Relicensing Study 3.3.5

Evaluate Downstream Passage of American Eel

Study Report

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

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EXECUTIVE SUMMARY

FirstLight Hydro Generating Company (FirstLight) is the current licensee of the Northfield Mountain Pumped Storage Project (NMPS Project, FERC No. 2485) and the Turners Falls Hydroelectric Project (Turners Falls Project, FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the NMPS and Turners Falls Projects using the FERC's Integrated Licensing Process (ILP). The current licenses for the NMPS and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018. This report documents the results of Study No. 3.3.5 *Evaluate Downstream Passage of American Eel*.

The purpose of this study was to characterize the downstream migration of adult silver phase American Eel through the Turners Falls and NMPS Projects and evaluate the impacts of project operations and environmental factors on migratory behavior. The methods employed to achieve the study objectives included the use of three primary technologies including Dual Frequency Identification Sonar (DIDSON), radio telemetry, and HI-Z Turb'N Tag (HI-Z Tag).

A DIDSON camera was used to monitor the downstream migration of adult silver phase American Eel in the Turners Falls Power Canal between August 1 and November 15 during both 2015 and 2016. Eel passed sporadically throughout the study period during both years, peaking in early August during 2015 and mid-October during 2016. Extrapolated DIDSON counts (based on data collected at the 10-m range setting) yielded an estimated 2,382 and 2,273 passing through the canal during 2015 and 2016, respectively.

FirstLight tagged and released 132 eel during 2015 with radio telemetry tags at two sites in the Turners Falls Impoundment (TFI), one site above (n=72) and one below (n=60) the NMPS intake/tailrace. TransCanada released an additional 165 eel above Vernon Dam as part of a concurrent relicensing study. A series of fixed radio telemetry stations were installed to monitor the downstream movements of tagged eel from just upstream of the NMPS intake/tailrace, through project features, and down to the Montague Wastewater Facility, which is located downstream of the bypass reach, Cabot Station tailrace, and the Deerfield River confluence. A Cormack-Jolly-Seber (CJS) mark recapture model estimated that 164 eel were detected in the TFI, two of which were entrained and detected in the Upper Reservoir. Cox Proportional Hazard regression models revealed that another 34 eel were detected upstream of the Northfield intake but were not subsequently detected downstream. The majority of eel passed the Turners Falls complex via the power canal, with 106 fish ultimately reaching the Cabot Station tailrace. Eel were much more likely to move at night, and especially during rain events.

HI-Z Turb'N Tag testing revealed 48-h survival rates of 86.8%, 88.4%, and 96% for eel passing through Bascule Gate 1 at Turners Falls Dam, Bascule Gate 4 at Turners Falls Dam, and Cabot Station powerhouse, respectively.

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LIST OF ABBREVIATIONS

cfs	cubic feet per second
CSOT	Convolved Samples Over Threshold
DIDSON	Dual Frequency Identification SONAR
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Hydro Generating Company
fps	feet per second
ft^2	square feet
HI-Z Tag	HI-Z Turb'N Tag
HF	high frequency
ILP	Integrated Licensing Process
LF	low frequency
m	meters
MDFW	Massachusetts Division of Fish and Wildlife
msl	mean sea level
NMPS Project	Northfield Mountain Pumped Storage Project
PAD	Pre-Application Document
PSP	Proposed Study Plan
RM	river mile
RSP	Revised Study Plan
SCADA	Supervisory Control and Data Acquisition System
SD1	Scoping Document 1
SD2	Scoping Document 2
SPDL	Study Plan Determination Letter
Turners Falls Project	Turners Falls Hydroelectric Project
TFD	Turners Falls Dam
TFI	Turners Falls Impoundment
USFWS	United States Fish and Wildlife Service
VY	Vermont Yankee Nuclear Power Plant

1 INTRODUCTION

FirstLight Hydro Generating Company (FirstLight) is the current licensee of the Northfield Mountain Pumped Storage Project (NMPS Project, FERC No. 2485) and the Turners Falls Hydroelectric Project (Turners Falls Project, FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the two Projects using the FERC's Integrated Licensing Process (ILP). The current licenses for NMPS 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 the RSP with certain modifications.

In its February 21, 2014 Determination Letter FERC approved Study No. 3.3.5 *Evaluate Downstream Passage of American Eel* with the following modifications:

- FERC recommended FirstLight include within its study report, a report on the telemetry array's testing and calibration.
- FERC recommended FirstLight provide telemetry coverage of the Northfield Mountain Upper Reservoir.
- To better understand the potential project effects on migration route selection and potential delayed downstream passage of American eels, FERC recommended that FirstLight provide telemetry detection coverage upstream of the Gatehouse.
- FERC recommended FirstLight conduct its proposed mobile telemetry tracking for passage-induced American eel mortality at least twice per week and utilize all fixed telemetry stations to detect and report eel mortality.

- FERC recommended FirstLight use radio telemetry tags for the study with a battery life of at least 90 days.
- FERC recommended FirstLight implement the hydroacoustic component of the study for two study seasons between August 1 and October 31.
- FERC recommended FirstLight consult with the United States Fish and Wildlife Service (USFWS), Massachusetts Division of Fisheries and Wildlife (MADFW) and the National Marine Fisheries Service (NMFS) and establish the typical operating condition of each test turbine evaluated during the study. FirstLight should provide the results of this consultation and file them for Commission approval with the Initial Study Report in September 2014.

Relative to the last bullet, in its Initial Study Report filed on September 15, 2014, FirstLight included its modified study plan along with the stakeholder consultation record.

FirstLight did note that between August 31, 2015 and February 17, 2016, one of the four pump-turbines (Unit 1) at the NMPS Project was removed from operation, thus FirstLight could no operate more than three pump-turbines in pumping mode during the sampling for Study No. 3.3.5 during the first year (2015) of study.

In its January 15, 2016 Determination Letter FERC stated the following:

"Not operating all four pump-turbines in pumping mode during the field sampling required by studies 3.3.3 and 3.3.5 is a variance from the approved study plan; however, additional sampling may not be necessary if FirstLight can derive a statistically valid approach for extrapolating to four pump-turbine pumping operation based on the data collected during pumping operation of the three available pump-turbines. In its final reports for studies 3.3.3 and 3.3.5, FirstLight should provide a detailed description of any calculations used to derive estimates of fish entrainment during four pump-turbine pumping operation, including a list of assumptions and support for such assumptions (i.e., statistical analysis, literature review, analysis of velocity profiles from Study 3.3.9 and observed entrainment, or analysis of the relationship between intake flow or velocity and entrainment rates from other power plants). To the extent possible, FirstLight should also include confidence intervals or other descriptions of the variance and uncertainty associated with any estimates of entrainment during operation of four pump-turbines in pumping mode".

1.1 Background

The timing of downstream migratory movements and rates of adult (silver phase) American Eel, *Anguilla rostrata* (eel), in the mainstem Connecticut River are not well understood. Preliminary data on the presence of "eel-sized" acoustic targets have been collected (Haro et al., 1999) within the Cabot Station forebay, supported by video monitoring at the Cabot Station downstream fish bypass. This was a short-term study, with acoustic monitoring performed between September 17 and October 5, 1998 and video monitoring conducted between September 18 and October 22, 1998. Additional data have been collected during daily monitoring of the downstream fish bypass at the Holyoke Dam (canal louver array) in 2004 and 2005 (Kleinschmidt Associates, 2005; 2006; Normandeau Associates, 2007); these studies also were of relatively short duration (spanning from October 5 to November 10, 2004 and September 9 to November 11, 2005) and the sampler was only operated at night.

As discussed in the PAD, 2-D and 3-D telemetry studies were conducted at Cabot Station in 1996, 1997, 2002 and 2003. Results of those studies indicate that a significant proportion (90-100%) of eel entering the Cabot forebay become entrained through the Station turbines (Brown, 2005; Brown et al., 2009). The PAD notes that the study conducted in 2003 determined that 15 of the 29 test eel were detected approximately 34 River Miles (RM) downstream at the Hadley Falls Station in Holyoke, MA. However, that study was not designed to assess turbine passage mortality.

1.2 Study Goals and Objectives

The goals of these studies are to:

- Better understand migration timing of adult, silver-phase American eel as it relates to environmental factors and operations at the Turners Falls Project and Northfield Mountain Project
- Collect information to determine the impact of the Turners Falls Project and Northfield Mountain Project on the outmigration of silver eel in the Connecticut River.

Specific objectives of the study are as follows:

- Characterize the general migratory timing and presence of adult, silver-phase American eel migrating past the Turners Falls Project and Northfield Mountain Project relative to environmental factors and operations.
- Quantify movement rates and proportion of eel passing downstream via various passage routes at the Turners Falls and Northfield Mountain Projects as well as evaluate the proportion of eel entrained. For the Northfield Mountain Project, the study will evaluate the proportion of eel entrained into the intake. For the Turners Falls Project, the study will evaluate the proportion of eel passing via the available routes of passage.
- Evaluate survival of adult silver eel passed at the available routes of passage at the Turners Falls Project.

2 STUDY AREA AND SURVEY SITE SELECTION

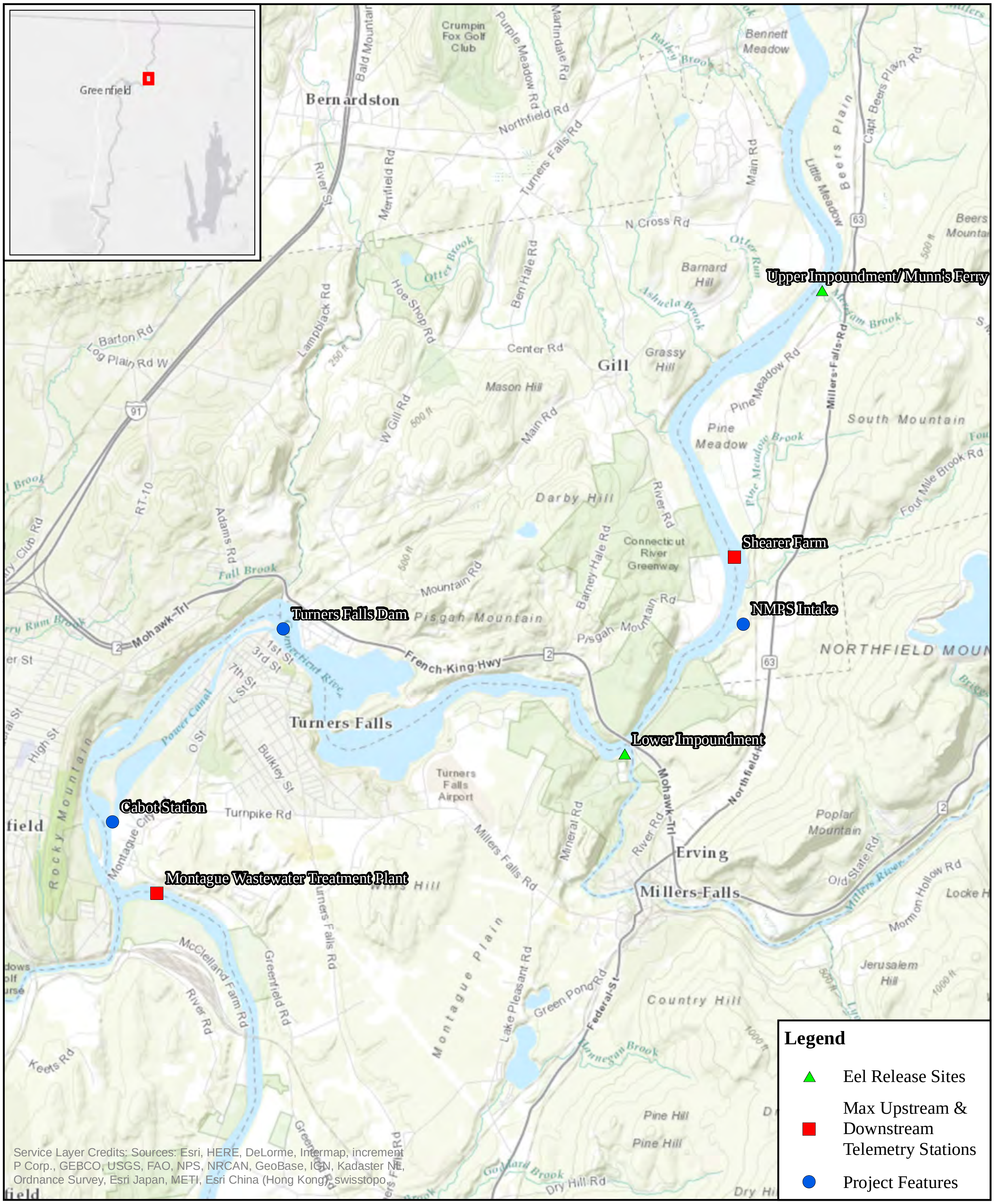
The study area consists of the Projects waters of the Connecticut River including a 12.3-mile-long reach from the Munn's Ferry area (RM 130.8) in the Turners Falls Impoundment (TFI), located approximately 3.3 RM upstream of the NMPS Project intake/discharge (RM 127.5) downstream to Montague City, MA (RM 118.5), located just below the Deerfield River confluence (Figure 2-1). This reach includes impounded and riverine portions of the Connecticut River extending from upstream of the NMPS Project to areas downstream of the Turners Falls Project. Eel migrating through this reach were subjected to Project infrastructure and influences of Project operations.

The Turners Falls Dam (TFD) is located at approximately RM 122 in the Towns of Gill and Montague, MA. The impoundment created by the TFD 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 leading to Station No. 1; 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 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 the TFD, 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 adjacent to Cabot Station consisting 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 trashrack opening is 217-feet-wide by 31-feet-high resulting in a gross area of 6,727 square feet (ft^2). The trashracks are orientated perpendicular to the flow. The clear bar-spacing is 0.9 inches (15/16 inch) for the upper 11 feet of the trashrack and 5 inches for the remaining portion. At full hydraulic capacity of 13,728 cfs (2,288/unit), the calculated approach velocity in front of the trashrack is approximately 2.0 feet per second (fps).

The entrance to Station No. 1 consist of eight bays, each 15-feet-wide for a total intake width of 120 feet. Trashracks protect the intake, extending 114-feet-wide by 20.5-feet-high and are angled across the entire entrance. With a normal canal elevation of approximately 173.5 feet above mean sea level (msl), the effective trashrack opening is approximately 114-feet-wide by 15.9 feet high, resulting in a gross area of approximately 1,813 ft^2. The bar rack thickness is 0.375 inches and the bars are spaced 3 inches on center, thus, the clear spacing between bars is 2.625 inches. At full hydraulic capacity of 2,210 cfs, the calculated average approach velocity is front of the trashracks is approximately 1.2 fps.

The NMPS Project consists of a) an upper reservoir and dam/dikes; b) an intake; c) pressure shaft; d) an underground powerhouse; and e) a tailrace. The TFI (Connecticut River) serves as a lower reservoir. The trashrack opening at the intake/tailrace is trapezoidal in shape and has a gross area opening of 4,400 ft^2. The bar thickness is 0.75 inches, with a clear spacing of 6 inches. Under maximum pumping conditions of 15,200 cfs, the calculated velocity in front of the trashracks is 3.5 fps.



FirstLight Power Resources

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

Relicensing Study 3.3.5

Figure 2-1: Overview of Study Area

Path: W:\gis\studies\3_3_5\maps\Figure2-1.mxd

3 METHODS

The study was conducted in accordance with the approved RSP and FERC's SPDL, except as noted in this report and as modified in consultation with the resource agencies, FERC and stakeholders during the consultation process. The methods used to achieve the study objectives included the use of three primary technologies including Dual Frequency Identification SONAR (DIDSON), radio telemetry and HI-Z Turb'N Tag (HI-Z Tag).

The evaluation of run timing and passage effectiveness was analyzed in relation to project operation and environmental factors including river flow, water temperature and precipitation. River flow, water temperature and generation were monitored continuously at fifteen-minute intervals throughout the study period. Water temperature was monitored within the Turners Falls power canal immediately upstream of Cabot Station. Operations and water temperature data were systematically collected and archived by FirstLight using a Supervisory Control and Data Acquisition system (SCADA). In addition, water quality was periodically monitored in the TFI and eel holding tanks using a YSI 556 water quality meter; data were recorded in a dedicated field notebook and included sample location, date, dissolved oxygen (mg/L), pH, conductivity (µS/cm), and water temperature (°C). Daily precipitation data were acquired from a weather station at nearby Athol, MA.

3.1 Migratory Timing of Eel (DIDSON)

The timing of adult eel migration through the Projects was evaluated using DIDSON technology. The RSP envisioned using both DIDSON and split beam hydroacoustics; however, the split beam monitoring approach was eliminated from the evaluation at the recommendation of the hydroacoustics expert (Aquacoustics) due to difficulties in definitively identifying eel and the relatively small sampling area achieved by the narrow beam of the split beam sonar (7° conical beam), which is not ideal for monitoring non-schooling species. The DIDSON's wider beam (~29° x 14°) and ability to detect anguilliform swimming is more effective for detecting and accurately identifying migrating eel.

DIDSON monitoring was performed between August 1, and November 15, 2015 and 2016. Data were collected using a Sound Metrics Corp. 300 m Rear Facing Connector Standard DIDSON mounted to the west canal wall immediately upstream (north) of the Power Street Bridge (Figure 3.1-1). It was deployed on a pole and affixed to the canal wall using a bracket (Figure 3.1-2). The DIDSON was deployed at an approximate depth of 3 feet (depth varied with canal surface water elevation; however the power canal is typically maintained around 173.5 ft msl) and aimed slightly upstream (~3° from perpendicular to the wall) and downward (~12° from parallel to the canal floor) (Figure 3.1-3). The DIDSON was intended to operate continuously throughout the study period.

3.1.1 Data Management and Analysis

Data were recorded continuously and written to a 3-Terabyte external hard drive on the control computer. Data were backed-up once every other week on a second external hard drive and archived. The DIDSON was networked and accessible via a *Go to My PC* account for real time remote access by the study team. The status of the monitoring system was checked regularly (~every other day) to ensure effective data collection.

The DIDSON was programmed to operate at three configurations and generated three 20-minute files per hour. During the first twenty minutes of each hour, data were collected at 1.8 MHz, high frequency (HF) (high resolution), with a corresponding monitoring range (window length) of 10 meters (m). The remaining two 20-minute files were recorded at 1.1 MHz, low frequency (LF) (low resolution), with a 20-m and 40-m window length, respectively. Increasing the window length beyond 15 m automatically lowered the resolution to 1.1 Mhz (LF), but increased the cross sectional area of the canal that was sampled.

Data were processed and analyzed using DIDSON v. 5.26.06 software by Sound Metrics Corporation. Data were filtered to remove empty frames (i.e., frames that did not contain targets of a defined size), using a process called Convolved Samples Over Threshold (CSOT), which substantially reduced file size and effort of manual review. The CSOT was developed using site-specific criteria for brightness (dB) and cluster size (cm^2) thresholds to identify eel and was based on information collected on-site. To develop the CSOT criteria, a subsample of data was visually reviewed to find reference eel targets that were used to define an appropriate CSOT for eel (Table 3.1.1-1). CSOT post-processing reduced each file by 20% to 100%. A subset of the resulting CSOT files from each of the frequency and window length files (HF/10m, LF/20m and LF/40m) were visually reviewed. Early in the review process, it was determined that only the HF/10m and LF/20m modes produced reliable images by which to identify eel. As such, only HF/10m files were reviewed in their entirety between the hours of 1700 and 0500, daily; and LF/20m files were reviewed in their entirety between the hours of 1700 and 0500 every other day. The final determination of eel targets were identified by observation of anguilliform swimming characteristics and target length (0.6 – 1.5 m). Figure 3.1.1-1 illustrates an example of a positively identified eel target. The length of each potential eel target was determined using the DIDSON software measuring tool and recorded.

Eel counts were extrapolated to account for the unsampled time periods (20-40 minutes of every hour) and for the unsampled cross-sectional area of the canal. The 10-m range setting sampled an area of approximately 12.28 m^2, while the 20-m range setting sampled about 49.1 m^2 of the entire 241.59 m^2 canal cross section. The 5-step extrapolation process accounted for both time and space. The first step divided the daily sampled 10-m and 20-m range counts by their respective sampled area to obtain a measure of density (no. of fish per m^2 of canal). Then, the density (fish/m^2) was multiplied by the total cross sectional area of the canal (241.59 m^2) (Figure 3.1-3). The next step divided the number of fish determined in the previous step by the number of minutes sampled per day to estimate the number of fish per minute, and extrapolated to obtain an estimate of the number of fish per day. The final step interpolates a count for days that were not sampled with a linear spline.

Table 3.1.1-1: Parameter settings for CSOT processing.

Frequency	Window Length (m)	Threshold (dB)	Min Cluster Area (cm^2)
High (HF)	10	2.5	300
Low (LF)	20	3.5	400
Low (LF)	40	3.5	400

Figure 3.1-1. The location of the DIDSON camera in the power canal in Turners Falls, MA

Figure 3.1-2. The DIDSON camera installation along the power canal wall at the Turners Falls Project, Turners Falls, MA

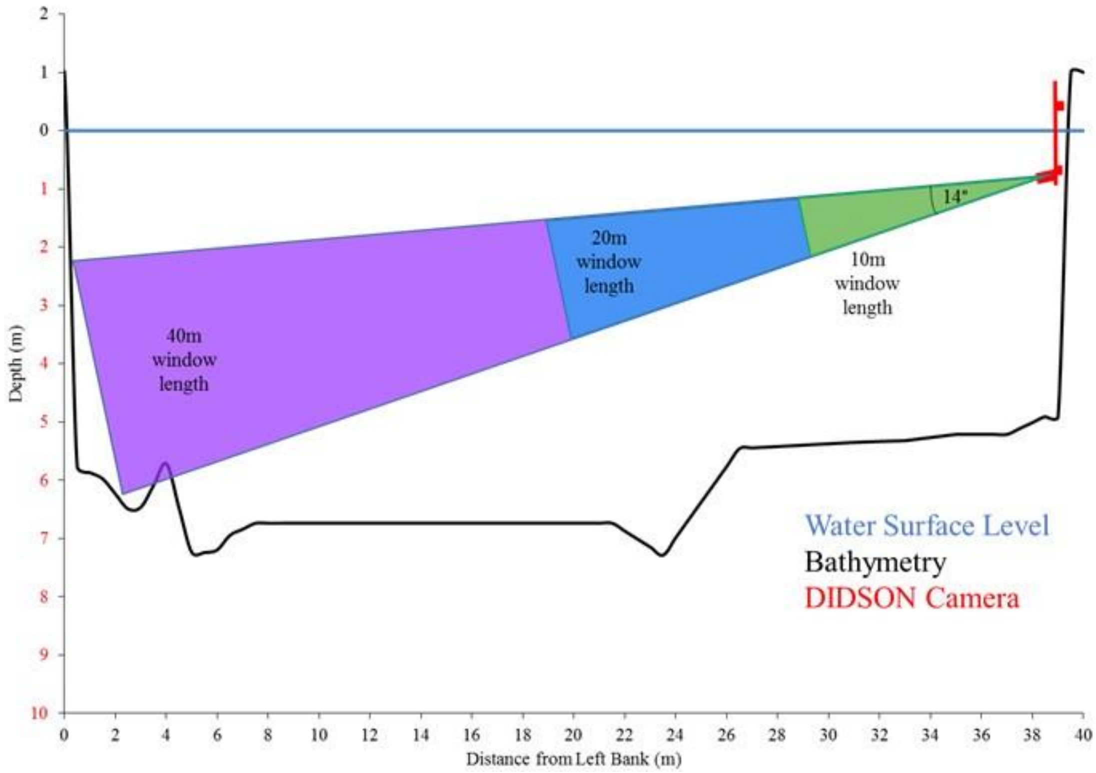


Figure 3.1-3. A section view of the power canal where the DIDSON was located, Turners Falls, MA

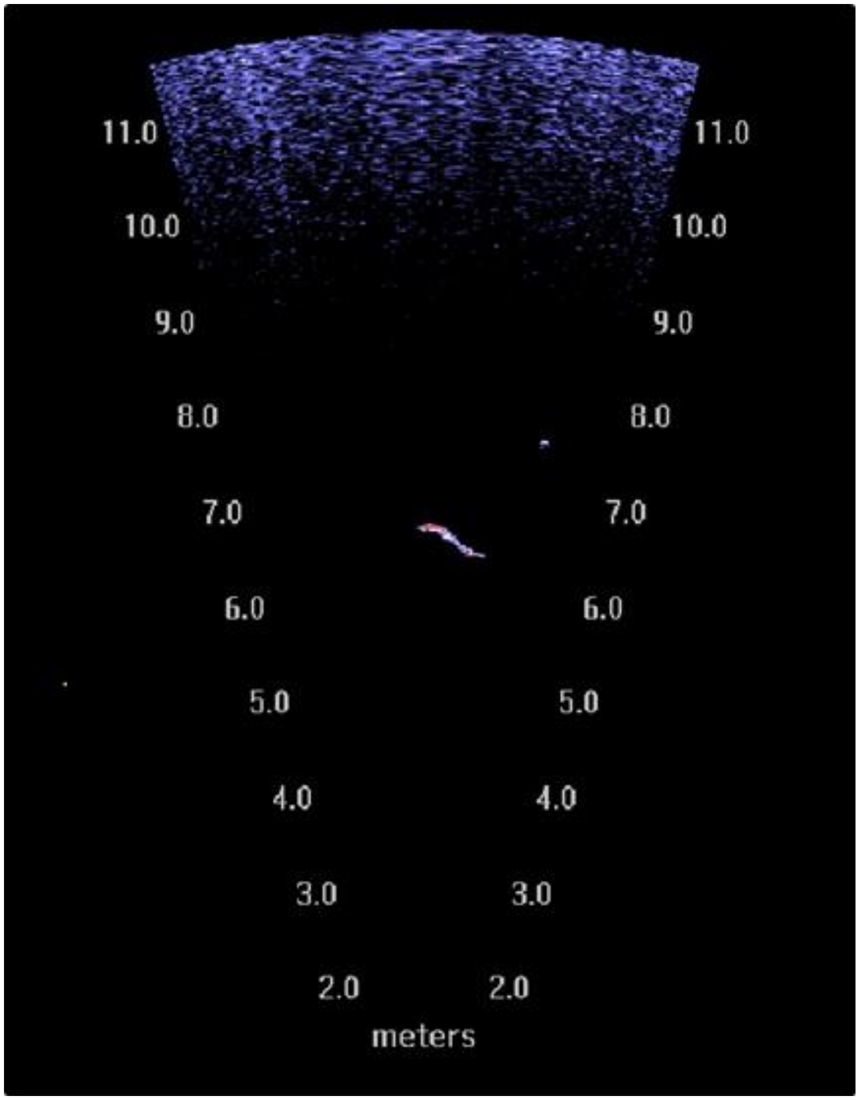


Figure 3.1.1-1: An example eel target (between 6 and 7 m range) with a length of 0.77 m as recorded by the DIDSON high frequency (HF) mode

3.2 Evaluation of Passage Routes and Rate of Movement (Radio Telemetry)

Beginning in October 2015, FirstLight employed radio telemetry techniques to evaluate route selection and rate of movement of emigrating eel as they passed through the NMPS and Turners Falls Projects. Concurrent study efforts employing radio telemetry methods were conducted upstream by TransCanada at the Bellows Falls, Wilder and Vernon Projects 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. However, the TransCanada Study Team inadvertently coded tags that overlapped some of those being used in the FirstLight juvenile shad evaluation. Additionally, two eel in the TransCanada study cohort were redundantly tagged with identical codes on the same frequency. These errors resulted in the elimination of 40 eel from this evaluation because their identities could not be verified. As such, 257 eel were used in this evaluation, including eels released by TransCanada (n=165, less the 40 redundant tags) and FirstLight (n=132).

3.2.1 Test Specimens

The route of passage and survival studies required a large number of eel (n=432). There was concern that collecting this quantity of eel within the Connecticut River drainage might not be achievable. As such, FirstLight proposed to import eel from a commercially available source. The study team investigated this option and determined that a reliable source of eels would be from a commercial fishery in Newfoundland, Canada. This option was vetted with the United States Fish and Wildlife Service (USFWS) and Massachusetts Division of Fish and Wildlife (MDFW) and it was concluded that importation from Canada was a viable option. At the request of the resource agencies, an importation plan was developed, which included a detailed procedure to collect, quarantine and test for pathogens prior to importation. For the FirstLight studies, the plan was submitted to MDFW on May 8, 2015 and amended on July 15 based on a request for further information by MDFW issued on June 6, 2015. The importation plan was ultimately accepted. An eel vendor, North Atlantic Aquaponics Ltd. and a pathogen testing facility, Atlantic Veterinary College - University of Prince Edward Island, provided the eels and tested for pathogens, respectively. Adult, silver phased eel were collected in the lower drainage of the source river and were actively emigrating. Following a quarantine inspection and pathogen testing (a three-week process), the eel were found to be free of pathogens (95% confidence) and were deemed suitable for use in the studies. A permit (No. 088.15LP, dated 10/20/15) was issued by MDFW, for the importation, transport and release into the Connecticut River in the State of Massachusetts in accordance with the importations plan, the RSP, and FERC's SPDL.

3.2.2 Eel Transport, Holding and Tagging

Test eel were flown from Canada into the State of Massachusetts via Logan International Airport. Eel were transported from the airport via truck to the Turners Falls Project where they were held in three 1,000 gallon tanks. The circular holding tanks were maintained with flow-through ambient river water supplied from the TFI. 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 2,000 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. The cascading flow helped to maintain an adequate dissolved oxygen level within the tanks. Circulated water was discharged back to the TFI via a stand pipe drain in each tank such that a depth of approximately 3ft was maintained. The holding tanks were covered with a 1/8-inch mesh netting to prevent escapement and shaded under canopies (Figure 3.2.2-1). Each tank was monitored for water quality and fish mortality on a nearly daily basis.

FirstLight tagged a total of 132 eel with TX-PSC-I-80-M Pisces Transmitters manufactured by Sigma Eight. The tags measured 10 mm x 28 mm and operated on two frequencies; 149.740 and 149.760. They were programed with a two-second burst and a mortality function, which defaulted to an eleven-second burst upon activation. The expected minimum tag life was approximately 90 days. Activation of mortality was based on relative motionlessness for a period of 6 hours.

Tagging consisted of internal implantation into the peritoneal cavity. Eel were sedated using a solution of water and MS 222. Once sedated, an area on the ventral side of the eel, anterior to the anal vent, was disinfected and a small incision was made. The tag was inserted into the cavity and the antenna was routed through the abdominal wall using a cannula such that the antenna was external. The incision was closed with sutures and an antibacterial ointment was applied to the incision site (Figure 3.2.2-2). Eel were held for a period of 4 to 8 hours after tagging and released into the TFI. The RSP envisioned that eel releases would occur at three locations: approximately 5 km upstream of the Northfield Mountain tailrace (upper TFI; n=72); approximately 3 km upstream of the Turners Falls Dam (lower TFI; n=30); and within the canal just downstream of the gatehouse (n=30). However, a misunderstanding resulted in release occurring at just two sites, in the upper (n=72) and lower (n=60) TFI, and no eel were released directly into the Turners Falls power canal (Figure 2-1).

Eel were tagged over six days and released in the evenings between October 26, and November 4, 2015 (Table 3.2.2-1). In addition to the FirstLight eel, the TransCanada study team released 165 eel at four locations: Bellows Falls impoundment (n=48), Bellows Falls canal (n=17), Wilder impoundment (n=50), and Vernon impoundment (n=50) (Table 3.2.2-2). Of these, 40 were removed from the evaluation as discussed in Section 3.2.

3.2.3 Fixed Telemetry Monitoring

Tagged eel were monitored at 13 locations within the study area in accordance with the RSP, FERC's SPDL and as amended during consultation with stakeholders during a meeting held on November 17, 2014. 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. 3.3.3 *Evaluate Downstream Passage of Juvenile American Shad*. Data were downloaded from each radio receiver approximately once a week from October 27 to December 3, 2015.

The radio telemetry monitoring system was tested and calibrated in the field prior to tagging and release of test fish (Appendix A). Figures 3.2.3-1 to 3.2.3-6 depict the approximate detection zones of the fixed monitoring locations listed in Table 3.2.3-1. Figure 3.2.3-7 depicts the telemetry network as it was used for modeling of emigrating American Eels.

3.2.4 Mobile Tracking

Mobile tracking was conducted accordance with the RSP and as amended in FERC's SPDL. Mobile tracking was conducted by boat using a Lotek SRX 800 connected to a 3-element yagi antenna and concentrated in the reach between the upper release site (i.e., 5 km upstream of the Northfield Mountain Project intake) and 5 km downstream of Cabot Station. Tracking was performed twice weekly to confirm route selection and the fates of passed fish. Eleven tracking events were conducted between October 27 and November 19, 2015 (Table 3.2.4-1).

3.2.5 Data Management

Data management consisted of removing false positive detections from the recaptures database. 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). True positives and true negatives are valid data points which indicate the presence or absence of a tagged fish. A false positive is a detection of a fish's presence when it is not there, while a false negative is a non-detection of a fish that is there. 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 fish that weren't there, or they can increase measures of delay when a fish has already passed. False positives are different from false negatives, which bias statistics in other ways. Inclusion of false negatives may negatively bias statistics because there is no way to know if a fish's absence from a receiver was because it truly wasn't there or if it was just not recaptured. The CJS model accounts for a receiver's recapture rate and removes this bias from rates of survival (successful passage) while the competing risks assessment only includes data from known detection histories. For the purposes of this study, we rely upon data and quantitative insight to reduce the amount of subjectivity in the analysis. Therefore, a probabilistic method for false positive data reduction was sought.

An algorithm (Naïve Bayes Classifier) used information from known good detections and known false positives to identify and remove false positives from the dataset. The Naïve Bayes classifier was nothing more than a database application designed to keep track of which feature (predictor) gives evidence to which class (true vs false positive) (Richert & Pedro-Coehlo, 2013). The known true and false positive detections and their associated predictor variables make up the training dataset. By sacrificing study tags and placing them at strategic locations throughout the study area for the duration of the study, beacon tags give the algorithm information on what a known true positive detection looks like. On the other hand, known false positive detections are generated by the telemetry receivers themselves, and consist of detections coded towards tags that were not present in the list of tags released for the study.

Following the algorithmic data reduction, quality assurance and control (QAQC) procedures were conducted for each receiver, and consisted of randomly selecting 50 American Eel and checking for systematic errors. Classification errors were identified, and reasoning 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.

Following algorithm QAQC, data reduction procedures were carried out with MS Access Query (SQL) methods. If the time stamp of the recapture occurred before the fish was released, then a recapture was deemed false positive. Further, if the calculated hit ratio for any detection was less than 10%, meaning it was only heard once out a possible series of 11 detections, the record was deemed as false positive. Following SQL data reduction, site specific information was exported and aggregated into a system wide recaptures database. The recapture history of each specimen could then be examined through space and time with a three-dimensional (3D) visual inspection tool (Figure 3.2.5-1). After assessing each fish with the visual inspection tool, stationary and mobile tracking data were analyzed.

3.2.6 Analysis of Telemetry Data

The three main objectives assessed with telemetry techniques are:

1. Characterize the general migratory timing and presence of adult, silver phase American Eel migrating past the Turners Falls Project and NMPS Project relative to environmental factors and operations.
2. Quantify movement rates and proportion of eel passing downstream via various passage routes at the Turners Falls and NMPS Projects. For the NMPS project, the study will evaluate the proportion of eel entrained into the intake. For the Turners Falls Project, the study will evaluate the proportion of eel passing via available route of passage.

3. Evaluate survival of adult silver eel passed at the available routes of passage at the Turners Falls complex.

Eels were tracked through a telemetry network that spanned the entire project, with receivers placed at strategic locations (Figure 3.2.3-7). The objectives were assessed via detections at each of these receivers. The analysis of telemetry data was twofold. First, simple proportions assess arrival at key project infrastructure. Then, we employed statistical methods capable of reducing bias from poor rates of detection and methods designed to assess time-to-project passage and overall rates of movement through project infrastructure. These methods included the Cormack-Jolly-Seber classic open population mark recapture model and an assessment of time-to-passage under a competing risks framework. The following sections will discuss mark recapture and time to event analysis, and will explain how we broke up the project into different segments for modeling.

3.2.6.1 Analysis of Overall Project Arrival and Survival with Mark Recapture (MARK)

Mark recapture survival analysis is typically used to assess passage through fish ladders or entire projects (Perry et al., 2013). Use of the term "survival" is standard for mark recapture analysis, which is predominantly used to assess the actual survival of marked animals over time. For our purposes, survival means the successful passage or arrival of marked American eel within an area of the project or its infrastructure. Use of the term survival should not convey mortality. Given that the time and distance traveled is very short for those stretches studied with Mark Recapture techniques (on the order of hours to less than 1,000 feet), mortality was not tested using a mark recapture framework.

Following Lebreton et al (1992) and Cooch & White (2006), the following model creation and selection procedure was followed for analysis of survival through projects:

1. Build a global model compatible with the biology of the species studied and with the design of the study,
2. Assess model fit using appropriate goodness of fit (GOF) measures,
3. Select a more parsimonious model using Akaikes Information Criteria (AIC) to limit number of formal tests,
4. Test for the most important biological questions by comparing this model with neighboring ones using likelihood ratio tests, and
5. Obtain maximum likelihood estimates of model parameters with estimates of precision.

