled and ledge channel sections of the bypassed reach downstream of Pawtucket Dam are presented in Table 5-18. Fallfish were the most abundant fish species collected within the pooled habitat within the Lowell bypassed reach and downstream of Pawtucket Dam, representing 47% of the total catch. Fish catch from the ledge channel habitat located in the lower portion of the bypassed reach was dominated by smallmouth bass which represented 60.6% of the total catch from that area. American eel represented 13.8% of the total electrofish catch from the ledge channel habitat within the Lowell bypassed reach.

5.2.4 Relative Abundance

CPUE values for back pack electrofish sampling within the Lowell bypassed reach downstream of Pawtucket Dam were standardized to a fixed unit of time or distance using the equations and methods provided in Section 5.1.4. Catch rates were highest for smallmouth bass, fallfish, and spottail shiner captured by back pack electrofish sampling in the 0.75 mile bypassed reach downstream of Pawtucket Dam during the 2019 sampling (Table 5-19). Values for fish per unit of effort were highest for spottail shiner and fallfish during the spring sampling event, fallfish and smallmouth bass during the summer sampling event and smallmouth bass and redbreast sunfish during the fall sampling event. A listing of CPUE rates for all species by season and habitat type is provided in Appendix D.

5.2.5 Biocharacteristics

Length frequency distributions for fish species where 25 or more individuals were collected and measured during the bypassed reach sampling are presented in Appendix E. The observed range for fish sizes recorded for species observed in the back pack electrofish catch from the reach downstream of the Pawtucket Dam fall within the expected bounds for those species in the northeastern U.S. (Table 5-11). A full listing of catch data is provided in Appendix F.

5.2.6 Habitat and Water Quality Characteristics

Tables 5-21 and 5-22 provide summaries of habitat and water quality information recorded for each of the 9, 50-m sample units surveyed within the Lowell bypassed reach during the spring, summer and fall seasons. A range of substrate types was sampled during each of the three seasons, ranging from areas of boulders to sand-silt-clay habitat. Sampled areas within the Lowell bypassed reach downstream of Pawtucket Dam were characterized by the presence of SAV over 0-25% of the sample area and the presence of general cover over 0-25% of the sample area. Mean water depth (as measured at quarter points of the electrofished area at the upper, middle, and lower points of each transect) was consistent among sample areas and season, ranging from 1.5-2.4 feet.

Water temperature was relatively consistent among sample units within each season[1] and averaged 22.9°C during the spring sampling, 23.8°C during the summer sampling, and 13.1°C during the fall sampling. Dissolved oxygen was measured at 8.9 mg/L or greater at all bypassed reach stations downstream of Pawtucket Dam regardless of season. Conductivity averaged 148 µs/cm during the spring sampling, 194 µs/cm during the summer sampling, and 100 µs/cm during the fall sampling. The average river pH in the bypassed reach was higher during the summer sampling event (7.8) than was observed during the spring (6.5) or fall (6.6).

[1] Water quality readings were available at only sample unit LBYP-011 during the spring event due to a malfunction with the meter handset during sampling.

Table 5–14. Sample unit habitat type and location for the spring, summer and fall Lowell bypassed reach fish community survey

Season	Sample Unit	Mesohabitat Type	Upstream		Downstream		Efish Bank
			Latitude	Longitude	Latitude	Longitude	
Spring	LBYP-011	Ledge Channels	42.65102	-71.32619	42.65094	-71.32679	West
	LBYP-013	Pooled Section	42.65087	-71.32739	42.65080	-71.32800	West
	LBYP-017	Pooled Section	42.65038	-71.32970	42.65007	-71.33015	West
Summer	LBYP-011	Ledge Channels	42.65102	-71.32619	42.65094	-71.32679	West
	LBYP-014	Pooled Section	42.65080	-71.32800	42.65070	-71.32859	West
	LBYP-018	Pooled Section	42.65007	-71.33015	42.64977	-71.33059	West
Fall	LBYP-011	Ledge Channels	42.65102	-71.32619	42.65094	-71.32679	West
	LBYP-013	Pooled Section	42.65087	-71.32739	42.65080	-71.32800	West
	LBYP-016	Pooled Section	42.65058	-71.32918	42.65038	-71.32970	West

Table 5–15. Back pack electrofish effort for the spring, summer and fall Lowell bypassed reach fish community survey

Season	Sample Unit	Sample			Settings (V/Hz)	No. Netters	No. Runs
		Date	Time	Duration (Sec)			
Spring	LBYP-011	6/28/2019	11:11	1270	550/100	4	1
	LBYP-013	6/28/2019	9:50	978	550/100	4	1
	LBYP-017	6/28/2019	12:47	1068	550/100	4	1
Summer	LBYP-011	8/27/2019	9:55	1048	550/100	4	1
	LBYP-014	8/27/2019	11:23	887	550/100	4	1
	LBYP-018	8/27/2019	13:25	917	550/100	4	1
Fall	LBYP-011	10/21/2019	12:02	1089	550/100	4	1
	LBYP-013	10/21/2019	11:06	922	550/100	4	1
	LBYP-016	10/21/2019	9:54	1033	550/100	4	1

Table 5–16. Number of fish captured within the bypassed reach downstream of Pawtucket Dam by back pack electrofishing during the spring, summer and fall sampling, 2019

Common Name	Spring	Summer	Fall	2019
	N	N	N	N
American Eel	10	18	5	33
Bluegill	2	1	0	3
Brown Trout	1	0	0	1
Fallfish	22	187	1	210
Largemouth Bass	0	2	0	2
Lepomis spp.	0	0	1	1
Longnose Dace	1	0	1	2
Margined Madtom	1	2	14	17
Redbreast Sunfish	1	5	7	13
Sea Lamprey	0	0	1	1
Smallmouth Bass	2	37	68	107
Spottail Shiner	39	49	0	88
Tessellated Darter	1	5	4	10
White Sucker	0	30	3	33
Yellow Bullhead	0	4	1	5
Total	**80**	**340**	**106**	**526**

Table 5–17. Percent composition of fish captured within the bypassed reach downstream of Pawtucket Dam by back pack electrofishing during the spring, summer and fall sampling, 2019

Common Name	Spring	Summer	Fall	2019
	Pct.	Pct.	Pct.	Pct.
American Eel	12.5	5.3	4.7	6.3
Bluegill	2.5	0.3	0.0	0.6
Brown Trout	1.3	0.0	0.0	0.2
Fallfish	27.5	55.0	0.9	39.9
Largemouth Bass	0.0	0.6	0.0	0.4
Lepomis spp.	0.0	0.0	0.9	0.2
Longnose Dace	1.3	0.0	0.9	0.4
Margined Madtom	1.3	0.6	13.2	3.2
Redbreast Sunfish	1.3	1.5	6.6	2.5
Sea Lamprey	0.0	0.0	0.9	0.2
Smallmouth Bass	2.5	10.9	64.2	20.3
Spottail Shiner	48.8	14.4	0.0	16.7
Tessellated Darter	1.3	1.5	3.8	1.9
White Sucker	0.0	8.8	2.8	6.3
Yellow Bullhead	0.0	1.2	0.9	1.0

Table 5–18. Number and percent composition of fish captured within the bypassed reach downstream of Pawtucket Dam by back pack electrofishing within pooled and ledge channel habitat areas, 2019

Common Name	Pooled Section		Ledge Channels	
	N	Pct.	N	Pct.
American Eel	20	4.6	13	13.8
Bluegill	3	0.7	0	0.0
Brown Trout	0	0.0	1	1.1
Fallfish	203	47.0	7	7.4
Largemouth Bass	2	0.5	0	0.0
Lepomis spp.	1	0.2	0	0.0
Longnose Dace	0	0.0	2	2.1
Margined Madtom	16	3.7	1	1.1
Redbreast Sunfish	4	0.9	9	9.6
Sea Lamprey	1	0.2	0	0.0
Smallmouth Bass	50	11.6	57	60.6
Spottail Shiner	88	20.4	0	0.0
Tessellated Darter	9	2.1	1	1.1
White Sucker	30	6.9	3	3.2
Yellow Bullhead	5	1.2	0	0.0

Table 5–19. Catch per unit of effort for fish captured within the bypassed reach downstream of Pawtucket Dam by back pack electrofishing during spring, summer, and fall, 2019

Common Name	Backpack E-Fish							
	Spring		Summer		Fall		Total	
	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m
American Eel	12.40	7.83	12.00	8.00	1.81	0.83	8.74	5.56
Bluegill	0.76	0.33	0.28	0.17	0.00	0.00	0.35	0.17
Brown Trout	1.48	1.00	0.00	0.00	0.00	0.00	0.49	0.33
Fallfish	20.65	11.17	48.72	31.17	0.36	0.17	23.24	14.17
Largemouth Bass	0.00	0.00	0.56	0.33	0.00	0.00	0.19	0.11
Lepomis spp.	0.00	0.00	0.00	0.00	0.84	0.33	0.28	0.11
Longnose Dace	1.48	1.00	0.00	0.00	1.48	1.00	0.98	0.67
Margined Madtom	1.48	1.00	0.52	0.33	6.03	2.67	2.68	1.33
Redbreast Sunfish	1.48	1.00	2.55	1.67	10.33	7.00	4.79	3.22
Sea Lamprey	0.00	0.00	0.00	0.00	0.84	0.33	0.28	0.11
Smallmouth Bass	2.95	2.00	40.15	27.00	63.33	38.17	35.48	22.39
Spottail Shiner	32.83	13.00	12.78	8.17	0.00	0.00	15.20	7.06
Tessellated Darter	0.38	0.17	2.52	1.67	1.93	0.83	1.61	0.89
White Sucker	0.00	0.00	7.83	5.00	4.43	3.00	4.09	2.67
Yellow Bullhead	0.00	0.00	1.11	0.67	0.36	0.17	0.49	0.28

Table 5–20. Minimum, mean, and maximum total length (mm) and weight (g) for fish captured within the bypassed reach downstream of Pawtucket Dam by back pack electrofish sampling during spring, summer, and fall, 2019

Common Name	No. Individuals	Total Length (mm)			Total Weight (g)		
		Min.	Mean	Max.	Min.	Mean	Max.
American Eel	33	100	285	550	2	78	325
Bluegill	3	35	107	175	1	50	120
Brown Trout	1	225	225	225	110	110	110
Fallfish	210	22	46	86	1	10	415
Largemouth Bass	2	69	72	75	5	6	7
Lepomis spp.	1	31	31	31	1	1	1
Longnose Dace	2	80	90	99	6	8	10
Margined Madtom	17	50	85	133	1	7	21
Redbreast Sunfish	13	37	165	395	1	53	180
Sea Lamprey	1	160	160	160	7	7	7
Smallmouth Bass	107	79	118	215	6	24	110
Spottail Shiner	88	40	75	97	1	8	180
Tessellated Darter	10	56	66	86	1	3	6
White Sucker	33	55	87	279	2	14	240
Yellow Bullhead	5	59	70	87	4	6	9

Table 5–21. Physical habitat measurements recorded for sample units within the bypassed reach downstream of Pawtucket Dam during spring, summer, and fall, 2019

Season	Habitat Type	Sample Unit	Habitat Parameter			
			Dominant Substrate	Pct. SAV	Pct. Cover	Mean Depth (ft)
Spring	Ledge Channels	LBYP-011	Boulder/Rip-Rap	0-25%	0-25%	1.5
	Pooled Section	LBYP-013	Cobble-Gravel	0-25%	0-25%	1.8
	Pooled Section	LBYP-017	Sand-Silt-Clay	0-25%	0-25%	1.7
Summer	Ledge Channels	LBYP-011	Boulder/Rip-Rap	0-25%	0-25%	1.5
	Pooled Section	LBYP-014	Cobble-Gravel	0-25%	0-25%	1.8
	Pooled Section	LBYP-018	Sand-Silt-Clay	0-25%	0-25%	2.4
Fall	Ledge Channels	LBYP-011	Boulder/Rip-Rap	0-25%	0-25%	1.5
	Pooled Section	LBYP-013	Cobble-Gravel	0-25%	0-25%	1.8
	Pooled Section	LBYP-016	Sand-Silt-Clay	0-25%	0-25%	1.6

Table 5–22. Water quality parameters recorded within the bypassed reach downstream of Pawtucket Dam during spring, summer, and fall, 2019

Season	Habitat Type	Sample Unit	Water Quality Parameter			
			Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (µs/cm)	pH
Spring	Ledge Channels	LBYP-011	22.9	9.5	148	6.5
	Pooled Section	LBYP-013	*	*	*	*
	Pooled Section	LBYP-017	*	*	*	*
Summer	Ledge Channels	LBYP-011	23.4	9.6	191	7.4
	Pooled Section	LBYP-014	23.9	9.1	195	7.8
	Pooled Section	LBYP-018	24.1	9.4	197	8.1
Fall	Ledge Channels	LBYP-011	13.2	9.8	104	6.3
	Pooled Section	LBYP-013	13.1	8.9	102	6.6
	Pooled Section	LBYP-016	13.0	10.6	95	6.8

* Water quality readings were available at only sample unit LBYP-011 during the spring event due to a malfunction with the meter handset during sampling

5.3 Historic Data

As described in the Lowell relicensing Pre-Application Document (PAD), the Merrimack River is home to a diverse assemblage of fishes, including cold water and warm water species. Stolte (1982; as cited in the Technical Committee for Anadromous Fishery Management of the Merrimack River Basin [Technical Committee] 1997) noted that during the last 150 years, over 15 non-indigenous species such as largemouth bass, smallmouth bass, walleye, common carp, rainbow trout, brown trout, various catfish species and goldfish have established through human introductions within the Merrimack River. At that time, the Merrimack River was identified as home to approximately 50 species of fish, nine of which were anadromous. The slower moving, ponded reaches of the Merrimack contain a higher predominance of warm water species whereas those areas with higher gradient contain the majority of cold water species. Hartel et al. (2002) identified a total of 57 reproducing fish species within the drainage; 21 primary species (i.e., those living full life cycle in freshwater), 8 secondary species (i.e., those with physiological capacity to move between fresh and salt water), 18 introduced species, and 10 diadromous species.

Fish assemblage sampling within the Lowell impoundment and bypassed reach during the spring, summer and fall of 2019 resulted in the identification of 24 fish species (Table 5-23). Of those species, 21 are considered freshwater and 3 are considered as diadromous. Based on information presented in Hartel et al. (2002) species observed during the 2019 fish sampling considered to be native to the Merrimack River watershed in Massachusetts represented 53% of the total catch across all seasons (12 species, 1,249 individuals). Conversely, species classified by Hartel et al. (2002) as introduced to the Merrimack River watershed represented 47% of the total catch across all seasons (12 species, 1,119 individuals).

Table 5–23. Classifications for fish species recorded within the Lowell impoundment and bypassed reach downstream of Pawtucket Dam during spring, summer, and fall, 2019

Common Name	Freshwater Resident	Diadromous	Native	Introduced
Alewife		X	X	
American Eel		X	X	
Black Crappie	X			X
Bluegill	X			X
Brown Trout	X			X
Channel Catfish	X			X
Common Carp	X			X
Fallfish	X		X	
Golden Shiner	X		X	
Largemouth Bass	X			X
Longnose Dace	X		X	
Margined Madtom	X			X
Pumpkinseed	X		X	
Redbreast Sunfish	X		X	
Rock Bass	X			X
Sea Lamprey		X	X	
Smallmouth Bass	X			X
Spottail Shiner	X			X
Tessellated Darter	X		X	
Walleye	X			X
White Perch	X		X	
White Sucker	X		X	
Yellow Bullhead	X			X
Yellow Perch	X		X	

6 Summary

The Lowell RSP identified two specific objectives for the fish assemblage study including (1) sampling to describe the fish assemblage structure, distribution, and abundance within the Project affected area along spatial and temporal gradients, and (2) a comparison of historical records of species occurrence with observations from this study.

Fish community sampling was conducted over spatial (impoundment versus bypassed reach) and temporal (spring, summer, and fall) gradients during 2019. Within the Lowell impoundment, fish were collected from standardized 500-m transects using a stratified random sampling design where mesohabitat type (i.e., impoundment, run, pool) was used to stratify. Once sites were identified, impoundment sampling was conducted via nighttime boat electrofishing, experimental gill netting, and minnow traps. Fish community data were collected from a total of 36, 500-m sample units during the spring, summer, and fall of 2019 (12 sites per season). A total of 1,847 individuals representing twenty-two fish species were collected from the Lowell impoundment during 2019 when all sampling seasons and sample units are considered. Spottail shiner (23.0%), redbreast sunfish (20.5%) and smallmouth bass (12.3%) were the three most numerically abundant species within the Lowell impoundment during the 2019 sampling. Centrarchid species were the most abundant within impoundment habitat with redbreast sunfish (24.2%), pumpkinseed (14.2%), and smallmouth bass (12.5%) representing the three most abundantly sampled species. Spottail shiner were the most abundantly sampled fish species in the pool (28.4%) and run (46.3%) habitat areas. The majority of catch in the impoundment was observed during boat electrofishing efforts.

Within the Lowell bypassed reach, fish were collected from standardized 50-m transects using a stratified random sampling design where habitat type was used to stratify. Site conditions were considered inappropriate or unsafe for sampling in two portions of the bypassed reach (i.e., the upper chute reach and downstream of the spill gate) and as a result back pack electrofish sampling in the bypassed reach occurred within the two middle reaches (i.e., the pooled section immediately downstream of the School Street Bridge and ledge channel area in the vicinity of the University Ave Bridge). A total of 526 individuals representing fourteen fish species were collected during back pack electrofishing efforts within the Lowell bypassed reach during 2019 when all sampling seasons and sample units are considered. Fallfish (39.9%), smallmouth bass (20.3%) and spottail shiner (16.7%) were the three most numerically abundant species within the Lowell bypassed reach during the 2019 sampling. Fallfish were the most abundant fish species collected within the pooled habitat within the Lowell bypassed reach and downstream of Pawtucket Dam, representing 47% of the total catch. Fish catch from the ledge channel habitat located in the lower portion of the bypassed reach was dominated by smallmouth bass which represented 60.6% of the total catch from that area.

Fish assemblage sampling within the Lowell impoundment and bypassed reach during the spring, summer and fall of 2019 resulted in the identification of 24 fish species. Approximately 53% of individuals collected during the 2019 sampling were classified as fish species native to the Merrimack River watershed in Massachusetts (12 species, 1,249 individuals). Conversely, 47% of the total catch across all seasons were classified as introduced to the Merrimack River watershed (12 species, 1,119 individuals).

7 Variances from FERC-Approved Study Plan

There was no variance from the methodologies and schedule as described in the FERC-approved study plan.

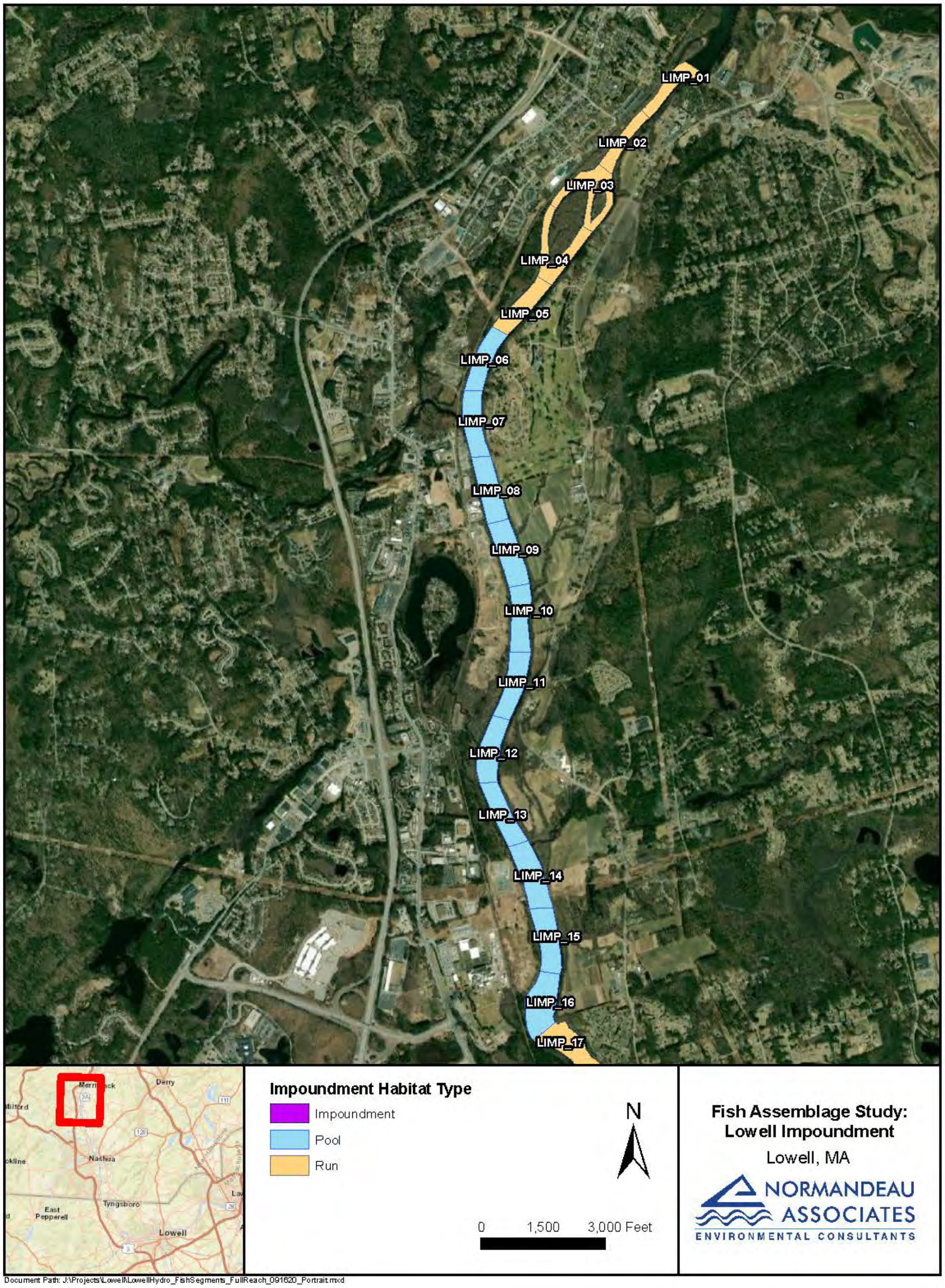
8 References

Hartel, K.E., D.B. Halliwell, and A.E. Launer. 2002. Inland Fishes of Massachusetts. Massachusetts Audubon Society.

Technical Committee for Anadromous Fishery Management of the Merrimack River Basin (Technical Committee). 1997. Strategic Plan and Status Review Anadromous Fish Restoration Program Merrimack River. Technical Committee for Anadromous Fishery Management of the Merrimack River Basin and Advisors to the Technical Committee.

9 Appendices

Appendix A. Spatial distribution of 500-m mesohabitat units for the 23.0 mile reach upstream of Pawtucket Dam.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LIMP_17
Impoundment Habitat Type
Impoundment
Pool
Run
N
0 1,500 3,000 Feet
Fish Assemblage Study:
Lowell Impoundment
Lowell, MA
NORMANDEAU ASSOCIATES
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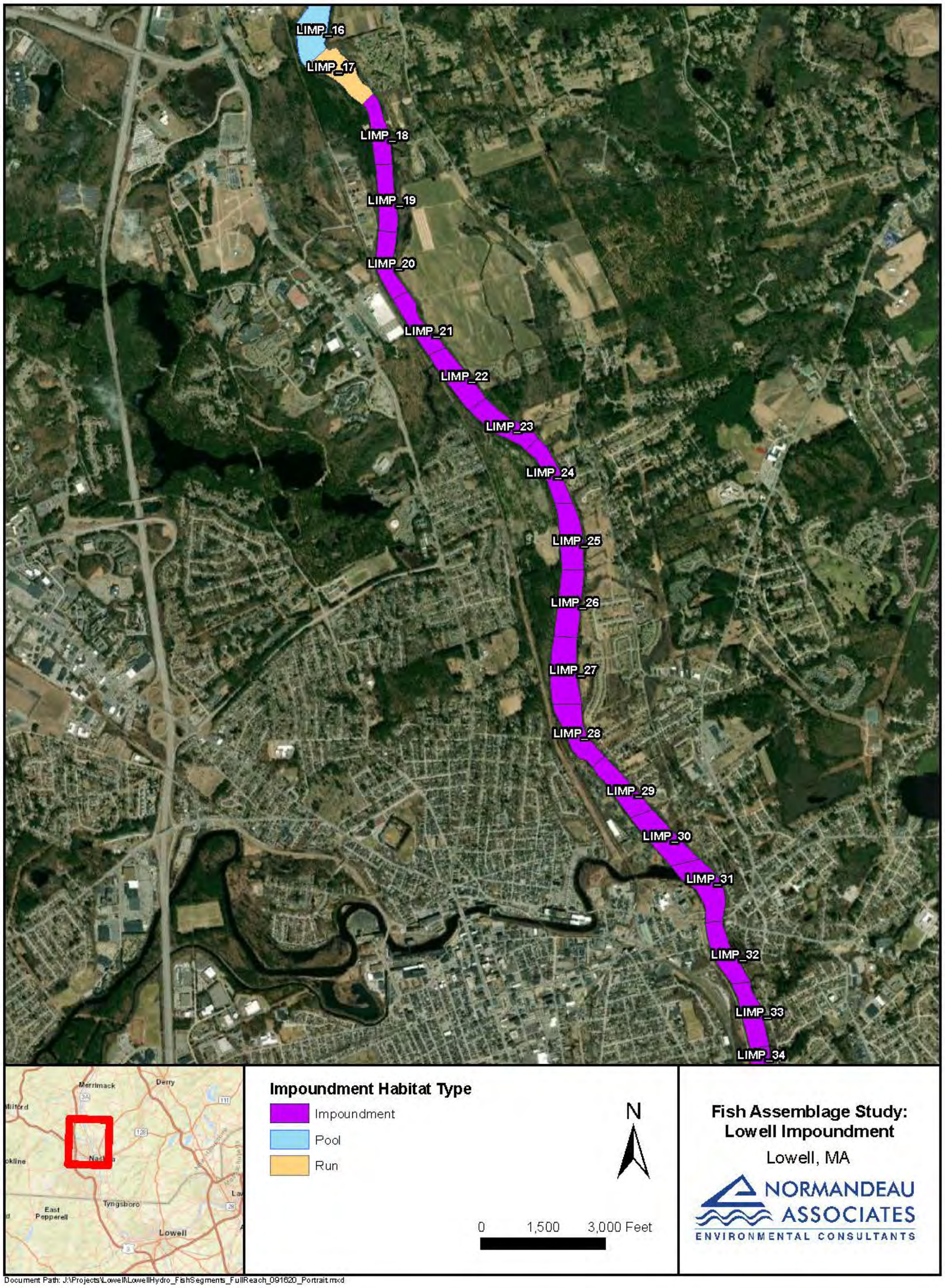
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Impoundment Habitat Type
Impoundment
Pool
Run
N
0 1,500 3,000 Feet
Fish Assemblage Study:
Lowell Impoundment
Lowell, MA
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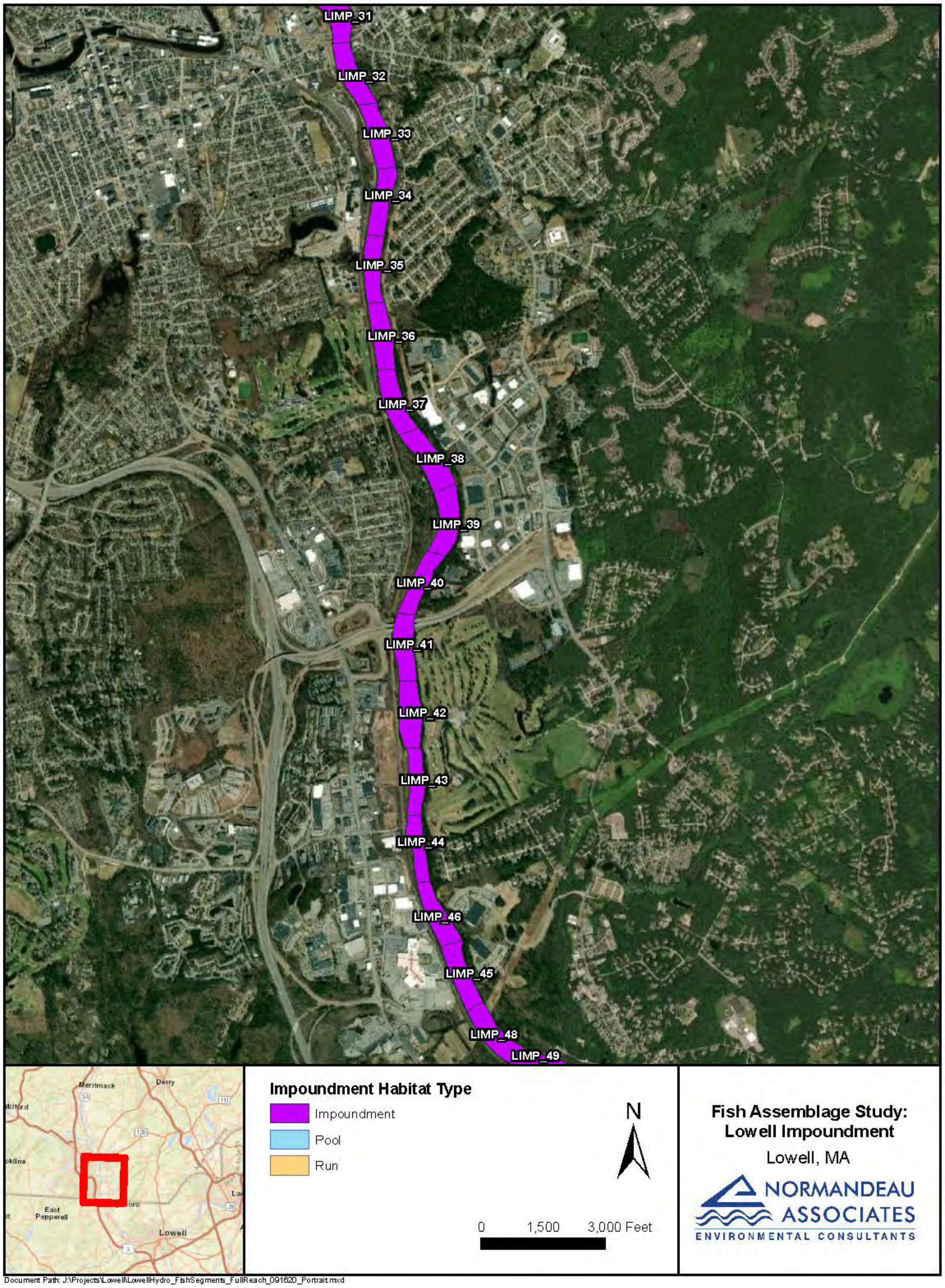
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Impoundment Habitat Type
Impoundment
Pool
Run
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Lowell, MA
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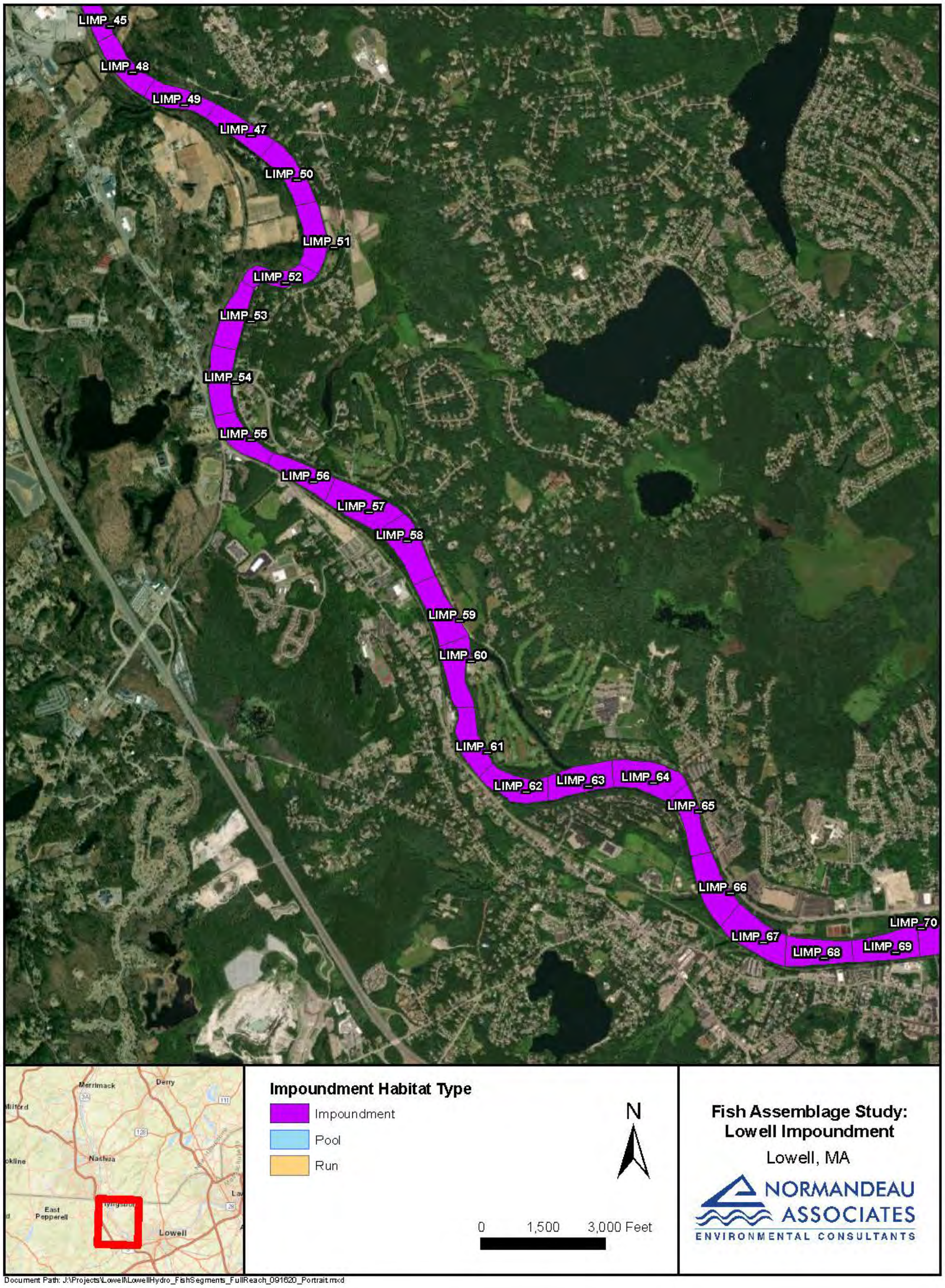
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Lowell
Impoundment Habitat Type
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Run
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3,000 Feet
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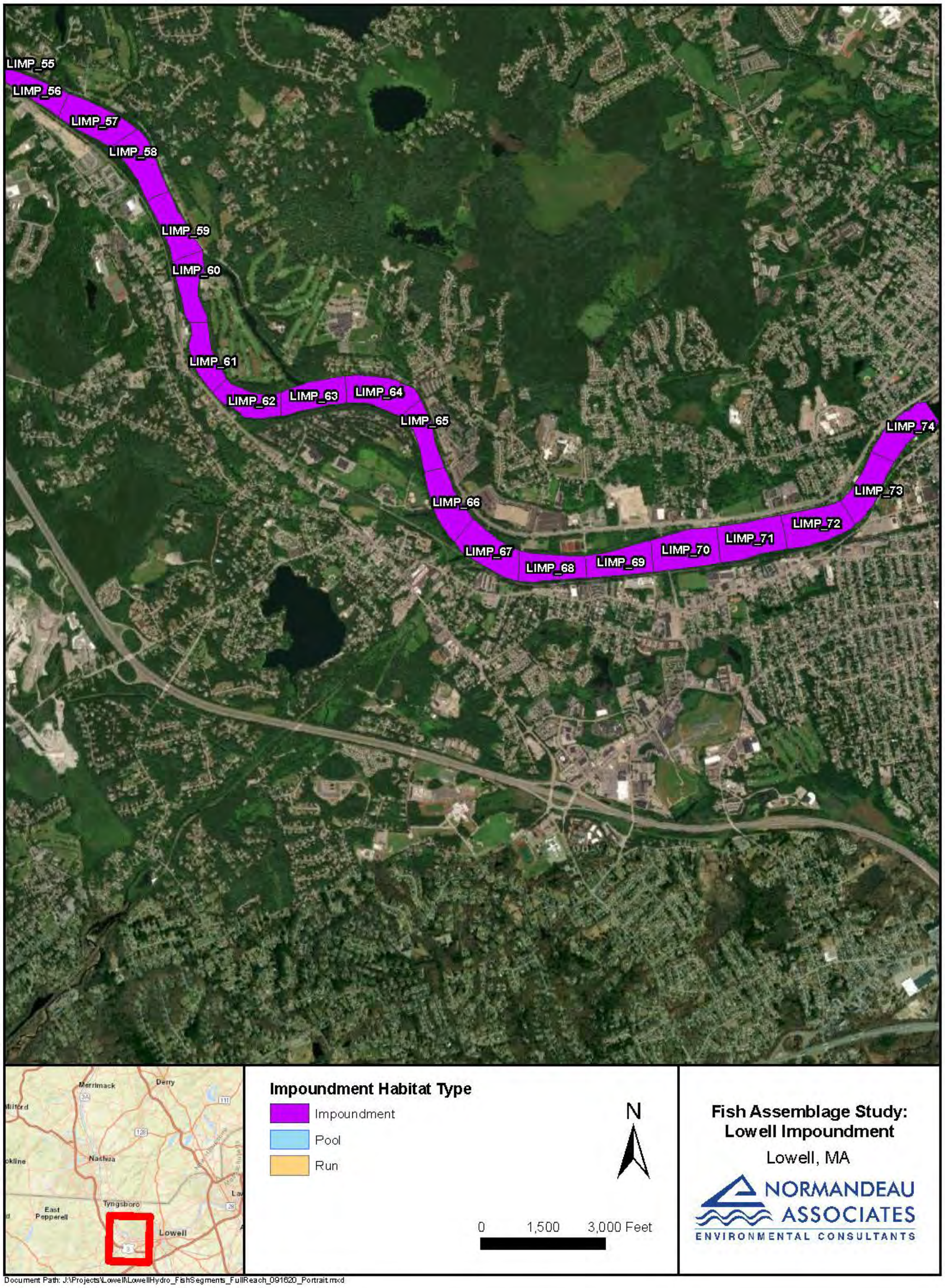
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Merrimack
Derry
Milford
Nashua
Tyngsboro
East Pepperell
Lowell
Impoundment Habitat Type
Impoundment
Pool
Run
N
0 1,500 3,000 Feet
Fish Assemblage Study: Lowell Impoundment
Lowell, MA
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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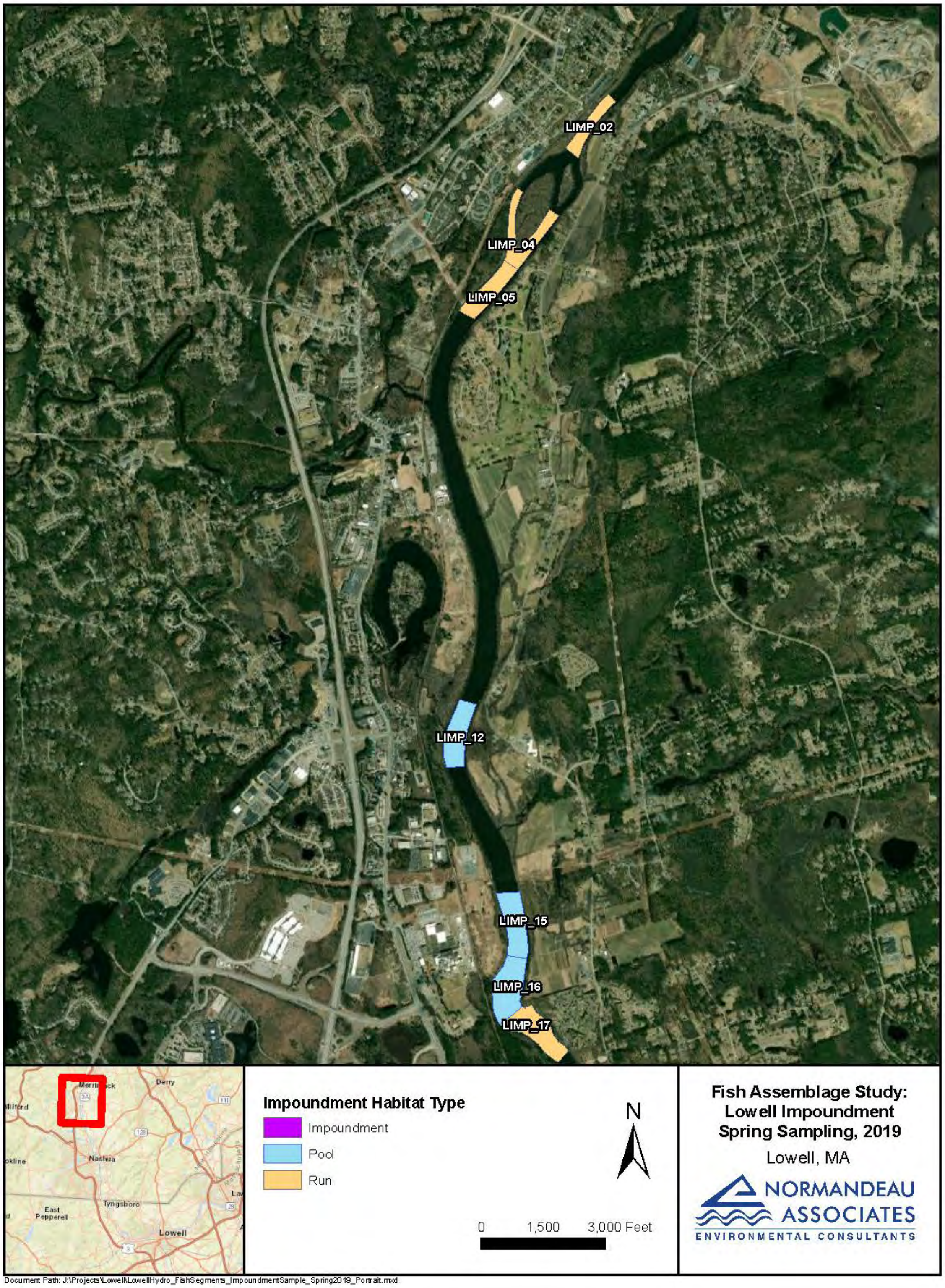
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LIMP_05
LIMP_12
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LIMP_17
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Nashua
Tyngsboro
East Pepperell
Lowell
Impoundment Habitat Type
Impoundment
Pool
Run
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0 1,500 3,000 Feet
Fish Assemblage Study:
Lowell Impoundment
Spring Sampling, 2019
Lowell, MA
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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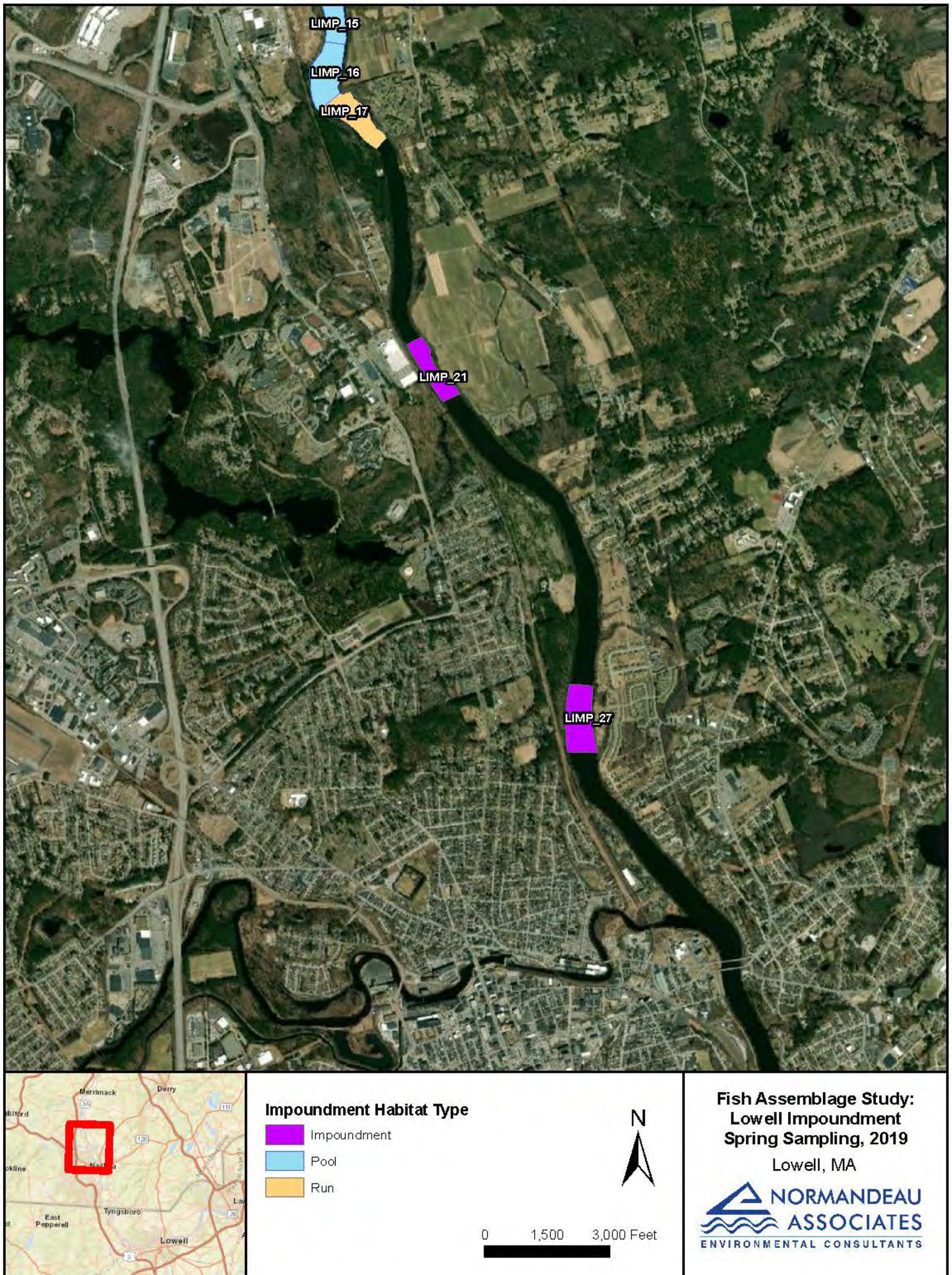

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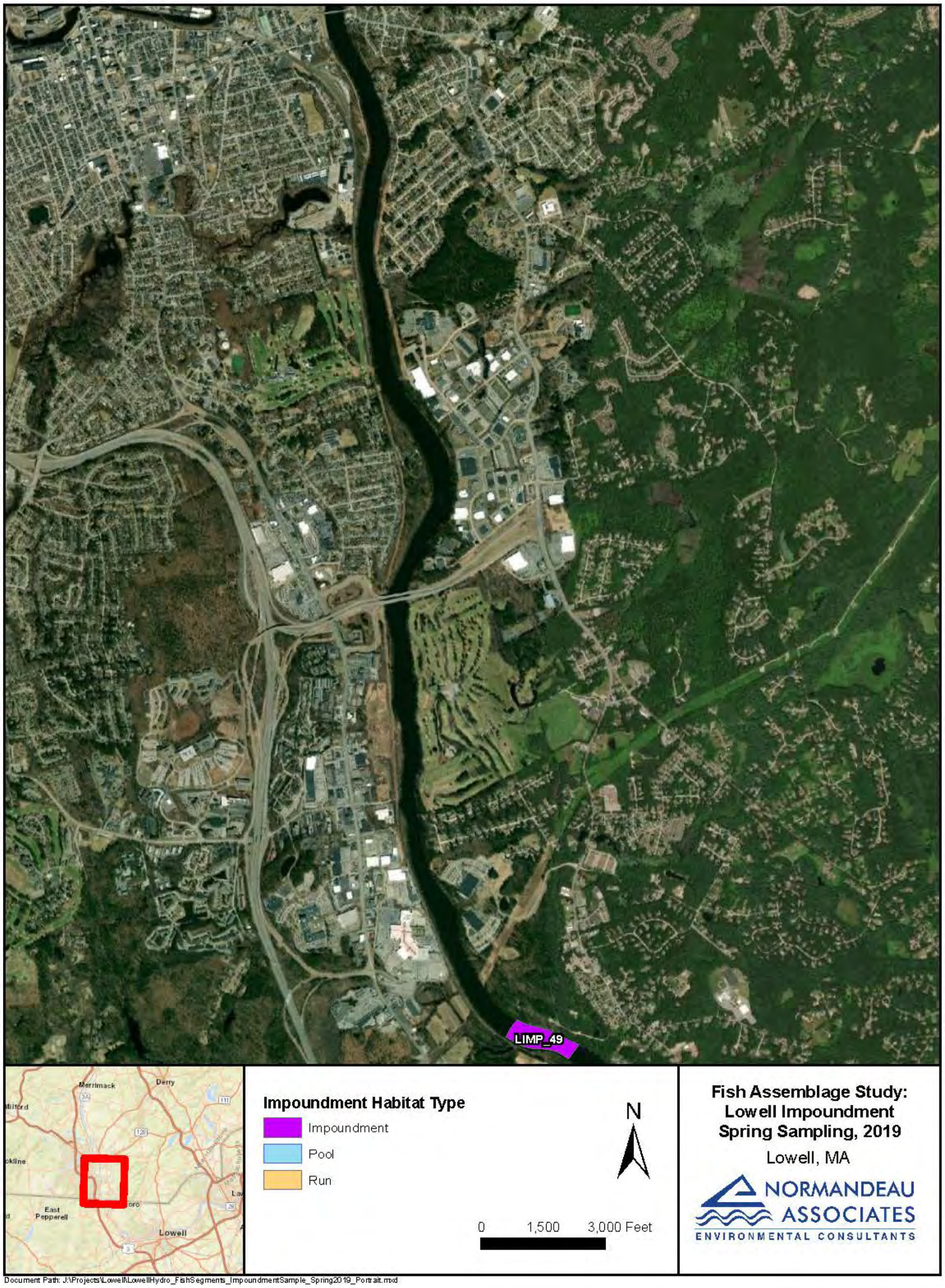
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East Pepperell
Lowell
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Lowell, MA
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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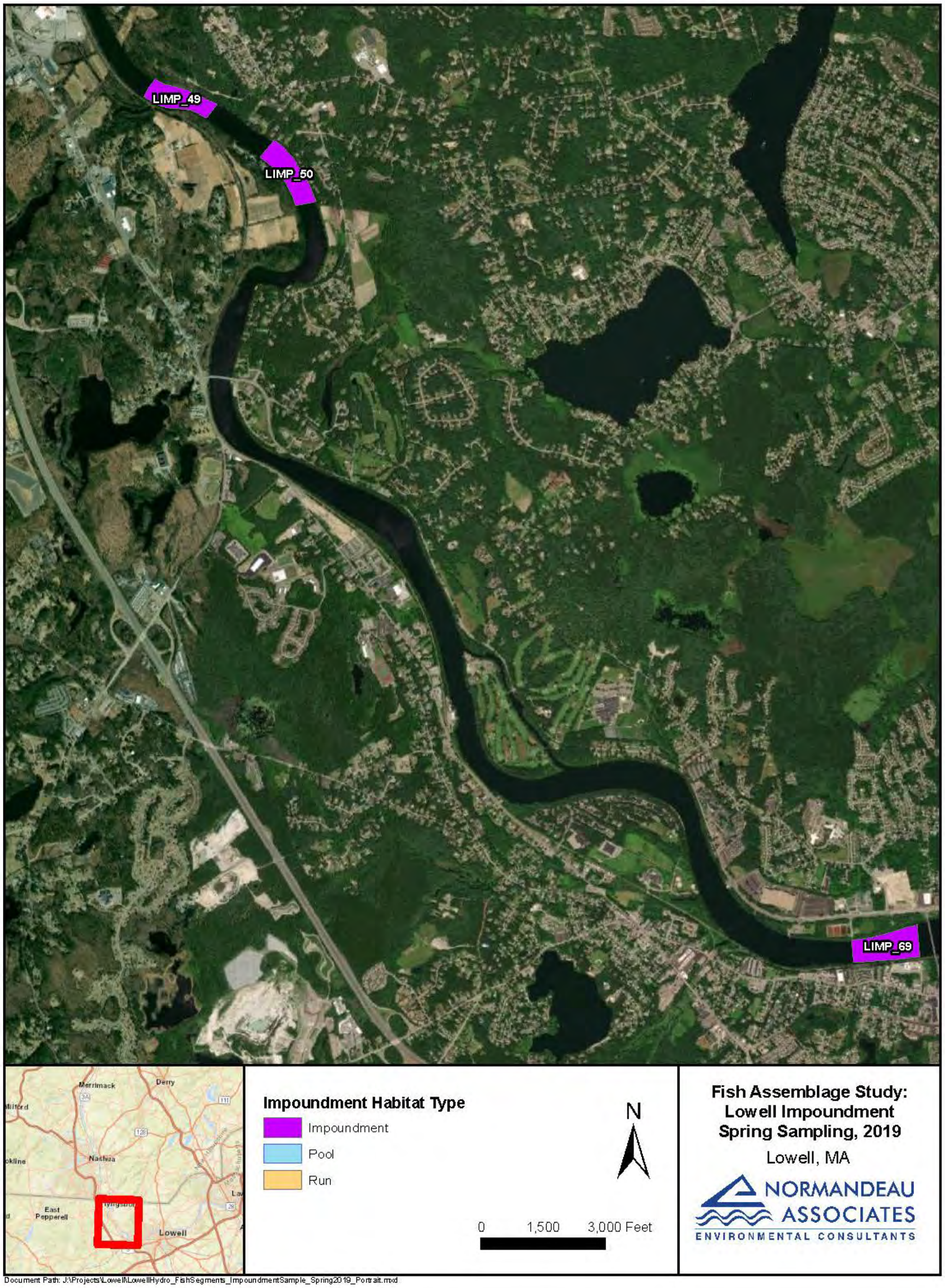
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Run
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Fish Assemblage Study: Lowell Impoundment Spring Sampling, 2019
Lowell, MA
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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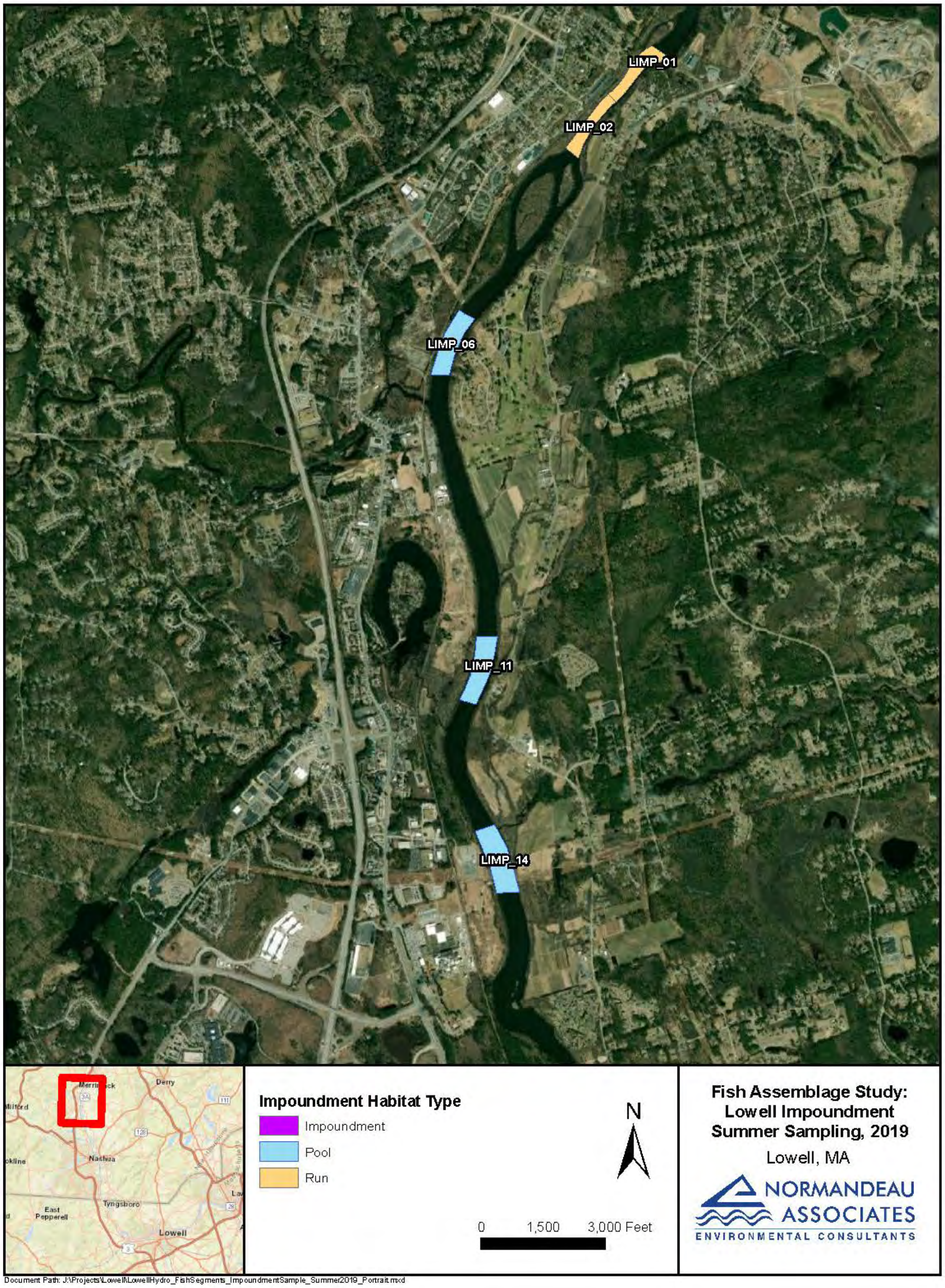
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East Pepperell
Lowell
Impoundment Habitat Type
Impoundment
Pool
Run
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Fish Assemblage Study:
Lowell Impoundment
Summer Sampling, 2019
Lowell, MA
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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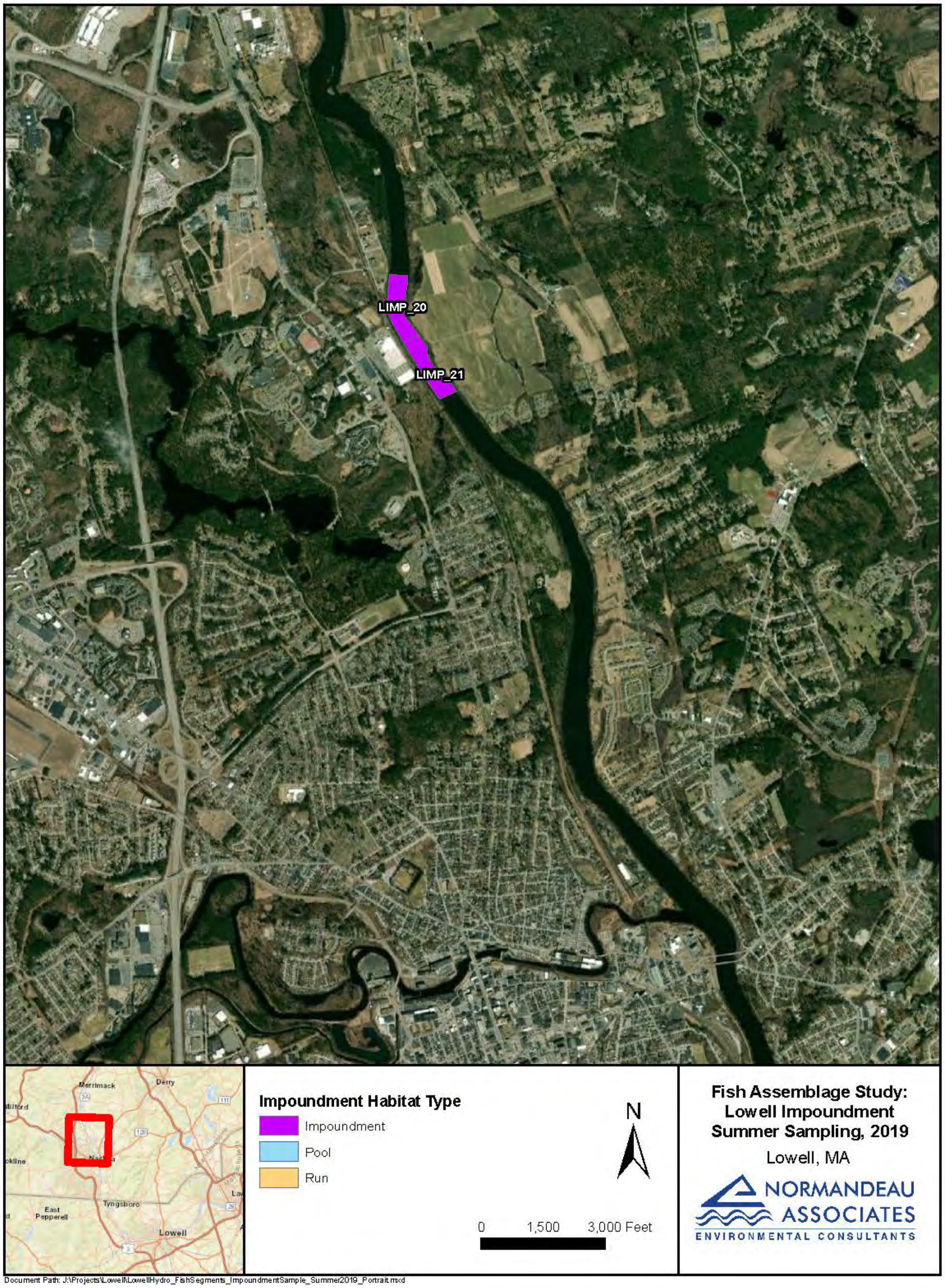
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East Pepperell
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Lowell
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Pool
Run
N
0
1,500
3,000 Feet
Fish Assemblage Study:
Lowell Impoundment
Summer Sampling, 2019
Lowell, MA
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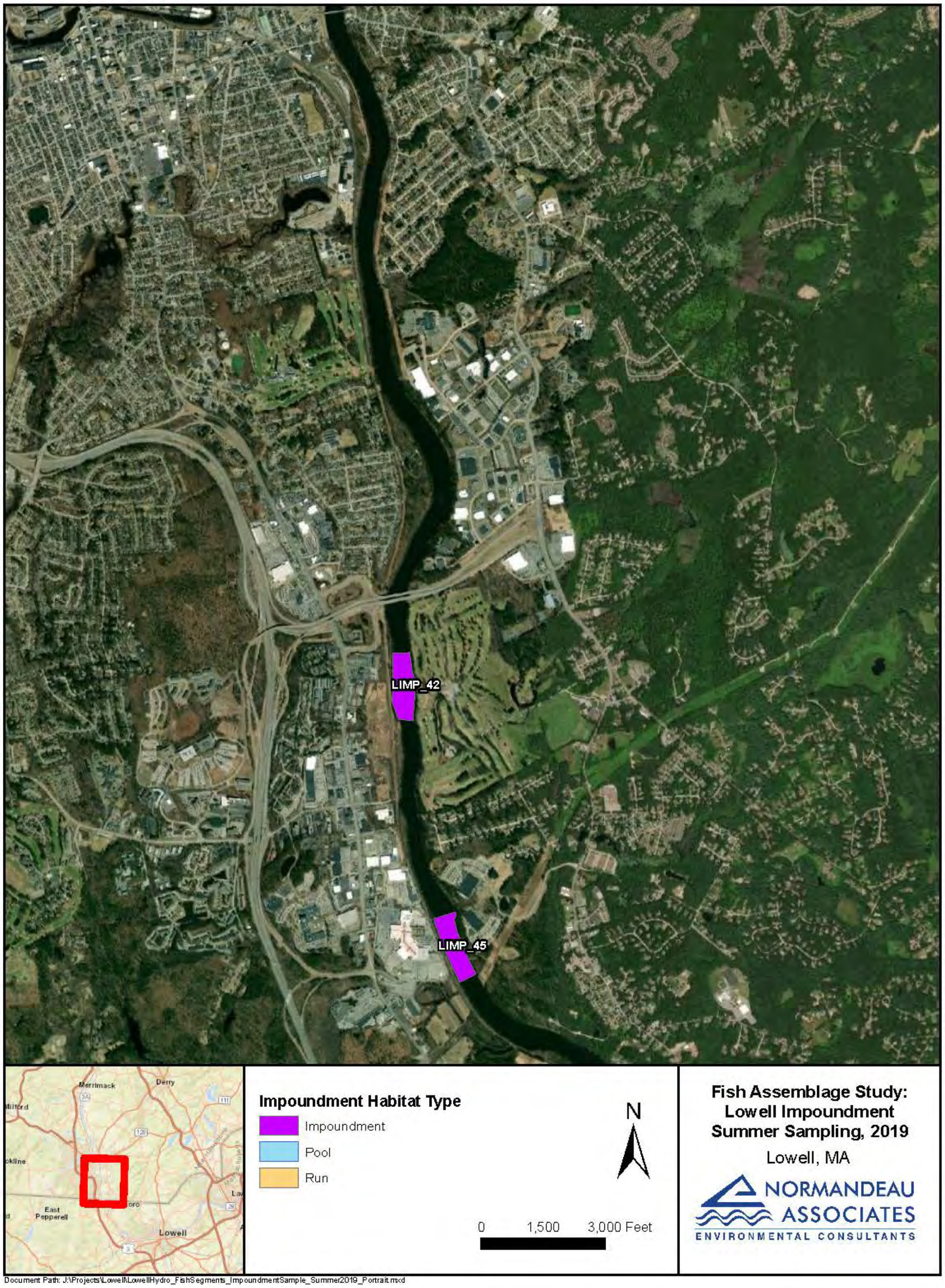
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Milford
East Pepperell
Lowell
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Impoundment
Pool
Run
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Fish Assemblage Study:
Lowell Impoundment
Summer Sampling, 2019
Lowell, MA
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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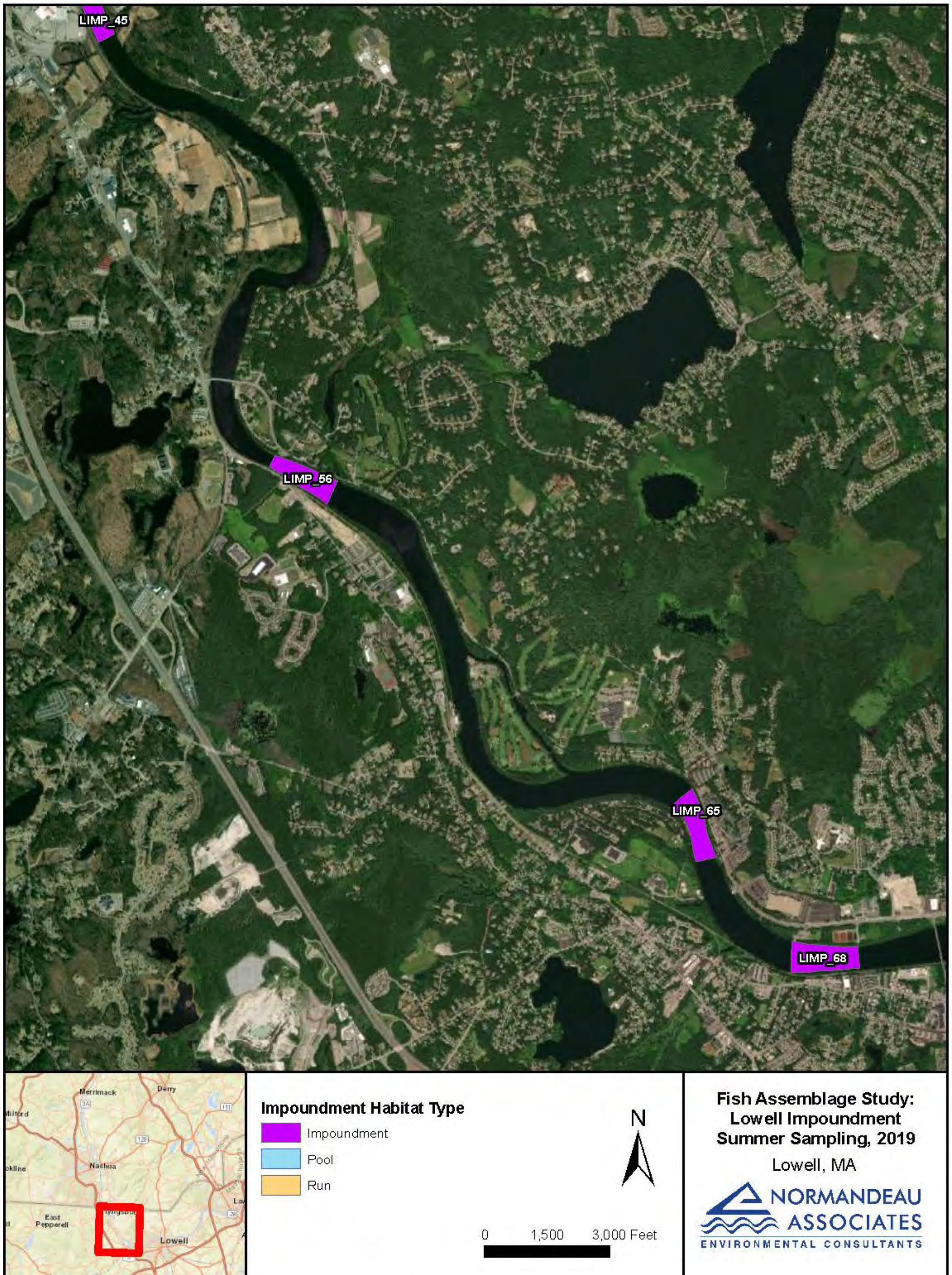

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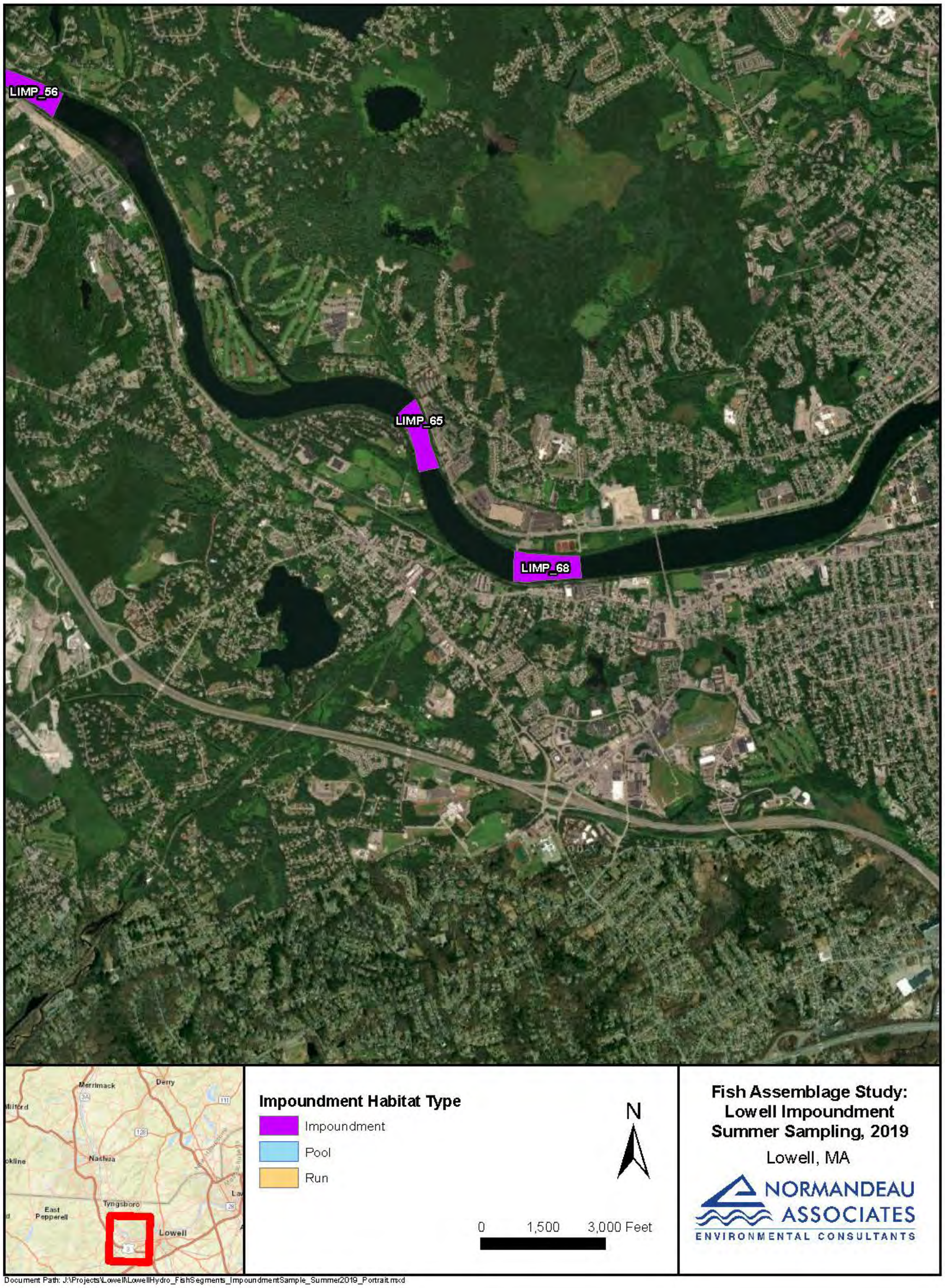
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Derry
Milford
Nashua
East Pepperell
Tyngsboro
Lowell
Impoundment Habitat Type
Impoundment
Pool
Run
N
0 1,500 3,000 Feet
Fish Assemblage Study:
Lowell Impoundment
Summer Sampling, 2019
Lowell, MA
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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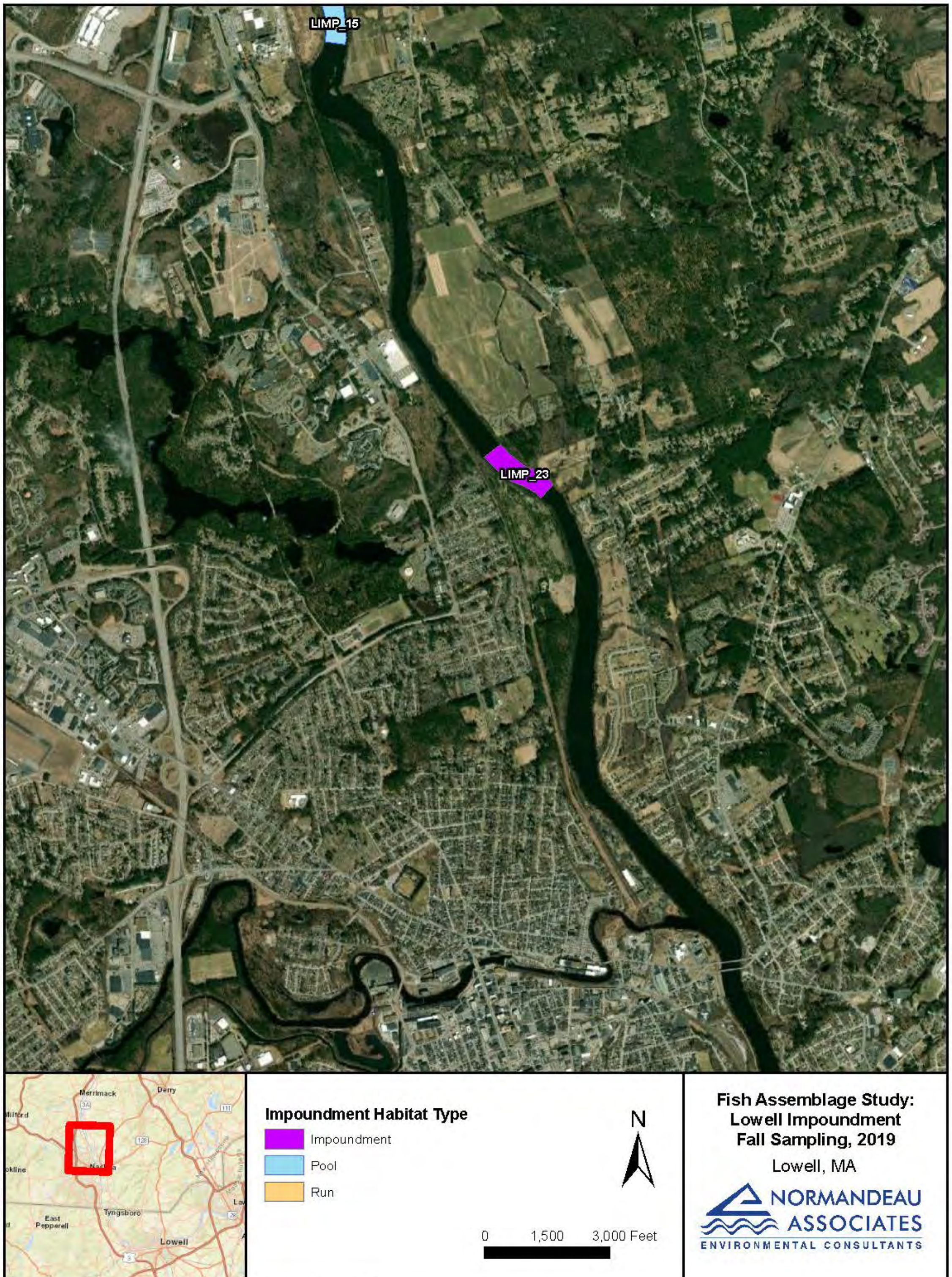
Document Path: J:\Projects\Lowell\LowellHydro_FishSegments_ImpoundmentSample_Fall2019_Portrait.mxd



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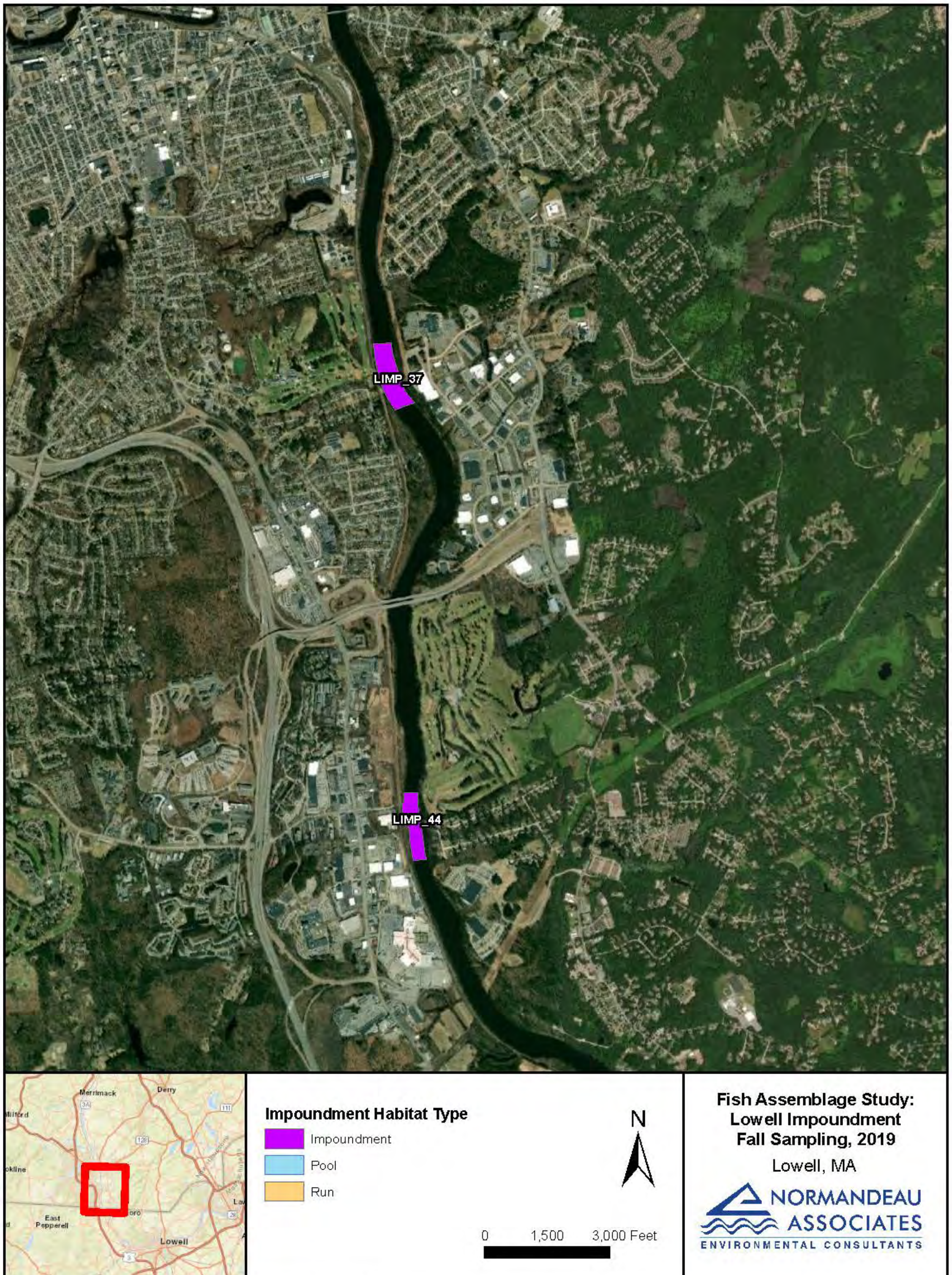

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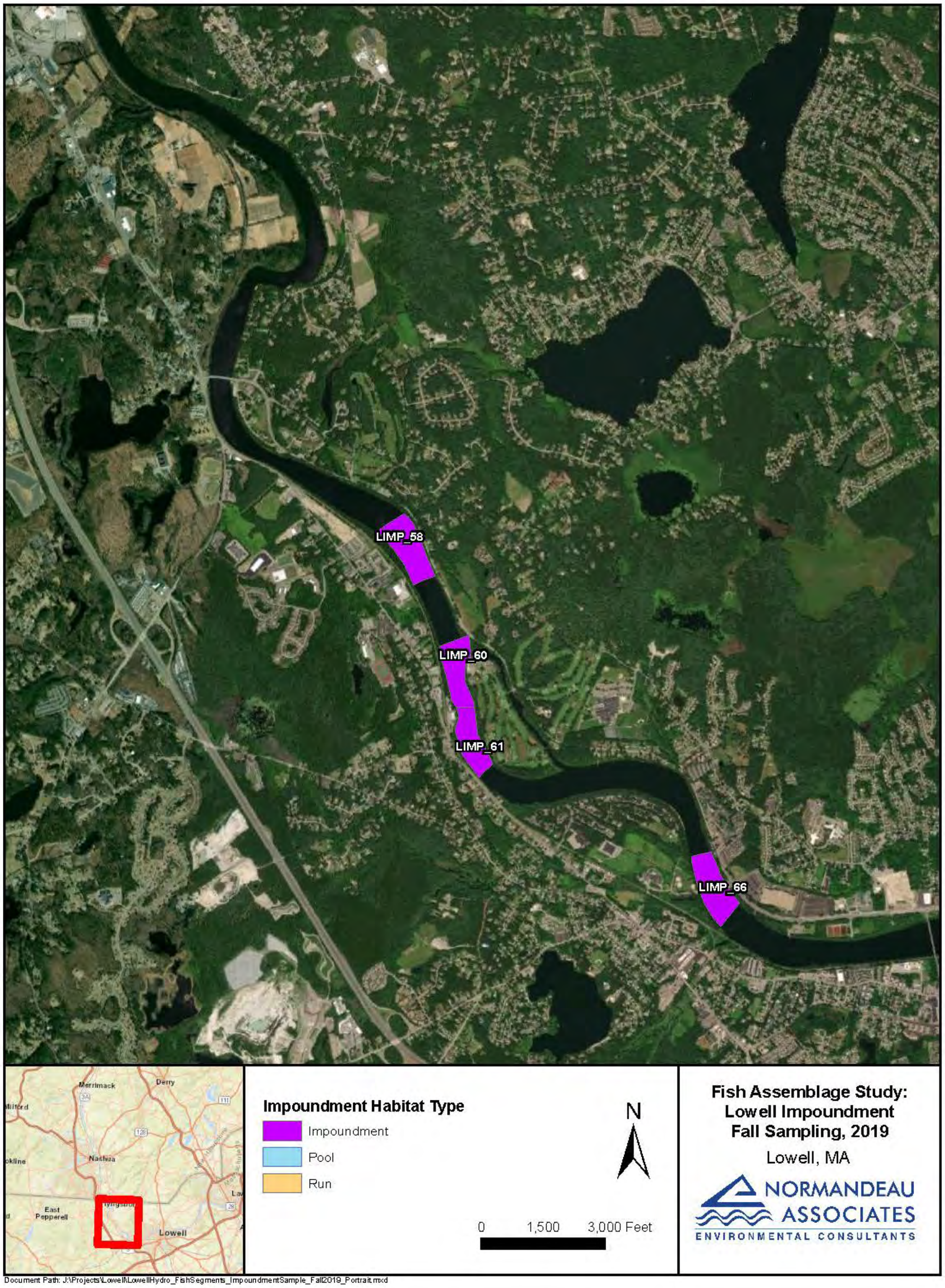
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LIMP_60
LIMP_61
LIMP_66
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Derry
Milford
Nashua
East Pepperell
Lowell
Impoundment Habitat Type
Impoundment
Pool
Run
N
0 1,500 3,000 Feet
Fish Assemblage Study:
Lowell Impoundment
Fall Sampling, 2019
Lowell, MA
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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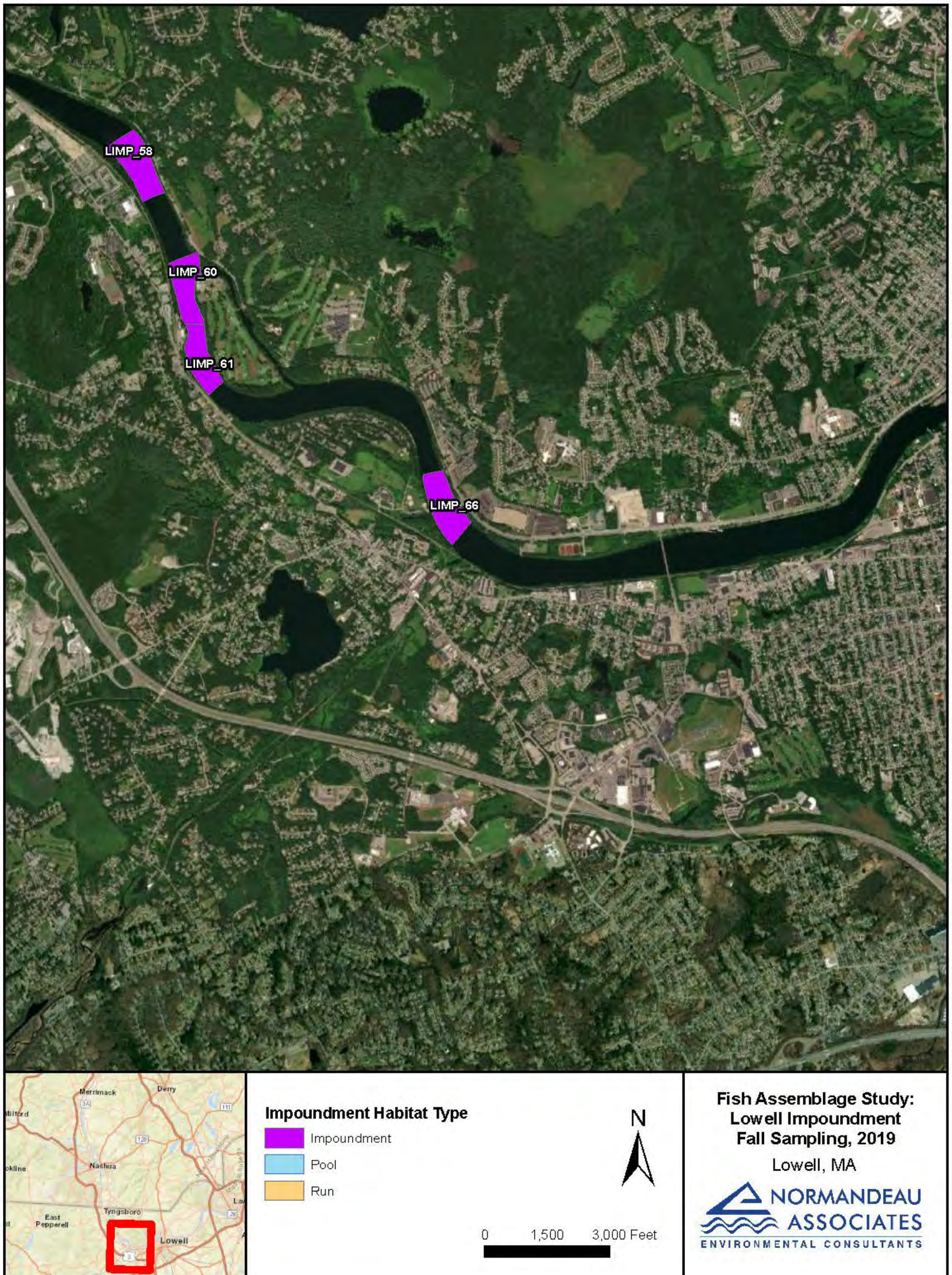

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Appendix B. Catch Per Unit of Effort (CPUE) information for boat electrofish and gill net sampling upstream of Pawtucket dam by season (spring, summer, and fall) and mesohabitat type (impoundment, pool, run).

Boat electrofish: Spring 2019

Common Name	Impoundment		Pool		Run		Total	
	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m
American Eel	1.07	0.05	0.00	0.00	0.53	0.03	0.53	0.03
Black Crappie	0.00	0.00	1.06	0.04	0.53	0.03	0.53	0.02
Bluegill	5.29	0.24	2.78	0.13	1.06	0.06	3.04	0.14
Common Carp	0.20	0.01	0.00	0.00	0.00	0.00	0.07	0.00
Fallfish	3.15	0.14	4.56	0.20	14.09	0.69	7.27	0.34
Golden Shiner	0.18	0.01	0.00	0.00	0.00	0.00	0.06	0.00
Largemouth Bass	0.00	0.00	0.51	0.02	0.53	0.03	0.34	0.02
Lepomis spp.	0.20	0.01	0.00	0.00	0.00	0.00	0.07	0.00
Margined Madtom	0.18	0.01	0.93	0.04	0.00	0.00	0.37	0.02
Pumpkinseed	1.87	0.09	0.00	0.00	0.53	0.03	0.80	0.04
Redbreast Sunfish	24.57	1.13	15.24	0.67	28.57	1.34	22.79	1.05
Rock Bass	0.47	0.02	1.06	0.04	2.05	0.09	1.19	0.05
Sea Lamprey	0.00	0.00	2.78	0.13	2.12	0.11	1.63	0.08
Smallmouth Bass	21.89	1.02	16.41	0.73	38.22	1.71	25.51	1.16
Spottail Shiner	38.11	1.64	23.84	1.04	43.91	1.97	35.29	1.55
Tessellated Darter	0.63	0.03	6.31	0.27	2.12	0.11	3.02	0.14
White Sucker	1.25	0.07	3.98	0.18	7.34	0.37	4.19	0.21
Yellow Bullhead	1.12	0.05	0.00	0.00	1.59	0.09	0.90	0.05
Yellow Perch	0.85	0.04	12.59	0.53	0.53	0.03	4.66	0.20

Boat electrofish: Summer 2019

Common Name	Impoundment		Pool		Run		Total	
	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m
Alewife	4.17	0.19	0.00	0.00	0.00	0.00	1.39	0.06
American Eel	1.30	0.06	0.48	0.02	4.72	0.20	2.17	0.09
Black Crappie	0.22	0.01	0.48	0.02	0.00	0.00	0.23	0.01
Bluegill	14.99	0.68	11.79	0.58	0.62	0.03	9.13	0.43
Common Carp	0.22	0.01	0.00	0.00	2.05	0.09	0.76	0.03
Fallfish	4.61	0.21	1.52	0.07	13.17	0.57	6.43	0.28
Golden Shiner	0.00	0.00	1.01	0.04	1.24	0.06	0.75	0.03
Largemouth Bass	4.04	0.19	6.13	0.29	2.67	0.11	4.28	0.20
Lepomis spp.	0.22	0.01	0.48	0.02	2.05	0.09	0.92	0.04
Margined Madtom	0.63	0.03	0.51	0.02	2.05	0.09	1.06	0.05
Pumpkinseed	26.72	1.21	1.45	0.07	0.62	0.03	9.60	0.44
Redbreast Sunfish	29.42	1.34	12.18	0.58	64.10	2.74	35.24	1.55
Rock Bass	0.22	0.01	0.51	0.02	0.00	0.00	0.24	0.01
Sea Lamprey	1.27	0.06	0.00	0.00	0.00	0.00	0.42	0.02
Smallmouth Bass	5.32	0.24	8.06	0.40	14.41	0.63	9.26	0.42
Spottail Shiner	0.45	0.02	18.23	0.82	59.13	2.51	25.94	1.12
Tessellated Darter	2.39	0.11	2.31	0.11	0.00	0.00	1.56	0.07
White Perch	0.23	0.01	0.00	0.00	0.00	0.00	0.08	0.00
White Sucker	0.00	0.00	1.95	0.09	1.86	0.09	1.27	0.06
Yellow Bullhead	2.92	0.13	2.46	0.11	0.62	0.03	2.00	0.09
Yellow Perch	0.00	0.00	0.00	0.00	0.62	0.03	0.21	0.01

Boat electrofish: Fall 2019

Common Name	Impoundment		Pool		Run		Total	
	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m
Alewife	13.23	0.83	3.98	0.18	13.23	0.83	10.15	0.61
American Eel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Black Crappie	0.00	0.00	0.93	0.04	0.00	0.00	0.31	0.01
Bluegill	2.21	0.12	5.04	0.22	2.21	0.12	3.15	0.15
Common Carp	0.20	0.01	0.00	0.00	0.20	0.01	0.13	0.01
Fallfish	7.81	0.38	26.66	1.20	7.81	0.38	14.09	0.65
Golden Shiner	0.37	0.02	4.24	0.18	0.37	0.02	1.66	0.07
Largemouth Bass	0.62	0.03	3.05	0.13	0.62	0.03	1.43	0.06
Margined Madtom	0.19	0.01	0.00	0.00	0.19	0.01	0.12	0.01
Pumpkinseed	3.20	0.19	0.00	0.00	3.20	0.19	2.13	0.13
Redbreast Sunfish	6.89	0.37	2.78	0.13	6.89	0.37	5.52	0.29
Rock Bass	0.16	0.01	0.00	0.00	0.16	0.01	0.10	0.01
Sea Lamprey	0.84	0.05	1.92	0.09	0.84	0.05	1.20	0.06
Smallmouth Bass	5.42	0.30	5.89	0.27	5.42	0.30	5.58	0.29
Spottail Shiner	5.62	0.26	13.65	0.58	5.62	0.26	8.30	0.37
Tessellated Darter	0.19	0.01	0.00	0.00	0.19	0.01	0.12	0.01
White Sucker	2.10	0.12	3.18	0.13	2.10	0.12	2.46	0.12
Yellow Bullhead	0.32	0.02	0.93	0.04	0.32	0.02	0.52	0.03
Yellow Perch	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Experimental gill net: Spring 2019

Common Name	Impoundment	Pool	Run	Total
	Fish/hr	Fish/hr	Fish/hr	Fish/hr
Bluegill	0.00	0.05	0.00	0.02
Fallfish	0.01	0.00	0.00	0.00
Margined Madtom	0.01	0.00	0.00	0.00
Smallmouth Bass	0.01	0.00	0.00	0.00
Spottail Shiner	0.00	0.00	0.10	0.03
White Sucker	0.01	0.00	0.03	0.02

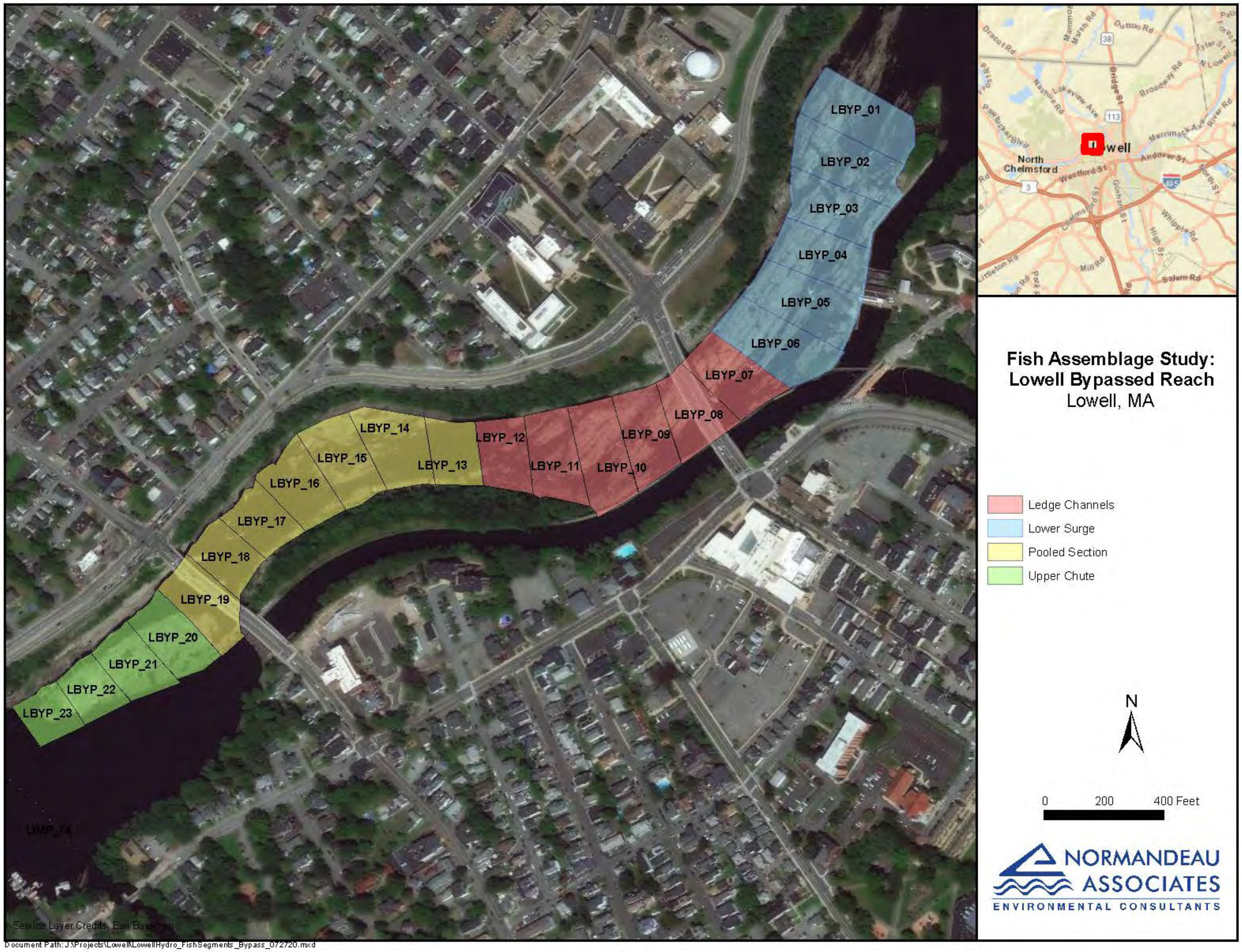
Experimental gill net: Summer 2019

Common Name	Impoundment	Pool	Run	Total
	Fish/hr	Fish/hr	Fish/hr	Fish/hr
Alewife	0.02	0.00	0.00	0.01
Channel Catfish	0.01	0.00	0.00	0.00
Common Carp	0.01	0.00	0.00	0.00
Fallfish	0.01	0.03	0.00	0.01
Golden Shiner	0.00	0.00	0.10	0.03
Pumpkinseed	0.01	0.00	0.00	0.00
Redbreast Sunfish	0.05	0.00	0.00	0.02
Smallmouth Bass	0.04	0.00	0.00	0.01
Walleye	0.01	0.00	0.00	0.00
White Sucker	0.01	0.03	0.00	0.01
Yellow Bullhead	0.20	0.00	0.03	0.08
Yellow Perch	0.02	0.00	0.00	0.01

Experimental gill net: Fall 2019

Common Name	Impoundment	Pool	Run	Total
	Fish/hr	Fish/hr	Fish/hr	Fish/hr
Spottail Shiner	0.00	0.05	0.00	0.02
Yellow Bullhead	0.01	0.00	0.10	0.04

Appendix C. Spatial distribution of 50-m habitat units for the 0.75 mile bypassed reach downstream of Pawtucket Dam.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LBYP_16
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LBYP_18
LBYP_19
LBYP_20
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LBYP_23
North Chelmsford
Fish Assemblage Study:
Lowell Bypassed Reach
Lowell, MA
Ledge Channels
Lower Surge
Pooled Section
Upper Chute
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400 Feet
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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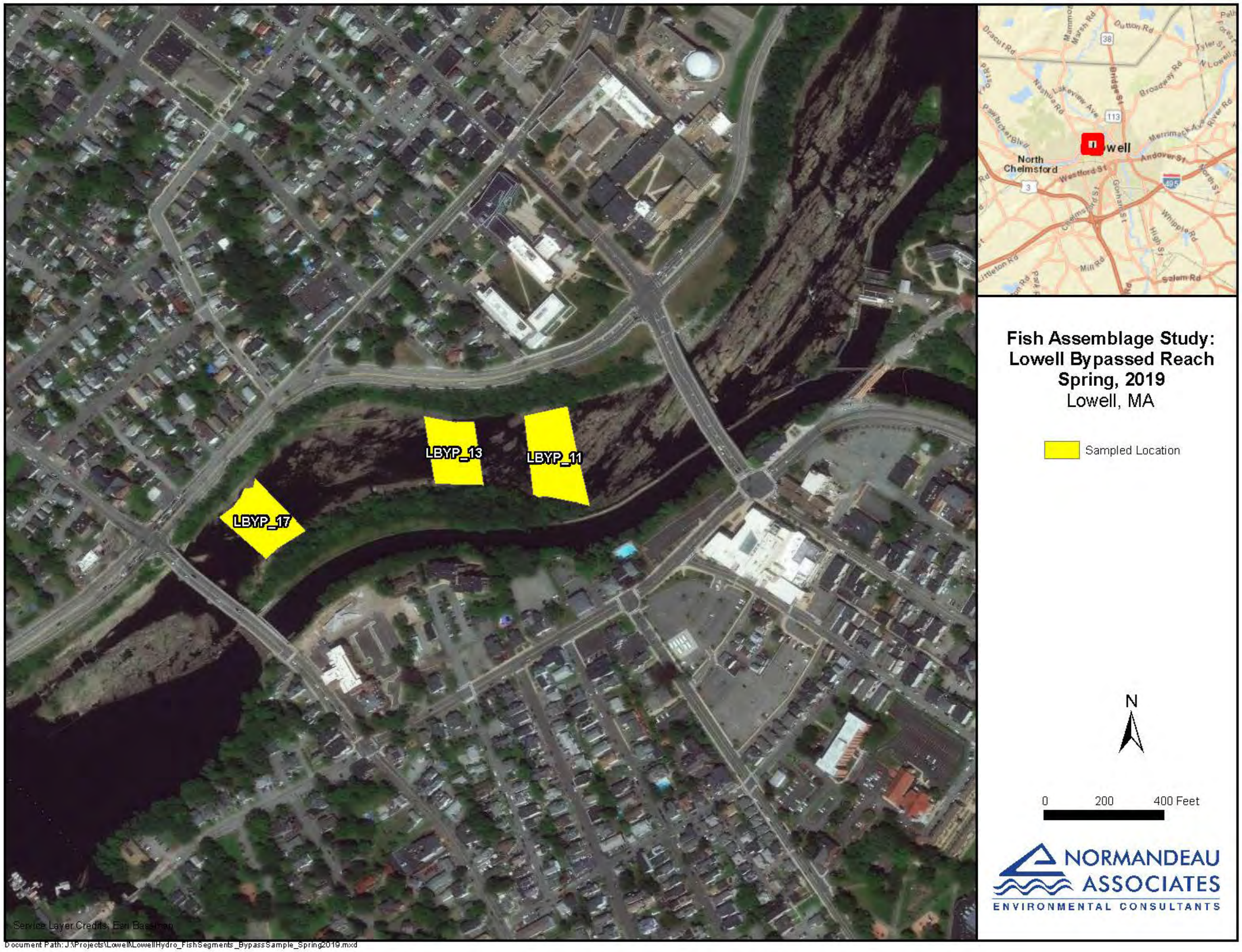
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North Chelmsford
Fish Assemblage Study:
Lowell Bypassed Reach
Spring, 2019
Lowell, MA
Sampled Location
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NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
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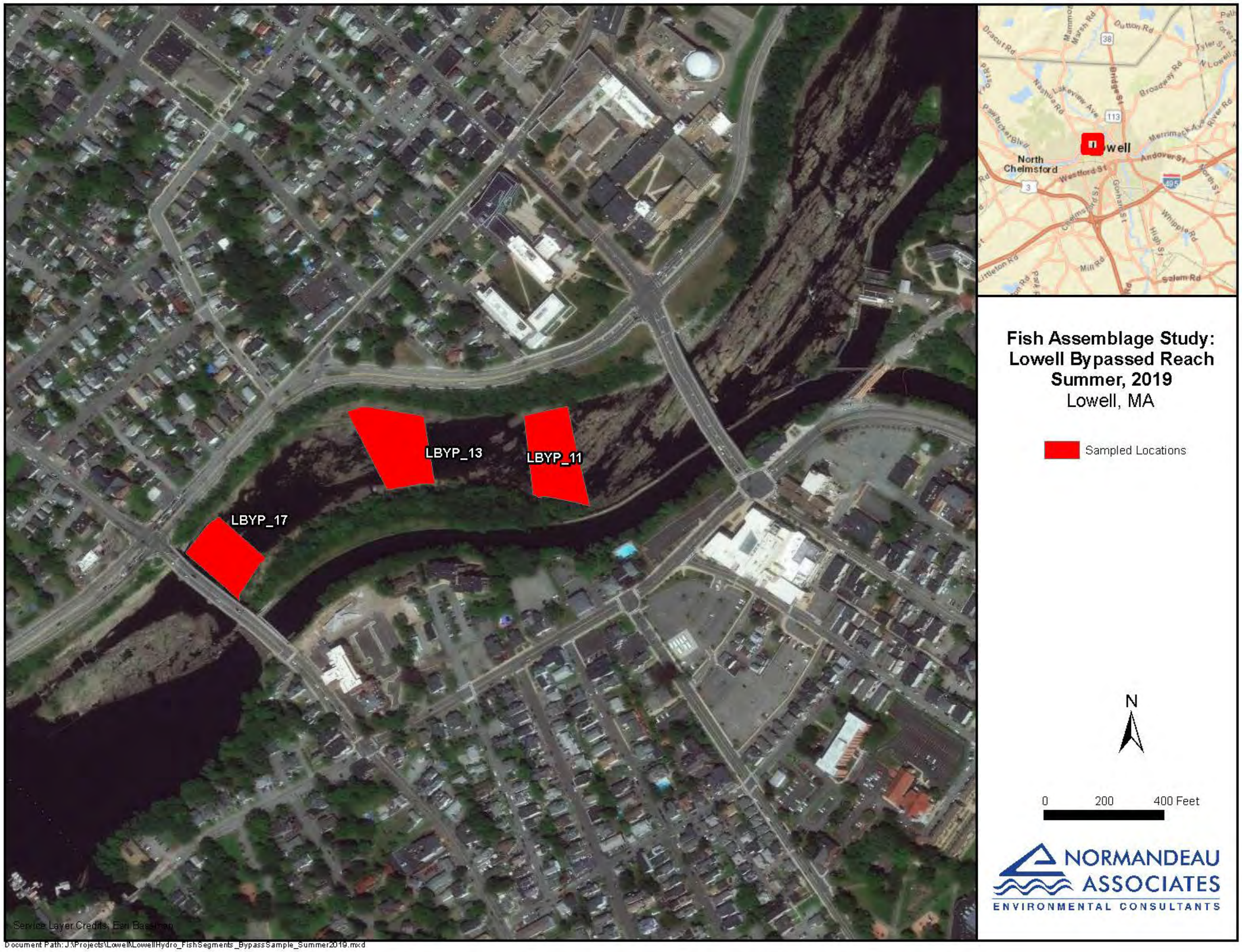

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North Chelmsford
Fish Assemblage Study: Lowell Bypassed Reach Summer, 2019
Lowell, MA
Sampled Locations
N
0 200 400 Feet
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS


LBYP_16
LBYP_13
LBYP_11
Fish Assemblage Study:
Lowell Bypassed Reach
Fall, 2019
Lowell, MA
Sampled Locations
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0 200 400 Feet
NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS
Service Layer Credits: Esri Basemap
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Appendix D. Catch Per Unit of Effort (CPUE) information for back pack electrofish sampling within the bypassed reach downstream of Pawtucket dam by season (spring, summer, and fall) and habitat type (pool and ledge channels).

Back pack electrofish: Spring 2019

Common Name	Ledge Channels		Pooled Section		Total	
	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m
American Eel	20.67	14.00	4.12	1.67	12.40	7.83
Bluegill	0.00	0.00	1.52	0.67	0.76	0.33
Brown Trout	2.95	2.00	0.00	0.00	1.48	1.00
Fallfish	20.67	14.00	20.62	8.33	20.65	11.17
Longnose Dace	2.95	2.00	0.00	0.00	1.48	1.00
Margined Madtom	2.95	2.00	0.00	0.00	1.48	1.00
Redbreast Sunfish	2.95	2.00	0.00	0.00	1.48	1.00
Smallmouth Bass	5.91	4.00	0.00	0.00	2.95	2.00
Spottail Shiner	0.00	0.00	65.66	26.00	32.83	13.00
Tessellated Darter	0.00	0.00	0.76	0.33	0.38	0.17

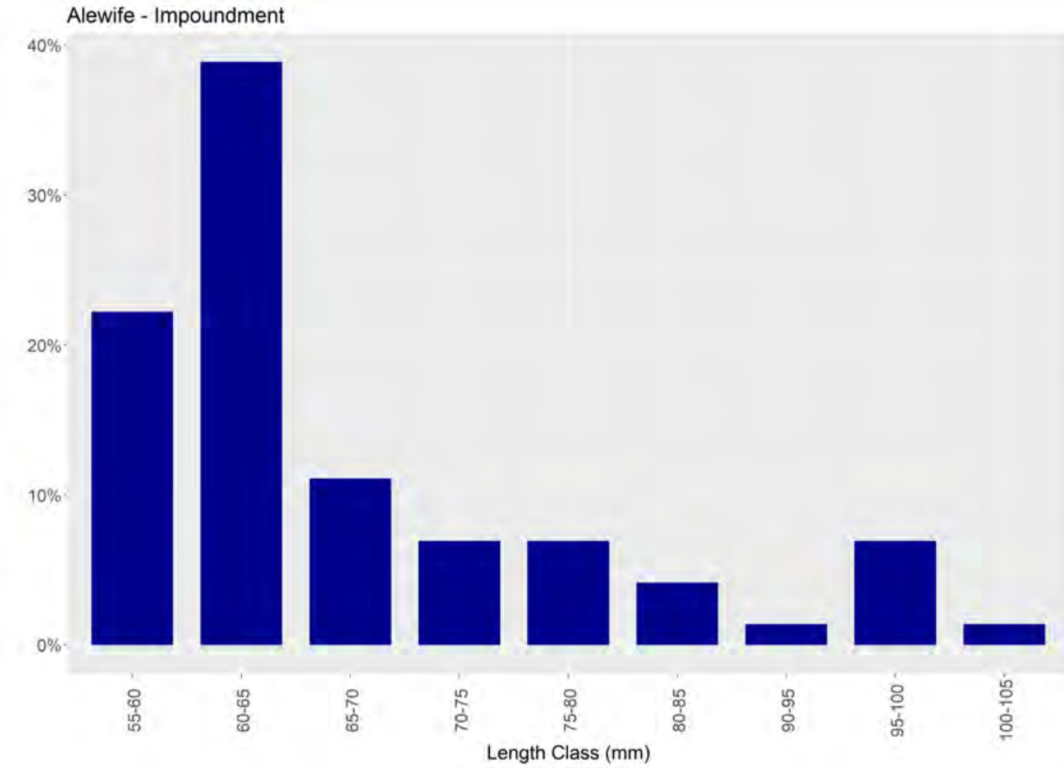
Back pack electrofish: Summer 2019

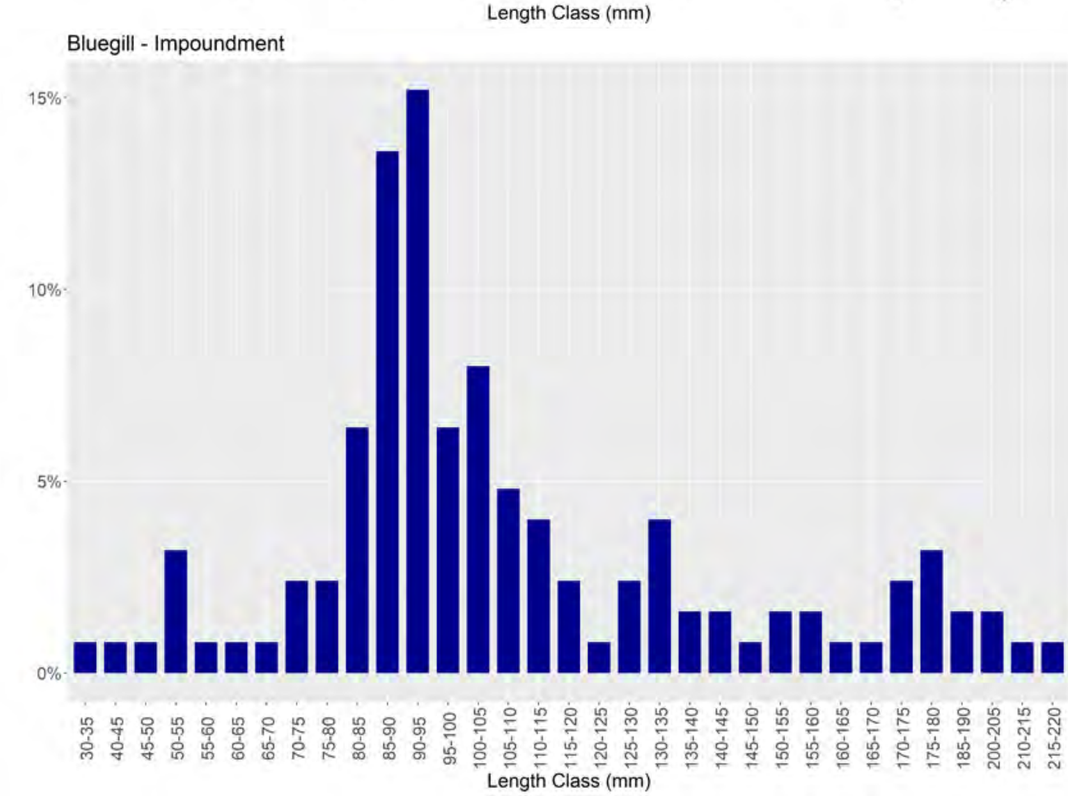
Common Name	Ledge Channels		Pooled Section		Total	
	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m
American Eel	17.72	12.00	6.28	4.00	12.00	8.00
Bluegill	0.00	0.00	0.56	0.33	0.28	0.17
Fallfish	0.00	0.00	97.43	62.33	48.72	31.17
Largemouth Bass	0.00	0.00	1.11	0.67	0.56	0.33
Margined Madtom	0.00	0.00	1.04	0.67	0.52	0.33
Redbreast Sunfish	2.95	2.00	2.15	1.33	2.55	1.67
Smallmouth Bass	73.82	50.00	6.49	4.00	40.15	27.00
Spottail Shiner	0.00	0.00	25.56	16.33	12.78	8.17
Tessellated Darter	2.95	2.00	2.08	1.33	2.52	1.67
White Sucker	0.00	0.00	15.66	10.00	7.83	5.00
Yellow Bullhead	0.00	0.00	2.22	1.33	1.11	0.67

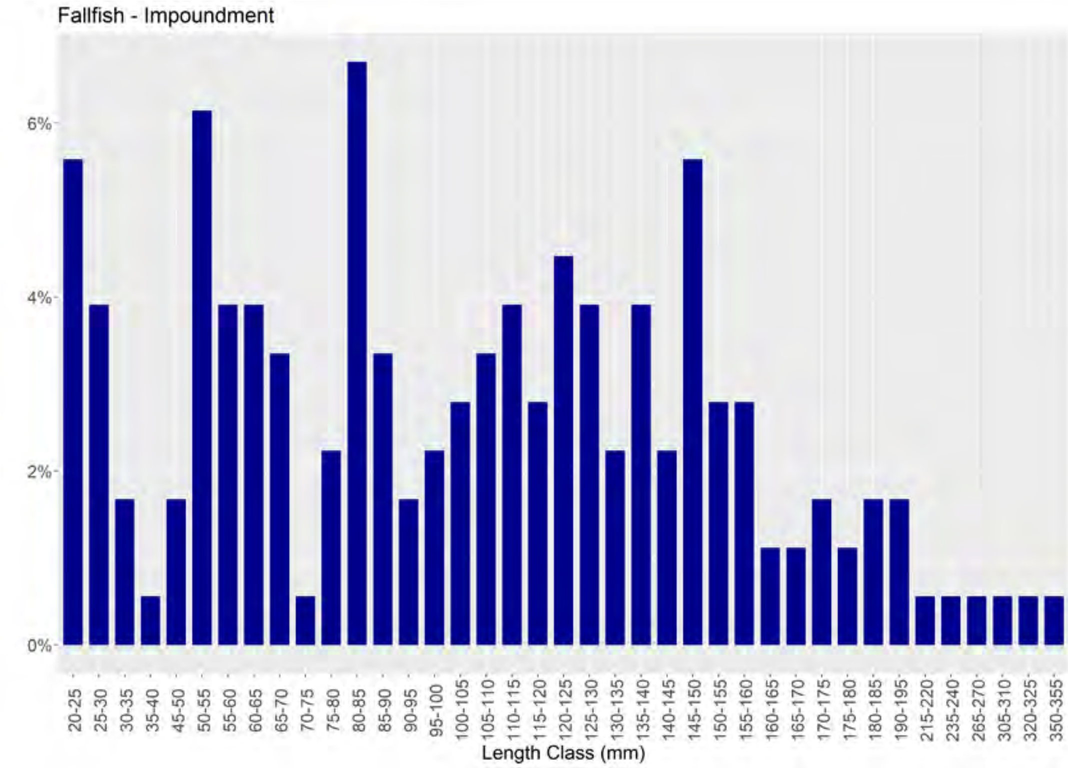
Back pack electrofish: Fall 2019

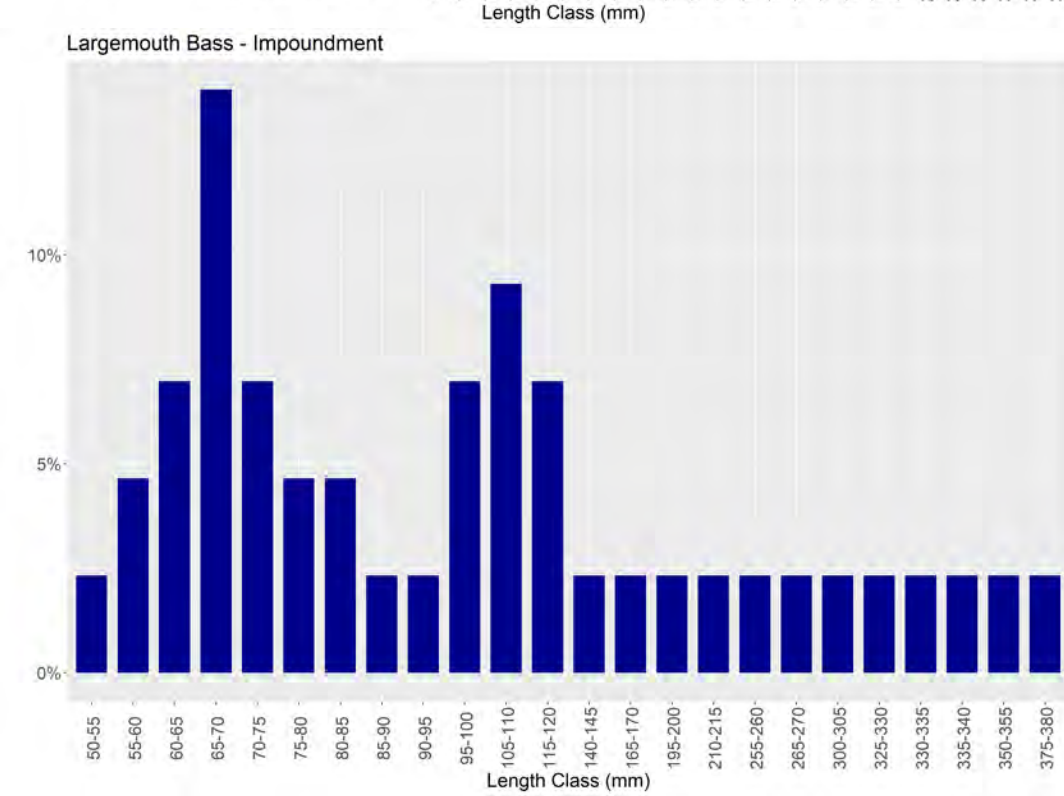
Common Name	Ledge Channels		Pooled Section		Total	
	Fish/hr	Fish/100m	Fish/hr	Fish/100m	Fish/hr	Fish/100m
American Eel	0.00	0.00	3.62	1.67	1.81	0.83
Fallfish	0.00	0.00	0.72	0.33	0.36	0.17
Lepomis spp.	0.00	0.00	1.68	0.67	0.84	0.33
Longnose Dace	2.95	2.00	0.00	0.00	1.48	1.00
Margined Madtom	0.00	0.00	12.06	5.33	6.03	2.67
Redbreast Sunfish	20.67	14.00	0.00	0.00	10.33	7.00
Sea Lamprey	0.00	0.00	1.68	0.67	0.84	0.33
Smallmouth Bass	88.58	60.00	38.08	16.33	63.33	38.17
Tessellated Darter	0.00	0.00	3.86	1.67	1.93	0.83
White Sucker	8.86	6.00	0.00	0.00	4.43	3.00
Yellow Bullhead	0.00	0.00	0.72	0.33	0.36	0.17

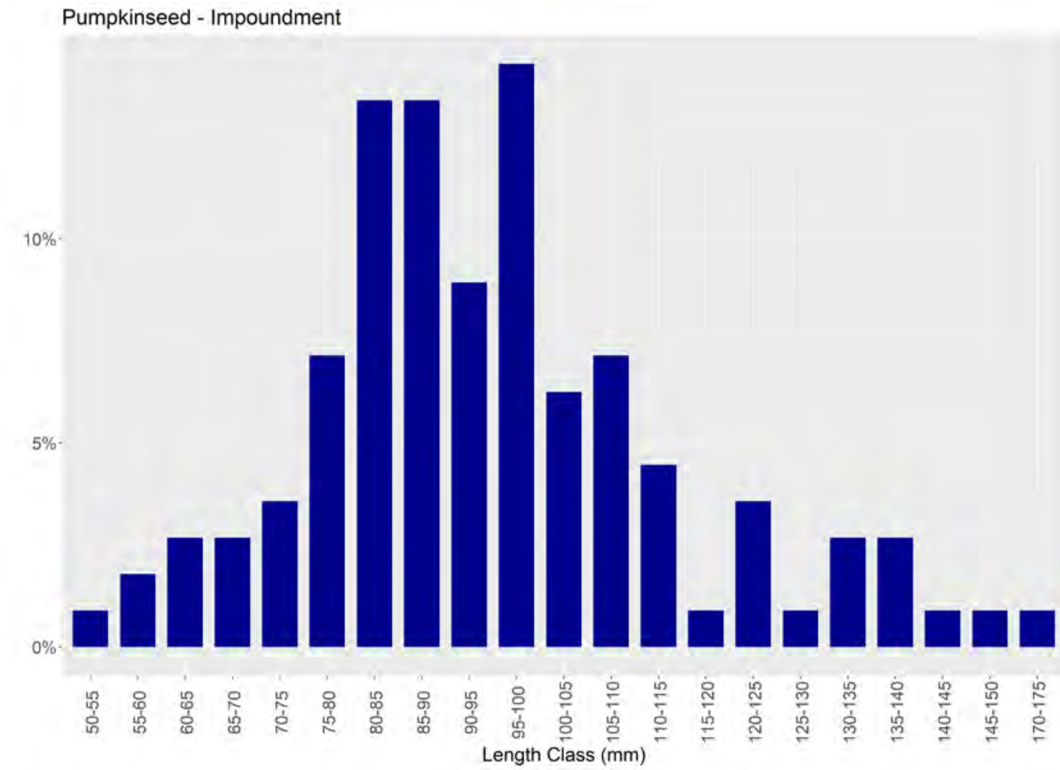
Appendix E. Length frequency distributions for common fish species collected by boat electrofish and experimental gill net sampling in the Lowell impoundment and back pack electrofish sampling within the bypassed reach downstream of Pawtucket dam.


