Relicensing Study 3.3.3

Evaluate Downstream Passage of Juvenile American Shad

Interim Study Report

Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

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EXECUTIVE SUMMARY

In support of relicensing efforts for the Northfield Mountain Pumped Storage and Turners Falls Hydroelectric Projects, juvenile American Shad emigration success through the project area was assessed in 2015 using a combination of radio telemetry, hydroacoustics, and HI-Z turb'n tag methodology. There were multiple study objectives, including: assessing the effects of the Projects on the timing, orientation, routes, migration rates, and survival of juvenile shad; determining the proportion of juvenile shad that pass downstream through the power canal versus over the dam under varied operational conditions, including a range of spill conditions; determining the rate of downstream movement within the impoundment, over the dam and through the bypass reach, or through the power canal; determining survival rates for juveniles spilled over/through dam gates, under varied operation conditions, including up to full spill during the annual fall power canal outage period; determining downstream passage timing, route selection, and rate of movement of juvenile shad through the power canal to Station No. 1, Cabot Station and the Cabot Station bypass; determining the rate of entrainment at the Northfield Mountain Project; determining the survival rate for juvenile shad entrained into Station No.1; and determining the survival rates for juvenile shad entrained at Cabot Station. Kleinschmidt served as the lead consultant for the overall field effort, with Aquacoustics providing support for the hydroacoustic assessment, and Normandeau Associates, Inc. (NAI) conducted the turbine and dam passage survival assessment with HI-Z turb'n tags.

Hydroacoustics were used to assess juvenile shad emigration run timing, duration, and magnitude, as well as entrainment. Three separate split beam sonar systems were deployed at three locations within the project area; one at the Northfield Mountain intake/tailrace, one at the upper portion of the Turners Falls Power Canal (along the Sixth Street Bridge), and one at the Cabot Station intake. The systems were operational and recorded data from August 1 to November 14, 2015. Split beam data were processed with the fish tracking module of Myriax Echoview software (Version 6). After applying an intensity threshold of -56 dB, which corresponded to a total fish length of 30 mm by conversion using Love's (1971) equation, the data were analyzed with an alpha-beta (α,β) tracking algorithm to identify the series of echoes generated by an individual fish as it passed through the acoustic beam. The tracking results were reviewed on an echogram and exported as a database containing time, target strength, 3-D positional information, and direction of travel for each fish detected.

The locations of the transducers at the Northfield Mountain intake area and in the Turners Falls Power Canal did not allow for data reduction to accurately estimate the run timing, duration, or magnitude of juvenile shad outmigration, thus rendering some objectives unattainable as scoped in the Revised Study Plan (RSP). Analysis of the data for these two locations revealed a substantial number of targets in these locations engaging in a milling behavior, rather than simply moving in a downstream direction. This behavior reduces the ability of the split beam system to enumerate individual targets and would lead to overestimates, as targets moving in and out of the beam are subject to being counted multiple times. At Cabot Station, the transducers were able to be placed near the entrance to the penstock where water velocities obligated entrainment resulting in very little milling observed in the data set such that estimates of run timing, duration, and magnitude were achieved and may be representative of the study area overall.

At Cabot Station, eight transducers were deployed to monitor the center bay of each unit plus the outermost bay on each side of the forebay. This configuration allowed for approximately 10% of the Cabot Station intake area to be monitored, with each transducer sampling 50% of the time. The locations of the transducers were such that observed targets were committed to passing through the station. Only data collected during times of generation were processed and expanded proportionally to account for the times and areas not sampled. Entrainment was assumed for those targets that were tracked to an elevation lower than the top of the Cabot penstock at elevation 160.26 feet (mean sea level, NGVD 29).

To verify the fish assemblage represented by the hydroacoustic data, 15 sampling events were performed at the Cabot Station bypass sampler between September 9 and October 28, 2015. Sampling events occurred

in the evening between 16:00-22:00 hrs. Nearly all fish collected were juvenile American Shad, 50 of which were randomly selected and measured for total length per event. These length data collected during sampling events were considered for length ranges of targets detected at Cabot Station and Northfield Mountain.

Review of the split beam sonar data indicated juvenile shad-sized targets were present in the vicinity of Cabot Station throughout the monitoring period spanning August 1 to November 14, 2015. Based on the results of sampling at the Cabot bypass sampler, targets within approximately ±15 mm from mean length of shad collected by month were considered to be American Shad. About 1,660,166 shad-sized targets (62-120 mm in length) were estimated to be entrained at Cabot Station between August 1 and November 14, 2015. The distribution of entrainment by unit was such that almost half (46%) of the overall entrainment was attributable to Unit 6, despite the more frequent operation of Unit 1. The daily volume (cubic feet, ft^3) of water passed through Cabot Station and entrainment estimates had a significant relationship. Based on concurrent observations at the bypass sampler and Cabot Station intake, it was estimated that an average of approximately 43% of juvenile shad exit the canal via the downstream bypass and 57% are subject to entrainment at Cabot Station. Diel movement was investigated at the Cabot Station intake and into and through the Turners Falls power canal using hydroacoustics and radio telemetry methods, respectively. Shad size targets were observed to be entrained during each hour of the day at Cabot station but were most prevalent during the afternoon and evening hours, with a peak at 20:00, when pump operations are not likely to occur at NMPS (~00:00 – 06:00). Approximately 75% of the shad movement, as determined by entrainment rate at Cabot Station, generally occurred during period of the day in which NMPS is idle or discharging, representing a period in which there is no risk of entrainment. Radio telemetry data supported this diel movement trend with data showing that tagged juvenile shad emigrated in the evenings generally before 23:00.

Radio telemetry techniques were used to evaluate route selection of emigrating juvenile shad as they passed through the Northfield Mountain and Turners Falls Projects. A Lotek NanoTag Series Model NTQ–1 was externally affixed to 218 juvenile shad. Fifty (50) juvenile shad were placed into a 90-gallon tank and tagged with mock tags that consisted of tin BB weights attached to a dry fly hook to serve as a control group to examine tagging effects and tag retention. The control experiment revealed significant mortality, tag loss and irregular swimming behavior of tagged shad. These observations leave the reliability of the study results in question. Because the study results are questionable, FirstLight was targeting to complete a supplemental juvenile shad radio telemetry study in October/November 2016 and emailed stakeholders a proposed study plan on September 19, 2016. The plan cited adjustments to the methods of collecting, holding and tagging of juvenile shad and the proposed release locations to reduce the level of mortality experienced in 2015 and yield additional data for analysis. A stakeholder meeting was held at the Northfield Visitors Center on September 20, 2016 to discuss, among other issues, the juvenile shad study plan. FirstLight indicated at the meeting that it had some reservations conducting the study due to low flow conditions. In the spring/summer of 2016, the northeast experienced a severe, prolonged drought and river flows on the Connecticut River were extremely low. In the end, on September 29, 2016, FirstLight notified stakeholders that it would not conduct the study because low flows would prevent key components of the study, such as route selection, from being completed and it would work with stakeholders to discuss next steps.

For the work conducted in 2015, groups of 20 tagged fish were released with 30 to 50 untagged fish to promote schooling behavior. Tagged shad were released at two sites in the Turners Falls Impoundment (TFI). Six release events occurred 1.5 miles upstream of the Northfield Mountain Project intake/tailrace, and 3 release events occurred in the lower impoundment, about 1.25 miles upstream of the Turners Falls Dam (TFD). All juvenile shad were tagged and released between October 12 and October 20, 2015.

Juvenile shad were monitored at 13 locations within the study area. The radio monitoring systems were outfitted with either an Orion receiver, a Lotek SRX 400 receiver, or a Lotek SRX 800 receiver, each paired with a combination of 3-element yagi antennas and/or dropper antennas. Data were downloaded from each radio receiver approximately once a week from September 28 to December 4, 2015 (date range inclusive of required American Eel monitoring period). A proprietary probabilistic method for removing false positives was developed and applied to the radio telemetry dataset. Data were then entered into a dedicated Microsoft Access database for analysis. A three-dimensional plot was created and analyzed for each juvenile shad detected in order to visually interpret route selection through the study area. The amount of time that each fish spent within the reach was calculated by using the time from release and determining the last known detection at any given fixed telemetry station. Distance from the release location to the last detection at the last known fixed telemetry station within the reach was determined in river miles (RM) and rate of travel was then calculated using distance per hour (RM/h).

A total of 183 juvenile American shad were released either 1.5 miles upstream of the Northfield Mountain intake/tailrace or 1.25 miles upstream of the TFD. A large proportion of tagged fish (n=70, 38% of releases) were never detected at any of the fixed telemetry stations. A similar proportion of tagged juvenile shad (n=71, 39% of releases) remained in the TFI and were never detected at or downstream of the TFD and Gatehouse. A total of 129 tagged juvenile Shad were released upstream of the NMPS intake/tailrace area. Of those 77 Shad (60% of release) were detected at Shearer Farms fixed telemetry monitoring station (T1 and T2) located approximately 1.2 river miles downstream of the release point and approximately 0.5 miles upstream of the NMPS intake/tailrace. These fish represent the cohort of emigrating fish that entered the NMPS area. Thirty two of these fish emigrated past the NMPS intake/tailrace area and continued downstream approximately 0.66 miles downstream of the NMPS intake/tailrace where they were detected at that Gill Banks monitoring station (T5 and T6) for a passage rate of 41.6 % through this reach of the TFI. Of the fish that entered this reach 72.7% were either detected in the NMPS intake/tailrace area, the upper reservoir or downstream of the NMPS intake/tailrace; leaving 27.3% undetected. Three fish were entrained and detected in the Upper Reservoir of Northfield Mountain, suggesting an entrainment rate of 3.9%. Twenty-one (21) additional fish were last detected at the Northfield Mountain intake/tailrace and were never detected again at any of the telemetry receiver stations. Of those 21 fish, 14 were last detected at the Northfield Mountain intake/tailrace during pumping operations. Only two juvenile shad (1% of releases) passed over the TFD and 16 (9% of releases) passed through to the power canal. The remainder of juvenile shad were either last detected at the Northfield Mountain intake/tailrace receiver station (n=21, 11% of releases) or the Northfield Mountain Upper Reservoir station (n=3, 2% of releases). Passage at the Turners Falls Project generally occurred during night hours, between 21:00 and 23:00.

Juvenile shad (n=113, 61.7% of releases) detected at the impoundment receiver stations exhibited a mean rate of downstream movement of 0.31 RM/h. Two fish passed over the TFD, one of which continued through the bypass reach to the Station No.1 tailrace at a rate of 1.45 RM/h. Three fish were detected as having passed the project through Cabot Station and were subsequently detected in the Cabot Station tailrace. Based on these fish, the mean rate of movement through the canal was 0.03 RM/h.

A separate group of 17 tagged juvenile shad were released into the Turners Falls Power Canal the evening before the annual drawdown on October 5, 2015. Subsequent to the release, mobile tracking was conducted along the entire length of the power canal in an attempt to relocate the tagged fish and determine escape routes. Mobile tracking efforts were initiated at approximately 13:10 on October 5 and seven of the fish released were detected in the canal. Five fish were detected in the area of release; two at the upper canal release site and three at the lower canal release site. One fish released in the upper canal was detected at the Station No. 1 forebay, although passage was not confirmed as Station No. 1 was not operating. Similarly, one fish released in the lower canal was detected in the vicinity of the Cabot Station forebay; however, Cabot Station was not operating at the time of detection and this individual was not detected at any station downstream of Cabot Station.

HI-Z Turb’N Tag techniques were used to assess survival and injury of juvenile shad passing through Cabot Station (Unit 2), Station No. 1 (Units 1 and 2/3), and Bascule Gates 1 and 4 at three discharge rates (1,500 cfs, 2,500 cfs and 5,000 cfs). Normandeau prepared a report under separate cover that detailed the methods and results of the dam and turbine passage survival studies. Due to high mortality of control fish, Normandeau reported that only direct 1-hour survival estimates were reliable; longer-term survival estimates were not.

The 1-hour direct survival rate for juvenile shad passing the TFD via Bascule Gate 1 ranged from 47.7% to 75.6%, with an overall survival rate of 63% for all conditions (1,500 cfs, 2,500 cfs, and 5,000 cfs) evaluated (NAI, 2016a). For Bascule Gate 4, 1-hour direct survival ranged from 59% to 73.6% with an overall mean of 64.8% survival for all conditions assessed (NAI, 2016a). For both gates, a greater percentage of fish were recaptured alive during the 5,000 cfs test condition. The injury rates on the recaptured juvenile shad suggested that passage conditions are more favorable for fish passing the dam via Bascule Gate 1 as compared to Bascule Gate 4.

The 95.0% survival (1-hour) for juvenile shad passed through the large Francis turbine at Cabot Station Unit 2 was near the median value of 94.7% for juvenile herring and shad obtained for 19 studies conducted at other hydroelectric projects (NAI, 2016a). The survival rates for the smaller Francis units at Station No. 1 (67.8 and 76.6%) were lower than survival rates at Cabot Station. The Francis units at Station No. 1 had the smallest runner diameter (39-55 inches) and the highest rotation rates (200 and 257 rpm) of the turbines tested, which likely contributed to the lower survival rates at Station No. 1 (NAI, 2016a).

In terms of survival, it appears that fish traveling the length of the power canal to Cabot Station have a greater likelihood of survival relative to fish that pass via the bascule gates at the Turners Falls Dam. The overall 1-hour direct survival rate for juvenile shad passing the Turners Falls Dam via the bascule gates was about 64% as compared to the 95% survival of those fish that pass through the turbines at Cabot Station. Passage from the power canal through Station No. 1 also appears to be a safer option for fish as opposed to passage via the Turners Falls Dam.

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cfs	cubic feet per second
cm	centimeter
CPUE	catch per unit of effort
CRASC	Connecticut River Atlantic Salmon Commission
°C	degrees Celsius
dB	decibel
DO	dissolved oxygen
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Hydro Generating Company
fps	foot/feet per second
ft	foot/feet
ft^2	foot/feet squared
ft^3	feet cubed or cubic feet
GPT	General Purpose Transceiver
g	gram
h	hour
ILP	Integrated Licensing Process
kHz	kilohertz
km	kilometer
MADFW	Massachusetts Division of Fish and Wildlife
mg/L	milligrams per liter
mm	millimeter
msl	mean sea level
MHz	megahertz
MW	megawatts
µs/cm	microsiemens per centimeter
ms	millisecond
NMFS	National Marine Fisheries Service
NAI	Normandeau Associates, Inc.
No.	number
PAD	Pre-Application Document
PSP	Proposed Study Plan
QAQC	quality assurance & quality control
RSP	Revised Study Plan
RM	river mile
RM/h	river mile per hour
rpm	rotations per minute
SD1	Scoping Document 1
SD2	Scoping Document 2
SE	standard error
SPDL	Study Plan Determination Letter
Tb	terabyte
TFD	Turners Falls Dam
TFI	Turners Falls Impoundment
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USR	Updated Study Report
VY	Vermont Yankee Nuclear Power Plant
W	Watts

1 INTRODUCTION

FirstLight Hydro Generating Company (FirstLight) is the licensee of the Northfield Mountain Pumped Storage Project (FERC No. 2485) and the Turners Falls Hydroelectric Project (FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the Northfield Mountain and Turners Falls Projects using the FERC's Integrated Licensing Process (ILP). The current licenses for Northfield Mountain and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018.

As part of the ILP, FERC conducted a public scoping process during which various resource issues were identified. On October 31, 2012, FirstLight filed its Pre-Application Document (PAD) and Notice of Intent with the FERC. The PAD included FirstLight's preliminary list of proposed studies. On December 21, 2012, FERC issued Scoping Document 1 (SD1) and preliminarily identified resource issues and concerns. On January 30 and 31, 2013, FERC held scoping meetings for the two Projects. FERC issued Scoping Document 2 (SD2) on April 15, 2013.

FirstLight filed its Proposed Study Plan (PSP) on April 15, 2013 and, per the Commission regulations, held a PSP meeting at the Northfield Visitors Center on May 14, 2013. Thereafter, FirstLight held ten resource-specific study plan meetings to allow for more detailed discussions on each PSP and on studies not being proposed. On June 28, 2013, FirstLight filed with the Commission an Updated PSP to reflect further changes to the PSP based on comments received at the meetings. On or before July 15, 2013, stakeholders filed written comments on the Updated PSP. FirstLight filed a Revised Study Plan (RSP) on August 14, 2013 with FERC addressing stakeholder comments.

On August 27, 2013, Entergy Corp. announced that the Vermont Yankee Nuclear Power Plant (VY), located on the downstream end of the Vernon Impoundment on the Connecticut River and upstream of the two Projects, will be closing no later than December 29, 2014. With the closure of VY, certain environmental baseline conditions will change during the relicensing study period. On September 13, 2013, FERC issued its first Study Plan Determination Letter (SPDL) in which many of the studies were approved or approved with FERC modification. However, due to the impending closure of VY, FERC did not act on 19 proposed or requested studies pertaining to aquatic resources. The SPDL for these 19 studies was deferred until after FERC held a technical meeting with stakeholders on November 25, 2013 regarding any necessary adjustments to the proposed and requested study designs and/or schedules due to the impending VY closure. FERC issued its second SPDL on the remaining 19 studies on February 21, 2014, approving Study No. 3.3.3 *Evaluate Downstream Passage of Juvenile American Shad* with certain modifications. FERC's recommended modifications to Study No. 3.3.3 are summarized as follows:

- Include results of telemetry array testing and calibration in the study report;
- Implement radio-telemetry tracking at Northfield Mountain upper reservoir; and
- Consult with the United States Fish and Wildlife Service (USFWS), Massachusetts Division of Fish and Wildlife (MADFW), and National Marine Fisheries Service (NMFS) to establish the typical operating condition of each test turbine evaluated during the juvenile shad outmigration season. In addition, FERC required FirstLight to make recommendations regarding how these operating conditions would be incorporated into the study and file them for FERC approval.

On November 4, 2014, FirstLight submitted a RSP for the acoustic evaluation of juvenile American Shad passage and entrainment to stakeholders and a meeting was subsequently held at the Northfield Visitors Center on November 17, 2014[1] to discuss the plan. Although no substantial changes to the RSP were required following the November 17th meeting, the Updated Study Report (USR) filed with FERC in

[1] Meeting minutes were filed with FERC on December 22, 2014.

September 2015 described several unanticipated, but necessary variances from the RSP. Brief summaries of the variances are as follows:

- Hatchery-raised juvenile shad were deemed unsuitable for use in behavioral studies (i.e., radio telemetry studies) as they did not appear to behave similar to wild fish[2]. In addition, the availability of hatchery fish for use in the survival portion of the study was not adequate to meet required sample sizes; therefore, wild fish were also used for the turbine and dam passage survival studies.
- Tracking of juvenile shad was accomplished utilizing the smallest transmitters that were available at the time, the Lotek NanoTag Series Model NTQ-1 (5 mm in width, 10 mm in length, 3 mm in depth, 0.26 g in air, and tag life of 10 days at 2-second burst rate).
- Additional telemetry receivers were installed at the Gatehouse and Cabot Station tailrace to increase monitoring throughout the Project area.
- Due to the configuration and operation of Station No. 1, the turbine passage survival assessment of a smaller unit at Station No. 1 was performed with both Units 2 and 3 running simultaneously, rather than Unit 2 alone.
- Due to safety concerns and review of historical operating records, dam passage survival was assessed at Bascule Gates 1 and 4 only.

1.1 Background Information

American Shad have had access to spawning and rearing habitat upstream of Turners Falls Dam (TFD) since passage was provided via fishways in 1980. Juvenile American Shad require downstream passage to complete their lifecycle and promote recruitment to the basin. Successful spawning and juvenile production, as well as effective downstream passage, are necessary to help achieve shad management restoration goals for the Connecticut River.

Downstream juvenile clupeid passage studies were conducted at Turners Falls in the fall of 1991 and 1992 (Harza & RMC 1992; 1993) to determine the percentage of juvenile shad and Blueback Herring that passed downstream via the bypass log sluice (or Cabot Station bypass) and the Cabot Station turbines. An estimated 54% (average bypass rate, weighted by estimated number bypassed) of the juvenile American Shad approaching Cabot Station were bypassed via the log sluice in 1991, prior to installation of a special broad-crested weir at the log sluice in 1992.

A broad-crested weir with an elliptical floor has been installed during the downstream fish passage season since 1992 to enhance fish passage. The broad-crested weir was designed to slow the acceleration in water velocity that typically occurs at sharp-crested weirs, and to narrow and deepen the entrance to the bypass, while maintaining the same discharge capacity. Following installation of the weir, an estimated 87% of juvenile shad passed through the log sluice in 1992. A follow-up study during fall 1993 determined that 94.4% of juvenile clupeids passed downstream via the log sluice after it was equipped with artificial above-water lighting (RMC 1994). The 1993 study was the last juvenile shad study conducted at the site prior to the present evaluation.

At NMPS, Northeast Utilities conducted entrainment field sampling studies in 1990 with a variety of methodologies including: electrofishing, haul seining, gills nets, otter trawl, frame trawl and hydroacoustics. The studies estimated entrainment at NMPS and demonstrated the effectiveness of various field sampling methods for collecting juvenile shad in the areas of Northfield Mountain Pumped Storage (NMPS) Project intake and the Turners Falls Impoundment (Harza et al. 1991). Electrofishing and haul seining were determined to be the most effective methods of collecting juvenile shad, with a total of 81 and 51 juvenile

[2] Feasibility testing was conducted by Normandeau Associates, Inc in 2014, which showed that the hatchery juvenile shad did not behave like wild stock juvenile shad.

shad collected, respectively (Harza et al. 1991). Electrofishing sampling resulted in the collection of 19 species, including shad, and only 8 species were collected using a haul seine (Harza et al. 1991). Gill nets were found to be size selective, collecting few American Shad and only those greater than 100 mm in total length. Trawl methods failed to collect any fish (Harza et al. 1991).

Hydroacoustic sampling at the Northfield Mountain Pumped Storage Project was conducted using two single beam transducers to monitor the intake area. Echograms illustrated how fish behavior was effected by station operations (Harza et al. 1991). Fishes were observed moving away from, or milling around the NMPS intake area during generation, with some milling occurring during pumping but the majority of fish moved toward the intake (Harza et al. 1991). These fishes were assumed to be entrained. Estimated entrainment rates of these fishes varied from 34 to 346 fishes/hour and 700-1,400 fish per pump cycle (Harza et al. 1991). A Spearman rank test suggested there was no correlation between entrainment rates and pump volume (Harza et al. 1991).

Field efforts at the NMPS Project in 1991 examined entrainment rates, and spatial and temporal distribution of juvenile American Shad. Entrainment was evaluated using simultaneous hydroacoustic sampling in the tailrace intake tunnel, and a frame trawl net sampling the upper reservoir intake/discharge tunnel (Harza 1992). Two hydroacoustic transducers were mounted on the intake racks oriented into the tunnel. A third top mounted transducer was added later in the sampling period. Hydroacoustic data were disregarded due to high noise level within the tunnel causing a high probability of missed and false targets (Harza 1992). Since these hydroacoustic data were rejected, data collected from the upper reservoir was expanded to estimate the rate of American Shad entrained. A 8’x8’x30’ framed trawl net was suspended at various elevations in front of the upper reservoir intake during pump cycles to sample entrained fish. Calculations estimated 16,000 American Shad were entrained within the study period from August 25 to October 20, 1991. Of these fish, 32% displayed injuries from turbine strikes (Harza 1992).

Studies at the NMPS Project continued in 1992. Juvenile shad and ichthyplankton were sampled to determine the spatial and temporal distribution of shad in relation to the NMPS intake area and the Turners Falls Impoundment (LMS 1993). No significant difference in ichthyoplankton densities were found between stations upstream, downstream, or in front of the NMPS intake area (LMS 1993). A significant difference in densities from day to night was only evident early in the season (June 30- July 1). Peak ichthyoplankton densities were collected on June 18, 1992. The peak catch per unit of effort (CPUE) for juvenile shad occurred on September 8, 1992. Electrofishing samples throughout the Turners Falls Impoundment did reveal a significantly greater CPUE upstream of the NMPS intake area (LMS 1993).

Fish entrainment was again evaluated in 1992, using a 5’ x 34’ framed net set in front of the tunnel opening in the upper reservoir (LMS 1993). The net sampled between 6.46% and 13.92% of the pumping cycle flow. During the 80.19 hours and 8,204,756 m^3 of water sampled, 331 juvenile shad were collected during pumping cycles from August to late October. An estimate of 37,260 juvenile shad were entrained during the late summer to fall migration season (LMS 1993).

1.2 Study Goal and Objectives

The goal of this study is to assess the effects of Project operations on juvenile shad emigration success. The specific objectives are as follows:

1. Assess the effects of the Projects on the timing, orientation, routes, migration rates, and survival of juvenile shad;
2. Determine the proportion of juvenile shad that pass downstream through the power canal versus over the dam under varied operational conditions, including a range of spill conditions;
3. Determine the rate of downstream movement within the impoundment, over the dam and through the bypass reach, or through the power canal;

4. Determine survival rates for juveniles spilled over/through dam gates, under varied operation conditions, including up to full spill during the annual fall power canal outage period;
5. Determine downstream passage timing, route selection, and rate of movement of juvenile shad through the power canal to Station No. 1, Cabot Station and the Cabot Station bypass;
6. Determine the rate of entrainment at the Northfield Mountain Project;
7. Determine the survival rate for juvenile shad entrained into Station No.1; and
8. Determine the survival rates for juvenile shad entrained at Cabot Station.

Objectives 4, 7, and 8 (survival rates for juvenile shad spilled over the dam (e.g., through the Bascule gates) or entrained through the turbines at Station No. 1 or Cabot Station) were assessed by Normandeau Associates Inc. (NAI) using HI-Z Turb'N tags and mark-recapture methods during October 2015. A report (NAI, 2016a) was prepared under separate cover that details the study methods and results; a copy is included in Appendix B herein.

2 STUDY AREA AND SURVEY SITE SELECTION

The study area includes a 10.2 mile reach of the Connecticut River extending from river mile (RM) 128.7 (above Long Island Sound) in the town of Northfield, MA, approximately 1.5 miles upstream of the NMPS intake/tailrace (RM 127.5), downstream to RM 118.5 in the town of Montague, MA (Figure 2-1). The Turners Falls Dam (TFD) is located at approximately RM 122 in the towns of Gill and Montague, MA. The Turners Falls Impoundment (TFI), created by the TFD (which also serves as the lower reservoir for the Northfield Mountain Project), is approximately 20 miles long, extending upstream through the Connecticut River valley to the base of Vernon Dam, located in Vernon, VT (RM 142).

The Turners Falls Project consists of: a) two individual concrete gravity dams separated by an island; b) a gatehouse controlling flow to the power canal; c) the power canal and a short branch canal; d) two hydroelectric powerhouses, located on the power canal, known as Station No. 1 and Cabot Station; e) a bypassed section of the Connecticut River; f) a reservoir known as the Turners Falls Impoundment (TFI), and g) one 13.8 kV line to the Montague substation. The Turners Falls Project is equipped with three upstream fish passage facilities, including (in order from downstream to upstream): the Cabot fishway, the Spillway fishway, and the Gatehouse fishway. The downstream fish passage facility is located at Cabot Station, at the downstream terminus of the power canal. Assuming no spill is occurring at Turners Falls Dam, fish moving downstream pass through the Gatehouse (which has no racks) and into the power canal. Fish may egress the canal through entrainment at Station No. 1 or Cabot Station or via the downstream fish passage facility which consists of a broad-crested weir developed specifically to enhance fish passage at the log sluice; the log sluice itself, which has been resurfaced to provide a passage route; above-water lighting; and a sampling facility. At Cabot Station the bar-spacing in the upper 11 feet of the intake racks was reduced to deter shad from passing through the turbines.

The Northfield Mountain Pump Storage (NMPS) Project consists of: a) an upper reservoir and dam/dikes; b) an intake; c) pressure shaft; d) an underground powerhouse; and c) a tailrace. The Turners Falls Impoundment (Connecticut River) serves as a lower reservoir.

For further detail of the Northfield Mountain and Turners Falls Projects refer to Section 3 of the PAD (FirstLight, 2012).

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Relicensing Study 3.3.3

Figure 2-1: Overview of Study Area

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3 METHODS

The impact of Projects operations on juvenile shad emigration was assessed using a combination of techniques, including hydroacoustics, radio telemetry, and HI-Z Turb'N tags. Details for the assessment of dam and turbine passage survival (using HI-Z Turb'N tags) are located in Appendix B.

3.1 Evaluation of Run Timing, Duration, and Magnitude (Hydroacoustics)

Juvenile shad run timing, duration, and magnitude, as well as entrainment at the Northfield Mountain Project during pumping operations and at Cabot Station during generation, were evaluated with the use of hydroacoustic (split beam sonar) systems. Specifically, four Simrad 333-kHz frequency multiplexing sonar systems each with four 7° circular split beam transducers were deployed at the following locations (see Figure 3.1-1): two systems at Cabot Station, one in the Turners Falls Power Canal immediately upstream of the Sixth Street Bridge, and one system at the intake/tailrace of the Northfield Mountain Project.

FirstLight began mobilization for the juvenile shad studies on July 9, 2015 with the installation of the hydroacoustic monitoring equipment. The installation was a joint effort by FirstLight, Kleinschmidt Associates, and Aquacoustics, Inc. (hydroacoustic specialist). Following installation, data collection was initiated on August 1, and continued through November 14, 2015.

3.1.1 Cabot Station

Hydroacoustic monitoring at Cabot Station was intended to enhance understanding of the timing, duration and magnitude of the juvenile American Shad migration in the vicinity of the station, as well as to evaluate entrainment. While fish number, size, and direction of travel can be measured with split beam hydroacoustic, an inherent limitation of the method is the inability to determine the species of the targets detected. As such, concurrent sampling of fishes at the Cabot downstream bypass sampler was used to investigate speciation of hydroacoustic targets.

3.1.1.1 Installation

At Cabot Station, each of the six turbines has three intake bays for a total of 18 bays. Transducers were installed in 8 of 18 intake bays (Figure 3.1.1-1); two of the bays for Unit 1 (Bays 1 and 2), one for Unit 2 (center bay), one for Unit 3 (center bay), one for Unit 4 (center bay), one for Unit 5 (center bay), and two for Unit 6 (Bays 17 and 18). Unit 1 is located closest to the downstream bypass. This setup allowed for monitoring in the center bay of each unit plus the outermost bay on each side of the forebay. The transducers associated with Units 1, 2 and 3 were routed to a General Purpose Transceiver (GPT 1) located on the intake deck, while the remaining transducers were directed to GPT 2.

The transducers were mounted on a pole and affixed to the head gates in a downward orientation angled approximately 7° upstream from vertical such that the transducers conical beams did not contact the intake infrastructure (Figure 3.1.1-2). In the final deployment, the head gates were lowered to their storage position and the transducers were situated at an elevation of about 165.26 feet mean sea level (msl) (NGVD 29) for the duration of the sampling period. All transducers were calibrated by Simrad prior to installation and any calibrations with differences greater than 0.5 decibels (dB) from the expected echo strength of the 22 mm tungsten carbide calibration sphere were offset during data processing.

3.1.1.2 Sampling Scheme

In the configuration described above, the eight transducers sampled a total of approximately 10% of the Cabot Station intake area. Each transducer sampled 50% of the time. Each GPT pinged on two transducers simultaneously (fast-multiplex), alternating every 15 minutes between two pairs (slow-multiplex). In this multiplexing scheme, GPT 1 started at the top of the hour with a fast-multiplex on Transducers 1 and 3. After 15 minutes, it switched to a fast-multiplex on Transducers 2 and 4, and so on. GPT 2 started at the top of the hour with a fast-multiplex on Transducers 5 and 7 and then switched to a fast-multiplex on Transducers 6 and 8. Slow multiplexing is required since echo sounders currently available cannot ping fast enough in fast multiplex mode to sample all four transducers effectively. Sampling parameters for the sonar systems included a power level of 35 watts (W) and pulse duration of about 0.128 milliseconds (ms).

Data collected at each split beam system were written to a 1 terabyte (Tb) hard drive on the control computer. The data were backed up to an external hard drive once per week for archiving. Each of the split beam systems was networked and accessed via a *Go to My PC* account for real time remote status monitoring by the study team.

3.1.1.3 Data Analysis

While the systems were programmed to record data continuously, only data collected during times of generation were processed. Split beam data were processed with the fish tracking module of Myriax Echoview software (Version 6). After applying an intensity threshold of -56 dB, which corresponded to a total fish length of 30 mm by conversion using Love's (1971) equation (see below), the data were analyzed with an alpha-beta (α,β) tracking algorithm to identify the series of echoes generated by an individual fish as it passed through the acoustic beam. The tracking results were reviewed on an echogram and exported as a database containing time, target strength, 3-D positional information for each fish detected and direction of travel.

The number of fish-sized targets detected was expanded proportionately to account for bays not sampled, time not sampled, and for the portion of the sampled bays that were not ensonified. The expansion factor used to account for the unensonified portion of a sampled bay was based on the effective beam width (which is a function of fish size and range) relative to the overall width of the bay sampled. This effective beam width depends on the acoustic beam pattern and the size of the target. Thus, for a given transducer, at any given range, a large fish can be detected over a wider portion of the intake cross-section than a smaller fish. This is a standard approach in which the expansion factor compensates for this differential detection probability. For each fish *i*, the expansion factor x_i was calculated as:

$$x_i = \frac{w}{b_i}$$

where w is width (m) of the intake, and b_i is the effective width (m) of the sonar beam for fish *i* at the range at which it is observed. For example, if a single fish was observed at a range where the effective beam width for a fish of its size was half the width of the intake, then the count was extrapolated to 2 fish to estimate the total number of fish in the area (one observed in the portion of the intake that was effectively covered by the sonar beam and one assumed to be in the portion that was not covered). The expansion factors were summed over all fish observed in a given time period to estimate the total number of fish (*F*) that passed through the intake:

$$F = \sum_i x_i$$

Estimates of fish length were calculated with Love's (1971) dorsal aspect equation for a frequency of 333 kHz:

Fish length (inches) = 10^((TS+23.9-0.9*Log10(λ)))/19.1)*1000)/25.4

where TS is the mean split beam-corrected acoustic size for all echoes within the given fish track, and λ is the wave length in meters. The initial 30-mm size filter was conservative and intended to ensure all fish targets were considered for further processing. Identification of targets as juvenile American Shad was assumed for those targets ranging in length comparable to the lengths of juvenile shad collected and measured at the Cabot Station bypass sampler during the sampling period (Section 3.1.4). In addition, entrainment was assumed for those targets that were tracked to an elevation lower than the top of the Cabot penstock at elevation 160.26 feet msl (NGVD 29), as all fish below this elevation were observed to be moving into the penstock, while fish above this elevation appeared to be milling (moving in all directions). The data were summarized to provide an estimate of the number of entrained fish per unit and per day. The relationship between daily entrainment and Cabot Station flow was also investigated.

3.1.2 Turners Falls Power Canal

Hydroacoustics were used to estimate the number of juvenile shad that emigrated through the Turners Falls Power Canal.

3.1.2.1 Installation

Excessive turbulence and air entrainment prevented effective hydroacoustic sampling at the Gatehouse; therefore, four transducers were deployed immediately upstream of the Sixth Street Bridge (about 0.4 river miles downstream of Gatehouse) along a transect perpendicular to the canal alignment (Figure 3.1.2-1) to monitor passage of juvenile shad through the canal. This location was upstream of the Station No. 1 intake canal, therefore all shad that entered the Cabot power canal through the Gatehouse and continued downstream migration were represented in the estimate. Each transducer was mounted on a sled and divers secured the four sleds to the canal bed with anchors at 5.8, 16.5, 20.7, and 28.7 meters from the right bank, with the transducers oriented vertically towards the surface (Figure 3.1.2-2). The conical beam spread at a 7° angle, thus maximizing the beam width and sampling area in the upper water column where juvenile shad tend to migrate (Figure 3.1.2-3). The transducer cables ran to a GPT cabinet that was installed on the bridge. All transducers were calibrated by Simrad prior to installation and any calibrations with differences greater than 0.5 dB from the expected echo strength of the 22 mm tungsten carbide calibration sphere were offset during data processing.

3.1.2.2 Sampling Scheme

The total area sampled by the four transducers in the Turners Falls Power Canal represented approximately 9% of the canal cross-section. The GPT alternated every 15 minutes (slow multiplex) between the four transducers (i.e., each transducer sampled 25% of the time). A slow multiplexing scheme was chosen to maximize the ping rate and minimize potential cross-talk between the transducers. Sampling parameters for the sonar system included a power level of 35 W and pulse duration of about 0.128 ms.

Similar to the Cabot Station set-up, data collected at the split beam system were written to a 1 Tb hard drive on the control computer. The data were backed up to an external hard drive once per week for archiving. The split beam system was accessible via a *Go to My PC* account for real time remote status monitoring by the study team.

3.1.2.3 Data Analysis

Split beam data were processed with the fish tracking module of Myriax Echoview software (Version 6). After applying an intensity threshold of -56 dB, the data were analyzed with an α,β tracking algorithm to identify the series of echoes generated by an individual fish as it passed through the acoustic beam. The tracking results were reviewed on an echogram and exported as a database containing time, target strength, 3-D positional information for each fish detected and direction of travel.

The number of tracked fish was normalized to a 1-meter-wide column, and expanded proportionately based on the transducer spacing to account for unsampled area across the width of the canal. The expansion factor to account for the unsampled area and conversion to fish length was the same as that used for the Cabot Station analysis (Section 3.1.1.3). The data were summarized to provide an estimate of the number of fish moving in a downstream direction. Fish were tallied based on their direction of movement through the beam. With the transducers mounted on the bed of the canal and oriented toward the surface, 0° was selected to indicate downstream orientation and 180° represented upstream-oriented movement. Only targets moving within ± 45° of 180° were counted as upstream moving fish, those within ± 45° of 0° were counted as moving downstream, and directions between those ranges were considered as milling fish. The net number of fish moving downstream was estimated as the number of downstream-directed fish minus the number of upstream-oriented fish.

3.1.3 Northfield Mountain Project

Hydroacoustic monitoring of the Northfield Mountain Project intake/tailrace was performed to estimate juvenile American Shad entrainment.

3.1.3.1 Installation

A single split beam system of four transducers was installed at the Northfield Mountain Project intake/tailrace channel. Each transducer was mounted to a bracket and affixed to the top of a concrete wall (Figure 3.1.3-1). The transducers were installed at an elevation of approximately 178 feet msl (~2 ft below the top of the intake structure and ~5 ft above the top of the intake opening), aimed downward, slightly away from the intake structure, approximately 10° downstream from vertical. Viewed from the front of the intake, each transducer was aimed along the center line of one of the four intake bays (Figure 3.1.3-2). All transducers were calibrated by Simrad prior to installation and any calibrations with differences greater than 0.5 dB from the expected echo strength of the 22 mm tungsten carbide calibration sphere were offset during data processing.

3.1.3.2 Sampling Scheme

The overall area sampled by the four transducers represented approximately 24% of the total intake area. Each transducer sampled 50% of the time. The GPT pinged on two transducers simultaneously (fast-multiplex), alternating every 15 minutes between two pairs (slow-multiplex). In this multiplexing scheme, the GPT started at the top of the hour with a fast-multiplex on Transducers 1 and 3. After 15 minutes, the GPT switched to a fast-multiplex on Transducers 2 and 4, and so on. Sampling parameters for the sonar system included a power level of 35 W and pulse duration of 0.128 ms.

3.1.3.3 Data Analysis

While the monitoring system was programmed to record data continuously, only data collected during pumping operations were used for target identification on echograms as these data were pertinent to entrainment. Further, discharge during generation created unfavorable flow conditions (e.g., increased turbulence) resulting in data unsuitable for target identification. This subset of the data (i.e. pumping) was initially processed using similar techniques as described for data collected at Cabot Station (see Section 3.1.1.3 above).

The following criteria were applied to filter the dataset and estimate the number of juvenile shad entrained at Northfield Mountain as follows:

1. The mean elevation of the fish for the duration it was tracked was less than or equal to 172 feet msl (top of the intake opening); and
2. The fish's movement was within ± 45° of an imaginary straight line spanning between the transducer and the intake (see Figure 3.1.3-3). Fish moving horizontally across the intake face or away from the intake were considered to be engaging in milling behavior; these fish were not considered to be entrained.
3. The size of a fish was within the expected length range of juvenile American Shad (62-120 mm in total length). The length criteria varied by month as shown in Table 4.1.1-1.

3.1.4 Verification Sampling

Concurrent with the hydroacoustic study, sampling was performed at the Cabot Station bypass sampler over several discrete events (15) to determine the species identity of targets observed in the hydroacoustic data and compare the proportion of juvenile shad passing via the downstream bypass (in the Turners Falls Power Canal) and Cabot Station. These sampling events began on September 9, 2015 and continued through October 28, 2015. Sampling was conducted during evening hours (generally between 16:00-22:00 hrs). All juvenile American Shad were counted during sampling and 50 were randomly selected and measured for total length per night.

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Northfield Mountain Pumped Storage Project No. 2485

Turners Falls Hydroelectric Project No. 1889

Relicensing Study 3.3.3

Figure 3.1-1. Hydroacoustic Monitoring Site Locations

N

0 0.3 0.6 1.2 Miles

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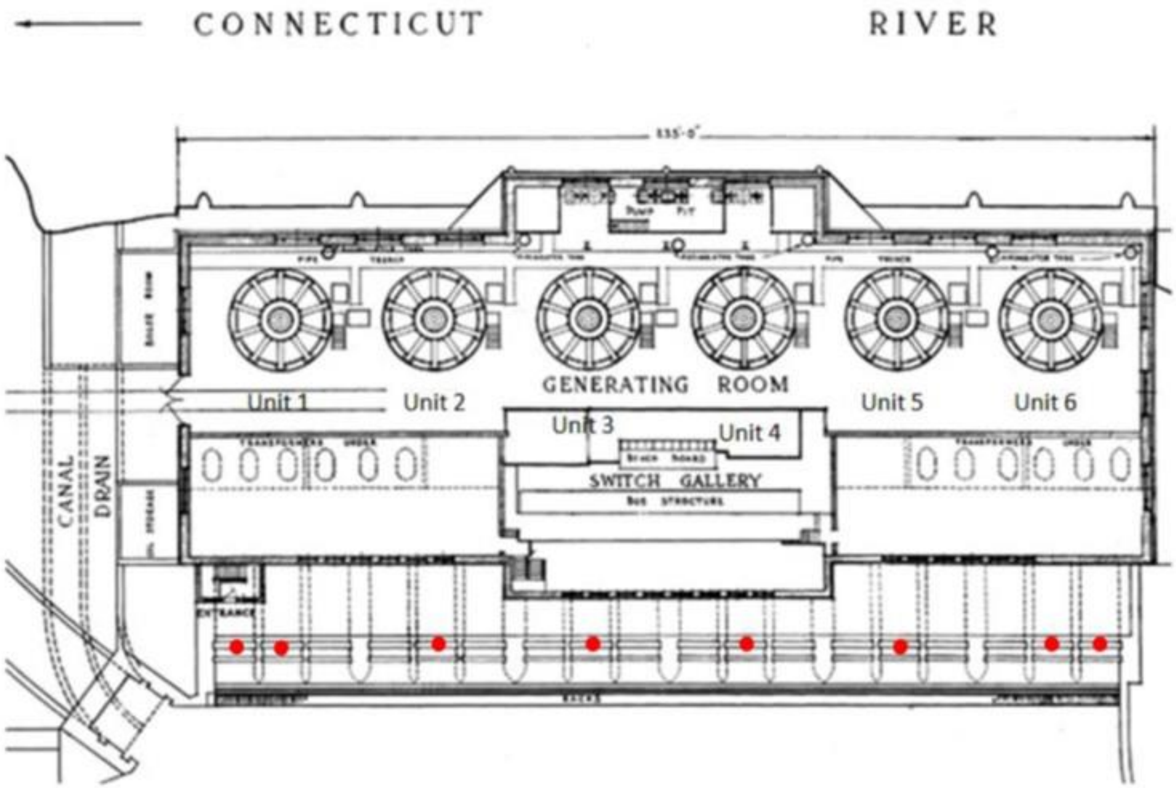


Figure 3.1.1-1: Overview of Cabot Station with the Red Circles Indicating the Location of the Split Beam Transducers used to Monitor Juvenile Shad Entrainment

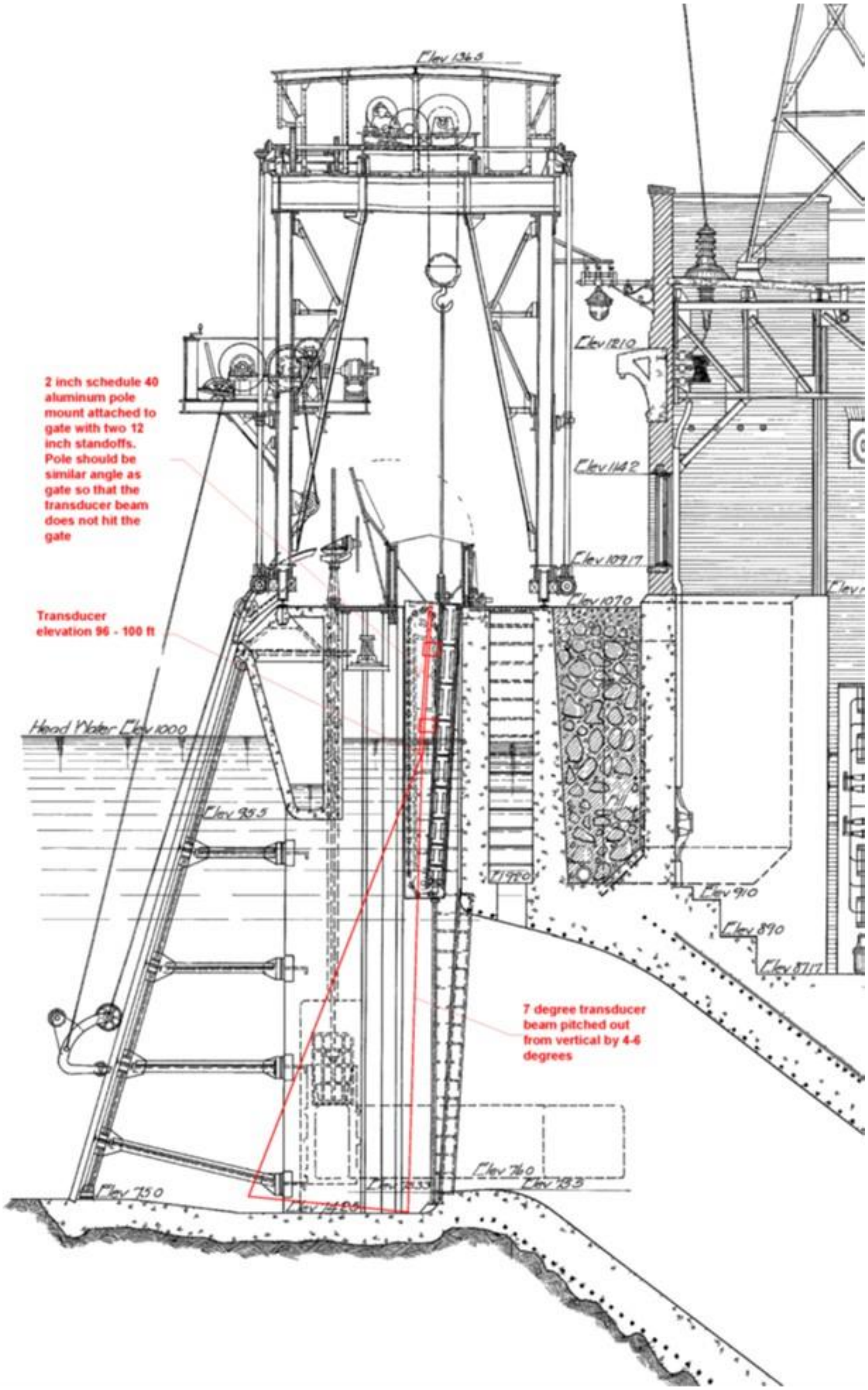


Figure 3.1.1-2: Cabot Station Section View through the Intake Bays at Unit 3 showing the Location of the Transducer Mount and an Outline of the Beam Volume Sampled. Please note that the elevation data presented in this drawing are from a datum no longer used at the projects.

Figure 3.1.2-1: Location of the Four Split Beam Transducers (in red, not to scale) used to Monitor Juvenile Shad as they Migrate through the Turners Falls Power Canal

Figure 3.1.2-2: Custom Leveling Mount used to Position the Split Beam Transducers on the Bottom of the Cabot Power Canal.

