Water Level and Flow Effects on Historic Resources Study Report

Lowell Hydroelectric Project (FERC No. 2790)

November 1, 2021

Prepared by:

HDR

Prepared for:

Boott Hydropower, LLC
Manchester, New Hampshire

Central Rivers Power

This page is intentionally left blank.

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
FERC	Federal Energy Regulatory Commission (or Commission)
ft	feet
ILP	Integrated Licensing Process
ISR	Initial Study Report
LNHP	Lowell National Historical Park
MADCR	Massachusetts Department of Conservation and Recreation
MW	megawatt
NGVD 29	National Geodetic Vertical Datum 1929
NHL	National Historic Landmark
NOI	Notice of Intent
NPS	National Park Service
PAD	Pre-Application Document
Project	Lowell Hydroelectric Project (or Lowell Project)
PSP	Proposed Study Plan
RL	river left
RM	river mile
ROR	run-of-river
RR	river right
RSP	Revised Study Plan
SD1	Scoping Document 1
SPD	Study Plan Determination
USDOI	U. S. Department of Interior

This page is intentionally left blank.

1 Introduction and Background

Boott Hydropower, LLC (Boott or Licensee) is the Licensee, owner, and operator of the 20.2-megawatt (MW) 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 Water Level and Flow Effects on Historic Resources 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 a headpond 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 (ft) 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 headpond with a normal maximum water surface elevation of 92.2 ft 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 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;
7) A 4.5-mile-long, 13.8-kilovolt transmission line connecting the powerhouses to the regional distribution grid;

[1] The Commission issued a Revised Process Plan and Schedule on June 12, 2020.

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 ft NGVD 29[2] (crest of the pneumatic flashboards), the surface area of the headpond encompasses an area of approximately 720 acres. The gross storage capacity between the normal surface elevation of 92.2 ft and the minimum pond level of 87.2 ft is approximately 3,600 acre-ft. 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 (Hay 1991). 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 (Hay 1991).

Several Project facilities are located within overlapping locally, state, and nationally designated parks and historic properties and/or preservation districts. The Project's Pawtucket Dam and E.L. Field Powerhouse are located along the mainstem of the Merrimack River. The Project's two-tiered network of man-made canals extends throughout downtown Lowell. The 5.5-mile-long canal system provides flow to the Project's Hamilton, Assets, Bridge Street, and John Street developments. The Hamilton, Assets, Bridge Street, and John Street power stations and turbines are housed in large former mill buildings. The mill buildings are not included in the Project; the Project Boundary includes only the turbines and associated equipment at these downtown mill sites. In addition to the Pawtucket Dam and hydroelectric developments, the 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 and Merrimack Gate, Rolling Dam, and the Boott Dam.

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

[2] Elevations throughout this study are reported or have been converted to the National Geodetic Vertical Datum 1929 (NGVD 29).

well as the private sector and local community carry out the legislative intent of the park unit. The Lowell National Historical Park is also listed on the National Register of Historic Places, 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.

1.2 Study Development

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 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
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
December 2, 2020	Draft License Application Filed
February 25, 2021	Second ISR Filed
April 30, 2021	Final License Application Filed

Boott has continued consultation with stakeholders regarding the approved studies as required by the Commission's SPD. In accordance with the schedule presented in the Revised Study Plan (RSP), 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.

The NPS previously indicated that changing water levels and flows in the Project's canal system have the potential to adversely affect historic canal structures. To document water levels under a range of operating conditions, Boott deployed pressure transducers (level loggers) in the canal system to record water level fluctuations at 15-minute intervals. By letter dated May 5, 2019, Boott consulted with the NPS regarding the specific locations for level logger deployment. In June 2019, level loggers were deployed at 10 locations in the canal system. Data from the level loggers were downloaded on an approximate monthly basis.

On December 18, 2019, Boott held a Study Workshop to discuss the Water Level and Flow Effects Study; Recreation and Aesthetics Study; Historically Significant Waterpower Equipment Study; and the Resources, Ownership, Boundaries, and Land Rights Study. During the workshop, the NPS clarified that their interest was related to the effects of the Pawtucket Dam pneumatic crest gate system that became operational in 2018. The NPS was concerned that the new pneumatic crest gate could increase flows to the downtown canal system and that higher flows could have the potential to adversely affect historic structures. During the December 18, 2019 Study Workshop, Boott explained that water levels in the downtown canal system are not affected by the crest gate and that any effects would be limited to structures along the Northern Canal and the Upper Pawtucket Canal (extending upstream from the Guard Lock Gate Complex to the mainstem of the Merrimack River). Given that water levels in the downtown canal system are not affected by crest gate operations, the NPS agreed that the historic resources along the Northern Canal and Upper Pawtucket Canal should be the focus of the Water Level and Flow Effects Study. Therefore, the NPS and Boott agreed that Boott should relocate level loggers to the Upper Pawtucket Canal and Northern Canal and remove the remaining level loggers from the downtown canal system. Boott relocated the level loggers in March 2020 and recorded water level fluctuations in the Upper Pawtucket Canal and Northern Canal in 15-minute intervals through late September 2020. During the 2020 deployment period, Boott recorded a wide range of flows in the Upper Pawtucket Canal and Northern Canal, including high flow events during the spring freshet and low flow events during the summer and early fall of 2020. Boott believes that this range of flows is appropriate to analyze potential Project-related water level and flow effects on historic structures in the Upper Pawtucket and Northern canals. Boott utilized the level logger data from the 2020 deployment period, Project operation data, existing drawings, and field observations to assess potential effects.

2 Study Goals and Objectives

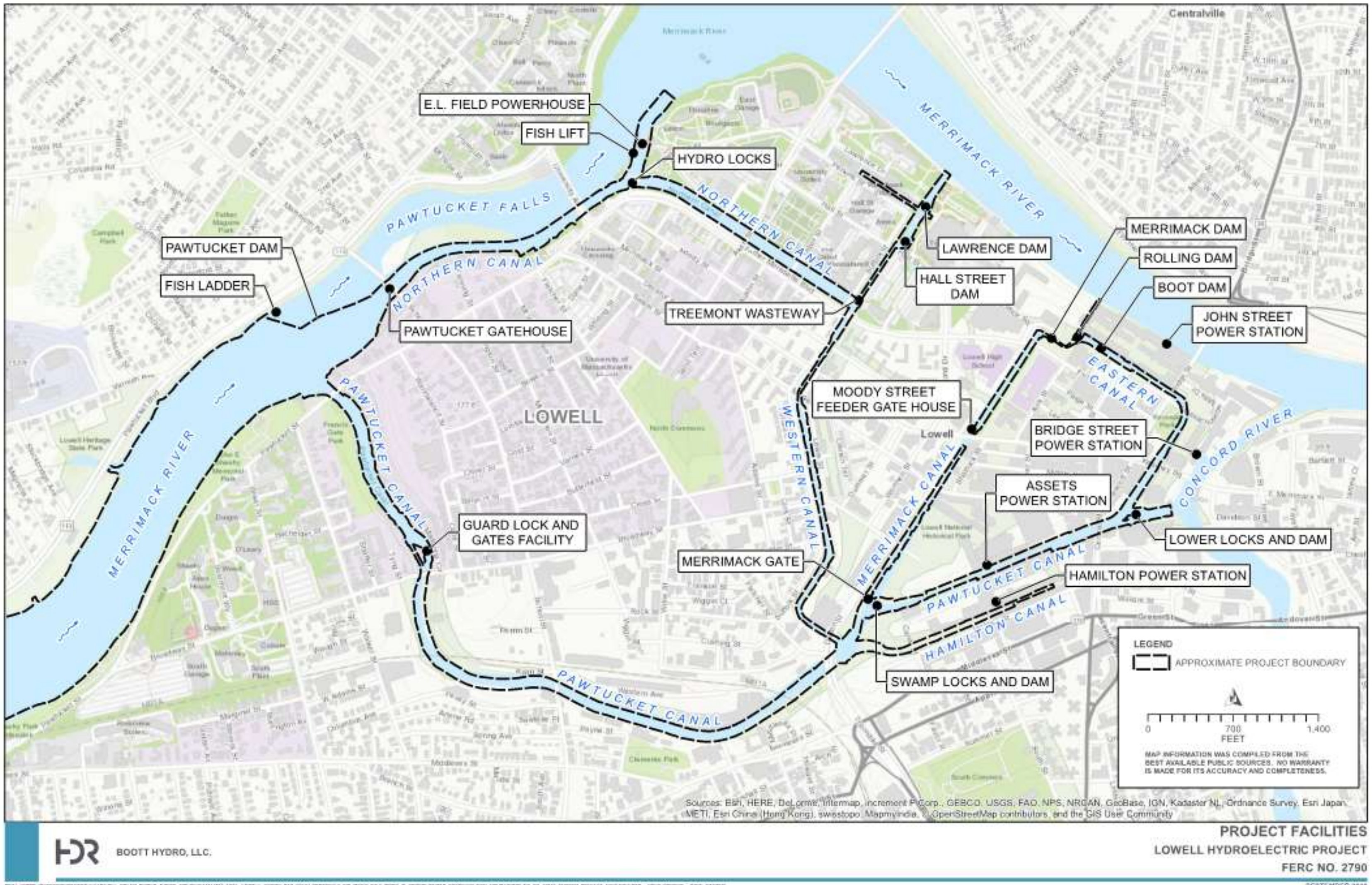
The goal of this study is to assess the potential effect of water level fluctuations within the headpond, Northern Canal, and the Pawtucket Canal (extending upstream from the Guard Lock Gate Complex to the mainstem of the Merrimack River) on the historic structures including the Pawtucket Gatehouse, the Waste Gate Building, the Guard Lock Gate Complex structures, and the Great Wall. The specific objectives of this study are as follows:

- Evaluate how Project operations, including manipulation of the new crest gate system, canal head gates, spillways, locks, fish passage structures, and generating units will change water levels in the Upper Pawtucket and Northern Canals;
- Determine the extent to which water flows or elevations are having an effect on historic resources;
- Conduct a structural assessment of the Great River Wall; and
- Identify potential impacts of current Project operations on nationally significant historic resources, including a structural assessment of the Great River Wall.