Alewife - Impoundment
40%
30%
20%
10%
0%
55-60
60-65
65-70
70-75
75-80
80-85
90-95
95-100
100-105
Length Class (mm)

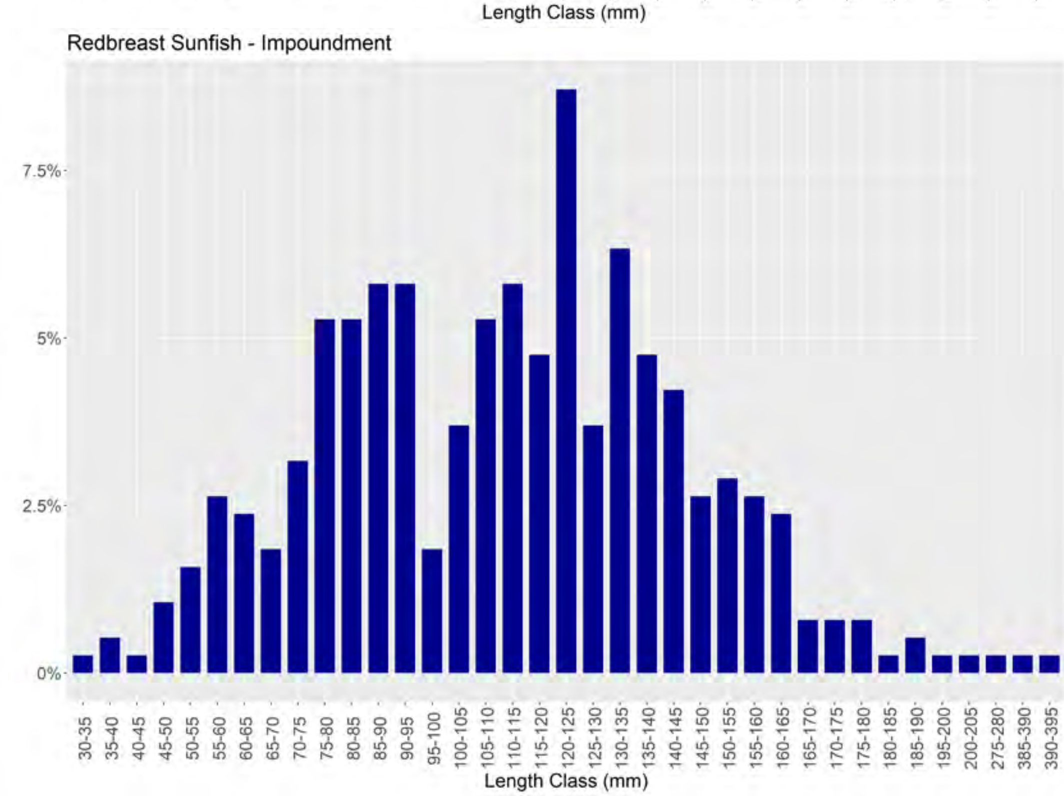

Bluegill - Impoundment
15%
10%
5%
0%
30-35
40-45
45-50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
100-105
105-110
110-115
115-120
120-125
125-130
130-135
135-140
140-145
145-150
150-155
155-160
160-165
165-170
170-175
175-180
185-190
200-205
210-215
215-220
Length Class (mm)


Fallfish - Impoundment
6%
4%
2%
0%
20-25
25-30
30-35
35-40
45-50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
100-105
105-110
110-115
115-120
120-125
125-130
130-135
135-140
140-145
145-150
150-155
155-160
160-165
165-170
170-175
175-180
180-185
190-195
215-220
235-240
265-270
305-310
320-325
350-355
Length Class (mm)

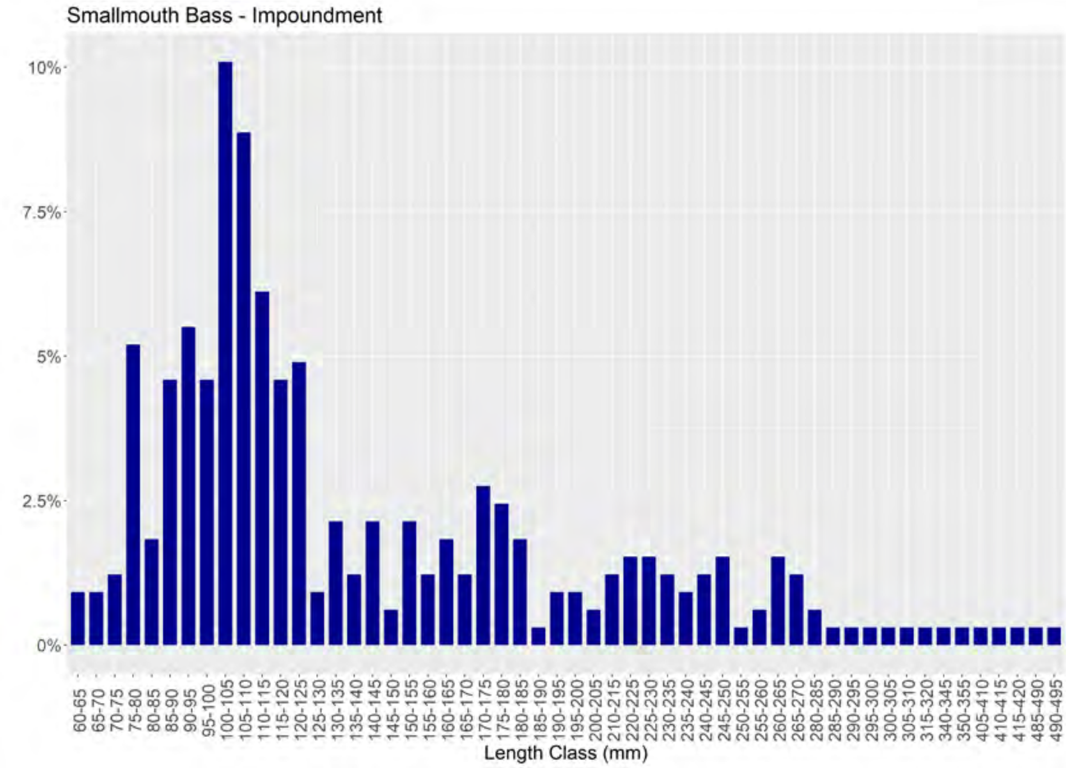

Largemouth Bass - Impoundment
10%
5%
0%
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
105-110
115-120
140-145
165-170
195-200
210-215
255-260
265-270
300-305
325-330
330-335
335-340
350-355
375-380
Length Class (mm)

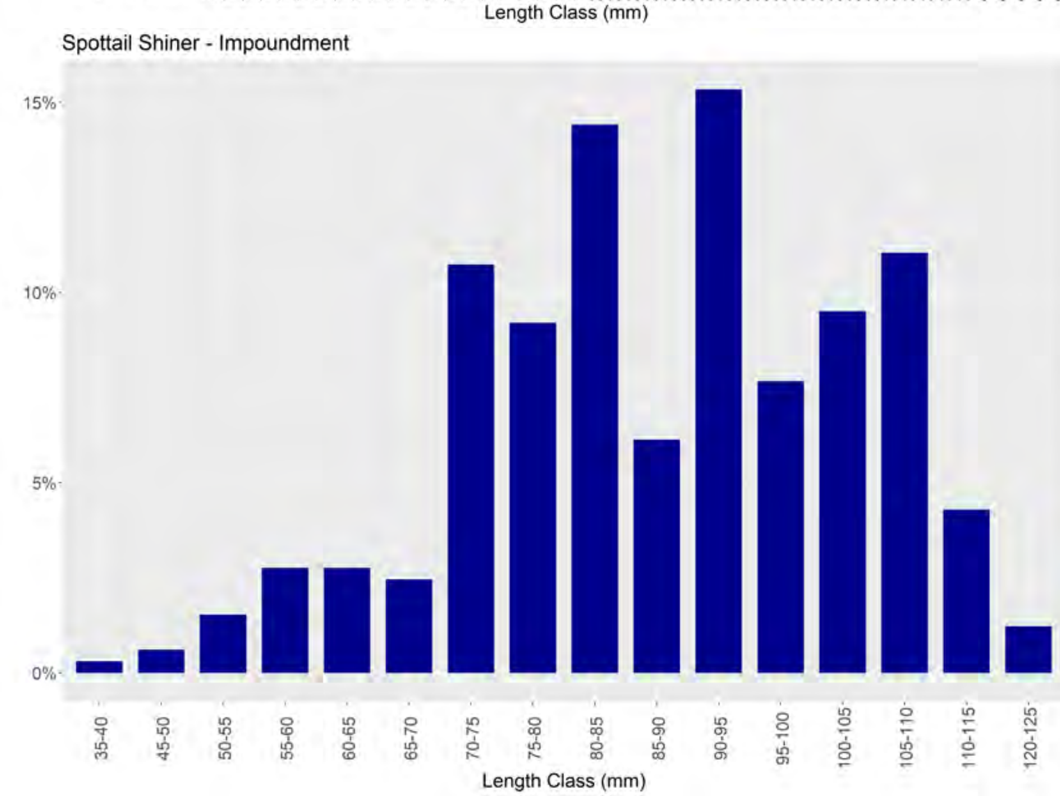


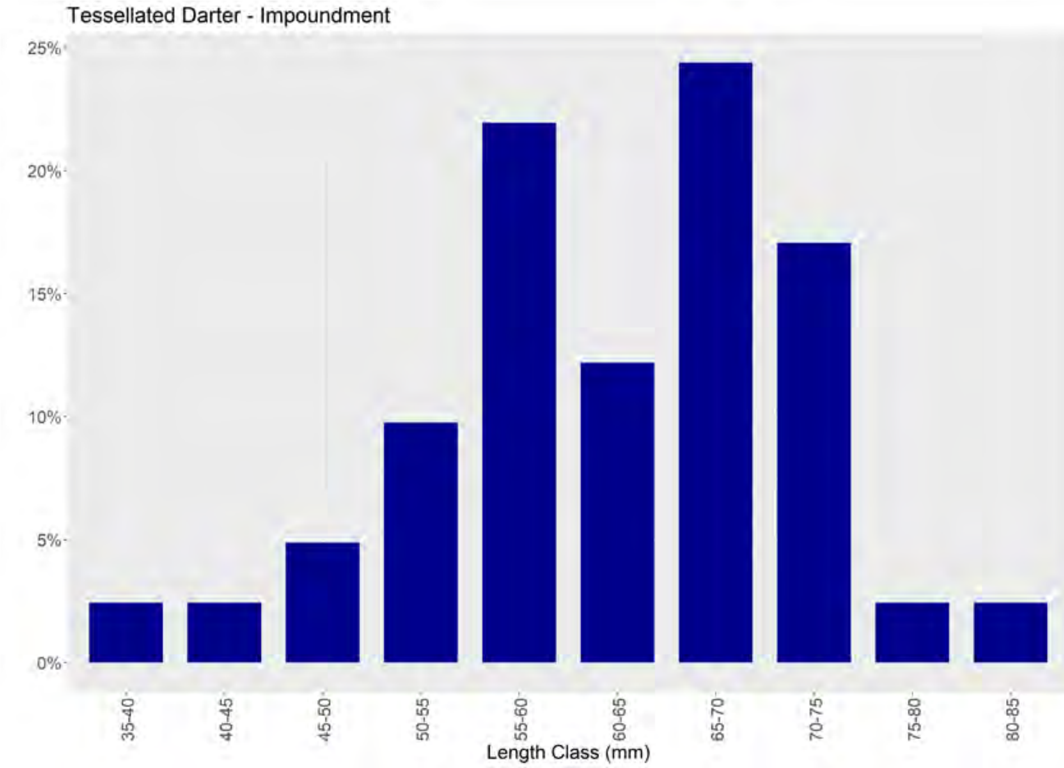
Pumpkinseed - Impoundment
10%
5%
0%
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
100-105
105-110
110-115
115-120
120-125
125-130
130-135
135-140
140-145
145-150
170-175
Length Class (mm)

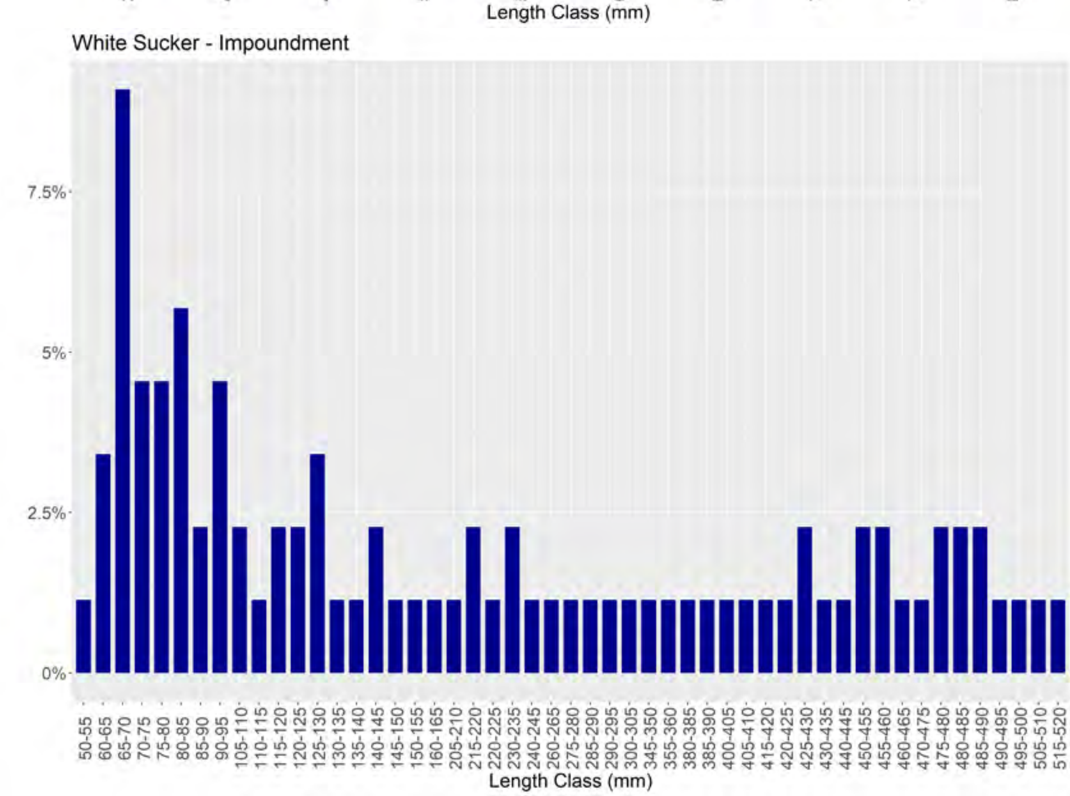


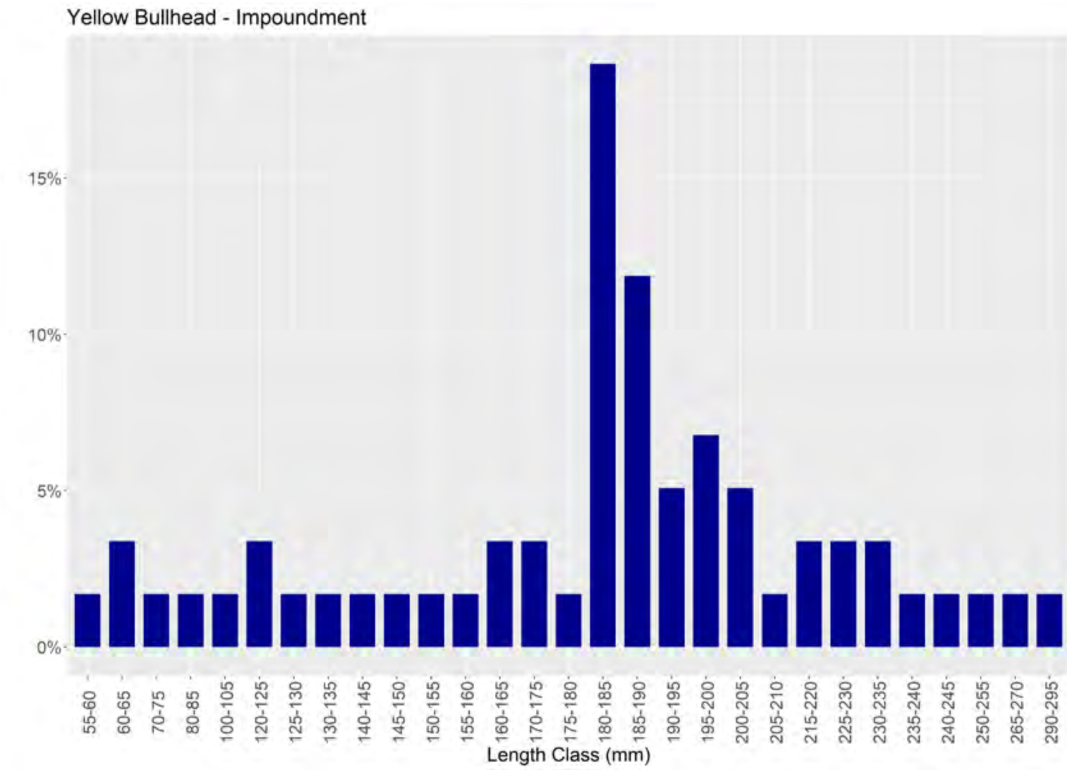
Redbreast Sunfish - Impoundment
7.5%
5%
2.5%
0%
30-35
35-40
40-45
45-50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
100-105
105-110
110-115
115-120
120-125
125-130
130-135
135-140
140-145
145-150
150-155
155-160
160-165
165-170
170-175
175-180
180-185
185-190
195-200
200-205
275-280
385-390
390-395
Length Class (mm)

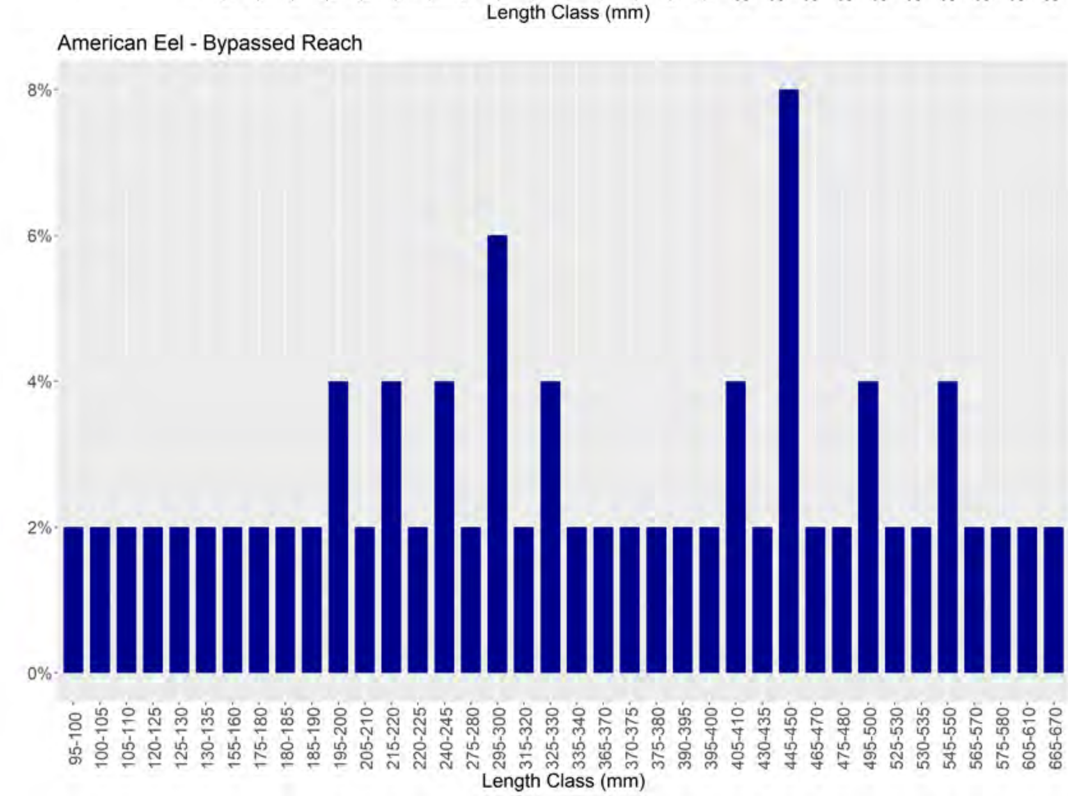

Smallmouth Bass - Impoundment
10%
7.5%
5%
2.5%
0%
Length Class (mm)

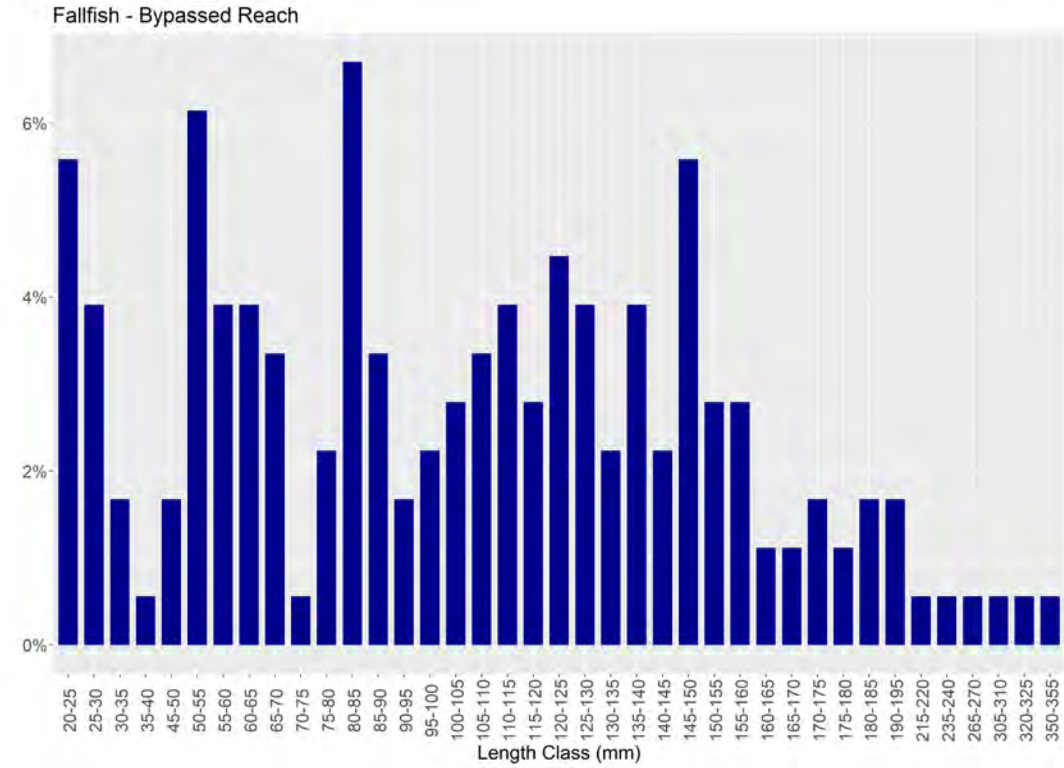

Spottail Shiner - Impoundment
15%
10%
5%
0%
35-40
45-50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
100-105
105-110
110-115
120-125
Length Class (mm)

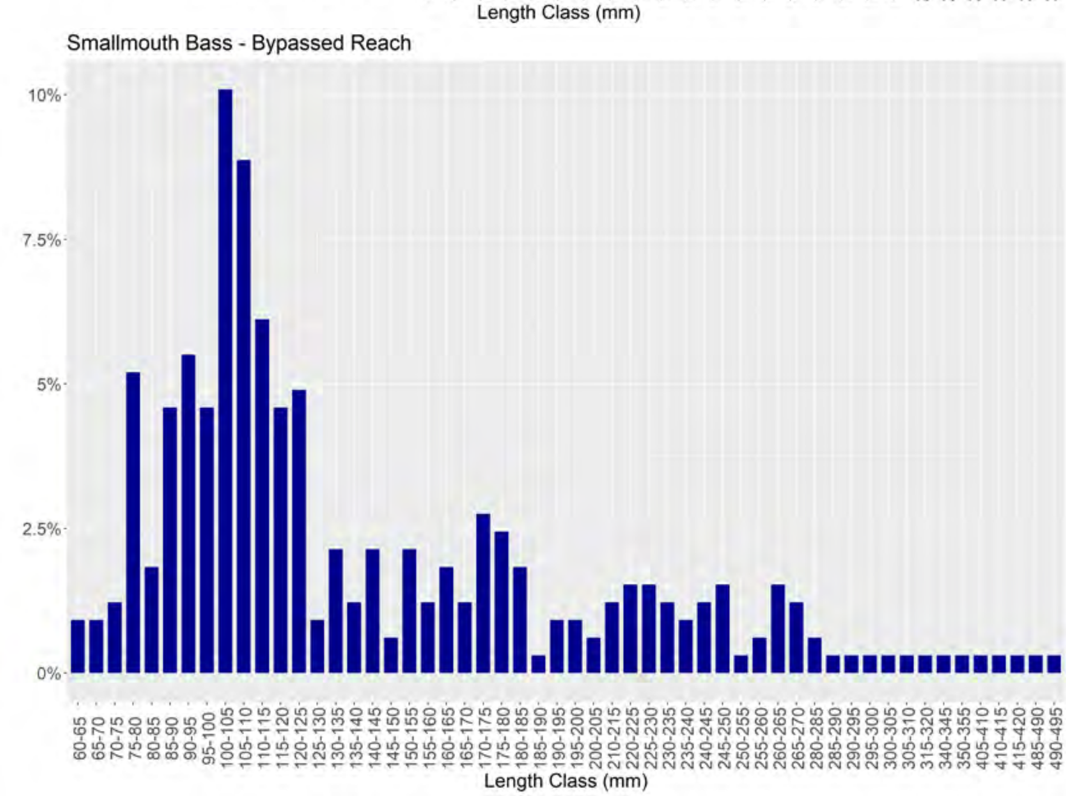

Tessellated Darter - Impoundment
25%
20%
15%
10%
5%
0%
35-40
40-45
45-50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
Length Class (mm)

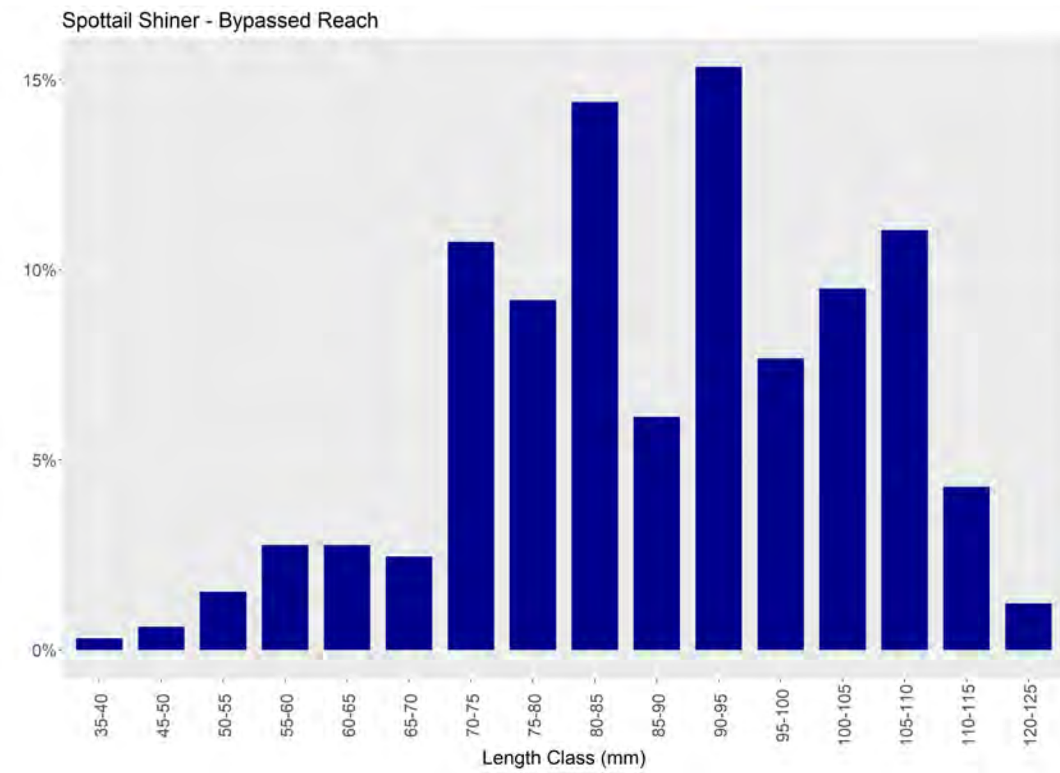

White Sucker - Impoundment
7.5%
5%
2.5%
0%
Length Class (mm)

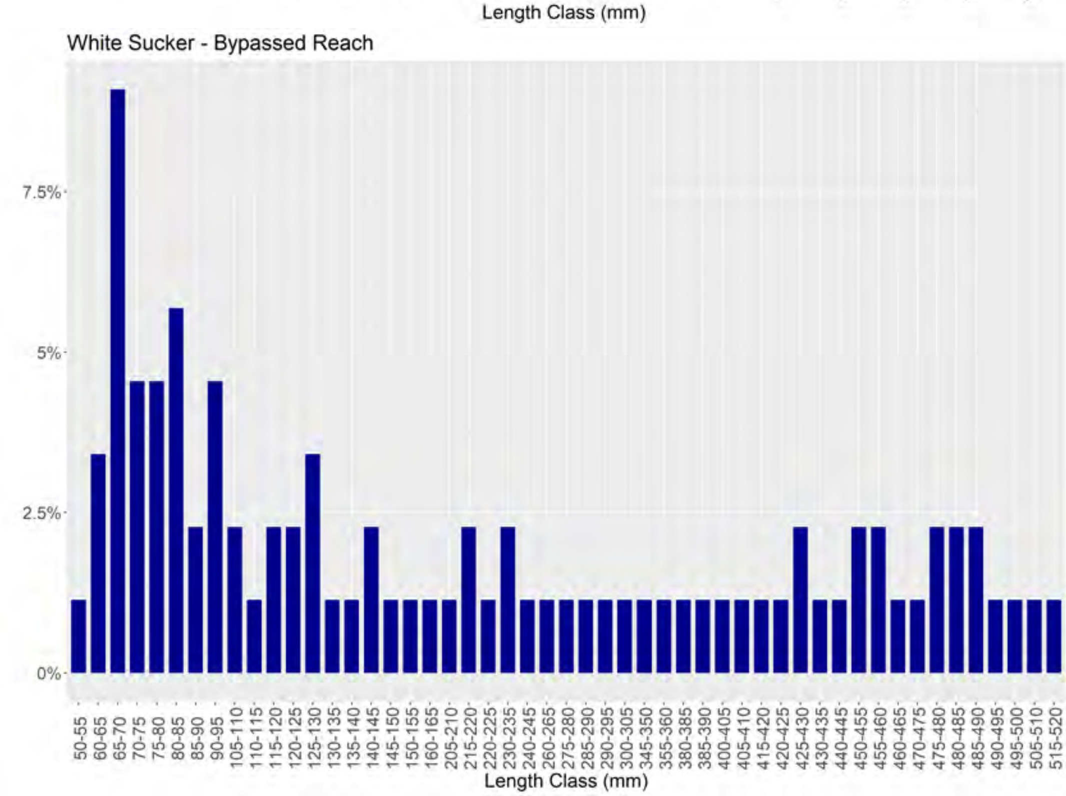

Yellow Bullhead - Impoundment
15%
10%
5%
0%
55-60
60-65
70-75
80-85
100-105
120-125
125-130
130-135
140-145
145-150
150-155
155-160
160-165
170-175
175-180
180-185
185-190
190-195
195-200
200-205
205-210
215-220
225-230
230-235
235-240
240-245
250-255
265-270
290-295
Length Class (mm)


American Eel - Bypassed Reach
8%
6%
4%
2%
0%
95-100
100-105
105-110
120-125
125-130
130-135
155-160
175-180
180-185
185-190
195-200
205-210
215-220
220-225
240-245
275-280
295-300
315-320
325-330
335-340
365-370
370-375
375-380
390-395
395-400
405-410
430-435
445-450
465-470
475-480
495-500
525-530
530-535
545-550
565-570
575-580
605-610
665-670
Length Class (mm)


Fallfish - Bypassed Reach
6%
4%
2%
0%
20-25 25-30 30-35 35-40 45-50 50-55 55-60 60-65 65-70 70-75 75-80 80-85 85-90 90-95 95-100 100-105 105-110 110-115 115-120 120-125 125-130 130-135 135-140 140-145 145-150 150-155 155-160 160-165 165-170 170-175 175-180 180-185 190-195 215-220 235-240 265-270 305-310 320-325 350-355
Length Class (mm)


Smallmouth Bass - Bypassed Reach
10%
7.5%
5%
2.5%
0%
60-65 65-70 70-75 75-80 80-85 85-90 90-95 95-100 100-105 105-110 110-115 115-120 120-125 125-130 130-135 135-140 140-145 145-150 150-155 155-160 160-165 165-170 170-175 175-180 180-185 185-190 190-195 195-200 200-205 210-215 220-225 225-230 230-235 235-240 240-245 245-250 250-255 255-260 260-265 265-270 280-285 285-290 290-295 295-300 300-305 305-310 315-320 340-345 350-355 405-410 410-415 415-420 485-490 490-495
Length Class (mm)


Spottail Shiner - Bypassed Reach
15%
10%
5%
0%
35-40
45-50
50-55
55-60
60-65
65-70
70-75
75-80
80-85
85-90
90-95
95-100
100-105
105-110
110-115
120-125
Length Class (mm)


White Sucker - Bypassed Reach
7.5%
5%
2.5%
0%
50-55
60-65
65-70
70-75
75-80
80-85
85-90
90-95
105-110
110-115
115-120
120-125
125-130
130-135
135-140
140-145
145-150
150-155
160-165
205-210
215-220
220-225
230-235
240-245
260-265
275-280
285-290
290-295
300-305
345-350
355-360
380-385
385-390
400-405
405-410
415-420
420-425
425-430
430-435
440-445
450-455
455-460
460-465
470-475
475-480
480-485
485-490
490-495
495-500
505-510
515-520
Length Class (mm)

Appendix F. Catch information for fish species collected by boat electrofish and experimental gill net sampling in the Lowell impoundment and back pack electrofish sampling within the bypassed reach downstream of Pawtucket dam (2019).

Report Appendix F available as Microsoft Excel data listing.

Technical Report for the Juvenile Alosine Downstream Passage Assessment

Lowell Hydroelectric Project (FERC No. 2790)

Prepared For
Boott Hydropower, LLC
Subsidiary of Central Rivers Power US, LLC
670 N. Commercial Street, Suite 204
Manchester, NH 03102

Central Rivers Power

Prepared By
Normandeau Associates, Inc.
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NORMANDEAU ASSOCIATES
ENVIRONMENTAL CONSULTANTS

February 25, 2021

Table of Contents

List of Tables

List of Figures

1 Introduction

A radio-telemetry assessment of the effects of project operation on downstream migrating juvenile alosines was conducted in support of the relicensing for the Lowell Hydroelectric Project (Lowell or Project), Federal Energy Regulatory Commission (FERC) No. 2790, as identified in the Revised Study Plan (RSP) submitted by Boott Hydropower, LLC (Boott) on January 28, 2019. The approach and methodology described in the RSP for the juvenile alosine study was approved without modifications by FERC in its Study Plan Determination (SPD) letter dated March 13, 2019.

In accordance with 18 C.F.R. § 5.15(c), Boott filed their Initial Study Report (ISR) with FERC on February 25, 2020. As described in the ISR, data analyses were in progress and scheduled for completion during 2020. On June 12, 2020 FERC issued a Revised Process Plan and Schedule and Determination on Requests for Study Modifications for the Lowell Hydroelectric Project (Revised PPS). In accordance with the Revised PPS, Boott filed their Revised ISR with FERC on September 30, 2020, which contained a full report for the Juvenile Alosine Downstream Passage Assessment. Boott held a revised ISR meeting on October 15, 2020 and representatives from FERC, U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Massachusetts Division of Fisheries and Wildlife (MADFW), Massachusetts Division of Marine Fisheries (MDMF), and the New Hampshire Fish and Game Department (NHFGD) had the opportunity to provide comments. Subsequent to the September 30, 2020 ISR meeting, the MADFW (November 25, 2020), NMFS (November 30, 2020), and MDMF (November 30, 2020) submitted written comments on the ISR to FERC. A summary of comments received and the corresponding responses is provided in Appendix D of this report. Where noted, the body of the report has been updated to reflect the content of those comments.

This final technical report provides a description of the objectives, methodologies and results of the 2019 radio-telemetry assessment to evaluate the effect of operations on downstream migrating juvenile alosines at the Lowell Project.

2 Objectives

The goal of this study was to determine the Lowell Project's impact on the outmigration of juvenile alosines.

Specific objectives included:

- Assess the effects of the Project on the timing, orientation, passage routes, and migration rates of juvenile alosines.
- Determine the proportion of juvenile alosines that select the Pawtucket Canal versus the E.L. Field Powerhouse, downstream bypass facility, or dam spill as a downstream passage route, under varied operational conditions.

- Determine if there are any delays associated with downstream movement related to either dam spill or the E.L. Field Powerhouse due to operations.

3 Project Description and Study Area

The Lowell Project is located at River Mile (RM) 41 on the Merrimack River in the City of Lowell in Middlesex County, Massachusetts, with an impoundment extending approximately 23 miles upstream into Hillsborough County, New Hampshire. The existing Lowell Project consists of: (1) a 1,093-foot-long, 15-foot-high masonry gravity dam (Pawtucket dam) that includes a 982.5-foot-long spillway with a crest elevation of 87.2 feet National Geodetic Vertical Datum 1929 (NGVD 29) topped by 5-foot-high pneumatically-operated crest gates deployed in five independently-operable zones; (2) a 720-acre impoundment with a normal maximum water surface elevation of 92.2 feet NGVD 29; (3) a 5.5-mile-long canal system which includes several small dams and gatehouses; (4) a powerhouse (E.L. Field) which uses water from the Northern Canal and contains two turbine-generator units with a total installed capacity of 15.0 megawatts (MW); (5) a 440-foot-long tailrace channel; (6) four powerhouses (Assets, Bridge Street, Hamilton, and John Street) housed in nineteenth century mill buildings along the Northern and Pawtucket Canal System containing 15 turbine-generator units with a total installed capacity of approximately 5.1 MW; (7) a 4.5-mile long, 13.8-kilovolt transmission line connecting the powerhouses to the regional distribution grid; (8) upstream and downstream fish passage facilities including a fish elevator and downstream fish bypass at the E.L. Field powerhouse, and a vertical-slot fish ladder at the Pawtucket dam; and (9) appurtenant facilities. At the normal pond elevation of 92.2 feet NGVD 1929 (crest of the pneumatic flashboards), the surface area of the impoundment encompasses an area of approximately 720 acres. The gross storage capacity between the normal surface elevation of 92.2 feet and the minimum pond level of 87.2 feet is approximately 3,600 acre-feet. The Project operates essentially in a run-of-river (ROR) mode using automatic pond level control, and has no usable storage capacity.

The study area for the juvenile alosine passage assessment included the section of the Merrimack River from the point approximately 1.0 mile upstream of the Pawtucket Gatehouse to a point approximately 2.1 miles downstream from the E.L. Field Powerhouse tailrace (Figure 3-1). The Upper Pawtucket Canal and Guard Locks facility were also considered as part of the study area.

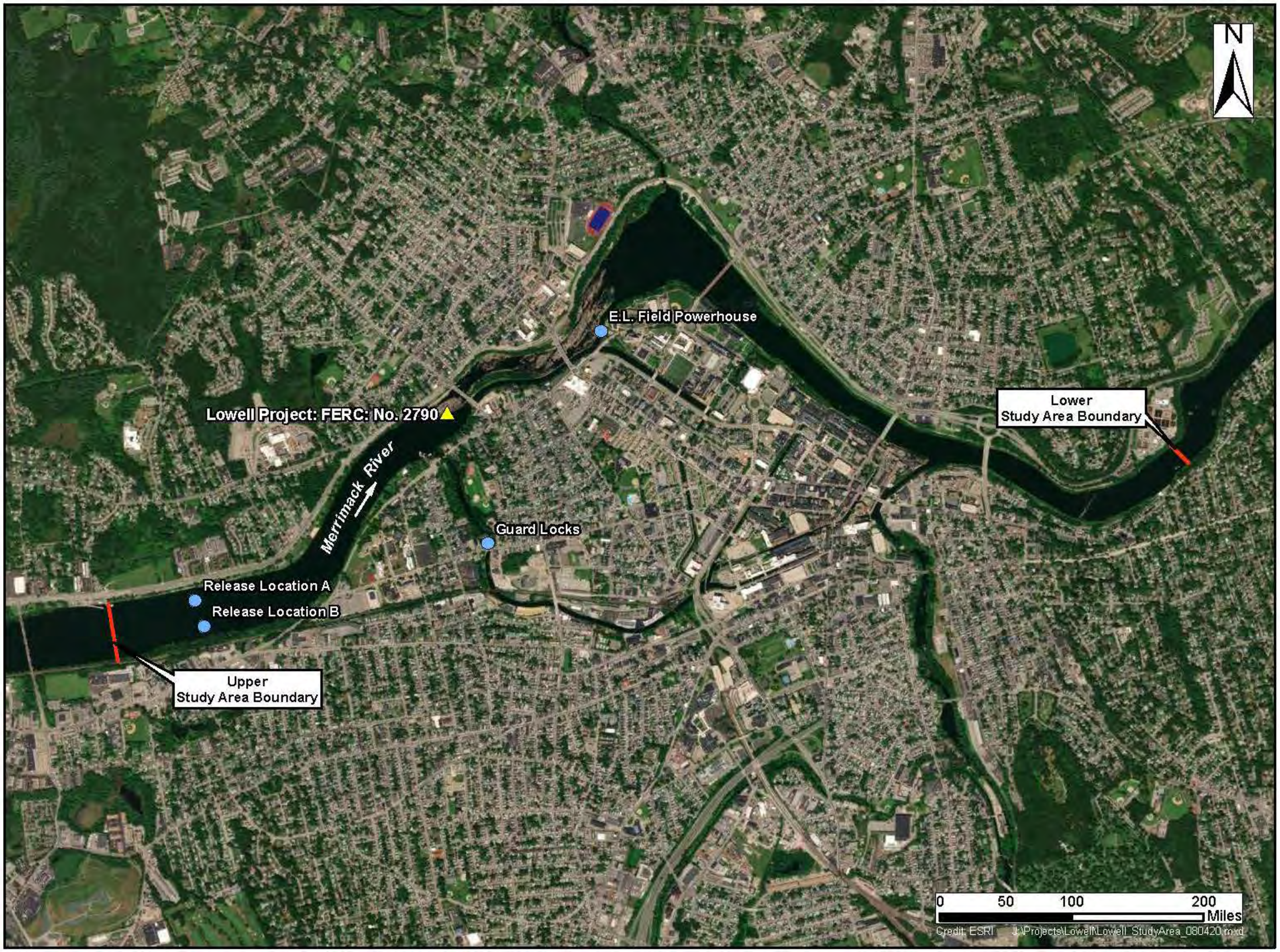

Figure 3–1. Merrimack River study reach considered during the fall 2019 juvenile alosine downstream passage assessment.

4 Methods

Downstream passage of juvenile alosines through the Lowell Project reach was evaluated using radio-telemetry during the fall of 2019. Following the release of radio-tagged individuals into the Lowell impoundment at a point approximately 1.0 miles upstream of the Pawtucket Gatehouse, downstream movements were monitored using a series of stationary radio-telemetry receivers in place at the Project as well as stationary monitoring stations installed at bank-side locations upstream and downstream of the Project to inform on general movements, distribution among available passage routes and continued downstream travel.

4.1 Radio Telemetry Equipment

Movements of radio-tagged individuals during the 2019 study were recorded via a series of stationary radio-telemetry receivers. Radio-telemetry equipment used during the evaluation of downstream passage at Lowell included Orion receivers, manufactured by Sigma Eight, as well as SRX receivers manufactured by Lotek Wireless. Each receiver was paired with either an aerial or underwater antenna (dropper antenna). Aerial antennas (four or six element Yagi) were utilized to detect radio-tagged individuals within the larger, more open sections of river, such as within the tailrace or at locations downriver of Lowell. Dropper antennas were fixed at downstream passage locations (e.g., downstream bypass).

Juvenile alosines radio-tagged during 2019 were equipped with a Lotek NTF-1-1 transmitter. The NTF-1-1 transmitters measured approximately 5 x 3 x 9.6 mm, weighed 0.24 grams and had an estimated battery life of 13 days when set at a 2.0 second burst rate. Each transmitter was coded to emit a unique identifying signal so that individual juvenile alosines could be identified by any given receiver.

4.2 Monitoring Stations

The RSP identified a total of ten monitoring stations to be set up at Lowell for the downstream juvenile alosine passage assessment. Each of the ten monitoring locations identified in the RSP were installed as described and each location consisted of a data-logging receiver, antenna, power source, and were configured to receive transmitter signals from a designated area continuously throughout the study period. During installation of each station, range testing was conducted to configure the antennas and receivers in a manner which maximized detection efficiencies at each location. The operation of the radio telemetry receivers was initially established during installation, then confirmed throughout the study period by using beacon tags. A number of beacon tags were stationed at strategic locations within the detection range of either multiple or single antennas, and they emitted signals at programmed time intervals. These signals were detected and logged by the receivers and used to record the functionality of the system throughout the study period.

The locations of monitoring stations installed for the 2019 juvenile alosine passage evaluation at Lowell are outlined here and presented in Figures 4-1 through 4-3.

Monitoring Station 20: This station was installed at a location downstream of the release location and upstream of Pawtucket Dam and was intended to detect radio-tagged juvenile alosines following their initial downstream movement away from the release location. Station 20 consisted of a single Lotek SRX receiver and an aerial antenna oriented perpendicular to the river channel and was located at a point approximately 0.6 miles upstream of the Pawtucket Gatehouse.

Monitoring Station 21: This station consisted of a single Lotek SRX radio-receiver and an aerial antenna located at the Project compressor building. Station 21 was installed and calibrated to provide information on radio-tagged juvenile alosines as they approached the upstream face of Pawtucket Dam. Detections at this location were used to inform on the arrival of radio-tagged juveniles at the Project.

Monitoring Station 24: Monitoring Station 24 consisted of a Lotek SRX radio-receiver and an aerial antenna installed to detect radio-tagged juvenile alosines which had entered the Pawtucket Canal system. The entrance to the Pawtucket Canal sits at a point upstream of the Pawtucket Dam and the Northern Canal. Station 24 was located at the Guard Locks, approximately 1,700 feet downstream from the entrance to the canal. The monitoring zone for Station 24 was focused downstream of the Guard Locks facility to ensure any detections recorded at that location were of fish which had definitively entered the downtown canal system.

Monitoring Station 26: Station 26 consisted of a single Orion radio-receiver and aerial antenna installed and calibrated to provide coverage of the upstream side of the Pawtucket Gatehouse. This station informed on radio-tagged juvenile alosines which had approached the upstream side of the Pawtucket Gatehouse.

Monitoring Station 28: Station 28 consisted of a single Lotek radio-receiver and aerial antenna installed and calibrated to provide coverage of the downstream side of the Pawtucket Gatehouse. This station informed on radio-tagged juvenile alosines which had successfully passed through the Pawtucket Gatehouse and entered the Northern Canal.

Monitoring Station 30: Station 30 consisted of a single Lotek SRX radio-receiver and aerial antenna installed and calibrated to provide detection information for radio-tagged juvenile alosines that passed through the Pawtucket Gatehouse, entered the E.L. Field Powerhouse forebay (i.e., the downstream potion of the Northern Canal) and were in the vicinity of the entrance to the downstream bypass and intake racks.

Monitoring Station 32: This station consisted of a single Orion radio-receiver and underwater drop antenna installed and calibrated to provide detection information for radio-tagged juvenile alosines exiting the forebay via the downstream bypass.

Monitoring Station 34: Station 34 consisted of a single Lotek SRX radio-receiver and aerial antenna installed and calibrated to scan across the bypassed reach at a point downstream of where the surge gate enters from the power canal and upstream from the downstream bypass.

Detections at this location confirmed downstream passage of juvenile alosines using the spillway or surge gate.

Monitoring Station 36: This station consisted of a single Lotek radio-receiver and aerial antenna installed at a location overlooking the project tailrace. Detections at this location were used to confirm the downstream passage of radio-tagged juvenile alosines via the E.L. Field powerhouse turbine units.

Monitoring Station 38: This station was installed at a point along the mainstem of the Merrimack River downstream of both the E.L. Field Powerhouse tailrace and the confluence with the Concord River. Station 38 consisted of a single Lotek SRX receiver and aerial antenna oriented perpendicular to the river channel and was installed at the Lowell Waste Water Treatment Plant, approximately 2.1 miles downstream of the tailrace.

4.3 Tagging and Release Procedures

Juvenile alosines were collected by boat electrofishing from Turtletown Pond in Concord, NH. Following collection, juvenile alosines were transported by tank truck to a temporary holding facility at the Garvins Falls Dam on the Merrimack River, Bow, NH. Once transferred to the holding tanks, collected juvenile alosines were allowed to acclimate for a minimum of 24 hours prior to tagging in order to observe for any latent post capture mortality.

NTF-1-1 transmitters were attached to a dry fly hook using bonding cement. The hook was inserted posterior to the dorsal fin with the majority of the tag and antenna trailing behind the insertion point (Figure 4-4). After tagging, fish were held in holding containers and maintained in ambient Merrimack River water until they were transported to the release site. As part of the 2019 passage route evaluation, a total of 10 separate release groups, each comprising up to 15 tagged and 15 untagged juvenile alosines, were released. Each release group was separated into two holding containers, each consisting of 7-8 tagged and 7-8 untagged juvenile alosines resulting in a total of 15 fish per container. Tagged juvenile alosines driven to the Rourke Brothers Boat Ramp in Lowell, MA and were then transported by boat to a location approximately 1.0 miles upstream of the Pawtucket Gatehouse. During each release event, the two holding containers were lowered over the side of the boat and the tagged and untagged juvenile alosines were allowed to volitionally exit the container. On each release date the total number of individuals placed in the river were split over two separate release points, one in the eastern third of the river and the other in the western third of the river. The date, time, and release location of each group of tagged alosines was recorded.

4.4 Data Collection

4.4.1 Stationary Telemetry Data

Receiver downloads occurred three to four times weekly during the period from the initial tag and release event until November 12, 2019 (i.e., six days beyond the anticipated battery life for radio-transmitters used for the final test fish release group (October 24, 2019)). Backup copies of all telemetry data were made prior to receiver initialization. Field tests at the time of download to ensure data integrity and receiver performance included confirmation of file integrity, confirmation that the last record was consistent with the downloaded data (beacon tags were critical to this step), and lastly, confirmation that the receiver was operational upon restart and actively collecting data post download. Within a data file, transmitter detections were stored as a single event (i.e., single data line). Each event included the date and time of detection, frequency, ID code, and signal strength.

4.4.2 Manual Telemetry Data

To provide supplemental detection information to the stationary receiver data set, manual tracking was conducted on a number of occasions from the time of initial release through mid-November, 2019. Manual effort was exerted in the vicinity of the Lowell Project (i.e., tailrace and headpond immediately upstream of Pawtucket Dam) on most dates when stationary telemetry equipment was checked. In addition, a number of boat or truck-based efforts were conducted to look for radio-tagged individuals within the lower Lowell impoundment and the reach of the Merrimack downstream to Lawrence.

4.4.3 Operational and Environmental Data

Merrimack River water temperature was recorded via a continuously operating logger installed within the Lowell intake canal. Hourly records for operations data were provided by Boott for the 2019 evaluation period and included:

- Headpond elevation (ft);
- Power canal elevation (ft);
- Headpond-power canal differential (ft);
- Tailrace elevation (ft);
- Head differential for E.L. Field turbines (ft);
- Total inflow (cfs);
- Unit 1 discharge (cfs) and output (KW);
- Unit 2 discharge (cfs) and output (KW);
- Downstream bypass discharge (cfs);
- Upstream fishway discharge (cfs);
- Downtown canal flow (cfs); and
- Spill flow through the bypassed reach (cfs).

4.5 Data Analysis

The tagging, telemetry and Project operations data sets collected as part of this effort were examined and used to evaluate a number of metrics related to downstream passage success and movement through the Project area.

4.5.1 Downstream Movement and Passage Route Selection

A complete record of all valid stationary receiver detections for each radio-tagged juvenile alosines was generated. The pattern and timing of detections in these individual records were reviewed, and a route of passage as well as project arrival and passage times were assigned to each radio-tagged individual. In the instance that a downstream route could not be clearly determined from the collected data, the passage event for that particular fish was classified as 'unknown'.

Where data were available, project residence times were calculated. Upstream residence duration was defined as the duration of time from the initial detection at Station 21 until the determined time of downstream passage. Time spent immediately upstream of the dam was further evaluated using initial detection times for radio-tagged juvenile alosines at Monitoring Stations 26 and 28 to provide an understanding of passage times associated with moving through the Pawtucket Gatehouse and entering into the Northern Canal approach to the E.L. Field powerhouse (i.e. "Pawtucket Gatehouse Passage"). Power canal residency was evaluated using the initial detection at Station 28 and the time of downstream passage to provide an understanding of the time spent within the Northern Canal prior to passage route selection (i.e. "Northern Canal Residence").

4.5.2 Time to Event Analysis

4.5.2.1 Cox Proportional Hazard Model

Utilizing available methodology for quantifying fish passage performance (Castro-Santos and Perry 2012), multi-variate Cox proportional hazard models were developed to assess the impact of various operational and environmental variables on the rate of passage success. Operational and environmental variables considered as part of this analysis included:

- Merrimack River water temperature (^{o}C);
- Head differential (ft) at the Pawtucket Gatehouse (i.e., headpond vs. Northern Canal);
- Bypassed reach spill flow (cfs);
- E.L. Field turbine discharge (cfs);
- Merrimack River inflow (cfs); and
- E.L. Field head differential (ft) (i.e., Northern Canal vs. tailwater).

Although additional variables such as turbine operation at E.L. Field (i.e., Unit 1, Unit 2, both, or neither) and head pond elevation (ft) were available, there was not enough resolution in the data during the fall 2019 passage period to provide meaningful results. This assessment on the rate of passage success focused on approach events at (1) the Pawtucket Gatehouse (i.e., Station 25), and (2) at the E.L. Field Powerhouse (i.e., Station 29).

Regression models for the time to event analyses were constructed using the *coxph*() function from the package "*survival*" in R (R Core Team 2020) and were used to evaluate the rate of passage success and identify operational hazards at sites which contained a physical barrier or a structure through which tagged individuals would have to navigate (i.e., the Pawtucket Gatehouse and E.L. Field Powerhouse).

The Cox proportional hazard regression can be described as a hazard function to evaluate the proportionate risk at time (t) such that

$$h(t) = h_0(t) \times exp(b_1x_1 + b_2x_2 + \ldots + b_ix_i)$$

where $h(t)$ represents that hazard at a given time point which is equal to the initial or baseline hazard at time 0:00 ($h_0(t)$) multiplied by e (the base of the natural logarithm) to the power of the additive relationship between each covariate (x_i) multiplied by its associated coefficient (b_i).

From the above equation, the relative impact of an operational parameter on the rate of passage success is represented by its associated coefficient. The hazard ratio of a given operational parameter is calculated by exponentiating the coefficient of a given parameter, which represents that multiplicative impact of that parameter. It is important to note that exponentiating these coefficients makes the value relative to a value of 1 (e^0), which represents a baseline of no hazard. For example, if the hazard ratio is greater than 1, e.g., 1.5, that will be interpreted as that covariate increasing the risk of passage failure by a factor of 1.5. Alternatively stated, a hazard ratio of 1.5 indicates that the associated covariate increases the risk by 50% as it is 0.5 greater than 1. In contrast, a hazard ratio below 1, e.g., 0.75, indicates that the associated covariate reduces the risk of passage failure by a factor of 0.75, or 25%. In short, a hazard ratio >1 indicates an increase in the risk of passage failure, a hazard ratio of 1 indicates no significant directional effect on passage, and a hazard ratio <1 indicates a reduction in the risk of passage failure.

4.5.2.2 Model Evaluation and Selection

As is the case with any statistical model, the type of model selected makes inherent assumptions about the nature of the data being modelled. The primary assumption of a Cox proportional hazard model is that the hazards are proportional. However, this assumption is not always appropriate for the data. As a result, the *cox.zph()* function was used during this assessment to assess the validity of the proportional hazard assumption. This function assessed scaled Schoenfield residuals to evaluate whether Cox regression residuals of each covariate in addition to the model as a whole are independent of time. In the event that the Schoenfield residuals are not independent of time, it can be said that the assumption of proportional hazards is violated and a Cox proportional hazards model may be misrepresentative of the true relationships between the selected covariates and passage success.

4.5.2.3 Event Definition

To evaluate the impact of operational parameters on passage success, instances of passage success and failure required definition and represent the ‘events’ (or passage attempts) in this analysis. Ostensibly, the transmitters deployed during this study should transmit a signal that when within range of a particular receiver will be detected every 2.0 seconds. However, various sources of outside noise or areas of poor coverage due to structures, etc. introduce variation into the frequency of detection for a unique transmitter’s signal. Given that different site locations and receiver types are subject to varying degrees of ambient noise, the duration between successive detections was calculated for each tagged individual at each receiver location. A threshold interval for determining continued presence of a transmitter within the detection zone of a specific receiver was identified as the 95th percentile of the observed set of interval durations. This value was calculated at 14.5 minutes for Station 26 and 25.2 seconds for Station 30. These two threshold values were then used to delineate when each event was started and completed for a tagged individual. The lengthier threshold value at Station 26 was likely a function of multiple entrances and exits of radio-tagged juveniles from the relatively limited detection zone (receiver was adjusted to only provide coverage in area immediately upstream of the Pawtucket Gatehouse). The departure of a radio-tagged individual from the detection zone of a particular receiver was determined when the time interval between successive detections exceeded the specific threshold interval for that zone.

From this, a passage failure event (assigned a value of 0) was defined as any duration where all detections lay within the 95th percentile of durations for all individuals at that site. Passage failure represents events in which a tagged individual enters the field of detection at a given site without passing to the next site (i.e., moving downstream) in the system. A passage success event (assigned a status of 1) was defined using the final instance of detection for a tagged individual at a singular site where that tagged individual was next detected at a downstream receiver (i.e., successfully passed). Passage success/failure (1/0) was used as the status coinciding with time in the Cox proportional hazard models. After defining passage events for every individual, the time duration for the regression was defined as the duration from one event to the next.

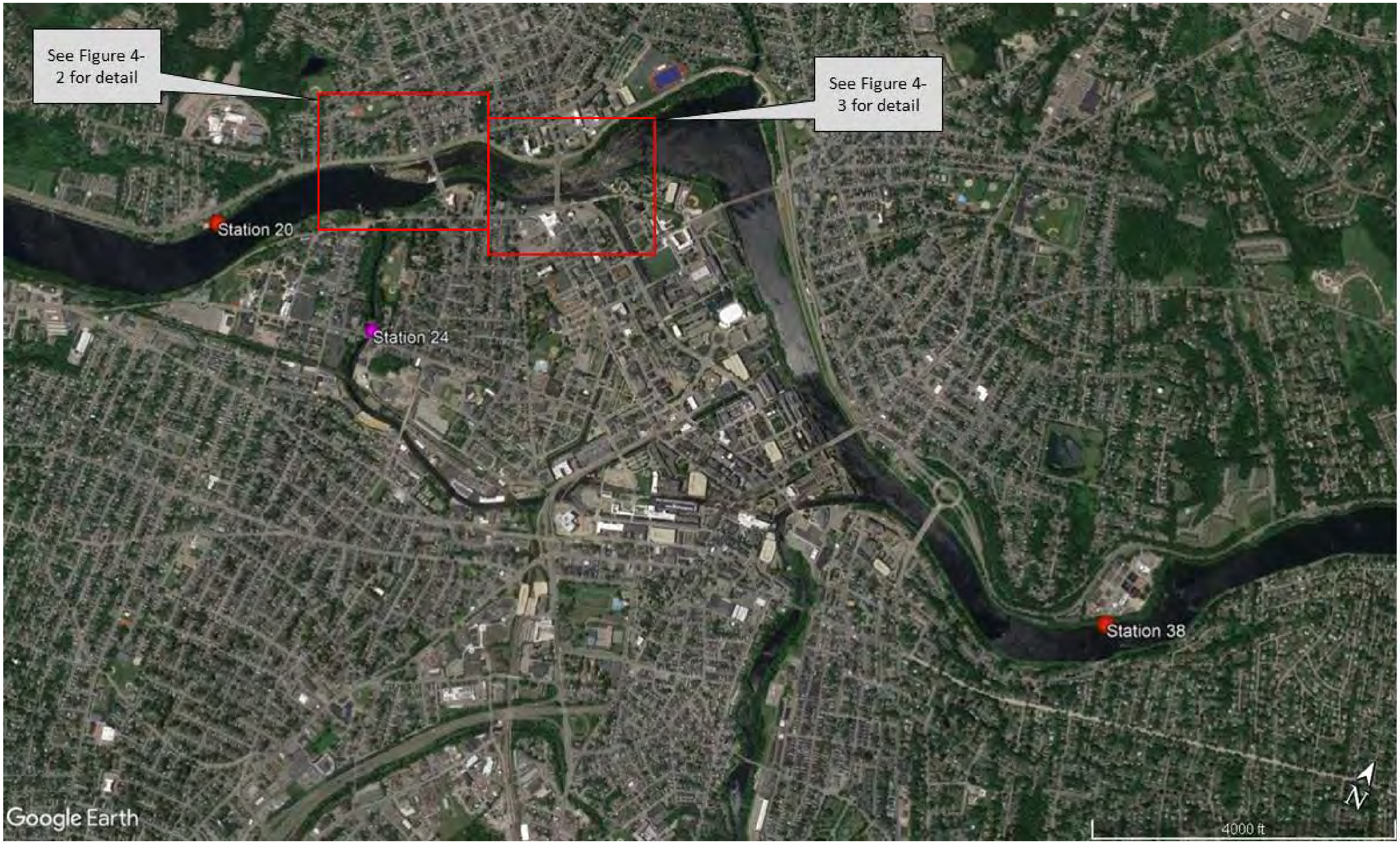

Figure 4–1. Locations and approximate detection areas for stationary radio-telemetry receivers installed during the 2019 juvenile alosine downstream passage assessment.

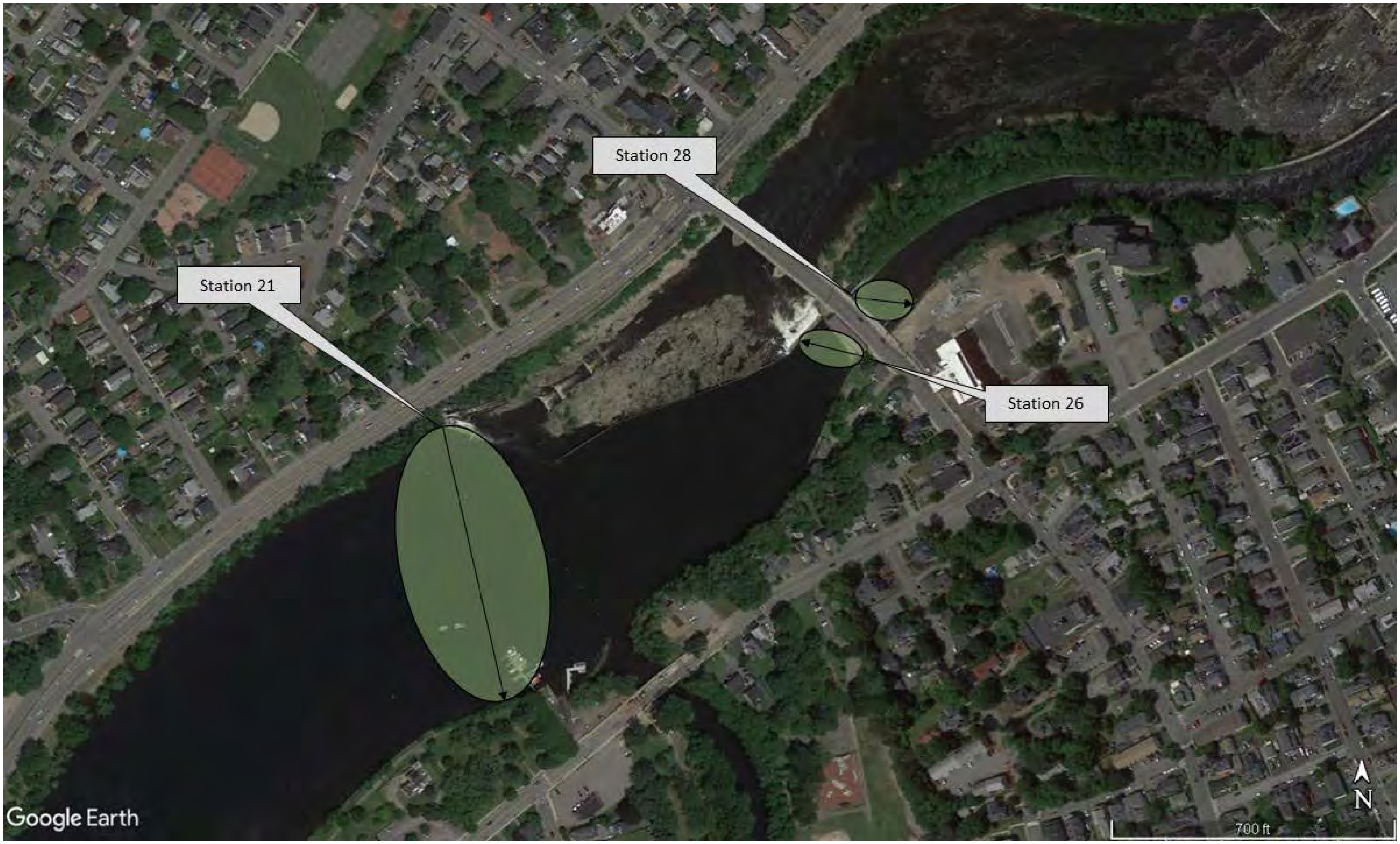

Figure 4–2. Locations and approximate detection areas for stationary radio-telemetry receivers installed upstream of Pawtucket Dam and at the Northern Gatehouse during the 2019 juvenile alosine downstream passage assessment at Lowell.

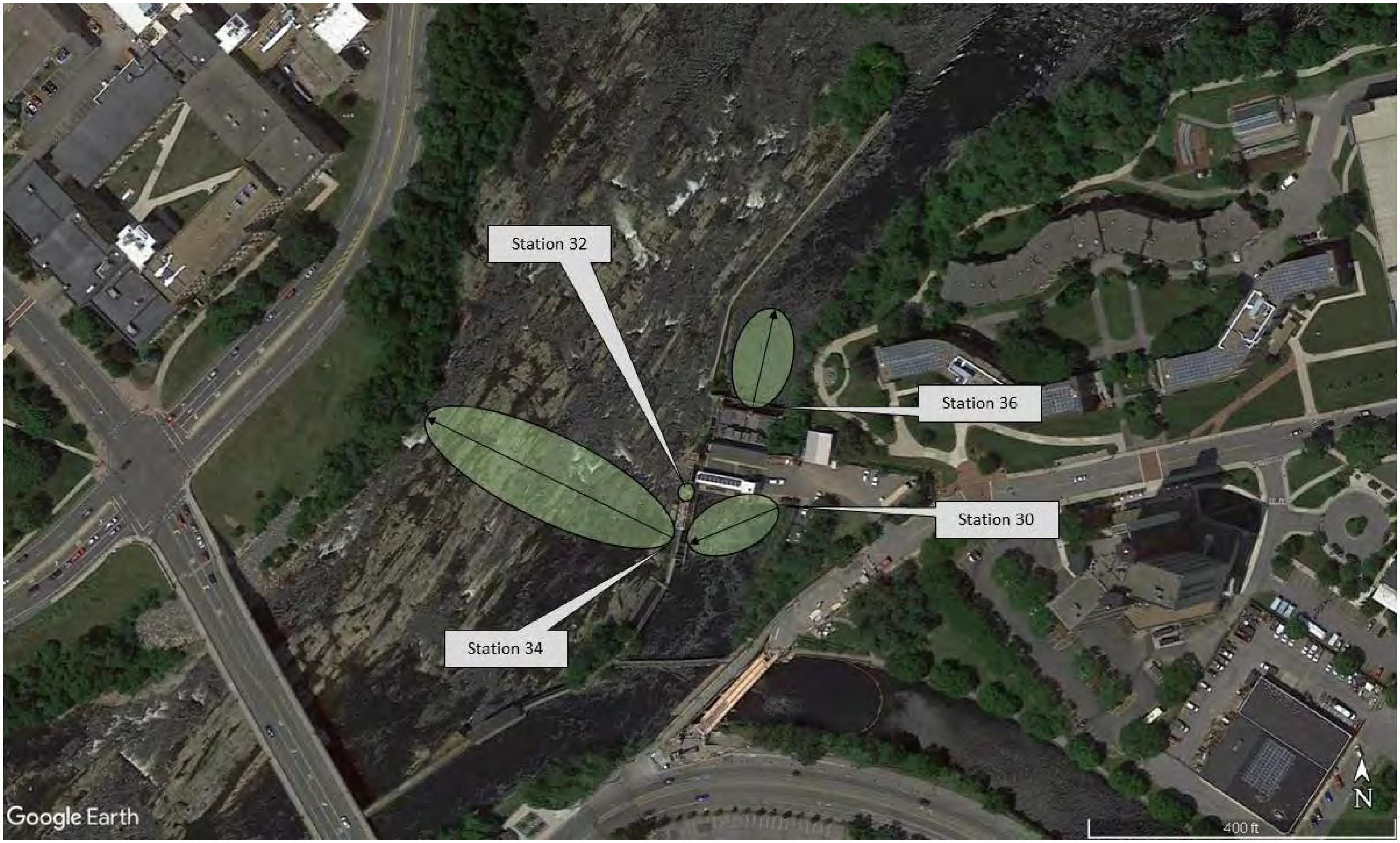

Figure 4–3. Locations and approximate detection areas for stationary radio-telemetry receivers installed in the vicinity of the E.L. Field Powerhouse during the 2019 juvenile alosine downstream passage assessment at Lowell.

Figure 4–4. Externally radio-tagged juvenile alosine showing relative position of transmitter attachment.

5 Results

5.1 Merrimack River Conditions and Lowell Project Operations

Figure 5-1 presents the Merrimack River flow and water temperature for the period of time from the first alosine release on October 9 until the end of the monitoring period on November 12, 2019. Merrimack River water temperature at the Project ranged from 16°C to 6°C during the monitoring period. Total river flow values represent the reported inflow at the Lowell Project and ranged between 1,089 and 11,435 cfs during the fall monitoring period. Figure 5-2 presents the monthly flow duration curves prepared for Lowell during the development of the Preliminary Application Document. The median flow condition at the Project is approximately 3,600 cfs during October and 6,500 cfs during November. Merrimack River conditions have a ~20% probability during October and a ~38% probability during November to exceed the ~8,000 cfs capacity of the E.L. Field powerhouse.

Table 5-1 summarizes the percentage of inflow records from the 2019 study period categorized by volume (to the nearest 1,000 cfs) as well as the percentage of time that each volume category is historically exceeded[1]. To help characterize the 2019 passage season, monthly exceedance probabilities less than 0.35 were classified as "high" flow conditions, 0.35 to 0.65 were classified as "normal" flow conditions, and greater than 0.65 were classified as "low" flow conditions. Inflows at the Project for the period October 9 through 31 were representative of high flow conditions (i.e., those with a probability of exceedance of less than 0.35) for 35% of the period, normal flow conditions (i.e., those with a probability of exceedance of 0.35-0.65) for 29% of the time and low flow conditions (i.e., those with a probability of exceedance of greater than 0.65) for 36% of the time. For the month of November, inflows were representative of high flow conditions 19% of the time, normal flow conditions 30% of the time and low flow conditions 51% of the time.

Flow duration information for the months of October and November (combined) is presented in Figure 5-3. The median flow condition during the two month period is near 5,000 cfs. When characterized using the flow condition criteria above, inflows at the Project for the period October 9 through November 12 were representative of high flow conditions (i.e., those with a probability of exceedance of less than 0.35) for 14% of the period, normal flow conditions (i.e., those with a probability of exceedance of 0.35-0.65) for 59% of the time and low flow conditions (i.e., those with a probability of exceedance of greater than 0.65) for 27% of the time (Table 5-1).

Figure 5-4 summarizes the allocation of water among the E.L. Field powerhouse, bypassed reach, downstream fishway, and downtown canal system at Lowell. Turbine units were in operation at the E.L. Field powerhouse for the duration of the study period with Unit 1 in operation throughout the study and Unit 2 coming online at 0900 on October 16. The

[1] Estimates of monthly exceedance estimated from monthly flow duration curves provided in Appendix H of the PAD.

downstream bypass was operated throughout the study period, passing approximately 132 cfs (i.e., 2% of the nameplate capacity of the E.L. Field turbine units; 6,600 cfs). A major spill event, associated with increases in river flows, occurred during the monitoring period. The event occurred from approximately October 29 to November 5, towards the end of the monitoring period. Flows to the downstream canal system represented between 15-20% of the 2,000 cfs canal capacity during October and 20% of the 2,000 cfs canal capacity for the majority of monitoring during early November. Due to overriding safety concerns, Boott limited operation of the turbine units within the downtown canal system during the study period. To the extent possible, Boott's operations staff attempted to operate the canal system as if there were canal units available, by opening gates when river flows exceeded the hydraulic capacity of the E.L. Field turbines (7,000 to 8,000 cfs). As a result, flows through the downtown canal system were largely restricted to passage via open gates. The Licensee manually recorded gate and unit settings once weekly during the study period within the downtown canal system. A breakdown of those values and related discharge estimates are provided in Appendix A.

Table 5–1. Frequency of occurrence of river inflow at Lowell (to nearest 1,000 cfs) during 2019 juvenile alosine downstream passage assessment and corresponding percentage of time flows are historically exceeded.

River Flow (Nearest 1k)	October 9-30, 2019		November 1-12, 2019		Oct 9 - Nov 30, 2019	
	Percentage of Month	Percentage of Month Historically Exceeded	Percentage of Month	Percentage of Month Historically Exceeded	Percentage of Period	Percentage of Period Historically Exceeded
1000	16.1%	90	-	> 95	10.6%	>95
2000	19.4%	85	-	> 95	12.7%	90
3000	6.0%	60	-	88	3.9%	76
4000	22.6%	45	14.5%	78	19.9%	63
5000	12.7%	34	36.6%	66	20.8%	50
6000	9.4%	27	11.1%	55	10.0%	42
7000	6.2%	23	12.8%	45	8.4%	35
8000	4.2%	19	6.6%	38	5.0%	29
9000	3.1%	16	4.8%	30	3.7%	24
10000	0.4%	14	3.5%	25	1.4%	21
11000	-	<5	10.4%	5	3.6%	5

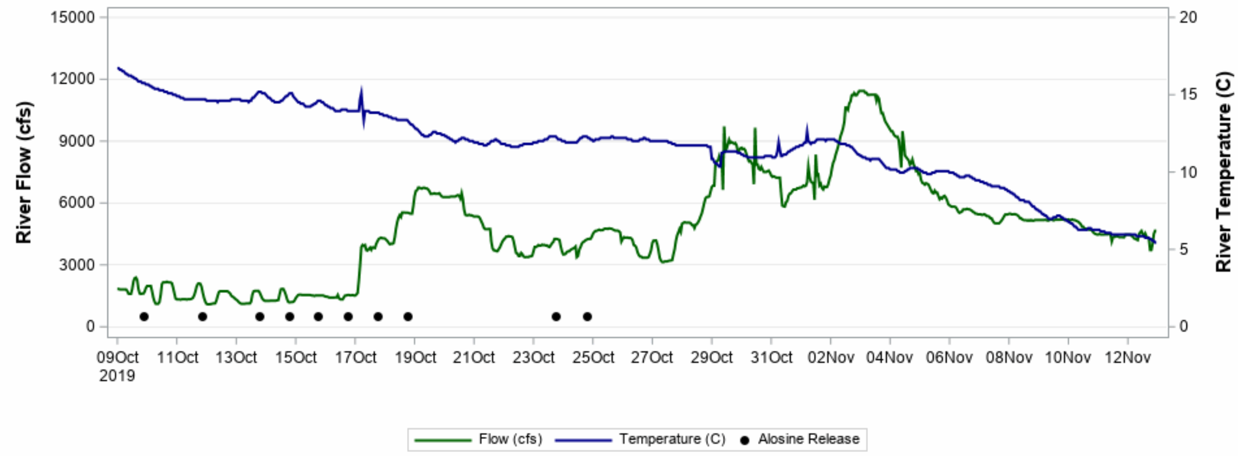

Figure 5–1. Merrimack River flow and water temperature at Lowell for the period October 9 to November 12, 2019.

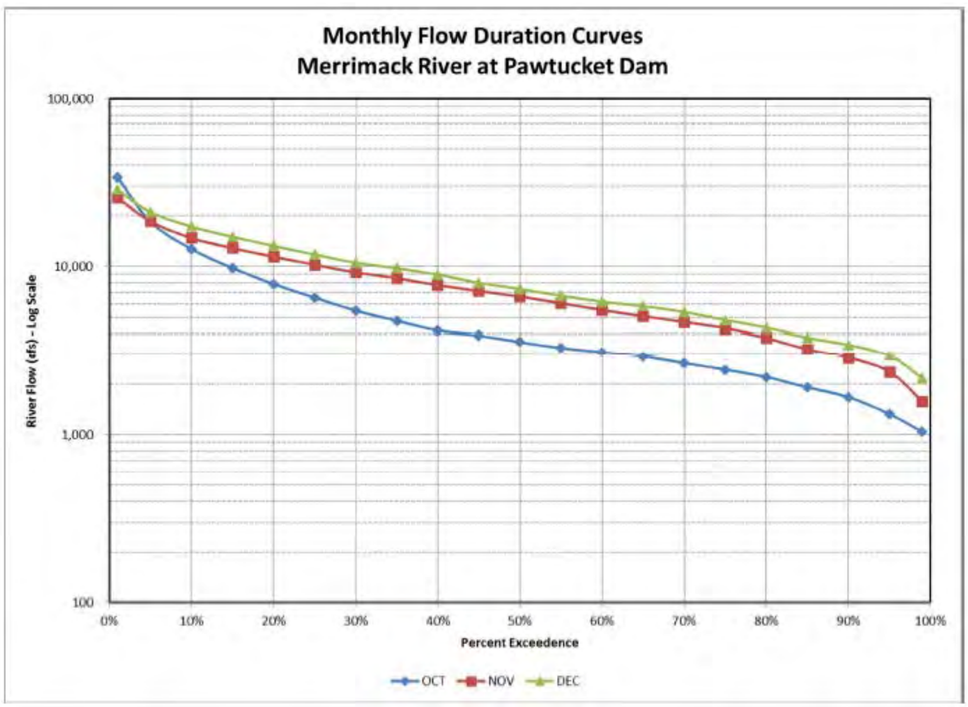

Figure 5–2. Flow duration curves for the months of October, November and December at the Lowell hydroelectric project.

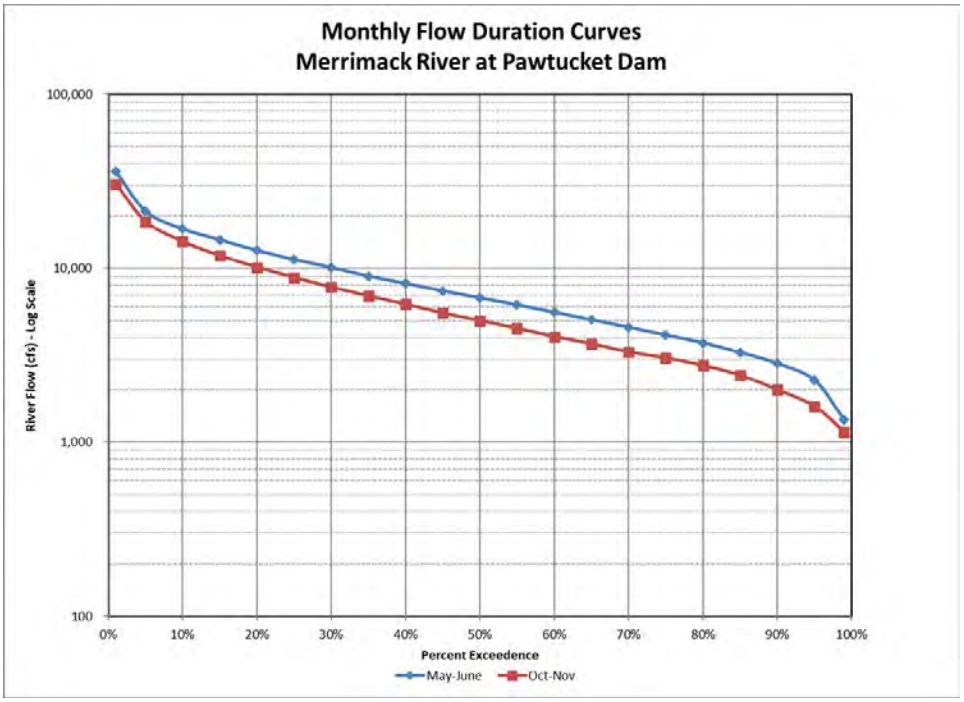

Figure 5–3. Flow duration curves for the two month period of October-November at the Lowell hydroelectric project.

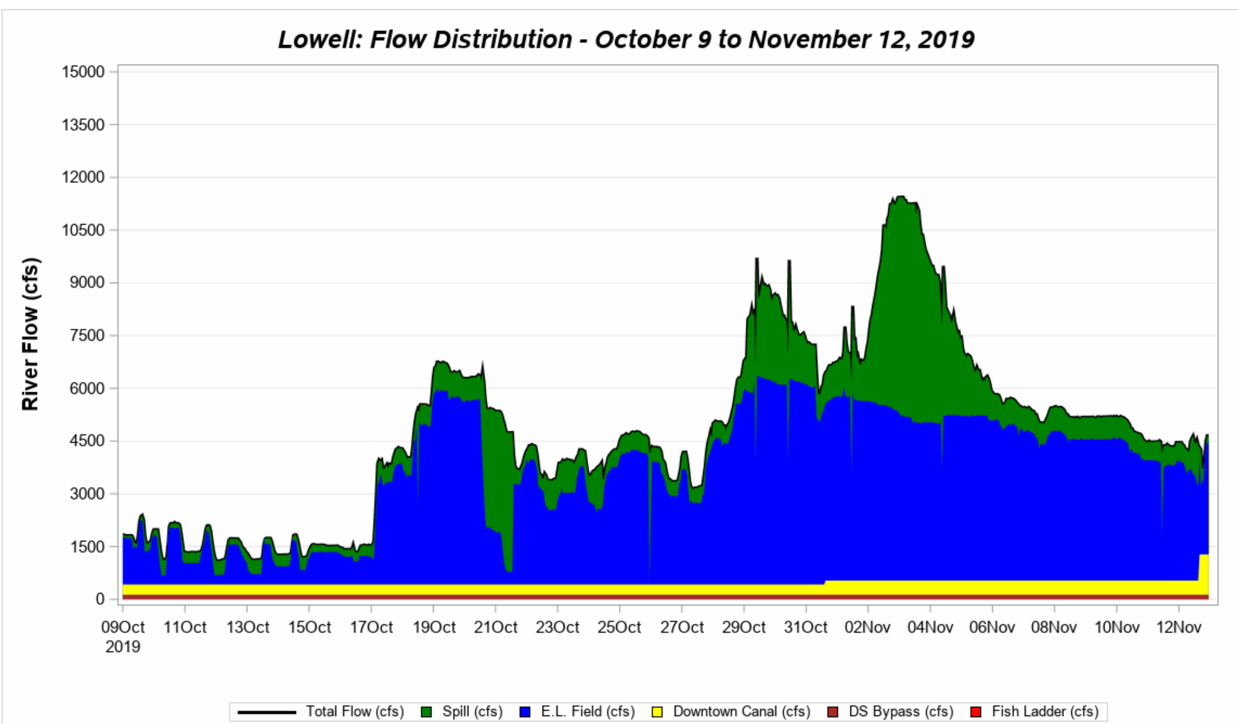

Figure 5–4. Total, spill, E.L. Field, downstream bypass and downstream canal system flow (cfs) for the period October 9 to November 12, 2019.

5.2 Monitoring Station Functionality

Radio-tagged juvenile alosines were released into the Merrimack River beginning in early October, 2019 and the RSP called for continuous monitoring at each stationary receiver location for 14 days after the final release of tagged fish. Figure 5-5 provides an overview of the continuity of monitoring at each of the ten stationary receiver locations during the fall period from the date of first release until November 12, 2019. The majority of the radio-telemetry monitoring stations installed to evaluate passage at Lowell during the fall study operated without issue for the full period.

Interruptions in continuous coverage were observed at two locations during the latter part of the 2019 monitoring period. These locations included Station 28 (downstream side of the Pawtucket Gatehouse) from 1900 on November 9 through the end of the monitoring period at Station 38 (receiver downstream of Lowell) from 0000 on November 5 to 1300 on November 7. There were no radio-tagged juvenile alosines which approached the Pawtucket Gatehouse after October 25 nor any downstream passage events for radio-tagged individuals after October 31. The late-season timing of these relatively short interruptions in coverage likely eliminated any potential impacts to the study results for monitoring juvenile alosine passage.

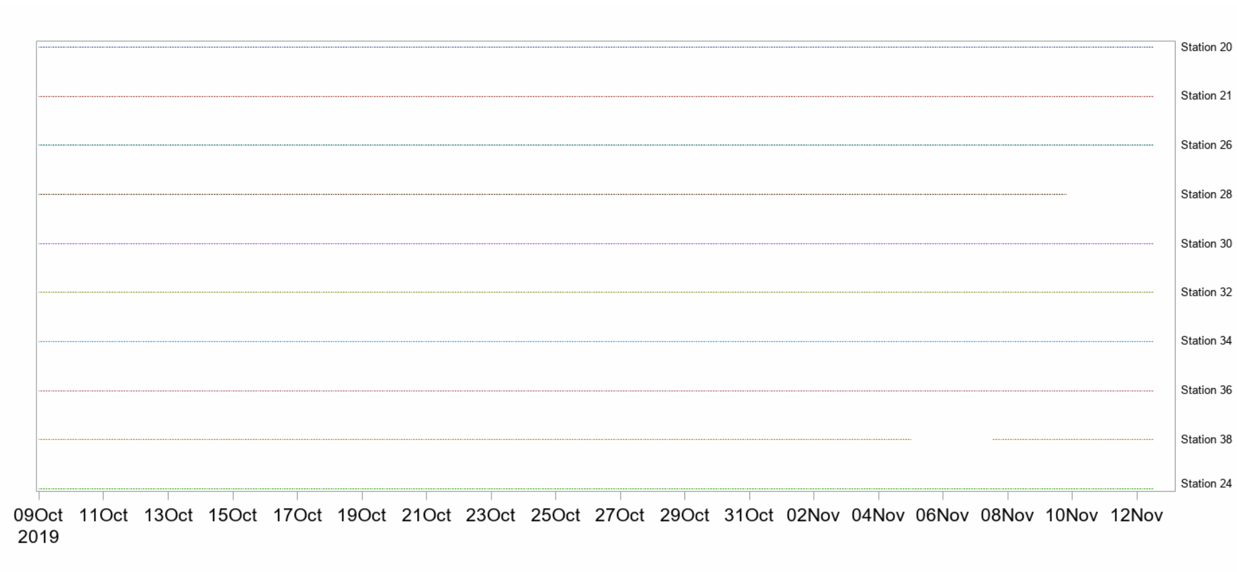

Figure 5–5. Operational coverage for telemetry receivers at Lowell during the juvenile alosine downstream passage assessment, October 9 to November 12, 2019.

5.3 Juvenile Alosine Tagging and Releases

Juvenile alosines were radio-tagged and released approximately 1.0 mile upstream of the Pawtucket Gatehouse starting on October 9 and ending on October 24. Table 5-2 provides a summary of the release dates and number of individuals released during the 2019 passage assessment. A total of 145 radio-tagged juvenile alosines were released over a span of 16 days and were potentially available for evaluation of downstream passage at Lowell. All test fish originated from Turtletown Pond in Concord, NH and were released with an equal number of untagged fish to promote schooling behavior. Fish tagged and released upstream of Lowell as part of the fall downstream passage evaluation ranged in length from 116 to 155 mm TL with a mean length of 134 mm. The majority of test fish (90%) measured between 125-144 mm. Mean length among release groups were similar across all ten release dates. A full listing of individuals radio-tagged and released as a part of this evaluation is included in Appendix B.

5.4 Project Arrival and Upstream Residence Duration

Releases of radio-tagged juvenile alosines were initiated on October 9, 2019. The distribution of arrival dates for radio-tagged alosines at the Pawtucket Dam as indicated by detection at Station 21 is provided in Figure 5-6. Initial detections for tagged alosines were recorded over a range of dates from October 9 through October 25 with all radio-tagged fish which successfully transited the approach reach doing so within a the first or second day after release.

Upstream residence (i.e., the duration of time radio-tagged individuals were present upstream of the Pawtucket Dam as determined for all individuals which approached and eventually passed downstream) was calculated as the duration of time from initial detection at Station 21 until confirmed downstream passage. When all individuals are considered, the upstream residence duration for radio-tagged juvenile alosines ranged between 0.4 hours to 4.8 days (Table 5-3; Figure 5-7). The median duration of time spent immediately upstream of the dam structure was 1.3 days, ranging from 0.8 hours to 3.6 days when examined among the ten separate release dates. Of the radio-tagged juvenile alosines which approached Pawtucket Dam, 42% passed in less than 24 hours and 68% in less than 48 hours after initial detection.

Outmigrating juvenile alosines encountering the Pawtucket Dam can (1) pass through the Pawtucket Gatehouse and enter the power canal (Northern Canal), (2) pass downstream over Pawtucket Dam via spill, or (3) enter the Pawtucket Canal and navigate downstream via the downtown canal system. The majority of radio-tagged juvenile alosines were determined to have passed through the Pawtucket Gatehouse and entered the Northern Canal to approach the E.L. Field powerhouse. The duration of time required to pass through the Pawtucket Gatehouse was evaluated as the difference in time of the initial detection for each individual radio-tagged juvenile at Stations 26 and 28 which independently monitored the upstream and downstream sides of that structure. The median duration of time for radio-tagged juvenile alosines to pass downstream of the Pawtucket Gatehouse following their approach at that structure was 0.1 hours (range <0.1 hours to 0.4 hours; Table 5-4), indicating rapid passage at that structure.

Whereas passage of radio-tagged juvenile alosines through the Pawtucket Gatehouse structure occurred relatively rapidly, the transit time for those tagged individuals to pass downstream of the Project after entering into the Northern Canal ranged from 0.2 hours up to 4.7 days (median = 22.0 hours; Table 5-5). Of those individuals, 56% were resident in the power canal upstream of E.L. Field for 24 hours or less. The overall percentage of radio-tagged juvenile alosines departing the power canal within 48 hours of entry increased to 68%.

5.5 Downstream Passage

A total of 145 radio-tagged juvenile alosines were released upstream of the Pawtucket Dam during the fall of 2019. The final disposition of all tagged juveniles is presented in Table 5-6. Three radio-tagged individuals (2% of total) did not approach the Pawtucket Dam following their initial release (as indicated by no detection at Station 21 or points further downstream). Three radio-tagged juvenile alosines (2.1% of the total approaching the dam) were determined to have entered the downtown canal system as evidenced by detection at the Guard Locks (Station 24). The majority of individual passed downstream of the Project via spill over the Pawtucket Dam (9.2%) or entered the power canal and approached the E.L. Field Powerhouse to pass downstream via the downstream bypass (12.0%) or turbine units (57.7%). A portion of individuals (18 fish; 12.7% of the total approaching the dam) failed to pass downstream. Reasons for this may include transmitter loss, predation, other mortality, or failure to locate a viable passage route. A definitive passage route could not be determined for nine individuals (6.3% of the total approaching the dam) and as a result those fish were classified as unknown.

Radio-tagged alosines were detected passing downstream between the dates of October 12 and October 31 (Figure 5-8) with a primary peak representing individuals associated with a number of release groups occurring on October 17-18. Passage events on the dates of October 17 and 18 represented 37.3% of the passage observed for radio-tagged juveniles during the study. Figure 5-9 presents the distribution of downstream passage events on an hourly basis. Passage occurred at almost all hours of the day with the highest passage rate occurring during the 1600 hour (10.7%). Overall passage was fairly uniform with 52% of detected events occurring between the hours of 1700 and 0500 and 48% between the hours of 0600 to 1600.

For each of the 115 individuals which were confirmed to have passed downstream of Lowell via a known passage route (i.e., turbine, downstream bypass, spill, or downtown canal system) the hourly record of Project operations (Section 5.1) at the time of passage was reviewed. The discharge at the selected route was identified and contrasted with the cumulative discharge for all non-selected routes at the time of downstream passage (Table 5-7). The majority of radio-tagged juvenile alosines passing downstream at Lowell did so via the E.L. Field turbine units (Table 5-6). The median discharge through the two E.L. Field turbine units at the time of passage for those individuals was 3,121 cfs. When examined by passage route, the median percentage of passage route flow at each known downstream passage route represented 79% of inflow for turbine passed juveniles, 8% of inflow for downstream bypass passed juveniles, 10% of inflow for spill passed juveniles, and 22% of inflow at the time of entry into the downtown canal system for three tagged juvenile alosines. Passage via the downstream route with the greatest proportion of flow at the time of passage occurred 65% of the time. A listing of route discharge at the time of downstream passage for each juvenile alosine is provided in Appendix E.

5.6 Downstream Transit

A single monitoring station was installed downstream of Lowell for the purpose of detecting radio-tagged juvenile alosines following passage at the Project. That receiver (Station 38) was located approximately 2.1 miles downstream of the project. The minimum, maximum, and quartile transit times through that reach are presented in Table 5-8 and Figure 5-10. The median transit time durations for tagged juvenile alosines moving downstream of Lowell was 6.2 hours (range = 1.0 hours to 1.8 days) for the 2.1 mile downstream reach.

5.7 Proportional Hazard

A total of 145 Pawtucket Gatehouse and 126 E.L. Field Powerhouse forebay events were defined based on recorded detections of juvenile alosines during the 2019 study to evaluate the impact of operational parameters on passage success. The median event duration recorded for radio-tagged juvenile alosines was 4.6 minutes for individuals in the detection field of Station 26 immediately upstream of the Pawtucket Gatehouse and 47 seconds for individuals in the detection field of Station 30 covering the area immediately upstream of the intakes to the downstream bypass and turbine units at the E.L. Field Powerhouse.

5.7.1 Pawtucket Gatehouse

The Pawtucket Gatehouse model failed to meet the criteria necessary to accept the assumption that hazards are proportional (Table 5-10). The water temperature and inflow parameters are not independent of time in this scenario ($p < 0.05$), which means these values may misrepresent the true nature of the relationships with passage success/failure. In addition, the full model also has a p-value less than 0.05, which suggests it may be misrepresenting or masking the relationships between operational variables and rate of passage for juvenile alosines at the Pawtucket Gatehouse. Although results of the Cox proportional hazard model for the Pawtucket Gatehouse are provided in Table 5-9 and illustrated in Figure 5-11, they were not evaluated due to the lack of significance for the full model.

5.7.2 E.L. Field Powerhouse

Results of the Cox proportional hazards model for E.L. Field forebay events suggest a positive relationship between water temperature and the forebay-tailrace head differential versus passage success, decreasing the probability of passage failure by 8% and 7%, respectively (Table 5-11). Despite these marginal impacts, neither water temperature nor the forebay-tailrace head differential were found to be statistically significant in this model. In order to make sure the data met the assumption of proportional hazards and ensure the use of an appropriate modelling framework, inflow and spill were maintained as continuous variables (Table 5-11). Both spill and inflow were found to be insignificant variables with no measurable impact on passage success in the forebay. The only operational variable with a statistically significant impact on the probability of passage failure to depart the E.L Field forebay was combined turbine discharge, which was split into three bins: 592-1980 cfs (i.e., low), 1980-3950 cfs (i.e., mid), and 3950-5930 cfs (i.e., high). As illustrated in Figure 5-12, the low generation condition was used as a reference for the mid and high generation conditions. Results suggest a strong, statistically significant interaction between the mid and high generation conditions in relation to passage failure from the E.L. Field forebay. Mid-levels of turbine discharge (1980 and 3950 cfs) increased the probability of passage failure from the E.L. Field forebay by 605%, while high levels of turbine discharge (3950-5930 cfs) increased the probability of passage failure from the E.L. Field forebay by 2223%. The E.L. Field forebay model achieved the criteria necessary to accept the assumption that hazards are proportional (Table 5-12).

5.8 Manual Tracking

In addition to the continuous monitoring provided by the 10 stationary receivers installed throughout the Project area for duration from early October through mid-November 2019, a total of 21 manual detections representing 13 individuals were recorded between October 21 and November 7. Manual tracking for radio-tagged juvenile alosines was most effective via foot and in the vicinity of Project structures (i.e., bypassed reach, tailrace, Northern Canal/forebay). Appendix C contains a listing of manual detections identified to those relative locations and classified as "Transit" for individuals which were subsequently detected at stationary receivers downstream of their manually determined position or "Stationary" for individuals which were not detected again at stationary receivers downstream of their manually determined position(s). The majority of detections were classified as stationary as indicated by a lack of future downstream detections. Two individuals were detected within the Northern Canal downstream of the Pawtucket Gatehouse prior to their eventual downstream passage at the Project (as determined by the stationary receiver data).

Table 5–2. Release date and number of radio-tagged juvenile alosines released upstream of the Pawtucket Dam during the downstream passage assessment, October 9 through November 12, 2019.

	Release Date									
	Oct. 9	Oct. 11	Oct. 13	Oct. 14	Oct. 15	Oct. 16	Oct. 17	Oct. 18	Oct. 23	Oct. 24
Number Released	15	15	14	15	15	15	15	15	15	11
Release Time	20:27	20:04	19:33	18:52	18:15	18:12	17:53	17:58	18:18	18:45
Minimum Length (mm)	123	123	125	125	124	123	122	123	116	126
Maximum Length (mm)	138	144	145	142	147	144	143	146	143	155
Mean Length (mm)	133	131	134	135	134	134	132	137	134	137

Table 5–3. Minimum, maximum, and quartile values of upstream residence duration (hours) for radio-tagged juvenile alosines released upstream of the Pawtucket Dam during the fall 2019 downstream passage assessment.

Release Date	Upstream Residence Duration (Hours)				
	Minimum	Maximum	Q25	Q50 (Median)	Q75
9-Oct	50.6	113.4	74.5	86.7	111.0
11-Oct	37.5	67.9	39.9	45.4	62.3
13-Oct	18.5	114.7	19.1	19.6	71.8
14-Oct	52.2	63.5	52.8	54.2	60.0
15-Oct	29.7	68.2	30.4	33.0	60.6
16-Oct	7.5	45.8	26.1	38.9	40.9
17-Oct	0.9	23.0	7.5	12.7	21.5
18-Oct	0.4	8.2	0.4	0.8	4.4
23-Oct	0.7	23.2	0.8	0.9	12.4
24-Oct	0.9	25.3	0.9	5.1	17.2
All	0.4	114.7	7.9	30.5	54.1

Table 5–4. Minimum, maximum, and quartile values of time to pass the Pawtucket Gatehouse and enter Northern Canal (hours) for radio-tagged juvenile alosines released upstream of the Pawtucket Dam during the fall 2019 downstream passage assessment.

Release Date	Pawtucket Gatehouse Passage (Hours)				
	Minimum	Maximum	Q25	Q50 (Median)	Q75
9-Oct	< 0.1	0.3	0.1	0.1	0.2
11-Oct	< 0.1	0.2	0.1	0.1	0.2
13-Oct	< 0.1	0.2	0.1	0.1	0.1
14-Oct	< 0.1	0.1	< 0.1	< 0.1	0.1
15-Oct	< 0.1	0.2	0.1	0.1	0.2
16-Oct	0.1	0.2	0.1	0.1	0.1
17-Oct	0.1	0.2	0.1	0.1	0.2
18-Oct	< 0.1	0.6	0.1	0.1	0.3
23-Oct	0.1	0.3	0.1	0.1	0.2
24-Oct	0.1	0.4	0.2	0.2	0.3
All	< 0.1	0.4	0.1	0.1	0.2

Table 5–5. Minimum, maximum, and quartile values of residence time within Northern Canal (hours) for radio-tagged juvenile alosines released upstream of the Pawtucket Dam during the fall 2019 downstream passage assessment.

Release Date	Northern Canal Residence (Hours)				
	Minimum	Maximum	Q25	Q50 (Median)	Q75
9-Oct	31.8	151.0	50.0	77.0	100.7
11-Oct	19.3	66.9	25.2	36.4	51.9
13-Oct	12.7	105.4	17.3	18.8	71.3
14-Oct	39.5	62.5	51.5	53.5	62.5
15-Oct	23.9	24.0	23.9	24.0	24.0
16-Oct	17.9	22.4	20.0	22.0	22.2
17-Oct	0.2	21.9	0.9	10.6	12.3
18-Oct	0.2	8.0	0.2	0.8	5.0
23-Oct	0.3	0.5	0.4	0.4	0.5
24-Oct	0.3	25.1	0.4	6.0	25.1
All	0.2	112.1	4.6	22.0	52.8

Table 5–6. Downstream passage route selection and percent utilization of route options after detection at Station 21 for radio-tagged juvenile alosines released upstream of Pawtucket Dam during the fall 2019 downstream passage assessment.

Release Date	Lowell Downstream Passage Route						
	Did not Detect	Did Not Pass	Downtown Canal System	Spill	Bypass	Turbine	Unknown
9-Oct	0	2	1	1	5	6	0
11-Oct	0	2	1	0	4	8	0
13-Oct	1	3	0	1	4	4	1
14-Oct	1	1	1	0	1	10	1
15-Oct	0	2	0	2	2	8	1
16-Oct	0	0	0	6	0	7	2
17-Oct	0	2	0	2	0	9	3
18-Oct	0	2	0	0	0	13	0
23-Oct	1	3	0	0	1	11	1
24-Oct	0	4	0	1	0	6	0
All	3	18	3	13	17	82	9
Percent Utilization		12.7%	2.1%	9.2%	12.0%	57.7%	6.3%

Table 5–7. Quartile conditions of project discharge at the time of downstream passage for radio-tagged juvenile alosines at the known route of passage and the cumulative sum of discharge at non-passage routes.

Passage Route	No. Using Route	Quartile	Route Discharge		Non-Route Discharge	
			cfs	%	cfs	%
Turbines	82	Q25	2362	71%	801	18%
		Q50	3121	79%	932	21%
		Q75	4504	82%	1029	29%
Downstream Bypass	17	Q25	132	8%	1418	91%
		Q50	132	8%	1586	92%
		Q75	132	9%	1586	92%
Spill	13	Q25	553	10%	4081	89%
		Q50	553	10%	4974	90%
		Q75	561	11%	4977	90%
Downtown Canal	3	Q25	290	20%	920	76%
		Q50	290	22%	1040	78%
		Q75	290	24%	1147	80%

Table 5–8. Minimum, maximum, and quartile values of downstream transit time (hours) for radio-tagged juvenile alosines following passage at the Lowell project during the fall 2019 downstream passage assessment.

Release Date	Downstream Transit (Hours)				
	Minimum	Maximum	Q25	Q50 (Median)	Q75
9-Oct	3.0	18.0	4.9	7.2	8.3
11-Oct	3.7	42.2	4.8	6.1	9.7
13-Oct	2.6	24.6	5.5	7.4	17.7
14-Oct	1.5	14.8	5.5	9.5	13.9
15-Oct	1.6	15.0	7.5	12.2	13.9
16-Oct	2.6	14.6	3.6	4.4	12.0
17-Oct	1.6	10.6	1.9	3.0	10.0
18-Oct	1.0	17.3	1.3	2.0	3.6
23-Oct	1.7	9.9	2.7	3.0	7.4
24-Oct	3.0	13.5	3.0	12.3	13.5
All	1.0	42.2	2.9	6.2	11.4

Table 5–9. Results of the Cox proportional hazards model for juvenile alosine passage through Pawtucket Gatehouse. Significance is determined by p < 0.05.

Pawtucket Gatehouse										
Model: Time to Event ~ Temperature + Inflow + Spill										
Model Parameter	*b*	se	z	P-value	Significance	e^{b}	e^{-b}	Lower .95	Upper .95	Percent Change Failure
Temp	-0.93	0.08	-11.04	<0.001	Significant	0.4	2.53	0.34	0.47	↓ 60%
Inflow	0	0	-2.36	0.02	No Hazard	1	1	1	1	0
Spill 2080-4150 cfs	0.84	0.52	1.62	0.11	Insignificant	2.31	0.43	0.84	6.37	↑ 131%
Spill 4150-6240 cfs	2.57	1.14	2.26	0.02	Significant	13.05	0.08	1.4	121.28	↑ 1205%

Significance is determined by $p < 0.05$.

Table 5–10. Output of the Schoenfield residual test for time independence of covariates in Cox proportional hazard model of Pawtucket Gatehouse passage events.

Variable	Chi-squared	df	P-Value
Temperature (°C)	8.22	1	0
Inflow (cfs)	9.03	1	0
Spill (cfs)	4.23	2	0.12
Full Model	14.54	4	0.01

Note: $p < 0.05$ indicates a violation of the proportional hazard assumption.

Table 5–11. Results of the Cox proportional hazards model for juvenile alosine passage through E.L. Field Powerhouse forebay.

Forebay										
Model: Time to Event ~ Temperature + Combined Turbine cfs + Spill + Inflow + ELF Head										
Model Parameter	*b*	se	z	P-value	Significance	e^b	e^{-b}	Lower .95	Upper .95	Percent Change Failure
Temp	-0.08	0.16	-0.52	0.60	Insignificant	0.92	1.09	0.68	1.25	↓ 8%
Inflow	0	0	-1.62	0.11	No Hazard	1	1	1	1	0
Spill	0	0	1.16	0.25	No Hazard	1	1	1	1	0
Turbine CFS 1980-3950 cfs	1.8	0.53	3.40	<0.001	Significant	6.05	0.17	2.14	17.07	↑ 605%
Turbine CFS 3950-5930 cfs	3.15	0.88	3.58	<0.001	Significant	23.23	0.04	4.15	130.02	↑ 2223%
ELF Head	-0.08	0.07	-1.05	0.30	Insignificant	0.93	1.08	0.8	1.07	↓ 7%

Significance is determined by $p < 0.05$.

Table 5–12. Output of the Schoenfield Residual test for time independence of covariates in Cox proportional hazard model of E.L. Field Powerhouse forebay events.

Variable	Chi-squared	df	P-Value
Temperature (°C)	1.06	1	0.3
Inflow (cfs)	0	1	0.97
Spill (cfs)	0.21	1	0.64
Turbine Discharge (cfs)	0.41	2	0.81
ELF Head Differential (ft)	0.02	1	0.88
Full Model	5.85	6	0.44

Note: $p < 0.05$ indicates a violation of the proportional hazard assumption.

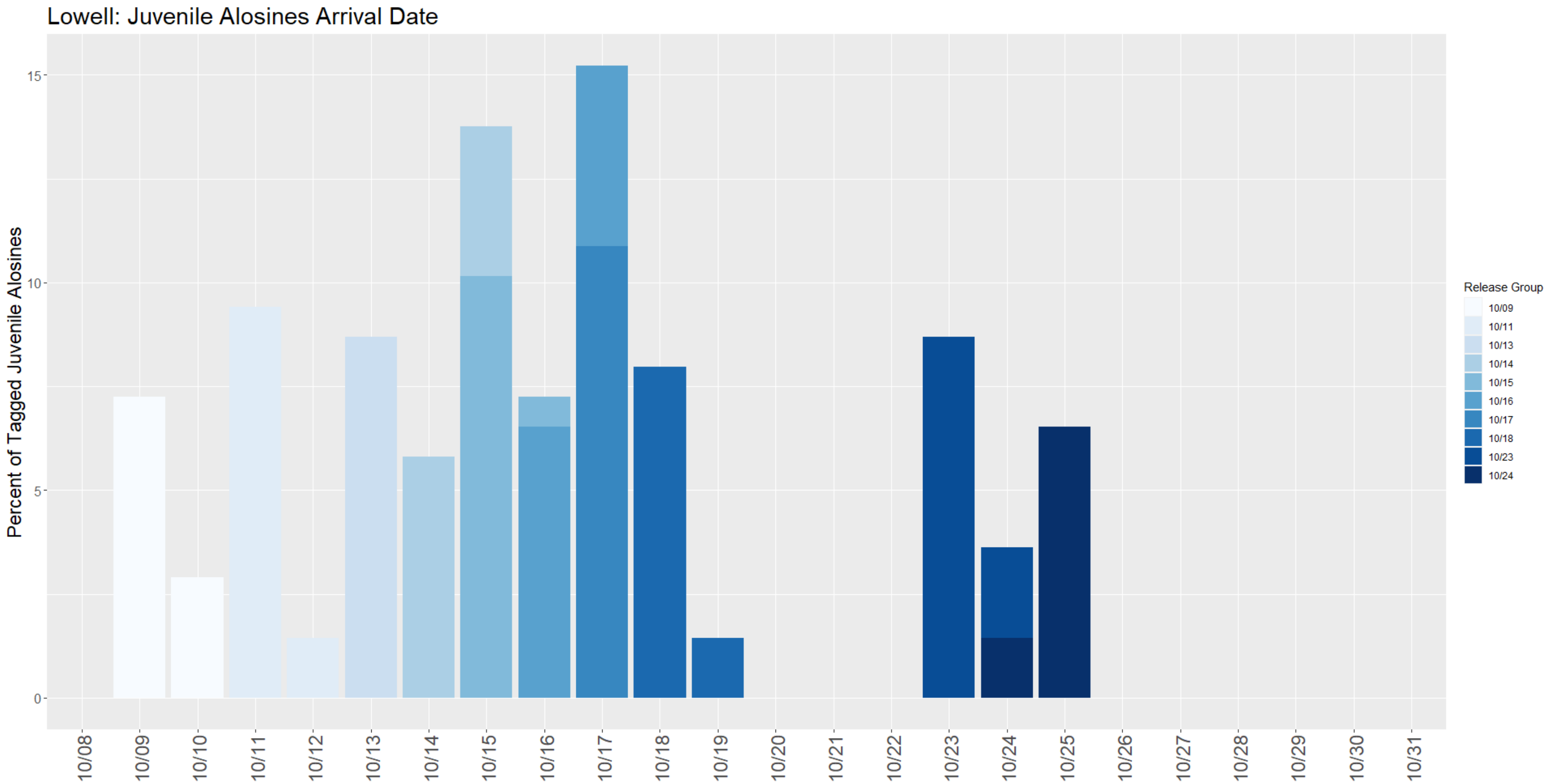

Figure 5–6. Distribution of Pawtucket Dam arrival dates for radio-tagged juvenile alosines released upstream of the Pawtucket Dam during the 2019 downstream passage assessment.

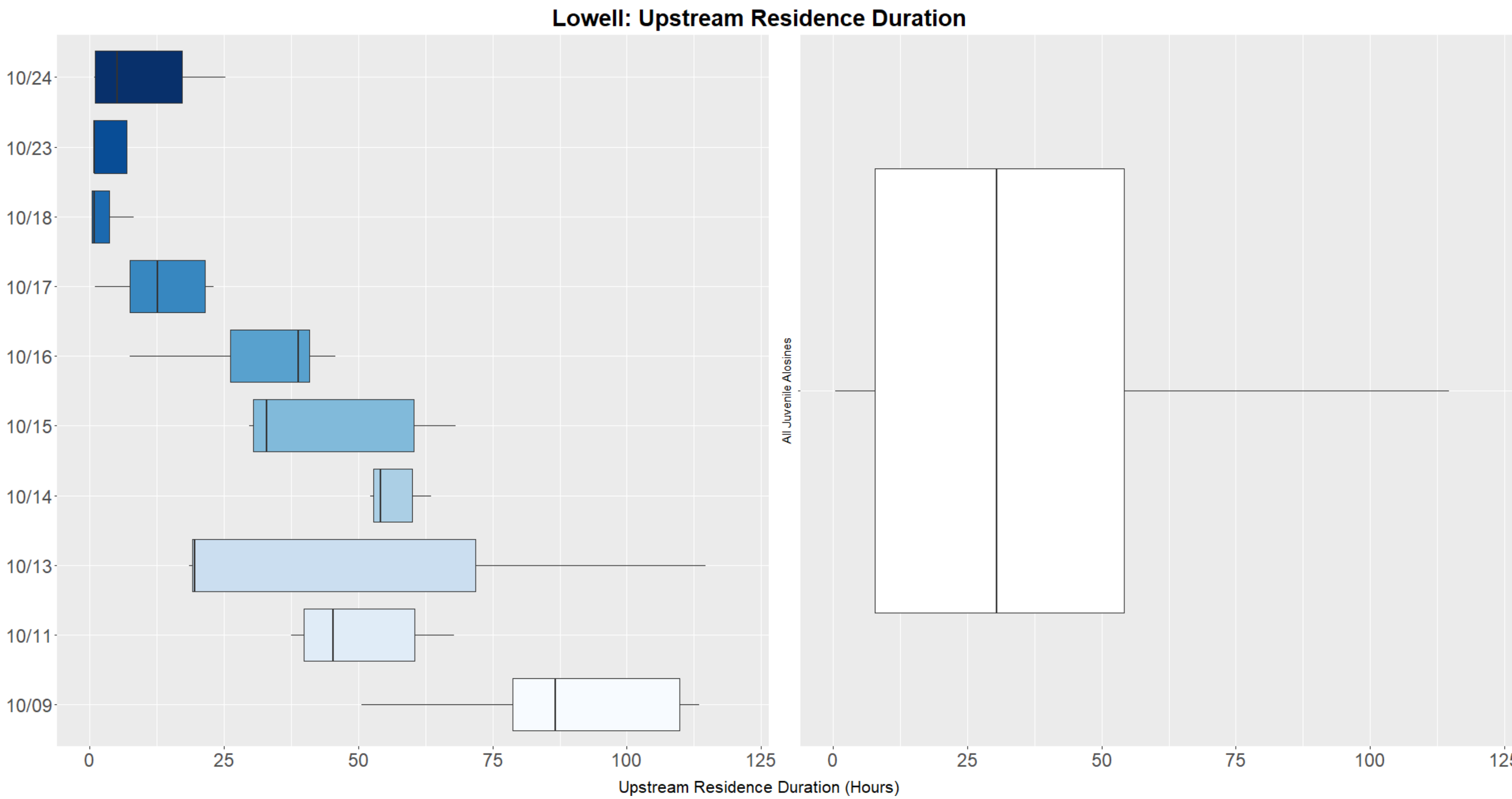

Figure 5–7. Box plot of upstream residence time for radio-tagged juvenile alosines passing downstream of Lowell during the 2019 downstream passage assessment. [2]

[2] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

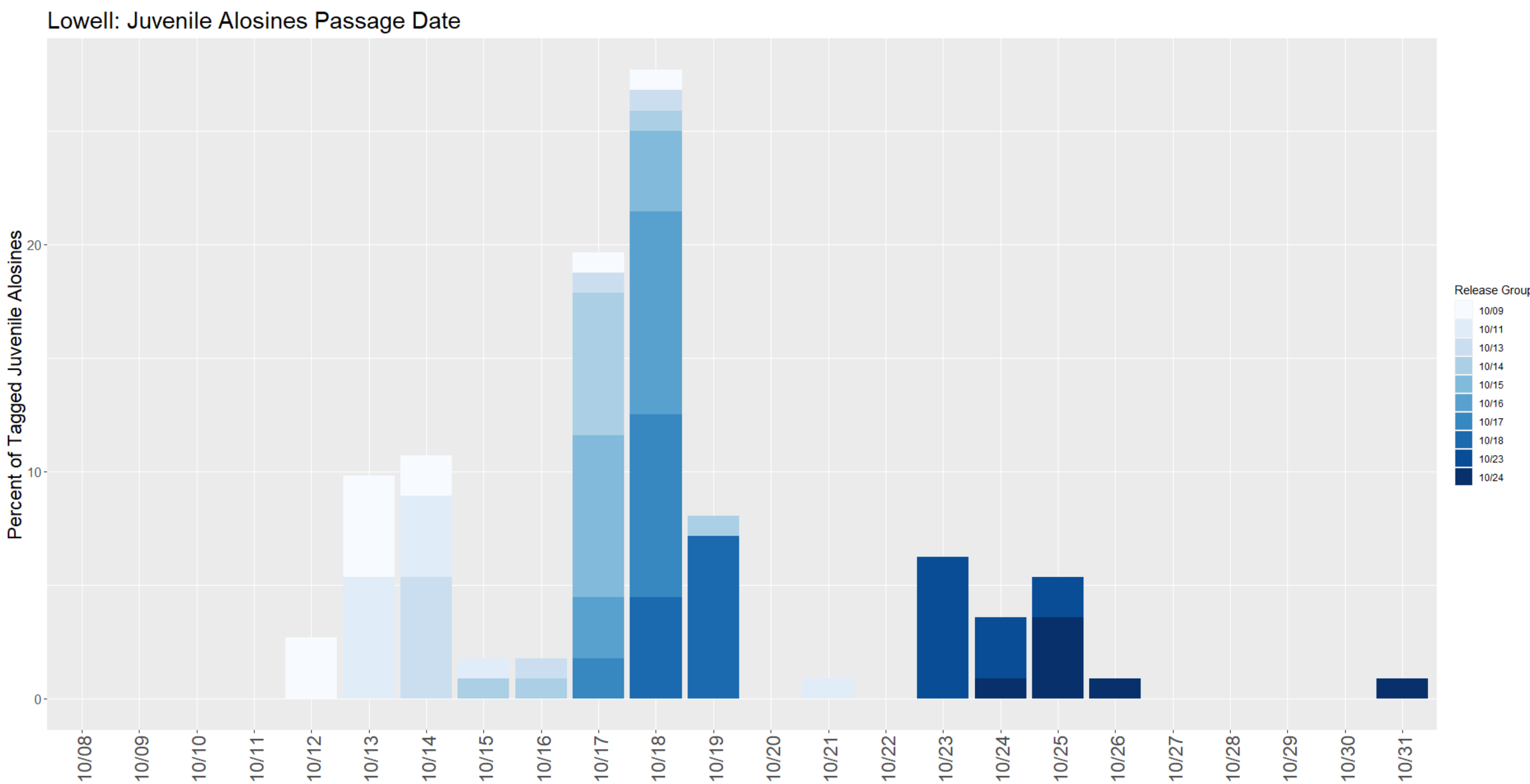

Figure 5–8. Distribution of Pawtucket Dam downstream passage dates for radio-tagged juvenile alosines during the 2019 downstream passage assessment.

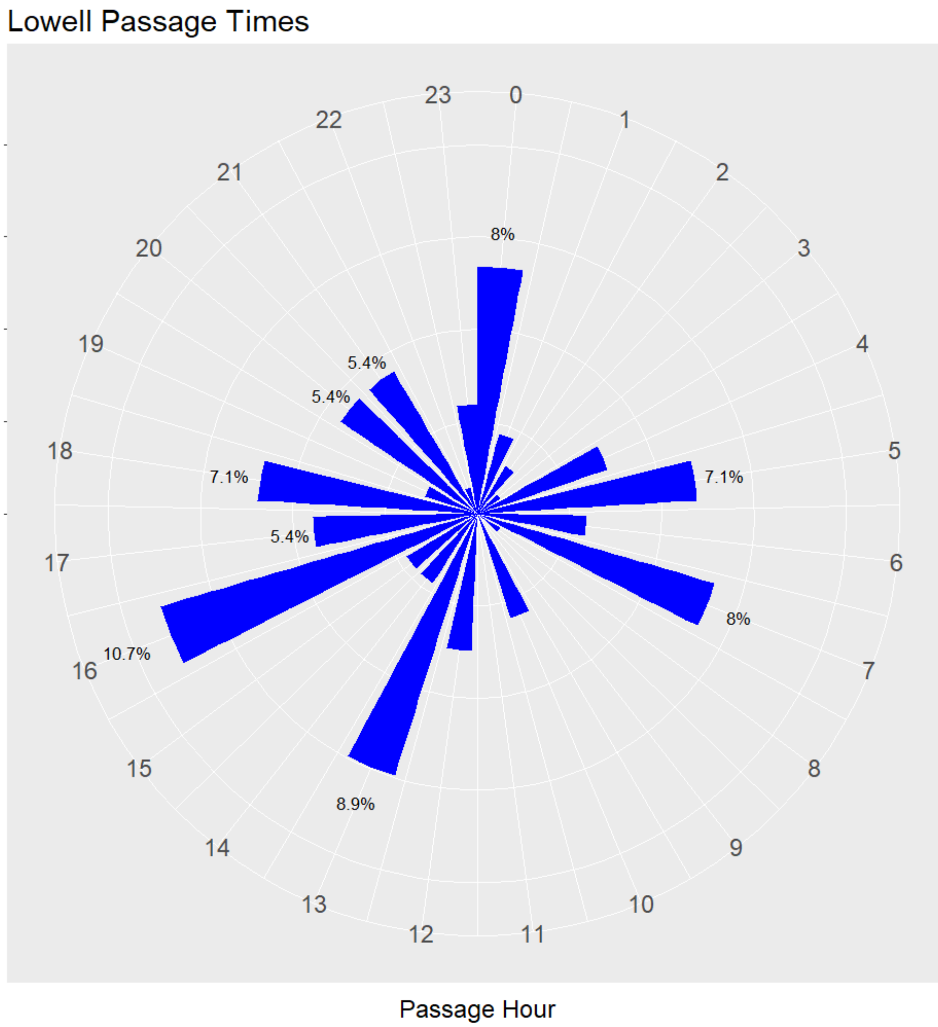

Figure 5–9. Distribution of downstream passage time for all radio-tagged juvenile alosine released upstream of Lowell during the 2019 downstream passage assessment.

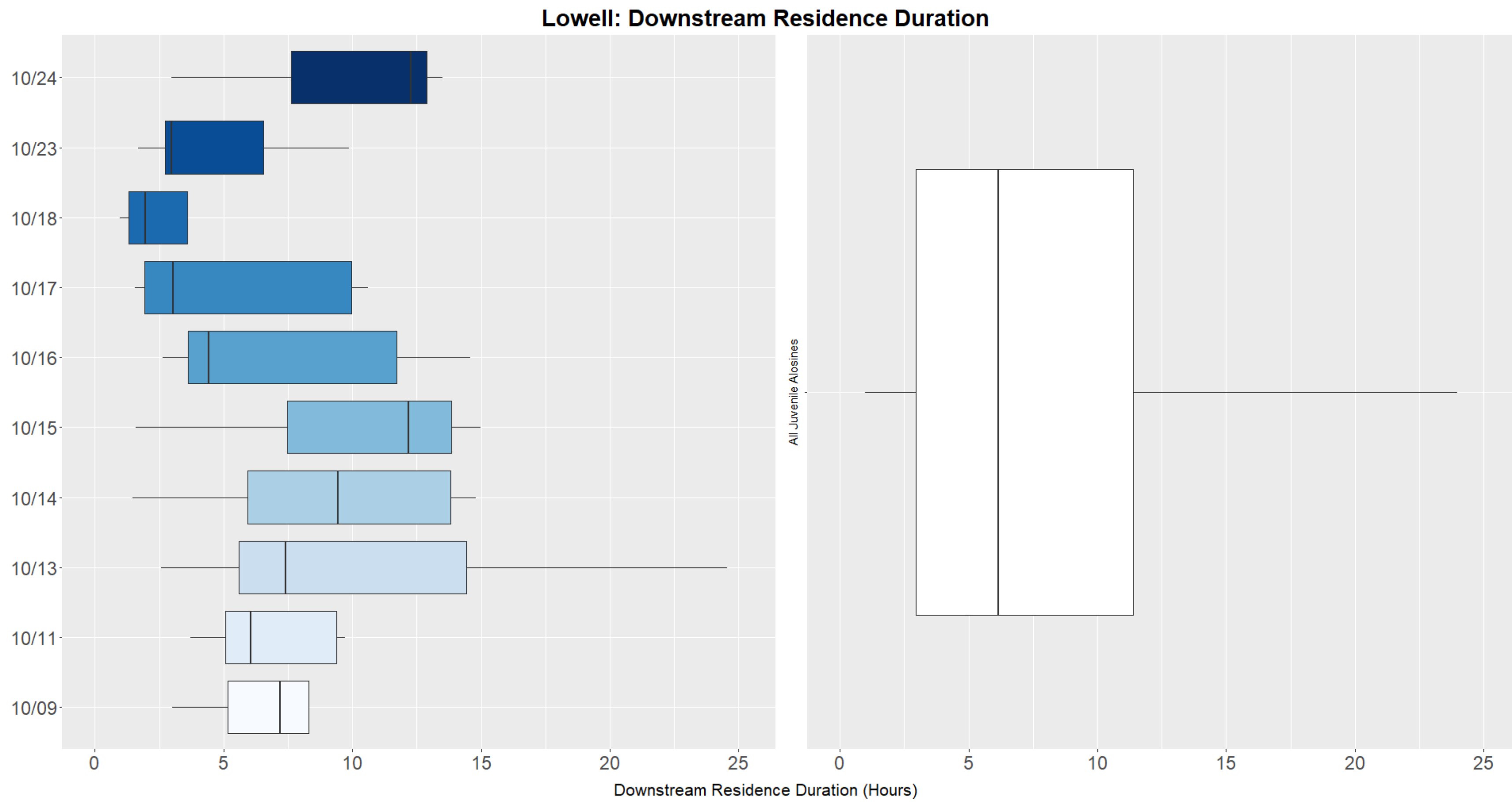

Figure 5–10. Box plot of downstream transit time for radio-tagged juvenile alosines following passage at Lowell during the 2019 downstream passage assessment. [3]

[3] The solid line represents the median while left and right portions of the box represent the first and third quartiles, respectively. Whiskers extend to the range of the data within the interquartile range (quartile*1.05) such that outliers outside of this range are not displayed.

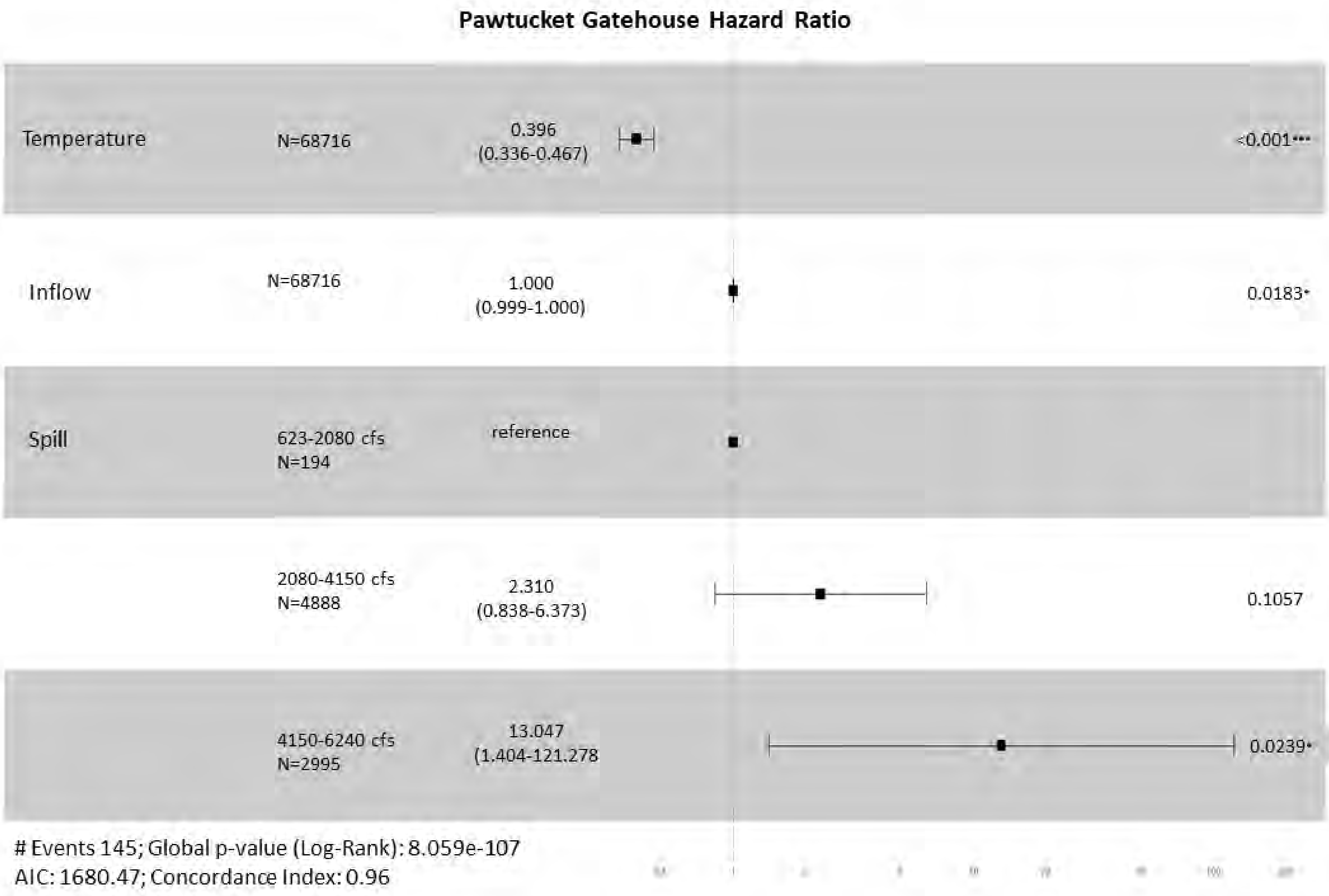

Figure 5–11. Cox proportional hazards model results for passage success of radio-tagged juvenile alosines at the Pawtucket Gatehouse.

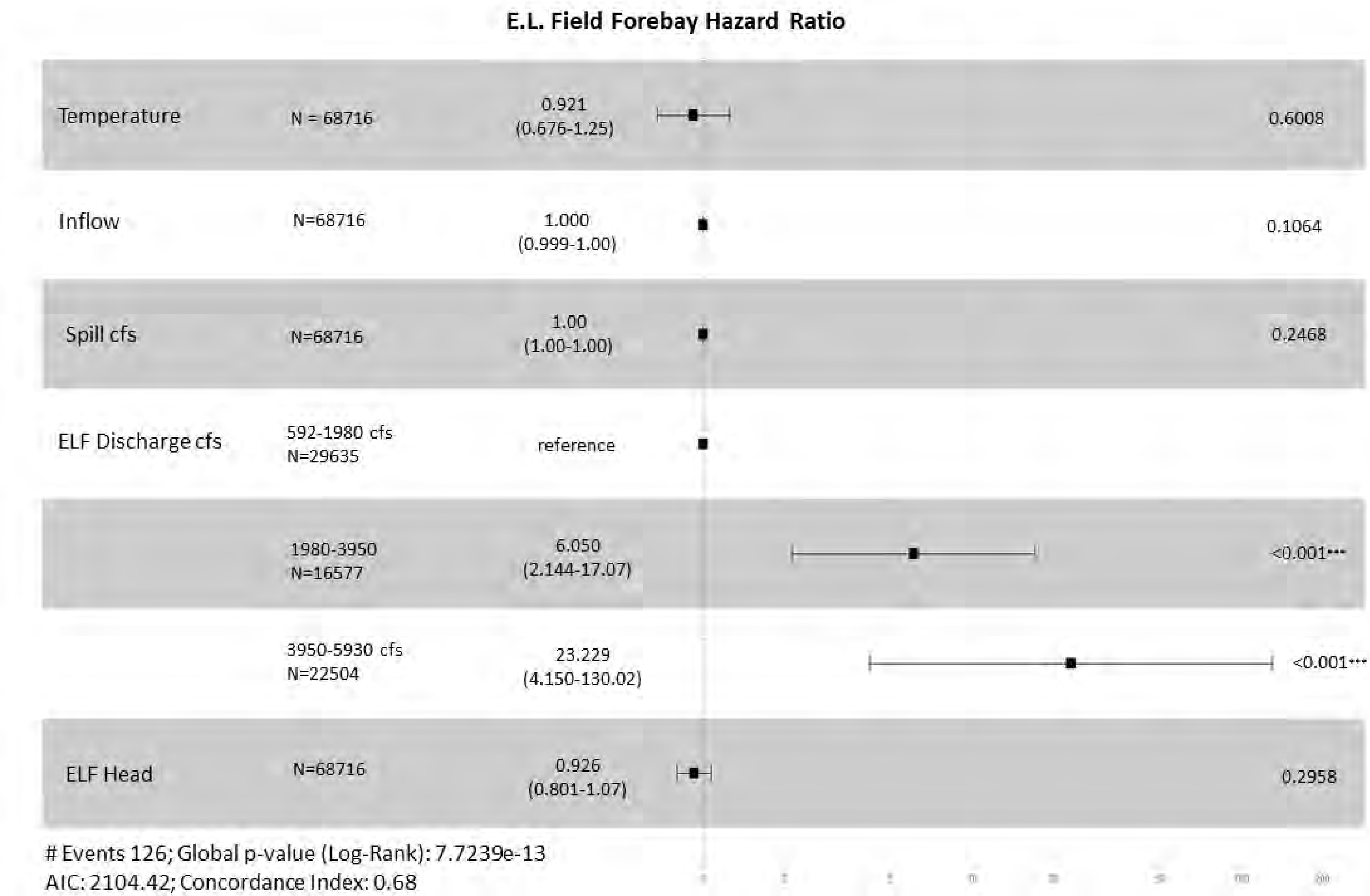

Figure 5–12. Cox proportional hazards model results for passage success of radio-tagged juvenile alosines at the E.L. Field Powerhouse forebay.

6 Summary

An evaluation of the potential impacts on the outmigration of juvenile alosines was conducted in support of the FERC relicensing of the Lowell Project on the Merrimack River. Downstream passage route utilization was evaluated using radio-telemetry during the 2019 fall migration season (October 9 to November 12, 2019). Monitoring of outmigrating juvenile alosines focused on the evaluation of the residence time immediately upstream of the Pawtucket Dam and prior to passage as well as passage route utilization at the Project.

A total of 145 juvenile alosines were tagged and released at mid-river locations approximately one mile upstream of the Pawtucket Gatehouse. Their subsequent downstream arrival and passage at the Project was monitored via a series of fixed-location telemetry receivers within the Lowell Project area. All of the juvenile alosines utilized for this study were collected from Turtletown Pond in Concord, New Hampshire and ranged in total length from 125-144 mm. Radio transmitters were bonded to small fish hooks and then externally affixed to each individual prior to their release. Releases of radio-tagged juveniles were spread over a 16 day period between October 9 and 24.

Upon initial detection at the Pawtucket Dam, the median duration of time spent immediately upstream of the dam structure was 1.3 days with 42% passing downstream within the first 24 hours of their initial detection. Closer examination of the total residence time for radio-tagged juvenile alosines indicated that all individuals determined to have entered the Northern Canal passed through the Pawtucket Gatehouse in less than 30 minutes. Upon entry into the Northern Canal, the median residence duration prior to downstream passage was longer (22.0 hours; range = 0.2 hours to 4.7 days). Nearly 70% of all downstream passage events for radio-tagged juvenile alosines occurred within 48 hours of initial detection in the E.L. Field forebay. The Cox proportional hazards model suggested a statistically significant interaction between the mid and high generation conditions in relation to passage failure from the E.L. Field forebay. The presence of higher generation flows increased the probability that a radio-tagged individual would approach downstream passage options in the power canal (i.e., turbines or downstream bypass) and reject the passage attempt relative to lower generation flows.

Outmigrating juvenile alosines encountering the Pawtucket Dam can (1) pass through the Pawtucket Gatehouse and enter the power canal, (2) pass downstream over Pawtucket Dam via spill, or (3) enter the Pawtucket Canal and navigate downstream via the downtown canal system. Individuals which enter the Northern Canal can subsequently pass downstream via one of the two turbine units at the E.L. Field Powerhouse, utilize the downstream bypass, or pass via the surge gate (operated only in the event of a station trip). During the 2019 evaluation the majority of radio-tagged individuals passed through the Pawtucket Gatehouse and approached the E.L. Field powerhouse. Of the individuals which approached the E.L. Field powerhouse and had a known downstream passage route, 83% eventually passed downstream via the turbine units[4]. Use of the existing downstream bypass system is estimated at 17%. The existing

[4] Note that downstream passage survival for juvenile alosines will be assessed as part of the desktop based *Fish Passage Survival Study*. Downstream passage survival was not estimated for radio-tagged juvenile alosines as part

downstream bypass at Lowell was last assessed for the effectiveness of passing juvenile alosines during 1994 and effectiveness was estimated at 37% during that study (Normandeau 1995). Only two percent of all radio-tagged juvenile alosines were determined to have entered the Pawtucket Canal and attempted downstream passage via the downtown canal system. Of the three individuals which entered the downtown canal system, one was determined to have exited the canal system and was detected downstream at Station 38.

7 Variances from FERC-Approved Study Plan

The FERC-approved RSP indicated that a total of 150 radio-tagged juvenile alosines. Five of the transmitters purchased for this study could not be activated. As a result, a total of 145 radio-tagged juvenile alosines were released and assessed for downstream passage at the Project. There were no additional variances from the FERC-approved study plan.

8 References

Castro-Santos, T. and R. Perry. 2012. Time-to-event analysis as a framework for quantifying fish passage performance. Pages 427-452 *in* N.S. Adams, J.W. Beeman, and J.H. Eiler, editors. Telemetry techniques: a user guide for fisheries research. American Fisheries Society, Bethesda, Maryland.

Normandeau Associates, Inc. (Normandeau). 1995. Use of the fish bypass by juvenile clupeids at the Lowell Hydroelectric Project during fall, 1994. Report Prepared for Consolidated Hydro, Inc.

R Core Team. (2020). R: A Language and Environment for Statistical Computing. Vienna, Austria.

of this assessment due to the uncertainty related to retention of externally mounted transmitters and the potential for negatively biasing a survival estimate due to loss of tags during the act of passage.

9 Appendices

Appendix A. Estimated weekly discharge values (cfs) for the Guard Locks, Swamp Locks, Hamilton Station, Section 8 Station, John Street Station, Boott Gate and Lower Locks.

BOOTT HYDROPOWER DOWNTOWN OPERATIONS: ESTIMATED FLOWS

Date	10/10/2019	10/17/2019	10/23/2019	10/31/2019	11/7/2019	11/12/2019
Time	900	1100	900	1445	1000	1530

Guard Locks						
Gate 1	197	197	197	246	246	529
Gate 2	128	128	128	0	0	0
Gate 3	0	0	0	0	0	0
Gate 4	0	0	0	0	0	176
Gate 5	0	0	0	197	197	441
Total	325	325	325	443	443	1145

Swamp Locks						
Gate 1	0	0	0	0	0	0
Gate 2	252	252	252	252	252	492
Bayboards opened	0	0	0	0	0	0
Total	252	252	252	252	252	492

Hamilton						
Unit 1	26	13	13	13	13	100
Unit 2	13	13	13	13	13	158
Unit 3	20	20	20	20	20	0
Unit 4	10	10	10	10	10	127
Unit 5	17	17	17	17	17	14
Hamilton Wasteway	0	0	0	0	0	0
Total	86	73	73	73	73	399

Section 8						
Unit 1	0	0	0	0	0	0
Unit 2	0	0	0	0	0	133
Unit 3	75	75	75	75	75	0
Total	75	75	75	75	75	133

John St.						
Unit 3	0	0	0	0	0	0
Unit 4	0	0	0	0	0	0
Unit 5	0	0	0	0	0	0
Unit 6	0	0	0	0	0	236
Total	0	0	0	0	0	236

Boott Gate						
Gate	0	0	0	0	0	0
Bayboards opened	0	0	0	0	0	0
Total	0	0	0	0	0	0

Lower Locks						
Gate	120	120	120	120	120	120
Bayboards opened	0	0	0	0	0	0
Total	120	120	120	120	120	120

Appendix B. Juvenile alosine tagging, release, and biocharacteristics information for the 2019 downstream passage assessment at Lowell.