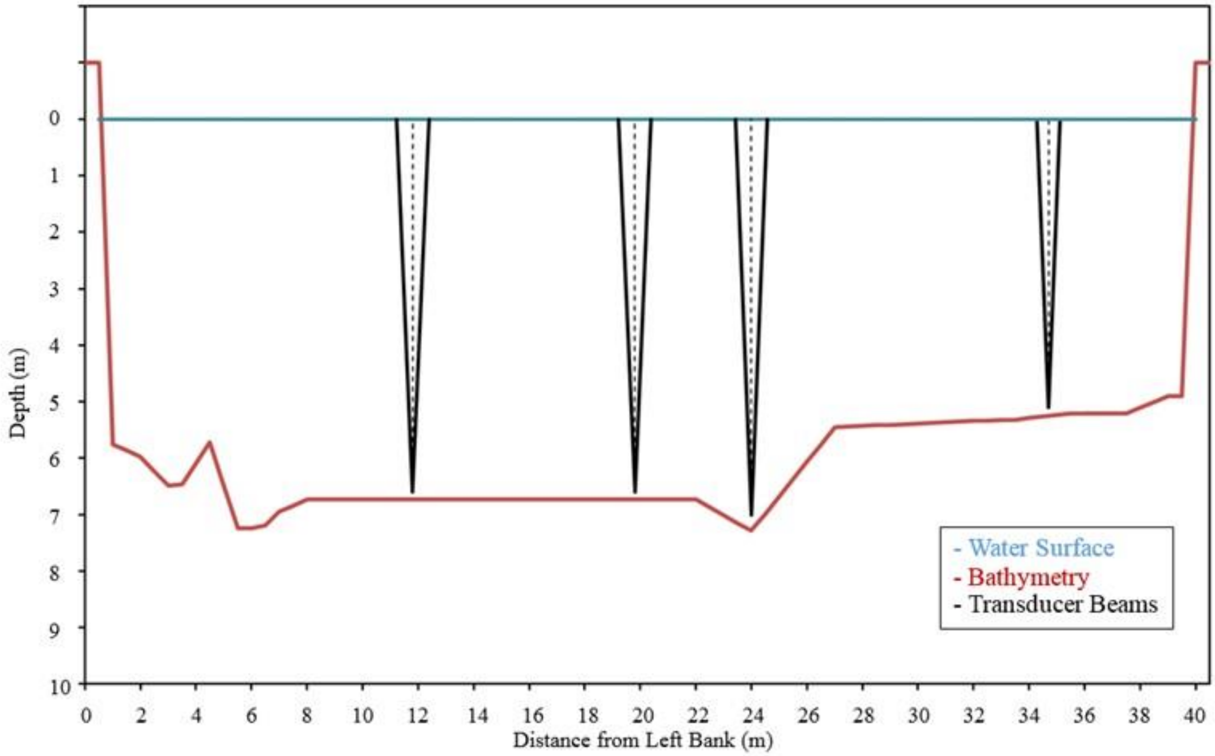


Figure 3.1.2-3: Section view of the Turners Falls Power Canal where the Four Split Beam Transducers were Located

Figure 3.1.3-1. Concrete Wall at the Northfield Mountain Project Intake/Tailrace where Transducers were Installed to Monitor Juvenile Shad Entrainment

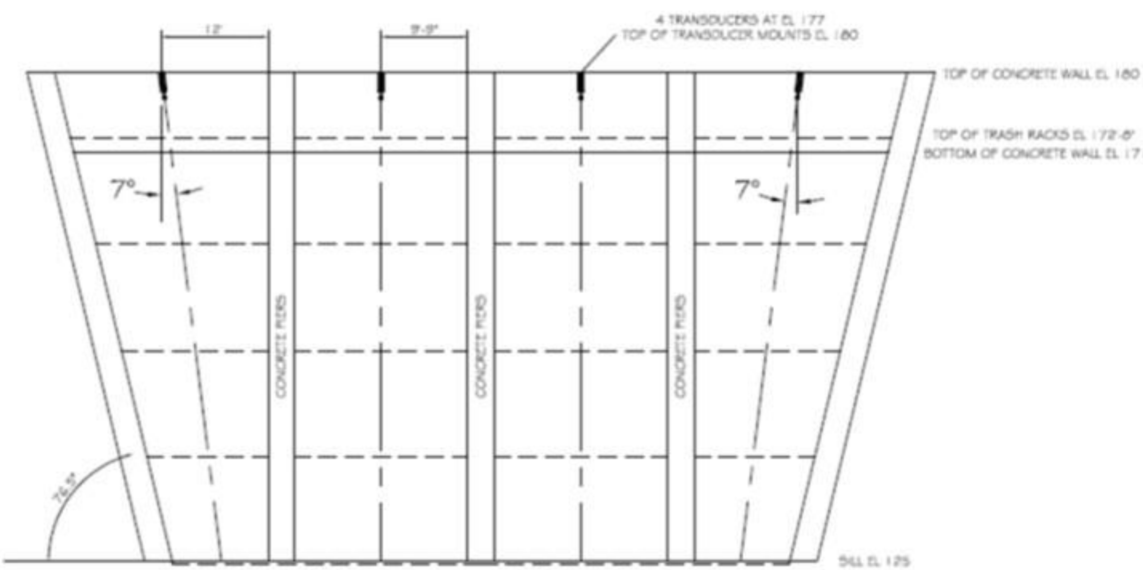


Figure 3.1.3-2: Section view of the Northfield Mountain Project Intake Structure depicting the Location and Orientation of the Split Beam Sonar used to Monitor Entrainment of Juvenile Shad

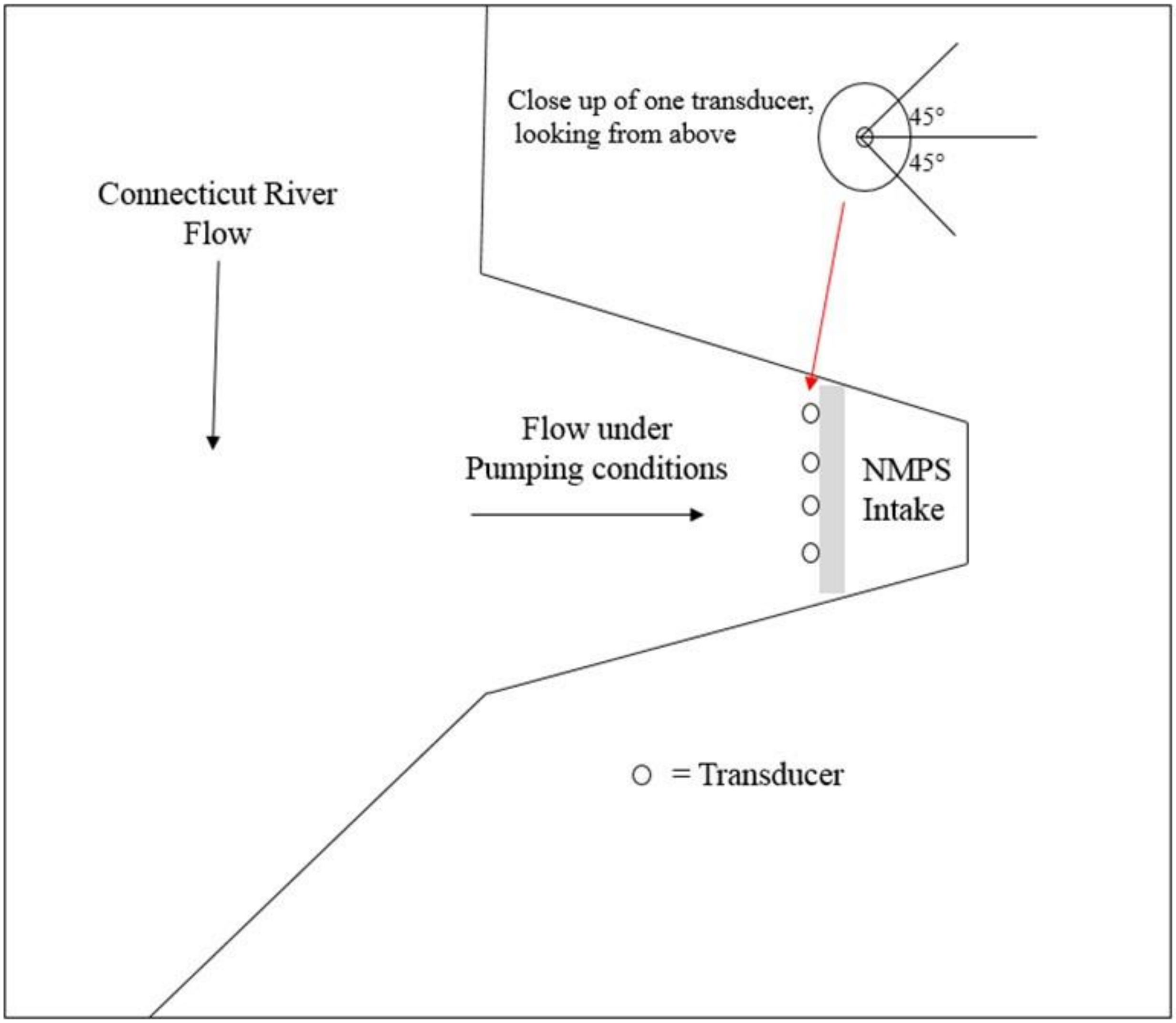


Figure 3.1.3-3. Overhead view of the NMPS intake/tailrace area depicting the area of monitoring via split beam hydroacoustics and the orientation of movement of fish targets within the acoustic beam.

3.2 Evaluation of Passage Routes (Radio Telemetry)

Radio telemetry techniques were used to evaluate route selection and rate of movement of emigrating juvenile shad as they passed through the Northfield Mountain and Turners Falls Projects.

3.2.1 Source of Test Specimens

Although the RSP envisioned the use of hatchery-reared juvenile shad, feasibility testing by the TransCanada study team in 2014 (NAI, 2014) showed that the behavior of hatchery fish appeared to be different than that of wild fish. Despite this observation, testing using hatchery fish was attempted in 2015 in favor of using the larger hatchery fish that could better handle the tag, but was abandoned due to high transport and handling mortality. In place of hatchery-reared juvenile shad, wild specimens were collected at the Cabot downstream bypass sampler between October 4 and October 19, 2015. Juvenile shad were collected in the evenings (generally between 16:00-22:00) and transported in an aerated live well (90 gallons) by truck to the TF Gatehouse where they were divided into three 1,000 gallon circular holding tanks with flow-through ambient river water supplied from the impoundment. A constant inflow to the tanks was provided by three sump pumps, each of which was powered by a dedicated electrical circuit. Flow from the pumps was distributed evenly between the tanks using a manifold system at a rate of approximately 2000 gallons per hour in each tank. The circulating inflow discharged from the inlet hoses at a height of approximately 6 inches above the water surface and was oriented along the outer wall of the circular tank. The cascading flow and orientation help to maintain an adequate dissolved oxygen level within the tanks and provided a circular flow into which the juvenile shad could orient. Circulated water was discharged back to the impoundment via a stand pipe drain in each tank such that a depth of approximately 3 ft was maintained. Salt blocks (50lb) were added to each of the tanks daily to raise the salinity within the holding tanks and reduce osmoregulatory stress by acclimatization to seawater, which has been shown to reduce handling stress, behavior perturbation and mortality (Shrimpton et al. 2001). The holding tanks were covered with a 1/8 inch mesh netting and shaded under canopies (Figure 3.2.2-1). Each tank was monitored for water quality and fish mortality on a nearly daily basis.

3.2.2 Tagging Methodology

A Lotek NanoTag Series Model NTQ–1 was externally affixed to 218 juvenile shad. Only shad displaying no external injuries or abnormalities (e.g. wounds, substantial scale loss, lesions, etc.) and no atypical behavioral characteristics were selected for tagging. The Lotek NanoTag is the smallest radio tag commercially available and has the following characteristics:

- 5 mm wide
- 3 mm high
- 10 mm long
- 0.26 g weight in air
- A tag life of 10 days at a 2 second burst rate

The juvenile shad tags operated on three frequencies; 150.340, 150.360, and 150.380 MHz. Concurrent study efforts were conducted upstream by TransCanada near the Vernon Project and tag frequencies and parameters were coordinated between the studies such that this study could take advantage of all the test fish in the study area.

Juvenile shad from the holding tanks were transported in small groups (~80) to the release location by boat in a live well (90 gallons). Large shad, free from scale loss and observable injuries were selected for tagging. Juvenile shad were transferred from the holding tank by brail and placed in a 5 gallon bath of carbonated water (~1 liter) and ambient river water (~19 liters) for approximately 1 minute, or until anesthetized. Tags were affixed to barbed No. 16 dry fly hooks (Figure 3.2.2-2) as recommended in the feasibility study conducted for TransCanada (NAI, 2014). The fish were kept in the water while the hooks were inserted into the dorsal musculature just below the dorsal fin. Once tagged, the fish were held in a small circular recovery tank (~8 gallons) for observation (approximately 15 minutes) to verify initial survival and tag retention (Figure 3.2.2-3). The transport tank and recovery tank were aerated and salted to maintain adequate levels of dissolved oxygen and minimize osmoregulatory stress. Once recovered from the tagging process, tagged fish were released along with 30 to 50 untagged juvenile shad to promote schooling behavior.

Fifty (50) juvenile shad was placed in a 90-gallon tank and tagged with mock tags that consisted of tin BB weights attached to dry fly hooks to serve as controls (Figure 3.2.2-4). The weight and approximate size of the control tag (~0.3 grams) was similar to the Lotek NanoTag. Control-tagged shad were held in an oval shaped 90 gallon tank with a flow through system to provide oxygenated water to the fish. The flow rate was approximately 200 gallons per hour. The status of the control fish was assessed by counting the number of mortalities in the tank each day, and recording if the tag remained attached or was shed. Total length (mm) was measured for each fish after the observation period, which lasted for 7 days.

3.2.3 Release Events

Tagged shad were released at two sites in the TFI. The first was approximately 1.5 miles upstream of the Northfield Mountain Project intake/tailrace and the other was in the lower impoundment, about 1.25 miles upstream of the TFD (Figure 3.2.3-1). The releases upstream of the Northfield Mountain Project occurred on six days between October 12 and 20, 2015 and on three days between October 12 and 15, 2015 at the lower impoundment site upstream of the TFD (Table 3.2.3-1). Upstream releases were scheduled such that cohorts of test fish would experience a range of NMPS Project pumping scenarios (i.e. 1, 2 and 3 pumps). Unit 4 was in an outage during the study period and did not operate.

3.2.4 Monitoring

Tagged juvenile shad were monitored at 13 locations within the study area in accordance with the RSP and FERC's SPDL (Table 3.2.4-1). The radio monitoring systems were outfitted with either an Orion receiver, a Lotek SRX 400 receiver, or a Lotek SRX 800 receiver. A combination of 3-element yagi antennas and dropper antennas were used throughout the study area. Stations with Lotek SRX 400 or 800 receivers were set up with two receivers to reduce the scan time. The first receiver was set to scan frequencies 149.400, 149.420, 149.440, 149.740, and 149.760 MHz. The second receiver was set to scan frequencies 150.340, 150.360, 150.380 and 150.600 MHz. The additional frequencies included here were in support of other telemetry studies including those conducted by TransCanada as well as for Study No. 3.3.5 *Evaluate Downstream Passage of American Eel*. Data were downloaded from each radio receiver approximately once a week from September 28 to December 4, 2015 (date range inclusive of required American Eel monitoring period).

The radio telemetry monitoring system was tested and calibrated in the field prior to tagging and release of test fish (Appendix A). Figures 3.2.4-1 to 3.2.4-6 depict the approximate detection zones of the fixed monitoring locations listed in Table 3.2.4-1.

3.2.5 Data Analysis

3.2.5.1 Data Reduction and Management

A proprietary probabilistic method for removing false positives was developed and applied to the dataset. Radio telemetry receivers record four types of detections based upon their binary nature; true positives, true negatives, false positives and false negatives (Beeman & Perry, 2012). False negatives arise from a variety of causes including insufficient detection area, collisions between transmitters, interference from ambient noise or weak signals (Beeman & Perry, 2012). While the probability of false negatives can be quantified from sample data as the probability of detection, quantifying the rate of false positives (type I error) is more problematic (Beeman & Perry, 2012). Inclusion of false positives in a dataset can bias study results in two ways: they can favor survivability through a project by including animals that weren't there, or they can increase measures of delay when an animal has already passed. For the purposes of this study, false positive reduction methods relied upon a few metrics, including power floors, reliance on consecutive detections in series, logical errors in site progression and subjective opinion. We relied upon data and quantitative insight to reduce the amount of subjectivity in the analysis.

Following removal of false positives, data were entered into a dedicated Microsoft Access database for analysis. Quality assurance and quality control (QA/QC) procedures were conducted for each receiver and consisted of checking for systematic errors for all juvenile shad tagged, released and detected in the telemetry network[3] (Figure 3.2.5-1). Such systematic errors included improbable site progression, or the acceptance or rejection of a detection when its supporting data provided overwhelming evidence to suggest that it belonged to another class. For example, these errors could include accepting a record as true with low power, low hit ratio (< 0.10), high misread ratio, non-consecutive detections and detections not in series. If systematic errors like this were identified, the analysis of the data at the site was reclassified after making adjustments to the model and training dataset. Following QA/QC procedures and removal of any remaining non-systematic but spurious detections, a three-dimensional visualization tool was developed to show the position of each tagged juvenile shad within the telemetry network over time. The tool was useful to determine passage routes and/or route selection and to perform a visual inspection of the data.

3.2.5.2 Rate of Movement

The amount of time that each fish spent within the impoundment was determined by using the time from release and last known detection at any given fixed telemetry station within the impoundment. Distance from the release location to the last known fixed telemetry station detection was determined in RMs. These data were used to calculate migration rate, distance per hour (RM/h). If a fish passed through the Turners Falls Project, the time of release to the time of the last detection closest to the dam and/or Gatehouse was used. The same procedure was used for the bypass reach and the power canal.

The time a fish spent in the TFI and the rates of movement included time in which the fish spent milling in front of a barrier (i.e, Turners Falls Dam or Gatehouse). If fish did not pass through the structures, they still remained in the impoundment and that time was factored into the rate of movement calculation regardless of how long they remained.

3.2.6 Canal Escapement during Drawdown

Prior to the drawdown of the Turners Falls Power Canal that FirstLight conducts annually in the fall for maintenance purposes, eight tagged juvenile shad were released in the upper portion of the canal just downstream of Gatehouse and nine were released in the lower portion of the canal where it begins to widen along Migratory Way (Figure 3.2.6-1). The intent was to gather information of the fate of juvenile shad in the canal as water is released for the drawdown event. Juvenile shad were tagged and released into the canal the evening of October 4, 2015. Subsequent to release, mobile tracking was performed on October 5, 2015 in an attempt to locate the tagged fish and determine escape routes. Mobile tracking was conducted along the entire length of the power canal on foot or via truck, using a Lotek SRX 800 receiver and a yagi antenna.

An objective of Study 3.3.18 *Impacts of the Turners Falls Canal Drawdown on Fish Migration and Aquatic Organisms* was to assess whether juvenile shad and American Eel abundance in the canal increases leading up to the time of its closure, due to delays in downstream passage (e.g., is fish accumulation occurring). This objective is addressed in the present study, regarding juvenile American Shad. Shad were monitored at the Cabot intake leading up to the canal drawdown using split beam hydroacoustics. These data were used to estimate entrainment rate at Cabot Station, which has an assumed positive relationship to shad

[3] The telemetry node refers to either a *Set* or a single *Telemetry* receiver/s, the *Edge* implies the connection between nodes.

abundance within the power canal such that as the entrainment rate increases so must the abundance in the canal. Entrainment rate at Cabot Station was plotted over time and used to investigate the potential for shad accumulation within the power canal leading up to the drawdown.

Figure 3.2.2-1. Tanks used to hold juvenile shad at the TF Gatehouse.

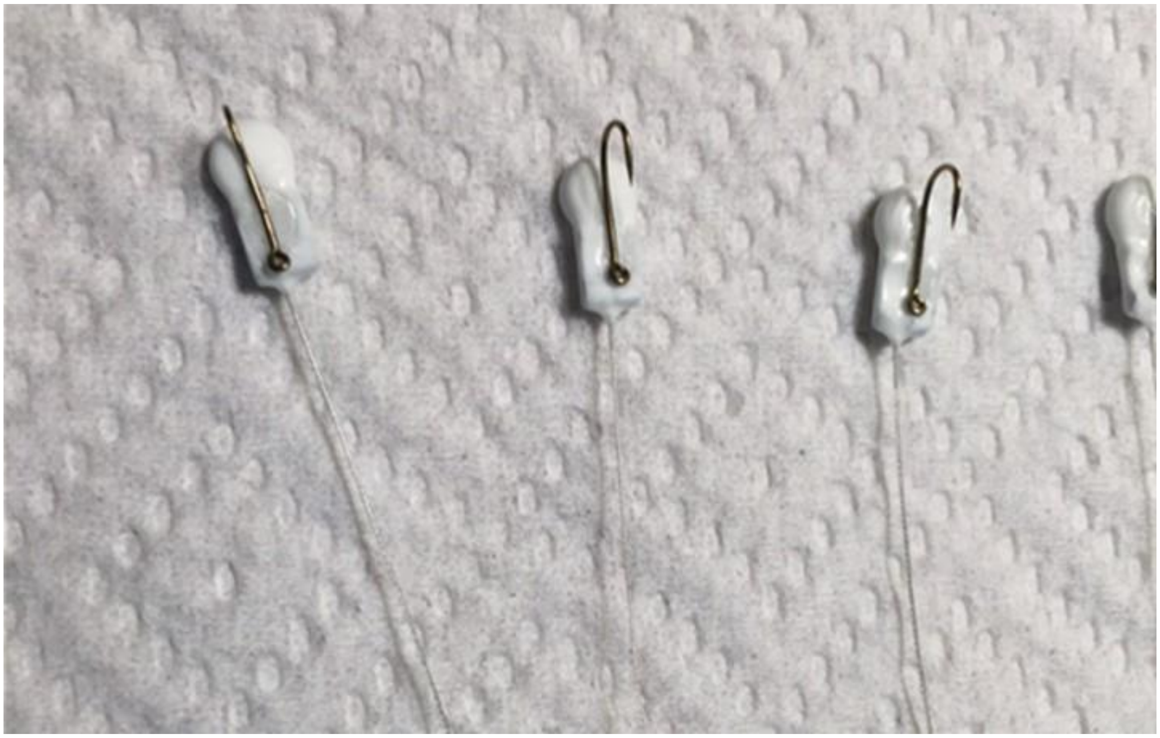
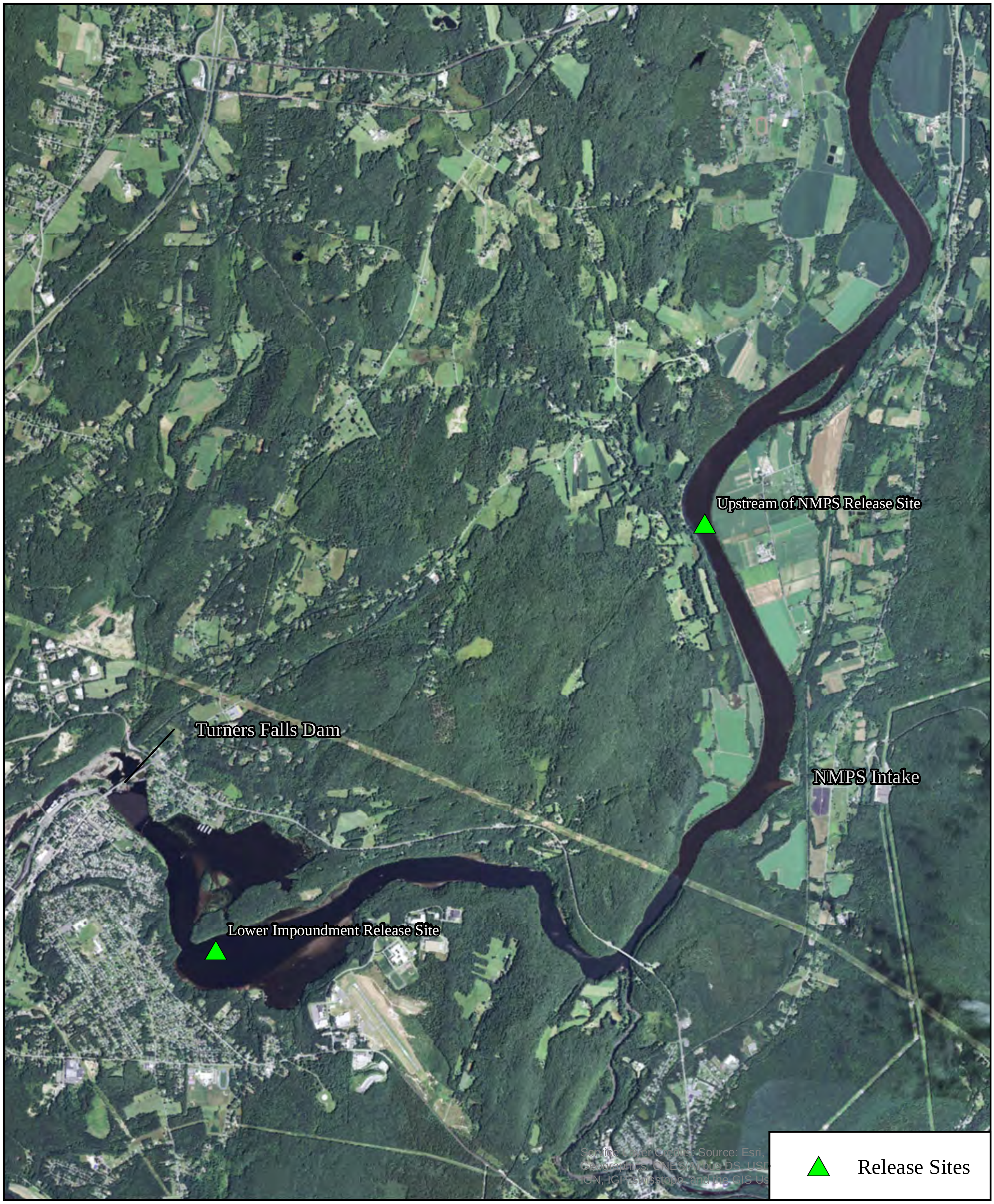


Figure 3.2.2-2. Lotek NanoTag Series Model NTQ–1 affixed to a No. 16 Dry Fly Fishing Hook

Figure 3.2.2-3. Tagged juvenile Shad in the Recovery Tank Prior to Release.

Figure 3.2.2-4. Juvenile Shad Equipped with Mock Tag



Northfield Mountain Pumped Storage Project (No. 2485)
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Relicensing Study 3.3.3

Figure 3.2.3-1: 2015 Juvenile Shad Telemetry Release Sites in TFI

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Northfield Mountain Pumped Storage Project (No. 2485)
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Relicensing Study 3.3.3

Figure 3.2.4-1: Radio Telemetry Station at Upper Reservoir

FirstLight Power Resources

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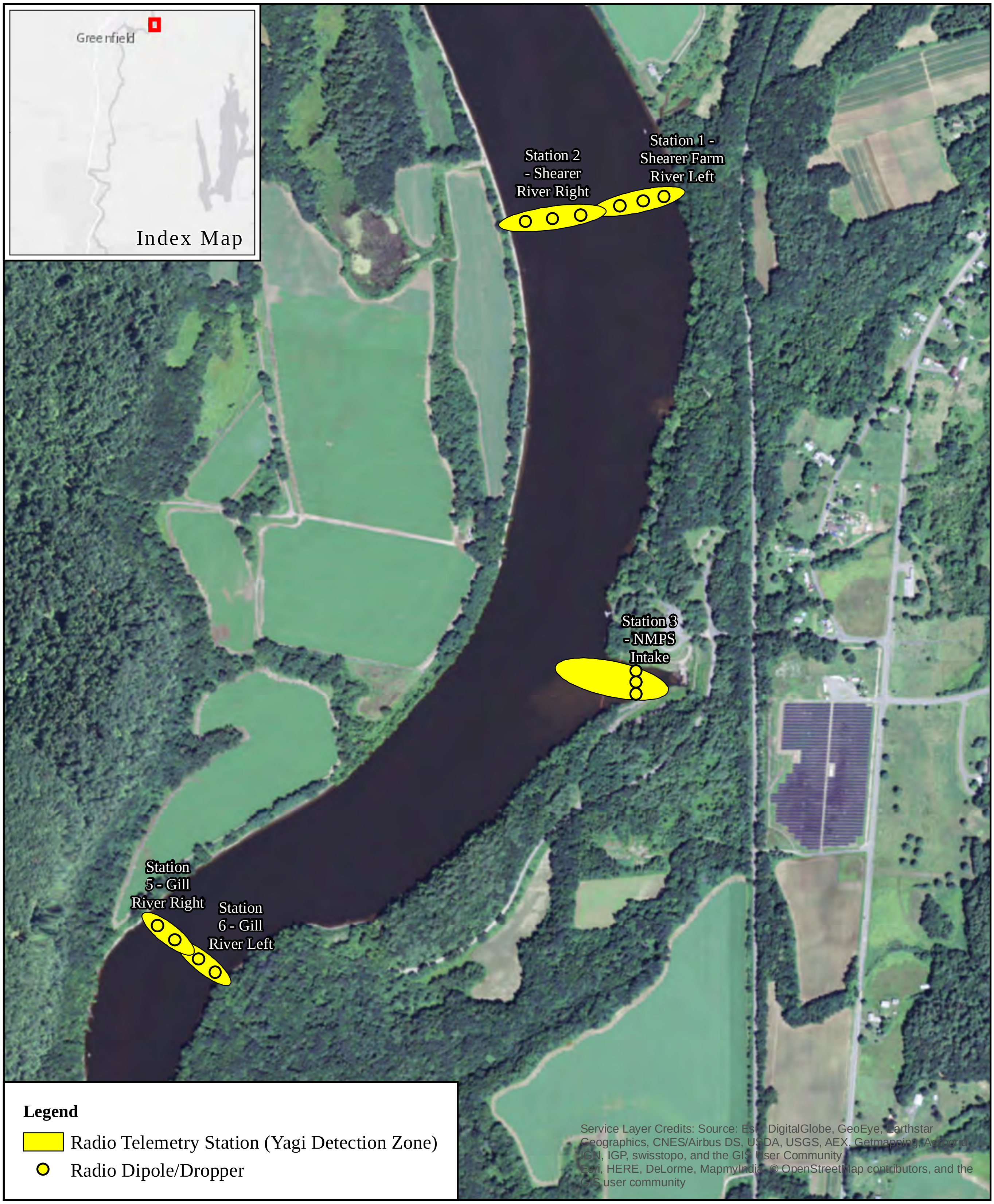

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Relicensing Study 3.3.3

Figure 3.2.4-2: Radio Telemetry Stations Near NMPS Intake

N

0 412.5 825 1,650 Feet

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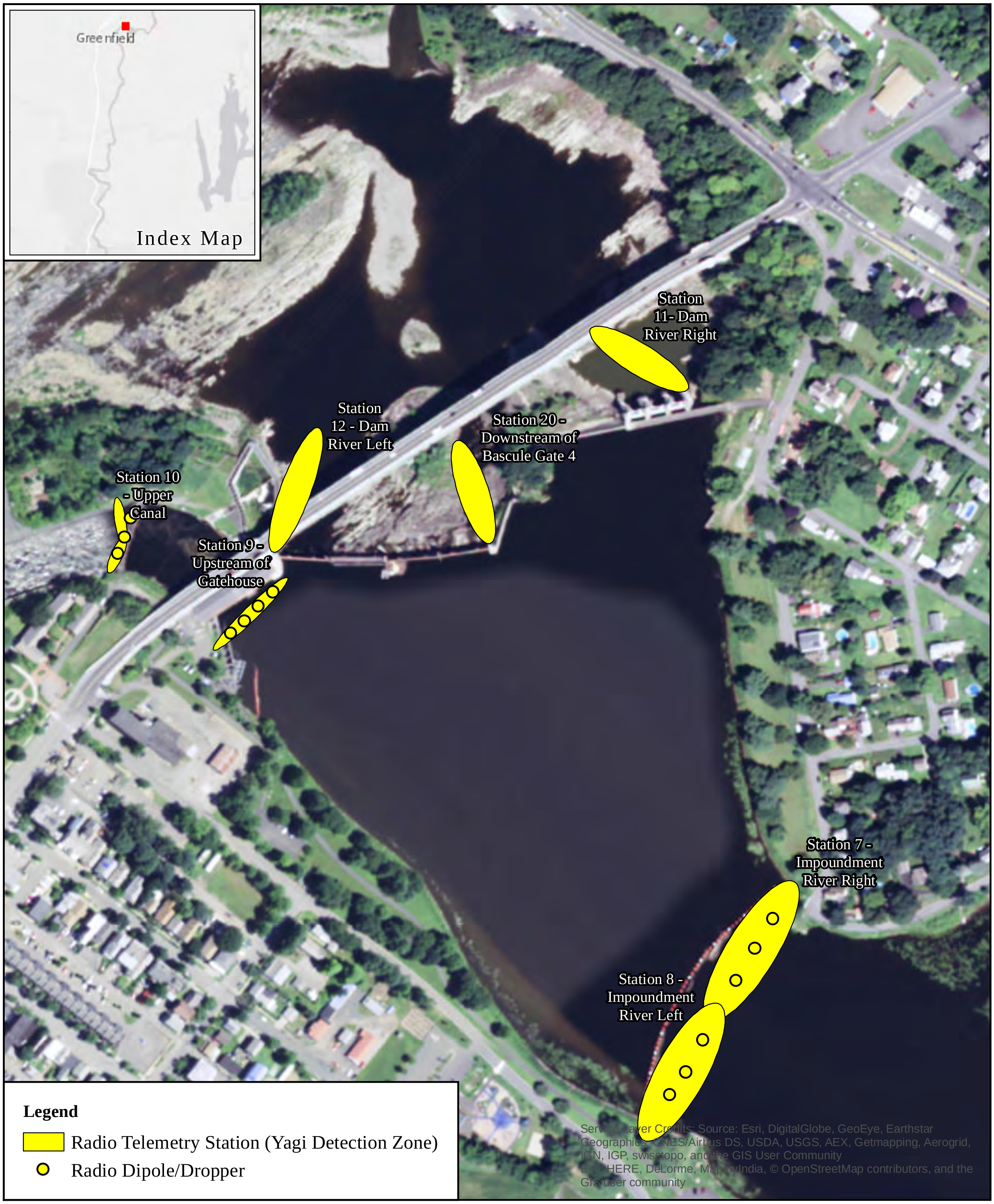

FirstLight Power Resources

Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

Relicensing Study 3.3.3

N

0 170 340 680 Feet

Figure 3.2.4-3: Radio Telemetry Stations Near Turners Falls Dam

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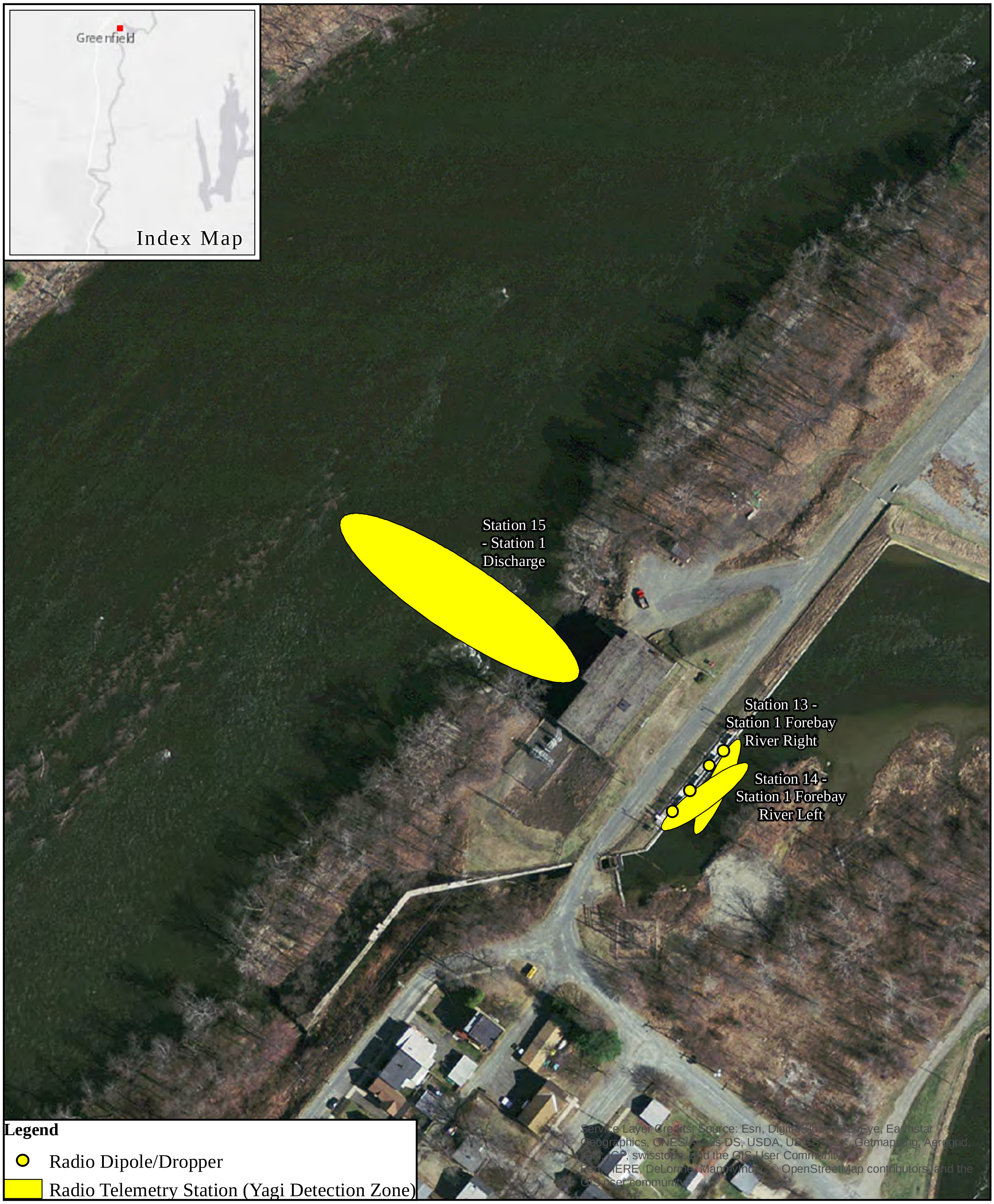

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Relicensing Study 3.3.3

Figure 3.2.4-4: Radio Telemetry Stations Near Station 1

FirstLight Power Resources

N

0 80 160 320 Feet

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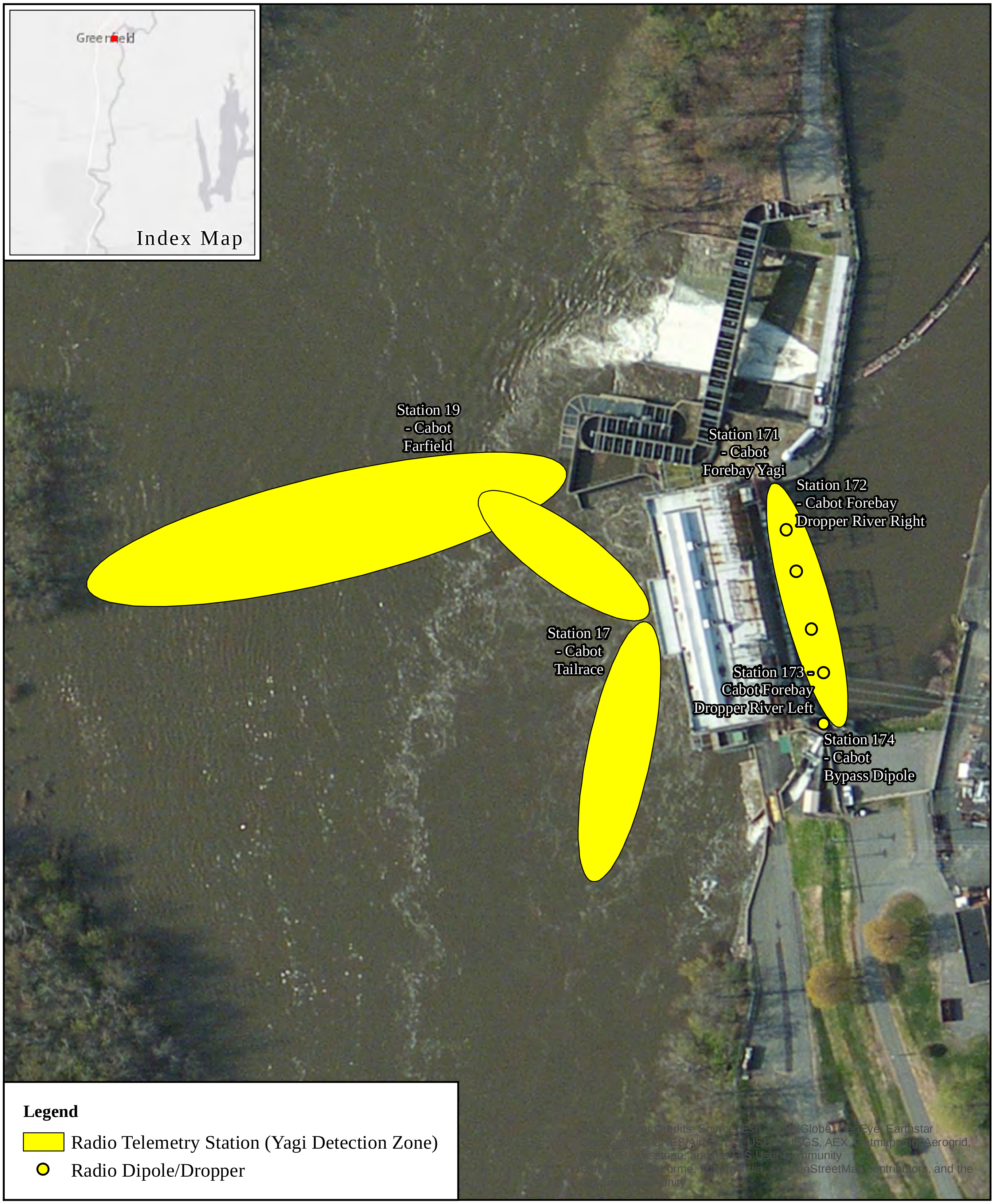

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Relicensing Study 3.3.3

Figure 3.2.4-5: Radio Telemetry Stations Near Cabot Station

N

0 70 140 280
Feet

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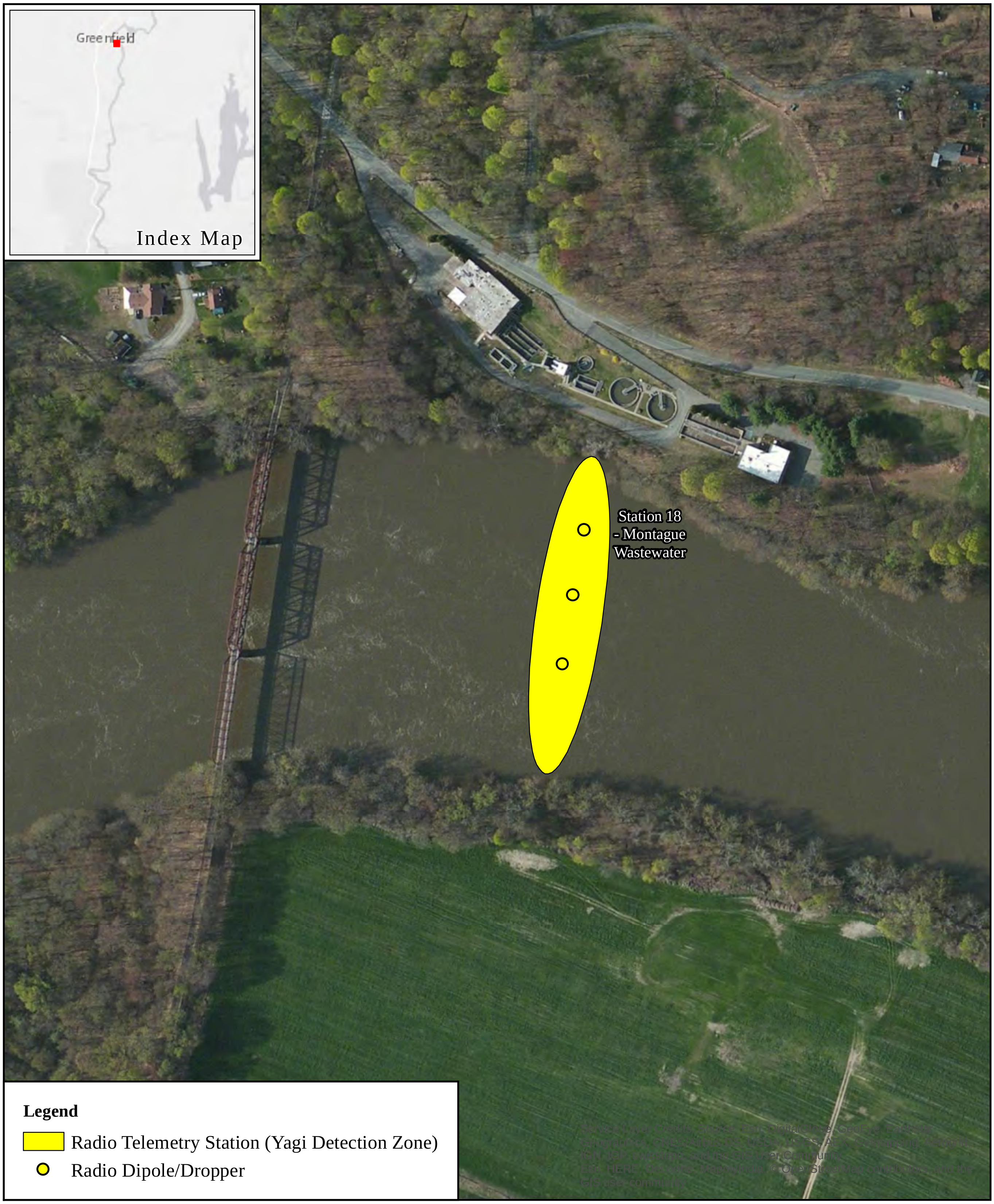

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Relicensing Study 3.3.3

Figure 3.2.4-6: Radio Telemetry Stations at Montague Wastewater

FirstLight Power Resources

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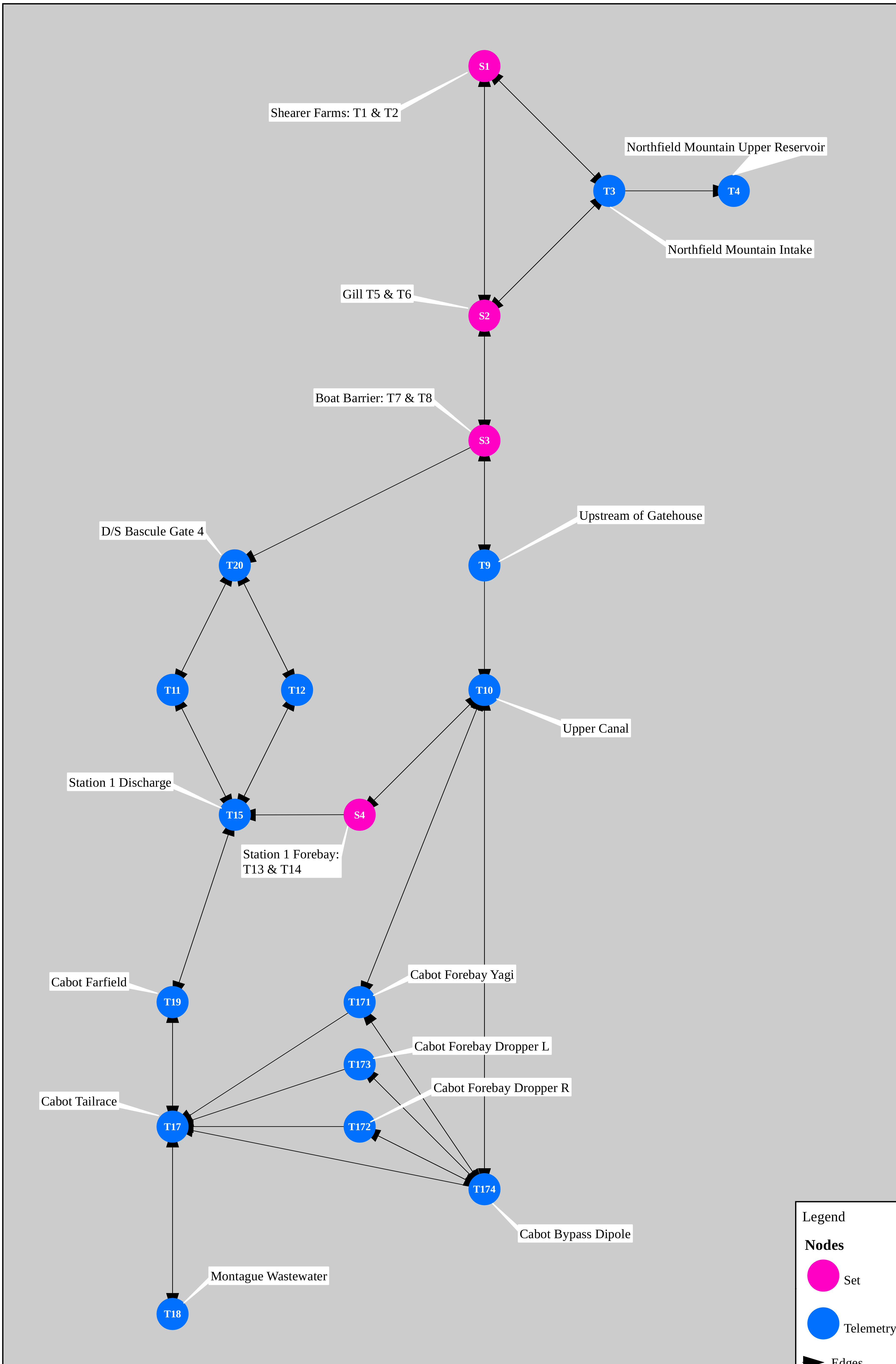

FIRSTLIGHT HYDRO GENERATING COMPANY
Northfield Mountain Pumped Storage Project No. 2485
Turners Falls Hydroelectric Project No. 1889

Relicensing Study 3.3.3

Figure 3.2.5-1: Radio Telemetry Network for Fall 2015 Juvenile Shad Passage Assessment

FirstLight Power Resources

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FirstLight Power Resources

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Relicensing Study 3.3.3

Figure 3.2.6-1: 2015 Juvenile Shad Telemetry Release Sites in Turners Falls Power Canal

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Table 3.2.3-1. Summary of Juvenile Shad Release Events

Release Location	Release Date	Release Time	Count	Cumulative Total	No. Units Pumping at NMPS
Upper Canal	October 4, 2015	20:45	8	8	1
Lower Canal	October 4, 2015	22:25	9	17	1
Upstream of TFD	October 12, 2015	19:20	20	37	2
Upstream of NMPS	October 12, 2015	20:45	20	57	2
Upstream of TFD	October 13, 2015	20:45	20	77	3
Upstream of NMPS	October 13, 2015	20:05	24	101	3
Upstream of TFD	October 15, 2015	19:45	23	124	3
Upstream of NMPS	October 15, 2015	20:10	24	148	3
Upstream of NMPS	October 16, 2015	20:55	24	172	2
Upstream of NMPS	October 19, 2015	19:10	24	196	3
Upstream of NMPS	October 20, 2015	20:10	22	218	2

Table 3.2.4-1. Telemetry Monitoring Station Locations and Equipment

Location	Station ID	RM	Receiver Station Equipment
Montague Wastewater	T18	118.5	A Lotek SRX receiver with double yagi antennae and two dropper antennas monitored the full width of the river
Cabot Station Tailrace	T17 & T19	119.3	A Lotek SRX with yagi antenna monitored the full river width. An Orion receiver and double yagi antennae monitored the trailrace immediately downstream of the station
Cabot Station Forebay	T171, T172, T173, & T174	119.3	Four radio receivers monitored the forebay area: 1) An Orion with a double yagi and two Orions with two dropper antennae each monitored the full width of the forebay area 2) An Orion with dipole antenna monitored the entrance to the Cabot downstream bypass
Station No. 1 Forebay	S4 (T13 & T14)	121.2	two Orions with yagi and two dropper antenna each monitored the full width of the forebay area
Station No. 1 Tailrace	T15	121.2	A Lotek SRX with yagi antenna monitored the tailrace area and the detection zone extended coverage across the full width of the wetted bypass reach
Below Turners Falls Dam	T11, T12, & T20	122.1	Three Orions receivers with double yagi antennae monitored the area below the dam, one on either side of the river bank and one mid dam to monitor the discharge from bascule gate 4.
Upper Canal	T10	122	An Orion with a yagi and three dropper antenna monitored the full width of the canal at the foot bridge located downstream of the Gatehouse in the upper canal to monitor fish entering the canal from upstream
Upstream of Gatehouse	T9	122.2	An Orion receiver with yagi and three dropper antennas was used to monitor the area immediately upstream of Gatehouse
Turners Falls Impoundment	S3 (T7 & T8)	122.4	Two Lotek SRX receivers, one on each side of the impoundment, with double yagi and five dropper antennae monitored the full width of the river
NMPS Gill Bank	S2 (T5 & T6)	127.2	Two Lotek SRX receivers, one on each side of the river, with double yagi and two dropper antennae monitored the full width of the river
NMPS Intake	T3	127.7	An Orion with double yagi and two dropper antennae monitored the intake area
NMPS Upper Reservoir	T4	127.7	An Orion with yagi and three dropper antennas was used to monitor the upper reservoir
Shearer Farms	S1(T1 & T2)	128.2	Two Lotek SRX recievers, one on each side of the river, with double yagi and six dropper antenna were used to monitor the full width of the river

3.3 Operation and Water Quality Data

FirstLight maintains a database of generation and flow data for the Northfield Mountain and Turners Falls Projects. Generation and/or flow data (15-minute intervals) for Northfield Mountain, the Turners Falls Power Canal, TFD, Station No. 1, and Cabot Station were extracted from FirstLight's database and summarized to assess Project effects on juvenile shad emigration. Water temperature and dissolved oxygen measurements recorded at 15-minute intervals were obtained from loggers installed in 2015 in support of Study No. 3.2.1 *Water Quality Monitoring Study*. Water Quality Monitoring Site No. 4 was located in the vicinity the Northfield Mountain intake/tailrace and Water Quality Monitoring Site No. 10 was located in the Turners Falls Power Canal. Data recorded during the juvenile shad study period were summarized to depict water temperature and dissolved oxygen levels in the vicinity of the Northfield Mountain intake/tailrace and Turners Falls Power Canal throughout the emigration period. Precipitation data were obtained online from Weather Underground's monitoring station located at the Orange Municipal Airport in Orange, MA (Station KORE) to investigate the potential relationship to the magnitude and timing of juvenile shad emigration.

4 RESULTS

4.1 Run Timing, Duration, and Magnitude (Hydroacoustics)

The split beam sonar systems recorded data throughout the 2015 juvenile American Shad emigration period. Results pertaining to the timing, duration, and magnitude of the 2015 outmigration event in relation to Cabot Station, the Turners Falls Power Canal, and the Northfield Mountain Project are presented below.

4.1.1 Cabot Station

Review of the split beam sonar data indicated juvenile shad-sized targets were present in the vicinity of Cabot Station throughout the monitoring period spanning August 1 to November 14, 2015. Based on the results of sampling at the Cabot bypass sampler (Section 4.1.4 below), targets within approximately ±15 mm from mean length of shad collected by month were considered to be American Shad (Table 4.1.1-1).