3 Study Area

In accordance with the Commission's SPD, the study area for the Water Level and Flow Effects on Historic Resources includes the Projects canal system and associated Project infrastructure within the FERC Project Boundary in the City of Lowell, limited to the Northern Canal from the canal headworks to the E.L. Field Powerhouse not including the portion of the Northern Canal downstream of the Hydro Locks. Also included in the study area is the Upper Pawtucket Canal from the confluence with the Merrimac River downstream to the Guard Lock Gate Complex (Figure 3-1) and the portion of the Project headpond in the proximity of the Pawtucket Dam.

Figure 3-1. Study Area for the Water Level and Flow Effects on Historic Resources Study Report



4 Methodology

4.1 Document Review of Existing Conditions

Boott reviewed available architectural and engineering evaluations of historic canal structures available from the NPS and other stakeholders, including documentation of previous maintenance and repairs to characterize existing conditions. Based on this document review, Boott identified properties that have previously been affected by water level or flow conditions. Copies of these documents are included in Appendix A of this study report.

4.2 Site Visit to Document Existing Conditions

The approved Water Level and Flow Effects Study Plan directed Boott to conduct a site visit with the NPS, to identify locations where fluctuating water levels or flows have previously caused adverse effects to historic structures along the canal system. As proposed by Boott, the intention of this field visit was to collect additional information from NPS staff who may have observed or documented potential adverse effects associated with Project-related flows or water levels, and to identify specific structures (or components of structures) that are of interest to the NPS. However, due to the ongoing COVID-19 pandemic, Boott sought alternatives to in-person meetings and field visits to protect the health and safety of all parties.

Accordingly, Boott consulted with the NPS via letter dated January 4, 2021 regarding previously documented issues related to Project-related flow effects or changing water levels along the canal system. Boott sought the NPS's assistance in identifying historic canal structures along the Upper Pawtucket and Northern Canals that have purportedly been affected by Project-related water levels or flows. Specifically, Boott sought any records of previous damage, maintenance, or repairs to structures along the Upper Pawtucket or Northern canals that have resulted from Project-related flows or water levels. Boott requested the NPS's assistance in identifying any other known issues related to water levels and flow effects on specific structures along these canals.

Boott conducted a site visit to historic canal structures with input from NPS to identify issues previously noted by the NPS related to the flow and water levels on historic structures. Due to COVID-19 guidance and restrictions, the site visit was conducted by Boott independently. The site visit was conducted on January 27, 2020 by Boott to visually assess the effects of water level fluctuations on the historic structures associated with the Northern and Upper Pawtucket Canals and to collect additional data in support of this study.

NPS provided written comments on February 3, 2021 in response to Boott's request for information. Following receipt of that information from NPS, Boott performed an additional data collection site visit on February 15, 2021 to collect additional elevation information for the historic structures detailed by NPS.

4.3 Canal Water Level Monitoring

To assess water levels under a range of operating conditions, Boott installed pressure transducers (level loggers) at four locations within the canal system that were identified in consultation with the NPS, and an additional atmospheric logger deployed near the E.L. Field Powerhouse (for calibration and barometric pressure correction).

The level loggers were installed on March 10, 2020 and were placed at a depth where they would remain below the water level during all field conditions during the study period. Accordingly, each installation established a sound, initial reference depth to which relative change (increase/decrease in water depth) was then recorded.

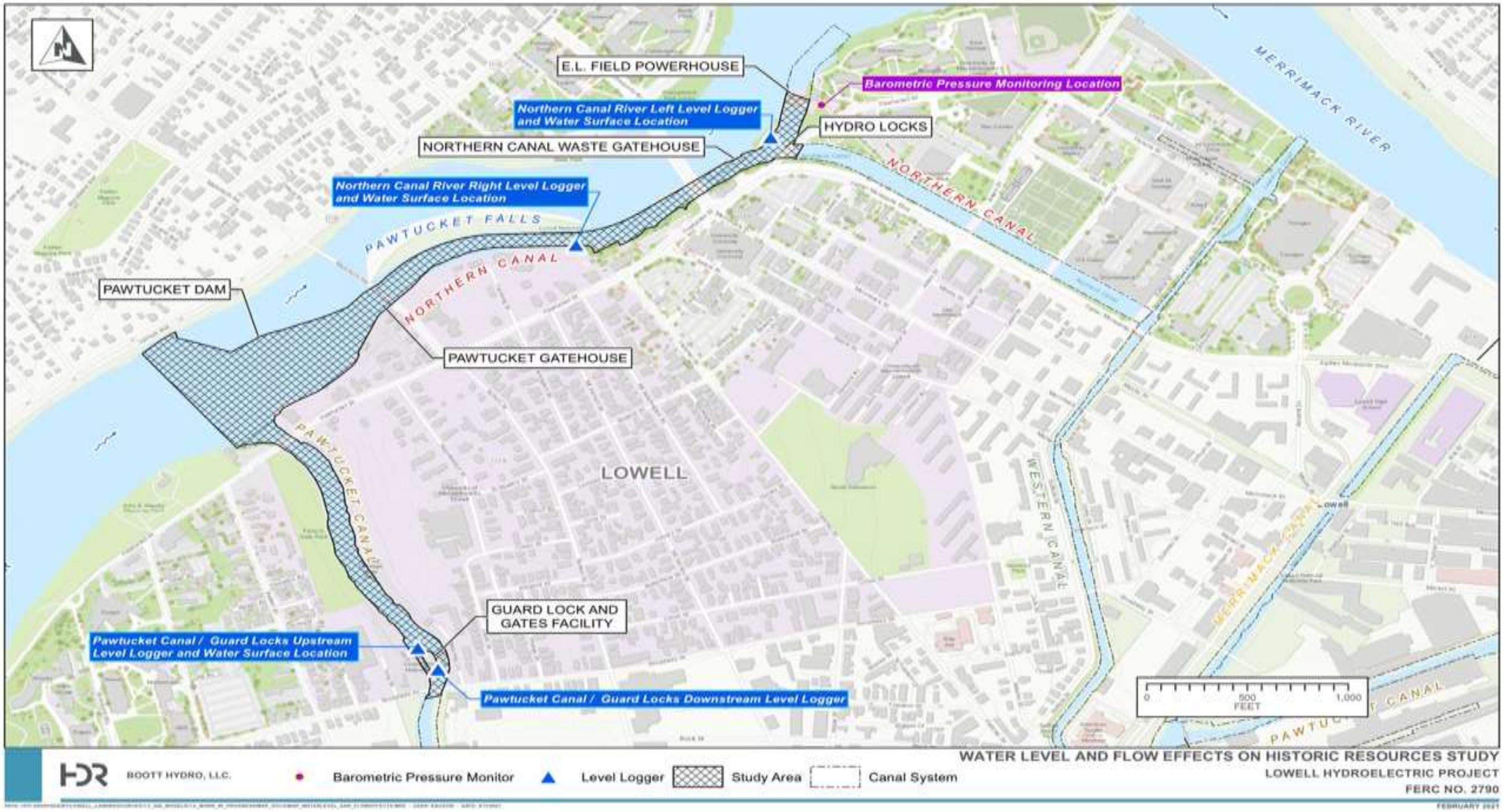
Additionally, each level logger was placed in an inconspicuous location on the channel bottom or tethered with weights to a non-movable object (i.e. rock, handrail, or tree). Each level logger recorded Kilopascal (kPa) pressure and Fahrenheit (°F) water temperature at 15-minute intervals. Pressure was converted to a relative sensor depth using Hoboware Pro™ software by Onset®, and the loggers have a stated operational range of 0 to 30 ft and an accuracy of ±0.03 ft.

At the time of installation, and during each data download event, the vertical distance from the water surface (above each level logger) was measured to a temporary local fixed reference point (“local benchmark”) which was used to correct any relative vertical change in level logger placement after data download events which occurred approximately monthly during the study period. Each local benchmark was then surveyed using an EOS Gold Global Positioning System with Real-Time Kinematic and sub-centimeter accuracy. Accordingly, the collected data was converted to an elevation which represents the elevation of the water surface at each location. This elevational data was then converted to the NGVD 29 using the National Oceanic and Atmospheric Administration’s Vertical Datum Transformation tool (VDatum) to match the existing elevation data in Boott’s Supervisory Control and Data Acquisition System (SCADA).

Level loggers were installed at 4 locations within the study area. Level logger locations are consistent with the areas of interest as identified by the NPS, with exact location within each area of interest determined by channel geometry, hydraulic conditions and field conditions.

A primary and backup level logger was installed at each location and recorded relative water depths at 15-minute intervals over the study period which extended from March 10 to September 23, 2020. Additionally, a single atmospheric logger was deployed within the study area at the E.L. Field Powerhouse to allow for calibration and barometric pressure correction. A total of nine instruments were deployed (eight in-water, and one atmospheric). The level logger locations include one location on the Northern Canal on river left (RL) adjacent to the Emergency Spillway Gate, a second location on the Northern Canal on river right (RR), near the intersection of Fletcher and Pawtucket Streets, and two locations (one upstream and one downstream) on the Pawtucket Canal at the Guard Lock Gate Complex and are depicted in Figure 4-1 below.