Frequency	Tag ID	Total Length (mm)	Release Date	Release Bank
150.360	27	134	10/9/2019	East
150.360	28	132	10/9/2019	East
150.360	30	136	10/9/2019	East
150.380	80	135	10/9/2019	East
150.380	87	134	10/9/2019	East
150.600	113	138	10/9/2019	East
150.600	140	126	10/9/2019	East
150.600	159	136	10/9/2019	East
150.360	26	134	10/9/2019	West
150.360	29	134	10/9/2019	West
150.380	68	129	10/9/2019	West
150.380	81	131	10/9/2019	West
150.380	83	137	10/9/2019	West
150.600	137	123	10/9/2019	West
150.600	143	128	10/9/2019	West
150.360	11	132	10/11/2019	East
150.360	12	137	10/11/2019	East
150.360	13	126	10/11/2019	East
150.380	67	133	10/11/2019	East
150.380	89	132	10/11/2019	East
150.380	91	138	10/11/2019	East
150.600	117	130	10/11/2019	East
150.600	136	123	10/11/2019	East
150.360	14	144	10/11/2019	West
150.360	15	126	10/11/2019	West
150.380	62	124	10/11/2019	West
150.380	75	129	10/11/2019	West
150.600	126	138	10/11/2019	West
150.600	144	128	10/11/2019	West
150.600	147	128	10/11/2019	West
150.360	32	138	10/13/2019	East
150.360	37	133	10/13/2019	East
150.360	40	127	10/13/2019	East
150.360	78	138	10/13/2019	East
150.380	79	140	10/13/2019	East
150.380	85	142	10/13/2019	East
150.380	107	132	10/13/2019	East
150.360	21	137	10/13/2019	West
150.360	34	128	10/13/2019	West
150.360	35	131	10/13/2019	West
150.360	45	134	10/13/2019	West
150.380	84	127	10/13/2019	West

Frequency	Tag ID	Total Length (mm)	Release	
			Date	Bank
150.380	96	129	10/13/2019	West
150.380	102	125	10/13/2019	West
150.360	17	141	10/14/2019	East
150.360	22	142	10/14/2019	East
150.360	25	139	10/14/2019	East
150.380	77	134	10/14/2019	East
150.380	95	137	10/14/2019	East
150.600	111	131	10/14/2019	East
150.600	133	137	10/14/2019	East
150.360	16	138	10/14/2019	West
150.360	20	134	10/14/2019	West
150.380	65	127	10/14/2019	West
150.380	70	135	10/14/2019	West
150.380	94	137	10/14/2019	West
150.600	112	133	10/14/2019	West
150.600	148	138	10/14/2019	West
150.600	149	125	10/14/2019	West
150.360	18	134	10/15/2019	East
150.360	19	124	10/15/2019	East
150.360	36	133	10/15/2019	East
150.380	82	129	10/15/2019	East
150.380	108	135	10/15/2019	East
150.600	122	133	10/15/2019	East
150.600	152	135	10/15/2019	East
150.360	23	127	10/15/2019	West
150.360	31	147	10/15/2019	West
150.380	69	141	10/15/2019	West
150.380	106	134	10/15/2019	West
150.380	110	127	10/15/2019	West
150.600	115	140	10/15/2019	West
150.600	119	132	10/15/2019	West
150.600	129	134	10/15/2019	West
150.360	42	136	10/16/2019	East
150.360	47	144	10/16/2019	East
150.360	60	133	10/16/2019	East
150.380	98	136	10/16/2019	East
150.380	100	128	10/16/2019	East
150.600	123	135	10/16/2019	East
150.600	153	133	10/16/2019	East
150.360	48	141	10/16/2019	West
150.360	56	132	10/16/2019	West
150.380	61	140	10/16/2019	West
150.380	97	128	10/16/2019	West
150.380	103	132	10/16/2019	West
150.600	127	138	10/16/2019	West
150.600	139	123	10/16/2019	West

Frequency	Tag ID	Total Length (mm)	Release	
			Date	Bank
150.600	154	137	10/16/2019	West
150.360	41	132	10/17/2019	East
150.360	43	133	10/17/2019	East
150.360	57	128	10/17/2019	East
150.380	88	143	10/17/2019	East
150.380	99	134	10/17/2019	East
150.600	120	139	10/17/2019	East
150.600	151	127	10/17/2019	East
150.360	44	140	10/17/2019	West
150.360	59	122	10/17/2019	West
150.380	64	124	10/17/2019	West
150.380	71	129	10/17/2019	West
150.380	92	127	10/17/2019	West
150.600	125	138	10/17/2019	West
150.600	134	122	10/17/2019	West
150.600	158	141	10/17/2019	West
150.360	49	142	10/18/2019	East
150.360	58	146	10/18/2019	East
150.360	82	123	10/18/2019	East
150.380	63	128	10/18/2019	East
150.380	93	138	10/18/2019	East
150.380	109	138	10/18/2019	East
150.600	130	135	10/18/2019	East
150.600	160	132	10/18/2019	East
150.360	46	129	10/18/2019	West
150.360	50	132	10/18/2019	West
150.380	90	131	10/18/2019	West
150.380	105	136	10/18/2019	West
150.600	114	133	10/18/2019	West
150.600	116	139	10/18/2019	West
150.600	155	123	10/18/2019	West
150.360	51	140	10/23/2019	East
150.360	55	139	10/23/2019	East
150.380	74	136	10/23/2019	East
150.380	76	124	10/23/2019	East
150.600	132	135	10/23/2019	East
150.600	142	116	10/23/2019	East
150.600	145	131	10/23/2019	East
150.600	156	138	10/23/2019	East
150.360	53	141	10/23/2019	West
150.360	54	132	10/23/2019	West
150.380	73	139	10/23/2019	West
150.380	101	143	10/23/2019	West
150.380	104	121	10/23/2019	West
150.600	118	141	10/23/2019	West
150.600	121	136	10/23/2019	West

Frequency	Tag ID	Total Length (mm)	Release	
			Date	Bank
150.380	72	131	10/24/2019	East
150.600	124	146	10/24/2019	East
150.600	141	155	10/24/2019	East
150.600	146	127	10/24/2019	East
150.600	150	141	10/24/2019	East
150.600	157	136	10/24/2019	East
150.380	86	132	10/24/2019	West
150.600	128	130	10/24/2019	West
150.600	131	139	10/24/2019	West
150.600	135	126	10/24/2019	West
150.600	138	140	10/24/2019	West

Appendix C. Listing of manual tracking detections within the Lowell Project area.

Date	Frequency	ID	Location	Type
10/21/2019	150.600	143	Bypassed Reach	Stationary
10/21/2019	150.600	136	Bypassed Reach	Stationary
10/21/2019	150.380	89	Northern Canal	Transit
10/21/2019	150.380	87	Tailrace	Stationary
10/21/2019	150.380	69	Northern Canal	Stationary
10/21/2019	150.380	62	Northern Canal	Stationary
10/21/2019	150.360	41	Northern Canal	Stationary
10/24/2019	150.600	136	Bypassed Reach	Stationary
10/24/2019	150.600	132	Northern Canal	Transit
10/24/2019	150.380	87	Tailrace	Stationary
10/24/2019	150.380	69	Northern Canal	Stationary
10/28/2019	150.600	157	Northern Canal	Stationary
10/28/2019	150.600	138	Northern Canal	Stationary
10/28/2019	150.600	124	Northern Canal	Stationary
10/28/2019	150.380	69	Northern Canal	Stationary
11/5/2019	150.600	146	Northern Canal	Stationary
11/5/2019	150.600	138	Northern Canal	Stationary
11/7/2019	150.600	157	Northern Canal	Stationary
11/7/2019	150.600	146	Northern Canal	Stationary
11/7/2019	150.600	138	Northern Canal	Stationary
11/7/2019	150.600	135	Tailrace	Stationary

Appendix D. Responses to September 30, 2020 Revised ISR meeting comments.

Comment No.	Agency	Comment	Response
1	FERC	Can Boott provide a Microsoft Excel file of station operations for the study period to allow for calculation of flow proportions by passage route?	Hourly operations records have been provided in Microsoft Excel format and include values for headpond elevation, forebay elevation, tailrace elevation, inflow, Unit 1 discharge, Unit 2 discharge, downstream bypass discharge, upstream fishway flow, downtown canal flow, and spill flow. The reported station operations at the time of downstream passage for each radio-tagged fish were identified. Section 5.5 of the final report has been modified to include a summary of the proportional volume of discharge through the selected passage route relative to non-selected routes (e.g., if a fish passed downstream via the turbines values reported for that individual would include the volume of water passing through the turbines vs. the volume of water passing downstream via alternative routes (i.e., downstream bypass or spill).
2	NMFS	Table 5-1 in Section 5-1 summarizes the percentage of inflow records from the 2019 study period categorized by volume as well as the percentage of time that each volume category is historically exceeded for the months of October and November. Is it possible to consider the study months of October and November as a	Section 5-1 has been updated to include an examination of Merrimack River conditions during the full October 9 – November 30, 2019 study period relative to flow exceedance probabilities.

		whole to classify the full study period by flow condition?	
3	MDFW	The Cox proportional hazards model for the Pawtucket Gatehouse failed to meet the criteria necessary to accept the assumption that hazards are proportional. Was a principal components analysis type approach considered to create new uncorrelated variables to increase interpretability of the data at that location?	The proportional hazards model for juvenile alosines at the Pawtucket Gatehouse was revisited and a variance inflation test (VIF-test) was conducted on all variables included in the original model. However, no two variables were found to be significantly correlated enough to consider removing or incorporating into an interaction term in the final model. As a result, no modifications were made to the model presented in the Revised ISR report.
4	MDFW and NMFS	In their Revised ISR comment letters both MDFW and NMFS commented: *The goal of the juvenile alosine and American eel downstream passage assessments was to determine the Lowell Project's impact on the outmigration of juvenile alosine and adult American eel. The specific objectives included assessing rates and delay to migration for alosine and evaluation of route specific mortality for American eel. Operation of turbine units in the downtown canal system did not occur during the study for safety reasons. This lack of operation significantly affects the study results and our ability to assess project related impacts. However, it is our understanding that the canal units will be decommissioned, as stated by CRP during a conference call with us and the US Fish and Wildlife Service on November 16, 2020.*	As stated in the DLA, Boott has elected to decommission the downtown canal units, and to remove the units and associated canal infrastructure from the new license.

		Decommissioning of the canal units should be confirmed in the Draft License Application. If confirmed, then additional evaluation of project impacts related to the canals are not necessary. However, is there is a change in this decision and the downtown canal units are part of the proposed action within the Draft License Application, then the agencies intend to request a second year of study once the canal units are fully operational to determine post-spawned adult alosine and American eel downstream migration route selection, passage efficiency, and residence duration associated with the power canal under various operational conditions, including a range of spill conditions.	

Appendix E. Project inflow and discharge by potential passage route at the time of downstream passage for radio-tagged juvenile alosines at Lowell.

		Passage			Reported cfs				
Frequency	ID	Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
150.380	68	10/11/2019	0:58:43	Downtown	1330	608	132	300	290
150.600	117	10/12/2019	1:03:28	Downtown	1089	272	132	395	290
150.380	87	10/12/2019	2:14:03	Turbine	1089	275	132	392	290
150.360	29	10/12/2019	3:54:47	Turbine	1107	282	132	403	290
150.600	159	10/12/2019	18:27:59	Turbine	1670	1038	132	210	290
150.360	27	10/13/2019	10:18:05	Turbine	1130	294	132	414	290
150.600	144	10/13/2019	13:35:10	Bypass	1718	1145	132	151	290
150.380	67	10/13/2019	13:38:28	Turbine	1718	1145	132	151	290
150.600	143	10/13/2019	13:41:22	Bypass	1718	1145	132	151	290
150.600	136	10/13/2019	13:42:34	Bypass	1718	1145	132	151	290
150.380	83	10/13/2019	13:43:25	Turbine	1718	1145	132	151	290
150.360	12	10/13/2019	13:43:41	Turbine	1718	1145	132	151	290
150.600	113	10/13/2019	13:45:51	Bypass	1718	1145	132	151	290
150.360	13	10/13/2019	13:54:11	Bypass	1718	1145	132	151	290
150.360	30	10/13/2019	13:57:48	Bypass	1718	1145	132	151	290
150.360	15	10/13/2019	14:09:02	Turbine	1718	1145	132	151	290
150.360	14	10/14/2019	0:05:48	Turbine	1258	516	132	320	290
150.380	91	10/14/2019	0:21:18	Bypass	1258	516	132	320	290
150.600	140	10/14/2019	10:56:36	Turbine	1565	1321	132	0	290
150.600	137	10/14/2019	15:05:40	Bypass	1712	936	132	354	290
150.600	126	10/14/2019	15:42:01	Turbine	1550	802	132	326	290
150.380	102	10/14/2019	16:17:23	Bypass	1550	802	132	326	290
150.360	37	10/14/2019	16:19:09	Bypass	1550	802	132	326	290
150.380	85	10/14/2019	16:53:41	Spill	1342	415	132	505	290
150.360	45	10/14/2019	17:29:46	Bypass	1342	415	132	505	290
150.380	75	10/14/2019	17:36:46	Turbine	1202	404	132	376	290
150.360	32	10/14/2019	18:32:42	Turbine	1182	414	132	346	290

Frequency	ID	Passage			Reported cfs				
		Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
150.360	34	10/14/2019	23:59:40	Turbine	1387	750	132	215	290
150.360	11	10/15/2019	1:00:43	Turbine	1467	861	132	184	290
150.360	25	10/15/2019	9:12:04	Downtown	1544	930	132	192	290
150.360	16	10/15/2019	16:02:50	Turbine	1514	931	132	161	290
150.600	149	10/16/2019	13:47:45	Turbine	1331	656	132	252	290
150.380	84	10/16/2019	20:21:18	Bypass	1523	802	132	299	290
150.380	81	10/17/2019	1:33:10	Bypass	1639	766	132	451	290
150.380	70	10/17/2019	4:13:10	Turbine	2990	2400	132	168	290
150.380	110	10/17/2019	4:16:57	Turbine	2990	2400	132	168	290
150.380	103	10/17/2019	4:46:22	Turbine	3858	2866	132	570	290
150.600	129	10/17/2019	4:47:56	Turbine	3858	2866	132	570	290
150.380	95	10/17/2019	4:50:24	Turbine	3858	2866	132	570	290
150.600	112	10/17/2019	5:01:24	Turbine	3858	2866	132	570	290
150.360	23	10/17/2019	5:02:19	Bypass	3858	2866	132	570	290
150.360	48	10/17/2019	5:08:50	Turbine	3858	2866	132	570	290
150.380	106	10/17/2019	5:08:53	Turbine	3858	2866	132	570	290
150.380	94	10/17/2019	5:13:05	Bypass	3858	2866	132	570	290
150.600	115	10/17/2019	5:14:24	Bypass	3858	2866	132	570	290
150.380	82	10/17/2019	5:47:32	Turbine	3966	2886	132	658	290
150.360	17	10/17/2019	6:06:50	Turbine	3966	2886	132	658	290
150.360	20	10/17/2019	6:52:11	Turbine	3920	3111	132	387	290
150.360	19	10/17/2019	7:01:11	Turbine	3920	3111	132	387	290
150.600	123	10/17/2019	7:15:30	Turbine	3920	3111	132	387	290
150.360	18	10/17/2019	7:26:13	Turbine	3920	3111	132	387	290
150.380	107	10/17/2019	17:23:22	Turbine	4015	3148	132	445	290
150.360	22	10/17/2019	17:36:23	Turbine	4140	3305	132	413	290
150.600	125	10/17/2019	19:53:59	Turbine	4289	3416	132	451	290
150.380	92	10/17/2019	20:17:37	Turbine	4289	3416	132	451	290
150.600	120	10/18/2019	1:05:56	Turbine	4220	3178	132	619	290

Frequency	ID	Passage			Reported cfs				
		Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
150.600	158	10/18/2019	7:11:57	Turbine	4048	3131	132	495	290
150.380	100	10/18/2019	7:19:50	Turbine	4048	3131	132	495	290
150.360	59	10/18/2019	7:42:33	Turbine	4333	3640	132	271	290
150.380	64	10/18/2019	8:48:12	Turbine	4749	4090	132	237	290
150.600	151	10/18/2019	10:15:06	Turbine	5075	4094	132	560	290
150.600	154	10/18/2019	12:01:18	Turbine	5410	2242	132	2746	290
150.600	127	10/18/2019	12:02:08	Spill	5410	2242	132	2746	290
150.600	122	10/18/2019	12:02:30	Turbine	5410	2242	132	2746	290
150.360	31	10/18/2019	12:03:59	Spill	5410	2242	132	2746	290
150.600	139	10/18/2019	15:20:09	Turbine	5535	4520	132	593	290
150.360	42	10/18/2019	16:19:50	Spill	5535	4552	132	561	290
150.360	60	10/18/2019	16:20:16	Spill	5535	4552	132	561	290
150.360	47	10/18/2019	16:20:16	Spill	5535	4552	132	561	290
150.380	79	10/18/2019	16:20:53	Turbine	5535	4552	132	561	290
150.380	77	10/18/2019	16:20:54	Turbine	5535	4552	132	561	290
150.360	43	10/18/2019	16:27:27	Turbine	5535	4552	132	561	290
150.380	88	10/18/2019	16:48:34	Spill	5530	4569	132	539	290
150.380	98	10/18/2019	16:49:06	Turbine	5530	4569	132	539	290
150.600	134	10/18/2019	17:10:13	Turbine	5530	4569	132	539	290
150.600	152	10/18/2019	18:07:11	Turbine	5530	4555	132	553	290
150.380	99	10/18/2019	18:13:03	Spill	5530	4555	132	553	290
150.360	36	10/18/2019	18:20:38	Spill	5530	4555	132	553	290
150.380	80	10/18/2019	18:22:47	Spill	5530	4555	132	553	290
150.380	97	10/18/2019	18:27:36	Spill	5530	4555	132	553	290
150.380	61	10/18/2019	18:53:15	Spill	5525	4542	132	561	290
150.360	50	10/18/2019	20:23:41	Turbine	5490	4457	132	611	290
150.380	90	10/18/2019	21:50:28	Turbine	5485	4554	132	509	290
150.600	114	10/18/2019	23:12:45	Turbine	5860	5091	132	348	290
150.360	49	10/18/2019	23:12:46	Turbine	5860	5091	132	348	290

Frequency	ID	Passage			Reported cfs				
		Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
150.600	116	10/18/2019	23:15:52	Turbine	5860	5091	132	348	290
150.380	63	10/19/2019	0:01:45	Turbine	6335	5372	132	541	290
150.360	58	10/19/2019	0:03:30	Turbine	6335	5372	132	541	290
150.360	46	10/19/2019	0:33:29	Turbine	6585	5448	132	715	290
150.600	160	10/19/2019	0:46:37	Turbine	6585	5448	132	715	290
150.600	130	10/19/2019	0:56:41	Turbine	6585	5448	132	715	290
150.380	93	10/19/2019	6:58:37	Turbine	6740	5512	132	806	290
150.380	109	10/19/2019	7:37:48	Turbine	6740	5522	132	796	290
150.600	155	10/19/2019	10:54:54	Turbine	6655	5512	132	721	290
150.380	65	10/19/2019	12:55:15	Turbine	6440	5285	132	733	290
150.380	89	10/21/2019	14:51:42	Turbine	3795	2855	132	518	290
150.380	101	10/23/2019	20:16:53	Turbine	4230	3373	132	436	290
150.600	142	10/23/2019	20:19:03	Turbine	4230	3373	132	436	290
150.600	145	10/23/2019	20:47:13	Turbine	4210	3073	132	715	290
150.360	53	10/23/2019	21:02:07	Turbine	4210	3073	132	715	290
150.380	104	10/23/2019	21:10:52	Turbine	4210	3073	132	715	290
150.360	51	10/23/2019	21:57:45	Turbine	3910	2755	132	732	290
150.380	74	10/23/2019	22:48:48	Turbine	3660	2595	132	643	290
150.380	73	10/24/2019	0:48:40	Turbine	3510	2349	132	739	290
150.380	76	10/24/2019	2:26:11	Turbine	3540	2319	132	799	290
150.600	121	10/24/2019	19:52:46	Turbine	4255	3322	132	512	290
150.600	131	10/24/2019	21:53:30	Turbine	4259	3336	132	500	290
150.380	86	10/25/2019	0:52:07	Spill	4589	3659	132	508	290
150.600	150	10/25/2019	5:23:18	Turbine	4709	3756	132	530	290
150.600	141	10/25/2019	6:58:53	Turbine	4684	3764	132	498	290
150.360	55	10/25/2019	7:29:32	Turbine	4684	3764	132	498	290
150.380	72	10/25/2019	14:35:58	Turbine	4755	3774	132	559	290
150.600	132	10/25/2019	21:00:26	Bypass	4631	3724	132	485	290
150.600	128	10/26/2019	7:04:55	Turbine	4285	3434	132	429	290

Frequency	ID	Passage			Reported cfs				
		Date	Time	Route	Inflow	Turbine	Bypass	Spill	Downtown
150.600	135	10/31/2019	17:07:14	Turbine	6580	5118	132	931	400

Lowell Hydroelectric Project (FERC No. 2790)

Fish Passage Survival Study

Prepared For
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Table of Contents

List of Tables

List of Figures

1 Introduction

To support the relicensing of the Lowell Hydroelectric Project (Lowell or Project), a desktop review to assess the potential survival of fish passing downstream through turbine units associated with the Project was performed. This Fish Passage Survival Study was identified in the Revised Study Plan (RSP) submitted by Boott Hydropower, LLC (Boott) to the Federal Energy Regulatory Commission (FERC) on January 28, 2019. The approach and methodology described in the RSP for the Fish Passage Survival Study was approved without modifications by FERC in its Study Plan Determination (SPD) letter dated March 13, 2019. The January 28, 2019 RSP indicated that Project turbines in the E.L. Field, Bridge Street, Hamilton and John Street powerhouses would be evaluated as part of the Fish Passage Survival Study. Boott has indicated that Final License Application for the Project (due to FERC by April 30, 2021) will exclude the Bridge Street, Hamilton and John Street stations as part of the Project in the future license. As a result, this report was prepared on behalf of Boott to provide a description of the objectives, methodologies and results of the desktop based fish passage survival evaluation to characterize potential effects to outmigrating diadromous fish species associated with the two turbine units housed in the E.L. Field powerhouse on the mainstem of the Merrimack River.

2 Study Goals and Scope

2.1 Goals and Objectives

The goal of this study was to assess the potential survival of fish passing downstream through the E.L. Field turbines and to inform estimates of Project passage survival for emigrating diadromous fish species (adult and juvenile American shad, river herring, and American eel). Specific objectives for this study were to:

- Assess the potential for impingement for the target species and life stages;
- Assess the potential for entrainment for target species and life stages;
- Conduct a desktop survival analysis to estimate passage survival of target species and life stages for each active turbine type; and
- Assess total Project survival for the target species and life stages.

2.2 Scope

This Fish Passage Survival Study provides the following:

- A description of the Project reservoir, intake structure, turbine units, and operational regime;
- A summary of available fisheries information recently collected within the Project area as well as a summary of recent diadromous fish species returns to the Project;
- An overview of the life history and habitat requirements for three target fish species identified in the RSP (i.e., American shad, river herring, and American eel);

- An assessment of impingement and entrainment potential as a function of (1) the existing rack spacing, (2) calculated approach velocities, (3) the physical dimensions of target fish species, and (4) the swim capabilities (i.e., burst speed) of target fish species;
- A review of information contained in the 1997 Electric Power Research Institute (EPRI) database to provide a summary of (1) the size class composition of target fish species, (2) entrainment densities of target fish species, and (3) calculated survival rates of target species for the subset of hydroelectric projects comparable to the Project;
- The calculation of site-specific turbine passage survival rates for target fish species using the USFWS Turbine Blade Strike Analysis Tool (TBSA); and
- The use of recently collected, species-specific, proportional route selection data to calculate an estimate of total project survival.

3 Methods

This study addresses the qualitative classification of impingement, entrainment, and the probability of turbine passage survival at the Project using a review of relevant biological criteria and physical Project characteristics for three diadromous fish species. Factors that can influence the potential for impingement or entrainment at a hydropower project include structural characteristics such as the size and depth of the intake structure, the velocity of water as it enters the intake structure, the location of the intake structure relative to fish habitat, and the biological and behavioral characteristics (e.g., size, movement or migration patterns, and habitat preferences) of the specific life stages of fish species of interest. The likelihood of impingement is also highly dependent on the physical features and water velocities found at or near the trash racks along with species-specific physiological capabilities (i.e., swim speed). Turbine survival rates are primarily affected by engineering factors such as the amount of head differential of a turbine, its number of blades, rotational speed, hydraulic capacity, and the length of an entrained fish.

3.1 Project Impoundment, Intake, and Turbine Description

The first step in the evaluation of the potential for fish impingement and entrainment was to describe the physical features of the impoundment, E.L. Field intake structure, and turbine units that will affect entrainment, impingement and turbine passage survival. Project dimensions were obtained from available engineering drawings of the Project. Tables 3-1 and 3-2 summarize pertinent Project and turbine parameters and are further described in Section 4.1.

3.2 Life History and Habitat Requirements of Target Fish Species

A description of the life history, habitat requirements, and behavior of fish species was compiled to determine the likelihood of presence near the Project intakes and to evaluate entrainment potential. The "Traits Based Assessment" of Čada and Schweizer (2012) was used to qualitatively assess the potential entrainment risk for fish species, which considers each species' primary location within the Project, preferred habitat, local movements and reproductive strategy. Species-specific behavioral requirements determine if and when a given life stage interacts with intake operation. The potential for each species to be susceptible to entrainment can be determined based on their life history characteristics in relation to the location of the Project's intake structure.

Categories of entrainment potential based on the likelihood that a fish species/life stage will be located near the intake structures are described as:

- None - species/life stage (e.g., adult, spawning, or juvenile) are not known to prefer the habitat near the intake structures
- Minimal - species may only occasionally be found occupying the habitat near the intake structures
- Moderate - species routinely or seasonally found occupying the habitat near the intake structures
- High - species likely to be found occupying the habitat near the intake structures

3.3 Entrainment Potential of Target Fish Species

The distance between bars on a trash rack (i.e., clear spacing) can affect the likelihood of an individual fish being excluded from moving through the trash rack and entering the turbine intakes. Fish species and life stages with a body width greater than the clear spacing are physically excluded from passing through a trash rack and becoming entrained. Proportional estimates of body width to total length (scaling factor) were compiled by Smith (1985) for a suite of fish species. These species-specific scaling factors were used to determine the minimum length of each species excluded from the turbines by the intake trash rack spacing. The clear spacing values were divided by the scaling factors to calculate the minimum length for each target species that would be excluded at the Project.

3.4 Electric Power Research Institute (EPRI) Entrainment Database Review

The Electric Power Research Institute (EPRI) 1997 entrainment database provides results from entrainment field studies conducted at 43 hydroelectric facilities east of the Mississippi River using full-flow tailrace netting. The database contains site characteristics of each of these facilities, as well as the total number of individuals of each species collected at each of the sites. The species counts are separated into variable size classes ranging from 2 to 30 inches.

A comparison of the EPRI entrainment database was made to provide a literature based assessment to compare with potential entrainment at the Project. To do so, the EPRI database was filtered for characteristics that match or are within a comparable range to those found at the Project which included the following:

1. Plants must be operated in run-of-river mode;
2. Total powerhouse hydraulic capacity must be within ±25% of the existing 6,600 cubic feet per second (cfs) capacity at Lowell (i.e. 4,950 to 8,250 cfs);

3. Trash rack clear spacing must be equal to or greater than the existing 7.25 inch rack spacing at Lowell; and
4. Entrainment data for fish species being considered at Lowell (i.e., American shad, river herring, and American eel) must be available.

Assuming one or more comparable projects were available from the EPRI database, collection totals of the Lowell target species from that set of locations were summarized by size class. In addition, the size class composition of the total number collected was summarized for each target species.

3.5 Impingement Potential of Target Fish Species

The ability for an individual fish to avoid being impinged or entrained at a powerhouse intake often depends on its swimming performance (Castro-Santos and Haro 2005). The swimming performance is directly related to the size of an individual fish; however, the swimming capability also varies among species based on morphological differences. Although there is no standard method that defines how swimming performance is measured, three commonly used definitions or types of swim speed are described in the scientific body of literature for fish (Katopodis and Gervais 2016). The three swim speed types, cruising, prolonged, and burst, are described as the following:

- Cruising or sustained swim speeds can be maintained indefinitely (Bain and Stevenson 1999);
- Prolonged swim speeds can be maintained between 5 and 8 minutes (Bain and Stevenson 1999); and
- Burst (also called startle, darting or sprint) swim speeds can be maintained for less than 20 seconds (Beamish 1978).

Burst swim speeds were used to assess if a fish can adequately escape involuntary impingement or entrainment. If a fish has a greater burst swim speed than the turbine intake approach velocity, it is capable of moving away from the intake flow field to avoid interaction. To assess swimming capabilities for the target fish species of interest, burst swim speeds were compiled from the available scientific literature.

To ascertain whether or not a certain size fish of a particular species is likely to be impinged or entrained, the burst swim speeds were compared to the calculated approach velocity of the intake trash racks at the maximum hydraulic capacity of the Project. The approach velocity at the Project intake was calculated using the velocity equation:

$$V = Q/A$$

Where:
Q = flow rate (cfs);
V = approach velocity (feet per second (fps)); and
A = area (square feet (ft^2)).

Fish species and sizes whose burst swim speeds are less than the approach velocity at the Project intake are susceptible to impingement at the trash racks if their body widths are greater than the trash rack spacing. If the body width of a fish is less than the trash rack spacing and its burst swim speed is less than the approach velocity, it is more susceptible to entrainment.

3.6 Turbine Survival Evaluation

To estimate survival of fish that entrain and pass through Project turbines, theoretical predictions were used to estimate a survival rate using a blade-strike model developed by the Department of Energy (Franke et al. 1997) that uses various turbine, fish and operations characteristics of a hydroelectric project to calculate a turbine blade strike and survival probability. This model was further modified by the United States Fish and Wildlife Service which produced the Turbine Blade Strike Analysis (TBSA) Tool that estimates the fraction of a population of fish that are killed by blade strike passing through a hydroelectric project (Towler and Pica 2018). TBSA creates a normally distributed population of fish described by its number, mean length, and standard deviation of length that are routed through hazards at a hydroelectric project, e. g., a turbine. Monte Carlo simulations are performed to determine the percentage of individuals subjected to turbine blade strike.

The TBSA is informed with turbine parameter values specific to the Project and calculated using methods outlined in Franke et al. (1997). The probability of blade strike in the model is based on several factors, including the number of runner blades, fish length, runner blade speed, turbine type, runner diameter, turbine efficiency, and total discharge. These factors are inputs into the model which predicts survival for a fish of a designated length, regardless of species. The TBSA model was used to predict turbine passage survival estimates expected for each target species in the Project area and up to the maximum lengths (rounded to whole inch) for each target fish species that could entrain through the existing trash rack spacing at the Project. The TBSA model simulations for American shad and river herring were run using a correlation factor (λ) of 0.2 which is the recommended conservative value (Towler and Pica 2018). An interim recommendation from the USFWS Fish Passage Engineering Group suggests the use of $\lambda = 0.4$ for American eels based on an analysis which evaluated the effect of varied TBSA correlation factors to adjust modeled estimates to match results from a series of empirical eel passage studies.

3.7 Electric Power Research Institute (EPRI) Turbine Survival Database Review

Similar to the comparison of the EPRI entrainment database review, the EPRI (1997) turbine survival database was reviewed to provide an equitable literature-based comparison of the turbine survival estimates calculated for the Project. To do so, the EPRI database was filtered for characteristics that match or are similar to those found at the Lowell Project. The following characteristics were selected to identify comparable projects:

1. Turbine type must be Kaplan;
2. Turbine hydraulic capacity must be within ±25% of the existing 3,300 cfs capacity at Lowell (i.e. 2,475-4,125 cfs);

3. Head rating must be within ±25% of the existing 39 feet of head at Lowell (i.e. 29 to 49 feet); and
4. Entrainment data for fish species being considered at Lowell (i.e., American shad, river herring, and American eel) must be available.

Assuming one or more comparable projects were identified within the EPRI survival database, the immediate, 24-hour, and 48-hour survival estimates were identified, if available, as they provided a range of time post-turbine passage for evaluating each species.

3.8 Qualitative Assessment of Entrainment and Turbine Survival Potential

Data collected during the literature review and site-specific evaluation process (i.e., habitat and life history, swim speeds, and turbine survival model estimates) were used to compile a qualitative assessment of the potential entrainment of target fishes. The qualitative assessment used a multi-step rank of:

- High (H)
- Moderate (M)
- Low (L)

Desktop impingement and entrainment assessments assigned an overall entrainment potential rank to each of the relevant life stages of target species considered based on consideration of habitat and life history, swim speed relative to intake velocity, and minimum exclusion lengths relative to trash rack spacing. In general, fish with life history attributes that include obligatory downstream migration are given a rating of ‘High’, while those with juvenile life history stages placing them in the vicinity of the intakes or as adults with swim speeds not necessarily greater than the approach velocity are labeled as ‘Moderate’ risk. Species with life history attributes that generally keep them away from the intakes or fish that had a burst swim speed greater than the intake velocity are listed as a ‘Low’ risk for entrainment. In relation to swim speed, regardless of life stage, fish are considered ‘High’ risk if the maximum burst speed does not exceed the intake velocity, ‘Moderate’ risk if the intake velocity falls within the range of burst swim speed, and ‘Low’ risk if the burst swim speed completely exceeded the intake velocity.

The entrainment potential classification for trash rack spacing depended on the minimum body length exclusion results. If the minimum exclusion length for the existing trash rack spacing was longer than the standard length for a juvenile or adult (i.e., many individuals of that species and life stage are likely to be shorter than the minimum exclusion length) it received a “High” entrainment risk potential. A “Moderate” entrainment risk potential was applied when the minimum exclusion length overlapped with a portion of the individuals that would be expected to achieve that length by the life stage indicated. A “Low” entrainment risk potential was applied when the minimum exclusion length of a trash rack was less than the standard length of the life stage being considered.

The risk categories for the turbine survival potential were based on the TBSA model estimates. TBSA results were converted to a qualitative ranking system similar to Winchell et al. (2000) for standard lengths of the juvenile and adult life stages. “High” survival potential was applied to estimates greater than 95%, “Moderate” for estimates between 85-95%, and “Low” for estimates less than 85%.

Table 3-1: Lowell Project impoundment and intake characteristics

Site Characteristic	Lowell Project	
Normal Full Pond Elevation (feet (ft))	92.2	
Operating Mode	Run-of-River	
Surface Area at Normal Full Pond (acres)	720	
Total Storage Volume (acre-feet)	3,600	
Impoundment Length (miles)	23	
Total Hydraulic Capacity (cfs)	6,600	
	Unit 1	**Unit 2**
Upper Rack Elevation (ft)	72.5	72.5
Bottom Rack Elevation (ft)	40.5	40.5
Trash Rack Spacing (in)	7.25	7.25
Trash Rack Height (ft)	32	32
Trash Rack Width (ft)	32.35	32.35
Trash Rack Surface Area (sq. ft)	1,034.72	1,034.72
Maximum Turbine Discharge (cfs)	3,300	3,300
Intake velocity (fps)	3.2	3.2

Table 3-2: Lowell Project turbine characteristics

Turbine Parameter	E.L. Field Turbines	
	1	2
Turbine Type	Kaplan	Kaplan
Number of Blades	5	5
Runner Diameter (ft)	12.7	12.7
Head (ft)	39.0	39.0
Rotational Speed (rpm)	120.0	120.0
Discharge at Max Capacity (cfs)	3,300	3,300
Discharge at Optimum Capacity (cfs)	2,683	2,683
Turbine Efficiency (%)	92.8	92.8

4 Results

4.1 Lowell Project Description

4.1.1 Project Location and Facilities

The Lowell Hydroelectric Project (Project) is located at the Pawtucket Dam on the Merrimack River in the City of Lowell in Middlesex County, Massachusetts. The Project is located approximately 11 miles upstream of the Lawrence Project (FERC No. 2800) and approximately 30 miles downstream of the Amoskeag Dam (a development of the Merrimack River Project, FERC No. 1893) in New Hampshire. The 116-mile-long Merrimack River begins at the confluence of the Winnipesaukee and Pemigewasset Rivers in Franklin, New Hampshire; flows southward into Massachusetts; and then travels northeast until it discharges into the Atlantic Ocean. The Project includes a single powerhouse, the 15.0-megawatt (MW) Eldred L. Field (E.L. Field) powerhouse constructed in 1985-1986 during Project redevelopment. The total installed capacity of the project is 15,012 kW.

The E.L. Field powerhouse utilizes the existing Pawtucket Dam and the first 2,200 feet of the Northern Canal. The powerhouse is located close to the canal, downstream of the University Avenue Bridge (also called the Moody Street Bridge), with an intake structure drawing water from the Northern Canal. A 440-foot tailrace channel, surge gate and fish passage facilities comprise other major E.L. Field powerhouse features.

The Project also includes the Guard Lock and Gates Facility ("Guard Locks") and the approximately 1,600-foot-long portion of the Pawtucket Canal leading from the Project impoundment to the Guard Locks.

4.1.2 Impoundment Characteristics

The Project operates in a run of river mode and has no usable storage capacity. The pond formed by the Pawtucket Dam extends approximately 23 miles upstream to Moore's Falls in Litchfield and Merrimack, New Hampshire. At the normal pond elevation of elevation of 92.2 feet NGVD 29 (crest of pneumatic crest gate), the surface area of the pond is reported to encompass an area of about 720 acres. The gross storage capacity between the normal surface elevation of 92.2 feet NGVD 29 and the minimum pond level of 87.2 feet NGVD 29 is approximately 3,960 acre-feet.

4.1.3 Powerhouse, Intake Structure, and Trash Racks

The E.L. Field powerhouse is a reinforced concrete structure. The powerhouse is approximately 109-feet-long by 96-feet-wide and houses two generating units with a total authorized generation of 15.0 MW. Each intake is equipped with trash racks with a clear spacing of 7.25 inches. Each unit intake rack covers an area of 1,034.72 ft^2. The powerhouse incorporates a separate conventional intake structure for each of the station's two identical units. Each intake is equipped with trashracks; intake and draft tube gate slots with permanent or bulkhead style gates for emergency shutdown and dewatering purposes are also provided. The powerhouse is equipped with a traversing trash rake to remove debris at the intake.

4.1.4 Downstream Bypass

The downstream fishway at the powerhouse consists of an adjustable-flow sluiceway and bypass adjacent to the intake headwall. Downstream migrants entering the bypass are quickly sluiced into an enlarged and deepened plunge pool located in the bypassed river reach next to the powerhouse. Natural channel braids in the riverbed allow emigrants to move downstream to the mainstem of the river, at the confluence of the river reach and tailrace.

4.1.5 Turbines

The Lowell Project includes two identical horizontal Kaplan turbines housed in the E.L. Field powerhouse with a total installed generating capacity of 15.0 MW. Each unit has a maximum hydraulic capacity of 3,300 cfs. See Table 3-2 for unit specifications.

4.1.6 Project Operations

The Project is operated in a ROR mode using the automatic pond level control capability of the E.L. Field Powerhouse. Boott normally operates the Project to maximize flow through the available units at the E.L. Field Powerhouse, then routes any additional flows through the Pawtucket Canal system. When river flows exceed the hydraulic capacity of the E.L. Field units (approximately 3,300 cfs per unit or 6,600 cfs for both units), excess flows up to approximately 2,000 cfs are routed through the downtown canal system. Any flows in excess of approximately 9,000 cfs are passed over the Pawtucket Dam spillway. The Project is required to maintain a minimum flow equal to 1,990 cfs or inflow, whichever is less, as measured immediately downstream from the Project.

4.2 Life History and Habitat Requirements of Target Fish Species

The Merrimack River watershed is home to a diverse assemblage of approximately 50 species of fishes, including cold water and warm water species, diadromous species, and introduced gamefish and non-gamefish species. The Fish Assemblage Study, conducted by Normandeau during the spring, summer and fall of 2019, consisted of boat electrofishing and gill net sampling to characterize the fish community in the Project impoundment. When all sample locations and gear types are considered, a total of 1,847 individuals representing twenty-two fish species were collected from the Lowell impoundment during 2019. The majority of fish collected were resident fish species with centrarchid and cyprinid species being most abundant. A summary of the fish captured in the 2019 study is provided in Table 4-1.

Diadromous species inherently have the highest likelihood of direct interaction with the Project as they are obligatory migrants which require passage upstream and downstream at the Project to complete their life cycles. Observations of diadromous species upstream of the Lowell Project during the Fish Assemblage Study were limited to observations of juvenile alewives during the summer and fall sampling events as well as a limited number of juvenile American eels during the three seasonal periods. Despite limited observations of diadromous fish species during the Fish Assemblage Study, American shad and river herring are documented annually utilizing the upstream passage facilities at the Project (i.e., the E.L. Field fish lift and Pawtucket Dam fish ladder). Camera-based counts of diadromous fish returns at Lowell conducted annually since 2018 are summarized in Table 4-2. For the period 2018-2020, an annual average of 8,232 American shad and 179,239 adult river herring have volitionally passed upstream of the Project. In addition, Boott has quantified upstream passage of juvenile American eels since 2014. A total of 974 individuals were passed upstream during the 2020 passage season. Due to their migratory requirements and presence in the Project area, the target species for this analysis included American shad, river herring (i.e., alewife and blueback herring), and American eel.

4.2.1 American Shad

American shad are an anadromous, highly migratory, coastal pelagic, schooling species that range from northern Labrador to Florida. They are the largest member of the herring family (Clupeidae), and females are larger than males at all ages. Mature male shad range from 12 to 17.5 inches (30.5 - 44.7 cm) and mature females range from 15 to 19 inches (38.3 - 48.5 cm) (Stier and Crance 1985). Males mature at age 4, while females mature at ages 5-7. The maximum age is 11 years. Spending the majority of their life in the sea, mature adults migrate upriver to natal rivers to spawn from May to July. Although shad spawn in freshwater, there is no apparent required distance upstream of brackish water (Stier and Crance 1985). American shad return downstream to marine waters soon after spawning. American shad are known to be prolific spawners, with females producing up to 600,000 eggs. After broadcast-spawning, fertilized eggs sink to the bottom, where they become lodged in rubble and water-harden. Hatching typically occurs after 1-2 weeks, dependent on water temperature. Larvae may remain in freshwater, or drift into brackish water and grow rapidly, transforming into juveniles approximately 4 to 5 weeks after hatching (Stier and Crance 1985). During the first fall of their life, juvenile shad leave fresh water and migrate in schools downstream to the sea. Upon reaching the ocean, they become long-range coastal migrants. While at sea, American shad form large schools and migrate vertically to feed on zooplankton.

Period and life stages of greatest likelihood of exposure to intakes at the Lowell Project:

- June-July: Following spawning at upstream locations, adult American shad migrate downstream to return to marine habitat

- September-October: Following time spent in upstream rearing habitat, juveniles migrate downstream to enter marine habitat.

4.2.2 River Herring (Alewife and Blueback Herring)

Alewife and blueback herring are clupeid species very similar in appearance and behavior. Since it is difficult to distinguish between the two species, they are frequently considered together under the collective term “river herring”. They are anadromous, euryhaline, coastal, and pelagic fish (Bigelow and Schroeder 1953, Cooper 1961, Collette and Klein-MacPhee 2002). Alewife range from the St. Lawrence River, Canada to North Carolina (Neves 1981), and mature between ages 3-6, and are typically 10 to 11 inches (250-280 centimeters (cm)) in length (Bigelow and Schroeder 1953). They form large schools during their spring spawning migrations from the ocean to coastal rivers. Spawning migrations occur in a south-to-north progression as water temperatures warm in the spring, typically taking place in late April to mid-May in the Gulf of Maine (Bigelow and Schroeder 1953). Blueback herring have a greater geographical range than alewife, ranging from Cape Breton, Nova Scotia to Florida. They also spawn in early June in the Gulf of Maine, roughly four weeks later in the season than alewife. Similar to alewife, blueback herring mature between the ages of 3-6 years. Adults require little or no current for spawning, utilizing ponds, lakes, or slow-flowing riverine areas at water temperatures of 13° to 20°C (55° to 68° F) (Otto et al. 1976, Wyllie et al. 1976, Kellogg 1982). There appears to be little preference for sediment type as spawning has been observed over hard sand, gravel, stone, detritus-covered bottoms and among sticks and vegetation (O'Dell 1934, Havey 1961). Eggs are about 1 millimeter (mm) in diameter, adhesive, and require 3 to 6 days to hatch over a temperature range of 16° to 22° C (61 to 72 °F). Larvae hatch at 0.1 to 0.2 inches (3 to 5 mm) in total length and become juveniles at approximately 0.8 inches (20 mm; Cianci 1969).

River herring have declined in recent years. The Atlantic States Marine Fisheries Commission reports that river herring stocks are depleted to near historic lows along the Atlantic coast (ASMFC 2012).

Period and life stages of greatest likelihood of exposure to intakes at the Lowell Project:

- May-June: Following spawning at upstream locations, adult river herring migrate downstream to return to marine habitat
- September-October: Following time spent in upstream rearing habitat, juveniles migrate downstream to enter marine habitat.

4.2.3 American Eel

The American eel is a catadromous species common in rivers, streams, lakes, tidal marshes and estuaries throughout the Northern Atlantic. It is native to Atlantic coastal waters from Newfoundland to South America. Males typically reach sizes up to 24 inches (61 cm) in length, while females reach larger sizes of 30 to 40 inches (76 to 102 cm). They are a long lived species, able to reach up to 30 years of age. Eels spend the majority of their lives in fresh water, but upon reaching maturity, they descend to the Atlantic Ocean in the fall. They migrate to the Sargasso Sea and spawn in February to April, dying shortly after. Females are prolific egg producers, with one female producing up to 20 million eggs. After spawning, leptocephalus larvae drift at sea for up to a year, and are gradually transported north by the Gulf Stream. As they approach the North American coast, the larvae metamorphose into unpigmented juveniles known as glass eels. During this metamorphosis, the body becomes cylindrical, the jaw and head are altered and the digestive tract becomes functional (Collette and Klein-MacPhee 2002). Glass eels appear in southern New England in March at 2 to 4 inches (~ 50-100 mm) in length. They migrate upstream at night into freshwater where they feed, and become pigmented; this is known as the "elver" life stage. They grow slowly until they sexually mature, which can take up to 20 years. However, eels are known to reach maturity as small as 11 inches (28 cm) for males and 18 inches (46 cm) for females. Once sexual maturity occurs in late summer to early fall, the eel begins moving downstream, the eyes and pectoral fins enlarge, and feeding stops (Collette and Klein-MacPhee 2002). Specific spawning migration routes and egg life history information are currently unknown.

Period and life stages of greatest likelihood of exposure to intakes at the Lowell Project:

- September-November: Adult "silver" eels migrate downstream to begin spawning migration to the Sargasso Sea.

Table 4-1. Number of fish captured upstream of Pawtucket Dam by boat electrofishing and experimental gill net during spring, summer and fall sampling, 2019

Common Name	Spring	Summer	Fall	2019
	N	N	N	N
Alewife	0	21	92	113
American Eel	6	10	1	17
Black Crappie	2	2	1	5
Bluegill	24	77	21	122
Channel Catfish	0	1	0	1
Common Carp	1	3	1	5
Fallfish	34	34	75	143
Golden Shiner	1	5	7	13
Largemouth Bass	2	32	7	41
Lepomis spp.	1	3	0	4
Margined Madtom	3	5	1	9
Pumpkinseed	10	126	19	155
Redbreast Sunfish	137	196	45	378
Rock Bass	3	2	2	7
Sea Lamprey	7	6	8	21
Smallmouth Bass	127	50	50	227
Spottail Shiner	160	79	185	424
Tessellated Darter	14	14	3	31
Walleye	0	1	0	1
White Perch	0	1	0	1
White Sucker	24	9	22	55
Yellow Bullhead	7	42	5	54
Yellow Perch	16	3	1	20
Total	**579**	**722**	**546**	**1847**

Table 4-2. Diadromous fish returns as documented using SalmonSoft recording software at the E.L. Field fish lift and Pawtucket Dam fish ladder for the period 2018-2020.

Net Upstream Passage at Lowell Project			
Year	River Herring	American Shad	American Eel
2018	311,867	14,046	49
2019	43,871	2,201	2
2020	181,979	8,450	2

4.3 Entrainment Potential of Target Fish Species

Minimum exclusion lengths for juvenile and adult migrant life stages for the existing trash rack clear spacing at the Lowell Project are presented in Table 4-3. Proportional estimates of body width to total length (scaling factor) collected from Smith (1985) were used to determine the minimum length of each target species that would be excluded from entraining through the trash racks present at the Lowell Project (minimum exclusion size = rack clear spacing/scaling ratio).

All of the calculated estimates yielded lengths for target species that are unlikely to be present in the Project (i.e., a length outside of the range expected for the species in the vicinity of the Lowell Project). For example, the minimum size of American shad predicted to be excluded by a 7.25-inch intake rack is 54.1 inches—a length not attained by this species. In all cases where the maximum size of the species did not exceed the minimum exclusion size, a designation of 'none' was applied (Table 4-3). The existing 7.25 inch clear rack spacing will not physically exclude target fish species considered for this evaluation from entrainment at the E.L. Field powerhouse

Table 4-3. Minimum length for target fish to be excluded from entrainment based on existing 7.25 inch trash rack spacing

Common Name	Scaling Factor for Body Width[1]	Typical Length (inches) for target species juveniles and adults potentially encountered at the Project		Calculated Minimum Exclusion Length (inches)*
American shad	0.134	Juvenile	2-6[1]	none
		Adult	15-23[2]	
River herring	0.105	Juvenile	1.5-6[1]	none
		Adult	9-13[3]	
American eel	0.037	Adult	25-41[4]	none

* "None" indicates that the calculated exclusion length exceeds the maximum length expected for the species at Lowell
1 Upper end of range based on 145 juvenile alosines handled as part of the Juvenile Alosine Downstream Passage Assessment; Lower end of range adopted from species review
2 Based on 544 adult American shad handled as part of the Upstream and Downstream Adult Alosine Passage Assessment
3 Based on 914 adult river herring handled as part of the Upstream and Downstream Adult Alosine Passage Assessment
4 Based on 162 adult eels handled as part of the Downstream American Eel Passage Assessment (Note Soucook River origin eels ranged 27-34 inches; St. Croix River origin eels ranged 24-41 inches)

4.4 Electric Power Research Institute (EPRI) Entrainment Database Review

The EPRI 1997 database was reviewed for comparable hydroelectric projects using the criteria presented in Section 3.4. Following exclusion of project locations with differing operational styles (i.e., not run-of-river) or capacities differing from Lowell by ±25%, a single location was identified (Table 4-4). Although the operating mode and total powerhouse capacity were comparable, the rack spacing at the Wisconsin River Diversion (2.2 inches) was considerably less than the relatively wide rack spacing present at Lowell (i.e., 7.25 inch clear spacing). Lacking a set of comparable hydroelectric projects, a qualitative comparison of existing entrainment data was not conducted as part of this Lowell analysis.

Table 4-4. Hydroelectric facilities identified within the EPRI (1997) entrainment database considered for comparison to the Lowell Project

Facility Name	Total Plant Capacity (cfs)	Operating Mode	Trash Rack Spacing (in)
Wisconsin River Division	5,150	ROR	2.2
Lowell	6,600	ROR	7.25

ROR = Run-of-river

4.5 Impingement Potential of Target Fish Species

A summary of burst swim speeds determined for adult and juvenile American shad and river herring and adult American eel is presented in Table 4-5. These data were obtained using the Swim Speed & Swim Time Tool[1] (Katopodis and Gervais 2016; Di Rocco and Gervais 2020). The expected size range for each species/life stage was evaluated relative to the data available in the Swim Speed & Swim Time Tool and five representative lengths were chosen for burst speed estimation from the database. For each species/life stage, the five representative lengths included the upper and lower bounds of the anticipated size range for the Project area as well as the 25th, 50th, and 75th percentile lengths within that range. Each unique species-length combination was input into the Swim Speed & Swim Time Tool and produced a relationship for swim speed and swim time for a particular body length. For each body length selected to be assessed for each species, the following estimates were recorded:

1. Speed (ft/s) achieved by 97.5% of individuals of species X at body length Y for 3 seconds;
2. Speed (ft/s) achieved by 87.5% of individuals of species X at body length Y for 3 seconds;
3. Speed (ft/s) achieved by 50% of individuals of species X at body length Y for 3 seconds;

[1] Available online at: http://www.fishprotectiontools.ca/speedtime.html

4. Speed (ft/s) achieved by 12.5% of individuals of species X at body length Y for 3 seconds; and

5. Speed (ft/s) achieved by 2.5% of individuals of species X at body length Y for 3 seconds.

It is understood that burst swim speeds may vary greatly among different fish species as well as among sizes of the same species. However, variation exists within individuals of the same species and size class. Katopodis and Gervais (2016) demonstrate ascending physical capabilities as a smaller portion of the test fish are represented by each speed rating. For example, 97.5% of Adult American shad in the 15 inch size class are expected to be capable of achieving a speed of 17.3 fps for a period of 3 seconds, while only 2.5% of American shad of the same size are expected to be able to achieve a speed of 26.8 fps for 3 seconds. For the purposes of this desktop evaluation values representing the 50th percentile of swim speed over a three second period were selected as representative of a fishes burst swim capability. The 50th percentile speed rating for the minimum, median, and maximum size of each of the target fish species and life stages is provided in Table 4-5. The full range of swim speed estimates for target fish species generated using the Swim Speed & Swim Time Tool are provided in Appendix A.

Figure 4-1 presents the estimated burst speeds for the target species and life stages relative to the calculated intake velocity under full generation at the E.L. Field powerhouse intake structure (3.2 fps). In general, target species whose burst swim speeds are less than the approach velocity at an intake are likely to be involuntarily impinged or entrained depending on the size of an individual and the intake rack spacing. Burst speeds for each of target species/life stages considered in this assessment that are in excess of the calculated intake velocity at the E.L. Field powerhouse suggests the potential for involuntary impingement or entrainment is low. Individuals with burst speeds less than the approach velocities at E.L. Field are more likely to be entrained than impinged as most will fit through the existing rack spacing of 7.25 inches (Section 4.3).

Table 4-5. Burst swim speed information compiled from scientific literature for target fish species

Common Name	Size potentially encountered the region (in)	Size included in burst speed estimate based on data availability	Burst Speed (fps) at minimum size[5]	Burst Speed (fps) at median size[5]	Burst Speed (fps) at maximum size[5]
American shad (Juv)	2-6[1]	2-6	5.2	8.4	11.2
American shad (Adult)	15-23[2]	10-15	16.2	19.0	21.5
River herring (Juv)	1.25-6[1]	1.25-6	3.6	7.8	11.2
River herring (Adult)	9-13[3]	9-12	15.1	16.7	18.4
American Eel	25-41[4]	21-45	11.0	14.9	18.4

1 Upper end of range based on 145 juvenile alosines handled as part of the Juvenile Alosine Downstream Passage Assessment; Lower end of range adopted from species review
2 Based on 544 adult American shad handled as part of the Upstream and Downstream Adult Alosine Passage Assessment
3 Based on 914 adult river herring handled as part of the Upstream and Downstream Adult Alosine Passage Assessment
4 Based on 162 adult eels handled as part of the Downstream American Eel Passage Assessment (Note Soucook River origin eels ranged 27-34 inches; St. Croix River origin eels ranged 24-41 inches)
5 Katopodis, C, and R Gervais. 2016. Fish Swimming Performance Database and Analyses. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/002., 550.

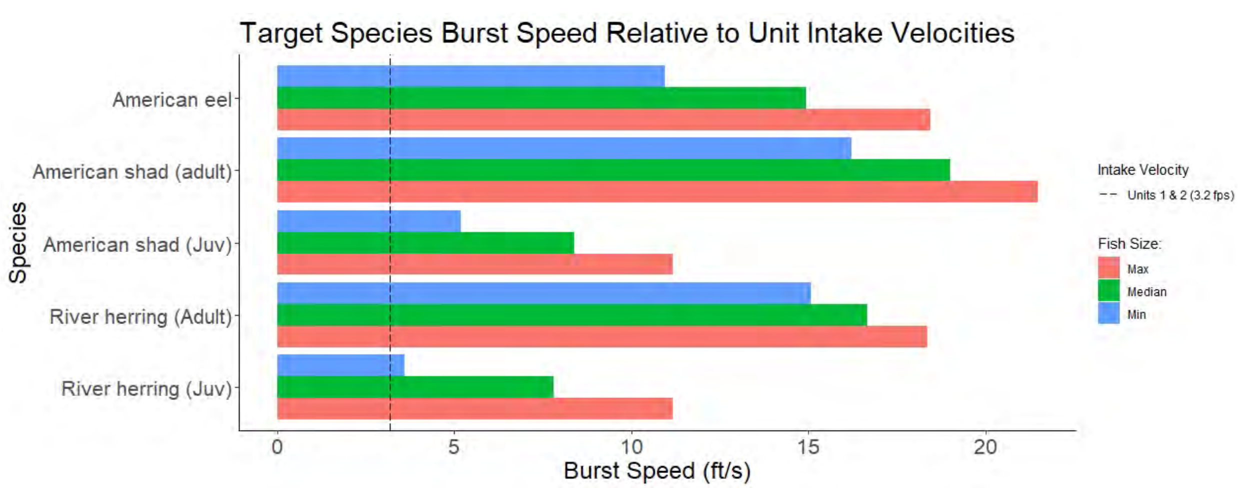

Figure 4-1. Burst swim speed of target fish species compared to calculated approach velocities at the Lowell intakes

4.6 Turbine Survival Evaluation

Table 4-6 provides a summary of the calculated TBSA turbine survival estimates for alosines (i.e., American shad and river herring) entrained through the E.L. Field Kaplan units. Survival values were estimated for the range of body lengths anticipated to be prone to entrainment based upon the minimum exclusion sizes presented in Table 4-3 as well as reasonable lengths expected to occur within the Project area. Estimates of turbine passage were inversely related to body length for each species/life stage considered with highest survival estimated for small juvenile shad or herring at 2 inches of length (~99%) and the lowest for adult American shad approaching 25 inches of length (~83%). A separate TBSA model was assembled for American eel which relied on recent USFWS guidance on the use of a varied correlation coefficient for that species (Table 4-7). The estimated range of survival for eels passing downstream through the E.L. Field turbines ranged from 71-39%. Similar to the trend observed for alosines, the rate of survival for adult eels was predicted to decrease as body size/length increased.

Table 4-6. TBSA predicted survival estimates for adult and juvenile American shad and river herring at the E.L. Field powerhouse.

Species/Life Stage	Size potentially encountered the region (in)	Body Length (Inches)							
		2 in	4 in	6 in	8 in	12 in	16	20	25
American shad (Juv)	2-6	98.6%	97.2%	95.9%					
American shad (Adult)	15-23						89.0%	86.4%	83.1%
River herring (Juv)	1.5-6	98.6%	97.2%	95.9%					
River herring (Adult)	9-13				94.8%	91.8%	89.0%		

Assumes full generation; λ = 0.2

Table 4-7. TBSA predicted survival estimates for adult American eels at the E.L. Field powerhouse.

Species/Life Stage	Size potentially encountered the region (in)	Body Length (Inches)						
		21	24	28	32	36	40	45
American eel (Adult)	25-41	71.2%	67.3%	61.8%	56.5%	51.7%	46.0%	39.1%

Assumes full generation; λ = 0.4

4.7 Electric Power Research Institute (EPRI) Turbine Survival Database Review

The EPRI 1997 survival database was reviewed for comparable hydroelectric projects using the criteria presented in Section 3.6. Following exclusion of project locations with differing turbine types (i.e., not Kaplan) or turbine unit capacities differing from Lowell by ±25%, a single location was identified (Table 4-8). Although the turbine style and capacity were comparable, the project head at Townsend Dam (16 feet) was considerably less than that at Lowell (i.e., 39 feet). In addition, entrainment survival data for the target species considered in this report were not available at Townsend Dam. Lacking a set of comparable hydroelectric projects, a qualitative comparison of existing entrainment survival data was not conducted as part of this Lowell analysis.

Winchell et al. (2000) provides a review of the EPRI (1997) database and a generalized summary of survival based on turbine type, runner speed, and fish size (Table 4-9). Winchell et al. (2000) reports mean survival rates (all fish species combined) for low speed axial flow (includes Kaplan) units to range from 95.4% for fish ≤ 4 inches to 87.2% for fish between 8 and 12 inches.

Table 4-8. Hydroelectric facilities identified within the EPRI (1997) turbine survival database considered for comparison to the Lowell Project

Facility Name	Turbine Type	Rated Head (ft)	Rated Flow (cfs) Per unit	Speed (rpm)	Runner Diameter (ft)	Runner Blades
Townsend Dam	Kaplan (Horizontal)	16	2,200	152	9.4	3
Lowell	Kaplan (Horizontal)	39	3,300	120	12.7	5

Table 4-9. Summary of fish survival rates by turbine type, speed, capacity and fish body size as compiled by Winchell et al. (2000)

Turbine Type	Runner Speed (rpm)	Hydraulic Capacity (cfs)	Fish Size (mm)	Average immediate survival (all species combined)		
				Minimum	Maximum	Mean
Axial Flow (Kaplan) Winchell (2000)	<300	636-1,203	<100	94.1%	98%	95.4%
		636-21,000	100-199	89.8%	98%	94.8%
		636-2,200	200-299	77.4%	97%	87.2%
		1203-2200	300+	86.8%	100%	93.4%

4.8 Qualitative Assessment of Entrainment and Turbine Survival Potential

Evaluating entrainment potential and subsequent survival for the target fish species required combining and synthesizing the species-specific behavioral traits, life stages, and swimming capabilities and comparing them to the Project's unique intake, water conveyance and infrastructure characteristics. The blending of these factors yielded a qualitative assessment of whether or not a target fish species will potentially entrain through the Project's intakes. In the event a fish becomes entrained, a secondary evaluation of the potential for that individual to survive passage through the Project's turbines depended primarily on its length and the physical parameters associated with the specific turbine. This final qualitative assessment took into consideration and summarized all of the factors that influenced entrainment and turbine passage and is presented in Table 4-10.

When the life history characteristics, behavior, and habitat use are considered, all species considered during this analysis (American eel, American shad, and river herring) are obligatory diadromous migrants. As such, they are required to pass the Project as part of their life cycle resulting in the classification of "high" entrainment potential for that category. All species/life stages considered in this assessment have the potential to become entrained through the existing 7.25 inch spaced racks because their body dimensions will permit them to fit through those openings. When the median burst swim speed rates are considered (Table 4-5), each species/life stage demonstrated potential to evade involuntary entrainment at Lowell. Only a portion of juvenile river herring in the low end of the expected size range for the species at Lowell would be expected to have a burst swim capability weak enough to be unable to avoid involuntary entrainment (Appendix A).

Outmigrating alosines are generally surface oriented as evidenced by their affinity for passing downstream of hydroelectric projects via overflow spillways or bypasses. That behavior may help to reduce the overall entrainment through the E.L. Field turbines at Lowell. Downstream bypass usage was quantified during the 2019 Juvenile Alosine Downstream Passage Assessment and 2020 Upstream and Downstream Adult Alosine Passage Assessment. Of the 99 radio-tagged juvenile alosines entering and passing downstream via the E.L. Field power canal, 17% utilized the existing downstream bypass facility and avoided turbine entrainment. Adult alosines which entered the Northern Canal upstream of the E.L Field intake structure exhibited higher rates of downstream bypass usage with 49% (97 of 200) of adult river herring and 52% (33 of 64) of adult American shad passing via the route.

Adult American eels are generally bottom oriented. Based on that generalized behavior during outmigration, their ability to fit through the existing rack spacing, and the presence of only a surface oriented downstream bypass it is expected that a high proportion of outmigrating eels which enter the Northern Canal upstream of the E.L. Field intake structure will entrain through the turbines. Entrainment of outmigrating silver eels was assessed during the 2019 Downstream American Eel Passage Assessment. During that study, 98.5% of tagged eels (134 of 136) which entered the Northern Canal were entrained at the E.L. Field turbine units.

The majority of individuals approaching the E.L. Field powerhouse are expected to be physically capable of avoiding involuntary entrainment due to their swimming capability relative to the intake velocity. However, it is still likely that individuals may voluntarily become entrained due to their need to migrate downstream to the marine environment. TBSA estimated survival rates for juvenile shad and river herring are expected to be high (>95%) whereas TBSA survival estimates for adults are classified as moderate (85-95%) for river herring to low (<85%) for larger bodied American shad. TBSA estimates of turbine survival for adult silver eels were low (<85%) over the full range of body lengths evaluated.

Table 4-10. Qualitative project passage survival potential for target fish species relative to factors influencing entrainment and turbine survival at Lowell

Species and Life Stage	Entrainment Potential			Survival
	Behavior, Habitat and Life History	Trash rack Clear Spacing	Swim Speed compared to Lowell Units	
		7.25 inches	(3.2 fps)	Kaplan
American Shad				
Juvenile	H	H	L	H
Adult	H	H	L	M-L
River Herring				
Juvenile	H	H	M-L	H
Adult	H	H	L	M
American Eel				
Adult (silver)	H	H	L	L

4.9 Total Project Survival

Empirical estimates of downstream passage survival were collected for adult American eels, river herring and American shad at Lowell during the 2019 Downstream American Eel Passage Assessment and 2020 Upstream and Downstream Adult Alosine Passage Assessment.

When all downstream passage routes are considered, the total project survival for adult American eels was estimated at 75.5% (75% CI = 71.4%-79.6%). An adequate sample size was available to produce a route-specific estimate of downstream passage survival for adult American eels at only the E.L. Field turbines (75.0%; 75% CI = 70.6%-79.4%). The limited number of radio-tagged eels passing the Project via spill (n = 4) or via the downstream bypass system (n = 2) were all determined to have successfully approached the Lawrence Project following downstream passage at Lowell. In the case of adult eels, the TBSA model (Table 4-7) tended to underestimate turbine survival.

When all downstream passage routes are considered for adult river herring, the total project survival at Lowell was estimated at 80.1% (75% CI = 76.7%-83.6%). When examined by passage route, survival was estimated for adult river herring passing through the downstream bypass at 87.8% (75% CI = 81.8%-91.5%) and for adult river herring passing downstream through the E.L. Field turbines at 73.9% (75% CI = 68.8%-79.1%). Similarly, total project survival at Lowell was estimated for adult American shad at 70.0% (75% CI = 64.5%-74.6%). When examined by passage route, survival was estimated for adult shad passing over the Pawtucket Dam via spill at 89.2% (75% CI = 82.6%-93.8%), through the downstream bypass at 82.6% (75% CI = 75.7%-90.9%) and through the E.L. Field turbines at 35.5% (75% CI = 25.8%-45.2%). In the case of adult alosines, the TBSA model (Table 4-6) tended to overestimate turbine survival.

An empirical estimate of juvenile alosine survival was not derived during the 2019 Juvenile Alosine Downstream Passage Assessment at Lowell. As a result, the TBSA desktop tool was used to estimate total project survival for juvenile alosines at the Project. The model required input of available downstream passage routes and an estimate of their proportional usage. Those rates were obtained from the 2019 study which estimated route usage for individuals passing the project via known mainstem routes as 11.6% via spill, 15.1% via the downstream bypass, and 73.2% via the E.L. Field turbine units. These observed route selection probabilities were imported into a multi-route TBSA model to evaluate the predicted whole-station survival for a normally-distributed population of 1,000 3.5 inch (S.D. ±1.0 inches) fish. For non-turbine routes (e.g., downstream bypass or spill), an estimate of passage mortality was required and was based on the empirical estimates obtained for adult alosines at the Project (12% at the downstream bypass and 11% via spill). Turbine-specific parameters were incorporated as previously described above in Table 3-2. Using this methodology, total project survival at Lowell for juvenile alosine-sized fish is estimated at 94.8%. Passage failures were attributed to fish passing downstream via the turbines (2.1% of total losses) and the downstream bypass facility/spill (3.1% of total losses).

These estimates of total project survival are all based on flow conditions during the study periods. As identified in the individual study reports the majority of the passage periods for these evaluations could be classified as normal to low flow. It is expected that changes in inflow will influence route selection and subsequently may affect the estimates of total project survival depending on the distribution of individuals among passage routes, each with their own specific passage survival rate.

5 Summary

Interactions with the Lowell Project for each of the species and life stages considered during this assessment are unavoidable based on their obligatory seasonal movements to complete portions of their life cycles. For all three target species (excluding American eel) individuals of both the adult and juvenile life stages are required to pass downstream of the Project in order to complete their life history. For this assessment, American eel was only considered as an entrainment/impingement risk during the adult life stage when they are actively out-migrating. Project interactions for alosines occur most frequently during the spring/early summer when post-spawn adults return downstream and during the fall/early winter when juveniles are migrating to the marine environment. Similar to juvenile alosines, the outmigration period for adult eels occurs during the fall time period.

As each of the target species/life stages are required to pass the Project as part of their life cycle, these species have a high probability of interacting with the E.L. Field turbine which resulted in a classification of “high” for the entrainment potential for that category. All species/life stages considered in this assessment have the potential to become entrained through the existing 7.25 inch spaced racks because their body dimensions will permit them to fit through those openings. When the median swim burst speed rates are considered, each species/life stage demonstrated potential to evade involuntary entrainment at Lowell. Only a portion of juvenile river herring in the low end of the expected size range for the species at Lowell would be expected to have a burst swim capability weak enough to be unable to avoid involuntary entrainment.

A TBSA assessment was conducted for fish lengths representative of (1) the size range of target species likely to be present at Lowell, and (2) body lengths less than the minimum exclusion length which would be subject to entrainment. The TBSA correlation value used in these analyses were based on a recent (December 8, 2020) USFWS memorandum that identified the use of a conservative value of $\lambda = 0.2$ for salmonids and alosine entrainment and $\lambda = 0.4$ for American eels. The TBSA analysis produced a range of survival estimates for turbine survival through the Project’s E.L. Field powerhouse Kaplan units. Within that range of estimates, the probability of mortality due to blade strike increased as body size increased, a trend also identified in a review of the 1997 EPRI database by Winchell *et al.* (2000).

Estimates of total station survival for each target species/life stage were developed via empirical study (e.g., adult American eel, river herring, and American shad) or via a TBSA model informed with available empirical data and specific parameters associated with the E.L. Field turbine units. Estimates of total station survival were calculated at 75.5% for adult American eels, 80.1% for adult river herring, and 70.0% for adult American shad. A desktop based estimate of juvenile alosine total project survival was calculated at 94.8%. As with any estimate of total project survival, these values represent downstream passage success over the range of conditions during the evaluation. As noted in the revised Initial Study Reports which provided these estimates, river conditions during the passage periods were classified as normal to low flow. It is expected that as inflow conditions change the distribution of fish among available downstream passage routes will also change. These shifts in the proportional use among passage routes has the potential to also shift the estimate of overall total project survival. The direction of that shift will be driven by the proportional use of passage routes with relatively higher or lower passage success rates for a particular species or life stage.

6 Variances from FERC-Approved Study Plan

The FERC-approved RSP indicated that Project turbines in the E.L. Field, Bridge Street, Hamilton and John Street powerhouses would be evaluated as part of the Fish Passage Survival Study. Since Boott has indicated that Final License Application for the Project (due to FERC by April 30, 2021) will exclude the Bridge Street, Hamilton and John Street stations as part of the Project in the future license, this effort focused on the two turbine units housed in the E.L. Field powerhouse on the mainstem Merrimack River.

The FERC-approved RSP proposed the use of a multiple-linear regression model for estimation of American eel turbine blade strike probabilities. This report substituted the newly available USFWS guidance for modification of the TBSA correlation factor (λ) from 0.2 to 0.4 to generate blade strike probabilities for American eels. In addition, turbine passage survival from the Downstream American Eel Passage Assessment was also included in this report and represents an empirical estimate of downstream passage survival for that species through the most frequently utilized passage route (i.e., the E.L. Field turbine units).

There were no additional variances from the FERC-approved study plan.

7 References

Atlantic States Marine Fisheries Commission (ASMFC). 2012. Stock Assessment Report No. 12-02: River Herring Benchmark Stock Assessment Volume 1. Accepted for management use May 2012.

Bain, M. and N. Stevenson. 1999. Aquatic Habitat Assessment: Common Methods. American Fisheries Society, Bethesda, Maryland.

Beamish, F. W. H. 1978. Swimming capacity. In: Hoar, W.S. and D.J. Randall, eds. Fish Physiology, Volume 7, Locomotion. Academic Press, NY. 576 pp.

Bigelow, H.B., and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. Fishery Bulletin 53: 1-577.

Čada, G. F. and P. E. Schweizer. 2012. The application of trait-based assessment approaches to estimate the effects of hydroelectric turbine passage on fish populations. Report ORNL/TM-2012/110. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Idaho Falls, Idaho. 36 pp.

Castro-Santos, T. and A. Haro. 2005. Biomechanics and fisheries conservation. Chapter 12 in Fish Physiology: Fish Biomechanics. Vol. 23. Elsevier, Inc.

Cianci, J.M. 1969. Larval development of the alewife, *Alosa psuedoharengus* Wilson, and the glut herring Alosa aestivalis Mitchill. Master's thesis, University of Connecticut. 62p.

Collette, B.B. and G.K. Klein-MacPhee, Eds. 2002. Bigelow and Schroeder's Fishes of the Gulf Of Maine, 3rd edition. Smithsonian Institution Press, 748 pp.

Cooper, R.A. 1961. Early life history and spawning migration of the alewife, *Alosa pseudoharengus*. Master's thesis. University of Rhode Island, Kingston, Rhode Island.

Di Rocco, R., and R. Gervais. 2020. SPOT: Swim Performance Online Tools. Available from http://www.fishprotectiontools.ca/.

Electric Power Research Institute (EPRI). 1997. Turbine entrainment and survival database - field tests. EPRI Report No. TR-108630.

Franke, G. F., D. R. Webb, R. K. Fisher, Jr., D. Mathur, P. N. Hopping, P. A. March, M. R. Headrick, I. T. Laczo, Y. Ventikos, and F. Sotiropoulos. 1997. Development of environmentally advanced hydropower turbine system design concepts. Prepared for U.S. Department of Energy, Idaho Operations Office.

Havey, K.A. 1961. Restoration of anadromous alewife at Long Pond, Maine. Transactions of the American Fisheries Society 90: 281-286.

Katopodis, C., and R Gervais. 2016. Fish Swimming Performance Database and Analyses. DFO Can. Sci. Advis. Sec. Res. Doc. 2016/002., 550. Available from http://www.dfo-mpo.gc.ca/csas-sccs/Publications/ResDocs-DocRech/2016/2016_002-eng.html.

Kellogg, R.L. 1982. Temperature requirements for the survival and early development of the anadromous alewife. The Progressive Fish-Culturist 44: 63-73

Neves, R.J. 1981. Offshore distribution of alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*, along the Atlantic coast. Fishery Bulletin 79(3):473-485.

O'Dell, T.T. 1934. The life history and ecological relationships of the alewife *Pomolobus pseudoharengus* (Wilson) in Seneca Lake, New York. Transactions of the American Fisheries Society 64: 118-124.

Otto, R. G., M. A. Kitchell, and J. O. Rice. 1976. Lethal and preferred temperatures of the alewife (*Alosa pseudoharengus*) in Lake Michigan. Transactions of the American Fisheries Society 105: 96-106.

Smith, C. L. 1985. The Inland Fishes of New York State. Albany, NY. New York Department of Environmental Conservation.

Steir, D.J. and J.H. Crance. 1985. Habitat suitability index models and instream flow suitability curves: American shad. U.S. Fish and Wildlife Service Biological Report 82(10.88). 34 pp.

Towler, B., J. Pica. 2018. Turbine Blade Strike Analysis freeware. Downloaded from: https://www.fws.gov/northeast/fisheries/fishpassageengineering.html

Winchell, F., S. Amaral, and D. Dixon. 2000. Hydroelectric turbine entrainment and survival database: an alternative to field studies. In: Hydrovision 2000: New Realities, New Responses. HCI Publications, Kansas City, MO.

Wyllie, M.C., E.R. Holmstrom, and R.K. Wallace. 1976. Temperature preference, avoidance, shock and swim speed studies with marine and estuarine organisms from New Jersey. Prepared by Ichthyological Associates, Inc., Ithaca, N.Y. for Public Service Electric and Gas Company. Bull. No. 15.

8 Appendices

Appendix A. Supporting tables for burst speed analysis

American shad (Juvenile)					
% indicates portion of test fish able to achieve speed listed (fps) for 3 seconds					
Size (in)	97.50%	87.50%	50%	12.50%	2.50%
2	4.17	4.56	**5.18**	5.87	6.43
3	5.51	6.04	6.89	7.81	8.56
4	6.76	7.38	**8.40**	9.58	10.47
5	7.91	8.66	9.84	11.19	12.24
6	8.96	9.81	**11.19**	12.70	13.91

American shad (Adult)					
% indicates portion of test fish able to achieve speed listed (fps) for 3 seconds					
Size (in)	97.50%	87.50%	50%	12.50%	2.50%
10	13.03	14.24	**16.21**	18.44	20.21
11.25	14.08	15.42	17.52	19.95	21.82
12.5	15.26	16.70	**19.00**	21.62	23.69
13.75	16.24	17.78	20.24	23.03	25.20
15	17.26	18.90	**21.49**	24.44	26.77

River herring (Juvenile)					
% indicates portion of test fish able to achieve speed listed (fps) for 3 seconds					
Size (in)	97.50%	87.50%	50%	12.50%	2.50%
1.25	2.90	3.18	**3.61**	4.10	4.49
2.44	4.72	5.18	5.87	6.69	7.32
3.63	6.27	6.86	**7.81**	8.89	9.74
4.81	7.68	8.40	9.55	10.86	11.91
6	8.96	9.81	**11.19**	12.70	13.91

River herring (Adult)					
% indicates portion of test fish able to achieve speed listed (fps) for 3 seconds					
Size (in)	97.50%	87.50%	50%	12.50%	2.50%
9	12.11	13.26	**15.09**	17.16	18.80
9.75	12.83	14.04	15.98	18.18	19.92
10.5	13.35	14.63	**16.67**	18.93	20.74
11.25	14.08	15.42	17.52	19.95	21.82
12	14.76	16.14	**18.37**	20.90	22.90

American eel					
% indicates portion of test fish able to achieve speed listed (fps) for 3 seconds					
Size (in)	97.50%	87.50%	50%	12.50%	2.50%
21	6.50	8.04	**10.96**	14.93	18.54
27	7.68	9.55	12.99	17.65	21.95
33	8.83	10.96	**14.93**	20.31	25.23
39	9.88	12.27	16.70	22.74	28.25
45	10.89	13.55	**18.44**	25.10	31.17

Technical Report
for the
Instream Flow Habitat Assessment and Zone of Passage Study

Lowell Hydroelectric Project (FERC No. 2790)

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Table of Contents

List of Tables

List of Figures

1 Introduction

Boott Hydropower, LLC (Boott) submitted their Revised Study Plan (RSP) to the Federal Energy Regulatory Commission (FERC) on January 28, 2019. Among the thirteen studies described in the RSP was the Instream Flow Habitat Assessment and Zone of Passage Study in the Bypassed Reach (the Study). FERC provided their Study Plan Determination (SPD) on March 13, 2019 and the Study was approved as filed. The purpose of this report is to describe study methodologies used to assess the flow:habitat relationship for target fish species and life stages in the Bypassed Reach (Bypass) and to evaluate the zone of passage assessment, and to detail the results of both Study components.

2 Objectives

As previously summarized in the RSP, there were two separate study elements requested to evaluate the bypassed reach, one pertaining to fish passage and one to aquatic habitat:

- Bypass Zone of Passage Assessment: determine flows which facilitate fish passage through the bypass reach through the use of detailed elevation and bathymetry data and two-dimensional (2D) modeling techniques;
- Instream Flow Habitat Assessment: determine impacts of a range of Project flows on wetted area and habitat for key aquatic species by conducting an instream flow study based on the Instream Flow Incremental Methodology (IFIM) process and one-dimensional (1D) modeling techniques.

These two study requests were subsequently combined into a single study. As detailed in the FERC-approved RSP, the Study was conducted via the application of a two-dimensional (2D) model of the bypassed reach to provide the results necessary to address both study elements and provide FERC with sufficient information to complete an environmental assessment.

3 Project Description and Study Area

The Lowell Project is located at River Mile (RM) 41 on the Merrimack River in the City of Lowell in Middlesex County, Massachusetts, with an impoundment extending approximately 23 miles upstream into Hillsborough County, New Hampshire. The existing Lowell Project consists of: (1) a 1,093-foot-long, 15-foot-high masonry gravity dam (Pawtucket dam) that includes a 982.5-foot-long spillway with a crest elevation of 87.2 feet National Geodetic Vertical Datum 1929 (NGVD 29) topped by 5-foot-high pneumatically-operated crest gates deployed in five independently-operable zones; (2) a 720-acre impoundment with a normal maximum water surface elevation of 92.2 feet NGVD 29; (3) a 5.5-mile-long canal system which includes several small dams and gatehouses; (4) a powerhouse (E.L. Field) which uses water from the Northern Canal and contains two turbine-generator units with a total installed capacity of 15.0 megawatts (MW); (5) a 440-foot-long tailrace channel; (6) four powerhouses (Assets, Bridge Street, Hamilton, and John Street) housed in nineteenth century mill buildings along the Northern and Pawtucket Canal System containing 15 turbine-generator units with a total installed capacity of approximately 5.1 MW; (7) a 4.5-mile long, 13.8-kilovolt transmission line connecting the powerhouses to the regional distribution grid; (8) upstream and downstream fish passage facilities including a fish elevator and downstream fish bypass at the E.L. Field powerhouse, and a vertical-slot fish ladder at the Pawtucket dam; (9) appurtenant facilities; and (10) a 4,000 ft Bypassed Reach, which is the subject of this Study. The Project operates essentially in a run-of-river (ROR) mode using automatic pond level control, and has no usable storage capacity. As part of its relicensing proposal, Boott proposes to remove the four mill powerhouses and associated canal infrastructure from the Project's FERC license, retaining only the Pawtucket Dam, Northern Canal, E.L. Field Powerhouse and fish passage facilities. More detailed information is provided in Boott's application for new license.

The study areas for the zone of passage assessment and the aquatic habitat assessment were identical and both confined to the Bypass. The study area encompassed the length of the Bypass from just below the School Street Bridge (yellow line in Figure 3-1) downstream approximately 3,000 ft to the confluence of the Bypass and tailrace (green line in Figure 3-1). The 2D model for the zone of passage component was initially extended upstream from the bridge through the series of concrete passage weirs, however the model was not able to accurately describe velocity patterns associated with the artificial weir structures and consequently the passage assessment focused on the bedrock habitat below the bridge.

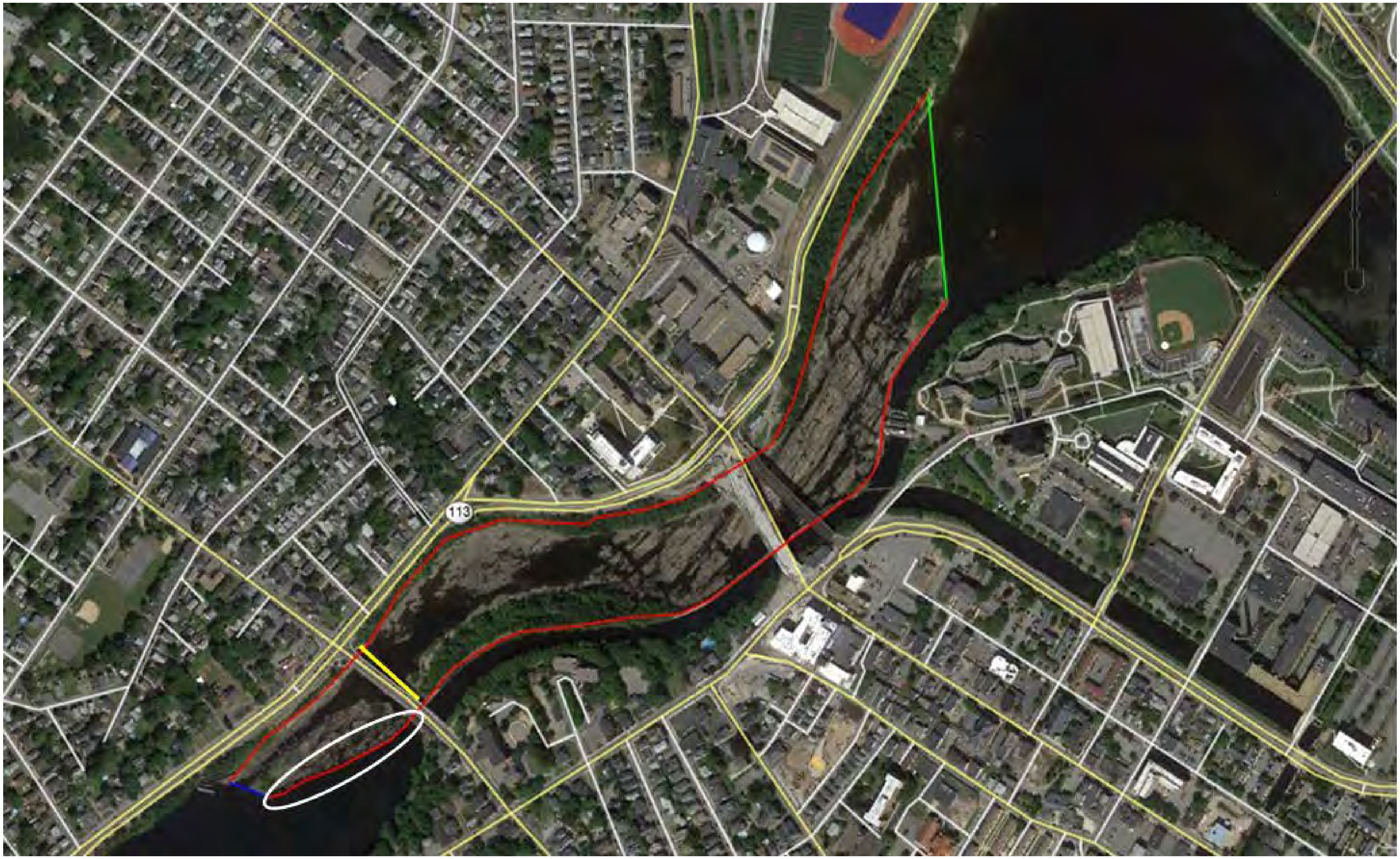


Figure 3–1. Spatial extent of the Bypassed Reach (red lines) showing the top boundary for both the zone of passage component and the aquatic habitat component (yellow line), the bottom boundary for both components (green line), and the parallel spillway (white oval) upstream of the modeled study reach.

4 Methods

4.1 2D Hydraulic Model

The 2D hydraulic model used to assess the zone of passage and aquatic habitat components of the instream flow study was River 2D (Steffler and Blackburn 2002), which is a depth-averaged model that incorporates Habitat Suitability Criteria (HSC) to evaluate the quantity and quality of aquatic habitat for selected species and life stages within the range of modeled flows. The River2D model uses a detailed topographic map of the study site to solve basic equations for conservation of mass and conservation of momentum in two horizontal directions to simulate water depths and velocities. Model inputs are bed topography, channel roughness, discharge at the upstream boundary, and water surface elevations at the downstream boundary. As noted in the River 2D manual "Obtaining an accurate representation of bed topography is likely the most critical, difficult, and time-consuming aspect of the 2D modeling exercise" (Steffler and Blackburn 2002). The topography for River 2D model is collected with higher density sampling in areas of more complex and/or rapidly varying habitat/bed features and lower densities in areas with more uniform topography (USFWS 2011). Some gaps in topography will occur in locations where depth, velocity, or other factors prevent safe data collection. The River 2D modules R2D_Bed and R2D_Mesh are used to generate bed topography and define the reach of interest using pointwise elevations and roughness.

Model calibration consists of adjusting the bed roughness values, if needed, in the model until a reasonable match is obtained between the simulated and measured water surface elevations. Water surface elevations predicted by the 2D model should be within 0.1 foot (0.031 m) of the water surface elevation measured at the upstream boundary (USFWS 2011). Once calibrated, the downstream water surface elevation and the inflow of the model are changed to simulate the flows of interest. Each flow change is run to a steady state solution. That is, for a constant inflow, the model is run until there is a constant outflow and the two flows are essentially equal. Typical convergence tolerance is within 1-5% of the inflow. Another measure of convergence is the solution change. Ideally, the solution change will become sufficiently small (0.00001) once converged. In some cases, the solution change will reach a relatively small value and not decrease any further, indicating a small, persistent oscillation at one or more points. This oscillation is often associated with a shallow node that alternates between wet and dry. This oscillation may be considered acceptable if the size of the variation is within the desired accuracy of the model (Steffler and Blackburn 2002). The ultimate goal is to define flow allocation through split channels and (in this case) accurately simulate fish migration pathways under low flow conditions.

The development of a 2D flow model requires the establishment of fixed boundaries at the upstream and downstream ends of the study reach. Those boundaries are required to be a single channel and be represented by a single water surface elevation (WSE) value for any given flow. The unique configuration of the spillway at the upstream end of the Bypass presents a challenge for establishment of the upstream boundary. The upstream fish ladder and associated attraction water system (AWS), as well as the 220 feet of pneumatic crest gate closest to the northern bank (blue line in Figure 3-1) will discharge water in a linear fashion down through the full length of the Bypass. However, under conditions where flows are released from any of the pneumatic crest gate sections along the 765 feet of spillway oriented parallel to the Bypass channel (white oval in Figure 3-1), that discharge will not enter the uppermost section of the Bypass in a linear fashion. Spill-related inflows converging into the upper section of the Bypass would confound the 2D model if the upstream boundary is placed above that inflow.

As a result, the upstream boundary for the zone of passage and the aquatic habitat components of the Study was placed just below the School Street Bridge (yellow line in Figure 3-1). With the upstream boundary located at the Bridge, inflows provided from either the fish ladder and associated AWS system or any of the pneumatic crest gate sections are available at the model boundary in a more uniform (non-converging) flow pattern, and as a result permits modeling over a wide range of inflows to assess both passage and aquatic habitat.

4.1.1 Calibration Flows

A minimum of three calibration flows are required for collection of WSE and total flow (Q) at the upstream boundary, and WSE at the downstream boundary. The RSP recommended low flow calibration flow of 500 cfs, which represents the discharge from the fish ladder and associated AWS. The suggested high calibration flow target was ~7,800 cfs, which was the maximum combined discharge for the fish ladder, AWS system and 220 foot pneumatic crest gate, with a middle flow target of ~4,150 cfs (the midpoint between low and high flow targets). The general rule of thumb for instream flow evaluations is the ability to model downwards approximately 50% of the low flow, and upwards approximately 2 to 2½ times the highest calibration flow. Following that guidance, the calibration flows proposed as part of this study will theoretically support modeling from 250 cfs up to over 15,000 cfs. Actual measured calibration flows were similar to the proposed flows and ranged from 482 cfs for the low flow, 4,345 cfs for the middle flow, and 7,011 cfs for the high flow. As a result, modeled estimates could be generated over a range of flows from 250 cfs to 14,000 cfs.

4.2 Field Sampling

4.2.1 WSE and Flow Measurements

Collection of low, middle, and high calibration flow data occurred on 23 October 2019, 10 December 2020, and 4 December 2020, respectively. At each flow, WSE data were collected at several locations: just below the dam, at the fish ladder entrance, and just below the School Street Bridge (the upper boundary of the 2D model, Figure 3-1). WSE's were measured with a Real-time kinematic GPS (RTK) with a vertical accuracy of 0.1 ft. Total Bypass flow at low flow was measured at the downstream side of the School Street bridge using a Teledyne RDI Rio Grande 1200 KHz Acoustic Doppler Current Profiler (ADCP). The high flow and mid-flow discharge values were provided by the Licensee prior to each data collection event. Bypass flows were estimated by subtracting the flow reported at USGS gage no. 01099500 (Concord River below River Meadow Brook, at Lowell, MA) from USGS gage no. 01100000 (Merrimack River below Concord River at Lowell, MA), yielding inflow to the Pawtucket Dam, then subtracting the calculated flow through the E.L. Field powerhouse turbines. Downtown canal flows were negligible during this period.

4.2.2 Bathymetry Measurements

As noted above, accurate bed elevation data is necessary to develop a 2D model that is representative of the actual study area. Stream bottom elevations within the Bypass were predominantly based on Light Detection and Ranging (LIDAR) data collected by Cornerstone Energy Services, Inc. on 24 October 2019 at a flow of 40 cfs. The estimated vertical and horizontal accuracy of the LIDAR output exceeded 0.1 ft. The LIDAR data was complemented by RTK measurements under riparian canopy and bridge structures where the LIDAR data was sparse or non-existent. RTK was also used to measure bathymetry in wadeable areas of the Bypass where LIDAR did not penetrate. This shallow water bathymetry data was collected during October 2019 under non-spill conditions within the Bypass. Bottom elevations in locations too deep to wade at low flow (i.e., depths >4 ft) were estimated using aerial photos, ADCP data, and RTK measurements. Substrate characterizations (see Section 4.2.3) were collected by two RTK crews at the same time.

4.2.3 Substrate Measurements

Bypass substrate was visually assessed on foot and via aerial photography in exposed bottom and shallow, wadeable areas using RTK to delineate polygons having specified substrate composition (Figure 4-1). Substrate was estimated in deeper, non-wadeable areas based on surrounding substrate characteristics and presence of eddy-forming features (e.g., bridge structures, point bars, etc.). Substrate composition was primarily used for assessing habitat suitability for each species and life-stage, according to their HSC (Section 4.4).

Polygons were defined by the percentage of dominant and subdominant substrate types in the following classes:

- Organics (ORG)
- Mud/Clay (MUD)
- Silt (SLT) (<0.003 inches)
- Sand (SND) (0.003-0.08 inches)
- Gravel (GRV) (0.08-2.5 inches)
- Cobble (COB) (2.5-10.1 inches)
- Boulder (BLD) (>10.1 inches)
- Bedrock (BED)

Where the substrate composition in a polygon was composed of two or more separate classes, the suitability of was calculated for each species and life-stage using the percentages of each type and the associated HSC values to calculate a weighted mean HSC value for that polygon. Crews noted that much of the gravel observed in the Bypass Reach was clean and laying on top of bedrock, suggesting it was very mobile and may not provide persistent habitat value.

4.3 2D Model Development

The RTK elevation data was combined with elevation data from the LIDAR to create the preliminary bed topography file. The resulting topography was edited in the River2D bed program by adding breaklines in order to refine the topography and interpolate between any gaps in coverage; resulting in the final digital elevation model used in the River2D program. In total, 692,252 survey points were used to create the topographic bed file (Figure 4-2), resulting in an overall point density of approximately 476 points/100 m^2. An artificial downstream extension was added to ensure a uniform outflow boundary and minimize any boundary effects in the model area of interest.

After finalizing the topographic bed file, a computational mesh was created for generating flow simulations. The final computational mesh had 18,223 nodes, 35,858 elements, and a mesh quality index of 0.38, which is within the River2D recommended quality index of 0.1 to 0.5 (Steffler and Blackburn 2002). Model calibration involved running the model at the three measured flows with a roughness value of 0.1. The modeled water surface elevations at the upstream end of the riffle were within 0.14 ft of the measured values (Table 4-1). After calibration, models were run to simulate flows from 250 cfs to 14,000 cfs. The downstream boundary conditions were set using a log-log rating curve created from the measured flows. A uniform Roughness (k_s) of 0.1 was used for all flow simulations

Model statistics for simulated flows are listed in Table 4-2. While solution change will ideally be below 0.00001 this is not always be achievable, especially at lower flows or in complex topography with many shallow depths. As noted in Steffler and Blackburn (2002):

> In some cases, the solution will reach a relatively small value of solution change (of the order of 0.03) and refuse to diminish further, regardless of the number of subsequent time steps. Usually, this indicates a small, persistent, oscillation at one (or sometimes more) points in the flow field. Often, the oscillation is associated with a shallow node that alternates between wet and dry. . . Finally, the oscillating solution may be considered acceptable, as the size of the variation may be within the desired accuracy of the simulation.

Given the high number of nodes in the model, the complexity of the topography, and the fact that the largest change was around our measurement accuracy, we found the results acceptable. In addition, the net Q was less than 1.1% in all of the model simulations, which is likely less than any error associated with flow measurements and the development of rating curves that were used to assign the upper and lower boundary conditions for the models, and the fact net Q was stable, we found the results to be acceptable. This rationale is consistent with findings in USFS (2011): "…we still considered these production cdg files for these sites to have a stable solution since the Net Q was not changing and the Net Q in all cases was less than 1.1%. In comparison, the accepted level of accuracy for USGS gages is generally 5%."

The bed elevations in wetted areas that were too dangerous or deep to collect topography with RTK were estimated using a combination of photos, aerial imagery, ADCP depth data and any nearby surveyed elevations.

4.4 Habitat Suitability Criteria (HSC)

HSC define the relative suitability of habitat variables for target species and life-stages, scaled from 0.0 (unsuitable habitat) to 1.0 (optimal habitat). HSC are the biological component of instream flow studies, and are directly incorporated into River2D for describing the flow:habitat relationship.

4.4.1 Target Species and Life-stages

Target fish species and life-stages were proposed for use in the RSP, then discussed and expanded upon during a May 21 2020 conference call with the relicensing participants. The species and associated life-stages used for the zone of passage component of this analysis are:

- American shad (adult passage)
- Blueback herring (adult passage)
- Alewife (adult passage)

HSC variables describing upstream passage criteria for each species were taken from USFWS (2019) and are presented in Table 4-3. The migratory species listed above (shad and river herring) are expected to require passage through the bypass reach to access upstream spawning habitat. Upstream passage criteria for American shad and river herring were generally taken from USFWS (2019) Fish Passage Engineering Design Criteria, which included maximum fish body depth, minimum weir opening depth, maximum weir opening velocity, and minimum weir opening width.

The species and associated life-stages used for the aquatic habitat component of this analysis are:

- American shad (juvenile, spawning)
- River herring (spawning)
- Smallmouth bass (fry, juvenile, adult, spawning)
- Fallfish (juvenile, adult)
- White sucker (fry, juvenile/adult, spawning)
- Longnose dace (juvenile, adult)
- Sea lamprey (spawning & incubation)
- Freshwater mussels (rearing)
- Benthic macroinvertebrates

The species and life stages listed above are those reasonably expected to utilize portions of the bypass for spawning and/or rearing. HSC variables describing aquatic habitat suitability for all species included mean column velocity, depth, and substrate are listed in Table 4-4, as well as the data sources associated with each HSC dataset. Graphical output of the HSC curves are presented in Appendix A.

Figure 4–1. Substrate polygon map of the Bypass Reach. See Section 4.2.3 for substrate code.

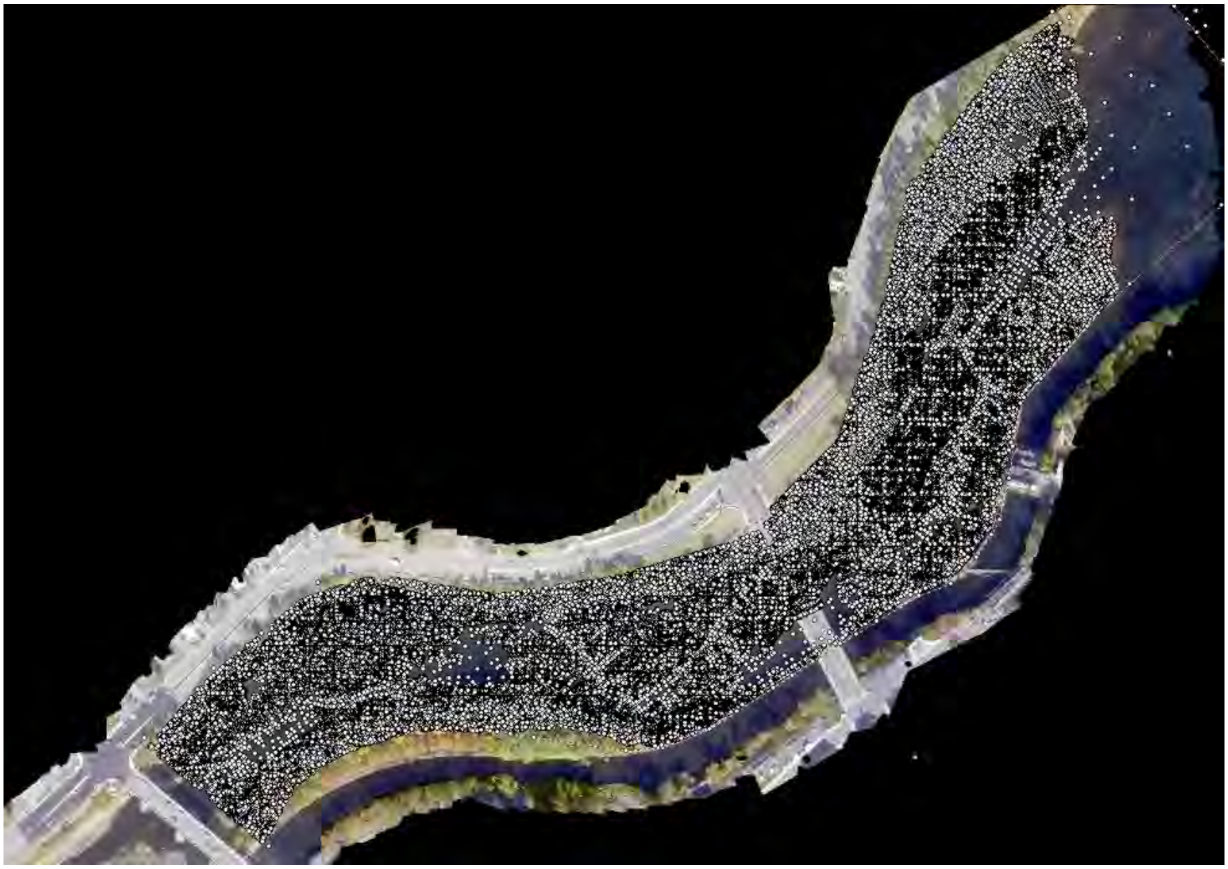


Figure 4–2. Topographic bed file for the 2D model (note-many nodes not visible in image).

Table 4–1. River2D calibration values.

Flow (cfs)	Measured stage (ft)	2D modeled stage (ft)	Difference (ft)
482	69.82	69.96	0.14
4,345	72.68	72.60	-0.08
7,011	73.74	73.62	-0.13

Table 4–2. River2D model simulation statistics.

Inflow (cfs)	Outflow (cfs)	Net Q	Solution Change
250.0	251.9	0.76%	6.94E-02
482.0	478.4	-0.74%	3.25E-02
1000.0	995.9	-0.41%	3.74E-02
2000.0	1977.9	-1.11%	4.87E-02
4345.0	4342.0	-0.07%	2.14E-02
6000.0	6000.2	0.00%	3.59E-02
8000.0	7999.6	-0.01%	3.41E-02
10000.0	9999.3	-0.01%	3.03E-02
12000.0	11993.6	-0.05%	2.82E-02
14000.0	14011.0	0.08%	4.25E-02

Table 4–3. Upstream passage criteria for river herring and American shad in the Bypass reach (criteria from USFWS 2019).

Species	Max Body Depth ft	Min Weir Depth ft	Max Weir Velocity fps	Min Weir Width ft
Blueback Herring	0.26	1.0	6.0	2.25
Alewife	0.29	1.0	6.0	2.5
American Shad	0.73	2.25	8.25	5.0

Table 4–4. HSC values according to species and life-stage. Data sources for mean column velocity (V), depth (D), and dominant substrate (S) HSC also shown.

Species	Life-stage	Velocity fps	HSC	Depth ft	HSC	Substrate	HSC	Source
American Shad	Juvenile	0.00	0.00	0.00	0.00	Organics	0.10	Stier & Crance 1985 (V), Greene et al. 2009 (D), Conowingo IFIM (S)
		0.20	1.00	0.66	0.50	Mud/clay	0.20	
		1.00	1.00	1.50	0.75	Silt	1.00	
		4.50	0.00	4.90	1.00	Sand	1.00	
				6.60	1.00	Gravel	1.00	
				13.20	0.75	Cobble	1.00	
				20.00	0.25	Boulder	0.60	
				50.00	0.00	Bedrock	0.40	
American Shad	Spawning	0.00	0.30	0.00	0.00	Organics	0.00	Hightower et al. 2012 (V), Hightower/Steir & Crance 1985 (D), Steir & Crance 1985 (S)
		0.70	0.75	1.60	0.40	Mud/clay	0.10	
		1.00	1.00	3.30	0.74	Silt	0.20	
		3.00	1.00	4.90	0.89	Sand	1.00	
		3.90	1.00	6.60	0.98	Gravel	1.00	
		5.60	0.00	8.20	1.00	Cobble	1.00	
				9.80	0.97	Boulder	0.60	
				11.50	0.92	Bedrock	0.40	
				13.10	0.85			
				14.80	0.77			
				16.40	0.68			
				18.00	0.60			
				19.70	0.53			
				21.30	0.46			
				50.00	0.00			
River Herring	Spawning	0.00	1.00	0.00	0.00	Organics	1.00	adapted from Pardue 1983 and Mather et al. 2012
		1.00	1.00	0.49	0.00	Mud/clay	1.00	
		1.01	0.00	0.50	1.00	Silt	1.00	
				9.80	1.00	Sand	0.10	
				9.90	0.00	Gravel	0.10	
						Cobble	0.10	
						Boulder	0.10	
						Bedrock	0.10	
Smallmouth Bass	Fry	0.00	0.60	0.00	0.00	Organics	0.10	Leonard et al. 1986
		0.19	1.00	0.28	0.06	Mud/clay	0.10	
		0.59	1.00	1.31	1.00	Silt	0.10	
		1.00	0.00	2.95	1.00	Sand	0.20	

Species	Life-stage	Velocity fps	HSC	Depth ft	HSC	Substrate	HSC	Source
				3.25	0.95	Gravel	0.30	
				4.59	0.40	Cobble	1.00	
				6.56	0.00	Boulder	1.00	
				10.00	0.00	Bedrock	0.50	
Smallmouth Bass	Juvenile	0.00	0.30	0.00	0.00	Organics	0.10	Groshens and Orth 1994 (V), Leonard et al. 1986 (D,S)
		0.17	0.66	0.52	0.00	Mud/clay	0.10	
		0.33	0.90	0.67	0.03	Silt	0.10	
		0.50	0.93	2.15	1.00	Sand	0.20	
		0.66	1.00	10.00	1.00	Gravel	0.30	
		0.83	1.00			Cobble	1.00	
		0.98	0.93			Boulder	1.00	
		1.15	0.87			Bedrock	0.50	
		1.31	0.84					
		1.47	0.77					
		1.64	0.70					
		1.81	0.62					
		1.98	0.47					
		2.30	0.27					
		2.62	0.17					
		2.95	0.09					
		3.94	0.03					
		4.59	0.00					
Smallmouth Bass	Adult	0.00	0.12	0.00	0.00	Organics	0.10	Groshens and Orth 1994 (V), Leonard et al. 1986 (D,S)
		0.17	0.66	0.92	0.00	Mud/clay	0.10	
		0.33	0.90	1.31	0.08	Silt	0.10	
		0.50	1.00	2.03	0.56	Sand	0.20	
		0.66	0.93	2.82	1.00	Gravel	0.30	
		0.83	0.82	6.00	1.00	Cobble	1.00	
		0.98	0.65	10.00	1.00	Boulder	1.00	
		1.15	0.53			Bedrock	0.50	
		1.31	0.46					
		1.47	0.42					
		1.64	0.36					
		1.81	0.32					
		1.98	0.25					
		2.30	0.15					
		2.62	0.08					
		2.95	0.06					
		3.94	0.04					
		4.59	0.04					
		5.00	0.00					
Smallmouth Bass	Spawning	0.00	1.00	0.22	0.00	Organics	0.00	Allen 1996 (V,S), Edwards et al. 1983 (D)

Species	Life-stage	Velocity fps	HSC	Depth ft	HSC	Substrate	HSC	Source
		0.45	1.00	0.50	0.02	Mud/clay	0.00	
		0.55	0.96	0.74	0.05	Silt	0.00	
		0.65	0.89	1.10	0.12	Sand	0.20	
		0.75	0.69	1.32	0.22	Gravel	1.00	
		0.85	0.34	1.53	0.34	Cobble	0.30	
		0.95	0.25	1.70	0.54	Boulder	0.00	
		1.05	0.20	1.90	0.90	Bedrock	0.00	
		1.15	0.16	2.05	0.97			
		1.25	0.14	2.18	0.99			
		1.65	0.11	2.40	1.00			
		1.85	0.09	4.75	1.00			
		2.35	0.04	4.95	0.97			
		2.55	0.02	5.10	0.91			
		2.75	0.00	5.40	0.62			
				5.80	0.40			
				6.10	0.27			
				6.50	0.17			
				6.95	0.09			
				7.30	0.04			
				7.75	0.02			
				8.00	0.00			
Fallfish	Juvenile	0.00	0.00	0.00	0.00	Organics	0.10	Gomez & Sullivan 2007
		0.10	0.60	0.40	0.00	Mud/clay	0.00	
		0.20	0.88	0.60	0.11	Silt	0.10	
		0.60	1.00	1.00	1.00	Sand	0.50	
		1.60	1.00	3.00	1.00	Gravel	1.00	
		2.00	0.40	4.00	0.27	Cobble	1.00	
		3.50	0.04	7.00	0.24	Boulder	0.20	
		4.30	0.00	8.00	0.07	Bedrock	0.00	
				100.00	0.07			
Fallfish	Adult	0.00	0.00	0.00	0.00	Organics	1.00	Gomez & Sullivan 2007
		0.10	1.00	0.50	0.00	Mud/clay	1.00	
		0.80	1.00	3.00	1.00	Silt	1.00	
		1.50	0.40	100.00	1.00	Sand	1.00	
		3.00	0.00			Gravel	1.00	
						Cobble	1.00	
						Boulder	1.00	
						Bedrock	1.00	
White Sucker	Fry	0.00	1.00	0.00	0.00	Organics	1.00	Twomey et al. 1984
		0.30	1.00	1.00	1.00	Mud/clay	1.00	
		1.00	0.00	100.00	1.00	Silt	1.00	
						Sand	1.00	
						Gravel	1.00	
						Cobble	1.00	
						Boulder	1.00	
						Bedrock	1.00	

Species	Life-stage	Velocity fps	HSC	Depth ft	HSC	Substrate	HSC	Source
White Sucker	Juvenile/ Adult	0.00	0.00	0.00	0.00	Organics	1.00	Twomey et al. 1984
		0.16	0.70	0.50	0.00	Mud/clay	1.00	
		0.33	1.00	2.30	1.00	Silt	1.00	
		0.49	1.00	3.30	1.00	Sand	1.00	
		0.66	0.70	9.80	0.50	Gravel	1.00	
		1.31	0.00	16.40	0.00	Cobble	1.00	
						Boulder	1.00	
						Bedrock	1.00	
White Sucker	Spawning	0.00	0.00	0.00	0.00	Organics	0.00	Twomey et al. 1984 (V,D), Gomez & Sullivan 2007 (S)
		0.50	0.40	0.50	1.00	Mud/clay	0.00	
		1.00	1.00	0.80	1.00	Silt	0.50	
		2.00	1.00	1.00	0.80	Sand	1.00	
		3.00	0.00	2.00	0.00	Gravel	0.90	
						Cobble	0.00	
						Boulder	0.00	
						Bedrock	0.00	
Longnose Dace	Juvenile	0.00	0.00	0.00	0.00	Organics	0.00	Gomez & Sullivan 2007
		0.75	1.00	0.75	1.00	Mud/clay	0.00	
		1.50	1.00	1.15	1.00	Silt	0.00	
		2.00	0.35	1.50	0.40	Sand	0.18	
		2.20	0.20	1.75	0.20	Gravel	1.00	
		2.50	0.13	2.00	0.14	Cobble	1.00	
		3.00	0.05	3.00	0.00	Boulder	0.50	
		4.00	0.00			Bedrock	0.00	
Longnose Dace	Adult	0.00	0.00	0.00	0.00	Organics	0.00	Gomez & Sullivan 2007
		0.75	1.00	0.10	0.00	Mud/clay	0.00	
		1.75	1.00	0.75	1.00	Silt	0.00	
		3.00	0.28	1.60	1.00	Sand	0.60	
		3.60	0.08	2.50	0.00	Gravel	1.00	
		4.50	0.00			Cobble	1.00	
						Boulder	0.80	
						Bedrock	0.00	
Sea Lamprey	Spawning	0.00	0.00	0.00	0.00	Organics	0.00	Kynard & Horgan (V,S), Kynard/GRH 2019 (D)
		0.30	0.00	0.13	0.00	Mud/clay	0.00	
		1.28	0.34	0.46	0.50	Silt	0.00	
		2.26	1.00	0.79	1.00	Sand	0.04	
		3.25	0.86	4.50	0.98	Gravel	1.00	
		4.23	0.30	5.50	0.78	Cobble	0.50	
		5.22	0.12	6.50	0.57	Boulder	0.02	
		6.20	0.08	7.50	0.43	Bedrock	0.00	
		6.23	0.00	8.50	0.28			
				9.50	0.15			

Species	Life-stage	Velocity fps	HSC	Depth ft	HSC	Substrate	HSC	Source
				10.50	0.07			
				11.50	0.04			
				12.50	0.01			
				13.50	0.00			
Freshwater Mussels	Rearing	0.00	0.50	0.00	0.00	Organics	0.00	Normandeau & Biodrawversity 2017
		0.10	1.00	1.50	1.00	Mud/clay	0.00	
		2.25	1.00	13.50	1.00	Silt	1.00	
		5.50	0.00	22.00	0.50	Sand	0.19	
				100.00	0.50	Gravel	0.72	
						Cobble	0.57	
						Boulder	0.29	
						Bedrock	0.17	
Benthic Macroinvertebrates	Rearing	0.00	0.00	0.00	0.00	Organics	0.50	Gomez & Sullivan 2000
		0.50	0.00	0.10	0.00	Mud/clay	0.50	
		1.50	1.00	0.40	1.00	Silt	0.20	
		3.50	1.00	3.00	1.00	Sand	0.10	
		4.60	0.50	5.00	0.50	Gravel	0.60	
		8.00	0.00	6.50	0.25	Cobble	1.00	
				8.00	0.15	Boulder	0.90	
				10.00	0.15	Bedrock	0.50	
				100.00	0.00			

5 Results

5.1 Zone of Passage Assessment

The zone of passage model was developed for three migratory species (Table 4-3) in the Bypass Reach from the School Street Bridge downstream 3,000 ft through the bedrock rapids to the tailrace confluence. The minimum flow that provided a continuous and unbroken pathway (or nearly unbroken pathway) meeting the passage criteria was estimated by modeling passage opportunities at flows ranging from 250 cfs to 14,000 cfs. The passage assessment utilized values for minimum passage depth and maximum passage velocity. The passage analysis did not account for channel widths, which are routinely used in assessing passage through weirs and ladders; however given the large scale of the Bypass Reach and the complexity of the bedrock habitat, it is unlikely that channel widths would be limiting.

Assessment of the zone of passage was problematic due to the highly complex bedrock habitat throughout most of the Bypass Reach. It should be noted that the 2D model utilized actual measurements for developing the elevation model, except in areas that remained too deep and fast at low flow to safely measure (Figure 5-1), and consequently is expected to be relatively accurate in most locations. In contrast, all velocities were estimated via the hydraulic model, and in a highly complex habitat such as the Bypass Reach, in particular the lower bedrock-dominated channel, the model resolution for velocities may not be sufficiently accurate or precise to confidently assess passability in some areas. Also, the estimated velocities represent mean column velocities and do not account for near bottom velocities, which would be expected to be lower than mean column. Likewise, the velocity assessment is not expected to accurately represent zones of slower velocities along the margins of bedrock channels. For these reasons, the passage assessment largely utilized the reliable depth bathymetry in association with species passage depth criteria to identify connectivity of passage channels for shad and herring, with focused comparisons of velocity characteristics at specific pinch-points, such as the steep, bedrock cross-over channels.

5.1.1 American Shad

Complete, uninterrupted connection from the lower boundary to the upper boundary and the series of passage weirs, when both depth and velocity was considered, was never achieved for American Shad (see Appendix B for passage conditions at all modeled flows and for depth-only and velocity-only passage maps). Looking at the 2.5 ft depth criteria alone showed that near full connectivity did not occur until flows exceeded 4,000 cfs. The lack of passage habitat at low flows was largely due to the deep passage criteria for shad (Table 4-3), which at 2.5 ft was more than double the average body depth of adult upstream migrants. As flows increased above 4,000 the depths became more suitable for passage, but estimated velocities began to exceed the 8.25 fps passage criteria in many of the bedrock channels, which resulted in additional gaps in passable habitat.

Because the deep depth criteria may not be realistic for shad swimming through natural channels (as opposed to jumping weirs or ascending ladders), this analysis was re-run using the same 1.0 ft depth criteria used for river herring. Decreasing the minimum depth criteria from

2.5 ft to 1.0 ft for shad resulted in almost continuous passage opportunities at just under 500 cfs when using depth alone (Figure 5-2), with multiple continuous pathways becoming available at flows of 1,000 cfs and above (Appendix B). Zooming in on one of the most critical passage locations at 482 cfs (yellow box in Figure 5-2) shows that the gaps in depth passage are relatively short (~5m) and are likely not an impediment to passage for adult shad (Figure 5-3, top map). Almost the entire area shown in Figure 5-3 possesses velocities less than the 8.25 fps criteria for American shad (Figure 5-3, bottom map). Depth suitability for passage continues to increase at higher flows (Figure 5-4), and velocities largely remain suitable for shad until flows exceed 6,000 cfs (Appendix B).

5.1.1 River Herring

Passage conditions for river herring, using a 1.0 ft minimum depth criteria are the same as for the reduced depth assessment for American shad (Figure 5-4), and show almost continuous passage opportunities at 482 cfs with multiple continuous pathways becoming available at flows over 1,000 cfs (Appendix B). Because the herring velocity criteria is somewhat slower at 6.0 fps than for American shad, the 2D model predicted more impassable area within the bedrock channels due to rapid currents, however it appears likely that herring could ascend the channels along the bottom or along the margins at 482 cfs (Figure 5-5). Velocities within the bedrock habitat increase with increasing flows, with excessive velocities through the bedrock at flows over 4,000 cfs (Appendix B).

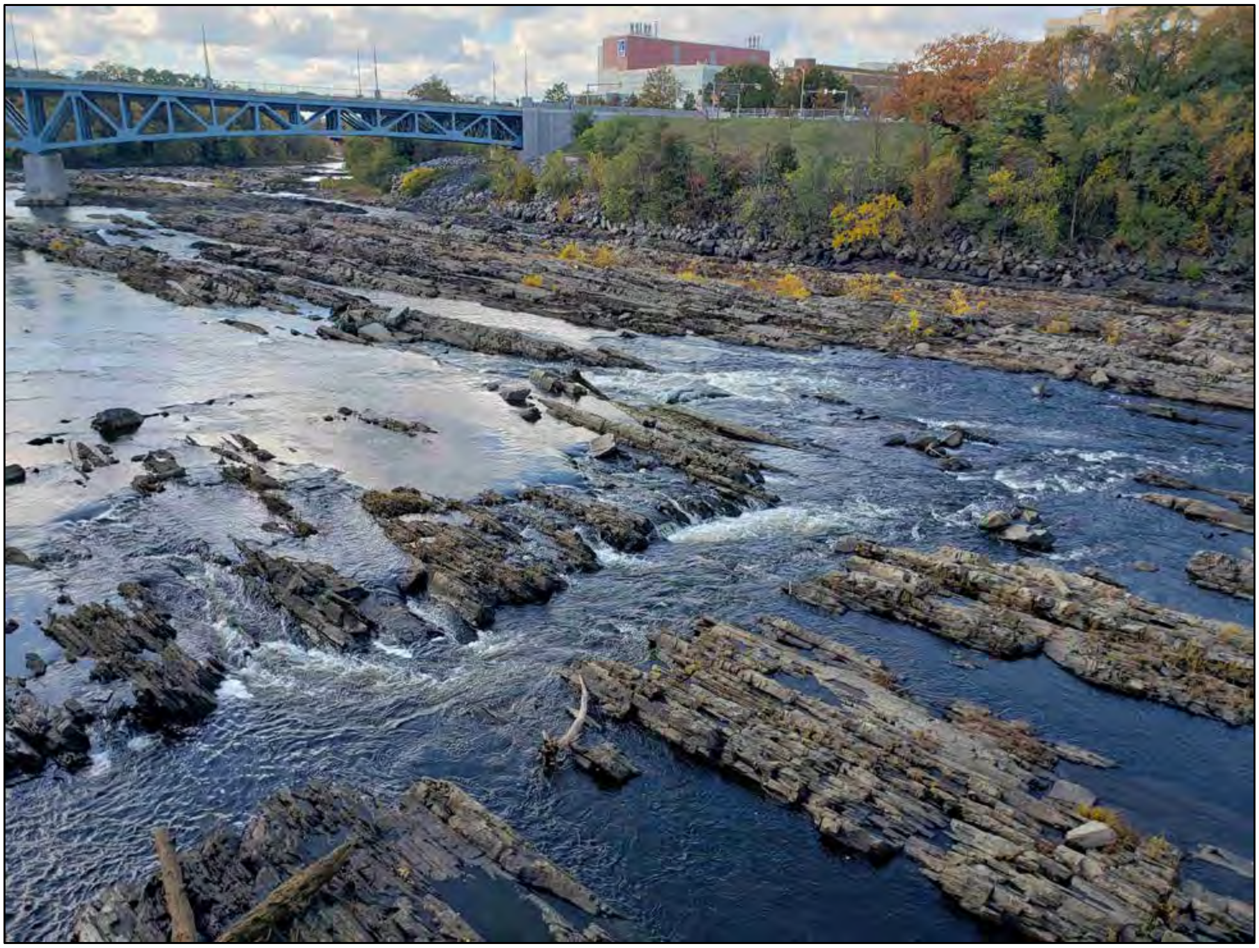


Figure 5-1. Complex deep and fast bedrock cross-over channels in the lower half of the Bypass Reach under low flow conditions. Image taken on Oct 23 2019 at a flow of approximately 480 cfs.

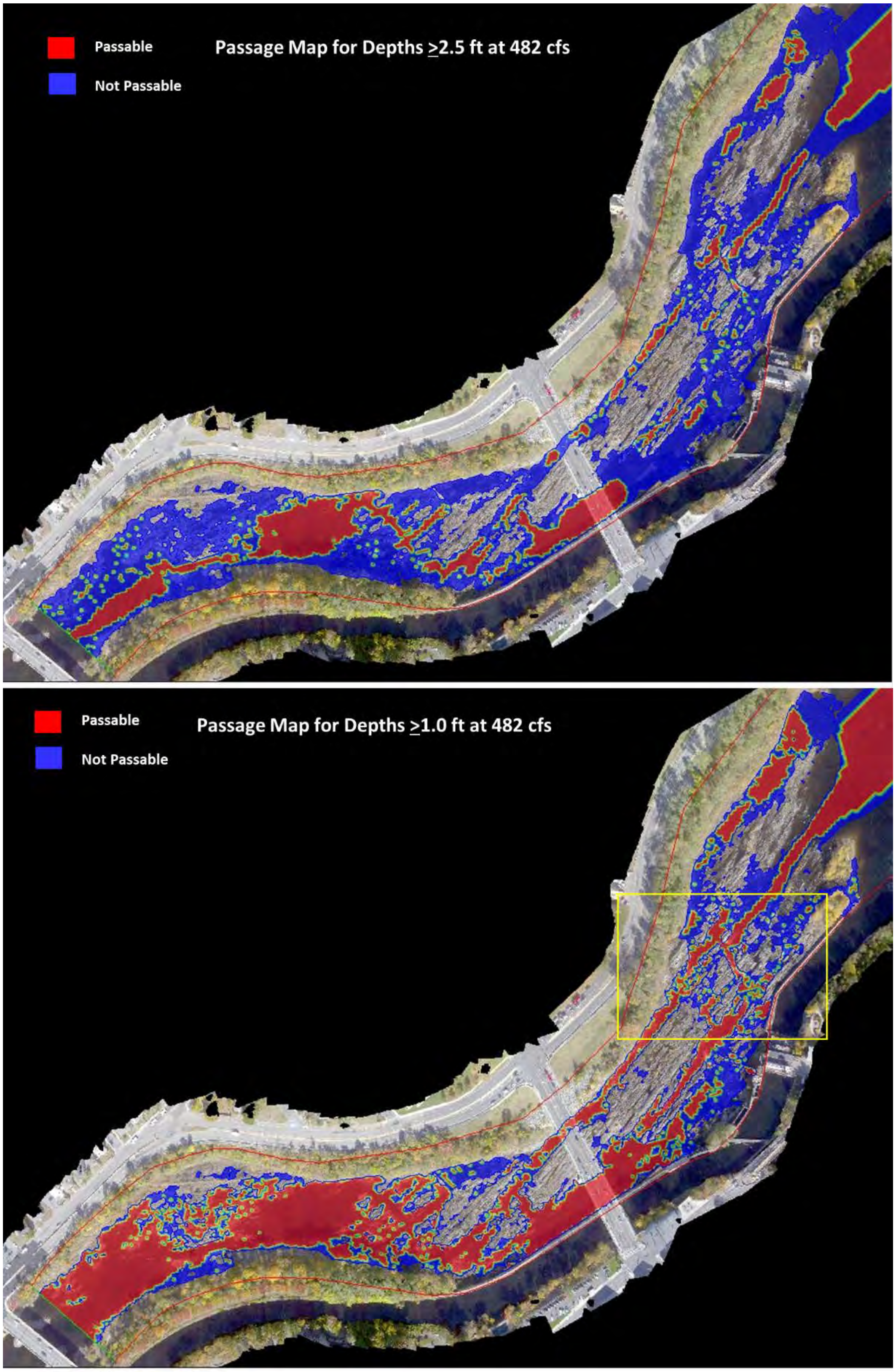
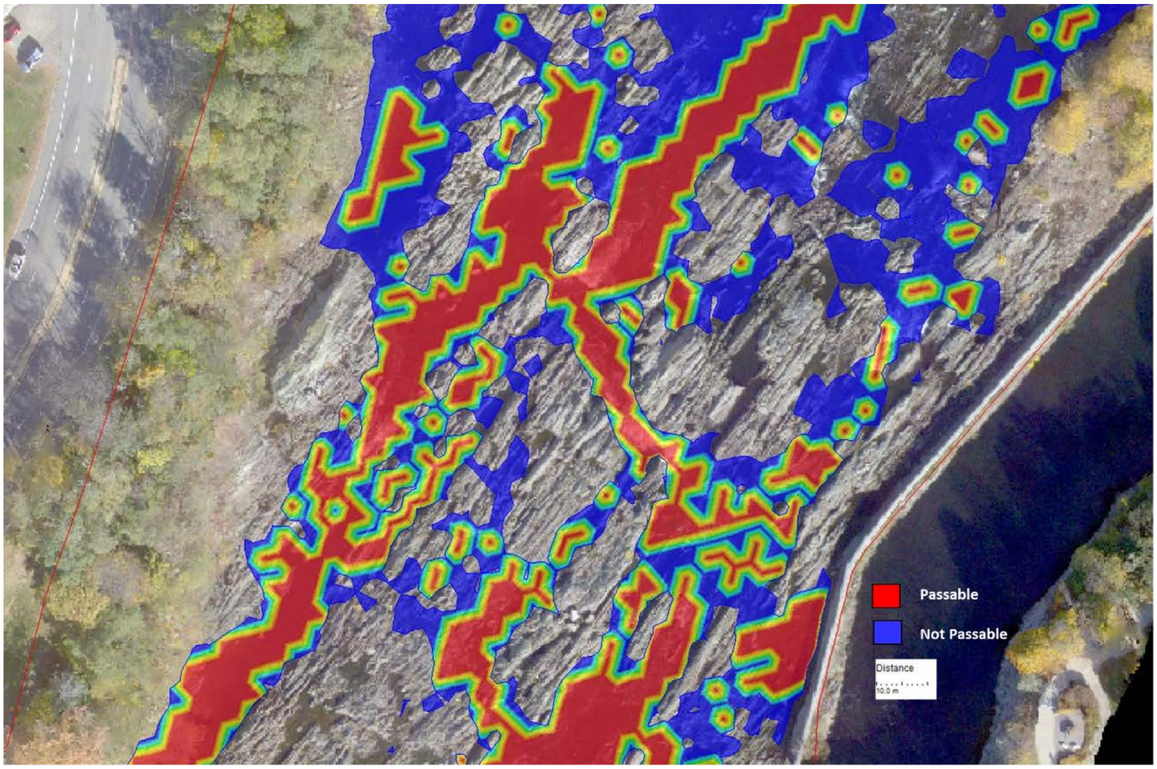


Figure 5-2. Comparative passage through Bypass Reach using minimum depth criteria of 2.5 ft (top map) and 1.0 ft (bottom map). Yellow box shows zoom area.



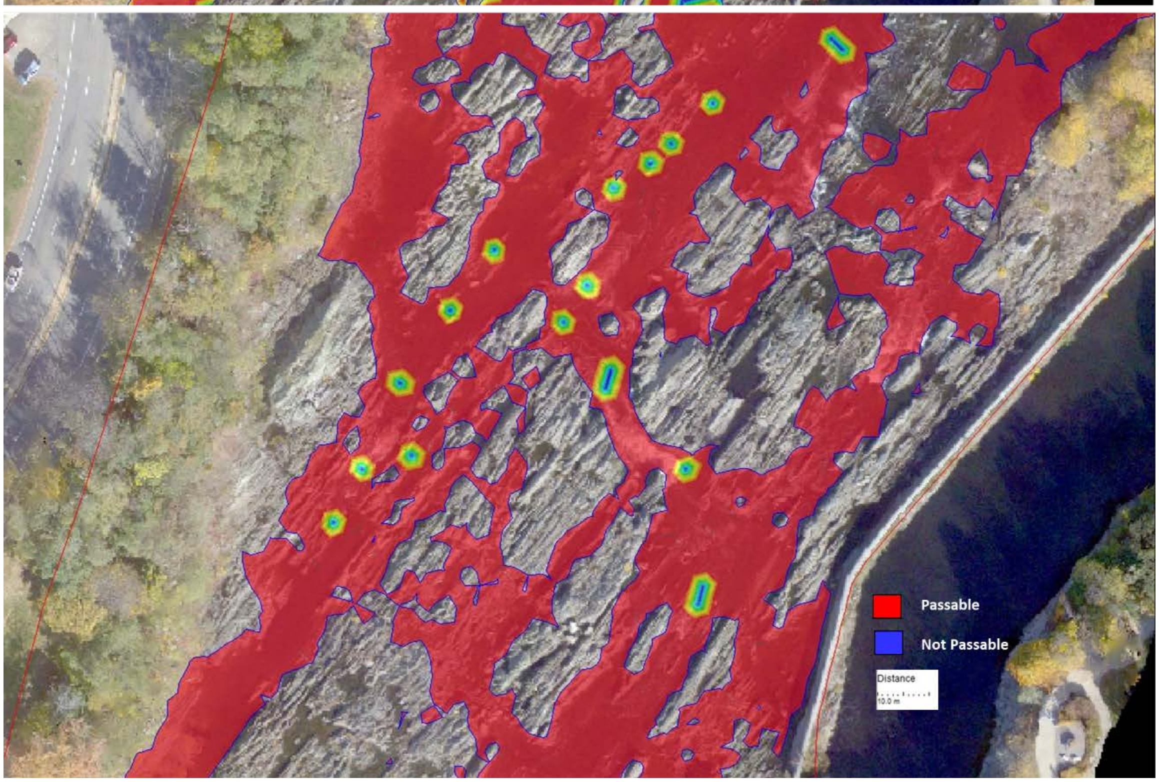


Figure 5-3. Close-up of bedrock cross-over channels in Bypass Reach showing 1 ft depth criteria (top map) and 8.25 fps velocity criteria (bottom map) for American shad at 483 cfs. (see Figure 5-1 for location of zoomed image).

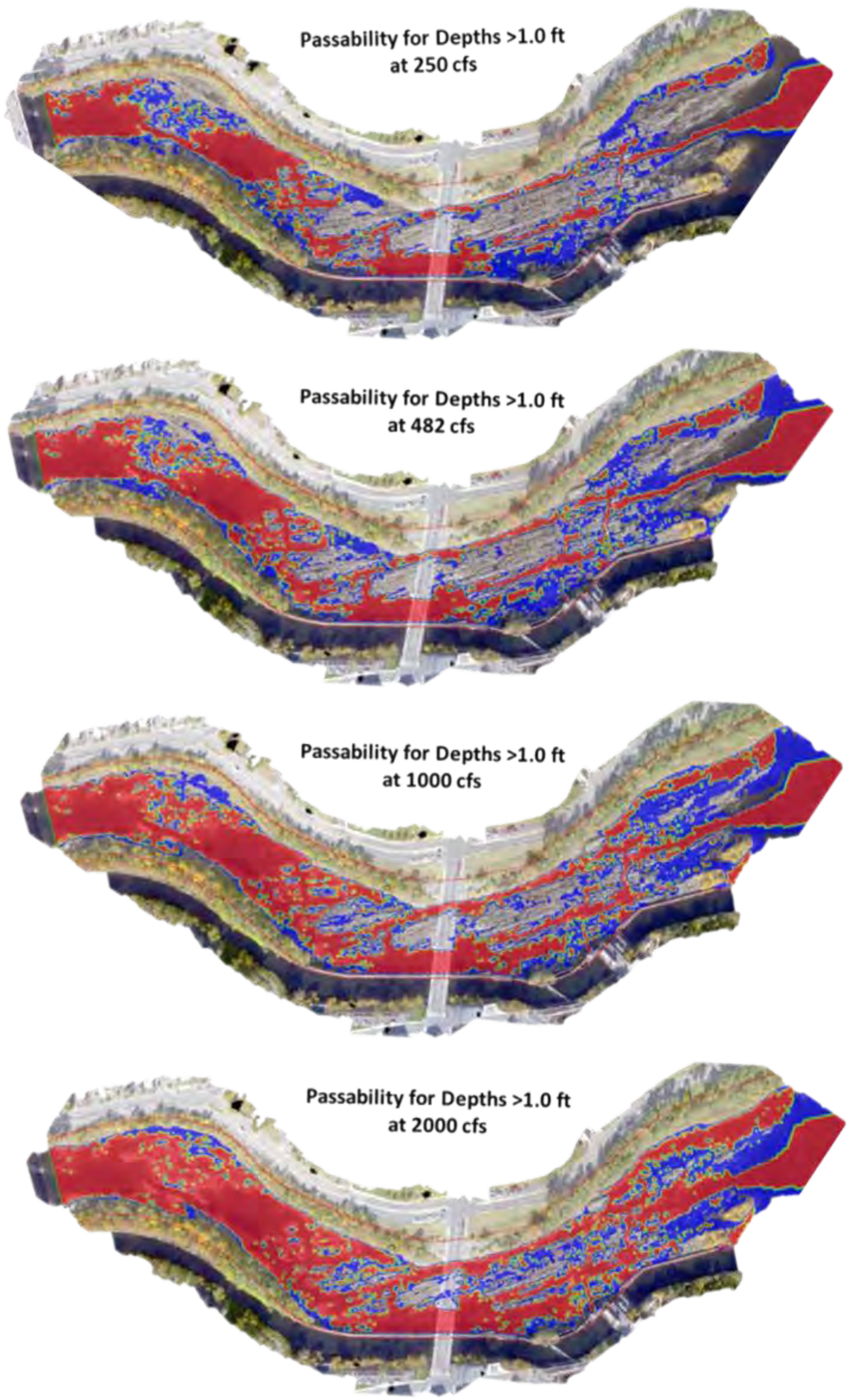


Figure 5-4. Comparative passage for American shad or river herring in the Bypass Reach for depths ≥1.0 ft at various flows. Red equal passable depth, blue non-passable.