Juvenile American Shad entrainment was observed throughout the study period, with an apparent trimodal peak in entrainment occurring on August 17, September 30, and November 8, 2015 (Figure 4.1.1-1). Considering the assumptions and filtering criteria defined in Section 3.1.1.3 above, it is estimated that 1,660,166 shad-sized targets (62-120 mm in length) were entrained at Cabot Station between August 1 and November 14, 2015. Flow through Cabot Station[4] fluctuated in relation to the number of units operating (Figure 4.1.1-1). The distribution of entrainment by unit was such that almost half (46%) of the overall seasonal entrainment was attributable to Unit 6, despite the more frequent operation of Unit 1 (Figure 4.1.1-2).

Entrainment was estimated on an hourly basis to investigate diel distribution. The hourly rate of entrainment was summed for each hour of the day to calculate the total entrainment of all 6 Cabot units (when in operation) to determine the proportion of hourly entrainment throughout the study period at Cabot Station. Entrainment occurred throughout the day, with peak entrainment occurring within the 2000 hour, during which 8.53% of the total entrainment occurred at Cabot Station (Figure 4.1.1-3). The proportion of entrainment generally increased from noon (2.65%) to the peak (8.53%) at 2000 hours and then decreased hourly to 1.88% by 0100 hours. The lowest proportion of entrainment at Cabot Station occurred between 0100 hours and 0900 hours.

The daily volume (cubic feet, ft^3) of water passed through Cabot Station and entrainment estimates were logarithmically transformed for normalization (Figures 4.1.1-4 and 4.1.1-5) and compared to investigate potential relationships with a linear regression (Figure 4.1.1-6). The relationship was determined to be significant ($p<0.05$). In this case, the significance of a positive correlation indicated that entrainment increased with the volume of water passed through Cabot Station.

Water temperature as recorded at Water Quality Site No. 10 in the Turners Falls Power Canal was about 25°C at the onset of the monitoring period, obtained a maximum of 26.5°C in mid-August, and decreased to 7.9°C by the end of the study period in mid-November (Figure 4.1.1-7). Dissolved oxygen levels remained adequate to support shad and other aquatic life (greater than 5.0 mg/L) throughout the monitoring period.

4.1.2 Turners Falls Power Canal

The high levels of milling behavior observed by shad sized targets in the Turners Falls Power Canal did not allow for data reduction to accurately estimate the run timing, duration, and magnitude of juvenile shad outmigration. Analysis of the data revealed a substantial number of targets that appeared to be milling as opposed to moving in a downstream direction. This presents difficulty when attempting to enumerate

[4] The hydraulic and electrical capacity of Cabot Station is 13,728 cfs and 62,016 kW, respectively. To estimate flow through Cabot station the following conversion factor was applied – 1 kWH ~ 0.2214 cfs (13,728/62,016).

individual targets as there are no means to account for targets moving in and out of the same beam or targets moving between beams (i.e., targets are subject to being counted multiple times). While the data suggest that juvenile American Shad sized-targets were present in the vicinity of the Sixth Street Bridge for the entire monitoring period, accurate estimates of the seasonal and daily distribution could not be determined due to the limitations described herein.

4.1.3 Northfield Mountain

Juvenile shad-sized targets were present in the vicinity of the Northfield Mountain Project intake/tailrace area for the duration of the monitoring period. Size criteria for assigning targets as juvenile American Shad were the same as those described above for Cabot Station (based on bypass sampler mean lengths). Similar to the discussion in Section 4.1.2 above, hydroacoustics data collected in the Northfield Mountain Project intake/tailrace channel could not be used for estimating the magnitude of juvenile American Shad entrained due to excessive milling observed in the data set. Some level of milling is common in split beam data sets and is accounted for in the entrainment estimate using criteria No. 2 described in Section 3.1.3.3. However, data collected at the NMPS intake exhibited such high levels of milling that a valid entrainment estimate could not be achieved. This result was likely due to the water velocity at the monitoring area, which was not high enough to obligate entrainment. Due to logistical constraints, the transducers at Northfield Mountain could only be mounted in front of the intake, a point at which fish were not obligated to pass due to low water velocities. An analysis of the data revealed that substantial milling of fish was observed at the monitoring location and this behavior prevented an accurate estimate of entrainment due to the potential for individual fish to be counted multiple times by moving into and out of the acoustic beam.

In 2015, the TransCanada study team evaluated the diel movement of juvenile shad at the Vernon Project located upstream of the NMPS intake. Through the use of radio telemetry methods they determined that the majority (85.5%) of tagged juvenile American Shad passed through Vernon Dam between the hours of 16:00 and 23:00, but only 8.7% of the 241 shad that passed through the Vernon facility migrated between 00:00 and 06:00, the hours when the majority of the pumping occurs at Northfield Mountain (NAI 2016).

Twenty three rain events occurred during FirstLight's study period ranging from trace amounts to nearly 2.4 inches of rain on September 30, 2015 (Figure 4.1.3-1). Water temperature as recorded at Water Quality Site No. 4 in the vicinity of the Northfield Mountain intake/tailrace was about 25°C at the onset of the monitoring period, obtained a maximum of 26.5°C in mid-August, and decreased to 7.9°C by the end of the study period in mid-November (Figure 4.1.3-2). Dissolved oxygen levels remained adequate to support shad and other aquatic life (greater than 5.0 mg/L) throughout the monitoring period.

4.1.4 Verification Sampling

Over 15 sampling nights between September 9 and October 28, 2015, 11,351 juvenile American Shad were counted at the Cabot Station bypass sampler (Table 4.1.4-1). Of these, 443 were measured for total length (Figure 4.1.4-1). Fish were not measured on the nights of October 12-14 and 19, 2015 in an attempt to reduce the stress from handling on fish that would later be used for the radio telemetry and survival components of this study. Measured shad ranged in length from 60 mm to 145 mm, with a mean total length for the entire sampling period of 91 mm. Mean total length increased throughout the course of the sampling period (Figure 4.1.4-2). The trend in mean length observed from fish collected at the Cabot Station bypass sampler was considered in analysis of the split beam sonar data as indicated above.

Observations of other species were noted during each sampling event. Nine individuals representing five species were observed (Table 4.1.4-1). Overall, juvenile American Shad dominated the catch and accounted for more than 99.9% of the observations. As such, it was assumed that 99.9% of the targets ranging in total length from 60 mm to 120 mm observed during processing of the split beam sonar data were juvenile American Shad.

The number of juvenile shad observed at the bypass sampler was directly compared (over the same period of time) to the number of juvenile shad-sized targets identified in echogram processing of Cabot Station split beam data (for all units in operation during that period) to investigate the proportion of bypassed shad versus estimated entrained shad as they migrate out of the canal (Figure 4.1.4-3; Table 4.1.4-2). Based on concurrent observations at the bypass sampler and Cabot Station intake, it was estimated that an average of approximately 43% of juvenile shad exit the canal via the downstream bypass and 57% are subject to entrainment at Cabot Station.

Table 4.1.1-1. Mean Length of Shad collected at Cabot Station Bypass Sampler and Ranges considered for Targets identified as Juvenile American Shad.

Month	Mean Length (mm)	Length (mm) Range for Shad Targets
August	77	62 – 92
September	92	75 – 107
October	103	88 – 118
November	109	94 – 120

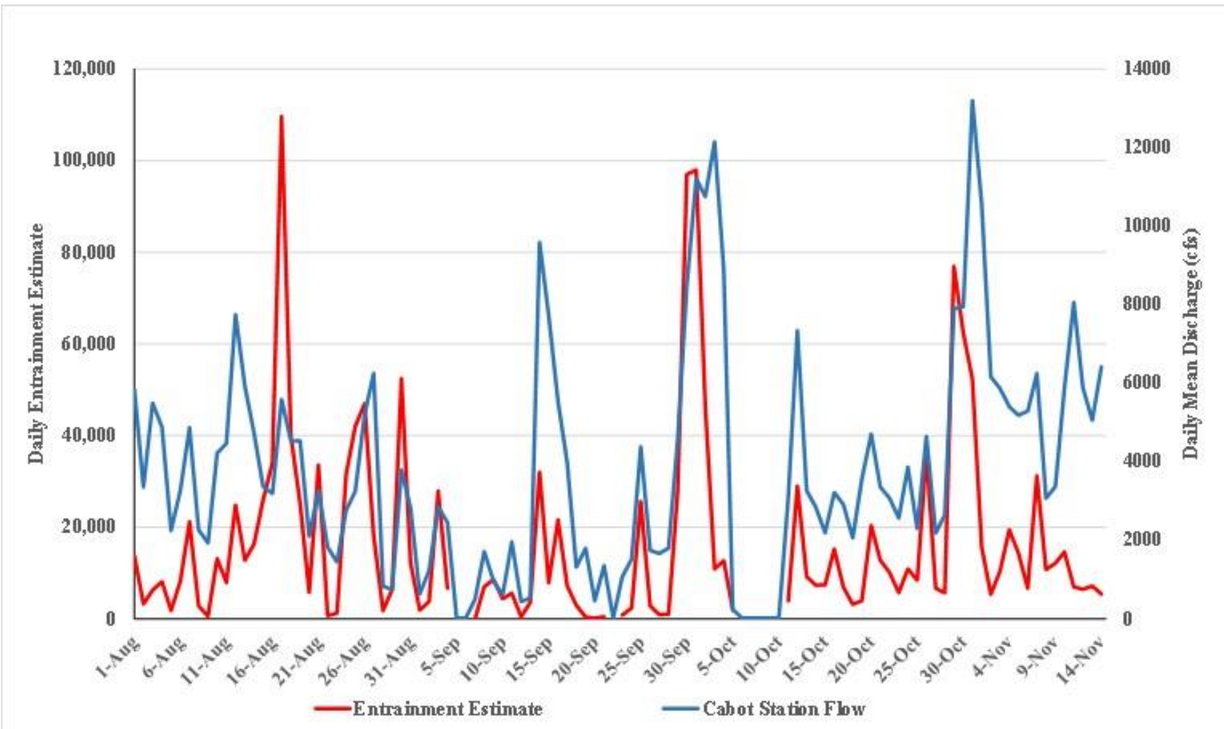

Figure 4.1.1-1. Estimated Entrainment of Juvenile Shad-Sized Targets and Daily Mean Flow at Cabot Station

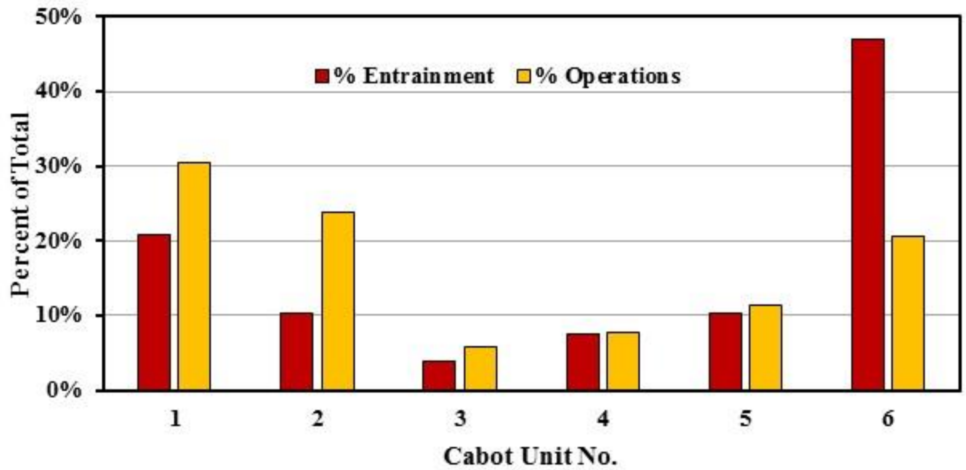

Figure 4.1.1-2. Proportion of Total Estimated Entrainment and Operations by Unit at Cabot Station during August 1 to November 15, 2015

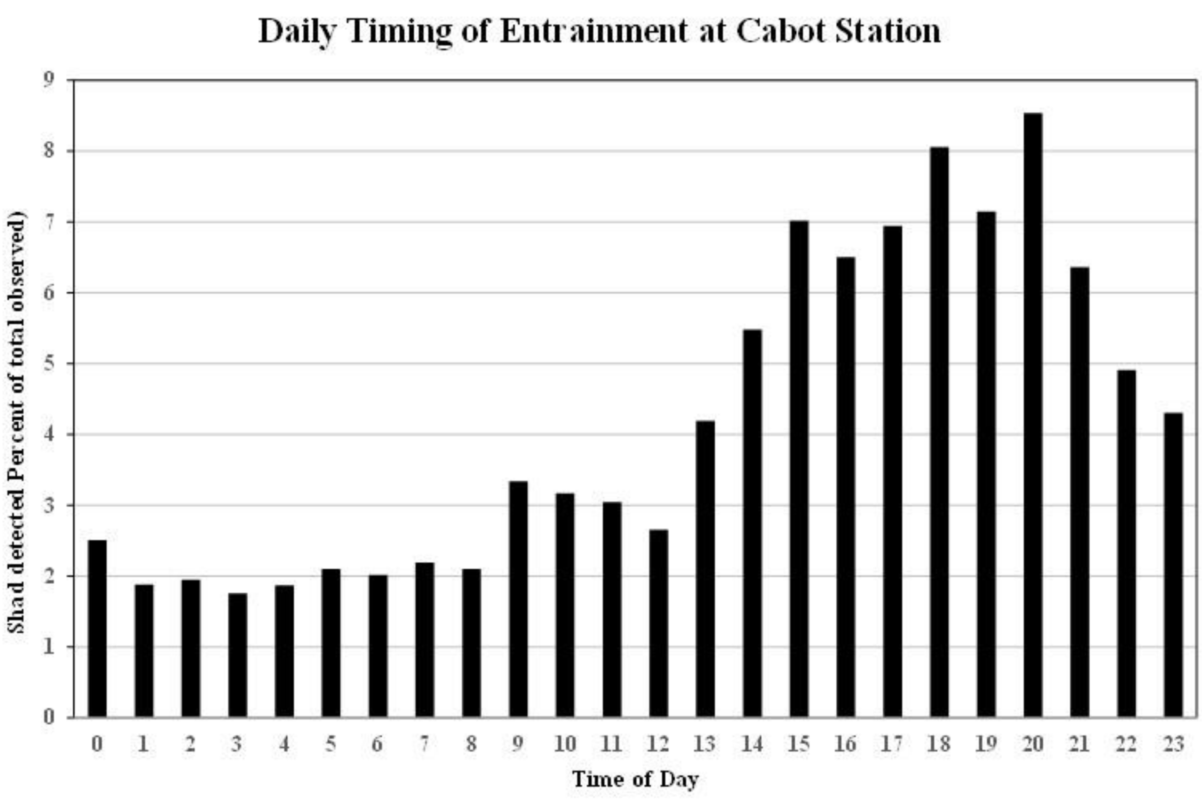

Figure 4.1.1-3. Diel distribution of entrainment at Cabot Station for all units throughout the study period August 1 – November 14, 2015.

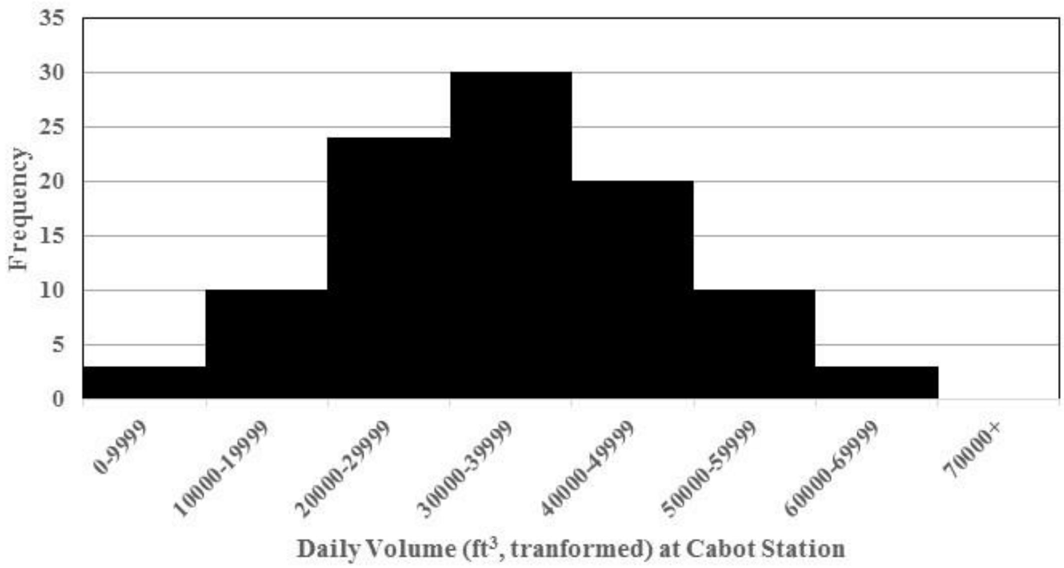

Figure 4.1.1-4. Histogram of Total Daily Volume (ft^3, transformed ^0.5) at Cabot Station from August 1 to November 14, 2015

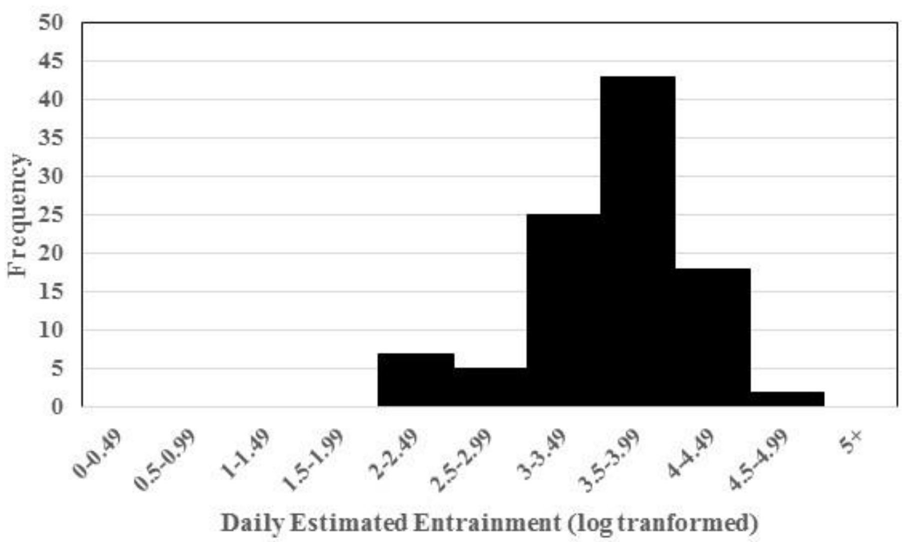

Figure 4.1.1-5: Histogram of Log Transformation of Daily Fish Counts at Cabot Station from August 1 to November 14, 2015

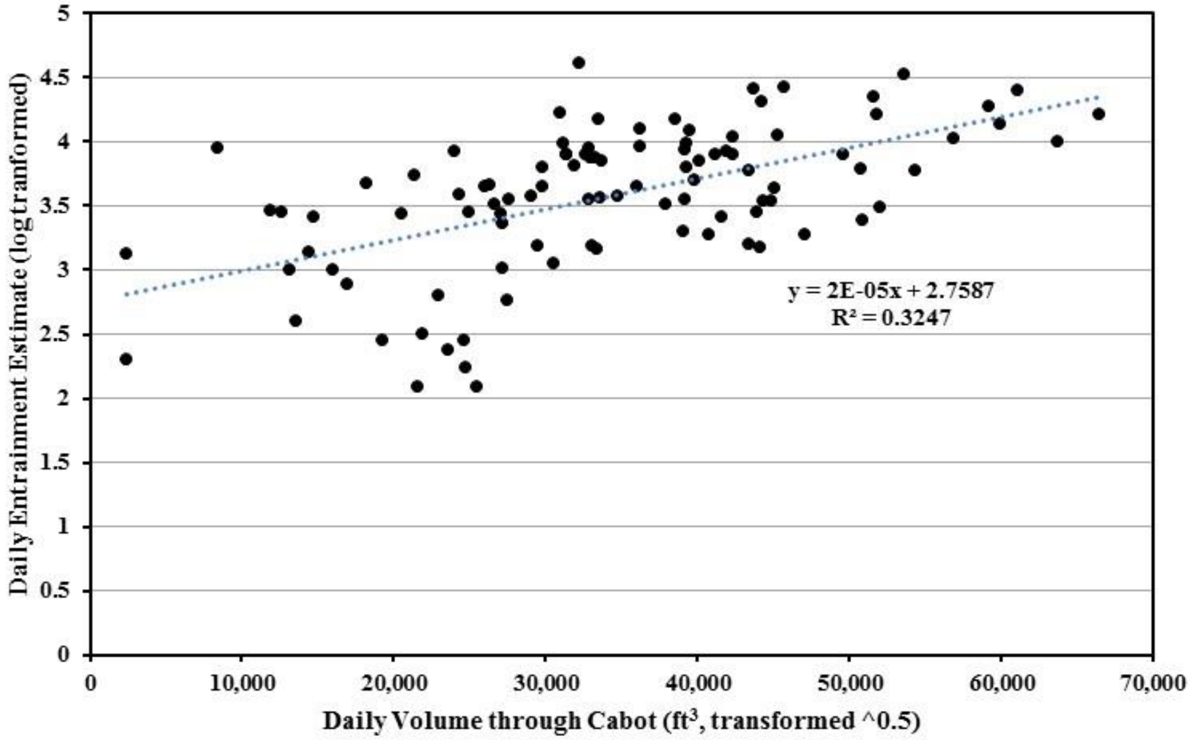

Figure 4.1.1-6: Relationship between Daily Total Volume (ft^3, transformed ^0.5) and the Daily Estimated Entrainment (log transformed) at Cabot Station from August 1 to November 14, 2015

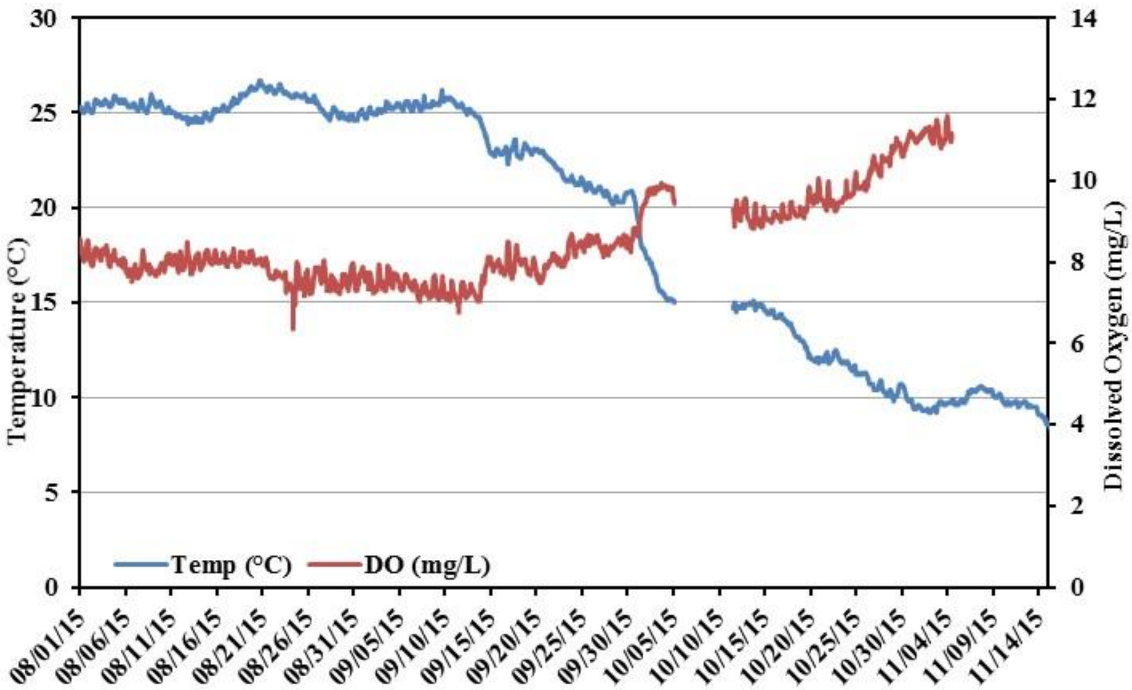

Figure 4.1.1-7. Continuous Water Temperature and Dissolved Oxygen Data recorded at Water Quality Station No. 10 located in the Turners Falls Power Canal.

No data were recorded during the canal outage from October 5 to October 10, 2015.

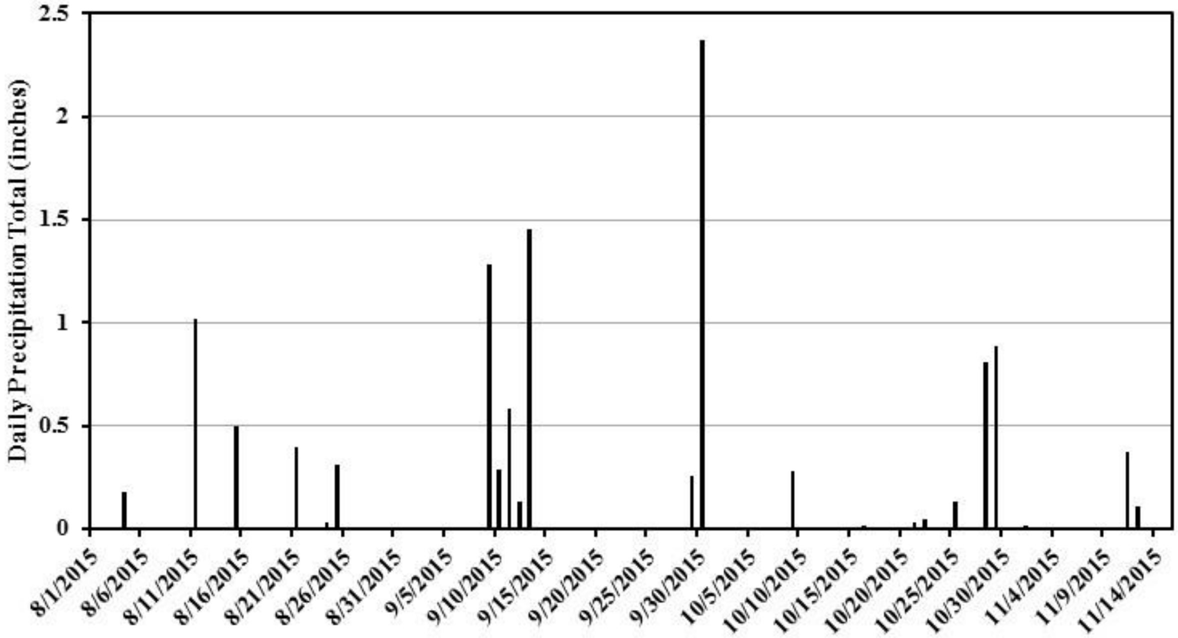

Figure 4.1.3-1. Total Daily Precipitation throughout the Monitoring Period as measured at Weather Station KORE in Orange, MA

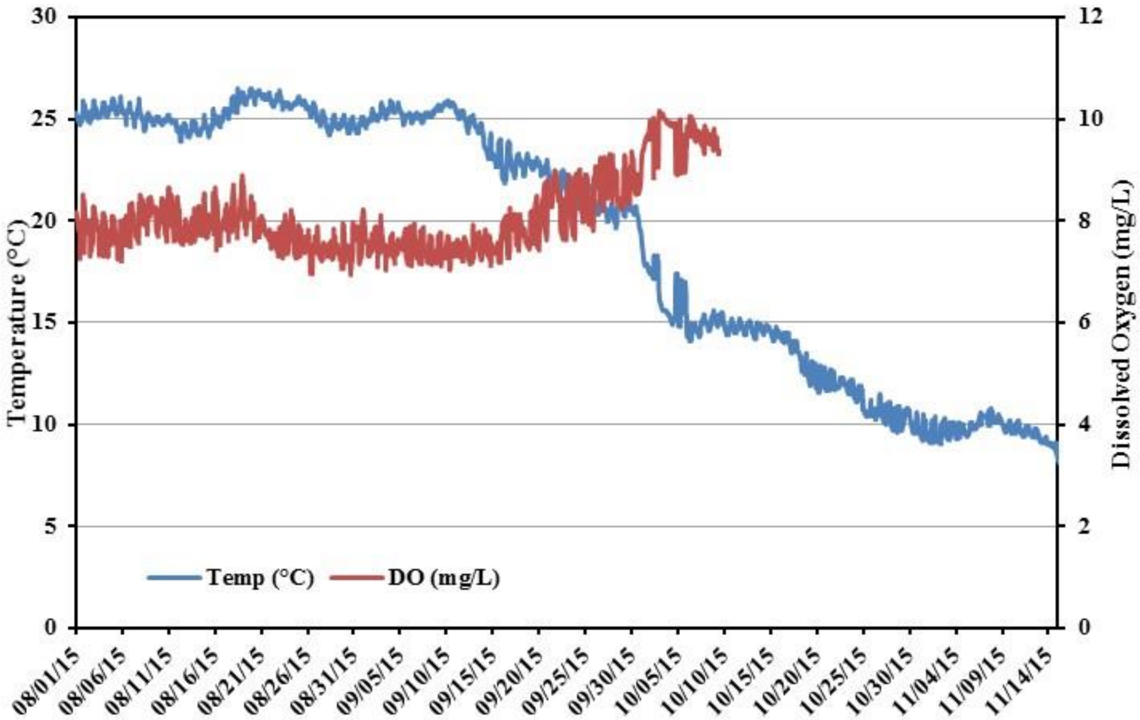

Figure 4.1.3-2. Continuous Water Temperature and Dissolved Oxygen Data recorded at Water Quality Station No. 4 Located in the Vicinity of the Northfield Mountain Project Intake/Tailrace Area.

The Water Quality Study required dissolved oxygen data collection through September 30, 2015. Water temperatures were collected through mid-November.

Table 4.1.4-1. Summary of Sampling Efforts at the Cabot Station Bypass Sampler in the Turners Falls Power Canal

Date	Start Time	End Time	Total Shad Count	Mean Total Length (mm)	Bycatch
9/9/15	15:45	18:15	0		
9/10/15	18:45	21:00	293	83.1	
9/15/15	16:00	22:00	1,263	82.2	1 Catfish, 1 Blueback Herring
9/17/15	16:30	22:12	1,770	80.4	1 Blueback Herring
9/21/15	15:30	22:30	158	87.7	
9/23/15	15:30	22:30	23	83.8	
9/28/15	15:30	22:00	20	95.3	
9/30/15	15:30	22:00	855	92.4	2 Eel
10/12/15	16:20	21:50	404	N/A	2 Smallmouth Bass, 1 Pickerel
10/13/15	16:20	22:00	1,032	N/A	
10/14/15	15:30	22:00	172	N/A	
10/19/15	16:00	22:00	976	N/A	
10/21/15	15:30	22:00	675	99.0	
10/26/15	15:40	22:00	2,086	99.4	
10/28/15	15:45	22:00	1,624	102.0	1 Eel
	Total		**11,351**		**9**

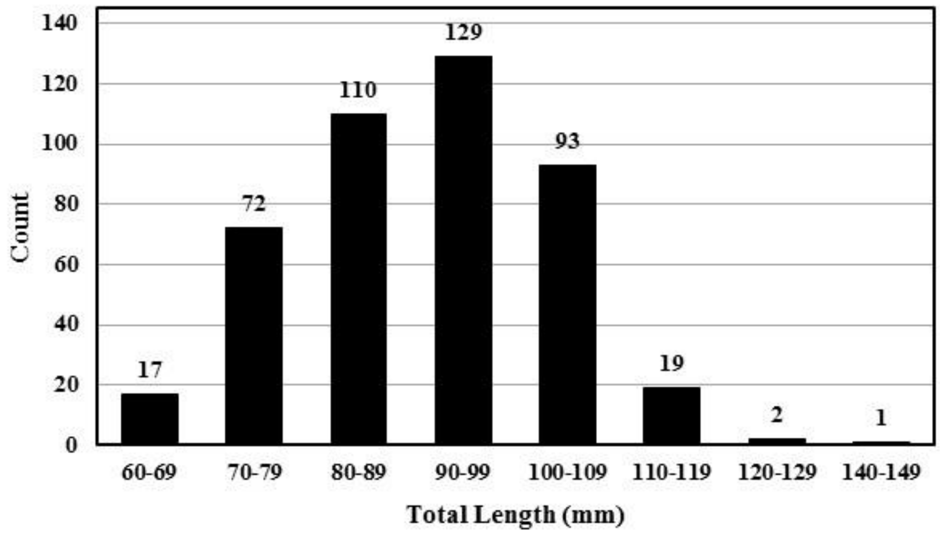

Figure 4.1.4-1: Length Distribution of Juvenile Shad collected at the Cabot Station Bypass Sampler

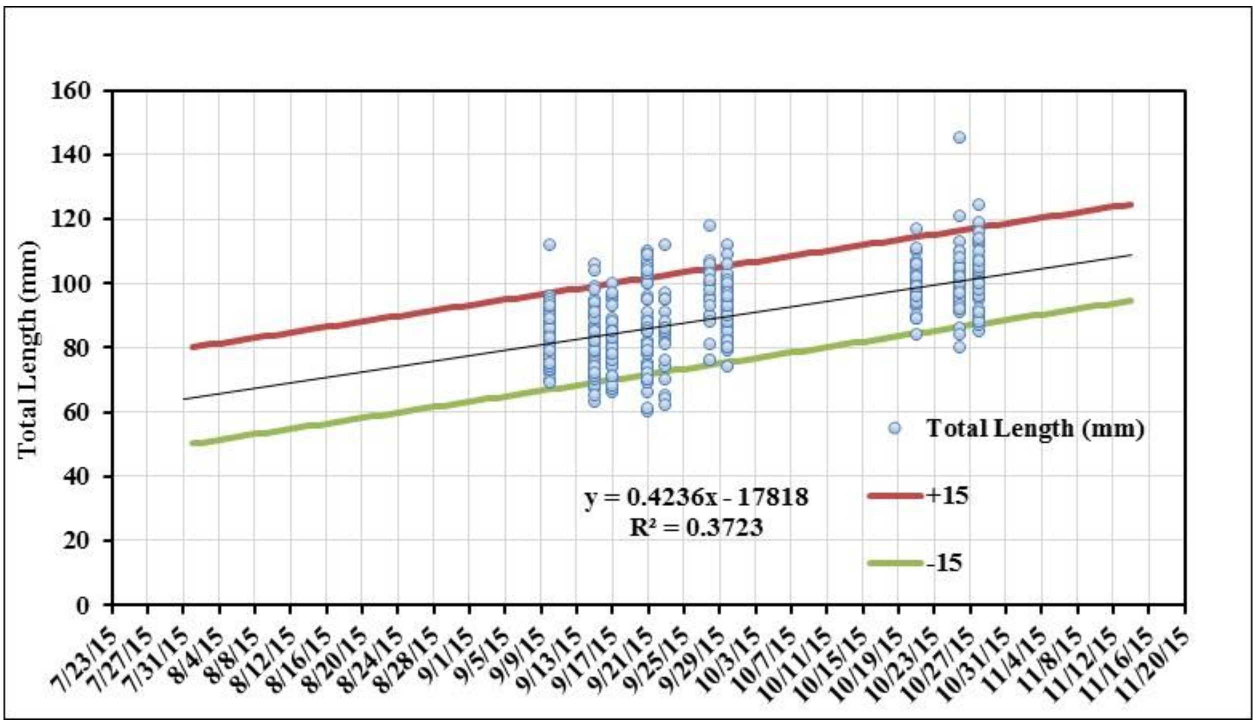

Figure 4.1.4-2: Total Length of Juvenile Shad measured at Cabot Station Bypass Sampler

Red and green lines indicate the range from the mean used in processing hydroacoustic data.

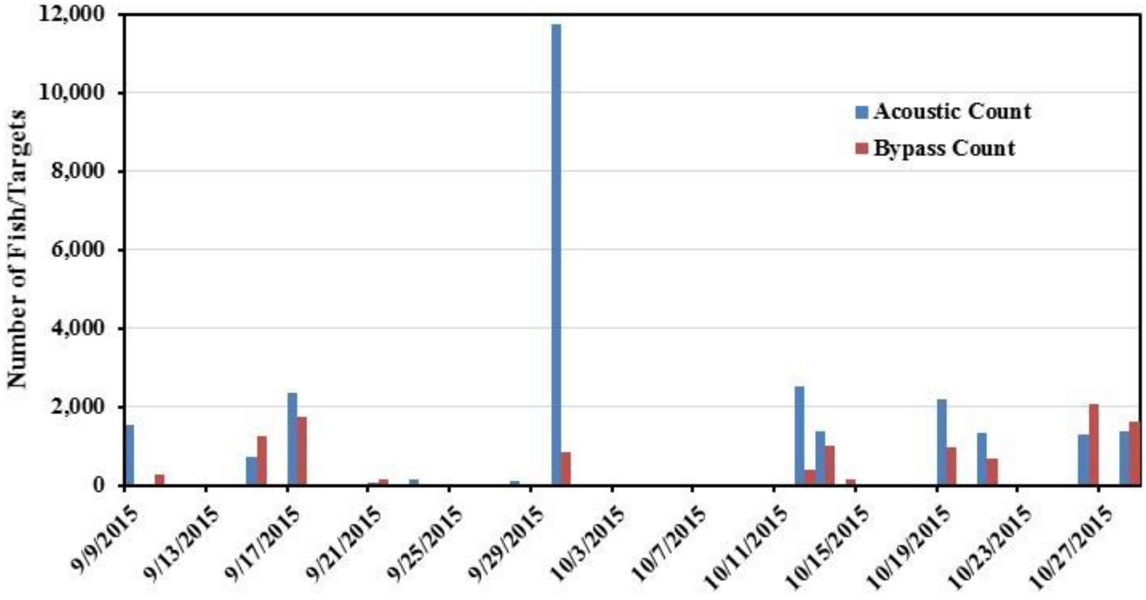

Figure 4.1.4-3. Counts of Juvenile Shad observed at Cabot Station Bypass Sampler and Acoustic Targets at Cabot Station Intake during Concurrent Sampling Events

Table 4.1.4-2. Summary of Concurrent Sampling Results to determine Juvenile Shad Passage Routes through the Canal

Date	Start Time	End Time	No. Units Operating	Total Count	% Bypass	% Cabot Station
9/9/2015	15:45	18:15	0 to 2	1,545	0%	100%
9/10/2015	18:45	21:00	0	293	100%	0%
9/15/2015	16:00	22:00	5 to 2	2,002	63%	37%
9/17/2015	16:30	22:12	5 to 0	4,153	43%	57%
9/21/2015	15:30	22:30	1	237	67%	33%
9/23/2015	15:30	22:30	1	197	12%	88%
9/28/2015	15:30	22:00	1	145	14%	86%
9/30/2015	15:30	22:00	6	12,617	7%	93%
10/12/2015	16:20	21:50	5 to 1 to 5	2,945	14%	86%
10/13/2015	16:20	22:00	1 to 0 to 3	2,414	43%	57%
10/14/2015	15:30	22:00	1 to 3	172	100%	0%
10/19/2015	16:00	22:00	1 to 4	3,187	31%	69%
10/21/2015	15:30	22:00	1 to 4	2,011	34%	66%
10/26/2015	15:40	22:00	2 to 4	3,404	61%	39%
10/28/2015	15:45	22:00	1 to 3	3,001	54%	46%
				Mean	**43%**	**57%**

4.2 Evaluation of Passage Routes (Radio Telemetry)

4.2.1 Tagging Control Experiment

Fifty (50) juvenile shad equipped with mock tags of the same weight and approximate size as the Lotek NanoTag were held to assess tag retention and mortality as well as any effects on behavior. The mock tags were affixed on October 15, 2015. Fish were observed each day post-tagging for one week and mortalities, tag loss and tag retention were recorded (Table 4.2.1-1). Mortality in the first two days was high; 40 juvenile shad (80%) had died by the end of the October 17. The mortality rate decreased in the remaining days of the experiment. Seven days after tagging, only one live fish remained in the control tank. Overall, 20 shad (40%) shed or lost their tags. Field staff noted that swimming behavior was irregular, such that fish were listing to one side (tag side down) and did not appear to be swimming normally.

4.2.2 Routes of Passage

A total of 218 juvenile shad were tagged and released at two locations (see Table 3.2.3-1). Despite prior consultation with the TransCanada study team, 48 radio-tagged American Eels were released in support of TransCanada relicensing efforts upstream of the Project area using identical frequencies and codes, after the tagged juvenile shad had been released. Of those, 18 redundant tag ID's (Table 4.2.2-1) had to be removed from the juvenile shad telemetry dataset to eliminate any ambiguity in the analysis. Of the remaining 200 tagged juvenile shad, 17 were released in the canal prior to the drawdown on October 4, 2015 to assess juvenile shad escape routes per the request of stakeholders.

The remaining tagged fish (n = 183) were released either 1.5 miles upstream of the Northfield Mountain intake/tailrace (n= 129) or 1.25 miles upstream of the TFD (n=54) (see Figure 3.2.3-1). A large proportion of tagged juvenile shad (n=70, 38% of releases) were never detected at any of the fixed telemetry stations (Figure 4.2.2-1). A similar proportion of tagged juvenile shad (n=71, 39% of releases) remained in the TFI and was never detected at or downstream of the TFD and Gatehouse. Only two juvenile shad (1% of releases) passed over the TFD and 16 (9% of release) passed through to the power canal. The remainder of juvenile shad were last detected at the Northfield Mountain Project intake/tailrace receiver station (n=21, 11% of releases) or the Northfield Mountain Upper Reservoir station (n=3, 2% of releases). All three shad detected in the upper reservoir were previously detected at the intake/tailrace station.

A total of 129 tagged juvenile Shad were released upstream of the NMPS intake/tailrace area. Of those, 77 shad (60% of release) were detected at Shearer Farms fixed telemetry monitoring station (T1 and T2) located approximately 1.2 river miles downstream of the release point and approximately 0.5 miles upstream of the NMPS intake/tailrace. These fish represent the cohort of emigrating fish that entered the NMPS area. Thirty two of these fish emigrated past the NMPS intake/tailrace area and continued downstream approximately 0.66 miles downstream of the NMPS intake/tailrace where they were detected at that Gill Banks monitoring station (T5 and T6) for a passage rate of 41.6 % through this reach of the TFI. Of the fish that entered this reach 72.7% were either detected in the NMPS intake/tailrace area, the upper reservoir or downstream of the NMPS intake/tailrace; leaving 27.3% undetected. Three fish were entrained and detected in the Upper Reservoir of Northfield Mountain, suggesting an entrainment rate of 3.9%. Twenty-one (21) additional fish were last detected at the Northfield Mountain intake/tailrace and were never detected again at any of the telemetry receiver stations. Of those 21 fish, 14 were last detected at the Northfield Mountain intake/tailrace during pumping operations.

After entering the Turners Falls Power Canal, juvenile shad (n=16) experienced various flow regimes (Figure 4.2.2-2). As depicted in Figure 4.2.2-2, twelve (12) fish (IDs 1, 2, 5, 6, 7, 9, 10, 12, 13, 14, 15 and 16) are only depicted as dashes because they were initially detected at the upstream end of the canal via mobile tracking and never detected subsequently at any other fixed telemetry sites within the canal or anywhere downstream (Table 4.2.2-2). Most of these fish presumably experienced the flow regimes depicted in Figure 4.2.2-2; however, it remains unknown whether they died, ended up in a non-detectable region of the canal, exited the canal without detection, or if the tags stopped working or were shed.

4.2.3 Rate of Movement

Juvenile shad (n=113, 61.7% of releases) detected at the impoundment receiver stations exhibited a mean rate of downstream movement of 0.31 RM/h (Table 4.2.3-1).

Two fish passed the TFD and only one was detected further downstream by the yagi antenna located at the Station No. 1 tailrace. The second fish that passed TFD was only detected immediately below the TFD and never again at any downstream stations. The fish that passed the TFD continued through the bypass reach to the Station No.1 tailrace at a rate of 1.45 RM/h (Table 4.2.3-1).

Sixteen juvenile shad (9% of releases) were detected at the upstream end of the canal and only four of those fish were detected subsequently further downstream (Table 4.2.2-2). Three shad were subsequently detected in the Cabot tailrace and were likely entrained. However, these shad were not detected at the Cabot forebay or bypass prior to detection in the tailrace. The one remaining fish was detected in the Cabot forebay but never detected downstream and presumably never left the canal, at least during the anticipated tag life. Based on these fish, the mean rate of movement through the canal was 0.03 RM/h (Table 4.2.3-1). No fish released in the impoundment was detected in the Station No. 1 Forebay.

4.2.4 Timing of Passage

Movement through the Turners Falls Project occurred during evening hours. Project passage occurred between 21:17 and 21:37 for the three fish that exited the canal via entrainment through Cabot Station on October 12, 2015. The time of passage of these shad through Cabot Station corresponded to a diel period of increased entrainment as evident by the split beam data, which determined that a substantial amount (6.4%) of the total entrainment observed at Cabot Station occurred during the 21:00 hour (see Figure 4.1.1-3). Passage at the TFD, for two individuals, occurred on October 12, 2015 at 21:34 and on October 13, 2015 at 23:22 when Bascule Gate 1 was spilling 5,945 and 1,487 cfs, respectively. Twelve of the 16 fish that entered the canal were first detected on October 12, 2015 between 21:17 and 22:02 (Table 4.2.2-2). Figure 4.2.4-1 depicts the distribution of flow between the TFD and Gatehouse on October 12 and 13. Bascule Gate 1 was the only gate spilling at the dam during the passage events.

4.2.5 Canal Drawdown

Seventeen (17) fish were released into the Turners Falls Power Canal on the evening of October 4, 2015 prior to the drawdown that commenced later that night. Following the initiation of the canal dewatering, mobile tracking efforts were initiated at approximately 13:10 on October 5 and seven (7) of the fish released were detected in the canal (Figure 4.2.5-1). Five (5) fish were detected in the same area of release; two (2) at the upper canal release site and three (3) at the lower canal release site. The final disposition of these fish, as well as the undetected fish (n=10) remains uncertain; however, possibilities include tag loss; mortality due to tagging or other cause; fish remained in the watered portion of the canal for the duration of the drawdown without detection; or fish exited the canal without detection.

One fish released in the upper canal was last detected in the vicinity of the Station No. 1 forebay. Based on FirstLight station logs, generation at Station No. 1 ceased at 19:30 on October 4, 2015 and the units remained offline until 08:45 on October 16, 2015 (Figure 4.2.5-2). While the fish was not subjected to turbine passage at Station No. 1 since the units were not operating, lack of subsequent detections in the bypass reach or further downstream in the lower canal prevents confirmation of passage downstream of the Project.

Similar to the upper canal released fish, one fish released in the lower portion of the canal was last detected at the Cabot Station forebay on October 5 at 13:57. As the canal was being dewatered, Cabot Station went offline on October 5 at approximately 06:00 and the units remained inactive until October 11, 2015 (see

Figure 4.1.1-1). Although passage cannot be confirmed, it is certain that this fish was not subjected to operational turbine passage effects, prior to re-watering of the canal.

An objective of Study 3.3.18 *Impacts of the Turners Falls Canal Drawdown on Fish Migration and Aquatic Organisms* was to assess whether juvenile shad and American eel abundance in the canal increases leading up to the time of its closure, due to delays in downstream passage (e.g., is fish accumulation occurring). The canal drawdown began in the late evening of October 4, 2015. Split beam hydroacoustics data collected at the Cabot Station intake indicated an increase in entrainment rate during the week leading up to the canal drawdown beginning on September 28, 2015 with a rate of 1,100 shad sized targets per day to a peak of approximately 98,000 entrained per day on October 1 (Figure 4.1.1-1). The increase in entrainment is related to the abundance of shad in the power canal such that as shad abundance increases in the forebay so does entrainment at Cabot Station. This increase in entrainment coincided with an increase in river flow and discharge at Cabot Station, which has a positive relationship with an increase in canal flow and intake velocity. The highest river flows experienced during the study occurred on October 3, 2015 the day before the start of the drawdown. The daily entrainment rate decrease to approximately 13,000 per day on October 4 immediately before the drawdown (Figure 4.1.1-1). Entrainment decreased prior to the decrease in discharge at Cabot Station suggesting that an accumulation of shad occurred during the relatively low flow period in the canal but shad were conveyed downstream during the increase in canal flow and discharge at Cabot Station prior to the drawdown.