Figure 4-1. Water Level and Flow Effects on Historic Resources Study Area



4.4 Project Operations Review

Boott reviewed Project operational data including headpond elevation, forebay elevation, Project operations, and Merrimack River flows. Boott then compared the results of these reviews to the water surface elevations recorded during the study periods, the elevations of historic structures and the existing conditions of those structures to determine the potential effect (if any) to the current conditions and expected conditions of such structures.

4.5 Visual Engineering Assessment of the Great River Wall

Boott conducted a review of prior structural engineering assessments of the Great River Wall, including review of available engineering and architectural drawings, maintenance records, photos and structural modifications. The results of this document review are summarized in Appendix B and filed with this report as Critical Energy Infrastructure Information (CEII).

On October 5-6, 2021, Boott visually assessed the existing conditions of the Great River Wall. The goal of this visit was to observe and photograph the existing condition of the Great River Wall that could be visually observed from the safety of available access points. The results of this document review are summarized in Appendix C and filed with this report as Critical Energy Infrastructure Information (CEII).

4.6 Analysis of Potential Project Related Effects

Boott analyzed the data collected in each of the five sections above to determine if and when Project operation flows into the canal system may have resulted in water levels reaching elevations to inundate wooden structural elements, or if periods of low flows may have caused damage to historic infrastructure.

5 Study Results

5.1 Documentation Review of Existing Conditions

Pursuant to the approved study plan, Boott reviewed several source documents to better understand the elevations of structures potentially effected by fluctuating water levels in the Northern and Upper Pawtucket Canals. The following list includes those documents reviewed[3].

- Proprietors Canal System Book of Facts.

[3] Some documents referenced in this study report and included in this list are considered Critical Energy Infrastructure Information (CEII) by the FERC and are not for public distribution and are also not included in Appendix A of this study report.

- Supporting Technical Information Document – Guard Locks and Gates Facility (NATDAM No. MA 00834) Lowell Hydroelectric Project FERC No. 2790-MA Lowell, Massachusetts. 2015.
- Dam Safety Inspection Report for the Lowell Hydroelectric Project FERC No. 02790-MA.
- U. S. Department of Interior (USDOI) comments on the PAD, comments on SD1, and study requests dated August 14, 2018 regarding Boott Hydropower, LLC, Lowell Hydropower Project (FERC No. 2790-072), Merrimack River, Middlesex County, MA, and Hillsborough County, NH.
- USDOI Request for Information Response February 3, 2021 regarding requested Information in response to Central Rivers Power letter dated 01/20/2021, Lowell Hydropower Project (FERC No. 2790-072), Water Level and Flow Effects on Historic Resources Study.
- Lowell Hydroelectric Project (FERC No. 2790) Exhibit E and F Drawings obtained from the circa 1980 Application for License for Major Project.
- Lowell Heritage State Park Drawings for the Lowell Canal System circa 1983. Department of Environmental Management division of Forests and Parks.
- E.L. Field Powerhouse operational data including but not limited to project generation, project flow, headpond elevations, project inflow, project outflow, fishway operations, etc.
- Historic American Engineering Record, National Park Service, Louis R. Scurci, 1974.
- Pawtucket Gatehouse Facility Ex Condition Photographs, 2020
- Northern Canal – New Lock Gates: Plans, Elevation Details, and Hardware. August 1984.
- Francis Guard Gate Sluice Gatehouse Ex Condition Photographs, 2020
- LNHP, Rehabilitate Northern Canal Waste Gatehouse. 100% Construction Documents June 28, 2018
- LNHP, Rehabilitate Northern Canal Waste Gatehouse. LOWE-225866 Project Specifications Construction Documents. NPS, Northeast Region 100% Submission June 28, 2018
- Project Scoping Report. Task Order #P17PD03094; Contract #P15PC00036; PMIS #225866 Northern Canal Waste Gatehouse. November 13, 2017.
- Rehabilitate Northern Canal Waste Gatehouse. LNHP, Lowell, MA Estimate Class A February 2, 2018.

Boott reviewed the above listed data to identify elevations, conditions, and other relevant information regarding historical structures that may be potentially affected by project operations related to water level fluctuations in the project headpond, Northern Canal and Upper Pawtucket Canal. While many of these documents contain relevant information related to the conditions of relevant historic structures, there are few, if any details on the elevations of these structures in relation to water level fluctuation.

5.2 Canal Water Level Monitoring

As noted above, the objective of this study was to analyze the potential effects of water level fluctuations from project operations in the Northern Canal and the Upper Pawtucket Canal on historic structures with a focus on the Pawtucket Gatehouse, the Northern Canal Waste Gatehouse, the Guard Lock and Gatehouse Complex and the Great Wall.

The level loggers and associated elevation data captured a sufficient range of operational conditions (including spring freshet flows and summer low flows) over the course of the deployment period, to show a typical period of water surface elevation at each of the locations listed above. Additionally, the water surface elevations of the Project headpond and the Project forebay over the available period of record (1995 through 2010) allowed Boott to analyze the potential effects of water level fluctuations on historic structures in and along these canals.

5.2.1 E.L. Field Headpond/Northern Canal Lock

Water surface elevations within the Project headpond at the Northern Canal Lock during the study period (March 10 – September 29, 2020) range from a minimum of 91.76 ft to a maximum of 92.30 ft for a range of 0.54 ft (Figure 5-1).

Figure 5-2 shows the estimated elevations of the top and bottom sill of the Pawtucket Gatehouse Lock Gate relative to the water level of the Project headpond.

Figure 5-1. Project Headpond Water Surface Elevation During 2020 Monitoring Period

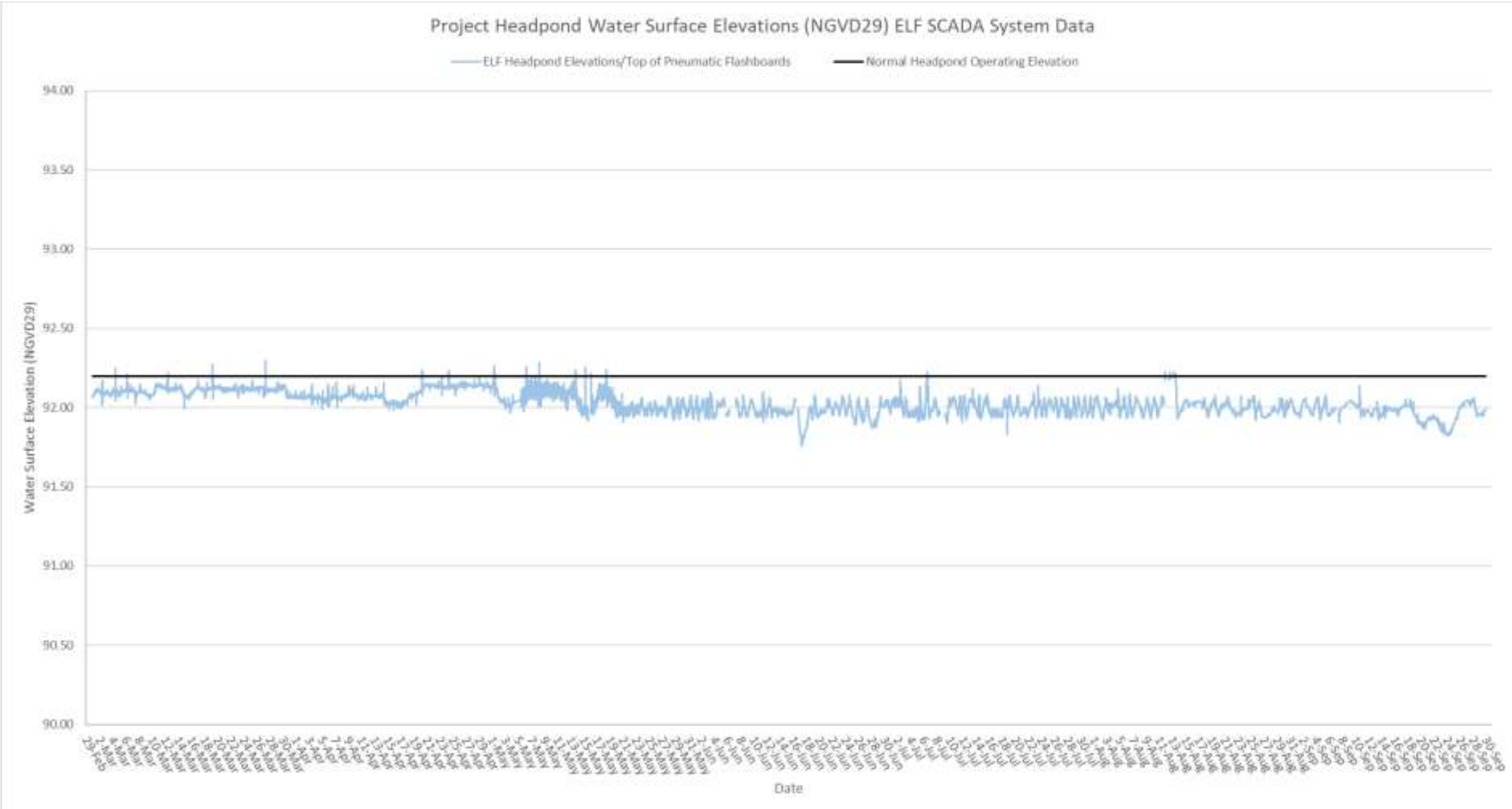
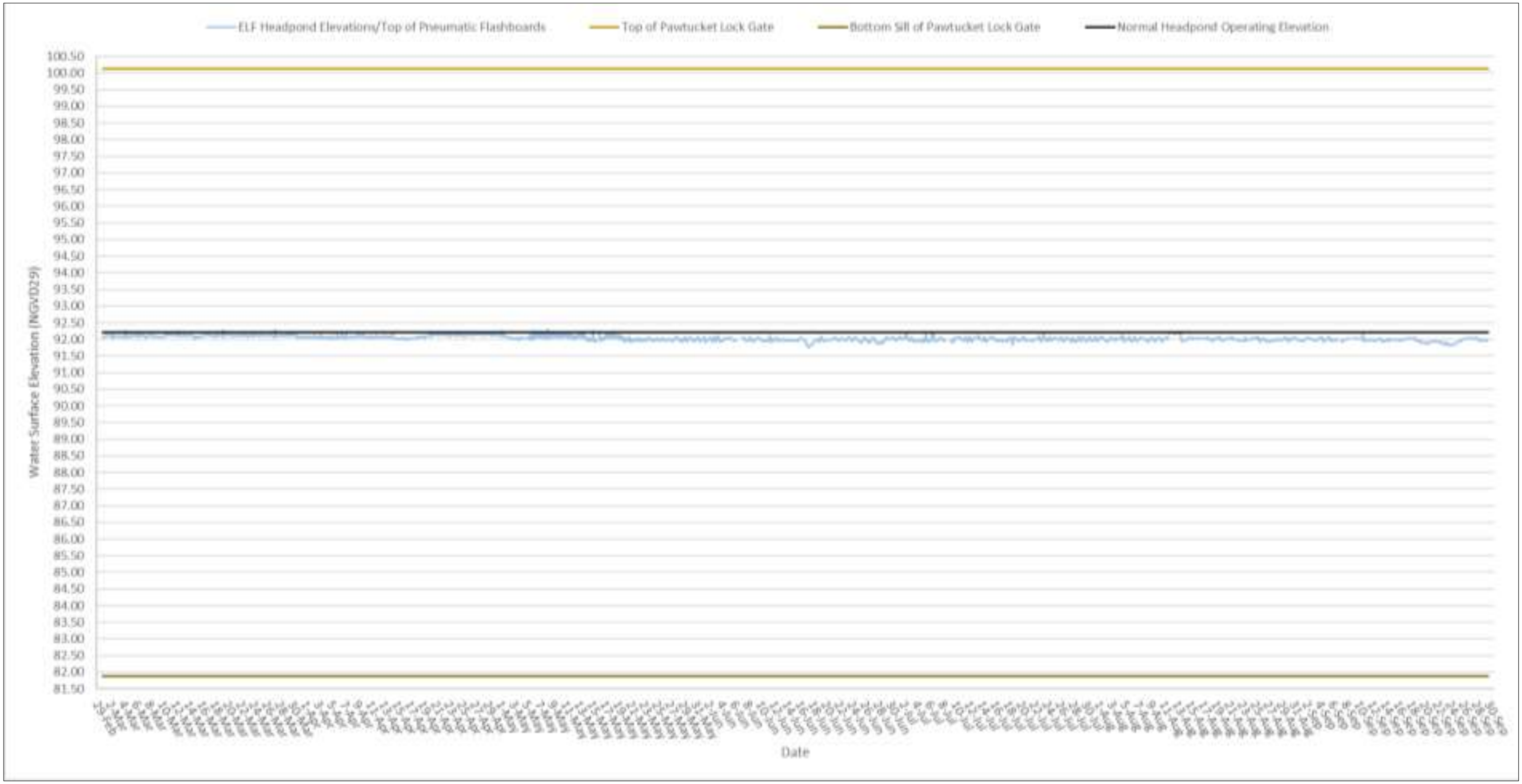