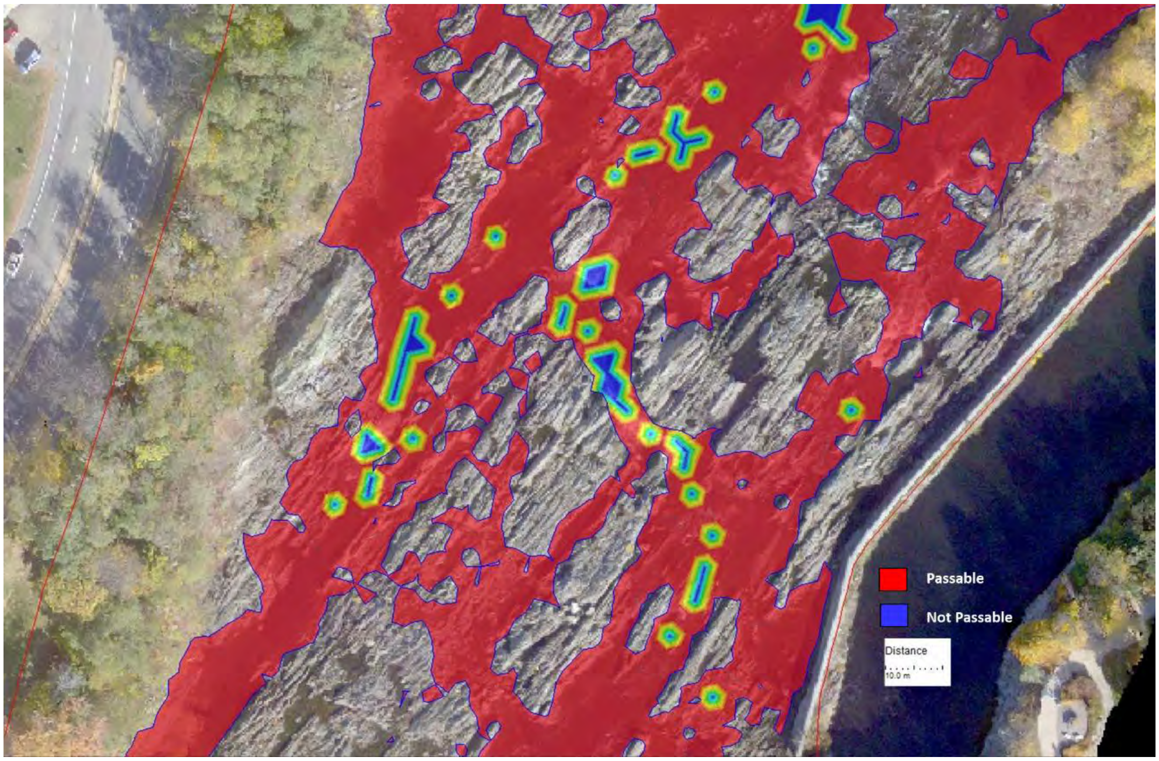


Figure 5-5. Close-up of bedrock cross-over channels in Bypass Reach showing 6.0 fps velocity criteria for river herring at 482 cfs. (see Figure 5-1 for location of zoomed image).

5.2 Aquatic Habitat Assessment

The aquatic habitat model was developed for 9 species and associated life stages in the Bypass Reach from the School Street Bridge downstream 3,000 ft through the bedrock rapids to the tailrace confluence at flows from 250 cfs to 14,000 cfs. An index of suitable habitat at each modeled flow, expressed as WUA in m^2, is presented in Table 5-1. Figure 5-6 illustrates the flow:habitat relationships for each species and life stage, and Figure 5-7 portrays the distribution and magnitude of WUA in the Bypass Reach for each species and life stage at the flow that provides maximum habitat.

5.2.1 American Shad

The index of suitable habitat (Table 5-1, Figure 5-6) for American shad juveniles remained relatively high (>10,000 m^2) at flows between 250 cfs and 2,000 cfs, with declining suitability to a minimum (3,641 m^2) at the maximum modeled flow of 14,000 cfs. The suitability index for shad spawning stayed high (>10,000 m^2) over a wider range of flows (1,000-8,000 cfs), with minima (~6,700 to ~5,700 m^2) at the lowest and the highest modeled flows, respectively. Most suitable habitat for both life stages occurred in the upper half of the modeled reach (Figure 5-7).

5.2.2 River Herring

The habitat index for spawning by river herring (Table 5-1, Figure 5-6) was highest at 3,110 m^2 at the lowest modeled flow (250 cfs), then progressively declined to 490 m^2 as flows increased to 14,000 cfs. Virtually all of the estimated habitat was of low suitability, due to the low suitability (0.1) for all rocky substrates (Table 4-4, Figure 5-7).

5.2.3 Sea Lamprey

Sea lamprey showed maximum habitat of 1,908 m^2 for spawning at 2,000 cfs flows (Table 5-1, Figure 5-6), with a declining habitat index to 355 m^2 at 14,000 cfs. Almost all of the suitable habitat occurred in the upper 1,000 ft of the modeled reach (Figure 5-7).

5.2.4 Fallfish

The habitat index for juvenile fallfish exceeded 1,000 m^2 at flows from 250 cfs to 2,000 cfs, with maximum habitat (3,134 m^2) at approximately 500 cfs (Table 5-1, Figure 5-6, Figure 5-7). Suitable habitat for adult fallfish was more available than for juveniles, with WUA estimates over 15,000 m^2 at flows from 250 cfs to 2,000 cfs, and a maximum of over 18,000 m^2 at 1,000 cfs. Juvenile habitat was largely restricted to the upper end of the modeled reach, whereas suitable habitat for adult fallfish was more widely distributed (Figure 5-7).

5.2.5 Longnose Dace

Suitable habitat for longnose dace juveniles was estimated at less than 1,000 m^2, except at about 500 cfs where WUA was 1,086 m^2 (Table 5-1, Figure 5-6). The habitat index for adult dace was somewhat higher, with WUA over 1,500 m^2 at flows from 250 cfs to 1,000 cfs, with a maximum of 2,414 m^2 at about 500 cfs. Most of the suitable habitat for both juvenile and adult dace occurred in the upper end of the modeled reach above the area dominated by bedrock ledges (Figure 5-7).

5.2.6 Smallmouth Bass

The index of suitable habitat was highest for smallmouth bass fry (10,617 m^2) and spawning (879 m^2) at the lowest modeled flow of 250 cfs (Table 5-1, Figure 5-6), which is not unexpected due to the fry's weak swimming ability and the associated need for low velocities at bass nests. Suitable habitat for juvenile bass remained relatively high (>10,000 m2) at flows from 250 cfs to 2,000 cfs, with a maximum habitat index of 13,820 m^2 at 1,000 cfs. Adult smallmouth bass also showed maximum habitat (8,021 m^2) at 1,000 cfs, with a progressive decline to 2,016 m^2 at a flow of 14,000 cfs. Moderate to highly suitable habitat for fry, juvenile, and adult bass was distributed in both upper and lower ends of the modeled Bypass Reach, although spawning habitat was rare and confined to the upper region near the School Street Bridge (Figure 5-7).

5.2.7 White Sucker

The estimated WUA for white sucker fry, juvenile/adult, and spawning life stages all maximized at low flows (Table 5-1, Figure 5-6). The fry life stage showed high WUA at flows from 250 cfs to 2,000 cfs, with a maximum of 25,085 m^2 at the lowest modeled flow. Juvenile/adult WUA was 12,398 m^2 at about 500 cfs, whereas spawning WUA maximized at only 159 m^2 at 250 cfs. The low habitat index for sucker spawning was likely due to the HSC, which gave zero suitability for any substrate other than silt, sand, and gravel, each of which were rare in the Bypass Reach (Table 4-4, Figure 4-1). Both moderate and high quality habitat occurred for sucker fry and juvenile/adult life stages throughout most of the modeled reach, although habitat was spotty in the bedrock ledges (Figure 5-7). Suitable habitat for spawning was very rare and of low quality, due to the relative lack of suitable spawning substrate.

5.2.8 Freshwater Mussels

The 2D model estimated relatively high values of WUA for freshwater mussels, with indexes over 10,000 m^2 at 1,000 and 2,000 cfs, and a maximum of 11,066 m^2 at 2,000 cfs (Table 5-1, Figure 5-6). The abundance of suitable habitat is likely due to the broad preferences for coarse substrate types (Table 4-4), although most habitat was of low quality except in the area just downstream of the School Street Bridge and a small area adjacent to the powerhouse tailrace (Figure 5-7).

5.2.9 Benthic Macroinvertebrates

BMI showed the highest estimates of WUA of all species groups, with a maximum of 24,062 m^2 at 2,000 cfs, and maintained high habitat values (>10,000 m2) from 500 cfs to 10,000 cfs (Table 5-1, Figure 5-6). The high magnitude of WUA was largely due to the BMI's relatively high HSC value for bedrock at 0.5 (Table 4-4), which likely overestimates suitability of bedrock for EPT taxa (mayflies, stoneflies, and caddisflies), in comparison to Simulids and other midge species that have broader substrate preferences. The 2D model predicted suitable habitat for BMI throughout the Bypass Reach, although the highest quality habitat occurred in the upper end of the reach and near the bottom of the reach (Figure 5-7).

Table 5–1. Weighted Usable Area (WUA) in m² in the Bypass Reach according to flow, species, and life stage.

Flow	American Shad		River Herring	Sea Lamprey	Fallfish	
cfs	Juvenile	Spawning	Spawning	Spawning	Juvenile	Adult
250	11,923	6,738	3,110	576	2,764	15,133
482	14,468	9,368	2,951	1,012	3,134	17,586
1,000	15,864	12,859	2,421	1,599	2,873	18,363
2,000	14,946	15,664	1,711	1,908	1,726	14,308
4,345	9,948	15,755	1,011	1,282	893	8,219
6,000	7,558	13,396	820	858	895	6,782
7,011	6,517	11,852	723	724	894	6,201
8,000	5,710	10,313	675	611	819	5,724
10,000	4,644	7,864	568	489	688	4,979
12,000	4,025	6,418	523	415	511	4,573
14,000	3,641	5,718	490	355	371	4,277

Flow	Smallmouth Bass				Longnose Dace	
cfs	Fry	Juvenile	Adult	Spawning	Juvenile	Adult
250	10,617	10,141	5,834	879	838	1,970
482	10,491	12,772	7,155	727	1,086	2,414
1,000	7,768	13,820	8,021	508	735	1,657
2,000	5,507	11,407	6,350	324	385	848
4,345	3,340	6,793	4,014	215	283	537
6,000	2,817	5,412	3,366	201	296	580
7,011	2,454	4,882	3,087	173	265	599
8,000	2,270	4,394	2,818	161	212	508
10,000	1,899	3,665	2,402	143	116	303
12,000	1,660	3,249	2,153	104	69	160
14,000	1,526	2,983	2,016	98	44	109

Flow	White Sucker			Freshwater Mussels	Benthic Macro-invertebrates
cfs	Fry	Juvenile	Adult	Rearing	Rearing
250	25,085	10,724	159	8,217	7,213
482	22,449	12,398	95	9,686	12,031
1,000	16,881	10,462	61	10,937	18,958
2,000	11,986	6,989	21	11,066	24,062
4,345	7,219	4,352	69	8,528	21,698
6,000	6,041	3,758	123	6,679	17,847
7,011	5,233	3,361	95	5,802	15,777
8,000	4,787	3,165	66	5,039	13,819
10,000	4,065	2,706	34	3,913	10,948
12,000	3,657	2,481	12	3,244	8,867
14,000	3,488	2,354	9	2,866	7,250

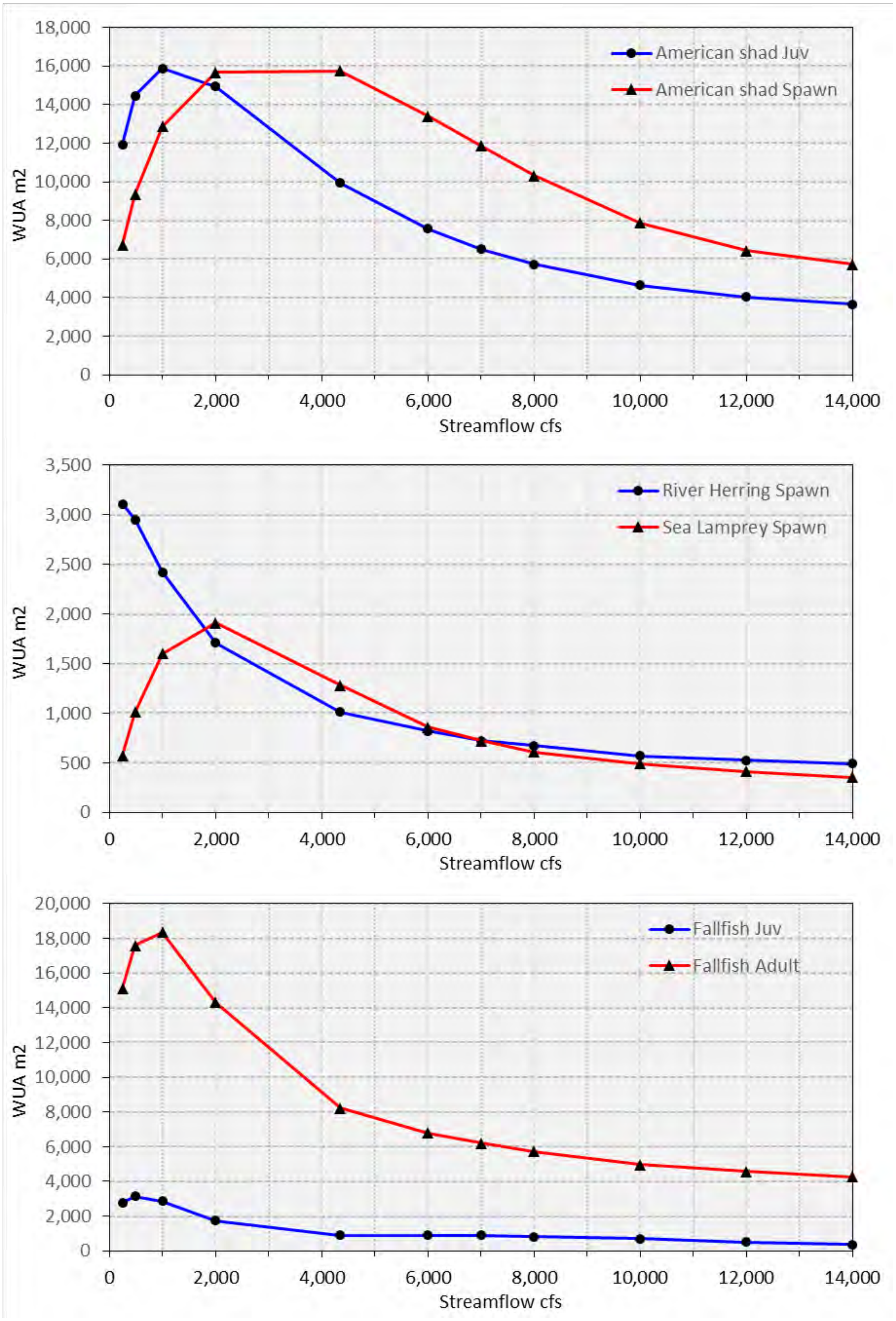


Figure 5-6. Relationship between WUA (m2) and flow (cfs) in Bypass Reach according to species and life stage.

Figure 5-6. (continued).

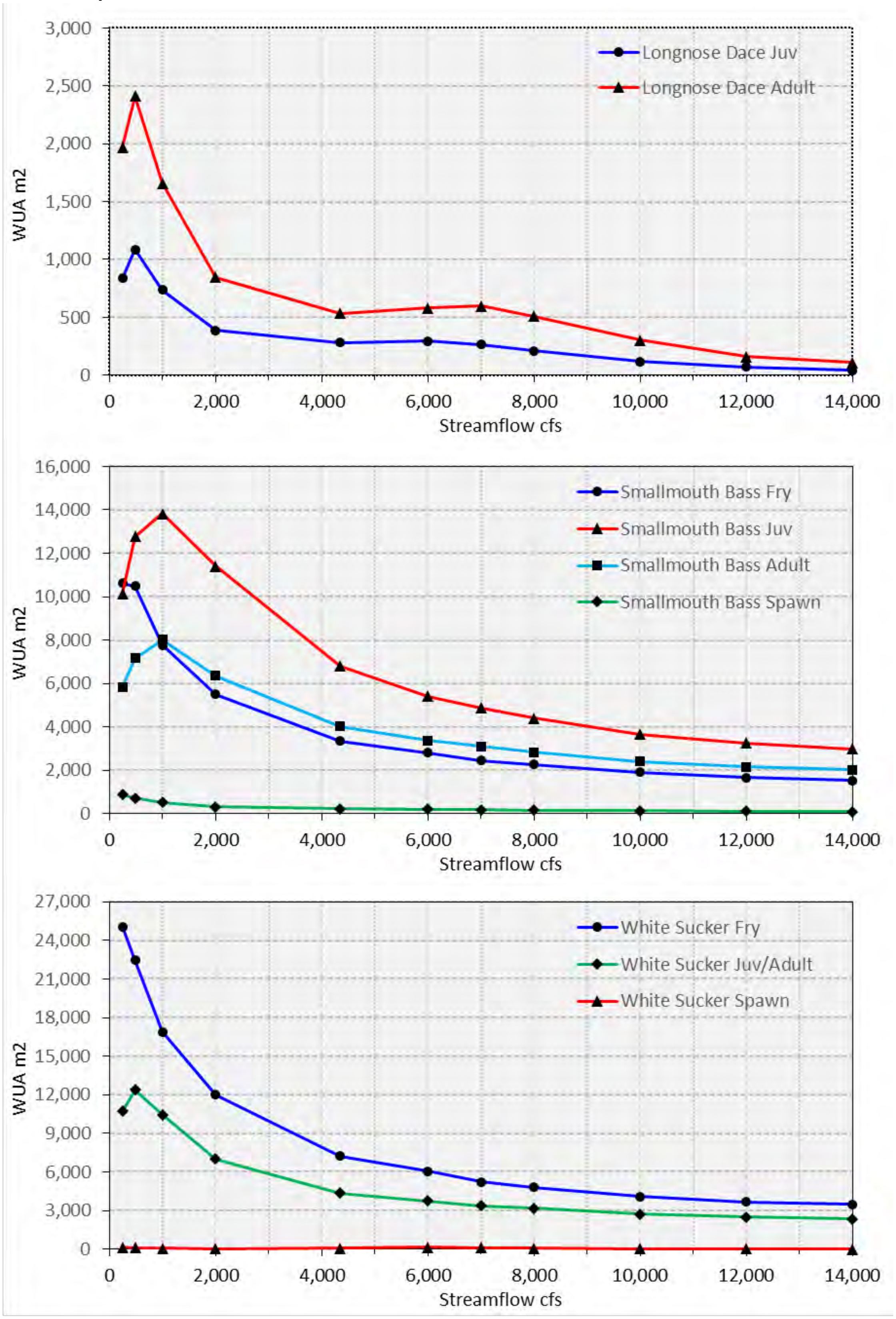
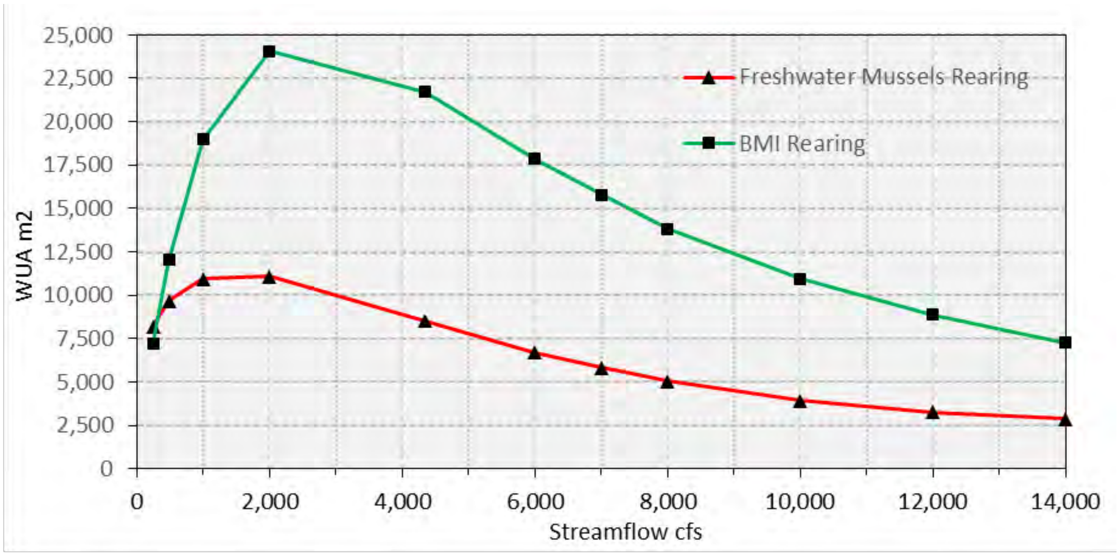


Figure 5-6. (continued).



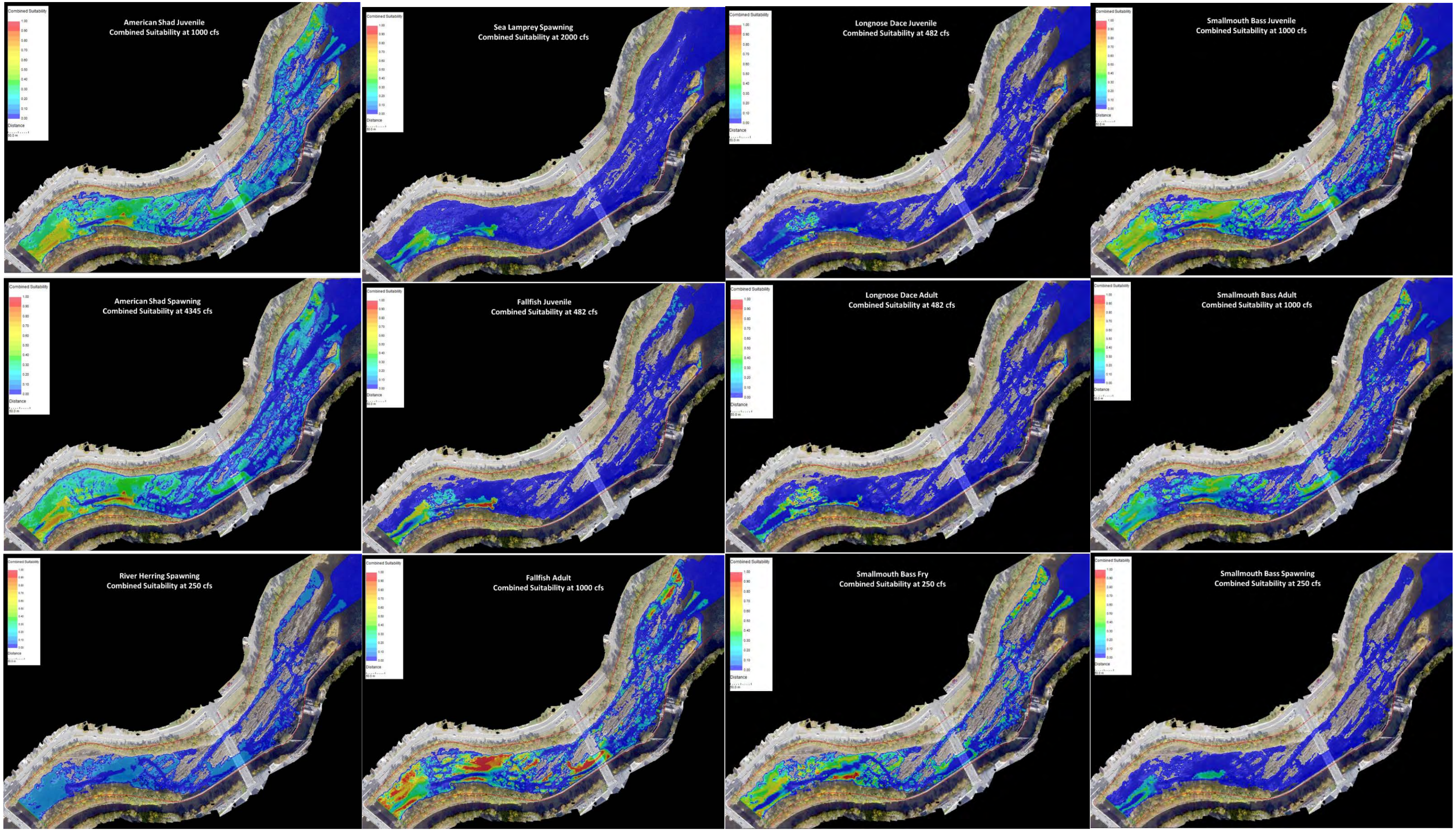


Figure 5-7. Bypass Reach showing combined suitability according to species and life stage.

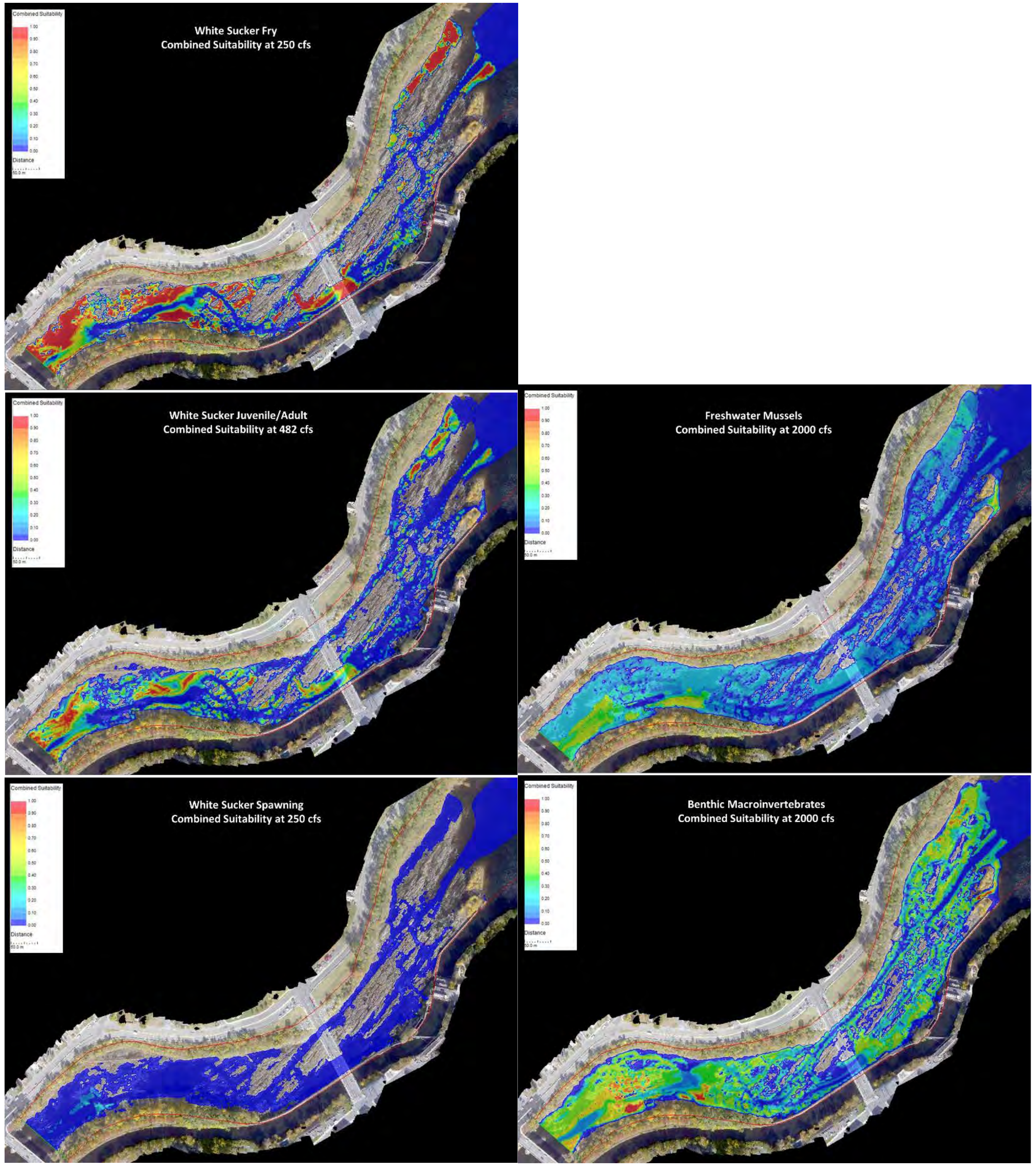


Figure 5-7. (continued)

6 Summary

A two-dimensional (2D) hydraulic model was developed in the Bypass Reach extending from the School Street Bridge downstream approximately 3,000 ft to the confluence with the powerhouse tailrace. The 2D model was calibrated at low (482 cfs), middle (4,345 cfs), and high (7,011 cfs) flows, with simulated flows ranging from 250 cfs to 14,000 cfs. Lidar and RTK measurements were utilized to develop a digital elevation model of the Bypass Reach. Visual surveys were also conducted on foot to delineate polygons consisting of specified substrate characteristics. The 2D model was utilized to assess the relationship between Bypass Flow and upstream passage through the bedrock dominated reach by adult migrant American shad and river herring (blueback herring, and alewife). The 2D model also assessed the relationship between Bypass flows and the quantity and quality of aquatic habitat, expressed as Weighted Usable Area (WUA), for 9 species groups and their associated life stages.

6.1 Summary of Zone of Passage Results

Assessment of the zone of passage was challenging due to the highly complex bedrock habitat throughout most of the Bypass Reach. Complete, uninterrupted connection from the lower boundary to the upper boundary at the School Street bridge, when utilizing passage criteria for both depth and velocity, was never achieved for either American shad or river herring. The 2D model identified numerous potential gaps in suitable passage habitat in the lower half of the Bypass Reach downstream of the University Avenue Bridge. From review of the zone of passage model imagery alone it is unclear if these gaps would be absolute barriers to upstream migration or if passage would be possible along the margins of the impassable gaps. Given the uncertainty in the modeled depth-averaged velocities through the lower, complex bedrock area, the passage analysis focused on flows meeting the depth criteria, with closer inspection of modeled velocities at identified pinch-points (e.g., narrow/fast bedrock channels).

In addition, the shad assessment was reanalyzed using a more realistic minimum depth of 1.0 ft (same as herring), which provided a near-continuous passage channel at flows of approximately 500 cfs, with multiple passage channels at higher flows (Figure 5-4). Passage opportunities based on depth alone increased with flows, but velocities became limiting at flows over 6,000 cfs (Appendix B). Likewise for river herring, depths became suitable for passage by 500 cfs, with excessive velocities through bedrock channels at flows of 4,000 cfs and greater. Note that these assessments do not account for channel widths, however given the large scale of the Bypass Reach and the complexity of the bedrock habitat, it is unlikely that channel widths would be limiting.

As part of the *Upstream and Downstream Adult Alosine Passage Assessment* study, movements of radio-tagged adult river herring and American shad were monitored within the Bypass Reach during spring 2020. As described in that technical report, flows through the Lowell Bypass Reach during the 2020 monitoring period were comprised of the ~500 cfs of water constituting the attraction and conveyance flow associated with the Pawtucket Dam fish ladder as well as incidental spill flow passing over the spillway. Incidental spill flows in excess of 500 cfs were present until May 21 after which incidental spill was reduced to near zero through the month of

June (Figure 6-1). A total of 105 unique foray events for radio-tagged adult river herring into the Bypass Reach were recorded during the 2020 study. These events were recorded over a range of dates from May 7 through May 23 with the majority of events occurring between May 17 and 19. When the average Bypass Reach discharge condition occurring during each upstream foray is considered, foray events resulting in successful passage at the Pawtucket Dam fish ladder occurred over a range of Bypass Reach flows from 883 to 4,432 cfs. Conversely, foray events which did not result in successful upstream passage and were determined to have ended at or near to the midpoint of the Bypass Reach occurred over a range of flows from 907-2,145 cfs and those that ended at the upstream end of the Bypass Reach occurred over a range of flows from 799 to 2,587 cfs. The probability of successful upstream passage for radio-tagged adult herring was evaluated using a Cormack Jolly-Seber model for the lower and upper portions of the Bypass Beach and was estimated at 72% and 92%, respectively. Although tagged adult herring were only detected through May 23 within the Lowell Bypass Reach, camera operations at the Pawtucket Dam fish ladder continued to document migrating river herring through the first week of June. Mean daily discharge values for flow through the Lowell Bypass Reach between May 24 and June 6 ranged from 900 to 546 cfs. A net total of 42,066 adult herring passed during that period (Figure 6-2)

Movements of radio-tagged adult American shad during the 2020 passage evaluation were limited to a single detection at the lowermost receiver station. When considered with findings from this zone of passage assessment it appears that shad have difficulty migrating upstream through the Bypass Reach. However, camera operations at the viewing window of the Pawtucket Dam fish ladder documented the upstream passage of 799 adult American shad over a range of dates from May 18 to June 26 with the majority of passage events documented during early and mid-June (Figure 6-3). Reported Merrimack River inflow during the period of peak shad detection in the Pawtucket Dam counting window during 2020 was below the E.L. Field Powerhouse capacity of 8,000 cfs; consequently no spill occurred over this period (Figure 6-1) and discharge through the Bypass Reach was limited to ~500 cfs from the Pawtucket Dam fish ladder (Figure 6-3).

Despite poor performance of tagged shad and the lack of passage connectivity through the Bypass Reach according to the 2D model (using the 2.5 ft minimum depth criteria), a proportion of adult shad were able to reach the Pawtucket Dam fish ladder under a Bypass flow of about 500 cfs. This is consistent with the revised 2D model using a 1.0 ft minimum depth criteria for shad, which suggested near continuous passage opportunities at a flow of approximately 500 cfs.

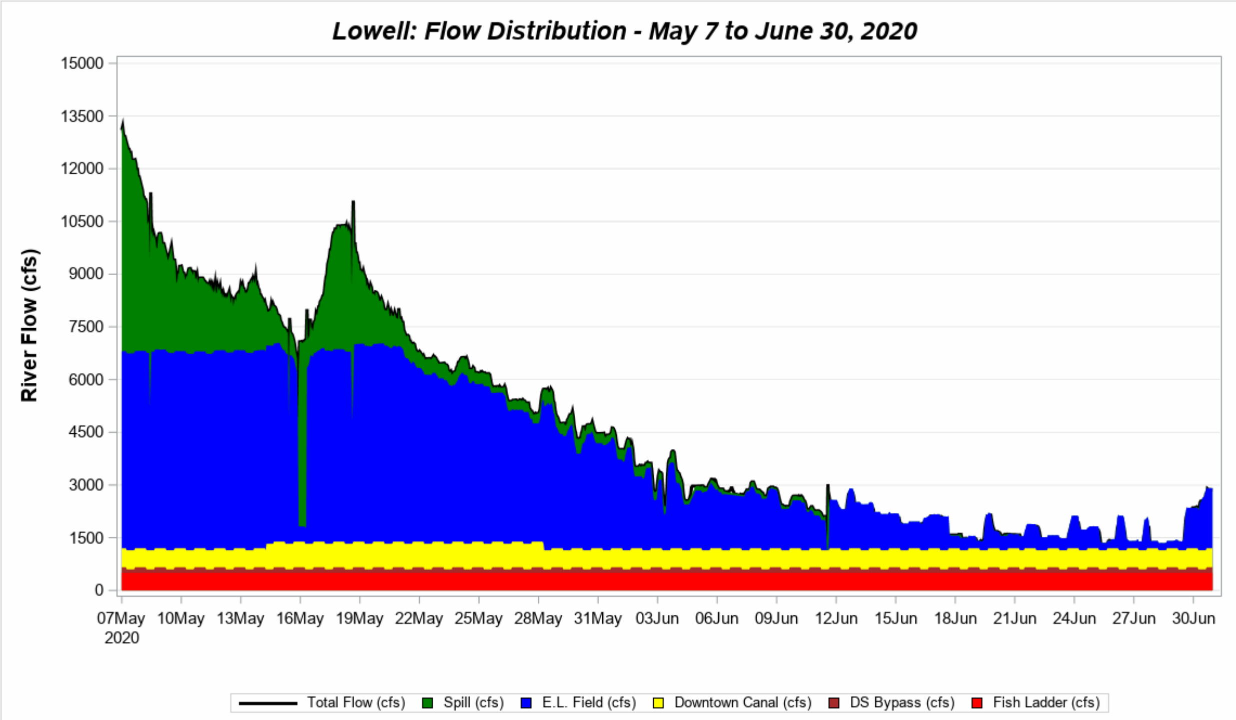


Figure 6-1. Total, spill, E.L. Field, fish ladder, downstream bypass and downtown canal system flow (cfs) for the period May 7 to June 30, 2020.

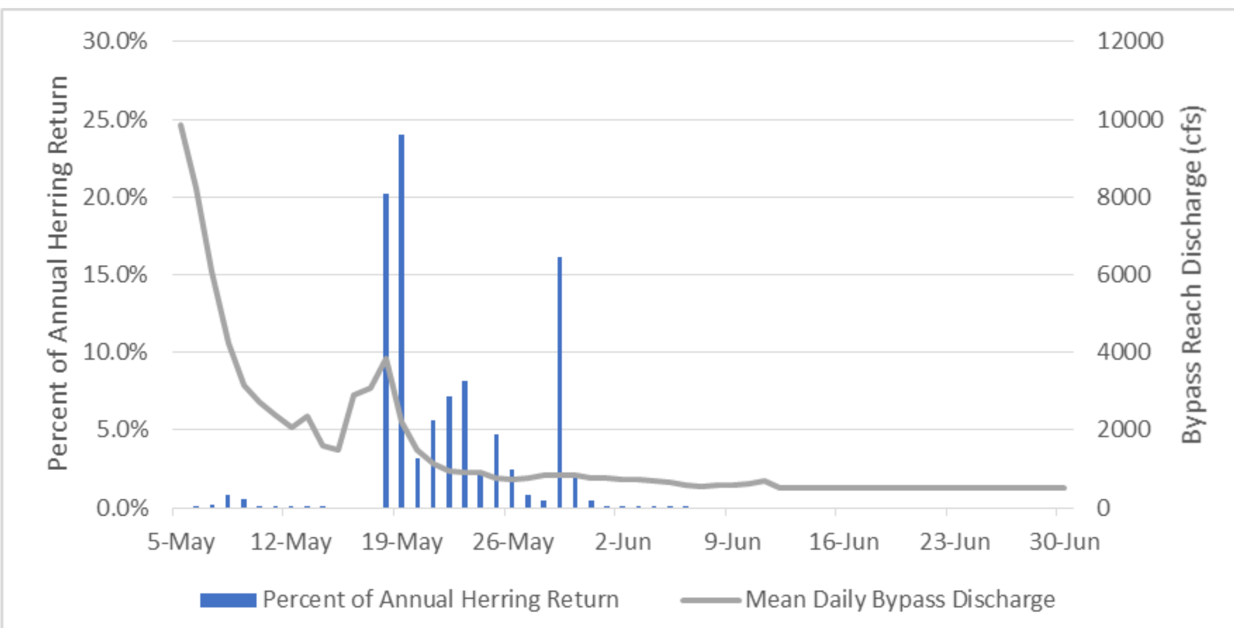


Figure 6-2. Pawtucket Dam fish ladder river herring counts and reported Lowell Bypass Reach discharge for the 2020 upstream passage season.

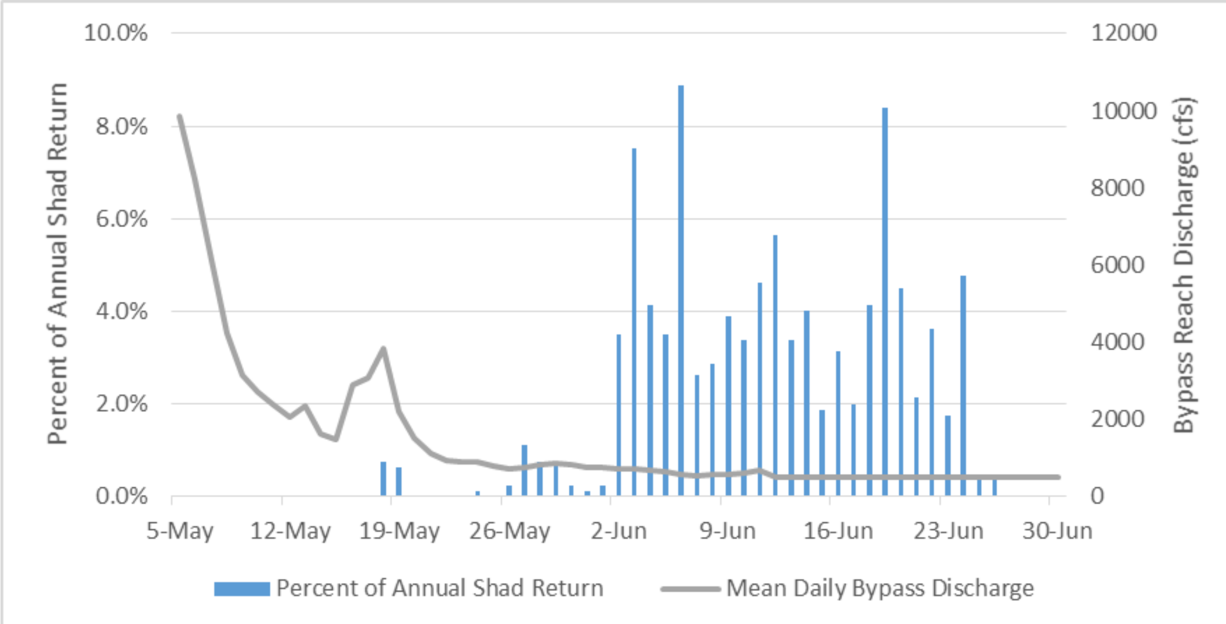


Figure 6-3. Pawtucket Dam fish ladder American shad counts and reported Lowell Bypass Reach discharge for the 2020 upstream passage season.

6.2 Summary of WUA Results

In most cases the habitat indexes for each species and life stage showed maximum suitable habitat at relatively low flows through the Bypass Reach (Table 5-1, Figure 5-6). Thirteen of the 17 assessments produced maximum WUA at flows of 1,000 cfs or less, with 3 other species/life stages (lamprey spawning, freshwater mussels, and BMI rearing) reaching maximum WUA at 2,000 cfs, and one species/life stage (shad spawning) showing maximum habitat at a higher flow (4,345 cfs). This result is primarily due to the steep, bedrock dominated habitat that characterizes the Bypass Reach. In terms of the magnitude of suitable habitat, the habitat index showed highest values for shad, adult fallfish, sucker fry, and BMI, each with maximum WUA estimates exceeding 15,000 m^2. In contrast, relatively little suitable habitat was predicted for lamprey spawning, bass spawning, sucker spawning, and juvenile longnose dace; all of which had maximum WUA values of less than 2,000 m^2. WUA distribution maps (Figure 5-7) revealed that most suitable habitat occurred in the upper 1,000 ft of the modeled reach, with limited suitable habitat in the lower, bedrock-dominated area.

7 Variances from FERC-Approved Study Plan

As previously noted, the 2D model for the zone of passage task was initially intended to encompass the series of weirs located in the upper end of the Bypass Reach upstream of the School Street Bridge. However the model was unable to run to a steady state solution due to unrealistically high velocities (greater than 2,000 fps) at nodes along the vertical edges of the weirs, which caused the time step to drop to infinitesimally small levels, and preventing the model from advancing beyond a few seconds. Consequently, the upstream boundary for both the zone of passage and the aquatic habitat elements of this study was placed just downstream of the School Street Bridge to avoid the transverse flow coming from the diagonal spillway.

The FERC-approved RSP notes that NMFS requested ADCP velocity data at randomly placed cross sections under the high calibration flow collection. Although not necessary for 2D model development, such data can be useful as validation data. However, we could not physically access locations for collecting validation data during the high flow event, and the current velocities in many areas was determined to be too fast and would exceed the capabilities of the ADCP trimaran. Consequently, transect validation data was not performed.

Due to the complexity of the bedrock-dominated habitat, both “minimum” and “optimal” passage flows were not identified. Instead, the minimum flow meeting passage depth criteria was identified for American shad and river herring, along with the range of potential passage flows based on both depth and velocity criteria.

There were no additional variances from the FERC-approved study plan in this task.

8 References

Allen, M.A. 1996. Equal area line-transect sampling for smallmouth bass habitat suitability criteria in the Susquehanna River, Pennsylvania. Pages B119-132 in M. LeClerc, C. Herve, S. Valentin, A. Boudreault, and Y. Cote, editors. Ecohydraulics 2000: Second international symposium on habitat hydraulics. Institut National de la Recherche Scientifique-Eau, Quebec, Canada.

Edwards, E.A., G. Gebhart, and O.E. Maughan. 1983b. Habitat suitability information: smallmouth bass. USDI, Fish and Wildlife Service FWS/OBS-82/10.36. 47pp.

Gomez and Sullivan Engineers, P.C. 2000. Lamoille River Hydroelectric Project, FERC Project No. 2205. Instream flow and habitat study report. Prepared for Central Vermont Public Service Corp.

Gomez and Sullivan Engineers, P.C. 2007. Glendale Hydroelectric Project FERC Project No. 2801. Final Report Bypass reach aquatic habitat and instream flow study.

Great River Hydro (GRH). 2019. ILP Study 9: Instream Flow Study – Final Report, Appendix A Habitat Suitability Criteria.

Greene, K.E., J.L. Zimmerman, R.W. Laney, and J.C. Thomas-Blate. 2009. Atlantic coast diadromous fish habitat: A review of utilization, threats, recommendations for conservation, and research needs. Habitat Management Series No. 9. Washington, D.C: Atlantic States Marine Fisheries Commission.

Groshens, T.P., and D.J. Orth. 1994. Transferability of habitat suitability criteria for smallmouth bass, Micropterus dolomieu. Rivers 4:194-212.

Hightower, J.E., J.E. Harris, J.K. Raabe, P. Brownell, and C.A. Drew. 2012. A Bayesian spawning habitat suitability model for American shad in Southeastern United States rivers. Journal of Fish and Wildlife Management 3(2):184-198.

Kynard, B. and M. Horgan. 2013. Habitat suitability index for sea lamprey redds. Unpublished manuscript. 5 pp.

Leonard, P.M., D.J. Orth, and C.J. Goudreau. 1986. Development of a method for recommending instream flows for fishes in the Upper James River, Virginia. Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, Blacksburg, VA. 122pp.

Mather, M.E., J.J. Frank, J.M. Smith, R.D. Cormier, R.M. Murth, and J.T. Finn. 2012. Assessing freshwater habitat of adult anadromous alewives using multiple approaches. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 4:188-200.

Normandeau and Biodrawversity. 2017. ILP Study 24 - Dwarf Wedgemussel and Co-Occurring Mussel Study: Development of Delphi Habitat Suitability Criteria. Prepared for TransCanada Hydro Northeast Inc. March 22, 2017.

Pardue, G.B. 1983. Habitat suitability index models: alewife and blueback herring. USDI, Fish and Wildlife Service FWS/OBS-82/10.58. 22pp.

Steffler, P., and J. Blackburn. 2002. River 2D, two-dimensional depth averaged model of river hydrodynamics and fish habitat, introduction to depth averaged modeling and user's manual. University of Alberta, September 30, 2002. 119pp.

Steir, D.J. and J.H. Crance. 1985. Habitat suitability index models and instream flow suitability curves: American shad. U.S. Fish and Wildlife Service Biological Report 82(10.88). 34 pp.

Twomey, K.A., K.L. Williamson, and P.C. Nelson. 1984. Habitat suitability index models and instream flow suitability curves: white sucker. United States Fish and Wildlife Service FWS/OBS-82/10.64. 56pp.

United States Fish and Wildlife Service (USFWS). 2011. Flow-habitat relationships for fall-run Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Clear Creek Road and the Sacramento River. Final Report, United States Fish and Wildlife Service, SFWO, Restoration and Monitoring Program, Sacramento, CA. 109pp.

United States Fish and Wildlife Service (USFWS). 2019. Fish passage engineering design criteria. USFWS Northeast Region R5, Hadley, MA. 248pp.

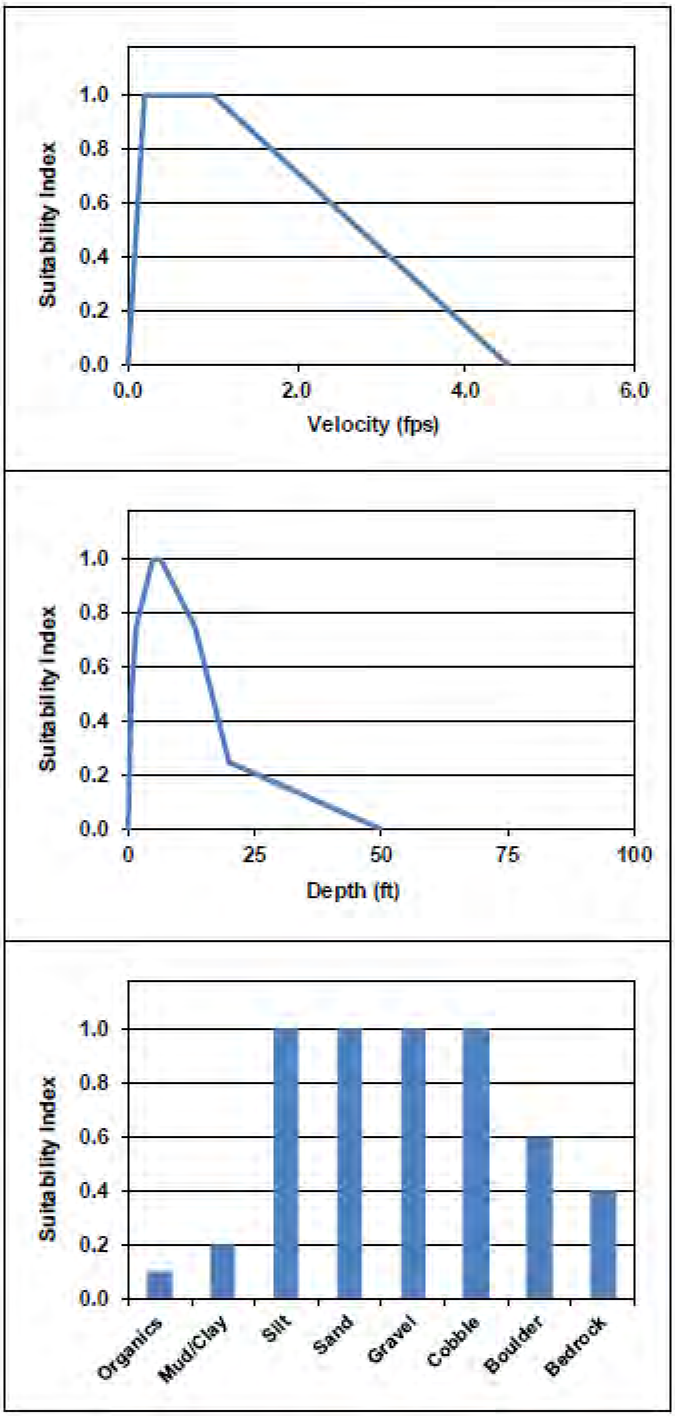
Yergeau, K.M. 1983. Population demography, riverine movement and spawning habitat of the sea lamprey, *Petromyzon marinus*, in the Connecticut River. M.S. Thesis, University of Massachusetts, Amherst, Massachusetts. 634 pp.

9 Appendices

Appendix A. Habitat suitability criteria for target species and life-stages.

American Shad Juvenile

Source:



Stier and Crance, 1985

Velocity (ft/s)	SI
0.00	0.00
0.20	1.00
1.00	1.00
4.50	0.00

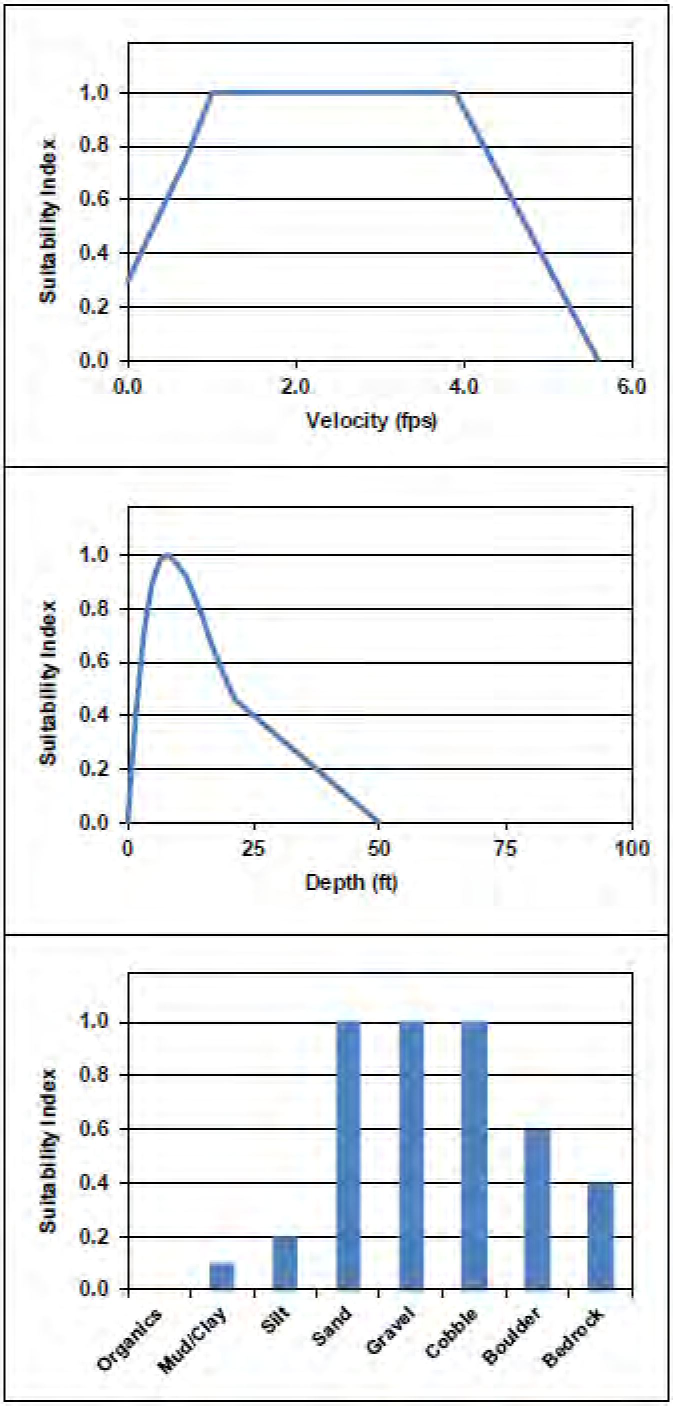
Greene et al., 2009

Depth (ft)	SI
0.00	0.00
0.66	0.50
1.50	0.75
4.90	1.00
6.60	1.00
13.20	0.75
20.00	0.25
50.00	0.00

Conowingo IFIM

Substrate	SI
Organics	0.10
Mud/Clay	0.20
Silt	1.00
Sand	1.00
Gravel	1.00
Cobble	1.00
Boulder	0.60
Bedrock	0.40

American Shad Spawning



Source:
Velocity based on data from Hightower et al., 2012

Velocity (ft/s)	SI
0.00	0.30
0.70	0.75
1.00	1.00
3.00	1.00
3.90	1.00
5.60	0.00

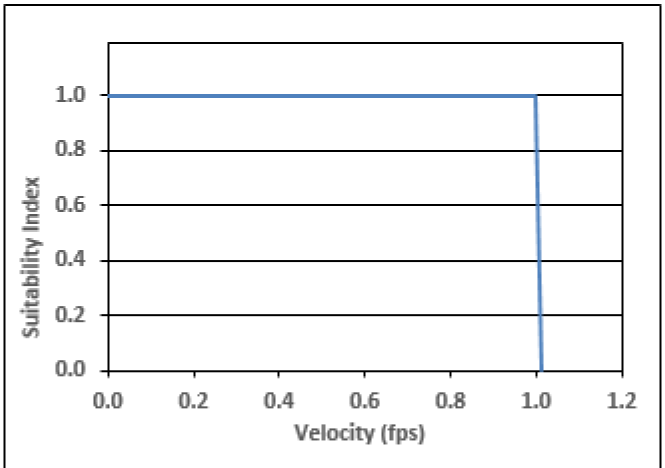
Hightower et al., 2012 and Stier and Crance, 1985

Depth (ft)	SI
0.00	0.00
1.60	0.40
3.30	0.71
4.90	0.89
6.60	0.98
8.20	1.00
9.80	0.97
11.50	0.92
13.10	0.85
14.80	0.77
16.40	0.68
18.00	0.60
19.70	0.53
21.30	0.46
50.00	0.00

Stier and Crance, 1985

Substrate	SI
Organics	0.00
Mud/Clay	0.10
Silt	0.20
Sand	1.00
Gravel	1.00
Cobble	1.00
Boulder	0.60
Bedrock	0.40

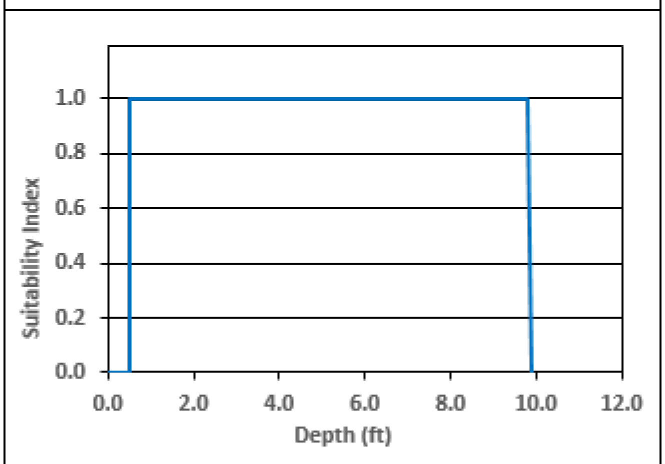
River Herring Spawning



Source:

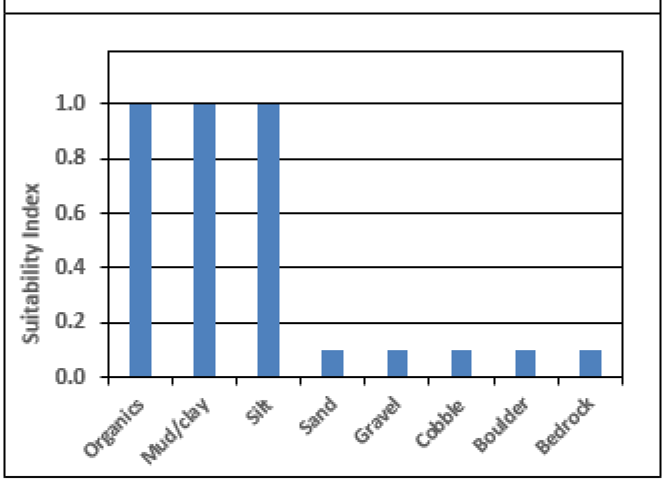
Adapted from Pardue 1983 and Mather et al. 2012

Velocity (ft/s)	SI
0.00	1.00
1.00	1.00
1.01	0.00



Adapted from Pardue 1983 and Mather et al. 2012

Depth (ft)	SI
0.00	0.00
0.49	0.00
0.50	1.00
9.80	1.00
9.90	0.00

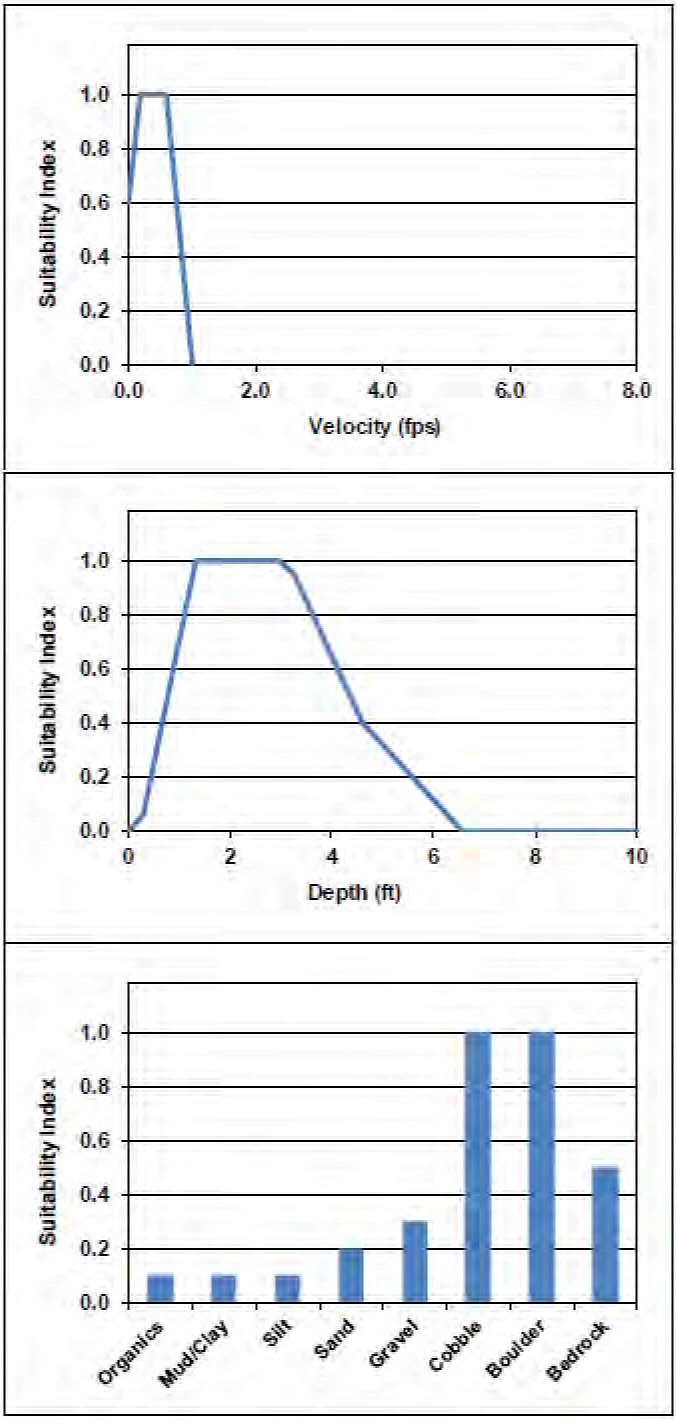


Adapted from Pardue 1983 and Mather et al. 2012

Substrate	SI
Organics	1.00
Mud/Clay	1.00
Silt	1.00
Sand	0.10
Gravel	0.10
Cobble	0.10
Boulder	0.10
Bedrock	0.10

Smallmouth Bass Fry

Source:
Leonard et al. 1986

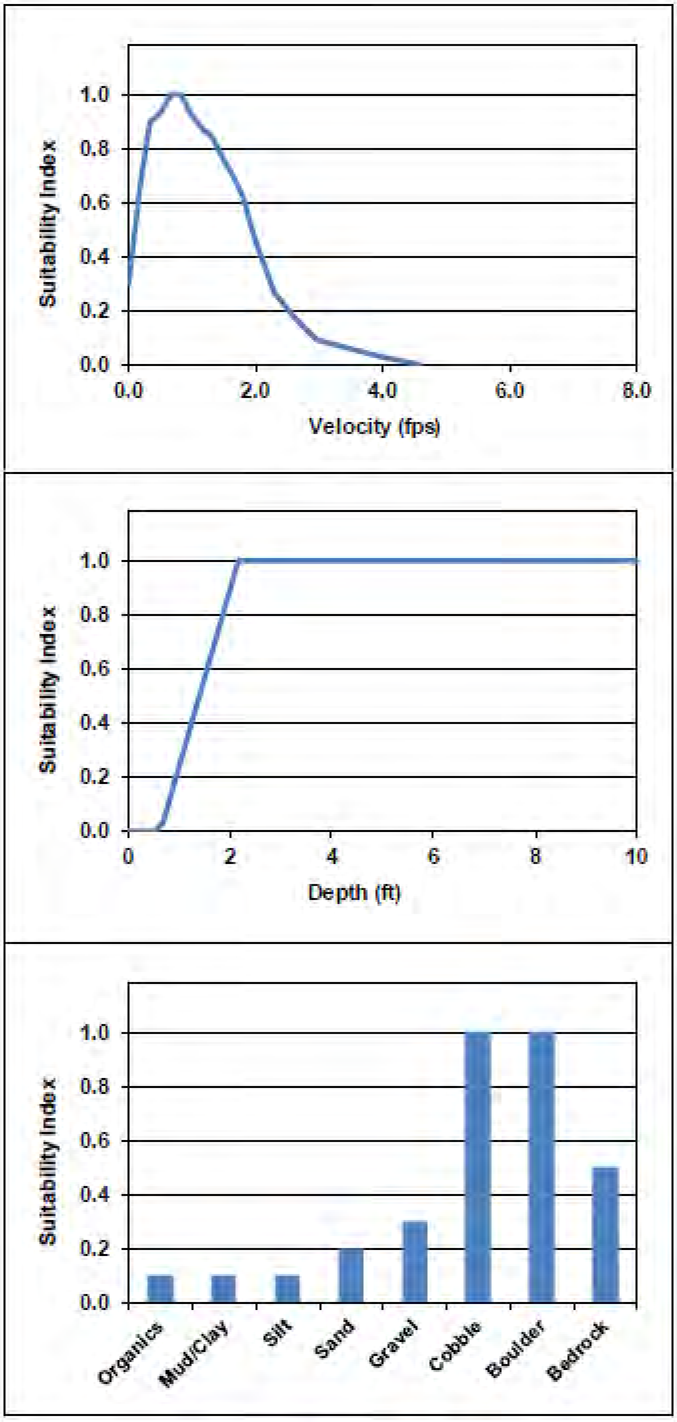


Velocity (ft/s)	SI
0.00	0.60
0.19	1.00
0.59	1.00
1.00	0.00

Depth (ft)	SI
0.00	0.00
0.28	0.06
1.31	1.00
2.95	1.00
3.25	0.95
4.59	0.40
6.56	0.00
10.00	0.00

Substrate	SI
Organics	0.10
Mud/Clay	0.10
Silt	0.10
Sand	0.20
Gravel	0.30
Cobble	1.00
Boulder	1.00
Bedrock	0.50

Smallmouth Bass Juvenile



Source:
Groshens and Orth 1994

Velocity (ft/s)	SI
0.00	0.30
0.17	0.66
0.33	0.90
0.50	0.93
0.66	1.00
0.83	1.00
0.98	0.93
1.15	0.87
1.31	0.84
1.47	0.77
1.64	0.70
1.81	0.62
1.98	0.47
2.30	0.27
2.62	0.17
2.95	0.09
3.94	0.03
4.59	0.00

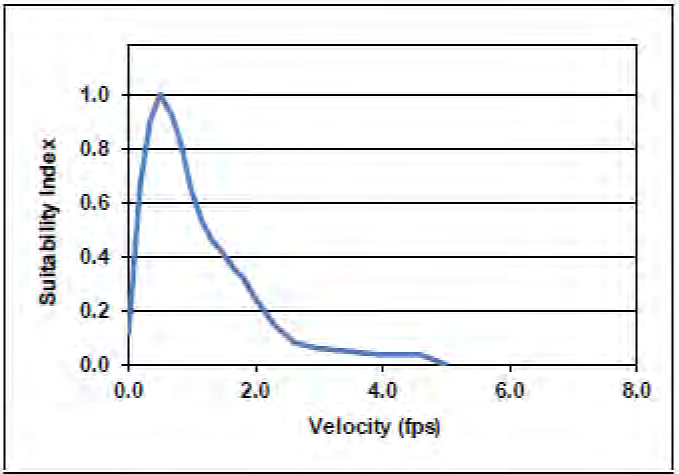
Leonard et al, 1986

Depth (ft)	SI
0.00	0.00
0.52	0.00
0.67	0.03
2.15	1.00
10.00	1.00

Leonard et al, 1986

Substrate	SI
Organics	0.10
Mud/Clay	0.10
Silt	0.10
Sand	0.20
Gravel	0.30
Cobble	1.00
Boulder	1.00
Bedrock	0.50

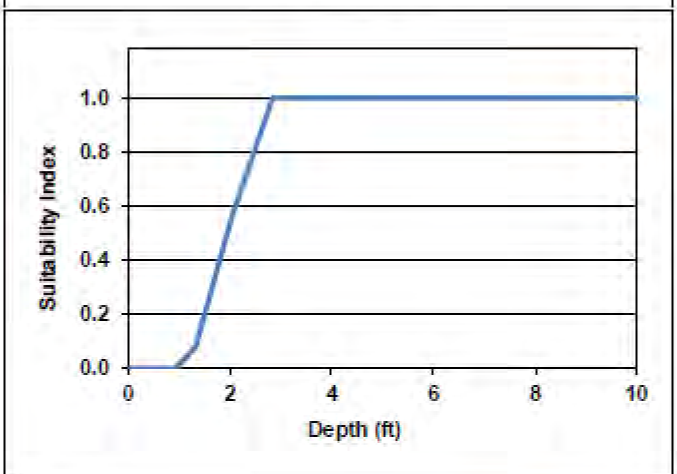
Smallmouth Bass Adult



Source:

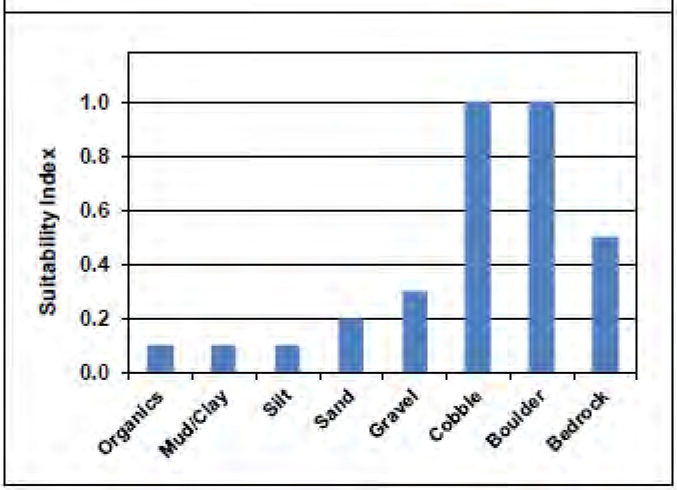
Groshens and Orth 1994

Velocity (ft/s)	SI
0.00	0.12
0.17	0.66
0.33	0.90
0.50	1.00
0.66	0.93
0.83	0.82
0.98	0.65
1.15	0.53
1.31	0.46
1.47	0.42
1.64	0.36
1.81	0.32
1.98	0.25
2.30	0.15
2.62	0.08
2.95	0.06
3.94	0.04
4.59	0.04
5.00	0.00



Leonard et al, 1986

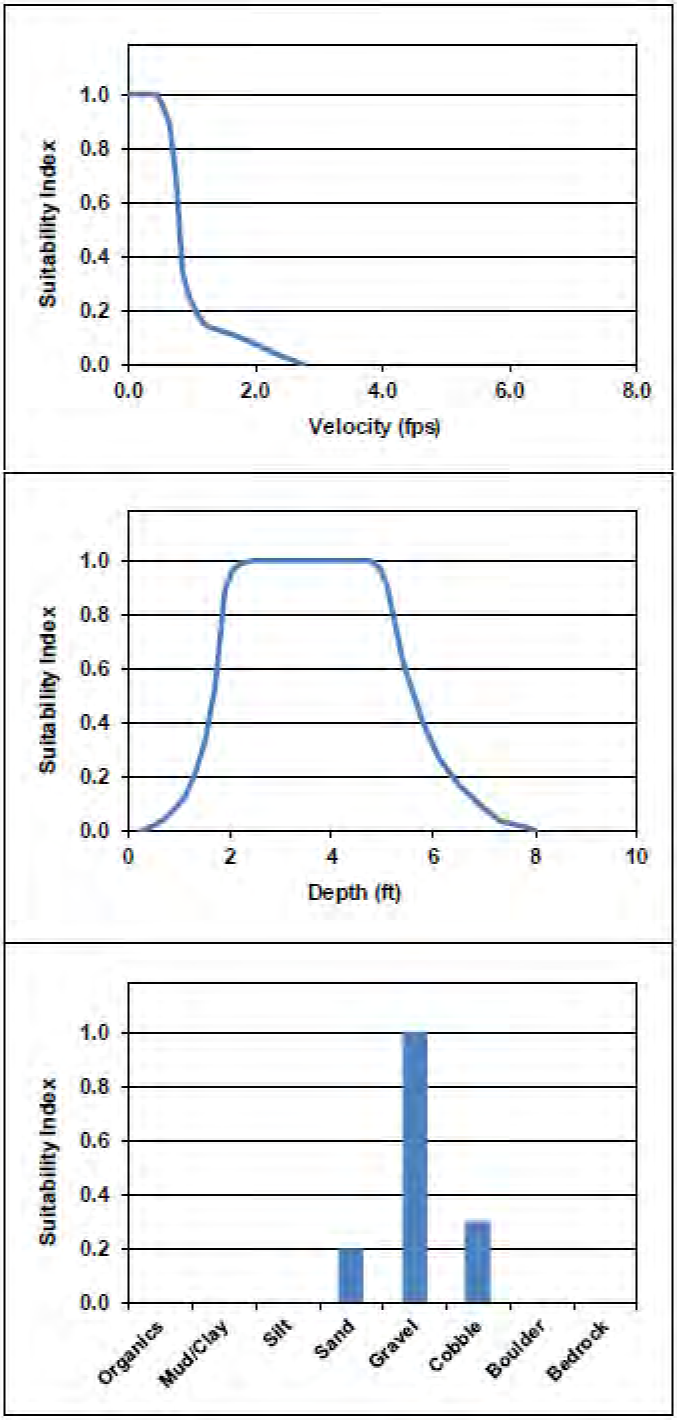
Depth (ft)	SI
0.00	0.00
0.92	0.00
1.31	0.08
2.03	0.56
2.82	1.00
6.00	1.00
10.00	1.00



Leonard et al, 1986

Substrate	SI
Organics	0.10
Mud/Clay	0.10
Silt	0.10
Sand	0.20
Gravel	0.30
Cobble	1.00
Boulder	1.00
Bedrock	0.50

Smallmouth Bass Spawning



Source:

Allen, 1996

Velocity (ft/s)	SI
0.00	1.00
0.45	1.00
0.55	0.96
0.65	0.89
0.75	0.69
0.85	0.34
0.95	0.25
1.05	0.20
1.15	0.16
1.25	0.14
1.65	0.11
1.85	0.09
2.35	0.04
2.55	0.02
2.75	0.00

Edwards et al., 1983

Depth (ft)	SI
0.22	0.00
0.50	0.02
0.74	0.05
1.10	0.12
1.32	0.22
1.53	0.34
1.70	0.54
1.90	0.90
2.05	0.97
2.18	0.99
2.40	1.00
4.75	1.00
4.95	0.97
5.10	0.91
5.40	0.62
5.80	0.40
6.10	0.27
6.50	0.17
6.95	0.09
7.30	0.04
7.75	0.02
8.00	0.00

Allen, 1996

Substrate	SI
Organics	0.00
Mud/Clay	0.00
Silt	0.00
Sand	0.20
Gravel	1.00
Cobble	0.30
Boulder	0.00
Bedrock	0.00

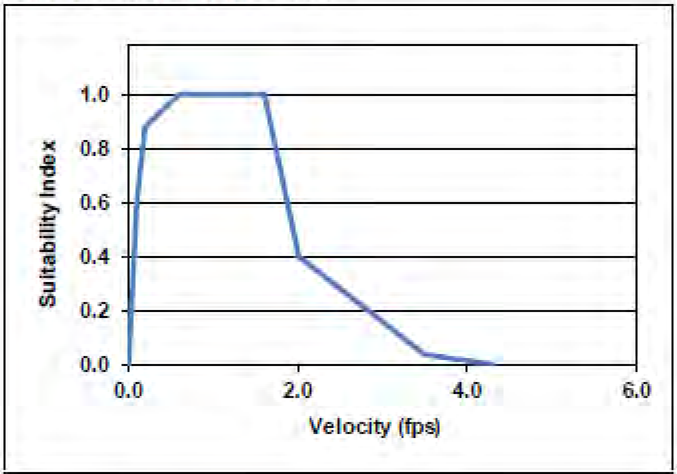
Fallfish Juvenile

Velocity and depth from brook trout fry curves (Deerfield River)

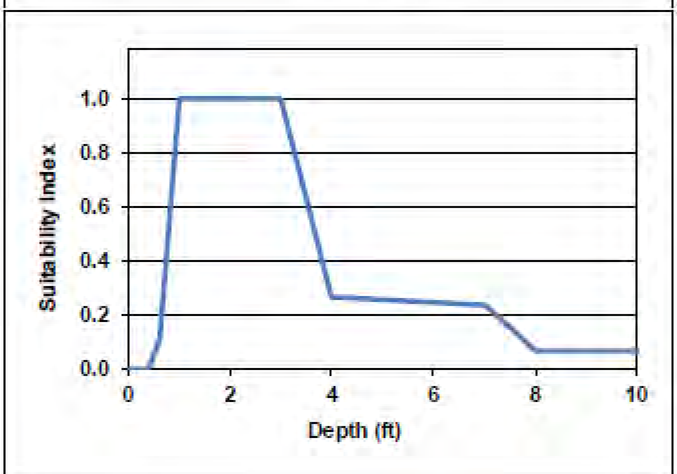
Substrate developed by Charles Ritzi

Source:

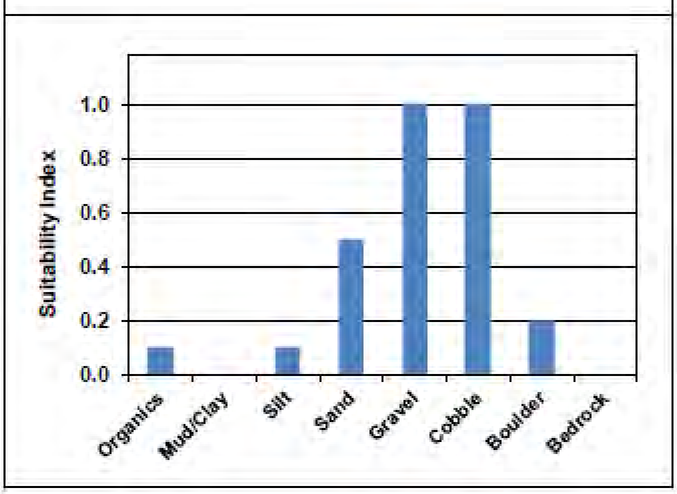
Gomez and Sullivan, 2007



Velocity (ft/s)	SI
0.00	0.00
0.10	0.60
0.20	0.88
0.60	1.00
1.60	1.00
2.00	0.40
3.50	0.04
4.30	0.00



Depth (ft)	SI
0.00	0.00
0.40	0.00
0.60	0.11
1.00	1.00
3.00	1.00
4.00	0.27
7.00	0.24
8.00	0.07
20.00	0.07
100.00	0.07

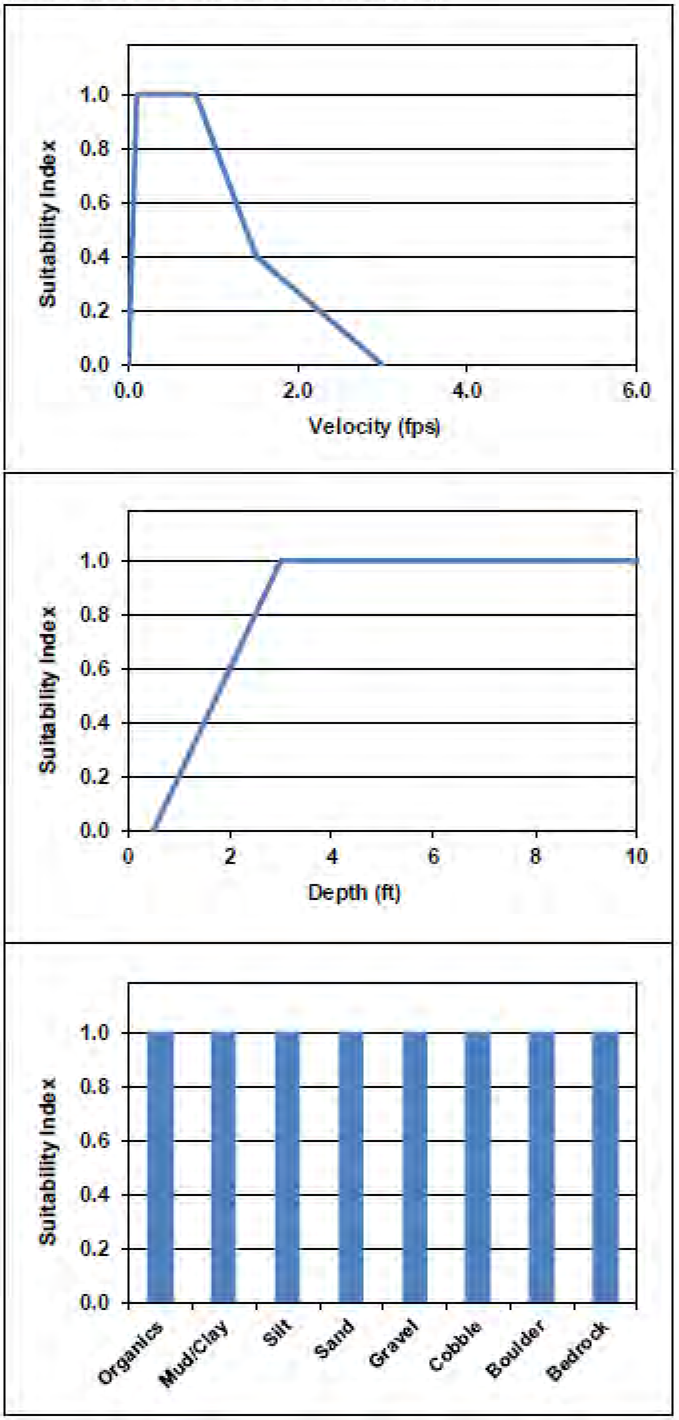


Substrate	SI
Organics	0.10
Mud/Clay	0.00
Silt	0.10
Sand	0.50
Gravel	1.00
Cobble	1.00
Boulder	0.20
Bedrock	0.00

Fallfish Adult

Developed from consultation with NYSDEC
(New York Dept. of Environmental Conservation)

Source:
Gomez and Sullivan, 2007

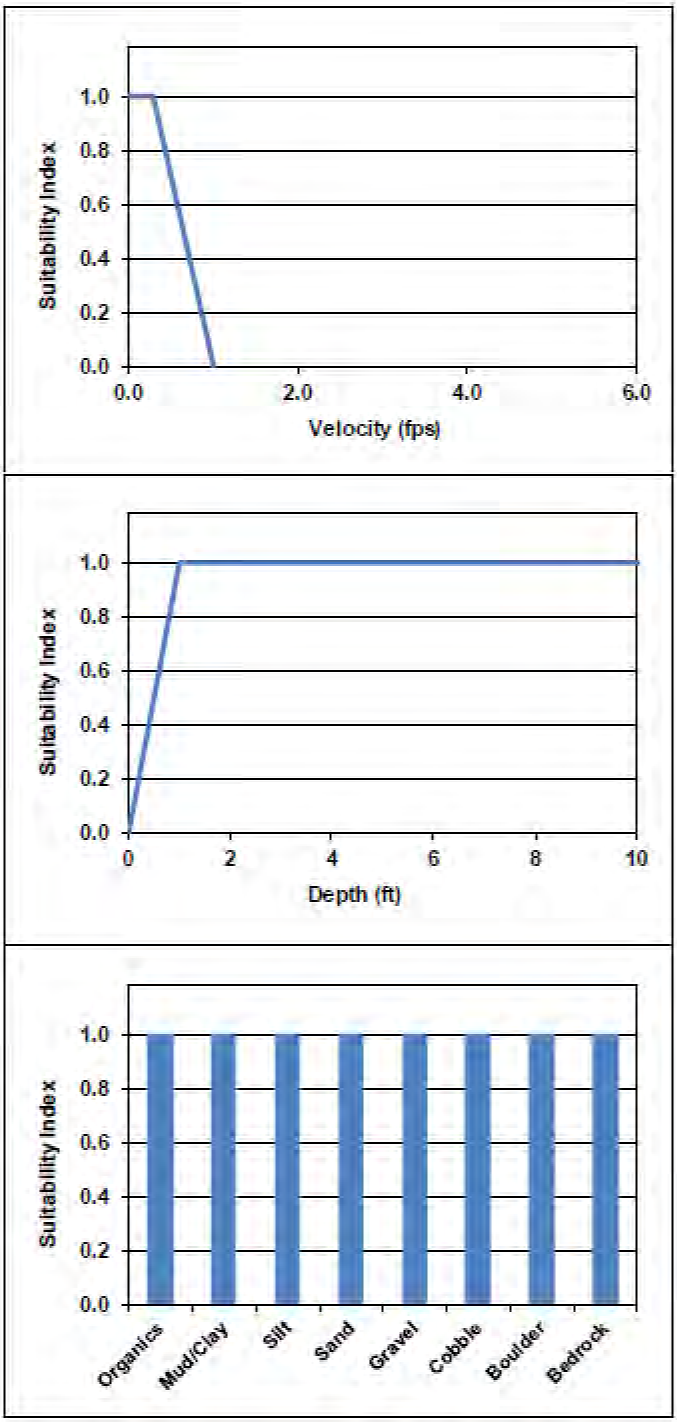


Velocity (ft/s)	SI
0.00	0.00
0.10	1.00
0.80	1.00
1.50	0.40
3.00	0.00

Depth (ft)	SI
0.00	0.00
0.50	0.00
3.00	1.00
100.00	1.00

Substrate	SI
Organics	1.00
Mud/Clay	1.00
Silt	1.00
Sand	1.00
Gravel	1.00
Cobble	1.00
Boulder	1.00
Bedrock	1.00

White Sucker Fry



Source:

Twomey et al., 1984

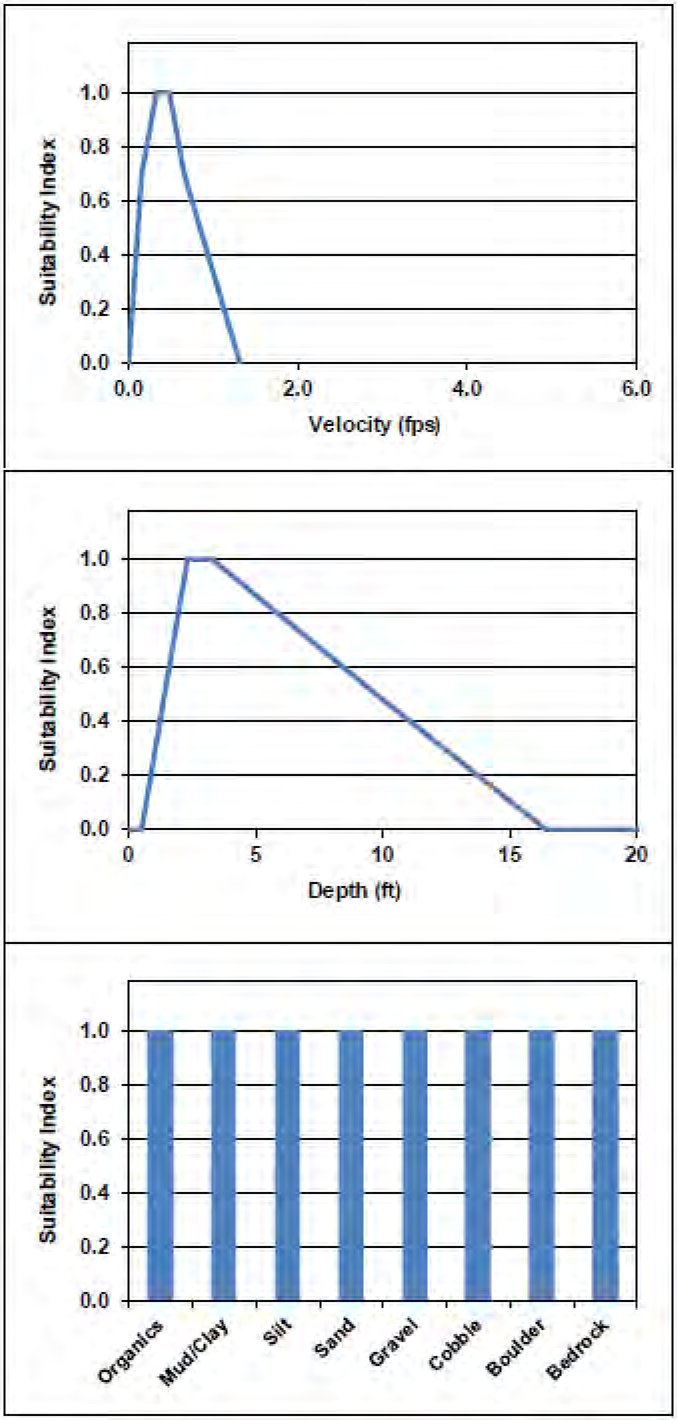
Velocity (ft/s)	SI
0.00	1.00
0.30	1.00
1.00	0.00

Depth (ft)	SI
0.00	0.00
1.00	1.00
100.00	1.00

Substrate	SI
Organics	1.00
Mud/Clay	1.00
Silt	1.00
Sand	1.00
Gravel	1.00
Cobble	1.00
Boulder	1.00
Bedrock	1.00

White Sucker Adult/Juvenile

Source:
Twomey et al., 1984

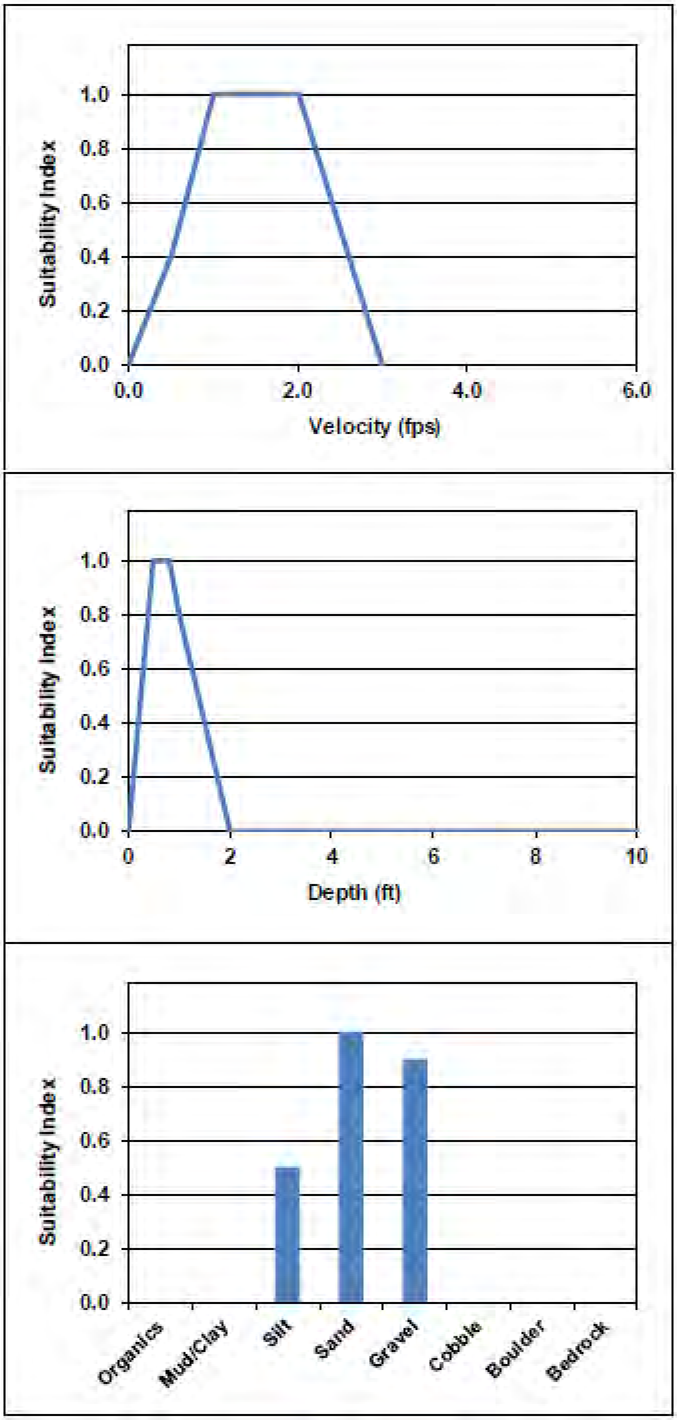


Velocity (ft/s)	SI
0.00	0.00
0.16	0.70
0.33	1.00
0.49	1.00
0.66	0.70
1.31	0.00

Depth (ft)	SI
0.00	0.00
0.50	0.00
2.30	1.00
3.30	1.00
9.80	0.50
16.40	0.00
100.00	0.00

Substrate	SI
Organics	1.00
Mud/Clay	1.00
Silt	1.00
Sand	1.00
Gravel	1.00
Cobble	1.00
Boulder	1.00
Bedrock	1.00

White Sucker Spawning & Incubation



Source:

Twomey et al., 1984

Velocity (ft/s)	SI
0.00	0.00
0.50	0.40
1.00	1.00
2.00	1.00
3.00	0.00

Depth (ft)	SI
0.00	0.00
0.50	1.00
0.80	1.00
1.00	0.80
2.00	0.00
100.00	0.00

Substrate Source:

Gomez and Sullivan, 2007

Substrate	SI
Organics	0.00
Mud/Clay	0.00
Silt	0.50
Sand	1.00
Gravel	0.90
Cobble	0.00
Boulder	0.00
Bedrock	0.00

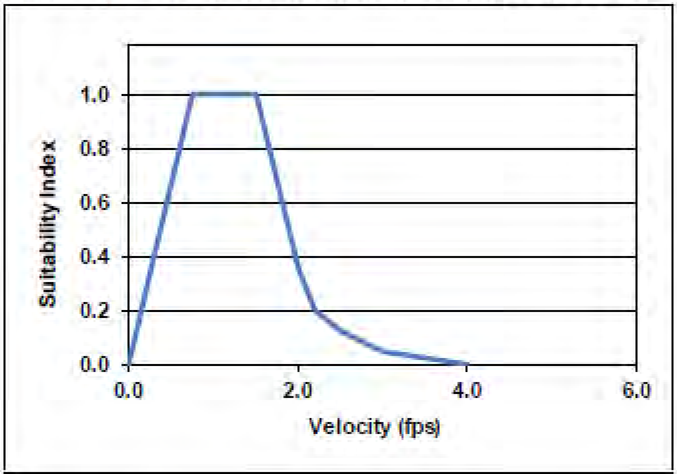
Longnose Dace Juvenile

Original curve identified as from USFWS HSC library

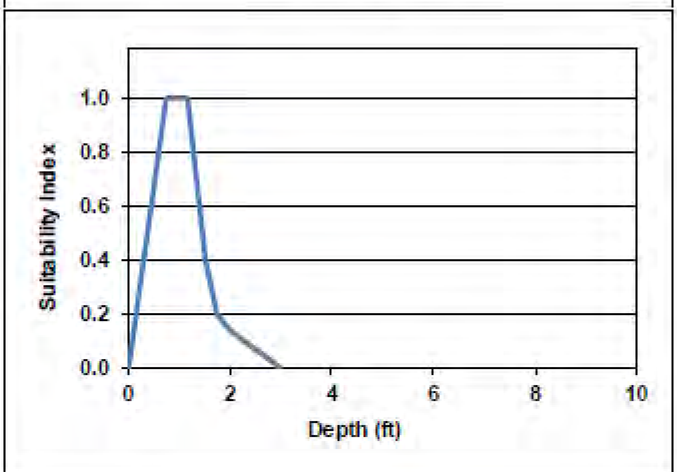
Modified by VDFW for the Lamoille River IFS (Gomez and Sullivan, 2000)

Source:

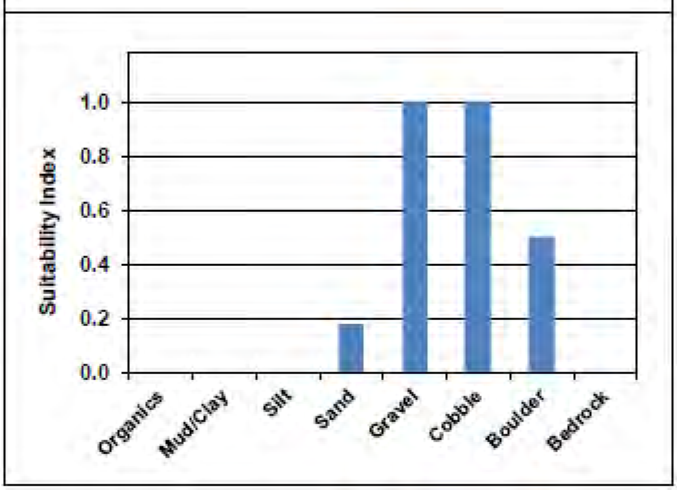
Gomez and Sullivan, 2000



Velocity (ft/s)	SI
0.00	0.00
0.75	1.00
1.50	1.00
2.00	0.35
2.20	0.20
2.50	0.13
3.00	0.05
4.00	0.00



Depth (ft)	SI
0.00	0.00
0.75	1.00
1.15	1.00
1.50	0.40
1.75	0.20
2.00	0.14
3.00	0.00



Substrate	SI
Organics	0.00
Mud/Clay	0.00
Silt	0.00
Sand	0.18
Gravel	1.00
Cobble	1.00
Boulder	0.50
Bedrock	0.00

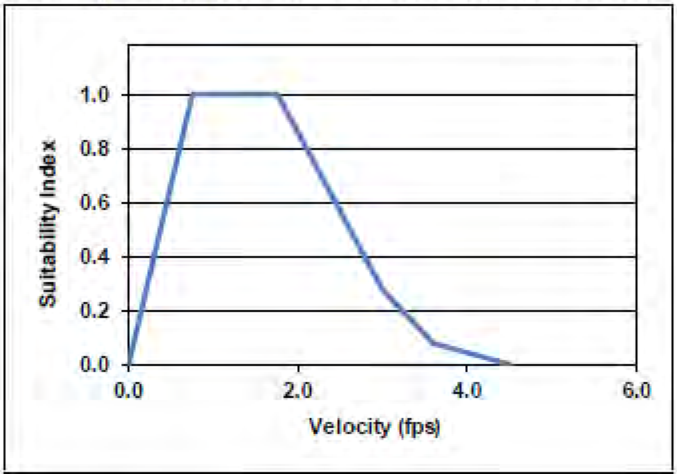
Longnose Dace Adult

Original curve identified as from USGS HSC library

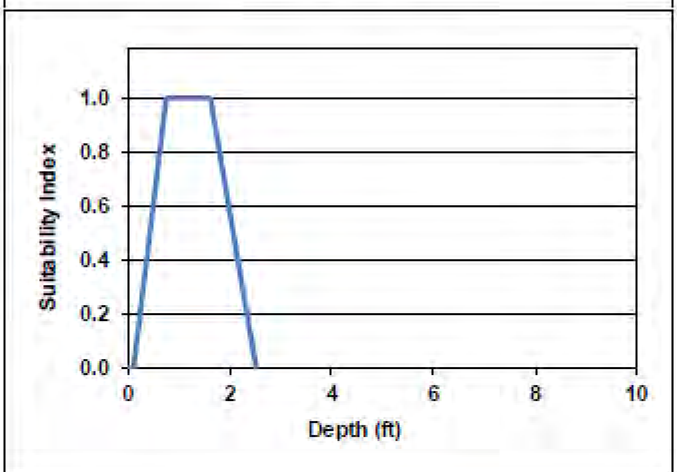
Modified by VDFW for the Lamoille River IFS (Gomez and Sullivan, 2000)

Source:

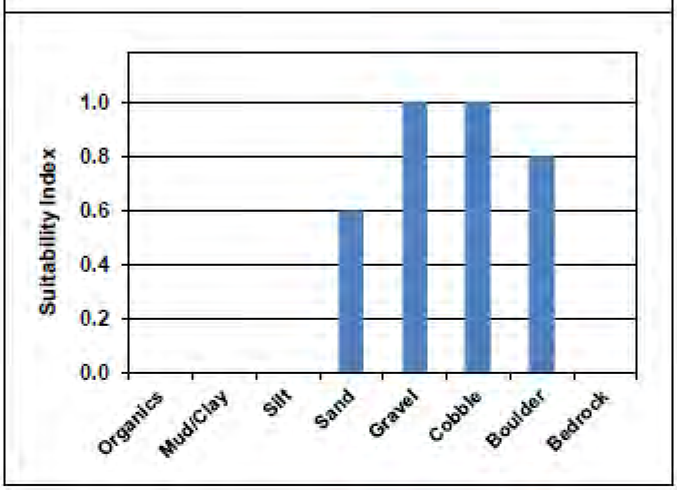
Gomez and Sullivan, 2000



Velocity (ft/s)	SI
0.00	0.00
0.75	1.00
1.75	1.00
3.00	0.28
3.60	0.08
4.50	0.00



Depth (ft)	SI
0.00	0.00
0.10	0.00
0.75	1.00
1.60	1.00
2.50	0.00

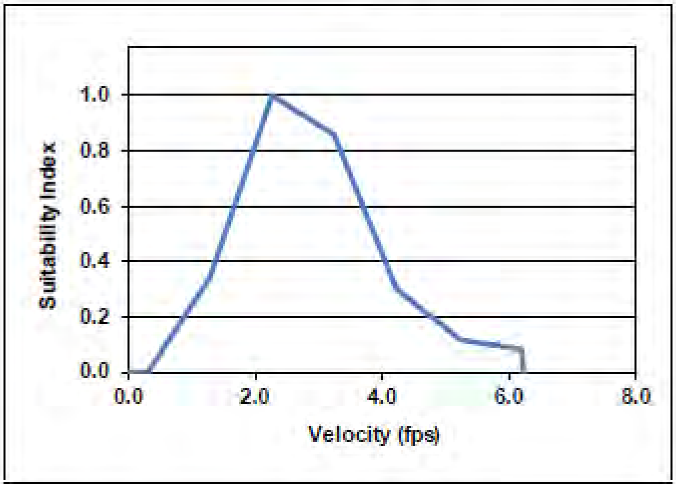


Substrate	SI
Organics	0.00
Mud/Clay	0.00
Silt	0.00
Sand	0.60
Gravel	1.00
Cobble	1.00
Boulder	0.80
Bedrock	0.00

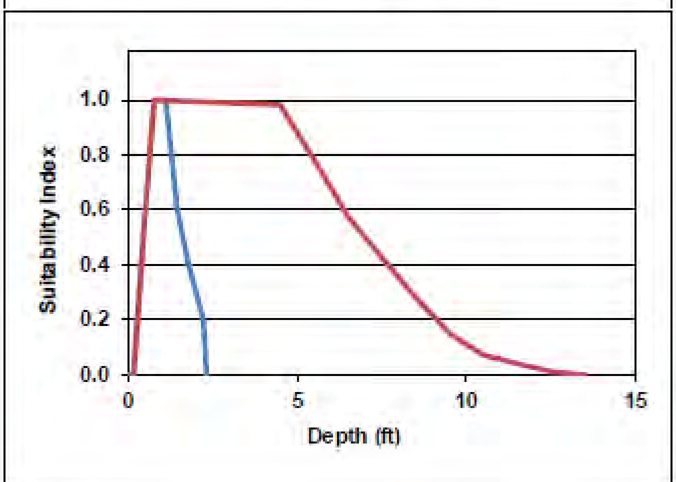
Sea Lamprey Spawning & Incubation

Modified by USFWS (2014) based on Yergeau 1983 (depth and substrate)

Source:
Kynard and Horgan, 2013
Yergeau, 1983



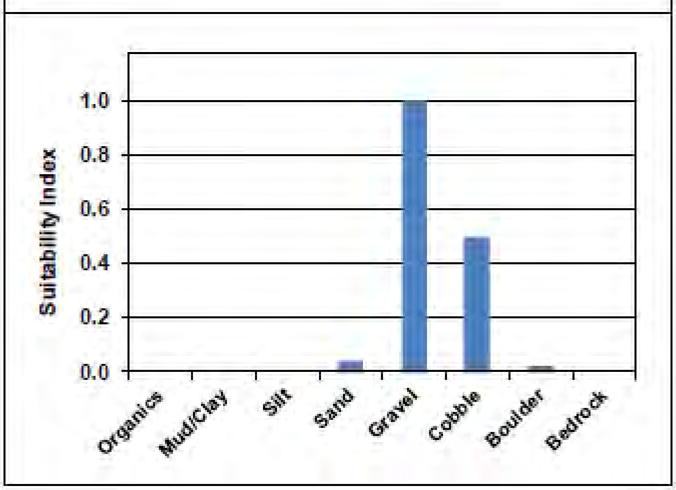
Velocity (ft/s)	SI
0.00	0.00
0.30	0.00
1.28	0.34
2.26	1.00
3.25	0.86
4.23	0.30
5.22	0.12
6.20	0.08
6.23	0.00



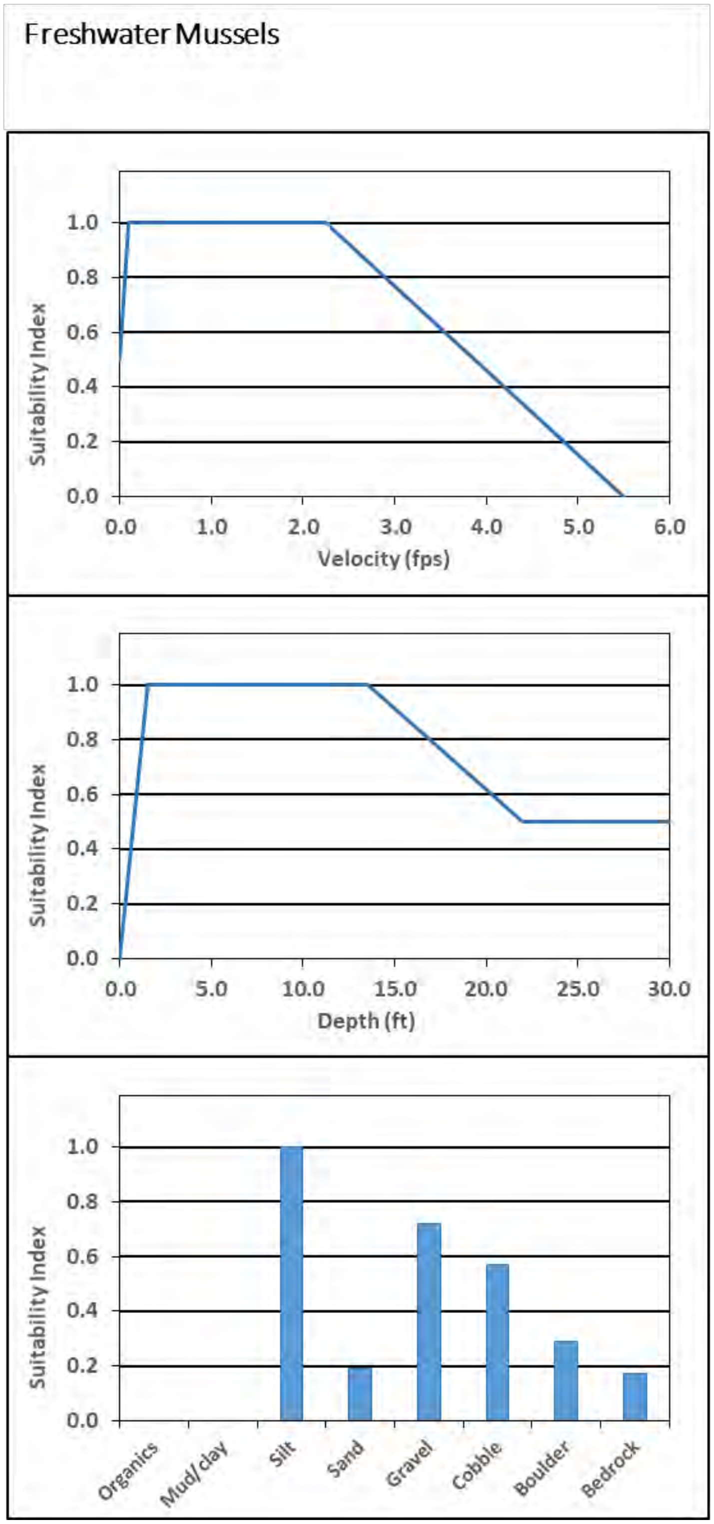
Depth (ft)	SI
0.00	0.00
0.13	0.00
0.46	0.50
0.79	1.00
1.12	1.00
1.44	0.60
1.77	0.40
2.20	0.20
2.30	0.00

Modified by NAI

Depth (ft)	SI
0.00	0.00
0.13	0.00
0.46	0.50
0.79	1.00
4.50	0.98
5.50	0.78
6.50	0.57
7.50	0.43
8.50	0.28
9.50	0.15
10.50	0.07
11.50	0.04
12.50	0.01
13.50	0.00



Substrate	SI
Organics	0.00
Mud/Clay	0.00
Silt	0.00
Sand	0.04
Gravel	1.00
Cobble	0.50
Boulder	0.02
Bedrock	0.00



Freshwater Mussels
Normandeau and Biodrawversity 2017

Freshwater Mussels

MCV (ft/s)	SI
0.00	0.50
0.10	1.00
2.25	1.00
5.50	0.00

Freshwater Mussels

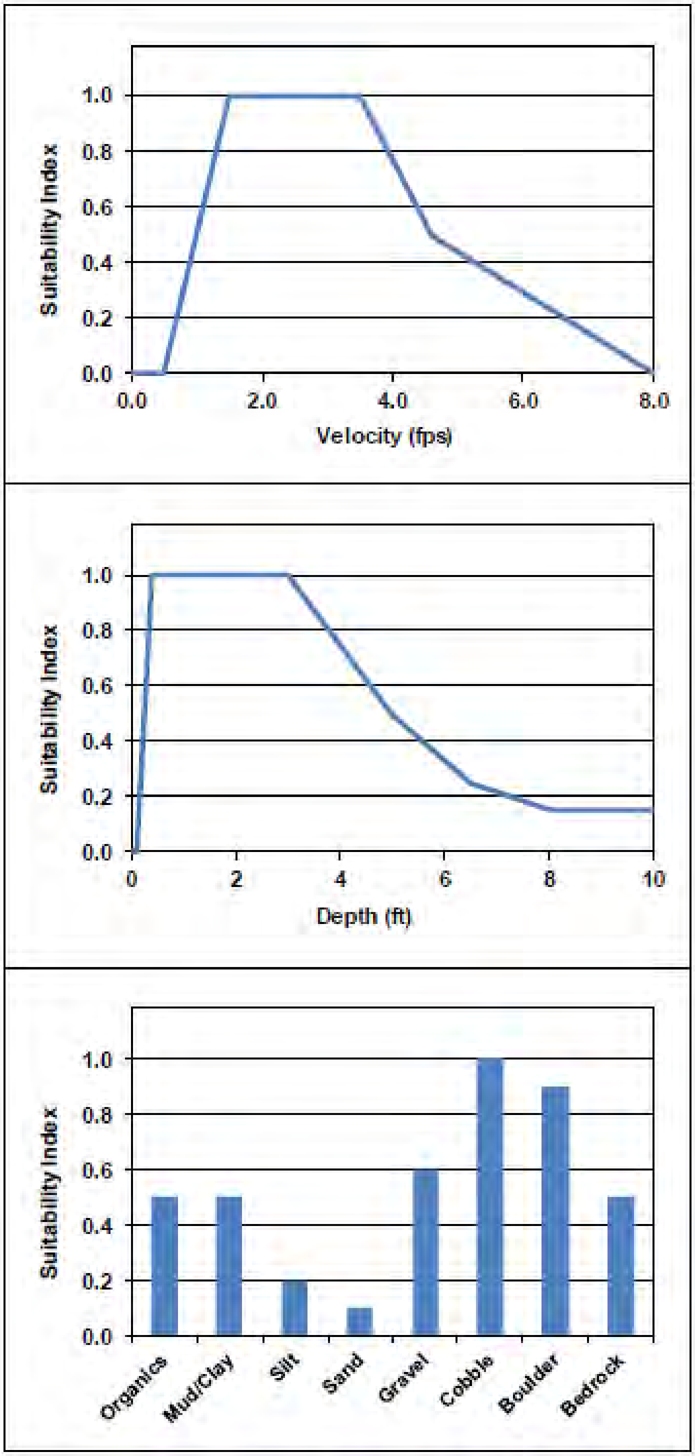
Depth (ft)	SI
0.00	0.00
1.50	1.00
13.50	1.00
22.00	0.50
30.00	0.50
100	0.5

Freshwater Mussels

Substrate	SI
Organics	0.00
Mud/Clay	0.00
Silt	1.00
Sand	0.19
Gravel	0.72
Cobble	0.57
Boulder	0.29
Bedrock	0.17

Macroinvertebrates

Source:
Gomez and Sullivan, 2000

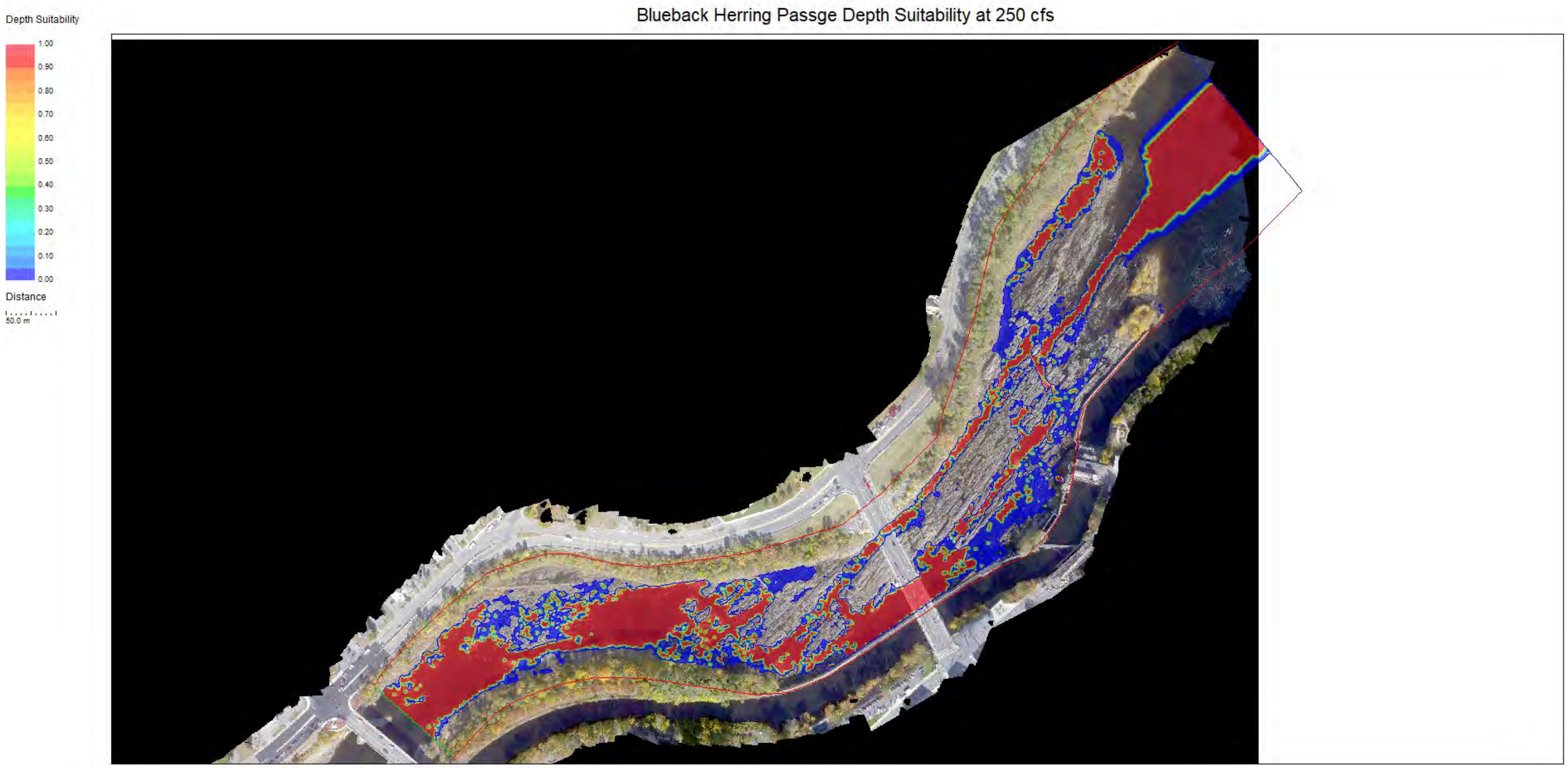


Velocity (ft/s)	SI
0.00	0.00
0.50	0.00
1.50	1.00
3.50	1.00
4.60	0.50
8.00	0.00

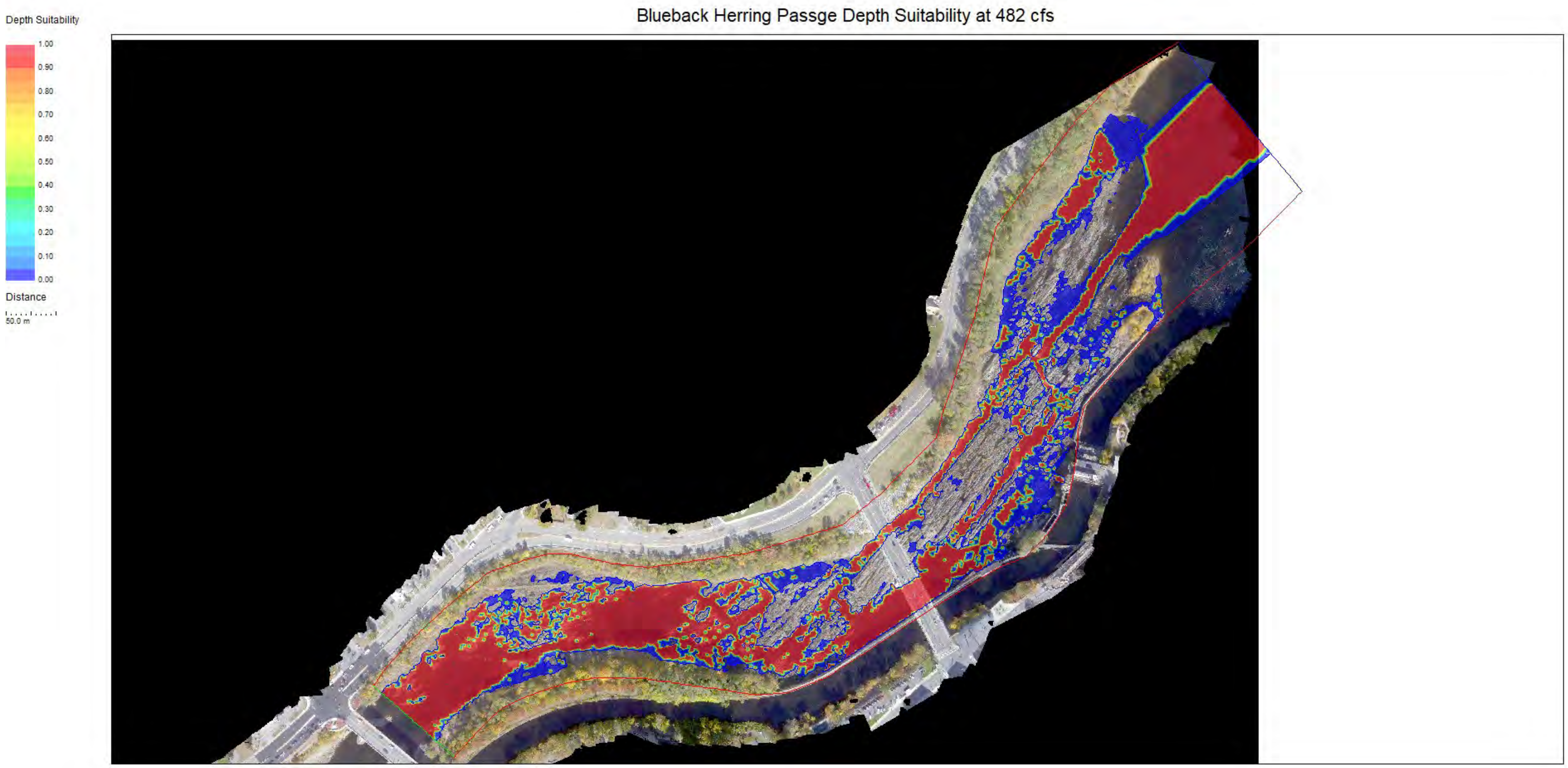
Depth (ft)	SI
0.00	0.00
0.10	0.00
0.40	1.00
3.00	1.00
5.00	0.50
6.50	0.25
8.00	0.15
10.00	0.15
100.00	0.00

Substrate	SI
Organics	0.50
Mud/Clay	0.50
Silt	0.20
Sand	0.10
Gravel	0.60
Cobble	1.00
Boulder	0.90
Bedrock	0.50

Appendix B. Zone of passage conditions for adult river herring and American shad – depth, velocity, and depth x velocity.

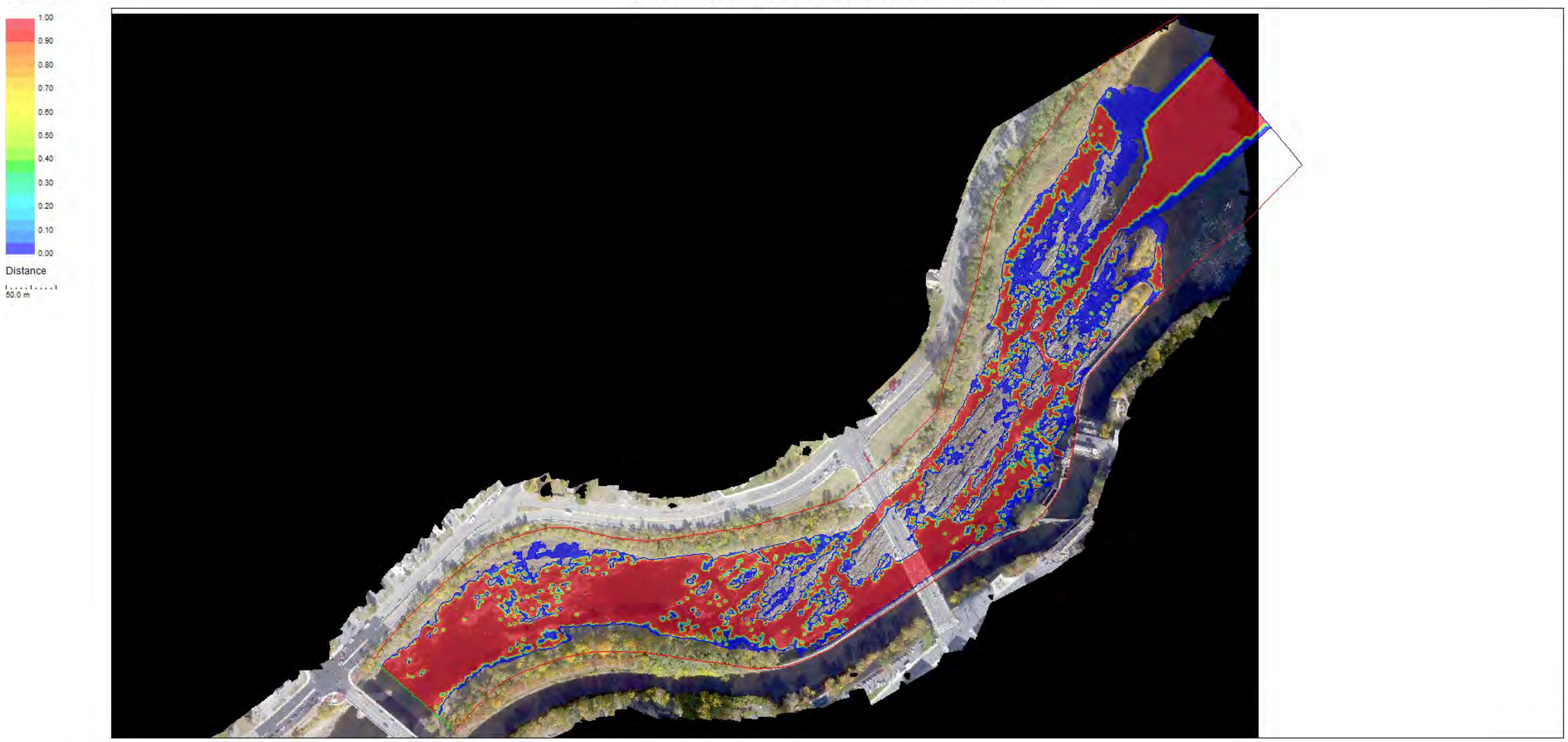


Note: Depth criteria = 1.0 ft. Same criteria for blueback herring and alewife. Map also represents passage for American shad using 1.0 ft depth criteria.

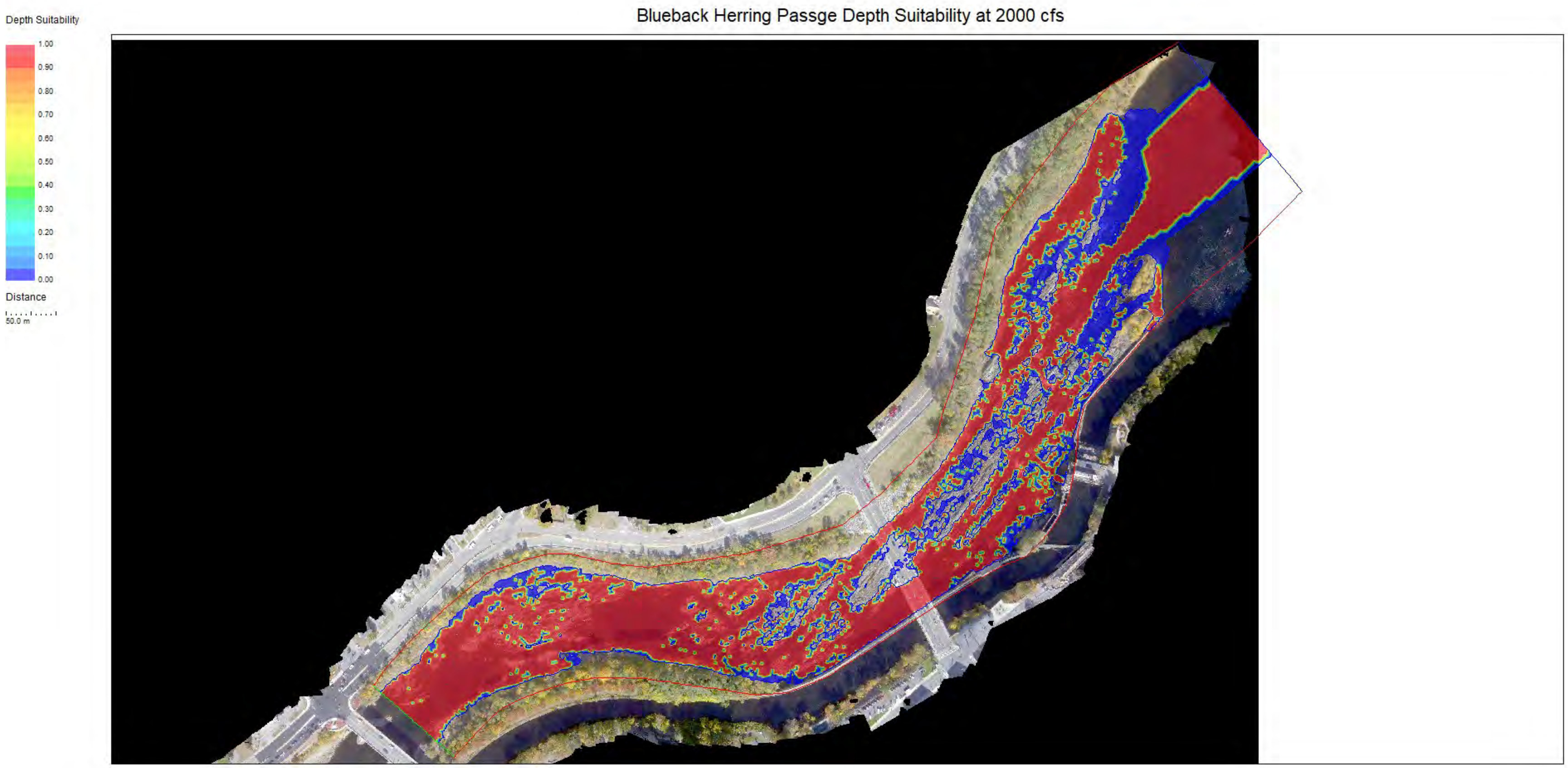


Note: Depth criteria = 1.0 ft. Same criteria for blueback herring and alewife. Map also represents passage for American shad using 1.0 ft depth criteria.

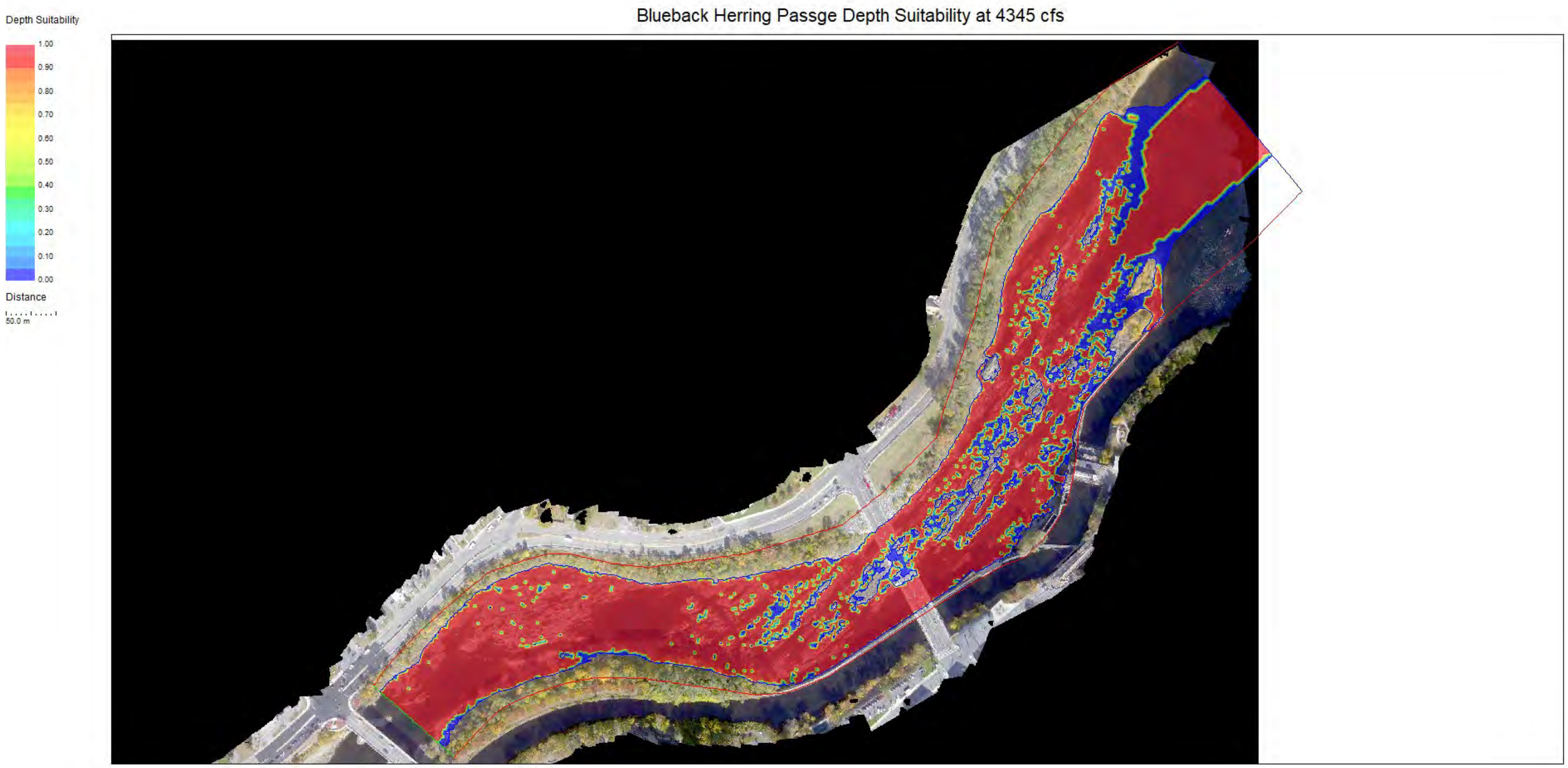
Blueback Herring Passge Depth Suitability at 1000 cfs



Note: Depth criteria = 1.0 ft. Same criteria for blueback herring and alewife. Map also represents passage for American shad using 1.0 ft depth criteria.



Note: Depth criteria = 1.0 ft. Same criteria for blueback herring and alewife. Map also represents passage for American shad using 1.0 ft depth criteria.