The full model estimated 4 survival parameters (ϕ) and 4 recapture probabilities (p), where survival was estimated between stations and recapture estimated at each station (Figure 3.2.6.1-1). Therefore, ϕ_2 estimates the percent of those fish detected within the Turners Falls Impoundment to arrive anywhere within the Turners Falls Project. The 'Project' site at Turners Falls includes the entire canal and bypass reach. Recapture anywhere within the project site means recapture at the entire site. Please note that the model cannot differentiate between survival and recapture at the last station.

3.2.6.2 Competing Risks: Time-to-Passage

A multi-state model is used to understand situations where a tagged eel transitions from one state to the next (Crowson, Atkinson, & Therneau, 2016). For our purposes, 'transition' means that a fish was detected in one location and eventually moves to another location. In traditional time-to-event modeling, the standard survival curve (Kaplan-Meier) can be thought of as a simple multi-state model with two states (alive and dead) and one transition between those two states (Crowson, Atkinson, & Therneau, 2016). For our purposes, these two states are staging and passing. The curve depicts the probability that a tagged fish remains within the staging location after a certain amount of time. However, for many of our locations, there were more than two potential end states. For example, those fish emigrating through the canal can pass via the bypass sluiceway, Cabot Station powerhouse, or through the Station No. 1 powerhouse.

Competing risks generalize the standard survival analysis of a single endpoint (as described above) into an investigation of multiple first event types (Allignol, Schumacher, & Beyersmann, 2011). Competing risks are the simplest multi-state model, where events are envisioned as transitions between states (Allignol, Schumacher, & Beyersmann, 2011), or movement from the staging site to a passing site. For competing risks, there is a common initial state for all models that all tagged fish move from (Allignol, Schumacher, & Beyersmann, 2011). For example, with the assessment of time to passage over Turners Falls Dam (TFD), our common initial state is the being present in the impoundment. When assessing entrainment at NMPS, our common initial state is being present within the intake area. When fish pass into the bypass reach or the canal, they enter an absorbing state, which is one in which the fish cannot return from. The baseline hazard is measured with the Nelson-Aalen cause specific cumulative incidence function. One can think of the hazard as the probability of the fish moving within the next time unit conditional on still being in the initial state (Allignol, Schumacher, & Beyersmann, 2011). For example, with regards to route of passage choice at the TFD, the hazard is the instantaneous probability that a fish will move from the impoundment to the canal (or bypass reach) in the next unit of time. The Nelson-Aalen $\hat{A}(t)$ is computed with (Allignol, Schumacher, & Beyersmann, 2011):

$$\hat{A}(t) = \sum_{k=1}^{K} \frac{number\ of\ individuals\ observed\ to\ transition\ into\ state\ i\ at\ t_k}{number\ of\ individuals\ at\ risk\ just\ prior\ to\ t_k}$$

Where t is a time of interest, K is the number of event times for fish entering state i, and k is an event time, or the duration an eel took to transition from the impoundment into a passing state. This formula is the number of individuals to experience the event of interest (i.e. passage into the canal from the impoundment) at event time t_k divided by the number of individuals still in the impoundment just prior to t_k. The probabilities across all discrete event times K are then summed. Therefore, the end probability is cumulative, and represents the probability that an eel will move from the impoundment into an absorbing state i. If we lose track of an eel, it is not censored at its last event time, rather it enters an unknown state. By attributing each tagged eel to a state at all times, we are ensured our final probabilities match empirical expectations. In other words, if 50 out of 100 eels transitioned into the canal, and 25 of 100 transitioned into the bypass reach, and we lost track of 25, the Nelson-Aalen cumulative incidence estimators will result in 50% transitioning into the canal, 25% transitioning into the bypass reach and 25% transitioning into an unknown state. Eels are only censored if they are still being tracked within the staging site until the end of study. If we happen to lose track of a fish before the end of the study, they enter an unknown state. After computing the Nelson-Aalen estimators for each route of passage (competing event), and plotting the survival function (Kaplan-Meier) for those fish still remaining in the impoundment, the probability of being in a state will sum to 1.0 for all states.

Following the computation of cause-specific Nelson-Aalen estimators, an assessment of delay was performed using Cox Proportional Hazards regression analysis for each separate event. The Cox models for each competing risk assessment were fit in a procedure analogous to multiple regression modeling, where individual time-dependent covariates were added in an iterative fashion constructing ever more complex models. Model quality was assessed with the omnibus likelihood ratio test statistic, the null hypothesis of which states that the model is not better than chance. If this statistic is rejected at the $\alpha = 0.05$ level, then the model is considered to be better than chance, and we observe the estimated hazard ratio associated with the covariate of interest and its significance. If the covariate is significant at the $\alpha = 0.05$ level, then we conclude that the estimated hazard ratio is significant, and interpret the results. Our statistic of interest is the hazard ratio, which is the ratio of the hazard rates corresponding to the conditions described by two levels of an explanatory variable (for example day vs night, or rain (in) vs no rain). Hazards are the instantaneous probability that a marked eel will experience the event of interest (i.e. passage into the canal) in the next period of time. In other words, it is the probability of a fish passing a structure right now. If our event of interest is passage into the canal from the TFD and our dependent covariate is rain in inches, the hazard ratio is the immediate probability of transitioning into the canal after one inch of rain over the immediate probability of transitioning into the canal with no rain. If the hazard ratio is > 1.0, this means the probability of transitioning into the canal during a rain event is higher than transitioning during dry conditions. The fish is more likely to transition during these times. When the hazard ratio is greater than 1.0, a unit increase in the covariate (i.e. rain) would increase the instantaneous probability of the event occurring. More eels would be expected to experience the event because the instantaneous probability of it occurring is greater, thus the overall delay is reduced. One would conclude that the population appears to experience less delay when the hazard ratio is > 1.0. If the hazard ratio is < 1.0 than the instantaneous risk decreases, and the proportion to have experienced the event at time (t) decreases, thus delay is incurred. The "best" model minimized AIC scores and/or had a significant omnibus statistic ($p < 0.05$) and informative hazard estimate ($HR \neq 1.0$).

Table 3.2.2-1. Location and time of tagged eel releases at the Turners Falls and Northfield Mountain Projects, Turners Falls and Northfield, MA.

Release Location	Release Date	Release Time	Count	Cumulative Total
Lower Impoundment	10/26/2015	23:37	8	8
Upper Impoundment	10/27/2015	0:00	8	16
Lower Impoundment	10/27/2015	23:07	12	28
Upper Impoundment	10/27/2015	23:20	16	44
Lower Impoundment	10/28/2015	22:49	20	64
Upper Impoundment	10/28/2015	23:16	12	76
Lower Impoundment	11/2/2015	22:40	20	96
Upper Impoundment	11/2/2015	23:05	12	108
Upper Impoundment	11/3/2015	23:05	12	120
Upper Impoundment	11/4/2015	23:02	12	132

Table 3.2.2-2. Location and time of eel releases at the TransCanada Projects, Bellows Falls, Wilder and Vernon, VT.

Release Location	Release Date	Release Time	Count	Cumulative Total
Vernon Impoundment	10/27/2015	17:45	10	10
Bellows Falls Impoundment	10/27/2015	18:20	10	20
Wilder Impoundment	10/27/2015	20:05	10	30
Vernon Impoundment	10/29/2015	13:05	10	40
Bellows Falls Canal	10/29/2015	17:32	7	47
Bellows Falls Impoundment	10/29/2015	17:52	10	57
Wilder Impoundment	10/29/2015	18:43	10	67
Vernon Impoundment	10/31/2015	13:40	10	77
Bellows Falls Canal	10/31/2015	18:05	10	87
Bellows Falls Impoundment	10/31/2015	18:22	10	97
Wilder Impoundment	10/31/2015	19:21	10	107
Vernon Impoundment	11/3/2015	15:55	10	117
Bellows Falls Impoundment	11/3/2015	16:45	9	126
Wilder Impoundment	11/3/2015	17:32	10	136
Vernon Impoundment	11/5/2015	15:35	10	146
Bellows Falls Impoundment	11/5/2015	16:20	9	155
Wilder Impoundment	11/5/2015	17:05	10	165

Table 3.2.3-1. Location and types of telemetry equipment used to evaluate silver eel emigration at the Turners Falls and Northfield Mountain Projects, Turners Falls and Northfield, MA.

Location	RM	Station ID	Receiver Station Equipment
Montague Wastewater	119.5	T18	A Lotek SRX receiver with double yagi antennae monitored the full width of the river
Cabot Station Tailrace	120	T17	A Lotek SRX with yagi antenna monitored the full river width. An Orion receiver and double yagi antennae monitored the tailrace immediately downstream of the station
Cabot Station Forebay	120	T171, T172, T173, & T174	Two radio receivers monitored the forebay area: 1) An Orion with double yagi and 3 dropper antennae 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	121	T13 & T14	An Orion with yagi and dropper antenna (one per penstock) monitored the full width of the forebay area
Station No. 1 Tailrace	121	T15	A Lotek SRX with yagi antenna monitored the tailrace area and the detection zone extended coverage across the full width of the bypass reach
Below Turners Falls Dam	122	T11 & T12	Two Lotek SRX receivers with double yagi antennae monitored the area below the dam, one on either side of the river bank
Upper Canal	122	T10	An Orion with a yagi antenna monitored the full width of the canal at a location downstream of the Gatehouse in the upper canal to monitor fish entering the canal from upstream
Upstream of Gatehouse	122	T9	An Orion receiver with yagi and dropper antennas was used to monitor the area immediately upstream of Gatehouse
Turners Falls Impoundment	122	T7 & T8	Two Lotek SRX with yagis and droppers monitored the full width of the river
NMPS Gill Bank	126.5	T5 & T6	Two Lotek SRX with yagis and droppers monitored the full width of the river
NMPS Intake	127	T3	An Orion with double yagi antennae and droppers monitored the intake area
NMPS Upper Reservoir	127	T4	An Orion with yagi and dropper antennas was used to monitor the upper reservoir
Shearer Farms	127.5	T1 & T2	Two Lotek SRX with yagis and droppers monitored the full width of the river

Table 3.2.4-1. Dates of mobile tracking conducted at the Turners Fall and NMPS Projects.

Tracking Event	Date
1	10/27/2015
2	10/28/2015
3	10/29/2015
4	11/3/2015
5	11/4/2015
6	11/5/2015
7	11/9/2015
8	11/10/2015
9	11/11/2015
10	11/18/2015
11	11/19/2015

Table 3.2.5-1. Example detection histories with their derived consecutive record length and hit ratio predictor feature levels.

Detections in series originating at the present detection (0)							Consecutive Record Length	Hit Ratio
-3	-2	-1	0	1	2	3		
0	1	0	1	0	1	0	1	3/7
0	0	1	1	1	0	0	3	3/7

Figure 3.2.2-1. Circular tanks used to hold adult eel during the study in Turners Falls and Northfield, MA

Figure 3.2.2-2. Example tag implantation conducted during the eel study at the Turners Falls and NMPS Projects. Note that the antenna is external to the eel.

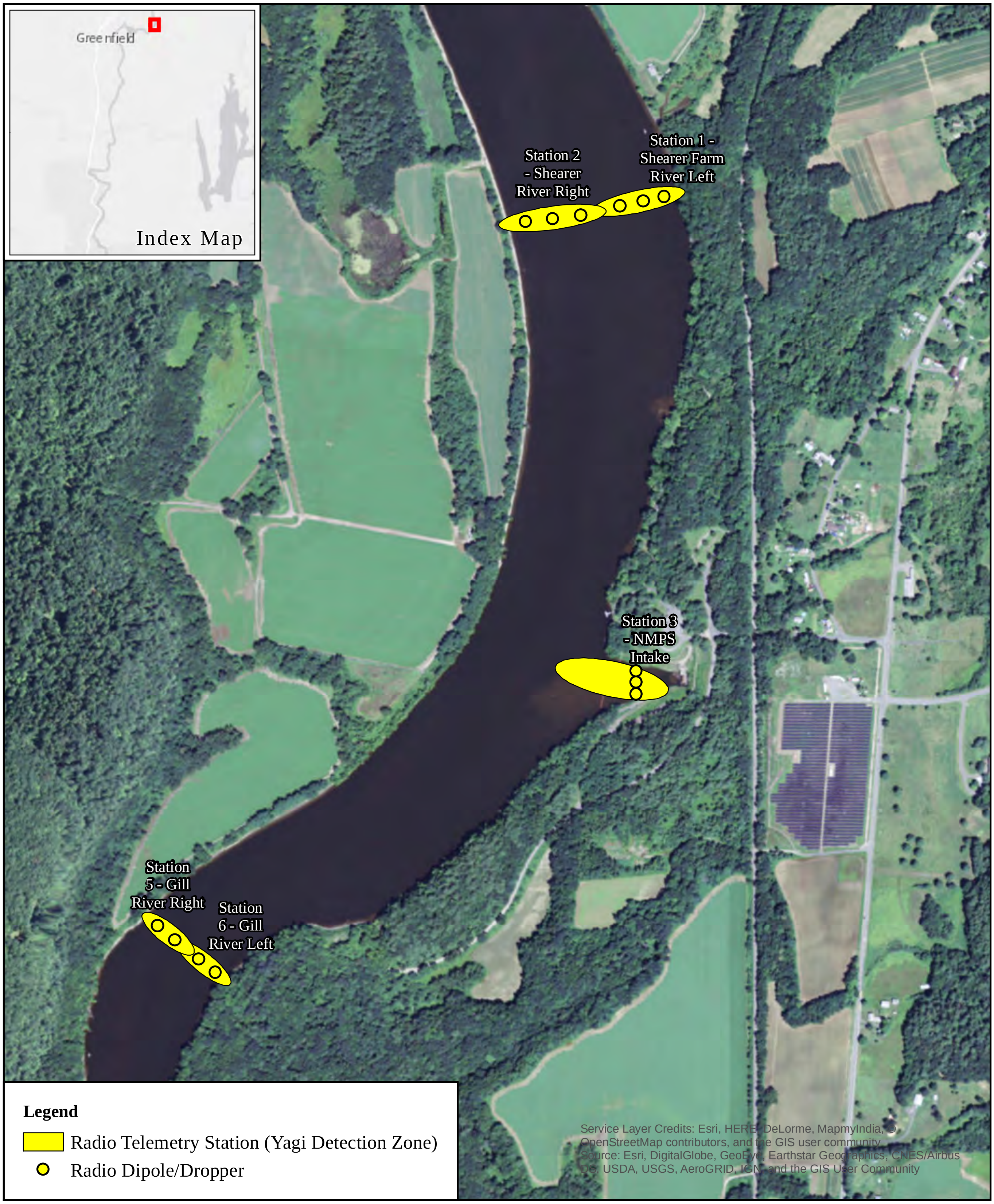
Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Relicensing Study 3.3.5

Figure 3.2.3-1: Radio Telemetry Station at Upper Reservoir

N

0 435 870 1,740
Feet

Path: W:\gis\studies\3_3_5\maps\Figure3.2.3-1.mxd



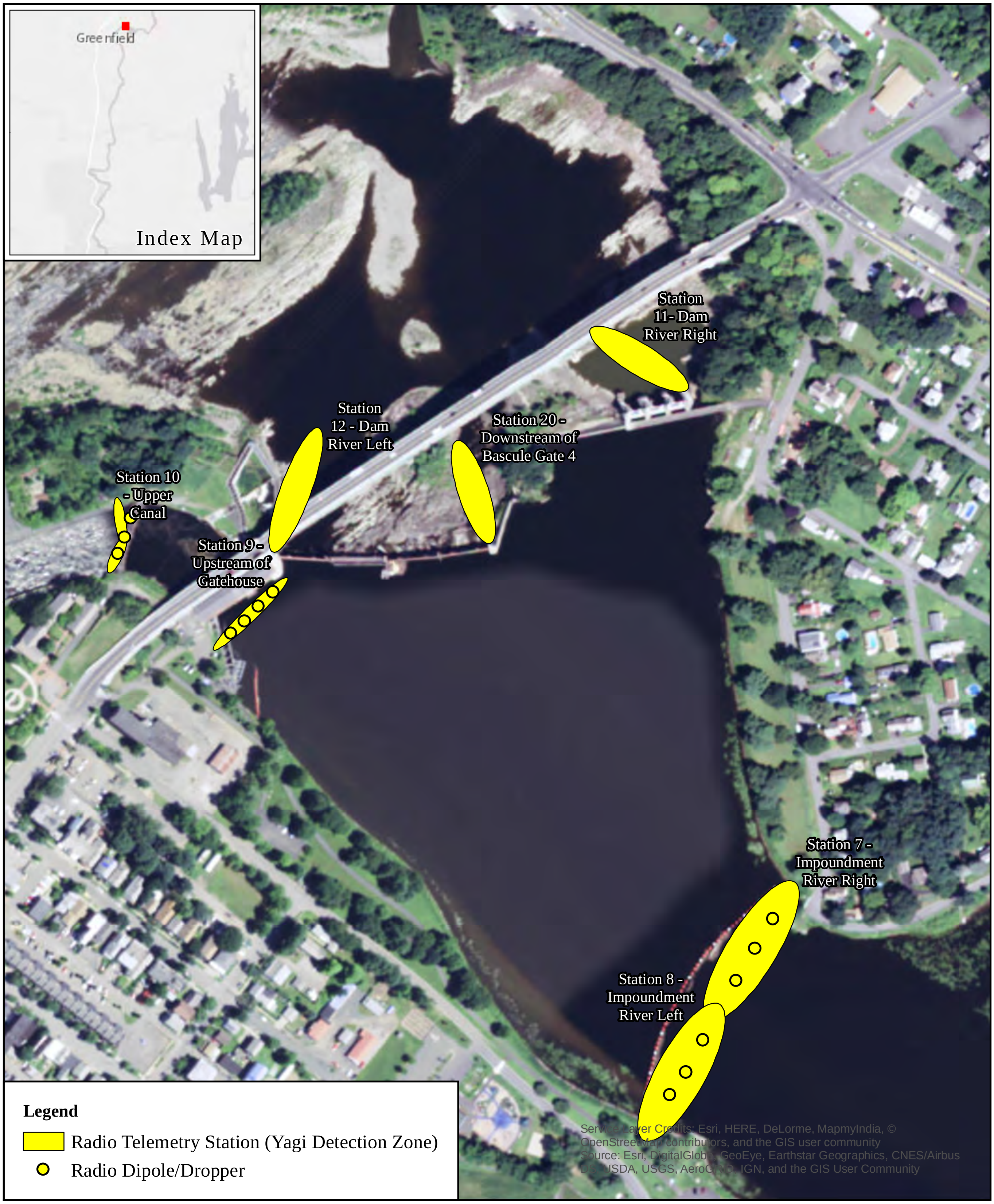
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

Relicensing Study 3.3.5

Figure 3.2.3-2: Radio Telemetry Stations Near NMPS Intake

FirstLight Power Resources

Path: W:\gis\studies\3_3_5\maps\Figure3.2.3-2.mxd



FirstLight Power Resources

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

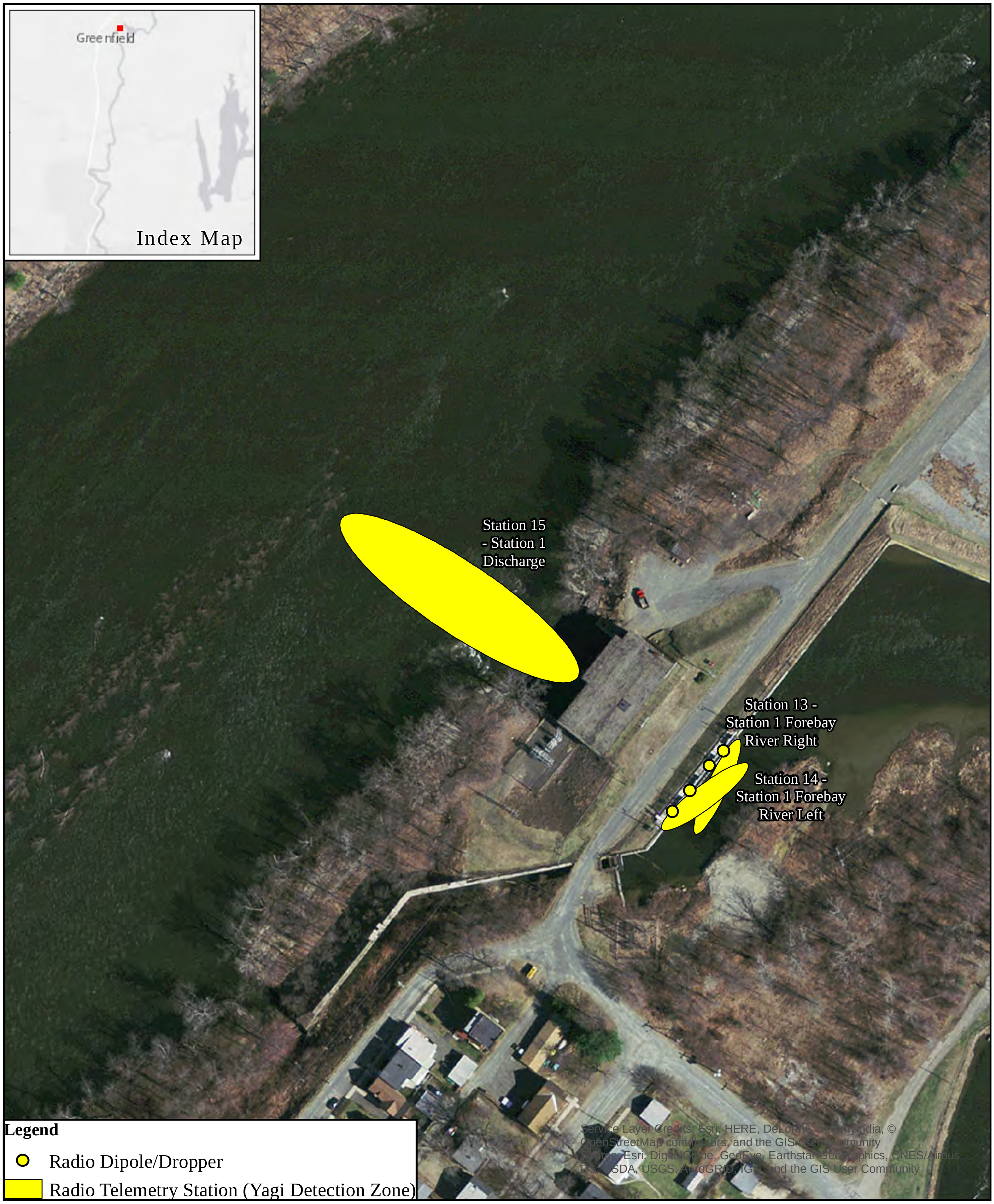
Relicensing Study 3.3.5

N

0 170 340 680 Feet

Figure 3.2.3-3: Radio Telemetry Stations Near Turners Falls Dam

Path: W:\gis\studies\3_3_5\maps\Figure3.2.3-3.mxd



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

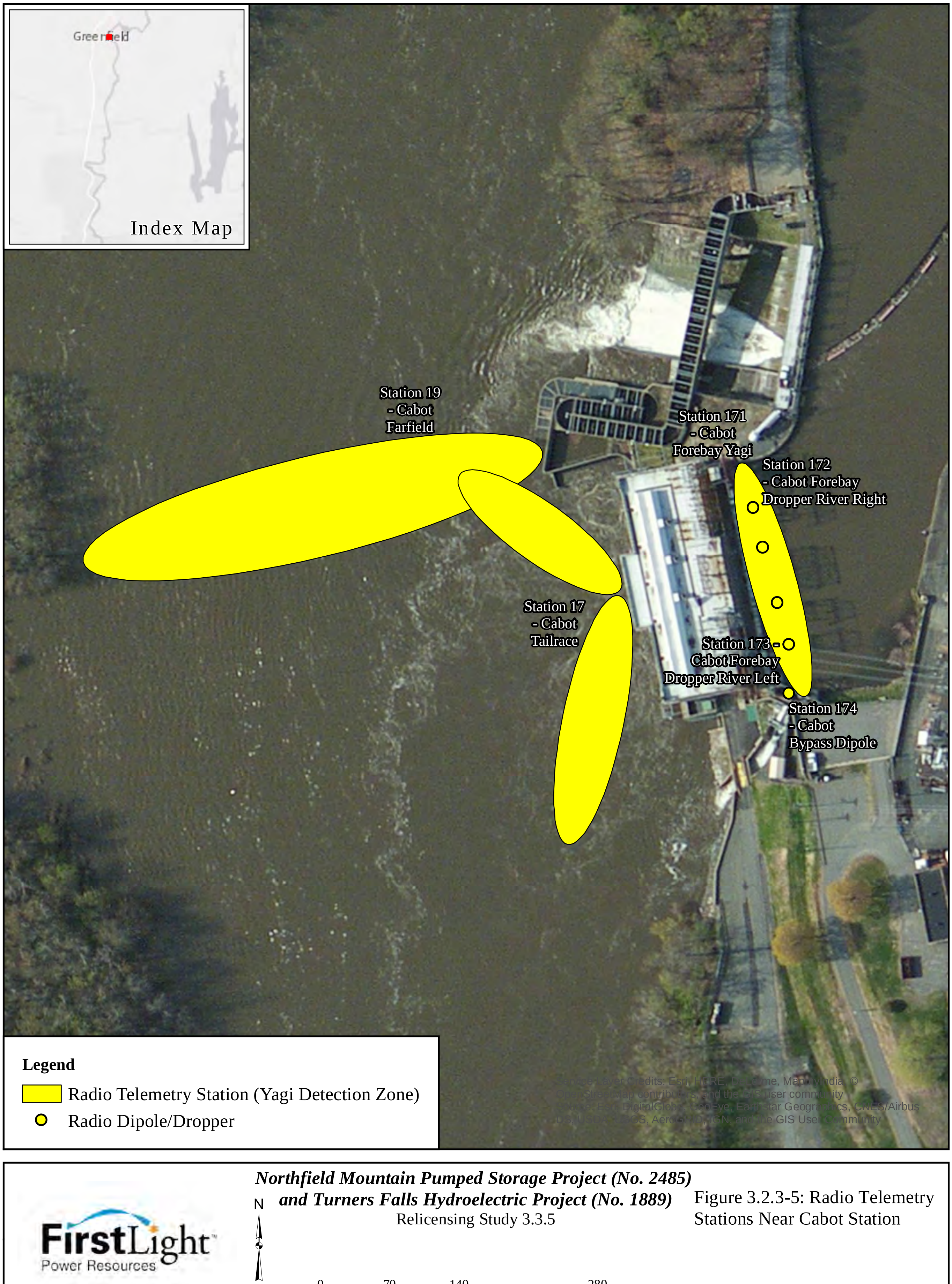
Relicensing Study 3.3.5

Figure 3.2.3-4: Radio Telemetry Stations Near Station 1

N

0 80 160 320 Feet

Path: W:\gis\studies\3_3_5\maps\Figure3.2.3-4.mxd

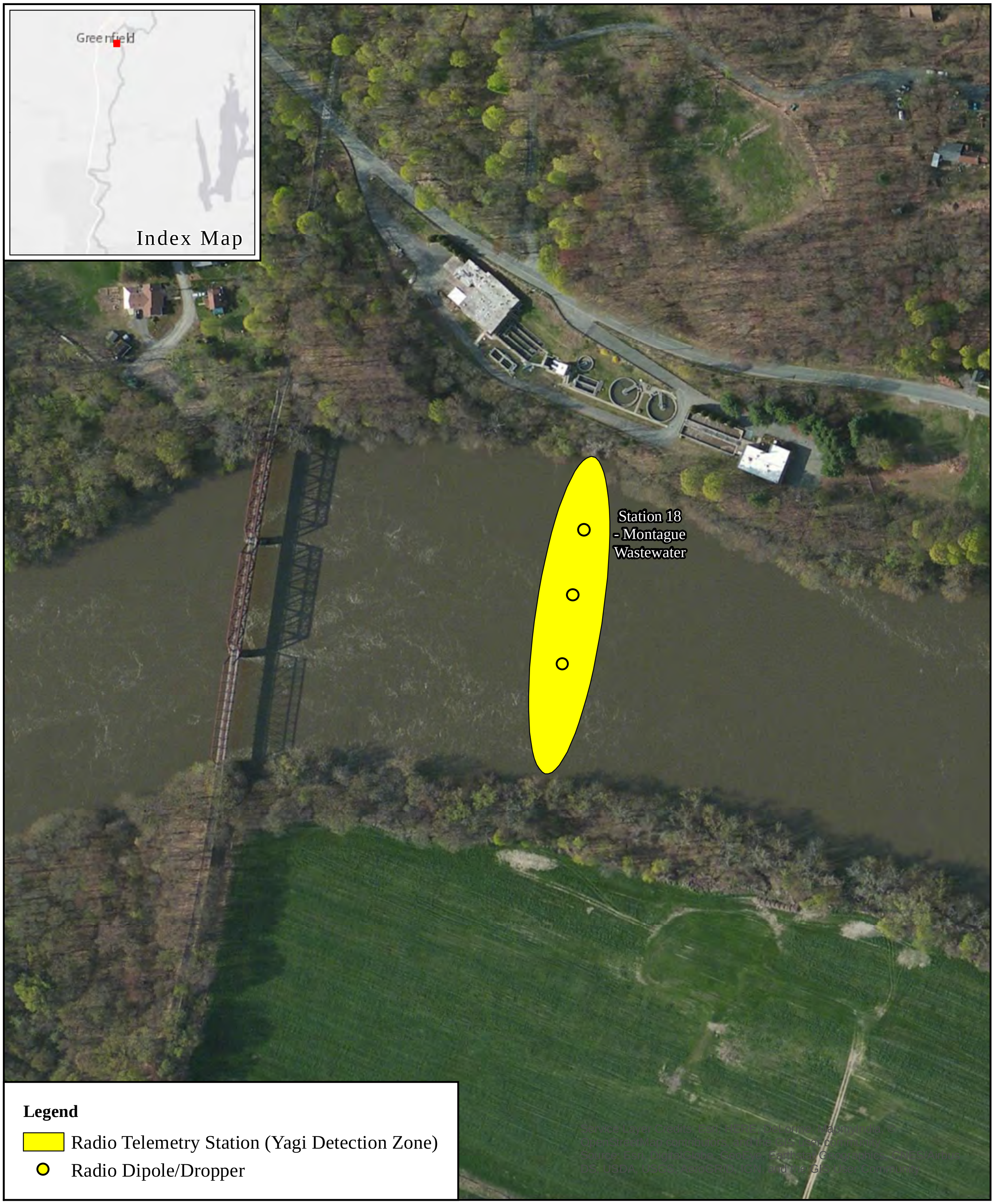


Northfield Mountain Pumped Storage Project (No. 2485)
and Turners Falls Hydroelectric Project (No. 1889)
Relicensing Study 3.3.5

Figure 3.2.3-5: Radio Telemetry Stations Near Cabot Station

FirstLight Power Resources

Path: W:\gis\studies\3_3_5\maps\Figure3.2.3-5.mxd



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

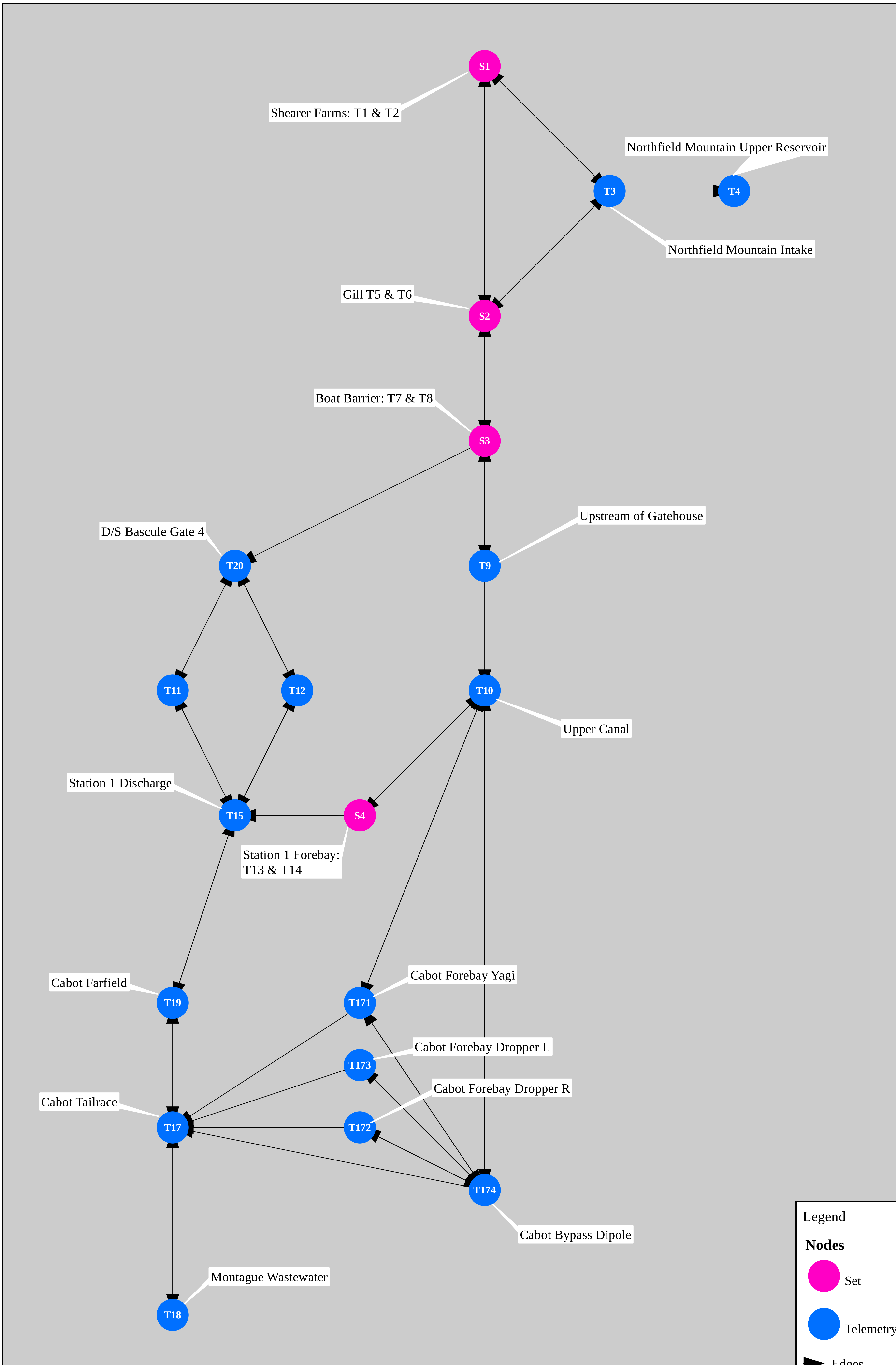
Relicensing Study 3.3.5

N

0 130 260 520 Feet

Figure 3.2.3-6: Radio Telemetry Stations at Montague Wastewater

Path: W:\gis\studies\3_3_5\maps\Figure3.2.3-6.mxd



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

Relicensing Study 3.3.5

Figure 3.2.3-7: Radio Telemetry Network for Fall 2015 Adult Eel Downstream Passage Assessment

FirstLight Power Resources

N

Path: W:\gis\studies\3_3_5\maps\Figure3.2.3-7.mxd

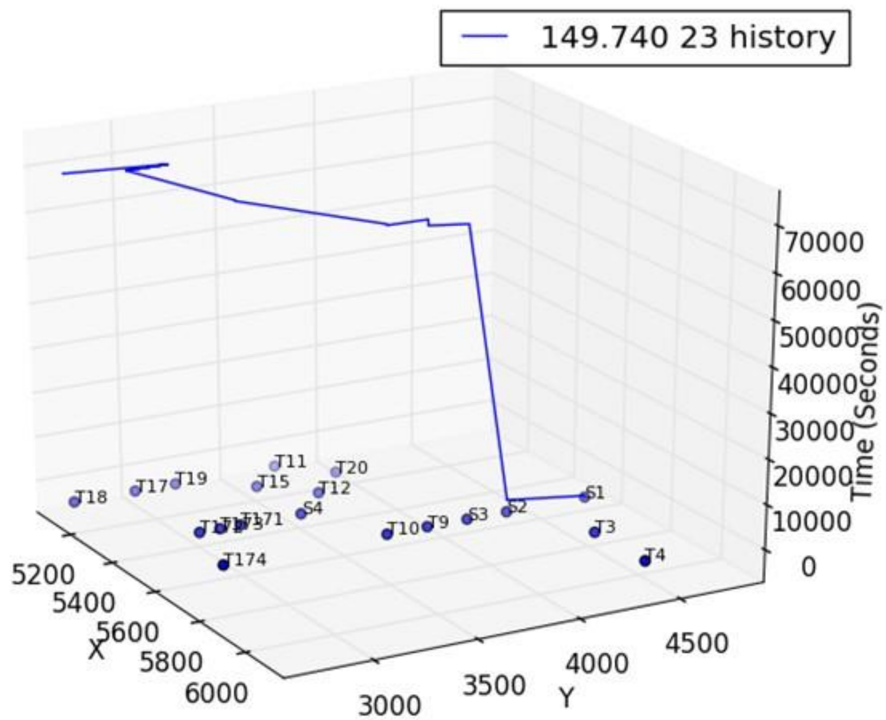


Figure 3.2.5-1. 3D visual inspection tool of a fish's path through the telemetry network over time.