Figure 5-2. Project Headpond Water Surface Elevation During 2020 Monitoring Period Relative to Top and Bottom Sills of the Northern Canal Lock Gate



5.2.2 Northern Canal

Water surface elevations within the Northern Canal collected during the study period ranged from a minimum of 85.30 ft to a maximum of 91.64 ft (Figure 5-3) with a range of 6.34 ft at the Northern Canal River Left (RL) location near the Emergency Surge Gate and from a minimum of 85.71 ft to a maximum of 92.14 ft (Figure 5-4) for a range of 6.43 ft at the Northern Canal River Right (RR) location, near the canal's mid-point between the Pawtucket Gatehouse and the E.L. Field powerhouse.

Based on the level logger data collected in the Northern Canal at the RL location, water surface elevations within the Northern Canal reached elevations greater than 91.5 ft (the normal maximum operating elevation of the Northern Canal) on one occasion during the monitoring period. Beginning on August 11 at approximately 9:45 PM through August 13 at approximately 3:45 p.m. the water surface elevation in the Northern Canal was greater than 91.5 ft reaching a maximum elevation of 91.64 ft (Figure 5-3).

Based on the level logger data collected in the Northern Canal at the RR location, water surface elevations within the Northern Canal reached elevations greater than 91.5 ft (the normal maximum operating elevation of the Northern Canal) on three occasions. On March 19 at approximately 9:00 a.m. the water surface reached a maximum elevation of 91.52 ft for less than 15 minutes. On May 15 at the RR location, the water surface elevation within the Northern Canal rose above 91.5 ft for approximately 10 hours and reached a maximum elevation of 91.62 ft. Beginning on August 11 at approximately 9:45 p.m. through August 13 at approximately 3:45 p.m. the water surface elevation in the Northern Canal at the RR location was greater than 91.5 ft reaching a maximum elevation of 91.64 ft (Figure 5-4).

Figure 5-3. Northern Canal River Left Location - Water Surface Elevation During 2020 Monitoring Period

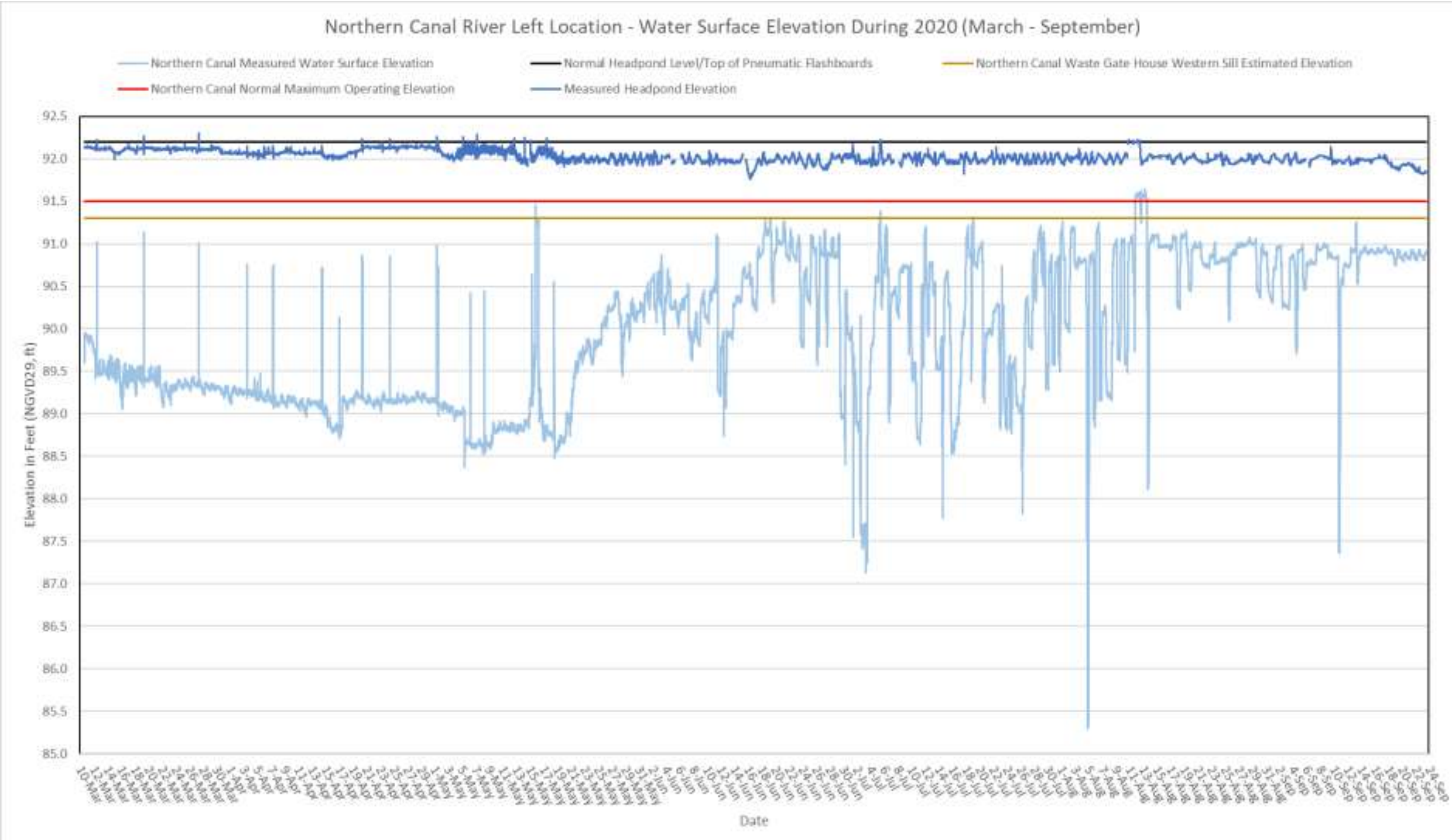
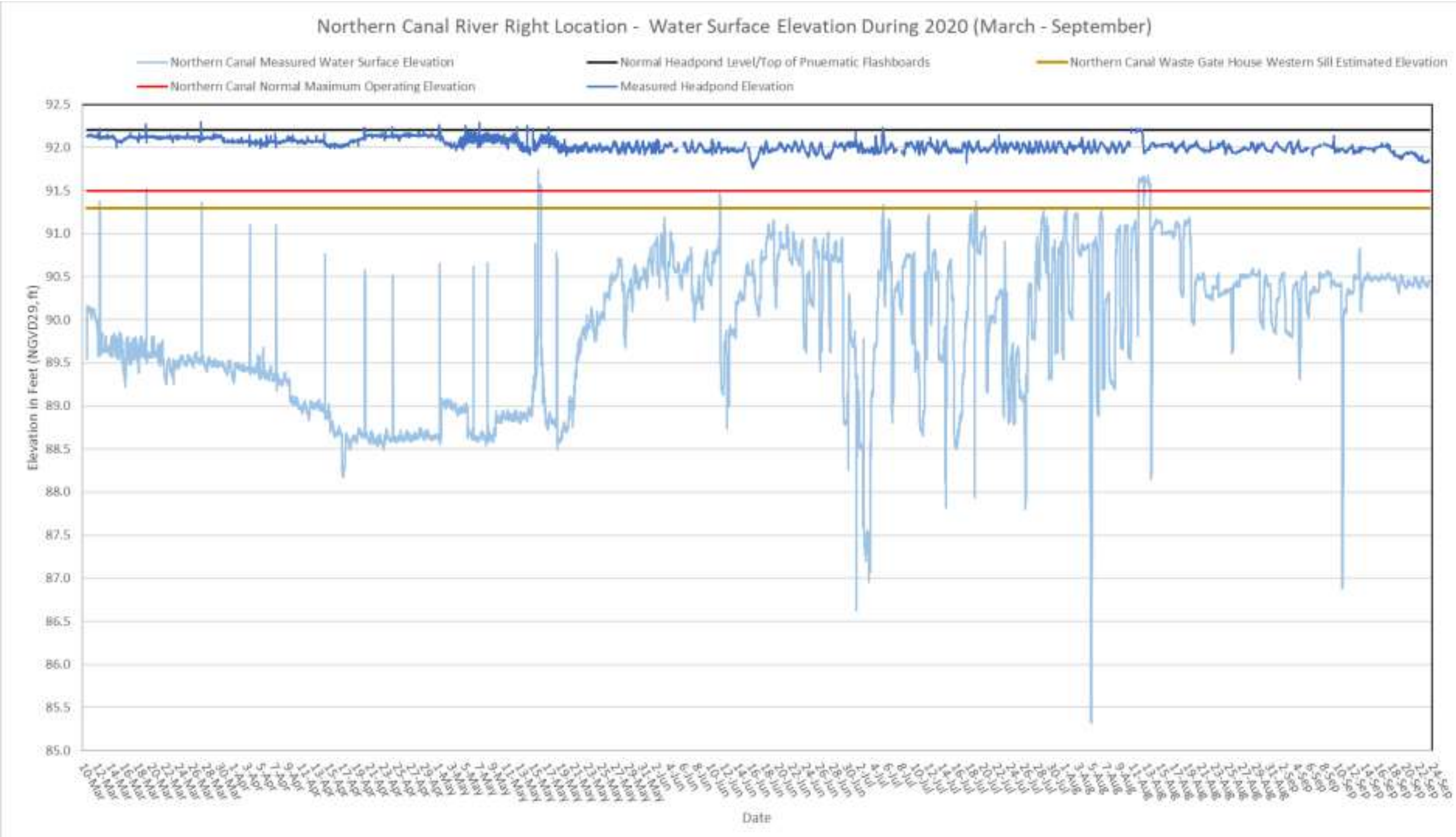