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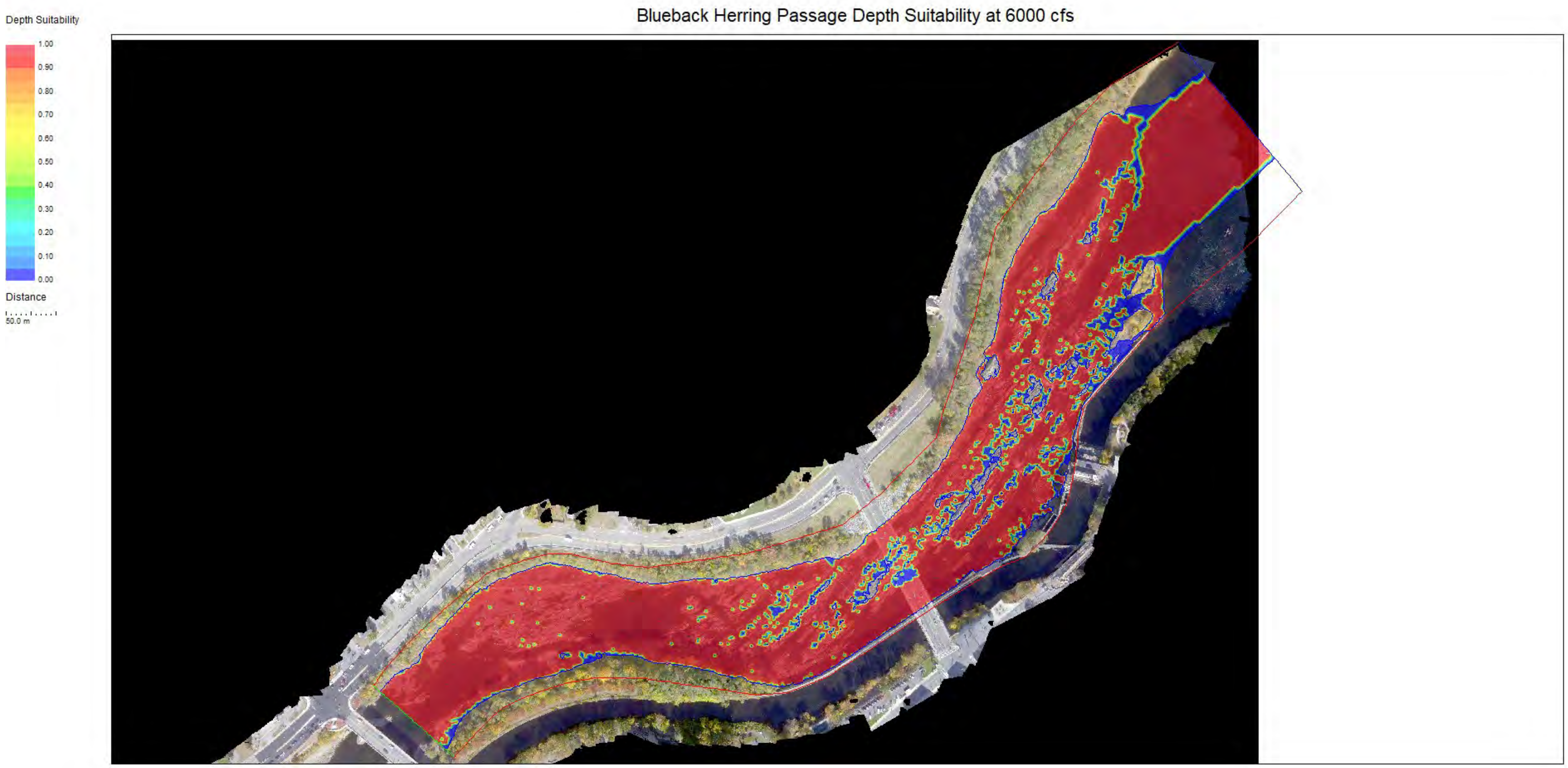

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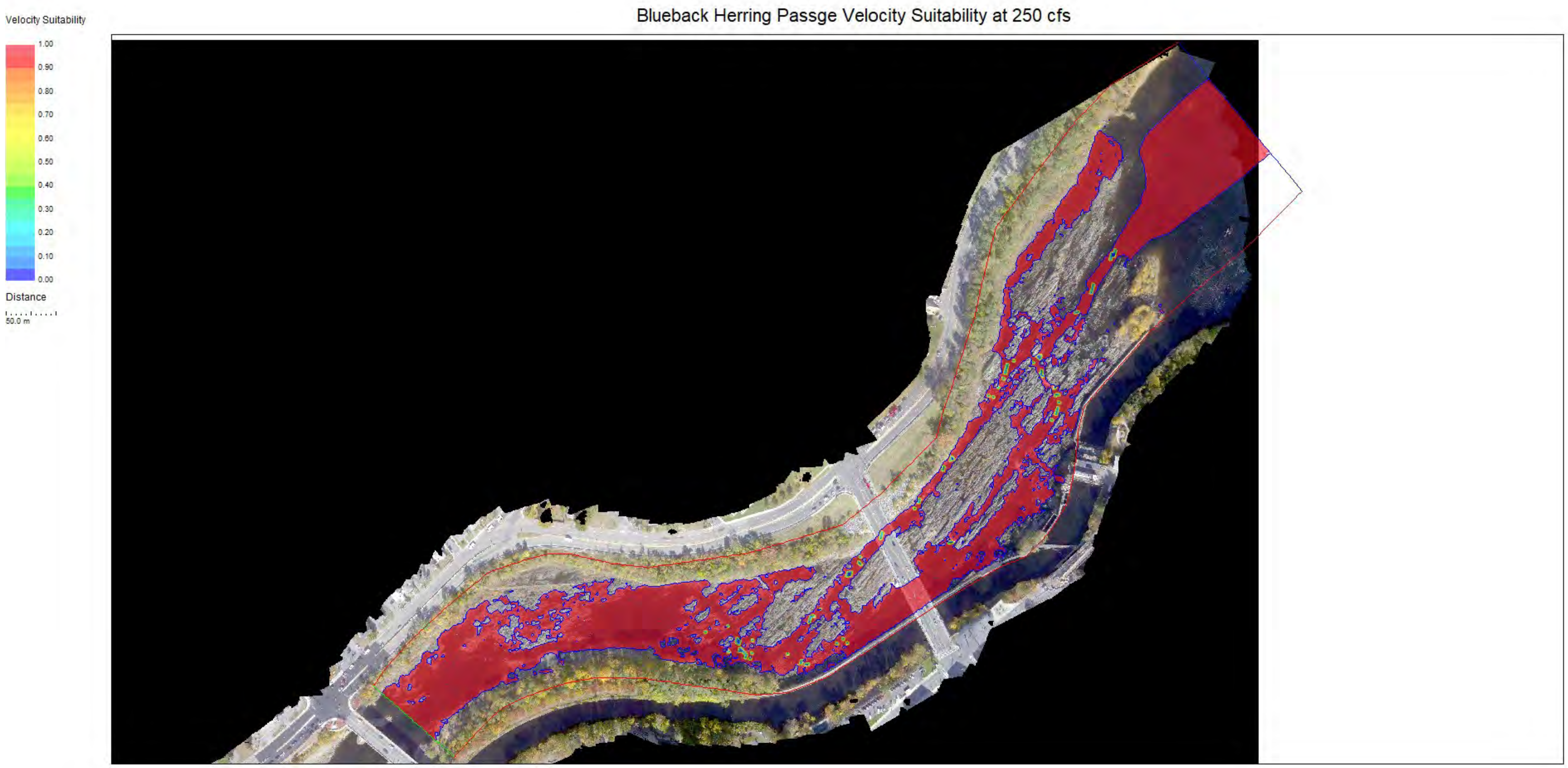
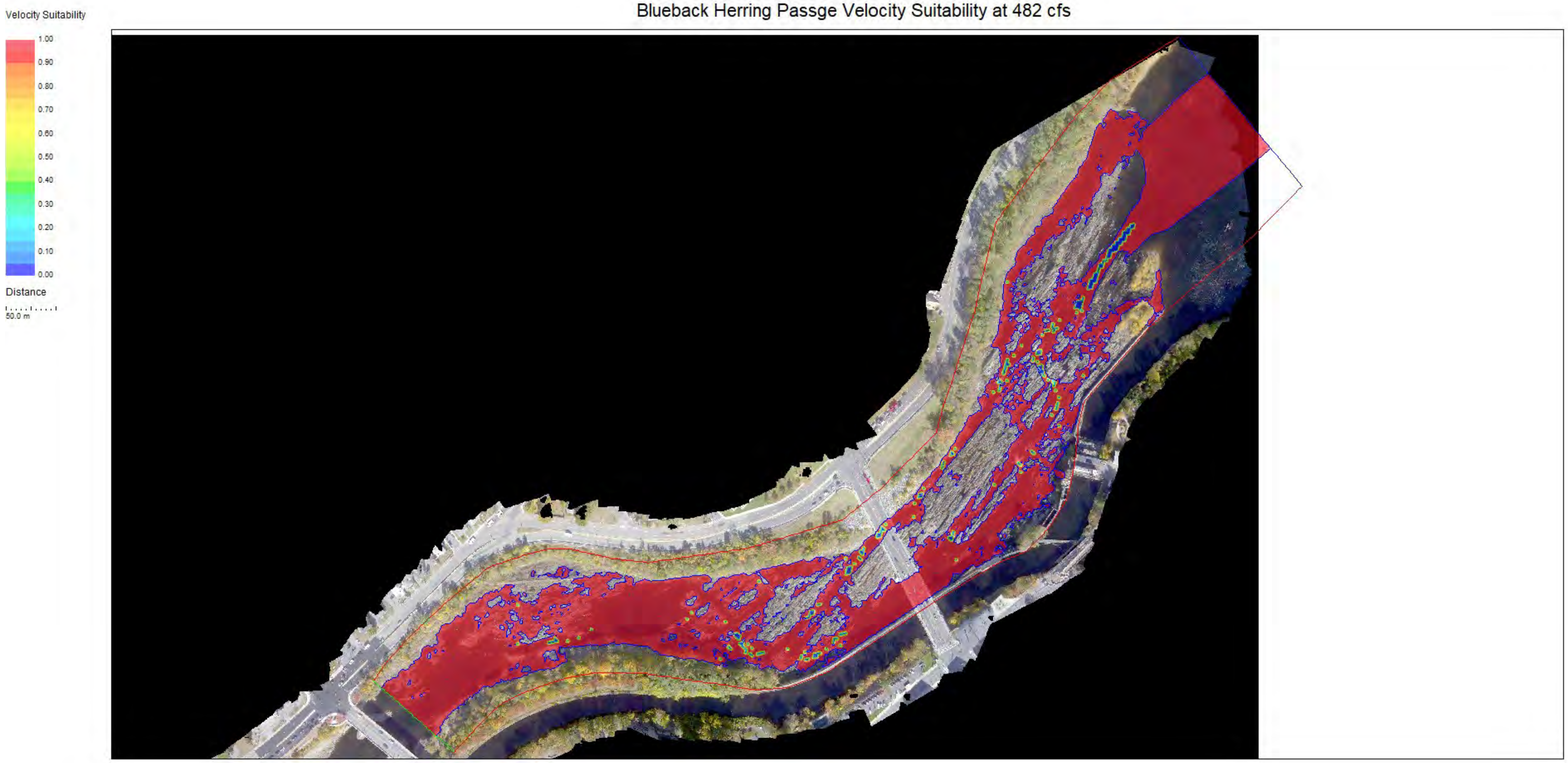


Note: Velocity criteria = 6.0 fps. Same criteria for blueback herring and alewife.

Blueback Herring Passge Velocity Suitability at 482 cfs



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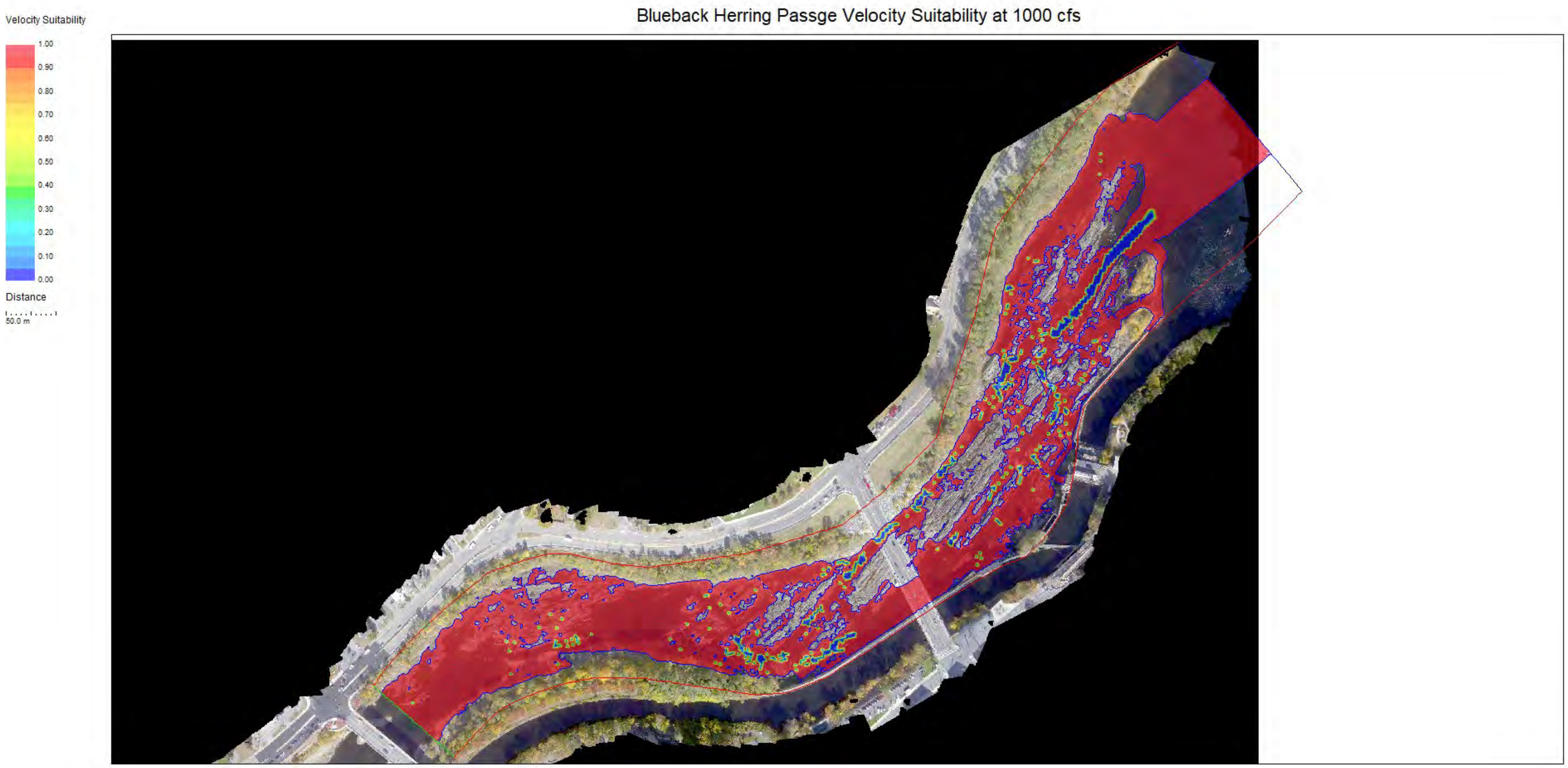

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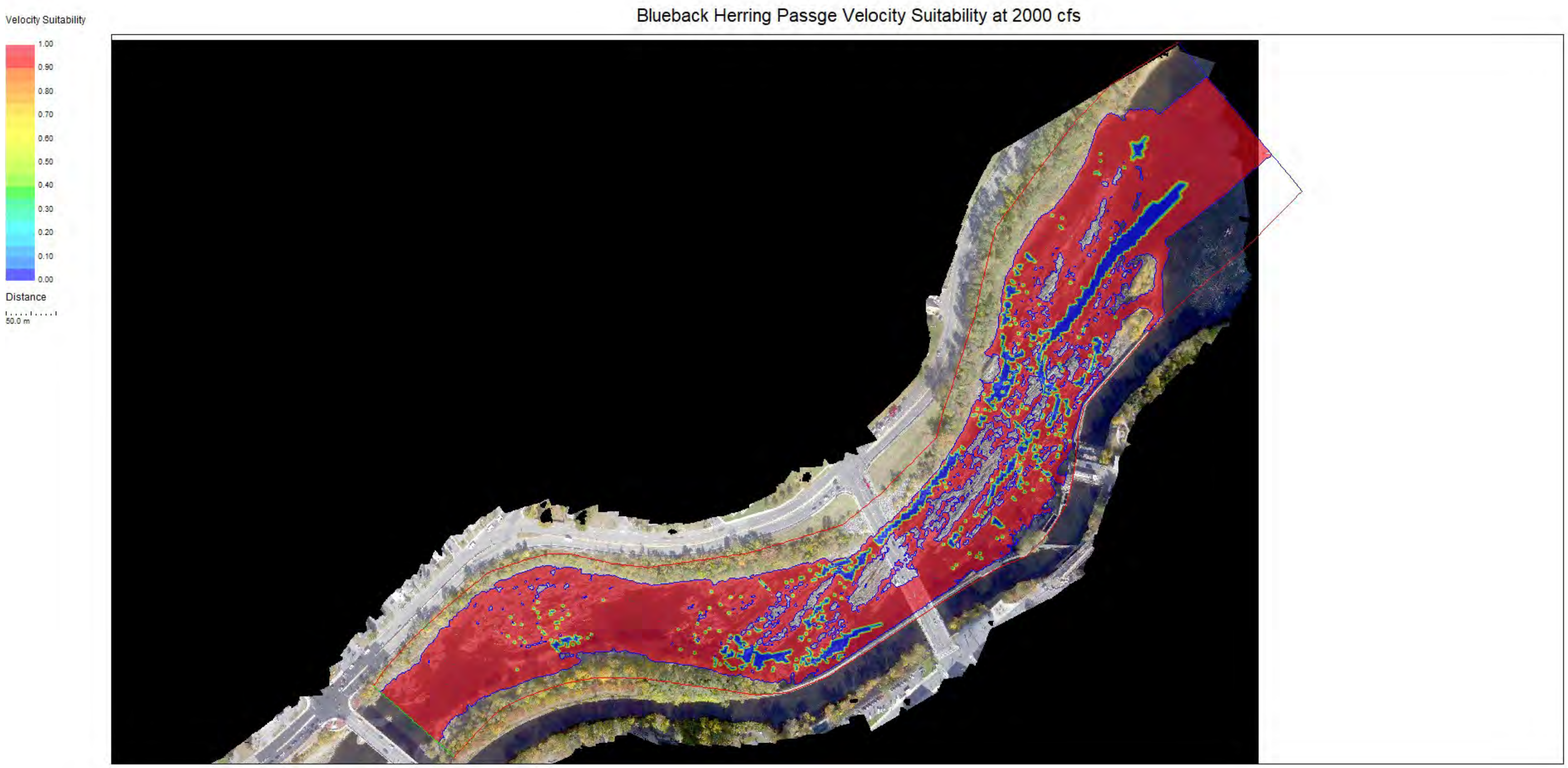

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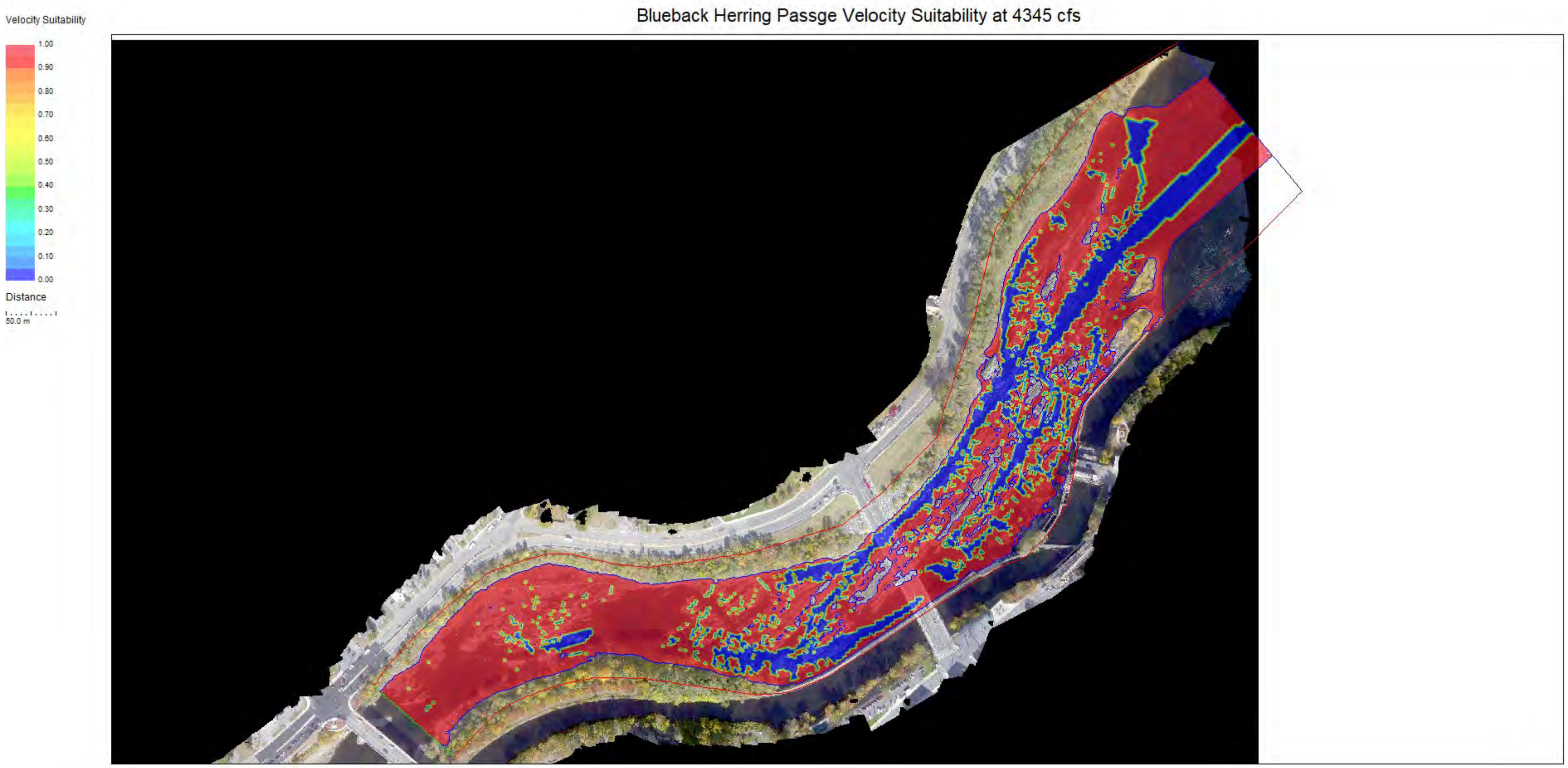

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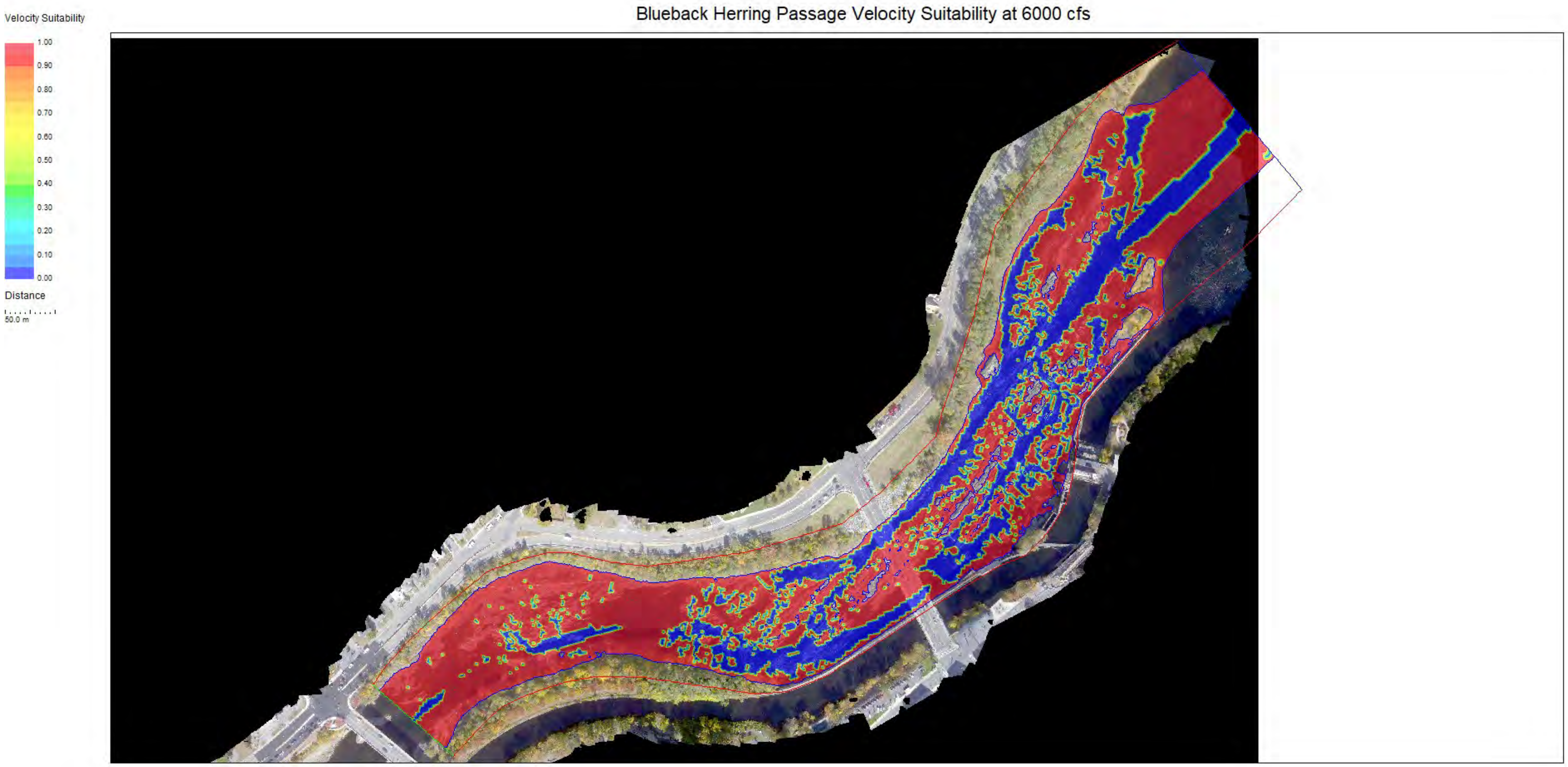

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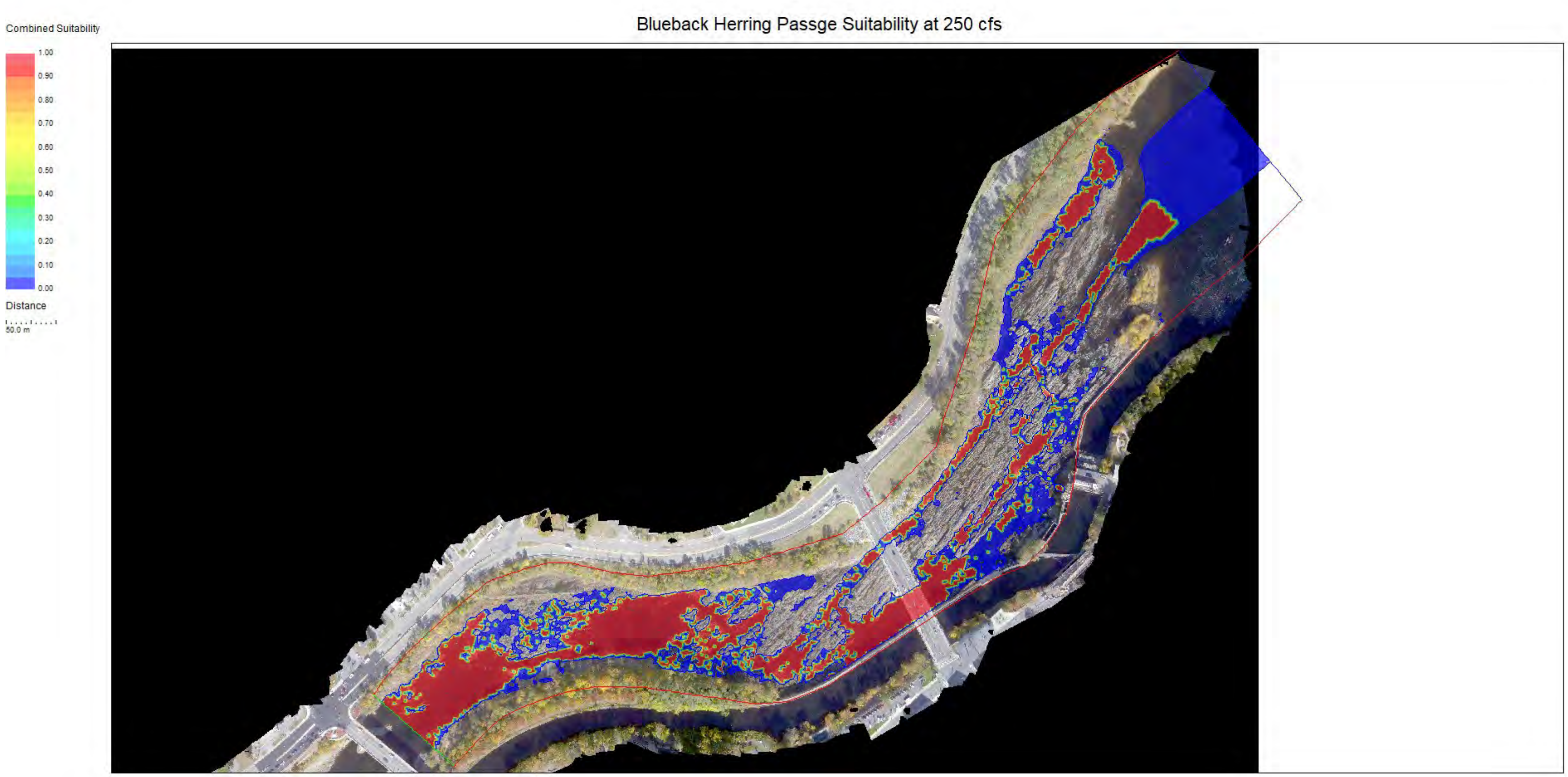

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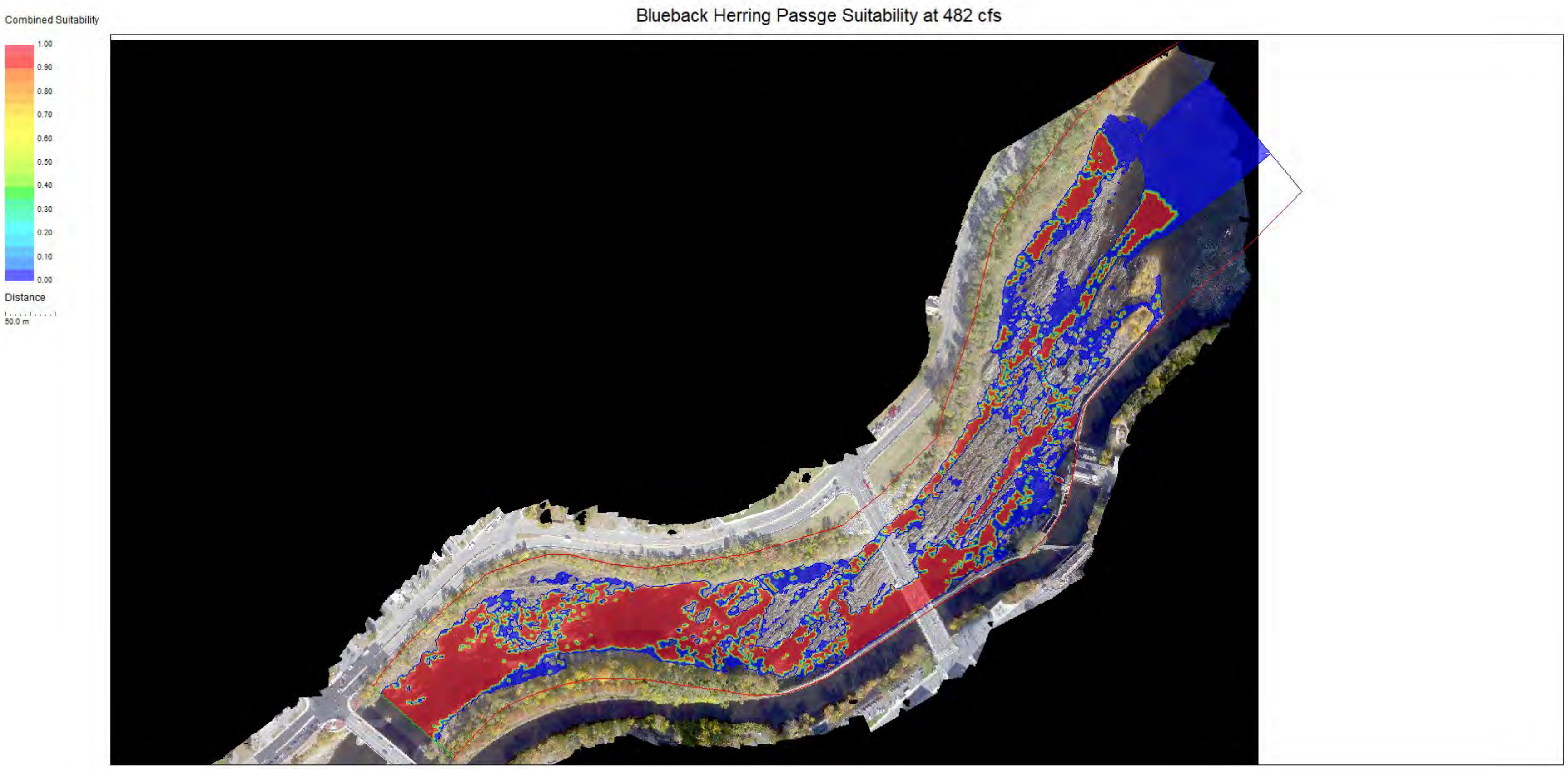

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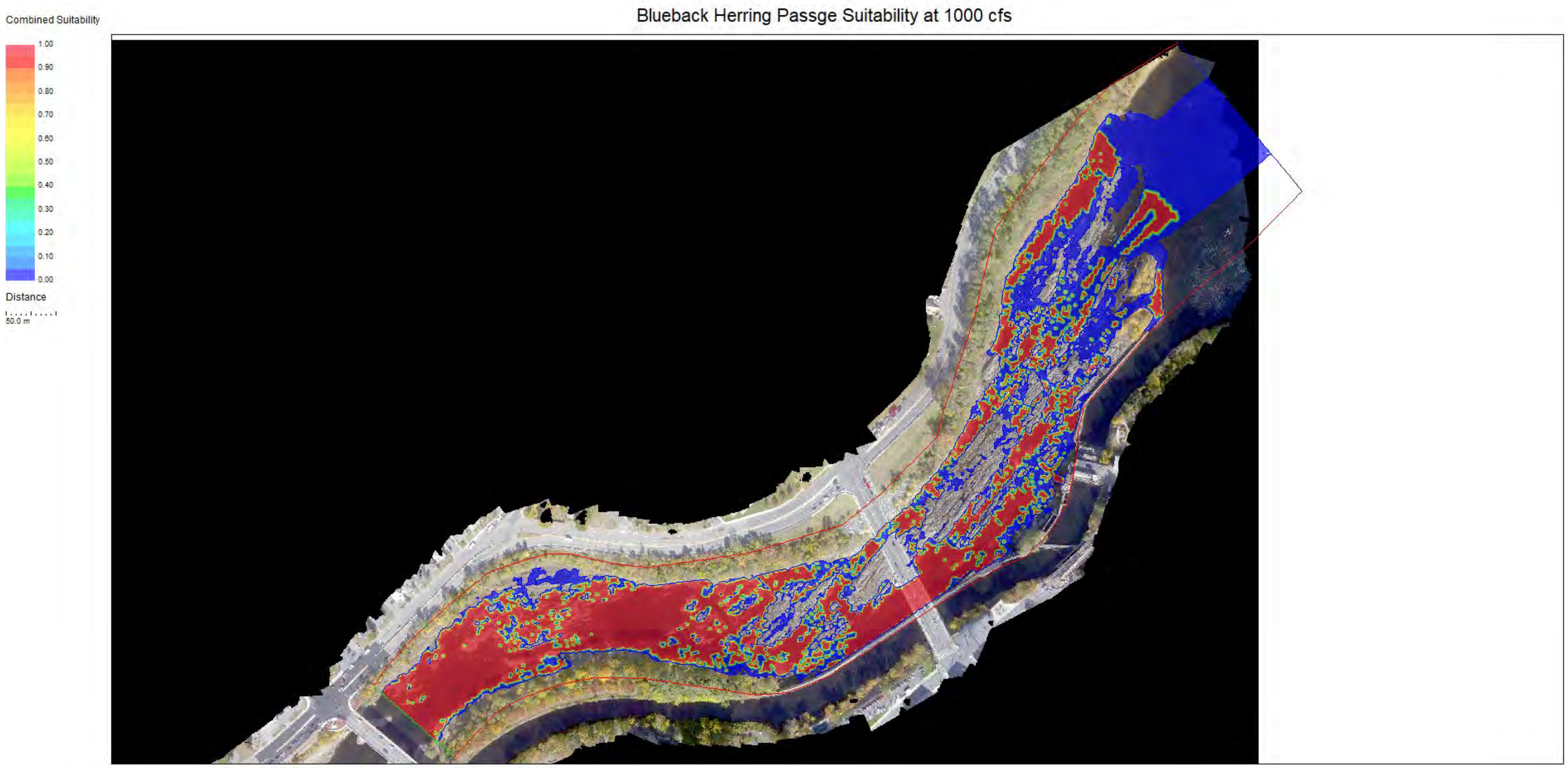

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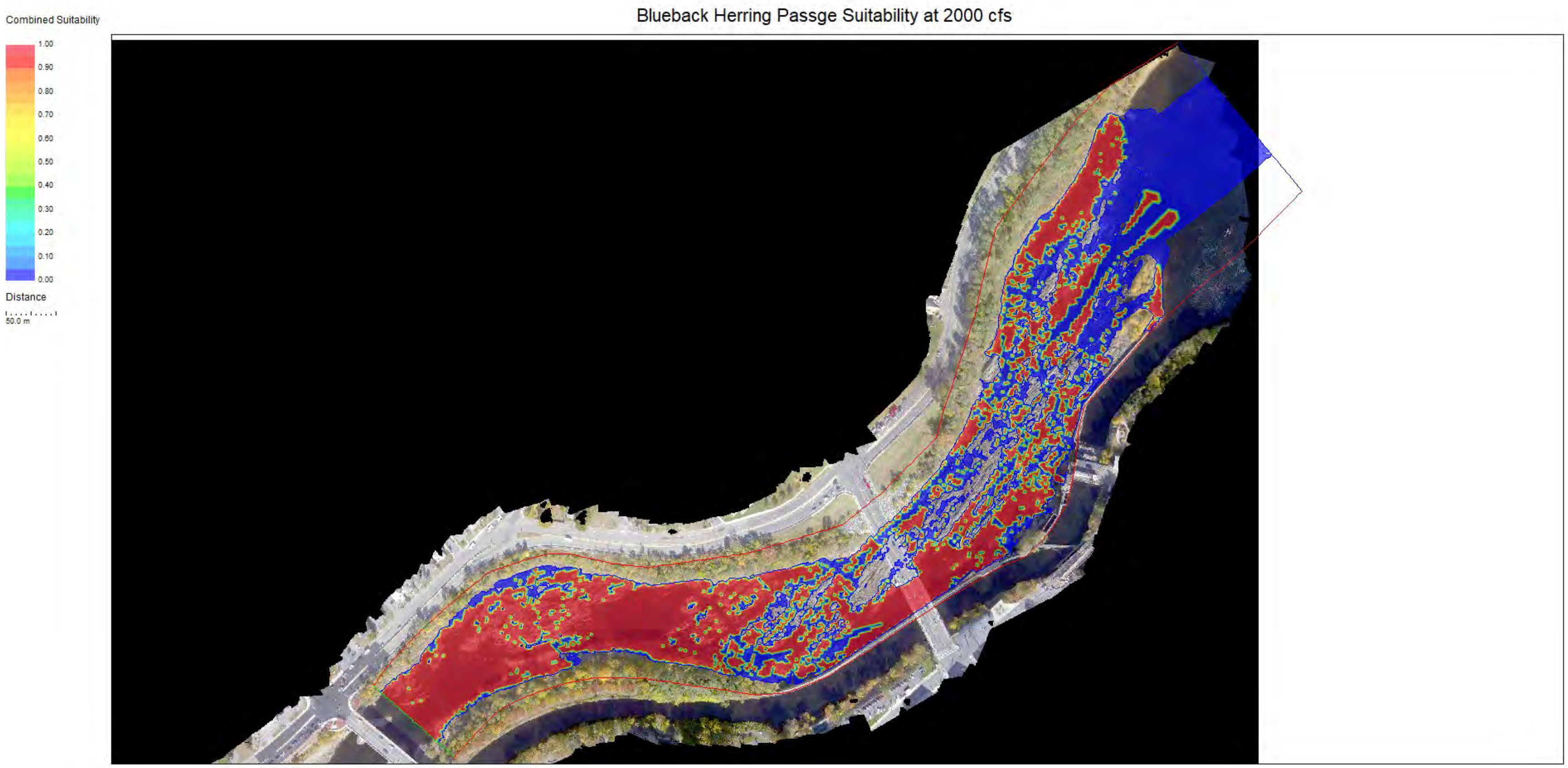

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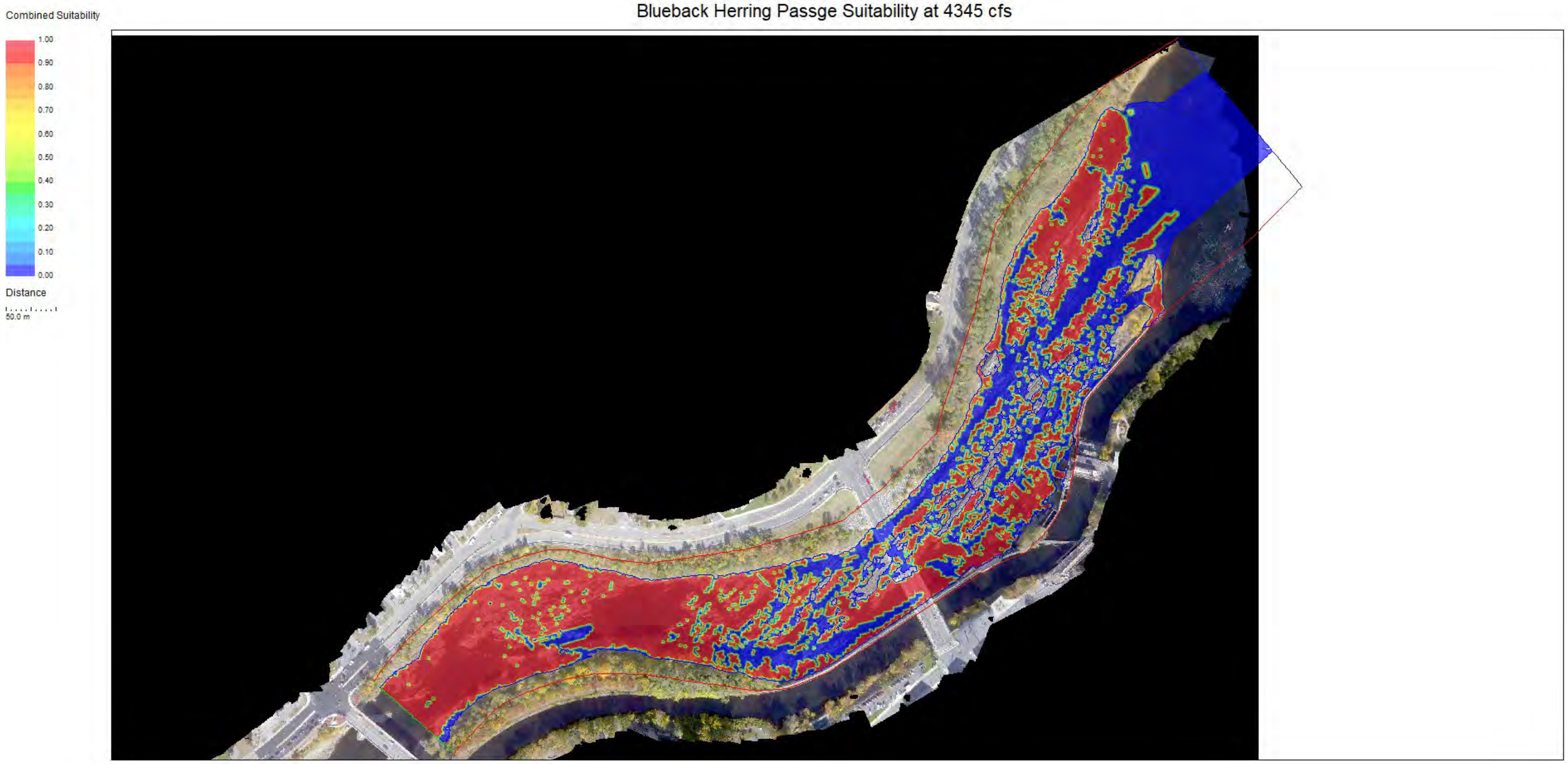

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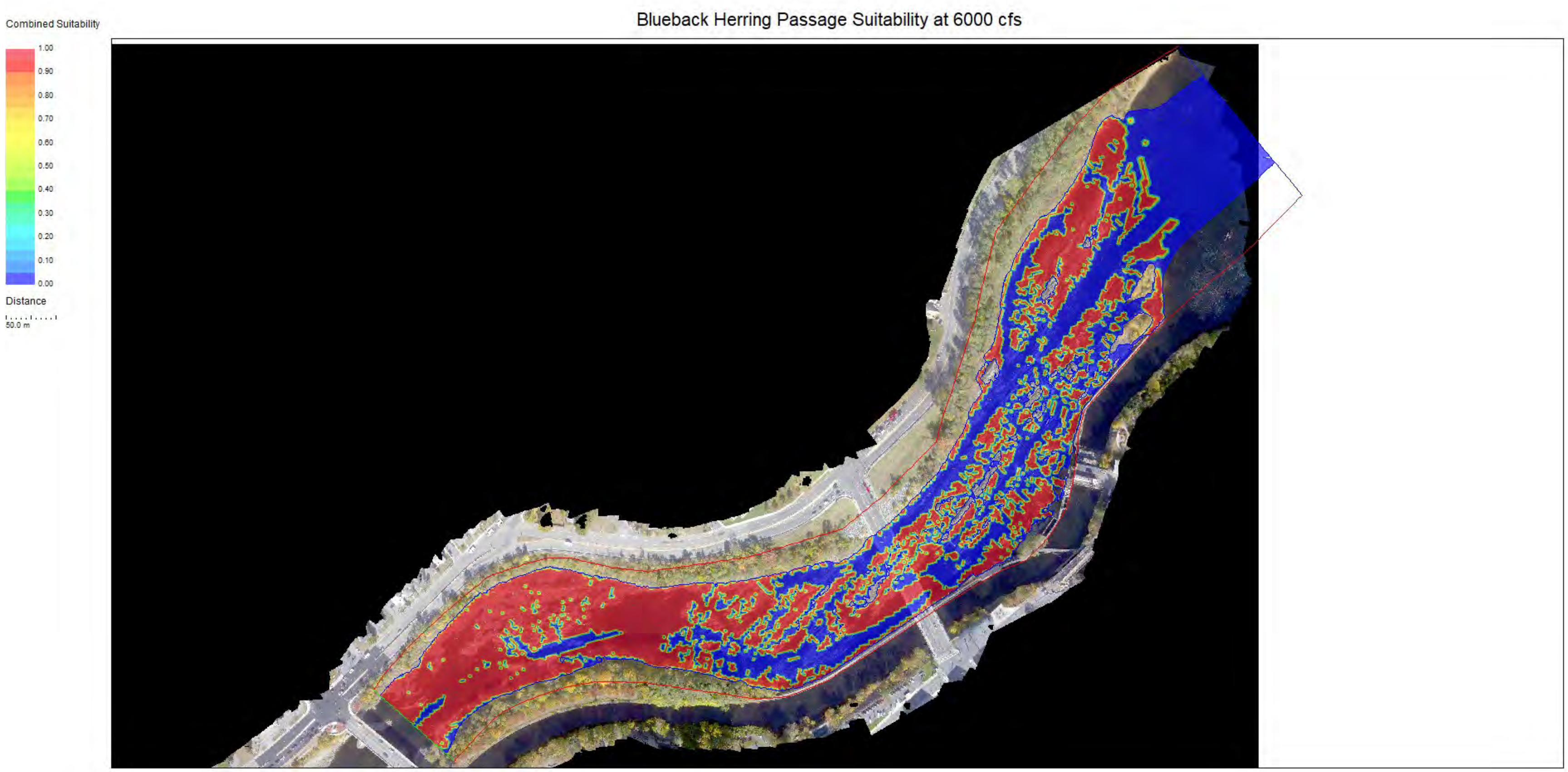

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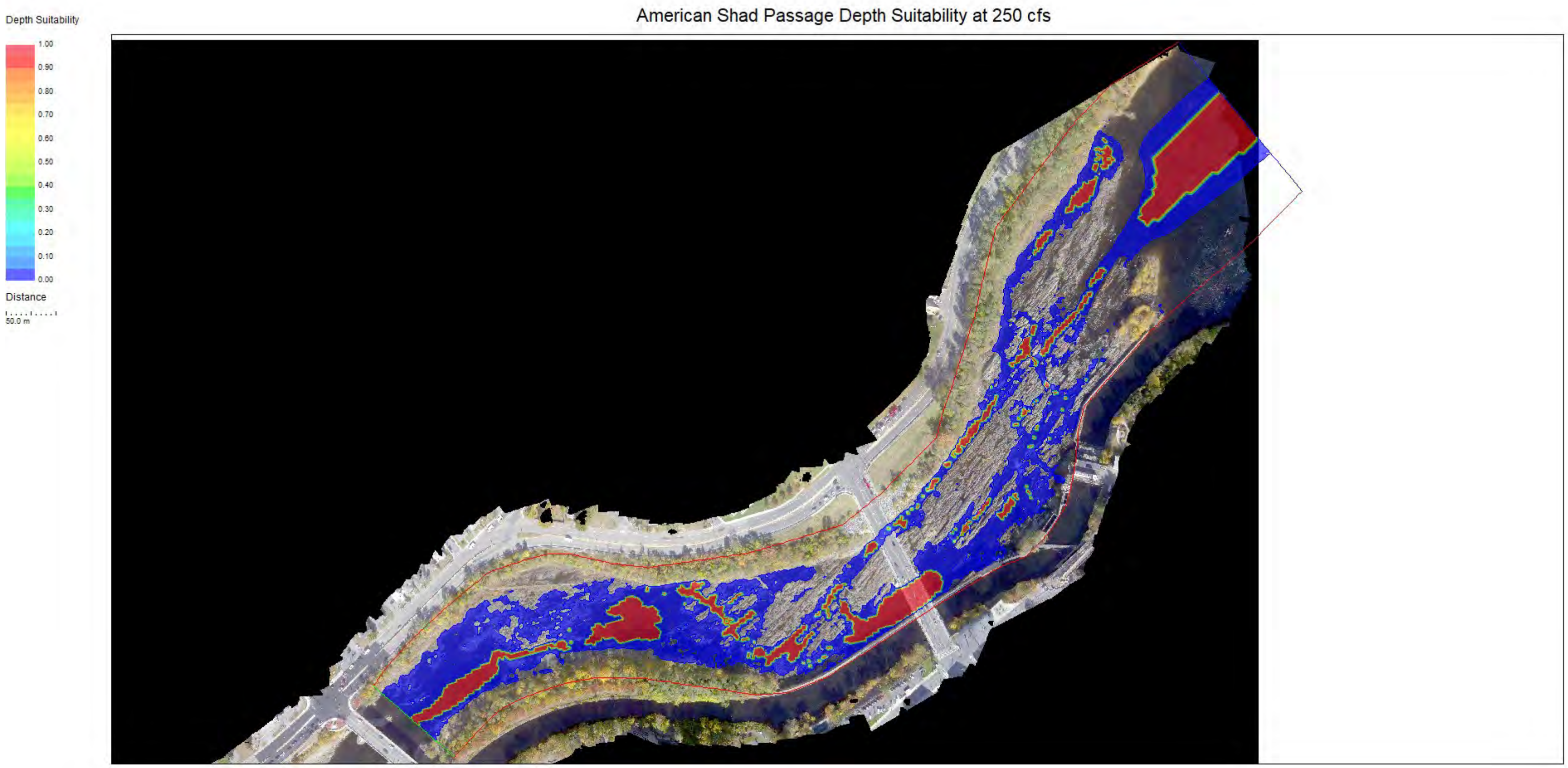

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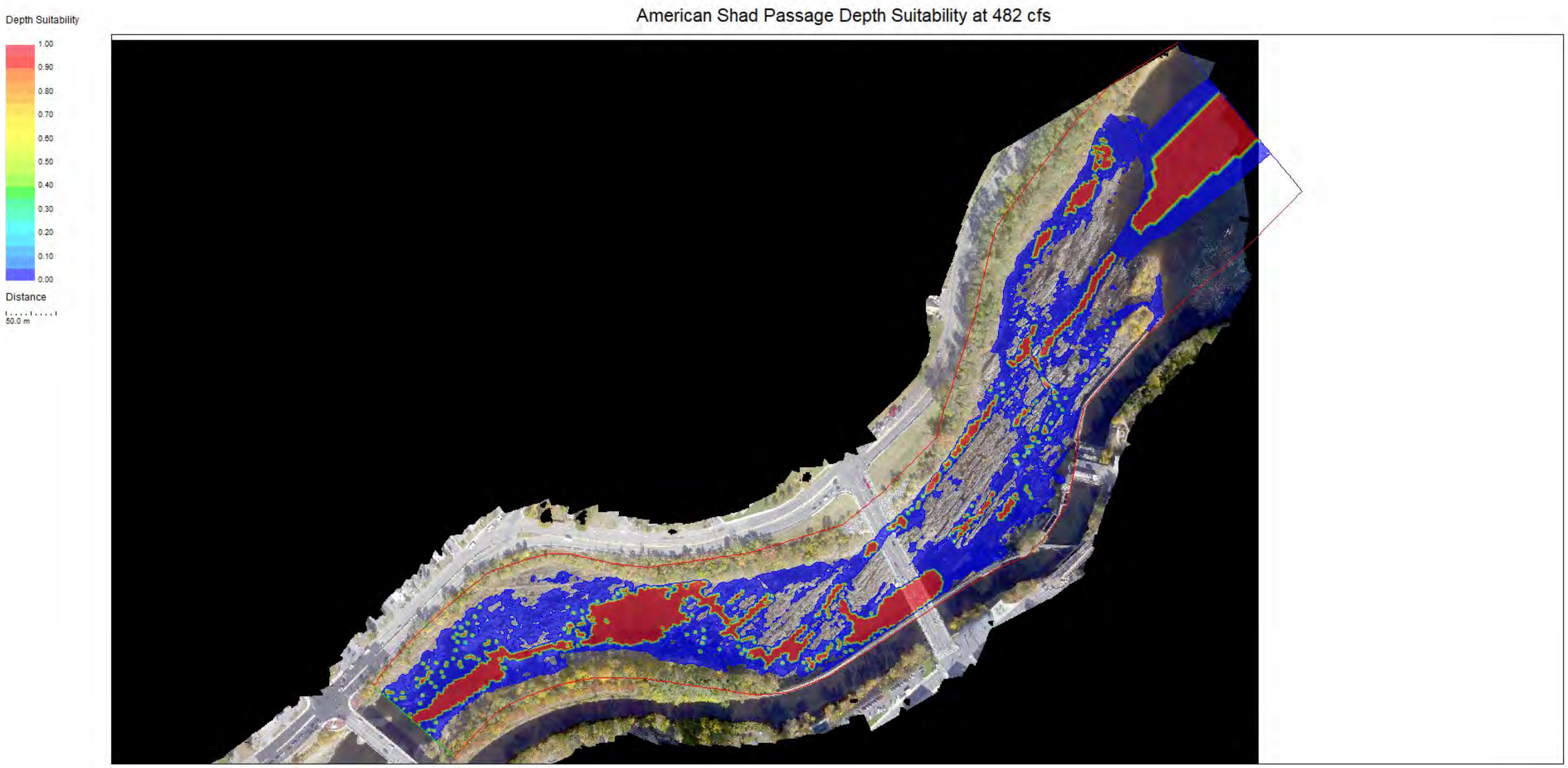

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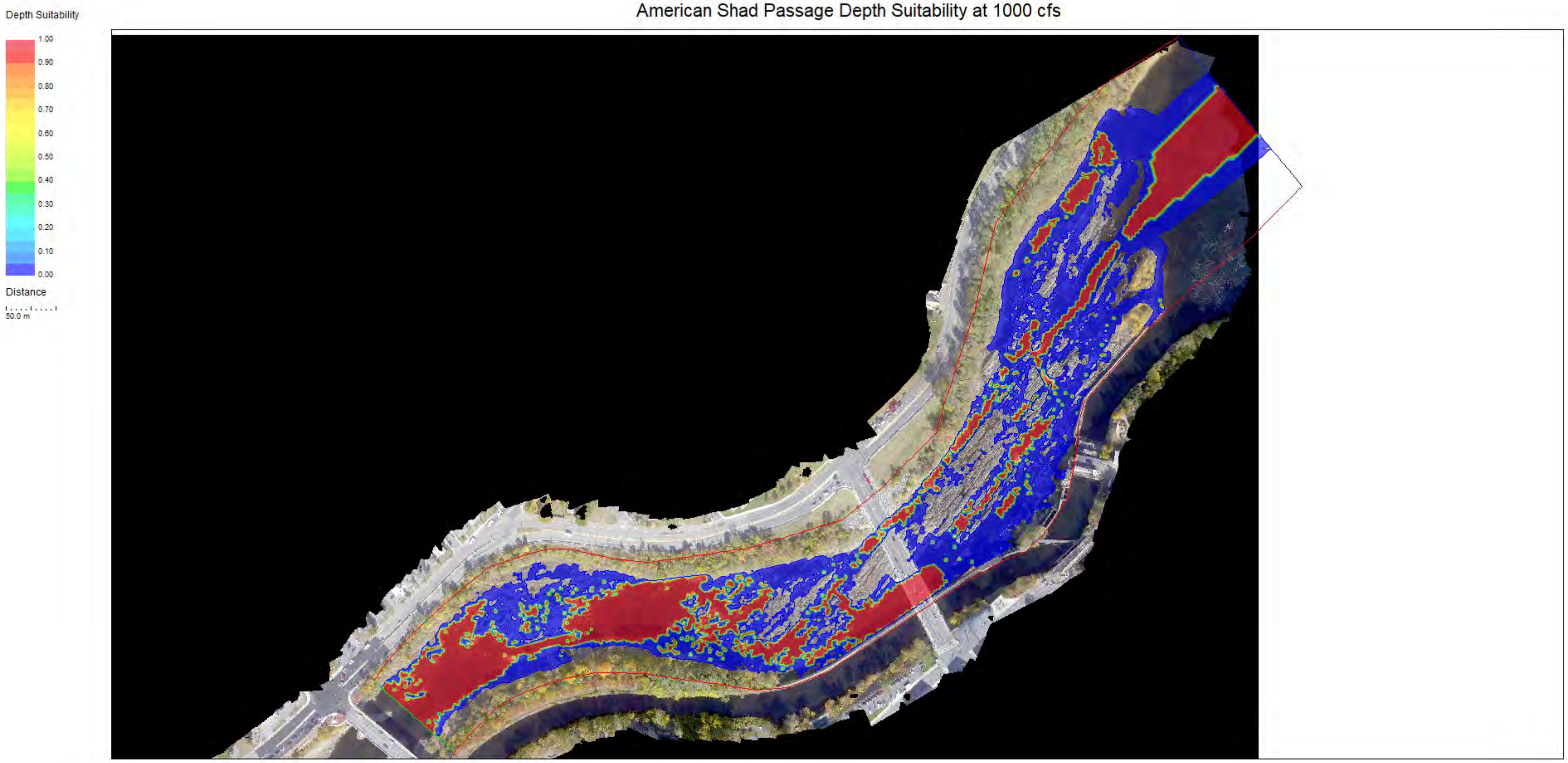
American Shad Passage Depth Suitability at 1000 cfs



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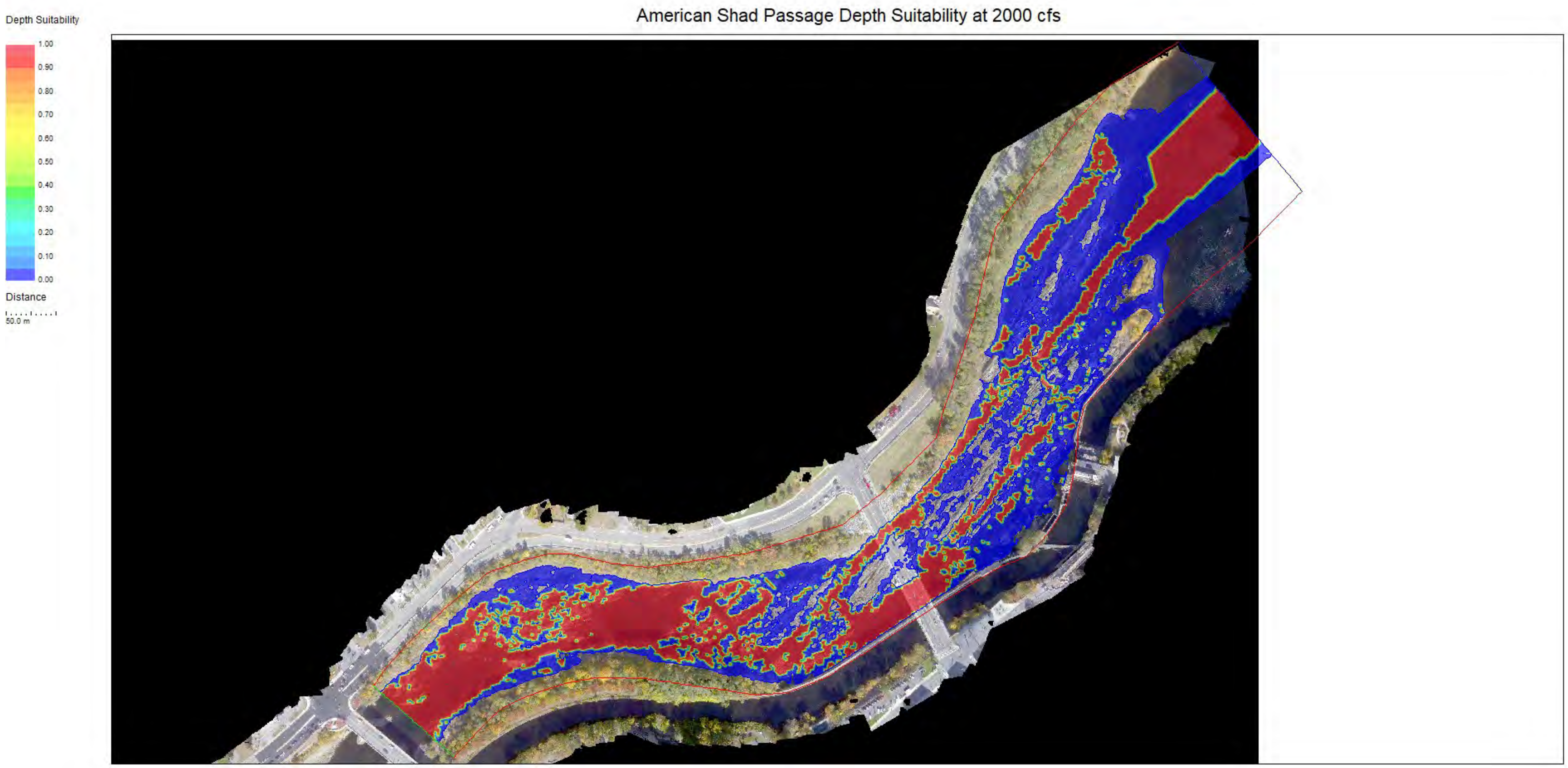

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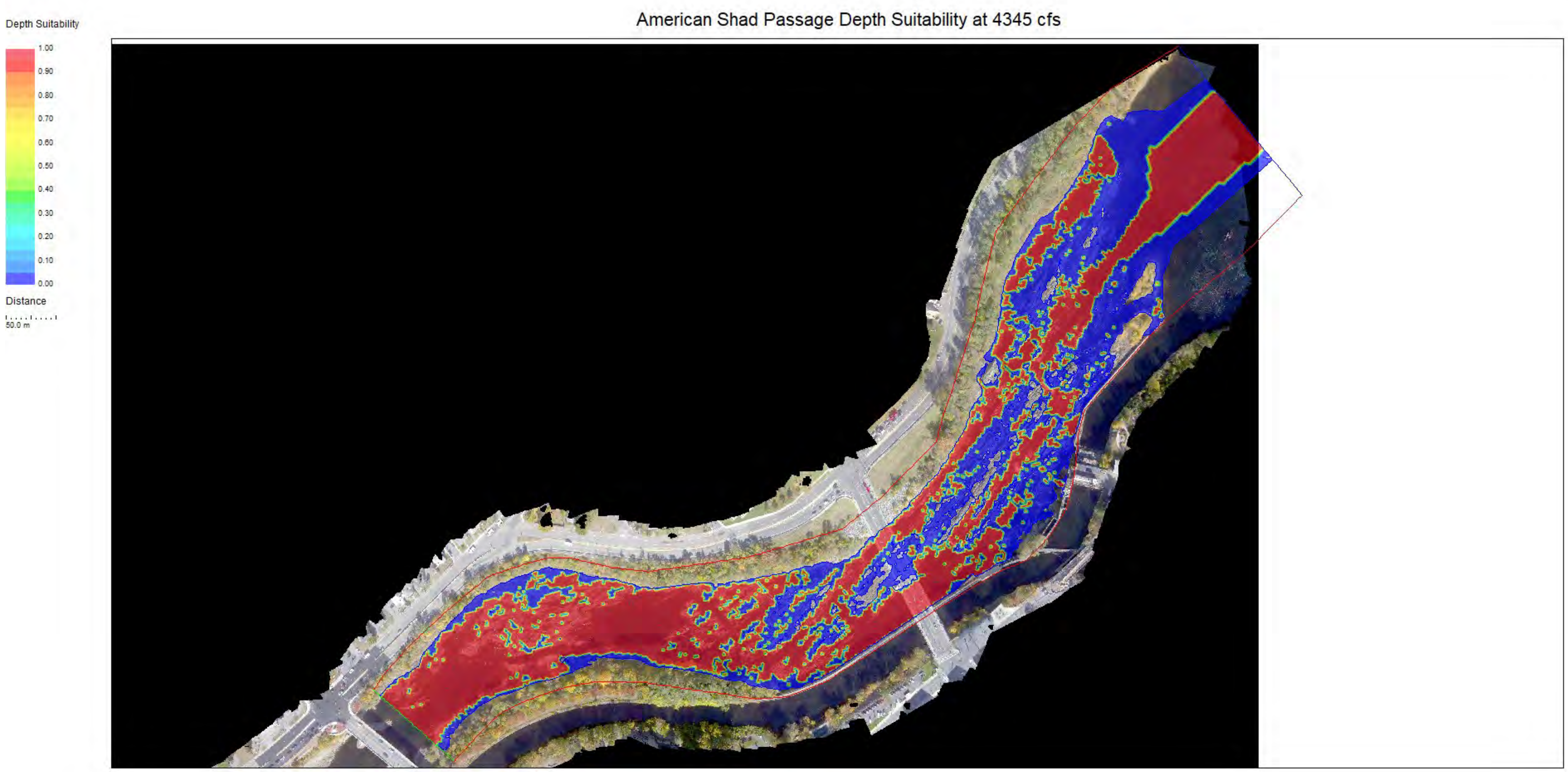

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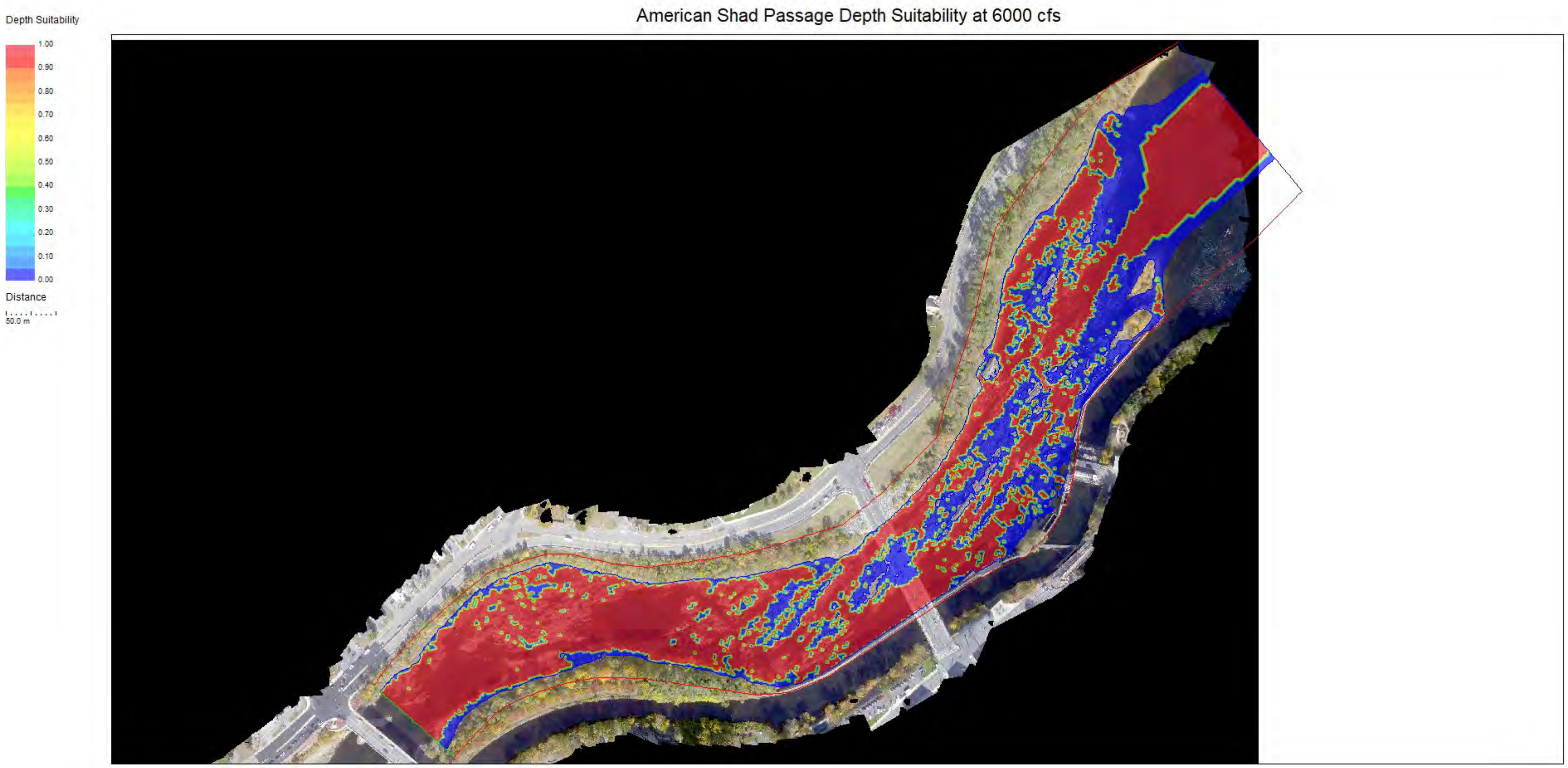

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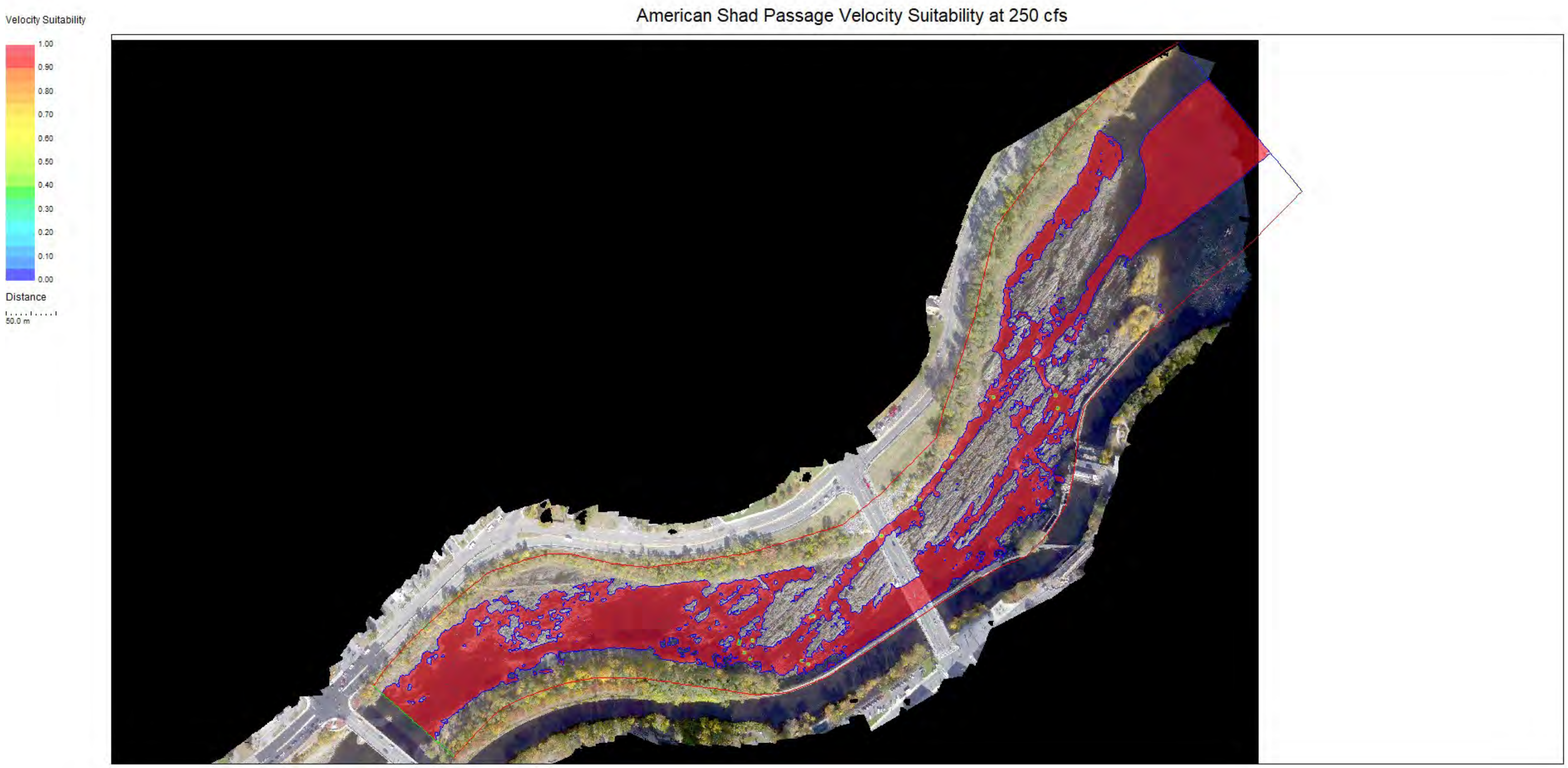

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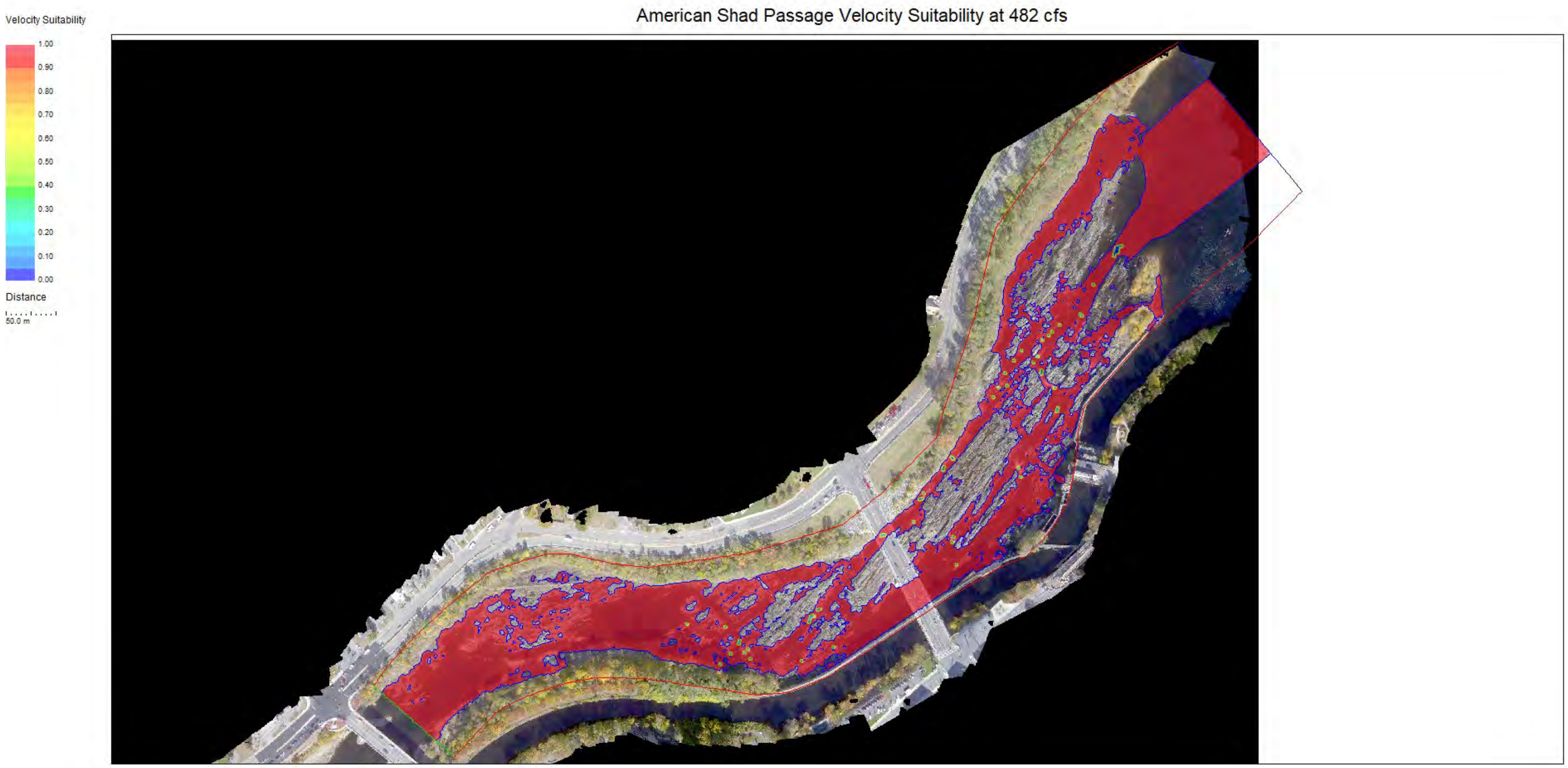

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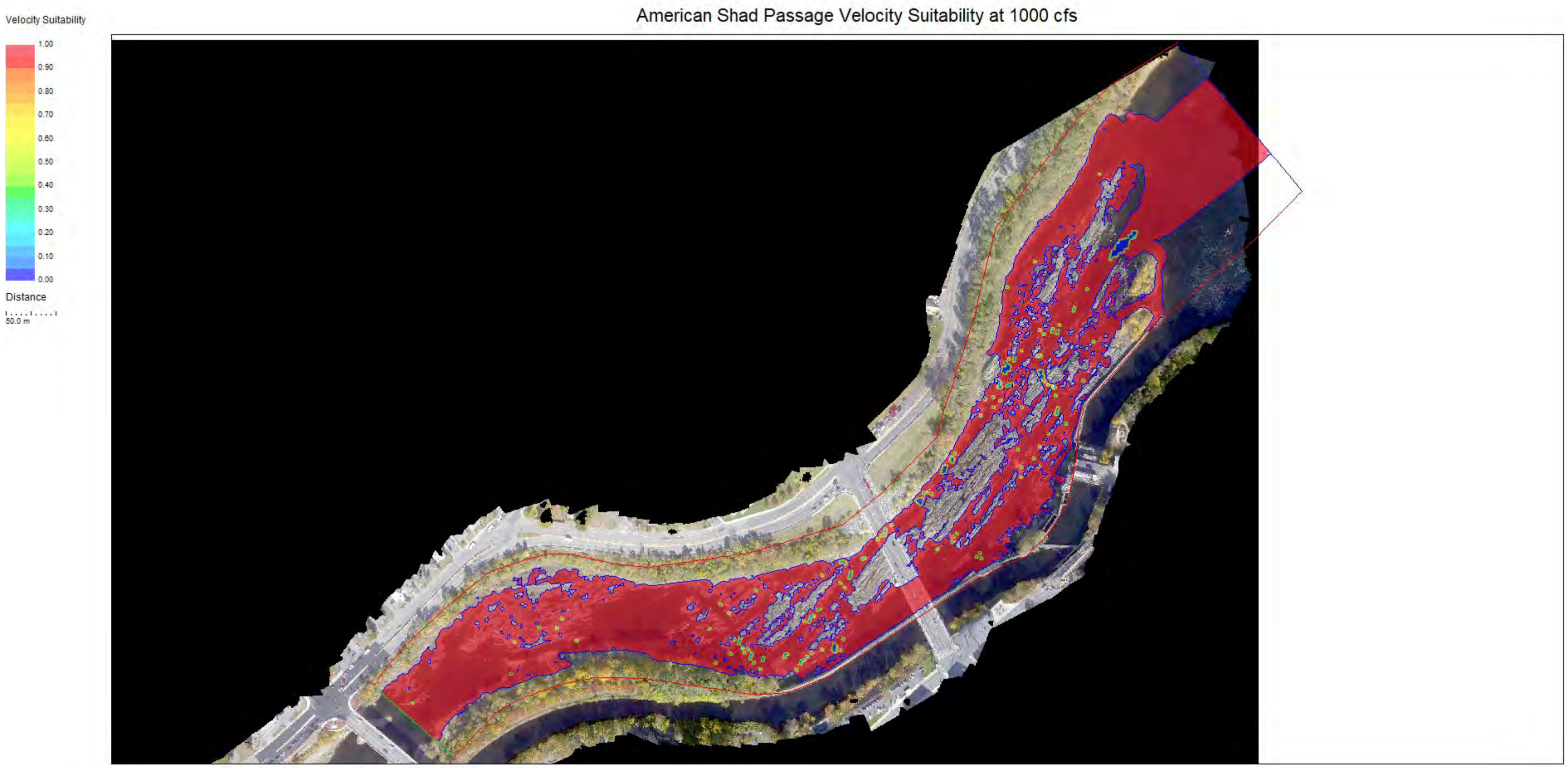

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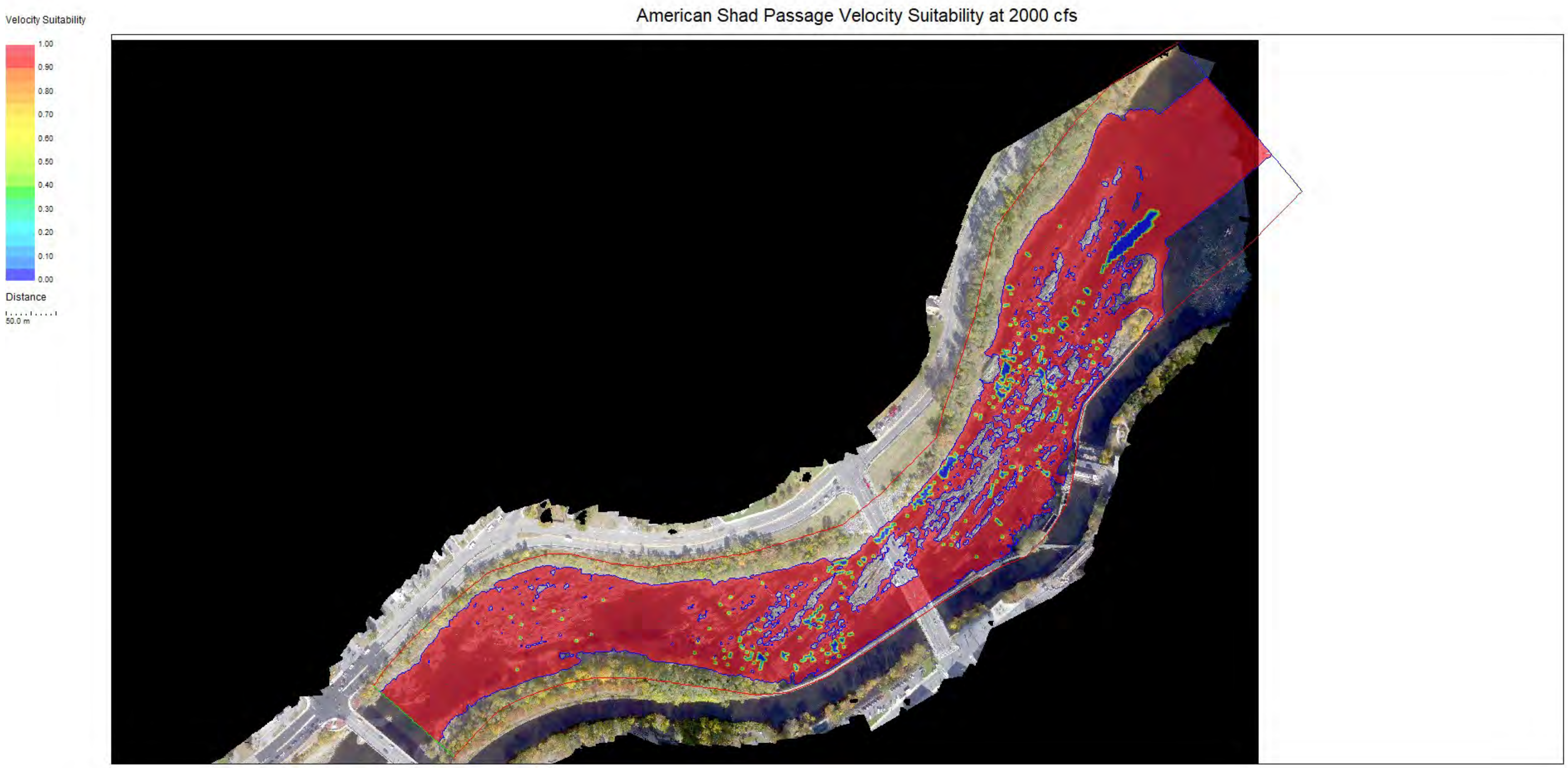

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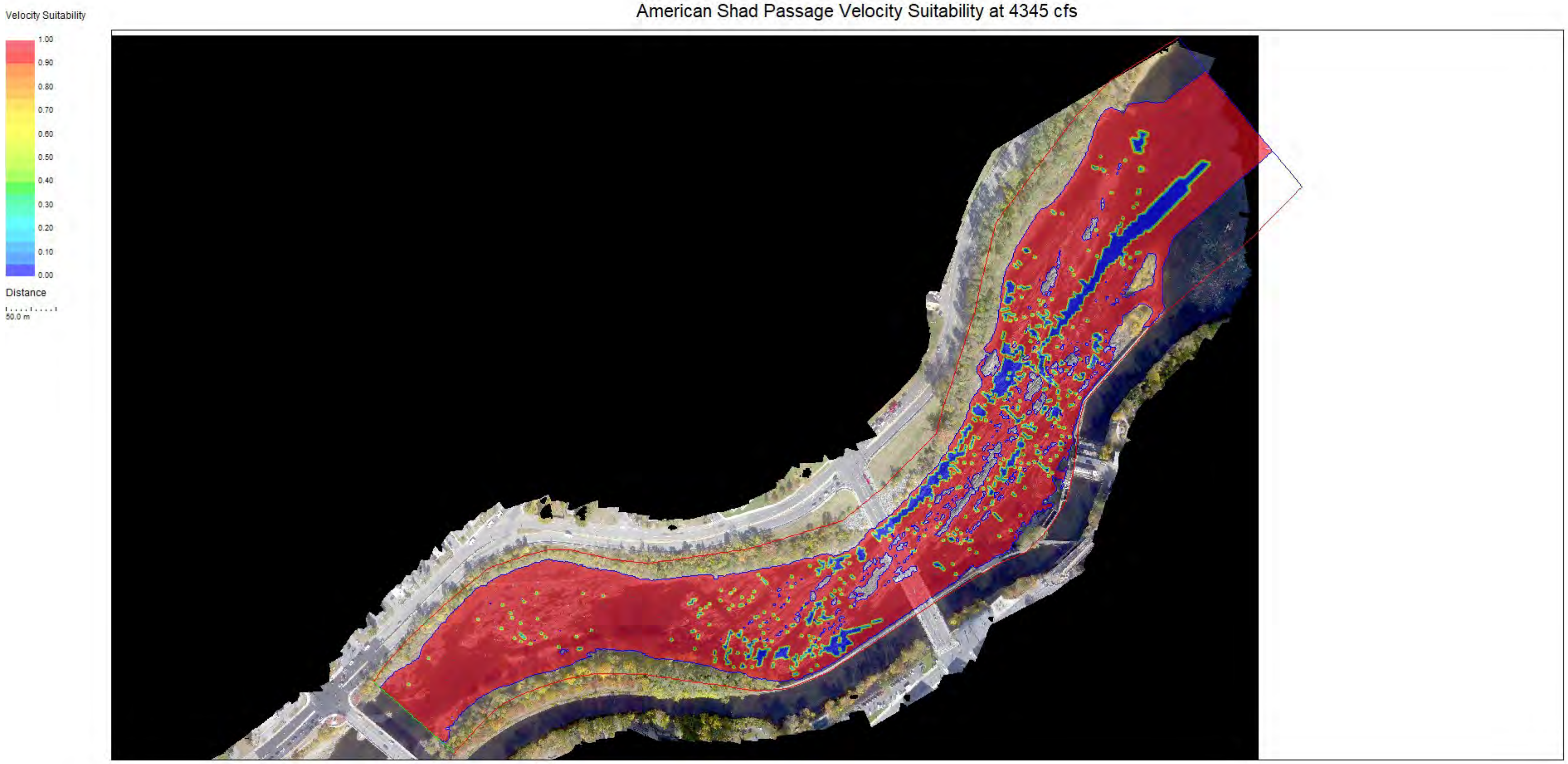

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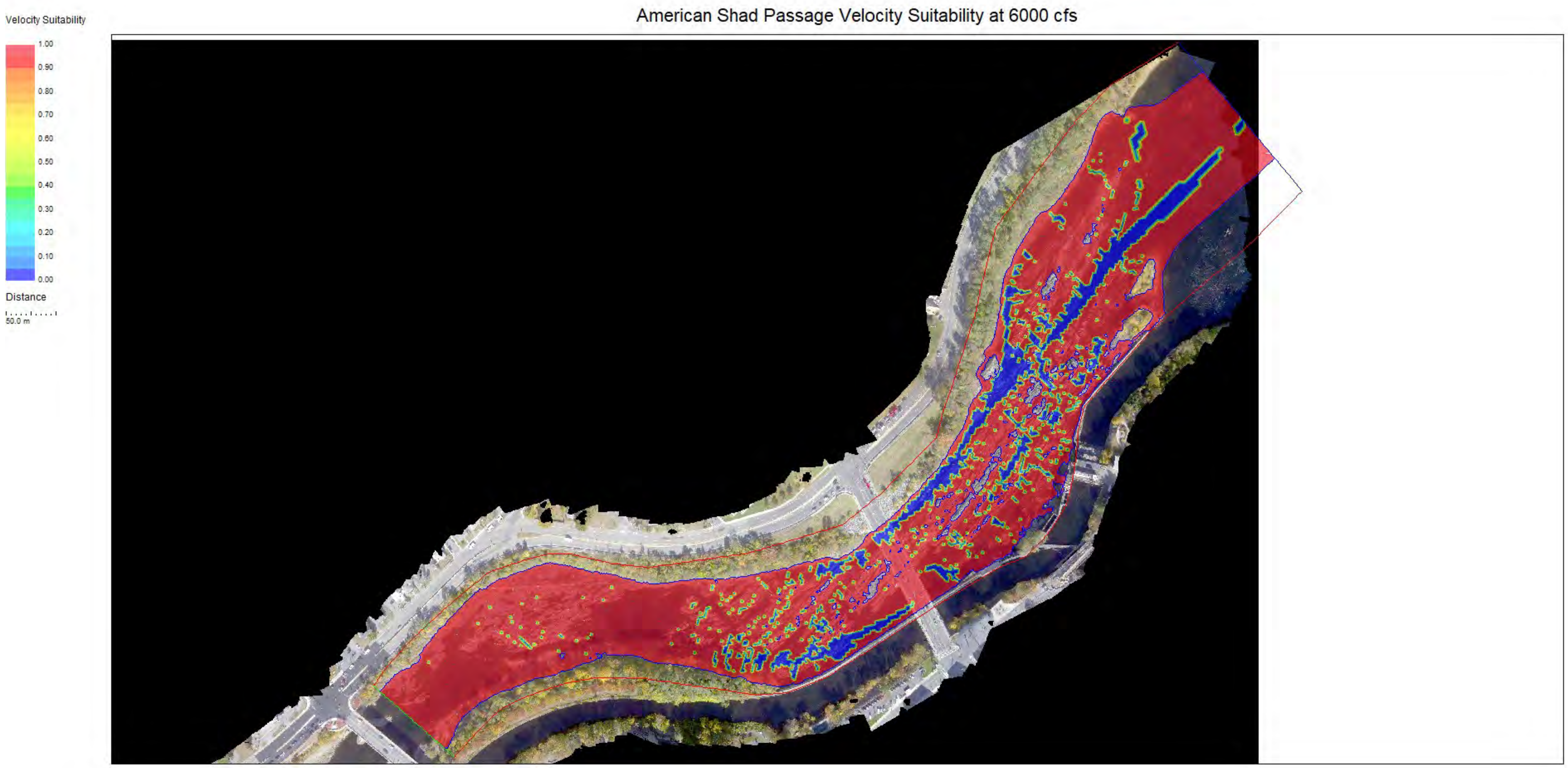

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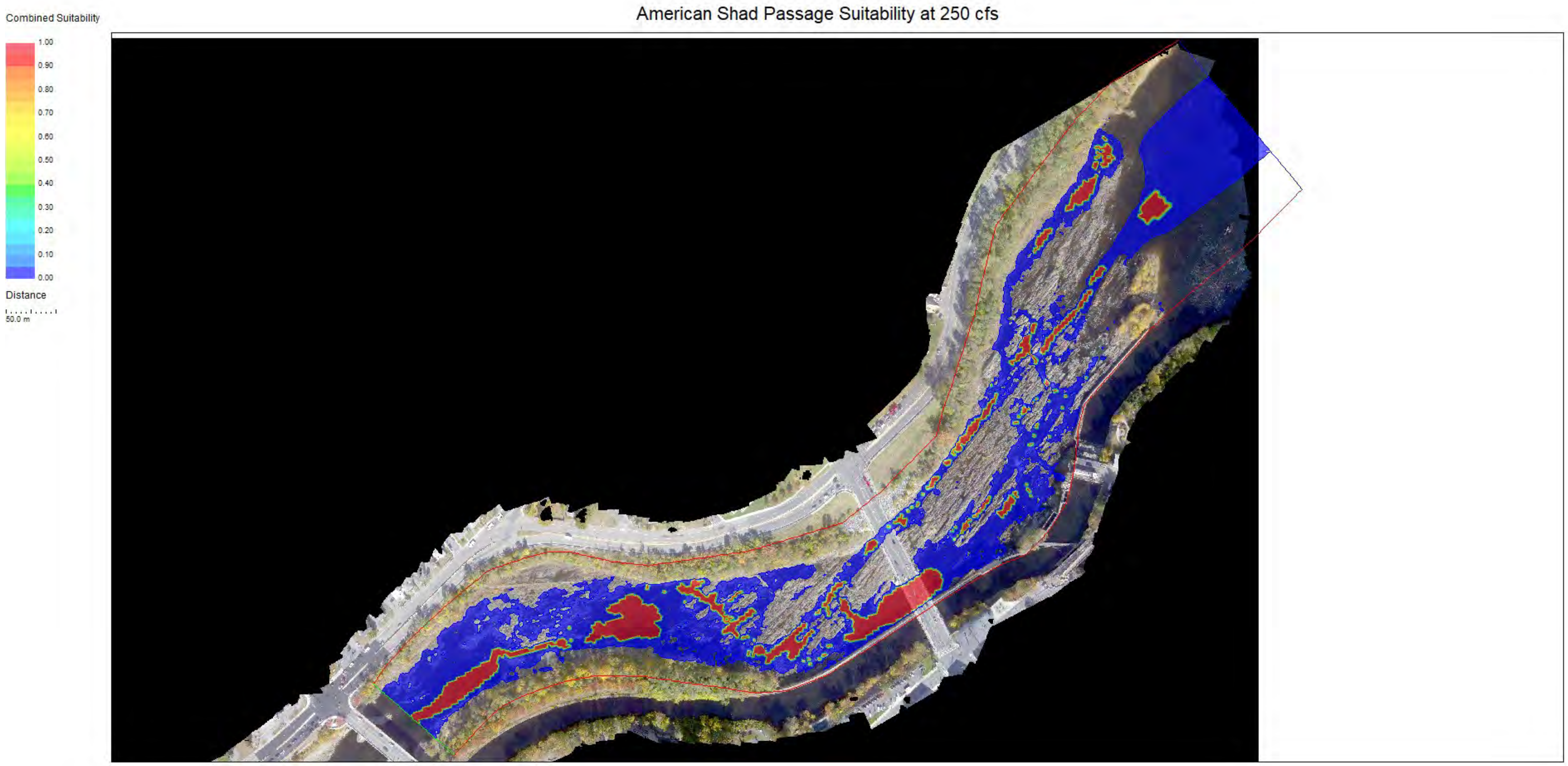

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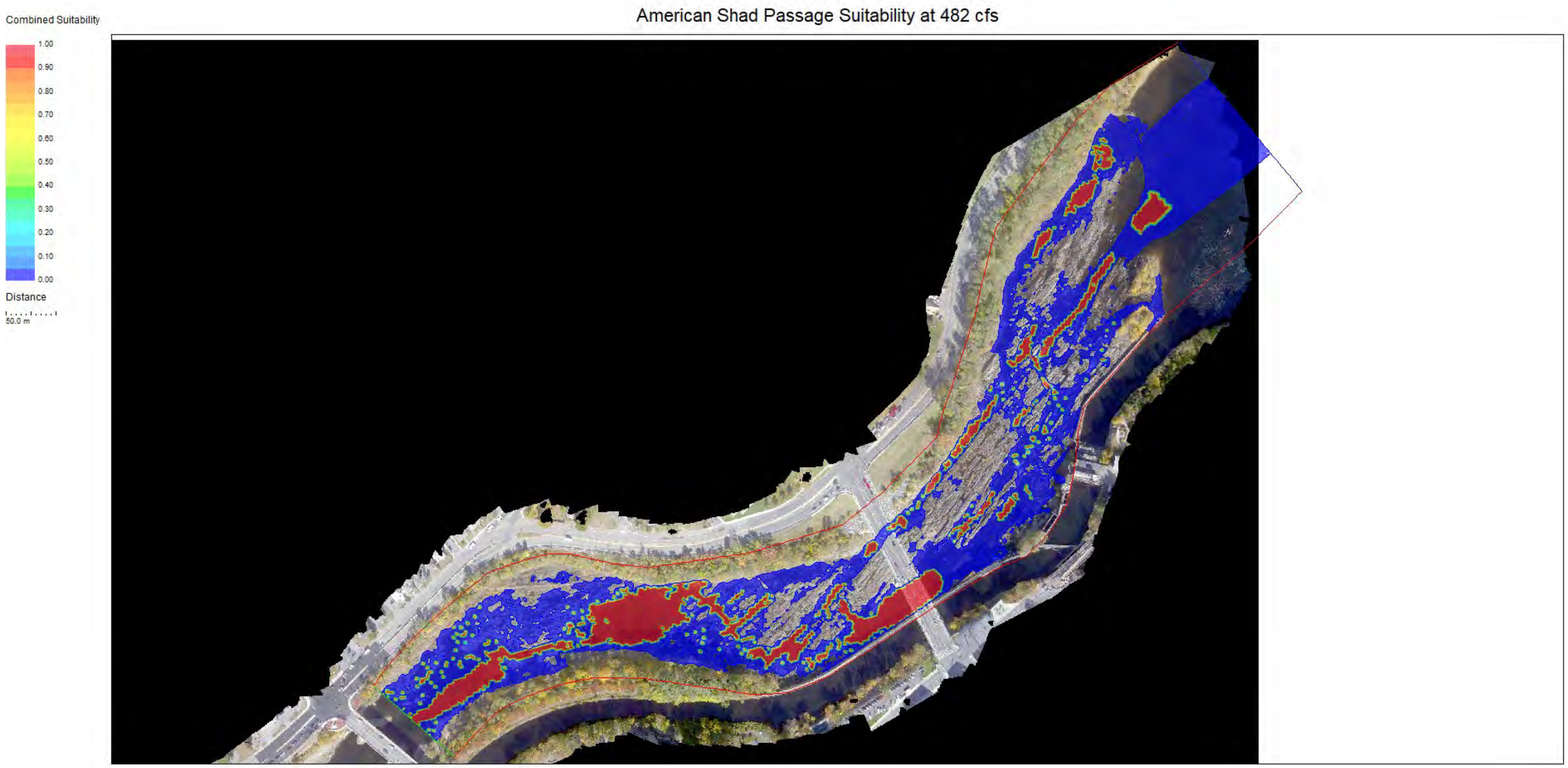

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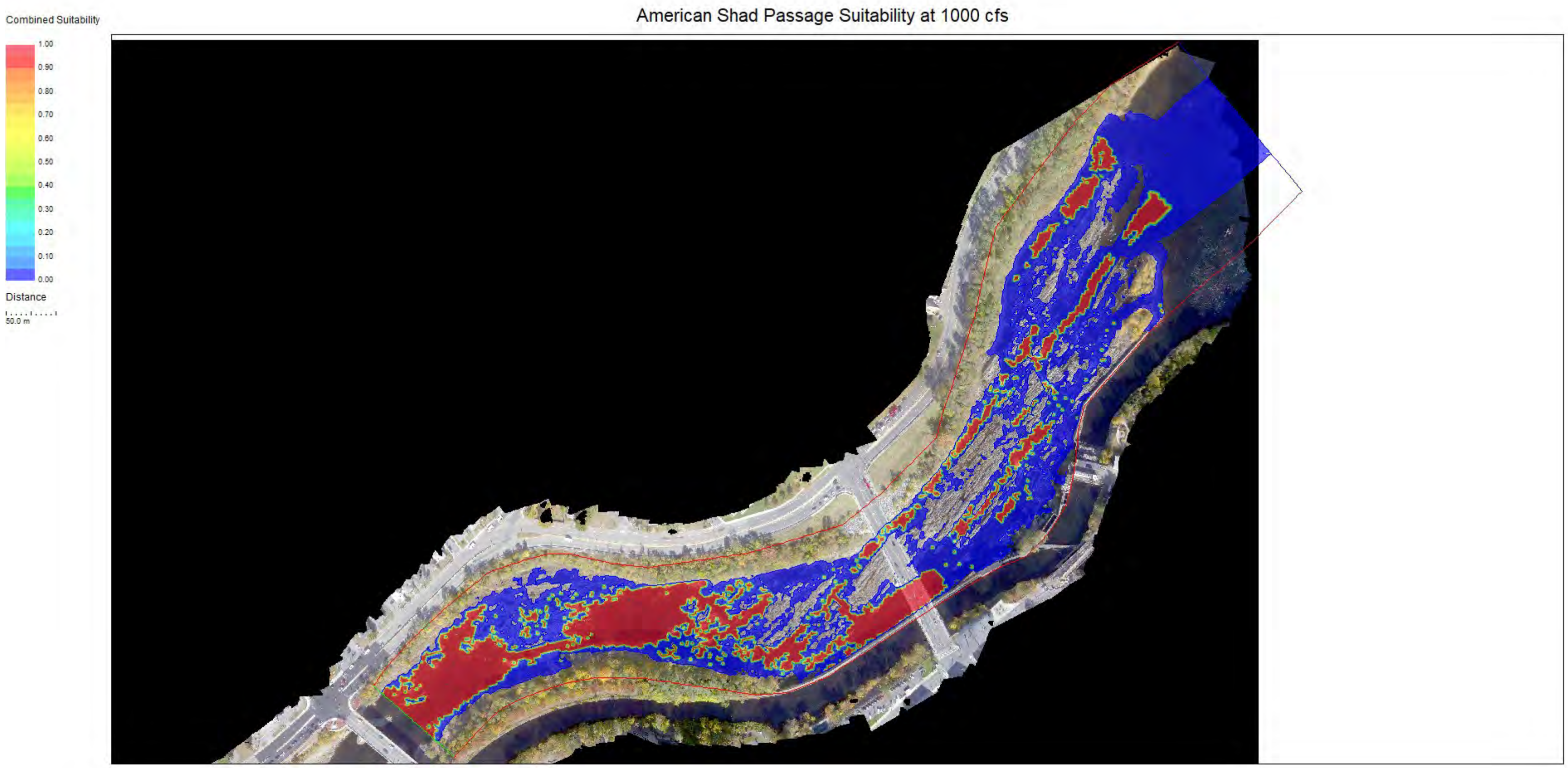

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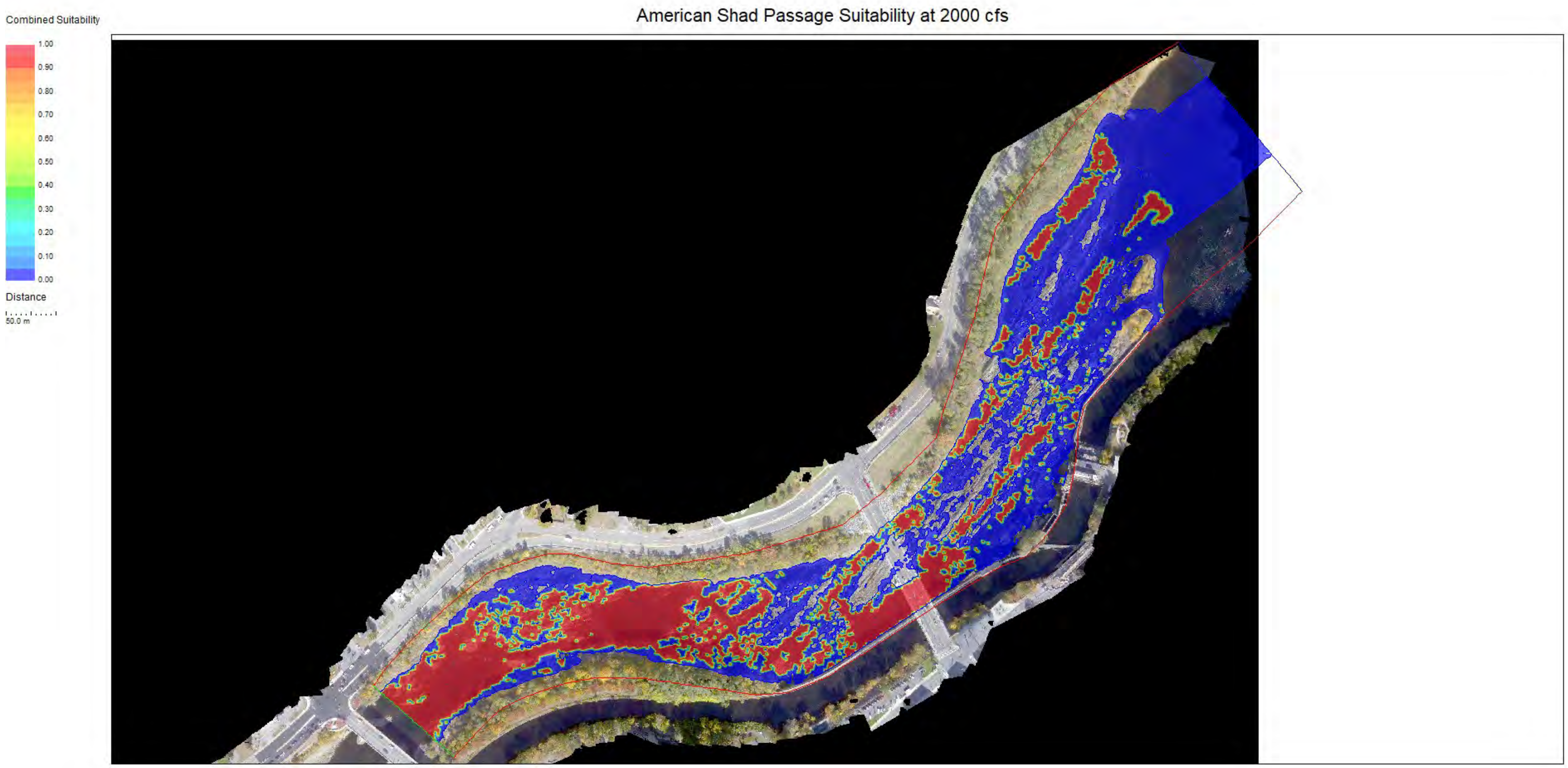

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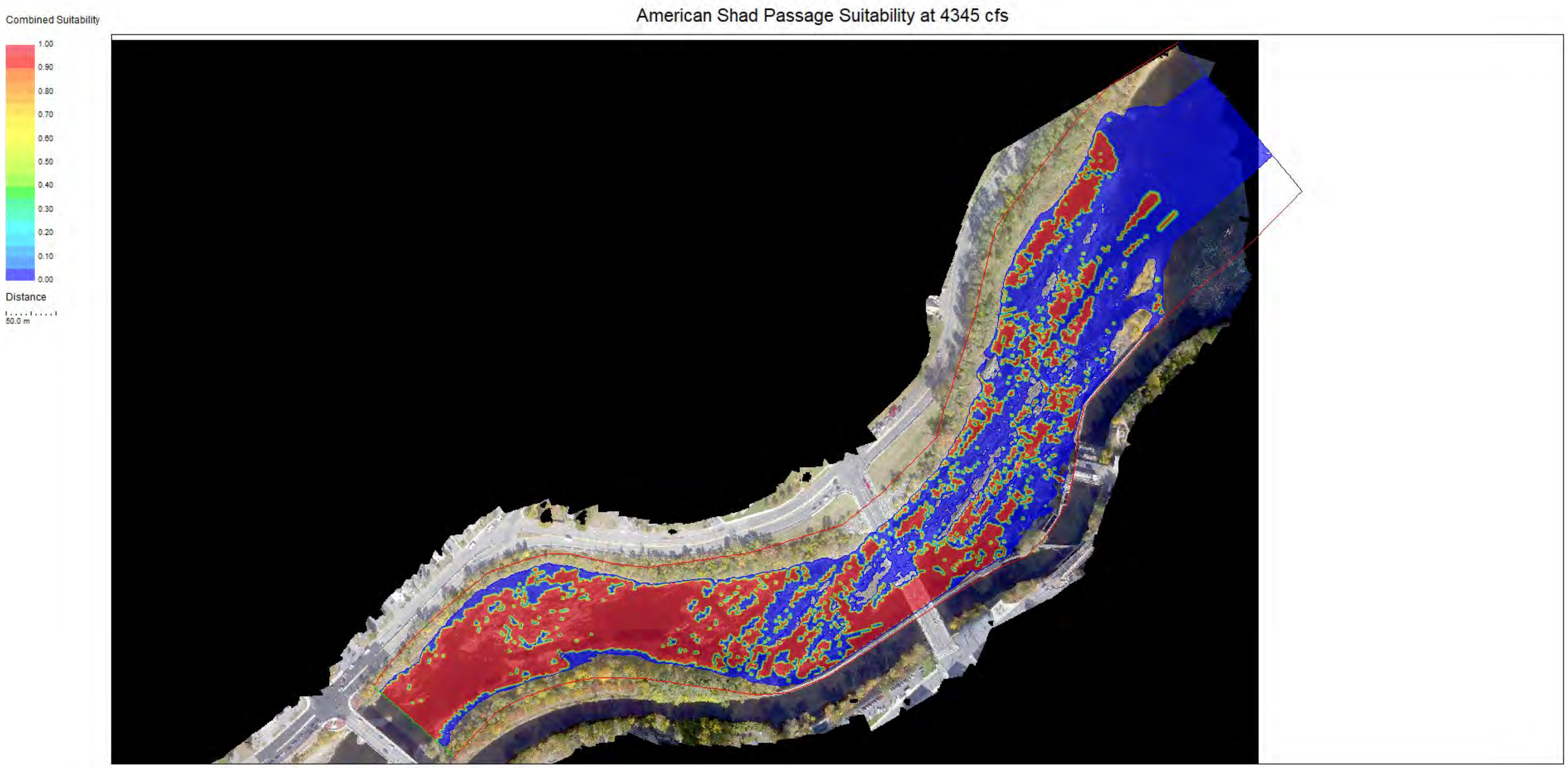

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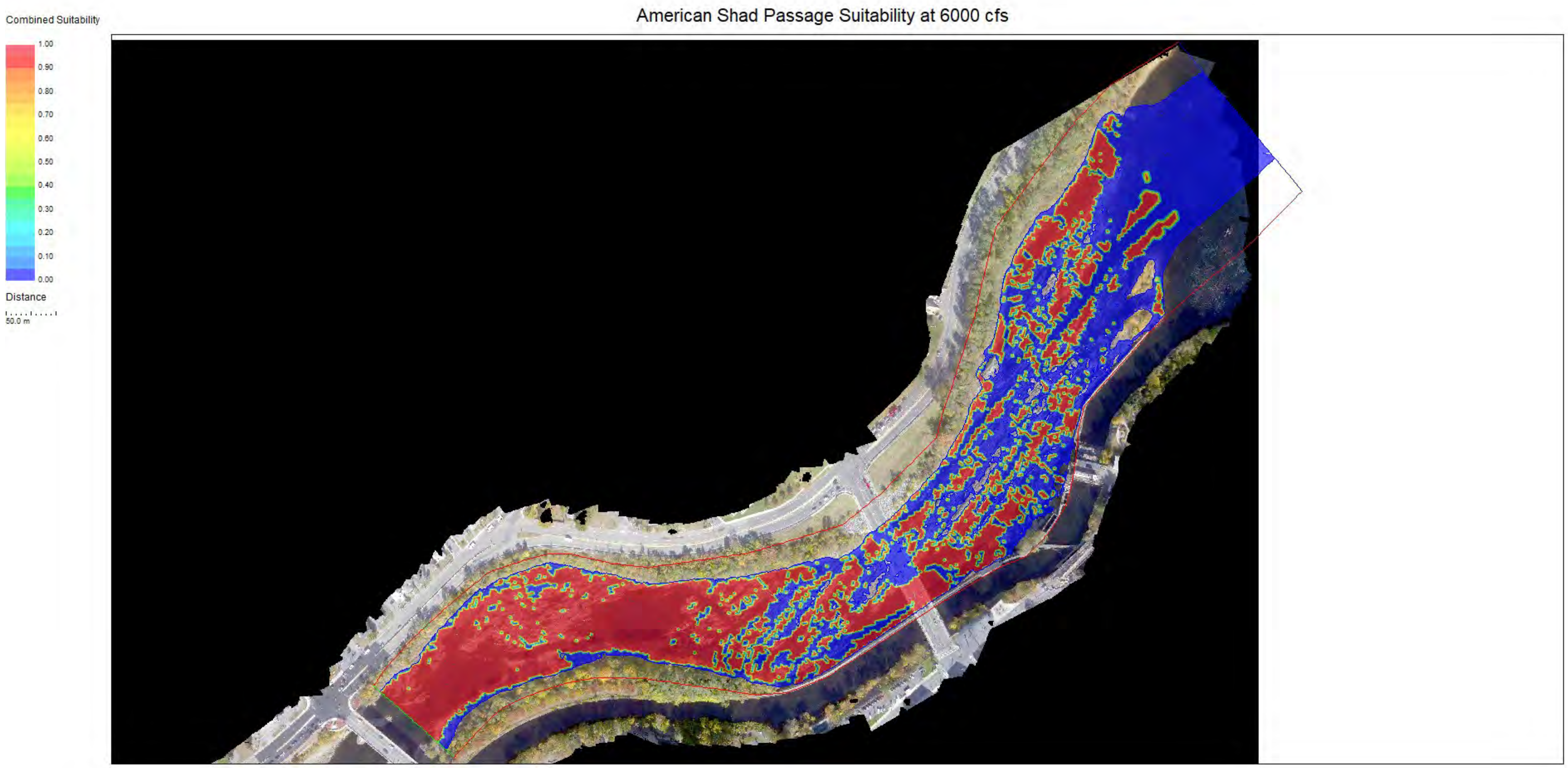

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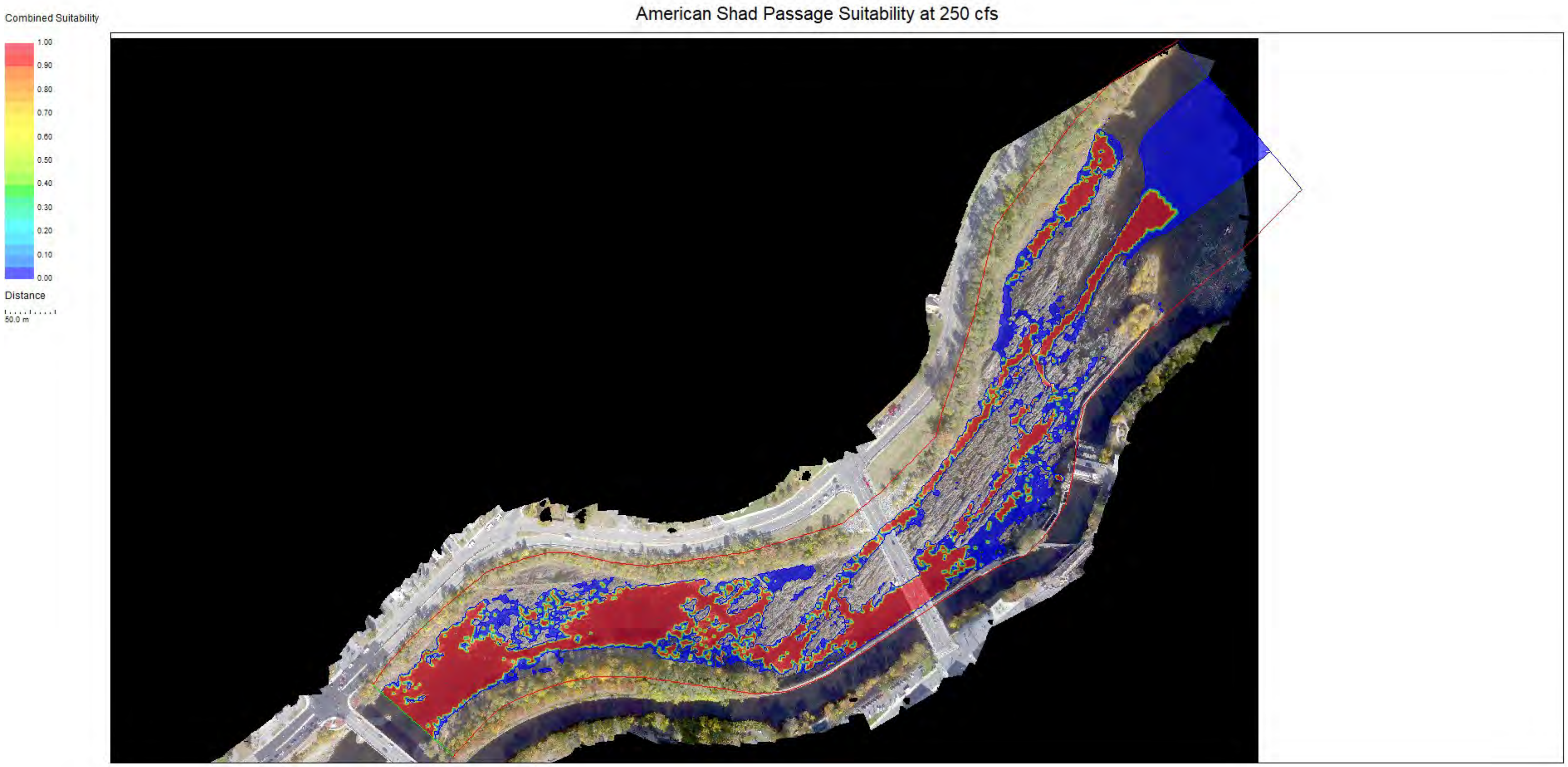

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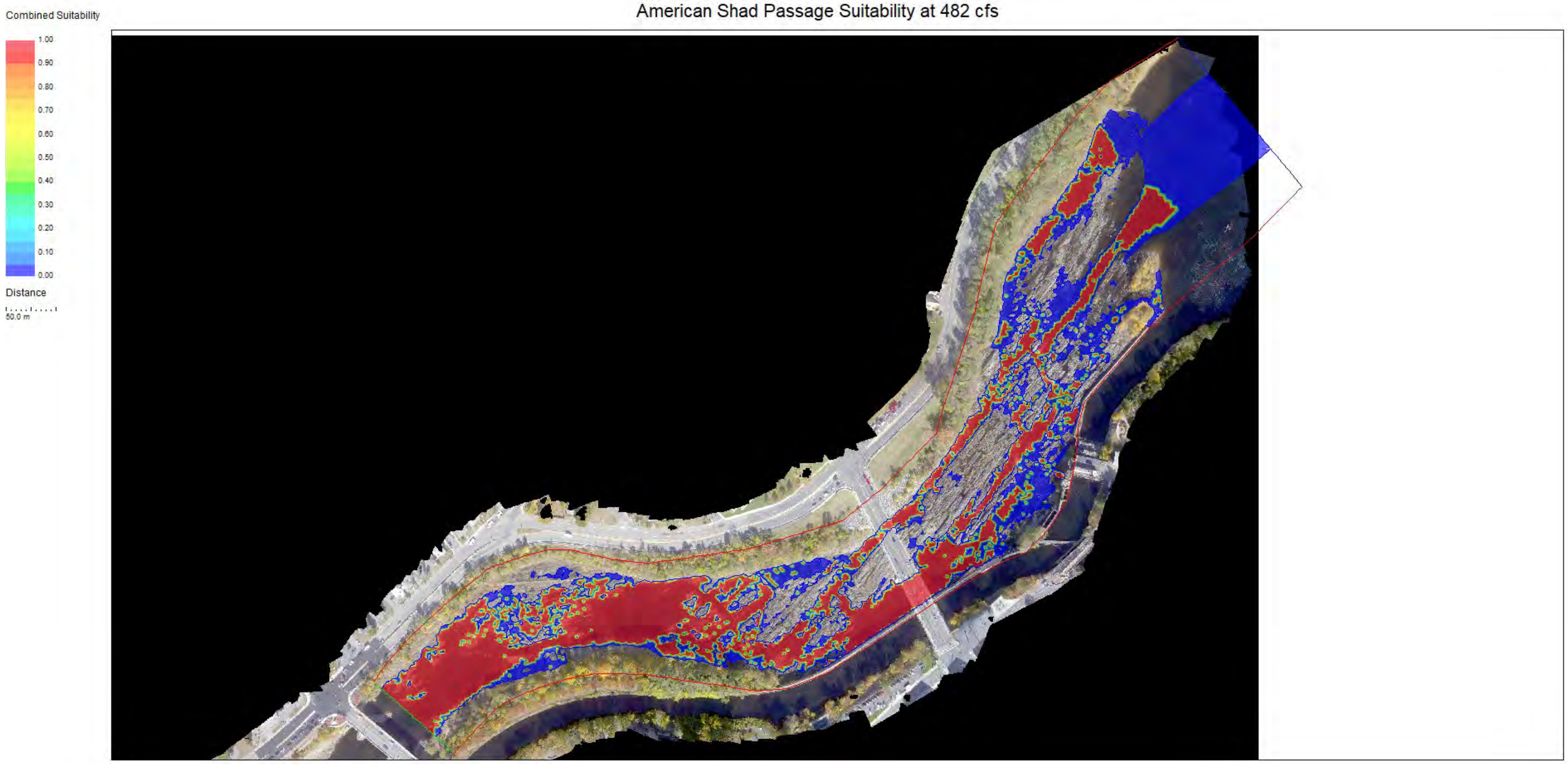

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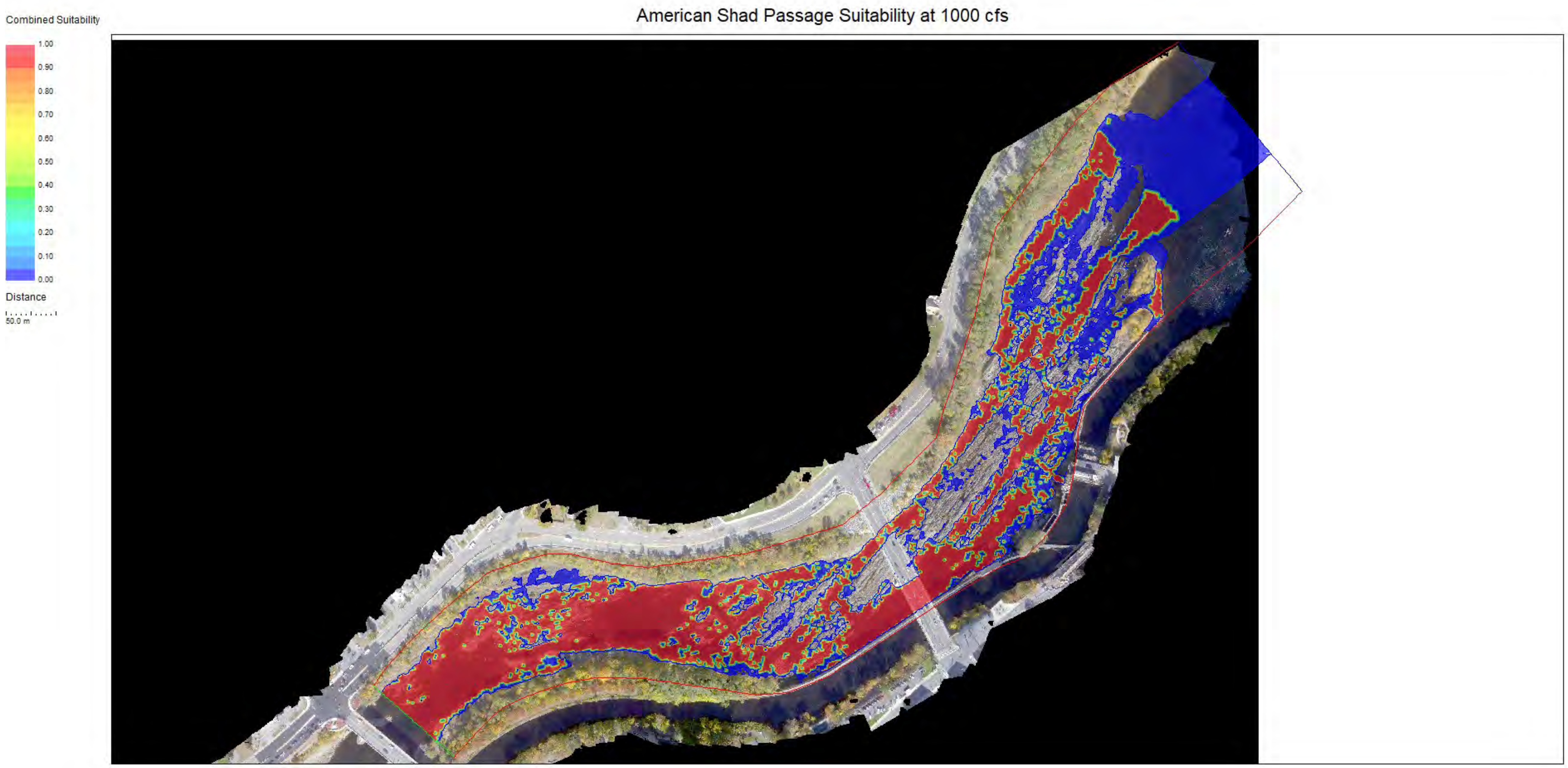

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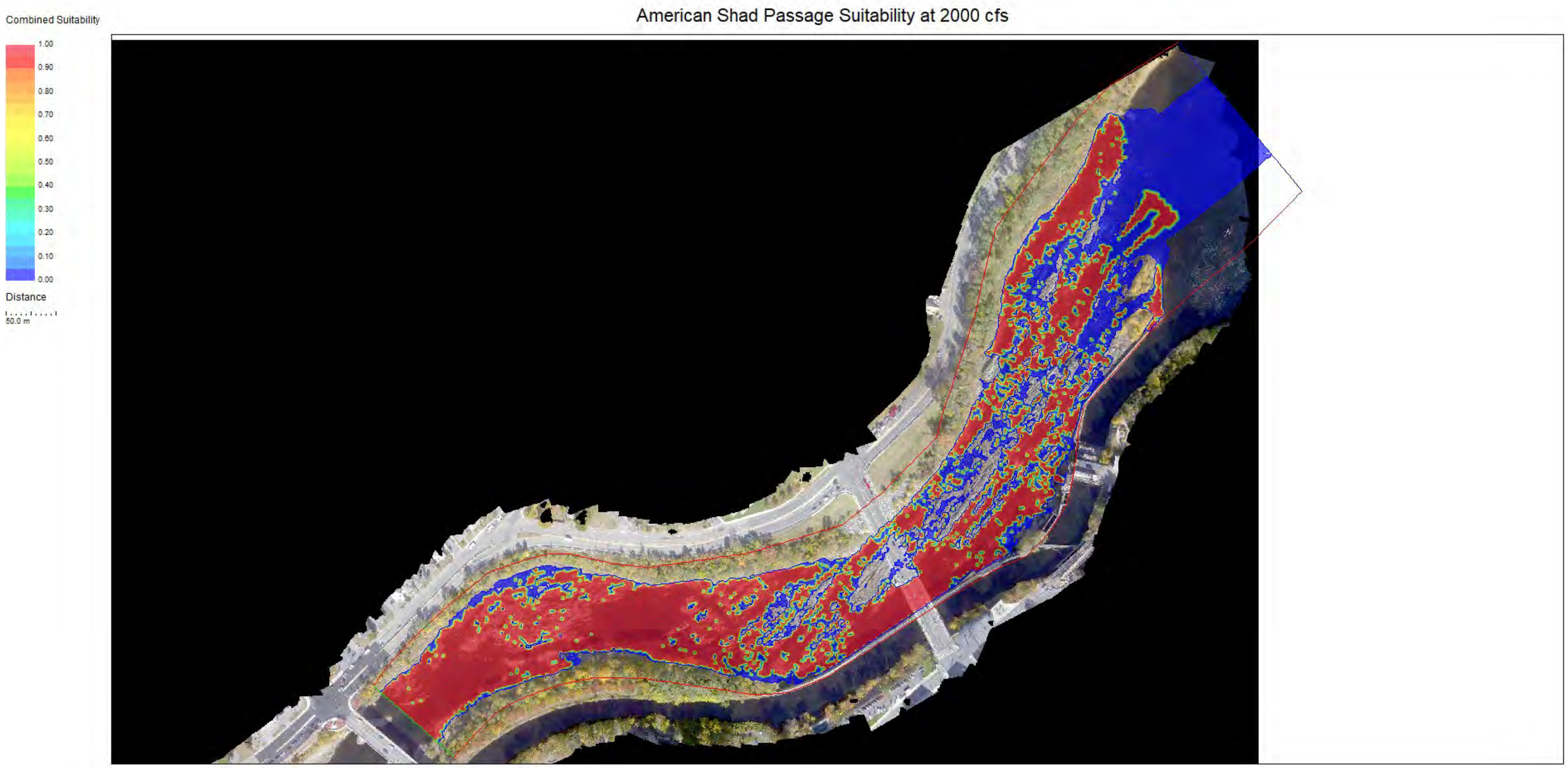

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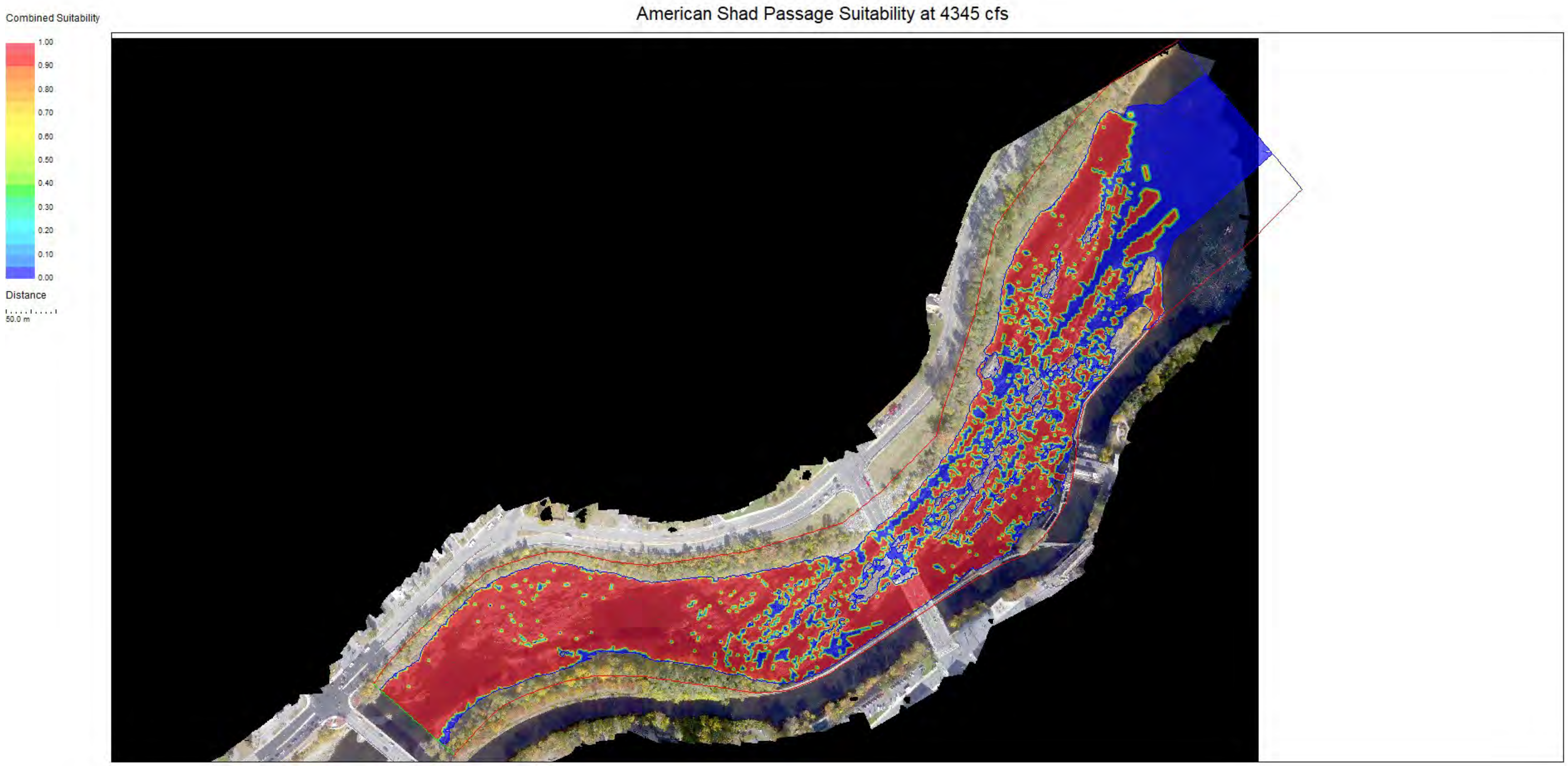

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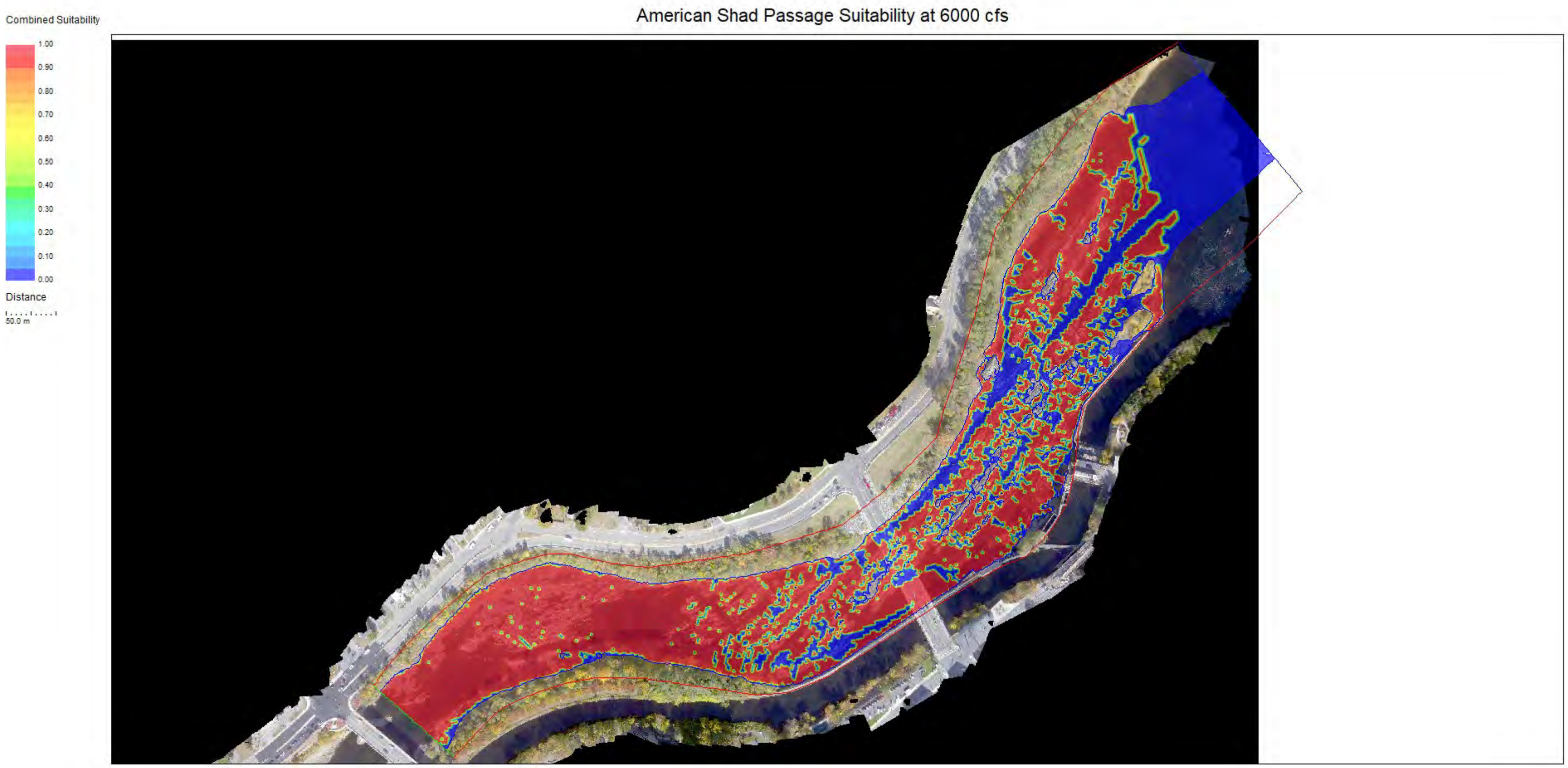

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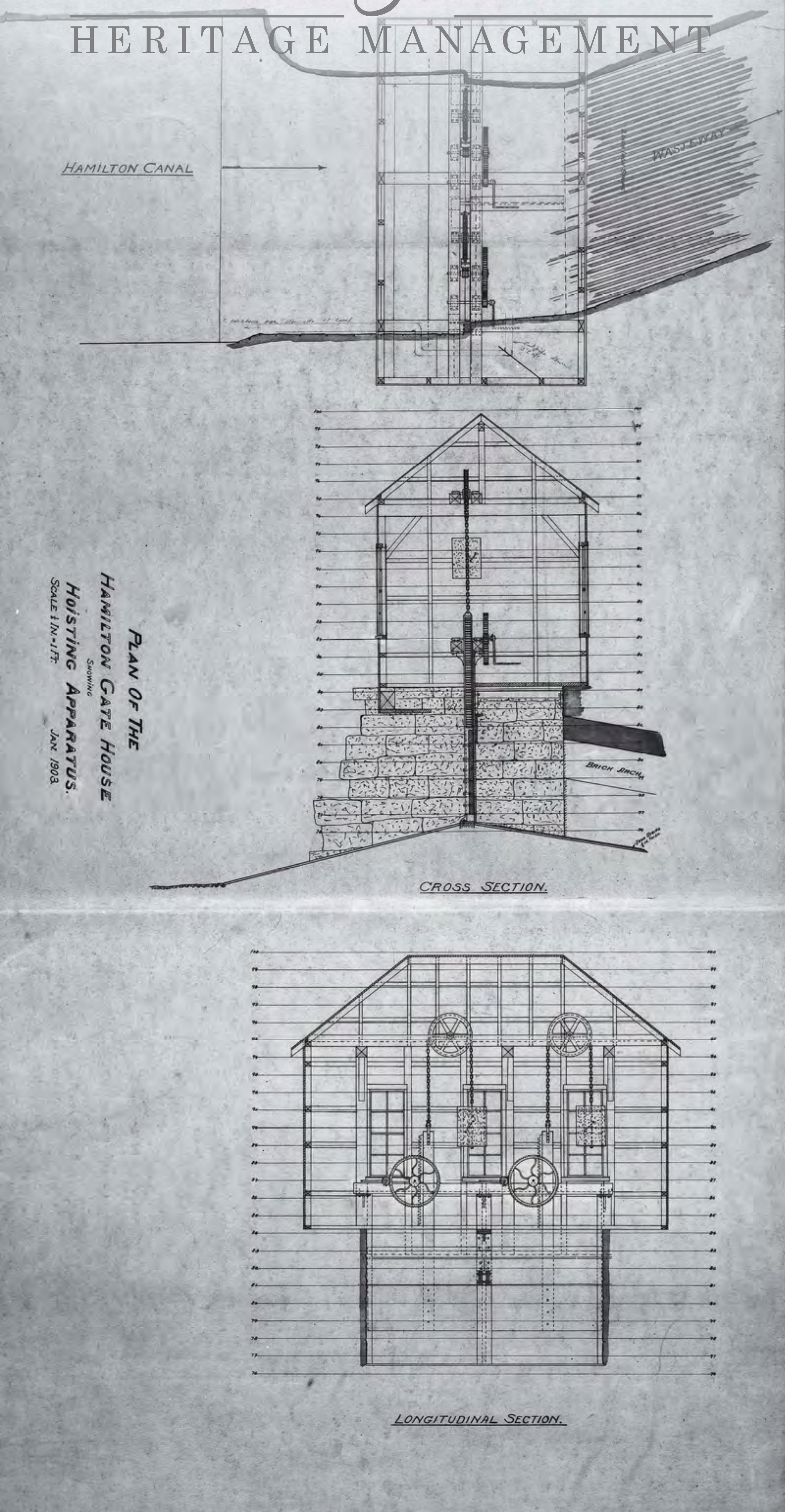
GRAY & PAPE
HERITAGE MANAGEMENT



Historically Significant Waterpower Equipment Study, Boott Hydropower, LLC, Lowell, Massachusetts

Lead Federal Agency:
Federal Energy Regulatory Commission
FERC No. 2790

Prepared for:
HDR
1304 Buckley Road, Suite 202
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20-60301.001

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Northeast Regional Manager
February 19, 2021

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

Boott Hydropower, LLC (Boott) is the licensee, owner, and operator of the 20.2-megawatt Lowell Hydroelectric Project (Project or Lowell Project) (FERC No. 2790). Boott operates and maintains the Project under a license from the Federal Energy Regulatory Commission (FERC or Commission). The Project's existing license expires April 30, 2023. Boott is pursuing a new license for the Project using the Commission's Integrated Licensing Process (ILP), as defined in 18 Code of Federal Regulations (C.F.R.) Part 5. In accordance with 18 C.F.R. § 5.15, Boott has initiated the Historically Significant Waterpower Equipment Study as provided in the study plan and schedule approved in the Commission's March 13, 2019, Study Plan Determination (SPD) for the Project. This report presents the results of the Historically Significant Waterpower Equipment Study.