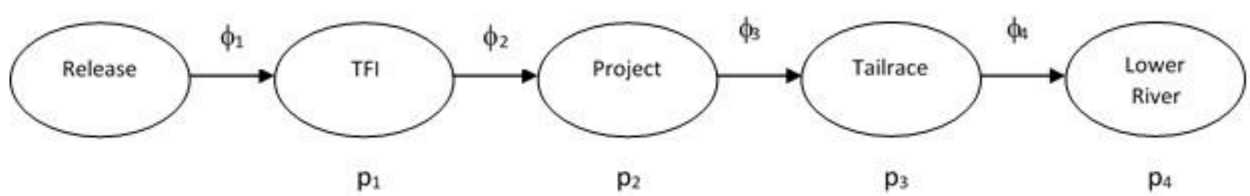


Figure 3.2.6.1-1. Graphical schematic of the MARK model to assess through project survival showing estimable parameters. Survival probabilities (ϕ_i) are assessed between stations while recapture rates (p_i) are measured at a station

3.3 Evaluation of Passage Survival (HI-Z Turb'N Tag)

On November 4-9, 2015, Normandeau Associates, Inc. conducted a study assessing whether operations at Cabot Station Unit 2, Station 1 (Units 1 and 2/3) and various flow scenarios over Bascule Gates 1 and 4 would affect the safe passage of emigrating adult silver-phased American Eels. The methods used in the evaluation are summarized in this section. A more detailed description of the methods can be found in the report entitled "Direct Injury and Relative Survival of Adult American Eels at The Turner's Falls Hydroelectric Project" in Appendix B.

Turbine and Bascule Gate passage survival was assessed using the HI-Z mark/recapture methodology. A total of 50 treatment eels were released into Cabot Station Unit 2, 30 into Unit 1 at Station 1, and 30 into Station 1 Units 2/3. Thirty (30) eels were released at Bascule Gates 1 and 4 at 2,500 and 5,000 cfs, and 35 at Bascule Gates 1 and 4 at 1,500 cfs. An additional 25 combined eels were released downstream of release sites and recollected as controls.

Each treated eel was affixed with 3-6 HI-Z balloon tags at two to three locations along the dorsal side of the eel. Radio tags were attached in combination with HI-Z tags to aid in tracking released eels. Treated eels were released through an induction apparatus that allowed the eels to pass freely to the desired release points at Cabot Station Unit 2, Station 1, and over Bascule Gates 1 and 4. After release, boat crews tracked the eels' movement, using radio signals, and then retrieved the eels when buoyed to the surface downstream of the Project.

Recaptured eels were placed into an on-board holding facility, and immediately examined for maladies including visible injuries and loss of equilibrium. These eel were then transported to shore and held in 900 gallon holding tanks for 48 hours to monitor for delayed effects due to tagging and turbine/dam passage. Mortalities of recaptured eels occurring after 1 hour (h) were assigned 48 h post-passage effects, although eels were observed at approximately 12-h intervals. Injuries were categorized by type, extent and area of body. Eel without visible injuries that were not actively swimming or swimming erratically were classified as having "loss of equilibrium". Eels that were alive at 48 h and free of major injuries were released into the river.

4 RESULTS

4.1 Project Operation, Discharge and Environmental Conditions

Project operation and environmental data were collected throughout the study period extending from August 1, to December 3, 2015 and from August 1, to November 15, 2016.

4.1.1 NMPS Operations

The NMPS Project pumps water during periods of low electrical demand, typically at night from midnight to 6:00 am, and discharges to generate electricity during periods of peak demand typically during daytime hours. This operational approach results in daily alternating period of pumping and discharge as shown in the generation graphs (Figure 4.1.1-1 and Figure 4.1.1-2). Operation (generation and/or pumping) occurred daily, with peak operation of 1,127 MW and 1,167 MW on August 23, and August 14, in 2015 and 2016, respectively. Operations were generally lower in the months of September, October and November, rarely exceeding 800 MW.

4.1.2 Cabot Station Operations

Cabot Station operated almost daily throughout the 2015 and 2016 study periods except during the annual canal drawdowns, which occurred between October 5 and October 11, 2015, and between September 19 and September 25, 2016, as illustrated in the generation graphs (Figure 4.1.2-1 and Figure 4.1.2-2). During the study period, generation ranged from a minimum of 0 MW to a maximum of 63 MW, but generation ranging between 9 MW and 40 MW in 2015 and between 0 MW and 40 MW in 2016 were more common. In terms of precipitation, 2016 was a dryer year and resulted in lower magnitude and less consistent generation at Cabot Station when compared to 2015. This trend extended through much of the study period with the exception of the month of November, which were similar in both 2015 and 2016.

4.1.3 Station No. 1 Operations

Station No. 1 operated during the study period in both 2015 and 2016 with generation generally occurring for extended periods interspersed between periods of non-generation as illustrated in the generation graphs (Figures 4.1.3-1). Peak generation of nearly 6 MW was more common in 2015 when compared to 2016. An extended period (~ 1 month) of consistent generation (~3 MW) occurred between August 26 and September 25, 2015 (Figure 4.1.3-1). Generation periods in October and November 2015 were generally shorter in duration and of higher magnitude. In 2016, generation was more consistent when compared to 2015, with prolonged periods of generation between August and mid-October ranging between 3.5 and 4.2 MW, except during a period of maximum generation on August 15 and 16 and during the canal drawdown (9/19/16 – 9/25/16) (Figure 4.1.3-1).

4.1.4 Turners Falls Dam Discharge

The TFD has seven structures for conveying water downstream including four bascule gates (Bascule Gates 1-4) located on the west side of the dam and three Taintor gates (Taintor Gates 1-3) located on the east side of the dam. Discharge at the dam occurred during the study period during both years of investigation, 2015 and 2016 (Figures 4.1.4-1 – 4.1.4-4).

In 2015, discharge via Bascule Gate 2 and 3 was very infrequent throughout the study period (Figures 4.1.4-2 and 4.1.4-3). In contrast, discharge from Bascule Gates 1 and 4 was more common, particularly in October and November (Figures 4.1.4-1 and 4.1.4-4). Much of the discharge experienced in October and November was associated with discharges required for concurrent survival studies being conducted with American Eel (November 4-9, 2015) and juvenile American Shad (October 19-24, 2015) at the dam, as well as conveying flow downstream during the canal outage (October 5 - 11, 2015). Discharge was greatest through Bascule

Gate 1, in 2015, with a maximum discharge of 12,865 cfs on October 10, 2015 (Figure 4.1.4-1). Discharge at Bascule Gate 2 occurred on two occasions: October 1 and November 21, 2015 with maximum discharges of 1,750 cfs and 4,850 respectively (Figure 4.1.4-2). Bascule Gate 3 discharged only once during the study period on November 21, 2015 with a maximum discharge of 6,340 (Figure 4.1.4-3). Discharge at Bascule Gate 4 occurred infrequently with spill events in October and November and a maximum discharge of 8,550 occurring on October 6, 2015 (Figure 4.1.4-4). The Taintor gates did not operate during the 2015 study period.

In 2016, the bascule gates operated very infrequently during the study period with discharge occurring primarily during the canal outage period (September 19 - 25, 2016), during which time the entire flow of the Connecticut River was conveyed through the dam. Discharge through the Taintor gates and Bascule Gate 2 did not occur during the 2016 study period and discharge through Bascule Gate 3 only occurred during the drawdown period with a maximum discharge of 11,956 cfs (Figure 4.1.4-3). Similarly, Bascule Gate 1 only discharged during the canal drawdown period with a maximum discharge of 10,500 cfs, except for a brief discharge of 337 cfs on September 28, 2016 (Figure 4.1.4-1). Bascule Gate 4 discharged only once during the 2016 study period on September 2, with a discharge of 10,000 cfs.

4.1.5 Connecticut River Discharge

The Connecticut River discharge is monitored by the USGS in Montague, MA. Figure 4.1.5-1 shows the discharge over time during the study periods in 2015 and 2016. Flows in the Connecticut River were higher (40%, between 8/1 and 11/15) in 2015 when compared to 2016. A high flow event occurred at the beginning of October 2015 with a maximum discharge of 38,000 cfs. Maximum discharge in 2016 was 15,800, occurring on August 26.

4.1.6 Precipitation

In 2015, a total of 32 rain events occurred ranging from trace amounts to a single day total of 2.37 inches on September 30 (Figure 4.1.6-1). In all, a total of 12.79 inches of rain fell during the 2015 stud period. As compared to 2015, 2016 was somewhat dryer with a total of 11.66 inches of rain. Thirty-four (34) rain events occurred during the 2016 study period ranging from trace amounts to a single day total of 2.07 inches on September 19, 2016 (Figure 4.1.6-1).

4.1.7 Water Temperature

Water temperature was similar in both years of study (Figures 4.1.7-1). Ranging from the mid 20’s in August to approximately 7.5 °C by mid-November, dropping approximately 17.5 degrees over the course of the study period (August to mid-November).

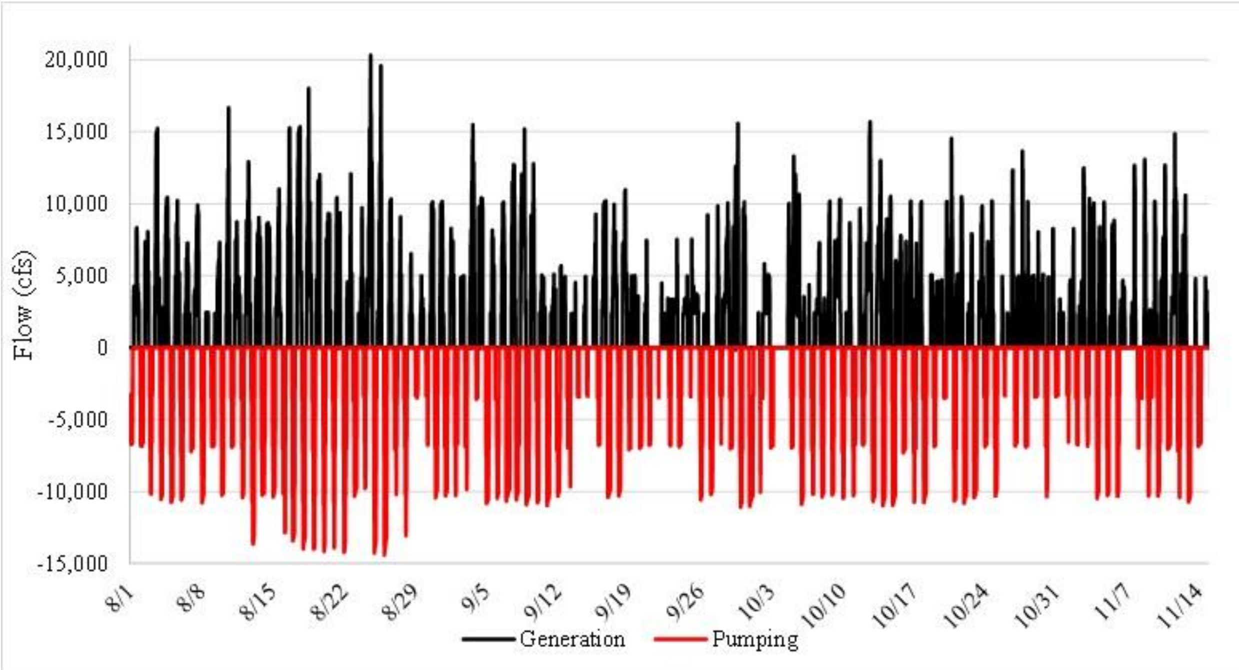


Figure 4.1.1-1. 2015 Operations at NMPS Project Northfield, MA.

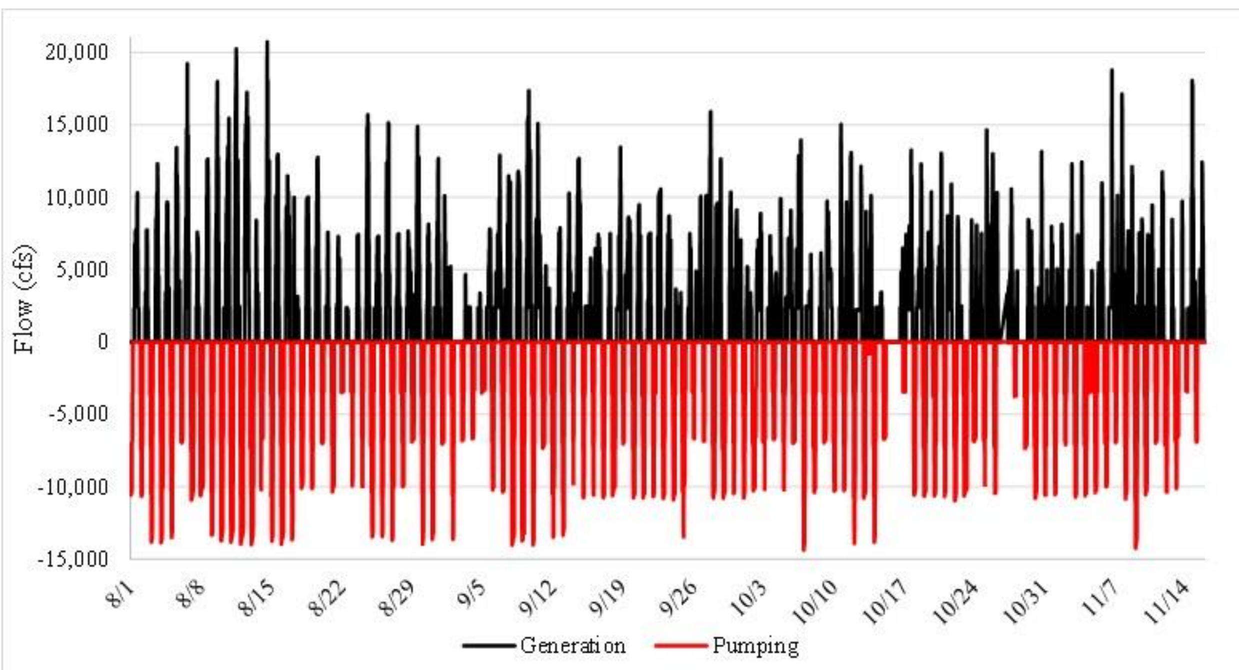


Figure 4.1.1-2. 2016 Operations at NMPS Project Northfield, MA.

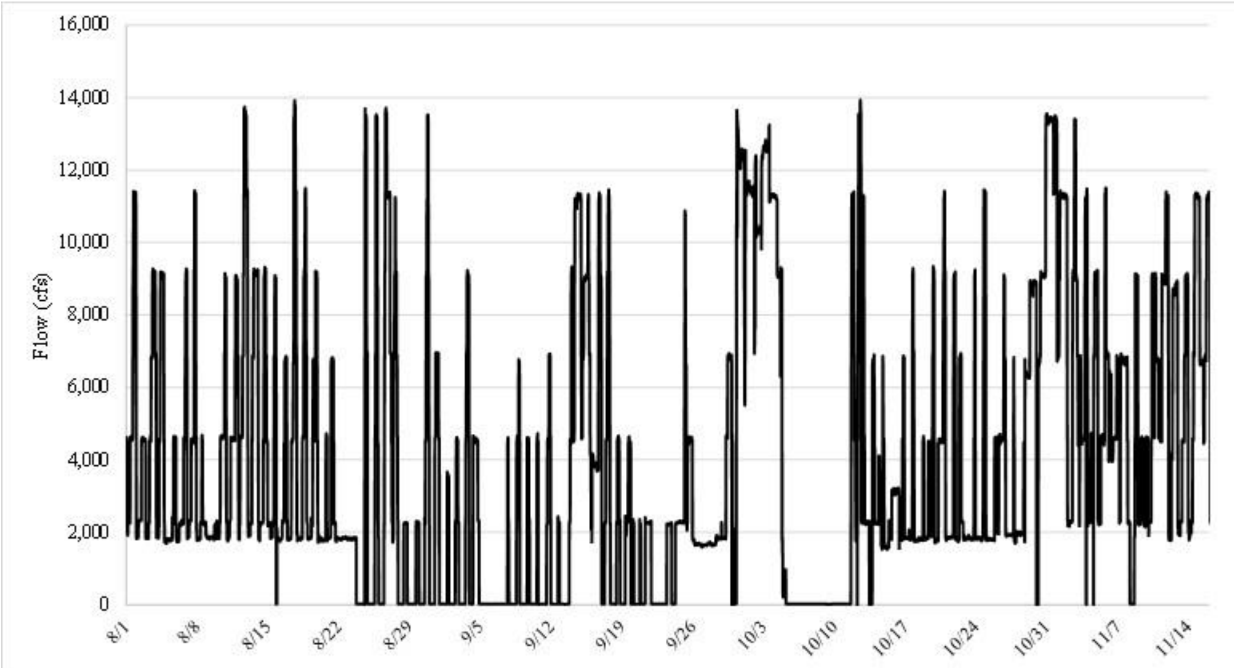


Figure 4.1.2-1. 2015 Operations at Cabot Station Turner Falls, MA.

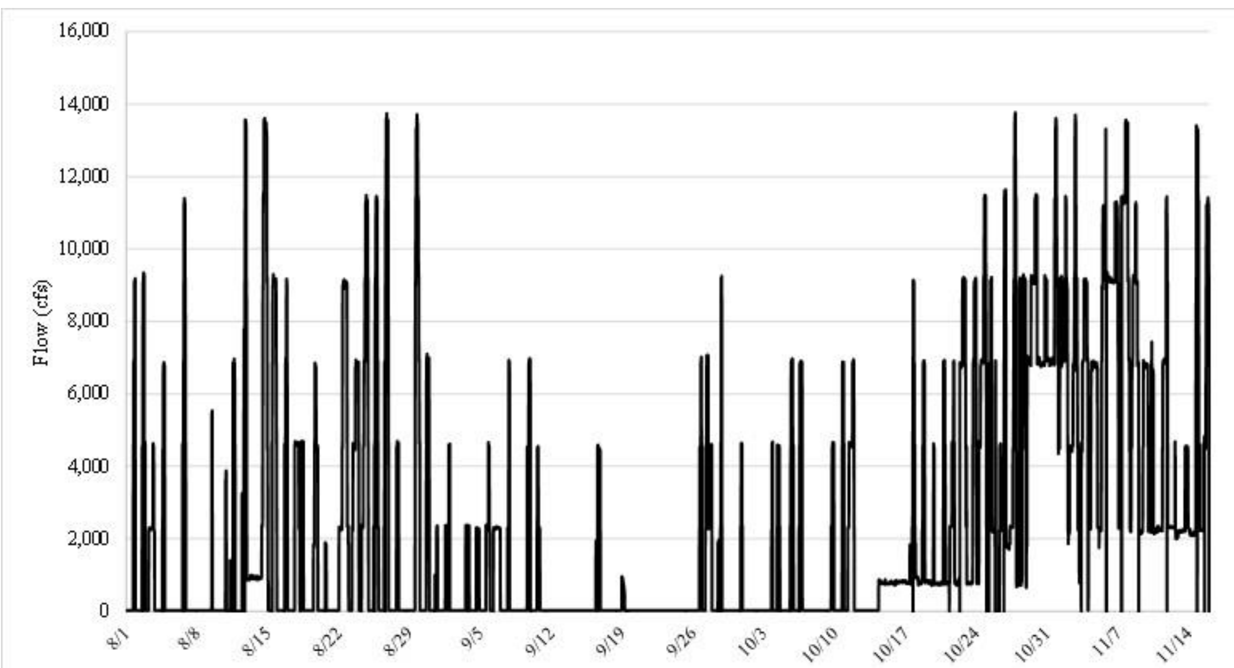


Figure 4.1.2-2. 2016 Operations at Cabot Station Turner Falls, MA.

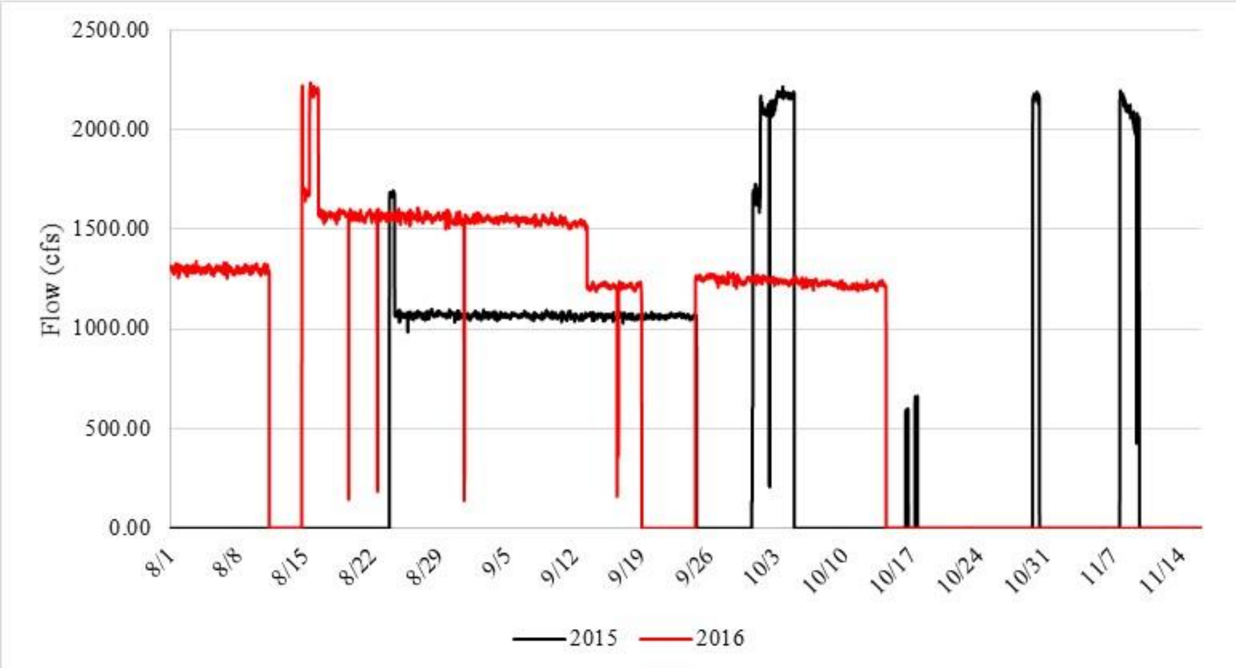


Figure 4.1.3-1. Operations at Station No.1 Turner Falls, MA.

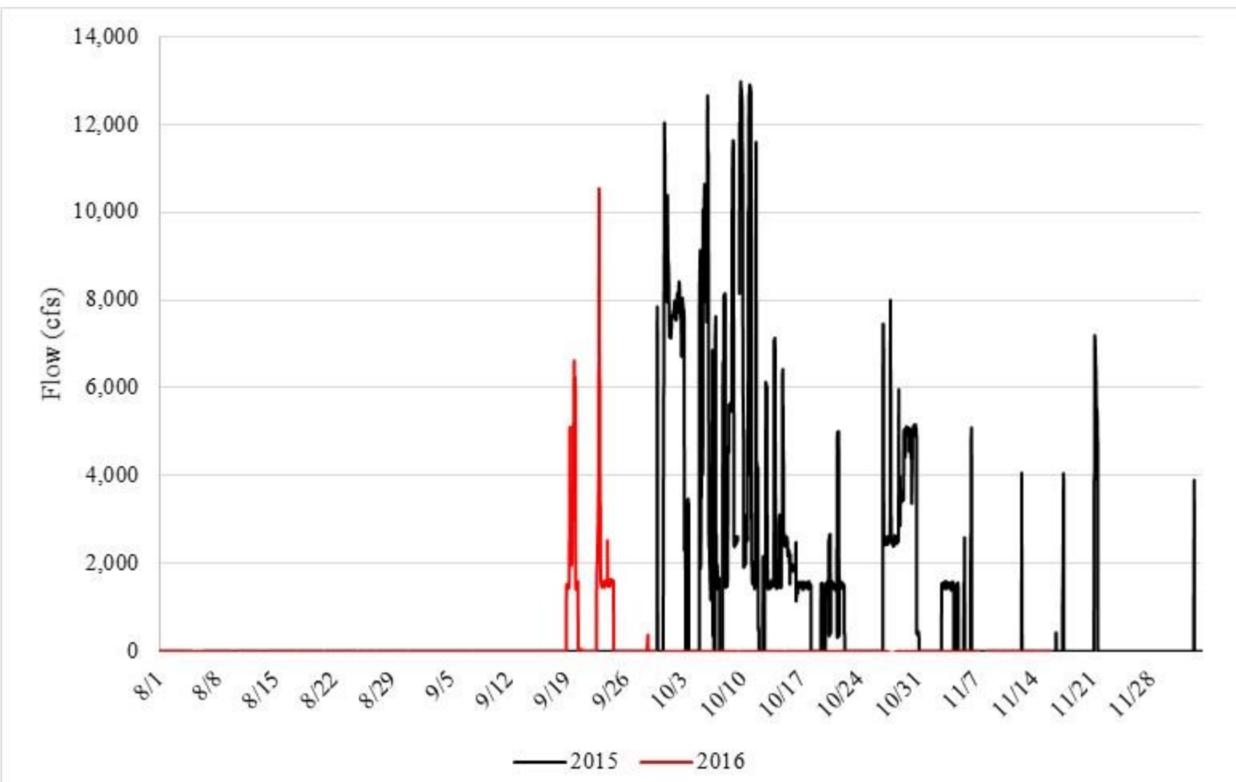


Figure 4.1.4-1. Discharge at the Turners Falls Dam, Bascule Gate No. 1, Turners Falls, MA.

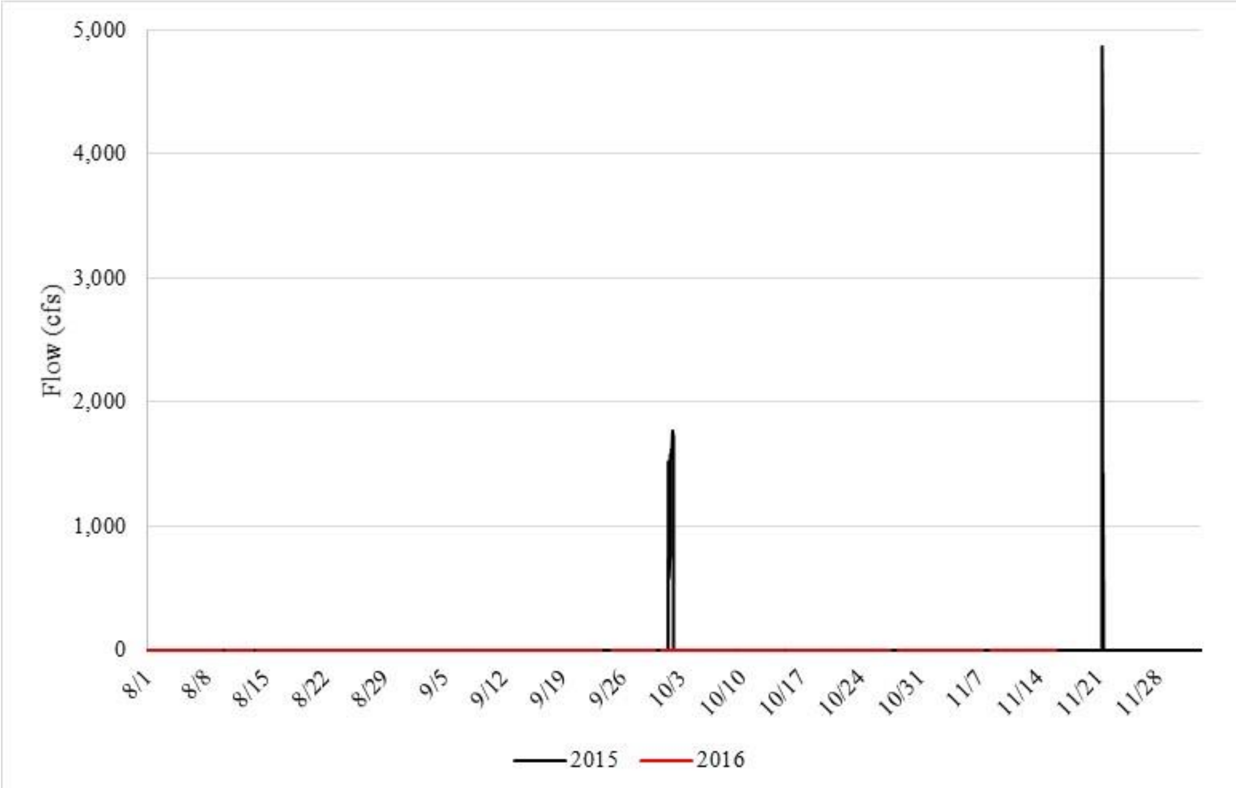


Figure 4.1.4-2. Discharge at the Turners Falls Dam, Bascule Gate No. 2, Turners Falls, MA.

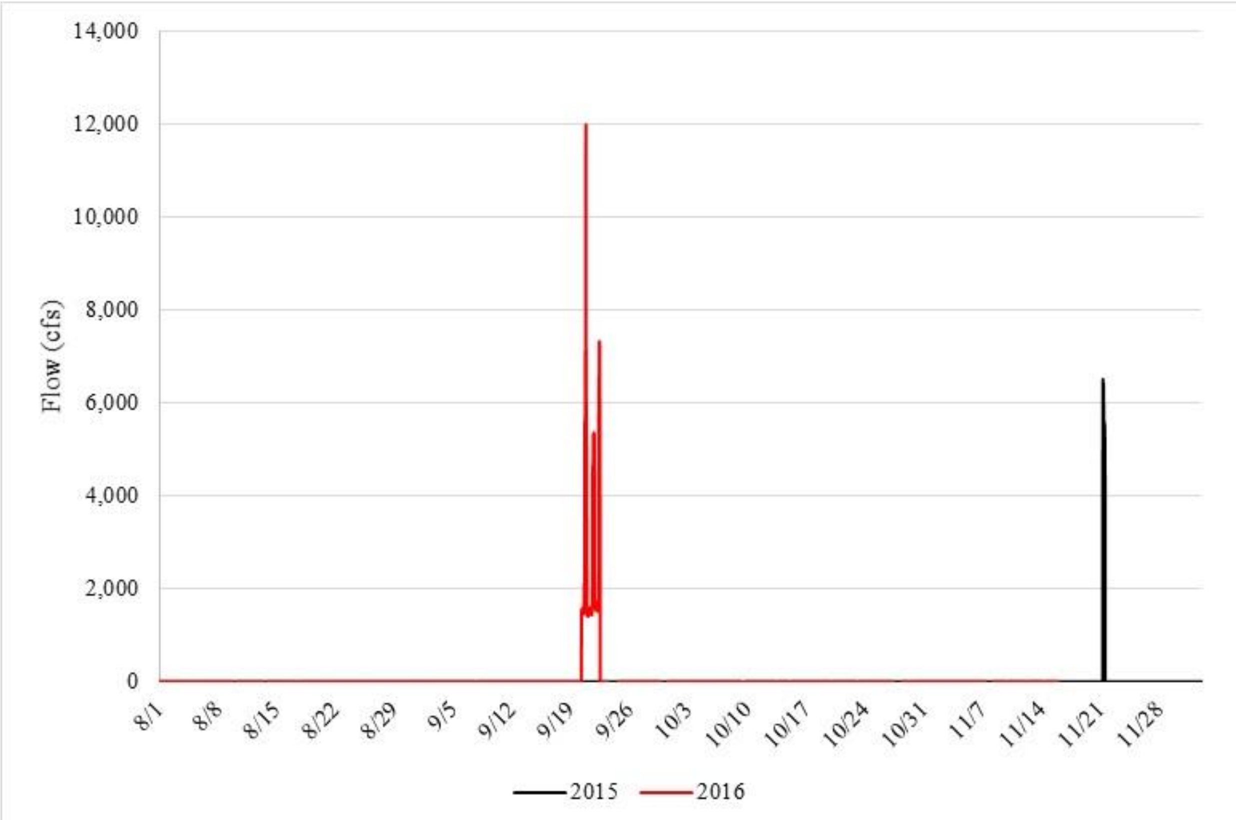


Figure 4.1.4-3. Discharge at the Turners Falls Dam, Bascule Gate No. 3, Turners Falls, MA.

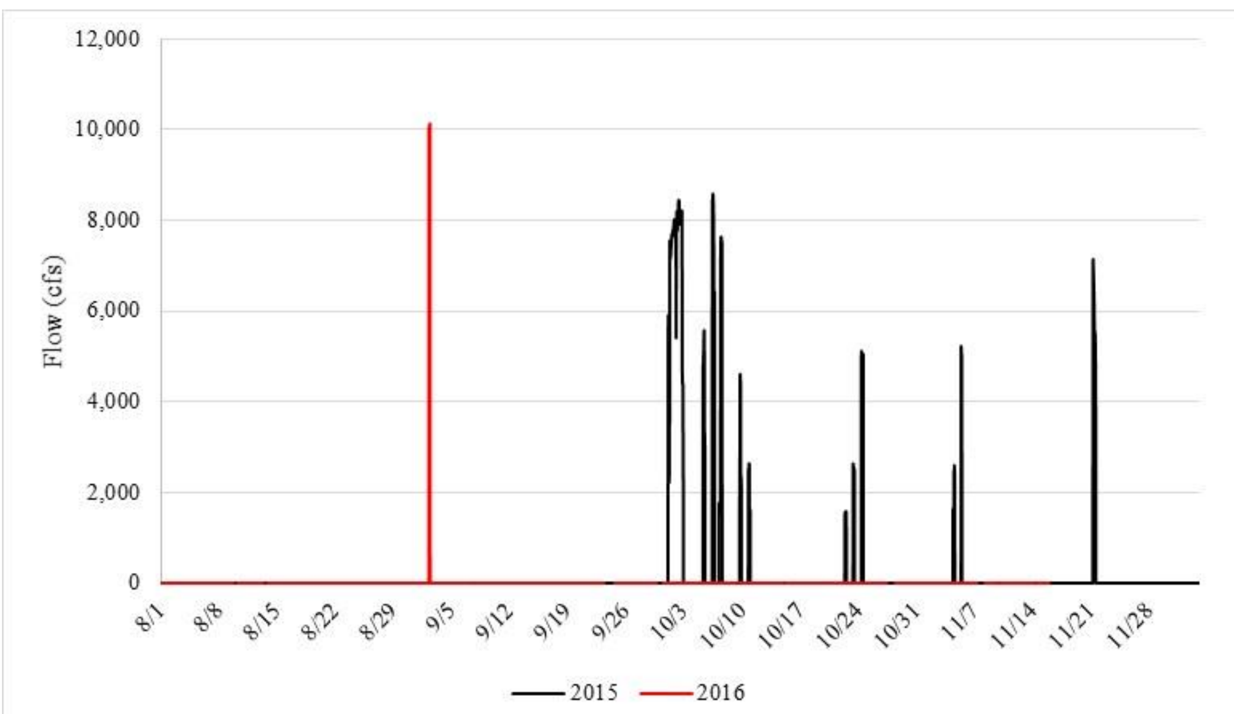


Figure 4.1.4-4. Discharge at the Turners Falls Dam, Bascule Gate No. 4, Turners Falls, MA.

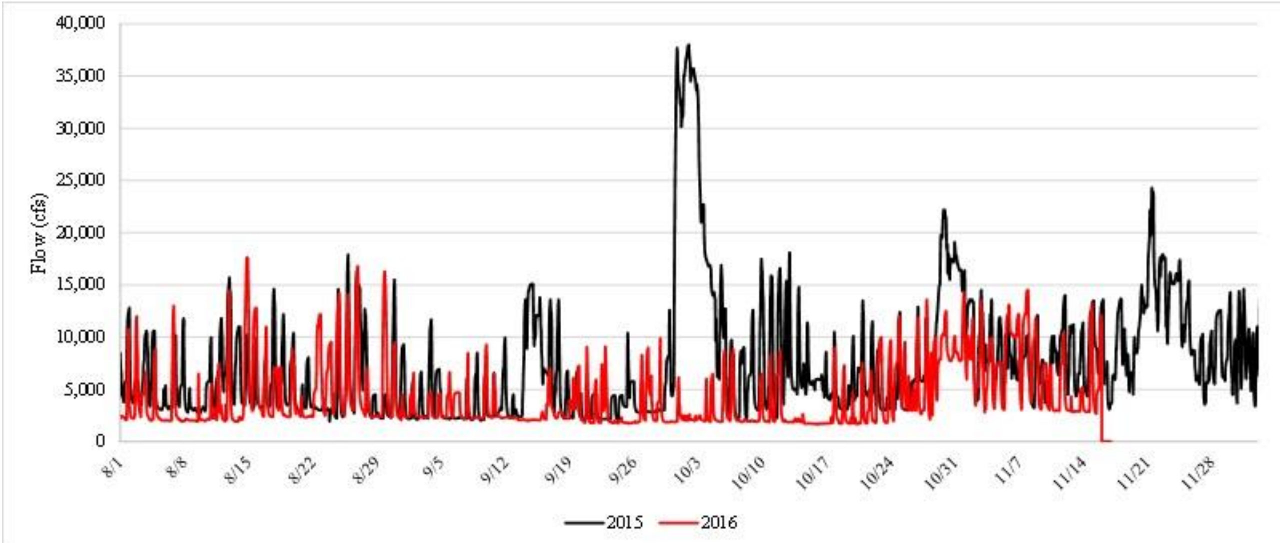


Figure 4.1.5-1. Connecticut River Flow as measured at the USGS Monitoring Station (USGS 01170500) Montague, MA during 2015 and 2016 study periods.