Figure 5-4. Northern Canal River Right Location - Water Surface Elevation During 2020 Monitoring Period. Pawtucket Canal



5.2.3 Upper Pawtucket Canal

Water surface elevations within the Upper Pawtucket Canal during the study period ranged from a minimum of 91.69 ft to a maximum of 92.35 ft (Figure 5-5) for a maximum range of 0.66 ft, and are consistent with the impoundment level data. Within the Lower Pawtucket Canal levels ranged from a minimum of 79.53 ft to a maximum of 86.21 ft (Figure 5-6) for a range of 6.68 ft. Water surface elevation data downstream of the Guard Lock Gate Complex were not collected following the June 12 download event due to loss of the downstream level loggers (Lower Pawtucket Canal). These loggers were not recovered nor replaced.

On one occasion during the study period, the water surface elevation within the Upper Pawtucket Canal reached an elevation greater than 92.2 ft (the normal operating elevation of the Project headpond). This event occurred from March 27 at approximately 11:30 a.m. and lasted for less than 15 minutes, reaching a maximum elevation of 92.29 ft.

The Lower Pawtucket Canal was drawn down approximately 6.5 ft from April 2 through April 7, 2020 to facilitate bridge reconstruction in downtown Lowell, but generally remained between elevations 88.25 ft and 89.47 ft, a range of 1.22 ft during the remaining study period.

Figure 5-5. 2020 Upper Pawtucket Canal Water Surface Elevation (March 10 - September 24)

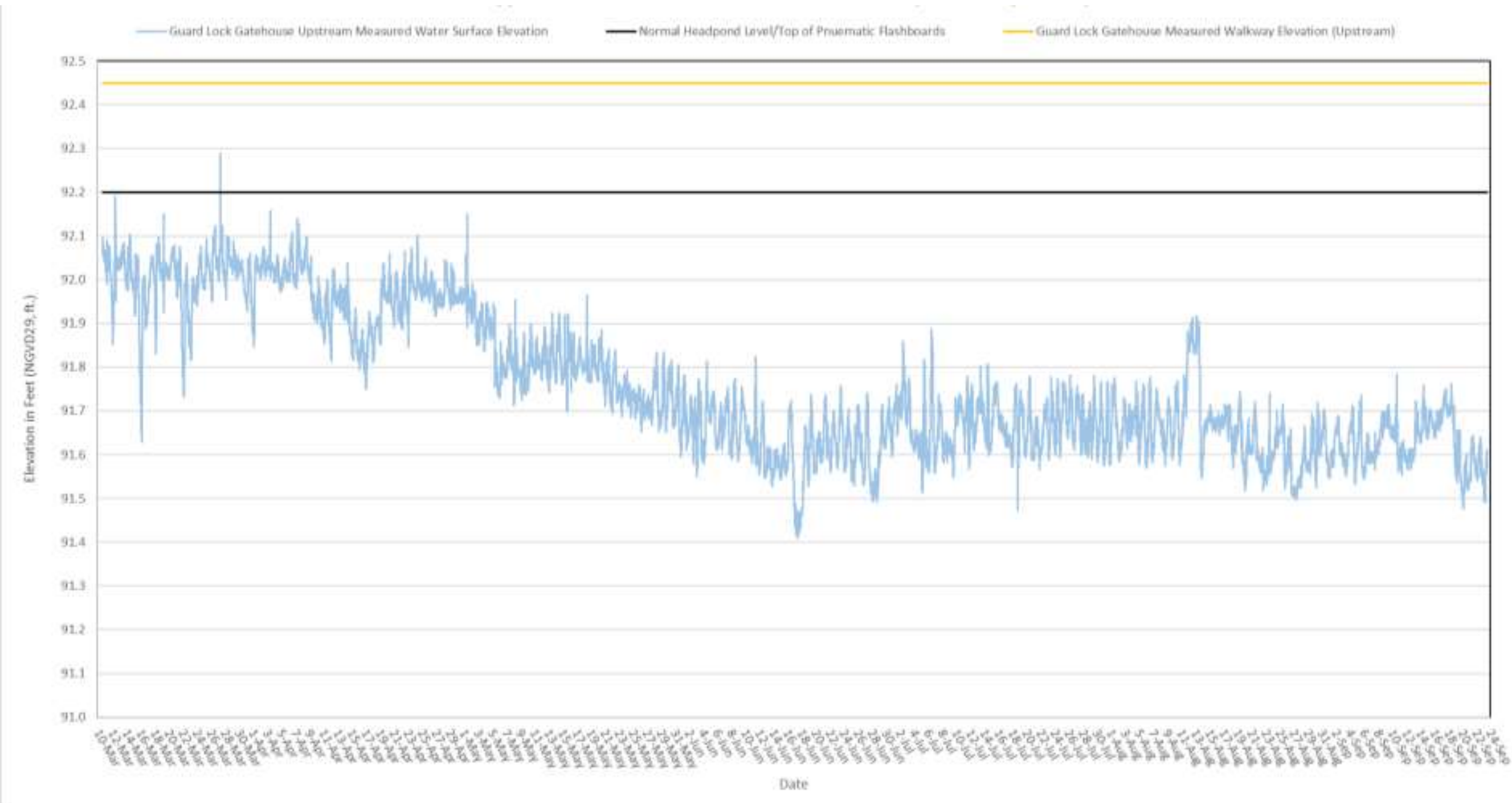
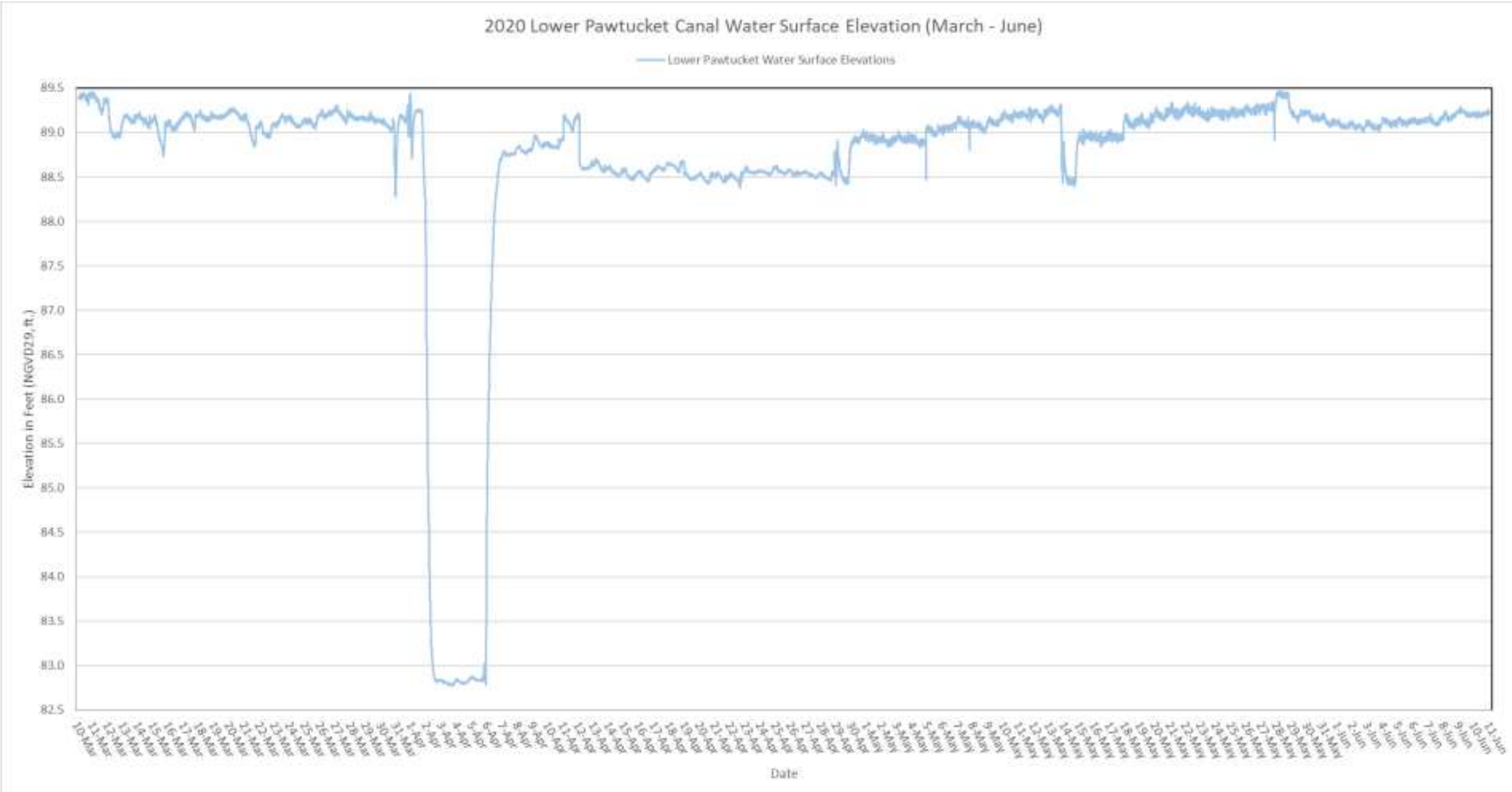