Table 4.2.1-1. Summary of Tagging Control Experiment based on 50 fish equipped with Mock Tags

	Holding Tank		Mortalities/Day		Tags Lost/Day		Tags Retained/Day	
Date	**Water Temperature (°C)**	**DO (mg/L)**	**No.**	**Mean Length (mm)**	**No.**	**Mean Length (mm)**	**No.**	**Mean Length (mm)**
10/15/2015	-	-	19	95.8	5	100.4	14	94.2
10/16/2015	14.8	9.2	20	93.3	10	93.1	10	93.4
10/17/2015	-	-	1	96.0	0	-	1	96.0
10/18/2015	-	-	0	-	0	-	0	-
10/19/2015	10.8	9.2	6	91.3	4	89.3	2	95.5
10/20/2015	11.5	10.0	2	90.5	1	93.0	1	88.0
10/21/2015	11.5	9.1	1	89.0	0	-	1	89.0
10/22/2015	-	-	0	-	0	-	0	-
Mean	**12.1**	**9.4**		**92.7**		**93.9**		**92.7**
		Total (%)	**49 (98%)**		**20 (40%)**		**29 (58%)**	

Table 4.2.2-1: Juvenile Shad Redundant Tag Summary with Tag Frequencies and Codes of those Fish Eliminated from Analysis

Count	Frequency/Code	Release Date	Impoundment Release Location
1	150.360/104	10/15/2015	Upstream of NMPS
2	150.360/107	10/15/2015	Upstream of NMPS
3	150.360/108	10/15/2015	Upstream of NMPS
4	150.360/109	10/15/2015	Upstream of TFD
5	150.360/116	10/15/2015	Upstream of TFD
6	150.360/119	10/13/2015	Upstream of NMPS
7	150.360/122	10/13/2015	Upstream of TFD
8	150.360/123	10/13/2015	Upstream of TFD
9	150.360/135	10/15/2015	Upstream of TFD
10	150.360/136	10/13/2015	Upstream of NMPS
11	150.360/137	10/13/2015	Upstream of TFD
12	150.360/138	10/20/2015	Upstream of NMPS
13	150.380/58	10/16/2015	Upstream of NMPS
14	150.380/59	10/15/2015	Upstream of TFD
15	150.380/62	10/13/2015	Upstream of TFD
16	150.380/132	10/13/2015	Upstream of TFD
17	150.380/133	10/13/2015	Upstream of NMPS
18	150.380/134	10/13/2015	Upstream of NMPS

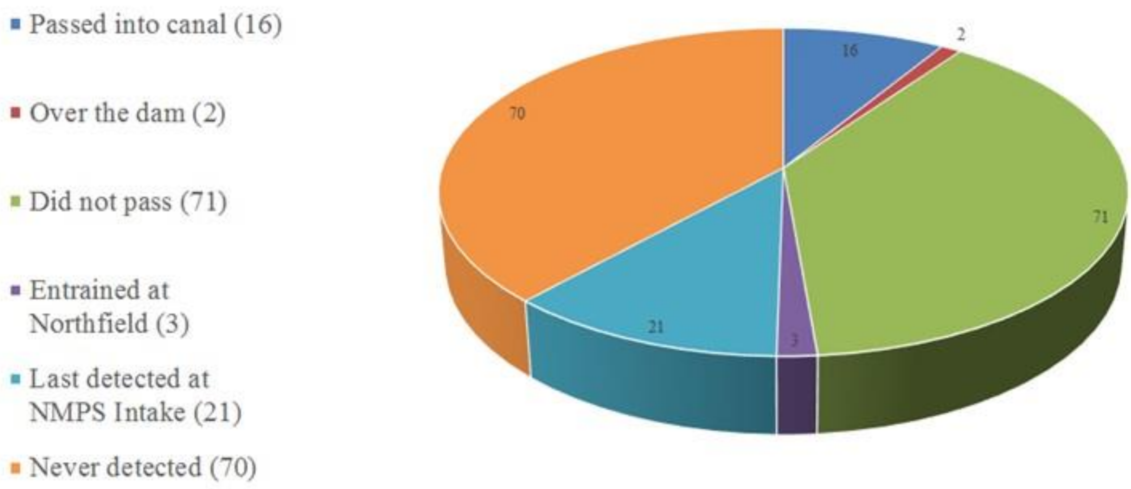

Figure 4.2.2-1: Final Disposition of 183 Juvenile Shad Tagged and Released Upstream of TFD and Upstream of the NMPS Intake/Tailrace

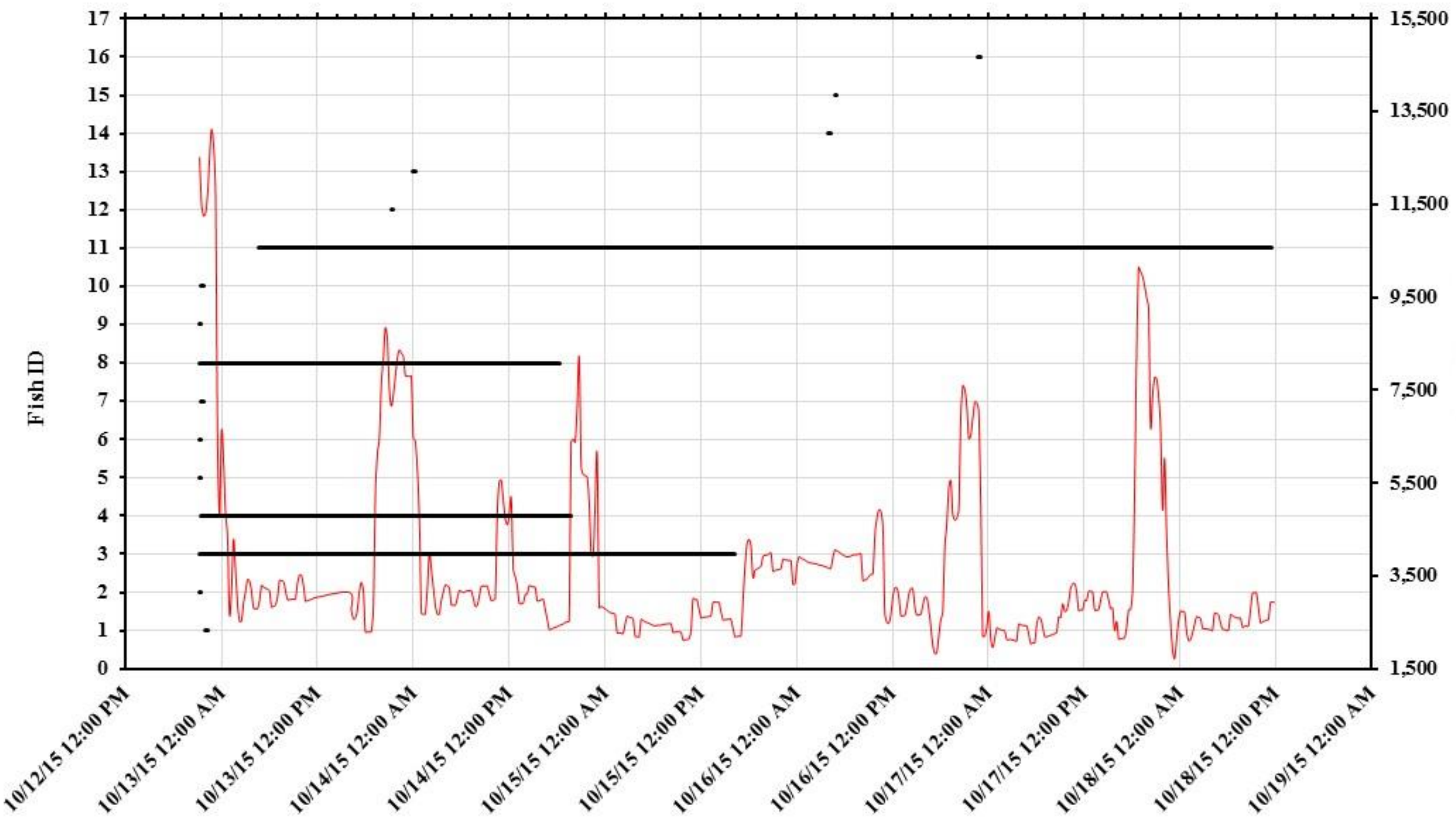

Figure 4.2.2-2: Juvenile Shad Duration in Turners Falls Power Canal under Various Operational Conditions (n = 16). The black lines indicate duration and the red line indicates flow

Table 4.2.2-2: Summary of Juvenile Shad Detected in the Turners Falls Power Canal

Fish ID	Release Date and Time	Release Location	Date and Time of First Detection	Duration to Last Detection h:min:sec	Last Detection Location
1	10/12/2015 19:20	Upstream of TFD	10/12/2015 22:02	0:1:2	T10 (Upper Canal)
2	10/12/2015 19:20	Upstream of TFD	10/12/2015 21:26	0:1:6	T10 (Upper Canal)
3	10/12/2015 19:20	Upstream of TFD	10/12/2015 21:17	66:58:0	T17 (Cabot Tailrace)
4	10/12/2015 19:20	Upstream of TFD	10/12/2015 21:37	46:8:0	T17 (Cabot Tailrace)
5	10/12/2015 19:20	Upstream of TFD	10/12/2015 21:22	0:0:48	T10 (Upper Canal)
6	10/12/2015 19:20	Upstream of TFD	10/12/2015 21:20	0:0:48	T10 (Upper Canal)
7	10/12/2015 19:20	Upstream of TFD	10/12/2015 21:34	0:0:54	T10 (Upper Canal)
8	10/12/2015 19:20	Upstream of TFD	10/12/2015 21:27	43:5:0	T17 (Cabot Tailrace)
9	10/12/2015 19:20	Upstream of TFD	10/12/2015 21:27	0:1:10	T10 (Upper Canal)
10	10/12/2015 19:20	Upstream of TFD	10/12/2015 21:40	0:0:44	T10 (Upper Canal)
11	10/12/2015 19:20	Upstream of TFD	10/13/2015 04:49	125:51:0	T171 (Cabot Forebay)
12	10/12/2015 19:20	Upstream of NMPS	10/13/2015 21:17	0:1:0	T10 (Upper Canal)
13	10/13/2015 21:05	Upstream of TFD	10/14/2015 00:10	0:0:48	T10 (Upper Canal)
14	10/15/2015 19:45	Upstream of TFD	10/16/2015 04:06	0:6:0	T10 (Upper Canal)
15	10/15/2015 19:45	Upstream of TFD	10/16/2015 04:50	0:2:0	T10 (Upper Canal)
16	10/13/2015 20:05	Upstream of TFD	10/16/2015 22:48	0:1:0	T10 (Upper Canal)

Table 4.2.3-1: Rates of Juvenile Shad Movement (RM/h) in the Turners Falls Impoundment, Bypass Reach and through the Turners Falls Power Canal

Reach	No. of Fish	Rate of Movement (RM/h)		
		Minimum	Maximum	Mean
Impoundment	113	0.007	1.58	0.31
Bypass Reach	1	1.45	1.45	1.45
Canal	4	0.015	0.05	0.03

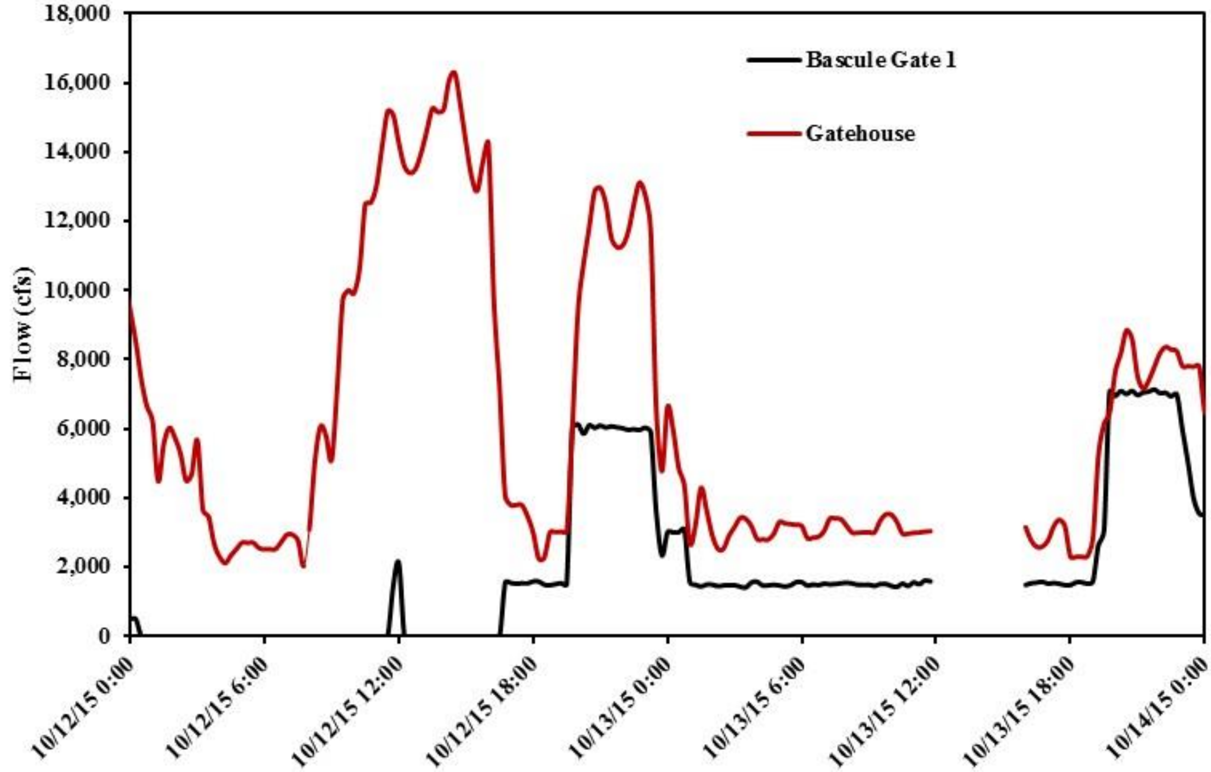

Figure 4.2.4-1. Flow Distribution between Bascule Gate 1 and Gatehouse during October 12 and 13, 2015

Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Relicensing Study 3.3.3

N

0 0.1 0.2 0.4
Miles

Figure 4.2.5-1: Juvenile Shad Locations in Turners Falls Power Canal During 2015 Drawdown

Path: W:\gis\studies\3_3_3\maps\Figure 4.2.5-1.mxd

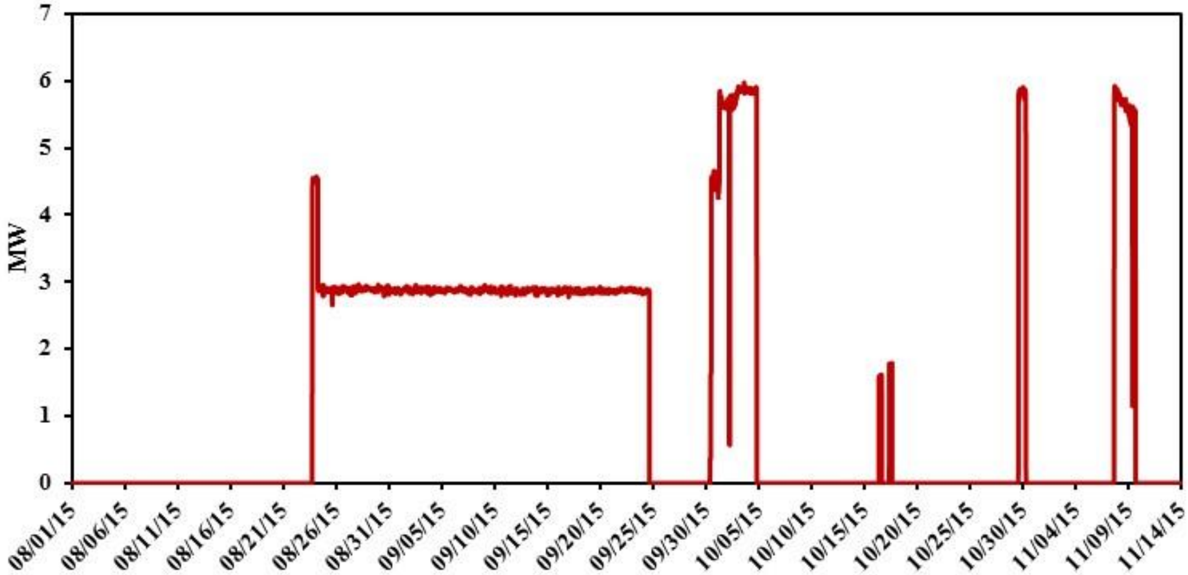

Figure 4.2.5-2. Station No. 1 Generation throughout Juvenile Shad Study Period (August 1 to November 15, 2015)

5 DISCUSSION

In support of the relicensing of the Turners Falls and Northfield Mountain Projects, juvenile shad assessments were conducted within the Project area to determine if operations affect emigration success. Results of the 2015 field efforts conducted during the outmigration season in relation to the specific objectives identified in Section 1.2 herein are discussed in the following sections.

In regard to the radio telemetry experiment, in any investigation involving juvenile American Shad, difficulties arise in obtaining accurate survival estimates. Juvenile American Shad are notoriously sensitive to stress; and transporting, handling, holding and tagging are problematic. In this study tagging control mortality was high and the tagged fish swam irregularly. The results suggested that handling and tagging substantially affected survival of the juvenile shad, such that only 2% (n=1) survived over the course of the 7-day observation period. Water temperature and dissolved oxygen were monitored in the holding tank and did not appear to be factors contributing to the low survival of tagged fish. In addition to mortalities, the field crew noted irregular swimming behavior of tagged fish upon release into the holding tank and throughout daily observations. The weight of the tag appeared to affect swimming capabilities as shad were observed swimming with their dorsoventral axis oriented nearly parallel to the surface (tag-side down) as opposed to typical swimming orientation. Combined with handling stress, it is likely that the many of the tagged shad were unable to sustain normal activity following the tagging process. Given these observations, the validity of the results of this study are left in question. While some results were achieved it is likely that the inherent problems of handling and tagging juvenile shad had a negative effect on the effectiveness of the study and its findings. The limited results are likely inadequate to definitively determine route selection and travel times due to the effectively small sample size.

The lack of detections and movement out of the impoundment may have been further exacerbated by tag retention issues and distance to release sites. Twenty (40% of total) of the mortalities observed in the control experiment were reported to have shed their tags. If tag loss occurred in any of the deeper areas (greater than 15 ft) of the lower impoundment, then detection by the aerial yagi antennas used during mobile tracking surveys would not be expected. In addition, fish released upstream of the Northfield Mountain intake/tailrace had to swim approximately 1 RM downstream to encounter the first fixed telemetry at Shearer Farms. Fish that were released upstream of TFD had to swim approximately 0.9 RM downstream to encounter the fixed telemetry station near the boat barrier in the impoundment. With a mean rate of movement in the impoundment of 0.3 RM/h, any mortality or tag loss that occurred within the first 3-4 hours post-release would have contributed to the low numbers of juvenile detected.

5.1 Proportion of Juvenile Shad Passing Downstream through the Power Canal versus over the Dam under varied Operational Conditions, including a Range of Spill Conditions

Based on the 18 fish released in the TFI that moved downstream, two passed over the TFD and 16 passed through Gatehouse to enter the power canal. On October 12, 2015, 10 fish passed into the power canal within 2-3 hours from release 1.25 miles upstream of the dam. Fish released above TFD the following evening (n= 20) also passed in a similar timeframe; however, fish released on October 15 were at large in the TFI for nearly 9 hours prior to entering the canal. Flow distribution between the Gatehouse and the TFD on the evening of October 12 during the three hours from the time of release to detection of the last fish in that first group of 10, was such that 50-68% of flow was directed to the power canal, while 32-50% was directed toward the TFD. The flow distribution remained similar on the night of October 15, although no juvenile were detected at the TFD and fish remained in the impoundment for a longer duration before passing into the power canal.

5.2 Rate of Downstream Movement within the Impoundment, over the Dam and through the Bypass Reach, or through the Power Canal

Assessment of the radio-telemetry data suggested the mean rate of movement within the impoundment ranged from less than 0.01 RM/h to 1.6 RM/h, with a mean rate calculated as 0.3 RM/h.

The rates of movement determined through the Turners Falls Power Canal and Bypass Reach were based on very few individuals. The rate of movement through the Turners Falls Power Canal ranged from 0.015 to 0.05 RM/h (n=4), and of the two fish that passed over the TFD one fish arrived in the vicinity of the Station No. 1 tailrace at a rate of 1.45 RM/h.

5.3 Survival Rates for Juveniles Spilled over/through Dam Gates, under varied Operation Conditions, including up to Full Spill during the Annual Fall Power Canal Outage Period

The 1-hour direct survival rate of juvenile shad passing the TFD via Bascule Gate 1 was 69.4%, 47.7% and 75.6% during flow releases of 1,500 cfs, 2,500 cfs and 5,000 cfs, respectively, with an overall survival rate of 63% (NAI, 2016a). For Bascule Gate 4, 1-hour direct survival was 64.2%, 59.0% and 73.6 during flow releases of 1,500 cfs, 2,500 cfs and 5,000 cfs, respectively, with an overall survival rate of 64.8% (NAI, 2016a). For both gates, a greater percentage of fish was recaptured alive during the 5,000 cfs test condition. NAI suggested that the shallower depth of water below the spillway under the low flow conditions (1,500 cfs) does not provide much of a cushion to protect fish from contacting structures in its path. Based on results from previous studies using HI-Z tagging methodology with juvenile salmonids, the survival of passed fish is affected by spillway slope, radius of flow deflectors, angle that spilled water intercepts deflectors and other structures, depth of water passing over the spillway, location of the fish in the spillway jet, and operating head (NAI, 2016a). As such, the boulder and concrete sill structures immediately downstream of Bascule Gates 1 and 4 likely contributed to lower survival of the passed juvenile American Shad under the lower flow conditions.

The injury rates on the recaptured juvenile shad suggested that passage conditions are more favorable for fish passing the dam via Bascule Gate 1 as compared to Bascule Gate 4 (NAI, 2016a). Approximately 30% of the shad passed via Bascule Gate 1 were visibly injured compared to 44% at Bascule Gate 4. Contrary to the survival results, injury rates at Bascule Gate 1 were greater at the 2,500 cfs (35.3%) and 5,000 cfs (34.7%) discharge scenarios as compared to the lower discharge (19% at 1,500 cfs).

5.4 Downstream Passage Timing, Route Selection, and Rate of Movement of Juvenile Shad through the Power Canal to Station No. 1, Cabot Station and the Cabot Station bypass

During the radio telemetry evaluation, 16 of the 183 tagged juvenile shad released in the TFI passed through Gatehouse into the power canal; however, subsequent movement was only detected for four (4) fish. Passage into the canal generally occurred during night, with 14 of 16 fish entering the canal between 21:00 and 23:00.

All four (4) of the tracked radio-tagged fish moved downstream in the canal past Station No. 1 and proceeded to the Cabot Station forebay, with three (3) passing through Cabot Station. Tracking of these four (4) fish indicated a downstream rate of movement ranging from 0.015 to 0.05 RM/h in the canal.

Based on concurrent observations at the bypass sampler and Cabot Station intake during 15 discrete verification sampling events conducted between September 9 and October 15, 2015, it was estimated that an average of approximately 43% of juvenile shad exit the canal via the downstream bypass and 57% were subject to entrainment at Cabot Station. These findings were in contrast with earlier reports by RMC, 1994 which estimated 94.4% of juvenile clupeids passed downstream via the log sluice after it was equipped with artificial above-water lighting). However, it is important to note that the distribution between those passed via the Cabot Station bypass and Cabot Station varied, even under similar operating conditions at Cabot and Station No. 1. For example, on September 21, only Unit 1 was operating at Cabot Station during the verification sampling time period, while Station No. 1 was generating slightly less than 3 MW. Under these conditions, it was estimated that 67% of shad passed via the bypass while 33% were entrained through Cabot Station. On September 23, under similar operating conditions at Cabot Station and Station No. 1, it was estimated that 12% of shad passed via the bypass and 88% exited the canal via Cabot Station. Since operating conditions remained similar between to the two sampling events, it is concluded that the discrepancy is not attributable to Project operations.

A large discrepancy in the number of shad bypassed and the number observed at the Cabot Station intake occurred on September 30. This observation may be the result of operation at Cabot Station. The station was running at capacity resulting in comparatively high flow field within the forebay areas, which may have obscured attraction flow to the bypass resulting in a reduction of passage through the bypass. However, no other direct comparisons were made during such operational conditions.

The distribution of entrainment amongst the six units at Cabot Station suggests that fish are attracted to the right side (as viewed looking downstream) of the intake when Unit 6 is operational. As fish move downstream through the power canal and approach Cabot Station, they may train along the wall adjacent to the emergency spillway structure (Figure 5.4-1), becoming more susceptible to entrainment at Unit 6. FirstLight's operating scheme designates Unit 1 as the priority unit (first on, last off) due to its proximity to the downstream bypass structure.

The diel timing of entrainment was investigated at Cabot Station, revealing an elevated period of entrainment between 13:00 and 23:00 with the peak occurring at 20:00. This trend presumably was related to an increase in diel movement by juvenile shad. This result corresponds with other studies conducted on the Connecticut River in 2015. The TransCanada study team found that 86.3 % of the 241 radio tagged shad that passed the Vernon Project did so between 15:00 and 23:00 (NAI, 2016). The split beam data collected at Cabot Station revealed a similar trend in movement in which the majority (60%) of fish that entrained through the Station did so during that same period (15:00-23:00).

5.5 Rate of Entrainment at the Northfield Mountain Project

The use of split beam sonar at the Northfield Mountain Project intake structure was not optimal for estimating entrainment since installing the equipment behind the trash racks was not an option[5]. While fish attributes such as size, three-dimensional position and direction of travel were quantified with the Northfield Mountain Project set-up, it is not certain that fish detected actually passed through the trash racks and were subjected to entrainment. The equipment was mounted in front of the trash racks where substantial milling was observed; for that reason entrainment could not be estimated with hydroacoustics.

Due to uncertainties with the split beam sonar data, the radio telemetry data were assessed to provide an indication of the rate of entrainment of juvenile shad at the Northfield Mountain Project. Of the 129 juvenile Shad released upstream of NMPS intake/tailrace, 77 were detected at the Shearer Farms monitoring site (T1and T2) located approximately 0.5 RM upstream from NMPS intake/tailrace. Tracking of these tagged fish revealed three were entrained and detected in the Upper Reservoir of Northfield Mountain, suggesting an entrainment rate of 3.9%. Twenty-one (21) additional fish were last detected at the Northfield Mountain intake/tailrace and were never detected again at any of the telemetry receiver stations. Of those 21 fish, 14 were last detected at the Northfield Mountain intake/tailrace during pumping operations. Of the 77 shad that were detected at Shearer Farms, 32 were detected approximately 0.66 miles downstream of the NMPS intake/tailrace at Gill Banks (T5 and T6) for a passage rate of 41.6 % through this reach of the TFI. Of the fish that entered this reach 72.7% were either detected in the NMPS intake/tailrace area, the upper reservoir

[5] Sampling downstream of the trash rack (as performed at Cabot Station) would be expected to provide a more accurate measure of entrainment since this represents the point of no return due to water velocity.

or downstream of the NMPS intake/tailrace; leaving 27.3% undetected. The fate of these fish is unknown; they may have been entrained and were not detected at the upper reservoir; or escaped the area without being detected again as a result of ceased migration, tag loss or mortality.

Given the poor tag retention and survival of the control fish, tag loss and/or mortality are plausible explanations of the fate of undetected fish but the data do not support a firm conclusion. The upper reservoir intake was a challenging location to monitor using radio telemetry methods with depth in excess of 90 ft. In addition to aerial yagi antennas, a series of four in-water stripped coaxial cable antennas were used to monitor for tagged shad at depth. Field testing of the detection array showed good coverage of the area but given the depth and width of the upper reservoir intake channel it is unlikely that 100% coverage was achieved. Given the uncertainty of fish that were undetected in the reach, a definitive estimate of entrainment using these radio telemetry results was not achieved.

5.6 Survival Rates for Juvenile Shad Entrained into Station No.1 and at Cabot Station

The 95.0% survival (1 h) for juvenile shad passed through the large Francis turbine at Cabot Station Unit 2 was near the median value of 94.7% for juvenile herring and shad obtained for 19 studies conducted at other hydroelectric projects (NAI, 2016a). The survival rates for the smaller Francis units at Station No. 1 (67.8% and 76.6%) indicate juvenile shad do not fare as well through Station No. 1 as compared to Cabot Station. The Francis units at Station No. 1 had the smallest runner diameter (39-55 inches) and the highest rotation rates (200 and 257 rpm) of the different turbines tested, which likely contributed to the lower survival rates at Station No. 1 (NAI, 2016a).

Fish traveling the length of the power canal and passing downstream through the turbines at Cabot Station have a greater likelihood of survival compared to fish that pass via the bascule gates at the TFD. The combined 1-hour direct survival rate for juvenile shad passing the TFD via the bascule gates was about 64% (based on the release of 362 fish) as compared to the 95% (based on the release of 120 fish) survival of those fish that pass through the turbines at Cabot Station. Passage from the power canal through Station No. 1 also appears to be a safer option for fish as opposed to passage via the TFD with a survival (1 h) of 67.8% and 76.6% at Unit 2/3 and Unit 1, respectively (based on the release of 90 fish at each unit).

Applying the high rate of survival (95%) of juvenile shad passed through the turbines at Cabot Station to the total number of shad estimated to be entrained reduces the overall impact. Throughout the radio telemetry component of this study, only one fish was detected in the forebay area of Station No. 1 (released in the canal prior to the drawdown), and Station No. 1 was not operational at the time due to the canal outage. Throughout the study period, Station No. 1 operated at partial capacity (~ 3 MW) continuously for about a one-month period from August 23 to September 24, 2015, and near full capacity intermittently during October and early November.

With respect to the entrainment estimates for Cabot Station, it is likely that the processing of hydroacoustic data overestimated the actual number of juvenile shad entrained. The discrete sampling conducted at the Cabot Station bypass sampler revealed that over 99.9% of the fish collected at the bypass were juvenile American Shad. This species assemblage information was used to reduce the estimate of shad entrainment by 0.01%. However, the surface oriented downstream bypass and its sampler was designed to pass/catch surface oriented species like juvenile American Shad, generally omitting cover-seeking or benthic-oriented species. These species would be subject to entrainment at the full depth Cabot intake and individuals of similar echo characteristics as juvenile shad may have contributed to the entrainment estimate but to what degree is not known. During the 2014 canal drawdown, which occurred from September 30 to October 4, 2014, field crews identified 22 fish species, with Spottail Shiner, Tessellated Darter, and American Shad dominating the overall abundance (FirstLight, 2015). The entrance to the bypass draws from the upper portion of the water column (Figure 5.6-1); bottom-oriented species such as the Tessellated Darter, and cover-oriented species such as Spottail Shiner, would not be expected to be among the species observed at the bypass sampler.

Figure 5.4-1. Overview of Downstream Portion of Power Canal and Cabot Station

Figure 5.6-1. Photo depicting Cabot Station Intake and Downstream Bypass during the 2015 Maintenance Outage

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APPENDIX A – TELEMETRY ARRAY TESTING AND CALIBRATION

APPENDIX A: Telemetry Array Testing and Calibration

Each telemetry station was tested with a Lotek NanoTag prior to any animals being tagged to ensure adequate power readings, range and proper calibration of equipment. Field staff turned on one tag to be used as a ‘test tag’ during the calibration period and did not use the same frequency and/or code during the study. The NanoTag was attached to fishing line and tested at a water depth of approximately 4 to 5 ft to mimic the swimming depth of juvenile American shad. One member of the field crew remained on land monitoring the receiver output signals and two field staff used a boat to test the targeted detection zone at each telemetry station. Communication via handheld radio allowed transfer of power signals at different locations that were recorded for calibration purposes.

A list of the receivers used for this study is provided in Table 3.2.4-1. Orion receivers output an average power number for each contact, which is recorded in decibel levels (dB). These numbers are negative, with less negative numbers being higher in signal strength (less sensitivity). Lotek receivers output an average power number for each contact, which is also recorded in decibel levels (dB). These numbers are positive, with high numbers indicating a stronger signal.

All station figures listed below show the position of the ‘test tag’ and the average power levels associated within the detection zones recorded during testing (noted in white). Several test detections were recorded at each location.

Montague Wastewater

Figure A-1: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish moving across the width of the river at River Mile 119.5. The smaller X's mark the approximate locations of the two in-water droppers used at this location to assist with monitoring the passage of juvenile shad. The radio test tag produced power levels ranging from 70s to 110 db with highest powers located near the bank of the river closest to the yagi antennas and attenuating slightly toward the far bank.

Cabot Station Tailrace

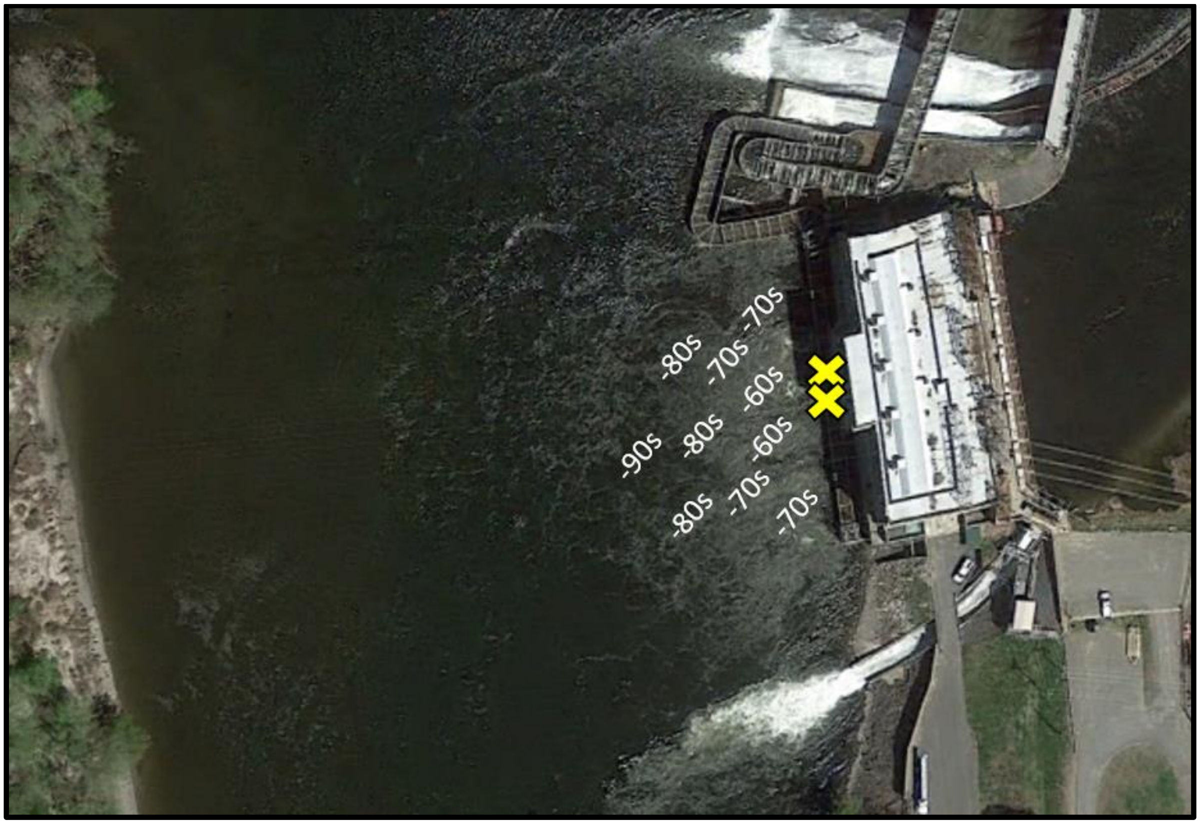

Figure A-2: The large yellow Xs mark the approximate placement of the two yagi antennas and the Orion receiver used to detect fish moving Cabot Station Tailrace at River Mile 120. The radio test tag produced power levels ranging from -60s to -90s db with highest powers located closest to the yagi antennas near Cabot Station and attenuating slightly further out in the tail waters.

Cabot Station Forebay

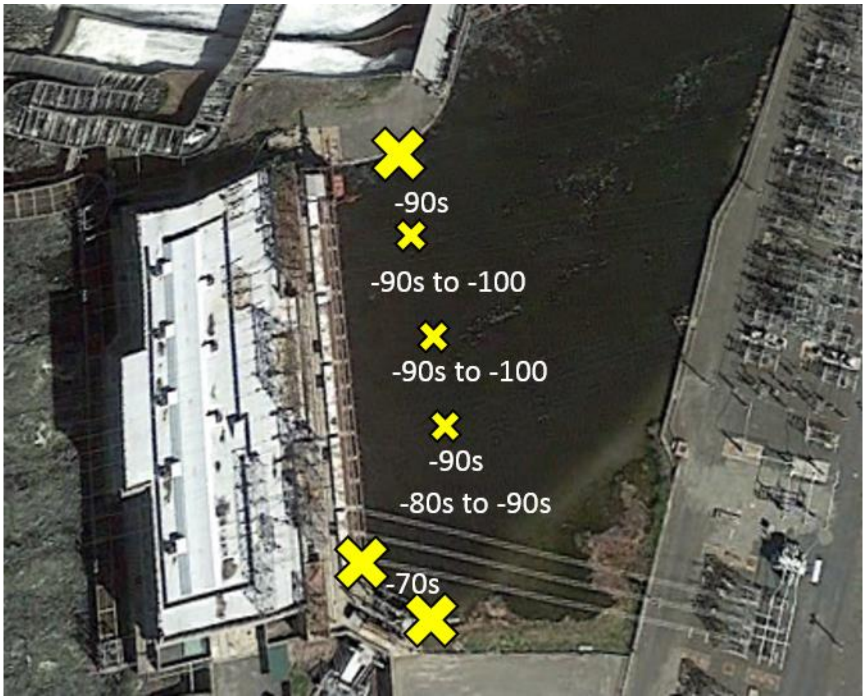

Figure A-3: The large yellow Xs mark the approximate placement of the yagi antennas, the dipole antenna and the Orion receivers used to detect fish moving across the Cabot Station Forebay at River Mile 120. The small Xs mark the approximate locations of the four in-water droppers used at this location to assist with monitoring the passage of downstream eel as well as juvenile shad. The radio test tag produced power levels ranging from -70s to 100 db with highest powers located near the bank of the river closest to the yagi antennas and attenuating slightly toward the far bank.

Station No. 1 Forebay

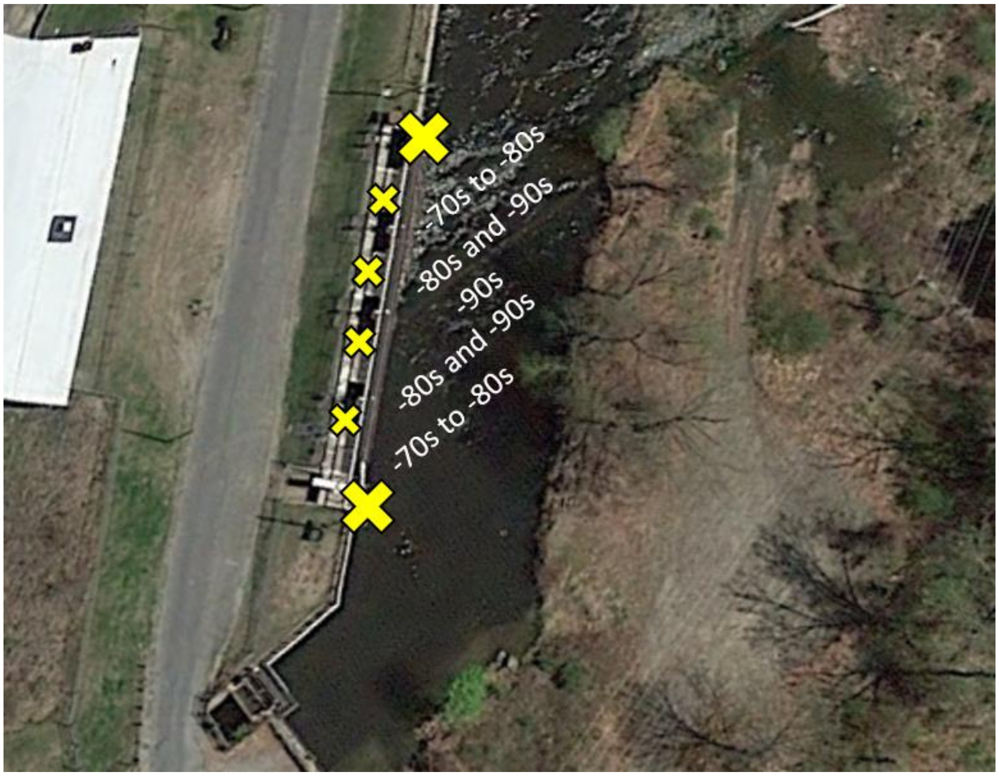

Figure A-4: The large yellow Xs mark the approximate placement of the yagi antennas and the Orion receivers used to detect fish moving across the Station No. 1 Forebay at River Mile 121. The small Xs mark the approximate locations of the four in-water droppers used at this location to assist with monitoring the passage of downstream eel as well as juvenile shad. The radio test tag produced power levels ranging from -70s to -90s db with highest powers located near yagi antennas and attenuating slightly in the middle of the forebay.

Station No. 1 Tailrace

Figure A-5: The large yellow X marks the approximate placement of the yagi antenna and the Lotek receiver used to detect fish within the Station No.1 tailrace at River Mile 121. The radio test tag produced power levels ranging from -70 to -90 with highest powers located closest to the yagi antennas and attenuated in the middle of the Station No. 1 Tailrace.

Below Turners Falls Dam (river left)

Figure A-6: The large yellow X marks the approximate placement of the yagi antennas and the Orion receivers used to detect fish below the Turners Falls dam (river left) and below Bascule Gate 4 at River Mile 122. The radio test tag produced power levels below the dam at river left ranging from -80 to -100s with highest powers located closest to the yagi antennas and attenuated farther out from the antenna. Below bascule gate 4, power levels ranged from -90s to -100s.

Below Turners Falls Dam (river right)

Figure A-7: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish below Turners Falls Dam at River Mile 122. The radio test tag produced power levels ranging from -80 to -90s with highest powers located closest to the yagi antennas and attenuated farther out from the antenna.

Upper Turners Falls Power Canal

Figure A-8: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish moving in the canal at River Mile 122. The small Xs mark the approximate locations of the three in-water droppers used at this location to assist with monitoring the passage of downstream eel as well as juvenile shad. The radio test tag produced power levels ranging from -70s to -100 db with highest powers located near yagi antenna and attenuating farther out from the antenna.

Upstream of Gatehouse

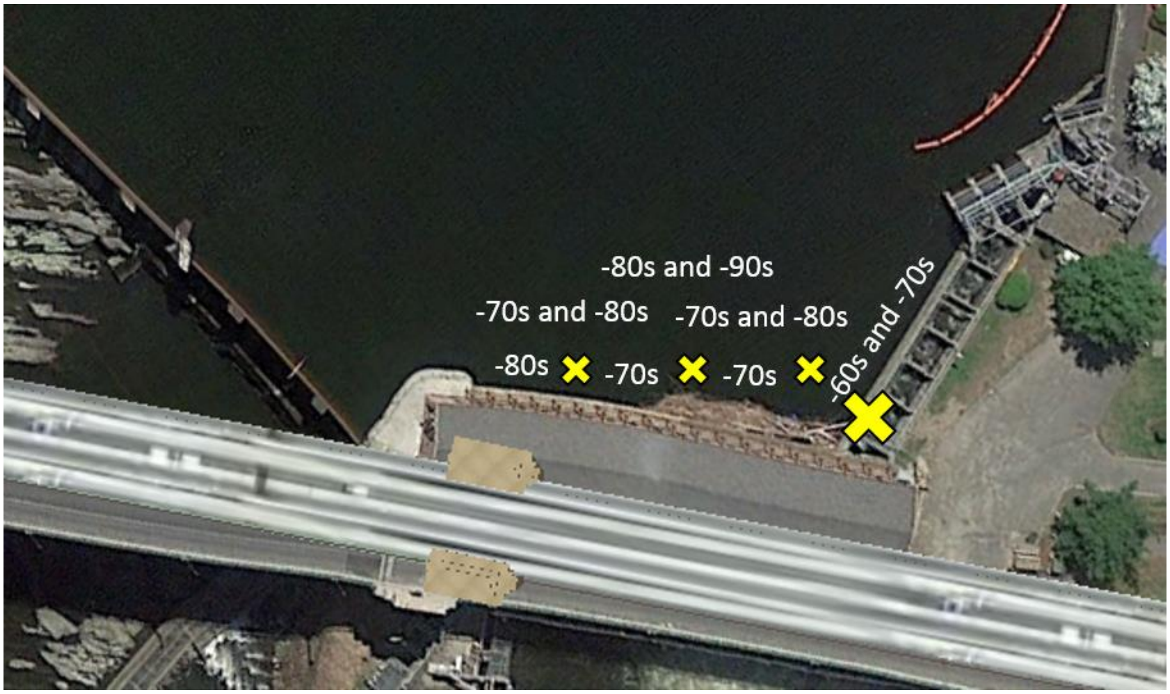

Figure A-9: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish just upstream of Gatehouse at River Mile 122. The small Xs mark the approximate locations of the three in-water droppers used at this location to assist with monitoring the passage of downstream eel as well as juvenile shad. The radio test tag produced power levels ranging from -60s to -90s db with highest powers located near yagi antenna and attenuating farther out from the antenna.

Turners Falls Impoundment

Figure A-10: The large yellow Xs mark the approximate placement of the yagi antennas and the Lotek receivers used to detect fish in the Turners Falls Impoundment at River Mile 122. The small Xs mark the approximate locations of the five in-water droppers used at this location to assist with monitoring the passage of downstream eel as well as juvenile shad. The radio test tag produced power levels ranging from 60 to 100 db with highest powers located near yagi antennas and attenuating farther out from the antennas.

NMPS Gill Bank

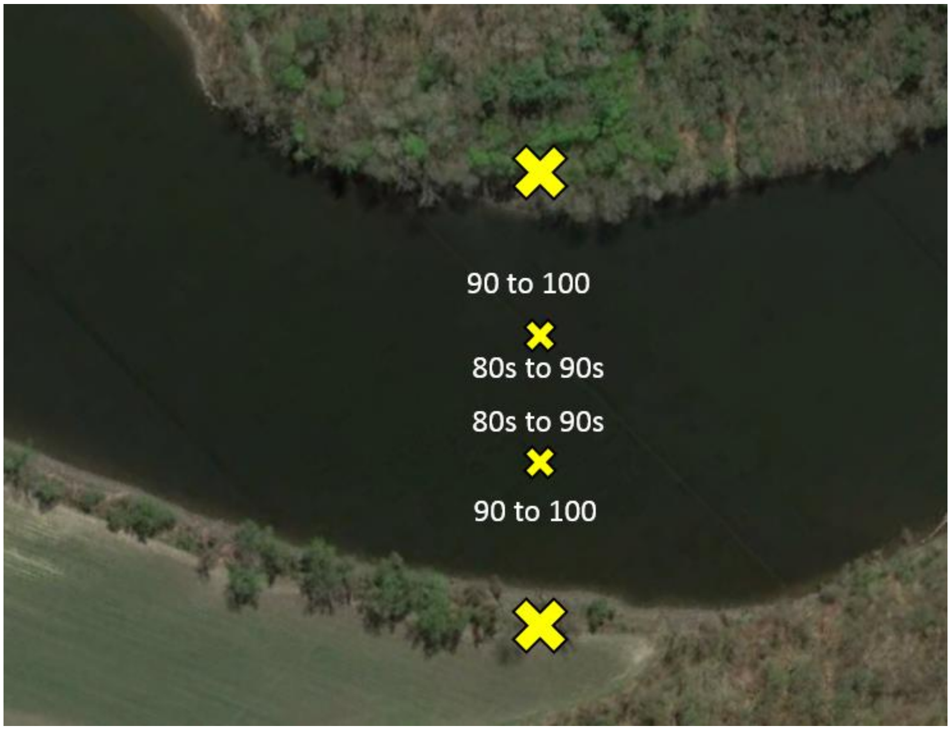

Figure A-11: The large yellow Xs mark the approximate placement of the yagi antennas and the Lotek receivers used to detect fish at Gill Bank at River Mile 126.5. The small Xs mark the approximate locations of the three in-water droppers used at this location to assist with monitoring the passage of downstream eel as well as juvenile shad. The radio test tag produced power levels ranging from 80s to 100 db with highest powers located near yagi antenna and attenuating farther out from the antenna.

NMPS Intake/Tailrace

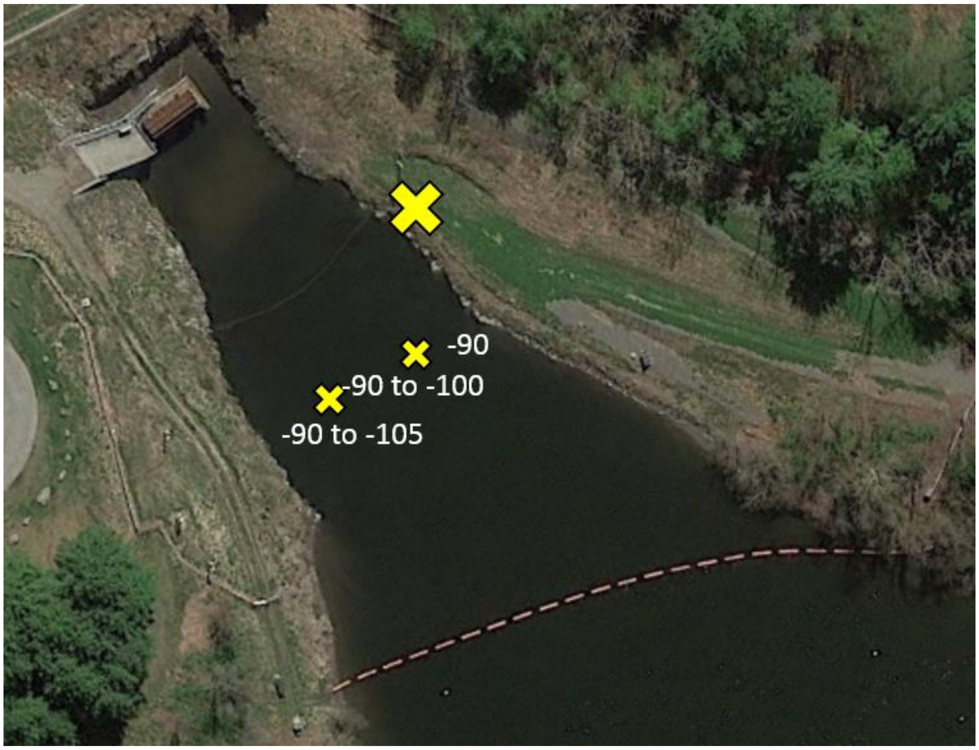

Figure A-12: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish in the NMPS Intake/Tailrace at River Mile 127. The small Xs mark the approximate locations of the two in-water droppers used at this location to assist with monitoring the passage of downstream eel as well as juvenile shad. The radio test tag produced power levels ranging from -90s to -105 db with highest powers located near yagi antenna and attenuating farther out from the antenna.

Northfield Mountain Upper Reservoir

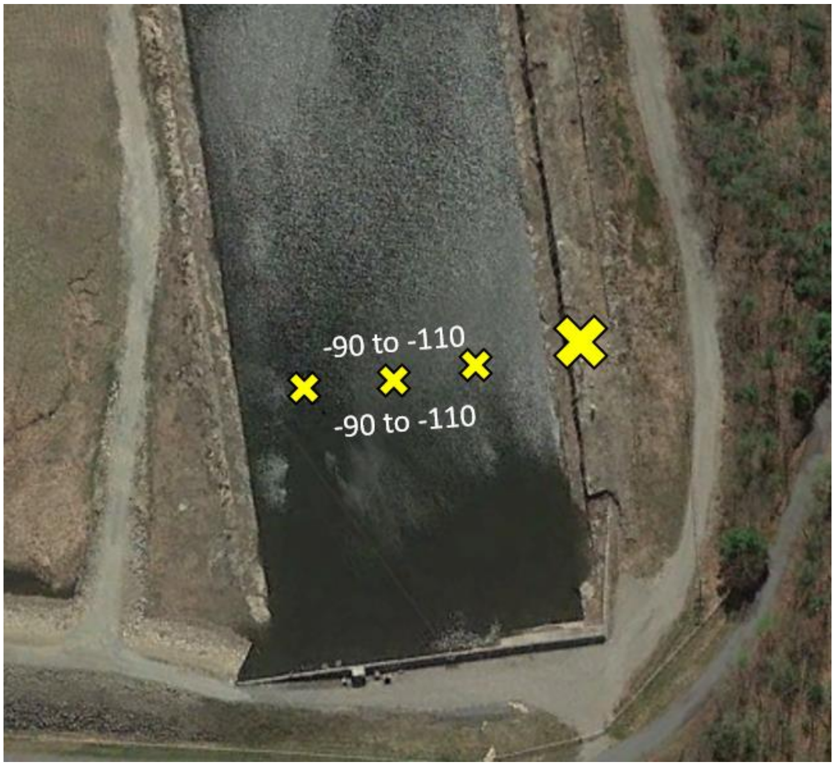

Figure A-13: The large yellow X marks the approximate placement of the yagi antenna and the Orion receiver used to detect fish in the Northfield Mountain Upper Reservoir. The small Xs mark the approximate locations of the three in-water droppers used at this location to assist with monitoring the passage of downstream eel as well as juvenile shad. The radio test tag produced power levels ranging from -90s to -110 db.

Shearer Farm

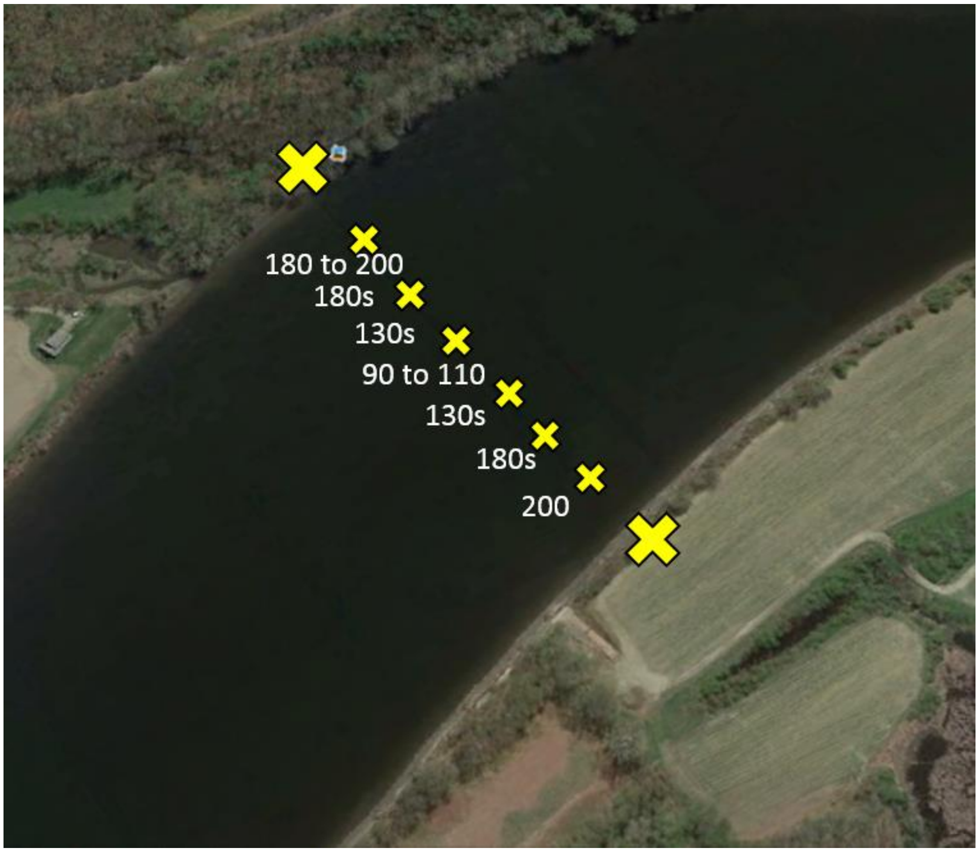

Figure A-14: The large yellow Xs mark the approximate placement of the yagi antennas and the Lotek receivers used to detect fish across Shearer Farm at River Mile 127.5. The small Xs mark the approximate locations of the six in-water droppers used at this location to assist with monitoring the passage of downstream eel as well as juvenile shad. The radio test tag produced power levels ranging from 90s to 200 db with highest powers located near yagi antenna and attenuating farther out from the antenna.