The Study Report's stated goals were to:

- Consult with the National Park Service (NPS) and conduct a site visit to identify historically significant waterpower equipment of interest to the NPS for potential future interpretation, exhibition, or as scrap equipment to maintain and operate other historic machinery;
- Photodocument historically significant waterpower equipment identified in consultation with the NPS;
- Conduct background research on the history of identified waterpower equipment, including designer/engineer, dates of manufacture and use, and an explanation of how the equipment was or is used;
- Document current ownership of historically significant waterpower equipment; and
- Prepare a report summarizing the results of the Historically Significant Waterpower Equipment Study.

2.0 HISTORIC BACKGROUND

The City of Lowell is considered the birthplace of large-scale manufacturing in the United States. Lowell's success depended upon a variety of factors, but one of the most significant was the efficient use of the Merrimack River's waterpower. Begun as a transportation canal, the Lowell Canal System evolved during the nineteenth century into one of the nation's most important waterpower sites.

The Merrimack River originates south of Franklin, New Hampshire, where the Pemigewasset and the Winnepesaukee rivers join. From this point, the Merrimack flows 110 miles, and drops 269 vertical feet, to its mouth in Newburyport, Massachusetts. One of the principal vertical drops along this route occurs at Pawtucket Falls, just south of the New Hampshire state line in Lowell. Here the free-flowing Merrimack dropped more than thirty feet over a series of rapids. Below Pawtucket Falls, the Merrimack swings sharply to the southeast where, after a mile or so, the Concord River flows into the mainstream from the south. The river then swings back to the northeast and continues roughly thirty-seven miles to the sea.[1]

In 1792, a group of Newburyport merchants formed a company to build a canal around Pawtucket Falls. Circumventing the falls was expected to increase the flow of forest products from New Hampshire to Newburyport. The Proprietors of the Locks and Canals on Merrimack River (PLC), as the enterprise was styled, began construction in fall 1792. Work progressed in fits and starts, with the canal opening to traffic in fall 1796.[2]

The canal had to be deepened and its locks rebuilt or repaired several times during its first decade of operation. By 1821, the canal, then known as the Pawtucket Canal, included three single locks, the Guard Locks, Minx Locks, and Swamp or Upper Locks, and a flight of three locks in a row, known as the Lower Locks.

In 1821, the Boston Manufacturing Company (BMC), founded in 1813 by Francis Cabot Lowell, a Boston merchant, was seeking a location for new cotton mills. The BMC operated a fully integrated cotton mill in Waltham, Massachusetts, the first such mill in the world. Raw cotton entered the mill and, because of mechanical operations driven by waterpower, emerged as cloth. In 1821, the firm sought a new location for the production and printing of calicoes, a form of cloth not then produced in the United States. The firm sought land and adequate waterpower for factories, print works, and corporate housing, and began secretly purchasing the stock of the PLC, as well as land near the Pawtucket Canal. By 1822, the new venture had acquired control of the PLC, had formed itself as the Merrimack Manufacturing Company, and was ready to enlarge the Pawtucket Canal, erect its first mill, and construct a branch canal to the mill site.[3]

The purpose of every modification to the canal system was to provide a dependable and predictable flow of water to each mill site. Initially, this involved securing a reliable flow through Pawtucket Canal. The gates of the canal's locks opened and closed, admitting and releasing water into the system in accordance with the needs of traffic on the canal. This method of operation failed to provide the predictable flow of water required by the mills, so one of the first major building campaigns entailed construction of dams at each of the canal locks. Between 1822 and 1824, the Merrimack

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[1] J.W. Meader, *The Merrimack River: Its Source and Its Tributaries* (Boston, MA: B.B. Russell, 1869).

[2] Patrick M. Malone. *Waterpower in Lowell: Engineering and Industry in Nineteenth-Century America* (Baltimore, MD: Johns Hopkins University Press, 2009), 12.

[3] Ibid., 22–24.

Manufacturing Company rebuilt the Pawtucket Canal to enable it to serve as both a power and transportation canal. The locks at the Guard Locks, Swamp Locks, and Lower Locks were rebuilt in stone, lined with wood. New dams, fitted with sluice gates, were constructed at each location. These dams created pools of water that could be used to provide water to the downstream mills, regardless of whether the canal locks were open or closed.[4]

Over a period of about twenty-five years, following the Merrimack Manufacturing Company's acquisition of control of the PLC in 1822, the transportation canal constructed around Pawtucket Falls was expanded and enlarged in a series of major building campaigns (Figure 2-1). By 1823, the newly constructed dam at Swamp Locks provided water for the Merrimack Canal. By 1826, the Lowell Canal branched off the Merrimack Canal and provided power for the Lowell Mills, while the Hamilton Canal branched off the Pawtucket Canal above Swamp Locks and provided power to the Appleton and Hamilton mills. In 1831, the Western Canal also branched off the Pawtucket Canal and served the Suffolk, Lawrence, and Tremont mills. In 1836, the Eastern Canal branched off the lower Pawtucket Canal and powered the Boott Mills. By 1836, the first stage of canal construction was complete. It constituted a two-level system, with the Western, Merrimack, Lowell, and Hamilton canals, all of which took their water from above Swamp Lock Dam, comprising the upper portion of the system, and the Lower Pawtucket and Eastern canals, fed from below Swamp Locks Dam, comprising the lower portions. The second great phase of construction was completed by 1848. Beginning in 1846, the construction of the Northern Canal and the Pawtucket Gatehouse brought water directly from the Merrimack River to the lower reaches of the Western Canal, reversed the flow of water in the upper reaches of the Western Canal, and, by means of the Moody Street Feeder, brought water to the lower stretch of the Merrimack Canal.[5]

This complex system of canals delivered the waterpower of the Merrimack River to the mills of ten textile corporations. Beside the lower Pawtucket Canal, stood the mills of the Hamilton, Appleton, Lowell, and Merrimack corporations, as well as the massive machine shop of the PLC. The Massachusetts and Boott mills stood between the Eastern Canal and the Merrimack River, while upstream were the Merrimack mills and the printworks and factories of the Lawrence Corporation. The Tremont and Suffolk mills flanked the Western Canal. This network of canals "formed a dynamic system which was only in equilibrium when proper water levels were maintained."[6] The engineering plan called for water to generate power on both levels of the system, to enter the lower canals only after passing through the wheel pit of an upper-level mill. This required upper-level water users to discharge at least as much water as the lower mills required.

Reduced discharge from upper-level mills could be offset by allowing supplemental water to flow directly from the upper to the lower levels. On the Western Canal, this could be done at the Hickey Hall Dam, while the flow in the Pawtucket Canal could be augmented by releasing water at Swamp Locks Dam. Managing the flow of water through this complex system required careful coordination. A system of dams and gatehouses helped control the flow of water and was intended to assure that all users were adequately supplied with power.

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[4] Anne Booth. "Historic Structure Report: Pawtucket Canal and Northern Canal Lock Structures: Historical Data Section." 3 vols., Harlan D. Unrau, ed. (Denver, CO: National Park Service Denver Service Center, 1981), 1:2.

[5] Louis C. Hunter. *A History of Industrial Power in the United States, 1780–1930; Volume One: Waterpower in the Century of the Steam Engine* (Charlottesville: University Press of Virginia, 1979), 255–261

[6]Patrick M. Malone. *Lowell Canal System* (Washington, D.C.: Historic American Engineering Record, 1975), 107.

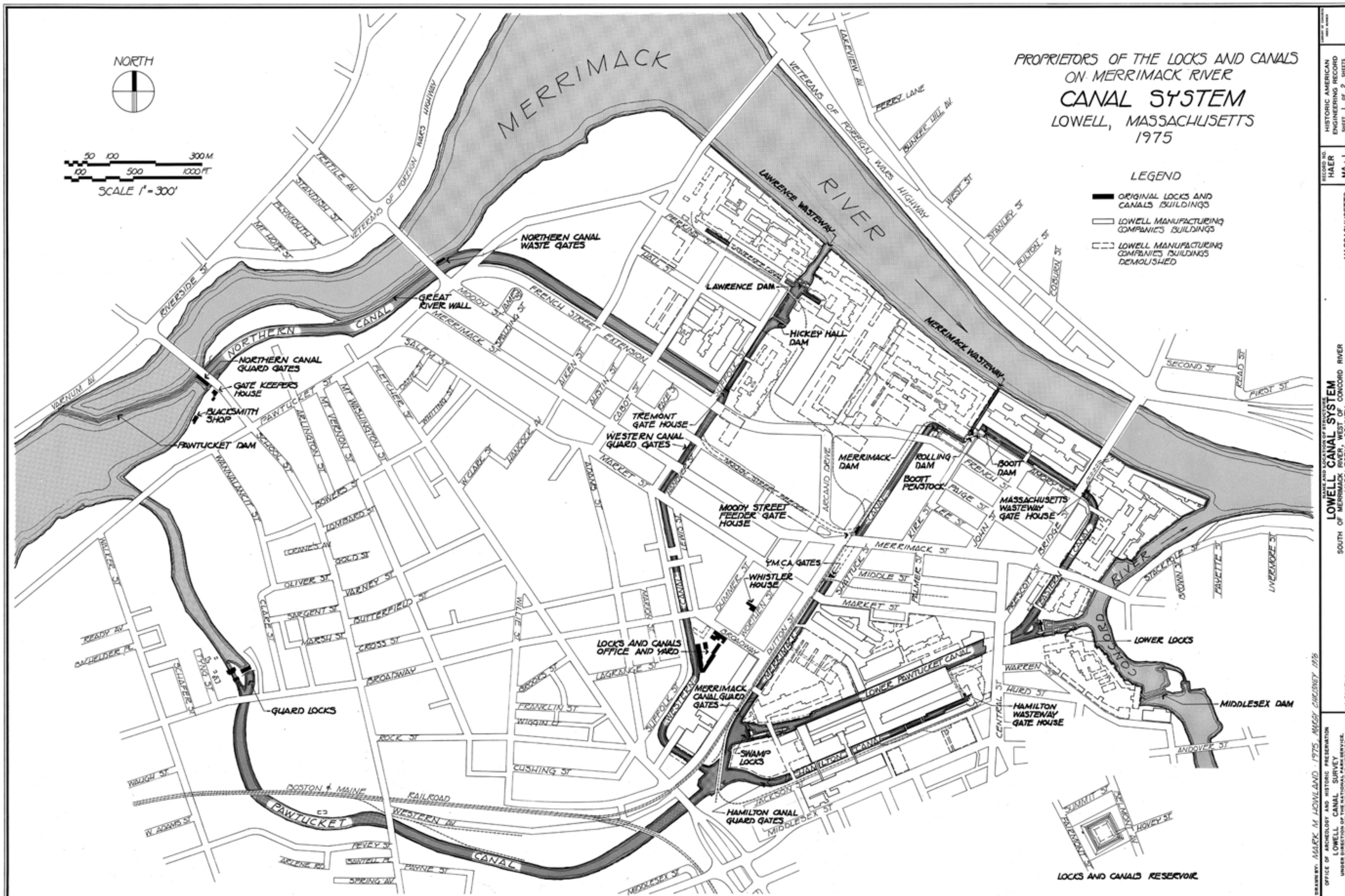

Figure 2-1. Historic American Engineering Record, Lowell Canal System, 1975.

3.0 STATUS AND SIGNIFICANCE

The Lowell Locks and Canals Historic District was listed in the National Register of Historic Places (NRHP) in 1976. The nomination's statement of significance reflects the standards of the time, and states that the district is significant "for its contributions to the development of Lowell as the first great industrial city in the United States." The statement of significance acknowledges the complex engineering involved in the construction of the canals and notes that "each new canal was built in an attempt to solve the problem of keeping all the mills supplied with a sufficient supply of power."[7] The established period of significance for the district is 1790–1870, though this periodization privileges the period when waterpower was used to directly drive mill machinery through the use of shafting and belting, and does not encompass the entire period of significance for the locks and canal system and its component resources.

The significance of the Lowell canal system is inherently bound up in the fact that it is a system whose successful operation is dependent upon all its individual component elements. No individual component element is more significant than any other since the successful functioning of the system relies upon all the components. Certainly, a particular canal, or a particular mill, could function without some elements of the system, but the system, as a whole, depended upon all its component elements. The resource is the system, not the system's individual elements.

After the initial design and construction of this system, lay a continuing series of engineering and management challenges to maintain and operate the system and, over time, to expand the system to meet growing demand. These challenges included meeting the at times conflicting requirements of power users, devising methods and equipment for measuring and monitoring the use of water, discouraging the waste of water, and, in periods of seasonal shortage or drought, rationing the use of the available water. Increasing the efficiency of the system by eliminating waste and improving the efficiency of every system component became imperative. This imperative applied to the penstocks, gates, and waterwheels of the mills, as well as to the dams and canals that supplied the water to the mills.[8]

The daily operation of this complex waterpower system, with multiple canals, dams, gate houses, and lesser elements, placed an enormous strain on the various system components. Floods, freshets, and other natural events compounded the wear and tear associated with daily operation. Many of the gates, sluices, and other elements that controlled the flow of water originally were constructed of wood and, therefore, subject to rot, and in need of regular maintenance, repair, and replacement. In addition to the daily wear and tear on system components, changes in the operations at individual mills could change demands for water, necessitating modifications to the system to meet this demand.[9]

These and other factors meant that since the initial construction of the Lowell Canal system nearly 200 years ago, the various component parts of the system have been subject to almost continuous repair, alteration, replacement, or improvement. In this environment of continual change, it follows that changes may be made to components of the system without adversely affecting the qualities and characteristics that make the system itself eligible for the NRHP.

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[7] Christine Boulding and Joe Orfant. "Lowell Locks and Canals Historic District," National Register of Historic Places Inventory-Nomination Form (Washington, D.C.: National Register of Historic Places, 1976).
[8] Hunter. *A History of Industrial Power*, 207.
[9] Ibid., 273–275.

4.0 CONSULTATION WITH NPS

In consultation with the NPS, Boott clarified the goals of this study during the December 18, 2019, Study Workshop held at the Lowell National Historical Park Visitor Center. The main goal of the study, as provided for in the approved study plan, was the identification of historically significant waterpower equipment "of interest to the NPS." However, Boott understands NPS's goals for this study include the determination of what original hydroelectric equipment is owned/operated by Boott within the Project Boundary is historically significant on a national level, not necessarily simply "of interest to the NPS." In other words, the selection of equipment to include in the analysis should not be limited to NPS' explicitly stated interest.

In July 2020, a site visit was held at Lowell to visit various locations associated with the control of water through the canal system. This tour included inspection of the Swamp Locks Gate House, the Hamilton Wasteway Gate House, the Lower Locks Gate House, the Boott Dam Gate House, the Moody Street Feeder Gate House, and the Northern Canal Gate House. Various types of gate operating mechanisms were observed. Discussions with NPS personnel indicated that they viewed the gate houses and their mechanisms as part of a larger system, as outlined above.

The majority of the gate operating equipment consisted of a rack-and-pinion system, originally operated by hand, but subsequently converted to electrical operation. The Boott Dam Gate House featured a hydraulic operating system, while the Northern Canal Gate House retained its original belt-driven line shafting, originally powered by the first Francis turbine installed in the United States.

5.0 HISTORICAL BACKGROUND OF OPERATING SYSTEM COMPONENTS

Gray & Pape conducted documentary research in the records held by the NPS at Lowell to identify the component elements of the larger canal system and the equipment used to operate water control devices throughout the system. The research effort also focused on developing a chronology of the alterations to individual components of the system. The results of the research effort are presented below (organized by canal) and progressing from upstream to downstream.

5.1 Pawtucket Canal - Guard Locks[10]

Between 1822 and 1823, Kirk Boott oversaw the reconstruction of the Guard Locks. Boott had a new channel cut around the existing locks and built a guard dam, with sluice gates, in this channel to regulate the flow of water downstream. In 1832, the dam was removed and rebuilt approximately 23 feet further downstream. At this date, the dam had five sluice gates sheltered in a wooden gate house. Subsequent modifications include:

- 1848 dam raised in height;
- 1856 sluice gates replaced;
- 1869 Francis-designed rack-and-pinon system for operating gates;
- 1870 Francis-designed hydraulic gate hoist system that employed five water-powered metal cylinders, each measuring 27 inches in diameter and 10 feet tall (cylinders, pistons, and rods manufactured by IP Morris & Company, rest of hoisting apparatus by Lowell Machine Shops[11]);
- 1870 existing brick gate house constructed;
- 1902 headgate sluices enlarged and extended;
- 1965 three middle hydraulic operating cylinders replaced, with oil hydraulic cylinders and pistons.

5.2 Pawtucket Canal - Swamp Locks[12]

Between 1822 and 1823, a 13-foot-tall stone dam, with sluice gates, was built adjacent to the Swamp Locks. The dam was rebuilt in a stepped configuration in 1841, at which time it is likely that the deep gate and sluiceway were added in the south portion of the dam. The dam underwent extensive repairs in 1850, and a gatehouse was constructed at about that time. Later alterations include:

- 1918 dam raised 1 foot in height;
- 1922 installed 2 additional 8-foot square waste gates and a small hydroelectric station to carry the Locks & Canal Yard light and power load; installation of waste gates required removal of 4 feet from top of dam for 20 feet[13];
- 1927–1928 sluice gate constructed between dam and locks, with gate house,

[10] Booth, "Historic Structure Report," 1:50–112.

[11] Proprietors of Locks and Canals Records, 1813–1962. Series II. General Files. Box 49, Folder 8 – Old Guard Locks, 1917–1949. On file at Lowell National Historic Park.

[12] Booth, "Historic Structure Report," 2:218–246.

[13] Proprietors of Locks and Canals Records, 1813–1962. Series II. General Files. Box 50, Folder 1 – Swamp Locks, 1897–1952. On file at Lowell National Historic Park.

- 1952 deep gate operation motorized with 3/4hp gear head motor, with sprockets and chain;
- 1953 gates converted to operate by remote control;
- 1971 north segment of gate house, covering 11 bays, removed.

5.3 Lower Pawtucket Canal - Lower Locks[14]

The Lower Locks were rebuilt in 1823, with a new dam constructed north of the locks. About 1841, a sluiceway was constructed at the north end of the dam. This was reconstructed and fitted with waste gates in 1887. Between 1946 and 1958, three concrete spillways were constructed over the dam.

5.4 Merrimack Canal[15]

In 1918, Locks and Canals proposed constructing a gate structure at Merrimack Dam. The Holyoke Machine Company of Worcester, Massachusetts, provided information for a hand-operated hoist system to be used for operation of a 3- by-8-foot gate. In October 1918, the work was delayed.

- Merrimack Canal Guard Gates
- YMCA Gates
- Moody Street Feeder Gate House
- Boott Penstock
- Merrimack Wasteway

5.5 Hamilton Canal - Wasteway Gate House

The two gates located in this building are operated by a rack-and-pinion system, with granite counterweights (Figure 5-1). The hoisting apparatus dates from 1903 and is similar in design and appearance to extant rack-and-pinion mechanisms in other locations, such as Swamp Locks and Lower Locks, within the system. This suggests that these rack-and-pinion mechanisms may all date from ca. 1900 (Figure 5-2).

5.6 Western Canal - Tremont Gates[16]

A 1911 blueprint shows a proposed arrangement for hoisting the gates by electric motor. In 1937, control of these gates was managed remotely from Lawrence Dam.

5.7 Western Canal - Lawrence Dam, Waterway & Canal[17]

In 1918, modifications were made to the existing hoist mechanism, which operated an 8.5-foot wide by 4.75-foot tall gate. The existing mechanism entailed three pairs of 12-inch iron wheels that rolled on an iron plate. The modifications were intended to permit operation by one man.

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[14] Booth, "Historic Structure Report," 2:323:343.
[15] Proprietors of Locks and Canals Records, 1813–1962. Series II. General Files. Box 50, Folder 5 - Merrimack Dam, 1915–1918. On file at Lowell National Historic Park.
[16] Proprietors of Locks and Canals Records, 1813–1962. Series II. General Files. Box 50, Folder 2 - Tremont Gates, 1911–1948. On file at Lowell National Historic Park.
[17] Proprietors of Locks and Canals Records, 1813–1962. Series II. General Files. Box 50, Folder 4 - Lawrence Dam, Wasteway, and Canal, 1913–1917. On file at Lowell National Historic Park.

Figure 5-1. Hamilton Wasteway Gate House, rack-and-pinion hoisting mechanism.

5.8 Northern Canal - Pawtucket Gate House[18]

The Northern Canal, which extended from the Merrimack River, just downstream from the Pawtucket Dam to the Western Canal, was designed and constructed between 1846 and 1848. The canal was intended to raise the total head of water by three feet. The Northern Canal Guard Gates, housed within the brick Guard House, control the flow of water into the canal. The ten guard, or sluice gates, were originally operated by a Francis turbine, the first turbine of this design ever constructed, that drove a system of belting and shafting (Figure 5-3, 5-4, 5-5, and 5-6). Alterations to the guard gates since 1848 include:

[18] Booth, "Historic Structure Report," 3:397–447.

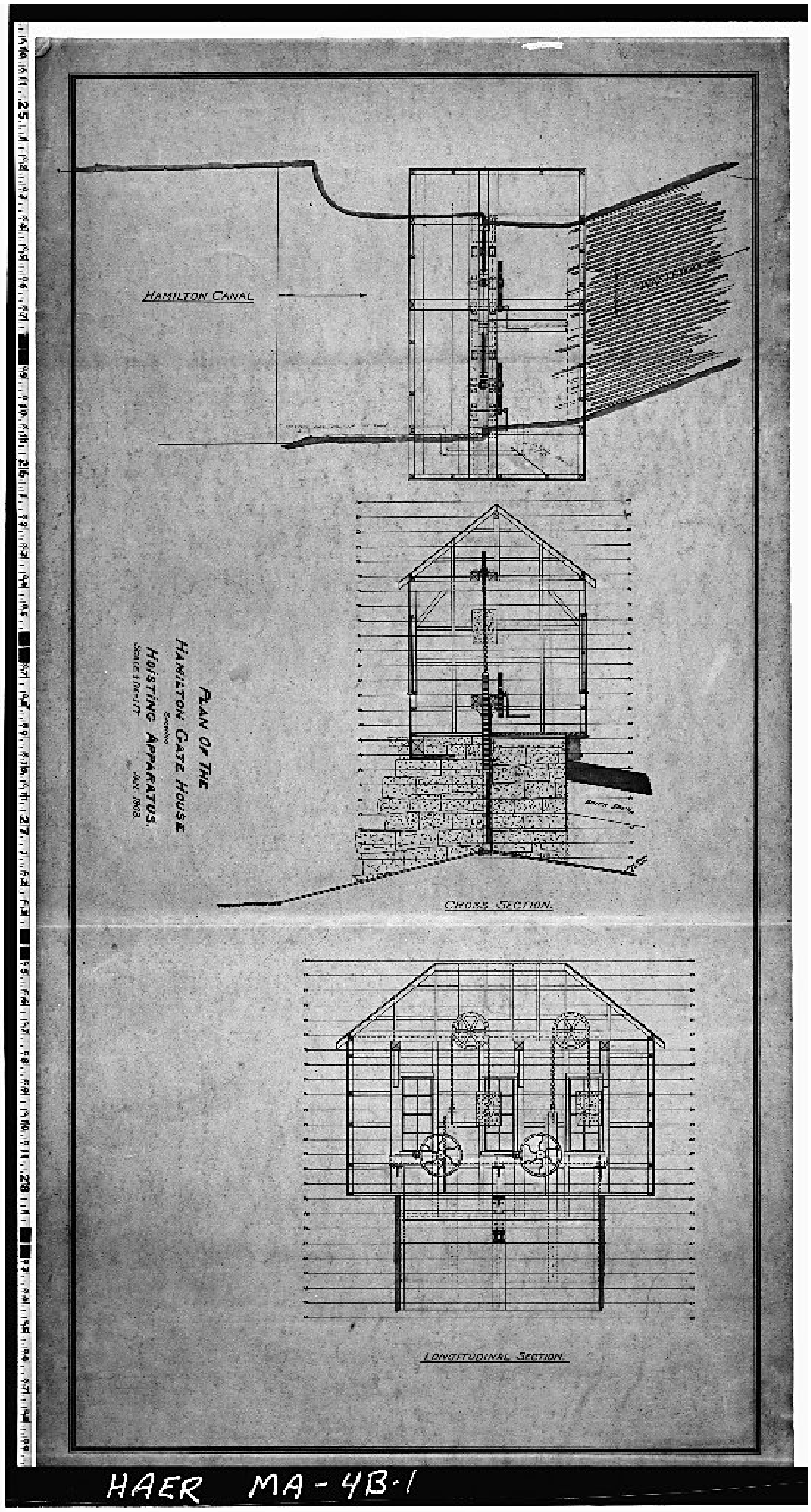

Figure 5-2. Hamilton Gate House hoisting apparatus, January 1903.


Figure 5-3. Belt drive sheave mounted atop Francis turbine.


Figure 5-4. Pawtucket Gate House, belt-and-line shaft system.

1878 main belt (96 feet long and 20 inches wide) replaced,
1881 main line shaft replaced,
1883 smaller belt pulleys replaced by friction pulleys and a clutch mechanism that permitted independent operation of each gate,
1891 turbine abandoned and hoist mechanism electrified,
1928 3 1891 electric motors replaced with a single 25-horsepower motor,
1950s 1928 electric motor replaced with a 10-horsepower motor for each gate.[19]

- Pawtucket Gate House
- Northern Canal Waste Gates
- Moody Street Feeder

[19] Thomas F. Mahlstedt. "Historic Structure Report: Northern Canal Guard Gatehouse Complex, Francis Gate Complex, Swamp Locks, Lower Locks: Archaeological Data Section." (Denver, CO: National Park Service Denver Service Center, 1983), 55.


Figure 5-5. Pawtucket Gate House, belt-and-line shaft system with electric motor drive in foreground.

Figure 5-6. Pawtucket Gate House, sluice gate casings, with belt drives above.

6.0 HISTORICALLY SIGNIFICANT WATERPOWER EQUIPMENT

As noted above, it is the totality of the system of waterpower and water-control machinery at Lowell that is historically significant. Removal and replacement of individual pieces of equipment was nearly continual, from the day the system first became operational. Removal or alteration of existing equipment would constitute an adverse effect upon the qualities that make the existing system historically significant if they prevented or precluded the system from operating. Several pieces of equipment appear to be historically significant, distinct from their role as a part of the larger system. These pieces of equipment include the surviving 1870 hydraulic gate hoist system at the Pawtucket Canal Guard Locks, and the Francis turbine powered belt-and-line shafting gate operating system at the Pawtucket Gate House. The extant gate operating system at the Moody Street Feeder Gate House (Figure 6-1 and 6-2) is likely also significant in its own right.

Figure 6-1. Moody Street Gate House, gate hoisting mechanisms.

Figure 6-2. Moody Street Gate House, detail of gate hoisting mechanism

7.0 CURRENT OWNERSHIP

Boott owns, or is responsible for, the equipment located within the canal systems gatehouses and other facilities, but is not responsible for most buildings, the canal prism, lock gates, or dams. In essence, Boott is only responsible for the equipment and devices that control the flow of water through the canal system. These elements, including flashboards, gates, and their operating equipment, have been upgraded and altered on many occasions.

The 1870 hydraulic gate hoist system at Pawtucket Canal Guard Locks is likely owned in part by PLC and the Commonwealth of Massachusetts, acting through the Massachusetts Department of Recreation and Conservation (MADCR). MADCR appears to own the Francis turbine-powered belt-and-line shafting gate operating system at the Pawtucket Gate House. The extant gate operating system at the Moody Street Feeder Gate House is also likely owned by PLC.

8.0 REFERENCES CITED

Booth, Anne. "Historic Structure Report: Pawtucket Canal and Northern Canal Lock Structures: Historical Data Section." 3 vols., Harlan D. Unrau, ed. Denver, CO: National Park Service Denver Service Center, 1981.

Boulding Christine and Joe Orfant. "Lowell Locks and Canals Historic District," National Register of Historic Places Inventory-Nomination Form. Washington, D.C.: National Register of Historic Places, 1976.

Hunter, Louis C. *A History of Industrial Power in the United States, 1780–1930; Volume One: Waterpower in the Century of the Steam Engine*. Charlottesville: University Press of Virginia, 1979.

Mahlstedt, Thomas F. "Historic Structure Report: Northern Canal Guard Gatehouse Complex, Francis Gate Complex, Swamp Locks, Lower Locks: Archaeological Data Section." Denver, CO: National Park Service Denver Service Center, 1983.

Malone, Patrick M. Malone. *Lowell Canal System*. Washington, D.C.: Historic American Engineering Record, 1975.

_____. *Waterpower in Lowell: Engineering and Industry in Nineteenth-Century America*. Baltimore, MD: Johns Hopkins University Press, 2009.

Meader, J.W. *The Merrimack River: Its Source and Its Tributaries*. Boston, MA: B.B. Russell, 1869.

Proprietors of Locks and Canals Records, 1813–1962. Series II. General Files. On file at Lowell National Historic Park.

Resources, Ownership, Boundaries, and Land Rights Study Report

Lowell Hydroelectric Project (FERC No. 2790)

February 25, 2021

Prepared by:

HDR

Prepared for:

Boott Hydropower, LLC
Manchester, New Hampshire

Central Rivers Power

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Contents

Tables

Figures

Appendices

List of Acronyms

Boott	Boott Hydropower, LLC (or Licensee)
C.F.R.	Code of Federal Regulations
cfs	cubic feet per second
Commonwealth	Commonwealth of Massachusetts
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission (or Commission)
FGMP	Final General Management Plan
GIS	Geographic Information System
GPS	Global Positioning System
ILP	Integrated Licensing Process
ISR	Initial Study Report
LHPC	Lowell Historic Preservation Commission
LNHP	Lowell National Historical Park
MADCR	Massachusetts Department of Conservation and Recreation
MADEM	Massachusetts Department of Environmental Management
MOU	memorandum of understanding
MW	megawatt
NHL	National Historic Landmark
NOI	Notice of Intent
NPS	National Park Service
PAD	Pre-Application Document
Project	Lowell Hydroelectric Project (or Lowell Project)
Proprietors	Proprietors of the Locks and Canals
PSP	Proposed Study Plan
RM	river mile
RMP	Resources Management Plan

ROR	run-of-river
RSP	Revised Study Plan
SD1	Scoping Document 1
SD2	Scoping Document 2
SPD	Study Plan Determination
Study Workshop	Lowell Hydroelectric Project Study Workshop

1 Introduction and Background

Boott Hydropower, LLC (Boott or Licensee) is the Licensee, owner, and operator of the 20.2-megawatt Lowell Hydroelectric Project (Project or Lowell Project) (FERC No. 2790). Boott operates and maintains the Project under a license from the Federal Energy Regulatory Commission (FERC or Commission). The Project's existing license expires on April 30, 2023. Boott is pursuing a new license for the Project using the Commission's Integrated Licensing Process (ILP) as defined in 18 Code of Federal Regulations (C.F.R.) Part 5.

In accordance with 18 C.F.R. § 5.15, Boott has conducted studies as provided in the study plan and schedule approved in the Commission's March 13, 2019 Study Plan Determination (SPD) for the Project.[1] This report describes the methods and results of the approved Resources, Ownership, Boundaries, and Land Rights Study conducted in support of a new license for the Project.

1.1 Project Description and Background

The Lowell Project is located at river mile (RM) 41 on the Merrimack River in the City of Lowell in Middlesex County, Massachusetts, with an impoundment extending approximately 23 miles upstream into Hillsborough County, New Hampshire. The existing Lowell Project consists of:

1) A 1,093-foot-long, 15-foot-high masonry gravity dam (Pawtucket Dam) that includes a 982.5-foot-long spillway with a crest elevation of 87.2 feet National Geodetic Vertical Datum 1929 (NGVD 29) topped by 5-foot-high pneumatically-operated crest gates deployed in five independently-operable zones;
2) A 720-acre impoundment with a normal maximum water surface elevation of 92.2 feet NGVD 29;
3) A 5.5-mile-long canal system which includes several small dams and gatehouses;
4) A powerhouse (E.L. Field) which uses water from the Northern Canal and contains two turbine-generator units with a total installed capacity of 15.0 megawatts (MW);
5) A 440-foot-long tailrace channel;
6) Four powerhouses (Assets, Bridge Street, Hamilton, and John Street) housed in nineteenth century mill buildings along the Northern and Pawtucket Canal systems containing 15 turbine-generator units with a total installed capacity of approximately 5.1 MW;

[1] The Commission issued a Revised Process Plan and Schedule on June 12, 2020.

7) A 4.5-mile-long, 13.8-kilovolt transmission line connecting the powerhouses to the regional distribution grid;

8) Upstream and downstream fish passage facilities including a fish elevator and downstream fish bypass at the E.L. Field Powerhouse, and a vertical-slot fish ladder at the Pawtucket Dam; and

9) Appurtenant facilities.

At the normal pond elevation of 92.2 feet NGVD 29 (crest of the pneumatic flashboards), the surface area of the impoundment encompasses an area of approximately 720 acres. The gross storage capacity between the normal surface elevation of 92.2 feet and the minimum pond level of 87.2 feet is approximately 3,600 acre-feet. The Project operates essentially in a run-of-river (ROR) mode using automatic pond level control and has no usable storage capacity.

The Project's primary features are located along the Merrimack River in the City of Lowell, Massachusetts. The City of Lowell was founded in the early 1820s by Boston merchant capitalists and became one of the most significant planned industrial cities in America. Lowell's factory system, which used the waterpower of the Merrimack River, incorporated new technologies to provide for the mass production of cotton cloth in mills throughout the city (National Park Service [NPS] 1981). Lowell established the pattern for large-scale waterpower development for the next 50 years.

Several Project facilities are located within overlapping locally, state, and nationally designated parks and historic properties/preservation districts. The Project's Pawtucket Dam and E.L. Field Powerhouse are located along the mainstem of the Merrimack River. The existing Project's two-tiered network of man-made canals extends throughout downtown Lowell. In addition to the Pawtucket Dam and hydroelectric developments, the existing Project also includes miscellaneous civil works in the City of Lowell, including the Guard Lock and Gates, Moody Street Feeder Gatehouse, Lawrence Dam, Hall Street Dam, Tremont Wasteway, Lower Locks and Dam, Swamp Locks and Dam, Merrimack Dam, Rolling Dam, and Boott Dam. As discussed in Boott's December 2, 2020 DLA for the Project, operation of the canal units is no longer economically feasible, and Boott has proposed to remove the downtown developments (Assets, Bridge Street, Hamilton, and John Street) and associated canal infrastructure from the Project's FERC license. Boott is not proposing to restart or continue generation at these four developments.

The canal system, the downtown mill sites, and many of the Project's civil works, are contributing resources to Lowell Locks and Canals National Historic Landmark (NHL) District. The canal system and many Project facilities are also located within the Lowell National Historical Park (LNHP) managed by the NPS and the larger Lowell Historic Preservation District. The LNHP was established by Congress in 1978 to "preserve and interpret the nationally significant historical and cultural sites, structures, and districts in Lowell, Massachusetts, for the benefit and inspiration of present and future generations." The park is by design a partnership park in which federal, state, and local governments as well as the private sector and local community carry out the legislative intent of the park unit. The LNHP is also listed on the National Register of Historic Places (NRHP), and certain properties within the park overlap with properties in the NHL District.

The Lowell Heritage State Park, established in 1974 as a precursor to the LNHP, is also located within the City of Lowell and is comprised of linear greenways along the Merrimack River and canal system and a collection of historic buildings and structures related to the industrial development of the city. These buildings and structures include Project features and properties located within the NHL District. The Lowell Heritage State Park is operated by the Massachusetts Department of Conservation and Recreation (MADCR) and features exhibits created in partnership with the NPS (MADCR 2018). With the exception of the Rynne Bathhouse, all of the built resources within the Lowell Heritage State Park fall within the Lowell Historic District, designated by the City of Lowell to "…ensure that development activities within the district are consistent with the preservation of its 19th century setting" (MADCR 2014). Portions of the Lowell Heritage State Park also overlap with the Lowell Locks and Canals NHL District and the LNHP.

Ownership, boundaries, and land/access rights of the downtown canal system in Lowell are complex. The existing Project is situated within several different and overlapping parks, and preservation/conservation districts. The park is by design a partnership park in which federal, state, and local governments as well as the private sector and local community carry out the legislative intent of the park unit.

On April 30, 2018, Boott initiated the ILP by filing a Pre-Application Document (PAD) and Notice of Intent (NOI) with the Commission. Major ILP milestones to-date are presented below in Table 1-1.

Table 1-1. Major ILP Milestones Completed

Date	Milestone
April 30, 2018	PAD and NOI Filed
June 15, 2018	Scoping Document 1 (SD1) Issued by FERC
July 17, 2018	FERC Agency and Public Scoping Meetings Conducted
July 18, 2018	Project Site Visit Held
September 27, 2018	Scoping Document 2 (SD2) Issued by FERC
September 28, 2018	Proposed Study Plan (PSP) Filed
October 18 & 19, 2018	PSP Meeting Conducted
January 28, 2019	Revised Study Plan (RSP) Filed
March 13, 2019	FERC Issued SPD
February 25, 2020	Initial Study Report (ISR) Filed
March 11, 2020	ISR Meeting
June 12, 2020	FERC Issued Revised Process Plan and Schedule

September 30, 2020	Revised ISR Filed
December 2, 2020	Draft License Application (DLA) Filed

Boott has continued consultation with stakeholders regarding the approved studies as required by the Commission's SPD. In accordance with the approved study plan, Boott has also provided stakeholders with Quarterly ILP Study Progress Reports that include a description of study activities conducted during the previous quarter, activities expected to occur in the next quarter, and identified variances from the approved study plan.

2 Study Goals and Objectives

The goal of this study is to determine current ownership of resources within the canal system and existing Project Boundary, and document maintenance responsibilities, access rights, and FERC jurisdiction. The specific objectives of this study are as follows:

- Determine the current ownership of resources within the canal system in a comprehensive manner;
- Record maintenance responsibilities and obligations to resources within the canal system;
- Clarify FERC jurisdiction;
- Document recreational, educational, or other land access rights to resources within the canal system; and
  Work with the MADCR, NPS, City of Lowell, and other parties to develop a Geographic Information System (GIS) database of resources, ownership, boundaries, and land rights.

3 Study Area

In accordance with the Commission's SPD, the study area for the Resources, Ownership, Boundaries, and Land Rights Study includes the existing FERC Project Boundary and associated structures in the downtown area (Appendix A).

4 Methodology

4.1 Literature Review and Analysis

Boott conducted desktop research and a literature review to compile and review available ownership and rights documentation to obtain a better understanding of the rights and responsibilities related to resources within the Project Boundary. As appropriate and relevant, public guidance and conceptual planning and/or management documentation was reviewed by Boott including the following:

- The 1980 *Details of the Preservation Plan*[2] prepared by the Lowell Historic Preservation Commission (LHPC), containing technical materials including a description of agreed-upon agency roles at the City, State, and Federal level.

- The 1981 *Final General Management Plan* (FGMP)[2] developed by NPS to provide a basis for visitor use, resource management, and general development within the LNHP.

- The 1990 *Preservation Plan Amendment*[2] developed by the LHPC summarizes accomplishments of the LNHP and outlines its proposed activities.

- The 1991 *Memorandum of Understanding* (MOU) executed by MADCR, NPS, and Boott for the purpose of maintaining, managing, and operating the Lowell canal system (MOU 1991).

On December 18, 2019, Boott held a Lowell Hydroelectric Project Study Workshop (Study Workshop)[3] with stakeholders. During the Study Workshop it was suggested that three legal documents establish most of the ownership, responsibilities, and land rights to the Lowell canal system. The 1984 *Deed, Bill of Sale and Grant of Easements*, also known as the *"Great Deed"* (Appendix B) details the sale of portions of the Project from the Proprietors of the Locks and Canals on the Merrimack River (Proprietors)[4] to Boott, as well as associated access and repair easements. The 1986 *Order of Taking* (Appendix C) details the take of properties, rights, and responsibilities from Boott and Proprietors to the Commonwealth, operating through MADCR. The 1995 *Grant of Easement* (Appendix D) describes the easement rights provided to the NPS from MADCR for specific properties and parcels around the canal system.

4.2 Geographic Information System Database

The GIS Database was developed using ESRI's ArcMap, ArcCatalog and ArcGIS Online. The GIS database has been published to create an existing service feature in ArcGIS Online. Incorporated into the GIS database is a point feature class with surveyed plans, .tiff and .jpg images. The Facility Location point feature class was created by spatially locating each parcel centroid listed on the existing exhibit maps relevant to any know easement or right of way along the power canals in Lowell, MA. The point features known as "Facility Location" were spatially located from several sources including existing exhibit maps, Google Earth and the LNHP website. Real Property GIS files were obtained from the City of Lowell Assessors office in January 2021 and are used to display background data as well as locating parcel ID and owner. Additionally, to

[2] This plan was approved by FERC on March 20, 2019 as a Comprehensive Plan under section 10(a)(2)(A) of the Federal Power Act.

[3] The meeting minutes of the December 18, 2019 Study Workshop were appended to the ISR filed with FERC on February 25, 2020.

[4] Proprietors is an existing limited liability corporation founded on June 27, 1792 to construct the Pawtucket Canal. In the early 1960s, the company was acquired by a group of Lowell investors who restructured its assets. Boott acquired much of the Lowell Project, including the Pawtucket Dam, from the Proprietors in December 1984.

enhance the user experience, each exhibit map was georeferenced to the parcel centroid in an effort to display the correct location within the canal system. Exhibit map images in the geodatabase appear as a pop-up in the known location.

5 Study Results

Pursuant to the approved study plan, Boott reviewed several sources to understand the ownership, rights, and responsibilities related to resources within the Project Boundary. The results of this analysis are divided into the following sections:

- **Section 5.1 Conceptual Planning of the Lowell Canal System:** identifies responsibilities and rights as presented in comprehensive plans and public planning documents issued for development and management of the Lowell canal system.

- **Section 5.2 Ownership of the Lowell Canal System:** presents the complex legal ownership of structures of the Lowell canal system based on a review of the 1984 *Great Deed* and 1986 *Order of Taking*.

- **Section 5.3 Easement Rights to the Lowell Canal System:** presents the legal easement rights to structures of the Lowell canal system based on a review of the 1984 *Great Deed*, the 1986 *Order of Taking*, and the 1995 *Grant of Easement*.

- **Section 5.4 Resource Rights in the Lowell Canal System:** identifies specific resources and their ownership and/or easement rights based on a review of public planning documents and the 1984 *Great Deed*, the 1986 *Order of Taking*, and the 1995 *Grant of Easement*.

- **Section 5.5 Historical Management Agreements:** discusses the two known historical management agreements which reflect the parties understanding of legal ownership, easement and resources, and management responsibilities.

- **Section 5.6 FERC Jurisdiction:** addresses one of the goals of the approved study plan by clarifying FERC jurisdiction.

The materials in this report comprise Boott's understanding of ownership, easement rights and resource rights to the Lowell canal system based on a review of planning documents, legal documents, and other available information. This report is limited to the documentation available to Boott during the course of the study. Further, this information is not intended to serve as legal or professional advice by Boott and should not be construed as such.

5.1 Conceptual Planning of the Lowell Canal System

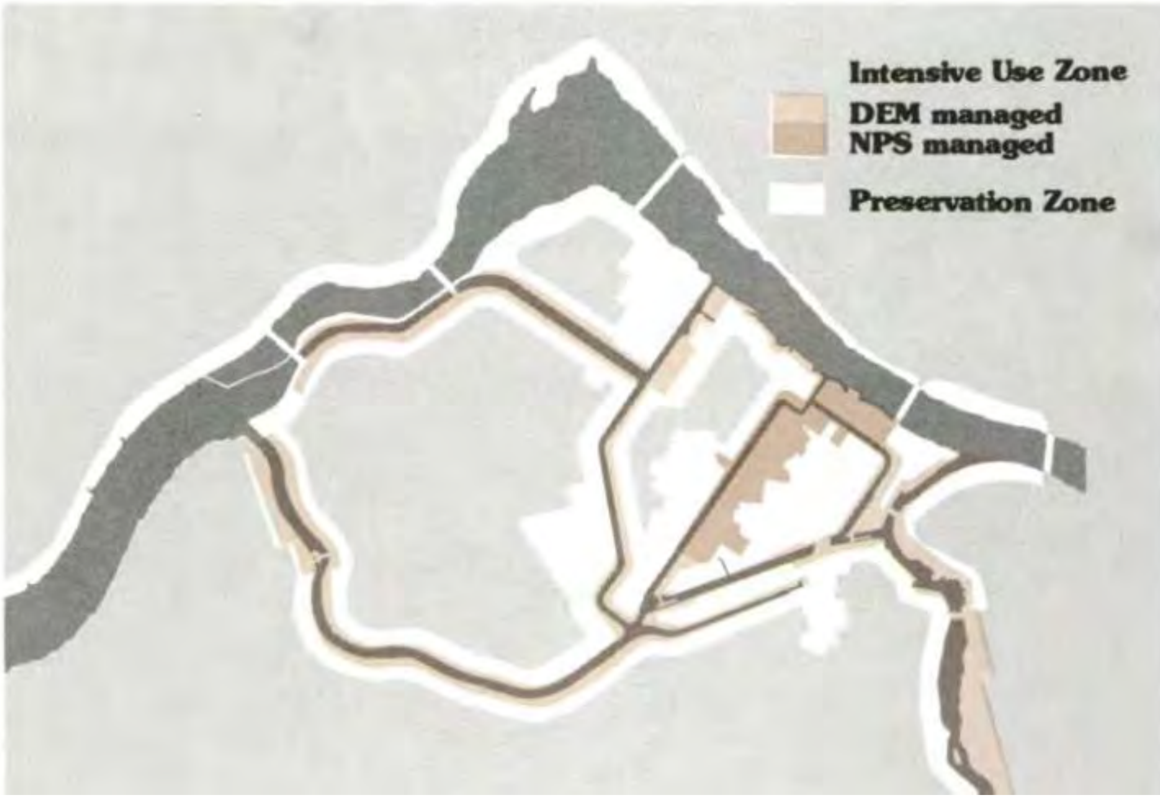
In 1975, the Lowell Historic Canal District Commission (LHCDC) was established by Congress to prepare a plan for the preservation and interpretation of Lowell's historic resources in and around the Lowell canal system. The *1977 Report of the LHCDC* (commonly referred to as the "Brown Book") produced the legislation that was passed by Congress in 1978 and signed into law by President Carter. This law established a two-tiered federal involvement: the LNHP acting as a unit of the NPS, and the Lowell Historic Preservation District (LHPD or the District)—administered by a commission under the Department of the Interior.

The *1977 Report of the LHCDC* proposed the creation of LNHP and presented the approach to developing the Lowell canal system and surrounding areas as a national park. The LHCDC stated that the key to development of the LNHP was a cooperative undertaking of the NPS and the Massachusetts Department of Environmental Management, the agency now known as MADCR. This partnership would "share state and federal resources, maximizing the effectiveness and abilities of each." Given the dense urban setting, it was understood that almost all the structures would remain in private ownership, but the structures would be developed and managed by NPS and MADCR (NHCDC 1977, p. 46). The authors further elaborated that "the NPS would develop an overall interpretive program and restore certain buildings and settings. The State would preserve the canal system and develop its recreational potentials." The specific responsibilities of each agency as identified in the *1977 Report of the LHCDC* are outlined below in Table 5-1 and Figure 5-1.

Table 5-1. Agency Responsibilities Identified in 1977 Report of the LHCDC

Agency	Responsibilities
NPS	interpretation, park wide downtown "cross-section" of 19th Century Lowell (including preservation, building and open space improvements, transportation and visitor services)
MADCR	canals, riverbanks, and related recreational areas gatehouses, locks and dams barge system

Figure 5-1. LNHP Management Responsibility Zones



Within the intensive use zone, both NPS and MADCR were tasked with acquiring and improving property, as well as developing and operating the major visitor attractions in the LNHP. The costs of park development, management, and maintenance would be shared on a *pro rata* basis between NPS and MADCR (LHCDC 1977). Additionally, the plan elaborated on the supportive involvement of local government, whose efforts in preservation in the downtown and elsewhere would dovetail in the LNHP.

In 1980, the *Preservation Plan* and *Details of the Preservation Plan* were published by the LHPC (LHPC 1980a; LHPC 1980b). *Details of the Preservation Plan* specified the roles of NPS, the Commonwealth of Massachusetts (acting through MADCR), and the City of Lowell. LNHP was to rehabilitate certain gatehouses and perform exterior façade improvements, among other tasks. MADCR's role was to acquire all or portions of the Lowell canal system, including the interpretive and recreational water access rights, and "also undertake the landscaping, repair and maintenance of all the basic canal structural components, canal related structures and canal related land for recreational use." The City of Lowell was to implement certain downtown street and pedestrian improvements, such as exposures of cobblestone streets, bricking, and paving of sidewalks.

In August 1981, NPS developed and issued the FGMP to provide a basis for visitor use, resource management, and general development within the LNHP. The FGMP states management of the Lowell canal system will be accomplished through cooperative agreements between private and public entities, but MADCR is the lead agency responsible for maintaining, developing, and renovating the major elements of the canal system (NPS 1981). Proprietors, the owner of most of the Lowell canal system at the time, was responsible for the maintenance and operation of the hydromechanical components.

The Preservation Plan Amendment was released in 1990 (LHPC 1990). This plan presented NPS and MADCR as the lead parties responsible for preservation and maintenance of the Lowell canal system. The report stated that "Boott uses canal water to generate hydropower and performs all maintenance tasks directly related to that end. This includes keeping up machinery like control gates and turbines located at various points along the system." The *Preservation Plan Amendment* acknowledged that MADCR has the right to maintain and repair canal walls.

The conceptual framework for the rights and responsibilities for management of the Lowell canal system remain consistent within the *1977 Report of the LHCDC*, the 1980 *Details of the Preservation Plan*, the 1981 FGMP, and the 1990 *Preservation Plan Amendment*. MADCR and NPS are presented as the main parties responsible for developing, renovating, and maintaining the major elements of the canal system. As discussed in the following sections, this collaborative approach to management of the Lowell canal system was solidified with a succession of legal documents exchanging property, easement rights, and resource rights.

5.2 Ownership of the Lowell Canal System

On January 16, 1984, the *Great Deed* was executed between Proprietors, Boott Mills[5], and Boott, and through this deed a considerable portion of the Lowell canal system was conveyed to Boott. Notably, certain portions or resources that were not conveyed to Boott in the 1984 *Great Deed* were later obtained by MADCR through the December 1, 1986 *Order of Taking*, or remain under the legal ownership of Proprietors. The following text describes the ownership of structures within the canal system based on an analysis of the 1984 *Great Deed* and the 1986 *Order of Taking*.

5.2.1 Pawtucket Canal

According to the 1984 *Great Deed* and the 1986 *Order of Taking*, the length of the Pawtucket Canal and Lower Pawtucket Canal are currently owned by the Proprietors, including the canal walls (to the exterior planes), beds, and bottoms (Appendix B, p. 2, 4-5). As described below, structures and fixtures within the Pawtucket Canal have mixed ownership, with certain structures being jointly or independently owned by Proprietors and MADCR. Boott is not known to have legal ownership of any structures of or within the Pawtucket Canal. The boundaries of ownership of the Pawtucket Canal structures discussed below are depicted in the Appendix E and the associated GIS database.

[5] Boott Mills was organized in the State of Massachusetts on May 29, 1964 and was the original co-Licensee of the Project with Proprietors. Boott Mills operated the downtown mill powerhouses before the Project was transferred to Boott in December 1984.

5.2.1.1 Francis Gatehouse

The Francis Gatehouse, also known as the Great Guard Gatehouse, is owned in part by MADCR and Proprietors. It is part of the Guard Lock and Gates facility, and houses the Great Guard Gate. Proprietors owns all buildings, structures, and fixtures of the Francis Gatehouse below an elevation of 106.2 ft Mean Sea Level (MSL). MADCR owns all buildings, structures, and fixtures associated with the Francis Gatehouse above 106.2 ft MSL, with the exception of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation. The fixtures and equipment of the Francis Gatehouse used in the ongoing maintenance and operation of hydroelectric power generation above 106.2 ft MSL are owned by Proprietors (Appendix C, p. 20; Appendix B, p. 2, 4-5).

5.2.1.2 Hydraulic Gatehouse

The Hydraulic Gatehouse, also known as the Old Guard Gatehouse, is owned in part by MADCR and Proprietors. It is also part of the Guard Lock and Gates facility, and houses the five headgates which control flow into the Pawtucket Canal. Proprietors owns all buildings, structures, and fixtures of the Hydraulic Gatehouse below an elevation of 88.2 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Hydraulic Gatehouse above 88.2 ft MSL, with the exception of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation. The fixtures and equipment of the Hydraulic Gatehouse used for ongoing maintenance and operation of hydroelectric power generation above 88.2 ft MSL are owned by Proprietors. (Appendix C, p. 20; Appendix B, p. 2, 4-5).

5.2.1.3 Guard Locks Locking Gatehouse

The Guard Locks Locking Gatehouse is owned in part by MADCR and Proprietors. Proprietors owns all structures and fixtures of the Guard Locks Locking Gatehouse below an elevation of 99.2 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Pawtucket Gatehouse above 99.2 ft MSL, with the exception of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation. The fixtures and equipment of the Guard Locks Locking Gatehouse used for ongoing maintenance and operation of hydroelectric power generation above 99.2 ft MSL are owned by Proprietors. (Appendix C, p. 21; Appendix B, p. 2, 4-5).

5.2.1.4 Guard Locks Lock Chambers

The Guard Locks Lock Chambers, also known as the Lower Locking Gate, are owned by Proprietors (Appendix C, p. 21; Appendix B, p. 2, 4-5).

5.2.1.5 Swamp Locks Gatehouse

The Swamp Locks Gatehouse is owned in part by MADCR and Proprietors. Proprietors owns all structures and fixtures of the Swamp Locks Gatehouse below an elevation of

89.2 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Swamp Locks Gatehouse above 89.2 ft MSL, with the exception of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation. The fixtures and equipment of the Swamp Locks Gatehouse used for ongoing maintenance and operation of hydroelectric power generation above 89.2 ft MSL are owned by Proprietors. (Appendix C, p. 16; Appendix B, p. 2, 4-5).

5.2.1.6 Swamp Locks Dam (North)

The Swamp Locks Dam (North) is owned in its entirety by the Proprietors (Appendix B, p. 2, 5). The Pawtucket Canal, and thus structures within the Pawtucket Canal, were not conveyed to Boott from Proprietors in the 1984 *Great Deed*. Similarly, MADCR did not acquire legal ownership of the Swamp Locks Dam (North) in the 1986 *Order of Taking* (Appendix C, p. 16-17).

5.2.1.7 Swamp Locks Dam (South)

The Swamp Locks Dam (South) is owned in its entirety by the Proprietors (Appendix B, p. 2, 5). The Pawtucket Canal, and thus structures within the Pawtucket Canal, were not conveyed to Boott from Proprietors in the 1984 *Great Deed*. Similarly, MADCR did not acquire legal ownership of the Swamp Locks Dam (South) in the 1986 *Order of Taking* (Appendix C, p. 17-18).

5.2.1.8 Lower Locks Gatehouse

The Lower Locks Gatehouse is owned in part by MADCR and Proprietors. Proprietors owns all structures and fixtures of the Lower Locks Gatehouse below an elevation of 74.2 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Lower Locks Gatehouse above 74.2 ft MSL, with the exception of structures and equipment used in the ongoing maintenance and operation of hydroelectric power generation. The fixtures and equipment of the Lower Locks Gatehouse used for ongoing maintenance and operation of hydroelectric power generation above 74.2 ft MSL are owned by Proprietors (Appendix C, p. 24; Appendix B, p. 2, 4-5).

5.2.1.9 Lower Locks Lock Chamber

The Lower Locks Lock Chamber is owned in its entirety by the Proprietors (Appendix B, p. 2, 5). The Pawtucket Canal, and thus structures within the Pawtucket Canal, were not conveyed to Boott from Proprietors in 1984. Similarly, MADCR did not acquire ownership of the Lower Locks Lock Chamber in the 1986 *Order of Taking* (Appendix C, p. 24-25).

5.2.1.10 Lower Locks Dam

The Lower Locks Dam is owned in its entirety by the Proprietors (Appendix B, p. 2, 5). The Pawtucket Canal, and thus structures within the Pawtucket Canal, were not conveyed to Boott from Proprietors in 1984. Similarly, MADCR did not acquire ownership of the Lower Locks Dam in the 1986 *Order of Taking* (Appendix C, p. 24-25).

5.2.2 Northern Canal

The Northern Canal was conveyed from Proprietors to Boott in the 1984 *Great Deed*. The Northern Canal was conveyed to the exterior plane of the canal walls, and includes all sluiceways, dams, and gates, except otherwise noted below (Appendix B, p. 2-3). Structures and fixtures within the Northern Canal have mixed ownership, with certain structures being jointly or independently owned by Proprietors, Boott, and MADCR. The boundaries of ownership of the Northern Canal structures discussed below are depicted in Appendix E and the associated GIS database.

5.2.2.1 Pawtucket Gatehouse

The Pawtucket Gatehouse (also known as the Northern Canal Gatehouse) is owned in part by MADCR and Boott. Boott owns all structures and fixtures of the Pawtucket Gatehouse below an elevation of 101.2 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Pawtucket Gatehouse above 101.2 ft MSL, with the exception of any structures needed for ongoing hydroelectric power generation. The fixtures and equipment of the Pawtucket Gatehouse used for ongoing maintenance and operation of hydroelectric power generation above 101.2 ft MSL are owned by Boott. (Appendix C, p. 11; Appendix B, p. 2-3).

5.2.2.2 Pawtucket Gatehouse Lock Chamber

The Pawtucket Gatehouse Lock Chamber above an elevation of 82.7 ft MSL was expressly reserved from conveyance to Boott in the 1984 *Great Deed* (Appendix B, p. 3), and likely remains under the legal ownership of Proprietors. There is no indication MADCR obtained legal ownership of the Pawtucket Gatehouse Lock Structures above the elevation of 82.7 ft MSL in the 1986 *Order of Taking* (Appendix C, p. 11-12).

5.2.2.3 Northern Canal Waste Gatehouse

The Northern Canal Waste Gatehouse is owned in part by Proprietors and MADCR. The Northern Canal Waste Gatehouse was expressly reserved (without limitation) from conveyance to Boott in the 1984 *Great Deed* (Appendix B, p. 5). In the 1986 *Order of Taking*, MADCR obtained ownership of all buildings, structures, and fixtures associated with the Northern Canal Waste Gatehouse above 92.2 ft MSL, with the exception of any fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation (Appendix C, p. 15). The fixtures and equipment of the Northern Canal Waste Gatehouse used for ongoing maintenance and operation above 92.2 ft MSL are likely still owned by Proprietors.

5.2.2.4 Great River Wall

The Great River Wall was expressly reserved from conveyance to Boott in the 1984 *Great Deed*, and likely remains under the legal ownership of Proprietors. The Great River Wall is the left retaining wall of the Northern Canal. It runs 2,485 feet from the Pawtucket Gatehouse to a natural rock outcrop upstream of the E.L. Field Powerhouse. MADCR did not acquire legal ownership of the Great River Wall in the 1986 *Order of Taking* (Appendix B, p. 5; Appendix C, p. 13-15).

5.2.2.5 Northern Canal Walkway

The Northern Canal Walkway runs atop the Great River Wall for most of its length. The portion of the Northern Canal Walkway atop the Great River Wall is likely still owned by Proprietors as a part of the Great River Wall. The westmost portion of the Northern Canal Walkway that diverts off the Great River Wall and extends into the Northern Canal Island (Parcel 29-B in Appendix A) is owned by MADCR.

5.2.3 Western Canal

The Western Canal was conveyed from Proprietors to Boott in the 1984 *Great Deed*, including the lower portion also known as the Lawrence Canal. The Western Canal was conveyed in its entirety to the exterior plane of the canal walls, and includes all sluiceways, dams, and gates, except those otherwise noted below (Appendix B, p. 2-3). Structures and fixtures within the Western Canal have mixed ownership, with certain structures being jointly or independently owned by Boott and MADCR. The boundaries of ownership of the Western Canal structures discussed below are depicted in the Appendix E and the associated GIS database.

5.2.3.1 Tremont Gatehouse

The Tremont Gatehouse is owned in part by Boott and MADCR. Boott owns all structures and fixtures of the Tremont Gatehouse below an elevation of 90.2 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Tremont Gatehouse above 90.2 ft MSL, with the exception of fixtures and structures needed for ongoing maintenance and operation of hydroelectric power generation. The structures and equipment of the Tremont Gatehouse used for ongoing maintenance and operation of hydroelectric power generation above 90.2 ft MSL are owned by Boott. (Appendix C, p. 7; Appendix B, p. 2-3).

5.2.3.2 Lawrence Dam

The Lawrence Dam is owned by Boott, and includes all appurtenant equipment or mechanisms, including the headrace, tailrace, and associated penstocks (Appendix B, p. 2-3).

5.2.3.3 Hall Street Dam

The Hall Street Dam is owned by Boott, and includes all appurtenant equipment or mechanisms, including the headrace, tailrace, and associated penstocks (Appendix B, p. 2-3).

5.2.4 Merrimack Canal

The Merrimack Canal was conveyed from Proprietors to Boott in the 1984 *Great Deed*. The Merrimack Canal was conveyed in its entirety to the exterior plane of the canal walls, and includes all sluiceways, dams, and gates, except those otherwise noted below (Appendix B, p. 2-3). Structures and fixtures within the Merrimack Canal have mixed ownership, with certain structures being jointly or independently owned by Proprietors, Boott, and MADCR. The boundaries of ownership of the Merrimack Canal structures discussed below are depicted in the Appendix E and the associated GIS database.

5.2.4.1 Merrimack Gates

The Merrimack Gates are owned by Boott, and includes all appurtenant equipment or mechanisms (Appendix B, p. 2-3).

5.2.4.2 YMCA Gates

The YMCA Gates are owned by Boott, and includes all appurtenant equipment or mechanisms (Appendix B, p. 2-3).

5.2.4.3 Moody Street Feeder Gatehouse

The Moody Street Feeder Gatehouse is likely owned in part by Proprietors and Boott. Structures of the Moody Street Feeder Gatehouse above an elevation of 92.2 ft MSL were expressly reserved from conveyance in the 1984 *Great Deed* (Appendix B, p. 3). There is no indication MADCR obtained legal ownership of the Moody Street Feeder Gatehouse above the elevation of 92.2 ft MSL in the 1986 *Order of Taking* (Appendix C), thus the legal ownership of the Moody Street Feeder Gatehouse above 92.2 ft MSL may remain with Proprietors.

5.2.4.4 Moody Street Feeder

The Moody Street Feeder is owned by Boott, and includes all appurtenant equipment or mechanisms, including the headrace, tailrace, and associated penstocks (Appendix B, p. 2-3).

5.2.5 Eastern Canal

The Eastern Canal was conveyed from Proprietors to Boott in the 1984 *Great Deed*. The Eastern Canal was conveyed in its entirety to the exterior plane of the canal walls, and includes all sluiceways, dams, and gates, except those otherwise noted below (Appendix B, p. 2-3). Structures and fixtures within the Eastern Canal have mixed ownership, with certain structures being jointly or independently owned by Boott and MADCR. The boundaries of ownership of the Eastern Canal structures discussed below are depicted in the Appendix E and the associated GIS database.

5.2.5.1 Massachusetts Wasteway Gatehouse

The Massachusetts Wasteway Gatehouse is owned in part by Boott and MADCR. Boott owns all structures and fixtures of the Massachusetts Wasteway Gatehouse below an elevation of 80.2 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Massachusetts Wasteway Gatehouse above 80.2 ft MSL, with the exception of fixtures and structures needed for ongoing maintenance and operation of hydroelectric power generation. The structures and equipment of the Massachusetts Wasteway Gatehouse used for ongoing maintenance and operation of hydroelectric power generation above 80.2 ft MSL are owned by Boott (Appendix C, p. 7; Appendix B, p. 2-3).

5.2.5.2 Boott Dam Gatehouse

The Boott Dam Gatehouse is owned in part by Boott and MADCR. Boott owns all structures and fixtures of the Boott Dam Gatehouse below an elevation of 74.2 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Boott Dam Gatehouse above 74.2 ft MSL, with the exception of fixtures and structures needed for ongoing maintenance and operation of hydroelectric power generation. The structures and equipment of the Boott Dam Gatehouse used for ongoing maintenance and operation of hydroelectric power generation above 74.2 ft MSL are owned by Boott. (Appendix C, p. 7; Appendix B, p. 2-3).

5.2.5.3 Boott Dam

The Boott Dam is owned by Boott, and includes all appurtenant equipment or mechanisms, including the headrace, tailrace, and associated penstocks (Appendix B, p. 2-3).

5.2.5.4 Rolling Dam Gatehouse (North)

The Rolling Dam Gatehouse (North) is owned in part by Boott and MADCR. Boott owns all structures and fixtures of the Rolling Dam Gatehouse (North) below an elevation of 83.7 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Rolling Dam Gatehouse (North) above 83.7 ft MSL, with the exception of fixtures and structures needed for ongoing maintenance and operation of hydroelectric power generation. The structures and equipment of the Rolling Dam Gatehouse (North) used for ongoing maintenance and operation of hydroelectric power generation above 83.7 ft MSL are owned by Boott (Appendix C, p. 29; Appendix B, p. 2-3).

5.2.5.5 Rolling Dam Gatehouse (South)

The Rolling Dam Gatehouse (South) is owned in part by Boott and MADCR. Boott owns all structures and fixtures of the Rolling Dam Gatehouse (South) below an elevation of 83.7 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Rolling Dam Gatehouse (South) above 83.7 ft MSL, with the exception of fixtures and structures needed for ongoing maintenance and operation of hydroelectric power generation. The structures and equipment of the Rolling Dam Gatehouse (South) used for ongoing maintenance and operation of hydroelectric power generation 83.7 ft MSL are owned by Boott (Appendix C, p. 29; Appendix B, p. 2-3).

5.2.5.6 Rolling Dam

The Rolling Dam is owned by Boott, and includes all appurtenant equipment or mechanisms, including the headrace, tailrace, and associated penstocks (Appendix B, p. 2-3).

5.2.5.7 Merrimack Dam

The Merrimack Dam is owned by Boott, and includes all appurtenant equipment or mechanisms, including the headrace, tailrace, and associated penstocks (Appendix B, p. 2-3).

5.2.6 Hamilton Canal

The Hamilton Canal was conveyed from Proprietors to Boott in the 1984 *Great Deed*. The Hamilton Canal was conveyed in its entirety to the exterior plane of the canal walls, and includes all sluiceways, dams, and gates, except those otherwise noted below (Appendix B, p. 2-3). Structures and fixtures within the Hamilton Canal have mixed ownership, with certain structures being jointly or independently owned by Boott and MADCR. The boundaries of ownership of the Hamilton Canal structures discussed below are depicted in the Appendix E and the associated GIS database.

5.2.6.1 Hamilton Gatehouse

The Hamilton Gatehouse is owned in part by Boott and MADCR. Boott owns all structures and fixtures of the Hamilton Gatehouse below an elevation of 90.2 ft MSL. MADCR owns buildings, structures, and fixtures associated with the Hamilton Gatehouse above 90.2 ft MSL, with the exception of fixtures and structures needed for ongoing maintenance and operation of hydroelectric power generation. The structures and equipment of the Hamilton Gatehouse used for ongoing maintenance and operation of hydroelectric power generation above 90.2 ft MSL are owned by Boott (Appendix C, p. 9; Appendix B, p. 2-3).

5.3 Easement Rights to the Lowell Canal System

On January 16, 1984, the *Great Deed* was executed between Proprietors, Boott Mills, and Boott, and through this deed various easement rights were conveyed to Boott. Additionally, MADCR later obtained easement rights to the canal system through the December 1, 1986 *Order of Taking*, and NPS obtained easement rights in the 1995 *Grant of Easement*. The following text describes the easement rights to the structures within the canal system based on an analysis of the 1984 *Great Deed*, the 1986 *Order of Taking*, and the 1995 *Grant of Easement*.

5.3.1 Pawtucket Canal

The 1984 *Great Deed* conveyed to Boott an easement to the Pawtucket Canal and Lower Pawtucket Canal. This easement was granted in common with Proprietors for the right to install conduits, pipes, and wiring, and the right to maintain, repair and replace the canal walls (Appendix B, p. 4-5).

In the 1986 *Order of Taking*, MADCR acquired a permanent and exclusive easement to all Pawtucket and Lower Pawtucket Canal walls, beds or bottoms, and to all dams and lock chambers located in the canals, for the following purposes (Appendix C, p. 33):

a) Support of all fixtures or structures of the Commonwealth now or hereafter attached;
b) Preservation and conservation;
c) Supplemental maintenance in addition to that performed by the Condemnees (the prior or current owner) and their successors and assigns;
d) Landscaping and erection of exhibits and structures;
e) Placement of barriers and fences;
f) Placement and attachment of docks, wharves, walls, and boat ramps of a temporary or permanent nature;
g) Placement of lighting and other utilities;
h) Operation and maintenance of boat locking chambers, if any, for any and all purposes; and
i) Any and all other uses consistent with the operation of the canal system as a park.

The 1995 *Grant of Easement* conveyed to NPS the right to construction and maintenance of improvements, including decking, lighting, benches, and landscaping at various structures and parcels of and around the Pawtucket Canal.

As understood based on a review of the described documents, MADCR has permanent and exclusive rights to all Pawtucket Canal walls, beds or bottoms for purposes a-i listed above. The expressed exclusivity of this easement indicates that MADCR's rights to implement any of those purposes at or in the Pawtucket Canal precede the rights of all other parties. Boott and Proprietors have the right, in common with each other, to install conduits, pipes, and wiring, and to maintain, repair, and replace the Pawtucket Canal walls. Additionally, through the 1995 *Grant of Easement*, MADCR conveyed to NPS easement rights at various structures and parcels of the Pawtucket Canal.

As described below, structures and fixtures within the Pawtucket Canal have mixed easement rights, with certain structures sharing similar rights among different parties. The boundaries of easements to structures are assumed to follow the boundaries of ownership, which are depicted in the Appendix E and the associated GIS database.

5.3.1.1 Francis Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Francis Gatehouse. Said easement consists of the exclusive right of operation and controlling the Francis Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Francis Gatehouse. In common with Proprietors and others entitled, Boott has the right to access Francis Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Pawtucket Canal walls, beds or bottoms for support of the Francis Gatehouse, structures, and fixtures, as well as the right to access the Francis Gatehouse (Appendix C, p. 20).

The 1995 *Grant of Easement* granted NPS the right for construction and maintenance of improvements such as walkway surfaces, lighting, railings, decking benches, and landscaping, and any other uses consistent with park uses (Appendix D, p. 2).

5.3.1.2 Hydraulic Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Hydraulic Gatehouse. Said easement consists of the exclusive right of operation and controlling the Hydraulic Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Hydraulic Gatehouse. In common with Proprietors and others entitled, Boott has the right to access Hydraulic Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Pawtucket Canal walls, beds or bottoms for support of the Hydraulic Gatehouse, structures, and fixtures, as well as the right to access the Hydraulic Gatehouse (Appendix C, p. 20).

The 1995 *Grant of Easement* granted NPS the right for construction and maintenance of improvements such as walkway surfaces, lighting, railings, decking benches, and landscaping, and any other uses consistent with park uses (Appendix D, p. 2).

5.3.1.3 Guard Locks Locking Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Guard Locks Locking Gatehouse. Said easement consists of the exclusive right of operation and controlling the Guard Locks Locking Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Guard Locks Locking Gatehouse. In common with Proprietors and others entitled, Boott has the right to access Guard Locks Locking Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1995 *Grant of Easement* granted NPS the right for construction and maintenance of improvements such as walkway surfaces, lighting, railings, decking benches, and landscaping, and any other uses consistent with park uses (Appendix D, p. 2).

5.3.1.4 Guard Locks Lock Chambers

MADCR has permanent and exclusive rights to the Guard Locks Lock Chambers for purposes a-i listed above in Section 5.3.1.

5.3.1.5 Swamp Locks Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Swamp Locks Gatehouse. Said easement consists of the exclusive right of operation and controlling the Swamp Locks Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Swamp Locks Gatehouse. In common with Proprietors and others entitled, Boott has the right to access Swamp Locks Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Pawtucket Canal walls, beds or bottoms for support of the Swamp Locks Gatehouse, structures, and fixtures, as well as the right to access the Swamp Locks Gatehouse (Appendix C, p. 16).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Swamp Lock Gatehouse (Appendix D, p. 3).

5.3.1.6 Swamp Locks Dam (North)

As understood based on a review of the described documents, Boott has the rights, in common with Proprietors, to install conduits, pipes, and wiring. Boott has the right to maintain and operate Swamp Locks Dam (North) (Appendix B, p. 4-5).

Additionally, MADCR has permanent and exclusive easement rights to Swamp Locks Dam (North) and all Pawtucket Canal walls, beds or bottoms for purposes a-i listed above in Section 5.3.1, provided those purposes do not interfere with Boott's use of the structure for hydroelectric power generation. The expressed exclusivity of this easement indicates that MADCR's rights to implement any of those purposes at Swamp Locks Dam (North) precede the rights of all other parties, including the land and/or property owner. All other property rights not mentioned reside with Proprietors, the present owner of the Pawtucket Canal and Swamp Locks Dam (North) (Appendix C, p. 16-17; Appendix B, p. 2, 4-5).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Swamp Locks Dam (North) (Appendix D, p. 3).

5.3.1.7 Swamp Locks Dam (South)

As understood based on a review of the described documents, Boott has the rights, in common with Proprietors, for the uninterrupted flowage of water past Swamp Locks Dam (South), as well as the rights to install conduits, pipes, and wiring. Boott has the right to maintain and operate Swamp Locks Dam (South) (Appendix B, p. 4-5).

Additionally, MADCR has permanent and exclusive easement rights to Swamp Locks Dam (South) and all Pawtucket Canal walls, beds or bottoms for purposes a-i listed above in Section 5.3.1, provided those purposes do not interfere with Boott's use of the structure for hydroelectric power generation. The expressed exclusivity of this easement indicates that MADCR's rights to implement any of those purposes at Swamp Locks Dam (South) precede the rights of all other parties, including the land and/or property owner. All other property rights not mentioned reside with Proprietors, the present owner of the Pawtucket Canal and Swamp Locks Dam (South) (Appendix C, p. 17-18; Appendix B, p. 2, 4-5).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Swamp Locks Dam (South) (Appendix D, p. 3).

5.3.1.8 Lower Locks Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Lower Locks Gatehouse. Said easement consists of the exclusive right of operation and controlling the Lower Locks Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Lower Locks Gatehouse. In common with Proprietors and others entitled, Boott has the right to access Lower Locks Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Pawtucket Canal walls, beds or bottoms for support of the Lower Locks Gatehouse, structures, and fixtures, as well as the right to access the Lower Locks Gatehouse (Appendix C, p. 16).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Lower Locks Gatehouse (Appendix D, p. 3).

5.3.1.9 Lower Locks Lock Chamber

MADCR has permanent and exclusive rights to the Lower Locks Lock Chamber for purposes a-i listed above in Section 5.3.1.

5.3.1.10 Lower Locks Dam

As understood based on a review of the described documents, Boott has the rights, in common with Proprietors, to install conduits, pipes, and wiring. Boott has the right, in common with Proprietors, to maintain and operate Lower Locks Dam (Appendix B, p. 4-5).

Additionally, MADCR has permanent and exclusive easement rights to Lower Locks Dam and all Pawtucket Canal walls, beds or bottoms for purposes a-i listed above in Section 5.3.1, provided those purposes do not interfere with Boott's use of the structure for hydroelectric power generation. The expressed exclusivity of this easement indicates that MADCR's rights to implement any of those purposes at Lower Locks Dam precede the rights of all other parties, including the land and/or property owner. All other property rights not mentioned reside with Proprietors, the present owner of the Pawtucket Canal and Lower Locks Dam (Appendix C, p. 24-25; Appendix B, p. 2, 4-5).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Lower Locks Dam (Appendix D, p. 3).

5.3.2 Northern Canal

In the 1986 *Order of Taking*, MADCR acquired a permanent and exclusive easement to all canal walls, beds or bottoms, and to all dams and lock chambers located in the Northern Canal for the following purposes (Appendix C, p. 33):

a) Support of all fixtures or structures of the Commonwealth now or hereafter attached;
b) Preservation and conservation;
c) Supplemental maintenance in addition to that performed by the Condemnees (the prior or current owner) and their successors and assigns;
d) Landscaping and erection of exhibits and structures;
e) Placement of barriers and fences;

f) Placement and attachment of docks, wharves, walls, and boat ramps of a temporary or permanent nature;
g) Placement of lighting and other utilities;
h) Operation and maintenance of boat locking chambers, if any, for any and all purposes; and
i) Any and all other uses consistent with the operation of the canal system as a park.

The 1995 *Grant of Easement* conveyed to NPS the right to construct and maintain improvements, including decking, lighting, benches, and landscaping at various structures and parcels of and around the Northern Canal.

As understood based on a review of the described documents, MADCR has permanent and exclusive rights to all Northern Canal walls, beds or bottoms for purposes a-i listed above. The expressed exclusivity of this easement indicates that MADCR's rights to implement any of those purposes at or in the Northern Canal precede the rights of all other parties. Additionally, through the 1995 *Grant of Easement*, MADCR conveyed to NPS easement rights at various structures and parcels of the Northern Canal.

As described below, structures and fixtures within the Northern Canal have mixed easement rights, with certain structures sharing similar rights among different parties. The boundaries of easements to structures are assumed to follow the boundaries of ownership, which are depicted in the Appendix E and the associated GIS database.

5.3.2.1 Pawtucket Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Pawtucket Gatehouse. Said easement consists of the exclusive right of operation and controlling the Pawtucket Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Pawtucket Gatehouse. Boott has the right to access Pawtucket Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Northern Canal walls, beds or bottoms for support of the Pawtucket Gatehouse, structures, and fixtures, as well as the right to access the Pawtucket Gatehouse (Appendix C, p. 16). MADCR also obtained an exclusive and permanent easement to the Pawtucket Gatehouse Wall and Lock Chamber for purposes a-i listed above in Section 5.3.2, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.2.2 Pawtucket Gatehouse Lock Chamber

In the 1986 *Order of Taking*, MADCR acquired a permanent and exclusive easement to the Pawtucket Gatehouse Lock Chamber for purposes a-i listed above in Section 5.3.2, provided that such activities do not interfere with Boott's hydroelectric power production.

The 1995 *Grant of Easement* granted NPS the right for construction and maintenance of improvements of the Pawtucket Gatehouse Lock Chamber (Appendix D, p. 2).

5.3.2.3 Northern Canal Waste Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Northern Canal Waste Gatehouse. Said easement consists of the exclusive right of operation and controlling the Northern Canal Waste Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Northern Canal Waste Gatehouse. Boott has the right to access Northern Canal Waste Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Northern Canal walls, beds or bottoms for support of the Northern Canal Waste Gatehouse, structures, and fixtures, as well as the right to access the Northern Canal Waste Gatehouse (Appendix C, p. 15).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Northern Canal Waste Gatehouse (Appendix D, p. 3).

5.3.2.4 Great River Wall

The 1984 *Great Deed* conveyed to Boott an easement for the right to maintain real and personal property of the Great River Wall. Said easement consists of the exclusive right of operation and controlling the Great River Wall, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms of the Great River Wall. Boott, in common with Proprietors, has the right to access Great River Wall for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent and exclusive easement in the Northern Canal walls, beds or bottoms, to implement any of the purposes a-i listed above in Section 5.3.2. All other property rights not previously mentioned reside with Proprietors, the present owner of the Great River Wall.

5.3.2.5 Northern Canal Walkway

The 1986 *Order of Taking* conveyed to MADCR a permanent and exclusive easement to the Northern Canal Walkway to implement any of the purposes a-i listed above in Section 5.3.2. All other property rights not previously mentioned reside with Proprietors, the present owner of the Northern Canal Walkway.

5.3.3 Western Canal

In the 1986 *Order of Taking*, MADCR acquired a permanent and exclusive easement to all canal walls, beds or bottoms, and to all dams and lock chambers located in the Western Canal for the following purposes (Appendix C, p. 33):

a) Support of all fixtures or structures of the Commonwealth now or hereafter attached;
b) Preservation and conservation;
c) Supplemental maintenance in addition to that performed by the Condemnees (the prior or current owner) and their successors and assigns;
d) Landscaping and erection of exhibits and structures;
e) Placement of barriers and fences;
f) Placement and attachment of docks, wharves, walls, and boat ramps of a temporary or permanent nature;
g) Placement of lighting and other utilities;
h) Operation and maintenance of boat locking chambers, if any, for any and all purposes; and
i) Any and all other uses consistent with the operation of the canal system as a park.

The 1995 *Grant of Easement* conveyed to NPS the right to construction and maintenance of improvements, including decking, lighting, benches, and landscaping at various structures and parcels of and around the Western Canal.

As understood based on a review of the described documents, MADCR has permanent and exclusive rights to all Western Canal walls, beds or bottoms for purposes a-i listed above. The expressed exclusivity of this easement indicates that MADCR's rights to implement any of those purposes at or in the Western Canal precede the rights of all other parties. Additionally, through the 1995 *Grant of Easement*, MADCR conveyed to NPS easement rights at various structures and parcels of the Western Canal.

As described below, structures and fixtures within the Western Canal have mixed easement rights, with certain structures sharing similar rights among different parties. The boundaries of easements to structures are assumed to follow the boundaries of ownership, which are depicted in the Appendix E and the associated GIS database.

5.3.3.1 Tremont Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Tremont Gatehouse. Said easement consists of the exclusive right of operation and controlling the Tremont Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Tremont Gatehouse. Boott has the right to access Tremont Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Western Canal walls, beds or bottoms for support of the Tremont Gatehouse, structures, and fixtures, as well as the right to access the Tremont Gatehouse (Appendix C, p. 26).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Tremont Gatehouse (Appendix D, p. 3).

5.3.3.2 Lawrence Dam

MADCR obtained an exclusive and permanent easement to the Lawrence Dam for purposes a-i listed above in Section 5.3.3, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.3.3 Hall Street Dam

MADCR obtained an exclusive and permanent easement to the Hall Street Dam for purposes a-i listed above in Section 5.3.3, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.4 Merrimack Canal

In the 1986 *Order of Taking*, MADCR acquired a permanent and exclusive easement to all Merrimack Canal walls, beds or bottoms, and to all dams and lock chambers located in the canals, for the following purposes (Appendix C, p. 33):

a) Support of all fixtures or structures of the Commonwealth now or hereafter attached;
b) Preservation and conservation;
c) Supplemental maintenance in addition to that performed by the Condemnees (the prior or current owner) and their successors and assigns;
d) Landscaping and erection of exhibits and structures;
e) Placement of barriers and fences;
f) Placement and attachment of docks, wharves, walls, and boat ramps of a temporary or permanent nature;
g) Placement of lighting and other utilities;
h) Operation and maintenance of boat locking chambers, if any, for any and all purposes; and
i) Any and all other uses consistent with the operation of the canal system as a park.

The 1995 *Grant of Easement* conveyed to NPS the right to construction and maintenance of improvements, including decking, lighting, benches, and landscaping at various structures and parcels of and around the Merrimack Canal.

As understood based on a review of the described documents, MADCR has permanent and exclusive rights to all Merrimack Canal walls, beds or bottoms for purposes a-i listed above. The expressed exclusivity of this easement indicates that MADCR's rights to implement any of those purposes at or in the Merrimack Canal precede the rights of all other parties. Additionally, through the 1995 *Grant of Easement*, MADCR conveyed to NPS easement rights at various structures and parcels of the Merrimack Canal.

As described below, structures and fixtures within the Pawtucket Canal have mixed easement rights, with certain structures sharing similar rights among different parties. The boundaries of easements to structures are assumed to follow the boundaries of ownership, which are depicted in the Appendix E and the associated GIS database.

5.3.4.1 Merrimack Gates

MADCR obtained an exclusive and permanent easement to the Merrimack Gates purposes a-i listed above in Section 5.3.4, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.4.2 YMCA Gates

MADCR obtained an exclusive and permanent easement to the YMCA Gates purposes a-i listed above in Section 5.3.4, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.4.3 Moody Street Feeder Gatehouse

MADCR obtained an exclusive and permanent easement to the Moody Street Feeder Gatehouse for purposes a-i listed above in Section 5.3.4, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.4.4 Moody Street Feeder

MADCR obtained an exclusive and permanent easement to the Moody Street Feeder for purposes a-i listed above in Section 5.3.4, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.5 Eastern Canal

In the 1986 *Order of Taking*, MADCR acquired a permanent and exclusive easement to all canal walls, beds or bottoms, and to all dams and lock chambers located in the Eastern Canal for the following purposes (Appendix C, p. 33):

a) Support of all fixtures or structures of the Commonwealth now or hereafter attached;
b) Preservation and conservation;
c) Supplemental maintenance in addition to that performed by the Condemnees (the prior or current owner) and their successors and assigns;
d) Landscaping and erection of exhibits and structures;
e) Placement of barriers and fences;
f) Placement and attachment of docks, wharves, walls, and boat ramps of a temporary or permanent nature;

g) Placement of lighting and other utilities;
h) Operation and maintenance of boat locking chambers, if any, for any and all purposes; and
i) Any and all other uses consistent with the operation of the canal system as a park.

As understood based on a review of the described documents, MADCR has permanent and exclusive rights to all Eastern Canal walls, beds or bottoms for purposes a-i listed above. The expressed exclusivity of this easement indicates that MADCR's rights to implement any of those purposes at or in the Eastern Canal precede the rights of all other parties. Additionally, through the 1995 *Grant of Easement*, MADCR conveyed to NPS easement rights at various structures and parcels of the Eastern Canal.

As described below, structures and fixtures within the Eastern Canal have mixed easement rights, with certain structures sharing similar rights among different parties. The boundaries of easements to structures are assumed to follow the boundaries of ownership, which are depicted in the Appendix E and the associated GIS database.

5.3.5.1 Massachusetts Wasteway Gatehouse

Through the 1986 *Order of Taking*, MADCR obtained a permanent easement in the canal walls, beds, and bottoms for support of the Massachusetts Wasteway Gatehouse, as well as any structures or fixtures of the Massachusetts Wasteway Gatehouse.

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Lower Locks Gatehouse (Appendix D, p. 3).

5.3.5.2 Boott Dam Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Boott Dam Gatehouse. Said easement consists of the exclusive right of operation and controlling the Boott Dam Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Boott Dam Gatehouse. Boott has the right to access Boott Dam Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Eastern Canal walls, beds or bottoms for support of the Boott Dam Gatehouse, structures, and fixtures, as well as the right to access the Boott Dam Gatehouse (Appendix C, p. 26).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Boott Dam Gatehouse (Appendix D, p. 3).

5.3.5.3 Boott Dam

MADCR obtained an exclusive and permanent easement to the Boott Dam for purposes a-i listed above in Section 5.3.5, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.5.4 Rolling Dam Gatehouse (North)

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Rolling Dam Gatehouse (North). Said easement consists of the exclusive right of operation and controlling the Rolling Dam Gatehouse (North), and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Rolling Dam Gatehouse (North). Boott has the right to access Rolling Dam Gatehouse (North) for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Eastern Canal walls, beds or bottoms for support of the Rolling Dam Gatehouse (North), structures, and fixtures, as well as the right to access the Rolling Dam Gatehouse (North) (Appendix C, p. 7).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Rolling Dam Gatehouse (North) (Appendix D, p. 3).

5.3.5.5 Rolling Dam Gatehouse (South)

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Rolling Dam Gatehouse (South). Said easement consists of the exclusive right of operation and controlling the Rolling Dam Gatehouse (South), and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Rolling Dam Gatehouse (South). Boott has the right to access Rolling Dam Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Eastern Canal walls, beds or bottoms for support of the Rolling Dam Gatehouse (South), structures, and fixtures, as well as the right to access the Rolling Dam Gatehouse (South) (Appendix C, p. 7).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Rolling Dam Gatehouse (South) (Appendix D, p. 3).

5.3.5.6 Rolling Dam

MADCR obtained an exclusive and permanent easement to the Rolling Dam for purposes a-i listed above in Section 5.3.5, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.5.7 Merrimack Dam

MADCR obtained an exclusive and permanent easement to the Merrimack Dam for purposes a-i listed above in Section 5.3.5, provided that such activities do not interfere with Boott's hydroelectric power production.

5.3.6 Hamilton Canal

In the 1986 *Order of Taking*, MADCR acquired a permanent and exclusive easement to all canal walls, beds or bottoms, and to all dams and lock chambers located in said canal and not otherwise noted for the following purposes (Appendix C, p. 33):

a) Support of all fixtures or structures of the Commonwealth now or hereafter attached;
b) Preservation and conservation;
c) Supplemental maintenance in addition to that performed by the Condemnees (the prior or current owner) and their successors and assigns;
d) Landscaping and erection of exhibits and structures;
e) Placement of barriers and fences;
f) Placement and attachment of docks, wharves, walls, and boat ramps of a temporary or permanent nature;
g) Placement of lighting and other utilities;
h) Operation and maintenance of boat locking chambers, if any, for any and all purposes; and
i) Any and all other uses consistent with the operation of the canal system as a park.

As understood based on a review of the described documents, MADCR has permanent and exclusive rights to all Hamilton Canal walls, beds or bottoms for purposes a-i listed above. The expressed exclusivity of this easement indicates that MADCR's rights to implement any of those purposes at or in the Hamilton Canal precede the rights of all other parties. Additionally, through the 1995 *Grant of Easement*, MADCR conveyed to NPS easement rights at various structures and parcels of the Hamilton Canal.

As described below, structures and fixtures within the Hamilton Canal have mixed easement rights, with certain structures sharing similar rights among different parties. The boundaries of easements to structures are assumed to follow the boundaries of ownership, which are depicted in the Appendix E and the associated GIS database.

5.3.6.1 Hamilton Gatehouse

The 1984 *Great Deed* conveyed to Boott an easement for the right to enter and maintain real and personal property in the Hamilton Gatehouse. Said easement consists of the exclusive right of operation and controlling the Hamilton Gatehouse, and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms inside Hamilton Gatehouse. Boott has the right to access Hamilton Gatehouse for repair and installation of the machinery and equipment, gauge equipment, and such other mechanisms located inside the gatehouse (Appendix B, p. 2, 5).

The 1986 *Order of Taking* conveyed to MADCR a permanent easement in the Hamilton Canal walls, beds or bottoms for support of the Hamilton Gatehouse, structures, and fixtures, as well as the right to access the Hamilton Gatehouse (Appendix C, p. 16).

The 1995 *Grant of Easement* granted NPS the right to conduct land and canal tours, run interpretive programs, and the right to maintain, improve, and restore the Hamilton Gatehouse (Appendix D, p. 3).

5.4 Resource Rights in the Lowell Canal System

Boott reviewed many sources to understand the resource rights to the Lowell canal system, including planning documents, the MOU, the 1984 *Great Deed* between Proprietors and Boott (Appendix B), the 1986 *Order of Taking* (Commonwealth of Massachusetts 1986), and the 1995 *Grant of Easement* (Appendix D).

For this study, resource rights are classified as such if they are owned by or issued to a party independently from any physical structure. The ownership and rights of physical resources, such as the canal system and gatehouses, are not discussed in this section because those rights are limited to specific structures and thus are addressed above in Sections 5.2 and 5.3.

5.4.1 Recreational Resource Rights of the Lowell Canal System

The 1977 *Report of the LHCDC* and the 1980 *Details of the Preservation Plan* indicated the Commonwealth agreed to preserve the canal system and develop its recreational potentials. The Commonwealth would also undertake the landscaping, repair and maintenance of all the basic canal structural components, canal related structures and canal related land for recreational use. By letter to dated May 14, 1980, MADCR stated that they were currently in the process of negotiating purchase rights to the Lowell canal system which would allow for recreational boating in the canals, stating further that use of the canals and implementation of the boating program were key elements of the Lowell Heritage State Park (Commonwealth 1980).

Through the 1986 *Order of Taking*, MADCR purchased “the exclusive right to use water in the entire canal system and the Merrimack River for recreational, educational, and navigational purposes” and the purposes shall be non-consumptive with respect to

Boott's hydroelectric generation (Appendix C). Included in the 1986 *Order of Taking* is a permanent and exclusive easement to MADCR for all canal walls, beds, or bottoms throughout the canal system for purposes consistent with the use of the canal system as a recreational park. These purposes specifically include placement and attachment of docks, wharves, walls, and boat ramps of a temporary or permanent nature (Appendix C). The 1995 *Grant of Easement* from MADCR to LNHP did not convey these exclusive recreation rights to LNHP, but does allow LNHP to hold boat tours through certain segments of the canal system (Appendix D).

The *1990 Preservation Plan Amendment* stated this about recreational resources of the canal system:

> "In general, water taxis, dinner boats, and other organized boating programs will be encouraged, subject to permission from the Heritage State Park [MADCR] which controls recreational boating rights on the canals."

In 1991, MADCR, the NPS, and Boott executed the MOU, which specifically identifies recreational resource rights as residing with MADCR, further stating MADCR was to "act on all special use permit requests for the recreational use of the Lowell canal system and provide copies of approved permits to Boott Hydro and Proprietors and the NPS."

Conceptual planning documents, legal ownership and easement documents, as well as the MOU, are all consistent regarding recreational resource rights. MADCR owns exclusive rights to use the entire canal system for recreational, educational, and navigational purposes. MADCR holds an exclusive and permanent easement for placement and attachment of docks, wharves, walls, and boat ramps of a temporary or permanent nature.

5.4.2 Air Resources of the Lowell Canal System

The 1986 *Order of Taking* transferred to MADCR "all air rights over the canals, including the canal walls and any dams thereon" (Appendix C).

5.4.3 Water and Flowage Resource Rights of the Lowell Canal System

Boott obtained water and flowage rights in the 1984 *Great Deed*. These rights include all riparian rights, water rights and mill rights of the canal system, for the uninterrupted flowage of water through the canals. Other uses of water in the Lowell canal system (e.g., surface water recreation) shall be non-consumptive with respect to hydroelectric generation except for reasonable amounts to operate locking gates. Proprietors retains the right to use up to 100 cfs of water from the canals for fire protection and process water (Appendix B; Appendix C).

5.5 Historical Management Agreements

There are two known historical management agreements between the parties with interests in the Lowell canal system. While these agreements have expired, they present an understanding between the parties of what their individual roles and responsibilities were regarding the Lowell canal system. Given the collaborative approach to ownership and easement rights to the Lowell canal system, the two agreements provide the best insight into delegation of regular management tasks such as ground maintenance, water levels, waterborne trash, and vegetation management.

Following establishment of the LNHP in 1978, MADCR, NPS, and Proprietors entered into an agreement in 1979 regarding management of the Lowell canal system. This agreement establishes MADCR as the lead party responsible for the maintenance of canal structural components, including canal banks and walls. As the lead party, MADCR was responsible for “landscaping and damage repair” to canal banks and walls, with assistance provided by NPS if needed. NPS was charged with the operation of the canal-related exhibits and services, and Locks and Canals (i.e. Proprietors and ultimately Boott) were responsible for the operation and maintenance of Pawtucket Dam and other hydromechanical parts of the Lowell canal system (NPS 1981). This agreement is presented below as Figure 5-2 and fully published in the 1981 FGMP.

Figure 5-2. 1979 Canal System Management Agreement

APPENDIX D: AGREEMENTS BETWEEN MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL MANAGEMENT AND NATIONAL PARK SERVICE CONCERNING CANAL USE, DEVELOPMENT, AND MANAGEMENT

Acquisition	Lead Agency
Canal Banks and Walls (variable boundary)	DEM
Gatehouses (11)	DEM assisted by NPS
Locks (2 single and 2 double)	DEM
Dam	Locks and Canals
Interpretive Water Access Rights/Recreational Boating	DEM
Water Use Rights/Hydro	NPS assisted by DEM
Bridges	DEM and City of Lowell
Canal Boats - 8 to 40 person capacity	Preservation Commission and NPS

Development	Lead Agency
Canal Banks and Walls (landscaping and damage repair)	DEM assisted by NPS
Locks	DEM/NPS
Gatehouses	DEM/NPS
Dam	Locks and Canals
Bridges	DEM/City of Lowell (DEM will coordinate, funding to be determined)
Barge Landings	DEM/NPS
Displays and Signs	DEM/NPS (joint effort prior to 4/80)

Maintenance	Lead Agency
Canal Banks and Walls	DEM
Locks	DEM
Gatehouses	DEM and Locks and Canals
Dam	Locks and Canals
Bridges	DEM/City of Lowell
Dredging/Debris Removal	DEM (initially NPS)
Barge Landings	NPS/DEM (Francis Gate, Northern Canal)
Boats	NPS
Water Flow Levels	NPS/Locks and Canals
Maintenance Staff	DEM or contractual arrangement

Visitor Services (4-month operation)	Lead Agency
Overall Cooperative Lead Agency	NPS
Interpretive Staffing	NPS/DEM
Boat Operators (16)	NPS
Security	NPS

In 1991, MADCR, the NPS, and Boott executed the MOU for the purpose of maintaining and operating the Lowell canal system.[6] The MOU was generated after the 1984 *Great Deed* and 1986 *Order of Taking*, and so it best represents an agreement between the parties of what their legal roles and responsibilities were. The MOU assigned specific responsibilities to each party and was filed with the Commission on April 25, 1991 (MOU

[6] Proprietors of the Locks and Canals on the Merrimack River was included as a party in the MOU but did not execute the agreement.

1991). The MOU included a provision expiring the agreement five years from the date of signing, with the option for renewal.

Article I of the MOU states that the agreement shall not diminish the rights and interests acquired by MADCR in the 1986 *Order of Taking*. The agreement shall not release or further bind Boott and Proprietors from their obligations under the FERC license or other obligations to maintain the Lowell canal system.

Article II of the MOU directs Proprietors to maintain the structural integrity of the walls, bottoms, and dam structures of the Pawtucket Canal to the extent they have the duty to do so as owner. Proprietors was to provide MADCR with any plans to alter the Pawtucket Canal and to obtain MADCR's written prior approval.

Article III of the MOU discusses the responsibilities of Boott, which includes maintaining canal walls, beds, bottoms, and dam structures to the extent they have a duty to do so as the owner. Article III(C) requires Boott to operate the canal system to provide the appropriate flows and water levels. Articles III(H-I) require Boott to obtain written approval from MADCR regarding any changes to the Gatehouses or canal walls which may affect the historic fabric of the system. Other article provisions require notification of drawdowns, access to the E.L. Field Powerhouse, and the payment of utility costs (heating and gas).

Article IV directed NPS to assist MADCR in the removal of litter and other waterborne trash from the Lowell canal system, and states NPS is responsible for maintaining and cleaning ("including removal of trash") all existing trash booms and safety lines/booms on the Lowell canal system. Article IV of the MOU directed NPS to assist MADCR in the removal and control of vegetation along the canal system, ("particularly that growing on and in the canal walls") and to assist MADCR in performing ground maintenance. NPS was tasked with assisting MADCR with the repair and maintenance of all historic gatehouses, such as the repair of architectural features, cleaning and repair of roof gutters, and the maintenance of locking gates and other mechanical devices.

Responsibilities assigned to MADCR under Article V of the MOU include routine maintenance of the gatehouses, serving as the lead agency for all grounds maintenance, keeping all grass, trees, and shrubs neatly trimmed and in a healthy condition, removing dead or diseased plants, fertilizing, pruning, and thinning of plants (as required), and approving ground maintenance or improvement plans as proposed by NPS. Article V directs MADCR to assist NPS in the removal and control of destructive vegetation along the canal system, and to cooperate with the NPS on developing a litter removal program for waterborne litter and trash on the canals. (MOU 1991). MADCR was to implement an annual safety inspection of the locking gates and gate chambers. This article also specified MADCR to reimburse NPS for time and materials for work done on the canal system. Notably, MADCR was to "act on all special use permit requests for the recreational use of the Lowell canal system and provide copies of approved permits to Boott Hydro and Proprietors and the NPS."

Article VI of the MOU directed NPS and MADCR to hold a joint annual meeting to develop an annual building maintenance program, annual destructive vegetation clearing program and canal surface water cleanup program. The annual programs were to be developed in accordance with each agency’s budget and seasonal staffing level. Under Article VI, MADCR was also directed to consult with NPS to develop a long-term capital improvement program for the canal system. The minutes of this annual meeting between MADCR and NPS were to be provided to Boott and the Proprietors each year (MOU 1991).

5.6 FERC Jurisdiction

One of the goals for this study was to clarify FERC jurisdiction. Section 23(b)(1) of the Federal Power Act (FPA) requires that each non-federal hydroelectric project, except those with pre-1920 federal permits that are still valid, falls under FERC jurisdiction if it: (1) is located on navigable waters of the United States; (2) occupies lands of the United States; (3) uses surplus water or water power from a government dam; or (4) is located on a body of water over which Congress has Commerce Clause jurisdiction, was constructed or modified after August 25, 1935, and affects interstate or foreign commerce.

All hydropower projects deemed jurisdictional must be licensed by FERC (or exempted from licensure), and the Project Boundary defines the geographical limits of FERC's jurisdiction. The Commission determines the limits of the Project Boundary based on lands and waters needed by the Licensee: (1) to construct and operate its Project and (2) to carry out other non-power project purposes such as fish passage and minimum flow requirements.

The Licensee is required to manage operations within the Project Boundary in accordance with the conditions set forth in the FERC license. Additionally, Section 10(c) of the FPA requires Licensees with to maintain the project works within the Project Boundary in a condition of repair adequate for the purposes of navigation and for the efficient operation of said works in the development and transmission of power, . . . to maintain and operate said works as not to impair navigation, and . . . conform to such rules and regulations as the Commission may from time to time prescribe for the protection of life, health, and property.

The FERC Project Boundary around the project impoundment, continuous project features, and noncontiguous Project works are presented in Exhibit G maps according to the methods required under 18 CFR §4.41(h)(2). The Exhibit G maps for the Lowell Hydroelectric Project will be filed with the FLA, to be filed with the Commission by April 30, 2021.

As stated in the DLA, Boott proposes to remove the four mill power stations and associated canal infrastructure from the new FERC license. The Project Boundary will be modified to remove much of the downtown canal infrastructure. However, Boott will continue to manage the canal structures, water levels and flows using best practices and consistent with current agreements with the NPS and other stakeholders.

6 Discussion and Conclusion

6.1 Ownership and Easement Rights to the Lowell Canal System

Ownership, easement rights, and use of the canal system in Lowell are complex, with intersecting roles between public agencies and private entities at the local, State, and Federal level. In their request for this study, NPS noted that the eventual goal of this study would be to denote which entity is ultimately responsible for specific resources. Boott's review of the documentation indicated that it is not possible to specify ultimate responsibility for most physical resources of the Lowell canal system because the LNHP was planned, designed, and launched as a collaboration between parties, and legal documents were executed to solidify this management framework. From the start of the park's conception in the 1977 *Report of the LHCDC*, the vision has always been "a creative partnership which would go beyond the reach of any single agency or level of government" (LHCDC 1977). Generally, the legal documentation issued in the form of the 1984 *Great Deed*, 1986 *Order of Taking*, and the 1995 *Grant of Easement* does not designate any party to be solely responsible for specific structures.

Ownership of the Lowell canal system is largely determined by the 1984 *Great Deed* and 1986 *Order of Taking*. Components of the canal system are owned by Proprietors, Boott, and MADCR. Proprietors owns much of the Pawtucket Canal and structures of the Pawtucket Canal. Boott owns the Northern Canal, Western Canal, Merrimack Canal, Eastern Canal, and Hamilton Canal. Boott owns specific dams, lock structures, and hydroelectric equipment within the canals they own, and this is largely determined based on elevation. MADCR owns most of the gatehouses and several other historical structures throughout the Lowell canal system.

Easement rights to structures of the Lowell canal system are held by Proprietors, Boott, MADCR, and NPS. In the 1984 *Great Deed*, Boott obtained easement rights, in common with Proprietors, to the Pawtucket Canal and structures of the Pawtucket Canal. These easement rights allow Boott to access, operate, maintain, repair, and replace the Pawtucket Canal and structures of the Pawtucket Canal. In the 1986 *Order of Taking*, MADCR obtained a permanent and exclusive easement to structures of the canal system, including canal walls, beds, and bottoms, for purposes including conservation, preservation, maintenance, and other uses consistent with the use of the system as a park. NPS obtained similar easement rights through the 1995 *Grant of Easement* from MADCR, including the right to maintain, repair, conduct grounds maintenance, and operate boat tours.

Most structures throughout the canal system have overlapping ownership and easement rights. A property owner (Proprietors, Boott, and/or MADCR) has a duty to achieve a reasonable standard of care[7] for the properties under their ownership. Each property owner has a right to conduct routine maintenance of their facilities to achieve a standard

[7] The Standard of Reasonable Care is typically defined as the degree of caution and concern for the safety of self and others that a reasonable person would exhibit.

of reasonable care, but they do not have an obligation to enhance or upgrade their properties. Similarly, a maintenance easement issued in common with others allows the holder to conduct routine maintenance of the property under easement, and allows others holding to also conduct routine maintenance, but the easement holder(s) is not required or permitted to upgrade or enhance the property.

An exclusive easement allows the easement owner to control and implement specific purposes as if they are the owner. MADCR has a permanent and exclusive easement over most of the canal system for the following purposes, which include enhancements and upgrades:

a) Support of all fixtures or structures of the Commonwealth now or hereafter attached;
b) Preservation and conservation;
c) Supplemental maintenance in addition to that performed by the Condemnees (the prior or current owner) and their successors and assigns;
d) Landscaping and erection of exhibits and structures;
e) Placement of barriers and fences;
f) Placement and attachment of docks, wharves, walls, and boat ramps of a temporary or permanent nature;
g) Placement of lighting and other utilities;
h) Operation and maintenance of boat locking chambers, if any, for any and all purposes; and
i) Any and all other uses consistent with the operation of the canal system as a park.

Given that MADCR's exclusive easement is throughout most of the canal system, it overlaps significantly with Boott and Proprietors' owned property. It is understood that Boott, Proprietors, and MADCR have a duty and right to maintain properties under their ownership to achieve a standard of reasonable care. Owners do not have an obligation or duty to upgrade or enhance their property. However, MADCR's exclusive easement throughout most of the Lowell canal system gives them the right to implement any of the purposes noted above, which include enhancements and upgrades, as if they were the owner. Accordingly, in cases of overlapping ownership and easement rights, it will almost entirely depend on the nature of the effort to determine obligations and responsibilities.

6.2 Resource Rights to the Lowell Canal System

For this study, resource rights were classified as such if they are owned by or issued to a party independently from any physical structure. Three resource rights were identified based on a review of the 1984 *Great Deed*, the 1986 *Order of Taking*, and the 1995 *Grant of Easement*.

Recreational resource rights are exclusively owned by MADCR. In early conceptual planning documents, MADCR was presented as the party that would own, implement, and manage any recreational resources. MADCR obtained such rights in the 1986 *Order of Taking*, including the exclusive right to use water for recreational, educational, or navigational purposes, and permanent and exclusive rights to build wharves, docks, and boat ramps. The 1990 *Preservation Plan Amendment* and the 1991 MOU, both issued after MADCR received all recreation rights, discuss MADCR's role as encouraging, managing, and approving different recreational activities throughout the Lowell canal system.

The two other identified resources are air resource rights, and water and flowage rights. Air resource rights have been owned by MADCR since issuance of the 1986 *Great Deed*. Water and flowage rights are owned by Boott and Proprietors, as established in the 1984 *Great Deed*.

6.3 Historical Management Agreements

There are two known historical management agreements between the parties with interests in the Lowell canal system. The two agreements provide the best insight into delegation of regular management tasks such as grounds maintenance, water levels, waterborne trash, and vegetation management.

The 1979 agreement states that NPS and MADCR were responsible for development and maintenance of canal walls and banks, including landscaping and repair and dredging/debris removal, as well as developing locks, gatehouses, bridges, barge landings, and displays and signs. Proprietors (ultimately Boott) were responsible for development and maintenance of the Pawtucket Dam, water levels and flows, and gatehouses.

The 1991 MOU was executed between MADCR, the NPS, and Boott. As owners of the canal walls, the MOU directed Proprietors and Boott to maintain the structural integrity of the walls, bottoms, and dam structures to the extent they have the duty to do so as owner (maintain a standard of reasonable care). Proprietors and Boott were to provide MADCR with any plans that might alter the historic fabric of the canal system, and to obtain MADCR's written prior approval. Boott was directed to operate the canal system to provide the appropriate flows and water levels.

The MOU directed NPS and MADCR to collaborate on most daily, routine management tasks regarding the Lowell canal system. They were to remove litter and other waterborne trash from the Lowell canal system, and maintain and clean all existing trash booms and safety lines/booms on the Lowell canal system. NPS and MADCR were directed to hold a joint annual meeting to develop an annual building maintenance program, annual destructive vegetation clearing program ("particularly that growing on and in the canal walls") and canal surface water cleanup program. NPS was tasked with assisting MADCR with the repair and maintenance of all historic gatehouses, such as the repair of architectural features, cleaning and repair of roof gutters, and the maintenance of locking gates and other mechanical devices.

7 Variances from FERC-Approved Study Plan

The Resources, Ownership, Boundaries, and Land Rights Study was conducted in full accordance with the methods described in the FERC-approved study plan.

8 Literature Cited

Commonwealth of Massachusetts (Commonwealth). 1986. *Order of Taking*. Commissioner of the Commonwealth, Boston, Massachusetts.

_____ 1995. *Grant of Easement*. Division of Capital Planning and Operations, Boston, Massachusetts.

Lowell Historic Canal District Commission (LHCDC). 1977. The Report of the LHCDC to the Ninety Fifth Congress of the United States of America. https://www.nps.gov/lowe/learn/management/upload/1977_-Brown-Book-_reduced.pdf [Accessed August 1, 2020].

Lowell Historic Preservation Commission (LHPC). 1980. Preservation Plan. https://www.nps.gov/lowe/learn/management/upload/1980-LOWE-Preservation-Plan.pdf [Accessed August 1, 2020].

_____ 1980. Details of the Preservation Plan. https://www.nps.gov/lowe/learn/management/upload/LOWE_475_D5_18-0612.pdf [Accessed August 1, 2020].

_____ 1990. Preservation Plan Amendment. https://www.nps.gov/lowe/learn/management/upload/LOWE_475_D5_A_0001-18-0613.pdf [Accessed August 1, 2020].

Massachusetts Department of Environmental Management. 1980. Letter of consultation on the Lowell Project License Application. Filed with the Federal Energy Regulatory Commission.

Memorandum of Understanding (MOU). 1991. Memorandum of Understanding Relative to the Maintenance and Operation of the Lowell Canal System. Filed with the Federal Energy Regulatory Commission.

National Park Service (NPS). 1980. Preservation Plan.

1981. Final General Management Plan. https://www.nps.gov/lowe/learn/management/upload/1981-LOWE-GMP.pdf [Accessed August 1, 2020].

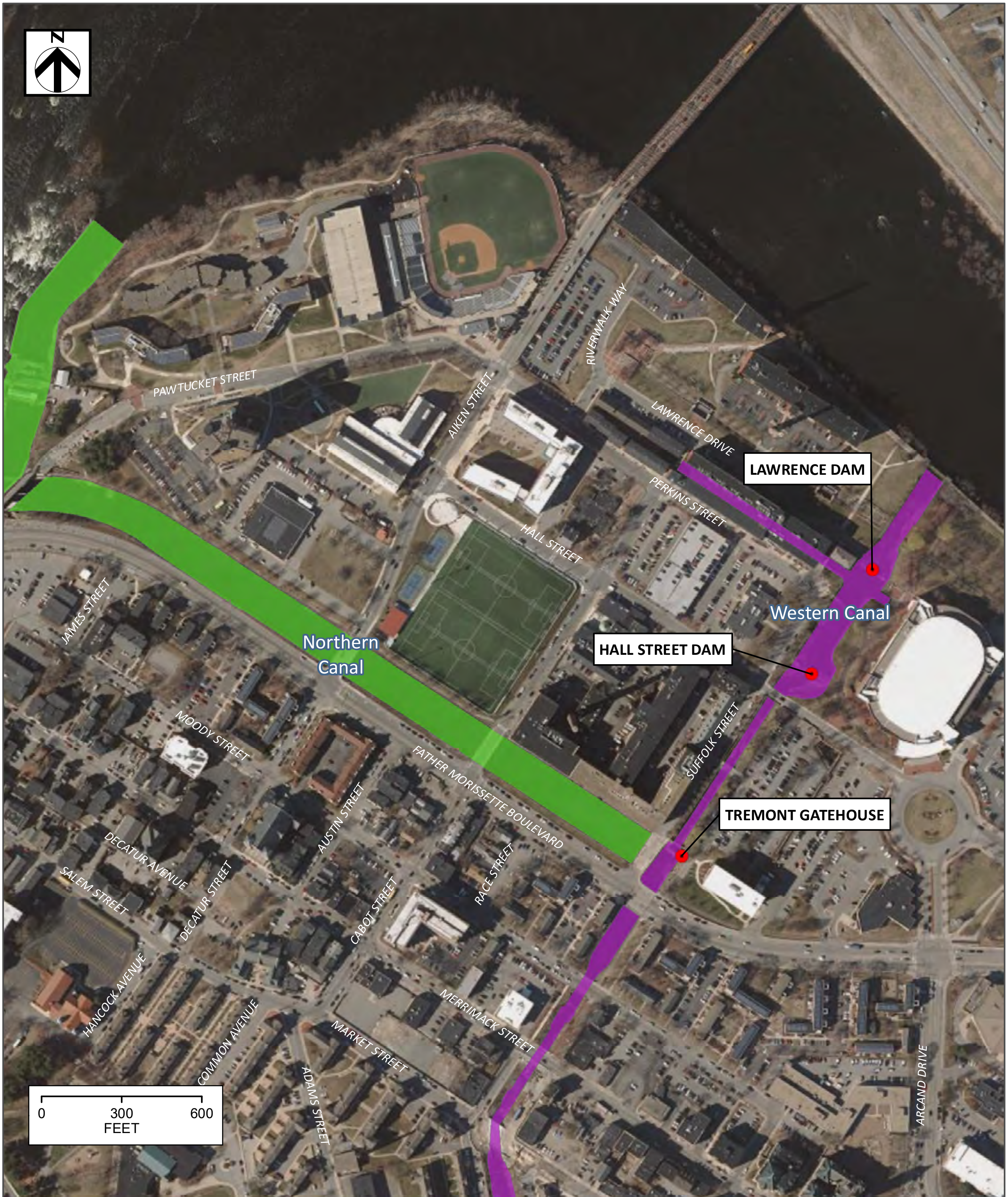
Proprietors of the Locks and Canals on the Merrimack River (Proprietors). 1984. Deed, Bill of Sale and *Grant of Easement*s.

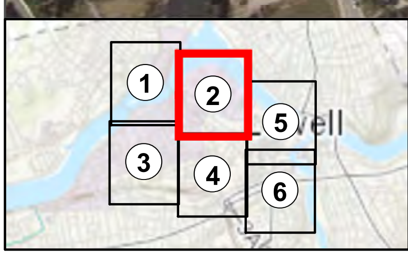
Appendix A - Project Study Area, Facilities, and Structures

Lowell Resources Facilities Map

Page 1 of 6

DATA SOURCES: Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community





Facility	Northern Canal
Eastern Canal	Pawtucket Canal
Hamilton Canal	Western Canal
Merrimack Canal	EOTROADS_ARC

Lowell Resources Facilities Map

Page 2 of 6

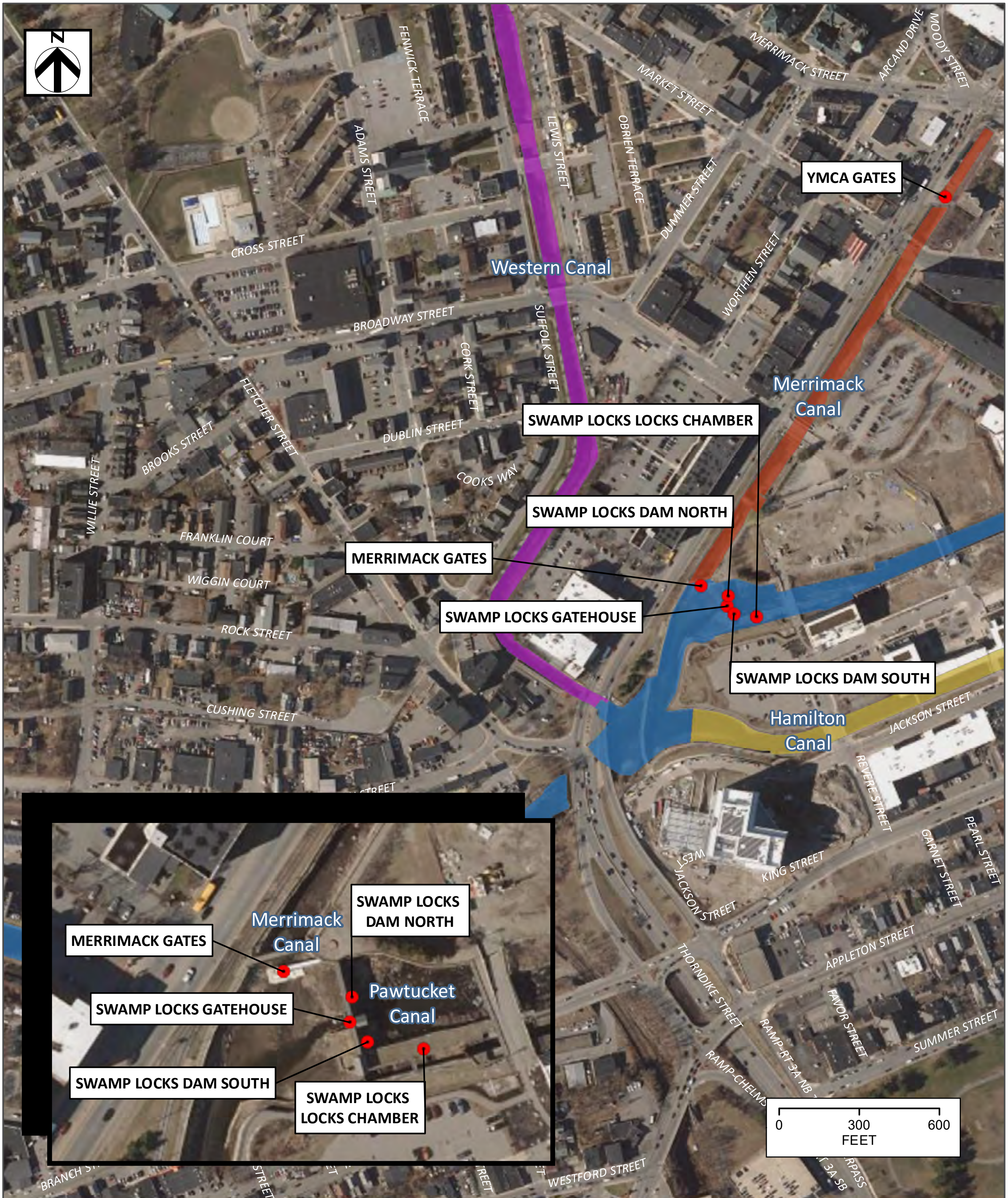
DATA SOURCES: Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

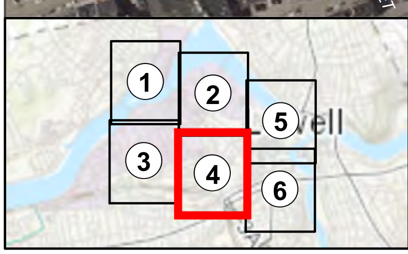
Facility		Northern Canal	
Eastern Canal		Pawtucket Canal	
Hamilton Canal		Western Canal	
Merrimack Canal		EOTROADS_ARC	

Lowell Resources Facilities Map

Page 3 of 6

DATA SOURCES: Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community



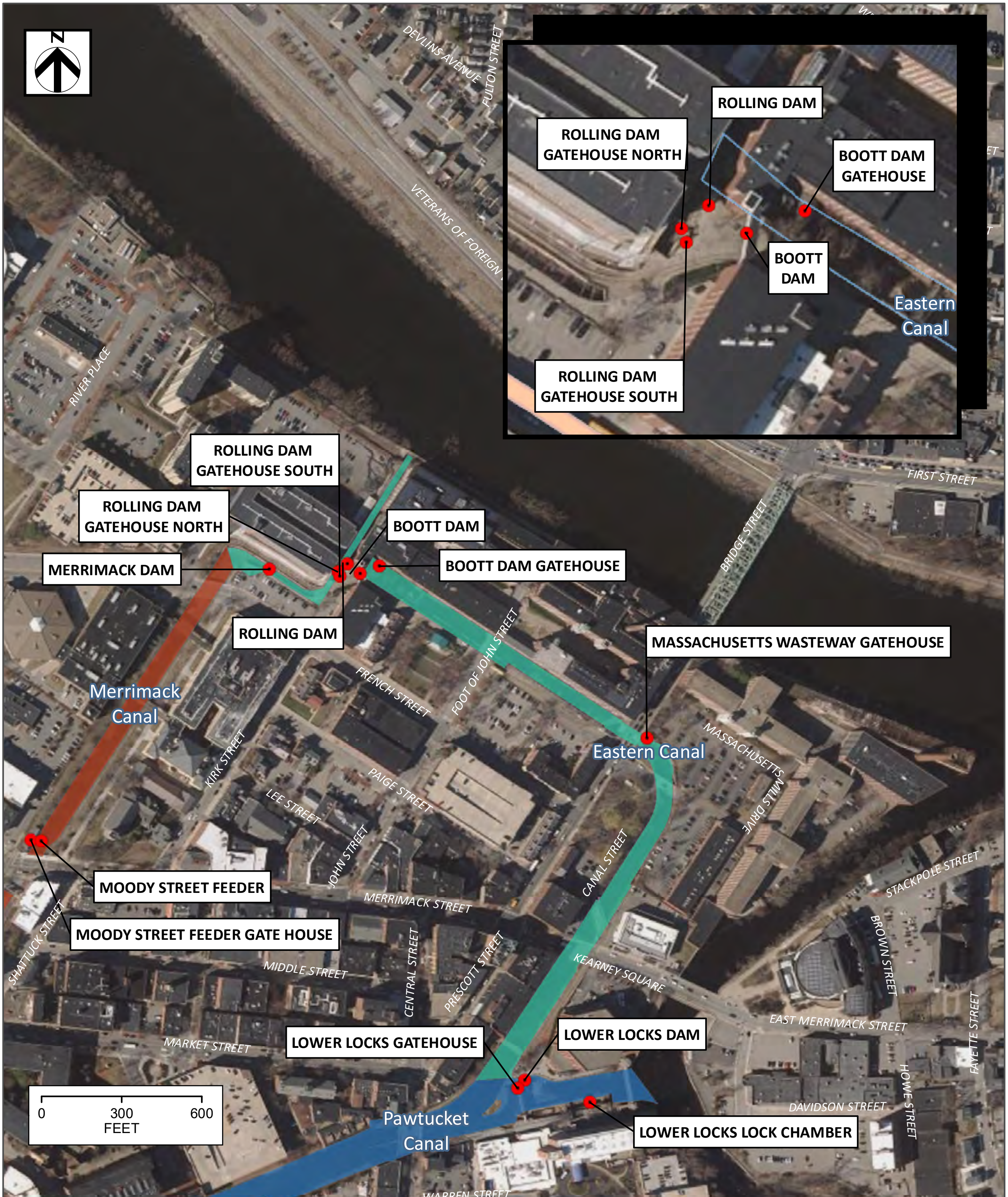


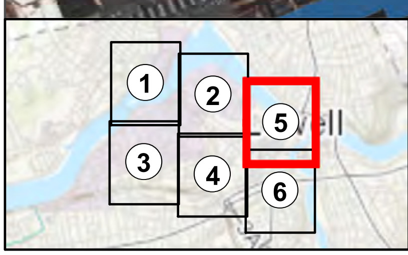
Facility	Northern Canal
Eastern Canal	Pawtucket Canal
Hamilton Canal	Western Canal
Merrimack Canal	EOTROADS_ARC

Lowell Resources Facilities Map

Page 4 of 6

DATA SOURCES: Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community



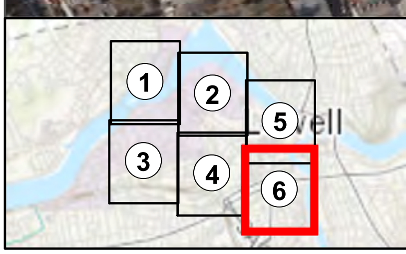


Facility	Northern Canal
Eastern Canal	Pawtucket Canal
Hamilton Canal	Western Canal
Merrimack Canal	EOTROADS_ARC

Lowell Resources Facilities Map

Page 5 of 6

DATA SOURCES: Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community



●	Facility		Northern Canal
	Eastern Canal		Pawtucket Canal
	Hamilton Canal		Western Canal
	Merrimack Canal		EOTROADS_ARC

Lowell Resources Facilities Map

Page 6 of 6

DATA SOURCES: Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Appendix B - 1984 *Great Deed*

BK2690 PG 542

See Agmt B. 7444 P. 302

DEED, BILL OF SALE AND GRANT OF EASEMENTS

PROPRIETORS OF THE LOCKS AND CANALS ON MERRIMACK RIVER and BOOTT MILLS, both Massachusetts corporations with offices at Foot of John Street, Lowell, Middlesex County, Massachusetts (together with their successors and assigns, the "Grantors"), for TEN DOLLARS and other good and valuable consideration, hereby grant with warranty covenants to BOOTT HYDROPOWER, INC., a Massachusetts corporation with offices at Foot of John Street, Lowell, Middlesex County, Massachusetts (together with its successors and assigns, the "Grantee"), the following land, easements, property and interests and rights in property all located (except as expressly noted) in Lowell, Middlesex County, Massachusetts:

A. Land, Waterways, Improvements. The land, together with the buildings, improvements, fixtures and other property appurtenant thereto, consisting of those lands, canals, dams or portions thereof and other property set forth below (collectively, the "Parcels"):

1. Parcel I: That certain parcel of land, situated on the northerly side of Jackson Street, being shown as a right of way on a plan of land entitled "Compiled Plan in Lowell, Mass. owned by Courier-Citizen Company" dated March 10, 1978, recorded with Middlesex County North District Registry of Deeds (the "Registry"), Book of Plans 126, Plan 112.