Figure 5-6. 2020 Lower Pawtucket Canal Water Surface Elevation (March 10 – June 11)

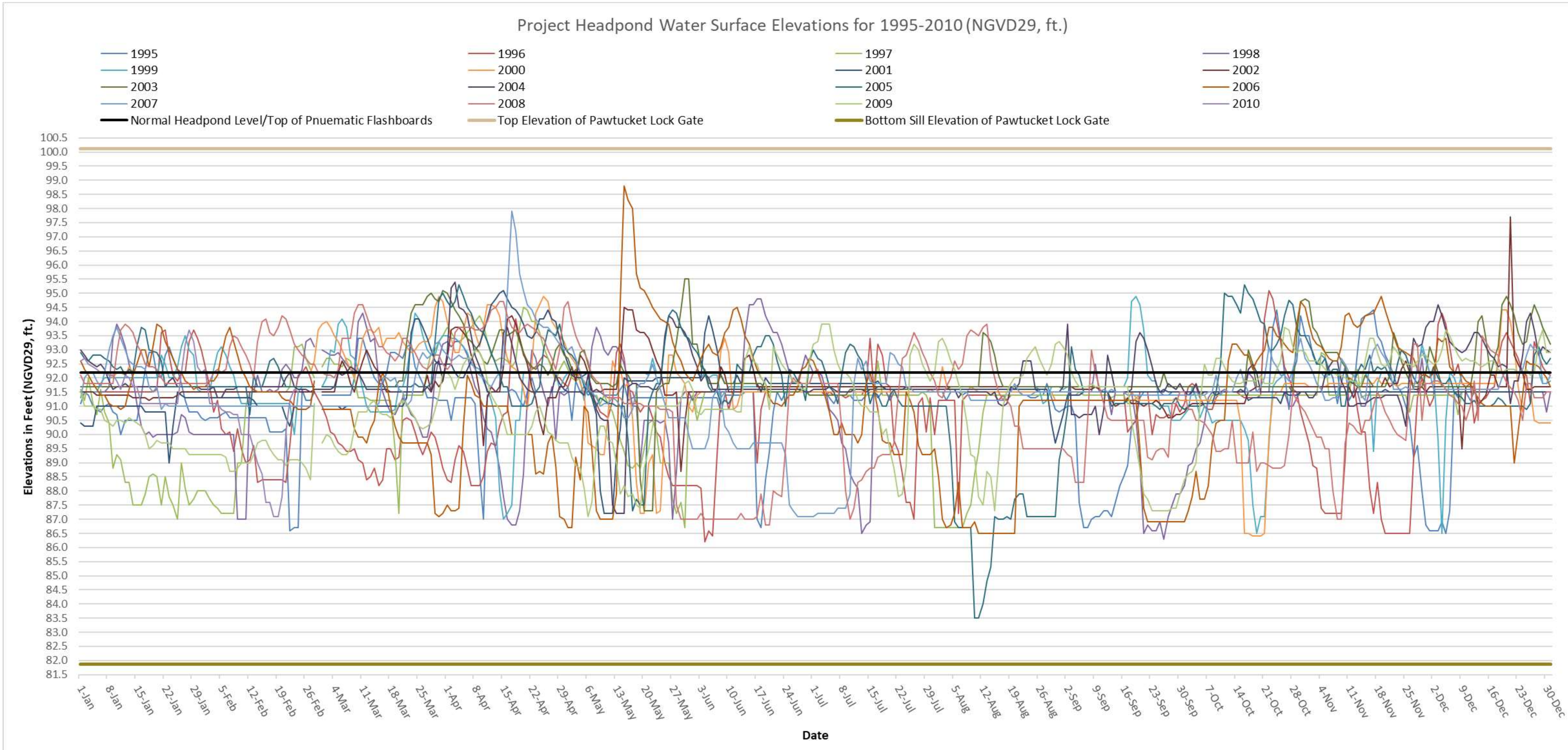


5.3 Project Operations Review

Boott has reviewed the operational data for the Pawtucket Dam headpond elevations and the E.L. Field Powerhouse forebay elevations for the available period of record (January 1995 through December 2010 (Figure 5-7 and Figure 5-8). These data are from the period when 5- foot- high wooden flashboards were deployed on the spillway crest, prior to the construction of the present pneumatic crest gate system. The data demonstrate that with the wooden flashboards, headpond levels were highly variable, due in large part to the Licensee's inability to maintain normal pond level when the flashboards were partially damaged or failed. Repair and replacement of the failed flashboards required a 5-foot drawdown of the project impoundment, typically for 2 days, to enable safe working conditions on the dam crest. In contrast, the pneumatic crest gate system maintains a steady impoundment level by automatically adjusting the height of the crest gate panels in response to increasing flows (Figure 5-1 and Figure 5-2). As flows recede the crest gates are automatically raised, thereby eliminating any need for impoundment drawdowns for flashboard repairs. With the original flashboards in place, headpond elevations were driven by the type of water year (wet, normal, dry) and were much more variable, although typical for a riverine environment. Figure 5-7 shows that during most normal years the headpond is maintained at or near crest elevation for a large portion of the year. Exceptions occur during seasonal spring freshet (mid-March to mid-April), during the fall rainy season (mid-October to early December) and during the occasional anomalous event.