APPENDIX B – DIRECT INJURY AND RELATIVE SURVIVAL OF JUVENILE AMERICAN SHAD AT THE TURNERS FALLS HYDROELECTRIC PROJECT (NAI, 2016a)

DIRECT INJURY AND RELATIVE SURVIVAL OF JUVENILE AMERICAN SHAD AT THE TURNERS FALLS HYDROELECTRIC PROJECT (NO. 1889)

Prepared for

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Prepared by

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July 2016

EXECUTIVE SUMMARY

The goal of this study was to assess whether operations at Cabot Station Unit 2, Station No. 1 (Units 1 and 2/3) and over the Bascule Gates (1 and 4) affects the safe and timely passage of emigrating juvenile American Shad (*Alosa sapidissima*). The objectives of this study were to quantify the movement rates, timing, and relative proportion of juvenile shad passing through various routes at the projects including through the turbines and spillways; and assess instantaneous and latent mortality and injury of juvenile shad passing through each type of route at each project.

FirstLight Hydro Generating Company (FirstLight) is licensed by the Federal Energy Regulatory Commission (FERC or the Commission) to operate the Turners Falls Hydroelectric Project (FERC No. 1889) and the Northfield Mountain Pumped Storage Project (FERC No. 2485). Both Projects utilize water from the Connecticut River to generate hydroelectric power. The current FERC licenses for both Projects expire on April 30, 2018. Every 30-50 years, licensees are required to relicense their hydroelectric facilities with FERC. Although the Turners Falls Project and Northfield Mountain Pumped Storage Project are currently licensed as separate projects, FirstLight is seeking a single license for both developments. By April 30, 2016, two years prior to license expiration, FirstLight was required to file their Final License Applications for both facilities.

One aspect of the relicensing protocol was to determine the survival probabilities (1 and 48 h) and injury rates for juvenile American Shad passing through Cabot Station Unit 2, Station No. 1 Units 1 and 2/3, and over Bascule Gates 1 and 4 at three different discharge rates of 1,500, 2,500 and 5,000 cubic feet per second (cfs). The results were obtained using the HI-Z Turb'N Tag (HI-Z Tag) recapture technique on October 14-24, 2015. The effects of turbine passage at Cabot Station Unit 2 were assessed with 120 treatment shad, and approximately 180 treatment fish were used in each of the assessments for Station No. 1 and Bascule Gates 1 and 4. A total of 146 control fish were released downstream of the treatment release sites. Mean recapture times for juvenile shad passed through Cabot Station Unit 2, Station No. 1 Unit 1 and Units 2/3 were 6.3, 3.5, and 4.0 minutes, respectively. Mean recapture times for the shad passing over Bascule Gate 1 at 1,500, 2,500 and 5,000 cfs were 6.8, 7.8, and 13.1 minutes, respectively. Mean recapture times for the shad passing over Bascule Gate 4 at 1,500, 2,500 and 5,000 cfs were 7.2, 10.1, and 13.8 minutes, respectively. Mean recapture time of all control shad was 3.6 minutes.

Juvenile shad used in this study were procured from electrofishing or seining efforts and held in tanks continuously supplied with ambient river water. Water temperature in the holding tanks ranged from 7.5 to 9.1°C during the study. Fish tagging, release, and recapture techniques were similar to those utilized for juvenile shad in numerous other passage survival studies.

A primary objective of the study was to release a sufficient number of juvenile American Shad to obtain passage survival estimates within a precision (ε) level of ± 10%, 90% of the time (α=0.10). Treatment juvenile shad were released through Francis turbines at Cabot Station Unit 2, Station No. 1 Units 1 and 2/3, and over Bascule Gates 1 and 4 with separate trials at three discharge rates of 1,500, 2,500 and 5,000 cfs per gate.The treatment shad ranged from 90-123 millimeters (mm) in length with a mean of 96 mm and control shad ranged from 90-122 mm with a mean of 97 mm. Recapture rates for the treatment shad at Cabot Station Unit 2, Station No. 1 Unit 1, and Units 2/3, were 94.2, 65.6, and 65.6%, respectively. Recapture rates for the treatment shad for Bascule Gate 1 ranged from 45.0 to 72.6% with a combined recapture rate of 60.4%. Recapture rates for the treatment shad for Bascule Gate 4 ranged from 56.7 to 68.3% with a combined recapture rate of 62.2%. All control released shad were recaptured.

Because of the sensitivity of American Shad to handling, control mortality during the delayed assessment period was high (33%). Therefore, it was determined that the estimated delayed (48 h) survivals were unreliable and are not reported.

The estimated immediate (1 h) survivals for Cabot Station Unit 2 and Station No. 1 Units 1 and 2/3 were 95.0, 67.8, and 76.6%, respectively. The estimated immediate (1 h) survivals for Bascule Gate 1 ranged from 47.7 to 75.6% with a combined survival of 63.0%. The estimated immediate (1 h) survivals for Bascule Gate 4 at ranged from 59.0 to 73.6% with a combined rate of 64.8%.

All recaptured treatment fish were examined for injuries. Visible injury rates ranged from 7.7 to 45% throughout the project. Fish free of visible injuries, having less than 20% scale loss per side, and free of loss of equilibrium were designated a malady-free status. Malady-free estimate rates were adjusted by any maladies incurred by control fish. The malady-free estimates for recaptured fish ranged from 55.9 to 92.7% throughout the project, with the lowest rate at Bascule Gate 4 at 1500 cfs discharge and highest rate at Cabot Unit 2.

The higher survival and lower injury rates of the juvenile shad passed through Cabot Station Unit 2 than those passed through Station No.1 units was likely due to Unit 2’s larger size and slower rotational speed. The relatively low survival and high injury rates for fish passing the bascule gates appears to be due primarily to the shad interacting with the bedrocks, boulders, and turbulent hydraulic conditions in the spillway basin.

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List of Abbreviations

AOQL	Average Outgoing Quality Limit
CRWC	Connecticut River Watershed Council
DO	Dissolved oxygen
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Hydro Generating Company
FWS	U.S. Department of the Interior – Fish and Wildlife Service
HA	Hydroacoustic
MDFW	Massachusetts Department of Fish and Wildlife
MFE	Malady-Free Estimate
μS/cm	Micro-Siemens per centimeter
NHDES	New Hampshire Department of Environmental Services
NHFGD	New Hampshire Fish and Game Department
NTU	Nephelometric Turbidity Units
RSP	Revised Study Plan
RTK	Real Time Kinematic Unit
SGCN	Species of Greatest Conservation Need
SN	Serial number
SSR	Site Selection Report
su	Standard units
TU	Trout Unlimited
USR	Updated Study Report
VFWD	Vermont Fish and Wildlife Department
WSE	Water surface elevation

1.0 INTRODUCTION

This study report presents the 2015 direct survival and injury of juvenile American Shad passing downstream through the Turners Falls Hydroelectric Project (FERC No. 1889) operated by FirstLight Hydro Generating Company, which is licensed by the Federal Energy Regulatory Commission (FERC or the Commission) to operate this project and the Northfield Mountain Pumped Storage Project (FERC No. 2485). Both Projects utilize water from the Connecticut River to generate hydroelectric power. The current FERC licenses for both projects expire on April 30, 2018. Every 30-50 years, Licensees are required to relicense their hydroelectric facilities with FERC. Although the Turners Falls Project and Northfield Mountain Pumped Storage Project are currently licensed as separate projects, FirstLight is seeking a single license for both developments. By April 30, 2016, two years prior to license expiration, FirstLight is required to file the Final License Application for the Project. Cabot Station Unit 2, Station No. 1 Units 1 and 2/3, and Bascule Gates 1 and 4 were recommended for evaluation for relicensing purposes (Figure 1-1). In order to suffice the relicensing requirements for this field-based study, the HI-Z Turb'N Tag (HI-Z tag) recapture technique (Heisey *et al.*, 1992) was utilized to provide survival and injury estimates of juvenile American Shad passed through the desired locations at specified test conditions.

2.0 STUDY GOALS AND OBJECTIVES

FirstLight conducted this study in the fall of 2015 to assess whether operations at Cabot Station Unit 2, Station No. 1 Units 1 and 2/3, and Bascule Gates 1 and 4 affect the safe and timely passage of emigrating American Shad. The specific objectives of this study were to:

2.1 Quantify the movement rates, timing, and relative proportion of juvenile American Shad passing via various routes at the projects including through the turbines at Cabot Station and Station No. 1, as well as over the Bascule Gates at three different discharges; and

2.2 Assess instantaneous and latent mortality and injury of shad passed through each turbine type and spillway. This study was designed to estimate the direct (1 and 48 h) survival and malady-free rates (shad without visible injuries and no loss of equilibrium) of juvenile American Shad passing Cabot Station Unit 2, Station No. 1 Units 1 and 2/3, and over the Bascule Gates 1 and 4. Survival and malady-free estimates were to be within ± 10%, 90% of the time. Survival and malady-free estimates were to be obtained under typical operating parameters, and Bascule Gates were evaluated at discharges of 1,500, 2,500, and 5,000 cfs.

This report addresses objective 2.2 only. A separate report prepared by Kleinschmidt Associates (Kleinschmidt) addresses objective 2.1.

3.0 PROJECT DESCRIPTION

The Turners Falls Hydroelectric Project and Northfield Mountain Pumped Storage Project are located on the Connecticut River in the states of Massachusetts, New Hampshire, and Vermont (Figure 1-1). The Turners Falls Dam is located at approximately river mile 122 (above Long Island Sound) on the Connecticut River in the towns of Gill and Montague, MA. The dam creates an impoundment extending upstream approximately 20 miles to the base of TransCanada's Vernon Hydroelectric Project Dam on the VT/NH border. A gatehouse at the Turners Falls Dam controls flow into a power canal that supplies two hydroelectric generating facilities: Cabot Station and Station No. 1. Cabot Station is located at the downstream terminus of the Power Canal and Station No. 1 is located approximately one-third of the way down the power canal. Station No. 1 and Cabot Station discharge into the Connecticut River approximately 0.9 miles downstream of the Turners Falls Dam. Discharge over the Turners Falls Dam is regulated by four bascule gates and three tainter gates.

3.1 Cabot Station and Station No. 1

Cabot Station houses six vertical, single runner Francis turbines (Figure 3-1) that provide a total station electrical capacity of 62.016 megawatts (MW) or roughly 10.336 MW/unit. The station has a total hydraulic capacity of approximately 13,728 cfs or roughly 2,288 cfs/unit (Tables 3-1 and 3-2). Station No. 1 operates under a gross head of approximately 43.7 feet, and has six horizontal Francis turbines with an approximate total electrical capacity and hydraulic capacity of 5,693 kilowatts (kW) and 2,210 cfs, respectively (Table 3-1). Two of the Francis units (Units 2/3) tested in this study share a common penstock.

3.2 Turners Falls Dam

The Turners Falls Dam consists of two individual concrete gravity dams, referred to as the Gill Dam and Montague Dam, which are connected by a natural rock island known as Great Island. The 630-foot-long Montague Dam is founded on bedrock and connects Great Island to the west bank of the Connecticut River. It includes four bascule type gates (Figures 3-2 and 3-3) and a fixed crest section. When fully upright, the tops of the Bascule Gates are at elevation 185.5 feet mean sea level (msl). The 495-foot-long Gill Dam connects Great Island to the east bank of the Connecticut River, and includes three tainter spillway gates. When closed, the elevation atop the tainter gates is 185.5 feet msl. Average discharges (cfs) through tested bascule gates are presented in table 3-2.

4.0 METHODS

Juvenile American Shad downstream passage was assessed by radio tagging and systematically monitoring fish movements and passage through the project area. Downstream turbine and bascule gate passage survival and injury was assessed with the HI-Z mark/recapture methodology used on juvenile shad during previous studies at other power stations (Normandeau Associates, Inc. 2010, 2011a, and 2011b) (Figure 4-1).

4.1 Source of Shad

Most of the juvenile American Shad used in the evaluation were obtained from the Connecticut River (collected via the Cabot Station downstream fish bypass sampler), but some were also collected by electrofishing and seining methodology in the Turners Falls Impoundment and Power Canal, respectively (Figure 4-2 and 4-3).

4.2 Study Designs

4.2.1 Procedures

Juvenile American Shad were released into the intakes of designated Francis units at Cabot Station, Station No. 1, and over spillway gates at three discharge scenarios (1,500, 2,500, and 5,000 cfs). After passage, live and dead shad were captured and the condition of each was examined. At the end of the 48 h holding period, all live and uninjured shad were released to the river. Survival and malady-free rates were estimated for each passage location. Descriptions of the observed injuries were recorded to help assess the probable causal mechanisms for injury/mortality.

4.2.2 Sample Size Calculations

Prior to initiating the study, the sample size requirement had been determined to fulfill the primary objective of obtaining survival estimates and malady-free rates within a pre-specified precision (ε) level. The sample size is a function of the recapture rate (PA) expected passage survival ($\hat{\tau}$) or mortality (1- $\hat{\tau}$), survival of control shad (S), and the desired precision (ε) at a given probability of significance (α). In general, sample size requirements decrease with an increase in control shad surviving, being malady-free and recapture rates (Mathur *et al.* 1996 and 2000). Only precision and α level can be strictly controlled by an investigator. Results of other turbine direct survival studies on juvenile shad (Normandeau Associates, Inc., 2010, 2011a, and 2011b) indicate a sample size of approximately 30-50 treatment (per scenario) and 25 combined control shad should be sufficient to attain survival estimates within ± 10%, 90% of the time, for the selected operating condition of the selected turbine at each project (Table 4-1). This number assumes close to 100% control survival, a recapture rate of 95%, and expected passage survival and malady-free rates greater than 85% for a specific study. A total of 120 treatment shad were released within the Unit 2 intake at Cabot Station (Table 4-2). Ninety fish were released at both Station No. 1 Unit 2/3 and Unit 1. Seventy-one combined control shad were released into the tailrace during the studies at Cabot Station and Station No. 1 treatment release sites. Approximately 60 fish were released at each discharge scenario (1,500, 2,500, and 5,000 cfs) at both Bascule Gates 1 and 4. Seventy-five control fish were released downstream of the spillway.

4.2.3 Tagging and Release

The fish tagging and release techniques followed those used for other similar turbine and spillway survival investigations (Heisey et al 1992; Mathur et al 2000; Normandeau Associates, Inc. et al 2000) and were similar for treatment and control groups. Control fish were released primarily to evaluate the effects of handling, tagging, releasing, and recapturing, as well as to provide additional data on recapture probabilities. Shad were randomly selected from the holding tanks located on the intake deck using brailing equipment to limit handling and transported in pails or tubs of ambient river water to the tagging site. Salt was added to pools, as it reduces the stress by assisting the fish's osmoregulation. Fish displaying abnormal behavior, severe injury, fungal infection, or descaling (≥ 20% per side) were not used. Placed in a tub with salt, juvenile fish were equipped with one un-inflated HI-Z tag and a small radio tag. Additionally, a fin was partially clipped (pelvic or caudal) to permit identification of fish in the event that any radio tag was dislodged (Figure 4-4). The HI-Z tag was attached by a stainless steel pin inserted via modified tagging gun through the musculature beneath the dorsal fin (Figure 4-5). The radio tag was attached in combination with the HI-Z tag (Figure 4-6). The HI-Z tags were activated by injecting a catalyst into each HI-Z tag (Figure 4-7), which causes the tags to inflate in approximately 2 to 4 minutes. Tags were activated while the shad was being gently handled by trained personnel.

Fish were placed individually into the induction system holding tub and released tail first (Figure 4-8). The inflation time of the tags was adjusted prior to the study to ensure fish would travel through the desired routes without pre-inflation of the HI-Z tags, which would affect the study design. Temperature and amount of water injected into tags prior to release were adjusted to ensure that the HI-Z tags worked effectively. A total of 662 juvenile American Shad were released throughout the study period to evaluate the treatment conditions, and146 fish were released as controls downstream of the turbines and spillway to evaluate the effects of handling, tagging, releasing, and recapturing.

All treatment and control fish were released through an induction apparatus (Figure 4-9). The induction apparatus was connected to 4-inch diameter hoses which directed the fish to the desired release points at Cabot Station Unit 2, Station No. 1, and over Bascule Gates 1 and 4 (Figure 4-10 and 4-11). The release hose was strategically placed to ensure shad would travel through the desired route. The induction system and each release hose were continuously supplied with river water by a 3-inch trash pump to ensure shad were transported quickly to the desired release point. Control shad were released through an identical induction apparatus attached to a 4-inch diameter flexible hose approximately 50 feet long and adjusted to ensure that the released fish would be directed into the tailrace.

4.2.4 Juvenile Shad Recapture Methods

After release (either as treatment or control), shad were tracked and then retrieved when buoyed to the surface downstream of the projects by one of three recapture boat crews. Boat crews were notified of the radio tag frequency of each fish upon its release. Fish were released in batches as not to overwhelm the tracking boats and to ensure the integrity of the released fish for the study. Radio signals were received on a loop antenna coupled to an Advanced Telemetry System receiver. The radio signal transmission (48 or 49 MHz) enabled the boat crews to follow the movement of each shad after passage and position the boats downstream for retrieval when shad buoyed to the surface (Figure 4-12). Recaptured shad were placed into an on-board holding facility and all tags were removed. Each shad was immediately examined for maladies consisting of visible injuries and loss of equilibrium, and assigned appropriate condition codes (Table 4-3). Tagging and data recording personnel were notified via a two-way radio system of each shad's recapture time and condition (Appendix A and B).

Buoyed fish were collected by trained Normandeau personnel while keeping the fish submersed in water at all times by utilizing a brailer to reduce handling stress (Figure 4-13). Fish were transported to shore and held in holding tanks (600 gal) to monitor delayed effects of tagging and turbine passage (Figure 4-14 to 4-15). Tanks were continuously supplied with ambient river water by two redundant pump systems connected to different electrical circuits, and were numbered to clarify test dates (Figure 4-14). The tanks were covered with netting or tarps to prevent shad escapement or predation. The shad were held for 48 hours based on the protocol established for HI-Z tag assessment (Heisey *et al.* 1992). Shad that were alive at 48 h and free of major injuries were released into the river.

4.2.5 Classification of Recaptured Juvenile Shad

As in previous investigations, (Mathur *et al*. 1996 and 2000; Normandeau Associates, Inc 2010, 2011a and 2011b; Normandeau Associates, Inc. and Skalski 1998 and 2005; North/South Consultants Inc. and Normandeau Associates, Inc. 2007 and 2009) the immediate post-passage status of an individual recaptured shad and recovery of inflated tags dislodged from shad were designated as alive, dead, or unknown. The following criteria have been established to make these designations: (1) alive—recaptured alive and remaining so for 1 hour; (2) alive—shad does not surface but radio signals indicate movement patterns; an unrecaptured shad was also classified as alive if no HI-Z tags were recaptured, and based on telemetry information the shad appeared to have moved into underwater structures that prevented the HI-Z tags from buoying it to the surface; (3) dead—recaptured dead or dead within 1 hour of release; (4)

dead—only inflated dislodged tag(s) are recovered, and telemetric tracking or the manner in which inflated tags surfaced is not indicative of a live shad; and (5) unknown—no shad or dislodged tags are recaptured, or radio signals are received only briefly, and the subsequent status cannot be ascertained.

Mortalities of recaptured shad occurring after 1 hour were assigned 48 hour post-passage effects, although shad were observed at approximately 12 h intervals. Dead shad were examined for maladies, and those that died without obvious injuries were necropsied to determine the probable cause of death. Additionally, all specimens alive at 48 hours were closely examined for injury. An initial examination of the shad when captured allowed detection of some injuries, such as bleeding and minor bruising that may not be evident after 48 hours due to natural healing processes.

4.2.6 Assessment of Juvenile Shad Injuries

All recaptured shad, dead or alive, were examined for type and extent of external injuries (Appendix C). Dead shad were also necropsied and examined for internal injuries when there were no apparent external injuries. Injuries were categorized by type, extent, and area of body. Shad without visible injuries that were not actively swimming or swimming erratically at recapture were classified as having “loss of equilibrium” (Tables 4-3 and 4-4). This condition has been noted in most past HI-Z tag direct survival/injury studies and often disappears within 10 to 15 min after recapture if the shad are not injured. Visible injuries and loss of equilibrium (LOE) were categorized as minor or major (Tables 4-4). The criteria for this determination are based primarily on field staff’s previous field observations.

A malady classification was established to include shad with visible injuries, and/or LOE. Shad without maladies were designated “malady-free”. The malady-free metric is established to provide a standard way to depict a specific passage route’s effects on the condition of entrained fish (Normandeau Associates, Inc. and Skalski 2005). The malady-free metric is based solely on shad physically recaptured and examined. Additionally, the malady-free metric in concert with site-specific hydraulic and physical data may provide insight into which passage conditions and locations provide the safest routes for shad passage.

4.2.7 Survival and Malady-Free Estimation

In any investigation involving juvenile American Shad, difficulties arise in obtaining accurate statistics concerning survival estimates. Juvenile American Shad are notoriously sensitive to stress, and transporting, handling, holding and tagging are problematic. Normandeau Associates, Inc. has conducted hundreds of HI-Z Tag downstream passage investigations using juvenile fish of other species and has often had 100% (or close to 100%) survival of control released fish at 48 h. During an investigation of yearling Chinook Salmon passing the removable spillway weir at Ice Harbor Dam on the Snake River in 2015, 120 tagged control fish (average size 136 mm) were released downstream of the dam and had a 48 hour survival rate of 100% (Normandeau Associates, Inc. 2015). Other studies yielded similar high control survival for juvenile salmonids; John Day Dam (2008) had 100% control survival (48 h) for 94 recaptured juvenile Rainbow Trout; Wanapum Dam turbine studies involving close to 2000 juvenile Chinook Salmon produced control survival rates (48 h) of 99% (Normandeau Associates, Inc. et al 2006).

However, in studies of juvenile shad conducted at Holtwood and Conowingo Dams on the Susquehanna River, control released shad had much lower survival rates even with the absence of any identifiable physical injuries (external or internal). A turbine passage study at Holtwood Hydroelectric Station in 1997 passed juvenile shad ranging from 105-135 mm (Normandeau Associates Inc. 1997). Due to an unacceptablly high control mortality of 35%, a valid 48 hour long-term survival could not be obtained. Similar problems with the sensitivity of shad (relatively high control mortality) occurred during several other studies involving juvenile shad (RMC 1992 and Normandeau Associates Inc and Gomez and Sullivan 2012). When juvenile shad have high mortality rates of control fish it becomes prudent to present only 1h survival estimates. Because the juvenile shad utilized in the present study had relatively high mortality rates (both test and control) in the 48 hour holding period, only the 1h survival estimates are considered reliable.

Turbine passage survival rates of fishes are estimated using paired release-recapture methods (Ricker 1975; Burnham et al. 1987). Unlike earlier investigations, however, recaptures of both alive and dead fish are possible with the HI-Z tag-recapture method (Heisey et al. 1992). Thus, parameters associated with the recapture of both alive and dead fish can be incorporated into a construction of a statistical model (Mathur et al. 1996). This, along with high recapture rates can be used to estimate passage survival with relatively high precision.

Maximum likelihood techniques were used to calculate the parameter estimates and their variances. The likelihood model is based on the following assumptions stated in Mathur et al. (1996): (1) the fate of each is independent; (2) the control and treatment fish come from the same population of inference and share the same natural mortality; (3) all alive fish have the same probability, P_A, of recapture; (4) all dead fish have the same probability, P_D, of recapture; and (5) passage survival($\hat{\tau}$) and natural survival (S) to the recapture point are conditionally independent. The likelihood model has four parameters (P_A, P_D, S, τ) and four minimum sufficient statistics (a_C, d_C, a_T, d_T).

The joint likelihood (L) for turbine-related mortality or survival is

$$L\,(S,\tau, P_A, P_D \mid R_C, R_T, a_C, a_T, d_C, d_T) =$$

$$\binom{R_C}{a_c d_C}(SP_A)^{a_C}\,((1-S)P_D)^{d_C}\,(1-SP_A-(1-S)P_D)^{R_C-a_C-d_C}$$

$$\times \binom{R_T}{a_T d_T} (S\tau P_A)^{a_T} ((1-S\tau)P_D)^{d_T} (1 - S\tau P_A - (1-S\tau)P_D)^{R_T - a_T - d_T} .$$

The estimators associated with the likelihood model are:

$$\hat{\tau} = \frac{a_T R_C}{R_T a_C}$$

$$\hat{S} = \frac{R_T d_C a_C - R_C d_T a_C}{R_C d_C a_T - R_C d_T a_C}$$

$$\hat{P}_A = \frac{d_C a_T - d_T a_C}{R_T d_C - R_C d_T}$$

$$\hat{P}_D = \frac{d_C a_T - d_T a_C}{R_C a_T - R_T a_C}$$

An alternative likelihood with three parameters (P, S, τ) is also constructed which assumes that the recapture probabilities for alive and dead fish are equal ($P_A = P_D$). Iterative procedures are used to estimate parameters for this model. Likelihood ratio tested ($P = 0.05$) the null hypothesis (H_o: $P_A = P_D$) versus the alternative model (H_A: $P_A \neq P_D$).

The confidence intervals on the estimated passage survival were calculated using the profile likelihood method (Hudson 1971). This method does not assume $\hat{\tau}$ to be normally distributed.

Where,

$\hat{\tau}$ = estimated survival
a_T = number of treatment alive shad recaptured
R_C = number of controls released
R_T = number of treatment shad released
a_C = number of control shad recaptured
$\hat{S}$ = estimate of natural survival to recapture
d_T = number of dead treatment shad recaptured
d_C = number of dead control shad recaptured

The variance (Var) and standard error (SE) of the estimated passage mortality ($1 - \hat{\tau}$) or survival ($\hat{\tau}$) are:

$$Var(1-\hat{\tau}) = Var(\hat{\tau}) = \frac{\tau}{SP_A}\left[\frac{(1-S\tau P_{A)}}{R_T} + \frac{(1-SP_A)\tau}{R_C}\right]$$

$$SE(1-\hat{\tau}) = SE(\hat{\tau}) = \sqrt{Var(1-\hat{\tau})} \quad .$$

Separate survival probabilities (1 and 48 h) and malady-free rates and their associated standard errors were estimated using the likelihood model described above in Normandeau Associates, Inc. and Skalski (1998). The formulas follow:

Direct Survival, 1 and 48 h

Where:

$$\hat{\tau}_i = \frac{a_{Ti} R_c}{R_{Ti} a_c},$$

R_{Ti} = Number of shad released for the ith treatment condition (i = 1,..., 9);

a_{Ti} = Number of shad alive for the ith treatment condition (i = 1,...,9);

R_c = Number of control shad released;

a_c = Number of control shad alive;

Malady-Free Estimates (MF)

Where:

$$MF_i = \frac{c_{Ti} R_c}{R_{Ti} c_c},$$

c_{Ti} = Total number of shad without maladies for treatment i (i = 1,...,9);

R_{Ti} = Number of shad recovered that were examined for maladies for treatment i (i = 1,...,9);

c_c = Number of control shad recovered without maladies;

R_c = Number of control shad recovered that were examined for maladies.

4.2.8 Assignment of Probable Sources of Injury

Limited controlled experiments (Neitzel *et al.*, 2000; Pacific Northwest National Laboratory *et al.*, 2001) to replicate and correlate each injury type/characteristic to a specific causative mechanism provides some indication of the cause of observed injuries in the field. However, these experiments were not conducted on shad. Some injury symptoms can be manifested by two different sources that may lessen the probability of accurate delineation of a cause and effect relationship (Eicher Associates, Inc., 1987). Only probable causal mechanisms of injury were assigned for the present investigation.

Some injuries (e.g., sliced bodies) may be assigned to a specific causative source with greater certainty (Normandeau Associates *et al*., 1995). Injuries likely to be associated with direct contact with turbine runner blades or structural components are classified as mechanical and include bruise, laceration, and severance of a fish's body (Dadswell *et al*., 1986; Eicher Associates, 1987; Normandeau, 2010 and 2011a, and 2011b). Passage through gaps between the runner blades and the hub or at the blade tips may result in pinched bodies (Normandeau Associates *et al*., 1995). Contact with the turbine structural components may result in bruising. Injuries likely to be attributed to shear forces for salmonids are decapitation, torn or flared opercula, and hemorrhaged eyes (Dadswell *et al*., 1986). The probable pressure-related effects are manifested as hemorrhaged internal organs and emboli in fins; however, pressure related forces can also cause bulging and hemorrhaged eyes.

4.3 Methods Specific to Each Station

4.3.1 Cabot Station

Shad were transported in a tank from holding pools adjacent to the bascule gates by truck and delivered to a covered holding tank with a capacity of approximately 600 gallons at Cabot Station. As with all scenarios, the transport/holding tank was supplied with aeration. This water-level-regulated, covered tank was located upstream on the head works of the facility to hold the shad prior to testing. An additional similar sized tank was located on the lower deck (adjacent to the control release point) to hold the shad after testing. Only shad in good physical condition were used for this study.

Ambient river water was continuously supplied to each tank and all shad were held for a minimum of 24 hours prior to tagging to allow shad time to recover from transport and handling stress. Water temperatures in the holding pools were comparable with river temperatures, which was 7.5º C.

The 146 control shad released at Cabot Station, Station No. 1, and at the bascule gates ranged in length from 90-122 mm, with an average of 97 mm (Figure 4-16).

One hundred and twenty treatment fish were released through Cabot Station Unit 2 approximately 5 ft below the intake ceiling. The treatment shad released ranged in length from 90-117 mm, with the average length of 97 mm (Figure 4-17).

4.3.2 Station No. 1

Each fish was corralled in the holding tank with a fine mesh seine net and then removed while in water by a brailer. These shad were transported from holding pools adjacent to the bascule gates by truck and delivered to a covered holding tank with a capacity of approximately 600 gallons at Station No. 1. This water-level-regulated, covered tank was located on the head works of the facility to hold the shad for at least 24 hours prior to testing. Only shad in good physical condition were used for this study. An additional similar sized tank was located adjacent to the holding pool and used to hold recaptured shad for delayed evaluation. As with all scenarios, the transport/holding tanks were supplied with aeration. The holding pools were continuously supplied with ambient river water that averaged around 7.7 ºC, and had a 50 lb block of salt placed at the bottom of the pool to initially provide salinity near 5 ppt. Continuous ambient flow gradually diluted the salt concentration, requiring replacing salt blocks periodically. Additionally, sufficient fine granular salt was also added to the fish transfer buckets to provide salinity near 5 ppt to assist in calming the fish prior to release.

Fish were released via four-inch flexible hoses passed through the vent pipes at Unit 1 and Units 2/3. The induction pipes were at the upstream end of an approximately 100-foot long circular penstock that led to the turbines. Units 2/3 had a common penstock that braided just upstream of these units, allowing the fish to pass through either unit. Ninety treatment shad ranging in length from 90-127 mm (average length of 96 mm) were released into the intake of Unit 1. Ninety treatment fish ranging in length from 90-127 mm (average length of 97 mm) were released into the intake of Units 2/3 (Figures 5-18 and 5-19).

4.3.3 Bascule Gates

Juvenile shad utilized for bascule gate testing were transported and held by the same methods described above. Water temperatures in the holding tanks were comparable with river temperature, which ranged from 8.0 to 9.1 ºC. The juvenile shad were released just upstream of Bascule Gates 1 and 4 via a four-inch flexible hose installed inside of a six-inch diameter steel pipe that was positioned over the flow toward the bascule gates (Figure 4-11). Sufficient length of the four-inch hose was deployed so its terminus was close enough to the crest of the bascule gates that fish were committed to passage. The desired flow (1,500, 2,500, or 5,000 cfs) through the tested bascule gate was commenced prior to the release of fish, and then the flow was curtailed to aid in fish recapture.

The 182 treatment shad released over Bascule Gate 1 at the 1,500, 2,500, and 5,000 cfs scenarios ranged in length from 90–122 mm, with the average length of 94 mm (Figures 4-20 to 4-22). The 180 treatment shad released over Bascule Gate 4 at the 1,500, 2,500, and 5,000 cfs scenarios ranged in length from 90–115 mm, with the average length of 94 mm (Figures 4-23 to 4-25).

5.0 RESULTS

5.1 Recapture Rates

5.1.1 Cabot Station Unit 2

Treatment shad were released through Cabot Station Unit 2 on October 14 and 15, 2015 (Table 4-2). Of the 120 released utilizing the HI-Z tag recapture technique, 115 (95.8%) were recaptured, 113 alive and 2 dead (Tables 5-1 and 5-2). Tags only were recaptured on four other fish and these fish were assigned dead. Nothing was observed on the remaining fish and it was assigned an undetermined status. Out of all of the test scenarios, Cabot Station Unit 2 performed the best, with the highest number of treatment shad recaptured.

5.1.2 Station No. 1

Treatment shad were released through the Francis turbines at Station No. 1 between October 16 and 17, 2015 (Table 4-2). Shad were released through Unit 1 and through Units 2/3 combined. Ninety treatment shad were released for both scenarios. Recapture rates were 75.6%and 72.2% for Unit 1 and Units 2/3, respectively (Table 5-1 and 5-2). Fifty-nine (65.6%) of the treatment shad released through Unit 1 and Unit 2/3 were recaptured alive. Tags only were recovered for 10.0% and 24.4% of the fish passed through these respective units and these fish were assigned a dead status. However, this status should be considered conservative since tags can be dislodged due to turbulent in-turbine and tailwater conditions that are not lethal. Nothing was recaptured on the remaining 14.4% and 3.3% of the shad passing Unit 1 and Units 2/3, and their status was undetermined. The recapture rate for the 71 control fish released into the tailrace downstream of the turbine discharges was 94.4%, all were alive. The status of the remaining control fish could not be determined.

5.1.3 Bascule Gates

Juvenile shad were released over the Bascule Gates from October 19-24, 2015 (Table 4-2). Treatment shad released at Bascule Gate 1 had low recapture rates ranging from 56.7% (2500cfs) to 79.0% (5000 cfs). The same trend held for Bascule Gate 4 with recapture rates ranging from 66.7% to 68.3% (Table 5-1). The overall percentages of fish recaptured alive were 60.4% and 62.2% at Bascule Gates 1 and 4, respectively. A relatively high percentage of the shad passed through Bascule Gates 1 (29.1%) and 4 (29.4%) were assigned a dead status based on the recapture of only tags or reception of only stationary radio signals. As mentioned above, a portion of these fish were likely alive. The turbulent conditions in the spillway discharge could have dislodged some of the tags without killing the fish (Figures 2-2 and 2-3)

The recapture rate for the control fish released downstream of the bascule gates was 100%. Ninety-six percent were recaptured alive and 4% were dead (Table 5-1).

5.2 Recapture Times

Recapture times (the time interval between shad release and subsequent recapture) for the shad released through Cabot Station Unit 2 ranged from 1 to 62 minutes and averaged 6.3 minutes. Recapture times for the shad released through Station No. 1 Unit 1, ranged from 1 to 11 minutes and averaged 3.5 minutes. For Station No. 1 Units 2/3, recapture times ranged from 2 to 12 minutes and averaged 4.0 minutes (Figure 4-26).

Recapture times for the shad released over the bascule gates was generally longer than recapture times for turbine passed fish because the recapture area was considerably more turbulent downstream of the spillway. Additionally some of the shad and detached tags could not be recovered until the spill over the tested bascule gate was curtailed. Recapture times through Bascule Gate 1 ranged from 3 to 88 minutes with averages of 6.8, 7.8 and 13.1 minutes at 1,500, 2,500, and 5,000 cfs, respectively (Figure 4-27).

Recapture times for the shad released over the Bascule Gate 4 were similar to those obtained at Bascule Gate 1 and ranged from 2 to 161 minutes with averages of 7.2, 10.1, and 13.8 minutes at 1,500, 2,500, and 5,000 cfs, respectively (Figure 4-28). There was a trend for longer recapture times with increased discharge at both bascule gates.

5.3 Survival Estimates

5.3.1 Cabot Station Unit 2

The 1 hour direct survival rate for Cabot Station Unit 2 passed shad was 95.0%, the highest observed for the present study. The precision of the 1 hour survival estimate for the Unit 2 shad was within ± 3.3%, 90.0% of the time (Tables 5-1 and 5-5).

5.3.2 Station No. 1

The 1 hour direct survival rates for shad passed through Units 1 and 2/3 at Station No. 1 were considerably lower than obtained at Cabot Station Unit 2 (Tables 5-1 and 5-5). Unit 1 survival was 76.6% and Units 2/3 survival was 67.8%. The precision of the 1 hour shad survival estimates for Station No. 1 Unit 1 was within ± 7.9%, 90% of the time and the corresponding precision at Units 2/3 was within ± 8.2%, 90% of the time. The survival estimates for fish passing Station No. 1 are likely higher because some of the assigned dead fish with only tags recaptured were likely alive.

5.3.3 Bascule Gate 1

The 1 hour direct survival rate for shad passing Bascule Gate 1 ranged 47.7% at 2,500 cfs to 75.6% at 5,000 cfs with a combined rate of 63.0% (Tables 5-1 and 5-5). The precision of the combined survival estimate for Bascule Gate 1 was ± 7.6.0%, 90% of the time.

5.3.4 Bascule Gate 4

The 1 hour direct survival rate for shad passing Bascule Gate 4 ranged from 59.0% at 2,500 cfs to 73.6% at 5,000 cfs with a combined rate of 64.8% (Tables 5-1 and 5-5). The precision of the combined survival estimate for Bascule gate 4 was ±8.1%%, 90% of the time. The survival rates at both bascule gates were highest at the 5,000 cfs discharge.

5.4 Injury Rate, Types, and Probable Source

5.4.1 Cabot Station Unit 2

Ten of the 115 recaptured Cabot Station Unit 2 shad (8.7%) had passage related injuries (Table 5-2). Four (3.5%) shad had damaged eyes; 3 (2.6%) had damaged gills, opercula, or isthmus; 3 (2.6%) had head damage (cuts, bruises, scrapes); and 2 (1.7%) had body damage (scrapes, bruises, cuts or torn fins). Six (5.2%) of the injured shad were considered to have major injuries and 4 (3.5%) minor (Table 5-3). Five (4.3%) injuries were attributed to shear forces, 4 (3.5%) to mechanical forces, and 1 (0.9%) to mechanical/shear forces.

5.4.2 Station No. 1

Of the 68 shad recaptured after passage through Station No. 1 Unit 1, 14 (20.6%) had visible passage related injuries (Table 5-2). Damaged eye(s) accounted for 8 (11.8%) of the injuries; 4 (5.9%) had gill/operculum/isthmus damage; 2 (2.9%) had cuts or bruises to the head; 1 (1.5%) was decapitated; and 1 (1.5%) shad had internal damage. Seventeen of the recaptured fish were classified as having a malady attributable to turbine passage; this included the 14 fish with visible injuries and 3 additional fish that died within an hour of capture but had no apparent injuries. The injuries were classified as major on 11 (16.2%) and minor on 6 (8.8%) of these fish with maladies (Table 5-3). Eleven (16.2%) of the maladies were attributed to shear forces; 2 (2.9%) to mechanical forces; 1 (1.5%) to mechanical/shear; and 3 (4.4%) were caused by undetermined forces.

Less of the recaptured shad that passed through Units 2/3 were visibly injured (5 of 65, 7.7%) than through Unit 1 (Table 5-2). Three (4.6%) had damaged eyes; 1 (1.5%) had a damaged operculum; and 1 (1.5%) had a hemorrhaged pectoral fin. An additional 5 fish that died within an hour of recapture were assigned a malady status. The maladies on eight of the 10 fish (12.3%) were considered major and 2 (3.1%) minor (Table 5-3). These maladies were attributed primarily to shear forces.

5.4.3 Bascule Gate 1

A total of 37 of the 125 (29.6%) shad examined after passage through Bascule Gate 1 were visibly injured (Table 5-2). The dominant injuries were internal damage including broken backbones (11.2%) and scrapes and bruises to the body (10.4%). The injury rates were highest at the 2,500 cfs discharge (35.3%)

and 5,000 cfs discharge (34.7%) and lowest at the 1,500 cfs disachrge (19.0%). The total number of fish with maladies was 38; only one additional fish with no visible injuries was assigned a malady status (Table 5-3). The percentages of Bascule Gate 1 fish assigned a major and a minor malady status were 23.2% and 7.2%, respectively. The majority (22.4%) of the maladies were attributed to mechanical forces.

5.4.4 Bascule Gate 4

The incidence of injuries was higher at Bascule Gate 4 than at Bascule Gate 1. A total of 54 of the 122 (44.3%) shad examined after passage through Bascule Gate 4 were visibly injured (Table 5-2). Injury to the gill cover and gills was observed on 17.2% of the recaptured fish. Other common injuries included scrapes and bruises to the body (11.5%); internal damage (8.2%); bruised/scraped head (7.4%); and scale loss (7.4%). The injury rates were similar (44 to 45%) for all three discharge levels. As observed for Bascule gate 1 only one additional fish with no visible injuries was assigned a malady status (Table 5-3). A total of 55 (45.1%) of the recaptured fish had a malady. More of the maladies were classified as minor (27.9%) than major (17.2%). Mechanical forces contributed to 27.9% of the maladies. The incidence of shear induced maladies was 12.3% which was higher than that observed at Bascule gate 1 (4%). The severity and cause of the maladies were similar at all three discharge levels at Bascule Gate 4.

5.5 Malady Free Estimates

5.5.1 Cabot Station and Station No. 1

The malady-free estimate (MFE) adjusted for controls of juvenile shad passed through Cabot Station Unit 2 was 92.7% (CI 4.9%) (Tables 5-4 and 5-5). It was the highest MFE of turbine passed fish. Station No. 1 Unit 1 shad had an MFE of 76.1% (CI 9.0%) and Station No. 1 Unit 2/3 shad had an MFE of 86.0% (CI 7.7%)

5.5.2 Bascule Gates

The MFE for Bascule Gate 1 passed shad was highest for the 1,500 cfs passed fish at 81.9% (CI 11.4%) (Tables 5-4 and 5-5). Bascule Gate 1 passed shad at 2,500 cfs and 5,000 cfs had MFE'S of 64.3% (CI 14.5%) and 68.0% (CI 12.0%), respectively. The combined MFE was 71.7% (CI 7.6%).

The MFE's for juvenile shad passed through Bascule Gate 4 were similar for the three flows: 1,500, 2,500 and 5,000 cfs (Tables 5-4 and 5-5). The respective MFE'S were 55.9%, (CI 13.5%), 57.3% (CI 13.5%) and 58.4% (CI 13.5%) with a combined rate of 57.2% (CI 8.1%).

Based on the condition of the recaptured juvenile shad after passage through the bascule gates it would appear that the most fish-friendly passage route was through Bascule Gate 1 (MFE 81.9%) at the lowest flow (1,500 cfs) and that the least fish-friendly passage route would be through Bascule Gate 4 (MFE

55.9%) at the lowest flow (1,500 cfs) (Tables 5-4 and 5-5). All MFE's for all flows through Bascule Gate 1 were higher than those through Bascule Gate 4.

6.0 ASSESSMENT OF PROJECT EFFECTS

6.1 Turbines

The characteristics of the turbines have an effect on the direct survival estimates of juvenile clupeids (Table 6-1). Generally, survival rates increase with an increase in runner diameter and operational head and decrease with an increase in number of blades and rotation rate.

The 95.0% survival (1 h) for juvenile shad passed through the large Francis turbine at Cabot Station Unit 2 was near the median value of 94.7% for juvenile herring and shad obtained for 19 studies conducted at other hydroelectric projects (Table 6-1). The survival rates for these projects ranged from 77.1% to 100.0%. The survival rate of 67.8 and 76.6% for the smaller Francis units at Station No. 1 indicates juvenile shad do not fare as well through Station No. 1 as compared to Cabot Station. The Francis units at Station No. 1 had the smallest runner diameter (39-55 inches) and the highest rotation rates (200 and 257 rpm) of the different turbines tested (Table 6-1). These factors likely contributed to the lower survival rates at Station No. 1.

6.2 Bascule Gates

The characteristics of spillway and fish bypass structures also affect the survival and condition of fish passing these structures. Extensive studies (21 different projects) on HI- Z tagged juvenile salmonids indicated that spillbay slope, radius of flow deflectors, angle spilled water intercepts deflectors and other structures, depth of water passing over the spillway, location of the fish in the spillway jet, and operating head can affect the condition of passed fish. The shallower the water cushion between a fish and the structures in the fish's path, the greater the chance for injuries. The boulder and concrete sill structures downstream of Bascule Gates 1 and 4 likely had the greatest detrimental effects on the passed juvenile American Shad. These conditions likely contributed most to the relatively low survival rates of 47.7-75.6% for the bascule gate passed fish (Table 5-5). The injury rates on the recaptured juvenile shad also indicated that passage conditions were not very fish friendly with visible injury rates of 29.6% and 44.3% on the recaptured fish passed through Bascule Gates 1 and 4, respectively.

Although numerous spillway studies have been conducted on juvenile salmonids only one study using more than 50 HI-Z tagged juvenile American Shad has been conducted at a spillway structure (RMC 1995). This study was conducted at the Cabot Station log sluice. Direct survival (1 h) was estimated to be between 98 and 100%. Five percent of the recaptured treatment fish had visible injuries. The gradual slope of the log sluice, sufficient water depth on the sluice, and absence of boulders at its outfall likely contributed to the high survival and low injury at this structure.

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Tables

Table 3-1

Characteristics of turbines at Turners Falls Hydroelectric Project where fish passage survival tests were conducted.

	Turbine			
	Cabot Unit 2	**Station No. 1 Unit 1**	**Station No. 1 Unit 2**	**Station No. 1 Unit 3**
Manufacturer:	GDF Suez Energy North America			
Type:	Francis	Francis	Francis	Francis
Rated Output (MW):	10.336	1.500	0.365	1.276
Approximate flow (cfs) at rated output:	2,288	560	140	500
No. of blades (buckets):	13	13	13	15
Runner speed (rpm)	97.3	200	257	200
Runner diameter (inches):	136.35	54.25 (2 runners)	38.88	55.3 (2 runners)
Runner height (inches):	19.7			
Leading edge of blade diameter (inches):	0.4			
Minimum distance between blades (inches):	2.9			
Distance between wicket gates (inches):	5.1			
No. of wicket gates:	24			
Operating head (ft):	60.0	43.7	43.7	43.7

Table 3-2

Daily average of utilized output and discharge at each FirstLight testing site.

Date	Location	MW	Discharge (cfs)
10/14/15	Cabot Station Unit 2	10.17	2254.57
10/15/15	Cabot Station Unit 2	10.4	2304.3
10/16/15	Station No. 1 Unit 2/3	1.6	591.27
10/17/15	Station No. 1 Unit 1	1.8	651.52
10/19/15	Bascule Gate 1: 1,500 cfs	N/A	1513.29
10/20/15	Bascule Gate 1: 2,500 cfs	N/A	2553.78
10/21/15	Bascule Gate 1: 5,000 cfs	N/A	4997.33
10/22/15	Bascule Gate 4: 1,500 cfs	N/A	1537.2
10/23/15	Bascule Gate 4: 2,500 cfs	N/A	2537.86
10/24/15	Bascule Gate 4: 5,000 cfs	N/A	4955.75

Table 4-1

Required sample sizes for treatment and control fish releases for various combinations of control survival, recapture probability, and expected passage survival probabilities of treatment fish. Precision (ε) of ≤ ± 0.10 at 1-α =0.90.

Control Survival (S)	Recapture Rate (P)	Expected Survival	Number of Fish
1	0.99	0.95	18
		0.90	29
		0.85	39
	0.95	0.95	39
		0.90	49
		0.85	57
	0.9	0.95	69
		0.90	76
		0.85	82
0.95	0.99	0.95	45
		0.90	54
		0.85	61
	0.95	0.95	67
		0.90	74
		0.85	80
	0.9	0.90	98
		0.95	103
		0.85	107
0.9	0.99	0.90	74
		0.95	81
		0.85	87
	0.95	0.90	98
		0.95	103
		0.85	107
	0.9	0.90	130
		0.95	133
		0.85	134

* Table values also applicable for malady-free estimates.

Table 4-2

Daily schedule of released juvenile American Shad passed through the Turners Falls Hydroelectric Project in October 2015. Controls released downstream of the treatment sites.

	Cabot Station Unit 2	Station No. 1 Unit 2/3	Station No. 1 Unit 1	Bascule Gate 1			Bascule Gate 4			Cabot Station Unit 2 Controls	Station No. 1 Unit 2/3 Controls	Station No. 1 Unit 1 Controls	Bascule Gate 1: 1,500 cfs Controls	Bascule Gate 1: 2,500 cfs Controls	Bascule Gate 1: 5,000 cfs Controls	Bascule Gate 4: 1,500 cfs Controls	Bascule Gate 4: 2,500 cfs Controls	Bascule Gate 4: 5,000 cfs Controls
				1,500 cfs	2,500 cfs	5,000 cfs	1,500 cfs	2,500 cfs	5,000 cfs									
Date																		
10/14/15	29									7								
10/15/15	91									23								
10/16/15		90									21							
10/17/15			90									20						
10/19/15				60									20					
10/20/15					60									10				
10/21/15						62									10			
10/22/15							60									10		
10/23/15								60									15	
10/24/15									60									10
Total	120	90	90	60	60	62	60	60	60	30	21	20	20	10	10	10	15	10

Table 4-3

Condition codes assigned to fish and dislodged HI-Z tags for fish passage survival studies.

Status Codes	Description		
*	Turbine/passage-related malady		
4	Damaged gill(s): hemorrhaged, torn or inverted		
5	Major scale loss, >20%		
6	Severed body or nearly severed		
7	Decapitated or nearly decapitated		
8	Damaged eye: hemorrhaged, bulged, ruptured or missing, blown pupil		
9	Damaged operculum: torn, bent, inverted, bruised, abraded		
A	No visible marks on fish		
B	Flesh tear at tag site(s)		
C	Minor scale loss, <20%		
E	Laceration(s): tear(s) on body or head (not severed)		
F	Torn isthmus		
G	Hemorrhaged, bruised head or body		
H	LOE		
J	Major		
K	Failed to enter system		
L	Fish likely preyed on (telemetry, circumstances relative to recapture)		
M	Minor		
P	Predator marks		
Q	Other information, concerning fish recapture		
R	Removed from sample		
T	Trapped in through the Rocks/recovered from shore		
V	Fins displaced, or hemorrhaged (ripped, torn, or pulled) from origin		
W	Abrasion / Scrape		
Survival Codes			
1	Recovered alive		
2	Recovered dead		
3	Unrecovered – tag & pin only		
4	Unrecovered – no information or brief radio telemetry signal		
5	Unrecovered – trackable radio telemetry signal or other information		
Dissection Codes			
1	Shear	M	Minor
2	Mechanical	N	Heart damage, rupture, hemorrhaged
3	Pressure	O	Liver damage, rupture, hemorrhaged
4	Undetermined	R	Necropsied, no obvious injuries
5	Mechanical/Shear	S	Necropsied, internal injuries
6	Mechanical/Pressure	T	Tagging/Release
7	Shear/Pressure	W	Head removed; i.e., otolith
B	Swim bladder ruptured or expanded		
D	Kidneys damaged (hemorrhaged)		
E	Broken bones obvious		
F	Hemorrhaged internally		
J	Major		
L	Organ displacement		

Table 4-4

Guidelines for major and minor injury classifications for fish passage survival studies using the HI-Z Tags.