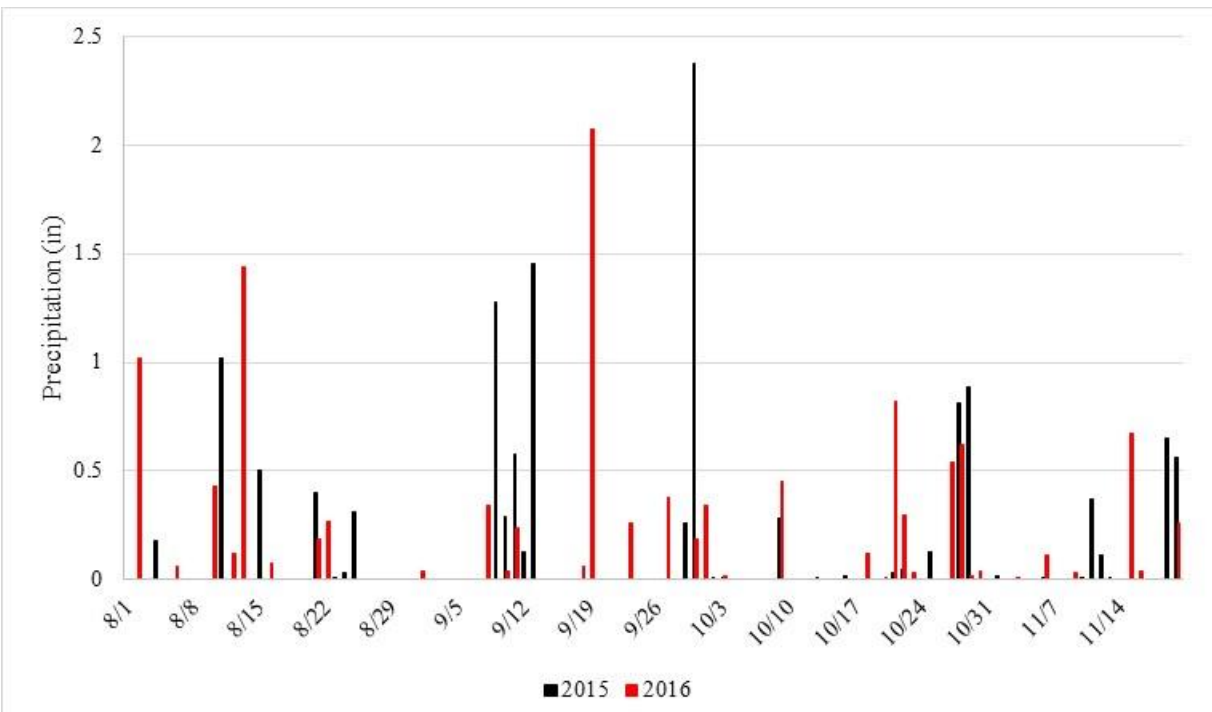


Figure 4.1.6-1. Precipitation near Turners Falls, MA.

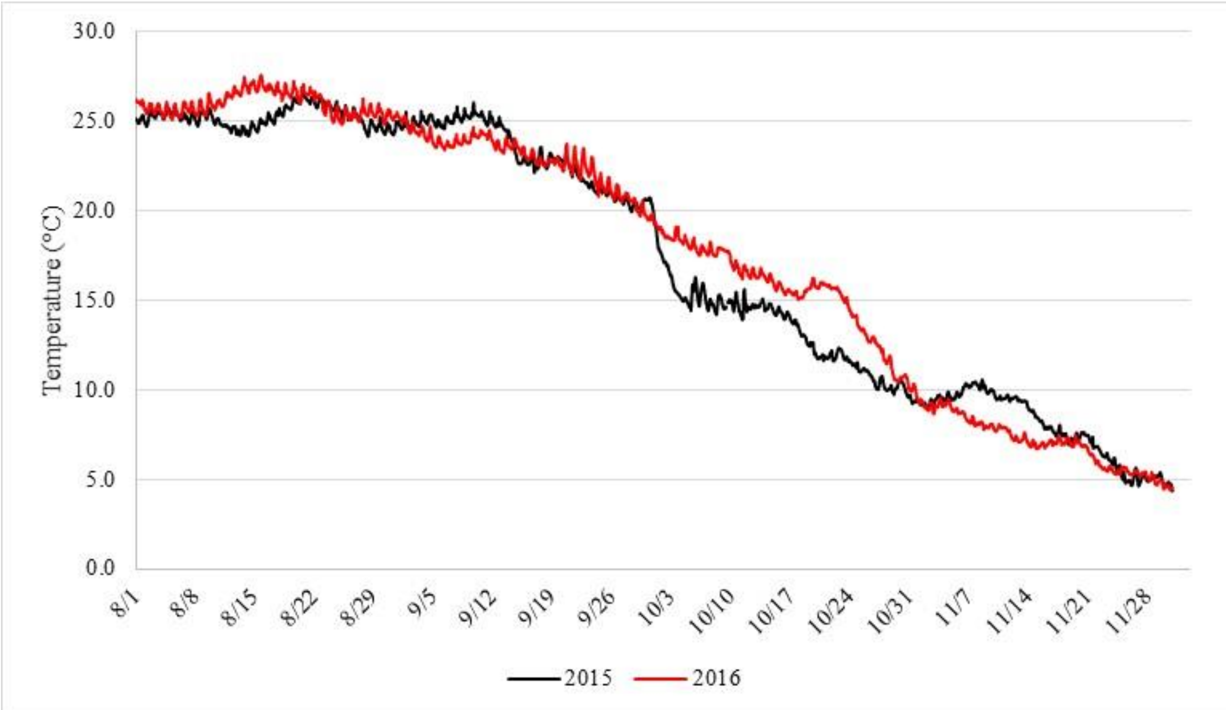


Figure 4.1.7-1. Water temperature (°C) as measured in the power canal Turners Falls, MA

4.2 Migratory Timing of Eel (DIDSON)

Data were collected with the DIDSON throughout the majority of the 2015 and 2016 study periods, except for the duration of the annual canal outages, as well as brief periods of equipment malfunction. In total, 37,460 minutes (97% of study period spanning 1700-0500, excluding annual canal drawdown) of data were reviewed for eel observation in 2015, and 32,920 minutes (86% of study period spanning 1700-0500, excluding annual canal drawdown) of data were reviewed in 2016. Table 4.2-1 summarizes the number of minutes sampled each day throughout the study period, and illustrates the days data were not collected.

Over the two-year sampling period, 41 eels were detected at the 10-m range setting, while 29 eels were detected within the 20-m range. Surprisingly, fewer fish were observed with the 20-m range setting even though it sampled a larger area of the canal. The raw counts were sparse, with many zero count days punctuated with a few fish over the sampling periods. The extrapolated counts of eels passing through the canal based on the 10-m and 20-m range settings for 2015 and 2016 are provided in Table 4.2-2. In 2015, the 10-m range estimate was 2,382 fish, while the 20-m range setting estimate was only 378 fish. For 2016, an estimated 2,273 eel passed through the canal based on the 10-m range data and about 529 individuals were estimated based on 20-m range data.

With a large number of zero count days, the interpolated plots (Figure 4.2-1 and Figure 4.2-2) appear sparse with many peaks interspersed between zero count days. Eel were observed moving through the canal between early August and mid-November during both years; however, in 2015, the largest counts appeared early in the season in August (Figure 4.2-1), while in 2016 the peak occurred late in mid-October (Figure 4.2-2).

Table 4.2-1. Summary of the number of minutes sampled per day.

	2015		2016	
Date	**10m/HF**	**20m/LF**	**10m/HF**	**20m/LF**
7/31	140	260	0	0
8/1	260	0	140	260
8/2	260	260	120	0
8/3	260	0	140	260
8/4	260	260	260	0
8/5	260	0	260	260
8/6	260	260	260	0
8/7	260	0	260	260
8/8	260	260	260	0
8/9	260	0	260	260
8/10	260	260	260	0
8/11	260	0	260	260
8/12	260	260	260	0
8/13	260	0	260	260
8/14	260	0	260	0
8/15	260	260	260	260
8/16	260	0	260	0
8/17	260	260	120	0*
8/18	260	0	0*	0*
8/19	260	260	140	260
8/20	260	0	260	0
8/21	260	260	260	260
8/22	260	0	260	0
8/23	260	260	260	260
8/24	260	0	260	0
8/25	260	260	260	260
8/26	260	0	260	0
8/27	260	260	260	260
8/28	260	0	260	0
8/29	260	260	260	260
8/30	260	0	260	0
8/31	260	260	260	200
9/1	140	0	80	0
9/2	0*	0*	0*	0*
9/3	140	0	0*	0*
9/4	260	260	0*	0*
9/5	260	0	0*	0*
9/6	260	260	0*	0*
9/7	260	0	140	260
9/8	260	260	260	0

	2015		2016	
Date	**10m/HF**	**20m/LF**	**10m/HF**	**20m/LF**
9/9	260	0	260	260
9/10	260	260	260	0
9/11	260	0	260	260
9/12	260	260	260	0
9/13	260	0	260	260
9/14	260	260	260	0
9/15	260	0	260	260
9/16	260	260	260	0
9/17	260	0	120	0*
9/18	260	260	0*	0*
9/19	260	0	0*	0*
9/20	260	260	0*	0*
9/21	260	0	0*	0*
9/22	260	260	0*	0*
9/23	260	0	0*	0*
9/24	260	260	0*	0*
9/25	260	0	0*	0*
9/26	260	260	140	260
9/27	260	0	260	0
9/28	260	260	260	260
9/29	220	0	260	0
9/30	120	0*	260	260
10/1	140	0*	260	0
10/2	260	260	260	260
10/3	260	0	260	0
10/4	160	0*	260	260
10/5	0*	0*	260	0
10/6	0*	0*	260	260
10/7	0*	0*	260	0
10/8	0*	0*	260	260
10/9	0*	0*	260	0
10/10	0*	0*	260	260
10/11	0*	0*	260	0
10/12	140	260	120	0*
10/13	260	0	0*	0*
10/14	260	260	140	260
10/15	260	0	260	0
10/16	260	260	260	260
10/17	260	0	260	0
10/18	260	260	260	260
10/19	260	0	260	0

	2015		2016	
Date	**10m/HF**	**20m/LF**	**10m/HF**	**20m/LF**
10/20	260	260	260	260
10/21	260	0	260	0
10/22	260	260	260	260
10/23	260	0	260	0
10/24	260	260	260	260
10/25	260	0	260	0
10/26	180	60	260	260
10/27	140	0	260	0
10/28	260	260	260	260
10/29	260	0	260	0
10/30	260	260	260	260
10/31	260	0	260	0
11/1	260	260	260	260
11/2	260	0	260	0
11/3	260	260	260	260
11/4	260	0	260	0
11/5	260	260	120	0*
11/6	260	0	0*	0*
11/7	260	260	0*	0*
11/8	260	0	140	0
11/9	260	260	260	260
11/10	260	0	260	0
11/11	260	260	260	260
11/12	260	0	260	0
11/13	260	260	260	260
11/14	260	0	260	0
11/15	260	260	260	260
11/16	260	0	120	0
Total	**25,180**	**12,280**	**21,800**	**11,120**

*DIDSON was shut down, no data collected.

Table 4.2-2. Extrapolated counts by DIDSON range setting and year.

Year	10 m	20 m
2015	2,382	378
2016	2,273	529

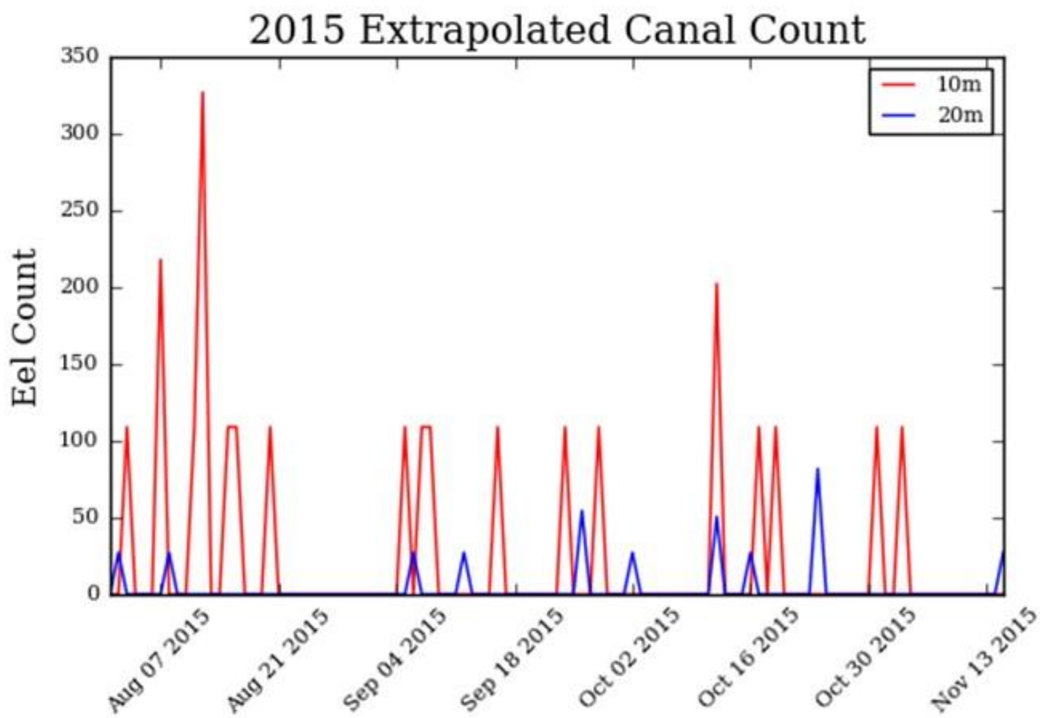


Figure 4.2-1. The 2015 extrapolated counts over time by range setting.

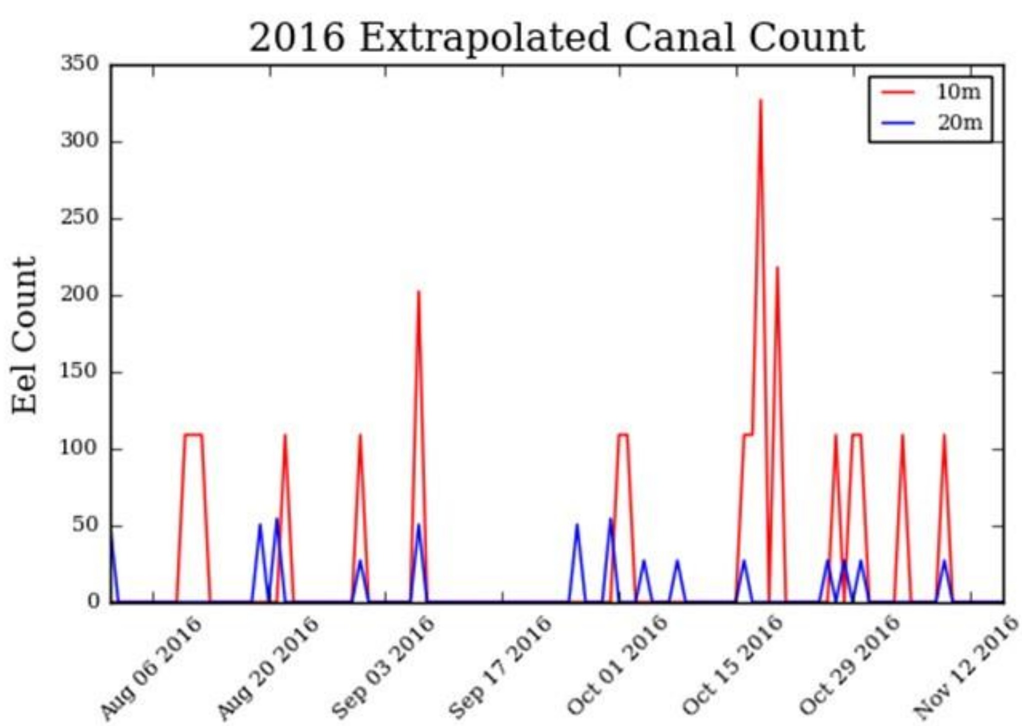


Figure 4.2-2. The 2016 extrapolated counts over time by range setting.

4.3 Overall Probability of Movement through Project

A Cormack-Jolly-Seber (CJS) open population mark recapture model was used to assess the proportion of marked silver phased American Eel to successfully pass the project. In total, the CJS model incorporated detection histories from 170 radio tagged American Eel from three release cohorts at four detection locations: impoundment, project, tailrace, lower river (Montague). For the fish released by TransCanada, the tagged eel that were determined to have duplicate juvenile shad frequencies were excluded from the analysis. Detections at any receiver within either of the project reaches means detection within the entire reach. The impoundment location consisted of all receivers within the TFI including Shearer Farms (T1, T2), the NMPS intake (T3), Gill Bank (T5, T6), TFI boat barrier (T7, T8) and the Gatehouse (T9). The remaining project locations consisted of receivers within the bypass reach (T20, T11, T12), the power canal (T10, T13, T14, T174), and both Station No. 1 tailrace (T15) and the Cabot Powerhouse (T171, T172 and T173). Project passage was assumed to occur when fish arrive in the Cabot Station tailrace (T17 and T19). The last receiver (T18) within the lower river at the Montague receiver location assessed the proportion of eel expected to arrive within the lower river after passing the project. The CJS model estimated four recapture probabilities (p) and four survival probabilities (ϕ). However, a limitation in the model exists at Montague because we cannot differentiate between fish that didn't arrive and those fish that were simply not detected by the telemetry equipment. We incorporated mobile tracking data into the recapture history within the lower river. If a marked eel was detected and deemed alive during mobile tracking in the region of the river from the Deerfield River confluence to the lowest mobile tracking station, it was incorporated into the lower river count.

Detection histories of the 170 valid silver phased American Eel can be found in Appendix C. In total, of the 170 tagged eel, 164 were detected by receivers and mobile tracking within the impoundment, 101 within the Turners Falls Project, 106 in the tailrace, and 10 within the lower river. Table 4.3-1 contains raw recapture counts per reach by release cohort. Note that there were some marked fish recaptured in the tailrace that were not recaptured within the project.

The CJS model reduces bias associated with low detection rates and provides confidence intervals around the estimate. The CJS model assumes that the arrival of a fish at each recapture occasion is independent; therefore, the proportion of fish expected to arrive within the lower river is the product of the individual reach survivals (1.0 * 0.69 * 0.91 * 0.31 = 19.5%) (Table 4.3-2). However, we have no confidence in the estimate of survival at the last detection (Table 4.3-3) due to the limitations of the model and low detection rate at Montague. As the confidence interval span from 0 to 1, it is equally likely the estimate of through-project survival is zero or 100% as calculated with the CJS. Regardless, both the raw count data, and project-tailrace survival show that a large proportion of marked eels passed the project. Out of the 170 released fish, 106 were recaptured in the tailrace (106/170 = 62.4%). If we were to multiply the first three recapture rates from the CJS model (release to tailrace survival), we would obtain 62.8% (1.0 * 0.69 * 0.91). Therefore, we have high confidence in the ability of the CJS model to estimate survival at least up until the Cabot Station tailrace.

FirstLight investigated the reasons for low rates of recapture at the Montague station. Of the 170 tagged eel, 106 fish were recaptured in the Cabot Station Tailrace (T17). All recaptured eel were "alive", with no tags reverting to the 11 sec mortality signal pattern. After noting the time at which each eel left the tailrace area, we searched for detections downstream at Montague Wastewater (T18). Although 76 of the 106 eel detected in the Tailrace also appeared to be detected at T18, only 10 tagged eel were positively identified, and considered recaptured at T18. The remaining fish were classified as 'false positive' because they were only detected once with no other detections in series. Many of the false detections appeared before the recaptured fish left the tailrace area, and had long periods of time between random detections. Table 4.3-4 lists the 10 eel that were confirmed recaptures at Montague, as well as an additional 19 eel which were detected once, with no other detections in series after the eel's last recapture at the tailrace. These detections have been misclassified as "false positive" due to the lack of repetition. However, the time frame suggests that these detections could possibly be true recaptures. A Cox Proportional Hazards regression model was fit to those fish that go missing from the tailrace and found that fish are 67 times more likely to transition into an unknown state from the tailrace at night when it rains (in) ($LR < 0.001$, $HR = 67.03$, $p < 0.001$). This suggests eel could have passed the Montague area during a time of higher flows, reducing the ability of the telemetry equipment at Montague to detect a motivated eel moving downstream from the Cabot tailrace. Figure 4.3-1 illustrates the time it took for each eel listed in Table 4.3-4 to travel from the Cabot Tailrace to the Montague station, and compares that time period to river flow. Most eel (24) passed Montague station within an hour of leaving the Cabot Tailrace (Figure 4.3-1). The travel time for the remaining 5 eel was from 14 hours to as long as 25 days.

Eel that successfully passed the Turners Falls Project and reached Cabot Tailrace did so very quickly. All of the 106 eel that passed the Project had reached and left Cabot Tailrace within 26 days of their release, well under the 90 day tag life expectancy (Figure 4.3-2). Of these 35% had moved beyond Cabot Tailrace within 2 days after release and 72% had moved through within 6 days of release.

Table 4.3-1. Raw recaptures within project reaches by release cohort.

Release Cohort	Impoundment	Project	Tailrace	Lower River
Lower Impoundment	48	38	38	6
TransCanada	54	31	32	1
Upper Impoundment	62	32	36	3
Sum	164	101	106	10

Table 4.3-2. The CJS estimates of Survival per study reach.

Parameter	Estimate (%)	Standard Error (%)	95% Confidence Interval	
			Lower Limit (%)	Upper Limit (%)
1: (ϕ) Release - Impoundment	1.0	0	1.0	1.0
2: (ϕ) Impoundment - Project	0.69	3.6	0.61	0.75
3: (ϕ) Project - Tailrace	0.91	2.8	0.85	0.97
4: (ϕ) Tailrace - Montague	0.31	110.36	0.0	1.0

Table 4.3-3. The CJS estimates of Recapture per study reach.

Parameter	Estimate (%)	Standard Error (%)	95% Confidence Interval	
			Lower Limit (%)	Upper Limit (%)
5: (p) Impoundment	0.96	1.4	0.92	0.98
6: (p) Project	0.87	3.3	0.79	0.92
7: (p) Tailrace	1.0	0	0.99	1.0
8: (p) Montague	0.31	110.42	0.0	1.0

Table 4.3-4. List off eel that were detected at Montague Station and their ID numbers as depicted in Figure 4.3-1.

Eel ID	Freq. Code	Confirmed/Possible Detection at Montague	Duration between last Tailrace & first Montague (hour)
1	149.760 27	Confirmed	14.8
2	149.760 32	Confirmed	0.6
3	149.760 30	Confirmed	0.5
4	149.740 32	Confirmed	0.3
5	149.740 23	Confirmed	0.4
6	149.760 40	Possible	0.5
7	149.760 37	Confirmed	0.5
8	149.760 35	Confirmed	0.3
9	150.340 101	Confirmed	0.5
10	149.740 48	Confirmed	0.3
11	149.760 51	Confirmed	0.5
12	149.760 46	Possible	1.3
13	149.740 29	Possible	0.6
14	149.740 22	Possible	0.5
15	149.740 44	Possible	0.3
16	150.360 176	Possible	14.1
17	150.360 164	Possible	613.1
18	150.340 181	Possible	0.3
19	150.380 188	Possible	0.3
20	150.340 143	Possible	0.4
21	149.740 83	Possible	0.4
22	150.380 124	Possible	0.5
23	150.380 112	Possible	0.9
24	149.740 51	Possible	0.7
25	150.380 118	Possible	0.5
26	150.360 141	Possible	0.5
27	150.340 54	Possible	322.5
28	150.340 173	Possible	0.3
29	149.740 78	Possible	0.6

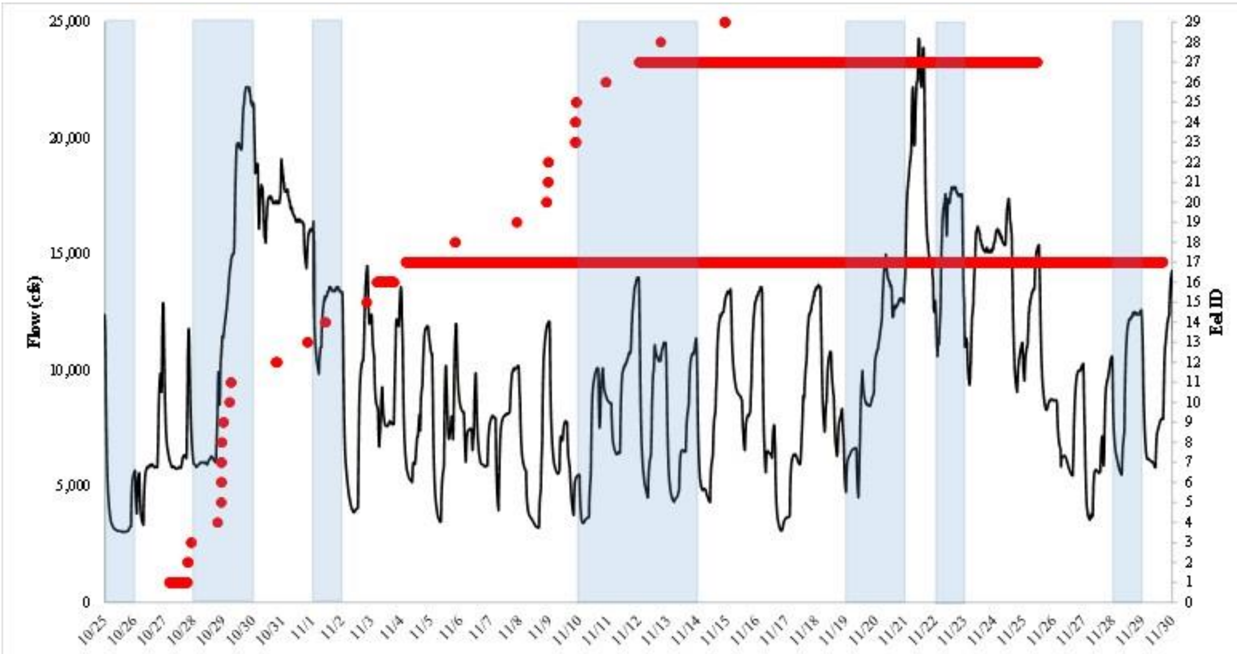


Figure 4.3-1 Flow at Montague (line) during the time at which each eel traveling between Cabot Station Tailrace and Montague Wastewater (red lines). Rain events are highlighted in blue.

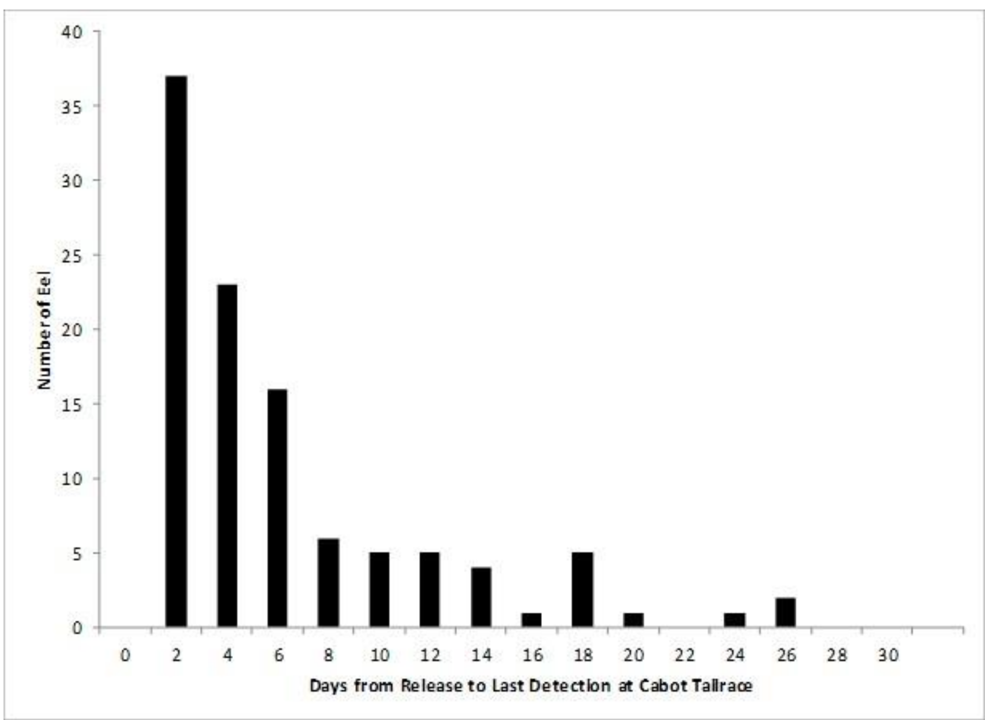


Figure 4.3-2 Elapsed time between release and an eel's last detection at Cabot Tailrace.

4.4 Competing Risks: Assessment of Entrainment at NMPS Project

Fish in the upper areas of the TFI are at risk of entrainment at the NMPS Project if they become attracted to the intake area (site T3). Fish may transition from the impoundment at Shearer Farms (T1 and T2) or from Gill Bank (T5 and T6) into the NMPS intake (T3). Once in the intake, they are at risk of entrainment into the upper reservoir (T4). The NMPS intake is transitional, meaning fish may move into and out of the area multiple times as long as they don't move into an absorbing state (entrainment). An absorbing state is one in which the fish cannot return from (i.e., entrainment). When we model each transition from the intake, we treat both the TFI and entrainment as absorbing states. If a fish visited the intake area more than once, each transition from the intake was modeled as a separate event. If a fish was entrained into the upper reservoir, it would not be identified within the intake at a later time. However, if a fish escaped into the impoundment, it could have another transition from/to the intake. For the competing risks assessment to match empirical expectations, all fish must be attributed to a state. If we censored individuals at their last detection within the intake, the probability of a fish having escaped or becoming entrained are positively biased. Therefore, if we lost track of a fish before the end of monitoring, it was placed in an unknown state. Placing fish into an 'unknown' absorbing state provides two important benefits. First, the Nelson-Aalen cumulative incidence plots will match empirical expectations. This means that the probability of a fish ending up in a state matches empirical data. Second, allowing fish to transition into an unknown state allows us to conclude whether or not those fish were entrained rather than losing the information they would provide through censoring. We can use the information immediately before a fish goes missing to understand the conditions that make a fish more likely to disappear. For example, are fish more likely to go missing when it is dark and NMPS is pumping? If so, one may conclude that those fish have likely been entrained. Fish were censored if and only if they remained within the intake region until the end of the study. Each competing risks assessment had three absorbing states; impoundment, entrainment, and an unknown-state.

In total, 161 fish from three release cohorts (Upper Impoundment, Lower Impoundment, and TransCanada) were recaptured at the telemetry receivers previously listed. The competing risks analysis has one staging site (Intake) and three competing risks (Impoundment, Entrainment, State-Unknown). Table 4.4-1 contains the raw recaptures within each state. Surprisingly, 15 of the lower impoundment fish released at the Millers River migrated upstream through the TFI and were recaptured either at Gill Bank or Shearer Farms, and 11 of those 15 fish were attracted to the intake. Of those 11 fish, one was confirmed entrained and three entered into the unknown state. Of the 161 fish to be recaptured within the Impoundment, 74 were attracted to the intake state (T3). Of those 74 fish, 11 made two transitions into the intake from the impoundment (149.740-40, 149.740-49, 149.740-56, 149.740-59, 149.760-65, 149.760-66, 149.760-75, 150.340-102, 150.340-57 and 150.380-118) and three fish made three transitions into the intake from the impoundment (149.760-34, 148.760-70 and 150.380-180). The competing risks analysis assessed the 91 transitions made from the intake where 55 escaped to the impoundment (55/91 = 60%), two were confirmed to have been entrained (2/91 = 2%) and 34 transitioned into an unknown state (34/91 = 37%).

From the intake, fish appear to escape to the impoundment fairly quickly with the minimum time-to-escape of 2.17 hours after release (Table 4.4-2). The first fish confirmed to be entrained at the intake took 153 hours since it was released. All 74 fish attracted to the intake transitioned to another location, including those 14 fish with more than one transition into the intake. The last fish to experience an event did so more than 25 days after release (Figure 4.4-1). The Nelson-Aalen cumulative incidence plot matches the empirical expectations (Figure 4.4-2). At the end of the study 60% of the transitions from the intake were an escape event (intake-to-impoundment).

Following creation of the cause-specific Nelson-Aalen cumulative incidence plot, a series of Cox Proportional Hazard regressions were fit to each event-type (route) to understand the effects of project operations and environmental factors on movement. The first event of interest was escaping the intake via movement into the impoundment. Model 1 (Table 4.4-3) incorporated rain (inches) as a time dependent covariate. The model was not significant (LR = 0.06). The estimated hazard ratio was 2.86 (0.99, 8.21).

Note the confidence interval includes 1.0, which means there is no effect. The second model incorporated NMPS operations. The model was not significant (LR = 0.91). The third model incorporated diurnal cues and was highly significant (LR < 0.001), with the hazard ratio of 0.20 (0.08, 0.46) suggesting that eel were much less likely to escape the intake during the day than at night. The fourth and best model had an AIC of 818.97. The model incorporated diurnal (day/night) cues as an interaction effect with rain (in). The model was significant (LR = 0.01) and indicates that an eel was 5.19 (1.74, 15.43) times more likely to transition to the impoundment from the intake during the night when it rains vs those nights when it doesn't rain. The more it rains at night, the more likely a fish is to successfully escape the intake and transition into the impoundment. Interestingly, daytime movement during a rain event was not significant, suggesting that the eel used in this study generally remained sedentary during daylight hours.

With only two eels confirmed entrained, the sample size was not adequate to perform a Cox regression on this transition. However, also of interest are the hazard ratios associated with passing into the unknown state. The first model (Table 4.4-4) incorporated rain events as a time-dependent covariate. Note, rain was not significant (p = 0.09) as the confidence interval contains 1.0 (0.81, 13.58). The second model had the lowest AIC and incorporated NMPS operations as a time dependent covariate in units of kcfs (1,000 cfs). The model was significant (LR < 0.001), with a hazard ratio of 0.68 (0.62, 0.75). These results indicate that a fish is most likely to transition into the unknown state when the operational flow is at its lowest, in other words, the probability of movement is highest when NMPS is pumping at maximum capacity. As pumping decreases, eels are less likely to transition into the unknown state. The third model incorporated diurnal cues (AIC = 470.75) and was significant (p < 0.001). The estimated hazard ratio was only 0.05 (0.01, 0.37) suggesting that fish are highly unlikely to transition into the unknown state during the day. Given that fish are much more likely to transition into the unknown state during nighttime or when NMPS is pumping, the fish that transition into the unknown state are likely entrained. To corroborate this result, the hour at which fish transitioned into the unknown state from the intake was plotted (Figure 4.4-3). With the exception of three fish that transitioned at 15:00, 16:00 and 19:00, all other fish transitioned at night when NMPS was in pumping mode.

In summary, 60% of eel detected at NMPS Intake escaped to the impoundment, 2% were confirmed to be entrained, and 37% entered an unknown state at the intake. Escapement into the impoundment was most heavily influenced by diurnal cues and rain, and fish were 5.19 times more likely to escape into the impoundment for every inch of rain that fell at night. Fish that entered an unknown state were most strongly influenced by NMPS operations and were 0.68 times as likely to enter an unknown state for every 1000 cfs increase in flow at NMPS, indicating that fish were more likely to enter an unknown state as pumping rates increased. Only 1 fish that entered the unknown state (149.740 34) was later recaptured downstream, and it transitioned on 10/19/2015 at 15:19:25.

Table 4.4-1. Raw recaptures within each NMPS intake project reach by release cohort.

Release Cohort	Intake	Impoundment	Entrainment	State-Unknown
TC	31	52	1	16
Lower Impoundment	11	48	1	3
Upper Impoundment	32	61	0	15
Sum	74	161	2	34

Table 4.4-2. Descriptive statistics of event times (hours) from the NMPS intake to an absorbing state

Event	Min	25%	Median	75%	Max
Entrainment	153.3	241.3	329.3	417.3	505.3
Escape	2.2	50.2	131.3	267.6	575.5
Unknown State	2.3	10.1	138.7	261.6	685.0

Table 4.4-3. Cox Proportional Hazards output for time-to-intake escapement.