2. Parcel II: That portion of the Merrimack River bounded as follows:

STARTING	from a point at the intersection of the easterly end of the upstream side of the Pawtucket Dam and the shoreline of the Merrimack River, thence
NORTHEASTERLY	along the shoreline of the Merrimack River to the intersection of the shoreline with land of The Commonwealth of Massachusetts, University of Lowell, described as Parcel 2 on a certain "Plan of Land in Lowell, Massachusetts prepared for Proprietors of Locks & Canals on Merrimack River and Massachusetts Wholesale Electric Co.; June 14, 1983" and recorded with the Registry in Plan Book 141, Plan 139, thence
NORTHWESTERLY	along said Parcel 2 to the centerline of the Merrimack River and continuing in the same direction to the opposing shoreline of the Merrimack River, thence
SOUTHWESTERLY	along the shoreline of the Merrimack River to the point of intersection with the westerly

end of the upstream side of the Pawtucket Dam, and thence

EASTERLY along the upstream side of the Pawtucket Dam to the point of beginning.

The Grantors also convey all their right, title and interest, if any, in and to the premises subject to the Lease dated September 28, 1983 between the University of Lowell and Boott Mills, notice of which Lease is recorded with the Registry in Book 2680, Page 281, said premises being shown as Parcels 1 and 2 on a certain Plan entitled "Plan of Land in Lowell, Massachusetts prepared for Proprietors of Locks and Canals on Merrimack River and Massachusetts Wholesale Electric Co.; June 14, 1983" and recorded with the Registry in Plan Book 141, Plan 139; provided, however, that the rights described in this paragraph shall not include any rights which Boott Mills has as lessee under said Lease.

Said Parcel II includes the Pawtucket Dam in its entirety and any and all equipment and mechanisms located in or on said dam or appurtenant thereto, including without limitation fishways and flashboards. Said Parcel II is subject to the rights of The Commonwealth of Massachusetts, the City of Lowell and others legally entitled to the use, maintenance and operation of the University Avenue Bridge and, pursuant to Chapter 132 of the Massachusetts Acts of 1835, the School Street Bridge crossing the same.

3. Parcel III: The land and waterways historically known and designated as follows:

A. The Northern Canal
B. The Western Canal
C. The Lower Western Canal
D. The Eastern Canal
E. The Merrimack Canal
F. The Lawrence Canal
G. The Hamilton Canal
H. The Moody Street Feeder

Said canals are conveyed in their entirety to the exterior plane of the existing canal walls, and including canal fences located thereon, the fee underlying the same, and all waterways and sluiceways forming a part of such canals, and including all dams and gates contained therein and including, but not limited to, the following dams and gates:

A. The Lawrence Dam
B. The Hall Street Dam
C. The Rolling Dam
D. The Merrimack Gates
E. The Boott Dam
F. The Northern Canal Headgates

Said dams and gates are conveyed together with the fee to the land underlying the same and all equipment and mechanisms located in or on said dams and gates or appurtenant thereto, including, but not limited to, wasteways, penstocks, tailraces, headgates and racks.

Parcel III includes all Grantor's interest in the following bridges crossing the canals described above:

A. Over Eastern Canal:	1.	East Merrimack Street
	2.	Bridge Street
B. Over Merrimack Canal:	1.	Merrimack Street (only 25 feet either side of center line)
C. Over Western Canal:	1.	Merrimack Street (only 25 feet either side of center line)
D. Over Northern Canal:	1.	Suffolk Street
	2.	Pawtucket Street

Parcel III is subject to rights of The Commonwealth of Massachusetts, the City of Lowell and others legally entitled to the use, maintenance and operation of the above described bridges and other existing bridges crossing the canals described above.

Grantors hereby expressly reserve from the within grant, and Parcel III does not include, that portion of those structures, historically known and designated as set forth below, in or above the aforementioned canals, dams and gates which is above the following noted elevations above Mean Sea Level, National Geodetic Vertical Datum (hereinafter collectively referred to as the "Gatehouses"):

A. Northern Canal Gatehouse, above 101.2 feet M.S.L., including the Northern Canal Gatehouse Locks, above 82.7 feet M.S.L.
B. Tremont Gatehouse, above 90.2 feet M.S.L.
C. Hamilton Gatehouse, above 90.2 feet M.S.L.
D. Massachusetts Wasteway Gatehouse, above 80.2 feet M.S.L.
E. Rolling Dam Gatehouse, above 83.7 feet M.S.L.
F. Moody Street Feeder Gatehouse (also known as Merrimack Gatehouse), above 92.2 feet M.S.L.;
G. Boott Dam Gatehouse, above 74.2 feet M.S.L.;

however, Parcel III does include all mechanisms, controls and other machinery and equipment located above said elevations which are necessary for the control and operation of the lands, dams and gates upon which the Gatehouses rest.

The Gatehouses are hereby intended to be severed from the lands, dams and gates upon which they rest, so that the Gatehouses will be considered real property of the Grantors separate from said land, dams and gates, and each may forever hereafter independently be conveyed, transferred, mortgaged and leased.

Grantors also hereby expressly reserve from the within grant, and Parcel III does not include, the so-called "Great River Wall," being the land and structures located thereon (including without limitation the Northern Canal Wastegate House, also called the High Bridge Gatehouse) dividing the Northern Canal and the Merrimack River which starts at the Northern Canal Gatehouse and extends northeasterly to the intersection of the Northern Canal with land of The Commonwealth of Massachusetts, University of Lowell, described as Parcel 1 on a certain "Plan of Land in Lowell, Massachusetts prepared for Proprietors of Locks & Canals on Merrimack River and Massachusetts Wholesale Electric Co.; June 14, 1983" and recorded with the Registry in Plan Book 141, Plan 139.

Said Parcel III also does not include those portions of canal walls previously conveyed as evidenced by instruments recorded with the Registry in Book 1428, Page 185, Book 1608, Page 357 and Book 1690, Page 429.

B. Easements. The following easements, newly created hereby, held or hereafter acquired by the Grantors, which are hereby made appurtenant to the Parcels:

1. Access and Repair. The Grantors grant an easement over the remaining lands of the Grantors, and grant the benefit of easements over lands of others, in each case which the Grantors may now or hereafter own, possess or have the right to use, for the purpose of obtaining access to the Parcels from public ways, for the providing of utilities necessary for the operation of the Parcels and entering on such portions of the property adjacent to the Parcels with personnel, equipment and materials for the purposes of maintaining, repairing, replacing, reconstructing and rebuilding the Parcels or any property located thereon.

2. Easement to Pawtucket Canal. The Grantors further grant an easement, in common with the Grantors and others entitled thereto, to the Pawtucket Canal, Lower Pawtucket

Canal, the Pawtucket Canal Guard Gate and Locks, the Swamp Locks Dam and the Lower Locks Dam for the uninterrupted flowage of water to the canals described in Parcel III above, together with the right to install conduits, pipes and wiring therein and the right to maintain, repair and replace the canal walls and fences on and bridges over said Pawtucket and Lower Pawtucket Canals and to maintain and operate the Pawtucket Canal Guard Gate and Locks, the Swamp Locks Dam and the Lower Locks Dam.

3. Easement for Access to Structures. The Grantors further grant easements to enter, and maintain real and personal property in, the Gatehouses and in addition those other structures in or adjacent to the above said canals and dams historically known and designated as follows:

A. Blacksmith Shop
B. Old Guard Locks Gatehouse
C. Swamp Locks Gatehouse
D. Lower Locks Gatehouse
E. Great River Wall (as described in Parcel III above), including without limitation the Northern Canal Wastegate House (also called the Highbridge Gatehouse)

Said easements consist of the exclusive right of operating and controlling the Gatehouses and the above said structures and locating, keeping in place, maintaining, replacing, operating, controlling and disposing of the control machinery and equipment, gauge equipment and other mechanisms located therein and, in common with the Grantors and others entitled thereto, for access to and for maintenance and repair of the Gatehouses and the above said structures and access to and maintenance, repair and installation of the control machinery and equipment, gauge equipment and such other mechanisms located therein as the same may from time to time be repaired, reconstructed or replaced. The Grantors further grant an easement over other lands of the Grantors, and grant the benefits of easements owned by Grantors over lands of others, in each case which the Grantors may now or hereafter own, possess or have the right to use, for powerlines, utilities and for access to and egress from the above said premises and public ways.

C. Water and Flowage Rights. The Grantors hereby grant to the Grantee any and all riparian rights, water rights and "Mill Powers" which the Grantors may have in the water flowing in the Merrimack River in Middlesex County, Massachusetts, and Hillsborough County, New Hampshire. Such rights include any and all water rights which may exist regardless of how acquired, including, without limitation, any and all water rights which Grantors may have by virtue of riparian rights or any and all water rights which may have been specifically granted to Grantors, or acquired through the conveyance of interests in any dam or flowage rights or acquired by prescription, whether now owned or hereafter acquired. Without limiting the generality of the foregoing, said rights include:

(i) the right, without payment of compensation therefor, to utilize all the waters of the Merrimack River upstream of the Pawtucket Dam, and the right to extract and use such water, subject only to the rights of riparian owners along the Merrimack River and rights previously granted in (x) Agreement between Grantors and the City of Lowell et al. dated June 21, 1875 recorded with the Registry in Book 128, Page 113, (y) Agreement between Grantors and the City of Lowell et al. dated December 31, 1875 recorded with the Registry in Book 114, Page 121, and (z) Release among Grantors and The Commonwealth of Massachusetts dated April 17, 1896 recorded with the Registry in Book 274, Page 225.

(ii) the right, without payment of compensation therefor, to dam and divert all the water from the Merrimack River for the distance from the Pawtucket Dam to the intersection of the Merrimack River and the Concord River, through the Pawtucket or Northern Canals or otherwise, and the right to extract and use such water, and

(iii) the right, without payment of compensation therefor, to overflow, flood, and cover to a height of 92.2 feet above Mean Sea Level (National Geodetic Vertical Datum) from July through February, and to a height of 91.2 feet above Mean Sea Level from March through June, real property in Middlesex County, Massachusetts, and Hillsborough County, New Hampshire, adjacent to the Merrimack River upstream from the current site of the Pawtucket Dam with flood water, slack space water or back water created by the operation of a dam or dams across the Merrimack River in the vicinity of the current site of the Pawtucket Dam together with the right to enter on such real property from time to time to maintain the dam or dams and the reservoir created by such dam or dams and to clear the reservoir of any structures, growth or other obstruction below elevation 92.2 feet above Mean Sea Level which interfere with the operation of such dam or dams across the Merrimack River.

Said rights are subject to rights previously conveyed pursuant to the Agreement dated March 7, 1983 between the Grantors and James T. Lichoulas, as trustee for the Appleton Trust, as amended, recorded with the Registry in Book 2611, Page 630 and pursuant to the Agreement dated February 1, 1982 among the Grantors, Corporation Investments, Inc., Kenneth M. Scagel, Sr., Kenneth M. Scagel, Jr., Atlantic Associates and Massachusetts Hydro Associates recorded with the Registry in Book 2611, Page 624.

D. Reservations. The Grantors for themselves, their successors and assigns, reserve the right to use the surface water in the canals described in Parcel III above and the Pawtucket Canal for recreation and transportation purposes, provided that said use and operation in any and all events does not interfere with the use and operation of the Parcels for the generation of power. The Grantors also reserve for themselves, their successors and assigns, the right to use up to a combined total of 100 cubic feet per second of water in such canals, and the right to use such canals, to maintain and operate existing steam distribution and fire protection systems owned by the Grantors and to provide process water for customers of the Grantors, including improvements to or expansions of such systems within said limitations of flowage.

Subject to the easements herein granted and conveyed, the Grantors further reserve for themselves, their successors and assigns, any and all surface land and all air space above the premises described above as Parcel III, and further reserve the right to have access to and occupy, use and develop such surface land and air space; provided, however, that the occupation, use and development of such surface land and air space in any and all events shall neither interfere in any way with the use or operation of any of the Parcels, the facilities or rights described herein nor any other property of Grantees used for the purpose of generating hydroelectric power nor interfere in any way with access to the premises described above as Parcel III for purposes of maintaining, repairing, replacing, reconstructing and rebuilding the premises described as Parcel III as may from time to time become necessary in connection with the operation and upkeep of the same.

E. Fixtures and Equipment. The Grantor hereby grants to Grantees all hydro and generating equipment of the Grantors, including all turbines, generators, governors, exciters, control panels, main breakers and extra parts, tools, patterns, blueprints and performance data, transformers, substations, electrical transmission lines, and related mechanisms necessary for the production and transmission of electricity to the generator control panels. Without limiting the generality of the foregoing, said property includes the turbines and generators (the "Turbines") listed and described in Exhibit A and all appurtenant equipment and fixtures located in the rooms housing the same and the electrical transformers (the "Transformers") listed and described in Exhibit B.

F. Easements. The property described in Section E above is conveyed with the benefit of the following easements:

1. Turbine Rooms. An easement to enter, occupy, use, maintain and repair the rooms in which the Turbines are located for the purpose of keeping in place, maintaining, operating, repairing, replacing and otherwise dealing with the Turbines and all appurtenant equipment and fixtures located in the rooms housing the same. Included is the right at all times to enter and have unrestricted access to such rooms for such purposes, and to remove or alter the walls thereof (both interior and exterior) to the extent necessary or convenient to such purposes, provided that such walls shall be restored to their original condition (or to a condition having a similar functional utility and appearance) promptly upon completion of the activity leading to their removal or alteration.

2. Penstocks and Tailraces. An easement to operate, maintain, repair and replace the existing penstocks leading to the Turbines from the Merrimack Canal, Eastern Canal or Hamilton Canal, as the case may be, and to remove any such penstock in order to replace it with a penstock of the same or a different size and construction. Also an easement to operate, maintain, repair and replace the existing tailraces leading from the Turbines to the Pawtucket Canal, the Concord River or the Merrimack River, as the case may be, and to remove any such tailrace in order to replace it with a tailrace of the same or a difference size and construction.

3. Transformers. An easement to keep in place, locate, operate, maintain, repair, remove and replace the Transformers and an easement for unrestricted access thereto for such purposes.

4. Transmission Lines. Also the right to use, maintain and repair existing electrical transmission lines from the generator control panels, including all substations and transformers, of the Grantors for the purpose of operating the aforesaid equipment and facilities, until such time as the aforesaid equipment and facilities are permanently disconnected from such transmission lines. Also the right to construct, reconstruct, operate, keep in place, maintain, repair, remove and replace electrical transmission lines and lines for the transmission of intelligence by electricity, including connection to the generator control panels, substations, transformers, junction boxes, wires, cables, conduits and other necessary appurtenances thereto, upon, over, across and under the lands, buildings, structures and easements of the Grantors for the purpose of generating and selling power, whether generated by the facilities described herein, or by other power facilities owned by the Grantee in the City of Lowell.

G. General. The land, easements, equipment and rights described herein are conveyed together with all necessary rights and easements for the purpose of utilizing the aforesaid facilities, equipment and fixtures for the purpose of producing and selling power, including the right to construct, reconstruct, modify and rehabilitate such facilities, equipment and fixtures now existing and to install additional facilities, equipment and fixtures of like purpose, including without limitation an unrestricted right of access over other lands, easements and buildings of the Grantors from existing public ways as are necessary to fulfill the purposes of the within grant and conveyance and the right to utilize the within conveyed premises, structures, facilities, waterways and equipment to their maximum potential for such purposes.

For Grantors's title, see the following:

Deed of James Parkhurst dated September 20, 1792, recorded with Middlesex South District Registry of Deeds, Book 108, Page 461;

Deed of Benjamin Melvin dated November 10, 1795, recorded with Middlesex South District Registry of Deeds, Book 115, Page 518;

Deed of Joseph Tyler dated March 17, 1797, recorded with Middlesex South District Registry of Deeds, Book 125, Page 97;

Deed of Nathan Tyler dated February 17, 1798, recorded with Middlesex South District Registry of Deeds, Book 128, Page 223; and

Deed of Merrimack Manufacturing Co. dated January 2, 1826, recorded with Middlesex South District Registry of Deeds, Book 269, Page 1.

The extent and nature of the consideration herein is such that deed stamps are not required.

Reference is made to plans available for inspection at the offices of Chicago Title Insurance Co., which is currently located at 133 Federal Street, Boston, Massachusetts, for general identification and location of certain of the premises conveyed hereby.

IN WITNESS WHEREOF, Proprietors of the Locks and Canals on Merrimack River and Boott Mills have caused their corporate seals to be hereto affixed, and these presents signed in their name and behalf by Melvin G. Lezberg, their President, hereunto duly authorized, this 16th day of January, 1984.

PROPRIETORS OF THE LOCKS AND CANALS ON MERRIMACK RIVER

by Melvin G. Lezberg

Melvin G. Lezberg
President

BOOTT MILLS, INC.

by Melvin G. Lezberg

Melvin G. Lezberg
President

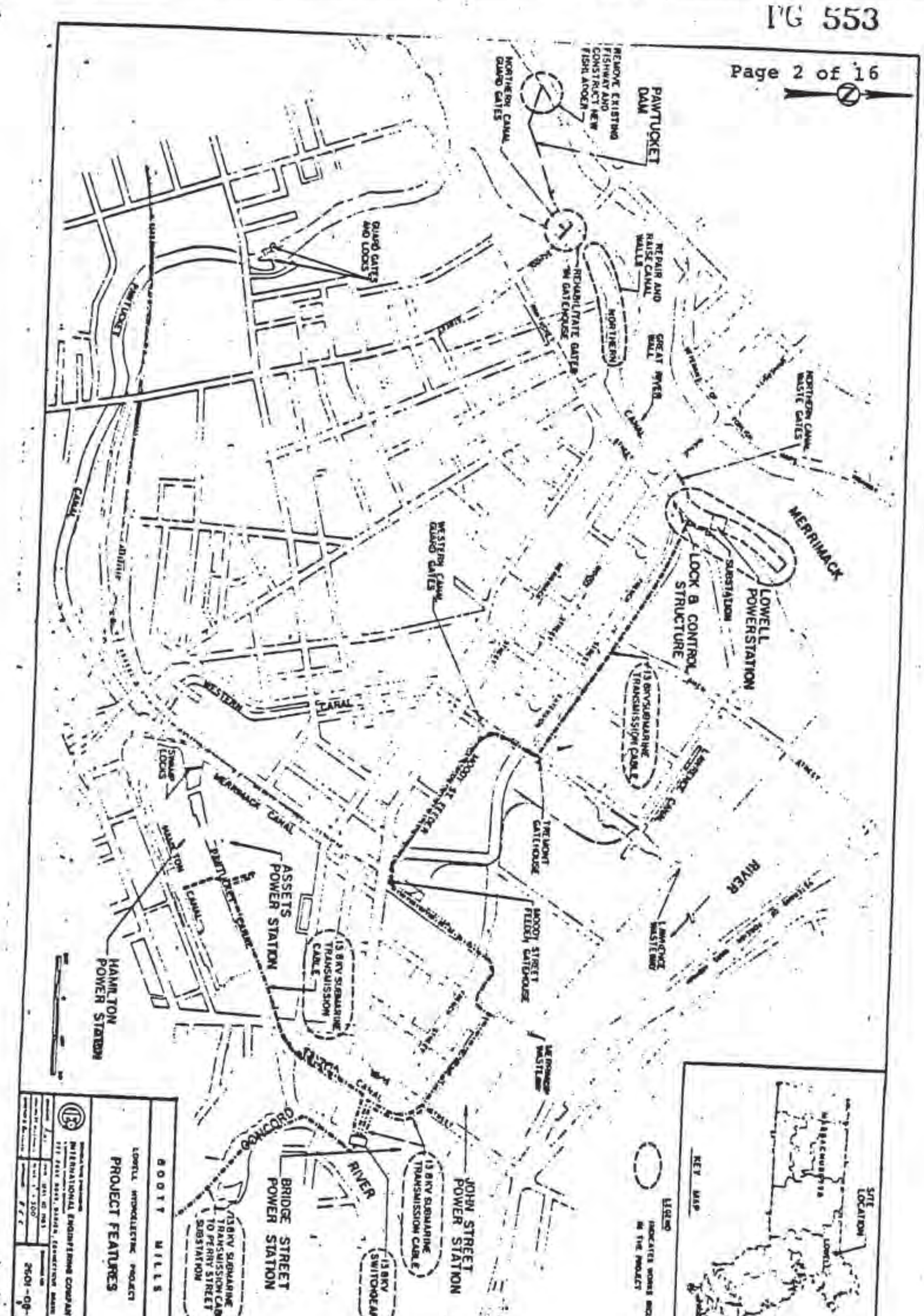
COUNTY OF NEW YORK)
STATE OF NEW YORK)

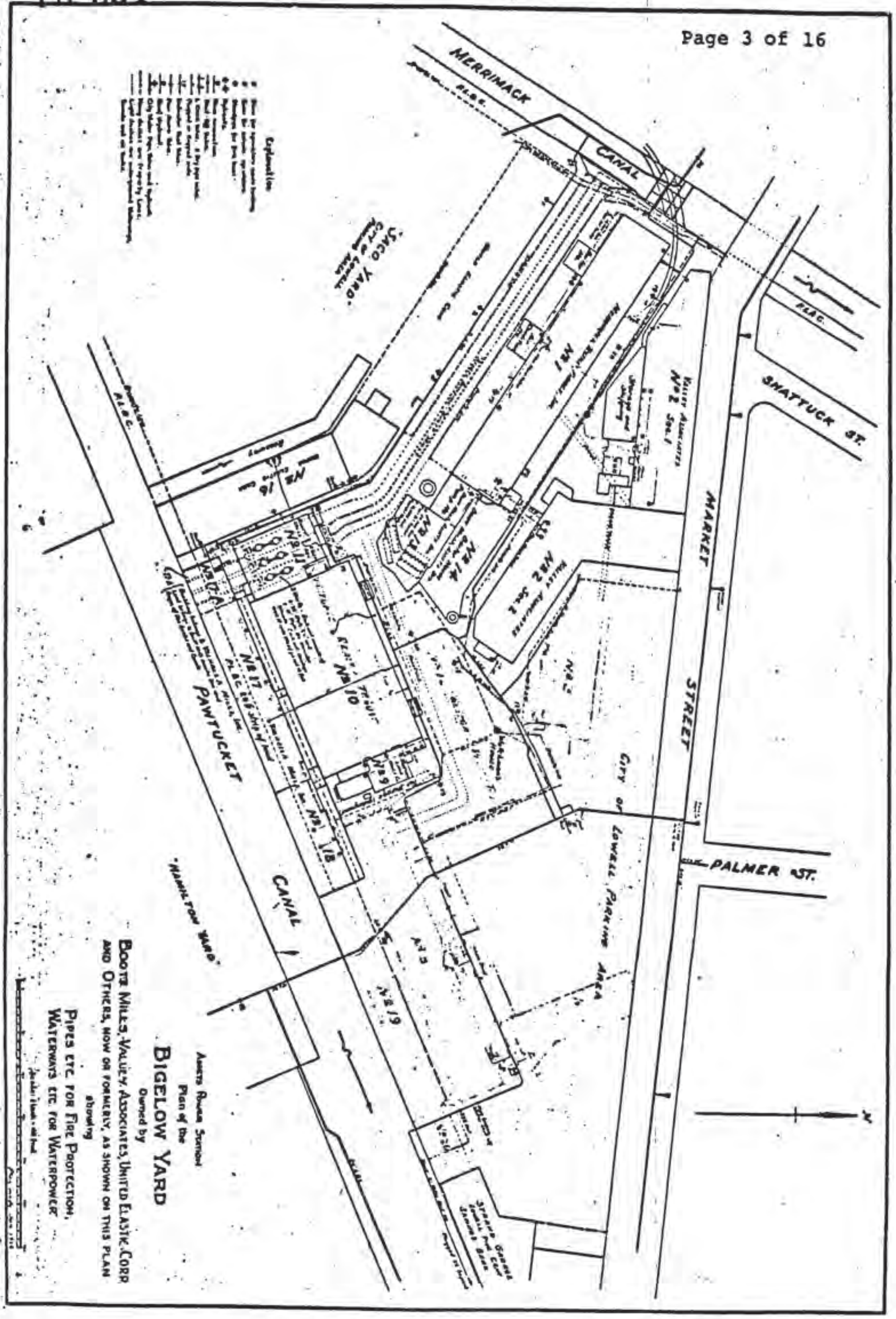
On this 16th day of January, 1984, personally appeared before me Melvin G. Lezberg, who being by me duly sworn did say that he is President of Boott Mills and of Boott Hydropower, Inc., and that this instrument was duly signed and sealed on behalf of such corporations, and such person acknowledged the foregoing to be the free act and deed of such corporations.

Notary Public
My Commission Expires:

[illegible]
Commission Expires March 30, 1986

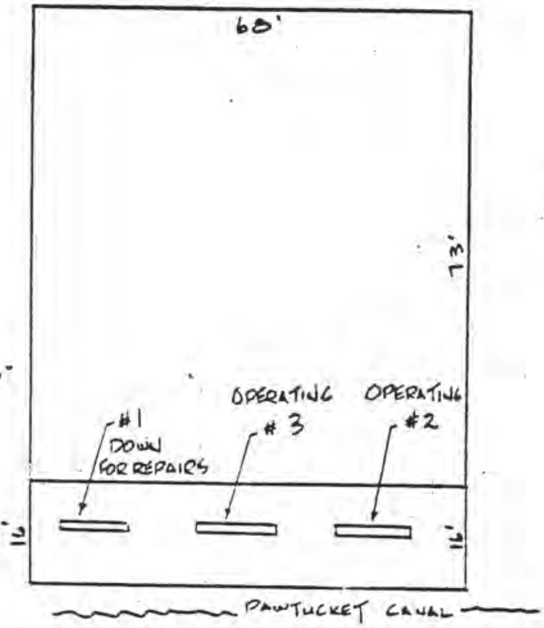
Description of Turbines and Generators


PAWTUCKET DAM
MERRIMACK
LOWELL POWERSTATION
LOCK & CONTROL STRUCTURE
WESTERN CANAL
MERRIMACK CANAL
ASSETS POWER STATION
HAMILTON POWER STATION
RIVER
JOHN STREET POWER STATION
BRIDGE STREET POWER STATION
CONCORD
RIVER
KEY MAP
SITE LOCATION
LEGEND
BOOTT MILLS
LOWELL HYDROELECTRIC PROJECT
PROJECT FEATURES


MERRIMACK
CANAL
SACO YARD
SHATTUCK ST.
MARKET
STREET
PALMER ST.
CITY OF LOWELL PARKING AREA
PAWTUCKET
CANAL
"HAMILTON YARD"
No 1
No 2
No 10
No 14
No 16
No 17
No 19
Plan of the
BIGELOW YARD
Owned by
BOOTT MILLS, VALLEY ASSOCIATES, UNITED ELASTIC CORP.
AND OTHERS, NOW OR FORMERLY, AS SHOWN ON THIS PLAN
showing
PIPES ETC. FOR FIRE PROTECTION,
WATERWAYS ETC. FOR WATERPOWER
Explanation

— DESCRIPTION —
— OF —
GENERATORS AND TURBINES
— LOCATED IN —
BOOTT MILLS, LOWELL, MA.
SCALE 1" = 20' — DECEMBER 1983

Desmarais



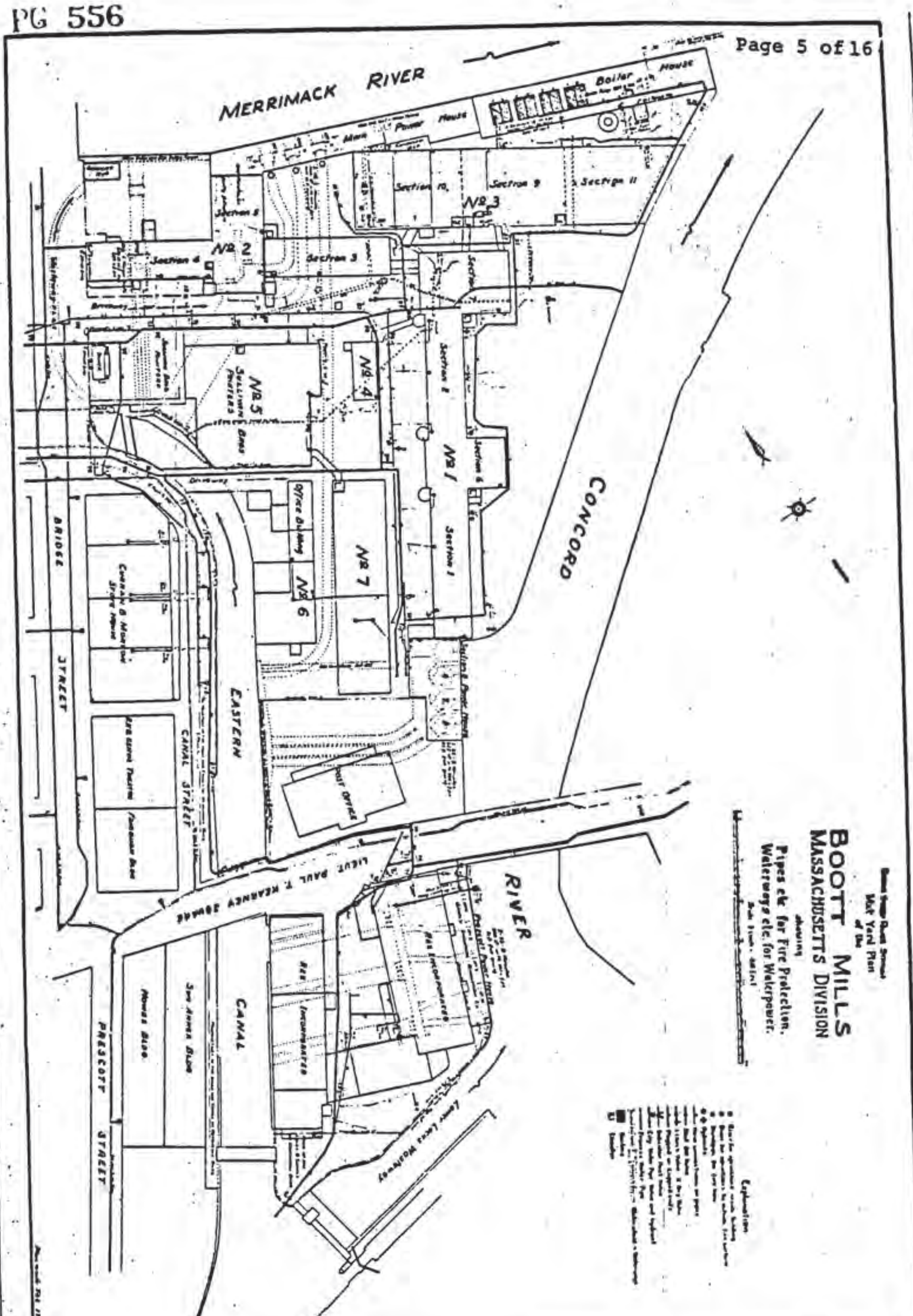
TURBINE DATA
#1 - #2 - #3
HERCULES DOUBLE
RUNNER STYLES "C & D"
33 AND 31 INCHES.

LOCATION: MARKET ST. ASSETS DIVISION
DESCRIPTION: 3 - GENERAL ELECTRIC ALTERNATING
CURRENT HORIZONTAL TYPE GENERATORS
GENERATOR NUMBERS: #1 - 227896
#3 - 227897
#2 - UNACCESSIBLE

COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais #29336
REGISTERED LAND SURVEYOR

I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

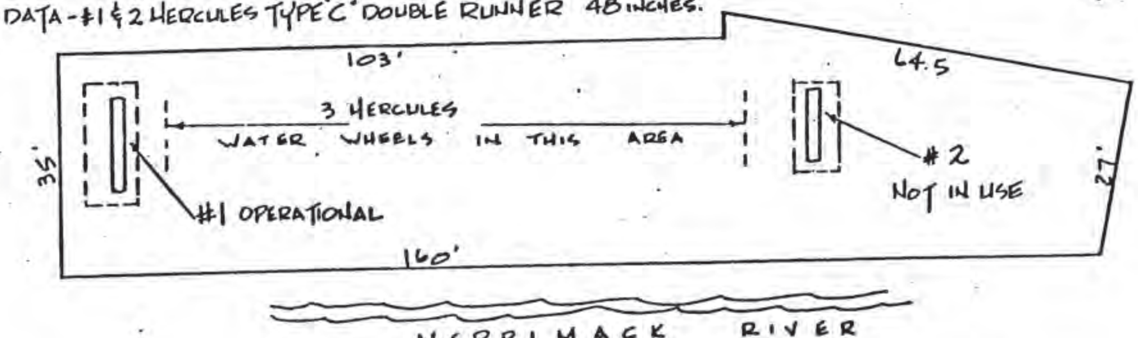
Raymond F. Desmarais R.L.S.


MERRIMACK RIVER
CONCORD RIVER
BOOTT MILLS
MASSACHUSETTS DIVISION
Pipes etc for Fire Protection,
Waterways etc. for Waterpower.
EASTERN CANAL
BRIDGE STREET
PRESCOTT STREET
CANAL STREET
LIEUT. PAUL F. KEARNEY SQUARE
Post Office
Office Building
Boiler House
Power House
Section 1
Section 2
Section 3
Section 4
Section 5
Section 9
Section 10
Section 11
No. 1
No. 2
No. 3
No. 4
No. 5
No. 6
No. 7

— DESCRIPTION —
— OF —
GENERATORS AND TURBINES
— LOCATED IN —
BOOTT MILLS, LOWELL, MA.
SCALE 1" = 20' —— DECEMBER 1983

Desmarais

LOCATION - BRIDGE ST. - MAIN POWER.
DESCRIPTION. 2 - GENERAL ELECTRIC HORIZONTAL GENERATORS
GENERATOR NUMBERS #1 - 214156 - 600V - 1250KW - 150AMPS.
NUMBER #2 NOT ACCESSIBLE - 750 KW - 600V
TURBINE DATA - #1 & 2 HERCULES TYPE "C" DOUBLE RUNNER 48 INCHES.



I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

Raymond F. Desmarais R.L.S.

COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais #29996
REGISTERED LAND SURVEYOR

— DESCRIPTION —
— OF —
GENERATORS AND TURBINES
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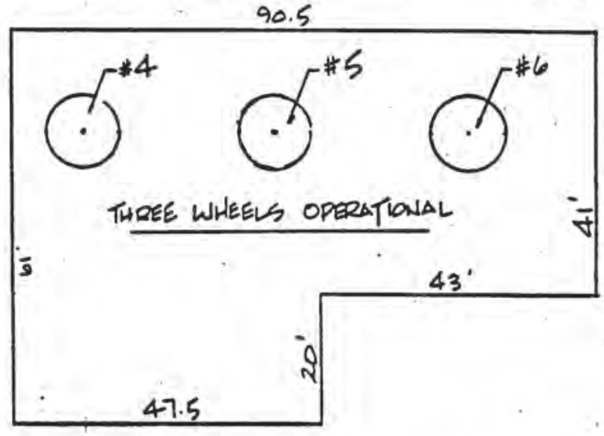
BOOTT MILLS, LOWELL, MA.

SCALE 1" = 20' ——— DECEMBER 1983



LOCATION - SECTION 8 POWER HOUSE - BRIDGE ST.
DESCRIPTION - GENERAL ELECTRIC TURBINES #4-5-6
GENERATOR NUMBER - #4-1353168 #5-1353169 #6-1353170
(ALL 600V - 360 K.W.)
TURBINE DATA - #4-#5-#6 HERCULES TYPE "D" SINGLE RUNNER 42 INCHES

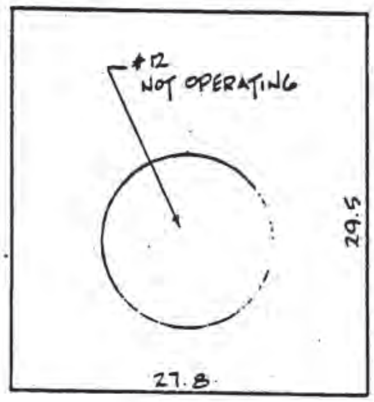
I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais
#29996
REGISTERED LAND SURVEYOR

Raymond F. Desmarais R.L.S.

— DESCRIPTION —
— OF —
GENERATORS AND TURBINES
— LOCATED IN —
BOOTT MILLS, LOWELL, MA.
SCALE 1" = 10' ——— DECEMBER 1983

Desmarais

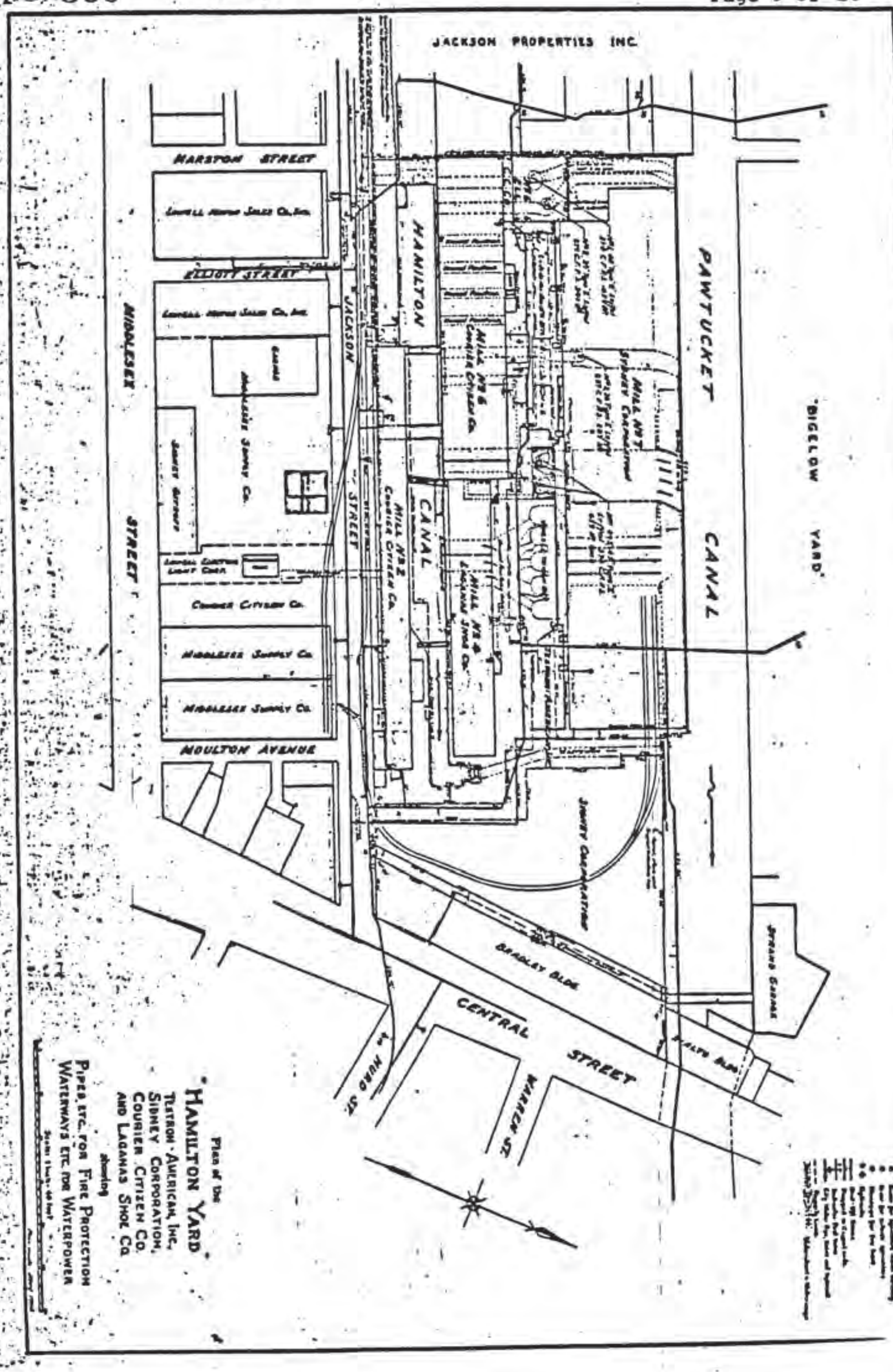


LOCATION - SECTION 4 - BRIDGE STREET
DESCRIPTION - GENERAL ELECTRIC - TURBINE #12
GENERATOR NUMBER - 2540290 - 600V
TURBINE DATA - MORGAN SMITH TYPE "S" SINGLE RUNNER 46.5 IN.

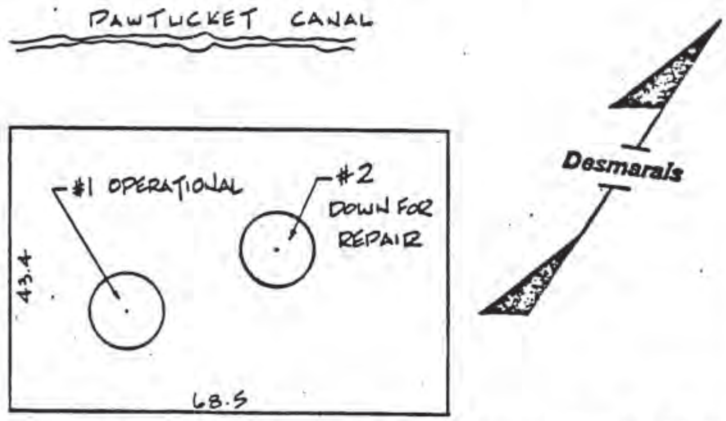
I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais
#29996
REGISTERED LAND SURVEYOR

Raymond F. Desmarais R.L.S.


JACKSON PROPERTIES INC.
MARSTON STREET
ELLIOTT STREET
MOULTON AVENUE
MIDDLESEX STREET
JACKSON STREET
HAMILTON CANAL
PAWTUCKET CANAL
BIGELOW YARD
CENTRAL STREET
HURD ST.
WARREN ST.
BRADLEY BLDG.
Lowell Motor Sales Co. Inc.
Middlesex Supply Co.
Courier Citizen Co.
Mill No 2 Courier Citizen Co.
Mill No 6 Courier Citizen Co.
Mill No 4 Laganas Shoe Co.
Mill No 7 Sidney Corporation
Sidney Corporation
Plan of the Hamilton Yard
Textron-American, Inc.
Sidney Corporation,
Courier Citizen Co.
and Laganas Shoe Co.
showing
Pipes, etc. for Fire Protection
Waterways etc. for Waterpower

— DESCRIPTION —
— OF —
GENERATORS AND TURBINES
— LOCATED IN —
BOOTT MILLS, LOWELL, MA.
SCALE 1" = 20' —— DECEMBER 1983



TURBINE DATA - #1 & 2 LEFFEL TYPE Z SINGLE RUNNER #1-45IN #2-39IN.
LOCATION - HAMILTON STATION - JACKSON ST.
DESCRIPTION - #1 WESTINGHOUSE ELEC. MFG. CO.
ALTERNATING CURRENT GENERATOR.
DESCRIPTION - #2 ELECTRIC MACHINERY CO.
GENERATOR NUMBERS - #1 - 2603203 #2 - 503508

I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais
#29996
REGISTERED LAND SURVEYOR

Raymond F. Desmarais R.L.S.

— DESCRIPTION —
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GENERATORS AND TURBINES
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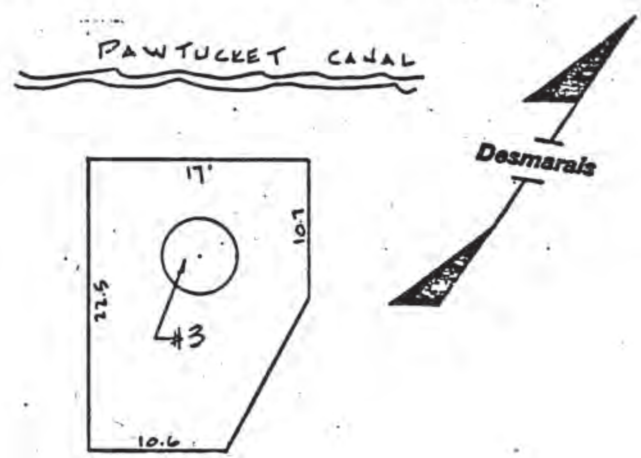
BOOTT MILLS, LOWELL, MA.

SCALE 1" = 10' ——— DECEMBER 1983



LOCATION - HAMILTON STA. - JACKSON ST.
DESCRIPTION - ELECTRIC MACHINERY
GENERATOR NUMBER - 353484
TURBINE DATA - NO. 3 LEFFEL TYPE Z SINGLE RUNNER 36 INCHES.

I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais
#29996
REGISTERED LAND SURVEYOR

Raymond F. Desmarais R.L.S.

— DESCRIPTION —
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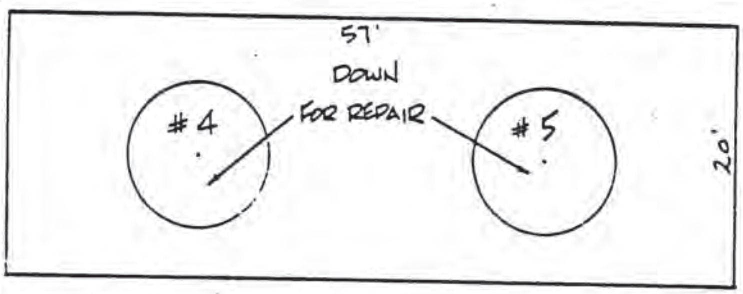
GENERATORS AND TURBINES
— LOCATED IN —
BOOTT MILLS; LOWELL, MA.
SCALE 1" = 10' ——— DECEMBER 1983

Desmarais

PAWTUCKET CANAL

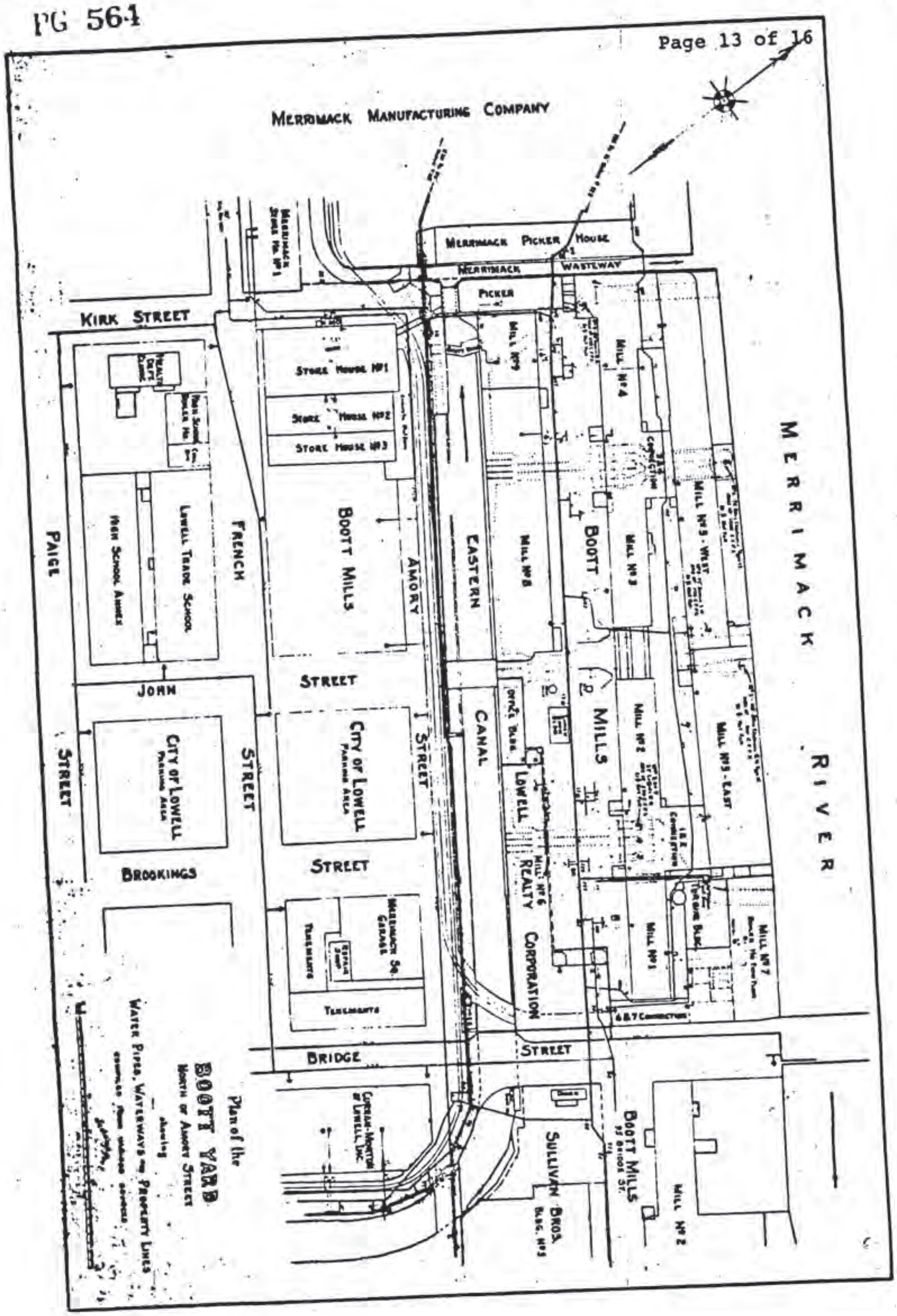


LOCATION - HAMILTON STATION - JACKSON ST.
DESCRIPTION - 2 - WESTINGHOUSE MFG. CO.
GENERATOR NUMBERS - #4 - 2603202 #5 - 2603201
TURBINE DATA - No. 4 & 5 LEFFEL TYPE Z SINGLE RUNNER 45 INCHES.

I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais
#29936
REGISTERED LAND SURVEYOR

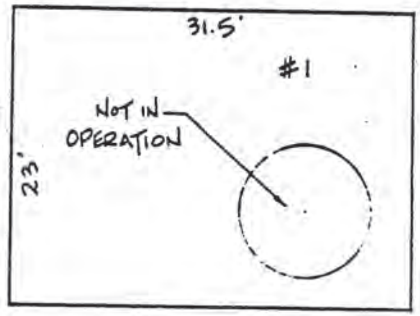
Raymond F. Desmarais RLS



Merrimack Manufacturing Company
Merrimack Picker House
Merrimack Wasteway
Picker
Kirk Street
Store House No1
Store House No2
Store House No3
Boott Mills
Amory Street
French Street
Paige Street
High School Annex
Lowell Trade School
Eastern Canal
Mill No8
Mill No9
Mill No4
Mill No3
Mill No3-West
Mill No3-East
Boott Mills
Mill No2
Mill No1
Mill No6
Mill No7
Merrimack River
John Street
City of Lowell Parking Area
Brookings Street
Office Bldg.
Lowell Realty Corporation
Tenements
Merrimack Sq. Garage
Bridge Street
Sullivan Bros.
Mill No2
Plan of the
BOOTT YARD

— DESCRIPTION —
— OF —
GENERATORS AND TURBINES
— LOCATED IN —
BOOTT MILLS, LOWELL, MA.

SCALE 1" = 10' ——— DECEMBER 1983



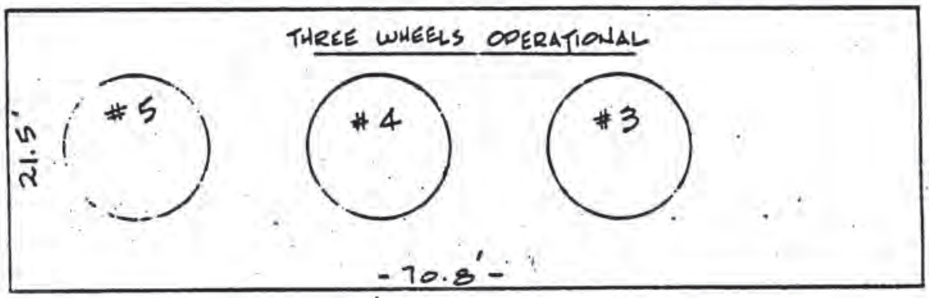
LOCATION — BUILDING 5-EAST — JOHN STREET.
DESCRIPTION — ALLIS-CHALMERS
WHITES HYDRAUCONE REGAINER #1
GENERATOR NUMBER 108799 — 600V — 481 AMPS
TURBINE DATA - ALLIS CHALMERS SINGLE RUNNER 45 INCHES

I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais
#29996
REGISTERED LAND SURVEYOR

Raymond F. Desmarais R.L.S.

— DESCRIPTION —
— OF —
GENERATORS AND TURBINES
— LOCATED IN —
BOOTT MILLS, LOWELL, MA.
SCALE 1" = 10' ——— DECEMBER 1983



LOCATION — MILL 1 & 2 CONNECTOR - JOHN STREET.
DESCRIPTION — G.E. - LEFFEL HYDRAULIC TURBINES
GENERATOR NUMBERS — #5-6637987 #4-6637986 #3-6637985
TURBINE DATA - LEFFEL SINGLE RUNNER 33 INCHES.

I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

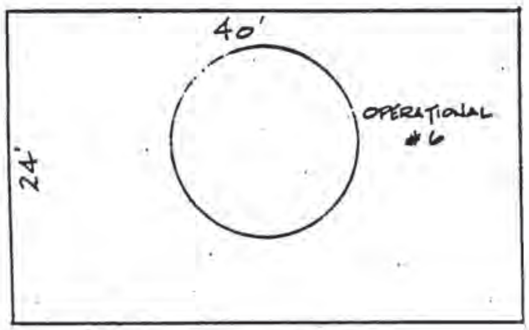
COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais
#29996
REGISTERED LAND SURVEYOR

Raymond F. Desmarais R.L.S.

Desmarais

— DESCRIPTION —
— OF —
GENERATORS AND TURBINES
— LOCATED IN —
BOOTT MILLS, LOWELL, MA.

SCALE 1" = 10' ——— DECEMBER 1983



LOCATION — BUILDING 5 - WEST END - JOHN STREET.
DESCRIPTION — ALLIS-CHALMERS HYDRAULIC TURBINE #6
GENERATOR NUMBER 113710 — 600V - 1445 AMPS.
TURBINE DATA - ALLIS CHALMERS SINGLE RUNNER 72 INCHES.

I CERTIFY THAT I HAVE EXAMINED THE PREMESIS AND THAT THE GENERATORS ARE LOCATED APPROXIMATELY AS SHOWN WITHIN THE CONFINES OF THE ROOM AND BUILDING DESCRIBED ABOVE.

COMMONWEALTH OF MASSACHUSETTS
Raymond F. Desmarais
#29996
REGISTERED LAND SURVEYOR

Raymond F. Desmarais R.L.S.

EXHIBIT B

Description of Transformers

Wagner Electric Company 2000 KVA, 13.8 KV Primary, 600 V Secondary, Three Phase, 60 Cycle Transformers:

(i) Serial No. YF 3229 located at Section 8 Power House, Bridge Street, and

(ii) Serial No. YF 3230 located at Market Street, Assets Division.

AFFIDAVIT

I, Richard G. Drury, on oath depose and say that while the premises described in the within instrument are not the same as described in or conveyed by prior recorded instruments identified sufficiently to locate the place of recording within the Registry, the within instrument does not create any new boundaries within the meaning of Mass. General Laws, Chapter 183, § 6A, since the premises being conveyed are bounded by known monuments consisting of canal walls, dams and river banks which have been established for over one hundred years.

Dated this 16th day of January 1984.

Richard G Drury

COMMONWEALTH OF MASSACHUSETTS

Middlesex, ss. January 16, 1984

Then personally appeared the above-named Richard G. Drury and made oath that the foregoing statement subscribed by him is true, before me

James F. D

Notary Public James W. Flood Jr.

My commission expires: JAN. 3, 1986

Rec Jan 19 1984 10:17AM #1846

Appendix C - 1986 *Order of Taking*

BK3830 PG 70

77480

ORDER OF TAKING

The Commonwealth of Massachusetts (the "Commonwealth"), acting by and through its Commissioner of Environmental Management, of 100 Cambridge Street, Boston, Massachusetts 02202, by virtue of the authority conferred by Chapter 132A, Sections 3 and 3A of the General Laws, does hereby take in the varying interests described in the attached Schedule "I" for conservation and recreation purposes, in accordance with Chapter 132A, Sections 3 and 3A of the General Laws, the parcels of land located in Lowell, Middlesex County, Massachusetts, containing the areas and being described as set forth in the attached Schedule "II" and being commonly referred to as the land and water of Proprietors of the Locks and Canals on Merrimack River and other supposed owners hereinafter described ("Condemnees").

All of the aforesaid premises are shown and delineated on a plan entitled "Plan of Land of Lowell Canal System for the Department of Environmental Management of land located in Lowell, Massachusetts," surveyed by Atlantic Engineering and Survey Consultants of Lynn, Massachusetts variously dated from May 23, 1983 to August 13, 1983, Scale 1" = 40', and recorded herewith.

Together with the right, title and interest of Condemnees in and to those rights of way, access, wharves, docks,

See Plan Book 157 Plan 69

See B3830 P70

See B3888 P99

See B3888 P103

1983 DEC 15 ... 2:36

shore and water rights, insofar as the same may be appurtenant to the canals and land hereby acquired, as stated on Schedule "I".

Said premises are acquired subject to the rights, privileges and easements as set forth in a deed of Boott Mills, et al to Boott Hydro dated January 16, 1984 and recorded with the Middlesex North Registry of Deeds at Book 2690, Page 542, except as expressly set forth herein.

Trees and structures, if any, upon the land are included in the taking.

Excepted from the rights herein taken by the Commonwealth are all easements for wires, pipes, conduits, poles and other appurtenances for the conveyance of water, sewage, gas, oil, electricity and telephone communication now lawfully in or upon the premises hereby taken.

For damages sustained by reasons of the aforesaid taking, and in accordance with the provisions of Chapter 79, Section 6 of the General Laws, as amended, awards have been made. The right is reserved to amend the award or to increase the amount of damages to be paid at any time prior to payment thereof for good cause shown.

SUPPOSED OWNERS

1. Proprietors of the Locks and Canals on Merrimack River.

2. Boott Hydropower, Inc.

3. Boott Mills

all with offices at Foot of John Street, Lowell, Middlesex County, Massachusetts, and

4. General Electric Credit Corporation

(all referred to herein as Condemnees), each as to their respective interests in any of the water, land or canals described in Schedule II.

All names of owners herein given, although supposed to be correct, are such only as to matters of opinion and belief.

IN WITNESS WHEREOF, the Commonwealth of Massachusetts has caused these presents to be executed in its name and behalf by James Gutensohn, its Commissioner of Environmental Management, hereunto duly authorized who does hereto set his hand this 1st of December, 1986.

THE COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF ENVIRONMENTAL
MANAGEMENT

By: James Gutensohn, Commissioner

December 1, 1986

Commonwealth of Massachusetts
Suffolk County, ss:

Then personally appeared before me the above James Gutensohn, Commissioner of the Department of Environmental Management, who acknowledged the foregoing as the free act and deed of the Department.

John S. Lenkiewicz
John S. Lenkiewicz, Notary Public

My Commission Expires November 30, 1990

Approved:

John J. Bradshaw
ASSOCIATE DEPUTY COMMISSIONER
for John I. Carlson, Deputy Commissioner
Division of Capital Planning &
Operations

Approved as to Form:

By: T. David Raftery
T. David Raftery, Chief
Eminent Domain Division
Assistant Attorney General

Approved:

Michael S. Dukakis
Michael S. Dukakis
Governor of the Commonwealth

A

PG. 74

COMMONWEALTH OF MASSACHUSETTS

CITY OF LOWELL

In City Council:

VOTE

Authorizing the Department of Environmental Management to exercise the power of eminent domain to acquire certain parcels of Land in Lowell for addition to the Lowell Heritage State Park.

BE IT VOTED BY THE CITY COUNCIL OF THE CITY OF LOWELL, as follows:

In accordance with the provisions of Chapter 132A, Section 3A of the General Laws, the City of Lowell hereby approves exercise of the power of eminent domain by the Department of Environmental Management to acquire the parcels of land and varying interests in lands located in Lowell, Middlesex County, Massachusetts, containing the areas and being described as set forth in the attached Schedule I and being commonly referred to as the Land and Water of Proprietors of the Locks and Canals on Merrimack River and other supposed owners.

In City Council March 12, 1985 Read twice and adopted 9 yeas.

/s/ William F. Busby, City Clerk

Approved by B. Joseph Tully, City Manager on March 13, 1985.

A True Copy
Attest:

William F. Busby
City Clerk

CERTIFICATE OF VOTE

On a motion duly made and seconded, it was

VOTED: That the Board of Environmental Management, pursuant to Chapter 79 of the General Laws, approves the exercise of the power of eminent domain by the Department of Environmental Management for the below described property;

The parcels of land and varying interests in lands located in Lowell, Middlesex County, Massachusetts, containing the areas and being described as set forth in the attached Schedule I and being commonly referred to as the Land and Water of Proprietors of the Locks and Canals on Merrimack River and other supposed owners.

I, John Capone, Secretary of the Board of Environmental Management of the Commonwealth of Massachusetts, do hereby certify that the foregoing is a true copy of a vote adopted by the Board of Environmental Management at a meeting duly called and held on March 28, 1985, a quorum being present and voting; and that said vote has not been rescinded or amended.

Attest, a true copy

John Capone

John Capone, Secretary

Date: March 28, 1985

SCHEDULE I

PROPERTY IDENTIFICATION

Eastern Canal

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Massachusetts Wasteway Gatehouse	Near Bridge St.	199	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 80.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
Boott Dam Gatehouse	Boott Mills	565	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 74.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in

SCHEDULE I (Cont'd)

Eastern Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Boott Dam Gatehouse (cont.)			perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
Boott Dam	Boott Mills	830	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature; (g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.

SCHEDULE I (Cont'd)

Eastern Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
CB-L/5721	Boott Penstock	2,511	Fee; reserving to Condemnees and their successors and assigns a permanent easement to flow water through the existing penstock located under said parcel together with the right to repair and replace said penstock and the right of access thereto.

Hamilton Canal

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Hamilton Gatehouse	Hamilton Wasteway	258	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 90.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
5345D	Near Jackson St.	8,637	Fee
5345C	Near Jackson St.	960	Fee

Hamilton Canal (cont.)

5345B	Near Jackson St.	368.5	Fee
5345A	Near Jackson St.	1,438	Fee

BK3830 PG 80

SCHEDULE I (cont'd)

Merrimack River

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Blacksmith Shop	Off School St.	1,204	Fee, reserving, however, for the Condemnees, their successors and assigns the right and easement for access to and use of said Blacksmith Shop for the purpose of maintaining and operating the Pawtucket Dam for hydroelectric power production.
Pawtucket Gatehouse	School St.	2,400	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 101.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
Pawtucket Gatehouse Wall & Lock Chamber	School St.	3,710	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures;

SCHEDULE I (cont'd)

Merrimack River (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Pawtucket Gatehouse Wall & Lock Chamber (cont.)			(e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature; (g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.
29; Lot 2	School St.	15,957	Fee
		Merrimack River Properties	
87	Front St.	57,587	Fee
92-B	Near VFW Hwy.	8,919	Fee
91-H	Aiken St. VFW Hwy.	53,971	Fee

SCHEDULE I (cont'd)

Merrimack River Properties (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Front Street	VFW Hwy.	43,593	Fee
89	VFW Hwy.	5,334	Fee
88	VFW Hwy. Front St.	735	Fee
89-A	Aiken St. VFW Hwy.	75,939	Fee
96-B	Goodwill Industries	20,709	Fee
102	VFW Hwy.	32,800	Fee
103	VFW Hwy. Textile Ave.	91,476	Fee
107	VFW Hwy.	34,000	Fee
107-A	VFW Hwy.	5,550	Fee —
99, 100 & 100A	School Street VFW Hwy.	1 acre	Fee
33-C-1	Aiken St.	38,369	Fee

Northern Canal

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Northern Canal Walkway	Near Moody St.	11,038	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature; (g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.

Northern Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Northern Canal Waste Gatehouse	Northern Walkway	999	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 92.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
65-Y	Cabot St. Suffolk St.	5,528	Fee
29-B	School St.	95,832	Fee
30-A	Moody St. Pawtucket St.	4,950	Fee
CB-B	Moody St.	13,865	Fee
29-A	Falls St.	18,586	Fee

Pawtucket Canal

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Swamp Locks Gatehouse		937	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 89.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
Swamp Locks Dam (North)		875	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature;

BK3830 PG 86

Pawtucket Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Swamp Locks Dam (North) (cont.)			(g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.
Swamp Locks Dam (South)		840	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature; (g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and

Pawtucket Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Swamp Locks Dam (South) (cont.)			(i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.
Swamp Locks Chamber		11,685	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature; (g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the

Pawtucket Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Swamp Locks Chamber (cont.)			use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.
CB-I	Junction of Hamilton & Pawtucket Canals	13,260	Fee, reserving, however, in the Condemnees, their successors and assigns the right and easement for access to such parcel for the purpose of maintaining a water supply system.
2B/2B-1/ 2D-1/2D-2	Thorndike St.	13,346	Fee, excepting those certain premises described in deed of Proprietors of Locks and Canals on Merrimack River to Joseph J. Flynn, Inc. dated February 8, 1961 and recorded at Book 1504, Page 447, Middlesex North Registry of Deeds.
CB-A/5	School St. Middlesex Pl.	39,000	Fee
CB-A/4	School St. Bridge	1,030	Fee
CB-A/3	School St.	22,500	Fee
CB-A/1	B&M Railroad	80	Fee
2B/2C-1/ 2C-2	Near Middlesex Pl.	4,011	Fee
17B	Kyan St.	3,728	Fee

BK3830 PG 69

Pawtucket Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
7A	Broadway	16,319	Fee
Francis Gatehouse	Off Broadway	491	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 106.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
Hydraulic Gatehouse	Off Broadway	1,377	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 88.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.

Pawtucket Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Locking Gatehouse	Off Broadway	1,100	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 99.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
Guard Locks Lock Chambers		5,984	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature;

BK3830 PG 91

Pawtucket Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Guard Locks Lock Chambers (cont.)			(g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.
8A, Lot 1	Broadway	19,848	Fee
8-B	Pawtucket St. Broadway	37,500	Fee
8-C	Off Broadway	5,660	Fee
13-B	Broadway Madonna Circle	26,200	Fee

Pawtucket Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Lower Locks Lock Chambers		9,127	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature; (g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.

Pawtucket Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Lower Locks Gate House		838	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 74.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
CB-H		11,100	Fee
9	Near Pawtucket St.	52	Fee
Lower Locks Dam		3,680	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences;

Pawtucket Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
			(f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature; (g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.

SCHEDULE I (cont'd)

Western Canal

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Tremont Gatehouse	Off Suffolk St.	382	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 90.2 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
5610 & 5362	Off Suffolk St.	894	Fee; reserving to Condemnees and their successors and assigns a permanent easement to flow water through the portions of the Western Canal located on said parcel together with the right to repair and replace such portions of the Western Canal and the right of access thereto.
CB-E, Lot C	Perkins St. Suffolk St.	5,844	Fee
CB-D, Lot J	Moody St.	282	Fee
CB-C, Lot I	Moody St. French St. Ext.	805	Fee
CB-D, Lot H	Moody St. Merrimack St.	1,167	Fee Fee

Western Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
CB-C, Lot G	Merrimack St. Moody St.	3,400	Fee Fee
CB-D, Lot F	Merrimack St. Hanover St. Market St.	2,310	Fee Fee Fee
CB-C, Lot E	Merrimack St. Market St. Suffolk St.	3,115	Fee Fee Fee
CB-D, Lot D	Market St. Lewis St. Jefferson St.	8,635	Fee Fee Fee
CB-D, Lot B	Jefferson St. Lewis St. Broadway	6,450	Fee Fee Fee
CB-C, Lot C	Suffolk St. Jefferson St. Market St.	10,905	Fee Fee Fee
CB-C, Lot A	Suffolk St. Broadway Jefferson St.	7,597	Fee Fee Fee
CB-E, Lot A	Suffolk St.	4,938	Fee
CB-D, Lot N	Off Worthen St.	3,000	Fee

SCHEDULE I (cont'd)

Western Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
24	Hayden St.	2,839	Fee
	Worthern St.		Fee
	Dutton St.		Fee

Merrimack Canal

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Rolling Dam Gate House North	Merrimack Wasteway	269	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 83.7 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.
Rolling Dam Gate House South	Merrimack Wasteway	248	Buildings, structures and fixtures (exclusive of fixtures and equipment used in the ongoing maintenance and operation of hydroelectric power generation) above elevation 83.7 feet M.S.L. in fee and a permanent easement in the canal walls and beds or bottoms for support of said buildings, structures and fixtures and exclusive access to such buildings, structures and fixtures except as to the Condemnees and their successors and assigns who shall retain such right of access to such buildings, structures and fixtures as shall be necessary in perpetuity for the maintenance and operation of the gates and canals for hydroelectric power production.

SCHEDULE I (cont'd)

Merrimack Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
YMCA Gates		300	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature; (g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.

Merrimack Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
Rolling Dam		630	Permanent and exclusive easement for the following purposes: (a) support of all fixtures or structures of the Commonwealth now or hereafter attached; (b) preservation and conservation; (c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns; (d) landscaping and erection of exhibits and structures; (e) placement of barriers and fences; (f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature; (g) placement of lighting and other utilities; (h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and (i) any and all other uses consistent with the operation of the Canal system as a park; provided, however, that such easement shall not include any use that would interfere with the use, maintenance or operation by the Condemnees and their successors and assigns of said parcel and the canal for hydroelectric power production.

SCHEDULE I (cont'd)

Merrimack Canal (cont.)

Parcel Name/Number	Location	Land Area Sq. Ft.	Interest Acquired
CB-G	Merrimack & Lower Pawtucket Canals	25,209	Fee

IN ADDITION TO THE ABOVE PARCELS, the Commonwealth hereby acquires:

A. A permanent and exclusive easement in all canal walls and beds or bottoms and in all dams and boat lock chambers located in said canals and not otherwise referred to in this Schedule I, for the following purposes:

(a) support of all fixtures or structures of the Commonwealth now or hereafter attached;

(b) preservation and conservation;

(c) supplemental maintenance in addition to that performed by the Condemnees and their successors and assigns;

(d) landscaping and erection of exhibits and structures;

(e) placement of barriers and fences;

(f) placement and attachment of docks, wharves, walls and boat ramps of a temporary or permanent nature;

(g) placement of lighting and other utilities;

(h) operation and maintenance of boat locking chambers, if any, for any and all purposes; and

(i) any and all other uses consistent with the operation of the canal system as a park.

B. All air rights over the canals, including the canal walls and any dams thereon, to the extent not already lawfully obstructed or occupied, for so long as such lawful obstruction or occupation continues uninterrupted in its present form.

C. The exclusive right to use the water in the entire canal system and the Merrimack River for recreational, educational and navigational purposes, which use shall be nonconsumptive with respect to hydroelectric power generation except for reasonable amounts to operate locking gates.

ALL OF THE TITLE, RIGHTS AND INTEREST DESCRIBED IN SCHEDULES I AND II ARE TAKEN BY THE COMMONWEALTH SUBJECT TO THE FOLLOWING LIMITATIONS AND RESERVATIONS:

A. Such title, rights and interest will be used solely for public park purposes and shall not be used by the Commonwealth or its successors or assigns for any commercial or nonpublic purpose.

SCHEDULE I (cont'd)

B. Condemnees and their successors and assigns retain the right of access to all parcels, buildings and structures to the extent necessary for the maintenance and operation of hydroelectric power production facilities.

C. There shall be reserved in the Condemnees, their successors and assigns an easement for wires, pipes, conduits, valves, pumps, poles and other equipment presently existing or hereafter to be installed for the operation, maintenance and extension of steam, fire protection, water supply systems, electricity, sewage, gas, oil, and telephone communication, provided that all such wires, pipes, conduits, valves, pumps, poles and other equipment to be installed in the future shall not be inconsistent with the Commonwealth's use and operation of the canal system as a public park, and provided further that all such wires, pipes, conduits, valves and pumps to be installed in the future relating to electricity, sewage, gas, oil, and telephone communication shall be installed below the surface of the land or water.

LEGAL DESCRIPTIONS FOR PARCELS SURVEYED

UNDER

D.E.M. CONTRACT NO. 97-82

LOWELL HERITAGE STATE PARK

1983

BK3830

PG 106

INDEX TO PLANS AND LEGAL DESCRIPTION
FOR
PARCELS SURVEYED UNDER D.E.M. CONTRACT 97-82
LOWELL CANAL SYSTEM

LOCATION/ GENERAL AREA	PARCEL DESIGNATION	PLAN FOUND SHEET NO.	LEGAL DESCRIPTION FOUND ON PAGE NO.
Pawtucket Canal	9	1	1
	13-B	2,3,4	2,3,4
	8-B	2,3,4	5,6,7
	Hydraulic Gatehouse	4	8
	8-C	4	9,10,11
	Francis Gatehouse	4	12
	Locking Gatehouse	4	13
	8-A (Lot 1)	4	14
	7-A	5	15
	17-B	6	16
	CB-A/1	7	17
	CB-A/3	7	18,19
	CB-A/4	7	20
	CB-A/5	8,9	21,22
	2B/2C-1/2C-2	10	23
	2B/2B-1/2D-1/2D-2	10	24
	CB-I	11	25,26,27
	Guard Locks - Lock Chamber	4	28,29,30
	Swamp Locks Dam (North & South)	12	31,32
	Swamp Locks Gatehouse	12	33,34
	Swamp Locks - Lock Chambers	11	35,36
	CB-G	13	37,38,39
	Lower Locks Dam	14	40
	Lower Locks Gatehouse	14	41
	CB-H	14	42
	Lower Locks Lock Chamber	14	43,44
Hamilton Canal	5345-A	15	45
	5345-B	15	46
	5345-C	15	47
	5345-D	15	48
	Hamilton Gatehouse	16	49

LOCATION/ GENERAL AREA	PARCEL DESIGNATION	PLAN FOUND SHEET NO.	LEGAL DESCRIPTION FOUND ON PAGE NO.
Merrimack Canal	CB-G	13	37,38,39
	YMCA Gates	17	50,51
	Rolling Dam	19	52
	Rolling Dam Gate-house(North & South)	19	53,54
Eastern Canal	Massachusetts Wasteway Gatehouse	18	55
	Boott Dam	19	56
	Boott Dam Gatehouse	19	57
	CB-L;5721	19	58,59
Northern Canal	Blacksmith Shop	20	60
	Pawtucket Gatehouse	20	61
	29, Lot 2	20	62
	Pawtucket Gatehouse Wall & Lock Chamber	20	63,64
	29-B	21,22	65
	29-A	22	66,67
	CB-B	23	68
	30-A	23	69
	Northern Canal Wasteway Gatehouse	23	70
	Northern Canal Walkway	22,23	71,72
	65-Y	25	73
Tremont Wasteway	Tremont Gatehouse	25	74
	CB-E, Lot A	25	75
	CB-E, Lot C	25	76,77
	5610, 5362	25	78
Western Canal	CB-C, Lot I	26	79
	CB-C, Lot G	26	80
	CB-C, Lot E	27	81
	CB-C, Lot C	27,28	82
	CB-C, Lot A	28	83

LOCATION/ GENERAL AREA	PARCEL DESIGNATION	PLAN FOUND SHEET NO.	LEGAL DESCRIPTION FOUND ON PAGE NO.
Western Canal continued	24	29	84
	CB-D, Lot J	26	85
	CB-D, Lot H	26	86
	CB-D, Lot F	27	87
	CB-D, Lot D	27,28	88
	CB-D, Lot B	28	89
	CB-D, Lot N	29	90
Riverfront	99 100 100A	30	91
	102	31	92
	103	31	93
	33 - C - 1	32	94
	92-B	33	95
	107-A	33	96
	107	33	97
	91-H	33,34	98
	89-A	35,36	99
	89	36	100
	88	36	101
	Front Street	36,37	102
	87	37,38	103
	96-B	38	104

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 9

Beginning at a point on the northwesterly line of Pawtucket Street, said point being at the south edge of the southerly granite wall of the Pawtucket Canal; thence along the line of land now or formerly of Lowell Motor Boat Club Inc.

S 72° -24' -48" E, a distance of fifty-nine and 13/100 feet (59.13) to the Merrimack River; thence by said river

N 75° -39' -15" E, a distance of three and 34/100 feet (3.34) to a point at the northerly end of the southerly granite wall of the Pawtucket Canal, said point being on the south edge of said wall; thence along the back edge of said wall

N 70° -37' -02" W, a distance of fifty-six and 32/100 feet (56.32) to the point of beginning.

Containing fifty-two (52) square feet of land, more or less.

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PROPOSED DESCRIPTION OF LAND

PARCEL: 13B

Beginning at an iron pin set at the northwesterly corner of Broadway and Madonna Circle; thence along the northerly line of Broadway

S 82° -56' -05" W, a distance of about seventy feet (70) to a point at the back edge of the easterly granite wall of the Pawtucket Canal; thence along the back edge of said canal wall

NORTHERLY, more or less, a distance of about one hundred sixty-three feet (163) to an angle in said wall; thence along the back edge of a granite wall appurtenant to the Pawtucket Canal as follows:

SOUTHEASTERLY, more or less, a distance of about twenty-six feet (26),

NORTHEASTERLY, more or less, a distance of about three feet (3), and

NORTHWESTERLY, and WESTERLY, more or less, a distance of about ninety-four feet (94) to a point on said wall at Parcel 8-C; thence along the easterly line of Parcel 8-C

NORTHERLY, more or less, a distance of about thirteen feet (13) to the southerly face of the Hydraulic Gatehouse; thence by the face of said gatehouse

N 69° -11' -23" E, a distance of about sixty-seven feet (67) to the southeasterly corner thereof, and

N 20° -48' -37" W, a distance of nineteen and 39/100 feet (19.39) to the northeast corner of said gatehouse; thence along the edge of the easterly granite wall of the Pawtucket Canal as follows:
NORTHERLY, more or less, a distance of about ninety-six feet (96),
WESTERLY, more or less, a distance of about three feet (3), and

SOUTHERLY, more or less, a distance of about thirty-eight feet (38) to a point on the easterly shoreline of aforesaid Pawtucket Canal; thence along said easterly shoreline

NORTHWESTERLY, more or less, a distance of about one thousand four hundred and sixty-four feet (1,464) to a point at the back edge of the easterly granite wall of said Pawtucket Canal; thence along said canal wall

NORTHWESTERLY, more or less, a distance of about twenty-six feet (26) to a point on the southerly line of Pawtucket Street; thence along said line of Pawtucket Street

N 50° -30' -01" E, a distance of about twenty-four feet (24) to an iron pin set at land now or formerly of the City of Lowell; thence along the westerly line of land of said City of Lowell as follows:

S 42° -57' -18" E, a distance of eighteen and 50/100 feet (18.50) to an iron pin set, Parcel: 13B (con't)

S 52° -22' -18" E, a distance of forty-five and 33/100 feet (45.33) to a drill hole set,

S 51° -03' -18" E, a distance of twenty-six and 92/100 feet (26.92) to an iron pin set,

S 45° -57' -08" E, a distance of ninety-nine and 63/100 feet (99.63) to an iron pin set,

S 27° -45' -08" E, a distance of nine and 13/100 feet (9.13) to a point,

S 23° -43' -08" E, a distance of one hundred sixty-six and 68/100 feet (166.68) to a drill hole set,

S 20° -16' -08" E, a distance of eighteen and 32/100 feet (18.32) to a drill hole set,

S 06° -36' -38" E, a distance of one hundred eight and 50/100 feet (108.50 to an iron pin set,

S 11° -40' -38" E, a distance of two hundred thirty-six and 01/100 feet (236.01) to an iron pin set,

S 17° -29' -58" E, a distance of thirty-six and 11/100 feet (36.11) to an iron pin set,

S 22° -11' -38" E, a distance of thirty-six and 39/100 feet (36.39) to an iron pin set,

S 30° -12' -38" E, a distance of one hundred thirty-one and 48/100 feet (131.48) to a drill hole in a stone bound found,

S 30° -12' -38" E, a distance of one hundred and 00/100 feet (100.00) to a drill hole in a stone bound found,

S 30° -12' -37" E, a distance of fifty-three and 52/100 feet (53.52) to a drill hole in a stone bound found,

SOUTHEASTERLY, more or less, by a curve to the left having a radius of two hundred twelve and 80/100 feet (212.80), an arc length of thirty-nine and 25/100 feet (39.25) to a drill hole in a stone bound found, and

S 40° -46' -41" E, a distance of sixty and 26/100 feet (60.26) to a point at land now or formerly of Thomas Riley; thence along the southwesterly line of Riley as follows:

S 40° -46' -41" E, a distance of ninety-one and 60/100 feet (91.60) to a drill hole in a stone bound found,

S 51° -27' -21" E, a distance of ninety-three and 41/100 feet (93.41) to a point, and

S 55° -19' -01" E, a distance of one hundred eight and 23/100 feet (108.23) to a P.K. nail set at Madonna Circle; thence along the westerly line of Madonna Circle

S 11° -00' -40" E, a distance of two hundred fifty-three and 76/100 feet (253.76) to the point of beginning.

Parcel: 13B (con't)

Containing twenty-six thousand and two hundred (26,200) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 8-B

Beginning at a point at the southwesterly corner of the parcel on the northerly line of Broadway, said point being N 82°-56'-05" E, a distance of fifty-two and 74/100 feet (52.74) of a stone bound found on the northerly line of Broadway; thence by land now or formerly of the Proprietors of Locks and Canals by five (5) courses as follows:

N 03°-54'-52" W, a distance of fifty-one and 47/100 feet (51.47) to a point,

N 27°-06'-12" W, a distance of eighty-eight and 85/100 feet (88.85) to a point,

N 28°-42'-32" W, a distance of one hundred eighty and 03/100 feet (180.03) to a point,

N 30°-21'-02" W, a distance of ninety-eight and 70/100 feet (98.70) to a point, and

N 40°-51'-32" W, a distance of sixty three and 10/100 feet (63.10) to a point; thence by land now or formerly of the Commonwealth of Massachusetts by four courses as follows:

N 39°-26'-01" W, a distance of eleven and 26/100 feet (11.26) to a point,

N 41°-26'-13" W, a distance of sixty-five and 21/100 feet (65.21) to a point,

N 40°-55'-22" W, a distance of twenty-eight and 28/100 feet (28.28) to a point, and

N 38°-57'-44" W, a distance of six and 35/100 feet (6.35) to a point; thence continuing by land now or formerly of the Commonwealth of Massachusetts by (19) courses as follows:

N 40°-51'-40" W, a distance of fifty-nine and 18/100 feet (59.18) to a point,

N 37°-55'-55" W, a distance of thirty-one and 65/100 feet (31.65) to a point,

N 29°-43'-39" W, a distance of forty-seven and 04/100 feet (47.04) to a point,

N 25°-59'-51" W, a distance of eighteen and 34/100 feet (18.34) to a point,

N 26°-07'-46" W, a distance of one hundred forty-seven and 13/100 feet (147.13) to a point, PARCEL: 8-B (cont')

N 57°-28'-20" W, a distance of zero and 73/100 feet (0.73) to a point,

N 22°-42'-54" W, a distance of forty-eight and 48/100 feet (48.48) to a point,

N 21°-32'-50" W, a distance of twenty and 27/100 feet (20.27) to a point,

N 14°-11'-07" W, a distance of one hundred forty-one and 00/100 feet (141.00) to a point,

N 04°-08'-34" E, a distance of sixty and 21/100 feet (60.21) to a point,

N 10°-37'-49" W, a distance of sixty-six and 11/100 feet (66.11) to a point,

N 10°-13'-54" W, a distance of forty-two and 29/100 feet (42.29) to a point,

N 19°-09'-50" W, a distance of seventeen and 85/100 feet (17.85) to a point,

N 19°-17'-12" W, a distance of fifty-nine and 17/100 feet (59.17) to a point,

N 24°-17'-55" W, a distance of forty-three and 27/100 feet (43.27) to a point,

N 29°-51'-29" W, a distance of forty-five and 82/100 feet (45.82) to a point,

N 33°-34'-42" W, a distance of thirty-six and 78/100 feet (36.78) to a point,

N 40°-05'-46" W, a distance of eighty and 63/100 feet (80.63) to a point, and

N 40°-40'-59" W, a distance of fifty-eight and 49/100 feet (58.49) to a drill hole with lead plug and brass pin found at the intersection with the southerly line of Pawtucket Street; thence

N 50°-30'-01" E, along the southerly line of Pawtucket Street, a distance of about six feet (6) to the westerly face of a granite wall on the westerly side of the Pawtucket Canal; thence

SOUTHERLY, more or less, along the westerly face of the aforementioned wall a distance of about fourty-five feet (45) to the end of the wall; thence continuing

SOUTHERLY, more or less, along the westerly bank of the Pawtucket Canal a distance of one thousand two hundred and eighty-one feet (1281) to a granite wall; thence continuing

SOUTHERLY, more or less, along the westerly face of said granite wall a distance of about eighty-one feet (81) to a drill hole set along the westerly face of the granite wall at the top of a set of concrete steps; thence

S 27°-16'-45" E, along the westerly face of the aforementioned granite wall, a distance of forty and 79/100 feet (40.79) to the northerly face of a building known as the Locking Gate House; thence

S 62°-43'-24" W, along the northerly face of the aforementioned building a distance of seven and 80/100 feet (7.80) to a building corner; thence

S 27°-16'-45" E, along the westerly face of the aforementioned building a distance of sixteen and 06/100 feet (16.06) to a building corner; thence

N 62°-43'-24" E, along the southerly face of the aforementioned building a distance of about six feet (6) to the westerly face of a granite wall on the westerly side of the Pawtucket Canal; thence

SOUTHERLY, more or less, along the aforementioned wall a distance of about fifty-five-feet (55) to the northwesterly corner of a building known as the Francis Gate House; thence

S 27°-26'-58" E, along the westerly face of the Francis Gate House a distance of thirteen and 41/100 feet (13.41) to the southwesterly corner of the Francis Gate House; thence by the westerly face of a granite wall on the westerly side of the Pawtucket Canal by five (5) courses as follows:

SOUTHERLY, about twelve feet (12),

WESTERLY, about thirteen feet (13),

SOUTHERLY, about three feet (3),

EASTERLY, about sixteen feet (16), and

SOUTHERLY, about six and 4/10 feet (6.4) to an iron pin set at the westerly face of said wall; thence continuing

SOUTHERLY, more or less, along the westerly face of the aforementioned wall about fifty-one feet (51) to an angle point in the wall; thence continuing

SOUTHERLY, more or less, along said wall a distance of about twenty-five feet (25) to an iron pin set at the westerly face of said wall, said iron pin being seventy-five and 37/100 feet (75.37) on a bearing of S 21°-00'-01" E, from the last mentioned iron pin; thence

SOUTHWESTERLY, more or less, along the westerly face of the aforementioned granite wall a distance of about twenty-eight feet (28) to the northerly line of Broadway; thence

S 82°-56'-05" W, along Broadway a distance of about twenty-two feet (22) to the point of beginning.

Containing thirty-seven thousand five hundred square feet (37,500) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: Hydraulic Gatehouse - Guard Locks

Beginning at the southeasterly corner of the Hydraulic Gatehouse, said corner being twenty and 43/100 feet (20.43) distant from the westerly line of Madonna Circle; thence along the southerly wall of the gatehouse by Parcel 13-B and Parcel 8-C

S 69° -11' -23" W, a distance of seventy-one and 00/100 feet (71.00) to the southwest corner thereof; thence along the westerly wall of the gatehouse by Parcel 8-C

N 20° -48' -37" W, a distance of nineteen and 39/100 feet (19.39) to the northwest corner thereof; thence along the northerly wall of the gatehouse by Parcel 8-C and crossing the Pawtucket Canal

N 69° -11' -23" E, a distance of seventy-one and 00/100 feet (71.00) to the northeast corner thereof; thence along the easterly wall of the gatehouse

S 20° -48' -37" E, a distance of nineteen and 39/100 feet (19.39) to the point of beginning.

Containing one thousand three hundred and seventy-seven (1,377) square feet of land, more or less.

ENGINEERING AND SURVEY CONSULTANTS
36 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 8-C

Beginning at an iron pin set at the most northerly corner of the parcel, said pin being set at the back edge of the granite wall of the Pawtucket Canal; thence running along the exposed back edge of said granite wall

S 70°-45'-09" E, a distance of fifty-one and 24/100 feet (51.24) to an iron pin set; thence continuing along the exposed back edge of said wall by three (3) courses as follows:

SOUTHEASTERLY, more or less, a distance of about thirty-seven feet (37) to a chisel-cut set in the wall, said chisel-cut bearing S 45°-23'-13" E, and being thirty-four and 88/100 feet (34.88) distant from the last point described,

SOUTHWESTERLY, more or less, a distance of about three feet (3), and

SOUTHERLY, more or less, a distance of about four feet to the most westerly corner of the Hydraulic Gate House, said corner bearing S 07°-38'-47" W, and being five and 59/100 feet distant from the last mentioned chisel-cut; thence along the southwesterly face of the Hydraulic Gate House

S 20°-48'-37" E, a distance of nineteen and 39/100 feet (19.39) to the most southerly corner of said Gate House; thence running along the southerly face of the Hydraulic Gate House

N 69°-11'-23" E, a distance of four feet, more or less, to a point; thence running perpendicular to the last mentioned course

SOUTHERLY, more or less, a distance of about thirteen feet (13) to a point on the westerly edge of a stone wall; thence running along the edge of said wall as follows:

SOUTHWESTERLY, more or less, a distance of about twenty-two feet (22) to a point,

SOUTHEASTERLY, more or less, a distance of about three feet (3) to a point,

NORTHEASTERLY, more or less, a distance of about eighteen feet (18) to a point, and

SOUTHERLY, more or less, a distance of about forty-one feet to a drill hole set at the back of exposed edge of said wall, said drill hole bearing S 13°-10'- 24" E, and being fifty-eight and 36/100 feet (58.36) distant from the aforementioned southwesterly corner of the Hydraulic Gate House; thence continuing along the back edge of the exposed wall as follows:

S 19°-32'-24" W, a distance of twenty-three and 95/100 feet (23.95) to an iron pin set, S 88°-10'-35" W, a distance of eleven and 14/100 feet (11.14) to an iron pin set,

N 29°-55'-13" W, a distance of thirteen and 01/100 feet (13.01) to an iron pin set,

N 35°-19'-04" W, a distance of twelve and 82/100 feet (12.82) to an iron pin set, and

N 11°-33'-48" W, a distance of eighteen and 18/100 feet (18.18) to a drill hole set; thence continuing along the edge of exposed wall:

NORTHEASTERLY, more or less, a distance of about fourteen feet to a point,

NORTHWESTERLY, more or less, a distance of about three feet (3) to a point,

SOUTHWESTERLY, more or less, a distance of about fourteen feet (14) to a point,

NORTHWESTERLY, more or less, a distance of about twelve feet to the southeasterly corner of the Francis Gate House, said corner bearing N 36°-56'-54" W, and being fifteen and 26/100 feet (15.26) distant from the last mentioned drill hole; thence running along the northeasterly face of the Francis Gate House

N 27°-26'-58" W, a distance of thirteen and 41/100 feet (13.41) to the northeasterly corner thereof; thence running along the back of the exposed granite wall

N 17°-56'-25" W, a distance of nine and 09/100 feet (9.09) to a drill hole set in the bottom step of some granite steps; thence continuing along the back edge of the wall

NORTHWESTERLY, more or less, a distance of about thirty-two feet (32) to a point on the southerly wall of the Locking Gate House; thence running along the face of the north end of the Gate House as follows:

N 62°-43'-24" E, a distance of about seven feet (7) to the northeasterly corner of the Gate House,

N 27°-16'-45" W, a distance of sixteen and 06/100 feet (16.06) to the northerly corner of the Gate House,

S 62°-43'-24" W, a distance of about eight and 7/10 feet (8.7) to a point on the northerly face of the Locking Gate House, said point being at the back of the exposed granite wall as hereinbefore mentioned; thence running along the back of said wall

NORTHWESTERLY, more or less, a distance of about zero and 7/10 feet (0.7) to a drill hole set, said drill hole bearing S 66°-57'-39" W, and being eight and 71/100 feet (8.71) distant from the aforementioned northerly corner of the Locking Gate House; thence continuing along the back edge of said wall

N 22°-50'-38" W, a distance of thirty-two and 98/100 feet (32.98) to the point of beginning.

Containing five thousand six hundred and sixty square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: FRANCIS GATE HOUSE

Beginning at the most northwesterly corner of the Francis Gate House, said corner being nineteen and 34/100 feet (19.34) distant from the northeasterly line of Parcel 8-A, Lot 1, and being on the easterly line of Parcel 8B; thence

N 62°-17'-23" E, along the northerly face of the Francis Gate House and across the lock chamber, a distance of thirty-six and 60/100 feet (36.60) to the most northerly corner thereof; thence running along the easterly building face

S 27°-26'-58" E, a distance of thirteen and 41/100 feet (13.41) to the southeasterly corner of said Francis Gate House; thence running along the southerly building face, and again crossing the lock chamber

S 62°-17'-23" W, a distance of thirty-six and 60/100 feet.(36.60) to the southeast building corner; thence running along the westerly building face, being the easterly line of Parcel 8B,

N 27°-26'-58" W, a distance of thirteen and 41/100 feet (13.41) to the point of beginning.

Containing four hundred and ninety-one (491) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: LOCKING GATE HOUSE

Beginning at the most southwesterly corner of the Locking Gate House, said point being twelve and 64/100 feet (12.64) distant from the easterly line of Parcel 8A, Lot 1 and being on the easterly line of Parcel 8B; thence

N 27°-16'-45" W, along Parcel 8B, a distance of sixteen and 06/100 feet (16.06) to a building corner; thence

N 62°-43'-24" E, along the northerly face of the building, crossing over the lock chamber and by part of parcel 8-C to the most northeasterly building corner a distance of fifty-one and 29/100 feet (51.29); thence

S 27°-16'-45" E, along the most easterly face of said building a distance of sixteen and 06/100 feet (16.06) to a corner; thence

S 62°-43'-24" W, along the face of said building a distance of seven and 89/100 feet (7.89) to a corner; thence

S 27°-16'-45" E, along the face of said building a distance of eight and 00/100 feet (8.00) to the most southeasterly corner of said building; thence

S 62°-43'-24" W, along the most southerly face of said building a distance of thirty-five and 40/100 feet (35.40) to a corner; thence

N 27°-16'-45" W, along the face of said building a distance of eight and 00/100 feet (8.00) to a corner; thence

S 62°-43'-24" W, along the face of said building a distance of eight and 00/100 feet (8.00) to the point of beginning.

Containing one thousand one hundred (1,100) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: 8-A ; LOT 1

Beginning at a stone bound found at the southwesterly corner of the parcel, said point being located at an angle on the northerly line of Broadway; thence

N 21°-35'-30" W, by land now or formerly of the Commonwealth of Massachusetts, one hundred ninety and 48/100 feet (190.48) to a concrete bound found; thence

N 21°-35'-30" W, by land now or formerly of Endevor Incorporated two hundred sixty-nine and 52/100 feet (269.52) to a point; thence by land now or formerly of the Proprietors of Locks and Canals by five (5) courses as follows:

S 40°- 51'- 32" E, a distance of sixty-three and 10/100 feet (63.10) to a point,

S 30°-21'-02" E, a distance of ninety-eight and 70/100 feet (98.70) to a point,

S 28°-42'-32" E, a distance of one hundred eighty and 03/100 feet (180.03) to a point,

S 27°-06'-12" E, a distance of eighty-eight and 85/100 feet (88.85) to a point, and

S 03°-54'-52" E, a distance of fifty-one and 47/100 feet (51.47) to a point on the northerly line of Broadway; thence

S 82°-56'-05" W, by said northerly line of Broadway, fifty-two and 74/100 feet (52.74) to the point of beginning.

Containing nineteen thousand eight hundred and forty-eight (19,848) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 7A

Beginning at an iron pin set at the northwesterly corner of the Parcel; said pin being a point on the southerly line of Broadway, said point bearing N 82° -56' -05" E and being sixteen and 85/100 feet (16.85) distant from an angle in said line; thence along said southerly line of Broadway

N 82° -56' -05" E, a distance of thirty-one and 29/100 feet (31.29) to a point at the back edge of the concrete wall of the Pawtucket Canal; thence running along the back edge of said wall as follows:

S 18° -33' -43" W, a distance of one hundred three and 20/100 feet (103.20 to an iron pin set at an angle in the wall,

S 08° -06' -33" W, a distance of sixty-five and 99/100 feet (65.99) to an iron pin set at an angle in the wall, and

S 05° -50' -20" E, a distance of one hundred ninety-two and 18/100 feet (192.18) to an iron pin set at an angle in the wall; thence continuing along the back edge of the concrete and then granite wall of the Pawtucket Canal as follows:

S 15° -12' -18" E, a distance of two hundred thirty-one and 72/100 feet (231.72) to an x-cut set at an angle in the wall, and

S 31° -44' -31" E, a distance of seventeen and 94/100 feet (17.94) to a point on the northerly line of location of the Boston and Maine Railroad; thence running along said railroad location line as follows:

N 84° -50' -16" W, a distance of fourteen and 34/100 feet (14.34) to a drill hole set at an angle in said location line, and

S 82° -00' -51" W, a distance of sixteen and 74/100 feet (16.74) to an iron pin set at the easterly line of land now or formerly of the City of Lowell; thence running along said land of the City of Lowell

N 15° -14' -25" W, a distance of two hundred sixty-four and 45/100 feet (264.45) to an iron pin found at the southerly corner of land now or formerly of the Commonwealth of Massachusetts; thence running along said land of the Commonwealth of Massachusetts by three (3) courses as follows:

N 05° -40' -50" W, a distance of one hundred seventy-eight and 07/100 feet (178.07) to an iron pin found,

N 08° -20' -10" E, a distance of seventy-two and 30/100 feet (72.30) to an iron pin set, and

N 18° -27' -01" E, a distance of ninety-one and 21/100 feet (91.21) to the point of beginning.

Containing sixteen thousand three hundred and nineteen square feet (16,319) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 17B

Beginning at an iron pin set at the most northerly corner of the parcel, said iron pin being a point on the southerly line of location of the Boston and Maine Railroad and bearing S 86° -04' -09" W, and being one hundred ten and 51/100 feet (110.51) distant from a drill hole in a stone bound found at an angle in said railroad location line; thence running along the southerly line of land now or formerly of the Transit Construction Company of Lowell by two (2) courses as follows:

S 58° -42' -31" E, a distance of one hundred thirty-three and 95/100 feet (133.95) to a point of curvature,

SOUTHEASTERLY, more or less, by a curve to the left having a radius of three hundred twenty-eight and 45/100 feet (328.45), an arc length of sixty-seven and 42/100 feet (67.42) to an iron pin set on the most westerly end of Kyan Street; thence running along Kyan Street

S 06° -15' -39" W, a distance of seventeen and 54/100 feet (17.54) to a point at the back edge of the granite wall of the Pawtucket Canal; thence running along the back edge of said wall by three (3) courses as follows:

NORTHWESTERLY, more or less, by a curve to the right having a radius of three hundred forty-five and 57/100 feet (345.57) an arc length of sixty-six and 15/100 feet (66.15) to an x-cut set,

N 58° -41' -18" W, a distance of ninety-six and 27/100 feet (96.27) to an x-cut set, and

N 59° -37' -26" W, a distance of seventy-two and 08/100 feet (72.08) to a point on the southerly location line of the Boston and Maine Railroad; thence running along said railroad location line

N 86° -04' -09" E, a distance of thirty-one and 32/100 feet (31.32) to the point of beginning.

Containing three thousand seven hundred and twenty-eight (3,728) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-A/1

Beginning at a point on the southerly line of location of the Boston and Maine Railroad, said point being the northeasterly corner of land now or formerly of P. H. Macheras Oil Company; thence along said railroad location line

N 86° -50' -03" E, a distance of twenty and 20/100 feet (20.20) to a point at land now or formerly of the City of Lowell; thence along the westerly line of land of the City of Lowell

S 03° -30' -25" E, a distance of seven and 87/100 feet (7.87) to a point on the northerly line of land now or formerly of P. H. Macheras Oil Company; thence along said northerly line of P. H. Macheras Oil Company

N 71° -55' -57" W, a distance of twenty-one and 72/100 feet (21.72) to the point of beginning.

Containing eighty (80) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-A/3

Beginning at the northwesterly corner of the parcel, said corner being a point on the southerly line of location of the Boston and Maine Railroad, and being at the northeasterly corner of Parcel CB-A/2 as hereinbefore described; thence along the southerly location line of said railroad

N 86° -50' -03" E, a distance of seventy-one and 11/100 feet (71.11) to a point at the back edge of the southerly granite wall of the Pawtucket Canal; thence running along the back edge of said canal wall as follows:

S 43° -21' -58" E, a distance of sixty-four and 39/100 feet (64.39) to an iron pin set,

S 56° -00' -37" E, a distance of forty-five and 26/100 feet (45.26) to an x-cut set,

S 59° -03' -48" E, a distance of ninety-five and 68/100 feet (95.68) to a point,

S 58° -56' -41" E, a distance of eighty-six and 22/100 feet (86.22) to a drill hole set,

WESTERLY, more or less, by a curve to the left a distance of about two hundred and seven (207) feet to a drill hole set,

S 84° -07' -29" E, a distance of one hundred thirty-three and 92/100 feet (133.92) to a drill hole set,

S 88° -59' -18" E, a distance of twenty-nine and 40/100 feet (29.40) to a drill hole set,

S 89° -44' -14" E, a distance of forty-two and 79/100 feet (42.79) to a drill hole set,

N 87° -29' -24" E, a distance of thirty-nine and 60/100 feet (39.60) to a drill hole set,

N 83° -30' -57" E, a distance of one hundred three and 57/100 feet (103.57) to an x-cut set,

N 83° -29' -15" E, a distance of sixty-two and 46/100 feet (62.46) to an x-cut set,

S 85° -49' -54" E, a distance of one hundred eighteen and 37/100 feet (118.37) to an x-cut set, and

SOUTHEASTERLY, more or less, by a curve to the right a distance of about fifty-nine feet (59) to an x-cut set; thence

S 64° -34' -09" E, a distance of six and16/100 feet (6.16) to a point on the westerly line of School Street; thence along said westerly line of School Street

S 09° -18' -05" E, a distance of twenty-two and 36/100 feet (22.36) to a point at land now or formerly of Marinel Transportation Inc.; thence along the northerly line of land of Marinel Transportation Inc. and land of Nicholas C. Sarris et al as follows:

N 73° -27' -35" W, a distance of ninety-three and 55/100 feet (93.55) to a point,

N 85° -19' -55" W, a distance of sixty-eight and 00/100 feet (68.00) to a point of curvature,

WESTERLY, more or less, by a curve to the left having a radius of one hundred twenty-two and 00/100 feet (122.00), an arc length of twenty-five and 20/100 feet (25.20) to a point,

S 83° -30' -25" W, a distance of one hundred sixty and 00/100 feet (160.00) to a point of curvature,

WESTERLY, more or less, by a curve to the right having a radius of four hundred forty-seven and 00/100 feet (447.00), an arc length of fifty-two and 03/100 feet (52.03) to a point,

N 89° -48' -15" W, a distance of fifty and 00/100 feet (50.00) to a point of curvature,

WESTERLY, more or less, by a curve to the right having a radius of six hundred twenty-six and 00/100 feet (626.00), an arc length of seventy-six and 05/100 feet (76.05) to a point,

N 83° -13' -35" W, a distance of eighty and 00/100 feet (80.00) to a point of curvature, and

NORTHWESTERLY, more or less, by a curve to the right having a radius of five hundred fifty and 22/100 feet (550.22), an arc length of one hundred eighty-seven and 46/100 feet (187.46) to a point at the end of a twenty foot wide private way; thence crossing the end of said private way

N 64° -26' -11" W, a distance of twenty-eight and 22/100 feet (28.22) to the southeasterly corner of land now or formerly of P. H. Macheras Oil Company; thence along the northeasterly line of land of said P. H. Macheras Oil Company by two (2) courses as follows:

N 58° -56' -27" W, a distance of two hundred ninety-two and 59/100 feet (292.59) to a point, and

N 71° -55' 57" W, a distance of forty-five and 70/100 feet (45.70) to a point at the southeasterly corner of Parcel CB-A/2 as hereinbefore described; thence along the easterly line of land of said Parcel CB-A/2

N 03° -30' -25" W, a distance of twelve and 54/100 feet (12.54) to the point of beginning.

Containing twenty-two thousand and five hundred (22,500) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-A/4

Beginning at the northwesterly corner of the Parcel, said corner being a point on the westerly line of School Street; thence crossing said School Street

S 64° -34' -09" E, a distance of fifty-eight and 41/100 feet (58.41) to a point on the easterly line of School Street; thence along said easterly line of School Street

S 09° -18' -05" E, a distance of twenty and 25/100 feet (20.25) to the corner of the concrete bridge abutment; thence crossing School Street by the face of said bridge abutment

N 66° -18' -20" W, a distance of fifty-seven and 23/100 feet (57.23) to a point on the westerly line of School Street, said point being at the northeasterly corner of land now or formerly of Marinel Transportation Inc.; thence along said westerly line of School Street

N 09° -18' -05" W, a distance of twenty-two and 36/100 feet (22.36) to the point of beginning.

Containing one thousand and thirty (1,030) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-A/5

Beginning at a point on the easterly line of School Street, said point being the northeasterly corner of Parcel CB-A/4 as hereinbefore described; thence

S 64° -34' -09" E, a distance of two and 24/100 feet (2.24) to an x-cut set at the back edge of the southerly granite wall of the Pawtucket Canal; thence running along the back edge of said canal wall as follows:

S 59° -30' -00" E, a distance of one hundred five and 94/100 feet (105.94) to an x-cut set,

S 63° -37' -19" E, a distance of one hundred ninety-three and 60/100 feet (193.60) to an x-cut set,

S 73° -36' -36" E, a distance of ninety-seven and 13/100 feet (97.13) to an x-cut set,

S 73° - 37' -46" E, a distance of seven hundred thirty-one and 97/100 feet (731.97) to an x-cut set,

EASTERLY, more or less, by a curve to the left a distance of about one hundred and seventy-seven feet (177) to a drill hole set,

EASTERLY, more or less, still by said curve, a distance of about two hundred and ninety-nine feet (299) to an iron pin set,

NORTHEASTERLY, more or less, by a curve to the left, a distance of about one hundred and forty-eight feet (148) to an x-cut set, and

N 57° -32' -42" E, a distance of two hundred forty-nine and 31/100 feet (249.31) to a point at the northwesterly corner of Parcel 2B/2C-1/2C-2 as hereinafter described; thence along the southeasterly line of Parcel 2B/2C-1/2C-2 and land now or formerly of Thomas M. Hughes

S 22° -45' -06" E, a distance of one hundred eight and 06/100 feet (108.06) to a point at an angle in the northerly line of Middlesex Place; thence along said northerly line of Middlesex Place

S 68° -00' -59" W, a distance of twenty-five and 00/100 feet (25.00) to a point at the southeasterly corner of land now or formerly of John A. and Sandra L. Crowe; thence along the easterly line of Crowe

N 22° -45' -06" W, a distance of eighty-five and 36/100 feet (85.36) to a point; thence along the northerly line of Crowe

S 57° -20' -02" W, a distance of two hundred seventy-seven and 58/100 feet (277.58) to a point at land now or formerly of Philip J. Stratos; thence along the northerly line of said Stratos

Parcel : CB-A/5 (con't)

S 60° -04' -29" W, a distance of one hundred four and 53/100 feet (104.53) to a point of curvature; thence along the northerly line of land now or formerly of said Stratos, Peter D. Hallissy, and Lowell Boys Club Association

SOUTHWESTERLY, more or less, by a curve to the right having a radius of six hundred sixteen and 00/100 feet (616.00), an arc length of five hundred one and 72/100 feet (501.72) to a point at the northwesterly corner of land of said Lowell Boys Club Association; thence along the westerly line of the Lowell Boys Club Association

S 16° -16' -54" E, a distance of five and 00/100 feet (5.00) to a point at land now or formerly of Josephine M. Brady; thence along the northerly line of Brady as follows:

N 71° -50' -47" W, a distance of fifty-two and 05/100 feet (52.05) to a point,

N 71° -59' -55" W, a distance of one hundred sixty-eight and 82/100 feet (168.82) to a point, and

N 73° -44' -25" W, a distance of two hundred eighty-nine and 62/100 feet to a point at land now or formerly of Donald A. Delmore; thence by the northerly line of said Delmore and of land now or formerly of Ronald E. and Denise E. Belley as follows:

N 73° -44' -25" W, a distance of two hundred ninety-one and 65/100 feet (291.65) to a point,

N 63° -41' -05" W, a distance of one hundred ninety-eight and 65/100 feet (198.65) to a point, and

N 59° -37' -45" W, a distance of ninety-three and 37/100 feet (93.37) to a point on the easterly line of School Street; thence along said easterly line of School Street

N 09° -18' -05" W, a distance of twenty-three and 58/100 feet (23.58) to the point of beginning.

Containing thirty-nine thousand (39,000) square feet of land, more or less.

5 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 2B/2C-1/2C-2

Beginning at an iron pin set at the most westerly corner of the parcel, said pin being at the northeasterly corner of Parcel CB-A and being at the back edge of the southerly granite wall of the Pawtucket Canal; thence along the back edge of said canal wall

N 57° -32' -42" E, a distance of forty-two and 67/100 feet (42.67) to a point on the southwesterly location line of the Boston and Maine Railroad; thence along said railroad location line as follows:

SOUTHEASTERLY, more or less, by a curve to the right having a radius of nine hundred sixty-seven and 73/100 feet (967.73), an arc length of forty-one and 01/100 feet (41.01) to a point,

N 51° -44' -05" E, a distance of ten and 85/100 feet (10.85) to an iron pin set, and

SOUTHEASTERLY, more or less, by a curve to the right having a radius of nine hundred seventy-seven and 73/100 feet (977.73), an arc length of twenty-one and 57/100 feet (21.57) to an iron pin set at land now or formerly of Thomas M. Hughes; thence along the northwesterly line of land of said Hughes

S 51° -44' -05" W, a distance of ninety-five and 31/100 feet (95.31) to a point on the easterly line of Parcel CB-A; thence along said easterly line of Parcel CB-A

N 22° -45' -06" W, a distance of sixty-four and 06/100 feet (64.06) to the point of beginning.

Containing four thousand and eleven (4,011) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 2B/2B-1/2D-1/2D-2

Beginning at the most northerly corner of the parcel, said corner being a point on the back edge of the southerly granite wall of the Pawtucket Canal and being on the northwesterly prolongation of the southwesterly line of Thorndike Street; thence by land now or formerly of the Proprietors of Locks and Canals and by said southwesterly line of Thorndike Street

S 30° -15' -09" E, a distance of seventy-one and 98/100 feet (71.98) to a point at land now or formerly of the City of Lowell; thence by the northwesterly line of land of said City of Lowell

S 51° -55' -38" W, a distance of one hundred eighty-one and 47/100 feet (181.47) to a point on the northeasterly location line of the Boston and Maine Railroad; thence along said railroad location line as follows:

NORTHWESTERLY, more or less, by a curve to the left having a radius of one thousand eighteen and 73/100 feet (1018.73), an arc length of fourteen and 66/100 feet (14.66) to a point,

S 48° -17' -17" W, a distance of six and 12/100 feet (6.12) to a point,

N 58° -18' -24" W, a distance of nineteen and 61/100 feet (19.61) to a point,

N 52° -12' -56" E, a distance of twenty-two and 05/100 feet (22.05) to a point, and

NORTHWESTERLY, more or less, by a curve to the left having a radius of one thousand thirty-three and 73/100 feet (1,033.73), an arc length of thirty-eight and 66/100 feet (38.66) to a point at the back edge of the southerly granite wall of the Pawtucket Canal; thence along the back edge of said canal wall

N 50° -48' -09" E, a distance of two hundred two and 09/100 feet (202.09) to the point of beginning.

Containing thirteen thousand three hundred and forty-six (13,346) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-I

Beginning at a drill hole set at the most westerly corner of the Parcel, said corner being at the juncture of the Pawtucket and Hamilton Canals; thence running along the back edge of the wall of the Pawtucket Canal by seven (7) courses as follows:

N 40° -41' -10" E, a distance of fifty-three and 20/100 feet (53.20) to a P.K. nail set,

N 22° -06' -49" E, a distance of one hundred one and 17/100 feet (101.17) to a P.K. nail set,

N 20° -16' -46" E, a distance of sixteen and 22/100 feet (16.22) to an x-cut set,

NORTHEASTERLY, more or less, by a curve to the right, a distance of about thirty-six feet (36) to a drill hole set,

S 72° -41' -05" E, a distance of twenty-seven and 06/100 feet (27.06) to an iron pin set,

N 85° -42' -05" E, a distance of thirty-three and 05/100 feet (33.05) to a point, and

N 04° -17' -55" W, a distance of nine and 85/100 feet (9.85) to an x-cut set at the back edge of the granite wall of the Swamp Locks, Upper Lock Chamber; thence running along the back edge of the wall of said Lock Chamber by three (3) courses as follows:

N 87° -04' -42" E, a distance of forty-nine and 47/100 feet (49.47) to an x-cut set,

N 85° -46' -53" E, a distance of one hundred thirty-nine and 78/100 feet (139.78) to an iron pin set, and

S 01° -48' -53" E, a distance of seven and 55/100 feet (7.55) to a drill hole set in the bevel of a concrete wall; thence running along said wall and crossing a Right-of-Way

N 81° -09' -40" E, a distance of fifty-two and 56/100 feet (52.56) to a point on the westerly line of Parcel CB-J/East as hereinafter described; thence running along the westerly line of Parcel CB-J/East

S 13° -10' -56" E, a distance of twenty-four and 42/100 feet (24.42) to a point; thence again crossing said Right-of-Way, and running by the northerly line of land now or formerly of the Pellon Corporation

S 85° -54' -08" W, a distance of three hundred twenty-eight and 90/100 feet (328.90) to a drill hole in a stone bound found; thence continuing along the line of land of said Pellon Corporation by ten (10) courses as follows:

S 21° -44' -28" W, a distance of one hundred forty-three and 34/100 feet (143.34) to a P.K. nail set,

S 87° -02' -19" E, a distance of five and 36/100 feet (5.36) to a P.K. nail set,

SOUTHEASTERLY, more or less, by a curve to the right having a radius of two hundred ninety and 18/100 feet (290.18), and an arc length of one hundred sevety-seven and 57/100 feet (177.57) to a P.K. nail set,

SOUTHEASTERLY, more or less, by a curve to the right having a radius of fifty and 42/100 feet (50.42), and an arc length of sixteen and 48/100 feet (16.48) to a point of reverse curvature,

SOUTHEASTERLY, more or less, by a curve to the left having a radius of fifty and 42/100 feet (50.42) and an arc length of thirteen and 19/100 feet ... pound curvature,

SOUTHEASTERLY, more or less, by a curve to the left having a radius of one hundred thirty-one and 47/100 feet (131.47), and an arc length of sixty-eight and 79/100 feet (68.79) to a point,

S 78° -13' -08" E, a distance of seventeen and 83/100 feet (17.83) to a point,

EASTERLY, more or less, by a curve to the left having a radius of two hundred sixteen and 37/100 feet (216.37), and an arc length of ninety-two and 98/100 feet (92.98) to a point, and

N 77° -09' -34" E, a distance of thirty-six and 03/100 feet (36.03) to a point at land now or formerly of Jackson Properties Inc.; thence running along the westerly line of land of said Jackson Properties Inc.

S 12° -38' -26" E, a distance of eight and 27/100 feet (8.27) to a point at the back edge of the wall of the Hamilton Canal; thence running along the back edge of the wall of said Hamilton Canal as follows:

S 77° -19' -26" W, a distance of forty-eight and 14/100 feet (48.14) to an iron pin set,

WESTERLY, more or less, a distance of about seventy-three feet (73) to an x-cut set,

NORTHWESTERLY, more or less, a distance of about eighty-two feet (82) to a point,

NORTHWESTERLY, more or less, a distance of about seventy-three feet (73) to a drill hole set,

NORTHWESTERLY, more or less, a distance of about seventy-three feet (73) to a drill hole set,

WESTERLY, more or less, a distance of about eighty-two feet (82) to a P.K. nail set, and

N 86° -36' -20" W, a distance of thirty-eight and 12/100 feet (38.12) to the point of beginning.

PARCEL: CB-1
Page 3

Containing thirteen thousand two hundred and sixty square feet of land (13,260), more or less.

PROPOSED DESCRIPTION OF LAND

PARCEL: Guard Locks Lock Chamber –

Begining at a drill hole set at the northwesterly corner of the parcel along the westerly face of the westerly granite lock chamber wall at the top of a set of granite steps, thence

S 27°-16'-45" E, along the westerly face of the aforementioned granite wall, a distance of forty and 79/100 feet (40.79) to the northerly face of a building known as the Locking Gate House; thence

S 62°-43'-24" W, along the northerly face of the aforementioned building a distance of seven and 80/100 feet (7.80) to a building corner; thence

S 27°-16'-45" E, along the westerly face of the aforementioned building a distance of sixteen and 06/100 feet (16.06) to a building corner; thence

N 62°-43'-24" E, along the southerly face of the aforementioned building a distance of about six feet (6) to the westerly face of a granite wall on the westerly side of the Pawtucket Canal; thence

SOUTHERLY, more or less, along the aforementioned wall a distance of about fifty-five-feet (55) to the northwesterly corner of a building known as the Francis Gate House; thence

S 27°-26'-58" E, along the westerly face of the Francis Gate House a distance of thirteen and 41/100 feet (13.41) to the southwesterly corner of the Francis Gate House; thence by the westerly face of a granite wall on the westerly side of the Pawtucket Canal by five (5) courses as follows:

SOUTHERLY, about twelve feet (12),

WESTERLY, about thirteen feet (13),

SOUTHERLY, about three feet (3),

EASTERLY, about sixteen feet (16), and

SOUTHERLY, about six and 4/10 feet (6.4) to an iron pin set at the westerly face of said wall; thence continuing

SOUTHERLY, more or less, along the westerly face of the aforementioned wall about fifty-one feet (51) to an angle point in the wall; thence continuing

SOUTHERLY, more or less, along said wall a distance of about twenty-five feet (25) to an iron pin set at the westerly face of said wall, said iron pin being seventy-five and 37/100 feet (75.37) on a bearing of S 21°-00'-01" E, from the last mentioned iron pin; thence

PARCEL: Guard Locks - Lock Chamber

Northeasterly, N 30° - 24'- 34"E, a distance of sixty two and 37/100 feet (62.37) to an iron pin set,

S 88°-10'-35" W, a distance of eleven and 14/100 feet (11.14) to an iron pin set,

N 29°-55'-13" W, a distance of thirteen and 01/100 feet (13.01) to an iron pin set,

N 35°-19'-04" W, a distance of twelve and 82/100 feet (12.82) to an iron pin set, and

N 11°-33'-48" W, a distance of eighteen and 18/100 feet (18.18) to a drill hole set; thence continuing along the edge of exposed wall:

NORTHEASTERLY, more or less, a distance of about fourteen feet to a point,

NORTHWESTERLY, more or less, a distance of about three feet (3) to a point,

SOUTHWESTERLY, more or less, a distance of about fourteen feet (14) to a point,

NORTHWESTERLY, more or less, a distance of about twelve feet to the southeasterly corner of the Francis Gate House, said corner bearing N 36°-56'-54" W, and being fifteen and 26/100 feet (15.26) distant from the last mentioned drill hole; thence running along the northeasterly face of the Francis Gate House

N 27°-26'-58" W, a distance of thirteen and 41/100 feet (13.41) to the northeasterly corner thereof; thence running along the back of the exposed granite wall

N 17°-56'-25" W, a distance of nine and 09/100 feet (9.09) to a drill hole set in the bottom step of some granite steps; thence continuing along the back edge of the wall

NORTHWESTERLY, more or less, a distance of about thirty-two feet (32) to a point on the southerly wall of the Locking Gate House; thence running along the face of the north end of the Gate House as follows:

N 62°-43'-24" E, a distance of about seven feet (7) to the northeasterly corner of the Gate House,

N 27°-16'-45" W, a distance of sixteen and 06/100 feet (16.06) to the northerly corner of the Gate House,

S 62°-43'-24" W, a distance of about eight and 7/10 feet (8.7) to a point on the northerly face of the Locking Gate House, said point being at the back of the exposed granite wall as hereinbefore mentioned; thence running along the back of said wall

PARCEL: Guard Locks - Lock Chamber

NORTHWESTERLY, more or less, a distance of about zero and 7/10 feet (0.7) to a drill hole set, said drill hole bearing S 66°-57'-39" W, and being eight and 71/100 feet (8.71) distant from the aforementioned northerly corner of the Locking Gate House; thence continuing along the back edge of said wall

N 22°-50'-38" W, a distance of thirty-two and 98/100 feet (32.98) to a point, thence

Westerly, S 73° - 44' - 18"W, a distance of thirty eight and 05/100 (38.05) to the point of begining.

Containing five thousand nine hundred and eighty four square feet (5,984) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: SWAMP LOCKS DAM/NORTH

Beginning at the southeasterly corner of the dam, said corner being the northeasterly corner of the northerly gatehouse as hereinbefore described; thence along the northerly wall of said northerly gatehouse

S 85° 34' -47" W, a distance of about fourteen feet (14) to the face of the dam, said face being about one foot (1) easterly from and parallel with the hereinbefore described westerly edge of the steel grate footbridge; thence running along the face of the dam

N 04° -25' -13" W, a distance of about sixty-one feet (61) to the face of a concrete wall; thence running along said concrete wall

EASTERLY, NORTHERLY, and EASTERLY, all of said directions being more or less, a distance of about fourteen feet (14) to a point along the wall at the toe of the dam; thence running along the toe of the dam

S 04° -25' -13" E, a distance of about sixty-four feet (64) to the point of beginning.

Containing eight hundred and seventy-five square feet (875) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: SWAMP LOCKS DAM/SOUTH

Beginning at the northwesterly corner of the dam, said corner being two and one-half feet (2.5) easterly from a westerly wall of the northerly gatehouse as hereinbefore described; thence running along the northerly line of the dam, said line being along a southerly wall in the aforesaid northerly gatehouse

N 85° -34' -47" E, a distance of about twenty-eight feet (28) to the northeast corner of the dam; thence running across the toe of the dam

S 04° -25' -13" E, more or less, a distance of about thirty feet (30) to the southeast corner of the dam; thence along the northerly face of a granite wall

S 85° -34' W, more or less, a distance of about twenty-eight feet (28) to the southwest corner of the dam, said corner being a point on the southerly wall of aforesaid northerly gatehouse; thence running along the face of the dam, said face being two and one-half feet (2.5) easterly from and parallel with a westerly wall of said gatehouse

N 04° -25' -13"W , a distance of about thirty feet (30) to the point of beginning.

Containing eight hundred and forty square feet (840) of land, more or less

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: SWAMP LOCKS GATEHOUSE

Beginning at the northwesterly corner of the parcel, said corner being a point along the southerly line of Parcel CB-G, bearing N 79° - 49' -52" E, and being three and 15/100 feet (3.15) distant from a drill hole set at an angle in said southerly line of Parcel CB-G; thence along said line of Parcel CB-G
N 79° -49' 52" E, a distance of three and 52/100 feet (3.52) to a point; thence running along the edge of a steel grate footbridge

S 04° -25' -13" E, a distance of sixty-four and 47/100 feet (64.47) to the northerly wall of the northerly gatehouse; thence running along the wall of said gatehouse as follows:

N 85° -34' -47" E, a distance of eleven and 22/100 feet (11.22) to a corner,

S 04° -25' -13" E, a distance of ten and 50/100 feet (10.50) to a corner,

S 85° -34' -47" W, a distance of nine and 75/100 feet (9.75) to a corner, and

S 04° -25'-13" E, a distance of thirty and 06/100 feet (30.06) to a point zero and 30/100 feet (0.30) beyond the southeasterly corner of the northerly gatehouse; thence

S 85° -34' -20" W, a distance of two and 00/100 feet (2.00) to a point one and 78/100 feet (1.78) distant from the northeasterly corner of the southerly gatehouse and along the prolongation of the easterly wall thereof; thence running to and along the easterly wall of said southerly gatehouse as follows:

S 03° -45' -33" E, a distance of twenty and 14/100 feet (20.14) to a corner,

S 86° -14' -27" W, a distance of twelve and 42/100 feet (12.42) to a corner,

N 03° -45' -33" W, a distance of eighteen and 36/100 feet (18.36) to a corner, and

N 86° -14' -27" E, a distance of six and 32/100 feet (6.32) to a point on the northerly wall of said southerly gatehouse, said point being along the prolongation of the westerly wall of the northerly gatehouse, and two and 01/100 feet (2.01) distant therefrom; thence running to and along the wall of said northerly gatehouse as follows:

N 04° -25' -13" W, a distance of thirty-one and 77/100 feet (31.77) to a corner,

S 85° -34' -47" W, a distance of three and 93/100 feet (3.93) to a corner,

PARCEL: SWAMP LOCK GATEHOUSE
Page 2

N 04° -25' -13" W, a distance of ten and 50/100 feet (10.50) to a corner, and

N 85° -34' -47" E, a distance of seven and 08/100 feet (7.08) to a point on the northerly wall of the northerly gatehouse at the westerly edge of the steel grate footbridge ; thence running along the westerly edge of said footbridge

N 04° -25' -13" W, a distance of sixty-four and 11/100 feet (64.11) to the point of beginning.

Containing nine hundred and thirty-seven square feet (937) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: SWAMP LOCKS - LOCK CHAMBER

Beginning at a cross-cut set at the most westerly corner of the parcel, said cross-cut being at the back edge of the southerly granite wall of the Pawtucket Canal and being on the northerly line of land of Parcel CB-I as hereinbefore described; thence crossing the headwaters of the Swamp Locks and running

N 60°-11'-35" E, a distance of forty-five and 57/100 feet (45.57) to a cut set on the northerly face of a concrete buttress; thence along the northerly face of said buttress

N 86°-14'-27" E, a distance of seven and 43/100 feet (7.43) to the westerly face of the Swamp Locks Gatehouse; thence running along the walls of said gatehouse:

S 03°-45'-33" E, a distance of four and 26/100 feet (4.26) to a corner,

N 86°-14'-27" E, a distance of twelve and 42/100 feet (12.42) to a corner, and

N 03°-45'33" W, a distance of one and 17/100 feet (1.17) to a point on the easterly wall of said Swamp Locks Gatehouse; continuing,

N 03°-45'33" W, a distance of eighteen and 96/100 feet (18.96) to a point at the northerly face of the southerly granite wall of the Lower Pawtucket Canal; thence running along said granite wall as follows:

N 85°-34'-20" E, a distance of forty-six and 21/100 feet (46.21) to a cut set in the face of said wall,

N 84°-43'-16" E, a distance of forty-three and 12/100 feet (43.12) to a cut set in the face of said wall, and

N 89°-50'-16" E, a distance of twenty and 87/100 feet (20.87) to a cut set in the face of said wall; thence running along the northerly face of the southerly granite wall of the Lower Pawtucket Canal and thence crossing a twenty foot passageway

N 86°-13'-40" E, a distance of sixty-six and 78/100 feet (66.78) to a point on the easterly line of said twenty foot passageway; thence running along the easterly line of said passageway

N 09°-30'-31" W, a distance of three and 95/100 feet (3.95) to the southerly shoreline of the Lower Pawtucket Canal; thence running along said southerly shoreline as follows:

N 85°-27'-15" E, a distance of forty-one and 46/100 feet (41.46) to a point,

N 88°-55'-33" E, a distance of eighty and 01/100 feet (80.01) to a point, and

PARCEL: SWAMP LOCKS — LOCK CHAMBER
Page 2

S 06°-40'-48" E, a distance of eleven and 18/100 feet (11.18) to a point at the bottom of the Swamp Locks Lower Lock Chamber; thence running along said Lower Lock Chamber

S 84°-08'-49" W, a distance of forty-eight and 05/100 feet (48.05) to a point; thence running, as follows:

S 00°-25'-22" E, a distance of twenty-seven and 89/100 feet (27.89) to a point on the northerly line of land now or formerly of the Pellon Corporation; thence alng the line of said Pellon Corporation

S 77°-16'-35" W, a distance of sixty-six and 89/100 feet (66.89) to a point on the easterly line of a twenty foot passageway leading to Jackson Street; thence along the easterly line of said passageway

N 13°-10'-56" W, a distance of eleven and 82/100 feet (11.82) to a point at the southerly wall of the Swamp Locks Lower Lock Chamber; thence along the southerly wall of the Swamp Locks Lower Lock Chamber as follows:

S 81°-09'-40" W, a distance of fifty-two and 56/100 feet (52.56) to a drill hole set in the face of a concrete wall, and

N 01°-48'-53" W, a distance of seven and 55/100 feet (7.55) to an iron pin set at the back edge of the southerly granite wall of the Swamp Locks Upper Chamber; thence running along the back edge of said granite wall as follows:

S 85°-46'-53" W, a distance of one hundred thirty-nine and 78/100 feet (139.78)

S 87°-04'-42" W, a distance of forty-nine and 47/100 feet (49.47) to the point of beginning.