1	A fish with only LOE is classified as major if the fish dies within 1 hour. If it survives or dies beyond 1 hour it is classified as minor.
2	A fish with no visible external or internal maladies is classified as a passage related major injury if the fish dies within 1 hour. If it dies beyond 1 hour it is classified as a non passage related minor injury.
3	Any minor injury that leads to death within 1 hour is classified as a major injury. If it lives or dies after 1 hour it remains a minor injury.
4	Hemorrhaged eye: minor if less than 50%. Major if 50% or more.
5	Deformed pupil(s) are a: major injury.
6	Bulged eye: major unless one eye is only slightly bulged. Minor if slight.
7	Bruises are size-dependent. Major if 10% or more of fish body per side. Otherwise minor.
8	Operculum tear at dorsal insertion is: major if it is 5 % of the fish or greater. Otherwise minor.
9	Operculum folded under or torn off is a major injury.
10	Scale loss: major if 20% or more of fish per side. Otherwise minor.
11	Scraping (damage to epidermis): major if 10% or more per side of fish. Otherwise minor.
12	Cuts and lacerations are generally classified as major injuries. Small flaps of skin or skinned up snouts are: minor.
13	Internal hemorrhage or rupture of kidney, heart or other internal organs that results in death at 1 to 48 hours is a major injury.
14	Multiple injuries: use the worst injury

Table 5-1

Tag-recapture data and survival estimates for juvenile American Shad passed through the Turners Falls Hydroelectric Project, October 2015. Controls released downstream of the treatment sites. Proportions are given in parentheses.

	Cabot Station		Station No. 1		Station No. 1		Bascule Gates 1								Bascule Gates 4								Cabot Station & Station No. 1 Combined Controls		Bascule Gates Combined Controls	
	Unit 2		Unit 2/3		Unit 1		1,500 cfs		2,500 cfs		5,000 cfs		Combined		1,500 cfs		2,500 cfs		5,000 cfs		Combined					
Number released	120		90		90		60		60		62		182		60		60		60		180		71		75	
Number recaptured alive	113	(0.942)	59	(0.656)	59	(0.656)	38	(0.633)	27	(0.450)	45	(0.726)	110	(0.604)	37	(0.617)	34	(0.567)	41	(0.683)	112	(0.622)	67	(0.944)	72	(0.960)
Number recaptured dead	2	(0.017)	6	(0.067)	9	(0.100)	4	(0.067)	7	(0.117)	4	(0.065)	15	(0.082)	4	(0.067)	6	(0.100)	0	(0.000)	10	(0.056)	0	(0.000)	3	(0.042)
Number assigned dead*	4	(0.033)	22	(0.244)	9	(0.100)	15	(0.250)	25	(0.417)	13	(0.210)	53	(0.291)	19	(0.317)	17	(0.283)	17	(0.283)	53	(0.294)	0	(0.000)	0	(0.000)
Tags only	4	(0.033)	22	(0.244)	9	(0.100)	10	(0.167)	11	(0.183)	4	(0.065)	25	(0.137)	3	(0.158)	1	(0.017)	3	(0.050)	7	(0.039)	0	(0.000)	0	(0.000)
Stationary radio signals	0	(0.000)	0	(0.000)	0	(0.000)	5	(0.083)	14	(0.233)	8	(0.129)	27	(0.148)	16	(0.267)	16	(0.267)	14	(0.233)	46	(0.256)	0	(0.000)	0	(0.000)
Number undetermined	1	(0.008)	3	(0.033)	13	(0.144)	3	(0.050)	1	(0.017)	0	(0.000)	4	(0.022)	0	(0.000)	3	(0.050)	2	(0.033)	5	(0.028)	4	(0.060)	0	(0.000)
1 hour survival rate		(0.950)		(0.678)		(0.766)		(0.694)		(0.477)		(0.756)		(0.630)		(0.642)		(0.590)		(0.736)		(0.648)				
SE 1 hr		(0.020)		(0.050)		(0.048)		(0.067)		(0.069)		(0.062)		(0.041)		(0.067)		(0.068)		(0.065)		(0.041)				
90% CI (+/-)		(0.033)		(0.082)		(0.079)		(0.110)		(0.114)		(0.102)		(0.067)		(0.110)		(0.112)		(0.107)		(0.067)				
Number held	113		59		59		38		27		45		110		37		34		41		112		67		72	
Number alive 48 h	86		48		31		28		4		9		41		4		6		7		17		45		48	
Number Died in holding	27		11		28		10		23		36		69		33		28		34		95		22		24	
Survival at 48 h		N/A**		N/A**		N/A**		N/A**		N/A**		N/A**		N/A**		N/A**		N/A**		N/A**		N/A**				
90% CI (+/-)		N/A		N/A		N/A		N/A		N/A		N/A		N/A		N/A		N/A		N/A		N/A				

* includes dislodged tags and stationary signals

**48 h survival estimate is deemed unreliable due to high (33%) control mortality during delayed assessment period.

~ 1 fish was preyed upon and marked as "assigned dead" (BG 1 5,000)

Table 5-2

Summary of visible injury types and injury rates observed on juvenile American Shad passed through the Turners Falls Hydroelectric Project, October 2015. Controls released downstream at each site.

				Injury Type*						
			Passage	Eye(s)	Gills/Operculum/Isthmus	Head		Body		Internal Damage
	No. Released	No. Examined	Related Visibly Injured	Hemorrhaged Bulged, Missing Ruptured	Torn, Scraped, Inverted Hemorrhaged Bent, Abraded, Bruised	Crushed, Cut Hemorrhaged Bruised, Scraped	Decapitated (Nearly or Partial)	Torn, Scraped Hemorrhaged Bruised, Fins torn	Scale Loss	Hemorrhage, Heart/Kidneys, Broken Back bone
					Cabot Station Unit 2					
	120	115 (0.958)	10 (0.087)	4 (0.035)	3 (0.026)	3 (0.026)	0 (0.000)	2 (0.017)	0 (0.000)	0 (0.000)
					Station No. 1 Units 2 and 3					
	90	65 (0.722)	5 (0.077)	3 (0.046)	1 (0.015)	0 (0.000)	0 (0.000)	1 (0.015)	0 (0.000)	0 (0.000)
					Station No. 1 Unit 1					
	90	68 (0.756)	14 (0.206)	8 (0.118)	4 (0.059)	2 (0.029)	1 (0.015)	0 (0.000)	0 (0.000)	1 (0.015)
					Station No. 1 Units 1-3 Combined					
Total	180	133 (0.739)	19 (0.143)	11 (0.083)	5 (0.038)	2 (0.015)	1 (0.008)	1 (0.008)	0 (0.000)	1 (0.008)
					Bascule Gate 1 at 1,500 cfs					
	60	42 (0.700)	8 (0.190)	3 (0.071)	0 (0.000)	3 (0.071)	0 (0.000)	5 (0.119)	0 (0.000)	3 (0.071)
					Bascule Gate 1 at 2,500 cfs					
	60	34 (0.567)	12 (0.353)	1 (0.029)	1 (0.029)	1 (0.029)	1 (0.029)	3 (0.088)	2 (0.059)	5 (0.147)
					Bascule Gate 1 at 5,000 cfs					
	62	49 (0.790)	17 (0.347)	1 (0.020)	3 (0.061)	3 (0.061)	1 (0.020)	5 (0.102)	1 (0.020)	6 (0.122)
					Bascule Gate 1 Combined					
Total	182	125 (0.687)	37 (0.296)	5 (0.027)	4 (0.032)	7 (0.056)	2 (0.016)	13 (0.104)	3 (0.024)	14 (0.112)
					Bascule Gate 4 at 1,500 cfs					
	60	41 (0.683)	18 (0.439)	0 (0.000)	6 (0.146)	3 (0.073)	0 (0.000)	7 (0.171)	5 (0.122)	3 (0.073)
					Bascule Gate 4 at 2,500 cfs					
	60	40 (0.667)	18 (0.450)	2 (0.050)	8 (0.200)	6 (0.150)	0 (0.000)	5 (0.125)	2 (0.050)	1 (0.025)
					Bascule Gate 4 at 5,000 cfs					
	60	41 (0.683)	18 (0.439)	2 (0.049)	7 (0.171)	0 (0.000)	0 (0.000)	2 (0.049)	2 (0.049)	6 (0.146)
					Bascule Gate 4 Combined					
Total	180	122 (0.678)	54 (0.443)	4 (0.033)	21 (0.172)	9 (0.074)	0 (0.000)	14 (0.115)	9 (0.074)	10 (0.082)
					Cabot Station & Station No. 1 Combined Control Fish					
Total	71	67 (0.944)	1 (0.015)	0 (0.000)	0 (0.000)	1 (0.015)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)
					Bascule Gates Combined Control Fish					
Total	75	75 (1.000)	2 (0.027)	1 (0.013)	0 (0.000)	1 (0.013)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)

*Many fish have multiple injury types.

Table 5-3

Summary of passage-related maladies and severity of maladies of juvenile American Shad passed through the Turners Falls Hydroelectic Project. Turners Falls, MA. October 2015.

No. of Fish Examined	Total With Passage-Related Maladies	LOE only	Mechanical	Pressure/Shear	Pressure /Mechanical	Shear	Mechanical/ Shear	Undetermined	Predation*	Severity: Minor	Severity: Major	Tag Tear**
						Cabot Station Unit 2						
115	10 (0.087)	0 (0.000)	4 (0.035)	0 (0.000)	0 (0.000)	5 (0.043)	1 (0.009)	0 (0.000)	0 (0.000)	4 (0.035)	6 (0.052)	0 (0.000)
						Station No. 1 Units 2/3						
65	10 (0.154)	2 (0.031)	1 (0.015)	0 (0.000)	0 (0.000)	4 (0.062)	0 (0.000)	5 (0.077)	0 (0.000)	2 (0.031)	8 (0.123)	0 (0.000)
						Station No. 1 Unit 1						
68	17 (0.250)	2 (0.029)	2 (0.029)	0 (0.000)	0 (0.000)	11 (0.162)	1 (0.015)	3 (0.044)	0 (0.000)	6 (0.088)	11 (0.162)	0 (0.000)
						Bascule Gate 1: 1,500 cfs						
42	8 (0.190)	0 (0.000)	8 (0.190)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.024)	7 (0.167)	1 (0.024)
						Bascule Gate 1: 2,500 cfs						
34	13 (0.382)	0 (0.000)	9 (0.265)	0 (0.000)	0 (0.000)	2 (0.059)	1 (0.029)	1 (0.029)	0 (0.000)	4 (0.118)	9 (0.265)	2 (0.059)
						Bascule Gate 1: 5,000 cfs						
49	17 (0.347)	0 (0.000)	11 (0.224)	0 (0.000)	0 (0.000)	3 (0.061)	3 (0.061)	0 (0.000)	2 (0.041)	4 (0.082)	13 (0.265)	3 (0.061)
						Combined						
125	38 (0.304)	0 (0.000)	28 (0.224)	0 (0.000)	0 (0.000)	5 (0.040)	4 (0.032)	1 (0.008)	2 (0.016)	9 (0.072)	29 (0.232)	5 (0.040)
						Bascule Gate 4: 1,500 cfs						
41	19 (0.463)	0 (0.000)	11 (0.268)	1 (0.024)	0 (0.000)	6 (0.146)	0 (0.000)	1 (0.024)	0 (0.000)	11 (0.268)	8 (0.195)	2 (0.049)
						Bascule Gate 4: 2,500 cfs						
40	18 (0.450)	0 (0.000)	11 (0.275)	0 (0.000)	0 (0.000)	5 (0.125)	2 (0.050)	0 (0.000)	0 (0.000)	12 (0.300)	6 (0.150)	4 (0.100)
						Bascule Gate 4: 5,000 cfs						
41	18 (0.439)	0 (0.000)	12 (0.293)	0 (0.000)	1 (0.024)	4 (0.098)	1 (0.024)	0 (0.000)	0 (0.000)	11 (0.268)	7 (0.171)	2 (0.049)
						Combined						
122	55 (0.451)	0 (0.000)	34 (0.279)	1 (0.008)	1 (0.008)	15 (0.123)	3 (0.025)	1 (0.008)	0 (0.000)	34 (0.279)	21 (0.172)	8 (0.066)
						Cabot Station and Station No. 1 Combined Controls						
67	1 (0.015)	0 (0.000)	1 (0.015)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.015)	0 (0.000)	0 (0.000)
						Bascule gates Combined Controls						
75	3 (0.040)	1 (0.013)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.000)	2 (0.027)	0 (0.000)	0 (0.000)	3 (0.040)	0 (0.000)

*Predator-related injuries not related to passage

**Flesh tear at tag site not related to passage

Table 5-4

Summary malady data and malady-free estimates for recaptured juvenile American Shad passed through the Turners Falls Hydroelectric Project, Octoberr 2015. Controls released downstream of the treatment sites. Proportions are given in parentheses.

	Cabot Station	Station No. 1	Station No. 1	Bascule Gate 1				Bascule Gates 4				Cabot Station Combined Controls	Bascule Gates Combined Controls
	Unit 2	Unit 2/3	Unit 1	1,500 cfs	2,500 cfs	5,000 cfs	BG1 Combined	1,500 cfs	2,500 cfs	5,000 cfs	BG4 Combined		
Number released	120	90	90	60	60	62	182	60	60	60	180	71	75
Number examined for maladies	115 (0.958)	65 (0.722)	68 (0.756)	42 (0.700)	34 (0.567)	49 (0.790)	125 (0.687)	41 (0.683)	40 (0.667)	41 (0.683)	122 (0.678)	67 (0.944)	75 (1.000)
Number with passage related maladies	10 (0.087)	10 (0.154)	17 (0.250)	8 (0.190)	13 (0.382)	17 (0.347)	38 (0.304)	19 (0.463)	18 (0.450)	18 (0.439)	55 (0.451)	1 (0.015)	3 (0.040)
Visible injuries	10 (0.087)	5 (0.077)	14 (0.206)	8 (0.190)	10 (0.294)	17 (0.347)	34 (0.272)	16 (0.390)	17 (0.425)	16 (0.390)	50 (0.410)	1 (0.015)	1 (0.013)
Loss of equilibrium only	0 (0.000)	2 (0.031)	2 (0.029)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.013)
Scale loss only	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	2 (0.059)	1 (0.020)	3 (0.024)	2 (0.049)	1 (0.025)	2 (0.049)	4 (0.033)	0 (0.000)	0 (0.000)
1 hr mortality w/ no visible injury or LOE	0 (0.000)	3 (0.046)	1 (0.015)	1 (0.024)	1 (0.029)	0 (0.000)	2 (0.016)	1 (0.024)	0 (0.000)	0 (0.000)	1 (0.008)	0	1
Number without passage related maladies	105 (0.913)	55 (0.846)	51 (0.750)	34 (0.810)	21 (0.618)	32 (0.653)	87 (0.696)	22 (0.537)	22 (0.550)	23 (0.561)	67 (0.549)	61 (0.910)	58 (0.773)
Without passage related maladies that died	23 (0.200)	9 (0.138)	26 (0.382)	5 (0.119)	18 (0.529)	25 (0.510)	48 (0.384)	20 (0.488)	18 (0.450)	18 (0.439)	55 (0.451)	21 (0.000)	23 (0.000)
Malady free rate	(0.927)	(0.860)	(0.761)	(0.819)	(0.643)	(0.680)	(0.717)	(0.559)	(0.573)	(0.584)	(0.572)		
SE	(0.030)	(0.047)	(0.055)	(0.069)	(0.088)	(0.073)	(0.046)	(0.082)	(0.083)	(0.082)	(0.049)		
90% CI (+/-)	(0.049)	(0.077)	(0.090)	(0.114)	(0.145)	(0.120)	(0.076)	(0.135)	(0.135)	(0.135)	(0.081)		

*Maladies include both visible injuries and LOE

Table 5-5

Summary Table of survival and malady-free estimates for juvenile American Shad passed through the Turners Falls Hydroelectric Project, October 2015.

	Cabot Station	Station No. 1	Station No. 1	Bascule Gate 1				Bascule Gate 4			
	Unit 2	Unit 2/3	Unit 1	1,500 cfs	2,500 cfs	5,000 cfs	Combined	1,500 cfs	2,500 cfs	5,000 cfs	Com
1 h Survival											
%	95.0	67.8	76.6	69.4	47.7	75.6	63.0	64.2	59.0	73.6	6
90% CI (±)	3.3	8.2	7.9	11	11.4	10.2	6.7	11.0	11.2	10.7	6
Malady-Free											
%	92.7	86	76.1	81.9	64.3	68.0	71.7	55.9	57.3	58.4	5
90% CI (±)	4.9	7.7	9	11.4	14.5	12.0	7.6	13.5	13.5	13.5	8

Table 6-1

Physical and hydraulic characteristics of hydroelectric dams for which HI-Z Tag turbine passage survival data are available for American Shad and Blueback Herring.

Station	State	Study Year	River	Species	Average Size (mm)	Unit Tested	Turbine Type	No. of Blades/ Buckets	Runner Speed (rpm)	Runner Dia. (in)	Peripheral Velocity (fps)	Test Discharge (cfs)	Project Head (ft)
Columbia	SC	1998	Broad/Congaree	Blueback Herring	141	2	H-Francis	14	164	64	45.8	800	28
Conowingo	MD	1993	Susquehanna	American shad	125	8	Mixed Flow	6	120	225	117.9	8,000	90
Conowingo	MD	2011	Susquehanna	American shad	119	5	Francis	13	81.8	203	72.5	5,080	89
Crescent	NY	1991	Mohawk	Blueback herring	91		Kaplan	5	144	108	67.9	1,520	27
Hadley Falls	MA	1991	Connecticut	American Shad	82*		Kaplan	5	128	170	95.0	4,200	52
Hadley Falls	MA	1991	Connecticut	American Shad	82*		Kaplan	5	128	170	95.0	1,550	52
Hadley Falls	MA	1991	Connecticut	American Shad	82*		Propeller	5	150	156	102.1	4,200	52
Holtwood Dam	PA	1991	Susquehanna	American Shad	125	10	Francis	16	94.7	164	67.8	3,500	51
Holtwood Dam	PA	1991	Susquehanna	American Shad	125	3	Francis	17	102.8	112	50.3	3,500	51
Holtwood Dam	PA	1997	Susquehanna	American Shad	119	9	Francis	13	94.7	164	67.8	3,000	51
Safe Harbor Dam	PA	1992	Susquehanna	American Shad	118	9	Mixed Flow	7	76.6	240	80.2	9,200	55
Safe Harbor Dam	PA	1992	Susquehanna	American Shad	118	9	Mixed Flow	7	76.6	240	80.2	9,200	55
Safe Harbor Dam	PA	1992	Susquehanna	American Shad	118	7	Kaplan (horiz.)	5	109.1	220	104.8	8,300	55
Stevens Creek	SC	1993	Savannah	Blueback Herring	203	3	Francis	14	75	135	44.2	1,000	28
York Haven, PA	PA	2002	Susquehanna	American Shad	114	7	Francis	18	84	78	28.6	850	23
York Haven, PA	PA	2002	Susquehanna	American Shad	118	3	Kaplan	4	200	93	81.2	1,100	21
Vernon	VT/NH	1995	Connecticut	American Shad	95	10	Francis	15	74	156	50.4	1,834	34
Vernon	VT/NH	2015	Connecticut	American Shad	98	4	Francis	13	133.3	62.5	36.4	1,000	35
Vernon	VT/NH	2015	Connecticut	American Shad	104	8	Kaplan	5	144	122	76.7	1,200	32
Cabot Station	MA	2015	Connecticut	American Shad	96	2	Francis	13	97.3	136	54.4	2304	60
Station No. 1	MA	2015	Connecticut	American Shad	96	1	Francis	13	200	54	47.1	651	44
Station No. 1	MA	2015	Connecticut	American Shad	96	2	Francis	13	257	39	43.7	591	44
Station No. 1	MA	2015	Connecticut	American Shad	96	3	Francis	15	200	55	47.5		44

Station	Sample Size Treatmen	Sample Size Control	Recapture Rate (%) Treatment	Recapture Rate (%) Control	1 h Survival	Source
Columbia	100	100	90.0	97.0	0.936	NAI (1999)
Conowingo	108	108	88.0	97.6	0.949	RMC (1994a)
Conowingo	138	76	88.4	97.3	0.899	NAI and Gomez and
Crescent	125	125	84.0	86.0	0.960	Mathur et al. (1996b)
Hadley Falls	100	100	76.0	76.0	0.973	RMC (1992b)
Hadley Falls	100	100	81.0	78.0	1.000	RMC (1992b)
Hadley Falls	120	120	74.2	83.3	0.891	RMC (1992b)
Holtwood Dam	100	80	81.0	90.0	0.894	RMC (1992a)
Holtwood Dam	100	80	78.0	93.8	0.835	RMC (1992a)
Holtwood Dam	40	20	80.0	85.0	0.905	NAI (1997)
Safe Harbor Dam	100	100	92.0	92.0	0.978	Heisey et al. (1992)
Safe Harbor Dam	99	100	96.0	98.0	0.989	Heisey et al. (1992)
Safe Harbor Dam	100	100	99.0	99.0	0.980	Heisey et al. (1992)
Stevens Creek	131	120	90.8	89.2	0.953	RMC (1994b)
York Haven, PA	94	100	64.0	82.0	0.771	NAI (2001)
York Haven, PA	100	100	78.0	82.0	0.927	NAI (2001)
Vernon	153	150	93.5	98.7	0.947	NAI (1996)
Vernon	151	150	87.4	97.3	0.917	draft
Vernon	150	150	94.0	97.3	0.952	draft
Cabot Station	120	71	95.8	94.4	0.950	present study
Station No. 1	90	71	75.6	94.4	0.766	present study
Station No. 1	90	71	72.2	94.4	0.678	present study

* Fork length measurements were recorded

**Units 2 and 3 have common penstock, only one survival estimate

Figures

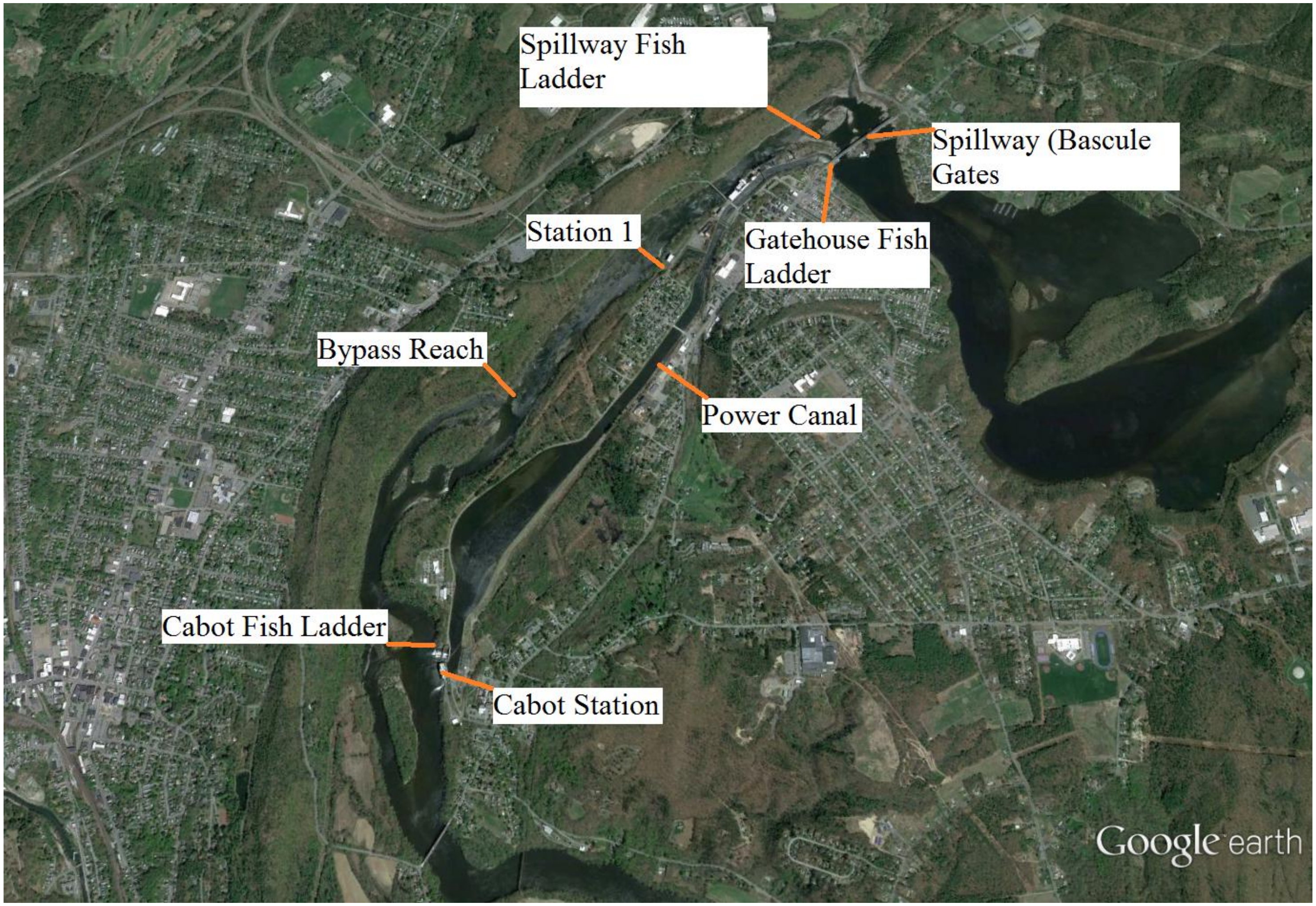

Figure 1-1 Aerial view of the FirstLight study locations.

Figure 3-1 Inside Cabot Station.

Figure 3-2 Flow conditions at Bascule Gate 1 with 1,500 cfs discharge; note spill jet interaction with concrete sill.

Figure 3-3 Downstream of Bascule Gate 4 at 5,000 cfs.

Figure 4-1 HI-Z Tag mark/recapture application on juvenile American Shad at Bascule Gate 1.

Figure 4-2 Electrofishing for juvenile American Shad.

Figure 4-3 Seining for juvenile shad in the Turners Falls power canal during the annual drawdown.

Figure 4-4 Partially clipping a pelvic or caudal fin to permit identification of fish during the 48 h holding period.

Figure 4-5 HI-Z tagging juvenile American Shad with a stainless steel pin through the musculature of the shad’s back via a modified tagging gun.

Figure 4-6 Attached radio tag in combination with the HI-Z tag to aid in tracking released shad.

Figure 4-7 The HI-Z tags activated by injecting a catalyst into each HI-Z tag.

Figure 4-8 Fish placed individually into the induction system tail first.

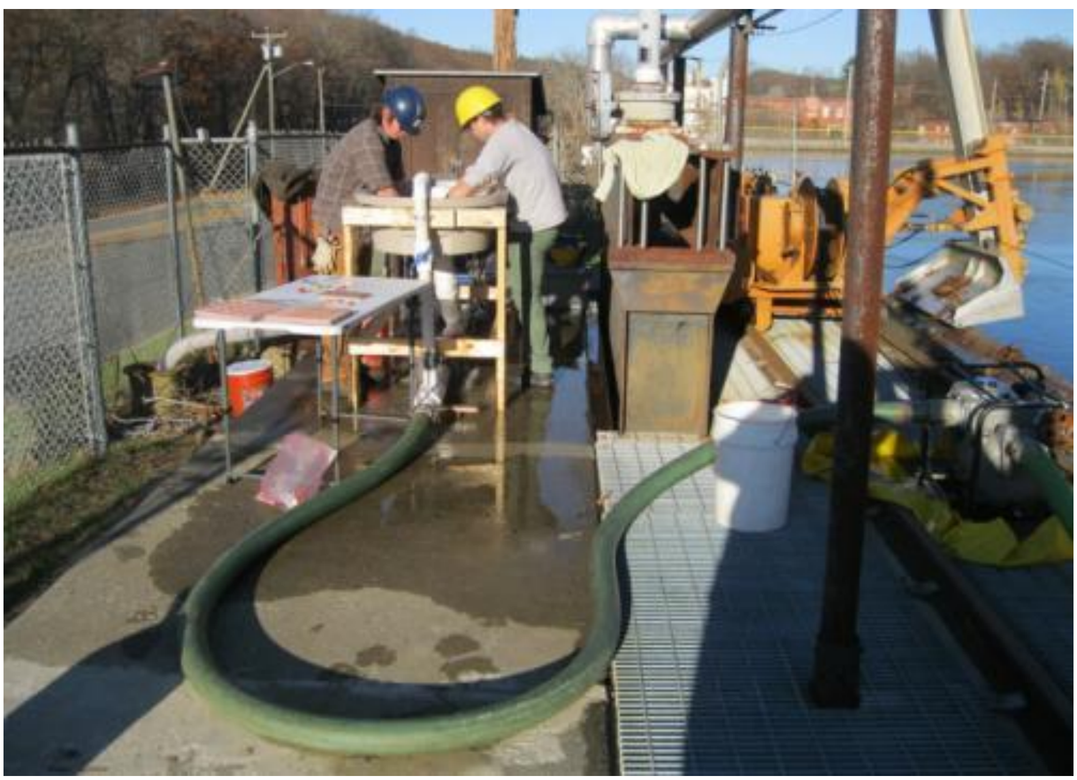

Figure 4-9 All treatment and control fish released through an induction apparatus.

Figure 4-10 The induction apparatus connected to 4-inch diameter hoses which allowed the shad to pass to the desired release points.

Figure 4-11 Metal pipe extension to release shad to the desired release point to ensure fish would pass over the Bascule Gates.

Figure 4-12 Boat crews positioned downstream for retrieval of released fish when buoyed to the surface.

Figure 4-13 Buoyed fish collected by a brailer to keep the fish submersed in water at all times and reduce handling stress.

Figure 4-14 Fish holding tanks continuously supplied with ambient river water by two redundant pump systems connected to different electrical circuits, and were numbered to clarify test dates.

Figure 4-15 Recaptured shad transported to shore and kept in holding tanks (600 gal) to monitor delayed effects of tagging and project passage.

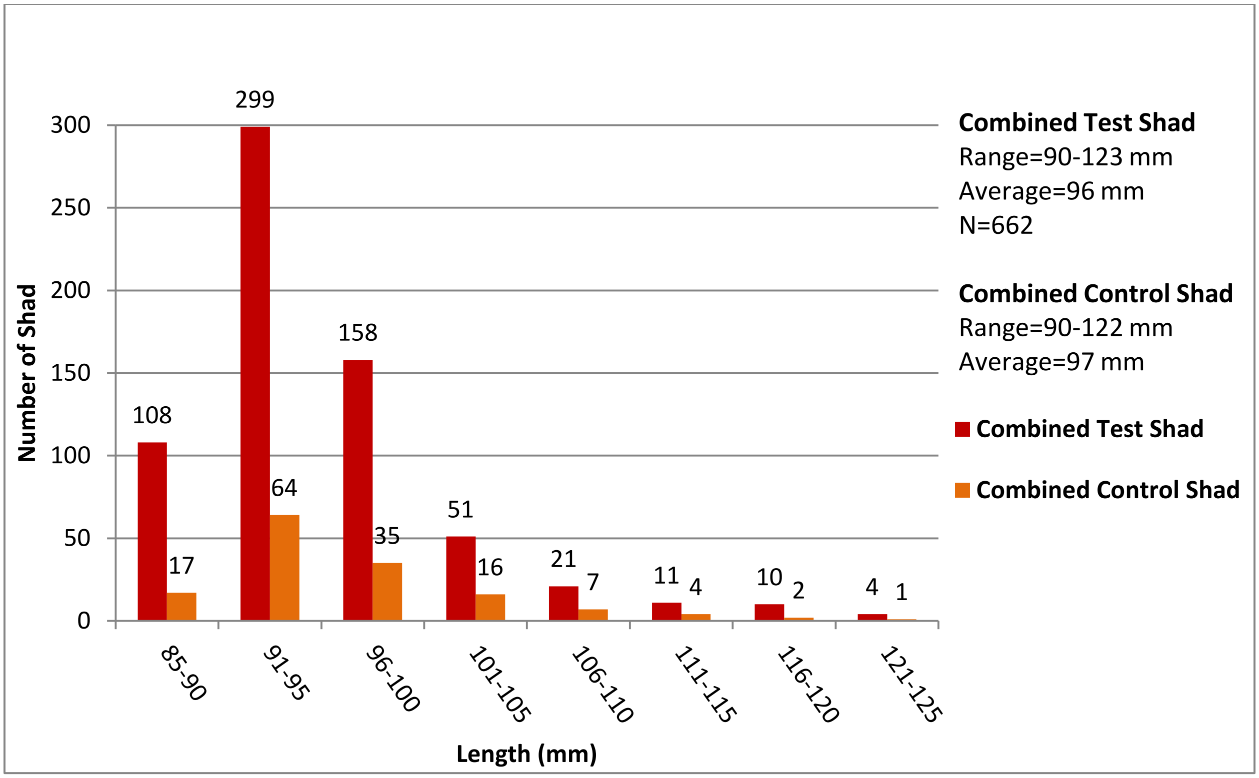

Figure 4-16 Length frequency for HI-Z tagged juvenile American Shad released at Cabot Station Unit 2, Station No. 1, and over Bascule Gates 1 and 4 compared to combined controls.

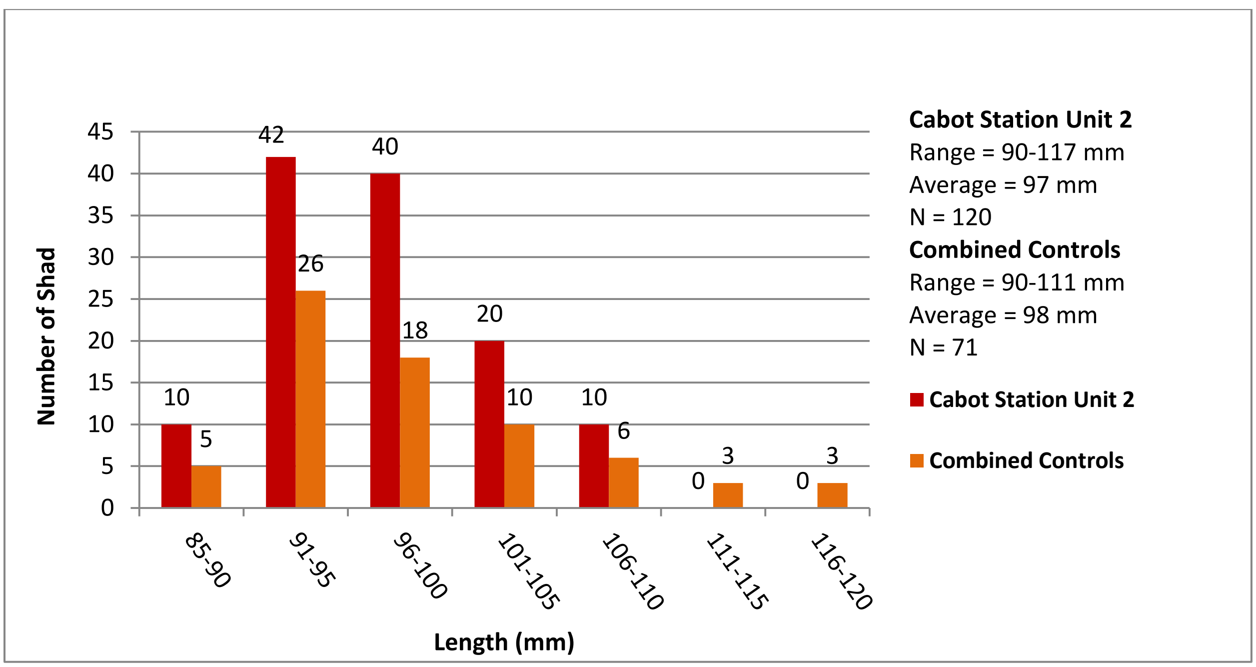

Figure 4-17 Length frequency for HI-Z tagged juvenile American Shad released at Cabot Station Unit 2, versus combined controls.

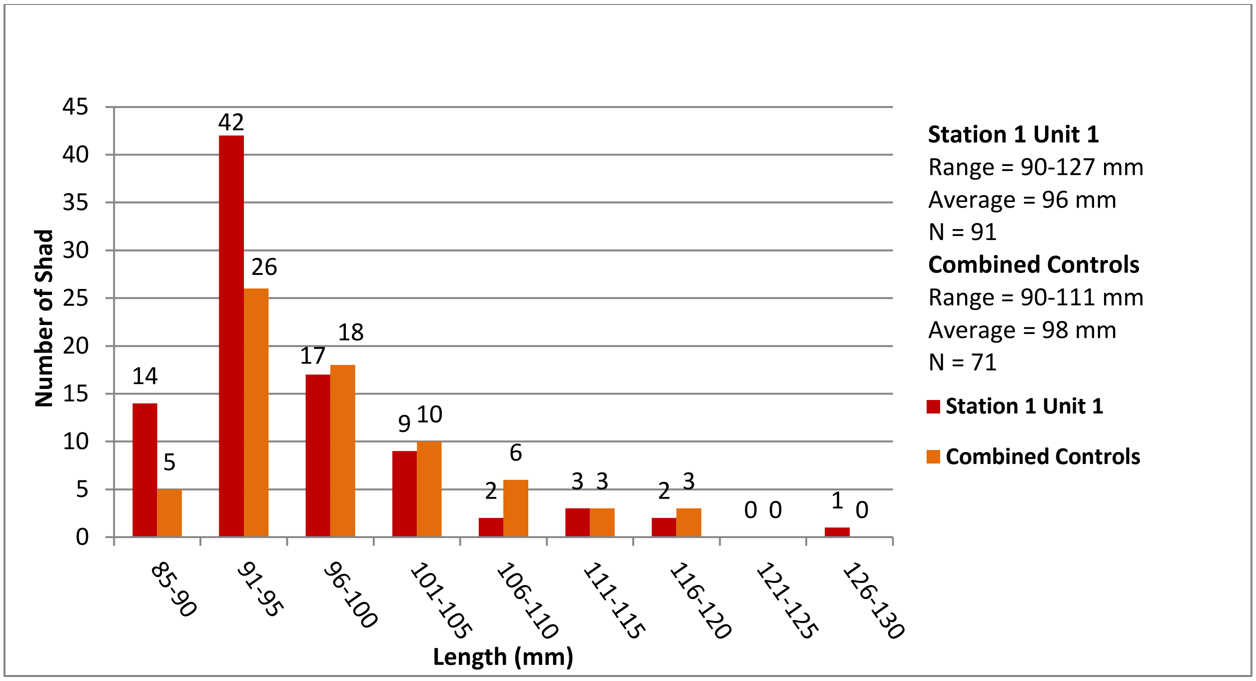

Figure 4-18 Length frequency for HI-Z tagged treatment juvenile American Shad released at Station No. 1 Unit 1 versus combined controls.

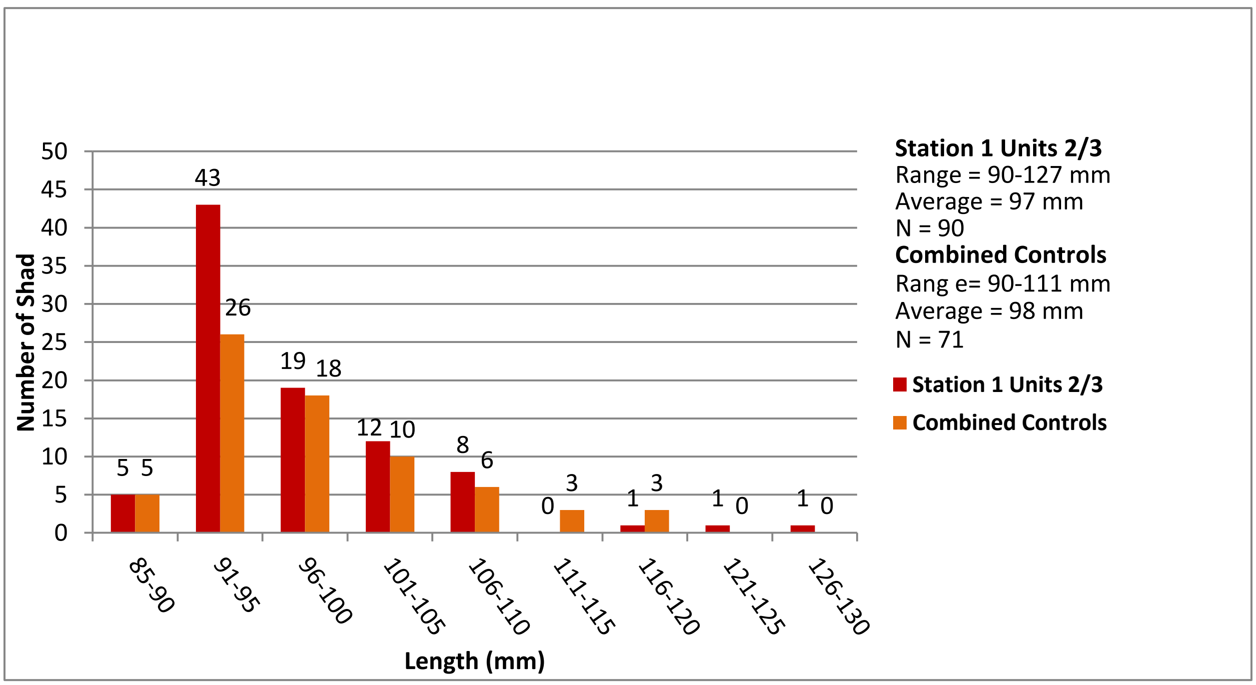

Figure 4-19 Length frequency for HI-Z tagged treatment juvenile American Shad released at Station No. 1 Units 2/3 versus combined controls.

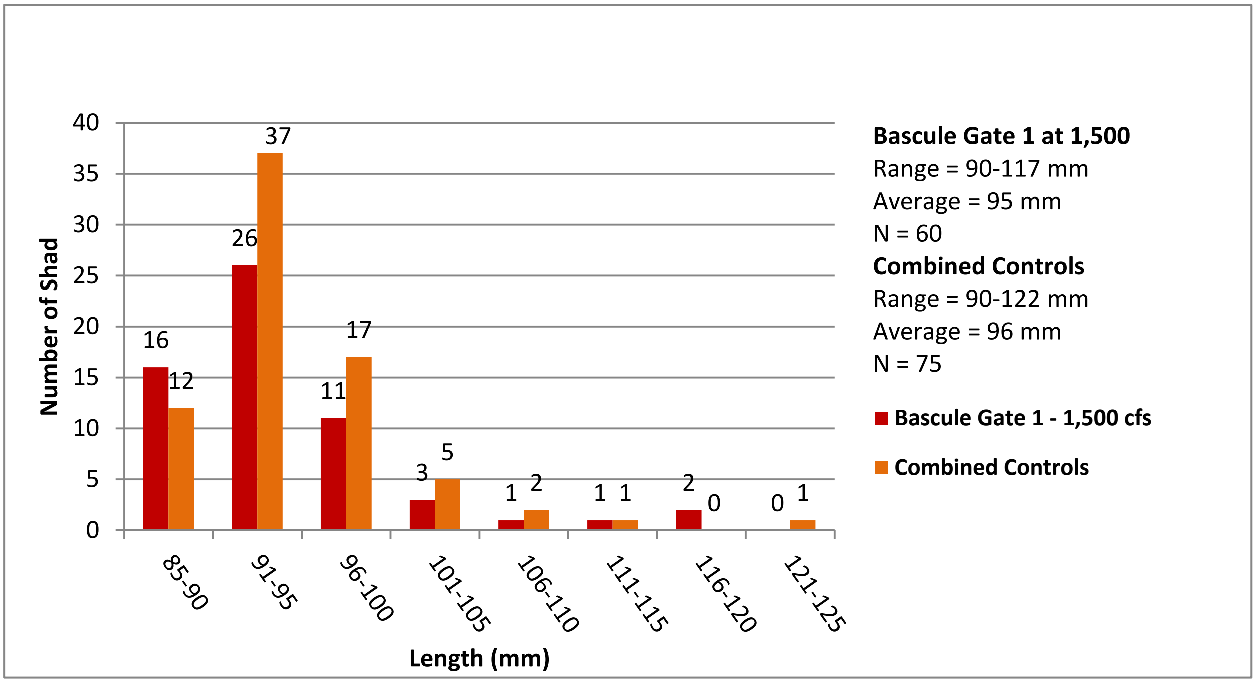

Figure 4-20 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 1 at 1,500 cfs versus combined controls.

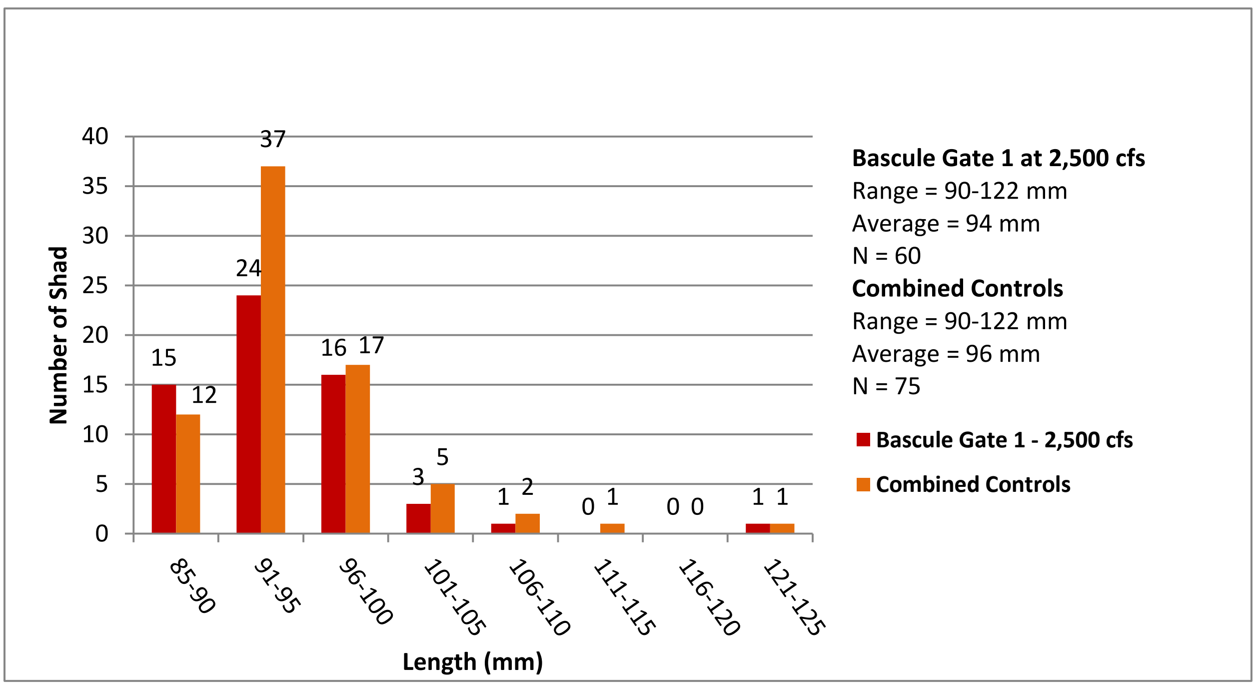

Figure 4-21 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 1 at 2,500 cfs versus combined controls.

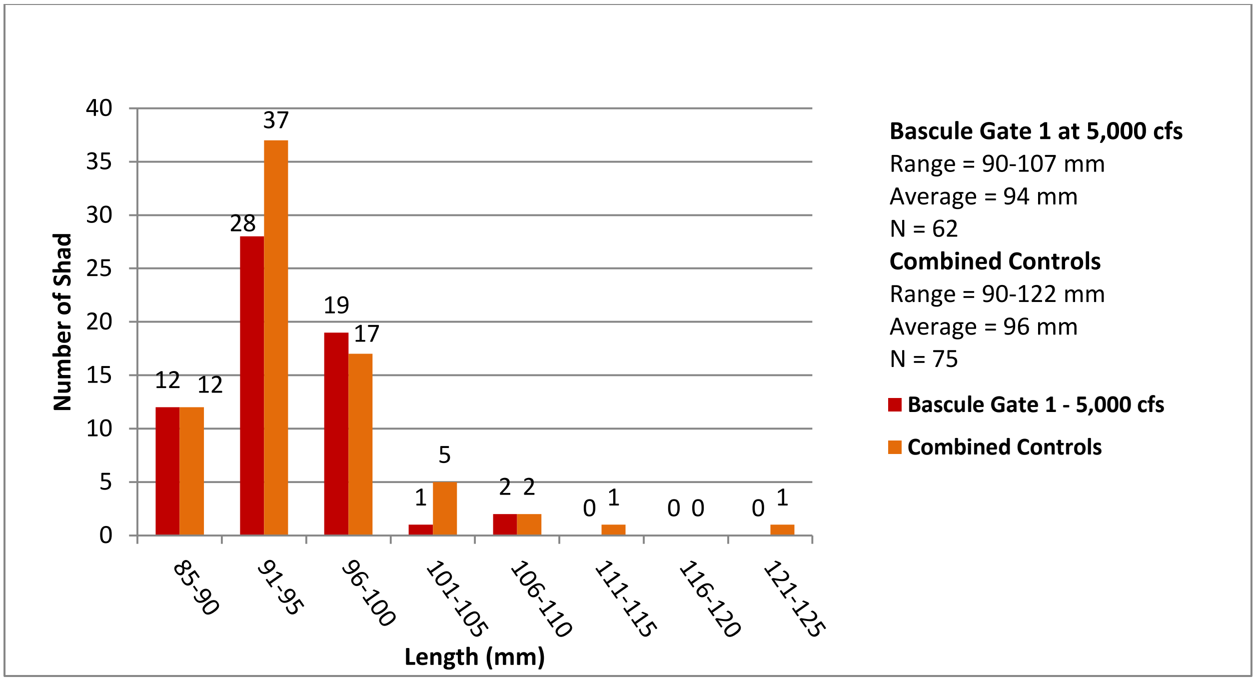

Figure 4-22 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 1 at 5,000 cfs versus combined controls.

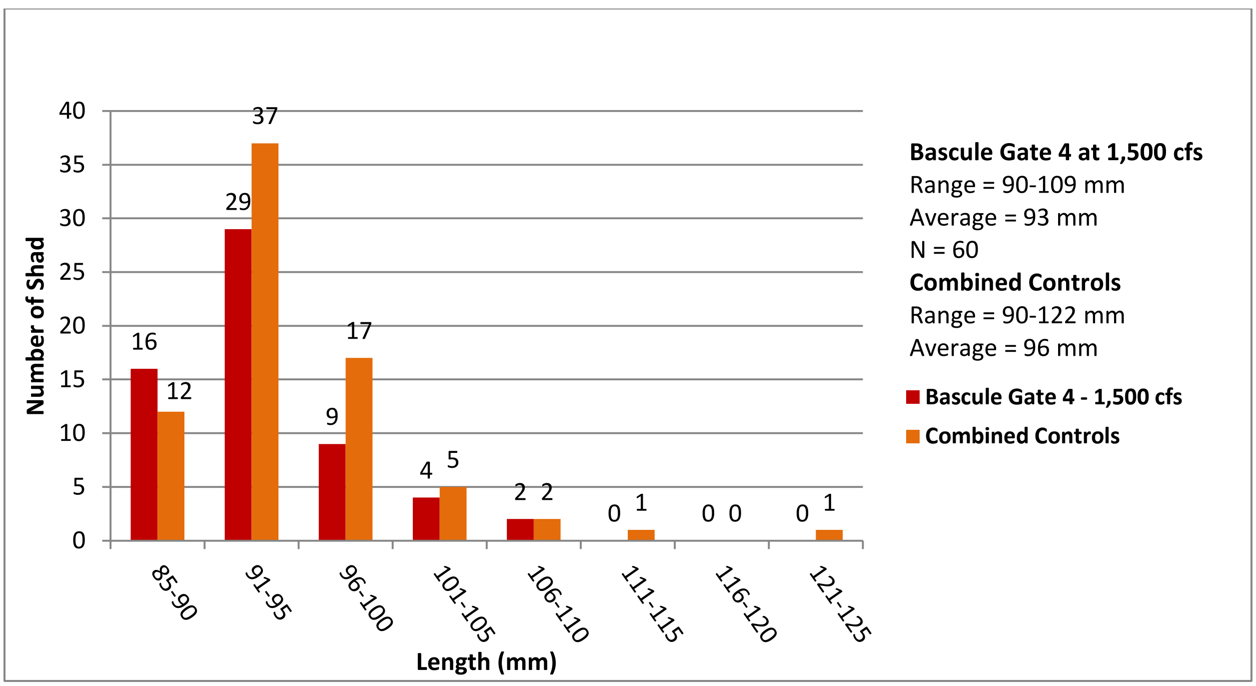

Figure 4-23 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 4 at 1,500 cfs versus combined controls.