Model Number	Covariates	AIC	LR test	Hazard Ratio	SE	p	(+/-)
1	Rain (in)	822.13	0.06	2.86	0.54	0.051	(0.99,8.21)
2	NMPS ops (kcfs)	843.51	0.91	0.99	0.02	0.91	(0.93,1.06)
3	Diurnal (day)	822.92	<0.001	0.20	0.43	< 0.01	(0.08,0.46)
4	Night:Rain (in)	818.97	0.01	5.19	0.55	0.003	(1.74,15.43)
	Day:Rain (in)			0.29	1.53	0.42	(0.01,5.95)

Table 4.4-4. Cox Proportional Hazards output for time-to-unknown state.

Model Number	Covariates	AIC	LR test	Hazard Ratio	SE	p	(+/-)
1	Rain (in)	467.60	0.11	3.33	1.68	0.09	(0.81,13.58)
2	NMPS ops (kcfs)	409.06	<0.001	0.68	0.05	<0.001	(0.62,0.75)
3	Diurnal (day)	470.75	<0.001	0.05	1.01	0.003	(0.01,0.37)

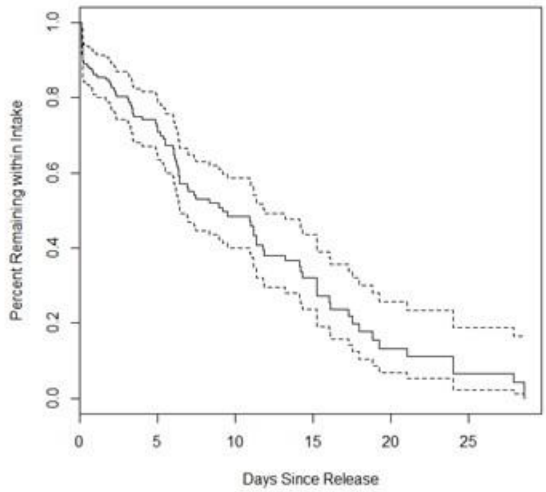


Figure 4.4-1. Kaplan-Meier survival curve for fish remaining in the NMPS intake

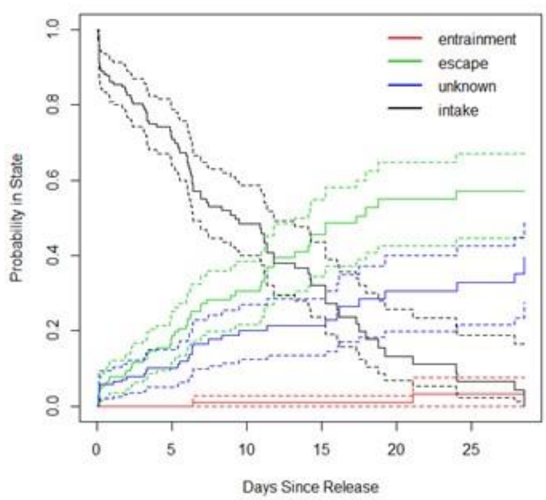


Figure 4.4-2. Nelson-Aalen cause-specific cumulative incidence curves showing probability in state at time (t) for the fish that escape, are entrained or who enter the unknown state. Note Kaplan-Meier curve for intake state superimposed on figure to show that probabilities sum to 1.0 at all event times.

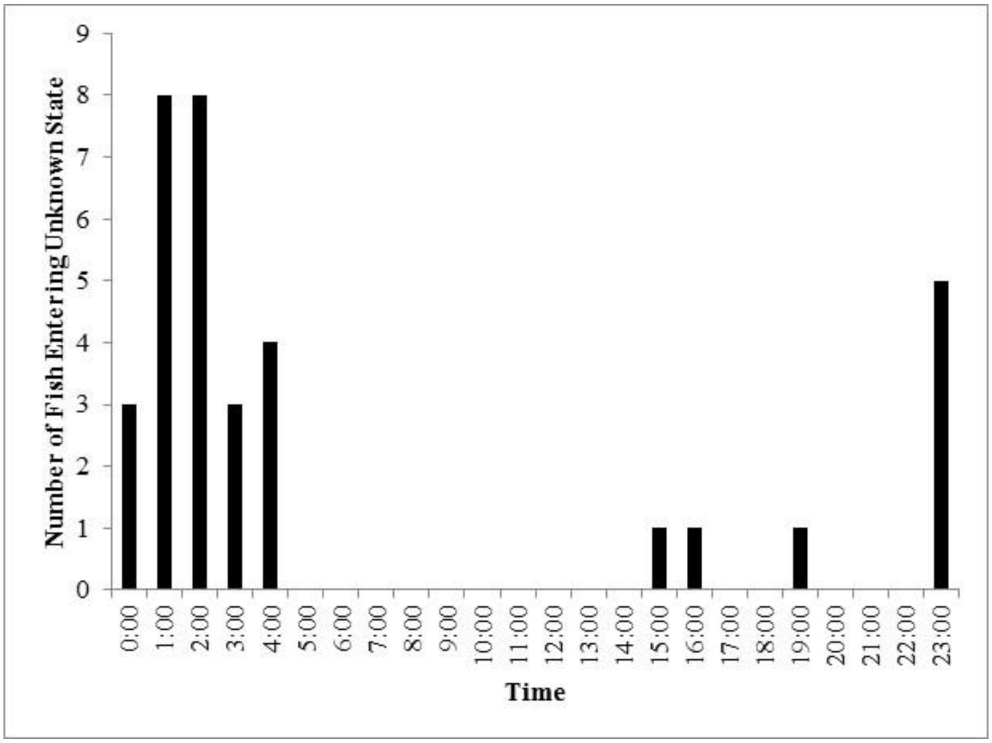


Figure 4.4-3. Hourly frequency plot showing when fish enter unknown-state.

4.5 Competing Risks: Assessment of Passage at Turners Falls Dam

Once arriving at TFD, emigrating adult silver phased American Eel are faced with route selection. Fish can either pass through the gatehouse and into the power canal, or they can pass over the bascule gates and into the bypass reach. Subsequent detections at any of the following receivers indicates that the fish has transitioned into the canal: T10, T13, T14, T171, T172, T173, and T174. Subsequent detections at any of the following receivers means that the fish has transitioned into the bypass reach: T11, T12, T20. The event time (transition into an absorbing state, which represents passage) was considered to be the first recapture in the absorbing state. Not all fish successfully transitioned from the impoundment into an absorbing state. Some fish were identified as 'dead' during mobile tracking, and their first detection in the dead state was time of death. Finally, there was a portion of fish that transitioned into an unknown state. These fish either passed downstream of the project undetected, shed their tags or died somewhere in the impoundment and were not recaptured with mobile tracking. Those fish that transition into an unknown state do so at their last recapture within the impoundment.

Fish overwhelmingly chose the canal over all release cohorts (Table 4.5-1). Of the 127 viable fish from all release cohorts, 88 chose the canal (88/127 = 69%). Over the course of the study, 19 of the 127 fish that entered this reach of the study entered into an unknown state before the study ended. Either these fish passed downstream undetected, shed their tag, died, or were not recaptured again during mobile tracking. Rather than censoring these individuals at their last impoundment time, they transition into an 'unknown' state so that our cumulative incidence (probability of being in a state at time t) matches empirical expectations.

Fish appeared to transition into the canal quickly at first, with the minimum event time occurring 2.75 hours after release (Table 4.5-2). Fish entered the canal throughout the entire study period, with the last canal event occurring at 593.5 hours (nearly 25 days) post-release. For the fish that chose the bypass reach, the median event time was 32.67 hours after release. Four fish remained within the impoundment until the end of the study.

The Kaplan-Meier survival plot shows the last fish to transition into an absorbing state did so 25 days after release (Figure 4.5-1). As expected, the in-state probabilities at the end of the study in the Nelson-Aalen cumulative incidence plots match empirical expectations (Figure 4.5-2). Cox Proportional Hazard regressions were conducted on fish that entered the canal and bypass reach.

The first event of interest was passage into the canal. A series of Cox Proportional Hazard regression models were fit (Table 4.5-3). Model 1 (Table 4.5-3) incorporated rain (inches) as a time dependent covariate. The model was significant and the estimated hazard ratio was 4.18 (1.18, 9.55) indicating that a tagged eel was 4.18 times more likely to transition into the canal per inch of rain. Model 5 had the lowest AIC of 1634.17, which incorporated diurnal (day/night) effects as an interaction effect with rain. The model was highly significant and indicates that an eel was 8.57 (3.76, 19.55) times more likely to transition into the canal during the night as it rains. The more it rains at night, the more likely a fish is to transition into the canal. Interestingly, daytime movement during a rain event was not significant meaning this transition rate was not different from baseline movement rates. Plausible models also exist with flow. An interaction model with diurnal cues and flow (Model 6, Table 4.5-3) found that fish were 1.11 times more likely to transition into the canal at night as Canal Flow increases by 1000 cfs. Similarly, fish are 1.47 times more likely to transition into the canal (Model 7, Table 4.5-3) at night as spill flow increases by 1000 cfs. These results suggest that fish are motivated by rain and flow events.

From the impoundment, fish may also pass into the bypass reach via the spillway. Five models were fit to this data, the first of which assessed the effect from rain (Table 4.5-4). Model 1 was highly significant and the estimated hazard ratio was 24.6 (6.191, 97.76) suggesting that eels pass over the spillway with greater frequency given greater rainfall, likely due to increased spill over the bascule gages. The second model incorporated diurnal cues; however, there was a convergence error as indicated by the confidence interval on the hazard ratio ranging between 0 and infinity. This error was due to the fact that all fish transitioned into the bypass reach at night. The third model incorporated spill flow and was significant. The hazard ratio was 1.19 (1.10, 1.29) suggesting fish are 1.19 times more likely to experience passage into the bypass reach as spill increases by 1,000 cfs. The fourth model incorporated canal flow, but was not significant. The fifth model included an interaction term for rain and spill, and not surprising the model was significant. The sixth and best model incorporated diurnal cues and rain and was significant. The estimated hazard ratio at night when it rains was very high, at 39.9 (10.3, 155). This result means that a fish is 39.9 times more likely to transition at night when it rains than at night when it doesn't rain. This suggests that fish are highly motivated to move at night when it rains.

In summary, 69% of the eel that reached TFD passed through gatehouse and into the canal, while 10% passed via spill into the bypass reach. Diurnal cues and rainfall were the strongest factors influencing passage for both of these routes. Eel were 8.57 times more likely to transition into the canal from TFI for every inch of rain at night and 39.9 times more likely to transition from TFI into the bypass reach via spill for every inch of rain at night.

Table 4.5-1. Raw recaptures within each TFD route selection reach.

Reach	TransCanada	Upper Impoundment	Lower Impoundment	All Cohorts
Impoundment	39	43	45	127
Canal	29	25	34	88
Bypass	2	7	4	13
Mortality	0	1	1	2
Unknown State	6	8	5	19

Table 4.5-2. Descriptive statistics of event times (hours) from the NMPS intake to an absorbing state

Event	Min	25%	Median	75%	Max
Canal	2.75	43.83	97.58	198.0	593.50
Bypass	20.10	21.11	32.67	53.83	143.50
Mortality	179.6	238.4	297.1	355.8	414.6
Unknown State	2.76	16.86	135.8	212.8	518.1

Table 4.5-3. Cox Proportional Hazards output for time-to-canal state.

Model Number	Covariates	AIC	LR test	Hazard Ratio	SE	p	(+/-)
1	Rain (in)	1647.84	0.001	4.18	0.42	< 0.001	(1.18,9.55)
2	Canal Flow (kcfs)	1678.07	< 0.001	1.11	0.03	< 0.001	(1.05,1.17)
3	Spill Flow (kcfs)	1683.06	0.004	1.10	0.02	< 0.001	(1.04,1.15)
4	Diurnal (Day = 1)	1636.65	< 0.001	0.10	0.42	< 0.001	(0.04,0.23)
5	Day:Rain (in)	1634.166	<0.001	0.11	1.55	0.172	(0.01,2.52)
	Night:Rain (in)			8.57	0.42	<0.001	(3.76,19.55)
6	Day: Canal Flow (kcfs)	1635.18	<0.001	0.85	0.07	0.02	(0.74,0.98)
	Night: Canal Flow (kcfs)			1.11	0.02	<0.001	(1.05,1.18)
7	Day: Spill Flow (kcfs)	1635.73	<0.001	0.76	0.26	0.292	(0.45,1.27)
	Night: Spill Flow (kcfs)			1.47	0.03	<0.001	(1.37.1.57)

Table 4.5-4. Cox Proportional Hazards output for time-to-bypass state.

Model Number	Covariates	AIC	LR test	Hazard Ratio	SE	p	(+/-)
1	Rain (in)	304.06	< 0.001	24.6	0.704	< 0.001	(6.19,97.76)
2	Diurnal (day)	305.29	< 0.001	0	3,772	0.996	(0, inf)
3	Spill Flow (kcfs)	313.82	0.003	1.19	0.04	< 0.001	(1.10,1.29)
4	Canal Flow (kcfs)	321.19	0.24	0.91	0.08	0.254	(0.78,1.07)
5	Rain: Spill Flow	300.38	< 0.001	2.18	0.14	< 0.001	(1.67, 2.86)
6	Day: Rain (in)	295.71	< 0.001	0.0	400	0.55	(0, inf)
	Night: Rain (in)			39.9	0.69	< 0.001	(10.3,155)

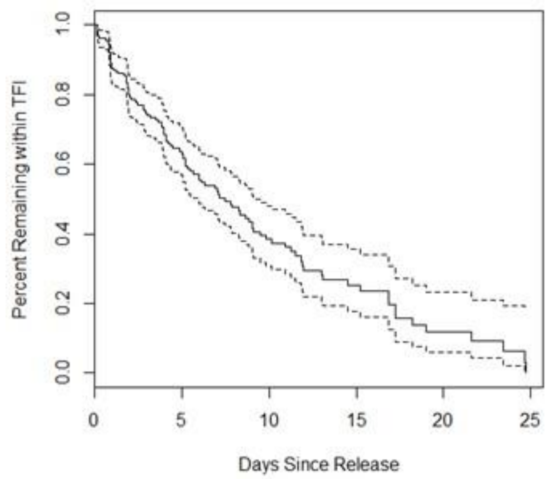


Figure 4.5-1. Kaplan-Meier survival curve for fish remaining in the Impoundment

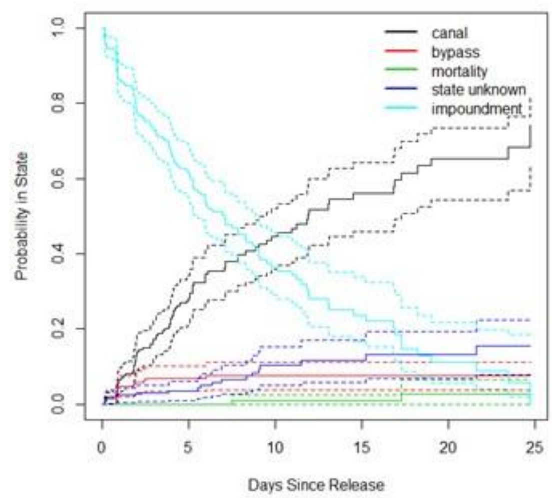


Figure 4.5-2. Nelson-Aalen cause-specific cumulative incidence curves showing probability in state at time (t) for those fish that pass into the canal, bypass reach, die or pass into the unknown state. Note Kaplan-Meier curve for impoundment state superimposed on figure to show that probabilities sum to 1.0 at all event times.

4.6 Competing Risks: Assessment of Escapement from the Power Canal

Once in the Power Canal, emigrating adult silver phased American Eel are faced with another route selection. Fish can escape the canal via either the Cabot Station powerhouse, the downstream bypass sluice, or the Station No. 1 powerhouse. Final detections of fish in the canal at T171, T172, or T173, followed by subsequent detections within the Cabot station tailrace (T17 - T19), indicate passage though Cabot Station turbines. Final detections of fish in the canal at T174, followed by subsequent detections in the tailrace, indicate passage via the downstream bypass adjacent to Cabot Station intake. Final detections of fish in the canal at T13 or T14, followed by subsequent detections in the bypass reach at T15 indicate passage through Station No. 1 turbines. The event time (transition into an absorbing state, or passage) was considered to be the last recapture in the canal before a subsequent detection further downstream of the project.

Fish overwhelmingly chose to escape the canal via Cabot Station powerhouse for all release cohorts (Table 4.6-1). Of the 87 viable fish from all release cohorts, 72 passed through the Cabot Station turbines (72/87 = 83%). Over the course of the study, we were unable to determine the passage route of five of the 87 fish that entered the power canal. Fish appeared to escape from the canal via Cabot Station quickly, with the minimum event time occurring 4.71 hours after release (Table 4.6-2). Fish exited the canal via Cabot Station throughout the entire study period, with a median passage time of 96.37 hours after release, and a final escape event occurring at 622.80 hours post-release. Fish that exited through the downstream bypass sluice had a median event time of 104.90 hours after release, while fish that chose the Station No. 1 route had a median event time 98.92 hours after release. A histogram (Figure 4.6-1) was developed for all fish exiting the power canal that exhibited the duration of time between their first detection in the canal and the first detection in the tailrace. We see a majority of the fish exiting the canal between 0 and 6 hours (Figure 4.6-1).

The Kaplan-Meier (Figure 4.6-2) survival plot shows the last fish to transition into an absorbing state did so after 25 days post release. As expected, the in-state probabilities at the end of the study on the Nelson-Aalen cumulative incidence plot (Figure 4.6-3) matched empirical expectations. Cox Proportional Hazard regressions were conducted on fish that exited the canal via the Cabot Station, the downstream bypass sluice, and Station No. 1.

The first event of interest for fish escaping the canal was passage through Cabot Station. A series of Cox Proportional Hazard regression models were fit (Table 4.6-3). The first model only incorporated diurnal cues as a time dependent covariate. The model was significant and the estimated hazard ratio was 0.10 (0.04, 0.29) indicating that a tagged eel was 0.10 times less likely to transition through Cabot Station during the day. The second model incorporated canal flow and was significant. The estimated hazard ratio was 1.28 (1.18,1.39) suggesting a fish was 1.28 times more likely to pass through the Cabot Station powerhouse for every 1,000 cfs in project discharge. The third model incorporated the rate of change in canal flow over 15 minutes (acceleration in flow) to understand ramping effects; however, the model was not significant (LR = 0.15). Model 4 has the best AIC value at 895.57, which incorporated diurnal (day/night) cues as an interaction effect with canal flow (kcfs). The model was highly significant (LR < 0.001) indicating that an eel was 1.26 (1.16, 1.36) times more likely to transition through Cabot Station with increased flows at night. In contrast, daytime movement through the Cabot Station powerhouse was not significant (HR = 1.01 (0.86, 1.18), p = 0.94). American eel are motivated to pass through the powerhouse at night during high Cabot discharge events.

The second event of interest for fish escaping the canal was passage through the downstream bypass sluice adjacent to Cabot Station intake at the terminus of the power canal. A series of Cox Proportional Hazard regression models were fit to assess diurnal effects, canal flow, and delta canal flow; however, none of the models was significant (Table 4.6-4). Similarly, a series of Cox Proportional Hazard regression models were fit to assess diurnal effects and canal flow on passage through Station No. 1 Powerhouse; however, none of these models was significant (Table 4.6-5). Given the small number of eels to experience an event through the bypass sluice or passage through Station No. 1 powerhouse, we cannot determine what operational effects or environmental cues increase the probability of transition.

In summary, 83% of eel in the canal escaped via Cabot Powerhouse, 8% escaped via the downstream bypass, and 3% escaped via Station 1 Powerhouse. The most important factors influencing escapement from the canal via Cabot Powerhouse were diurnal cues and canal flow and eel were 1.26 times more likely to escape the canal via Cabot Powerhouse for every 1000 cfs increase in canal flow at night.

Table 4.6-1. Raw recaptures within each canal escapement absorbing state.

Route	TC	Upper Impoundment	Lower Impoundment	All Cohorts
Cabot Powerhouse	22	24	26	72
Downstream Bypass	4	0	3	7
Station 1 Powerhouse	2	0	1	3
Unknown Route	1	1	3	5

Table 4.6-2. Descriptive statistics of event times from the canal to an absorbing state

Event	Min	25%	Median	75%	Max
Cabot Powerhouse	4.71	44.14	96.37	191.50	622.80
Downstream Bypass	21.96	66.44	104.90	121.80	125.90
Station 1 Powerhouse	66.52	82.72	98.92	191.50	284.20
Unknown Route	70.83	94.98	169.10	285.00	404.20

Table 4.6-3. Time to event model statistics for Cabot Powerhouse passage models.

Model Number	Covariates	AIC	LR test	Hazard Ratio	SE	p	(+/-)
1	Diurnal (Day = 1)	914.51	<0.001	0.10	0.52	<0.001	(0.04,0.29)
2	Canal Flow (kcfs)	913.39	<0.001	1.28	0.04	<0.001	(1.18,1.39)
3	Delta Canal Flow (1000 ft^3/s^2)	949.31	0.15	<0.001	116	0.13	(0.00,$1.1*10^{22}$)
4	Day: Canal Flow (kcfs)	895.57	<0.001	1.01	0.08	0.94	(0.86, 1.18)
	Night: Canal Flow (kcfs)			1.26	0.04	<0.001	(1.16, 1.36)

Table 4.6-4. Time to event model statistics for Downstream Bypass passage models.

Model Number	Covariates	AIC	LR test	Hazard Ratio	SE	p	(+/-)
1	Diurnal (Day = 1)	96.13	<0.01	<0.001	9537	1	(0, INF)
2	Canal Flow (kcfs)	102.31	0.38	1.10	0.11	0.38	(0.88, 1.38)
3	Delta Canal Flow (kcfs)	103.08	0.94	<0.001	464	0.95	(0, INF)

Table 4.6-5. Time to event model statistics Station 1 Powerhouse passage models.

Model Number	Covariates	AIC	LR test	Hazard Ratio	SE	p	(+/-)
1	Diurnal (Day = 1)	43.61	0.88	0.83	1.23	0.88	(0.08, 9.13)
2	Canal Flow (kcfs)	102.24	0.36	1.41	0.37	0.35	(0.69, 2.89)

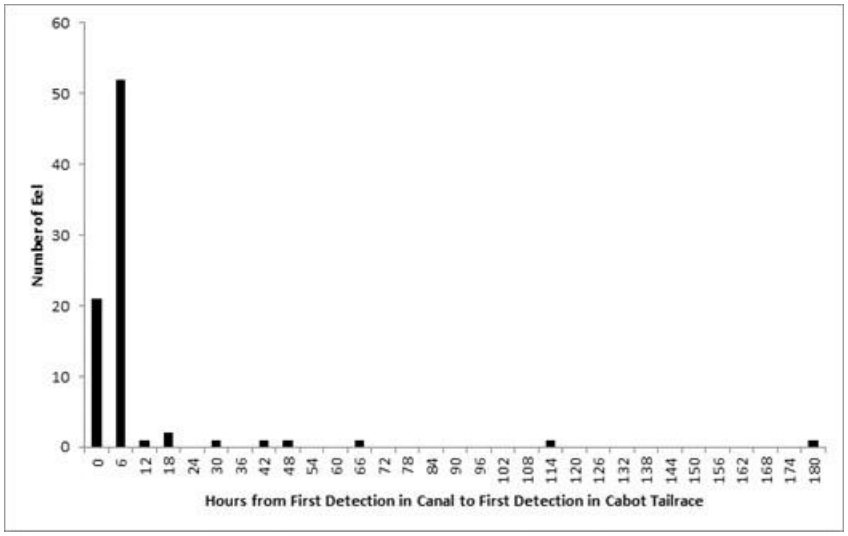


Figure 4.6-1. Histogram of durations for all fish within the canal. The durations in hours were calculated between the first detection in the canal and the first detection within Cabot Tailrace.

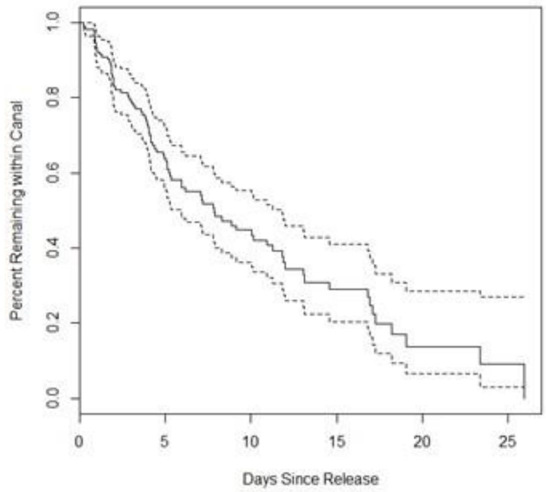


Figure 4.6-2. Kaplan-Meier survival curve for fish remaining in the canal

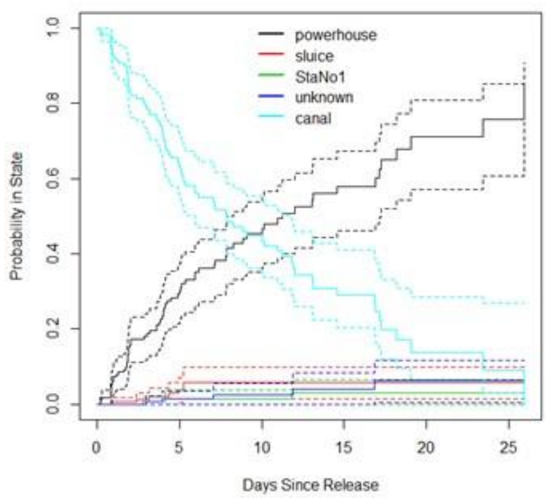


Figure 4.6-3. Nelson-Aalen cause-specific cumulative incidence curves showing probability in state at time (t) for those fish that pass through the powerhouse, bypass sluice, station no.1 power house or pass into the unknown state. Note Kaplan-Meier curve for canal state superimposed on figure to show that probabilities sum to 1.0 at all event times.

4.7 Evaluation of Passage Survival (HI-Z Turb'N Tag)

The results of the survival evaluation are summarized herein; a complete report is provided in Appendix B.

4.7.1 Cabot Station

Forty-nine (49) of the 50 (98.0%) eels released at Cabot Station were recaptured within an average of 6.8 minutes. All 25 control eel were recaptured with no injuries or mortalities. Of the recaptured eels at Cabot Station, two had visible injuries attributed to mechanical forces, but neither died within the 48-hour monitoring period. Another eel died during the 48-h holding period, but had no visible injuries externally or internally. Survival of eel within 1 hour of turbine passage at Cabot Station Unit 2 was 98%, and 96% after 48 hours (Table 4.7-1). This was higher than survival rates from six other projects with propeller type turbines where survival ranged from 62-93%.

4.7.2 Station No. 1

Twenty-seven (27) of the 30 (90.0%) treatment eel were recaptured within 2 to 11 minutes after passage through Station No. 1, Unit 1. No injuries were evident, and no additional mortalities occurred within 48 hours (Table 4.7-1). Only 19 (63.3%) of the 30 eel released through Units 2/3 were recaptured. Recapture times ranged from 2 to 87 minutes and averaged 9.6 minutes. Eighteen (18) of the recaptured eel were alive, one was found dead, and three were injured. Injuries included hemorrhaging, broken bones, bruising, and cuts. The lower survival at Units 2/3 (62.1%) appears to be partially due to a portion of the eels passing through the smaller and faster rotating Unit 2. Also, only HI-Z inflated balloon tags were retrieved on 33.3% of the 30 passed fish, and these fish were assigned a dead status; however, this is likely conservative since eels have been recaptured in good condition with several of the tags missing.

4.7.3 Bascule Gates

Ninety-five (95) eels were released throughout three flow scenarios, 1,500, 2,500, and 5,000 cfs over Bascule Gate 1. Recapture rates at each of the test flows were 85.7, 80.0, and 83.3%, respectively, with a combined recapture rate of 83.2%. Recapture times for the eels released over Bascule Gate 1 at the three flow rates ranged from 2 to 85 minutes and the averages ranged from 6.4 and 11.3 minutes. All recaptured eel (79) were alive, with only one minor injury reported. Of the remaining eel, 10 eels were detected with stationary radio signals and were considered dead. The condition of the remaining four was unknown. The survival rate at Bascule Gate 1 under flow scenarios 1,500, 2,500, and 5,000 cfs was 88.2, 85.7, and 86.2% respectively at both hour 1 and 48 (Table 4.7-1). The overall 48-h survival was 86.8%. Overall, 12.6% of the mortality was assigned to eels that were not retrieved.

Recapture rates at Bascule Gate 4 ranged from 88.6 to 93.3%. One eel was recaptured dead from decapitation, and one was found bleeding from the mouth. The overall recapture rates for Bascule Gate 4 was 91.6%. Recapture times at the three flows ranged from 2 to 139 minutes, and the averages ranged from 4 and 17 minutes. Survival rate at Bascule Gate 4 under 1,500 cfs was 88.6, but dropped to 82.9% due to one delayed mortality within the 48-hour monitoring period. No internal or external injuries were observed in this eel. Survival at 1 h and 48 h was 90.0% and 93.3% when eels were passed Bascule Gate 4 at 2,500 and 5,000 cfs, respectively (Table 4.7-1). The overall 48-h survival at Bascule Gate 4 was 88.4% (Table 4.7-1).

The Bascule Gates should be viable means to safely pass most emigrating eels if they are drawn to surface spill; however, these Bascule Gates do not appear to offer a safer passage route than the Cabot Station turbines.

Table 4.7-1. Summary of 1-hour and 48-hour survival rates and 90% CI (+/-) for each study site.

Station	Number Released	1-hour Survival Rate (90% CI +/-)	48-hour Survival Rate (90% CI +/-)
Cabot Station Unit 2	50	98 (3.3)	96.0 (4.6)
Station No. 1 Unit 2/3	30	62.1 (14.8)	62.1 (14.8)
Station No. 1 Unit 1	30	90.0 (9.1)	90.0 (9.1)
Bascule Gate 1 (combined)	95	86.8 (5.8)	82.9 (5.9)
1,500 cfs	35	88.2 (4.0)	88.2 (4.0)
2,500 cfs	30	85.7 (7.4)	85.7 (7.4)
5,000 cfs	30	86.2 (10.5)	86.2 (10.5)
Bascule Gate 4 (combined)	95	90.5 (4.9)	88.4 (5.4)
1,500 cfs	35	88.6 (8.7)	82.9 (10.5)
2,500 cfs	30	90.0 (9.1)	90.0 (9.1)
5,000 cfs	30	93.3 (7.6)	93.3 (7.6)
Combined Controls	25	100	100

5 DISCUSSION

The CJS model showed that 164 of the 170 viable eels were recaptured within the impoundment, however only 101 were recaptured within the project (anywhere within the bypass reach or power canal). This drop off in raw recaptures was corroborated with the impoundment-to-project survival rate of 69% from the CJS, meaning that slightly more than 30% of the fish are not expected to arrive anywhere within the project (bypass reach or power canal) after arriving in the impoundment (i.e., they do not pass and remain in the impoundment). Two fish were confirmed to be entrained at NMPS entrained, and we suspect that up to 34 more were likely entrained. Those 34 fish were placed into an unknown state after leaving the intake. Cox Proportional Hazards regression found that those 34 fish were more likely to transition into the unknown state at night when NMPS is typically in pumping mode. At the Turners Falls Project, all of the fish that entered the power canal escaped. The only fish that passed from the impoundment into the project and were not recaptured within the Cabot Station tailrace, were those that passed into the bypass reach. This suggests that survival for those fish that pass via spill is lower than those fish that pass through the Cabot powerhouse. The results from the HI-Z Turb'N Tag testing (Appendix B) support this, with overall survival rates of 86.8% and 88.4% for fish passing over Bascule Gates 1 and 4, respectively, and an overall survival rate of 96% for fish passing through Cabot Station turbines.

Not surprisingly, eels are motivated to move at night when it rains. The probability that fish will transition into both the canal and bypass reach was higher during these times. Fish were 8.57 (3.76,19.55) times more likely to transition into the canal from the impoundment at night when it rains as opposed to at night when it isn't raining and 39.9 (10.3,155) more likely to transition into the bypass reach at night when it rains. Fish are more than likely transitioning into the bypass reach when water is spilling over the TFD. Previous studies have shown increased eel movement at night (Haro et al., 2000 and Brown et al., 2009) and after heavy rain events (Durif et al., 2003).

For fish that are emigrating, a proportion of the eels released into the lower TFI near the confluence of the Millers River swam upstream and were recaptured within the upper impoundment/intake area. In total, 15 of the lower impoundment fish migrated upstream through the TFI and were recaptured either at Gill Bank or Shearer Farms, and 11 of those 15 fish were attracted to the intake. Of those 11 fish, one was confirmed entrained and three entered into the unknown state. Therefore, four fish released 2.3 rkm below the intake, swam upstream and were entrained. Of the 19 fish that we lost track of in the Turners Falls route selection model, five were found to have migrated upstream and were possibly entrained. This behavior is not uncommon for tagged eels, in a small study with European Eels, almost all tagged individuals moved upstream after release (Durif et al., 2003).

FirstLight investigated the low recapture rates at Montague because the through-project survival rates were very low in both the raw count (6%) and CJS (19.5%) estimates. These results directly contrast with the survival estimates from the HI-Z Turb'N Tag testing at the bascule gates and Cabot Station turbines, where 48-hour survival estimates ranged from 86.8 to 96%, respectively. All of the fish that transitioned through the powerhouse and were recaptured at T17 displayed 'alive' signals, so we do not believe these fish died. Further, analysis found that the fish entered an unknown state at night after rain events, which indicates they were motivated to move downstream. The raw count and CJS survival estimates both relied heavily on recaptures at the Montague monitoring station, and we believe that there may have been a poor detection rate for eel at Montague. Of the 106 eel detected at Cabot Station tailrace, only 10 eel were detected further downstream at the Montague monitoring site (Table 5-1). The last tagged eel to be detected at Montague was observed at 06:32 AM on October 29, 2015. Despite the fact that the overwhelming majority (89%) of eel that were detected at Cabot Station tailrace left the tailrace after that time, no subsequent eel detections were observed at the Montague receivers. Given that most of the fish that transitioned from the Cabot Station tailrace to Montague did so in less than 30 minutes (Table 5-1), we would have expected a large proportion of fish departing from Cabot Station tailrace after October 29, 2015 06:32 AM to be detected at Montague shortly after their departure. Additionally, mobile tracking data confirmed that three eel passed the Montague Wastewater site without being detected after October 29, 2015. The weather station at the Orange Municipal Airport in Athol, MA showed that 0.89 inches of rain fell on October 29, 2015, with wind gusts of up to 29 mph (Weather Underground 2017). Similarly, USGS Gage 01170500 shows a spike in discharge on October 29, 2015 (Figure 5-1)

The DIDSON camera data produced sparse counts. We primarily had zero count days punctuated with days where 1 to 3 fish were captured for the entire study period. The peak migration time differed between years. In 2015, the largest counts appeared early in the season in August (Figure 4.2-1), while in 2016 the peak occurred later in mid-October (Figure 4.2-2). Surprisingly, the 20-m range setting produced smaller counts even though it sampled a larger area of the canal. In 2015, the 10-m range estimate of migration magnitude was 2,382 fish, while the 20-m range setting estimate was only 378 fish. This disparity is reflective of the differences in the raw counts between the two years of study. Over the two-year sampling period, 41 eels were detected at the 10-m range setting, while 29 eels were captured within the 20-m range. Having the same or smaller counts at the 20-m range setting means that their extrapolated counts will be lower. This is because the fish per m^2 number is much smaller for the 20-m range than the 10-m range. For example, if one fish was captured at the 10-m range, the density is 0.08 fish per m^2 (1/12.28 m^2) while the density based on the 20-m count(s) is 0.02 fish per m^2. When extrapolated out to the canal cross sectional area, this results in 19.6 fish at the 10-m range and 4.9 fish at the 20-m range. Thus, we can conclude that more canal area sampled does not necessarily mean higher counts. Many more fish would have to be recaptured in the 20-m range and that did not happen. In 2015, there were 17 days in which both the 10-m and 20-m range detected eels. Of those, higher counts with the 10-m data occurred on 7 days and there was only one where both the 10-m and 20-m counts of eel were identical. In 2016, there were 18 days in which both the 10-m and 20-m range were sampled and eel observed. Of those days, only 4 days had higher counts at the 10-m range. Even though some days had higher 20-m counts, they were not high enough to influence the extrapolation. Regardless, the 10-m counts were extrapolated to the entire day and the 10-m count is reflective of a 24-hour period. Given that we had more complete coverage with the 10-m count, we believe the 10-m count is an acceptable estimate of the magnitude of the migration through the canal.

Table 5-1. Eel recaptured at both Cabot Station tailrace and Montague Wastewater monitoring sites.