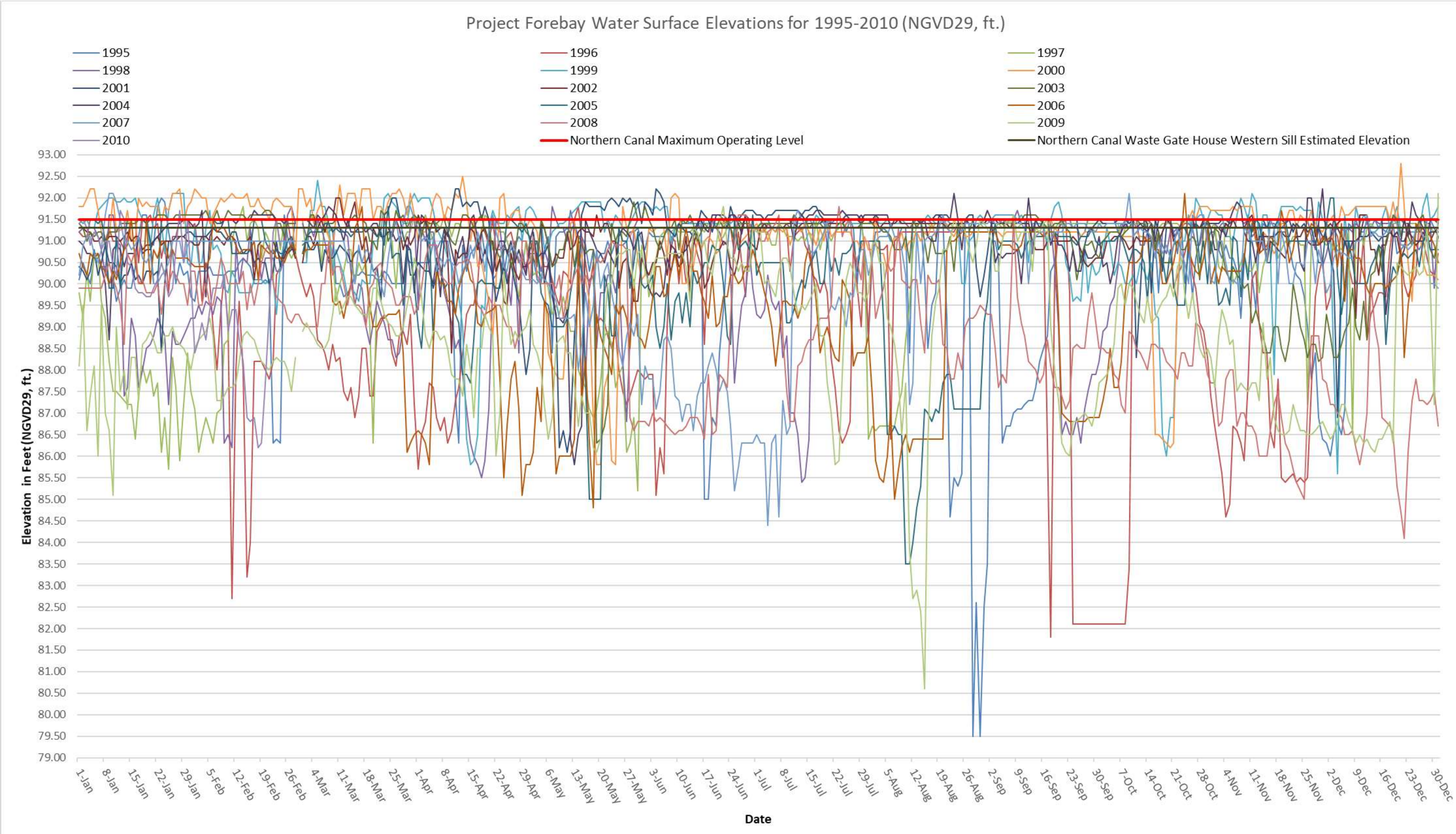
Notable in both the current data set with the crest gate (Figure 5-3 and Figure 5-4) and the historic data set with flashboards (Figure 5-3 and Figure 5-4) is that there is often a large water level differential across the Pawtucket Gatehouse, often reaching 3 or more feet. Normally, this differential would be only 0.7 ft, i.e., 92.2 ft normal pond elevation versus 91.5 ft maximum Northern Canal elevation. However larger differentials may occur, typically due to debris accumulation on the upstream side of the gatehouse, which restricts flow through the headgates (Photo 5-1). Large differentials are most common during the late winter and spring, when increased river flows bring large amounts of river debris down the river. This is a factor which has not been changed by the replacement of the original wooden flashboards with the pneumatic crest gates. Boott has not analyzed the data sufficiently to determine whether there is any difference in differentials between the pre- and post- crest gate data.

Figure 5-7. Merrimack River – Pawtucket Dam Headpond Elevations for Period of Record (1995-2010)[4]



[4] Period of Record Data 1995-2010 was recorded with 5-foot high wooden flash boards in operation and prior to the installation of the automated pneumatic flashboards along the crest of the Pawtucket Dam.

Figure 5-8. Northern Canal E.L. Field Powerhouse Forebay Elevations for Period of Record (1995-2010)



5.4 Visual Assessment of the Great River Wall

The review of prior structural engineering assessments of the Great River Wall and the visual observation are designated as CEII and as such are not available for public distribution.

5.5 Analysis of Potential Project Related Effects

Pursuant to the RSP, Boott analyzed the information obtained from sections 5.1 through 5.4 above, to assess the potential for project related effects to cause adverse impacts to the historical structures along the Northern and Upper Pawtucket Canals. Factors that may have the potential to effect historic resources can vary according to several factors including but not limited to Project operations, the magnitude and duration of natural high and low flow events, river debris and trash accumulation, natural decay, Project related maintenance, and non-Project related maintenance by other entities.

5.5.1 Northern Canal Lock and Pawtucket Gatehouse

The Northern Canal Lock and the Pawtucket Gatehouse (Photo 5-1) is located at the southern abutment of the Pawtucket Dam and controls flow into the Northern Canal. It is principally constructed of dressed masonry with concrete over lintels and contains ten 8-foot-wide by 15-foot-high, motor-operated, timber sliding gates which feed the Northern Canal. Another small intake opening feeds a presently unused wheel, which formerly powered the gate mechanisms through a line shaft. The structure's water passages are nearly 80 ft in length. A small navigation lock is located at the southerly end of the Pawtucket Gatehouse (Photo 5-2) (Boott 2017).

The Project is operated in a run of river mode (ROR) where outflow approximates inflow, generally maintaining the Project headpond at or near elevation 92.2 ft (see Figures 5-1 through 5-4). Under normal operations, Boott operates the Project to prioritize the E.L. Field Powerhouse generating units. When flows exceed the 6,600 cfs combined hydraulic capacity of the E.L. Field generating units, it has been Boott’s practice to divert up to 2,000 cfs to the downtown canal units when they are operable. Flows higher than 8,600 cfs (the combined capacity of the E.L. Field Powerhouse and the canal units) are spilled over the Pawtucket Dam spillway and into the Project’s bypass reach. The pneumatic crest gate system has a control system which maintains a constant upstream water level during increasing flows, by automatically lowering the crest gate panels as the spillway flow increases.

The concrete and masonry gatehouse show normal wear from exposure to the natural river conditions and Project water level fluctuation. Based on a review of existing documentation and consultation with the NPS, Boott did not identify potential Project-related effects on the gatehouse.

Photo 5-1. Northern Canal Lock and Pawtucket Gatehouse.

Photo 5-2. Pawtucket Gatehouse at Northern Canal Gate entrance (prior to 2018 gate damage).

Potential Project-related effects have been documented at the Northern Canal lock structure. The lock structure is controlled by a set of timber miter gates, with one set of gates at the upstream entrance/exit and a second set at the downstream entrance/exit. The gates are subject to routine water level fluctuations (see Figure 5-1 through Figure 5-4) that can deteriorate wooden and metal elements. While the magnitude of fluctuation in the Project's headpond has been significantly reduced by the implementation of the pneumatic crest gates, the gates are subject to routine seasonal high flow events. Portions of the gates are also continuously submerged, which contributes to natural deterioration of wooden and metal elements over time. Photo 5-3 shows the normal water level that is maintained approximately midway on the gate height, and Photo 5-4 shows the deterioration of wood and metal on the removed gate normally below the water surface.

On August 26, 2018, the right (facing downstream) timber gate controlling the upstream entrance/exit to the Northern Canal lock was damaged. The damage to the gate was caused by an unusual back surge of water moving upstream through the Northern Canal, caused by a water level transducer malfunction. Under normal operations, the existing surge gate would be automatically activated upon full shutdown of the E.L. Field units to discharge the resulting back-surge of flow into the bypass reach. In this instance, the surge gate did not open because the malfunctioning transducer at the Pawtucket Gatehouse caused the E.L. Field units to back down rapidly but did not cause the them to trip off-line. As a result, the rapid unit backdown created a water-hammer effect that surged up the Northern Canal and into the miter gates. The gates had been previously chained together at their upper corner (See Photo 5-3), which prevented the gates from opening and releasing the surge as it moved upstream, and thus causing the right gate to break. Boott has recently removed the gate from service, and it is currently under repair.

Other factors which have likely contributed to the deterioration of the miter gates include, but are not limited to, high flows in the Merrimack River and natural deterioration of the submerged portions of the wooden gate structure, neither of which are attributable to Project operations.

Photo 5-3. Damage to the Northern Canal Lock Timber Gate.

Photo 5-4. Photo of wear of submerged portion of the Northern Canal Gate removed for repair.

5.5.2 Northern Canal Waste Gatehouse

The Northern Canal Waste Gatehouse is a single-story, heavy-timber-framed building, built circa 1872 atop the Great River Wall which houses gate operators for four canal release gates (Photo 5-5). Based on consultation with the NPS, Boott identified potential Project-related effects on certain wooden structural elements of the Northern Canal Waste Gatehouse. The wooden sills of the gatehouse have experienced deterioration. Boott reviewed Northern Canal water level data recorded in 2020 to determine if Northern Canal water levels could be a contributing factor to the deterioration of the sill.

Photo 5-5. Northern Canal Waste Gatehouse atop the Northern Canal.