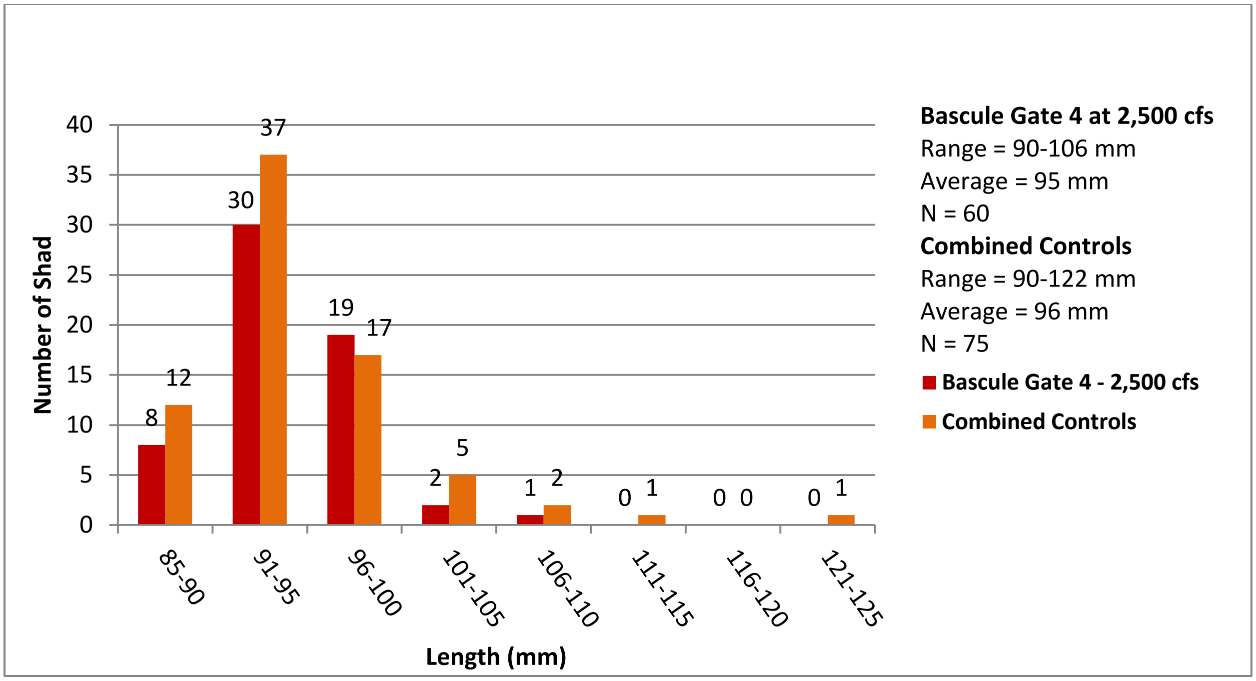

Figure 4-24 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 4 at 2,500 cfs versus combined controls.

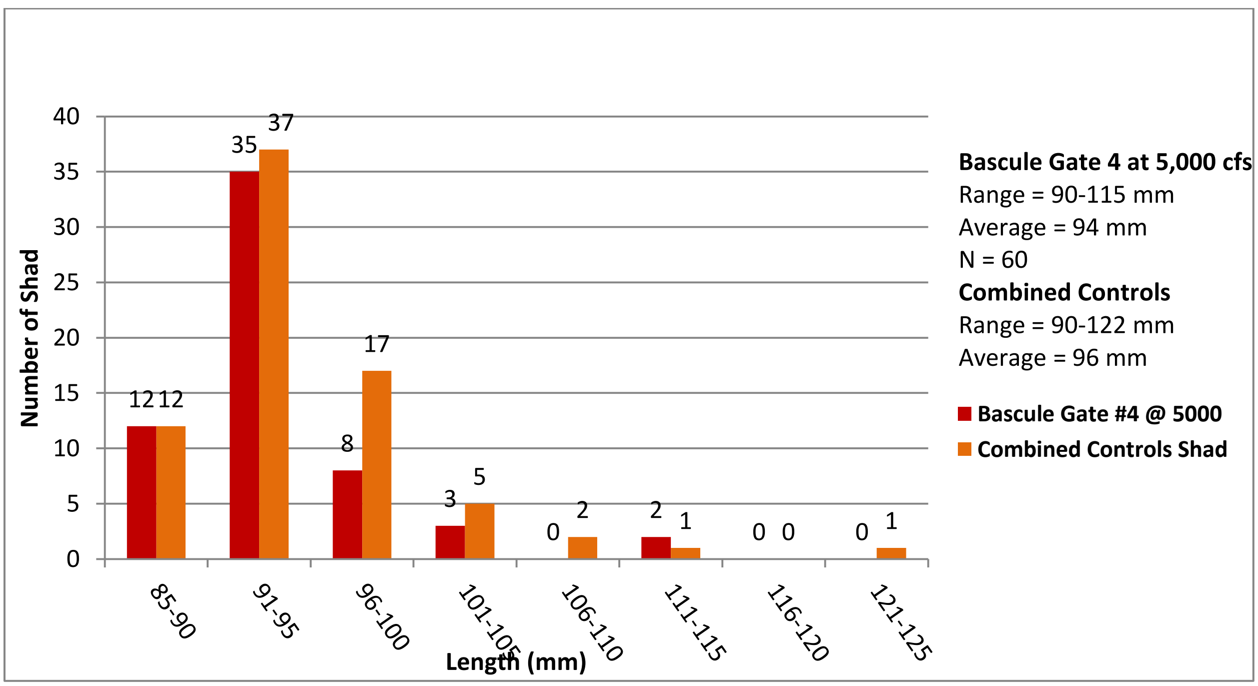

Figure 4-25 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 4 at 5,000 cfs versus combined controls.

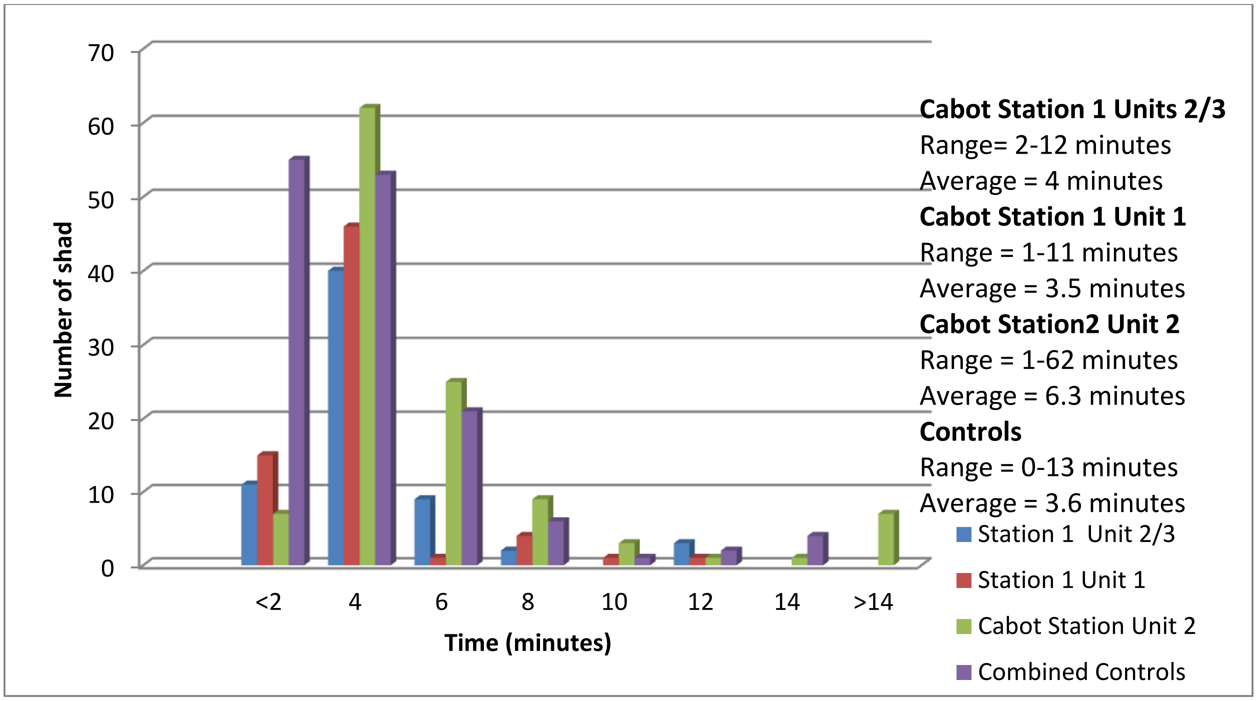

Figure 4-26 Recapture times for HI-Z tagged treatment juvenile American Shad released at Cabot Station Unit 2, Station No. 1 Unit 1, and Station No. 1 Unit 2/3 and combined controls.

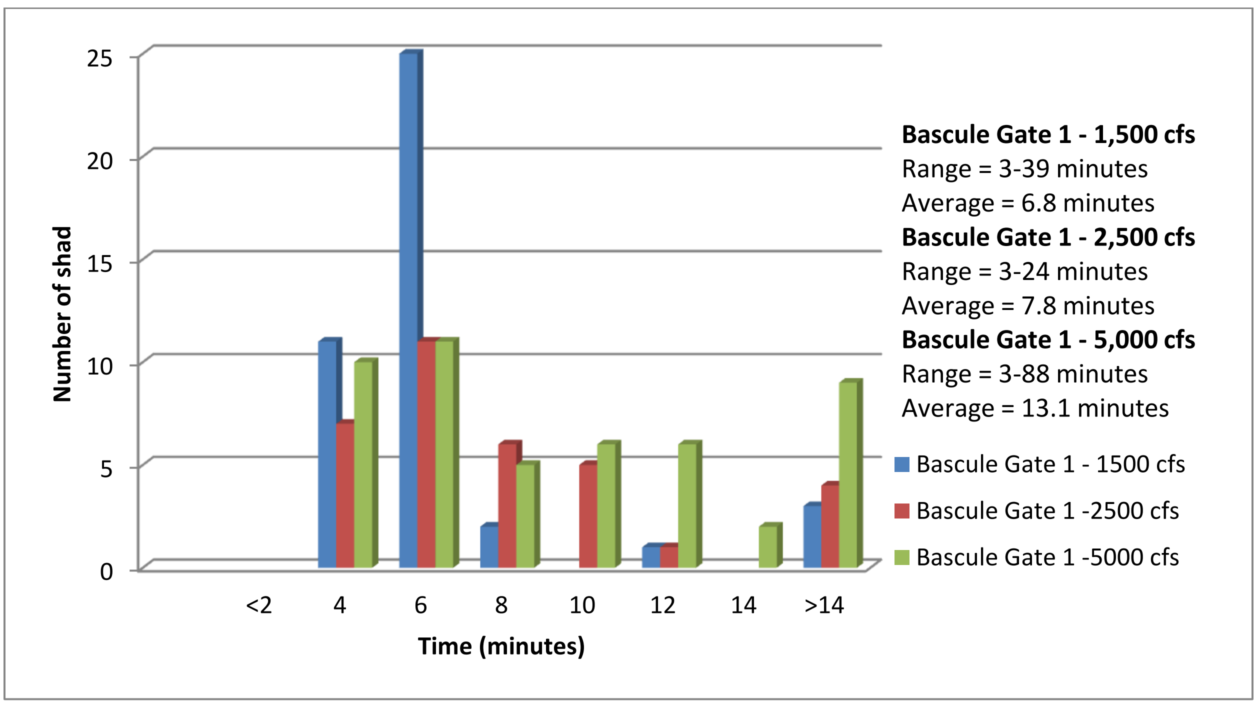

Figure 4-27 Recapture times for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 1 into 1,500, 2,500, and 5,000 cfs conditions.

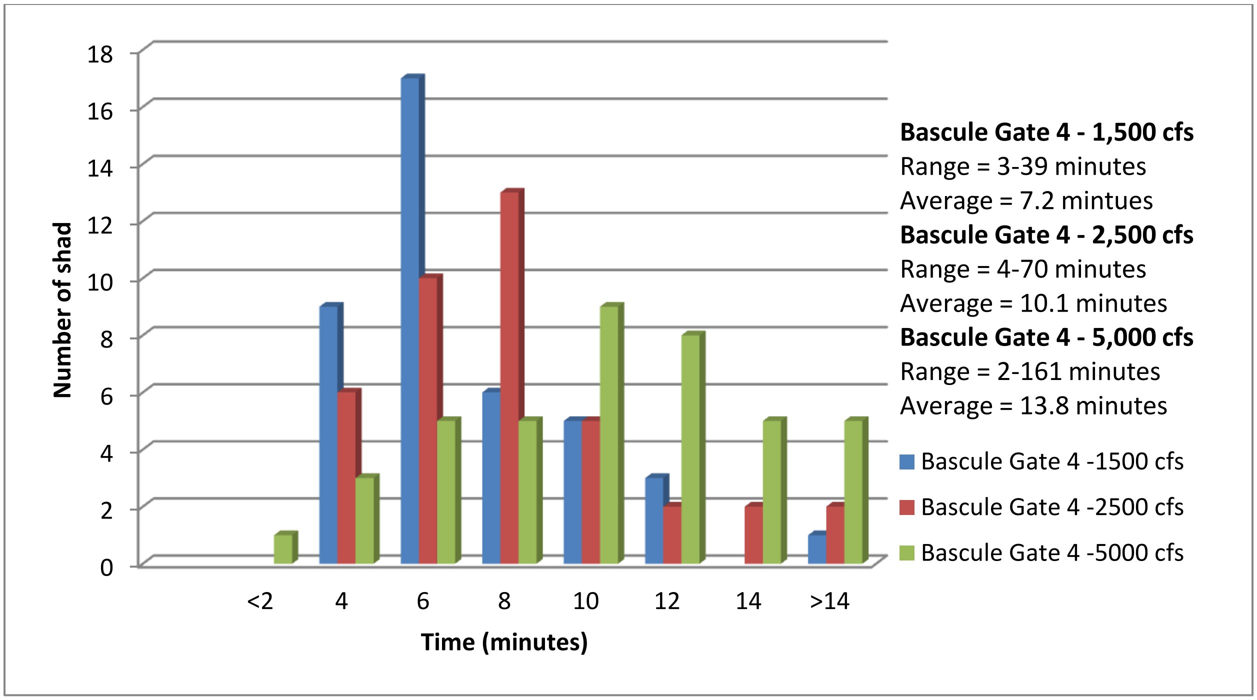

Figure 4-28 Recapture times for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 4 into 1,500, 2,500, and 5,000 cfs conditions.

APPENDIX A

INDIVIDUAL FISH DISPOSITION DATA

Appendix A

Fish ID	Total Length (mm)		Time: Re-leased	Time: Re-covered	Time: Minutes at large	No. HI-Z tags recovered	Survival Code	Status Codes 1	Status Codes 2	Status Codes 3	Status Codes 4
1	105	11:59			0		R				
2	90	12:07	12:10	*3*	1	1	A				
3	90	12:12			0		R				
4	90	12:19	12:52	*33*	1	1	A				
5	98	12:36	12:40	*4*	1	1	A				
6	113	12:38	12:42	*4*	1	1	A				
7	97	12:40	12:46	*6*	1	1	A				
8	91	12:44	12:48	*4*	1	1	A				
9	90	12:46	12:56	*10*	1	1	A				
10	92	12:50					R				
11	100	13:01					R				
12	95	13:17	13:23	*6*	1	1	A				
13	91	13:20	13:26	*6*	1	1	A				
14	90	13:22					R				
15	103	14:10	14:13	*3*	1	1	A				
16	91	14:12	14:16	*4*	1	1	A				
17	93	14:14	14:27	*13*	1	1	A				
18	92	14:18	14:21	*3*	1	1	A				
19	92	14:18	14:24	*6*	1	1	A				
20	92	14:27	14:28	*1*	1	1	A				
21	94	14:31	14:35	*4*	1	1	H	*			
22	92	14:33	14:38	*5*	1	1	A				
23	92	14:33	14:39	*6*	1	1	A				
24	98	14:35	14:45	*10*	1	1	A				
25	91	14:36	14:41	*5*	1	1	A				
26	94	14:40	15:27	*47*	1	1	H	*			
27	106	14:44					R				
28	96	14:45	14:52	*7*	1	1	A				
29	90	14:48	14:52	*4*	1	1	A				
30	116	14:50	14:56	*6*	1	1	A				
31	98	14:27	15:11	*44*	1	1	A				
32	90	14:58	15:06	*8*	1	1	A				
33	92	14:49	15:06	*17*	1	1	H	*			
34	90	15:00	15:07	*7*	1	1	H	*			
35	96	15:07	15:14	*7*	1	1	A				
C01	116	15:30	15:33	*3*	1	1	A				
C02	103	15:31	15:39	*8*	1	1	A				
C03	111	15:32	15:37	*5*	1	1	A				
C04	91	15:40	15:43	*3*	1	1	A				
C05	91	15:42	15:46	*4*	1	1	A				
C06	117	15:44	15:46	*2*	1	1	A				
C07	95	15:34					R				
C08	97	15:46	15:50	*4*	1	1	A				
1	91	10:38	10:42	*4*	1	1	A				
2	101	10:39	10:44	*5*	1	2	A	*			
3	99	10:40	10:45	*5*	1	1	A				

4	92	10:42	10:46	4	1	1	A			
5	102	10:45	10:48	3	1	1	A			
6	104	10:46	10:49	3	1	1	A			
7	96	10:47	10:51	4	1	1	A			
8	90	10:54	10:57	3	1	1	A			
9	97	10:55	11:00	5	1	1	A			
10	94	10:56	11:02	6	1	2	8	*		
11	98	11:02	11:05	3	1	1	A			
12	98	11:03	11:05	2	1	1	A			
13	102	11:04			1	3				
14	106	11:05	11:08	3	1	1	H	*		
15	111	11:11	11:15	4	1	1	9	*		
16	102	11:12	11:16	4	1	1	A			
17	99	11:12	11:15	3	1	1	A			
18	99	11:13	11:18	5	1	1	A			
19	93	11:14	11:19	5	1	1	A			
20	95	11:32	11:35	3	1	1	A			
21	94	11:33	11:35	2	1	1	A			
22	96	11:34	11:37	3	1	1	A			
23	94	11:35	12:37	62	1	1	A			
24	95	11:36	11:40	4	1	1	A			
25	117	11:37	11:42	5	1	1	H	9	*	
26	97	11:38	11:41	3	1	1	A			
27	96	11:39	11:42	3	1	1	A			
28	91	11:40	11:43	3	1	1	A			
29	90	11:40	11:46	6	1	1	A			
30	105	12:00	12:19	19	1	1	A			
31	104	12:01	12:04	3	1	1	A			
32	117	12:02	12:04	2	1	1	A			
33	94	12:02	12:06	4	1	1	A			
34	92	12:03	12:10	7	1	1	A			
35	93	12:11	12:14	3	1	1	A			
36	101	12:12	12:18	6	1	1	A			
37	91	12:13	12:17	4	1	1	E	*		
38	100	12:31	12:33	2	1	1	A			
39	91	12:31	12:34	3	1	1	A			
40	96	12:33	12:36	3	1	1	A			
41	93	12:34	12:41	7	1	1	A			
42	92	12:35	12:38	3	1	1	A			
43	101	12:37	12:41	4	1	1	A			
44	99	12:43	12:47	4	1	1	A			
45	103	12:44	12:56	12	1	1	A			
46	92	12:45			1	3				
47	91	12:47	12:50	3	1	1	A			
48	91	12:48			1	3				
49	92	12:49			1	3				
50	93	12:51	12:54	3	1	1	A			
51	93	12:53	12:56	3	1	1	A			
52	98	13:10	13:13	3	1	1	A			
53	104	13:11	13:14	3	1	1	A			
54	90	13:13	13:17	4	1	1	A			
55	99	13:15			0	4				
56	93	13:16	13:20	4	1	1	H	E	G	*
57	96	13:17	13:20	3	1	1	A			
58	91	13:36	13:39	3	1	1	A			
59	116	13:37	13:40	3	1	1	A			
60	96	13:38	13:44	6	1	1	G	*		

61	104	13:39	13:42	*3*	1	1	A	
62	112	13:40	13:42	*2*	1	1	A	
63	96	13:46	13:48	*2*	1	1	A	
64	98	13:47	13:51	*4*	1	1	A	
65	97	13:49	13:52	*3*	1	1	A	
66	106	13:49	13:56	*7*	1	1	A	
67	99	13:50	13:58	*8*	1	1	A	
68	93	13:55	14:00	*5*	1	1	A	
69	95	13:58	14:04	*6*	1	1	A	
70	106	13:59	14:03	*4*	1	1	A	
71	90	14:01	14:06	*5*	1	1	A	
72	96	14:01	14:07	*6*	1	1	A	
73	97	14:03	14:07	*4*	1	1	A	
74	108	14:03	14:07	*4*	1	1	H	*
75	96	14:05	14:09	*4*	1	1	A	
76	115	14:17	14:20	*3*	1	1	A	
77	96	14:18	14:22	*4*	1	1	A	
78	104	14:18	14:22	*4*	1	1	H	*
79	100	14:20	14:27	*7*	1	1	A	
80	96	14:21	14:24	*3*	1	1	A	
81	96	14:22	14:28	*6*	1	1	A	
82	116	14:24	14:28	*4*	1	1	A	
83	98	14:26	14:46	*20*	1	1	A	
84	95	14:35	14:38	*3*	1	1	A	
85	98	14:35	14:39	*4*	1	1	H	*
86	98	14:36	14:41	*5*	1	1	A	
87	98	14:37	14:40	*3*	1	1	A	
88	98	14:38	14:41	*3*	1	1	A	
89	96	14:39	14:44	*5*	1	1	A	
90	111	14:41	14:45	*4*	1	1	A	
91	93	14:43	14:53	*10*	1	1	A	
C01	104	9:13	9:16	*3*	1	1	A	
C02	93	9:14	9:20	*6*	1	1	A	
C03	93	9:15	9:20	*5*	1	1	A	
C04	94	9:17	9:20	*3*	1	1	A	
C05	96	9:18	9:22	*4*	1	1	A	
C06	106	9:21	9:26	*5*	1	1	A	
C07	102	9:22	9:26	*4*	1	1	A	
C08	92	9:23	9:28	*5*	1	1	A	
C09	92	9:24	9:27	*3*	1	1	A	
C10	96	9:30	9:43	*13*	1	1	H	*
C11	93	9:32	9:37	*5*	1	1	A	
C12	99	9:34	9:38	*4*	1	1	A	
C13	90	9:35	9:40	*5*	1	1	A	
C14	90	9:40	9:46	*6*	1	1	A	
C15	95	9:42	9:45	*3*	1	1	A	
C16	94	9:43	9:48	*5*	1	1	A	
C17	103	9:46	9:53	*7*	1	1	A	
C18	92	9:47	9:51	*4*	1	1	A	
C19	91	9:49	9:53	*4*	1	1	A	
C20	97	9:50	10:00	*10*	1	1	A	
C21	115	9:53	9:56	*3*	1	1	A	
C22	98	9:54	9:59	*5*	1	1	A	
C23	96	9:56	9:59	*3*	1	1	A	

1	98	10:05	10:09	4	1	1	H	B	*	8
2	97	10:07			2		R			
3	94	10:08			1	3				
4	92	10:22	10:26	4	1	2	A	*		
5	102	10:24	10:29	5	1	1	A			
6	103	10:31			0	4				
7	92	10:33	10:38	5	1	1	A			
8	98	10:42	10:45	3	1	1	A			
9	109	10:44	10:46	2	1	1	A			
10	90	10:46	10:50	4	1	1	A			
11	97	10:48			1	3				
12	92	10:51			1	3				
13	92	10:52	10:56	4	1	1	A			
14	95	10:58	11:00	2	1	1	A			
15	92	11:01	11:03	2	1	1	A			
16	92	11:07	11:12	5	1	1	H	*		
17	95	11:08			1	3				
18	96	11:09	11:13	4	1	1	A			
19	96	11:13			0		R			
20	95	11:14			0	4				
21	107	11:16	11:18	2	1	1	A			
22	91	11:18			1	3				
23	95	11:19	11:21	2	1	1	A			
24	103	11:30			1	3				
25	103	11:33	11:37	4	1	1	H	*		
26	97	11:34	11:38	4	1	2	A	*		
27	101	11:35			0	4				
28	92	11:36	11:39	3	1	2	H	*		
29	106	11:38	11:42	4	1	2	H	*		
30	106	11:40			1	3				
31	91	11:49			1	3				
32	91	11:50			1	3				
33	91	11:52	11:56	4	1	1	A			
34	92	11:59	12:01	2	1	1	A			
35	91	11:59	12:02	3	1	1	H	*		
36	95	12:02	12:05	3	1	1	A			
37	92	12:03	12:14	11	1	1	A			
38	94	12:04	12:08	4	1	1	H	*		
39	90	12:05	12:12	7	1	1	H	*		
40	92	12:06	12:12	6	1	1	A			
41	98	12:07	12:11	4	1	1	A			
42	122	12:09	12:13	4	1	1	A			
43	91	12:10			1	3				
44	93	12:17			1	3				
45	100	12:19	12:22	3	1	1	A			
46	92	12:21	12:24	3	1	1	A			
47	95	12:22	12:28	6	1	1	H	8	*	
48	95	12:28	12:31	3	1	1	A			
49	105	12:32	12:43	11	1	1	H	*		
50	96	12:34			1	3				
51	103	12:36	12:39	3	1	1	A			
52	96	12:38	12:50	12	1	1	A			
53	96	12:39	12:46	7	1	1	H	*		
54	93	12:40			0		R			
55	95	12:42	12:45	3	1	1	H	*		
56	103	12:50	12:53	3	1	1	A			

57	105	12:51	12:54	3	1	2	A	*	
58	100	12:53	12:59	6	1	1	A		
59	106	12:54			1	3			
60	94	12:55	12:58	3	1	1	H	*	
61	92	12:57	13:00	3	1	1	H	8	*
62	93	13:03	13:06	3	1	1	H	*	
63	95	13:04	13:07	3	1	1	H	*	
64	94	13:12			1	3			
65	93	13:13			0		R		
66	92	13:14			1	3			
67	107	13:16	13:19	3	1	1	A		
68	93	13:17	13:19	2	1	1	H	*	
69	90	13:18	13:21	3	1	1	A		
70	90	13:21	13:23	2	1	1	A		
71	99	13:22			1	3			
72	94	13:29	13:32	3	1	1	H	*	
73	95	13:30			1	3			
74	120	13:32	13:35	3	1	2	F	*	
75	95	13:34			1	3			
76	96	13:35			1	3			
77	101	13:36	13:40	4	1	1	G	*	H
78	96	13:37	13:41	4	1	1	A		
79	92	13:38	13:41	3	1	1	A		
80	101	13:40	13:44	4	1	1	A		
81	96	13:42			1	3			
82	107	13:59	14:03	4	1	1	H	*	
83	95	14:00	14:06	6	1	1	A		
84	137	14:01	14:07	6	1	1	A		
85	92	14:01	14:07	6	1	1	H	*	
86	96	14:03	14:06	3	1	1	A		
87	96	14:06	14:09	3	1	1	A		
88	106	14:08	14:10	2	1	1	A		
89	92	14:13	14:15	2	1	1	A		
90	99	14:15					R		
91	90	14:16			1	3			
92	91	14:18	14:20	2	1	1	A		
93	97	14:19	14:22	3	1	1	A		
94	105	14:21	14:24	3	1	1	A		
95	100	14:23			1	3			
C02	92	14:58	15:00	2	1	1	A		
C01	97	14:56					R		
C03	98	15:01	15:02	1	1	1	H	*	
C04	96	15:03			0	4			
C05	104	15:05	15:07	2	1	1	H	*	
C06	95	15:07	15:09	2	1	1	A		
C07	96	15:05	15:10	5	1	1	A		
C08	104	15:14	15:17	3	1	1	A		
C09	100	15:16	15:20	4	1	1	A		
C10	91	15:17			0	4			
C11	93	15:19					R		
C12	95	15:22	15:27	5	1	1	H	*	
C13	96	15:24	15:26	2	1	1	A		
C14	111	15:25	15:27	2	1	1	A		
C15	99	15:28	15:29	1	1	1	H	*	
C16	94	15:30	15:32	2	1	1	A		

C17	102	15:45	15:49	*4*	1	1	A		
C18	95	15:47	15:49	*2*	1	1	A		
C19	105	15:49	15:52	*3*	1	1	A		
C20	95	15:50	15:52	*2*	1	1	A		
C21	97	15:52	15:53	*1*	1	1	A		
C22	107	15:53	15:55	*2*	1	1	A		
C23	92	15:54			0	4			
2	95	9:40	9:49	*9*	1	1	A		
1	100	9:39					R		
3	96	9:41			1	3			
4	127	9:50	9:53	*3*	1	1	A		
5	94	9:51	9:55	*4*	1	1	H	*	
6	98	9:53	9:55	*2*	1	1	H	*	
7	100	9:54	9:56	*2*	1	1	A		
8	97	9:55	9:58	*3*	1	2	8	*	
9	105	9:55	9:58	*3*	1	1	A		
10	98	9:57	10:04	*7*	1	1	H	*	
11	93	9:59	10:02	*3*	1	1		8	*
12	95	10:00	10:03	*3*	1	1	A		
13	92	10:02	10:04	*2*	1	1	H	*	
14	90	10:04			1	3			
15	94	10:07	10:08	*1*	1	1	A		
16	98	10:15	10:17	*2*	1	1	A		
17	90	10:16	10:18	*2*	1	1	A		
18	103	10:16			1	4			
19	93	10:18	10:20	*2*	1	1	A		
20	97	10:20	10:23	*3*	1	1	H	8	*
21	92	10:26	10:30	*4*	1	1		G	*
22	93	10:27	10:31	*4*	1	1	A		
23	103	10:34	10:36	*2*	1	2	H	*	
24	101	10:35	10:38	*3*	1	1	A		
25	98	10:36	10:40	*4*	1	1	A		
26	92	10:45	10:48	*3*	1	1	H	*	
27	103	10:46	10:53	*7*	1	1	A		
28	95	10:48			1	3			
29	97	10:48			0	4			
30	95	10:49	10:51	*2*	1	1	A		
31	95	10:50	10:54	*4*	1	1	A		
32	96	10:51	10:59	*8*	1	1	H	*	
33	90	10:52	10:54	*2*	1	1	A		
34	94	11:03	11:14	*11*	1	1	H	*	
35	91	11:04	11:06	*2*	1	1	H	*	
36	94	11:04	11:08	*4*	1	2	H	*	
37	101	11:05	11:09	*4*	1	1	A		
38	92	11:08	11:11	*3*	1	2	8	9	*
39	116	11:09	11:12	*3*	1	1	A		
40	111	11:11	11:15	*4*	1	1	A		
41	96	11:13	11:17	*4*	1	2	A	*	
42	98	11:13	11:16	*3*	1	1	A		
43	92	11:38	11:41	*3*	1	1	A		
44	112	11:40	11:44	*4*	1	1	A		
46	90	11:44	11:47	*3*	1	1	A		
47	95	11:44			0	4			
48	94	11:45	11:49	*4*	1	1	A		
49	91	11:47	11:50	*3*	1	1	A		

50	93	11:48			0	4			
51	95	11:49	11:52	*3*	1	1	A		
52	108	11:50	11:54	*4*	1	1	A		
53	91	11:51	11:59	*8*	1	1	G	*	
54	97	11:53	11:57	*4*	1	1	A		
55	90	11:54	11:58	*4*	1	2	7	*	
56	91	12:12	12:15	*3*	1	1	A		
57	97	12:14	12:16	*2*	1	1	H	*	
58	90	12:15	12:17	*2*	1	1	A		
59	95	12:16			0	4			
60	94	12:18			1	3			
61	92	12:19	12:21	*2*	1	1	A		
62	107	12:22					R		
63	90	12:24			0	4			
64	94	12:26	12:30	*4*	1	2	8	*	
65	93	12:34	12:37	*3*	1	1	9	*	
66	98	12:35	12:38	*3*	1	1	H	*	
67	94	12:36			1	3			
68	92	12:38	12:40	*2*	1	1	H	*	
69	90	12:39	12:42	*3*	1	2	8	*	
70	90	12:41	12:44	*3*	1	1	A		
71	103	12:42	12:45	*3*	1	1	9	*	
72	92	12:43	12:46	*3*	1	1	H	*	
73	99	12:55			0	4			
74	114	12:55			0	4			
75	103	12:56			1	3			
76	92	12:58	13:01	*3*	1	1	H	*	
77	94	13:05	13:08	*3*	1	1	H	*	8
78	94	13:06			1	3			
79	96	13:09			0	4			
80	106	13:11			1	3			
81	92	13:13			0	4			
82	105	13:14	13:19	*5*	1	1	G	*	
83	120	13:16	13:19	*3*	1	1	A		
84	91	13:22			1	3			
85	93	13:23	13:26	*3*	1	2	8	*	
86	90	13:23	13:27	*4*	1	1	A		
87	91	13:24	13:27	*3*	1	1	A		
88	90	13:28	13:32	*4*	1	1	A		
89	90	13:30			0	4			
90	95	13:31	13:34	*3*	1	1	A		
91	90	13:43			0	4			
92	90	13:44	13:47	*3*	1	1	H	*	
93	93	13:49			0	4			
C01	91	14:42	14:44	*2*	1	1	A		
C02	90	14:43	14:44	*1*	1	1	A		
C03	90	14:45	14:49	*4*	1	1	A		
C04	94	14:47			0	4			
C05	97	14:49	14:53	*4*	1	1	A		
C06	93	14:49					R		
C07	98	14:50	14:52	*2*	1	1	A		
C08	91	14:52	14:55	*3*	1	1	A		
C09	96	15:00	15:01	*1*	1	1	A		
C10	90	15:01	15:03	*2*	1	1	A		
C11	93	15:05	15:07	*2*	1	1	A		

C12	103	15:06	15:09	*3*	1	1	A			
C13	109	15:07	15:13	*6*	1	1	A			
C14	100	15:08	15:10	*2*	1	1	A			
C15	95	15:16	15:17	*1*	1	1	A			
C16	107	15:17	15:19	*2*	1	1	A			
C17	103	15:18	15:20	*2*	1	1	A			
C18	91	15:19	15:21	*2*	1	1	A			
C19	94	15:21	15:23	*2*	1	1	A			
C20	107	15:23	15:24	*1*	1	1	A			
C21	101	15:26	15:27	*1*	1	1	A			
1	90	10:49			1	3				
2	99	10:54	10:57	*3*	1	1	A			
3	95	10:55			1	3				
4	97	10:58					R			
5	98	11:03	11:09	*6*	1	1	H	*		
6	93	11:04			1	3				
7	97	11:05	11:10	*5*	1	1	A			
8	90	11:18					R			
9	96	11:19			1	3				
10	92	11:20	11:25	*5*	1	1	H	B	E	*
11	93	11:50	11:56	*6*	1	1	A			
12	92	11:50			0	5				
13	94	11:50	11:55	*5*	1	1	A			
14	90	11:52	11:56	*4*	1	1	A			
15	99	12:00	12:06	*6*	1	1	A			
16	95	12:00			1	3				
17	90	12:02	12:07	*5*	1	2	8	G	*	
18	95	12:03			1	3				
19	92	12:13	12:17	*4*	1	1	A			
20	101	12:17	12:22	*5*	1	1	A			
21	117	12:18	12:23	*5*	1	1	G	*		
22	90	12:19			1	3				
23	90	12:20			0	5				
24	108	12:21	12:26	*5*	1	1	A			
25	93	12:21	12:26	*5*	1	2	A	*		
26	111	12:49					R			
27	93	12:50	12:56	*6*	1	1	A			
28	90	12:50	13:07	*17*	1	1	A			
29	91	12:51	13:30	*39*	1	1	H	E	*	
30	90	12:51	12:56	*5*	1	2	A	*		
31	90	12:52			0	4				
32	96	13:02	13:30	*28*	1	1	H	*		
33	98	13:04	13:09	*5*	1	1	A			
34	93	13:07			0	4				
35	116	13:08	13:13	*5*	1	1	A			
36	96	13:09	13:14	*5*	1	2	V	*		
37	90	13:11	13:22	*11*	1	1	H	*		
38	105	13:12	13:18	*6*	1	1	H	*		
39	96	13:59	14:06	*7*	1	1	A			
40	90	13:59	14:05	*6*	1	1	A			
41	97	14:01	14:07	*6*	1	1	A			
42	93	14:01	14:07	*6*	1	1	H	*		
43	90	14:06	14:13	*7*	1	1	A			
44	94	14:07			0	5				
45	95	14:08	14:14	*6*	1	1	A			
46	90	14:23	14:29	*6*	1	1	A			
47	91	14:24			1	3				

48	94	14:25	14:30	5	1	1	H	*		
49	93	14:25	14:28	3	1	1	H	*		
50	90	14:26			1	3				
51	93	14:38	14:41	3	1	1	A			
52	91	14:38	14:41	3	1	1	W	G	*	
53	94	14:38	14:41	3	1	1	A			
54	92	14:44			0	4				
55	101	14:45			0	5				
56	97	14:48	14:52	4	1	1	A			
57	95	14:50	14:54	4	1	1	A			
58	90	14:51	14:56	5	1	1	H	*		
59	113	14:52	14:58	6	1	1	H	8	E	*
60	95	15:00	15:04	4	1	1	A			
61	90	15:02	15:06	4	1	1	H	*		
62	93	15:03			1	3				
63	90	15:05			0	5				

C01	95	16:00	16:04	4	1	1	A	
C02	90	16:03	16:04	1	1	1	A	
C03	95	16:03	16:04	1	1	1	A	
C04	109	16:06	16:07	1	1	1	A	
C05	98	16:08	16:15	7	1	2	A	*
C06	93	16:10	16:21	11	1	1	A	
C07	93	16:11	16:22	11	1	1	A	
C08	90	16:12	16:15	3	1	1	A	
C09	92	16:14	16:17	3	1	1	A	
C10	94	16:15	16:16	1	1	1	A	
C11	113	16:17	16:18	1	1	1	A	
C12	95	16:18	16:20	2	1	1	A	
C13	122	16:20	16:22	2	1	1	A	
C14	90	16:23	16:23	0	1	1	A	
C15	94	16:24	16:24	0	1	1	A	
C16	91	16:25	16:27	2	1	1	A	
C17	90	16:27	16:31	4	1	1	A	
C18	90	16:27	16:32	5	1	1	H	*
C19	96	16:30	16:32	2	1	1	A	
C20	100	16:32	16:33	1	1	1	H	*

1	122	9:01	9:07	6	1	1	A		
2	97	9:07	9:18	11	1	2	A	*	
3	94	9:08			1	3			
4	90	9:13			0	5			
5	93	9:13	9:22	9	1	1	H	E	*
6	96	9:21			0	5			
7	91	9:22			0	5			
8	94	9:23			0	5			
9	94	9:24			1	3			
10	96	9:24	9:34	10	1	1	H	*	
11	98	9:47	9:52	5	1	1	A		
12	101	9:48	9:55	7	1	1	B	*	
13	92	9:49			0	5			
14	96	9:50	9:54	4	1	1	A		
15	106	9:51			0	4			
16	91	9:54	10:01	7	1	2	7	*	
17	90	9:55	9:59	4	1	1	A		

18	93	9:57			1	3				
19	95	10:32	10:52	*20*	1	1	A			
20	104	10:32			0	5				
21	91	10:34			0	5				
22	101	10:45	10:50	*5*	1	1	5	*		
23	92	10:47			1	3				
24	94	10:48			1	3				
25	99	10:49			1	3				
26	93	10:50			1	3				
27	91	11:09			1	3				
28	97	11:12	11:17	*5*	1	2	A	*		
29	100	11:12	11:16	*4*	1	1	A			
30	91	11:14	11:23	*9*	1	2	B	*		
31	97	11:15	11:19	*4*	1	1	H	W	*	
32	96	11:15			1	3				
33	94	11:18			1	5				
34	95	11:19					R			
35	96	11:20	11:44	*24*	1	2	E	*	G	B
36	90	11:21	11:37	*16*	1	1	H	*		
37	90	11:22	11:38	*16*	1	1	A			
38	93	12:15	12:23	*8*	1	1	A			
39	90	12:16	12:20	*4*	1	1	A			
40	100	12:18			0	5				
41	99	12:22	12:31	*9*	1	2	5	*		
42	90	12:22	12:30	*8*	1	1	H	*		
43	90	12:24	12:27	*3*	1	1	H	*		
44	96	12:26			1	3				
45	100	12:54	12:58	*4*	1	1	A			
46	90	12:54	13:02	*8*	1	1	H	*		
47	90	12:56	13:01	*5*	1	1	H	*		
48	95	12:57			0	5				
49	98	12:59			0	5				
50	92	13:00			0	5				
51	91	13:01	13:07	*6*	1	1	H	*		
52	90	13:02	13:11	*9*	1	1	A			
53	90	13:30	13:36	*6*	1	1	H	*		
54	91	13:31	13:37	*6*	1	2	8	*		
55	90	13:32	13:39	*7*	1	1	H	*		
56	90	13:34	13:40	*6*	1	1	H	*		
57	90	13:34			0	5				
58	92	13:36	13:41	*5*	1	1	H	*		
59	91	13:36			1	3				
60	90	13:37	13:43	*6*	1	1	A			
61	93	13:40			0	5				
C11	91	14:38	14:40	*2*	1	1	H	*		
C12	96	14:39	14:44	*5*	1	1	A			
C13	96	14:40	14:43	*3*	1	1	H	*		
C14	104	14:42	14:47	*5*	1	1	A			
C15	90	14:43	14:49	*6*	1	1	H	*		
C16	96	14:45	14:46	*1*	1	1	H			
C17	95	14:46	14:50	*4*	1	2	H	*		
C18	95	14:47	14:51	*4*	1	1	A			
C19	104	14:47	14:51	*4*	1	1	A			
C20	92	14:49	14:53	*4*	1	2	8	*		

1	95	9:34	9:41	*7*	1	1	A			
2	100	9:35	9:42	*7*	1	1	A			
3	98	9:36	9:47	*11*	1	1	A			
4	90	9:37			0	5				
5	90	9:37			1	3				
6	105	9:38	9:43	*5*	1	1	H	*		
7	95	10:02	10:11	*9*	1	1	H	*		
8	106	10:03	10:38	*35*	1	1	H	*		
9	96	10:04	10:12	*8*	1	1	A			
10	95	10:12			1	3				
11	91	10:05	10:10	*5*	1	1	H	*		
12	95	10:06			0	5				
13	90	10:07	10:18	*11*	1	1	H	*		
14	90	10:38	10:55	*17*	1	2	7	*		
15	97	10:38	10:50	*12*	1	2	E	*		
16	93	10:40	10:50	*10*	1	1	H	*		
17	98	10:40	10:46	*6*	1	1	A			
18	93	10:41					R			
19	92	10:42	10:47	*5*	1	1	A			
20	92	10:42	10:53	*11*	1	1	G	*	W	
21	95	10:43	10:54	*11*	1	1	H	*		
22	91	11:35	11:41	*6*	1	1	H	9	*	
23	99	11:36			1	3				
24	107	11:36	11:51	*15*	1	1	H	*		
25	96	11:37			0	5				
26	96	11:38	11:41	*3*	1	1	H	W	*	
27	95	11:39	11:42	*3*	1	1	H	*		
28	90	11:39	12:36	*57*	1	1	H	W	*	
29	92	11:40	11:49	*9*	1	2	9	B	8	*
30	90	12:33	12:37	*4*	1	1	H	*		
31	97	12:34	12:39	*5*	1	1	A			
32	95	12:34			0	5				
33	92	12:35	12:40	*5*	1	1	H	*		
34	90	12:35	14:03	*88*	1	2		P	*	
35	92	12:36			0	5				
36	96	12:36	12:42	*6*	1	1	H	*		
37	100	12:36			0	5				
38	92	12:37	13:25	*48*	1	1	9	*		
39	94	13:18	13:21	*3*	1	1	H	*		
40	95	13:18	13:25	*7*	1	1	H	*		
41	97	13:18			0	5				
42	92	13:18	13:27	*9*	1	1	H	W	*	
43	90	13:19	13:44	*25*	1	1	H	*		
44	95	13:20	13:24	*4*	1	1	H	*		
45	90	13:20			0	5	P			
46	90	14:00	14:06	*6*	1	1	H	*		
47	92	14:00	14:48	*48*	1	1	H	*		
48	96	14:00	14:06	*6*	1	1	H	*		
49	99	14:01	14:14	*13*	1	1		H	*	
50	98	14:01	14:05	*4*	1	1	H	*		
51	91	14:02	14:13	*11*	1	1	H	P		
52	91	14:05	14:19	*14*	1	1	H	V	*	
53	90	14:05			0	5				
54	97	14:49	14:53	*4*	1	1	A			
55	93	14:50	14:59	*9*	1	1	H	*		
56	96	14:50	14:54	*4*	1	1	A			

57	90	14:51	14:57	*6*	1	1	A			
58	92	14:52	15:01	*9*	1	1	H	*		
59	95	15:08	15:16	*8*	1	1	H	*		
60	95	15:09	15:13	*4*	1	1	H	*		
61	91	15:09	15:12	*3*	1	1	H	*		
62	96	15:10	15:36	*26*	1	1	H	*		
63	99	15:10			1	3				

C01	90	15:53	15:56	*3*	1	1	A			
C02	95	15:54	15:57	*3*	1	1	A			
C03	92	15:55	15:58	*3*	1	1	A			
C04	96	15:56	15:58	*2*	1	1	A			
C05	95	15:57	16:00	*3*	1	1	A			
C06	95	15:58	16:02	*4*	1	1	A			
C07	92	15:59	16:05	*6*	1	1	A			
C08	97	15:55	16:08	*13*	1	1	H	*		
C09	95	15:56	16:09	*13*	1	1	H	*		
C10	95	15:57	16:05	*8*	1	1	A			

1	90	10:37			0	5				
2	97	10:38	10:41	*3*	1	2	B	5	*	
3	90	10:38	10:46	*8*	1	1	B	H	*	
4	90	10:46	10:56	*10*	1	1	5	G	*	
5	91	10:47			0	5				
6	90	10:48	10:56	*8*	1	1	H	B	*	
7	90	10:48	10:51	*3*	1	1	H	*		
8	91	11:01	11:04	*3*	1	1	H	*		
9	92	11:27	11:33	*6*	1	1	A			
10	91	11:28	11:34	*6*	1	1	H	*		
11	90	11:29	11:39	*10*	1	1	A			
12	95	11:29	11:34	*5*	1	2	B	9	E	*
13	90	11:30	11:36	*6*	1	1	A			
14	92	11:30	11:35	*5*	1	1	H	*		
15	90	11:31			0	5	L			
16	92	11:33	11:38	*5*	1	1	B	H	*	
17	94	11:33	11:38	*5*	1	1	A			
18	90	11:34	11:45	*11*	1	1	H	5	*	
19	92	12:24	12:36	*12*	1	1	H	*		
20	90	12:25	13:04	*39*	1	1	H	*		
21	95	12:25	12:34	*9*	1	1	H	9	*	
22	91	12:26			1	3				
23	91	12:26	12:31	*5*	1	1	H	*		
24	100	12:37					R			
25	92	12:27	12:33	*6*	1	1	H	*		
26	97	12:28	12:31	*3*	1	1	H	5	*	
27	97	12:29			0	5				
28	91	12:29	12:38	*9*	1	1	B	H	*	
29	100	12:30					R			
30	94	12:31			0	5				
31	93	12:59	13:05	*6*	1	1	9	*		
32	95	13:01	13:06	*5*		2	R			
33	91	13:01			1	3				
34	94	13:02	13:10	*8*	1	1	V	H	*	
35	92	13:03	13:07	*4*	1	1	H	B	*	
36	90	13:04	13:10	*6*	1	1	A			

37	95	13:05	13:11	*6*	1	1	H	*		
38	90	13:07	13:13	*6*	1	1	H	*		
39	98	13:08			0	5				
40	96	13:10			0	5				
41	96	13:42	13:46	*4*	1	1	H	*		
42	91	13:43			0	5				
43	90	13:43	13:48	*5*	1	2	9	B	*	
44	100	13:44	13:52	*8*	1	1	H	5	*	9
45	93	13:44	13:50	*6*	1	2	A	*		
46	103	13:45			0	5				
47	102	13:50	14:01	*11*	1	1	H	*		
48	91	13:51			1	3				
49	95	13:52	13:59	*7*	1	1	H	*		
50	93	13:54			0	5				
51	109	14:36	14:41	*5*	1	1	A			
52	90	14:37	14:43	*6*	1	1	H	*		
53	94	14:38	14:48	*10*	1	1	H	*	9	
54	91	14:39	14:43	*4*	1	1	H	E	*	
55	103	14:40			0	5				
56	96	14:40			0	5				
57	90	14:41	14:45	*4*	1	1	A			
58	96	14:44			0	5				
59	95	14:45	14:49	*4*	1	1	A			
60	90	14:46			0	5				
61	106	14:46	14:53	*7*	1	1	H	*		
62	102	14:47			0	5				
63	93	14:48			0	5				
C01	98	15:48	15:50	*2*	1	1	A			
C02	90	15:49	15:52	*3*	1	1	A			
C03	107	15:50	15:54	*4*	1	1	A			
C04	104	15:50	15:53	*3*	1	1	H	*		
C05	98	15:51	15:53	*2*	1	1	A			
C06	95	15:51	15:55	*4*	1	1	A			
C07	97	15:52	15:57	*5*	1	1	A			
C08	98	15:52	15:57	*5*	1	1	A			
C09	94	15:55	16:03	*8*	1	1	A			
C10	90	15:55	15:58	*3*	1	1	A			
1	93	10:18	10:26	*8*	1	1	9	*		
2	101	10:18			0	5				
3	106	10:18	10:25	*7*	1	1	A			
4	92	10:19			0	4				
5	94	10:19			0	4				
6	91	10:21	10:28	*7*	1	2	B	*		
7	99	10:22	10:26	*4*	1	1	A			
8	91	10:22	10:33	*11*	1	1	A			
9	94	10:23					R			
10	91	10:23					R			
11	98	11:09	11:16	*7*	1	2	G	*	9	
12	91	11:10	11:19	*9*	1	2	8	B	*	
13	91	11:10	11:18	*8*	1	2	F	E	*	
14	95	11:11	11:19	*8*	1	1	H	W	*	
15	100	11:12	11:16	*4*	1	1	H	B	*	
16	98	11:13	11:18	*5*	1	1	A			

17	96	11:52	11:59	7	1	1	A			
18	96	11:52			0	4				
19	98	11:53			0	5				
20	93	11:53	12:00	7	1	1	H	E	*	
21	98	11:54	12:00	6	1	1	A			
22	91	11:54	12:02	8	1	1	H			
23	96	11:56	12:00	4	1	1	A			
24	95	11:56	12:04	8	1	1	H	*		
25	95	11:58			0	5				
26	90	11:59	13:09	70	1	1	B	H	*	
27	99	12:00	12:06	6	1	1	A			
28	98	12:00			0	5				
29	98	12:01			0	5				
30	98	12:02	12:12	10	1	1	A			
31	90	12:23	12:30	7	1	1	H	*		
32	90	12:23	12:33	10	1	1	H	5	9	*
33	91	12:24			0	5				
34	96	12:24	12:29	5	1	1	H	*		
35	91	12:25	12:32	7	1	2	E	*		
36	91	12:25	12:34	9	1	1	9	H	*	
37	96	12:27			0	5				
38	90	12:28			0	5				
39	93	12:29	12:35	6	1	1	H	9	*	
40	90	12:30	12:34	4	1	1	H	B	*	
41	91	12:55			0	5				
42	94	12:55	13:01	6	1	1	A			
43	90	12:56			0	5				
44	95	12:57	13:01	4	1	1	H	*		
45	98	12:57			0	5				
46	91	12:58	13:03	5	1	1	H	*		
47	92	12:58			0	5				
48	91	12:59			0	5				
49	90	12:59	13:04	5	1	1	A			
50	98	13:00	14:03	63	1	2		G	9	*
51	90	14:05	14:10	5	1	1	H	*		
52	93	14:06	14:19	13	1	1	H	5	*	
53	93	14:07	14:21	14	1	1	H	*		
54	94	14:08	14:20	12	1	1	H	5	*	
55	95	14:10	14:15	5	1	1	H	*		
56	104	14:12	14:16	4	1	1	H	*		
57	94	14:14	14:22	8	1	1	H	B	*	
58	97	14:15	14:24	9	1	1	A			
59	93	14:17			0	5				
60	100	14:17			0	5				
61	93	14:18			0	5				
62	95	14:19			1	3				
C01	90	15:39	15:41	2	1	1	A			
C02	95	15:41	15:43	2	1	1	A			
C03	94	15:43	15:56	13	1	1	A			
C04	90	15:47	15:50	3	1	1	A			
C05	97	15:50					R			
C06	92	15:51	15:59	8	1	1	A			
C07	91	15:52	15:54	2	1	1	A			
C08	91	15:52	15:54	2	1	1	A			
C09	96	15:56	16:01	5	1	1	A			

C10	104	16:04	16:08	4	1	1	H	*	
C11	91	16:02	16:04	2	1	1	A		
C12	97	16:06	16:08	2	1	1	A		
C13	95	16:13	16:17	4	1	1	A		
C14	92	16:13	16:16	3	1	1	A		
C15	92	16:13	16:15	2	1	1	A		
C16	94	16:15	16:17	2	1	1	H	*	
1	100	10:09			1	3			
2	94	10:10	10:24	14	1	1	A		
3	97	10:11	10:23	12	1	1	H	5	*
4	92	10:12	10:27	15	1	1	H	*	
5	92	10:13			0	5			
6	115	10:45	10:51	6	1	1	A		
7	90	10:46	10:58	12	1	1	H	*	
8	94	10:47					R		
9	90	10:47	10:55	8	1	1	H	*	
10	94	10:48	11:05	17	1	1	H	9	*
11	92	10:48	11:01	13	1	1	H	*	
12	90	10:48			0	5	L		
13	91	10:49			0	5			
14	90	11:44	11:52	8	1	1	H	B	*
15	95	11:45	14:26	161	1	1	H	*	
16	90	11:45			1	3			
17	93	11:46			1	3			
18	105	11:46	11:51	5	1	1	A		
19	93	11:47			0	5			
20	91	11:47	11:54	7	1	1	H	*	
21	92	11:48	11:53	5	1	1	A		
22	95	11:48	11:58	10	1	1	H	*	
23	90	11:49	12:26	37	1	1	H	*	
24	93	11:50			0	5			
25	95	12:28	12:34	6	1	1	A		
26	95	12:29	12:33	4	1	1	A		
27	90	12:30	12:33	3	1	1	H	*	
28	91	12:31			0	5			
29	91	12:32			0	5			
30	90	12:33			0	5			
31	94	12:33	12:40	7	1	1	H	*	
32	90	12:34	12:43	9	1	1	A		
33	90	12:34	12:45	11	1	1	H	*	
34	97	12:35	12:44	9	1	1	A		
35	91	13:09	13:18	9	1	1	H	W	*
36	95	13:09	13:20	11	1	1	A		
37	90	13:10			0	5			
38	111	13:10	13:25	15	1	1	A		
39	100	13:11	13:20	9	1	1	H	*	
40	94	13:11			0	4			
41	95	13:12	13:23	11	1	1	A		
42	95	13:12	13:25	13	1	1	A		
43	96	13:13			0	5			
44	92	13:14			0	4			
45	90	13:50					R		
46	93	13:50	14:01	11	1	1	H	*	
47	95	13:51					R		
48	91	13:52	13:54	2	1	1	8	*	

49	93	13:53	14:03	*10*	1	1	B	W	*
50	105	13:54	14:08	*14*	1	1	A		
51	91	13:56	14:08	*12*	1	1	H	*	
52	98	13:57	14:04	*7*	1	1	H	E	*
53	100	13:58	14:07	*9*	1	1	H	*	
54	104	13:59			0	5			
55	98	14:29	14:32	*3*	1	1	A		
56	90	14:29	14:39	*10*	1	1	H	V	*
57	95	14:29	14:40	*11*	1	1	H	*	
58	92	14:30	14:35	*5*	1	1	A		
59	91	14:31			0	5			
60	95	14:32	14:41	*9*	1	1	H	*	
61	95	14:33			0	5			
62	94	14:33	14:47	*14*	1	1	H	W	*
63	94	14:34			0	5			
C01	97	16:30	16:33	*3*	1	1	H	*	
C02	95	16:27	16:29	*2*	1	1	A		
C03	95	16:20	16:23	*3*	1	1	H	*	
C04	95	16:24	16:27	*3*	1	1	A		
C05	92	16:30	16:32	*2*	1	1	H	*	
C06	95	16:32	16:35	*3*	1	1	H	*	
C07	100	16:33	16:35	*2*	1	1	A		
C08	90	16:34	16:37	*3*	1	1	A		
C09	98	16:37	16:40	*3*	1	1	A		
C10	101	16:39	16:42	*3*	1	1	A		

APPENDIX B

DAILY TAG/RECAPTURE DATA

Appendix B

Daily data for recaptured juvenile American Shad passed through Cabot Station, Unit 2, Station No. 1 Unit 1, and 2/3, and over the Bascule Gates 1 and 4 at 1,500, 2,500, and 5,000 cfs. October 2015. Combined controls released into the tailrace downstream of the three stations.