Fish ID	Last Detection at Cabot Tailrace	First Detection at Montague	Time Gap Between Cabot Tailrace and Montague (min)
149.760 27	10/27/2015 4:23:54 AM	10/27/2015 7:08:45 PM	885
149.760 32	10/27/2015 7:11:28 PM	10/27/2015 7:47:27 PM	36
149.760 30	10/27/2015 10:12:49 PM	10/27/2015 10:42:57 PM	30
149.740 32	10/28/2015 7:19:08 PM	10/28/2015 7:38:05 PM	19
149.740 23	10/28/2015 10:16:09 PM	10/28/2015 10:37:35 PM	21
149.760 37	10/28/2015 10:29:11 PM	10/28/2015 10:56:20 PM	27
149.760 35	10/28/2015 10:44:13 PM	10/28/2015 11:02:45 PM	18
150.340 101	10/29/2015 12:12:13 AM	10/29/2015 12:40:28 AM	28
149.740 48	10/29/2015 5:04:22 AM	10/29/2015 5:25:07 AM	21
149.760 51	10/29/2015 6:03:21 AM	10/29/2015 6:32:05 AM	29

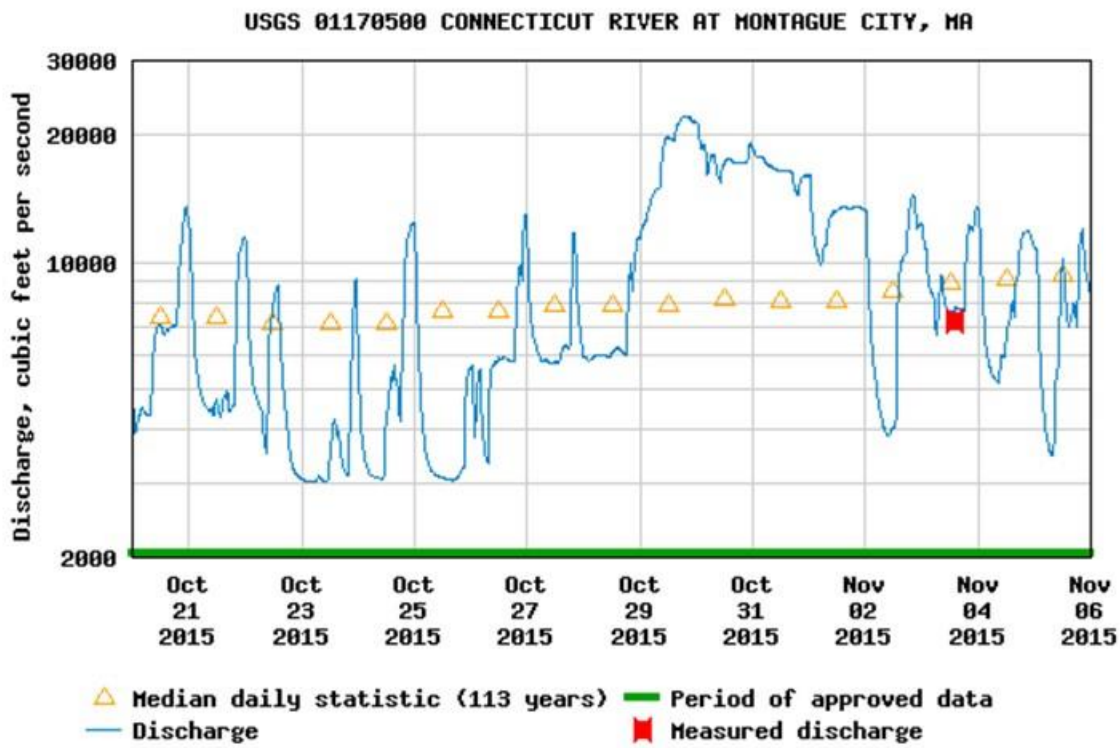


Figure 5-1. USGS Gage 01170500 around October 29, 2015.

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APPENDIX A – RADIO TELEMETRY MONITORING SYSTEM CALIBRATION

Montague Wastewater

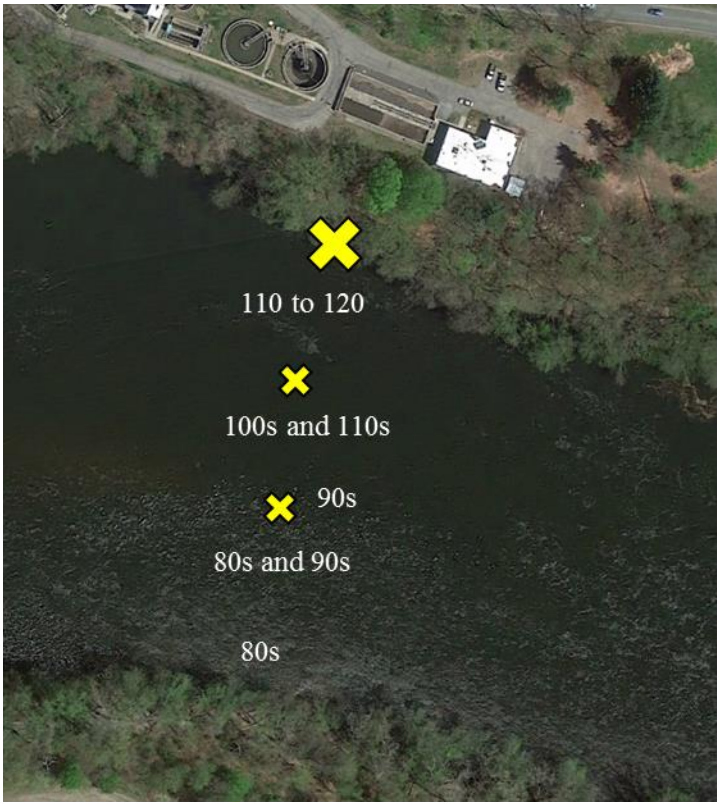

Figure A-1: The large X marks the approximate placement of the Yagi antenna used, in conjunction with a Lotek SRX receiver, to detect fish moving across the width of the river at River Mile 119.5. The small X's mark the approximate placement of the in-water droppers used to assist with monitoring the passage of downstream eel. The radio test tag produced power levels ranging from 80s to 120s, with the highest readings located near the bank of the river, closest to the Yagi antennas, and attenuating slightly toward the far bank.

Cabot Station Tailrace

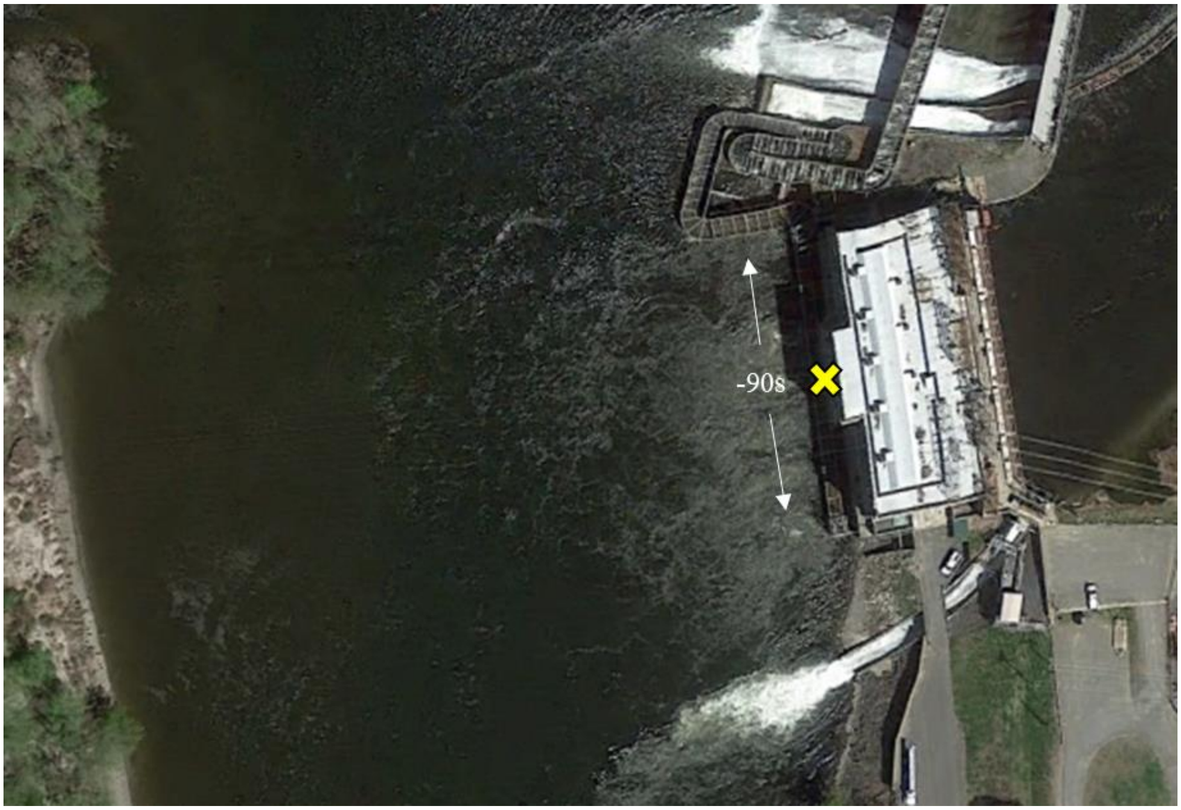

Figure A-2: The X marks the approximate placement of two Yagi antennas used, in conjunction with an Orion receiver, to detect fish within the vicinity of the Cabot Station Tailrace. The radio tag was tested at a depth of 5ft. Power levels remained consistent, between 90 and 100 dB, across the tailrace.

Cabot Station (far field)

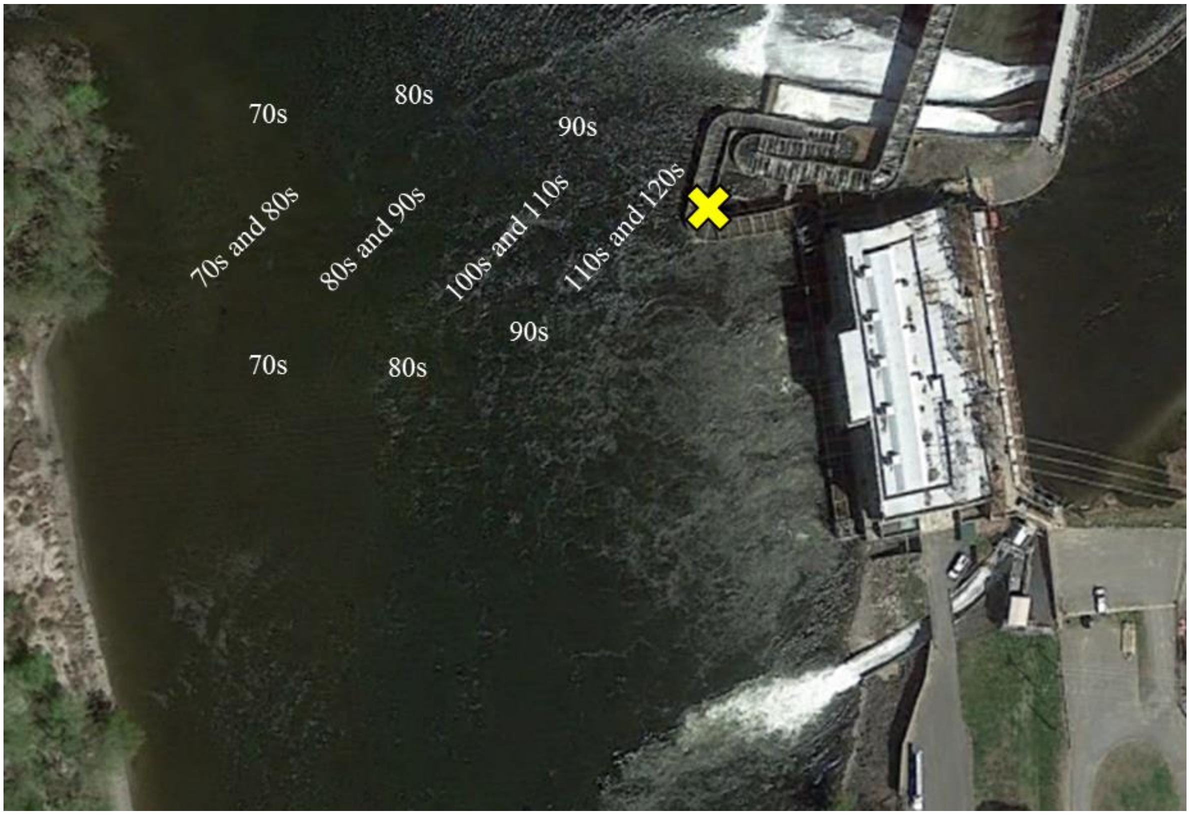

Figure A-3: The X marks the approximate placement of a Yagi antenna used, in conjunction with a Lotek 400 receiver, to detect fish across the width of the river passing Cabot Station at River Mile 120. The radio tag was tested at a depth of 5ft, producing power levels between 70s and 120s. The highest powers were located closest to the Yagi antenna, near the first bend in the Cabot Station Fish Ladder, and attenuating toward the far bank of the river.

Cabot Station Forebay

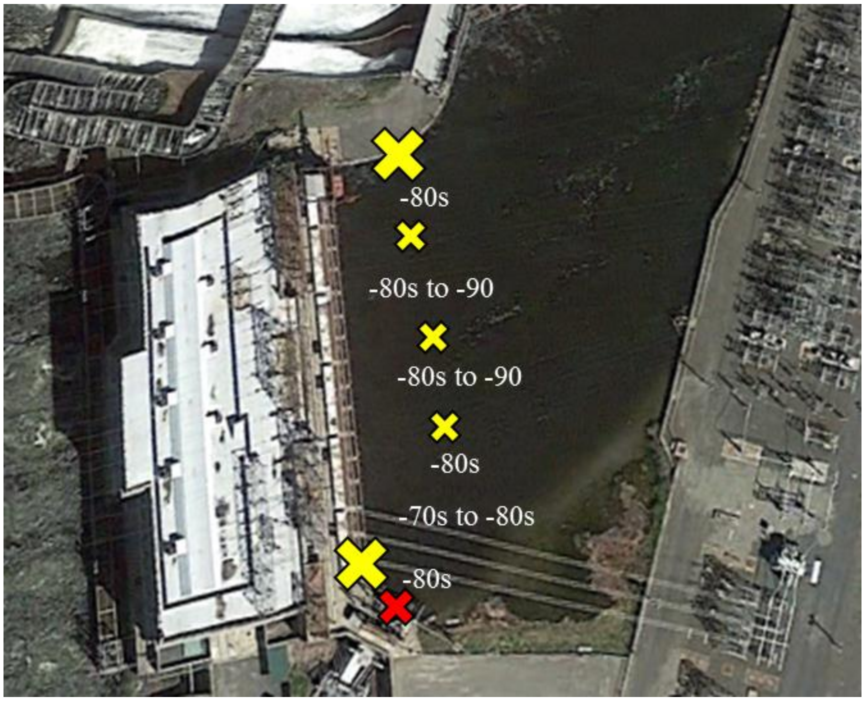

Figure A-4: The large Yellow X's mark the approximate placement of the Yagi antennas and Orion receivers used to detect fish within the vicinity of the Cabot Station forebay. Small yellow X's mark the approximate placement of three in-water droppers used to assist with monitoring the passage of downstream eel nearer to the intake grates. A radio tag was tested at a depth of approximately 2.5ft. Power levels remained strong across the forebay ranging from -70 to -90 db. The small red X marked the location of a dipole antenna and Orion receiver used to monitor eel moving through the downstream bypass. The test tag was read within a 20ft radius with power levels in the -80s db.

Station No. 1 Forebay

Figure A-5: The large X's mark the approximate placement of the Yagi antennas and Orion receivers used to detect fish within the vicinity of the Station No. 1 Forebay. Small X's mark the placement of four in-water droppers used to assist with monitoring eel passing through the intake. A radio test tag produced power levels ranging from -60 to -90 dB, with higher power levels closer to the Yagi antennas and slightly lower power levels toward the middle of the forebay.

Below Turners Falls Dam (River Left)

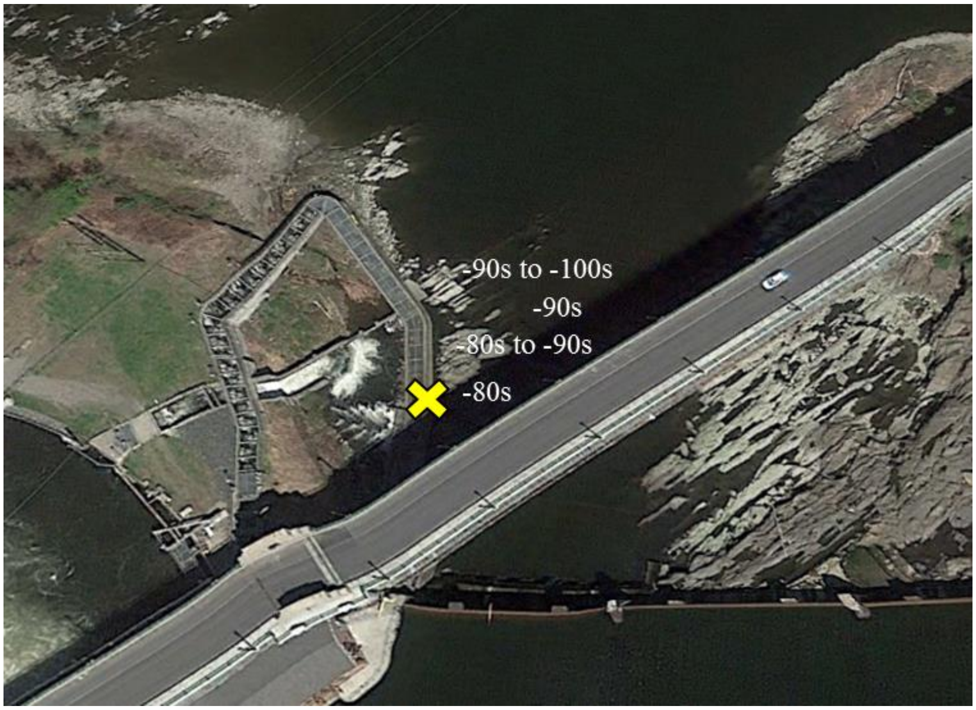

Figure A-6: The X marks the approximate placement of the Yagi antennas used, in conjunction with an Orion receiver, to detect fish within the vicinity of the fishway below the Turners Falls Dam, at River Mile 122. The radio test tag produced power levels ranging from -80 to -100s dB, with higher power levels closer to the Yagi antenna.

Below Turners Falls Dam (Bascule Gate No. 4)

Figure A-7: The X marks the approximate placement of the Yagi antennas used, in conjunction with an Orion receiver, to detect fish below Bascule Gate 4. The radio test tag produced power levels ranging from -90 to -100s db.

Below Turners Falls Dam (River Right)

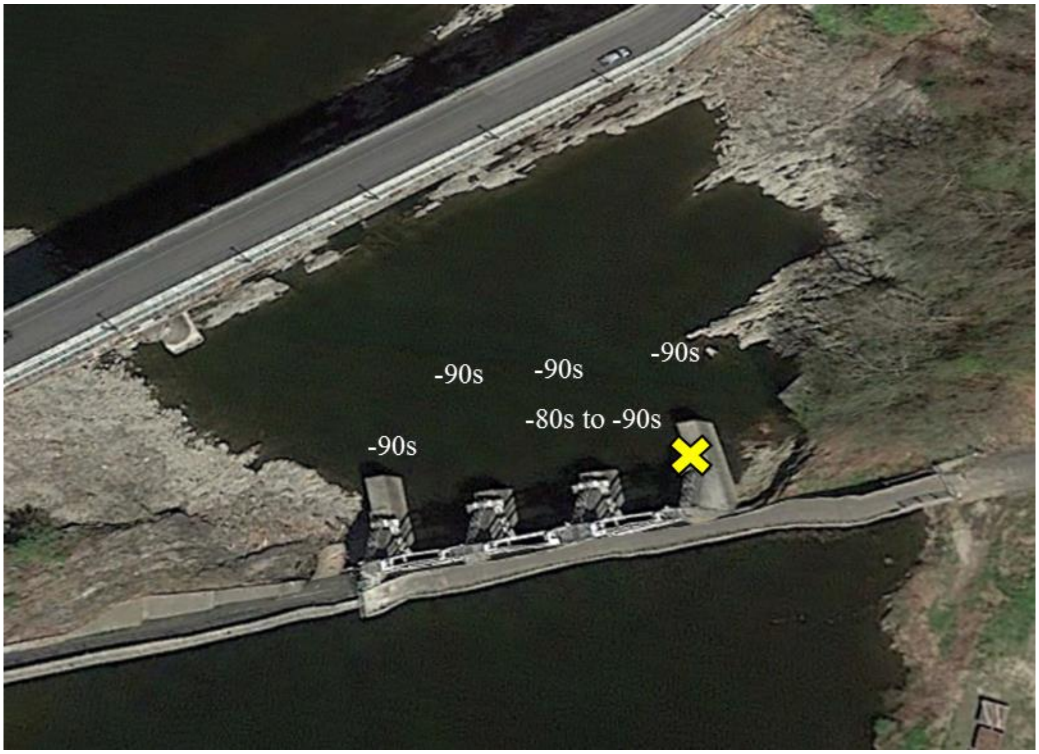

Figure A-8: The X marks the approximate placement of the Yagi antennas and Orion receiver used to detect fish below the Turners Falls Dam at River mile 122. The radio test tag produced power levels ranging from -80 to -90s dB, with highest power levels located closest to the Yagi antenna.

Upstream of Gatehouse

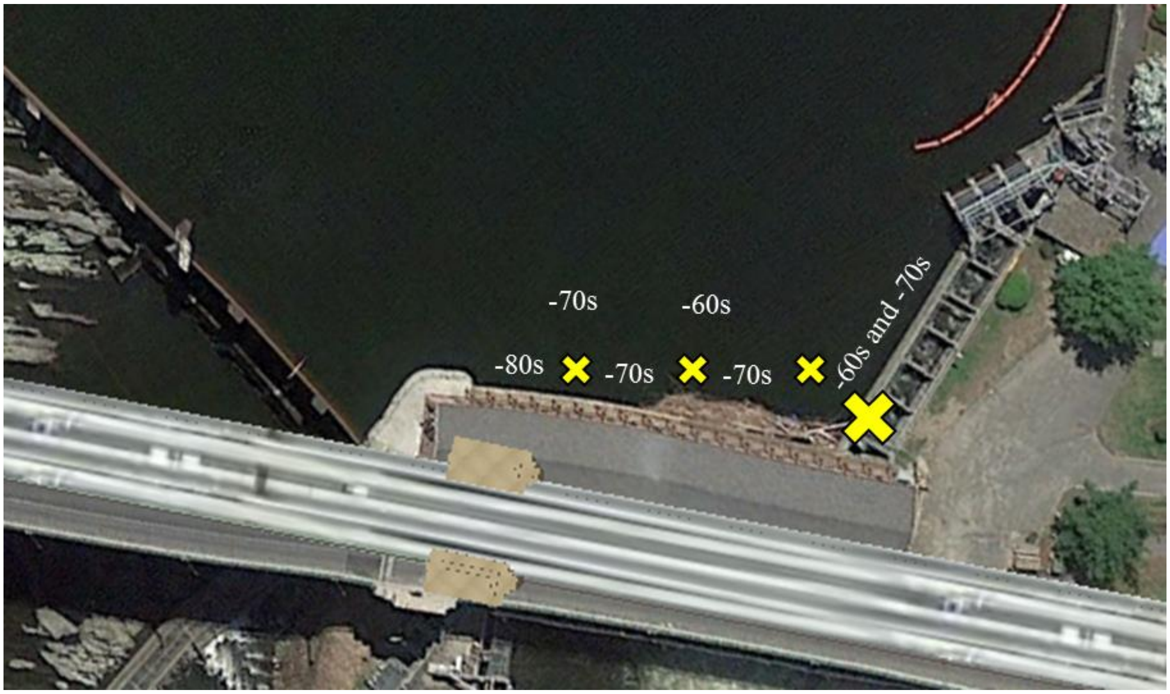

Figure A-9: The large X marks the approximate placement of the Yagi antenna and Orion receiver used to detect fish moving within the area upstream of the Gatehouse. Small X's mark the approximate placement of three in-water droppers used at this location to assist with monitoring the passage of downstream eel. The radio tag was tested at a depth of approximately 5 ft. Power levels remained consistent during testing, ranging from -70 to -80 db. The in-water dropper antennas were later removed on 10/29/2016 due to repeated fowling from floating detritus.

Upper Canal

Figure A-10: The large X marks the approximate placement of the Yagi antenna used, in conjunction with an Orion receiver, to detect fish moving through the power canal downstream of the Gatehouse. Small X's mark the approximate placement of three in-water droppers used at this location to assist with monitoring the passage of downstream eel. The radio tag was tested at a depth of approximately 2 to 3 ft. Power levels remained consistent around -70 to -80 dB across the canal, and attenuated out to -90 dB downstream of the bridge.

Turners Falls Impoundment

Figure A-11: The large X marks the approximate placement of each Yagi antenna and the Lotek SRX receiver used to detect fish across the width of the river, upstream of Turners Falls Dam. Small X's mark the approximate placement of five in-water droppers used at this location to assist with monitoring the passage of downstream eel. Power levels between the droppers ranged from 50s to 90s, with the test tag at 15 ft. A small area in the middle of the river had no detections with the tag at 15 ft, but registered at 5ft with a power level ranging from 60s to 70s.

NMPS Gill Bank

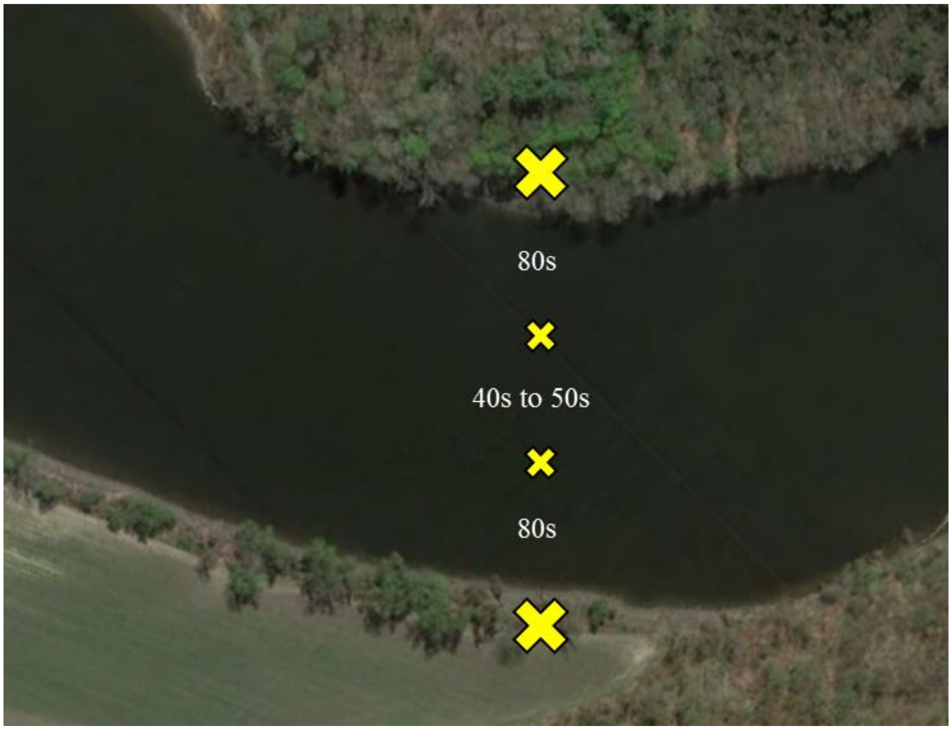

Figure A-12: The large X's mark the approximate placement of each Yagi antenna and the Lotek SRX receivers used to detect fish at Gill Bank, River Mile 126.5. Small X's mark the approximate placement of two in-water droppers used at this location to assist with monitoring the passage of downstream eel. A radio tag was tested at a depth of approximately 15ft. Power levels between the two droppers ranged from 40s to 50s and increased to 80s closer to the Yagi antennas.

NMPS Intake

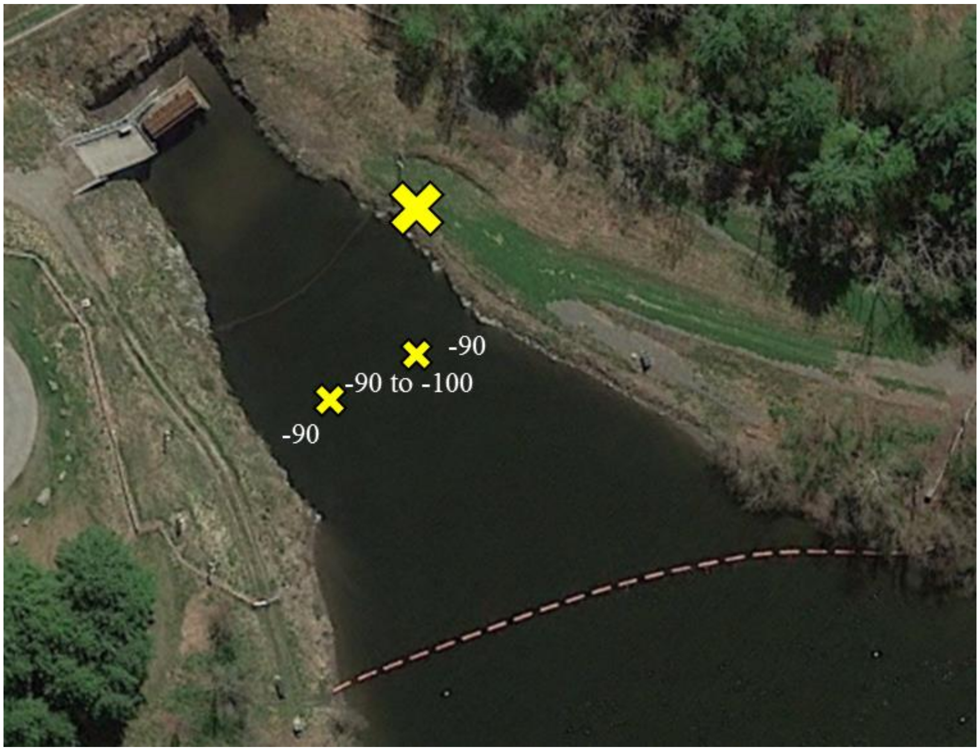

Figure A-13: The large X marks the approximate placement of the Yagi antenna and the Orion receiver used to detect fish moving across the entire NMPS intake. Small X's mark the approximate placement of two in-water droppers used at this location to assist with monitoring the passage of downstream eel. The radio test tag was read with power levels ranging from -90 to low -100 dB across the width of the intake.

NMPS Upper Reservoir

Figure A-14: The large X marks the approximate placement of the Yagi antenna and Orion receiver used to detect fish in the Northfield Mountain Upper Reservoir intake/discharge. Small X's mark the approximate placement of three in-water droppers used at this location to assist with monitoring the passage of downstream eel. The radio tag was tested at a depth of approximately 5 ft. Power levels remained consistent across the intake ranging from -80 to -90s db. Some noise was detected at this site, and amplification was used with the Orion receiver.

Shearer Farms

Figure A-15: The large X's mark the approximate placement of the Yagi antennas and Lotek SRX receivers used to detect fish near Shearer Farm at River Mile 127.5. Small X's mark the approximate placement of six in-water droppers used at this location to assist with monitoring the passage of downstream eel. The radio tag was tested at a depth of approximately 7 to 10 ft, and produced power levels ranging from 130 to 250, with higher power levels closer to the Yagi antennas and attenuating farther out from the antennas. No amplification was needed at this location.

APPENDIX B– DIRECT INJURY AND RELATIVE SURVIVAL OF ADULT AMERICAN EELS AT THE TURNERS FALLS HYDROELECTRIC PROJECT

DIRECT INJURY AND RELATIVE SURVIVAL OF ADULT AMERICAN EELS AT THE TURNER'S FALLS HYDROELECTRIC PROJECT

Prepared for

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Revised Final

January 2017

EXECUTIVE SUMMARY

The overall goal of this study was to assess whether operations at Cabot Station Unit 2, Station 1 (Units 1 and 2/3) and over the Bascule Gates (1 and 4) would affect the safe passage of emigrating adult silver-phase American Eels (*Anguilla rostrata*).

FirstLight Power Resources is licensed by the Federal Energy Regulatory Commission (FERC or the Commission) to operate the Turner's 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. By April 30, 2016, two years prior to license expiration, FirstLight was required to file their Final License Applications for both facilities.

A primary objective of this study was to release a sufficient number of adult American Eels to obtain passage survival estimates within a precision (ε) level of ± 10%, 90% of the time (α=0.10). A target number of 30 eels were proposed for each treatment condition along with 25 combined controls. Treatment eels were released through a vertical Francis turbine at Cabot Station and three horizontal Francis turbines at Station 1, and over Bascule Gates 1 and 4 at three treatment discharges of 1,500, 2,500 and 5,000 cfs. Francis Units 2 and 3 have a common penstock thus survival could not be determined for each unit.

Eels used in this study were procured from a source in Newfoundland and held at each project in a tank, continuously supplied with ambient river water. Water temperature ranged from 7.5 to 9.1°C during the study. Fish tagging, release, and recapture techniques were similar to those used for adult fish in numerous other passage survival studies.

The results were obtained using the HI-Z Turb'N Tag (HI-Z Tag) recapture technique on November 4-9, 2015. The effects of turbine passage at Cabot Station Unit 2 were assessed with 50 treatment eels. The effects of turbine passage at Station 1 through Unit 1 and Units 2/3 were assessed with 60 treatment fish. The effects of spillbay passage through Bascule Gates 1 and 4 were assessed by releasing 95 treatment eels at both locations. A total of 25 control eels were released downstream of the treatment sites.

The treatment eels ranged from 400-960 mm in length with a mean of 692 mm. Control eels ranged from 560-920 mm with a mean of 715 mm. Recapture rates for the treatment eels at Cabot Station Unit 2, Station 1 Unit 1, and Units 2/3, were 98.0, 86.7, and 63.3%, respectively. Recapture rates for the treatment eels for Bascule Gate 1 at 1,500, 2,500, and 5,000 cfs were 85.7, 80.0, and 83.3%, respectively, with a combined recapture rate of 83.2%. Recapture rates for the treatment eels for Bascule Gate 4 at

1,500, 2,500, and 5,000 cfs were 88.6, 90.0, and 93.3%, respectively, with a combined recapture rate of 90.0%. All control released eels were recaptured for all scenarios.

Mean recapture times for eels passed through Cabot Station Unit 2, Station 1 Unit 1, and Station 1 Units 2/3 were 6.8, 4.0, and 9.6 minutes, respectively. Mean recapture times for the eels passing over Bascule Gate 1 at 1,500, 2,500, and 5,000 cfs were 11.3, 9.7, and 6.4 minutes, respectively. Mean recapture times for the eels passing over Bascule Gate 4 at 1,500, 2,500, and 5,000 cfs were 17, 4.0, and 6.5 minutes, respectively. Mean recapture time of the control eels was 3.1 minutes.

The estimated immediate (1 h) survivals for Cabot Station Unit 2 and Station 1 Units 1 and 2/3 were 98.0, 90.0, and 62.1%, respectively. The estimated immediate (1 h) survivals for Bascule Gate 1 at 1,500, 2,500, and 5,000 cfs were 88.2, 85.7, and 86.2%, respectively. The estimated immediate (1 h) survivals for Bascule Gate 4 at 1,500, 2,500, and 5,000 cfs were 88.6, 90.0, and 93.3%, respectively.

The estimated immediate (48h) survivals for Cabot Station Unit 2 and Station 1 Units 1 and 2/3 were 96.0, 90.0, and 62.1%, respectively. The estimated immediate (48h) survivals for Bascule Gate 1 at 1,500, 2,500, and 5,000 cfs were 88.8, 85.7, and 86.2%, respectively. The estimated immediate (48h) survivals for Bascule Gate 4 at 1,500, 2,500, and 5,000 cfs were 82.9, 90.0, and 93.3%, respectively.

All the post-turbine passage recaptured treatment fish were examined for injuries. The total treatment fish that had visible injuries for Cabot Station Unit 2 and Station 1 Units 1 and 2/3 were 2, 0 and 3, respectively. None of the control fish had visible injuries. One fish was injured at Bascule Gate 1 at 1,500 cfs, and none at the other discharge rates. Two fish were injured at Bascule Gate 4 at 1,500 cfs and another at 2,500 cfs. None were injured at Bascule Gate 4 at 5,000 cfs.

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 at Cabot Station Unit 2, Station 1 Unit 1 and Units 2/3, and Bascule Gates 1 and 4 at 1,500, 2,500, and 5,000 cfs were 95.9% (CI 4.6%), 100%, 79.0% (CI 15.5 %), 96.7% (CI 5.4%), 100%, 100%, 96.8% (CI 5.3%), 96.3% (CI 5.9%), and 100%, respectively.

The 96% survival for adult eels passed through the Cabot Station Unit 2 was higher than that obtained at six other projects with propeller type turbines where survival ranged from 62 - 93%. Survival was also high (90%) for the eels passed through the Station 1 Unit 1. The study results indicate that adult eels should incur little mortality or injury passing the Francis units; however if power demands and flow conditions permit Station 1Units 2/3 at should be operated last because of low estimated survival (62.1%).

The present study indicates that the Bascule Gates 1 and 4 should pass eels with relatively high survival (at least 86.8 and 88.4%) and minimal injury (less than 3%). Survival was likely higher because some of the non-recaptured eels assigned a dead status were likely alive. The Bascule Gates should be viable means to safely pass most emigrating eels if they are drawn to surface spill; however these Bascule Gates do not appear to offer a safer passage route than the Cabot Station turbines.