Containing eleven thousand six hundred and eighty five square feet (11,685), of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-G

Beginning at a drill hole set at the most southeasterly corner of the parcel, said drill hole being at the back edge of the northerly granite wall of the Lower Pawtucket Canal and the westerly wall of a wasteway appurtenant thereto; thence along the back edge of said granite canal wall:

S 77° -29' -58" W, a distance of one hundred eighty-four and 15/100 feet (184.15) to an x-cut set, and

S 77° -30' -59" W, a distance of one hundred sixty-nine and 44/100 feet (169.44) to a point at the inlet of an abandoned penstock; thence continuing along the back edge of said canal wall, more or less, and running under a concrete slab deck erected over a portion of the canal

S 88° -10' -10" W, a distance of three hundred fifty-seven and 82/100 feet (357.82) to a drill hole set in the top of a concrete wall; thence

N 76° -48' -05" W, a distance of twenty-eight and 87/100 feet (28.87) to a P.K. nail set in the pavement of the margin roadway; thence

N 64° -01' -21" W, a distance of sixty-one and 75/100 feet (61.75) to a P.K. nail set; thence

S 79° -49' 52" W, a distance of forty-one and 03/100 feet (41.03) to a drill hole set at the back edge of the concrete wall of the Pawtucket Canal; thence along the back edge of said concrete wall as follows:

N 73° -14' -07" W, a distance of nine and 54/100 feet (9.54) to a point,

N 51° -46' -40" W, a distance of seventeen and 24/100 feet (17.24) to a point, and

NORTHWESTERLY, more or less, by a curve in said wall to an iron pin set, said pin bearing N 22° -38' -49" W, and being five and 64/100 feet (5.64) distant from the point last mentioned; thence

N 43° -25' -34" E, a distance of sixty-seven and 95/100 feet (67.95) to a point; thence

N 08° -17' -03" W, a distance of six and 00/100 feet (6.00) to a drill hole set at the back edge of the southerly granite wall of the Merrimack Canal; thence along said granite canal wall

N 42° -20' -18" E, a distance of one hundred two and 32/100 feet (102.32) to a P.K. nail set, and

N 36° -47' -04" E, a distance of thirty-one and 41/100 feet (31.41) to an iron pin set; thence running under a bridge over said Merrimack Canal

N 43° -41' -11" E, a distance of sixty-three and 21/100 feet (63.21) to a point; thence

Parcel: CB-3 (con()

S 46° -18' -49" E, a distance of eleven and 59/100 feet (11.59) to a point; thence in part by the back edge of the granite wall

N 43° -30' -36" E, a distance of one hundred four and 47/100 feet (104.47) to an iron pin set; thence crossing the inlet of an abandoned penstock

N 46° -43' -29" E, a distance of thirty-eight and 32/100 feet (38.32) to an iron pin set; thence along the back edge of a granite wall as follow

N 41° -47' -54" E, a distance of seventy-two and 39/100 feet (72.39) to a point, and

N 44° -05' -17" E, a distance of ninety-five and 94/100 feet (95.94) to an iron pin set; thence running along the shoreline of the Merrimack Canal more or less, as follows:

N 25° -13' -45" E, a distance of thirty and 15/100 feet (30.15) to an iron pin set,

N 34° -16' -58" E, a distance of twenty-two and 39/100 feet (22.39) to an x-cut set, and

S 48° -14' -10" E, a distance of twelve and 75/100 feet (12.75) to an iron pin set at the back edge of a granite wall; thence along the back edge of said wall

N 43° -46' -07" E, a distance of one hundred twenty-six and 24/100 feet (126.24) to an iron pin set, and still by the edge of said wall

N 43° -46' -07" E, a distance of twenty-four and 02/100 feet (24.02) to the end thereof; thence

N 22° -32' -24" E, a distance of twenty-three and 98/100 feet (23.98) to the back corner of a concrete wall; thence along the back edge of said wall as follows:

N 25° -42' -52" E, a distance of thirteen and 29/100 feet (13.29) to a point,

N 49° -58' -52" E, a distance of twenty-one and 23/100 feet (21.23) to a point, and

N 67° -34' -51" E, a distance of twenty-five and 07/100 feet (25.07) to a point on the edge of said wall at land now or formerly of C.W.S. Associates Trust; thence by land of C.W.S. Associates and land of the Commonwealth of Massachusetts as follows:

S 46° -38' -52" E, a distance of nine and 00/100 feet (9.00) to a point, and

S 43° -41' -11" W, a distance of six hundred eighteen and 92/100 feet (618.92) to a drill hole in a concrete bound found at land now or formerly of the Pellon Corporation; thence by land of said Pellon Corporation as follows:

S 43° -41' -03" W, a distance of twenty-two and 75/100 feet (22.75) to a point,

S 43° -07' -46" W, a distance of sixty-five and 21/100 feet (65.21) to a point

S 41° -58' -46" W, a distance of one hundred and 40/100 feet (100.40) to a point,

S 48° -01' -14" E, a distance of fourteen and 54/100 feet (14.54) to a point,

N 89° -49' -46" E, a distance of thirty-seven and 98/100 feet (37.98) to a point,

S 62° -42' -14" E, a distance of forty-eight and 00/100 feet (48.00) to a point,

S 74° -47' -14" E, a distance of twenty-seven and 00/100 feet (27.00) to a point,

N 88° -10' -46" E, a distance of three hundred fifty-six and 93/100 feet (356.93) to a P.K. nail set, and

N 77° -31' -26" E, a distance of three hundred fifty-three and 06/100 feet (353.06) to a drill hole set at the back edge of the westerly granite wall of a wasteway; thence along the back edge of said wall

S 12° -33' -54" E, a distance of eighteen and 50/100 feet (18.50) to the point of beginning.

Containing twenty-five thousand two hundred and nine (25,209) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: LOWER LOCKS DAM

Beginning at a point at the southwesterly corner of the parcel, said point being two feet (2) distant from and parallel with the westerly face of the Lower Locks Gate House as hereinbefore described; thence crossing the Pawtucket Canal and running along the face of the Lower Locks Dam

N 06° -25' -46" E, a distance of eighty-seven feet (87) more or less to a point at the northerly end of the dam; thence running along the northerly end of the Lower Locks Dam

EASTERLY, more or less, a distance of about forty-one feet (41) to the base of said Dam; thence crossing the Pawtucket Canal and running across the base of the dam

SOUTHERLY, more or less, a distance of about ninety-eight feet (98) to a point at the base of granite of the Lower Locks; thence running along the southerly line of the Lower Locks Dam, being at the base of granite of said Lower Locks

WESTERLY, more or less, a distance of about forty-six feet (46) to the point of beginning.

Containing three thousand six hundred and eighty square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: LOWER LOCKS GATE HOUSE

Beginning at the southwesterly corner of the Lower Locks Gate House, said corner being at an angle in the northerly line of Parcel CB-K as hereinbefore described; thence running along the westerly face of the Gate House, more or less, and across the Pawtucket Canal, by five (5) courses as follows:

N 06° -25' 46" E, a distance of sixty-four and 78/100 feet (64.78) to a point,

N 83° -34' 14" W, a distance of two and 50/100 feet (2.50) to a point,

N 06° -25' -46" E, a distance of twelve and 25/100 feet (12.25) to a point,

S 83° -34' 14" E, a distance of two and 50/100 feet (2.50) to a point, and

N 06° -25' -46" E, a distance of eighteen and 10/100 feet (18.10) to the northwesterly corner of the Gate House, being at land now or formerly of the City of Lowell and known as the Rex Lot; thence along the northerly face of the Lower Locks Gate House by land now or formerly of the City of Lowell

S 83° -34' -14" E, a distance of seven and 50/100 feet (7.50) to the northeasterly corner of the Gate House; thence running along the easterly face of said Gate House, and crossing the Lower Locks Dam, by five (5) courses as follows:

S 06° -25' -46" W, a distance of eighteen and 10/100 feet (18.10) to a point,

S 83° -34' -14" E, a distance of seven and 70/100 feet (7.70) to a point,

S 06° -25' -46" W, a distance of twelve and 25/100 feet (12.25) to a point,

N 83° -34' 14" W, a distance of seven and 70/100 feet (7.70) to a point, and

S 06° -25' -46" W, a distance of sixty-four and 78/100 feet (64.78) to the southeasterly corner of the Lower Locks Gate House, being at an angle in the northerly line of Parcel CB-K as hereinbefore described; thence along said northerly line of Parcel CB-K along the southerly face of the Gate House

N 83° -34' -14" W, a distance of seven and 50/100 feet (7.50) to the point of beginning.

Containing eight hundred and thirty-eight square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-H

Beginning at an iron pin set at the southwesterly corner of the parcel, said iron pin being at the base of a granite retaining wall and being at an angle in the line of land now or formerly of Lowell Revitalization Corporation; thence running along the easterly line of land of said Lowell Revitalization Corporation

N 06° -44' -32" E, a distance of twenty and 32/100 feet (20.32) to an iron pin set at the back edge of the granite wall of the Pawtucket Canal; thence along the edge of said granite canal wall

S 84° -53' -27" E, a distance of sixty-eight and 96/100 feet (68.96) to a drill hole set at the southwesterly corner of a concrete wall; thence along the back edge of said concrete wall, more or less, crossing an old penstock

S 85° -57' -30" E, a distance of sixty-nine and 79/100 feet (69.79) to an x-cut set near the back edge of the granite wall of the Lower Locks; thence

S 44° -46' -55" E, a distance of eight and 86/100 feet (8.86) to an iron pin set; thence along the back edge of the exposed granite wall of the Lower Locks

S 83° -28' -56" E, a distance of one hundred ten and 00/100 feet (110.00) to a drill hole set near the back edge of said wall of the Lower Locks; thence

S 83° -10' -03" E, a distance of one hundred thirty-six and 39/100 feet (136.39) to an iron pin set at the base of the last granite stone of the Lower Locks; thence along the granite base stones of the Lower Locks

N 06° -01' -39" E, a distance of eleven feet (11) more or less to the Pawtucket Canal; thence along the Pawtucket Canal and the Concord River

EASTERLY, more or less, a distance of about one hundred and thirty feet (130) to a point; thence running along the northerly line of land now or formerly of the City of Lowell and Lowell Revitalization Corporation

N 83° -15' -28" W, a distance of five hundred and fourteen feet (514), more or less, to the point of beginning.

Containing eleven thousand one hundred square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: LOWER LOCKS LOCK CHAMBERS

Beginning at the most westerly corner of the parcel, said corner being a point on the northerly line of Parcel CB-H as hereinbefore described and bearing S 85° -57' 30" E, and being forty-nine and 55/100 feet (49.55) distant from a drill hole set in the southwesterly end of a concrete wall; thence running to a point on the northerly side of the Lower Locks

N 12° -49' -10" E, a distance of twenty-three and 64/100 feet (23.64); thence running along the outer edge of the granite blocks

S 82° -56' -24" E, a distance of seventeen and 44/100 feet (17.44) to a point on the southerly prolongation of the westerly line of the Lower Locks Gate House; thence

N 06° -25' -46" E, a distance of one and 49/100 feet (1.49) to the southwesterly corner of the Lower Locks Gate House as hereinafter described; thence along the southerly face of said Gate House

S 83° -34' -14" E, a distance of seven and 50/100 feet (7.50) to the southeast corner of the Lower Locks Gate House; thence along the easterly wall of said Gate House

N 06° -25' -46" E, a distance of four and 76/100 feet (4.76) to a point; thence along the northerly edge of the concrete capped wall of the Lower Locks

S 83° -18' -52" E, a distance of one hundred twenty-six and 25/100 feet (126.25) to a point; thence along the northerly top edge of granite of the Lower Locks by three (3) courses as follows:

N 89° -40' -25" E, a distance of nine and 86/100 feet (9.86) to a point,

S 82° -53' -58" E, a distance of ninety-eight and 75/100 feet (98.75) to a point, and

N 80° - 11' -21" E, a distance of eleven and 35/100 feet to a point at the base of the granite blocks of the Lower Locks; thence running along the base of said blocks

S 06° -01' -39" W, a distance of thirty-eight and 00/100 feet (38.00) to an iron pin set at the base of the last granite stone on the southeasterly end of the Lower Locks, said iron pin being at an angle in the northerly line of Parcel CB-H as hereinbefore described; thence running along the southerly line of the Lower Locks, being the northerly line of Parcel CB-H, by four (4) courses as follows:

N 83° -10' -03" W, a distance of one hundred thirty-six and 39/100 feet (136.39) to a drill hole set in granite, PC-152

PARCEL: LOWER LOCKS LOCK CHAMBERS (CONT.)

N 83° -28' -56" W, a distance of one hundred ten and 00/100 feet (110.00) to an iron pin set,

N 44° -46' -55" W, a distance of eight and 86/100 feet (8.86) to an x-cut set in granite, and

N 85° -57' -30" W, a distance of twenty and 24/100 feet (20.24) to the point of beginning.

Containing nine thousand one hundred and twenty-seven square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 5345A

Beginning at the southwesterly corner of the parcel, said corner bearing N 12° -38' -52" W, and being twenty-three and 00/100 feet (23.00) distant from the northerly line of Jackson Street; thence running along the easterly line of land now or formerly of James T. Lichoulas, trustee of Appleton Trust

N 12° -38' -52" W, a distance of ten and 91/100 feet (10.91) to a cut set at the face of a concrete wall; thence running along the southerly line of land now or formerly of the Proprietors of Locks and Canals and along said wall

N 84° -56' -46" E, a distance of forty-eight and 75/100 feet (48.75) to a drill hole set at the corner of said wall; thence running along the easterly line of land now or formerly of the Proprietors of Locks and Canals

N 02° -30' -39" E, a distance of seventeen and 68/100 feet (17.68) to a point at the Hamilton Canal; thence running along the southerly side of the Hamilton Canal

N 86° -56' -46" E, a distance of sixty-four and 37/100 feet (64.37) to a point on the northwesterly line of Parcel 5345C as hereinafter described; thence running along said northwesterly line of Parcel 5345C by two (2) courses as follows:

SOUTHWESTERLY, more or less, by a curve to the right having a radius of one hundred forty-two and 00/100 feet (142.00), an arc length of eighteen and 55/100 feet (18.55) to a point of compound curvature, and

SOUTHWESTERLY, more or less, by a curve to the right having a radius of ninety-eight and 00/100 feet (98.00), an arc length of thirty-four and 00/100 feet (34.00) to a point at the southeasterly corner of Parcel 5345B as hereinafter described; thence running along the easterly line of Parcel 5345B

N 12° -38' -52" W, a distance of five and 50/100 feet (5.50) to a point; thence running along the northerly line of Parcel 5345B, said line being twenty-three and 00/100 feet (23.00) distant from and parallel with the northerly line of Jackson Street

S 77° -21' -08" W, a distance of sixty-seven and 00/100 feet (67.00) to the point of beginning.

Containing one thousand four hundred and thirty-eight square feet (1,438) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 5345B

Beginning at the northwesterly corner of the parcel, said corner being the southwesterly corner of Parcel 5345A as hereinbefore described; thence running along the southerly and easterly lines of Parcel 5345A by two (2) courses as follows:

N 77° -21' -08" E, a distance of sixty-seven and 00/100 feet (67.00) to a point, and

S 12° -38' -52" E, a distance of five and 50/100 feet (5.50) to a point at land now or formerly of James T. Lichoulas, Trustee of Appleton Trust; thence running by land now or formerly of said James T. Lichoulas, Trustee

S 77° -21' -08" W, a distance of sixty-seven and 00/100 feet (67.00) to a point on the easterly line of other land owned now or formerly by James T. Lichoulas, Trustee of Appleton Trust; thence along said easterly line of Lichoulas

N 12° -38' -52" W, a distance of five and 50/100 feet (5.50) to the point of beginning.

Containing three hundred and sixty eight and 50/100 (368.5) square feet of land more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 5345C

Beginning at the southwesterly corner of the parcel, said corner being the southeasterly corner of Parcel 5345B as hereinbefore desribed; thence along the southerly line of Parcel 5345A by two (2) courses as follows:

NORTHEASTERLY, more or less, by a curve to the left having a radius of ninety-eight and 00/100 feet (98.00), an arc length of thirty-four and 00/100 feet (34.00) to a point of compound curvature; and

NORTHEASTERLY, more or less, by a curve to the left having a radius of one hundred forty-two and 00/100 feet (142.00), an arc length of nineteen and 29/100 feet (19.29) to a point at the Hamilton Canal; thence along the southerly line of said Hamilton Canal

N 77° -21' -08" E, a distance of forty-five and 00/100 feet (45.00) to a point; thence by land now or formerly of the Proprietors of Locks and Canals

S 20° -51' -08" W, a distance of twenty and 00/100 feet (20.00) to a point on the northerly line of land now or formerly of James T. Lichoulas, Trustee of Appleton Trust; thence along said northerly line of Lichoulas

S 77° -21' -08" W, a distance of eighty-four and 00/100 feet (84.00) to the point of beginning.

Containing nine hundred and sixty (960) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: 5345D

Beginning at the southwesterly corner of the parcel, said point being the southeasterly corner of Parcel 5345C as hereinbefore described; thence along the easterly line of Parcel 5345C

N 20° -51' -08" E, a distance of seventeen and 87/100 feet (17.87) to a point at the Hamilton Canal; thence running along the back edge of the southerly wall of said canal by five (5) courses as follows:

N 77° -47' -01" E, a distance of thirty-three and 52/100 feet (33.52) to a punch mark set at the edge of a steel bridge girder,

N 76° -53' -30" E, a distance of twenty-one and 79/100 feet (21.79) to another punch mark set at the edge of a steel bridge girder,

N 77° -18' -27" E, a distance of one hundred fifty-nine and 96/100 feet (159.96) to a cut set at the back edge of the wall,

N 77° -29' -54" E, a distance of two hundred fifty-six and 02/100 feet (256.02) to a drill hole set at the back edge of the wall, and

N 76° -33' -10" E, a distance of one hundred seven and 84/100 feet (107.84 to a point at land now or formerly of Courier Citizen Company; thence by the westerly line of land of said Courier Citizen Company

S 12° -38' -52" E, a distance of fifteen and 80/100 feet (15.80) to a point at land now or formerly of James T. Lichoulas, Trustee of Appleton Trust; thence running by the northerly line of land of said James T. Lichoulas, Trustee

S 77° -21' -08" W, a distance of five hundred eighty-eight and 99/100 feet (588.99) to the point of beginning.

Containing eight thousand six hundred and thirty-seven (8,637) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: HAMILTON GATEHOUSE

Beginning at a point on the westerly line of the Hamilton Canal at the head of the Hamilton Wasteway, said point bearing northeasterly, more or less, and being twenty-one and 05/100 feet (21.05) distant from the southeasterly corner of a building foundation; thence running along the westerly face of the Hamilton Gatehouse by land now or formerly of John Adden Furniture, Inc.

N 12° -40' -17" W, a distance of twelve and 18/100 feet (12.18) to the northwesterly corner of the gatehouse, said corner bearing southeasterly, more or less, and being twenty and 40/100 feet (20.40) distant from the northeasterly corner of a building foundation; thence running along the northerly and easterly faces of the Hamilton Gatehouse, by land now or formerly of John Adden Furniture, Inc.; by two (2) courses as follows:

N 77° -19' -43" E, a distance of twenty-one and 18/100 feet (21.18) to the northeast corner of the gatehouse,

S 12° -40' -17" E, a distance of twelve and 18/100 feet (12.18) to the southeast corner of the gatehouse; thence running along the southerly face of the gatehouse, by land now or formerly of John Adden Furniture, Inc. and crossing the Hamilton Canal

S 77° -19' -43" W, a distance of twenty-one and 18/100 feet (21.18) to the point of beginning.

Containing two hundred and fifty-eight (258) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: Y.M.C.A. GATES

Beginning at a point at the southeasterly corner of lot B, said point being the line of the southeasterly wall of the Merrimack Canal; thence running along said southeasterly canal wall

S 43°-05'-08" W, a distance of about twelve feet (12) to a point at the most southerly end of the concrete gate structure; thence crossing the Merrimack Canal and running along the southwesterly edge of the concrete and wood gate structure as follows:

NORTHERLY, more or less, by a curve to the right, a distance of about seven feet (7) to an angle,

NORTHWESTERLY, more or less, a distance of about fifteen feet (15) to an angle,

SOUTHWESTERLY, more or less, a distance of about two feet (2) to an angle,

WESTERLY, more or less, a distance of about two feet (2) to an angle,

NORTHERLY, more or less, a distance of about two feet (2) to an angle,

NORTHEASTERLY, more or less, a distance of about two feet (2) to an angle,

NORTHWESTERLY, more or less, a distance of about fourteen feet (14) to an angle, and

SOUTHWESTERLY, more or less, by a curve to the right, a distance of about ten feet (10) to a point on the southeasterly face of the northwesterly canal wall; thence running along said canal wall

N 43°-42'-49" E, a distance of about sixteen feet (16) to a point on the southwesterly face of the granite wall crossing the canal; thence running along the southwesterly face of said granite wall

SOUTHEASTERLY, more or less, a distance of about four feet (4) to a corner in the concrete gate structure; thence running along the northeasterly edge of the concrete and wood gate structure as follows:

SOUTHWESTERLY, more or less, a distance of about one foot (1) to an angle,

SOUTHEASTERLY, more or less, a distance of about fifteen feet (15) to an angle,

NORTHEASTERLY, more or less, a distance of about five feet (5) to an angle,

EASTERLY, more or less, a distance of about two feet (2) to an angle,

SOUTHERLY, more or less, a distance of about two feet (2) to an angle,

PARCEL: Y.M.C.A. GAI_S PG 159

Page 2

SOUTHWESTERLY, more or less, a distance of about five feet (5) to an angle, and

SOUTHEASTERLY, more or less, a distance of about twenty feet (20) to the point of beginning.

Containing three hundred square feet (300) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: ROLLING DAM

Beginning at an iron pin set on the southeasterly line of the Merrimack Wasteway, said pin being at an angle in the northwesterly line of Parcel CB-L/5721 as hereinbefore described; thence running along said southeasterly line of the Merrimack Wasteway by the northwesterly line of Parcel CB-L/5721 and by land now or formerly of Boott Mills

S 48° -17' -38" W, a distance of about thirty-five feet (35) more or less, to the face of the Rolling Dam; thence running across the Merrimack Wasteway by the face of said Rolling Dam

NORTHWESTERLY, more or less, a distance of about eighteen feet (18) to a point on the northwesterly line of the Merrimack Wasteway, being at land now or formerly of Lowell Union Properties Inc.; thence along the southeasterly line of said Lowell Union Properties Inc., being the northwesterly line of the Merrimack Wasteway,

N 48° -15' -38" E, a distance of thirty-five feet (35), more or less, to a point at the base of the Rolling Dam; thence crossing the Merrimack Wasteway and running along the base of said Rolling Dam

SOUTHEASTERLY, more or less, a distance of about eighteen feet (18) to the point of beginning.

Containing six hundred and thirty square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
6 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: ROLLING DAM GATE HOUSE/NORTH SECTION

Beginning at the northwesterly corner of the Rolling Dam Gate House, said corner being a point on the southeasterly line of land, now or formerly of Lowell Union Properties Inc., said southeasterly line of land also being the northwesterly line of the Merrimack Canal Wasteway, the aforesaid point of beginning bearing N 48° -15' -38" E and being fifty-seven and 58/100 feet (57.58) distant from a drill hole found in an angle in the wall of the Merrimack Canal; thence along the southeasterly line of land now or formerly of Lowell Union Properties Inc.

N 48° -15' -38" E, by the northwesterly line of the Merrimack Canal Wasteway and the Rolling Dam along the northwesterly face of the Rolling Dam Gate House, a distance of eleven and 15/100 feet (11.15) to a point; thence crossing the Rolling Dam and running along the northeasterly face of the Rolling Dam Gate House S 42° -02' -28" E, a distance of seventeen and 90/100 feet (17.90) to a point on the northwesterly line of land now or formerly of Boott Mills, being the southeasterly line of the Merrimack Canal Wasteway; thence running through the Rolling Dam Gate House along said southeasterly line of the Merrimack Canal Wasteway

S 48° -17' -38" W, a distance of twenty-seven and 29/100 feet (27.29) to a point on the southwesterly building face of the Rolling Dam Gate House, said point bearing N 20° -06' -35" E and being zero and 45/100 feet (0.45) distant from the most southwesterly corner thereof; thence crossing the Merrimack Canal Wasteway and running along the westerly and southwest building lines of the Rolling Dam Gate House by two (2) courses as follows:

N 20° -06' -35" E, a distance of eighteen and 26/100 feet (18.26) to a point, and

N 42° -02' -28" W, a distance of nine and 26/100 feet (9.26) to the point of beginning.

Containing two hundred and sixty-nine square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: ROLLING DAM GATE HOUSE/SOUTH SECTION

Beginning at a point on the northeasterly face of the Rolling Dam Gate House, said point being on the southeasterly line of the Merrimack Canal Wasteway and bearing S 48° -17' -38" W, and being nineteen and 37/100 feet (19.37) distant from an iron pin set at the northwesterly corner of Parcel CB-L/5721 as hereinbefore described; thence running by land now or formerly of Boott Mills along the building face of the Rolling Dam Gate House by four (4) courses as follows:

S 42° -02' -28" E, a distance of four and 07/100 feet (4.07) to a point,

S 20° -06' -35" W, a distance of twenty-two and 94/100 feet (22.94) to a point, said point bearing N 42° -45' -53" W, and being thirty-four and 96/100 feet (34.96) distant from the most northerly corner of Store House No. 1,

N 68° -42' -56" W, a distance of sixteen and 49/100 feet (16.49) to a point, and

N 20° -06' -35" E, a distance of zero and 45/100 feet (0.45) to a point on the southeasterly line of the Merrimack Canal Wasteway; thence along said southeasterly line of the Merrimack Canal Wasteway

N 48° -17' -38" E, a distance of twenty-seven and 29/100 feet (27.29) to the point of beginning.

Containing two hundred and forty-eight (248) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: MASSACHUSETTS WASTEWAY GATE HOUSE

Beginning at the northwesterly corner of the Massachusetts Wasteway Gate House, said corner bearing S 41° -44' -51" E, and being three and 74/100 feet (3.74) distant from the southeasterly line of Bridge Street; thence running along the face of the Massachusetts Wasteway Gate House by land now or formerly of the Proprietors of Locks and Canals, by three (3) courses as follows:

N 48° -15' -09" E, a distance of seven and 67/100 feet (7.67) to a corner,

S 41° -44' -51" E, a distance of twenty-six and 00/100 feet (26.00) to a corner, and

S 48° -15' -09" W, a distance of seven and 67/100 feet (7.67) to the most southerly corner of said Gate House, being a point on the southeasterly side of the Eastern Canal; thence along the southwesterly face of the Massachusetts Wasteway Gate House

N 41° -44'-51" W, a distance of twenty-six and 00/100 feet (26.00) to the point of beginning.

Containing one hundred and ninety-nine square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: BOOTT DAM

Beginning at a point on the northeasterly line of Parcel CB-L/5721, said point bearing N 43° -08' -52" W, and being about ten feet (10) distant from the northwesterly corner of the Boott Dam Gate House as hereinbefore described; thence running along the base of the Boott Dam, being the southeasterly line of Parcel 5721A,

NORTHEASTERLY, more or less, a distance of about thirty-nine feet to a point at the outer corner of a concrete siphon of the Boott Dam, said point being at land now or formerly of Boott Mills; thence along the line of land of Boott Mills

SOUTHEASTERLY, more or less, a distance of about six feet (6) to a point at the most northerly corner of the Boott Dam Gate House; thence along the northeasterly wall of the Boott Dam Gate House, being the southwesterly wall of Mill No.9 of the Boott Mills

S 41° -17' -01" E, a distance of fourteen feet (14) more or less, to a point at the face of the Boott Dam; thence running across the Eastern Canal along the face of said Boott Dam

SOUTHWESTERLY, more or less, a distance of about forty-two feet (42) to a point on the southwesterly wall of Boott Dam Gate House, said point being on the northeasterly line of Parcel CB-L/5721 as hereinbefore described; thence running along said northeasterly line of Parcel CB-L/5721 and the southwesterly wall of said Boott Dam Gate House

N 38° -32' -55" W, a distance of eight feet (8.0), more or less, to the northwest corner of the Gate House; thence continuing along the northeasterly line of aforesaid Parcel CB-L/5721

N 43° -08' -52" W, a distance of ten feet (10) more or less, to the point of beginning.

Containing eight hundred and thirty square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: BOOTT DAM GATE HOUSE

Beginning at the most northerly corner of the Boott Dam Gate House, said corner being a point on the southwesterly wall of Mill No. 9 of the Boott Mills, bearing S 41°-17'-01" E and being twenty nine and 46/100 feet (29.46) distant from southeasterly wall of the Picker Building; thence

S 41°-17'-01" E, along the southwesterly wall of Mill No. 9 of the Boott Mills sixteen and 67/100 feet (16.67) to a point on the Eastern Canal; thence crossing said Eastern Canal and running along the southeasterly face of the Boott Dam Gate House by two (2) courses as follows:

S 39°-34'-16" W, a distance of eighteen and 98/100 feet (18.98) to a point, and

S 56°-14'-08" W, a distance of twenty-two and 05/100 feet (22.05) to a point on the northeasterly line of Parcel CB-L/5721 as hereinbefore described, said point being the most southerly corner of the Boott Dam Gate House; thence

N 38°-32'-55" W, along the southwesterly face of the Boott Dam Gate House a distance of eleven and 01/100 feet (11.01) to a point; thence crossing said Eastern Canal and running along the wall of the Boott Dam Gate House by three(3) courses as follows:

N 56°-14'-08" E, a distance of nineteen and 50/100 feet (19.50) to a point,

N 51°-14'-58" W, a distance of four and 90/100 feet (4.90) to a point, and

N 39°-34'-16" E, a distance of twenty-one and 87/100 feet (21.87) to the point of beginning.

Containing five hundred and sixty-five (565) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-L/5721

Beginning at a point at the southeasterly corner of the parcel, said point being on the northeasterly line of land now or formerly of Boott Mills, and bearing N 41°-34'-09" W, and being sixty and 23/100 feet (60.23) distant from the westerly termination of Amory Street; thence

N 41°-34'-09" W, along the northeasterly line of land now or formerly of Boott Mills, a distance of one hundred fifty-eight and 92/100 feet (158.92) to an iron pin set at the southeasterly face of the southeasterly wall of the Rolling Dam; thence

N 48°-17'-38" E, along said southeasterly face of the southeasterly wall of the Rolling Dam, a distance of eight and 61/100 feet (8.61) to an iron pin set at an angle in the southerly wall of the Merrimack Wasteway; thence

N 70°-36'-40" E, along the southerly face of a wall, a distance of Nine and 91/100 feet (9.91) to a cross-cut set at an angle in said wall; thence

S 40°-30'-36" E, along the southwesterly face of the southwesterly wall of the Eastern Canal, a distance of four and 65/100 feet (4.65) to a point on th northwesterly face of a brick building; thence running along the face of said brick building by five (5) courses as follows:

S 48°-17'-38" W, a distance of zero and 71/100 feet (0.71) to a point,

S 40°-24'-35" E, a distance of ten and 40/100 feet (10.40) to a point,

S 50°-12'-21" W, a distance of twelve and 73/100 feet (12.73) to a point,

S 40°-24'-35" E, a distance of twenty-one and 36/100 feet (21.36) to a point, and

N 48°-23'-37" E, a distance of thirteen and 50/100 feet (13.50) to a point at the southwesterly face of the southwesterly wall of the Eastern Canal; thence running along said southwesterly face of the southwesterly wall of the Eastern Canal

S 43°-08'-52" E, a distance of thirty-five and 00/100 feet (35.00) to a point at the most westerly corner of the Boott Dam Gate House as hereinafter described; thence

S 38°-32'-55" E, along the southwesterly face of the Boott Dam Gate House, a distance of eleven and 07/100 feet (11.07) to a point at the most southerly corner thereof; thence along the southwesterly face of the southwesterly wall of the Eastern Canal

S 42°-29'-19" E, a distance of seventy-two and 12/100 feet (72.12) to a point; thence

S 45°-11'-23" W, along the northwesterly edge of a concrete capstone, a distance of eighteen and 69/100 feet (18.69) to a PK nail set at the point of beginning.

PARCEL: CB-L/5721 (cont'd)

Containing two thousand five hundred and eleven (2,511) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: Blacksmith Shop

Beginning at the most southerly corner of the Blacksmith Shop, said corner bearing N 49° -46' -36" W, and being twnety-six and 24/100 feet (26.24) distant from the northwesterly line of land now or formerly of Flago Realty Corporation; thence along the face of the Blacksmith Shop follows:

N 66° -55' -23" W, a distance of eight and 15/100 feet (8.15) to a corner,

N 23° -51' -49" E, a distance of seven and 18/100 feet (7.18) to a corner,

N 65° -45' -09" W, a distance of seventeen and 26/100 feet (17.26) to a corner,

N 24° -09' -04" E, a distance of forty-five and 47/100 feet (45.47) to a corner,

S 65° -45' -09" E, a distance of twenty-five and 19/100 feet (25.19) to a corner, and

S 23° -51' -49" W, a distance of fifty-two and 48/100 feet (52.48) to the point of beginning.

Containing one thousand two hundred and four (1,204) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: PAWTUCKET GATE HOUSE

Beginning at the most southeasterly corner of the Pawtucket Gate House, said point being fifteen and 35/100 feet (15.35) northwesterly from the westerly line of Parcel 29; thence

N 46°-55'-36" W, along the most southerly face of the building a distance of one hundred eighteen and 70/100 feet (118.70) to a point; thence on a curve to the right

NORTHWESTERLY, more or less, along the face of said building a distance of five feet (5) to a point; thence

N 43°-12'-10" E, along the most westerly face of said building a distance of sixteen and 40/100 feet (16.40) to a building corner, said corner being set back from the southerly line of Pawtucket Street a distance of zero and 60/100 feet (0.60); thence

S 46°-55'-36" E, along the most northerly face of said building a distance of one hundred twenty-two and 04/100 feet (122.04) to the most northeasterly building corner, said corner being set back from the southerly line of Pawtucket Street a distance of zero and 46/100 feet (0.46); thence

S 43°-12'-10" W, along the most easterly face of said building a distance of nineteen and 75/100 feet (19.75) to the point of beginning.

Containing two thousand and four hundred (2,400) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: 29, Lot 2

Beginning at a drill hole set on the southwesterly line of School Street, said drill hole being at the northwesterly corner of land now or formerly of the Commonwealth of Massachusetts; thence along the westerly line of land of said Commonwealth of Massachusetts by two (2) courses as follows:

S 42° -50' -42" W, a distance of seventy-six and 30/100 feet (76.30) to an iron pin set, and

S 24° -14' -32" W, a distance of seventy-two and 91/100 feet (72.91) to an iron pin set; thence along the southwesterly line of land of the Commonwealth of Massachusetts

S 61° -39' -08" E, a distance of ninety-seven and 41/100 feet (97.41) to a point on the northwesterly line of land now or formerly of the American Red Cross; thence along the northwesterly lone of land of said American Red Cross and of Flago Realty Corporation

S 40° -13' -24" W, a distance of two hundred twenty and 81/100 feet (220.81) to an x-cut in a stone bound found at land of Irene Desmarias; thence along the northeasterly line of land now or formerly of said Desmarias as follows:

N 23° -03' -25" W, a distance of forty-two and 34/100 feet (42.34) to a point, and

N 19° -33' -29" E, a distance of twenty-two and 00/100 feet (22.00) to a drill hole set in the granite retaining wall of the Merrimack River; thence along the Merrimack River by said retaining wall:

N 48° -01' -43" W, a distance of ten and 00/100 feet (10.00) to a drill hole set,

N 23° -55' -13" E, a distance of one hundred sixty-five and 57/100 feet (165.57) to a point,

N 24° -14' -32" E, a distance of seventy-four and 06/100 feet (74.06) to a drill hole set, and

N 42° -50' -42" E, a distance of seventy-seven and 48/100 feet (77.48) to a drill hole set on the southwesterly line of School Street; thence along said line of School Street

S 46° -51' -34" E, a distance of seven and 00/100 feet (7.00) to the point of beginning.

Containing fifteen thousand nine hundred and fifty-seven (15,957) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 • PG 171

PROPOSED DESCRIPTION OF LAND

PARCEL: PAWTUCKET GATE HOUSE WALL AND LOCK CHAMBER

Beginning at a point at the most southeasterly corner of a brick building called the Pawtucket Gate House, said point being fifteen and 35/100 feet (15.35) distant from the northwesterly line of Parcel 29; thence

N 46°-55'-36" W, along the most southerly face of the building, a distance of one hundred eighteen and 70/100 feet (118.70) to a point; thence along a curve to the right along the face of said building a distance of five feet (5) to a point; thence

N 43°-12'-10" E, along the most westerly face of said building a distance of sixteen feet (16), more or less, to the end of a granite wall at the face of a concrete and granite wall; thence

NORTHWESTERLY, along said concrete and granite wall a distance of sixteen (16) feet, more or less; thence

SOUTHERLY, more or less, by the face of a granite wall by the following distances: ten feet (10), more or less, thence thirteen feet (13), more or less, and eight feet (8), more or less, around a curved section of wall; thence

SOUTHEASTERLY, along the face of the aforementioned granite wall, said face of wall being approximately parallel with and two and 7/10 feet (2.7) south of the southerly face of the Pawtucket Gate House, a distance of one hundred and twelve feet (112), more or less, to an angle point; thence along the face of said wall a distance of ten feet (10), more or less; thence along the face of said wall around a curve a distance of seven feet (7), more or less; thence along the face of said wall a distance of ten feet (10), more or less; thence

SOUTHEASTERLY, along a concrete wall, said wall being approximately parallel with School Street a distance of fifteen feet (15), more or less, to a point; thence

N 42°-50'-42" E, along land now or formerly of the Proprietors of Locks and Canals, a distance of twenty-three feet (23), more or less, to a drill hole set at the southerly line of School Street; thence

N 46°-51'-34" W, along the southerly line of School Street and land now or formerly of the Proprietors of Locks and Canals a distance of three feet (3), more or less, to a point; thence

NORTHEASTERLY, approximately perpendicular to the southerly line of School Street and under the School Street Bridge along the easterly face of the easterly granite wall of the lock chamber, fifty-eight feet (58), more or less, to the northerly line of School Street; thence

SOUTHEASTERLY, along said granite wall and the northerly line of School Street a distance of six feet (6), more or less, to a point; thence

PARCEL: PAWTUCKET GATE HOUSE WALL AND LOCK CHAMBER (cont'd)

NORTHEASTERLY, along the westerly face of a granite wall by land now or formerly of the Proprietors of Locks and Canals one hundred and twenty feet (120), more or less, and seventeen feet (17), more or less, to the shoreline; thence

SOUTHWESTERLY, along the westerly face of the easterly granite wall of the Northern Canal a distance of ninety-three feet (93), more or less, to a point; thence

NORTHWESTERLY, crossing the Lock Chamber a distance of nineteen feet (19), more or less, to the westerly face of the westerly granite of the Lock Chamber; thence

SOUTHWESTERLY, along said face of wall a distance of thirty-six feet (36), more or less, to the northerly line of School Street; thence

S 46°-51'-34" E, along the northerly line of School Street a distance of three feet (3), more or less, to a point; thence

SOUTHWESTERLY, approximately perpendicular to the northerly line of School Street and under the School Street Bridge along the westerly face of the westerly granite wall of the lock chamber, fifty-eight feet (58), more or less, to the southerly line of School Street; thence along the easterly face of the Pawtucket Gate House

S 43°-12'-10" W, a distance of twenty feet (20), more or less, to the point of beginning.

Containing three thousand seven hundred and ten (3,710) square feet, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND
PARCEL: 29-B

Beginning at a point on the northeasterly line of School Street and on the northerly side of the Northern Canal; thence along the line of School Stre

N 46°-51'-34" W, a distance of about fifteen feet (15) to the face of a concre wall at the Merrimack River; thence by the Merrimack River along said wall

NORTHEASTERLY, more or less, a distance of about twenty-four feet (24) to the shoreline of the Merrimack River; thence along said shoreline

NORTHEASTERLY and EASTERLY, more or less, a distance of about one thousand two hundred and twenty five feet (1,225) to a point on the northwesterly line of the Northern Canal Walkway; thence along the northwesterly line of said walkway

SOUTHWESTERLY, more or less, a distance of about three hundred and twenty-one feet (321) to the westerly end of the walkway; thence by the westerly end of the walkway

SOUTHERLY, more or less, a distance of seven and 5/10 feet (7.5) to a point at the back edge of the northerly granite wall of the Northern Canal; thence along said canal wqll as follows:

S87°-35'-13" W, a distance of thirty-eight and 82/100 feet (38.82) to an iron pin set,

WESTERLY, more or less, a distance of about two hundred and one feet (201) to an iron pin set,

SOUTHWESTERLY, more or less, a distance of about two hundred and thirty-eight (238) feet to an iron pin set, and

SOUTHWESTERLY, more or less, a distance of about one hundred and ninety-nine feet (199) to a point at the base of some granite steps; thence by the base of said steps

SOUTHEASTERLY, more or less, a distance of about two feet (2) to the water fac of the northerly granite wall of the Northern Canal; thence along said canal wall

S 54°-34'-18" W, a distance of ten and 34/100 feet (10.34) to a point, and

S 42°-34'-31" W, a distance of eighty-eight and 02/100 feet (88.02) to the point of beginning.

Containing two and 2/10 acres (2.2), more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: 29-A

Beginning at a point at the northerly end of Falls Street, said point being on the northeasterly line thereof and bearing N 34°-31'-55" W and being one hundred fifty-one and 93/100 feet (151.93) distant from the northwesterly line of Pawtucket Street; thence running across the end of Falls Street

S 58°-04'-50" W, a distance of about twenty-six feet (26) to a point on the northeasterly line of land now or formerly of Robert Richards; thence along said line of Richards as follows:

N 33°-25'-55" W, a distance of about nine feet (9) to a point of curvature,

NORTHWESTERLY, more or less, by a curve to the left having a radius of twenty-four and 77/100 feet (24.77), an arc length of twenty-five and 13/100 feet (25.13) to a point of tangency, and

S 88°-25'-35" W, a distance of sixty-two and 28/100 feet (62.28) to a point at land now or formerly of Mathias Laurin; thence along the northerly line of said Laurin

S 88°-08'-35" W, a distance of one hundred eighty and 86/100 feet (180.86) to the center face of a granite post at land now or formerly of Lord Associates; thence along the northeasterly and northerly lines of Lord Associates as follows:

N 26°-09'-54" W, a distance of forty-four and 03/100 feet (44.03) to a point,

S 88°-37'-06" W, a distance of ninety -four and 07/100 feet (94.07) to a point of tangency, and

WESTERLY, more or less, by a curve to the left having a radius of six hundred ninety feet (690.00), an arc length of one hundred twenty-nine and 61/100 feet (129.61) to a point at land now or formerly of the Proprietors of Locks and Canals; thence along the northeasterly line of land of said Proprietors of Locks and Canals

N 21°-40'16" W, a distance of nineteen and 23/100 feet (19.23) to a point at the southerly edge of the southerly granite wall of the Northern Canal; thence running along said canal wall as follows:

N 86°-13'-11" E, a distance of one hundred twenty and 86/100 feet (120.86) to an iron pin set,

N 88°-06'-10" E, a distance of one hundred thirty-seven and 58/100 feet (137.58) to an iron pin set,

N 88°-29'-09" E, a distance of one hundred fifty and 63/100 feet (150.63) to an iron pin set,

S 89°-25'-37" E, a distance of thirty-three and 70/100 feet (33.70) to a point, PARCEL: 29-A (cont'd)

N 86°-35'-12" E, a distance of fifty-four and 77/100 feet (54.77) to an iron pin set,

S 87°-37'-19" E, a distance of thirteen and 46/100 feet (13.46) to a point,

S 64°-33'-48"E, a distance of fourteen and 65/100 feet (14.65) to a point,

S 46°-05'-09" E, a distance of ten and 58/100 feet (10.58) to an iron pin set

S 32°-44'-56" E, a distance of ten and 85/100 feet (10.85) to a point, and

S 35°-07'-44" E, a distance of twenty and 45/100 feet (20.45) to a drill hole set at the base of some steps; thence crossing said steps

S 35°-07'-44" E, a distance of about four feet (4) to the face of a granite wall; thence by said wall:

S 58°-04'-50" W, a distance of about sixteen feet (16) to a point, and

SOUTHERLY, more or less, a distance of about five feet (5) to the point of beginning.

Containing eighteen thousand five hundred and eighty-six square feet (18,586) of land, more or less.

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66 Rand Street, Lynn, MA 01904
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PROPOSED DESCRIPTION OF LAND
PARCEL: CB-B

Beginning at a point on the southwesterly line of University Ave. point bearing N 45°-19'-56" W and being six and 51/100 feet (6.51) distant from the point of curvature leading to Pawtucket Street; thence along a wall by land now or formerly of Faneros

S 53°-32'-58" W, a distance of twenty-eight and 57/100 feet (28.57) to a drill hole in a stone bound found; thence running by land now or formerly of Faneros, by land of the Members of the Catholic Association, and by land of Reppucci

S 53°-32'-58" W, a distance of four hundred ninety-five and 24/100 feet (495.24) to the face of a granite wall at land now or formerly of said Reppucci; thence along land of Reppucci by said wall:

N 37°-59-38" W, a distance of eleven and 75/100 feet (11.75) to a drill hole in a stone bound found, and

S 57°-39'-52" E, a distance of one hundred seven and 63/100 feet (107.63) to a point at the face of said granite wall; thence

NORTHWESTERLY, more or less, a distance of about seven feet (7) to the southeasterly shoreline of the Northern Canal; thence along said canal shoreline

NORTHEASTERLY, more or less, a distance of about six hundred and twenty-seven feet (627) to a point on the southwesterly line of University Ave. thence along said line of University Ave.

S 45°-19'-56" E, a distance of about twenty-eight feet (28) to the point of beginning.

Containing thirteen thousand eight hundred and sixty-five square feet (13,865 of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
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PROPOSED DESCRIPTION OF LAND
PARCEL: 30-A

Beginning at a drill hole found in the capstone of a granite wall on the northwesterly line of Pawtucket Street, said drill hole being at the point of curvature leading to University Avenue thence along University Avenue

WESTERLY, more or less, by a curve to the right having a radius of thirty-seven and 90/100 feet (37.90), an arc length of fifty-six and 65/100 feet (56.65) to a point of tangency on the northeasterly line of said University Avenue thence along said line of University Avenue

N 45°-19'-56" W, a distance of twenty-nine feet(29), more or less, to the sout easterly shoreline of the Northern Canal; thence along said shoreline

NORTHEASTERLY, more or less, a distance of about one hundred and seventy feet (170) to a point on the northwesterly line of Pawtucket Street; thence along the line of Pawtucket Street:

S 45°- 19'-34" W, a distance of about thirty feet (30) to a drill hole in a stone bound found, and

S 49°-01'-35" W, a distance of ninety and 35/100 feet (90.35) to the point of beginning.

Containing four thousand nine hundred and fifty square feet (4,950) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
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PROPOSED DESCRIPTION OF LAND
PARCEL: NORTHERN CANAL WASTE GATEHOUSE

Beginning at a point on the southwesterly wall of the Northern Canal Waste Gatehouse, said point being the northeasterly corner of the Northern Canal Walkway as hereinafter described; thence running by the northerly end of said walkway and by the Merrimack River

N 29°-58'-11" W, a distance of thirteen and 58/100 feet (13.58) to the southwest corner of the gatehouse; thence along the wall of the gatehouse as follows:

N 60°-01'-49" E, by the Merrimack River, a distance of sixty-seven and 39/10 feet (67.39) to a corner,

S 29°-58'-11" E, a distance of fourteen and 82/100 feet (14.82) to a corner at the Northern Canal, and, along said canal

S 60°-01'-49" W, a distance of sixty-seven and 39/100 feet (67.39) to the southeast corner of the gatehouse; thence along the southwesterly wall of the gatehouse

N 29°-58'-11" W, a distance of one and 24/100 feet (1.24) to the point of beginning.

Containing nine hundred and ninety-nine square feet (999) of land , more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
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PROPOSED DESCRIPTION OF LAND
PARCEL: NORTHERN CANAL WALKWAY

Beginning at a point on the southwesterly wall of the Northern Canal Waste Gatehouse, said point being one and 24/100 feet (1.24) distant from the southeasterly corner thereof; thence running along the southeasterly edge of the granite walkway along the Northern Canal as follows:

S 55°-59'-38" W, a distance of thirty-five and 35/100 feet (35.35) to a point

S 54°-48'-52" W, a distance of four hundred ninety-one and 45/100 feet (491.45) to a point,

S 55°-30'-18" W, a distance of forty and 24/100 feet (40.24) to a point,

S 58°-18'-36" W, a distance of thirty-six and 51/100 feet (36.51) to a point,

S 60°-52'-05" W, a distance of twenty-five and 18/100 feet (25.18) to a point,

S 63°-25'-15" W, a distance of eighteen and 43/100 feet (18.43) to a point,

S 64°-23'-07" W, a distance of thirteen and 70/100 feet (13.70) to a point,

S 66°-21'-58" W, a distance of thirty-one and 35/100 feet (31.35) to a point,

S 68°-30'30" W, a distance of thirty-one and 77/100 feet (31.77) to a point,

S 72°-39-30" W, a distance of thirty and 91/100 feet (30.91) to a point,

S 75°-12'31" W, a distance of thirty-three and 70/100 feet (33.70) to a point,

S 78°-46'-51" W, a distance of thirty-nine and 43/100 feet (39.43) to a point,

S 82°-18'-38" W, a distance of thirty and 40/100 feet (30.40) to a point,

S 85°-23'-04" W, a distance of thirty-seven and 57/100 feet (37.57) to a point,

S 87°-43'-27" W, a distance of twenty-six and 22/100 feet (26.22) to a point, and

S 88°-33'-07" W, a distance of two hundred fifty-eight and 29/100 feet (258.29) to a point at the end of a granite wall of the Northern Canal; thence running by the westerly end of the walkway and along Parcel 29-B

N 01°-26'-54" W, a distance of nine and 5/10 feet (9.5) to a point on the northwesterly edge of the walkway; thence running along the edge of said walkway by Parcel 29-B and the Merrimack River

EASTERLY and NORTHEASTERLY, more or less, a distance of about one thousand one hundred and seventy-seven feet (1,177) to a point on the southwesterly 71

BK3830

PG 180

PARCEL: NORTHERN CANAL WALKWAY (contd.)

the northwesterly edge of the walkway, said northwesterly edge being nine and 5/10 feet (9.5) distant from and running parallel with the southeasterly edge of the walkway as hereinbefore described; thence along the southwesterly wall of the Northern Canal Waste Gatehouse

S 29°-58'-11" E, a distance of ten and 06/100 feet (10.06) to the point of beginning.

Containing eleven thousand and thirty-eight square feet (11,038) of land, more or less.

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66 Rand Street, Lynn, MA 01904
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PROPOSED DESCRIPTION OF LAND
PARCEL: 65-Y

Beginning at a point on the southeasterly line of Cabot Street, said point being at the land edge of the easterly granite wall of the Northern Canal; thence along said line of Cabot Street

N 48°-17'-37" E, a distance of eleven and 56/100 feet (11.56) to a point at land now or formerly of Murray Printing Company; thence along the south-westerly line of Murray Printing Company

S 41°-39'- 43" E, a distance of four hundred seventy-four and 89/100 feet (474.89) to a point on the northwesterly line of Suffolk Street; thence along said line of Suffolk Street

S 48°-19'-10" W, a distance of eleven and 73/100 feet (11.73) to a point at the land edge of the easterly granite wall of the Northern Canal; thence along said canal wall:

N 41°-38'-39" W, a distance of four hundred fifty-one and 42/100 feet (451.42) to a drill hole set, and

N 41°-38'-39" W, a distance of twenty-one and 27/100 feet (21.27) to the point of beginning.

Containing five thousand five hundred and twenty-eight square feet (5,528) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
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PROPOSED DESCRIPTION OF LAND

PARCEL: TREMONT GATEHOUSE

Beginning at the southeasterly corner of the gatehouse, said corner being at the head of the Tremont Wasteway, and bearing N 41° -52' -13" W and being twelve and 55/100 feet (12.55) distant from the northwesterly line of land now or formerly of the Commonwealth of Massachusetts; thence across the head of said Tremont Wasteway

N 41° -52' -13" W, a distance of thirty-one and 30/100 feet (31.30) to the most westerly corner of the gatehouse; thence by a granite wall and by Part Parcels 5610 & 5362 as hereinafter described as follows:

N 48° -07' - 47" E, a distance of twelve and 20/100 feet (12.20) to a corner,

S 41° -52' - 13" E, a distance of thirty-one and 30/100 feet (31.30) to a corner, and

S 48° -07' - 47" W, a distance of twelve and 20/100 feet (12.20) to the point of beginning.

Containing three hundred and eighty-two (382) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
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PROPOSED DESCRIPTION OF LAND
PARCEL: CB-E LOT A

Beginning at a point on the southeasterly line of Suffolk Street, said point being at a thirty foot right-of-way; thence along said thirty foot right-of-way

S 41°-36'-20" E, a distance of ten and 40/100 feet (10.40) to a PK nail set in a wood deck; thence along the back edge of the northwesterly granite wall of the Tremont Wasteway

S 48°-19'-26" W, a distance of four hundred seventy-five and 86/100 feet (475.86) to a PK nail set in a wall; thence along said wall

N 40°-26'-22" W, a distance of ten and 36/100 feet (10.36) to a point on the southeasterly line of Suffolk Street; thence along said line of Suffolk Street

N 48°-19'-10" E, a distance of four hundred seventy-five and 65/100 feet (475.65) to the point of beginning.

Containing four thousand nine hundred and thirty-eight square feet (4,938) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
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PROPOSED DESCRIPTION OF LAND
PARCEL: CB-E LOT C

Beginning at an iron pin set at the northeast corner of Suffolk Street and Perkins Street; thence along the northeasterly line of Perkins Street

N 41°-40'-50" W, a distance of seventy- two and 52/100 feet (72.52) to a PK nail set at land now or formerly of George W. McQuade; thence along the southeasterly line of McQuade

N 48°-19'-10" E, a distance of twenty and 02/100 feet (20.02) to a PK nail set at the back edge of the southwesterly granite wall of the Lawrence Canal; thence along said canal wall:

S 43°-07'-56" E, a distance of twenty-one and 56/100 feet (21.56) to a chain link fence post,

S 43°-07'-56" E, a distance of thirteen and 81/100 feet (13.81) to a chain link fence post,

S 40°-33'-30" E, a distance of forty and 14/100 feet (40.14) to a chain link fence post, and

S 12°-24'-37" E, a distance of eight and 32/100 feet (8.32) to a chain link fence post at the Lower Level of the Western Canal; thence along the back edge of the northwesterly granite wall of said Lower Level of the Western Canal as follows:

S 25°-02'-30" W, a distance of eight and 53/100 feet (8.53) to a chain link fence post,

S 47°-47'-35" W, a distance of thirty-five and 25/100 feet (35.25) to a chain link fence post,

S 47°-19'-23" W, a distance of thirtytwo and 29/100 feet (32.29) to an iron pin set,

S 49°-49'-54" W, a distance of eighty-five and 90/100 feet (85.90) to an iron pin set,

S 47°-51'-11" W, a distance of one hundred twenty-four and 42/100 feet (124.42 to a point,

S 65°-28'-17" W, a distance of sixteen and 37/100 feet (16.37) to an iron pin set, and

S 49°-24'-19" W, a distance of forty-eight and 63/100 feet (48.63) to a drill hole set on the northeasterly line of a thirty foot right-of-way; thence along said right-of-way

N 41°-36'-20" W, a distance of seven and 47/100 feet (7.47) to a point on the southeasterly line of Suffolk Street; thence along said line of Suffolk Street

N 48°-19'-10" E, a distance of three hundred thirty-three and 85/100 feet (333.85) to the point of beginning. 76

PARCEL: CB-E LOT C (cont'd.)

Containing five thousand eight hundred and forty-four square feet (5,844) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: PART PARCELS 5610 & 5362

Beginning at a point on the southeasterly line of Suffolk Street, said point being at the southwesterly corner of Parcel CB-E Lot A; thence along said Parcel CB-E Lot A

S 40° -26' - 22" E, a distance of ten and 36/100 feet (10.36) to a PK nail set in a granite wall; thence along the wall and crossing the Tremont Wasteway

S 40° - 26' - 22" E, a distance of twenty-nine and 98/100 feet (29.98) to a chisel cut set in said wall at land now or formerly of the Commonwealth of Massachusetts; thence along the northwesterly line of land of the Commonwealth of Massachusetts as follows:

S 48° - 21' - 10" W, a distance of thirteen and 29/100 feet (13.29) to a point,

S 41° - 26' - 38" E, a distance of twelve and 63/100 feet (12.63) to a point, and

S 48° - 19' - 12" W, a distance of fourteen and 26/100 feet (14.26) to an x-cut set on the granite wall at the head of the Tremont Wasteway; thence by the head of said Tremont Wasteway

N 41° - 52' - 13" W, a distance of twelve and 55/100 feet (12.55) to the southeasterly corner of the Tremont Gatehouse; thence along the walls of said gatehouse as follows:

N 48° - 07' - 47" E, a distance of twelve and 20/100 feet (12.20) to a corner,

N 41° - 52' - 13" W, a distance of thirty-one and 30/100 feet (31.30) to a corner, and

S48° - 07' - 47" W, a distance of nine and 20/100 feet (9.20) to a point at the back edge of the granite wall at the head of the Tremont Wasteway; thence along said wall

N 21° - 11' - 46" W, a distance of ten and 44/100 feet (10.44) to a point on the southeasterly line of Suffolk Street; thence along said line of Suffolk Street:

N 53° - 13' - 55" E, a distance of eight and 00/100 feet (8.00) to an angle in said street, and

N 48° - 19' - 10" E, a distance of fourteen and 00/100 feet (14.00) to the point of beginning.

Containing eight hundred and ninety-four (894) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: CB-C LOT I

Beginning at a point on the northeasterly line of Moody Street, said point being an iron pin set at the southeasterly corner of land now or formerl of the Lowell Apartments; thence along the southeasterly line of said Lowell Apartments

N 33°-10'-15" E, a distance of two hundred twelve and 43/100 feet (212.43) to a point on the southwesterly line of French Street Extension; thence along said line of French Street Extension

S 56°-01'-24" E, a distance of one and 63/100 feet (1.63) to a point at the back edge of the northwesterly granite wall of the Western Canal; thence along the back edge of said canal wall as follows:

S 33°-09'-14" W, a distance of four and 16/100 feet (4.16) to an iron pin set,

S 33°-09'14" W, a distance of one hundred fifty-one and 42/100 feet (151.42) to an iron pin set,

S 17°-32'-06" W, a distance of fifty-seven and 31/100 feet (57.31) to an iron pin set, and

S 28°-57'-00" W, a distance of one and 65/100 feet (1.65) to a point on the northeasterly line of Moody Street; thence along said line of Moody Street

N 56°-50'-00" W, a distance of seventeen and 25/100 feet (17.25) to the point of beginning.

Containing eight hundred and five square feet (805) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND
PARCEL: CB-C LOT G

Beginning at a point on the northeasterly line of Merrimack Street, said point being at the southerly corner of land now or formerly of the Lowell Development Authority; thence along the southeasterly line of said Lowell Development Authority, being the southeasterly line of a fifteen foot wide easement of the Proprietors of Locks and Canals

N 33°-10'-15" E, a distance of one hundred seventy-two and 90/100 feet (172.9(to a spike set on the southwesterly line of Moody Street; thence along said line of Moody Street

S 56°-50'-00" E, a distance of sixteen and 37/100 feet (16.37) to a point at the back edge of the northwesterly granite wall of the Western Canal; thence along the Western Canal, in part by the back edge of a granite wall and in part by the shoreline thereof

SOUTHERLY, more or less, along the shoreline and two sections of granite distances of forty feet (40), seventy-five feet (75), and fifty-nine feet (59) to a drill hole set on the northeasterly line of Merrimack Street; thence along said line of Merrimack Street

N 56°-50'-00" W, a distance of twenty and 90/100 feet (20.90) to the point of beginning.

Containing three thousand four hundred square feet (3,400) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-C, Lot E

Beginning at a spike set at the northeasterly corner of Suffolk Street and Market Street; thence running along the easterly line of Suffolk Street

N 33° -10' -15" E, a distance of one hundred seventy-one and 85/100 feet (171.85) to a drill hole set at the corner of Merrimack Street; thence running along the southerly line of said Merrimack Street

S 56° -50' -00" E, a distance of seventeen and 55/100 feet (17.55) to a point at the land edge of the granite wall of the Western Canal; thence running along said wall of the Western Canal

S 32° -46' -59" W, a distance of one hundred seventy and 98/100 feet (170.98) to a point on the northerly line of Market Street; thence along the line of Market Street

N 56° -46' -50" W, a distance of eighteen and 71/100 feet (18.71) to the point of beginning.

Containing three thousand one hundred fifteen (3,115) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-C Lot C

Beginning at a drill hole set at the northeasterly corner of Suffolk Street and Jefferson Street; thence running along the easterly line of Suffolk Street

N 11° -11' -30" W, a distance of four hundred eighty-two and 44/100 feet (482.44) to a spike set in the granite curb at the point of curvature leading to Market Street; thence

NORTHEASTERLY, more or less, by a curve to the right having a radius of eleven and 46/100 feet (11.46), an arc length of twenty-six and 87/100 feet (26.87) to an x-cut set in the concrete walk; thence running along the southerly line of Market Street

S 56° -46' -50" E, a distance of about eighteen feet (18) to the westerly shoreline of the Western Canal; thence along the westerly shoreline of said Western Canal

SOUTHERLY, more or less, a distance of about four hundred eighty feet (480) to a point on the northerly line of Jefferson Street; thence running along said northerly line of Jefferson Street

S 78° -52' -10" W, a distance of about twenty-five feet (25) to the point of beginning.

Containing ten thousand nine hundred and five square feet (10,905) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-C Lot A

Beginning at a drill hole set in the concrete sidewalk at the northeasterly corner of Suffolk Street and Broadway; thence running along the easterly line of Suffolk Street

N 11° -11'-30" W, a distance of three hundred twenty-one and 90/100 feet (321.90) to a drill hole set at the southeasterly corner of Suffolk Street and Jefferson Street; thence running along the southerly line of Jefferson Street

N 78°-52' -10" E, a distance of twenty-three and 58/100 feet (23.58) to a drill hole set on the westerly line of the Western Canal; thence running along the back edge of the concrete retaining wall of said Western Canal as follows:

S 11° -18' -00" E, a distance of one hundred sixty and 76/100 feet (160.76 to a spike set, and

S 11° -11' -27" E, a distance of one hundred sixty-one and 69/100 feet (161.69) to the northerly line of Broadway; thence running along said northerly line of Broadway

S 80° -04' -33" W, a distance of twenty-three and 88/100 feet (23.88) to the point of beginning.

Containing seven thousand five hundred and ninty-seven square feet (7,597) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: 24

Beginning at the northwesterly corner of Dutton Street and Hayden Street, said corner being the southeasterly corner of the parcel described; thence along the northwesterly line of Hayden Street

S 80°-30'-30" W, a distance of one hundred fifty and 82/100 feet (150.82) to the easterly line of Worthen Street; thence along said Worthen Street

N 09°-34'-16" W, a distance of seventeen and 24/100 feet (17.24) to a point at the back edge of the southeasterly granite wall of the Western Canal; thence along said canal wall

N 80°-23'-13" E, a distance of one hundred fifty-four and 75/100 feet (154.75) to a point on the westerly line of Dutton Street; thence along said Dutton Street

SOUTHERLY, more or less, by a curve to the right having a radius of one thousand two hundred ten and 46/100 feet (1,210.46), an arc length of eighteen and 01/100 feet (18.01) to the point of beginning.

Containing two thousand eight hundred and thirty-nine square feet (2,839) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND
PARCEL: CB-D LOT J

Beginning at an iron pin set on the northeasterly line of Moody Street, said pin being at the southwesterly corner of land now or formerly of Lowell Apartments; thence along said northeasterly line of Moody Street

N 56°-50-00" W, a distance of ten and 28/100 feet (10.28) to a point at the back edge of the southeasterly granite wall of the Western Canal; thence along said canal wall:

N 33°-40'-12" E, a distance of four and 62/100 feet (4.62) to an iron pin set and

N 45°-45'-12" E, a distance of forty-seven and 00/100 feet (47.00) to a point at land now or formerly of Lowell Apartments; thence along the northwesterly line of said Lowell Apartments

S 33°-09'-51" W, a distance of fifty and 49/100 feet (50.49) to the point of beginning.

Containing two hundred and eighty-two square feet (282) of land, more or less

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: CB-D LOT H

Beginning at a point on the northeasterly line of Merrimack Street, said point being at the southwesterly corner of land now or formerly of the Lowell Development Authority; thence along said northeasterly line of Merrimack Street

N 56°-50'-00" W, a distance of ten and 83/100 feet (10.83) to a drill hole set at the land edge of the granite wall of the Western Canal; thence running along the land edge of the southeasterly granite wall of the Western Canal as follows:

N 31°-14'-15" E, a distance of twenty-seven and 54/100 feet (27.54) to a dril hole set,

N 32°-55'-07" E, a distance of sixty-five and 39/100 feet (65.39) to an iron pin set,

NORTHEASTERLY, more or less, a distance of about thirty-eight feet (38) to an iron pin set, said pin bearing N45°-02'-42" E, and being thirty-six and 79/100 feet (36.79) distant from the last point mentioned,

N 28°-16'-36" E, a distance of thirty-eight and 94/100 feet (38.94) to an iron pin set, and

N 28°-31'46" E, a distance of four and 92/100 feet (4.92) to a point on the southwesterly line of Moody Street; thence along said line of Moody Street

S 56°-50'-00" E, a distance of eight and 19/100 feet (8.19) to a drill hole set at land now or formerly of the Lowell Development Authority; thence along the northwesterly line of said Lowell Development Authority

S 33°-09'-51" W, a distance of one hundred seventy-two and 90/100 feet (172.90) to the point of beginning.

Containing one thousand one hundred and sixty-seven square feet (1,167) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-D, LOT F

Beginning at an iron pin set at the northwesterly corner of Market Street and Hanover Street; thence along the northerly line of Market Street

N 56° -46' -50" W, a distance of thirteen and 80/100 feet (13.80) to a point at the back edge of the granite wall of the Western Canal thence running along the back edge of said wall as follows:

N 33° -29' -15" E, a distance of seven and 86/100 feet (7.86) to an iron pin set,

N 33° -29' -15" E, a distance of sixty-three and 90/100 feet (63.90) to an iron pin set,

N 33° -43' -33" E, a distance of thirty-eight and 38/100 feet (38.38) to an iron pin set,

N 32° -27' -04" E, a distance of fifty-eight and 96/100 feet (58.96) to a drill hole set, and

N 32° -27' -04" E, a distance of two and 81/100 feet (2.81) to a point on the southerly line of Merrimack Street; thence along said southerly line of Merrimack Street

S 56° -50' -00" E, a distance of thirteen and 79/100 feet (13.79) to a drill hole set at the corner of Hanover Street; thence along the westerly line of Hanover Street

S 33° -09' -51" W, a distance of one hundred seventy-one and 91/100 feet (171.91) to the point of beginning.

Containing two thousand three hundred and ten (2,310) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-D, Lot D

Beginning at a spike set at the northwesterly corner of Jefferson Street and Lewis Street; thence running along the northerly line of Jefferson Street.

S 78° -52' -10" W, a distance of about twenty-three feet (23) to the easterly shoreline of the Western Canal; thence along said shoreline of the Western Canal

NORTHERLY, more or less, a distance of about four hundred and fifty-two feet (452). to a point on the southwesterly line of Market Street; thence along said southwesterly line of Market Street

S 56° -46' -50" E, a distance of about forty-five feet (45) to a drill hole set in the concrete sidewalk at the southwesterly corner of Market Street and Lewis Street; thence along the westerly line of Lewis Street

S 11° -11' -30" E, a distance of four hundred eleven and 18/100 feet (411.18) to the point of beginning.

Containing eight thousand six hundred and thirty-five (8,635) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND

PARCEL: CB-D, Lot B

Beginning at a drill hole set in the granite curb at the northwesterly corner of Broadway and Lewis Street; thence running along the northerly line of Broadway

S 80° -04' -33" W, a distance of about twenty-five feet (25) to the easterly shoreline of the Western Canal; thence running along said easterly shoreline of the Western Canal

NORTHERLY, more or less, a distance of about three hundred and twenty- eight feet (328) to a point on the southerly line of Jefferson Street; thence along said line of Jefferson Street

N 78° -52' -10" E, a distance of about twenty-four feet (24) to a spike set at the corner of Lewis Street; thence running along the westerly line of Lewis Street

S 11° -11' -30" E, a distance of three hundred twenty-four and 02/100 feet (324.02) to the point of beginning.

Containing six thousand four hundred and fifty (6,450) square feet of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: CB-D LOT N

Beginning at a point on the westerly line of land now or formerly of Joan Fabrics Corp., said point bearing S 09°-30'-00" E, and being two hundred ninety-eight and 92/100 feet (298.92) distant from an iron pin found on the southerly line of Broadway; thence along said westerly line of Joan Fabrics Corp.

S 09°-29'-38" E, a distance of two hundred twenty-eight and 20/100 feet (228.20) to an old artillery shell found at the corner of land now or formerly of Dutton Street Associates; thence along the westerly line of land of Dutton Street Associates

S 09°-32'-27" E, a distance of two hundred five and 81/100 feet (205.81) to other land of said Dutton Street Associates; thence along the northerly line of said other land of Dutton Street Associates

S 80°-27'-33" W, a distance of seven and 47/100 feet (7.47) to a point at the back edge of the easterly granite wall of the Western Canal; thence along said canal wall as follows:

N 09°-14'-49" W, a distance of three hundred sixty-eight and 43/100 feet (368.43) to a point,

N 12°-53'-42" W, a distance of twenty-nine and 63/100 feet (29.63) to a point, and

N 38°-44'-15" W, a distance of twenty-one and 18/100 feet (21.18) to a point at land now or formerly of George and Demosthenes Macheras; thence along the southeasterly line of said Macheras

N 35°-57'-53" E, a distance of twenty-five and 00/100 feet (25.00) to the point of beginning.

Containing three thousand square feet (3,000) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND
PARCEL: 99,100, 100A

Beginning at a point on the southerly side of the V.F.W. Highway, said point being the most northwesterly corner of the parcel described; thence along the southerly line of the V.F.W. Highway

NORTHEASTERLY, more or less, by a curve to the right having a radius of two thousand feet (2000.00) even, and an arc length of two hundred twelve and 18/100 feet (212.18) to a stone bound found; thence still along the V.F.W. Highway

N 56°-41'-14" E, a distance of eight hundred eleven and 23/100 feet (811.23) to a point; thence still along the V.F.W. Highway

NORTHEASTERLY, more or less, by a curve to the left having a radius of one thousand two hundred eighty three feet (1283.00) even, and an arc length of two hundred twenty five and 29/100 feet (225.29) to an iron pin set; thence by land of the City of Lowell

S 50°-00'-00" E, a distance of two and 52/100 feet (2.52) to an iron pin set; thence still by land of the City of Lowell

N 46°-52'-40"E, a distance of sixty seven and 21/100 feet (67.21) to an iron pin set; thence still by land of the City of Lowell

S 50°-00'-00" E, a distance of three and 91/100 feet (3.91) to an iron pin set; thence still by land of the City of Lowell

N 53°-44'-51" E, a distance of eighty eight and 49/100 feet (88.49) to a drill hole set at the westerly line of School Street; thence along the westerly line of School Street

SOUTHEASTERLY, more or less, by a curve to the right having a radius of forty two feet (42.00) even with an arc length of fourteen feet (14.00) even to an iron pin set; thence still along the westerly line of School Street

S 51°-42'-02" E, a distance of fourteen feet (14+) to the shore line of the Merrimack River; thence along the northerly bank of the Merrimack River

SOUTHWESTERLY, more or less, a distance of one thousand fifty five feet (1055 ±) more or less to a point; thence by land of the Commonwealth of Massachusetts

N 32°-31'-48" W, a distance of twenty nine feet (29 ±) more or less to the point of beginning.

Containing one (1) acre of land more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
Parcel 102

Beginning at a point on the southerly side of the V.F.W. Highway, said point being the most northeasterly corner of the parcel described ; thence running along the southerly line of the V.F.W. Highway

EASTERLY, more or less, by a curve to the left having a radius of four hundred feet (400.00) even, and an arc length of one hundred seventy nine and 82/100 feet (179.82) to a pin in lead plug found; thence still along the V.F.W. Highway

S 42°-58'-22" W, a distance of two hundred ninty two and 18/100 feet (292.18) to a drill hole found in a concrete wall, thence by land now or formerly of the City of Lowell by five (5) courses as follows

S 49°-20'-00" E, a distance of twelve and 86/100 feet (12.86), thence

S 22°-40'- 00"W, a distance of fifty seven and 05/100 feet (57.05), thence

S 39°-41'-58" W, a distance of one hundred fourteen and 44/100 feet (114.44), thence

S 43°-51'-22" E, a distance of nineteen and 90/100 feet (19.90), thence

S 43°-14'-31" W, a distance of seventy six and 80/100 feet (76.80), to the intersection of the easterly line of School Street, thence along the easterly line of School Street

S 51°-42'-02" E, a distance of fourteen feet (14 ±) to a point; thence by the northerly side of the Merrimack River

NORTHEASTERLY, more or less, seven hundred and seven feet (707±), more or less, to a point; thence by parcel 103 now or formerly belonging to the Proprieters of Locks and Canals

NORTHERLY, more or less, a distance of fifteen feet (15±), more or less, to the point of beginning.

Containing thirty two thousand eight hundred square feet of land (32,800) more or less.

ATLANTIC ENGIN.EERING AND SURVEY(CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND
PARCEL : 103

Beginning at a point on the southerly side of the V.F.W. Highway, said point being the most northwesterly corner of the parcel described; thence along the southerly line of the V.F.W. Highway

NORTHEASTERLY, more or less, by a curve to the right having a radius of four hundred feet (400.00) even and an arc length of one hundred eighty seven and 38/100 feet (187.38) to a pin in lead plug found; thence continuing by the V.F.W. Highway by seven (7) courses as follows

S 84°-25'-46" E, a distance of one hundred fifty eight and 89/100 feet (158,89) to a pin in lead plug found; thence

EASTERLY, more or less, by a curve to the left having a radius of one thousand feet (1000.00) even and an arc length of one hundred twenty seven and 64/100 feet (127.64) to a pin in lead plug found; thence

N 88°-15'-26" E, a distance of seventy three and 64/100 feet (73.64) to a pin in lead plug found; thence

EASTERLY, more or less, by a curve to the left having a radius of four hundred eighty three feet (483.00) and an arc length of one hundred thirty eight and 56/100 feet (138.56) to a pin in lead plug found; thence

N 71°-49'-13" E, a distance of one hundred ninty one and 28/100 feet (191.28) to a stone bound found; thence

NORTHEASTERLY, more or less, by a curve to the left having a radius of four hundred eighty three feet (483.00) even and an arc length of two hundred twenty seven and 29/100 feet (227.29) to a stone bound found; thence

N 44°-51'-30" E, a distance of sixty and 84/100 feet (60.84) to a point; thence

SOUTHEASTERLY, more or less, by a curve to the right having a radius of sixty five feet (65.00) and an arc length of one hundred one and 83/100 feet (101.83) to a point at the easterly lind of Textile Avenue; thence along the easterly line of Textile Avenue

S 45°-23'-00" E, a distance of seventy six feet (76 ±), more or less, to the shore line of the Merrimack River; thence along the shoreline of the Merrimack River

WESTERLY , more or less, a distance of one thousand four hundred twenty five feet (1425 ±) to a point; thence by two (2) courses by lot 102 now or formerly of the Proprieters of Locks and Canals

NORTHEASTERLY, more or less, a distance of one hundred fifteen feet (115 ±) more or less to a point; thence

NORTHERLY, more or less, a distance of fifteen feet (15 ±) more or less to the point of beginning.

Containing two and 1/10 acres (2.1) of land more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: 33-C-1

Beginning at a point on the Northerly side of Aiken Street, said point being the most southeasterly corner of the parcel described; thence along the southerly side of the Merrimack River

N 48°-21'-35" W, a distance of three hundred thirty five and 92/100 feet (335.92) to a point; thence still along the southerly side of the Merrimack River

NORTHERLY, more or less, by a curve to the left having a radius of three hundred and two feet (302.00) and an arc length of one hundred seventy eight and 16/100 feet (178.16) to a point; thence by land of the Commonwealth of Massachusetts

S 33°-06'-10" W, a distance of eighty six and 26/100 feet (86.26) to a point; thence by two (2) courses by other land of the Commonwealth of Massachusetts as follows

SOUTHEASTERLY, more or less, by a curve to the right having a radius of two hundred twenty-seven feet (227.00) and an arc length of one hundred seventy and 88/100 feet (170.88) to a point; thence

S 48°-21'-35" E, a distance of three hundred forty one and 61/100 feet (341.61) to a land court disk found at the intersection of Aiken Street; thence by two (2) courses by Aiken Street as follows

N 33°-03'-40" E, a distance of thirty seven and 39/100 feet (37.39) to a spike found in a granite wall; thence

N 41°-28'-15" E, a distance of thirty eight and 03/100 feet (38.03) to the point of beginning.

Containing thirty eight thousand three hundred sixty nine (38,369) square feet of land more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: 92-B

Beginning at a point at the northeasterly corner of the parcel, said point bearing S 48°-05'-10" W, and being two hundred fifty-four and 91/100 feet (254.91) distant from the southwesterly line of the Veterans of Foreign Wars Highway; thence along the northwesterly line of Parcel 91-H

S 48°-05'-10" W, a distance of fifty-two and 45/100 feet (52.45) to the line of the Merrimack River as established in 1882; thence along said established river line

NORTHWESTERLY, by a curve to the left having a radius of one thousand eight hundred and 00/100 feet (1800.00), an arc length of one hundred seventy-five and 62/100 feet (175.62) to a point at land now or formerly of the Proprietors of Locks and Canals; thence along the southwesterly line of said Proprietors

N 42°-27'-56" E, a distance of fifty-two and 44/100 feet (52.44) to a point on the southwesterly line of land now or formerly of the City of Lowell; thence along said line of the City of Lowell

SOUTHEASTERLY, more or less, by a curve to the right having a radius of one thousand eight hundred fifty and 00/100 feet (1850.00), an arc lenght of one hundred eighty and 53/100 feet (180.53) to the point of beginning.

Containing eight thousand nine hundred and nineteen square feet (8,919) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: 107-A

Beginning at a point on the northeasterly line of the Veterans of Foreign Wars Highway, said point being on the southerly line of the City of Lowell Water Works right-of-way; thence along said right-of-way by the chord of a curve to the right

S 75°-35'-05" E, a distance of one hundred forty-one and 35/100 feet (141.35) to a point at land now or formerly of the City of Lowell; thence along the northwesterly line of the City of Lowell

S 42°-27'-56" W, a distance of eighty-eight and 64/100 feet (88.64) to a point on the northeasterly line of aforesaid Veterans of Foreign Wars Highway; thence along said northeasterly line of said highway

N 37°-27'-28" W, a distance of one hundred twenty-six and 70/100 feet (126.70) to the point of beginning.

Containing five thousand five hundred and fifty square feet (5,550) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS

66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: 107

Beginning at a point on the southwesterly line of the Veterans of Foreign Wars Highway, said point being on the easterly line of the Merrimack River and Beaver Brook; thence along said southwesterly line of said highway

SOUTHEASTERLY, more or less, by a curve to the right, having a radius of six hundred and seventy-three feet (673.00), an arc length of three hundred and ninety feet (390), more or less, to a point at land now or formerly of the City of Lowell; thence along the northwesterly line of said City of Lowell

S 42°-27'-56" W, a distance of about two hundred and twenty-one feet (221) to the Merrimack River; thence along the Merrimack River

NORTHWESTERLY, more or less, a distance of about four hundred and seventeen feet (417) to the point of beginning.

Containing thirty-four thousand square feet (34,000) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND
PARCEL: 91-H

Beginning at a point at the northwesterly corner of the Veterans of Foreign Wars Highway and Aiken Street, said corner being the southeasterly corner of the parcel described; thence along the northwesterly line of Aiken Street

S 41°-28'-15" W, a distance of fifty and 43/100 feet (50.43) to a point on the line of the Merrimack River as established in 1882; thence along said river line:

N 41°-04'-05" W, a distance of four hundred ninety-six and 25/100 feet (496.25) to a point of curvature, and

NORTHWESTERLY, more or less, by a curve to the left having a radius of one thousand eight hundred and 00/100 feet (1800.00), an arc length of five hundred eighty-six and 33/100 feet (586.33) to a point on the southeasterly line of Parcel 92-B; thence along Parcel 92-B

N 48°-05'-10" E, a distance of fifty-two and 45/100 feet (52.45) to a point on the southwesterly line of land now or formerly of the City of Lowell; thence along land of said City of Lowell:

SOUTHEASTERLY, more or less, by a curve to the right having a radius of one thousand eight hundred fifty and 00/100 feet (1850.00), an arc length of five hundred eighty-six and 57/100 feet (586.57) to a point of tangency, and

S 41°-04'-05" E, a distance of four hundred nine and 07/100 feet (409.07) to a point on the southeasterly line of the Veterans of Foreign Wars Highway; thence along said line of said highway

S 41°-04'-05" E, a distance of eighty and 63/100 feet (80.63) to the point of beginning.

Containing fifty-three thousand nine hundred and seventy-one square feet (53,971) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: 89-A

Beginning at the southwesterly intersection of Aiken Street and the Veterans of Foreign Wars Highway; thence along the southwesterly line of said Veterans of Foreign Wars Highway as follows:

S 41°-04'-05" E, a distance of one thousand forty-seven and 87/100 feet (1047.87) to a stone bound found,

S 48°-55'-55" W, a distance of ten and 00/100 feet (10.00) to a stone bound found,

S 41°-04'-05" E, a distance of three hundred eighty-six and 95/100 feet (386.95) to a stone bound found,

N 46°-00'-19" E, a distance of ten and 00/100 feet (10.00) to a stone bound found, and

S 41°-04'-05" E, a distance of one hundred sixty-two and 54/100 feet (162.54) to a point at Parcel 89; thence along the northwesterly line of Parcel 89

S 43°-30'-57" W, a distance of fifty and 22/100 feet (50.22) to the line of the Merrimack River as established in 1882; thence along said established river line

N 41°-04'-05" W, a distance of one thousand five hundred ninety-five and 04/100 feet (1595.04) to a point on the southeasterly line of Aiken Street; thence along said line of Aiken Street

N 41°-28'-15" E, a distance of fifty and 43/100 feet (50.43) to the point of beginning.

Containing seventy-five thousand nine hundred and thirty-nine square feet (75,939) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: 89

Beginning at a point on the southwesterly line of the Veterans of Foreign Wars Highway, said point being at the southeasterly corner of Parcel 89-A; thence along the southwesterly line of said highway

S 39°-15'-25" E, a distance of one hundred twenty-six and 36/100 feet (126.36) to a point at land of the City of Lowell; thence along the northwesterly line of said City of Lowell

S 40°-56'-33" W, a distance of thirty-one and 86/100 feet (31.86) to a point on the northeasterly line of Front Street; thence along said line of Front Street

N 49°-03'-27" W, a distance of one hundred three and 85/100 feet (103.85) to a point on the line of the Merrimack River as established in 1882; thence along said established river line

N 41°-04'-05" W, a distance of twenty-three and 14/100 feet (23.14) to a point at the southerly corner of Parcel 89-A; thence along the southeasterly line of Parcel 89-A

N 43°-30'-57" E, a distance of fifty and 22/100 feet (50.22) to the point of beginning.

Containing five thousand three hundred and thirty-four square feet (5,334) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND
PARCEL: 88

Beginning at a point on the southwesterly line of the Veterans of Foreign Wars Highway said point bearing S 39°-15'-25" E and being two hundred eighteen and 95/100 feet (218.95) distant from a stone bound found on the southwesterly line of said highway; thence along said southwesterly highway line

S 39°-15'-25" E, a distance of ninety-three and 59/100 feet (93.59) to an angle point in said highway at the northeasterly line of Front Street; thence along the northeasterly line of Front Street

N 49°-03'-27" W, a distance of ninety-two and 22/100 feet (92.22) to a point at land now or formerly of the City of Lowell; thence along the southeasterly line of said City of Lowell

N 40°-56'-33" E, a distance of fifteen and 93/100 feet (15.93) to the point of beginning.

Containing seven hundred and thirty-five square feet (735) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: FRONT STREET

Beginning at an angle in the southwesterly line of the Veterans of Foreign Wars Highway, said angle bearing S 39°-15'-25" E and being three hundred thirteen and 54/100 feet (313.54) distant from a stone bound found on the southwesterly line of said highway; thence along said highway line as follows:

S 49°-03'-27" E, a distance of six hundred sixty-four and 13/100 feet (664.13) to a point,

S 45°-11'-13" E, a distance of one hundred thirty-four and 37/100 feet (134.37) to a point,

S 41°-11'-50" W, a distance of eight and 40/100 feet (8.40) to a point,

S 42°-13'-24" E, a distance of seventy-five and 11/100 feet (75.11) to a point,

S 47°-24'-48" E, a distance of one hundred forty-nine and 68/100 feet (149.68) to an EPLP found in the top of a concrete wall,

S 62°-18'-45" E, a distance of four hundred twenty-two and 90/100 feet (422.90) to a point, and

S 58°-36'-38" E, a distance of one hundred four and 74/100 feet (104.74) to a point; thence

S 41°-13'-00" W, a distance of nine and 80/100 feet (9.80) to a point at Parcel 87; thence along the northeasterly line of Parcel 87 as follows:

N 57°-06'-30" W, a distance of one hundred thirteen and 62/100 feet (113.62) to a point,

N 62°-18'-45" W, a distance of four hundred twenty-seven and 10/100 feet (427.10) to a point, and

N 49°-03'-27" W, a distance of one thousand twelve and 30/100 feet (1012.30) to a point on the river line of the Merrimack River as established in 1882; thence along said established river line

N 41°-04'-05" W, a distance of two hundred eighty-seven and 79/100 feet (287.79) to a point at Parcel 89; thence along the southwesterly lines of Parcel 89, land of the City of Lowell, and Parcel 88

S 49°-03'-27" E, a distance of two hundred eighty-eight and 29/100 feet (288.29) to the point of beginning.

Containing forty-three thousand five hundred and ninety-three square feet (43,593) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395 •

PROPOSED DESCRIPTION OF LAND
PARCEL: 87

Beginning at the most northerly corner of the parcel, said corner being a point on the southwesterly line of Front Street and on the line of the Merrimack River as established in 1882: thence along the southwesterly line of said Front Street as follows:

S 49°-03'-27" E, a distance of one thousand twelve and 30/100 feet (1012.30) to a point,

S 62°-18'-45" E, a distance of four hundred twenty-seven and 10/100 feet (427.10) to a point, and

S 57°-06'-30" E, a distance of one thirteen and 62/100 feet (113.62) to a point; thence

S 41°-13'-00" W, a distance of ten and 54/100 feet (10.54) to the line of the Merrimack River as established in 1882; thence along said established river line as follows:

N 62°-33'-00" W, a distance of five hundred twenty-eight and 07/100 feet (528.07) to a point of curvature,

NORTHWESTERLY, more or less, by a curve to the right having a radius of one thousand seven hundred seventy-one and 00/100 feet (1771.00), an arc length of six hundred sixty-four and 00/100 feet (664.00) to a point of tangency, and

N 41°-04'-05" W, a distance of three hundred seventy-one and 22/100 feet (371.22) to the point of beginning.

Containing fifty-seven thousand five hundred and eighty-seven square feet (57,587) of land, more or less.

ATLANTIC ENGINEERING AND SURVEY CONSULTANTS
66 Rand Street, Lynn, MA 01904
(617) 593-3395

PROPOSED DESCRIPTION OF LAND
PARCEL: 96-B

Beginning at an iron pin set at the northwesterly corner of the parcel, said pin being a point on the southwesterly line of land now or formerly of Merrimack Valley Goodwill Industries; thence along said line of Merrimack Valley Goodwill Industries

S 87°-57'-49" E, a distance of two hundred thirteen and 26/100 feet (213.26) to a point at land now or formerly of the General Board of the Church of the Nazarene; thence along the line of land of said General Board of the Church of the Nazarene as follows:

S 20°-09'-52" W, a distance of fifty-five and 23/100 feet (55.23) to a point,

S 69°-55'-39" E, a distance of forty and 88/100 feet (40.88) to an iron pin set, and

S 05°-14'-17" W, a distance of eighty and 00/100 feet (80.00) to the Merrimack River; thence along the Merriamck River by the shoreline of March 1975

N 64°-43'-08" W, a distance of two hundred fifty-three and 62/100 feet (253.62) to an iron pin set at land now or formerly of the City of Lowell; thence along the easterly line of said City of Lowell

N 05°-17'-28" E, a distance of forty-five and 00/100 feet (45.00) to the point of behinning.

Containing twenty-thousand seven hundred and nine square feet (20,709) of land, more or less.

Appendix D – 1995 *Grant of Easement*

GRANT OF EASEMENT

The COMMONWEALTH OF MASSACHUSETTS, acting by and through its Division of Capital Planning and Operations ("Grantor"), notwithstanding the provisions of sections 40E through 40J, inclusive, of Chapter 7 of the General Laws, in accordance with Chapter 149 of the Acts of 1992, for nominal consideration paid, does hereby grant to the UNITED STATES OF AMERICA, acting by and through the United States Department of the Interior, having a usual place of business at 222 Merrimack Street, Lowell, Massachusetts, 01852, ("Grantee") a perpetual easement, in common with others and subject to the terms and conditions of this grant, over, on and in the property known as the Lowell Heritage State Park in Lowell, Massachusetts (the "Property") in the locations described on Exhibit A attached hereto for the purposes specified herein:

Easement Area I = Tracts 104-26, 107-07, 107-15, 107-22, 107-23, 107-24, 107-25, 107-26, 107-27, 107-28, 107-29, 110-02, 111-09, 111-22, 111-23, and 111-24

GRANTEE, its successors and assigns, shall have the right, in conjunction with others, to use the premises described herein for all purposes consistent with the Act establishing the Lowell National Historical Park, Public Law 95-290, as amended, (16 U.S.C., Sections 410cc et seq.), hereinafter referred to as the Act, and consistent with Chapter 149 of the Acts of 1992, hereinafter referred to as the Special Act, which purposes shall include: facilitation and provision of a continuous public pedestrian walkway along the Western canal, construction and maintenance of improvements, which improvements include but shall not be limited to: walkway surface at the edge of the Western Canal, decking, lighting, railing, benches, landscaping, signs and public art.

Easement Area II = Tract 107-35

GRANTEE, its successors and assigns, shall have the right, in conjunction with others, to use the premises described herein for all purposes consistent with the Act and consistent with the Special Act, which purposes shall include: facilitation and provision of a continuous public pedestrian walkway and linear park along the Western canal, construction and maintenance of improvements, which improvements include but shall not be limited to: walkway surface at the edge of the Western Canal, decking, lighting, aerial and/or buried telecommunications cable, benches, landscaping, signs and public art.

Easement Are III = Tracts 110-03, 110-06, 110-07, 110-09, 110-14, 110-20, 111-26

GRANTEE, its successors and assigns, shall have the right, in conjunction with others, to use the premises described herein for all purposes consistent with the Act and consistent with the Special Act, which purposes shall include: facilitation and provision of a continuous public pedestrian walkway and linear park along the Pawtucket canal, construction and maintenance of improvements, which improvements include but shall not be limited to: walkway surface at the edge of the Pawtucket Canal, decking, lighting, railing, benches, landscaping, signs and public art.

Easement Area IV = Tracts 105-09, Tract 105-10, Tract 105-14, Tract 105-15

GRANTEE, its successors and assigns, shall have the right, in conjunction with others, to use the premises described herein for all purposes consistent with the Act and consistent with the Special Act, which purposes shall include: facilitation and provision of a continuous public pedestrian walkway and linear park along the junction of the Pawtucket Canal, Merrimack River and the Northern Canal, maintenance and operation of the Gatekeeper's House, so-called, and of the Blacksmith Shop, so-called, construction and maintenance of improvements, which improvements include but shall not be limited to: maintenance and renovation of the Gatekeeper's House and the Blacksmith Shop, walkway surface at the edge of the Pawtucket Canal, the Northern Canal and the Merrimack River, decking, lighting railing, benches, landscaping, signs and public art.

Easement Area V = Tract 111-17

GRANTEE, its successors and assigns, shall have the right, in conjunction with others, to use the premises described herein for all purposes consistent with the Act and consistent with the Special Act, which purposes shall include: facilitation and provision of a continuous public pedestrian walkway and linear park along the Hamilton Canal, construction and maintenance of improvements, which improvements include but shall not be limited to: walkway surface at the edge of the Hamilton Canal, decking, lighting, railing, benches, landscaping, signs and public art.

Easement Area VI = Tract 107-21

GRANTEE, its successors and assigns, shall have the right, in conjunction with others, to use the premises described herein for all purposes consistent with the Act and consistent with the Special Act, which purposes shall include: facilitation and provision of a continuous public pedestrian walkway along the Eastern Canal and Merrimack Canal Wasteway, construction and maintenance of improvements, which improvements include but shall not be limited to: walkway surface at the edge of the Eastern Canal and Merrimack Canal Wasteway, decking, lighting, railing, benches, landscaping, signs and public art.

Easement Area VII = Tract 107-39

GRANTEE, its successors and assigns, shall have the right, in conjunction with others, to use the premises described herein for all purposes consistent with the Act and consistent with the Special Act, which purposes shall include: facilitation and provision of a continuous public pedestrian walkway along the Northern Canal, construction and maintenance of improvements, which improvements include but shall not be limited to: walkway surface at the edge of the canal, decking, lighting, railing, benches, landscaping, signs and public art.

Easement Area VIII = Tracts 103-11, 105-13, 107-13, 107-38, 107-40, 108-21, 111-32, 111-33, 111-34, 112-01, 112-04

GRANTEE, its successors and assigns, shall have the right, in conjunction with others, to use the premises described herein for any and all purposes consistent with the Act and consistent with the Special Act, which purposes shall include, but not be limited to: conducting land and canal tours, running interpretive programs and the maintenance, improvement and restoration of Gatehouses and support structures, Dams and Lock Chambers.

The rights conveyed hereunder are conveyed subject to all matters of record at the Middlesex County Registry of Deeds.

All work performed by Grantee, its successors and assigns, pursuant to this easement shall at all times be performed in accordance with all applicable federal laws, statutes, and regulations including, but not limited to, 40 U.S.C. Section 619.

By its acceptance of this easement, the Grantee agrees that its liability relating to this easement shall be governed by the Federal Tort Claims Act, 28 U.S.C. Sections 2671 et seq.

By its acceptance of this easement, the Grantee agrees that its exercise of the Grantee's rights hereunder shall not interfere with the Grantor's use and operation of the Property as a state park or with the use, maintenance, or operation for hydroelectric power production by Boott Hydropower, Inc., their successors and assigns.

In the event that the easement granted herein ceases to be used in connection with the purposes described herein, then the Grantee's interest in such easement area shall revert to the Grantor.

IN WITNESS WHEREOF, the Commonwealth of Massachusetts has caused these presents to be signed, sealed, acknowledged and delivered in its name and on its behalf by the undersigned, as the duly appointed and authorized Commissioner of the Division of Capital Planning and Operations on this 1st day of June, 1995.

Lark Jurev Palermo

Lark Jurev Palermo,
Commissioner
Division of Capital Planning
and Operations

COMMONWEALTH OF MASSACHUSETTS

Suffolk, ss. June 1, 1995

Then personally appeared the above named Lark Jurev Palermo, Commissioner of the Division of Capital Planning and Operations, and acknowledged the foregoing instrument to be the free act and deed of the Commonwealth of Massachusetts before me.

Notary Public

STEPHEN J. HINES
Type or Hand-Print Name
My Commission Expires October 14, 1999

Approved as to form:

Assistant Attorney General

Exhibit A

to Grant of Easement from Commonwealth of Massachusetts to United States of America dated as of June 1, 1995

Exhibit A consists of the 42 Tracts of land listed below. A metes and bounds description for each Tract is attached and incorporated in this Exhibit A.

Tract 103-11
Tract 104-26
Tract 105-09
Tract 105-10
Tract 105-13
Tract 105-14
Tract 105-15
Tract 107-07
Tract 107-13
Tract 107-15
Tract 107-21
Tract 107-22
Tract 107-23
Tract 107-24
Tract 107-25
Tract 107-26
Tract 107-27
Tract 107-28
Tract 107-29
Tract 107-35
Tract 107-38
Tract 107-39
Tract 107-40
Tract 108-21
Tract 110-02
Tract 110-03
Tract 110-06
Tract 110-07
Tract 110-09
Tract 110-14
Tract 110-20
Tract 111-09
Tract 111-17
Tract 111-22
Tract 111-23
Tract 111-24
Tract 111-26
Tract 111-32
Tract 111-33
Tract 111-34
Tract 112-01
Tract 112-04

Z:\WP51\LHPC\ExhibitA

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 999 square feet, more or less

Interest: Easement

Date: February 3, 1994

TRACT 103-11

A certain parcel of land with buildings, structures and fixtures, thereon, commonly known as the Northern Canal Waste Gate House, located in Lowell, Middlesex County, Massachusetts along the Northern Canal, so called, and further bounded and described as follows:

Beginning at a point on the southwesterly wall of the Northern Canal Waste Gate House, said point being the northeasterly corner of the Northern Canal Walkway, as shown on the plan hereinafter described; thence running by the northerly end of said walkway and by the Merrimack River

N 29° 58' 11" W, a distance of 13.58 feet to the southwest corner of the gate house; thence along the wall of the gate house as follows:

N 60° 01' 49" E, by the Merrimack River, a distance of 67.39 feet to a corner,

S 29° 58' 11" E, a distance of 14.82 feet to a corner at the Northern Canal, and, along said canal

S 60° 01' 49" W, a distance of 67.39 feet to the southeast corner of the gate house; thence along the southwesterly wall of the gate house

N 29° 58' 11" W, a distance of 1.4 feet to the point of beginning.

Containing 999 square feet of land, more or less.

Being shown as the Northern Canal Waste Gate House on sheet 23 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 5,844 square feet, more or less

Interest: Easement

Date: January 13, 1994

TRACT 104-26

A certain parcel of land situated in Lowell, Middlesex County, Massachusetts, along the Western Canal, so called, and being further bounded and described as follows:

Beginning at an iron pin set at the northeast corner of Suffolk Street and Perkins Street; thence along the northeasterly line of Perkins Street

N 41° 40' 50" W, a distance of 72.52 feet to a PK nail set at land now or formerly of George W. McQuade; thence along the southeasterly line of McQuade

N 48° 19' 10" E, a distance of 20.02 feet to PK nail set at the back edge of the southwesterly granite wall of the Lawrence Canal; thence along said canal wall:

S 43° 07' 56" E, a distance of 21. 56 feet to a chain link fence post,

S 43° 07' 56" E, a distance of 13.81 feet to a chain link fence post,

S 40° 33' 30" E, a distance of 40.14 feet to a chain link fence post, and

S 12° 24' 37" E, a distance of 8.32 feet to a chain link fence post at the Lower Level of the Western Canal; thence along the back edge of the northwesterly granite wall of said Lower Level of the Western Canal as follows:

S 25° 02' 30" W, a distance of 8.53 feet to a chain link fence post,

S 47° 47' 35" W, a distance of 35.25 feet to a chain link fence post,

S 47° 19' 23" W, a distance of 32.29 feet to an iron pin set,

S 49° 49' 54" W, a distance of 85.90 feet to an iron pin set,

S 47° 51' 11" W, a distance of 124.42 feet to a point,

S 65° 28' 17" W, a distance of 16.37 feet to an iron pin set, and

S 49° 24' 19" W, a distance of 48.63 feet to a drill hole set on the northeasterly line of a thirty foot right-of-way; thence along said right of way

N 41° 36' 20" W, a distance of 7.47 feet to a point on the southeasterly line of Suffolk Street; thence along said line of Suffolk Street

N 48° 19' 10" E, a distance of 333.85 feet to the point of beginning

Containing 5,844 square feet of land, more or less.

Being shown as Parcel CB-E, Lot C on sheet 25 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 15,957 square feet, more or less

Interest: Easement

Date: February 1, 1994

TRACT 105-09

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Northern Canal and the Merrimack River, so called, and known and numbered as 23.1 School Street and further bounded and described as follows:

Beginning at a drill hole set on the southwesterly line of School Street, said drill hole being at the northwesterly corner of land now or formerly of the Commonwealth of Massachusetts by two courses as follows:

S 42° 50' 42" W, a distance of 76.30 feet to an iron pin set, and

S 24° 14' 32" W, a distance of 72.91 feet to an iron pin set; thence along the southwesterly line of land of the Commonwealth of Massachusetts

S 61° 39' 08" E, a distance of 97.41 feet to a point on the northwesterly line of land now or formerly of the American Red Cross; thence along the northwesterly line of land of said American Red Cross and now or formerly of Flago Realty Corporation

S 40° 13' 24" W, a distance of 220.81 feet to an x-cut in a stone bound found at land now or formerly of Irene Desmarais; thence along the northeasterly line of said land now or formerly of said Desmarais as follows:

N 23° 03' 25" W, a distance of 42.34 feet to a point, and

N 19° 33' 29" E, a distance of 22 feet to a drill hole set in the granite retaining wall of the Merrimack River; thence along the Merrimack River by said retaining wall:

N 48° 01' 43" W, a distance of 10 feet to a drill hole set,

N 23° 55' 13" E, a distance of 165.57 feet to a point,

N 24° 14' 32" E, a distance of 74.06 feet to a drill hole set, and

N 42° 50' 42" E, a distance of 77.48 feet to a drill hole set on the southwesterly line of School Street; thence along said line of School Street

S 46° 51' 34" E, a distance of 7 feet to the point of beginning.

Containing 15,957 square feet of land, more or less.

Being shown as Parcel 29, Lot 2 on sheet 20 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

EXHIBIT A

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 13,678 square feet, more or less

Interest: Easement

Date: February 1, 1994

TRACT 105-10

A certain parcel of land, with the buildings thereon, located in Lowell, Middlesex County, Massachusetts along the Northern Canal and the Merrimack River, so called, and known and numbered as 23 School Street and further bounded and described as follows:

Beginning at the Easterly corner of the premises at a point in the Southwesterly line of School Street in said Lowell, where the Southeasterly face of a retaining wall intersects said School Street, which point is distant 199.75 feet Northerly from a drill hole in a stone bound set in the line of said School Street;

Thence, S 45° 20' W by the said face of the said wall and by land now or formerly of Harold F. Harrington et. als. and land now or formerly of the American National Red Cross, 111 feet, to a point;

Thence, at an angle S 56° 3' W still by said last named land and said wall, 12.46 feet to a point;

Thence, N 46° 2' 30" W by other land now or formerly of Proprietors of the Locks and Canals on Merrimack River, 97.36 feet to a stake at still other land now or formerly of said Proprietors of Locks and Canals;

Thence, N 39° 51' 40" E 72.91 feet to a point;

Thence, at an angle of 58° 27' 50" E still by said Proprietors of Locks and Canals; land and in part by the Southeasterly face of another retaining wall 76.30 feet to said School Street;

Thence, S 31° 14' 30" E by said School Street 91.78 feet to the point of beginning.

Containing 13,678 square feet of land, more or less.

Being shown on a plan of land entitled "Plan of Land in Lowell, Mass. for Prop. of Locks and Canals, July 5, 1960, Dana F. Perkins & Sons, Inc., C.E.'s and Surveyors," which plan is recorded with the Middlesex Northern District Registry of Deeds, Plan Book 93, Plan 59A.

Also being shown as Parcel 29, Lot 1 on sheet 20 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with said Registry of Deeds at Plan Book 157, Plan 69.

Being the same premises conveyed to the Commonwealth of Massachusetts by deed of Paul J. Desmarais and Lorraine L. Desmarais recorded with said Registry of Deeds at Book 2279, Page 435.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 2,400 square feet, more or less

Interest: Easement

Date: February 3, 1994

TRACT 105-13

A certain parcel of land with buildings, structures and fixtures thereon, commonly known as the Pawtucket Gate House, located in Lowell, Middlesex County, Massachusetts over the Northern Canal, so called, and the Merrimack River and near School Street and further bounded and described as follows:

Beginning at the most southeasterly corner of the Pawtucket Gate House, said point being 15.35 feet northwesterly from the westerly line of Parcel 29 as shown on the plan hereinafter described; thence

N 46° 55' 36" W, along the most southerly face of the building a distance of 118.70 feet to a point; thence on a curve to the right

NORTHWESTERLY, more or less, along the face of said building a distance of 5 feet to a point; thence

N 43° 12' 10" E, along the most westerly face of said building a distance of 16.40 feet to a building corner, said corner being set back from the southerly line of School Street a distance of 0.60 feet; thence

S 46° 55' 36" E, along the most northerly face of said building a distance of 122.04 feet to the most northeasterly building corner, said corner being set back from the southerly line of School Street a distance of 0.46 feet; thence

S 43° 12' 10" W, along the most easterly face of said building a distance of 19.75 feet to the point of beginning.

Containing 2,400 square feet of land, more or less.

Being shown as a brick gate house on sheet 20 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 24 May 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Meaning and intending the description of the above-referenced parcel to be the same parcel described at Book 3830, Page 169 of the above referenced taking and which description in the taking incorrectly referred to School Street as Pawtucket Street.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 3710 square feet, more or less

Interest: Easement

Date: August 19, 1994

TRACT 105-14

The land and buildings commonly known as the Pawtucket Gatehouse Wall and Lock Chamber, located on the Northern Canal, in Lowell, Middlesex County, Massachusetts, and further bounded and described as follows:

Beginning at a point at the most southeasterly corner of a brick building called the Pawtucket Gatehouse, said point being 15.35 feet distant from the northwesterly line of Parcel 29 as shown on the Plan hereinafter described; thence

N 46° 55' 36" W, along the most southerly face of the building, a distance of 118.70 feet to a point; thence along a curve to the right along the face of said building a distance of 5 feet to a point; thence

N 43° 12' 10" E, along the most westerly face of said building a distance of 16 feet, more or less, to the end of a granite wall at the face of a concrete and granite wall; thence

NORTHWESTERLY, along said concrete and granite wall a distance of 16 feet, more or less; thence

SOUTHERLY, more or less, by the face of a granite wall by the following distances: 10 feet, more or less, thence 13 feet, more or less, and 8 feet, more or less, around a curved section of wall; thence

SOUTHEASTERLY, along the face of the aforementioned granite wall, said face of wall being approximately parallel with and 2.7 feet south of the southerly face of the Pawtucket Gatehouse a distance of 112 feet, more or less, to an angle point; thence along the face of said wall a distance of 10 feet, more or less; thence along the face of said wall a distance of 10 feet more or less; thence along the face of said wall around a curve a distance of 7 feet, more or less; thence along the face of said wall a distance of 10 feet more or less; thence

SOUTHEASTERLY, along a concrete wall, said wall being approximately parallel with School Street a distance of 15 feet, more or less, to a point; thence

N 42° 50' 42" E, along land now or formerly of the Proprietors of Locks and Canals, a distance of 23 feet, more or less, to a drill hole set at the southerly line of School Street; thence

N 46° 51' 34" W, along the southerly line of School Street and land now or formerly of the Proprietors of Locks and Canals a distance of 3 feet, more or less, to a point; thence

NORTHEASTERLY, approximately perpendicular to the southerly line of School Street and under the School Street Bridge along the easterly face of the easterly granite wall of the lock chamber, 58 feet, more or less, to the northerly line of School Street; thence

SOUTHEASTERLY, along said granite wall and the northerly line of School Street a distance of 6 feet, more or less, to a point; thence

NORTHEASTERLY, along the westerly face of a granite wall by land now or formerly of the Proprietors of Locks and canals 120 feet, more or less, and 17 feet, more or less, to the shoreline; thence

SOUTHWESTERLY, along the westerly face of the easterly granite wall of the Northern Canal a distance of 93 feet, more or less, to a point; thence

NORTHWESTERLY, crossing the Lock Chamber a distance of 19 feet, more or less, to the westerly face of the westerly granite of the Lock Chamber; thence

SOUTHWESTERLY, along said face of wall a distance of 36 feet, more or less, to the northerly line of School Street; thence

S 46° 51' 34" E, along the northerly line of School Street a distance of 3 feet, more or less, to a point; thence

SOUTHWESTERLY, approximately perpendicular to the northerly line of School Street and under the School Street Bridge along the westerly face of the westerly granite wall of the lock chamber, 58 feet, more or less, to the southerly line of School Street; thence along the easterly face of the Pawtucket Gatehouse

S 43° 12' 10" W, a distance of 20 feet, more or less, to the point of beginning.

Containing 3710 square feet, more or less.

Being shown on sheet 20 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 1 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM Lowell Historic Preservation Commission

Area: 3710 square feet, more or less

Interest: Easement

Date: August 19, 1994

TRACT 105-15

The land and buildings commonly known as the Blacksmith Shop, located along the Northern Canal and Merrimack River, in Lowell, Middlesex County, Massachusetts, and further bounded and described as follows:

Beginning at the most southerly corner of the Blacksmith Shop, said corner bearing N 49° 46' 36" W, and being 26.24 feet distant from the northwesterly line of land now or formerly of Flago Realty Corporation; thence along the face of the Blacksmith Shop as follows:

N 66° 55' 23" W, a distance of 8.15 feet to a corner,

N 23° 51' 49" E, a distance of 7.18 feet to a corner,

N 65° 45' 09" W, a distance of 17.26 feet to a corner,

N 24° 09' 04" E, a distance of 45.47 feet to a corner,

S 65° 45' 09" E, a distance of 25.19 feet to a corner, and

S 23° 51' 49" W, a distance of 52.48 feet to the point of beginning.

Containing 1,204 square feet of land, more or less.

Being shown on sheet 20 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 1 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 282 square feet, more or less

Interest: Easement

Date: January 13, 1994

TRACT 107-07

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Western Canal, so called and known and numbered as 251 Moody Street, and further bounded and described as follows:

Beginning at an iron pin set on the northeasterly line of Moody Street, said pin being at the southwesterly corner of land now or formerly of Lowell Apartments; thence along said northeasterly line of Moody Street

N 56° 50' 00" W, a distance of 10.28 feet to a point at the back edge of the southeasterly granite wall of the Western Canal; thence along said canal wall:

N 33° 40' 12" E, a distance of 4.62 feet to an iron pin set and

N 45° 45' 12" E, a distance of 47.00 feet to a point at land now or formerly of Lowell Apartments; thence along the northwesterly line of said Lowell Apartments

S 33 ° 09' 51" W, a distance of 50.49 feet to the point of beginning.

Containing 282 square feet of land, more or less.

Being shown as Parcel CB-D, Lot J on sheet 26 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 0.01 of an acre, more or less

Interest: Easement

Date: June 25, 1992
Revised: February 3, 1994

TRACT 107-13

Two certain parcels of land with buildings, structures and fixtures thereon, commonly known as the Rolling Dam Gate House, located in Lowell, Middlesex County, Massachusetts over the Merrimack Canal and Wasteway, so called, and near French Street and further bounded and described as follows:

PARCEL I:

Beginning at the northwesterly corner of the Rolling Dam Gate House, said corner being a point in the southeasterly line of land, now or formerly of Lowell Union Properties Inc., said southeasterly line of land also being the northwesterly line of the Merrimack Canal Wasteway, the aforesaid point of beginning bearing N 48° 15' 38" E, and being 57.58 feet distant from a drill hole found in an angle in the wall of the Merrimack Canal; thence along the southeasterly line of land now or formerly of Lowell Union Properties Inc.

N 48° 15' 38" E by the northwesterly line of the Merrimack Canal Wasteway and the Rolling Dam along the northwesterly face of the Rolling Dam along the northwesterly face of the rolling Dam Gate House, a distance of 11.15 feet the a point;

Thence, crossing the Rolling Dam and running along the northeasterly face of the Rolling Dam Gate house S 42° 02' 28" E, a distance of 17.90 feet to a point on the northwesterly line of land now or formerly of Boott Mills, being the southeasterly line of the Merrimack Canal Wasteway;

Thence, running through the Rolling Dam Gate House along said southeasterly line of the Merrimack Canal Wasteway

S 48° 17' 38" W, a distance of 27.29 feet to a point on the southwesterly building face of the Rolling Dam Gate House, said point bearing N 20° 06'35" E and being 0.45 feet distant from the most southwesterly corner thereof; thence crossing the Merrimack Canal Wasteway and running along the westerly and southwest building lines of the Rolling Dam Gate House by two courses as follows:

N 20° 06' 35" E, a distance of 18.26 feet to a point, and

N 42° 02' 28" W, a distance of 9.26 feet to the point of beginning.

Containing 269 square feet of land, which is 0.01 of an acre, more or less.

PARCEL II:

Beginning at a point on the northeasterly face of the Rolling Dam Gate House, said point being on the southeasterly line of the Merrimack Canal Wasteway and bearing S 48° 17' 38" W, and being 19.37 feet distant from an iron pin set at the northwesterly corner of Parcel CB-L/5721 as shown on the plan hereinafter described; thence running the following four courses by land now or formerly of Boott Mills along the building face of the Rolling Dam Gate House:

S 42° 02' 28" E, a distance of 4.07 feet to a point,

S 20° 06' 35" W, a distance of 22.94 feet to a point, said point bearing N 42° 45' 53" W, and being 34.96 feet distant from the most northerly corner of Store House No. 1,

N 68° 42' 56" W, a distance of 16.49 feet to a point and

N 20° 06' 35" E, a distance of 0.45 feet to a point on the southeasterly line of the Merrimack Canal Wasteway;

Thence, along said southeasterly line of the Merrimack Canal Wasteway N 48° 17' 38" E, a distance of 27.29 feet to the point of beginning.

Containing 248 square feet of land, more or less, which is 0.01 of an acre, more or less.

Both Parcels I and II being shown as the Rolling Dam Gate House North and South on sheet 19 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 24 May 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 805 square feet, more or less

Interest: Easement

Date: January 13, 1994

TRACT 107-15

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Western Canal, so called and known and numbered as 271 Moody Street, and further bounded and described as follows:

Beginning at a point on the northeasterly line of Moody Street, said point being an iron pin set at the southeasterly corner of land now or formerly of the Lowell Apartments; thence along the southeasterly line of said Lowell Apartments

N 33 ° 10' 15" E, a distance of 212.43 feet to a point on the southwesterly line of French Street Extension; thence along said line of French Street Extension

S 56° 01' 24" E, a distance of 1.63 feet to a point at the back edge of the northwesterly granite wall of the Western Canal; thence along the back edge of said canal wall as follows:

S 33° 09' 14" W, a distance of 4.16 feet to an iron pin set,

S 33° 09' 14" W, a distance of 151.42 feet to an iron pin set,

S 17° 32' 06" W, a distance of 57.31 feet to an iron pin set and

S 28° 57' 00" W, a distance of 1.65 feet to a point on the northeasterly line of Moody Street; thence along said line of Moody Street

N 56° 50' 00" W, a distance of 17.25 feet to the point of beginning.

Containing 805 square feet of land, more or less.

Being shown as Parcel CB-C, Lot I on sheet 26 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 2,511 square feet, more or less

Interest: Easement

Date: February 1, 1994
Revised: March 27, 1995

TRACT 107-21

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Eastern Canal and Merrimack Wasteway, so called, and further bounded and described as follows:

Beginning at a point at the southeasterly corner of the parcel, said point being on the northeasterly line of land now or formerly of Boott Mills, and bearing N 41° 34' 09" W, and being 60.23 feet distant from the westerly termination of Amory Street; thence

N 41° 34' 09" W, along the northeasterly line of land now or formerly of Boott Mills, a distance of 158.92 feet to an iron pin set at the southeasterly face of the southeasterly wall of the Rolling Dam; thence

N 48° 17' 38" E, along said southeasterly face of the southeasterly wall of the Rolling Dam, a distance of 8.61 feet to an iron pin set at an angle in the southerly wall of the Merrimack Wasteway; thence

N 70° 36' 40" E, along the southerly face of a wall, a distance of 9.91 feet to a cross-cut set at an angle in said wall; thence

S 40° 30' 36" E, along the southwesterly face of the southwesterly wall of the Eastern Canal, a distance of 4.65 feet to a point on the northwesterly face of a brick building; thence running along the face of said brick building by five courses as follows:

S 48° 17' 38" W, a distance of 0.71 feet to a point,

S 40° 24' 35" E, a distance of 10.40 feet to a point,

S 50° 12' 21" W, a distance of 12.73 feet to a point,

S 40° 24' 35" E, a distance of 21.36 feet to a point, and

N 48° 23' 37" E, a distance of 13.50 feet to a point at the southwesterly face of the southwesterly wall of the Eastern Canal; thence running along said southwesterly face of the southwesterly wall of the Eastern Canal

S 43° 08' 52" E, a distance of 35.00 feet to a point at the most westerly corner of the Boott Dam Gate House as shown on the plan hereinafter described; thence

S 38° 32' 55" E, along the southwesterly face of the Boott Dam Gate House a distance of 11.07 feet to a point at the most southerly corner thereof; thence along the southwesterly face of the southwesterly wall of the Eastern Canal

S 42° 29' 19" E, a distance of 72.12 feet to a point; thence

S 45° 11' 23" W, along the northwesterly edge of a concrete capstone, a distance of 18.69 feet to a PK nail set at the point of beginning.

Containing 2,511 square feet of land, more or less.

Being shown as Parcel CB-L/5721 on sheet 19 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 4,938 square feet, more or less

Interest: Easement

Date: January 13, 1994

TRACT 107-22

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Western Canal, so called and Suffolk Street, and between French Street Extension and Hall Street and further bounded and described as follows:

Beginning at a point on the southeasterly line of Suffolk Street, said point being at a thirty foot right-of-way; thence along said thirty foot right-of way

S 41° 36' 20" E, a distance of 10.40 feet to a PK nail set in a wood deck; thence along the back edge of the northwesterly granite wall of the Tremont Wasteway

S 48° 19' 26" W, a distance of 475.86 feet to a PK nail set in a wall; thence along said wall

N 40° 26' 22" W, a distance of 10.36 feet to a point on the southeasterly line of Suffolk Street; thence along said line of Suffolk Street

N 48° 19' 10" E, a distance of 475.65 feet to the point of beginning

Containing 4,938 square feet of land, more or less.

Being shown as Parcel CB-E, Lot A on sheet 25 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 10,905 square feet, more or less

Interest: Easement

Date: January 13, 1994

TRACT 107-23

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Western Canal, so called, known and numbered as 540 Market Street and further bounded and described as follows:

Beginning at a drill hole set at the northeasterly corner of Suffolk Street and Jefferson Street; thence running along the easterly line of Suffolk Street

N 11° 11' 30" W, a distance of 482.44 feet to a spike set in the granite curb at the point of curvature leading to Market Street; thence

Northeasterly, more or less, by a curve to the right having a radius of 11.46 feet, an arc length of 26.87 feet to an x-cut set in the concrete walk; thence running along the southerly line of Market Street

S 56° 46' 50" E, a distance of about 18 feet to the westerly shoreline of the Western Canal; thence along the westerly shoreline of said Western Canal

Southerly, more or less, a distance of about 480 feet to a point on the northerly line of Jefferson Street; thence running along said northerly line of Jefferson Street

S 78 52' 10" W, a distance of about 25 feet to the point of beginning.

Containing 10,905 square feet of land, more or less.

Being shown as Parcel CB-C, Lot C on sheets 27 and 28 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 8,635 square feet, more or less

Interest: Easement

Date: January 13, 1994

TRACT 107-24

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Western Canal, so called, known and numbered as 520 Market Street and further bounded and described as follows:

Beginning at a spike set at the northwesterly corner of Jefferson Street and Lewis Street; thence running along the northerly line of Jefferson Street,

S 78° 52' 10" W, a distance of about 23 feet to the easterly shoreline of the Western Canal; thence along said shoreline of the Western Canal

Northerly, more or less, a distance of about 452 feet to a point on the southwesterly line of Market Street; thence along said southwesterly line of Market Street

S 56° 46' 50" E, a distance of about 45 feet to a drill hole set in the concrete sidewalk at the southwesterly corner of Market Street and Lewis Street; thence along the westerly line of Lewis Street

S 11° 11' 30" E, a distance of 411.18 feet to the point of beginning

Containing 8,635 square feet of land, more or less.

Being shown as Parcel CB-D, Lot D on sheets 27 and 28 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: City of Lowell and Comm. of MA/DEM
Date of Description: March 16, 1994
Revised: Oct. 7, 1994
Interest: Easement

Tract 107-25(Ecumenical Plaza)

All of that certain brick and concrete platform, together with the air rights, lying over the Western Canal in the City of Lowell, County of Middlesex and Commonwealth of Massachusetts, excluding the canal walls, and known as Ecumenical Plaza; Said Plaza is shown on Sheet No. 28 of a plan entitled "Lowell Canal System, Commonwealth of Massachusetts, Department of Environmental Management, Division of Forests and Parks, Lowell Heritage State Park, Lowell Massachusetts," and prepared by Atlantic Engineering and Survey Consultants and recorded in the Middlesex North Registry of Deeds in Plan Book 157, Plan 69.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 3,115 square feet, more or less

Interest: Easement

Date: January 13, 1994

TRACT 107-26

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Western Canal, so called, known and numbered as 570 Merrimack Street and further bounded and described as follows:

Beginning at a spike set at the northeasterly corner of Suffolk Street and Market Street; thence running along the easterly line of Suffolk Street

N 33° 10' 15" E, a distance of 171.85 feet to a drill hole set at the corner of Merrimack Street; thence running along the southerly line of said Merrimack Street

S 56° 50' 00" E, a distance of 17.55 feet to a point at the land edge of the granite wall of the Western Canal; thence running along said wall of the Western Canal

S 32° 46' 59" W, a distance of 170.98 feet to a point on the northerly line of Market Street; thence along the line of Market Street

N 56° 46' 50" W, a distance of 18.71 feet to the point of beginning.

Containing 3,115 square feet of land, more or less.

Being shown as Parcel CB-C, Lot E on sheet 27 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 2,310 square feet, more or less

Interest: Easement

Date: January 26, 1994

TRACT 107-27

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Western Canal, so called, known and numbered as 550 Merrimack Street and further bounded and described as follows:

Beginning at an iron pin set at the northwesterly corner of Market Street and Hanover Street; thence along the northerly line of Market Street

N 56° 46' 50" W, a distance of 13.80 feet to a point at the back edge of the granite wall of the Western Canal thence running along the back edge of said wall as follows:

N 33° 29' 15" E, a distance of 7.86 feet to an iron pin set,

N 33° 29' 15" E, a distance of 63.90 feet to an iron pin set,

N 33° 43' 33" E a distance of 38.38 feet to an iron pin set,

N 32° 27' 04" E, a distance of 58.96 feet to a drill hole set, and

N 32° 27' 04" E, a distance of 2.81 feet to a point on the southerly line of Merrimack Street; thence along said southerly line of Merrimack Street

S 56° 50' 00" E, a distance of 13.79 feet to a drill hole set at the corner of Hanover Street, thence along the westerly line of Hanover Street

S 33° 09' 51" W, a distance of 171.91 feet to the point of beginning.

Containing 2,310 square feet of land, more or less.

Being shown as Parcel CB-D, Lot F on sheet 27 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 3,400 square feet, more or less

Interest: Easement

Date: January 26, 1994

TRACT 107-28

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Western Canal, so called, known and numbered as 571 Merrimack Street and further bounded and described as follows:

Beginning at a point on the northeasterly line of Merrimack Street, said point being at the Southerly corner of land now or formerly of the Lowell Development Authority; thence along the southeasterly line of said Lowell Development Authority, being the southeasterly line of a fifteen foot wide easement now or formerly of the Proprietors of Locks and Canals

N 33° 10' 15" E, a distance of 172.90 feet to a spike set on the southwesterly line of Moody Street; thence along said line of Moody Street

S 56° 50' 00" E, a distance of 16.37 feet to a point at the back edge of the northwesterly granite wall of the Western Canal; thence along the Western Canal, in part by the back edge of a granite wall and in part by the shoreline thereof

SOUTHERLY, more or less, along the shoreline and two sections of granite distances of 40 feet, 75 feet and 59 feet to a drill hole set on the northeasterly line of Merrimack Street; thence along said line of Merrimack Street

N 56° 50' 00" W, a distance of 20.90 feet to the point of beginning.

Containing 3,400 square feet of land, more or less.

Being shown as Parcel CB-C, Lot G on sheet 26 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 1,167 square feet, more or less

Interest: Easement

Date: January 26, 1994

TRACT 107-29

A certain parcel of land located in Lowell, Middlesex County, Massachusetts along the Western Canal, so called, known and numbered as 551 Merrimack Street and further bounded and described as follows:

> Beginning at a point on the northeasterly line of Merrimack Street, said point being at the southwesterly corner of land now or formerly of the Lowell Development Authority; thence along said northeasterly line of Merrimack Street
>
> N 56° 50' 00" W, a distance of 10.83 feet to a drill hole set at the land edge of the granite wall of the Western Canal; thence running along the land edge of the southeasterly granite wall of the Western Canal as follows:
>
> N 31° 14' 15" E, a distance of 27.54 feet to a drill hole set,
>
> N 32° 55' 07" E, a distance of 65.39 feet to an iron pin set,
>
> NORTHEASTERLY, more or less, a distance of 38 feet, more or less, to an iron pin set, said pin bearing N 45° 02' 42" E, and being 36.79 feet distant from the last point mentioned,
>
> N 28° 16' 36" E, a distance of 38.94 feet to an iron pin set, and
>
> N 28° 31' 46" E, a distance of 4.92 feet to a point on the southwesterly line of Moody Street; thence along said line of Moody Street
>
> S 56° 50' 00" E, a distance of 8.19 feet to a drill hole set at land now or formerly of the Lowell Development Authority; thence along the northwesterly line of said Lowell Development Authority
>
> S 33° 09' 51" W, a distance of 172.90 feet to the point of beginning.
>
> Containing 1,167 square feet of land, more or less.

Being shown as Parcel CB-D, Lot H on sheet 26 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 6 July 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.

Purported Owner: Commonwealth of MA/ DEM

Lowell Historic Preservation Commission

Area: 0.258 acres, more or less

Interest: Easement

Date: April 21, 1994
Revised: Sept. 26, 1994
(LHPC)

TRACT 107-35

A certain parcel of land located along the Western Canal, so called, and being located on the North side of Father Morrissette Boulevard (formerly known as French Street Extension) and East of Suffolk Street in Lowell, Middlesex County, Massachusetts, and being further bounded and described as follows:

Beginning at a point on the North side of said Father Morrissette Boulevard and the Southeasterly face of the Southeasterly wall of said Western Canal, said point is located 0.78 feet, more or less, Southeasterly of a pin in lead in the concrete walk;

Thence, continuing along the Southeasterly face of the Southeasterly wall by the following five courses:

N 31° 46' 38" E, 65.67 feet, more or less, to a point,

N 78° 53' 20" E, 11.04 feet, more or less, to a point,

N 33° 03' 52" E, 38.74 feet, more or less, to a point,

N 27° 47' 30" W, 8.29 feet, more or less, to a point, and

S 33° 03' 25" W, 0.88 feet, more or less, to a point;

Thence, N 57° 28' 58" W, 12.37 feet, more or less, to a point on the Southerly corner of the Tremont Gatehouse;

Thence, N 57° 28' 58" W, 40.58 feet, more or less, along said Gatehouse, to a point;

Thence, N 33° 03' 23" E, 28.84 feet, more or less, to a point;

Thence, S 55° 42' 09" E, 40.34 feet, more or less, to a point;

Thence, S 33° 05' 23" W, 13.29 feet, more or less, to a point;

Thence, S 56° 42' 25" E, 2.19 feet, more or less, to a point;

Thence, N 31° 36' 15" E, 14.94 feet, more or less, to a point;

Thence, N 33° 00' 23" E, 17.25 feet, more or less, to a point;

Thence, S 56° 53' 59" E, 95.16 feet, more or less, along land now or formerly of the Trustees of Wannalancit Office and Technology Center Trust, to a point;

Thence, S 33° 05' 46" W, 134.61 feet, more or less, along land now or formerly of the Commonwealth of Massachusetts, to a capped iron rod set;

Thence, by a curve to the right with a radius of 676.06 feet, more or less and a length of 5.31 feet, more or less, to a point;

Thence, by a curve to the right with a radius of 39.00 feet, more or less and a length of 63.96 feet, more or less, to a point;

Thence, N 33° 49' 13" E, 60.46 feet, more or less, to a point;

Thence, N 56° 10' 47" W, 24.77 feet, more or less, to a point;

Thence, S 33° 49' 13" W, 60.46 feet, more or less, to a point;

Thence, S 13° 09' 26" E, 93.24 feet, more or less, by a curve to the Left with a radius of 63.77 feet, more or less, and an arc length of 104.57 feet, more or less, to a point;

Thence, N 58° 45' 20" W, 65.05 feet, more or less, along Father Morrissette Boulevard, by a curve to the Right with a radius of 720.00 feet, more or less, and an arc length of 65.07 feet, more or less, to a stone bound found;

Thence, N 56° 09' 59" W, 14.51 feet, more or less, to the point of beginning.

Containing 11,226 square feet of land, more or less, which is 0.258 acres, more or less.

Being shown as Proposed Easement Number 2 on a plan entitled "Canalway Easement Plan of Land in Lowell, MA, Middlesex County, prepared for Lowell Historic Preservation Commission" by Ainsworth Associates, Inc., dated September 16, 1994 and recorded herewith.

Being a portion of the premises conveyed to the Commonwealth of Massachusetts, Department of Environmental Management by deed of Frank E. Barrett and Claire N. Barrett dated May 27, 1977 and recorded with said Registry of Deeds at Book 2251, Page 234.

Purported Owner: Commonwealth of Massachusetts (DEM)

Lowell Historic Preservation Commission

Area: 565 square feet, more or less.

Interest to be Acquired: Easement

Date: June 30, 1994

TRACT 107-38

All that certain parcel of land with the improvements thereon commonly known as the Boott Dam Gatehouse, located on the Eastern Canal, so called, in Lowell, Middlesex County, Massachusetts, and further bounded and described as follows:

Beginning at the most northerly corner of the Boott Dam Gate House, said corner being a point on the southwesterly wall of Mill No. 9 of the Boott Mills, bearing S 41° 17' 01" E and being 29.46 feet distance from the southeasterly wall of the Picker Building; thence

S 41° 17' 01" E, along the southwesterly wall of Mill No. 9 of the Boott Mills 16.67 feet to a point on the Eastern Canal; thence crossing said Eastern Canal and running along the southeasterly face of the Boott Dam Gate House by two courses as follows:

S 39° 34' 16" W, a distance of 18.98 feet to a point, and

S 56° 14' 08" W, a distance of 22.05 feet to a point on the northeasterly line of Parcel CB-L/5721 as shown on the plan hereinafter described, said point being the most southerly corner of the Boott Dam Gate House; thence

N 38° 32' 55" W, along the southwesterly face of the Boott Dam Gate House a distance of 11.01 feet to a point; thence crossing said Eastern Canal and running along the wall of the Boott Dam Gate House by three courses as follows:

N 56° 14' 08" E, a distance of 19.50 feet to a point,

N 51° 14' 58" W, a distance of 4.90 feet to a point, and

N 39° 34' 16" E, a distance of 21.87 feet to the point of beginning.

Containing 565 square feet of land, more or less.

Being shown as the Boott Dam Gate House on sheet 19 of a set of plans entitled "Lowell Heritage State Park, The Lowell Canal System" by Atlantic Engineering and Survey Consultants, dated July 1 1983, recorded with the Middlesex Northern District Registry of Deeds in Plan Book 157 plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds in Book 3830, at Page 70.

Purported Owner: Commonwealth of Massachusetts (DEM)

Lowell Historic Preservation Commission

Area: 5,528 square feet, more or less.

Interest to be Acquired: Easement

Date: June 30, 1994

TRACT 107-39

All that certain parcel of land located along the Northern Canal, so called and also located near Cabot Street, in Lowell, Middlesex County, Massachusetts and further bounded and described as follows:

Beginning at a point on the southeasterly line of Cabot Street, said point being at the land edge of the easterly granite wall of the Northern Canal; thence along said line of Cabot Street

N 48° 17' 37" E, a distance of 11.56 feet to a point at land now or formerly of Murray Printing Company; thence along the southwesterly line of Murray Printing Company

S 41° 39' 43" E, a distance of 474.89 feet to a point on the northwesterly line of Suffolk Street; thence along said line of Suffolk Street

S 48° 19' 10" W, a distance of 11.73 feet to a point at the land edge of the easterly granite wall of the Northern Canal; thence along said canal wall:

N 41° 38' 39" W, a distance of 451.42 feet to a drill hole set, and

N 41° 38' 39" W, a distance of 21.27 feet to the point of beginning.

Containing 5,528 square feet of land, more or less.

Being shown as Parcel 65-Y on sheet 25 of a set of plans entitled "Lowell Heritage State Park, The Lowell Canal System" by Atlantic Engineering and Survey Consultants, dated July 1 1983, recorded with the Middlesex Northern District Registry of Deeds in Plan Book 157 plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds in Book 3830, at Page 70.

Purported Owner: Commonwealth of Massachusetts (DEM)

Lowell Historic Preservation Commission

Area: 382 square feet, more or less.

Interest to be Acquired: Easement

Date: June 30, 1994

TRACT 107-40

All that certain parcel of land together with the improvements thereon commonly known as the Tremont Gatehouse located near the Tremont Wasteway, so called, in Lowell, Middlesex County, Massachusetts, and further bounded and described as follows:

Beginning at the southeasterly corner of the gatehouse, said corner being at the head of the Tremont Wasteway, and bearing N 41° 52' 13" W and being 12.55 feet distant from the northwesterly line of land now or formerly of the Commonwealth of Massachusetts; thence across the head of said Tremont Wasteway

N 41° 52' 13" W, a distance of 31.30 feet to the most westerly corner of the gatehouse; thence by a granite wall and by Part Parcels 5610 and 5362 as shown on the plan hereinafter described, as follows:

N 48° 07' 47 " E, a distance of 12.20 feet to a corner,

S 41° 52' 13" E, a distance of 31.30 feet to a corner, and

S 48° 07' 47" W, a distance of 12.20 feet to the point of beginning.

Containing 382 square feet of land, more or less.

Being shown as the Tremont Gatehouse on sheet 25 of a set of plans entitled "Lowell Heritage State Park, The Lowell Canal System" by Atlantic Engineering and Survey Consultants, dated July 1 1983, recorded with the Middlesex Northern District Registry of Deeds in Plan Book 157 plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds in Book 3830, at Page 70.

Purported Owner: Commonwealth of MA/DEM

Lowell Historic Preservation Commission

Area: 199 square feet, more or less

Interest: Easement

Date: February 3, 1994

TRACT 108-21

A certain parcel of land with buildings, structures and fixtures thereon, commonly known as the Massachusetts Wasteway Gate House, located in Lowell, Middlesex County, Massachusetts over the Eastern Canal, so called, and near Bridge Street and further bounded and described as follows:

Beginning at the northwesterly corner of the Massachusetts Wasteway Gate House, said corner bearing S 41° 44' 51" E, and being 3.74 feet distant from the southeasterly line of Bridge Street; thence running along the face of the Massachusetts Wasteway Gate House by land now or formerly of the Proprietors of Locks and Canals, by three courses as follows:

N 48° 15' 09" E, a distance of 7.67 feet to a corner,

S 41° 44' 51" E, a distance of 26 feet to a corner, and

S 48° 15' 09" W, a distance of 7.67 feet to the most southerly corner of said Gate House, being a point on the southeasterly side of the Eastern Canal; thence along the southwesterly face of the Massachusetts Wasteway Gate House

N 41° 44' 51" W, a distance of 26 feet to the point of beginning.

Containing 199 square feet of land, more or less.

Being shown as the Massachusetts Wasteway Gate House on sheet 18 of a set of plans entitled "Lowell Canal System, Lowell Heritage State Park, Lowell, Massachusetts" prepared by Atlantic Engineering and Survey Consultants, dated 24 May 1983 and recorded with the Middlesex Northern District Registry of Deeds at Plan Book 157, Plan 69.

Being a portion of the premises taken by the Commonwealth of Massachusetts by Order of Taking dated December 1, 1986 and recorded with said Registry of Deeds at Book 3830, Page 70.