	10/14	10/15	10/16	10/17	10/19	10/20	10/21	10/22	10/23	10/24	
-	Cabot Station Unit 2		Cabot Station No. 1 Units 2/3	Cabot Station No. 1 Unit 1	Bascule Gates 1: 1,500 cfs	Bascule Gates 1: 2,500 cfs	Bascule Gates 1: 5,000 cfs	Bascule Gates 4: 1,500 cfs	Bascule Gates 4: 2,500 cfs	Bascule Gates 4: 5,000 cfs	Totals
Number released	29	91	90	90	60	60	62	60	60	60	662
Number alive	29	84	59	59	38	27	45	37	34	41	453
Number recovered dead	0	2	6	9	4	7	4	4	6	0	42
Assigned dead	0	4	22	9	15	25	13	19	17	17	141
Dislodged tags	0	4	22	9	10	11	4	3	1	3	67
Stationary radio signals	0	0	0	0	5	14	8	16	16	14	73
Undetermined	0	1	3	13	3	1	0	0	3	2	26
Held and Alive 1 h	29	84	59	59	38	27	45	37	34	41	453
Alive 24 h	23	66	48	35	31	6	9	5	7	8	238
Alive 48 h	21	65	48	31	28	4	9	4	6	7	223

	10/14	10/15	10/16	10/17	10/19	10/20	10/21	10/22	10/23	10/24	
	Cabot Station Unit 2		Cabot Station No. 1 Units 2/3	Cabot Station No. 1 Unit 1	Bascule Gates 1: 1,500 cfs	Bascule Gates 1: 2,500 cfs	Bascule Gates 1: 5,000 cfs	Bascule Gates 4: 1,500 cfs	Bascule Gates 4: 2,500 cfs	Bascule Gates 4: 5,000 cfs	Totals
Number released	7	23	21	20	20	10	10	10	15	10	146
Number alive	7	23	18	19	19	8	10	10	15	10	139
Number recovered dead	0	0	0	0	1	2	0	0	0	0	3
Assigned dead	0	0	0	0	0	0	0	0	0	0	0
Dislodged tags	0	0	0	0	0	0	0	0	0	0	0
Stationary radio signals	0	0	0	0	0	0	0	0	0	0	0
Undetermined	0	0	3	1	0	0	0	0	0	0	4
Held and Alive 1 h	7	23	18	19	19	8	10	10	15	10	139

Appendix B

Daily malady data for recaptured wild juvenile American Shad passed through Cabot Station Unit 2, Station No. 1 Unit 1, and 2/3, and over the Bascule Gates 1 and 4 at 1,500, 2,500, and 5,000 cfs. October 2015. Combined controls released into the tailrace downstream of the three stations.

	Cabot Station Unit 2
Number released	120
Number examined	115
Passage related maladies	10
Visible injuries	10
Loss of equilibrium only	0
No obvious injuries, dead 1h	0
Without maladies (passage related)	105
With non-passage maladies	28

	Station No. 1 Unit 2/3
Number released	90
Number examined	65
Passage related maladies	10
Visible injuries	5
Loss of equilibrium only	2
No obvious injuries, dead 1h	3
Without maladies (passage related)	55
With non-passage maladies	19

	Station No. 1 Unit 1
Number released	90
Number examined	68
Passage related maladies	17
Visible injuries	14
Loss of equilibrium only	2
No obvious injuries, dead 1h	1
Without maladies (passage related)	56
With non-passage maladies	3

	Bascule Gate 1 1,500 cfs
Number released	60
Number examined	42
Passage related maladies	9
Visible injuries	8
Loss of equilibrium only	0
No obvious injuries, dead 1h	1
Without maladies (passage related)	33
With non-passage maladies	9

	Bascule Gate 1 2,500 cfs
Number released	60
Number examined	34
Passage related maladies	13
Visible injuries	12
Loss of equilibrium only	0
No obvious injuries, dead 1h	1
Without maladies (passage related)	21
With non-passage maladies	18

	Bascule Gate 1 5,000 cfs
Number released	62
Number examined	49
Passage related maladies	17
Visible injuries	17
Loss of equilibrium only	0
No obvious injuries, dead 1h	0
Without maladies (passage related)	32
With non-passage maladies	25

	Bascule Gate 1 Combined
Number released	182
Number examined	125
Passage related maladies	39
Visible injuries	37
Loss of equilibrium only	0
No obvious injuries, dead 1h	2
Without maladies (passage related)	86
With non-passage maladies	52

	Bascule Gate 4 1,500 cfs
Number released	60
Number examined	41
Passage related maladies	19
Visible injuries	18
Loss of equilibrium only	0
No obvious injuries, dead 1h	1
Without maladies (passage related)	22
With non-passage maladies	21

	Bascule Gate 4 2,500 cfs
Number released	60
Number examined	40
Passage related maladies	18
Visible injuries	18
Loss of equilibrium only	0
No obvious injuries, dead 1h	0
Without maladies (passage related)	23
With non-passage maladies	20

	Bascule Gate 4 5,000 cfs
Number released	60
Number examined	41
Passage related maladies	18
Visible injuries	18
Loss of equilibrium only	0
No obvious injuries, dead 1h	0
Without maladies (passage related)	23
With non-passage maladies	18

	Bascule Gate 4 Combined
Number released	180
Number examined	122
Passage related maladies	55
Visible injuries	54
Loss of equilibrium only	0
No obvious injuries, dead 1h	1
Without maladies (passage related)	67
With non-passage maladies	59

	Cabot Station & Station No. 1 Combined Controls
Number released	71
Number examined	67
Passage related maladies	1
Visible injuries	1
Loss of equilibrium only	0
No obvious injuries, dead 1h	0
Without maladies (passage related)	61
With non-passage maladies	25

	Bascule Gates 1 & 4 Combined Controls
Number released	75
Number examined	75
Passage related maladies	3
Visible injuries	1
Loss of equilibrium only	1
No obvious injuries, dead 1h	1
Without maladies (passage related)	58
With non-passage maladies	25

APPENDIX C

DETAILED FISH INJURY DATA

Appendix C

Incidence of maladies, including injury, scale loss, and temporary loss of equilibrium (LOE) observed on released wild juvenile American Shad passed through the Turners Falls Hydroelectric Project, October 2015. Combined controls released into the tailrace downstream of the stations.

Date	Test Lot	Fish ID	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Cabot Station Unit 2				
10/14/15	1	021	dead	24h	LOE	No	No	Minor	Undetermined
10/14/15	1	026	dead	24h	LOE	No	No	Minor	Undetermined
10/14/15	1	029	alive		LOE	No	No	Minor	Undetermined
10/14/15	1	033	alive		LOE	No	No	Minor	Undetermined
10/14/15	1	034	dead	24h	LOE	No	No	Minor	Undetermined
10/15/15	2	C07	dead	24h	Bruise on Head	Yes	No	Major	Mechanical
10/15/15	2	C10	alive		LOE	No	No	Major	Undetermined
10/15/15	2	002	dead	1h	Operculum Damage	Yes	Yes	Major	Shear
10/15/15	2	010	dead	1h	Missing Both Eyes	Yes	Yes	Major	Shear
10/15/15	2	014	alive		LOE	No	No	Minor	Undetermined
10/15/15	2	015	alive		Cut left. Operculum	No	No	Minor	Undetermined
10/15/15	2	020	dead	24h	Bruise on Head	Yes	Yes	Major	Mechanical
10/15/15	2	025	alive		LOE, right Operculum Damage	Yes	No	Major	Shear
10/15/15	2	033	dead	24h	Ruptured right Eye, Min. Hem left Eye	Yes	Yes	Major	Shear
10/15/15	2	037	alive		r. Laceration on Caudal Peduncle	Yes	No	Major	Mechanical
10/15/15	2	056	dead	24h	Lg. Bruise-top of Head and Body, LOE, Cut on Rt. Side of Tail	Yes	Yes	Major	Mechanical
10/15/15	2	060	alive		Hem Snout	Yes	No	Major	Mechanical
10/15/15	2	074	alive		LOE	No	No	Minor	Undetermined

10/15/15	2	078	dead	24h	LOE	No	No	Minor	Undetermined
10/15/15	2	084	dead	24h	Bulging and Hem, Left Eye	Yes	Yes	Major	Shear
10/15/15	2	085	alive		LOE	No	No	Minor	Undetermined

Date	Test Lot	Fish ID	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Station No. 1 Units 2/3				
10/16/15	1A	001	dead	24h	LOE. Bulging l. eye	Yes	Yes	Major	Shear
10/16/15	1A	004	dead	1h	Necropsied, no obvious injuries	Yes	No	Minor	Undetermined
10/16/15	1A	016	dead	24h	LOE	No	No	Minor	Undetermined
10/16/15	1A	025	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	026	dead	1h	Necropsied, no obvious injuries	Yes	No	Major	Undetermined
10/16/15	1A	028	dead	1h	LOE	Yes	No	Major	Undetermined
10/16/15	1A	029	dead	1h	LOE	Yes	No	Major	Mechanical
10/16/15	1A	035	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	038	dead	24h	LOE	No	No	Minor	Undetermined
10/16/15	1A	039	dead	24h	LOE	No	No	Minor	Undetermined
10/16/15	1A	047	alive		LOE, Bulging Eyes	Yes	No	Minor	Shear
10/16/15	1A	049	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	053	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	055	dead	24h	LOE	No	No	Minor	Undetermined
10/16/15	1A	057	dead	1h	Necropsied, no obvious injuries	Yes	No	Major	Undetermined
10/16/15	1A	060	dead		LOE	No	No	Minor	Undetermined
10/16/15	1A	061	dead	24h	Missing right Eye	Yes	Yes	Major	Shear
10/16/15	1A	062	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	063	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	068	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	072	alive		LOE	No	No	Minor	Undetermined

10/16/15	1A	074	dead	1h	Torn Isthmus	Yes	Yes	Major	Shear
10/16/15	1A	077	alive		LOE, Hem. R. pectoral	Yes	No	Major	Mechanical
10/16/15	1A	082	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	085	dead	24h	LOE	No	No	Minor	Undetermined
10/16/15	1A	C03	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	C05*	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	C12*	alive		LOE	No	No	Minor	Undetermined
10/16/15	1A	C15*	dead	24h	LOE	No	No	Minor	Undetermined

Date	Test Lot	Fish ID	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Station No. 1 Unit 1				
10/17/15	2A	005	dead	24h	LOE	No	No	Minor	Undetermined
10/17/15	2A	006	dead	24h	LOE	No	No	Minor	Shear
10/17/15	2A	008	dead	1h	LOE, Hem. R. pectoral	Yes	Yes	Major	Mechanical
10/17/15	2A	010	alive		LOE	No	No	Minor	Undetermined
10/17/15	2A	011	alive		LOE, Hem. R. eye	Yes	No	Minor	Shear
10/17/15	2A	013	dead	48h	LOE	No	No	Minor	Undetermined
10/17/15	2A	020	alive		LOE, bulging eyes, Hem behind operc.	Yes	No	Minor	Shear
10/17/15	2A	021	alive		LOE	Yes	No	Minor	Shear
10/17/15	2A	023	dead	1h	LOE	Yes	No	Major	Undetermined
10/17/15	2A	026	dead	24h	LOE	No	No	Minor	Undetermined
10/17/15	2A	032	dead	24h	LOE	No	No	Minor	Undetermined
10/17/15	2A	034	dead	24h	LOE	No	No	Minor	Undetermined
10/17/15	2A	035	dead	24h	LOE	No	No	Minor	Undetermined
10/17/15	2A	036	dead	1h	LOE	Yes	No	Major	Undetermined
10/17/15	2A	038	dead	1h	R. Eye Missing, R. Operculum, Torn	Yes	Yes	Major	Shear
10/17/15	2A	041	dead	1h	Necropsied, no obvious injuries	Yes	No	Major	Undetermined
10/17/15	2A	053	dead	24h	Hem, Snout	Yes	Yes	Major	Mechanical
10/17/15	2A	055	dead	1h	Decapitated	Yes	Yes	Major	Shear
10/17/15	2A	057	alive		LOE	No	No	Minor	Undetermined

10/17/15	2A	064	dead	1h	Ruptured r. eye	Yes	Yes	Major	Shear
10/17/15	2A	065	alive		Hem. R. Operculum	Yes	No	Minor	Shear
10/17/15	2A	066	alive		LOE	No	No	Minor	Undetermined
10/17/15	2A	068	alive	24h	LOE	No	No	Minor	Undetermined
10/17/15	2A	069	dead	1h	Bulging r. Eye	Yes	Yes	Major	Shear
10/17/15	2A	071	alive		Bleeding r. Operculum	Yes	No	Minor	Shear
10/17/15	2A	072	dead	24h	LOE	No	No	Minor	Undetermined
10/17/15	2A	076	alive		LOE	No	No	Minor	Undetermined
10/17/15	2A	077	dead	24h	LOE, Ruptured r. Eye, Internal Hem.	Yes	Yes	Major	Shear/Mech.
10/17/15	2A	082	alive		Wounded Snout	Yes	No	Minor	Mechanical
10/17/15	2A	085	dead	1h	Ruptured l. Eye	Yes	Yes	Major	Shear

Date	Test Lot	Fish ID	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Bascule Gate 1 at 1,500 cfs				
10/19/15	3	5	dead	24h	LOE	No	No	Minor	Undetermined
10/19/15	3	10	dead	24h	Tear above tag site	Yes	No	Major	Mechanical
10/19/15	3	14	dead	48h	Ruptured L. eye, broken back	Yes	No	Major	Mechanical
10/19/15	3	17	dead	1h	Hem. eye, Bruised head, broken back	Yes	No	Major	Mechanical
10/19/15	3	21	alive		Hem. Snout	Yes	No	Minor	Mechanical
10/19/15	3	29	alive		cut above caudal peduncle	Yes	No	Major	Mechanical
10/19/15	3	32	alive		LOE	No	No	Minor	Undetermined
10/19/15	3	36	dead	1h	bruising and bleeding pectoral fin	Yes	No	Major	Mechanical
10/19/15	3	37	alive		LOE	No	No	Minor	Undetermined
10/19/15	3	38	dead	48h	LOE	No	No	Minor	Undetermined
10/19/15	3	42	alive		LOE	No	No	Minor	Undetermined
10/19/15	3	048	dead	24h	LOE, tear at tag site	No	No	Minor	Tag related
10/19/15	3	049	alive		LOE	No	No	Minor	Undetermined
10/19/15	3	052	dead	24h	Bruised, Scraped Head	Yes	Yes	Major	Mechanical
10/19/15	3	058	alive		LOE	No	No	Minor	Undetermined

10/19/15	3	059	dead	24h	L. Eye Bleeding, LOE, Gash, L side anal fin	Yes	Yes	Major	Mechanical
		061	dead	24h	LOE	No	No	Minor	Undetermined
Controls									
10/19/15	3								
10/19/15	3	C05*	dead	1h	Necropsied, no obvious injuries	Yes	No	Major	Undetermined
10/19/15	3	C18*	dead	24h	LOE	No	No	Minor	Undetermined
10/19/15	3	C20*	alive		LOE	No	No	Minor	Undetermined

Date	Test Lot	Fish ID	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Bascule Gate 1 at 2,500 cfs				
10/20/15	4	002	dead	1h	Bruise, Scrape on Body and Head	Yes	Yes	Major	Mechanical
10/20/15	4	005	alive		LOE, Gash L. side	Yes	No	Minor	Mechanical
10/20/15	4	010	dead	24h	LOE, Broken Back	Yes	Yes	Major	Mechanical
10/20/15	4	012	dead	24h	Tear at Tag Site	No	No	Major	Tag R.
10/20/15	4	016	dead	1h	Decapitated	Yes	Yes	Major	Shear
10/20/15	4	019	dead	24h	Broken Back	Yes	Yes	Major	Mechanical
10/20/15	4	022	dead	24h	>20% Descale L. Side	Yes	No	Minor	Mechanical
10/20/15	4	028	dead	1h	Necropsied, no obvious injuries	Yes	No	major	Undetermined
10/20/15	4	030	dead	1h	Tear at Tag Site	No	No	Major	Tag R.
10/20/15	4	031	dead	24h	LOE, Scrape R. Side	Yes	Yes	Minor	Mechanical
10/20/15	4	035	dead	1h	L. Oper., Tear, Head Bruise, Broken Back	Yes	Yes	Major	Mech/Shear
10/20/15	4	036	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	041	dead	1h	LOE	Yes	Yes	Major	Mechanical
10/20/15	4	042	dead	24h	LOE, Broken Back	Yes	No	Major	Mechanical
10/20/15	4	043	dead	24h	LOE, Broken Back	Yes	Yes	Major	Mechanical
10/20/15	4	046	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	047	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	051	dead	24h	LOE	No	No	Minor	Undetermined

10/20/15	4	053	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	054	dead	1h	L. Eye Bulge	Yes	No	Major	Shear
10/20/15	4	055	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	056	dead	48h	LOE	No	No	Minor	Undetermined
10/20/15	4	058	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	C11*	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	C13*	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	C15*	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	C16*	alive		LOE	No	No	Minor	Undetermined
10/20/15	4	C17*	dead	1h	LOE	Yes	No	Major	Undetermined
10/20/15	4	C18*	dead	24h	LOE	No	No	Minor	Undetermined
10/20/15	4	C20*	dead	24h	Hemm. L. Eye, Bruise on Head	Yes	Yes	Major	Mech/Shear

Date	Test Lot	Fish ID	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Bascule Gate 1 at 5,000 cfs				
10/21/2015	5	006	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	007	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	008	dead	24h	LOE, Broken Back	Yes	No	Major	Mechanical
10/21/2015	5	011	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	013	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	014	dead	1h	Decapitated.	Yes	Yes	Major	Shear
10/21/2015	5	015	dead	1h	Smashed Face	Yes	Yes	Major	Mechanical
10/21/2015	5	016	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	020	alive	24h	Ventral Side Abrasion	Yes	No	Minor	Mechanical
10/21/2015	5	021	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	022	dead	24h	LOE, L. Operculum, Hem,	Yes	No	Minor	Shear
10/21/2015	5	024	dead	24h	LOE, Internal Hem,	Yes	No	Major	Mech/Shear
10/21/2015	5	026	alive	1h	LOE, Scraped Nose	Yes	No	Minor	Mechanical
10/21/2015	5	027	dead	24h	LOE	Yes	No	Minor	Undetermined

10/21/2015	5	028	dead	24h	LOE, L Scrape on Nose	Yes	No	Minor	Mechanical
10/21/2015	5	029	dead	1h	Missing L, Eye, Laceration on Head/Body, R.Operc Tear	Yes	Yes	Major	Mech/Shear
10/21/2015	5	030	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	033	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	034	dead	1h	Predation (Chunk out of Caudal)	No	Yes	Major	Predation
10/21/2015	5	036	dead	24h	LOE, Broken Back	Yes	Yes	Major	Mechanical
10/21/2015	5	038	dead	24h	Damaged (Bent) R/L Operculum	Yes	Yes	Major	Undetermined
10/21/2015	5	039	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	040	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	042	dead	24h	LOE, Scrape L. Side, Internal Hemm.	Yes	Yes	Major	Mechanical
10/21/2015	5	043	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	044	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	046	dead	24h	LOE, Scale Loss >50%	Yes	Yes	Major	Mechanical
10/21/2015	5	047	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	048	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	049	dead	24h	LOE, Scrape on Head	Yes	Yes	Minor	Mechanical
10/21/2015	5	050	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	051	dead	24h	Predation	No	Yes	Major	Predation
10/21/2015	5	052	dead	24h	LOE, Bleeding Pec Fin	Yes	No	Minor	Mech/Shear
10/21/2015	5	055	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	058	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	059	dead	24h	LOE, Broken Back	Yes	No	Minor	Mechanical
10/21/2015	5	060	alive		LOE	No	No	Major	Undetermined
10/21/2015	5	061	dead	24h	LOE, Broken Back	Yes	No	Minor	Mechanical
10/21/2015	5	062	dead	24h	LOE	No	No	Major	Undetermined
10/21/2015	5	C08*	dead	24h	LOE	No	No	Minor	Undetermined
10/21/2015	5	C09*	dead	24h	LOE	No	No	Minor	Undetermined

Date	Test Lot	Fish ID	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Bascule Gate 4 at 1,500 cfs				
10/22/2015	6	002	dead	1h	LOE, Scale Loss>50%	Yes	Yes	Major	Mechanical
10/22/2015	6	004	dead	24h	Bruise behind head (body) Major scale loss	Yes	Yes	Minor	Mechanical
10/22/2015	6	007	dead	24h	LOE, Scale Loss>50%	No	No	Minor	Undetermined
10/22/2015	6	008	dead	24h	LOE	No	No	Minor	Undetermined
10/22/2015	6	010	dead	24h	LOE	No	No	Minor	Undetermined
10/22/2015	6	012	dead	1h	Tag Tear, R. side laceration, R. Operc Scrape	Yes	Yes	Major	Mechanical
10/22/2015	6	014	dead	24h	LOE	No	No	Minor	Undetermined
10/22/2015	6	018	dead	24h	LOE, > 20% descaled both sides, broken back	Yes	Yes	Major	Mechanical
10/22/2015	6	019	dead	24h	LOE, Chin Scrape, Int. Hem.	Yes	Yes	Major	Mechanical
10/22/2015	6	020	dead	24h	LOE, Scrape L. Head, Bent R. Pectoral	Yes	Yes	Minor	Mechanical
10/22/2015	6	021	dead	24h	LOE, L Torn Operculum	Yes	Yes	Minor	Shear
10/22/2015	6	023	dead	24h	LOE	No	No	Minor	Undetermined
10/22/2015	6	025	dead	24h	LOE, Scrape L. Head	Yes	Yes	Minor	Mechanical
10/22/2015	6	026	dead	48h	LOE, > 20% descaled both sides	Yes	No	Minor	Mechanical
10/22/2015	6	028	dead	48h	LOE, Tag Tear, Broken Back	Yes	Yes	Major	Mechanical
10/22/2015	6	031	dead	24h	L. Operc.Tear	Yes	Yes	Minor	Shear
10/22/2015	6	034	alive		LOE, Pelvic and Anal Fin Hem.	Yes	No	Minor	Shear/Press.
10/22/2015	6	037	dead	24h	LOE, Small Puncture L. Side	Yes	No	Minor	Mechanical
10/22/2015	6	038	dead	24h	LOE	No	No	Minor	Undetermined
10/22/2015	6	041	dead	24h	LOE	No	No	Minor	Undetermined
10/22/2015	6	043	dead	1h	LOE, L Operculum Tear, Tag Tear	Yes	Yes	Major	Shear
10/22/2015	6	044	dead	24h	LOE, R. Operculum Tear,> 20% descaled	Yes	Yes	Minor	Shear
10/22/2015	6	045	dead	1h	Necropsied, No Obvious Injuries	No	No	Major	Undetermined

10/22/2015	6	047	dead	24h	LOE	No	No	Minor	Undetermined
10/22/2015	6	051	dead	24h	Tag Tear, Bent Pelvic Fin	Yes	Yes	Major	Shear
10/22/2015	6	052	dead	24h	LOE	No	No	Minor	Undetermined
10/22/2015	6	053	dead	24h	LOE, R. Operculum Flare	Yes	Yes	Minor	Shear
10/22/2015	6	054	alive		LOE, Small Puncture L. Side	Yes	No	Minor	Mechanical
10/22/2015	6	061	alive		LOE	No	No	Minor	Undetermined
10/22/2015	6	C04*	dead	24h	LOE	No	No	Minor	Undetermined

Date	Test Lot	Fish ID	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Bascule Gate 4 at 2,500 cfs				
10/23/2015	7	001	alive		R. Operculum. Tear	Yes	No	Minor	Shear
10/23/2015	7	011	dead	1h	R./L. Operc. Tear, Inter Hem, Ruptured R Eye	Yes	Yes	Major	Shear/Mech
10/23/2015	7	012	dead	1h	Severe Tag Tear, Hem R. Eye	Yes	Yes	Major	Shear
10/23/2015	7	013	dead	1h	Torn isthmus, Lacer. Head	Yes	Yes	Major	Mechanical
10/23/2015	7	014	alive		LOE, Scrape on body	Yes	No	Minor	Mechanical
10/23/2015	7	020	dead	24h	Broken Jaw, Lacer., R. side	Yes	No	Major	Mechanical
10/23/2015	7	021	dead	24h	Bruising along R&L body	Yes	No	Minor	Mechanical
10/23/2015	7	022	dead	24h	LOE	No	No	Minor	Undetermined
10/23/2015	7	024	dead	24h	Min. Hem dorsal fin base	Yes	No	Minor	Mechanical
10/23/2015	7	026	dead	24h	LOE	No	No	Minor	Undetermined
10/23/2015	7	027	dead	48h	Bruise behind head	Yes	No	Minor	Mechanical
10/23/2015	7	031	dead	24h	LOE	No	No	Minor	Undetermined
10/23/2015	7	032	dead	24h	LOE, >20% R. Scale loss, R. Operc. Flare	Yes	No	Minor	Shear
10/23/2015	7	034	dead	24h	LOE	No	No	Minor	Undetermined
10/23/2015	7	035	dead	1h	Broken Jaw	Yes	Yes	Major	Mechanical
10/23/2015	7	036	dead	24h	LOE, R Operc. Flare	Yes	Yes	Minor	Shear
10/23/2015	7	039	dead	24h	LOE, R Operc. Flare and Scraped	Yes	No	Minor	Shear/Mech
10/23/2015	7	044	dead	24h	LOE	No	No	Minor	Undetermined

10/23/2015	7	046	dead	24h	LOE	No	No	Minor	Undetermined
10/23/2015	7	049	dead	24h	Tag Tear, L. Operc. Flare	Yes	Yes	Minor	Shear
10/23/2015	7	050	dead	1h	L. Operc flare, bruise head	Yes	Yes	Major	Shear/Mech
10/23/2015	7	051	dead	24h	LOE, min bruise body	Yes	No	Minor	Mechanical
10/23/2015	7	052	dead	24h	LOE>20% R. Scale loss both sides, hemm dorsal	Yes	Yes	Minor	Mechanical
10/23/2015	7	053	dead	24h	LOE	No	No	Minor	Undetermined
10/23/2015	7	054	dead	24h	LOE>20% R. Scale loss both sides,	Yes	No	Minor	Mechanical
10/23/2015	7	055	dead	24h	LOE, bruise on head	Yes	No	Minor	Mechanical
10/23/2015	7	056	alive		LOE	No	No	Minor	Undetermined
10/23/2015	7	C16*	dead	24h	LOE	No	No	Minor	Undetermined

Date	Test Lot	Fish ID	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Bascule Gate 4 at 5,000 cfs				
10/24/2015	8	003	dead	24h	LOE> 20% descaled both sides	Yes	No	Minor	Mechanical
10/24/2015	8	004	dead	24h	LOE, L. Operc. Flare, inter hem	Yes	No	Major	Shear/Mech
10/24/2015	8	007	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	009	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	010	dead	24h	LOE, Scrape L&R operc.	Yes	No	Minor	Mechanical
10/24/2015	8	014	dead	24h	LOE, Tear, broken back	Yes	No	Major	Mechanical
10/24/2015	8	015	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	022	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	023	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	027	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	031	dead	24h	LOE> 20% descaled both sides, tag tear	Yes	No	Major	Mechanical
10/24/2015	8	033	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	034	dead	24h	Internal Hem.	Yes	No	Major	Shear/Press.
10/24/2015	8	035	dead	24h	LOE, Small scrape R. operc.	Yes	No	Minor	Mechanical
10/24/2015	8	039	dead	24h	LOE, min. hem, L. eye	Yes	No	Minor	Shear

10/24/2015	8	046	dead	24h	LOE, Hem. L. operc.	Yes	No	Minor	Shear
10/24/2015	8	048	alive		Hem. L. Eye	Yes	No	Minor	Shear
10/24/2015	8	049	dead	24h	Tear, Scrape L. operc	Yes	No	Minor	Mechanical
10/24/2015	8	051	dead	24h	LOE, Broken back	Yes	No	Major	Mechanical
10/24/2015	8	052	dead	24h	LOE, L. side body punctures	Yes	No	Minor	Mechanical
10/24/2015	8	053	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	055	dead	24h	Broken back	No	No	Major	Mechanical
10/24/2015	8	056	alive		LOE, missing part of dorsal fin	Yes	No	Minor	Mechanical
10/24/2015	8	057	dead	24h	LOE, min L. operc tear	Yes	No	Minor	Shear
10/24/2015	8	060	dead	24h	LOE, broken back	Yes	No	Major	Mechanical
10/24/2015	8	062	dead	48h	L. Scrape operc.	Yes	No	Minor	Mechanical
10/24/2015	8	C03*	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	C05*	dead	24h	LOE	No	No	Minor	Undetermined
10/24/2015	8	C06*	dead	24h	LOE	No	No	Minor	Undetermined

*control fish

APPENDIX D

SURVIVAL AND MALADY-FREE STATISTICAL OUTPUTS

```
One hour survival estimates for juvenile American Shad passed through
Cabot Station Unit 2 and Station No. 1 Unit 2/3; combined controls.
Control 71 released, 67 alive, 0 dead
Cabot Station Unit 2 120 released, 113 alive, 6 dead
Station No. 1 Unit 2/3 90 released, 59 alive, 28 dead
=====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     1.0     N/A       Control group survival*
Pa = Pd  0.9715 (0.0099)   Recovery probability
S2 =     0.9496 (0.0201)   Cabot Station: Unit 2 survival
S3 =     0.6782 (0.0501)   Station No. 1: Unit 2/3 survival

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -114.7842
```

Tau =   0.9496 (0.0201)   Cabot Station: Unit 2/Control ratio
Tau =   0.6782 (0.0501)   Station No. 1: Unit 2/3/Control ratio

```
Z statistic for the equality of equal turbine survivals:
              5.0305

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00009843  0.00000000  0.00000000
0.00000000  0.00000000  0.00040234  0.00000000
0.00000000  0.00000000  0.00000000  0.00250872

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.9166, 0.9826)   (0.5958, 0.7606)
95 percent: (0.9103, 0.9889)   (0.5800, 0.7763)
99 percent: (0.8979, 1.0012)   (0.5492, 0.8071)
=====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       0.0021
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```

```
One hour survival estimates for juvenile American Shad passed through
Station No. 1 Unit 2/3 and Station No. 1 Unit 1; combined control.
Control 71 released, 67 alive, 0 dead
Unit 2/3 90 released, 59 alive, 28 dead
Unit 1 90 released, 59 alive, 18 dead
====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     1.0     N/A       Control group survival*
Pa = Pd  0.9203 (0.0171)   Recovery probability
S2 =     0.6782 (0.0501)   Station No. 1 Unit 2/3 survival
S3 =     0.7662 (0.0482)   Station No. 1 Unit 1 survival

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -166.3047

Tau =    0.6782 (0.0501)   Station No. 1: Unit 2/3/Control ratio
Tau =    0.7662 (0.0482)   Station No. 1: Unit 1/Control ratio

Z statistic for the equality of equal turbine survivals:
              1.2666

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00029216  0.00000000  0.00000000
0.00000000  0.00000000  0.00250872  0.00000000
0.00000000  0.00000000  0.00000000  0.00232623

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.5958, 0.7606)   (0.6869, 0.8456)
95 percent: (0.5800, 0.7763)   (0.6717, 0.8608)
99 percent: (0.5492, 0.8071)   (0.6420, 0.8904)
====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       0.0053
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```

```
One hour survival estimates for juvenile American Shad passed through
Bascule Gate 1 at  1500 cfs and Bascule Gate 1 at  2500 cfs; combined
controls.
Control 75 released, 72 alive, 3 dead
Bascule Gate 1 at  1500 cfs 60 released, 38 alive, 19 dead
Bascule Gate 1 at  2500 cfs 60 released, 27 alive, 32 dead
=====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     0.9600 (0.0226)   {Control group survival
Pa = Pd  0.9795 (0.0102)   Recovery probability
S2 =     0.6667 (0.0624)   Bascule Gate 1 at  1500 cfs survival
S3 =     0.4576 (0.0649)   Bascule Gate 1 at  2500 cfs survival

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -109.0662

Tau =    0.6944 (0.0671)   Bascule Gate 1 at  1500 cfs/Control ratio
Tau =    0.4767 (0.0685)   Bascule Gate 1 at  2500 cfs/Control ratio

Z statistic for the equality of equal turbine survivals:
              2.2715

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000
0.00000000  0.00010304  0.00000000  0.00000000
0.00000000  0.00000000  0.00389864  0.00000000
0.00000000  0.00000000  0.00000000  0.00420682

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.5841, 0.8048)   (0.3640, 0.5894)
95 percent: (0.5630, 0.8259)   (0.3425, 0.6109)
99 percent: (0.5217, 0.8671)   (0.3003, 0.6531)
=====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       2.3944
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```

```
One hour survival estimates for juvenile American Shad passing through
Bascule Gate 1 at  5000 cfs and Bascule Gate 4 at  1500 cfs; combining
control.
Control 75 released, 72 alive, 3 dead
Bascule Gate 1 at  5000 cfs 62 released, 45 alive, 17 dead
Bascule Gate 4 at  1500 cfs 60 released, 37 alive, 23 dead
====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     0.9600 (0.0226)   {Control group survival
Pa = Pd  1.0     N/A       Recovery probability*
S2 =     0.7258 (0.0567)   Bascule Gate 1 at  5000 cfs survival
S3 =     0.6167 (0.0628)   Bascule Gate 4 at  1500 cfs survival

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -88.9540

Tau =    0.7560 (0.0616)   Bascule Gate 1 at  5000 cfs/Control ratio
Tau =    0.6424 (0.0671)   Bascule Gate 4 at  1500 cfs/Control ratio

Z statistic for the equality of equal turbine survivals:
              1.2475

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00320986  0.00000000
0.00000000  0.00000000  0.00000000  0.00393981

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.6546, 0.8575)   (0.5320, 0.7528)
95 percent: (0.6352, 0.8769)   (0.5108, 0.7739)
99 percent: (0.5973, 0.9148)   (0.4695, 0.8152)
====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       0.0000
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```

```
One hour survival estimates for juvenile American Shad passing through
Bascule Gate 4 at  2500 cfs and Bascule Gate 4 at  5000 cfs; combining
control.
Control 75 released, 72 alive, 3 dead
Bascule Gate 4 at  2500 cfs 60 released, 34 alive, 23 dead
Bascule Gate 4 at  5000 cfs 60 released, 41 alive, 17 dead
====================================================
RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)
         estim. std.err.
S1 =     0.9600 (0.0226)   Control group survival
Pa =     1.0     N/A       Live recovery probability*
Pd =     0.8958 (0.0441)   Dead recovery probability
S2 =     0.5667 (0.0640)   Bascule Gate 4 at  2500 cfs survival
S3 =     0.6833 (0.0601)   Bascule Gate 4 at  5000 cfs survival

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.

 log-likelihood : -107.1484

Tau =    0.5903 (0.0681)   Bascule Gate 4 at  2500 cfs/Control ratio
Tau =    0.7118 (0.0648)   Bascule Gate 4 at  5000 cfs/Control ratio

Z statistic for the equality of equal turbine survivals:
              1.2934

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00194408  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00409259  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000  0.00360648

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.4783, 0.7023)   (0.6053, 0.8183)
95 percent: (0.4568, 0.7237)   (0.5849, 0.8387)
99 percent: (0.4150, 0.7656)   (0.5450, 0.8786)

Estimating parameters for MODEL #2
fletch finished (1)



====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)
```

```
         estim. std.err.
S1 =     0.9600 (0.0226)   {Control group survival
Pa = Pd  0.9744 (0.0113)   Recovery probability
S2 =     0.5965 (0.0650)   Bascule Gate 4 at  2500 cfs survival
S3 =     0.7069 (0.0598)   Bascule Gate 4 at  5000 cfs survival

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -109.3749

Tau =    0.6213 (0.0693)   Bascule Gate 4 at  2500 cfs/Control ratio
Tau =    0.7364 (0.0646)   Bascule Gate 4 at  5000 cfs/Control ratio

Z statistic for the equality of equal turbine survivals:
              1.2140

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000
0.00000000  0.00012812  0.00000000  0.00000000
0.00000000  0.00000000  0.00422262  0.00000000
0.00000000  0.00000000  0.00000000  0.00357231

Confidence intervals:
            Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.5074, 0.7353)   (0.6300, 0.8427)
95 percent: (0.4856, 0.7571)   (0.6097, 0.8630)
99 percent: (0.4430, 0.7997)   (0.5699, 0.9028)

====================================================


Likelihood ratio statistic for equality of recovery probabilities:
       4.4528

Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635

====================================================
```

```
One hour survival estimates for juvenile American Shad passing through
combined Bascule Gate 1 and combined Bascule Gate 4 combining control.
Control 75 released, 72 alive, 3 dead
Bascule Gate 1 Combined 182 released, 110 alive, 68 dead
Bascule Gate 4 Combined 180 released, 112 alive, 63 dead
====================================================
RESULTS FOR FULL MODEL (UNEQUAL LIVE/DEAD RECOVERY)
         estim. std.err.
S1 =     0.9600 (0.0226)   Control group survival
Pa =     1.0     N/A       Live recovery probability*
Pd =     0.9371 (0.0203)   Dead recovery probability
S2 =     0.6044 (0.0362)   Bascule Gate 1 survival
S3 =     0.6222 (0.0361)   Bascule Gate 4 survival

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.

 log-likelihood : -287.6873
```

Tau =   0.6296 (0.0406)   Bascule Gate 1/Control ratio
Tau =   0.6481 (0.0406)   Bascule Gate 4/Control ratio

```
Z statistic for the equality of equal turbine survivals:
              0.3234

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00041242  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00131375  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000  0.00130590

Confidence intervals:
            Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.5628, 0.6963)   (0.5813, 0.7150)
95 percent: (0.5501, 0.7091)   (0.5685, 0.7278)
99 percent: (0.5251, 0.7340)   (0.5435, 0.7528)

Estimating parameters for MODEL #2
fletch finished (1)


====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)
```

```
          estim. std.err.
S1 =      0.9600 (0.0226)   {Control group survival
Pa = Pd  0.9794 (0.0068)   Recovery probability
S2 =      0.6180 (0.0364)   Bascule Gate 1 survival
S3 =      0.6400 (0.0363)   Bascule Gate 4 survival

* --  Because of contraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -289.1732

Tau =     0.6437 (0.0409)   Bascule Gate 1/Control ratio
Tau =     0.6667 (0.0409)   Bascule Gate 4/Control ratio

Z statistic for the equality of equal turbine survivals:
              0.3967

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000
0.00000000  0.00004616  0.00000000  0.00000000
0.00000000  0.00000000  0.00132630  0.00000000
0.00000000  0.00000000  0.00000000  0.00131657

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.5765, 0.7109)   (0.5993, 0.7340)
95 percent: (0.5636, 0.7238)   (0.5864, 0.7469)
99 percent: (0.5385, 0.7489)   (0.5613, 0.7721)

====================================================


Likelihood ratio statistic for equality of recovery probabilities:
       2.9717

Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635

====================================================
```

```
Malady-free rates for Juvenile American Shad passing through Cabot
Station: Unit 2 and Cabot Station No. 1: Unit 2/3 combined controls.
Controls 67 examined, 66 malady-free, 1 malady
Cabot Station: Unit 2 115 examined, 105 malady-free, 10 maladies
Station No. 1: Unit 2/3 65 examined, 55 malady-free, 10 maladies
====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     0.9851 (0.0148)   {Control group malady-free
Pa = Pd  1.0     N/A       Recovery probability*
S2 =     0.9130 (0.0263)   Cabot Station: Unit 2 malady-free
S3 =     0.8462 (0.0448)   Station No. 1: Unit 2/3 malady-free

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -67.0787

Tau =    0.9269 (0.0301)   Cabot Station: Unit 2/Control ratio
Tau =    0.8590 (0.0472)   Station No. 1: Unit 2/3/Control ratio

Z statistic for the equality of equal turbine malady-frees:
             1.2125

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00021944  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00069039  0.00000000
0.00000000  0.00000000  0.00000000  0.00200273

Confidence intervals:
            Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.8774, 0.9764)   (0.7813, 0.9367)
95 percent: (0.8679, 0.9859)   (0.7664, 0.9515)
99 percent: (0.8494, 1.0044)   (0.7374, 0.9806)

====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       0.0000
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```

```
Malady-free rates for juvenile American Shad passed through Station No. 1:
Units 2/3 and Station No. 1: Unit 1; combined controls.
Controls 67 examined, 66 malady-free, 1 malady
Station No. 1: Units 2/3 65 examined, 55 malady-free, 10 maladies
Station No. 1: Unit 1 68 examined, 51 malady-free, 17 maladies

====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     0.9851 (0.0148)   {Control group survival
Pa = Pd  1.0     N/A       Recovery probability*
S2 =     0.8462 (0.0448)   Station No. 1: Unit 2/3 survival
S3 =     0.7500 (0.0525)   Station No. 1: Unit 1 survival

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -71.3420

Tau =    0.8590 (0.0472)   Station No. 1: Units 2/3/Control ratio
Tau =    0.7614 (0.0545)   Station No. 1: Unit 1/Control ratio

Z statistic for the equality of equal turbine survivals:
              1.3532

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00021944  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00200273  0.00000000
0.00000000  0.00000000  0.00000000  0.00275735

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.7813, 0.9367)   (0.6717, 0.8511)
95 percent: (0.7664, 0.9515)   (0.6545, 0.8682)
99 percent: (0.7374, 0.9806)   (0.6210, 0.9018)
====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       0.0000
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```

```
Malady-free rates for juvenile American Shad passed through Bascule Gate
1: 1500 cfs and 2500 cfs; combined controls.
Controls 75 examined, 72 malady-free, 3 maladies
Bascule Gate 1 at 1500 cfs 42 examined, 33 malady-free, 9 maladies
Bascule Gate 1 at 2500 cfs 34 examined, 21 malady-free, 13 maladies
====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     0.9600 (0.0226)   {Control group malady-free
Pa = Pd  1.0     N/A       Recovery probability*
S2 =     0.7857 (0.0633)   Bascule Gate 1 at 1500 cfs malady-free
S3 =     0.6176 (0.0833)   Bascule Gate 1 at 2500 cfs malady-free

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -57.0351

Tau =    0.8185 (0.0687)   Bascule Gate 1 at 1500 cfs/Control ratio
Tau =    0.6434 (0.0881)   Bascule Gate 1 at 2500 cfs/Control ratio

Z statistic for the equality of equal turbine malady-frees:
              1.5666

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00400875  0.00000000
0.00000000  0.00000000  0.00000000  0.00694586

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.7054, 0.9315)   (0.4984, 0.7884)
95 percent: (0.6838, 0.9531)   (0.4706, 0.8161)
99 percent: (0.6415, 0.9954)   (0.4165, 0.8703)
====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       0.0000
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```

```
Malady-free rates for juvenile American Shad passed through Bascule Gate 1
at 5000 cfs and Bascule Gate 4 at 1500 cfs; combined controls.
Controls 75 examined, 72 malady-free, 3 maladies
Bascule Gate 1 at 5000 cfs 49 examined, 32 malady-free, 17 maladies
Bascule Gate 4 at 1500 cfs 41 examined, 22 malady-free, 19 maladies
====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     0.9600 (0.0226)   {Control group malady-free
Pa = Pd  1.0     N/A       Recovery probability*
S2 =     0.6531 (0.0680)   Bascule Gate 1 at 5000 cfs malady-free
S3 =     0.5366 (0.0779)   Bascule Gate 4 at 1500 cfs malady-free

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -72.5360

Tau =    0.6803 (0.0726)   Bascule Gate 1 at 5000 cfs/Control ratio
Tau =    0.5589 (0.0822)   Bascule Gate 4 at 1500 cfs/Control ratio

Z statistic for the equality of equal turbine malady-frees:
              1.1062

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00462393  0.00000000
0.00000000  0.00000000  0.00000000  0.00606494

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.5608, 0.7997)   (0.4237, 0.6941)
95 percent: (0.5379, 0.8226)   (0.3979, 0.7200)
99 percent: (0.4933, 0.8673)   (0.3473, 0.7706)
====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       0.0000
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```

```
Malady-free rates for juvenile American Shad passed through Bascule Gate 4
at 2500 cfs and at 5000 cfs; combined controls.
Controls 75 examined, 72 malady-free, 3 maladies
Bascule Gate 4 at 2500 cfs 40 examined, 22 malady-free, 18 maladies
Bascule Gate 4 at 5000 cfs 41 examined, 23 malady-free, 18 maladies
====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     0.9600 (0.0226)   {Control group malady-free
Pa = Pd  1.0     N/A       Recovery probability*
S2 =     0.5500 (0.0787)   Bascule Gate 4 at 2500 cfs malady-free
S3 =     0.5610 (0.0775)   Bascule Gate 4 at 5000 cfs malady-free

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -68.2348
```

Tau =   0.5729 (0.0830)   Bascule Gate 4 at 2500 cfs/Control ratio
Tau =   0.5843 (0.0819)   Bascule Gate 4 at 5000 cfs/Control ratio

```
Z statistic for the equality of equal turbine malady-frees:
              0.0980

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00618748  0.00000000
0.00000000  0.00000000  0.00000000  0.00600686

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.4363, 0.7095)   (0.4496, 0.7191)
95 percent: (0.4102, 0.7357)   (0.4238, 0.7449)
99 percent: (0.3591, 0.7868)   (0.3735, 0.7952)

====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       0.0000
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```

```
Malady-free rates for juvenile American Shad passed through Bascule Gate 1
combined cfs and Bascule Gate 4 combined cfs combined controls.
Controls 75 examined, 72 malady-free, 3 maladies
Bascule Gate 1 Combined cfs 125 examined, 86 malady-free, 39 maladies
Bascule Gate 4 Combined cfs 122 examined, 67 malady-free, 55 maladies
====================================================
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

         estim. std.err.
S1 =     0.9600 (0.0226)   {Control group malady-free
Pa = Pd  1.0     N/A       Recovery probability*
S2 =     0.6880 (0.0414)   Bascule Gate 1 Combined malady-free
S3 =     0.5492 (0.0450)   Bascule Gate 4 Combined malady-free

* --  Because of constraints in the data set, this probability is assumed
      equal to 1.0; not estimated.


 log-likelihood : -174.1551

Tau =    0.7167 (0.0464)   Bascule Gate 1 Combined/Control ratio
Tau =    0.5721 (0.0488)   Bascule Gate 4 Combined/Control ratio

Z statistic for the equality of equal turbine malady-frees:
              2.1479

Compare with quantiles of the normal distribution:

                                1-tailed   2-tailed
  For significance level 0.10:   1.2816     1.6449
  For significance level 0.05:   1.6449     1.9600
  For significance level 0.01:   2.3263     2.5758

Variance-Covariance matrix for estimated probabilities:

0.00051200  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00000000  0.00000000
0.00000000  0.00000000  0.00171725  0.00000000
0.00000000  0.00000000  0.00000000  0.00202935

Confidence intervals:
             Turbine 1 Tau      Turbine 2 Tau
90 percent: (0.6404, 0.7929)   (0.4917, 0.6524)
95 percent: (0.6258, 0.8075)   (0.4764, 0.6678)
99 percent: (0.5973, 0.8360)   (0.4463, 0.6978)
====================================================
Likelihood ratio statistic for equality of recovery probabilities:
       0.0000
Compare with quantiles of the chi-squared distribution with 1 d.f.:

  For significance level 0.10:  2.706
  For significance level 0.05:  3.841
  For significance level 0.01:  6.635
```