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List of Abbreviations

AOQL	Average Outgoing Quality Limit
C°	Celsius
CRWC	Connecticut River Watershed Council
Cfs	Cubic feet per second
DO	Dissolved oxygen
FERC	Federal Energy Regulatory Commission
FirstLight	First Light Power Resources
FWS	U.S. Department of the Interior – Fish and Wildlife Service
gal	Gallon
h	Hour
HA	Hydroacoustic
K.A.	Kleinsmith and Associates
kW	Kilowatts
LOE	Loss of equilibrium
MA	Massachusetts
MDFW	Massachusetts Department of Fish and Wildlife
MFE	Malady Free Estimates
MHz	Megahertz
mm	millimeters
MW	Megawatts
µS/cm	Micro-Siemens per centimeter
NH	New Hampshire
NHDES	New Hampshire Department of Environmental Services
NHFGD	New Hampshire Fish and Game Department
NTU	Nephelom metric Turbidity Units
RPM	Revolutions per minute
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 direct survival and injury of adult American Eels passing downstream through the Turner's Falls Hydroelectric Project (FERC No. 1889) operated by FirstLight Power Resources (First Light), which is licensed by the Federal Energy Regulatory Commission (FERC) 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. By April 30, 2016, two years prior to license expiration, FirstLight is required to file their Final License Applications for both projects. Cabot Station Unit 2, Station 1 Units 1-3, and Bascule Gates 1 and 4 were recommended for evaluation for relicensing purposes. 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 designated and utilized to provide survival and injury estimates of adult American Eel passed through the desired locations at specified test conditions (Figure 1-1).

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 1 Units 1 and 2/3, and Bascule Gates 1 and 4 affect the safe and timely passage of emigrating silver-phase American Eels (Figures 2-1 to 2-3).

The specific objectives of this study were to:

2.1 Quantify the movement rates, timing, and relative proportion of silver-phase eels passing via various routes at the projects including through the turbines at Cabot Station, Station 1, and over the Bascule Gates at different discharge rates; and

2.2 Assess instantaneous, latent mortality and injury of silver-phase eels passed through each turbine type and spillway. This study was designed to estimate the direct (1 and 48h) survival and malady-free rates (eels without visible injuries and no loss of equilibrium) of adult American eels passing Cabot Station Unit 2, Station 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 near the settings the turbine units are operated at most of the time, and Bascule Gates were evaluated at discharges of 1,500, 2,500, and 5,000 cfs. This report deals only with items in objectives 2.2. A separate report prepared by Kleinschmidt Associates (K.A.) addresses objective 2.1.

3.0 PROJECT DESCRIPTION

The Turner’s Falls Hydroelectric Project and Northfield Mountain Pumped Storage Project are located on the Connecticut River in the states of Massachusetts (MA), New Hampshire (NH), and Vermont (VT) (Figure 1-1).

The greater portion of the Turner Falls Project and Northfield Mountain Project, including developed facilities and most of the lands in the Project boundary, are located in Franklin County, MA; specifically, in the towns of Erving, Gill, Greenfield, Montague, and Northfield. The impoundment created by the Turner’s Falls Dam extends northerly into the town of Hinsdale in Cheshire County, NH and the town of Vernon in Windham County, VT.

The Turner’s 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 in VT/NH. At the Turner’s Falls Dam is a gatehouse controlling flow into a power canal. Associated with this canal are the development's two hydroelectric generating facilities: Cabot Station and Station 1. Cabot Station is located at the downstream terminus of the power canal. Station 1 is located approximately one-third of the way down the power canal, while the Cabot Station and Station 1 discharge into the Connecticut River approximately 0.9 miles downstream of the Turner’s Falls Dam. Discharge over the Turner’s Falls dam is regulated by four Bascule Gates and three tainter gates (Figures 1-1 and 2-1 to 2-3).

The Northfield Mountain Project is a pumped-storage facility that utilizes the Turner’s Falls Impoundment as its lower reservoir. The tailrace of the Northfield Mountain Project is located approximately 5.2 miles upstream of Turner’s Falls Dam on the east side of the impoundment. The Northfield Mountain Project includes a man-made upper reservoir situated atop Northfield Mountain to the east of the tailrace. Water is typically pumped from the Turner Falls Impoundment to the upper reservoir at night, while generation occurs during the day. When generating, water is passed via an underground pressure shaft to an underground powerhouse. An underground tailrace tunnel then delivers water to the Turner’s Falls impoundment. Inflow into the Turner’s Falls impoundment is primarily dependent upon the operations of the Northfield Mountain Project and flow in the Connecticut River.

3.1 Station 1 and Cabot Station

FirstLight has two hydroelectric facilities located on the power canal, including Cabot Station and Station 1. Cabot Station is located at the downstream terminus of the power canal. The powerhouse houses six vertical, Francis type, single runner turbines. Cabot Station has a total station electrical capacity of 62.016 megawatts (MW) or roughly 10.336 MW/unit (Table 3-1). The station has a total hydraulic capacity of approximately 13,728 cfs or roughly 2,288 cfs/unit. Station 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 and 3) tested in this study share a common penstock.

3.2 Turner Falls Dams

The Turner's 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 and a fixed crest section which is normally not overflowed. When fully upright, the top of the Bascule Gates are at elevation 185.5 feet mean sea level (msl). The 493-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 at elevation 185.5 feet msl.

4.0 METHODS

Silver-phase American Eel downstream passage was assessed by radio tagging and systematically monitoring fish movements and passage through each of the routes through the projects. Downstream turbine and Bascule Gate passage survival and injury was assessed by using the HI-Z mark/recapture methodology used on adult eels during previous studies at other power stations (Normandeau Associates, Inc. 2010, 2011a and 2011b).

4.1 Source of Eels

The only reliable source to collect silver-phase American Eels in the Connecticut River Basin is the Holyoke Canal Bypass Sampler. Due to the large number of silver-phase American Eels needed to fulfill the requirements of relicensing studies for the FirstLight Project as well as the TransCanada Projects and Conte Lab research, it was determined that no in-basin source would be sufficient. As a result, FirstLight and TransCanada proposed to import eels from out-of-basin sources and submit a sample for fish disease assessment prior to release into the Connecticut River. This issue was discussed in more detail at a working group consultation conference call on February 10, 2015 and comments with recommendations were provided by Vermont Fish and Wildlife Division, (VFWD) and New Hampshire Fish and Game Division, (NHFGD) on March 25, 2015 and April 9, 2015, respectively.

FirstLight and TransCanada consultants jointly prepared and submitted to NHFGD, VFWD, and MDFW a "Plan for Implementation of Adult American Eels to the Connecticut River Basin in 2015" (Normandeau and Kleinschmidt, 2015) which proposed to procure eels from a source in Newfoundland likely to collect sufficient numbers, and proposed a series of pathogens tests and testing protocols. NHFGD and VFWD provided comments on the plan and additional recommendations on June 4, 2015, and Normandeau provided additional information in response on July 16, 2015 (to NHFGD) and July 17, 2015 (to VFWD). Kleinschmidt had similar interactions and communications with MDFW. All related documents and communications were included in Appendix C of the Updated Study Report (USR) filed on September 14, 2015.

All pathology tests conducted as part of eel importation had acceptable results and both states issued import permits after review of the pathology test reports. However, due to the need to import eels and the timing of their receipt, the study included a variance from the RSP in that the route selection portion of the study was delayed beyond the expected start of the study in late August.

4.2 Study designs

Adult American Eels were released into the intakes of designated Francis turbines at Cabot Station Unit 2, and Units 1 and 2/3 at Station 1. Eels were released upstream of Bascule Gates 1 and 4 at discharges of 1,500, 2,500, and 5,000 cfs. Control eels were released downstream of the treatment sites. After passage, live and dead eels were captured and the condition of each was examined. At the end of the 48h holding period, all alive and uninjured eels 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. The operational and physical parameters measured during the release of treatment adult eels through the turbines, Bascule Gates and controls are presented in Table 4-1.

4.2.1 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 eels (S), and the desired precision (ε) at a given probability of significance (α). In general, sample size requirements decrease with an increase in control eels 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 adult eels (Normandeau Associates 2010, 2011a and b) indicate a sample size of approximately 30-50 treatment (per scenario) and 25 combined control eels should be sufficient to attain survival estimates within ± 10%, 90% of the time for the selected operating conditions of the selected turbines/spillways at each Project. This number assumes close to 100% control survival, a recapture rate of 95% and expected passage survival and malady-free rates >85% for a specific study (Table 4-2). Although HI-Z tagged eels had not been previously passed through spillway scenarios it was assumed that survival and malady-free rates could be higher than for eels passed through turbines. A total of 50 treatment eels were released into Cabot Station Unit 2, 30 into unit 1 at Station 1, and 30 into Station 1 Units 2/3 at. Thirty eels were released at Bascule Gates 1 and 4 at 2,500 and 5,000 cfs, and 35 at Bascule Gates 1 and 4 at 1,500 cfs. Twenty-five control eels were released downstream of the treatment sites (Table 4-3).

4.2.2 Tagging and Release

Handling procedures for tagging, release, and recapture of eels were similar for treatment and control groups. Eels were randomly selected from the holding tanks located near the intake decks of the turbines and near Bascule Gates at the Turner's Falls Dam. Eels were captured with dip nets and transported in pails or tubs to the tagging sites.

In order to bring large adult eels to the surface for rapid recapture, three to six HI-Z balloon tags were attached with small cable ties through the musculature at two or three locations along the dorsal side of the eels via a curved cannula needle. Radio tags were attached in combination with one of the HI-Z tags to aid in tracking released eels. Specially designed eel restraint devices developed and built by Normandeau aided in tagging treatment and control eels (Figures 4-1and 4-2).

Eels were individually marked and identified with small numbered Floy tags. The tubular Floy tags were inserted into musculature near the anterior region of the dorsal fin. Just prior to release, the HI-Z tags were activated by injecting a small amount of water into each HI-Z tag, which causes the tags to inflate in approximately 2 to 4 minutes. Tags were activated while the eel was still in the restraining device (Figure 4-3).

All treatment eels were released through an induction apparatus. The induction apparatus was connected to 4-inch diameter hoses which allowed the eels to pass freely to the desired release points at Cabot Station Unit 2 and Station 1, and over Bascule Gates 1 and 4 for treatment eels. The induction system and each release hose had a continuous supply of river water supplied by a 3-inch trash pump to ensure eels were transported quickly to the desired release point. Control eels were released through an identical induction apparatus attached to a 4-inch diameter flexible hose approximately 50 feet long that release eels into the tailrace downstream of the turbines and downstream of the spillway at the Bascule Gates (Figures 4-4 and 4-5).

4.2.3 Adult Eel Recapture Methods

After release (either as treatment or control), the eels were tracked and then retrieved when buoyed to the surface downstream of the Projects by one of three recapture boat crews (Figure 4-6). Boat crews were notified of the radio tag frequency of each eel upon its release. Radio signals were received on a Loop antenna coupled to an Advanced Telemetry System receiver. The radio signal transmission (48 or 49 megahertz (MHz)) enabled the boat crews to follow the movement of each eel after passage and position the boats downstream for retrieval when eels were buoyed to the surface. Recaptured eels were placed into an on-board holding facility, and all tags were removed with the exception of the Floy Tag. Each eel was immediately examined for maladies consisting of visible injuries and loss of equilibrium, and assigned appropriate condition codes. Tagging and data recording personnel were notified via a two-way radio system of each eel's recapture time and condition (Table 4-4).

Recaptured eels were transported to shore and held in holding tanks (900 gallons (gal)) to monitor delayed effects of tagging and turbine passage (Figure 4-7). The eels were held for 48h based on the protocol established for HI-Z tag assessment (Heisey *et al.* 1992). Tanks were continuously supplied with ambient river water by two redundant pump systems connected to different electrical circuits. Water level in the tanks was maintained at a minimum of 20 inches below the top of the tanks and the tanks were covered with netting or tarps to prevent eel escapement or predation. Eels that were alive at 48h and free of major injuries were released into the river.

4.2.4 Classification of Recaptured Adult Eels

As in previous investigations on adult fish, (Mathur *et al*. 1996 and 2000; Normandeau 2010, 2011a and b; Normandeau Associates, Inc. and Skalski 1998 and 2005; North/South Consultants Inc. and Normandeau Associates, Inc. 2007, 2009; Normandeau Associates, Inc. 2010 and 2011a and b) the immediate post-passage status of an individual recaptured eel and recovery of inflated tags dislodged from eel 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 h; (2) alive—eels does not surface but radio signals indicate movement patterns; an unrecaptured eel was also classified as alive if no HI-Z tags were recaptured, and based on telemetry information the eel 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 h 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 eel; and (5) unknown—no eels or dislodged tags are recaptured, or radio signals are received only briefly, and the subsequent status cannot be ascertained (Table 4-4).

Mortalities of recaptured eels occurring after 1 h were assigned 48h post-passage effects although eels were observed at approximately 12 h intervals. Dead eels 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 48h were closely examined for injury. An initial examination of the eels when captured allowed detection of some injuries, such as bleeding and minor bruising that may not be evident after 48h due to natural healing processes.

4.2.5 Assessment of Adult Eel Injuries

All recaptured eels, dead or alive, were examined for type and extent of external injuries. Dead eels 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. Eels without visible injuries that were not actively swimming or swimming erratically at recapture were classified as having "loss of equilibrium". 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 eels are not injured. Visible injuries and loss of equilibrium (LOE) were categorized as minor or major. The criteria for this determination are based primarily on field staff's previous field observations (Table 4-5).

A malady classification was established to include eels with visible injuries and/or LOE. Eels 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 eels (Normandeau Associates, Inc. and Skalski 2005). The malady-free metric is based solely on eels physically recaptured and examined. Additionally, the malady-free metric in concert with site-specific hydraulic and physical data may provide insight into what passage conditions and locations provide safer eels passage.

4.2.6 Survival and Malady-Free Estimation

In order to obtain the survival estimate comparable to other HI-Z tag direct survival studies, survival estimates were calculated based on classifications presented above (Section 4.2.4). Because of the limited number of control eels, all controls were combined for the survival and injury analysis. The release and recapture data were analyzed by a likelihood ratio test to determine whether recapture probabilities were similar for dead (P_D) and alive (P_A) fish (Mathur *et al*. 1996). The statistic tested the null hypothesis of the simplified model (Ho: P_A=P_D) versus the alternative generalized model (Ha: $P_A \neq P_D$). The simplified model has three parameters (P, S, τ) with three minimum sufficient statistics (a_c, a_T, d_T) while the alternative generalized model (recapture probabilities of alive and dead fish are unequal) has four parameters (P_A, P_D, S, τ) and four minimum sufficient statistics (a_c, a_T, d_c, d_T). If homogeneity ($P > 0.05$)

was revealed by the chi-square test, turbine and spillway passage survival can be estimated by the simplified model with increased precision. The maximum likelihood estimators associated with the model are:

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

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

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

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

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 48h) and malady-free rates and their associated standard errors were estimated using the likelihood model given in Mathur *et al*. (1996) and Normandeau Associates Inc. and Skalski 1998. The formulas follow:

Direct Survival, 1 and 48h

Where:

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

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

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

R_c = Number of control eels released;

a_c = Number of control eels alive;

Malady-Free (MF) Eels

Where:

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

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

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

C_c = Number of control eels recovered without maladies;

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

Eels that were still alive at 48h but had injuries (i.e. tail severed, multiple backbone fractures) that would eventually lead to death or prevent them from migrating to the ocean were considered functionally dead when calculating the 48h survival estimates.

4.2.7 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 eels. 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 the eel's body (Dadswell *et al*. 1986; Eicher Associates 1987; Normandeau 2010 and 2011a and b). 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). However, shear induced injuries in eels are not well documented. 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

Eels were transported in a tank from holding pools near the Gatehouse Fish Ladder adjacent to the Bascule Gates by truck and delivered to a covered holding tank with a capacity of approximately 300 (gal.) 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 eels prior to testing. An additional similar sized tank was located on the lower deck (adjacent to the control release point) to hold the eels after testing runs. Only eels in good physical condition were used for this study.

A continual supply of ambient river water was supplied to each tank and all eels were held for a minimum of 12-24 h prior to tagging which allowed eels time to recover from transport and handling stress. Water temperatures in the holding pools were comparable with river temperatures, which was 7.5º C.

Treatment eels (50) were released into the intake of Unit 2. Eels were released via a four-inch diameter flexible hose that was passed through the vent pipe with the terminus of the release hose approximately five feet below the intake ceiling. The treatment eels released ranged in length from 580-900 millimeters, (mm), with the average length of 683 mm (Figure 4-8). The 25 combined control eels were released downstream of the test sites. Control eels ranged in length from 560-920 mm, with an average length of 715 mm (Figure 4-8).

4.3.2 Station 1

Eels were transported in a tank by truck and delivered to Station 1 from eel holding pools adjacent to the Bascule Gates and delivered to a covered holding pool with a capacity of approximately 300 gal. This water-level-regulated, covered tank was located near the station intake area. An additional similar sized pool was located in the same area to hold eels for the 48h post-passage delayed assessment period. As with all scenarios, the transport/holding tank was supplied with aeration. These tanks were continuously supplied with ambient river water. Water temperature in this tank was comparable with river temperature, which was 7.7º C.

Eels were released via four-inch flexible hoses passed through the vent pipes at Unit 1 and Units 2/3. However, the 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. The 30 treatment eels released through Unit 1 ranged in length from 550-770 mm, with the average length of 636 mm. The 30 treatment eels released through Units 2/3 ranged in length from 540-800 mm, with the average length of 665 mm. Only eels in good physical condition were used for this study (Figures 4-9 and 4-10).

4.3.3 Bascule Gates

Eels 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 9.1º C. The eels 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 towards the Bascule Gates. Sufficient length of the four-inch hose was deployed so its terminus was close enough to the crest of the Bascule Gates that the eels 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 5 to 10 eels, and then the flow was curtailed to aid in eel recapture.

Treatment eels at Bascule Gate 1 at the 1,500, 2,500, and 5,000 cfs discharge scenarios ranged in length from 630 to 930 mm (695 mm average), 530 to 960 mm (701 mm average), and 530 to 960 mm (711 mm average), respectively (Figure 4-11 to 4-13). Treatment eels at Bascule Gate 4 at the 1,500, 2,500, and 5,000 cfs discharge scenarios ranged in length from 510 to 910 mm (751 mm average), 600 to 810 mm (681 mm average), and 400 to 930 mm (694 mm average), respectively (Figures 4-14 to 4-16).

5.0 RESULTS AND DISCUSSION

Recapture rates; recapture times; survival estimates; injury rates, types, and probable sources; and malady-free estimates are provided for Cabot Station, Station 1, and the Bascule Gates are presented below.

5.1 Recapture Rates

5.1.1 Cabot Station

Treatment eels were released through Francis Unit 2 at Cabot Station on November 7, 2015. Forty-nine of the 50 (98.0%) released eels were recaptured. The status of the one un-retrieved eel was undetermined. Out of all of the test scenarios, Cabot Station Unit 2 had the highest recapture rate. The control eels were combined for all the scenarios. All 25 control eels were recaptured (100%) (Table 5-1).

5.1.2 Station 1

Treatment eels were released through the Francis Units 1 and 2/3 at Station 1 on November 9, 2015. Thirty treatment eels were released through Unit 1 and Units 2/3. Twenty-seven (90.0%) were recaptured after passage through Unit 1. Only inflated HI-Z tags were recaptured on the remaining three fish. Whereas, only 19 (63.3%) of the 30 released eels were captured after passing through Units 2/3. Eighteen of recaptured eels were alive and one was dead. Only HI-Z inflated tags were recaptured on 10 eels and the remaining one eel was undetermined. This scenario was the lowest eel recapture rate of all the scenarios tested at the FirstLight Project (Table 5-1).

5.1.3 Controls

The 25 eels released as controls were assigned to all the treatment releases. This procedure has been used in past studies where the number of specimens available for a study is limited; which was the present case. Additionally, this allocation of control fish to different test conditions has proven to be sufficient if control recapture rate are near or is 100%. Twenty-five control eels were released; 25 (100%) control eels were collected, and the fish were held for the 48 h delayed observation. Control fish recapture times ranged from under two minutes to 12 minutes, with an average recapture time at 2 minutes. Control eels ranged in size from 560-920 mm, with an average size of 715 mm.

5.1.4 Bascule Gates

Eels were released over the Bascule Gates between November 4 and 6, 2015. Treatment eels (95) released at Bascule Gate 1 had recapture rates of 85.7, 80.0, and 83.3% at the three discharge rates of 1,500, 2,500, and 5,000, respectively. All recaptured eels (79) were alive. Of the remaining 16 released eels, only inflated HI-Z tags were retrieved on two released eels, and only stationary radio signals were detected on another 10 eels. The status of the remaining four fish could not be determined (Table 5-1).

Recapture rates were slightly higher at Bascule Gate 4, ranging from 88.6 to 93.3%. One eel was dead at recapture. The overall recapture rates for Bascule Gates 1 and 4 were 83.2 and 91.6%, respectively (Table 5-1).The relatively high percentage (10.5% for Gate 1, 7.4% for Gate 4) of un-retrieved eels where only a signal was detected was likely due to the ability of eels to move into underwater crevices before the HI-Z tags could buoy them to the surface. Underwater boulders and rock shelves were much more prevalent downstream of the Bascule Gates than the turbines.

The eels with only the HI-Z tags recaptured were assigned a dead status at all of the treatment sites. The recapture rate for the combined controls was 100% (Table 5-1.).

5.2 Recapture Times

5.2.1 Turbines (Cabot Station and Station 1)

Recapture times (the time interval between eel release and subsequent recapture) for the eels released through Cabot Station Unit 2 ranged from 3 to 20 minutes and averaged 6.8 minutes. Recapture times (for the eels released through Station 1 Unit 1, ranged from 2 to 11 minutes and averaged 4 minutes. For Station 1 Units 2/3, recapture times ranged from 2 to 87 minutes and averaged 9.6 minutes (Figure 5-1).

5.2.2 Bascule Gates

Recapture times for the eels released over the Bascule Gate 1 at the three flow rates ranged from 2 to 85 minutes and the averages ranged from 6.4 and 11.3 minutes. Recapture times for the eels released over the Bascule Gate 4 at the three flows ranged from 2 to 139 minutes and the averages ranged from 4 and 17 minutes (Figures 5-2 and 5-3) A few eels became entrapped in underwater boulders and crevices and were not recaptured until the eel escaped after 22 to 139 minutes. Some eels apparently did not escape.

5.3 Survival Estimates

5.3.1 Cabot Station

The 1 h direct survival rate for Cabot Station Unit 2 was very high at 98%, with a survival rate at 48h of 96%. The precision of the 48h survival estimates for the Unit 2 eels was within ±4.6%, 90% of the time (Table 5-1).

5.3.2 Station 1

The 1 h direct survival rate for Unit 1 was also high at 90%. No eels died during the delayed assessment period; therefore the 48h survival rate was also 90%. The precision of the survival estimates for Unit 1 eels was within ±9.1%, 90% of the time. The 1 and 48h direct survival rate for Units 2/3 was low at 62.1%. The precision of the 1 and 48h survival estimates for the Units 2/3 eels was within ±14.8%, 90% of the time. The lower survival at Units 2/3 appears to be partially due to a portion of the eels passing through the smaller and faster rotating Unit 2. Also, only HI-Z inflated balloon tags were retrieved on 33.3% of the 30 passed fish, and these fish were assigned a dead status; however, this is likely conservative since eels have been recaptured in good condition with several of the tags missing (Table 5-1).

5.3.3 Bascule Gate 1

The 1 and 48h survival rates at 1,500 cfs were 88.2% (CI 4.0%). Eel survival (1 and 48h) at the 2,500 cfs scenario was 85.7% (CI 7.4%). Survival at the highest discharge of 5,000 cfs was 86.2% (CI 10.5%) at both 1 and 48h. The overall 48h survival was 86.8% (CI 5.9%). None of the recaptured fish passed through Bascule Gate 1 were dead or died in holding. Overall, 12.6% of the mortality was assigned to eels that were not retrieved. As noted above, this is likely conservative and survival is likely higher (Table 5-1).

5.3.4 Bascule Gate 4

The 1 h survival rate at 1,500 cfs was 88.6% (CI 8.7%) but dropped to 82.9% (CI 10.5%) because two eels died during the 48h delayed assessment period (Table 5-1). Survival at 1 and 48h was 90.0% (CI 9.1%) and 93.3% (CI 7.6%) when eels were passed at 2,500 and 5,000 cfs, respectively. The overall 48h eel survival at Bascule Gate 4 was 88.4% (CI 5.4%) (Table 5-1).The overall 1 h survival rate through Bascule Gate 4 (90.5%) was higher than through Bascule Gate 1 (86.2%) partially due to fewer fish being assigned dead because only tags were recaptured or there was only a stationary signal. Injury Rate, Types, and probable Source

5.4 Injury Rate, Types, and probable Source

5.4.1 Cabot Station

Two of the 49 recaptured Unit 2 eels (4.1%) had passage related injuries. Both of these eels had bleeding from the mouth. These injuries were attributed to mechanical forces and classified as major; neither of those eels died. Another eel died during the 48h assessment period, however, no external or internal injuries were observed (Tables 5-2 to 5-4).

5.4.2 Station 1

None of the 26 eels recaptured after passage through Station 1 Unit 1 were injured. However, three of the nineteen (15.8%) recaptured eels passed through Units 2/3 were injured. One eel received a strike to the head area and tail which resulted in hemorrhaging and broken bones. The second eel has bruising on its back and the third had cuts. The injuries to these three eels were classified as major and attributed to mechanical forces. A fourth eel was lethargic at recapture but fine at 48h (Tables 5-2 to 5-4).

5.4.3 Bascule Gates

Only one (1.3%) of the 79 recaptured eels after passage through Bascule Gate 1 was injured. This eel had a piece missing from its tail, however the injury was considered minor and appeared to be related to striking something during passage. Two (2.3%) of the 86 recaptured eels from Bascule Gate 4 were injured. One eel was bleeding from the mouth and the other eel was missing its head (Tables 5-1 to 5-3). Injuries were classified as major and strike-induced. However, what could have caused an eel to be decapitated after passing over a Bascule Gate is not obvious. A third eel also died during the delayed assessment period, but no external or internal injuries were observed. Although the sample size was small (30-35 fish) for each of the tested discharge rates, none of the eels passed at the higher flow of 5,000 cfs through either Bascule Gate was injured (Tables 5-2 to 5-4).

5.5 Malady-Free Estimates (MFE)

5.5.1 Turbines

The malady-free estimate for eels passed through Cabot Station Unit 2 was 95.9% (CI 4.6%). Since none of the recaptured eels that passed Station 1 Unit 1 were injured, the malady-free estimate was 100% for this unit (Table 5-5). The lowest malady-free rate was 79.0% (CI 15.5%) for the eels passed through Station 1 Units 2/3. Since Units 1 and 3 at Station 1 are similar, and Unit 2 is considerably smaller and rotates faster, the lower malady-free rate observed at Units 2/3 was likely attributable to eels passed through Unit 2.

5.5.2 Bascule Gates

The malady-free rate was 100% for eels passed through Bascule Gate 1 at 2,500 and 5,000 cfs, and 96.7% for the eels passed at 1,500 cfs (Table 5-5). The overall malady-free rate for Bascule Gate 1 was 98.7%

(CI 2.1%). Eels passed through Bascule Gate 4 at 5,000 cfs had a 100% malady-free rate, followed by 96.8 and 96.3% at 1,500 and 2,500 cfs respectively. The overall malady-free rate for Bascule Gate 4 passed eels was 97.7% (CI 2.6%).

5.6 Comparison with Other Projects

5.6.1 Turbines

The 96% 48h survival at Cabot Station Unit 2 was higher than that at six other projects with propeller type turbines where survival ranged from 62 to 93% (Table 5-6).These turbines had four to six blades compared to the 13 buckets at Cabot. The turbine passage survival (48h) at four of these large (240.0 to 262.6 in diameter) propeller type turbines ranged from 73.5 to 93.0%. These turbines had rotation rates close to 99 rpm. The number of blades appeared to affect survival the most with lower survival rates of 78.6 and 73.5% for the five and six bladed units versus 93.0 and 92.4% for four bladed units. The two other smaller (189 and 122 in diameter) propeller turbines with five blades and slightly higher runner speed (112.5 and 144 rpm) had generally lower survival (62.0 to 87.5%).

Adult HI-Z tagged eels have been passed through seven different Francis Units; this includes the four from the present study (Cabot Station Unit 2, Station 1 Units 1 and 2/3). Three of the larger units, including Cabot Station Unit 2, had 13 buckets, 136.4 in diameter, and runner speeds of 97.3 rpm (Table 5-6). The 48h survival for these units was quite high at 96 to 98%. Two smaller Francis Units, including Station 1 Unit 1, with 13 buckets, 54.3 in diameters, and 200 rpms had 90% (Station 1 Unit 1) and 93.5% survival rates. The lower survival at Unit 1 may have been related to its smaller diameter and higher rpm. Station 1 Units 2/3 had the lowest survival of 62.1%. Because these two units had a common penstock the portion of eels that passed through each unit could not be determined. However Unit 2 was the smallest (38.9 in) and highest rotating (257 rpm) of all the units tested.

Based on above data turbine type, number of blades, runner diameter, and rotation rate appear to be the main factors affecting the direct turbine passage survival of adult eels. These relationships are shown in Figures 5-4 to 5-6 and indicate that eels fare best passing large low rpm Francis turbines.

5.6.2 Bascule Gates

The passage of adult eels through the Bascule Gates is the only HI-Z tag study where adult eels have been passed through a spillway structure. Numerous other direct survival/injury studies on juveniles of other species have been conducted at spillways and fish bypass structures. Ten studies have been conducted on adult fish and these were all on salmonids. Survival (48h) of the adult fish (mean lengths 446-716 mm) ranged from 9-100% and injury rates from 0-100%. Survival rates were greater than 96% and injury rates less than 25 for seven of these studies. Low survival and high injury occurred when the adult fish were discharged within a thin veil of water and onto structures and boulders downstream of the spill site. Although eels appear to be hardier than the other species tested these studies indicate the following factors affect survival/injury of spillway passed fish: spill volume, configuration of spill, spillbays with and without flow deflectors, sear/pressure forces, season, collision with spill basin structures, depth of water “cushion” of the transport water, travel path and trajectory within the spill jet, interception angle of spill with chute and flow deflector, and post passage lateral transport of fish (Johnson *et al*. 2003; Normandeau Associates Inc. 2004, 2011c,d, 2013, 2014a,b; Normandeau Associates, Inc. and Skalski 2005,2006a,b; Normandeau Associates, Inc. *et al*. 1996; Heisey *et al*. 2008a,b). Based on these findings depth of water discharged over the Bascule Gates and the boulders and concrete in the spill jet path should have the most effect on the condition of the Bascule Gate passed eels.

6.0 ASSESSMENT OF PROJECT EFFECTS

6.1 Turbines

Based on the present study adult eels should incur little mortality (≤4%) or injury (≤4.1%) passing the large Francis units at the Cabot Station. Eels should also fare quite well (approximately 90% survival and little injury) passing the larger of the Francis units at Station 1. However, the units that have a common penstock leading to both a larger and smaller unit could inflict up to 40% mortality. If power demands and flow conditions permit operating unit two through seven last should be considered.

6.2 Bascule Gates

Although the tested discharges (1,500, 2,500, and 5,000 cfs) through Bascule Gates 1 and 4 were turbulent and it appeared that some of the eels were directed towards boulders and concrete sills in the spill basin eel passage respective survival was still 86.8 and 88.4%. These estimates are likely conservative since some of the eels assigned dead (tags only recaptured or only stationary radio signal) were likely alive. Additionally the malady-free rate of the recaptured eels was high at 98.7 and 97.3% for Bascule Gate 1 and 4 passed fish. Although not fully supported by the survival estimates the malady-free estimates indicated that the eels fared better at the higher discharges. The present study indicates that Bascule Gate passage should be a viable means for passing eels; however this route did not appear to be substantially better than passage through the Francis units at the Cabot Station.

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TABLES

Table 3-1

Characteristics of turbines at Turner's Falls Hydroelectric Project where fish passage survival tests were conducted.

	Turbine			
	Cabot Unit 2	**Station 1 Unit 1**	**Station 1 Unit 2**	**Station 1 Unit 3**
Manufacturer:	GDF Suez Energy North America			
Type:	Francis	Francis	Francis	Francis
Rated Output (MW):	62.016	1.500	0.365	1.276
Approximate flow (cfs/cms) 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 4-1
Average discharge through Bascule Gates 1 and 4, Cabot Station Unit 2, and Station 1 Units 1 and 2/3 during HI-Z tagged adult eel releases, November 2015.

	Turbines		
Date	**Location**	**MW**	**Discharge (cfs)**
11/4/15	**Bascule Gate 4: 1500 cfs***	N/A	1525.2
11/4/15	**Bascule Gate 4: 2500 cfs***	N/A	2494.2
11/5/15	**Bascule Gate 4: 1500 cfs***	N/A	1576
11/5/15	**Bascule Gate 4: 5000 cfs***	N/A	5024.3
11/5/15	**Bascule Gate 1: 1500 cfs***	N/A	1478.9
11/5/15	**Bascule Gate 1: 2500 cfs***	N/A	2563.3
11/6/15	**Bascule Gate 1: 2500 cfs***	N/A	2539
11/6/15	**Bascule gate 1: 5000 cfs***	N/A	4975.3
11/7/15	**Cabot Station: Unit 2****	10.3	2273.7
11/9/15	**Cabot Station 1: Unit 2/3****	5.5	2068.3
11/9/15	**Cabot Station 1: Unit 1****	5.6	2046.5

*Spillway

**Turbine

Table 4-2

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 to obtain a precision (ε) of ≤±0.10 at 1-α =0.90.

Control Survival (S)	Recapture Rate (P)	Expected Survival	Number of Fish
1.0	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 4-3

Daily release schedule of adult American Eels passed through Cabot Station Unit 2, Station 1 Unit 1, and Units 2/3, and over Bascule Gates at Turner's Falls, MA November 2015. Controls released downstream of treatment sites.

	Water Temperature (°C)	Bascule Gates 4			Bascule Gates 1			Cabot Station Unit 2	Station 1: Unit 2/3	Station 1: Unit 1	Combined Controls
		1500 cfs	2500 cfs	5000 cfs	1500 cfs	2500 cfs	5000 cfs				
Date											10
11/4/15	8.7	30	30								10
11/5/15	7.3	5		30	35	15					
11/6/15	9.3					15	30				
11/7/15	9.3							50			5
11/9/15	8.5								30	30	

Table 4-4

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 4-5

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	Scraping (damage to epidermis): major if 10% or more per side of fish. Otherwise minor.
11	Cuts and lacerations are generally classified as major injuries. Small flaps of skin or skinned up snouts are: minor.
12	Internal hemorrhage or rupture of kidney, heart or other internal organs that results in death at 1 to 48hours is a major injury.
13	Multiple injuries: use the worst injury

Table 5-1

Tag-recapture data and estimated 1 h and 48 h survival for adult American Eels passed through Cabot Station Unit 2, Station No. 1 Unit 1 and Units 2/3, and over the Bascule Gates 1 and 4 at 1,500, 2,500, and 5,000 cfs, November 2015. Controls released into the tailrace downstream of the three stations. Proportions are given in parentheses.

	Cabot Sation Unit 2	Station No. 1 Unit 2/3	Station No. 1 Unit 1	Bascule Gates 1				Bascule Gates 4				
				1,500 cfs	2,500 cfs	5,000 cfs	BG 1 Combined	1,500 cfs	2,500 cfs	5,000 cfs	BG 4 Combined	Combined Controls
Number released	50	30	30	35	30	30	95	35	30	30	95	25
Number recaptured alive	49 (0.980)	18 (0.600)	27 (0.900)	30 (0.857)	24 (0.800)	25 (0.833)	79 (0.832)	31 (0.886)	27 (0.900)	28 (0.933)	86 (0.905)	25 (1.000)
Number recaptured dead	0 (0.000)	1 (0.033)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.033)	0 (0.000)	1 (0.011)	0 (0.000)
Number assigned dead*	1 (0.020)	10 (0.333)	3 (0.100)	4 (0.114)	4 (0.133)	4 (0.133)	12 (0.126)	4 (0.114)	2 (0.067)	2 (0.067)	8 (0.084)	0 (0.000)
Dislodged tags	0 (0.000)	10 (0.333)	3 (0.100)	0 (0.000)	1 (0.033)	1 (0.033)	2 (0.021)	1 (0.250)	0 (0.000)	0 (0.000)	1 (0.011)	0 (0.000)
Stationary radio signals	1 (0.020)	0 (0.000)	0 (0.000)	4 (0.114)	3 (0.100)	3 (0.100)	10 (0.105)	3 (0.086)	2 (0.067)	2 (0.067)	7 (0.074)	0 (0.000)
Number undetermined	0 (0.000)	1 (0.033)	0 (0.000)	1 (0.029)	2 (0.067)	1 (0.033)	4 (0.042)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)
Number held	49	18	27	30	24	25	79	31	27	28	86	25
1 hour survival rate	(0.980)	(0.621)	(0.900)	(0.882)	(0.857)	(0.862)	(0.868)	(0.886)	(0.900)	(0.933)	(0.905)	
SE	(0.020)	(0.090)	(0.055)	(0.024)	(0.045)	(0.064)	(0.036)	(0.053)	(0.055)	(0.046)	(0.030)	
90% CI (+/-)	(0.033)	(0.148)	(0.091)	(0.040)	(0.074)	(0.105)	(0.059)	(0.087)	(0.091)	(0.076)	(0.049)	
Number alive 48 h	48	18	27	30	24	25	79	29	27	28	84	25
Number Died in holding	1	0	0	0	0	0	0	2	0	0	2	0
48 hour survival rate	(0.960)	(0.621)	(0.900)	(0.882)	(0.857)	(0.862)	(0.868)	(0.829)	(0.900)	(0.933)	(0.884)	
SE	(0.028)	(0.090)	(0.055)	(0.024)	(0.045)	(0.064)	(0.036)	(0.064)	(0.055)	(0.046)	(0.033)	
90% CI (+/-)	(0.046)	(0.148)	(0.091)	(0.040)	(0.074)	(0.105)	(0.059)	(0.105)	(0.091)	(0.076)	(0.054)	

* includes dislodged tags and stationary signals

Table 5-2

Incidence of maladies, including injury, and temporary loss of equilibrium (LOE) observed on released Adult Eels passed through Cabot Station Unit 2, Station 1 Units 1 and 2/3, and Bascule Gates 1 and 4 at 1,500, 2,500, and 5,000 cfs, November 2015. Controls released downstream of the treatment sites.