As shown in Figure 5-3 and Figure 5-4, the Northern Canal Waste Gatehouse has wooden sill which overhangs the Northern Canal, with a bottom elevation of approximately 91.3 ft NGVD29. The normal maximum operating elevation of the Northern Canal is 91.5 ft. Figure 5-3 and Figure 5-4 show that the canal water surface elevations for the study period occasionally exceeded the bottom sill elevation, thereby inundating the heavy timber bottom sill on the south side of the structure (Photo 5-6). The Northern sill of the Waste Gatehouse has also deteriorated, due to natural exposure to the nearby river and atmospheric conditions, as well as its proximity to the spillway immediately to the east. It is possible that splashing water from the adjacent spillway may have contributed to the deterioration of the eastern third of the northern sill timber. Repeated inundation and drying of the timber sill can be a contributing factor to deterioration. Other factors, including the age of the wooden timbers, general maintenance, weathering, and atmospheric conditions are also likely to have contributed to the deterioration of the southern sill, and the eastern portion of the northern sill. The age of the sills is not known, i.e., it is not known if the existing sills are the original timbers from the 1872 construction of the gatehouse.

Photo 5-6. Northern Canal Waste Gatehouse underlying timber sill.

5.5.3 Guard Lock and Gates Facility

The Upper Pawtucket Canal branches off the Merrimack River a few hundred feet upstream of the Pawtucket Dam and feeds water into the downtown canal system via the Guard Lock and Gates Facility ("Guard Locks"). The facility consists of the following structures: 1) the Guard Gatehouse which houses 5 sluice gates to convey flow to the Lower Pawtucket Canal; 2) a 24 ft wide granite masonry Lock Canal with two pairs of wooden lock gates; 3) the timber and wood framed Lock House located above the upstream lock gate; 4) the Francis Gatehouse (or Great Gatehouse) timber and wood framed structure over the Lock Canal which houses the 25' high x 25' wide Francis (or Great) Gate. The Guard Gatehouse is separated from the Lock Canal and associated Lock House and Francis Gatehouse by an island with walls of granite, ledge, or concrete (Photo 5-7).

In its consultation comments, the NPS identified potential Project-related effects on the Guard Lock and Gates Facility. Specific issues identified by the NPS included damage to the upstream side of the gatehouse (including the upstream wooden walkway), erosion of the steps leading to the gatehouse, and damage to the entry door on the east side of the Gate House. Boott reviewed the available information regarding the condition of the Guard Locks Facility with respect to the potential impacts identified by the NPS.

Photo 5-7. 1976 - Guard Lock and Gates Facility viewed from upstream. The Guard Gatehouse is on the left and the Lock Canal and Lock House are on the right.

Photo 5-8. 2019 - Guard Lock and Gate Facility.

Water levels in the Pawtucket Canal upstream of the Guard Locks complex are essentially the same as the project impoundment and remained below the normal headpond level of 92.2 ft NGVD29 throughout the study period except for one occasion. On March 27, 2020 between 11:30 a.m. and 12:00 p.m. the water level in the Pawtucket Canal upstream of the Guard Locks reached 92.29 ft. Figure 5-5 shows the water surface elevation during the study period and the estimated elevation of the Guard Gatehouse walkway (**Error! Reference source not found.**).

Water levels in the Upper Pawtucket Canal remained below the walkway at the base of the Guard Lock Gatehouse for the entire study (Figure 5-5 and Photo 5-8). The elevation of the walkway (92.45 ft), the clapboard siding (92.45 ft), and the bottom of the mid-level windows (94.08 ft) are all above the normal water level of the Upper Pawtucket Canal (Figure 5-5). Under normal operating conditions, these features are rarely inundated. However, high flow events that are beyond Boott's control can cause water levels to exceed normal operating conditions and may inundate the walkway, clapboard siding, and mid-level windows. As described above, the pneumatic crest gate control system maintains a constant upstream impoundment elevation under elevated flow conditions by automatically adjusting the height of the crest gate panels. The crest gates would be fully lowered at river flows of approximately 35,000 cfs, above which the impoundment and Upper Pawtucket Canal level would rise uncontrolled. Thus, river flows in excess of 35,000 cfs could cause the Upper Pawtucket Canal to inundate the wooden structural elements of the gatehouse; however, these conditions are outside of the ability of the project to control the impoundment water level and therefore not attributable to Project operations.

While normal Project operating conditions do not appear to be having a significant effect on the wooden structural elements of the gatehouse, the presence of waterborne trash and debris may adversely affect the gatehouse. Trash and debris accumulate upstream from Guard Lock Gatehouse, including large logs and timbers. While the magnitude of fluctuation in the Project headpond has been significantly reduced by the implementation of the pneumatic crest gates (see Figure 5-1), the Pawtucket Canal is subject to routine seasonal high flow events, which are more likely to convey trash and debris from upriver areas. While trash and debris that accumulate upstream from the gatehouse have the potential to damage exterior wooden elements and windows under such high flow conditions, natural high flow events and waterborne trash are not related to Project operations. Boott retains a crane service to remove the trash and debris from in front of the Pawtucket Gatehouse once or twice each year.

Boott notes that the top of the steps (104.87 ft) leading to the lower level door of the Guard Gatehouse and the bottom sill of the lower level door itself (100.34 ft) are significantly above the maximum recorded Project headpond elevation for the recent period of record. According to the historic data for the period of record (1995 – 2010) the maximum elevation of the Project headpond was 98.8 ft in 2006. As such, apparent damage to these structural elements are not related to Project operations. The flood of March 20, 1936 was the only event high enough to inundate the gatehouse stairs, reaching a peak elevation of 107.3 ft at a flow of 173,000 cfs.

As is discussed in the Resources, Ownership, Boundaries, and Land Rights Study Report (Study 10), all of the structures within the Guard Lock and Gates Facility are owned by the Proprietors of Locks and Canals and the Commonwealth of Massachusetts, under the administration of the MADCR. In general, the Proprietors own the substructure of each building while the Commonwealth owns the buildings and fixtures above the foundations. Boott generally has easement rights to operate and maintain the water control equipment within each structure. NPS also retains rights to access and implement improvements such as walkway surfaces, lighting, railings, decking, benches, and landscaping. As owners, Proprietors and the Commonwealth have a right and a duty to maintain properties under their ownership, but they do not have an obligation to enhance or upgrade their properties. Similarly, an easement, such as that issued to Boott and/or NPS, allows the holder to conduct routine maintenance of the property under easement.

6 Conclusions

Wooden structural elements of the historic resources located along the Upper Pawtucket and Northern Canals appear most susceptible to damage from submergence, periodic inundation, and waterborne trash.

While the magnitude of fluctuation in the Project's headpond and the Pawtucket Canal has been significantly reduced by the implementation of the pneumatic crest gates, the Merrimack River is subject to routine seasonal high flow events that are beyond Boott's control.

High flow events can also mobilize waterborne trash and debris that have the potential to damage wooden structural elements; however, neither high flow events nor the presence of waterborne trash and debris in the Merrimack River are attributable to Project operations.

The operation of the Northern Canal has caused periodic inundation of the sill at the Northern Canal Waste Gatehouse. This inundation may be one factor in the continued deterioration of the gatehouse's southern sill. Spray from the canal spillway may also be contributing to deterioration along the eastern end of the northern sill.

While normal Project operations do not appear to be adversely affecting the Pawtucket Gatehouse Lock Structure beyond normal wear, at least one incident appears to have contributed to recorded damage to the upstream miter gate. The canal surge event that occurred in 2018 was caused by the malfunction of a water level transducer. The effect of the resulting surge was exacerbated by the practice of chaining the gates closed. This anomalous incident does not represent normal Project operations, and Boott is repairing the damage to the gate.

7 Variances from FERC-Approved Study Plan

The Water Level and Flow Effects on Historic Resources Study Report was conducted in full accordance with the methods described in the FERC-approved study plan except for the following variances:

- During meetings and consultation with the NPS after the issuance of the SPD, the stakeholders agreed to reduce the focus of this study limiting it to the Upper Pawtucket Canal from the Merrimack River downstream to the Guard Locks, and including a portion of the Project headpond in proximity to the Pawtucket Dam and the Northern Canal from the Pawtucket Dam to the E.L. Field Powerhouse.
- Because of the current COVID-19 pandemic, neither multiple-party site visits nor public meetings were conducted as part of this study. Boott consulted with the NPS to identify previous damage to historic resources within the study area and to collect additional information on the nature and extent of the damage.

8 Germane Consultation and Correspondence

A summary of germane correspondence and consultation related to the Water Level and Flow Effects on Historic Resources Study Report is presented in Table 8-1. Appendix D provides copies of relevant correspondence.

Table 8-1. Germane Consultation and Correspondence

Date	Type	From	To	Subject
May 5, 2019	Letter	Boott	NPS	Consultation on locations for level logger deployment
January 4, 2021	Letter	Boot	NPS	Request for Information for Water Level and Flow Effects on Historic Resources Study
February 3, 2021	Letter	NPS	Boott	Response to Requested Information

9 Literature Cited

Hay. (1991). A History of Hydroelectric Power in New York State. Albany, NY: New York State Museum.

Massachusetts Department of Conservation and Recreation (MADCR). 2014. Lowell/Greater Brook Planning Unit.

_____ 2018. Comments on the Pre-Application Document and Scoping Document. Filed with the Federal Energy Regulatory Commission. https://elibrary.ferc.gov/eLibrary/filedownload?fileid=15002412

National Park Service. (NPS). 1981. Final General management Plan https://www.nps.gov/Lowell/learn/management/upload/1981-LOWE-GMP.pdf [Accessed August 1, 2020].

Appendix A - Documents Reviewed

Appendix B - Engineering Document Review of the Great River Wall (Critical Energy Infrastructure Information)

Appendix C - Visual Engineering Assessment of the Great River Wall (Critical Energy Infrastructure Information)

Appendix D - Germaine Consultation and Correspondence