Date	Test Lot	Fish VI	Live/Dead		Maladies	Passage Malady*	Photo	Malady Severity	Probable Cause
					Bascule Gate 4 at 1500 cfs				
11/4/2015	8E	41	dead	24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
11/4/2015	8E	45	dead	24h	Bleeding from mouth	Yes	No	Major	Mechanical
					Bascule Gate 4 at 2500 cfs				
11/4/2015	8E	56	dead	1h	Decapitated	Yes	Yes	Major	Mechanical
					Bascule Gate 1 at 1500 cfs				
11/5/2015	9E	200	alive		Chunk out of Tailfin	Yes	No	Minor	Mechanical
					Cabot Station Unit 2				
11/7/2015	11E	138	dead	24h	Necropsied, no obvious injuries	No	No	Minor	Undetermined
11/7/2015	11E	143	alive		Bleeding from mouth	Yes	No	Major	Mechanical
11/7/2015	11E	382	alive		Bleeding from mouth	Yes	No	Major	Mechanical
					Station 1 Units 2/3				
11/9/2015	12E	452	alive		LOE	Yes	No	Minor	Undetermined
11/9/2015	12E	466	dead	1h	LOE, bleeding from gills, bruising on head and tail, broken neck	Yes	Yes	Major	Mechanical
11/9/2015	12E	468	alive		Bruising on body	Yes	Yes	Major	Mechanical
11/9/2015	12E	469	alive		Cut on right Pec. Fin, and bleeding	Yes	No	Major	Mechanical

Table 5-3
Summary of visible injury types and injury rates observed on recaptured adult American Eels passed through Cabot Station Unit 2, Station 1 Units 1 and 2/3, and over the Bascule Gates 1 and 4 at 1500, 2500, and 5000 cfs, November 2015. Controls released downstream of treatment sites. Proportions are given in parentheses.

				Injury Type*						
				Eye(s)	Gills/Operculum/Isthmus	Head		Body		Internal Damage
	No. Released	No. Examined	Passage Related Visibly Injured	Hemorrhaged Bulged, Missing Ruptured	Torn, Scraped, Inverted Hemorrhaged Bent, Abraded, Bruised	Crushed, Cut Hemorrhaged Bruised, Scraped	Decapitated (Nearly or Partial)	Severed (Nearly Severed)	Torn, Scraped Hemorrhaged Bruised, Fins torn	Hemorrhage, Heart/Kidneys, Broken Back bone
						Cabot Station Unit 2				
	50	49 (0.980)	2 (0.041)	0 (0.000)	0 (0.000)	2 (0.041)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)
						Station 1 Units 2 and 3				
	30	19 (0.633)	3 (0.158)	0 (0.000)	1 (0.053)	1 (0.053)	0 (0.000)	0 (0.000)	3 (0.158)	1 (0.053)
						Station 1 Unit 1				
	30	26 (0.867)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)
						Station Units 1-3 Combined				
Total	60	45 (0.750)	3 (0.067)	0 (0.000)	1 (0.022)	1 (0.022)	0 (0.000)	0 (0.000)	3 (0.067)	0 (0.000)
						Bascule Gate 1 @ 1500 cfs				
	35	30 (0.857)	1 (0.033)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.033)	0 (0.000)
						Bascule Gate 1 @ 2500 cfs				
	30	24 (0.800)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)
						Bascule Gate 1 @ 5000 cfs				
	30	25 (0.833)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)
						Bascule Gate 1 Combined				
Total	95	79 (0.832)	1 (0.013)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.013)	0 (0.000)
						Bascule Gate 4 @ 1500 cfs				
	35	31 (0.886)	1 (0.032)	0 (0.000)	0 (0.000)	1 (0.032)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)
						Bascule Gate 4 @ 2500 cfs				
	30	28 (0.933)	1 (0.036)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.033)	0 (0.000)	0 (0.000)	0 (0.000)
						Bascule Gate 4 @ 5000 cfs				
	30	28 (0.933)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)
						Bascule Gate 4 Combined				
Total	95	86 (0.905)	2 (0.023)	0 (0.000)	0 (0.000)	1 (0.011)	1 (0.011)	0 (0.000)	0 (0.000)	0 (0.000)
						Combined Control Fish				
Total	25	25 (1.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)

*Many fish have multiple injury types.

Table 5-4
Probable sources and severity of maladies observed on recaptured adult American Eels passed through Cabot Station Unit 2, Station 1 Units 1 and 2/3, and over the Bascule Gates 1 and 4 at 1500, 2500, and 5000 cfs, November 2015. None of the controls released downstream of treatment sites were injured. Proportions are given in parentheses.

No. of Fish Examined	Total With Maladies	LOE only	Mechanical	Pressure /Mechanical	Shear	Mechanical/ Shear	Undetermined	Severity: Minor	Severity: Major
				Cabot Station 2					
49	**2 (0.041)**	0 (0.000)	2 (0.041)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	2 (0.041)
				Station 1: Unit 1					
26	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)
				Station 1: Unit 2/3					
19	4 (0.211)	1 (0.053)	3 (0.158)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.053)	2 (0.105)	2 (0.105)
				Bascule Gate 1: 1500 cfs					
30	1 (0.033)	0 (0.000)	1 (0.033)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.033)	0 (0.000)
				Bascule Gate 1: 2500 cfs					
24	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)
				Bascule Gate 1: 5000 cfs					
25	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)
				Bascule Gate 4: 1500 cfs					
31	1 (0.032)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.032)	0 (0.000)	1 (0.032)
				Bascule Gate 4: 2500 cfs					
28	1 (0.036)	0 (0.000)	1 (0.036)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.036)
				Bascule Gate 4: 5000 cfs					
28	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)

Table 5-5

Malady data and malady-free estimates for recaptured adult American Eels passed through Cabot Station Unit 2, Station 1 Units 1 and 2/3, and over the Bascule Gates 1 and 4 at 1500, 2500, and 5000 cfs, November 2015. Controls released downstream of the treatment sites. Proportions are given in parentheses.

	Cabot St. 2: Unit 2	Station 1: Unit 1	Station 1: Units 2/3	Bascule Gates 1				Bascule Gates 4				Combined Controls (Cabot Station & Bascule Gates)
				1500 cfs	2500 cfs	5000 cfs	BG 1 Combined	1500 cfs	2500 cfs	5000 cfs	BG 4 Combined	
Number released	50	30	30	35	30	30	95	35	30	30	95	25
Number examined for maladies	49 (0.980)	26 (0.867)	19 (0.633)	30 (0.857)	24 (0.800)	25 (0.833)	79 (0.832)	31 (0.886)	27 (0.900)	28 (0.933)	86 (0.905)	25 (1.000)
Number with passage related maladies	2 (0.041)	0 (0.000)	4 (0.211)	1 (0.033)	0 (0.000)	0 (0.000)	1 (0.013)	1 (0.032)	1 (0.037)	0 (0.000)	2 (0.021)	0 (0.000)
Visible injuries	2 (0.041)	0 (0.000)	3 (0.158)	1 (0.033)	0 (0.000)	0 (0.000)	1 (0.013)	1 (0.032)	1 (0.037)	0 (0.000)	2 (0.021)	0 (0.000)
Loss of equilibrium only	0 (0.000)	0 (0.000)	1 (0.053)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0	0 (0.000)
Number without passage related maladies	47 (0.959)	26 (1.000)	15 (0.789)	29 (0.967)	24 (1.000)	25 (1.000)	78 (0.987)	30 (0.968)	26 (0.963)	28 (1.000)	84 (0.977)	25 (1.000)
Without passage related maladies that died	1 (0.020)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	0 (0.000)	1 (0.032)	0 (0.000)	0 (0.000)	1 (0.012)	0 (0.000)
Malady free rate	(0.959)	(1.000)	(0.790)	(0.967)	(1.000)	(1.000)	(0.987)	(0.968)	(0.963)	(1.000)	(0.977)	
SE	(0.028)	(0.000)	(0.094)	(0.033)	(0.000)	(0.000)	(0.013)	(0.032)	(0.036)	(0.000)	(0.016)	
90% CI (+/-)	(0.046)	(0.000)	(0.155)	(0.054)	(0.000)	(0.000)	(0.021)	(0.053)	(0.059)	(0.000)	(0.026)	

Table 5-6

Physical and hydraulic characteristics of propeller type and Francis turbines and corresponding direct survival/injury data on adult HI-Z tagged eels passed through these turbines.

Station	Study Year	River	Turbine Type	No. of Blades/Buckets	Runner speed (rpm)	Runner diameter (in)	Project Head (ft)	Test Discharge (kcfs)	Source
Beaucaire	2010	Rhone	Bulb	4	94.0	245.7	45.0	11.1	NAI 2011a
Fessenheim	2009	Rhine	Kaplan	4	88.2	262.6	50.0	12.8	NAI 2010
Ottmarsheim	2010	Rhine	Kaplan	5	93.8	246.0	51.2	11.1	NAI 2011b
Robert Moses *	1997	St. Lawrence	Propeller	6	99.2	240.0	82.0	9.0	NAI and Skalski 1998
Cabot (Unit 2)	***2015***	***Connecticut***	***Francis***	**13**	**97.3**	**136.4**	**60.0**	**2.3**	***present study***
Station 1 (Unit 1)	***2015***	***Connecticut***	***Francis***	**13**	**200.0**	**54.25 (2 runners)**	**43.7**	**0.7**	***present study***
Station 1 (Unit 2)**	***2015***	***Connecticut***	***Francis***	**13**	**257.0**	**38.9**	**43.7**	**0.6**	***present study***
Station 1 (Unit 3)**	***2015***	***Connecticut***	***Francis***	**15**	**200.0**	**55.3 (2 runners)**	**43.7**	**0.6**	***present study***
Vernon	***2015***	***Connecticut***	***Francis***	***13***	***133.3***	***62.5***	***35***	***0.9***	**Draft**
Vernon	***2015***	***Connecticut***	***Francis***	***12***	***75***	***110***	***34***	**1.3**	**Draft**
Vernon	***2015***	***Connecticut***	***Kaplan***	***5***	***144***	***122***	***32***	***1.0***	**Draft**
Vernon	***2015***	***Connecticut***	***Kaplan***	***5***	***144***	***122***	***32***	***1.7***	**Draft**
Bellows Falls	***2015***	***Connecticut***	***Francis***	***15***	***85.7***	***174***	***57***	3.2	**Draft**
Wilder	***2015***	***Connecticut***	***Kaplan***	***5***	***112.5***	***180***	***49***	**4.7**	**Draft**

Station	Species	Average Length (mm)	Sample Size	Recapture Rate (%)	48h Survival (%)	48h SE (%)	Visibly injured %	Dominant Injury
Beaucaire	European eel	686	275	95.6	93.0	1.5	6.5	bruised head/body
Fessenheim	European eel	704	281	96.1	92.4	2.2	11.5	severed or nearly severed body
Ottmarsheim	European eel	750	300	98.0	78.6	2.3	26.5	Head/body severed or nearly sev.
Robert Moses *	American eel	1020	240	86.0	73.5	3.4	36.7	severed body
Cabot (Unit 2)	***American eel***	**683**	**50**	**98.0**	**96.0**	**2.7**	**4.1**	bleeding from mouth
Station 1 (Unit 1)	***American eel***	**636**	**30**	**86.7**	**90.0**	**6.2**	**0.0**	
Station 1 (Unit 2)** **Station 1 (Unit 3)****	***American eel***	**665**	**30**	**63.3**	**62.1**	**9.0**	**15.8**	bruised head/body

Vernon	***American eel***	***818***	***48***	***93.8***	***93.5***	***3.6***	***35.6***	***bruises on body/head***
Vernon	***American eel***	***796***	***48***	***95.8***	***97.9***	***2.1***	***8.7***	***bruises on body/head***
Vernon	***American eel***	***813***	***48***	***95.8***	***87.5***	***4.8***	***28.3***	***bruises on body/head***
Vernon	***American eel***	***795***	***50***	***88.0***	***74.0***	***6.2***	***27.3***	***severed body***
Bellows Falls	***American eel***	***816***	***50***	***100.0***	***98.0***	***2.0***	***14.0***	***bruises on body/head***
Wilder	***American eel***	***821***	***50***	***94.0***	***62.0***	***6.9***	***42.6***	***severed or bruised body***

*88 hour survival, little mortality beyond 24 hour
**Fish released into common penstock; exact unit passed is not known

FIGURES

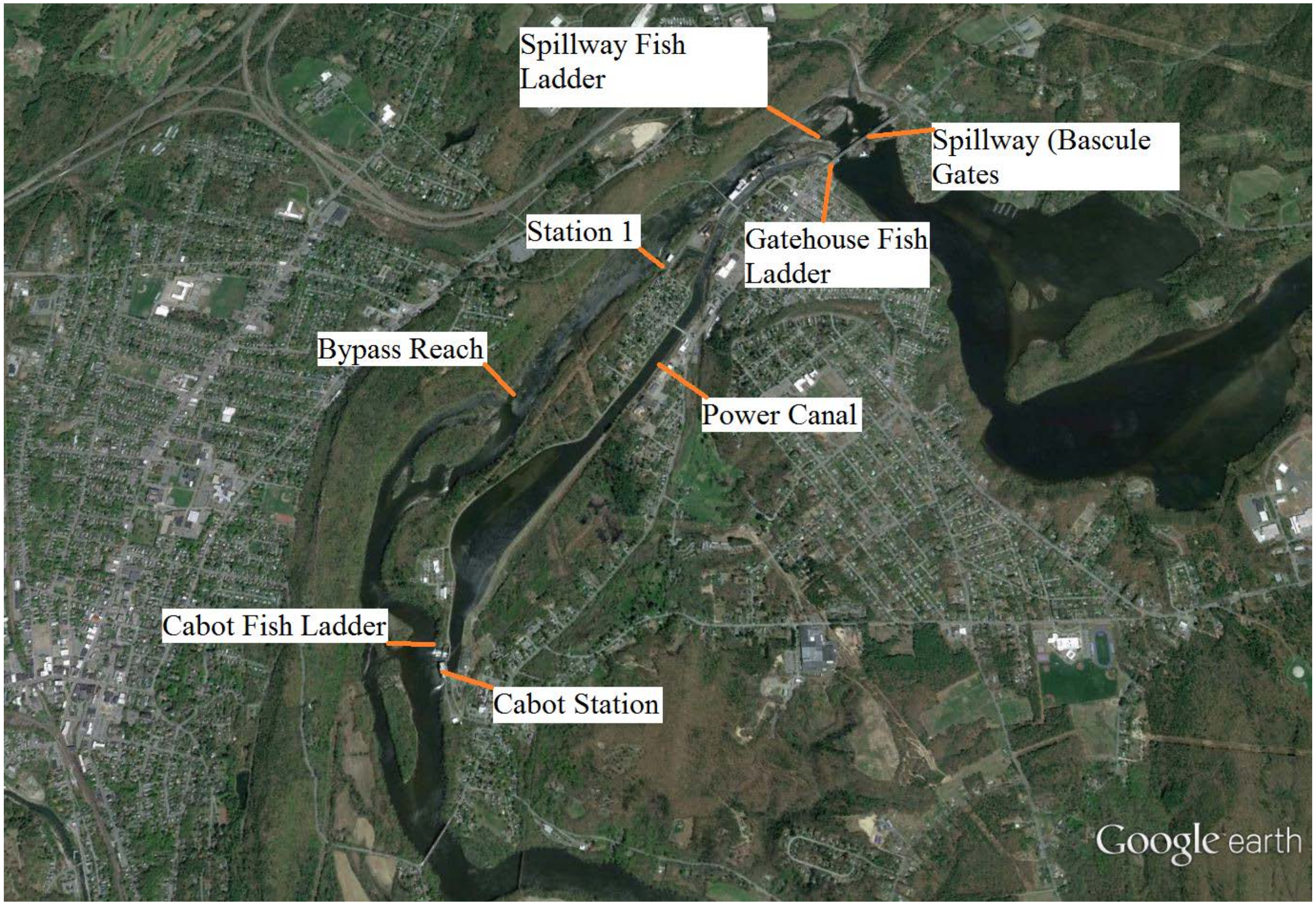

Figure 1-1: Aerial view of the First Light study locations.

Figure 2-1: Inside Cabot Station.

Figure 2-2: Downstream of Bascule Gate 1.

Figure 2-3: Downstream of Bascule Gate 4.

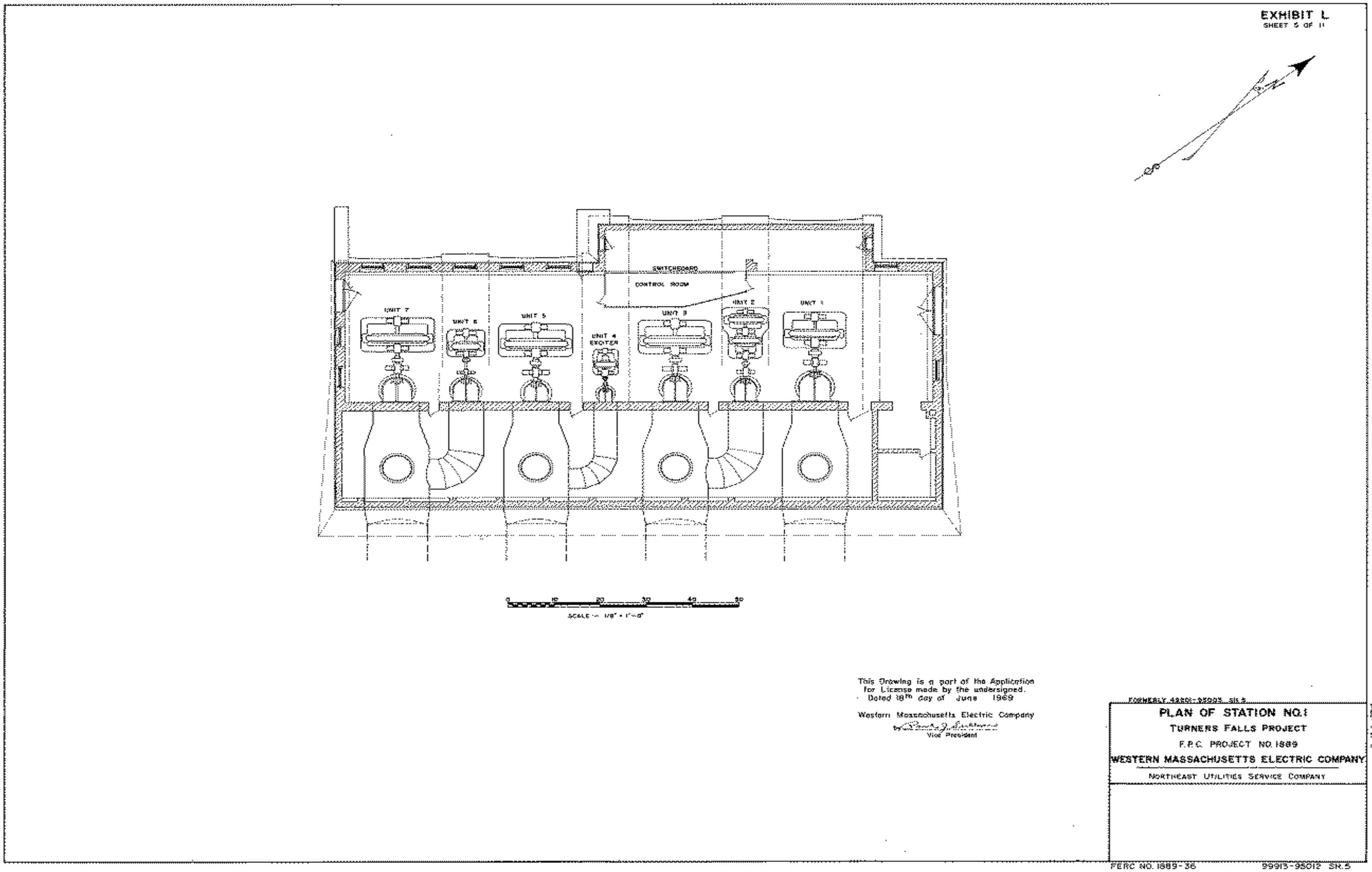

Figure 3-1: Shared penstocks at Station 1. Unit 1 is shown at the far right and Units 2/3 are second and third from right with a common penstock.

Figure 4-1: Three to six HI-Z balloon tags attached with a small cable tie through the musculature at two or three locations along the eel's back via a curved cannula needle. Radio tags attached in combination with one of the HI-Z tags to aid in tracking released eels.

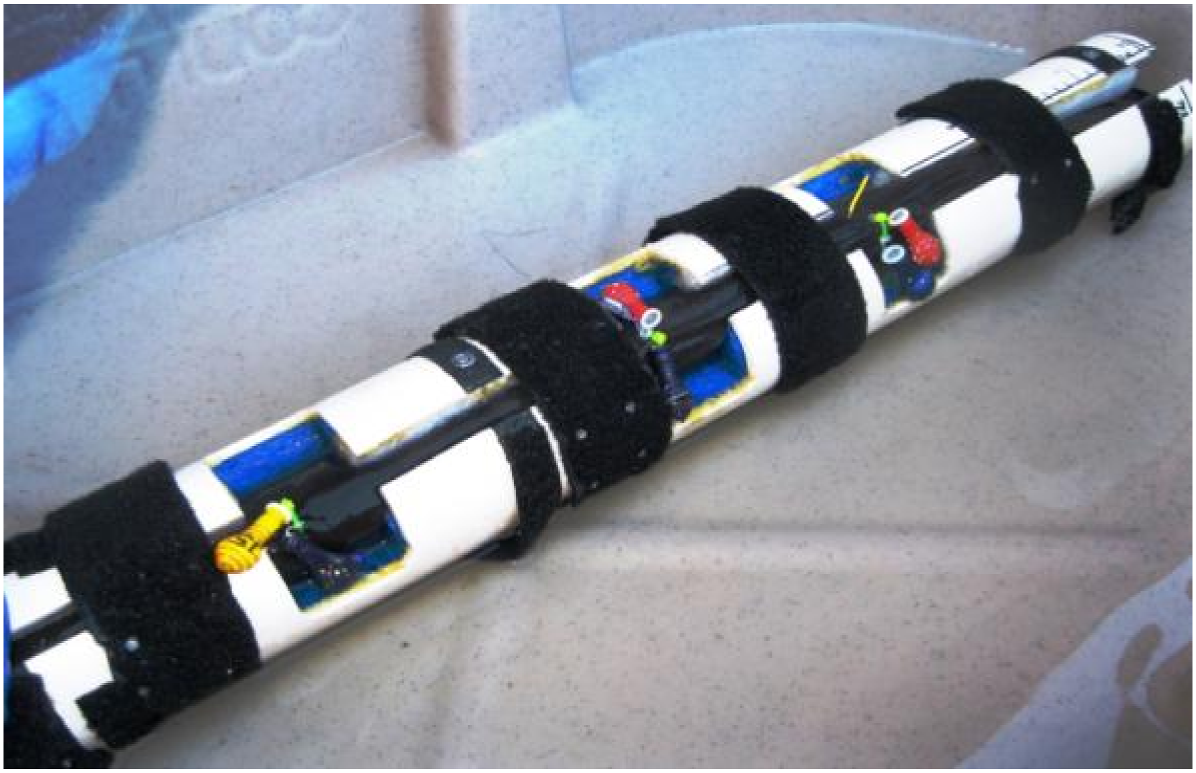

Figure 4-2: Specially designed eel restraining device used to aid in HI-Z tagging adult American Eels.

Figure 4-3: Injecting catalyst into a HI-Z tag attached to an adult American Eel at just prior to release.

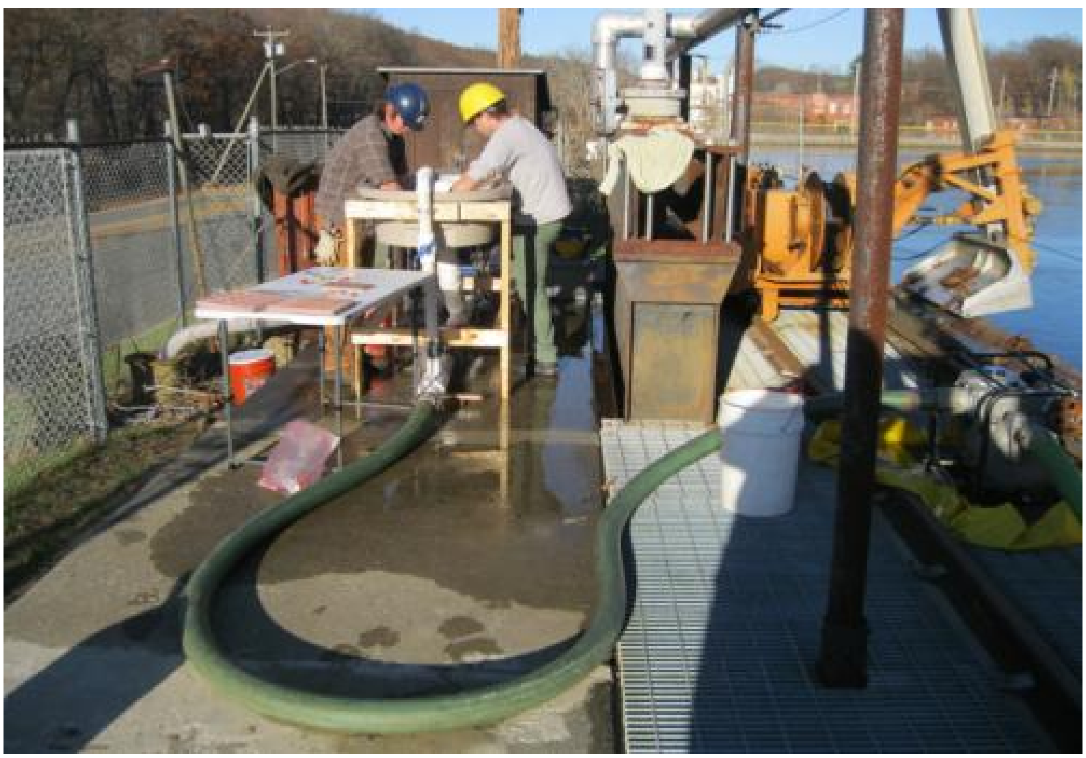

Figure 4-4: Adult eels released through an induction apparatus. The induction system and release hose supplied with river water by a 3-inch trash pump that transported eels quickly to the desired release point.

Figure 4-5: Six-inch diameter steel pipe with inserted four-inch diameter flexible hose that directed eels towards Bascule gates 1 and 4.

Figure 4-6: Boat crews were positioned downstream for retrieval when eels were buoyed to the surface.

Figure 4-7: On shore eel holding tanks (900 gal) to monitor delayed effects of tagging and turbine passage. Tanks continuously supplied with ambient river water by two redundant pump systems connected to different electrical circuits.

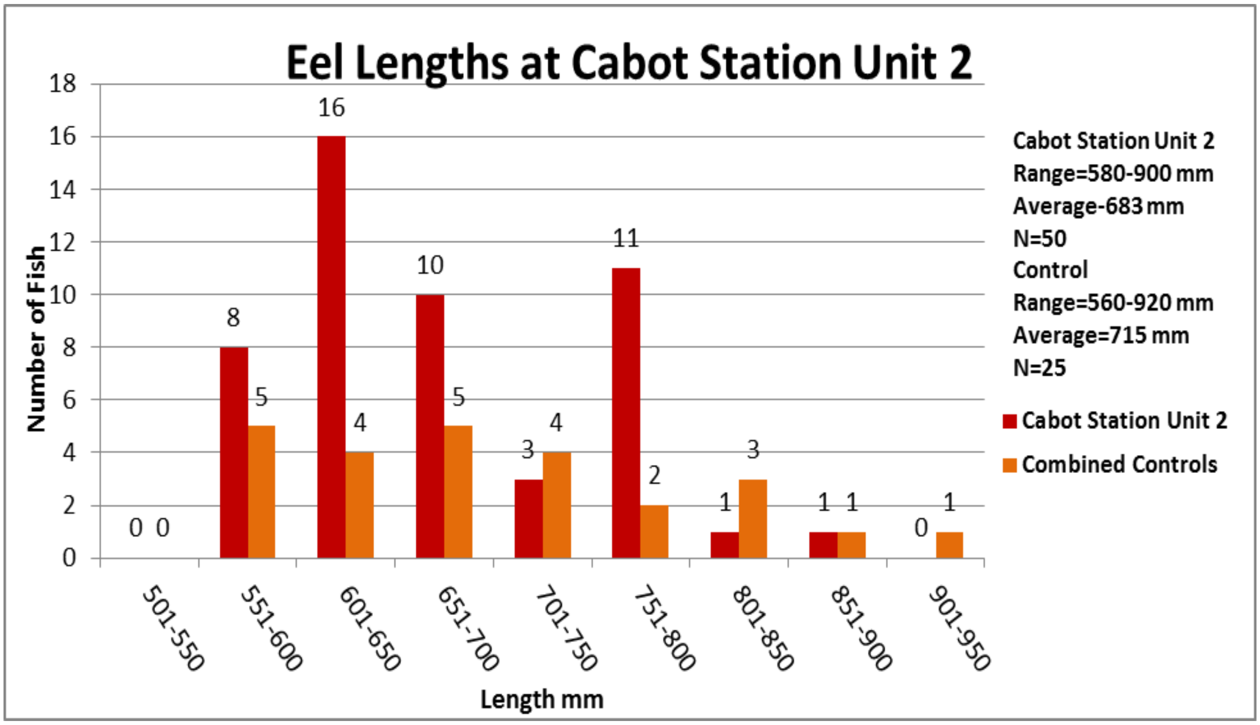

Figure 4-8: Length frequency for HI-Z tagged adult American Eels released at Cabot Station Unit 2, versus combined controls.

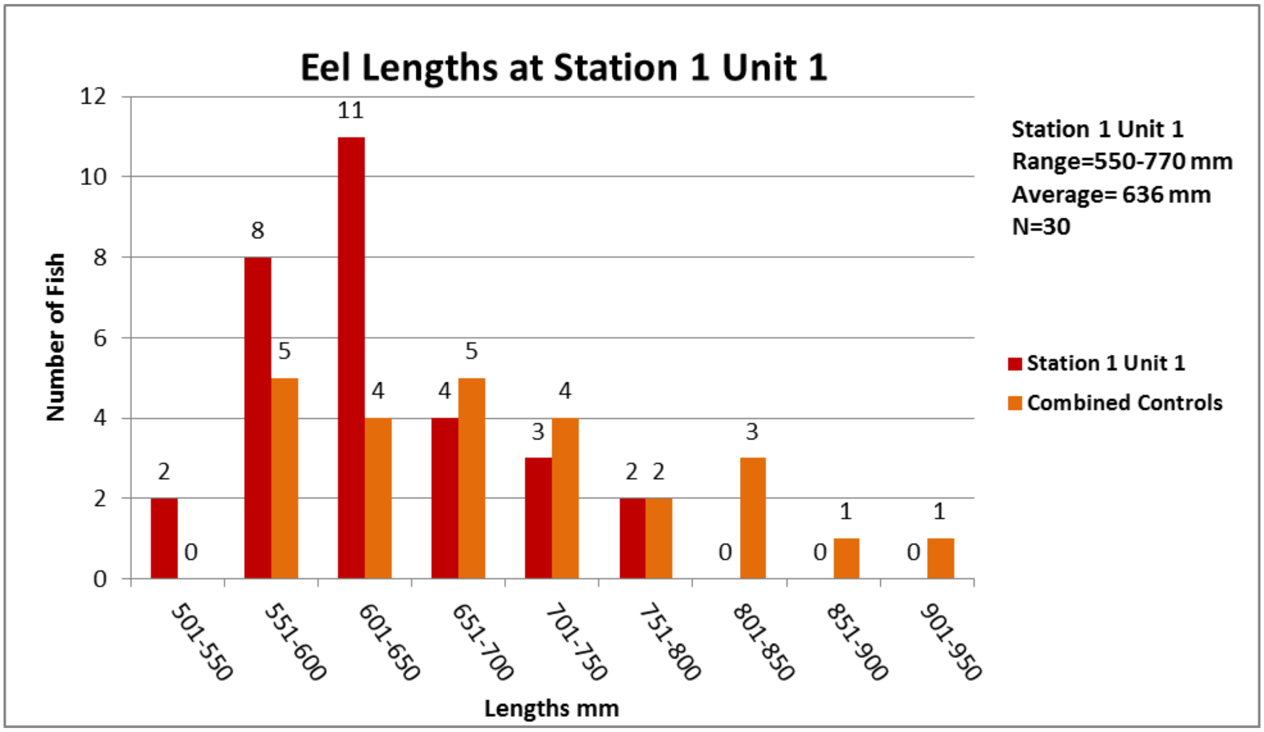

Figure 4-9: Length frequency for HI-Z tagged treatment adult American Eels released at Station 1 Unit 1 versus combined controls.

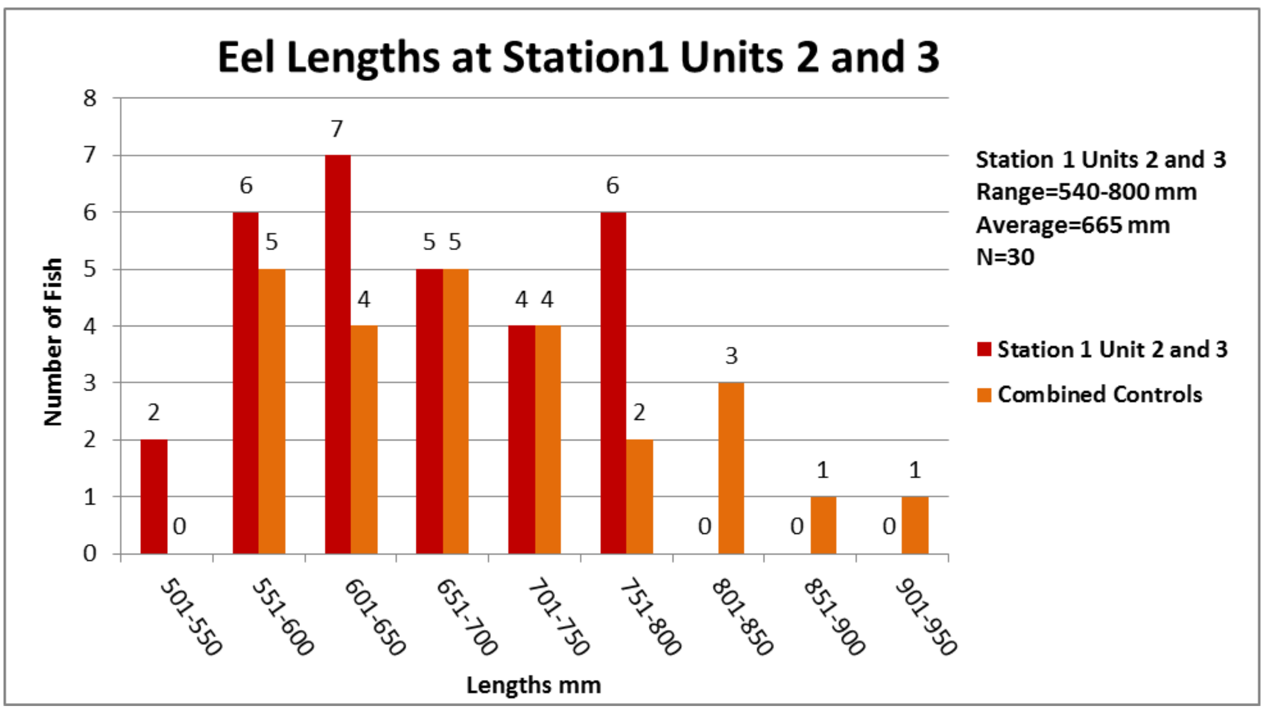

Figure 4-10: Length frequency for HI-Z tagged treatment adult American Eels released at Station 1 Units 2/3 versus combined controls.

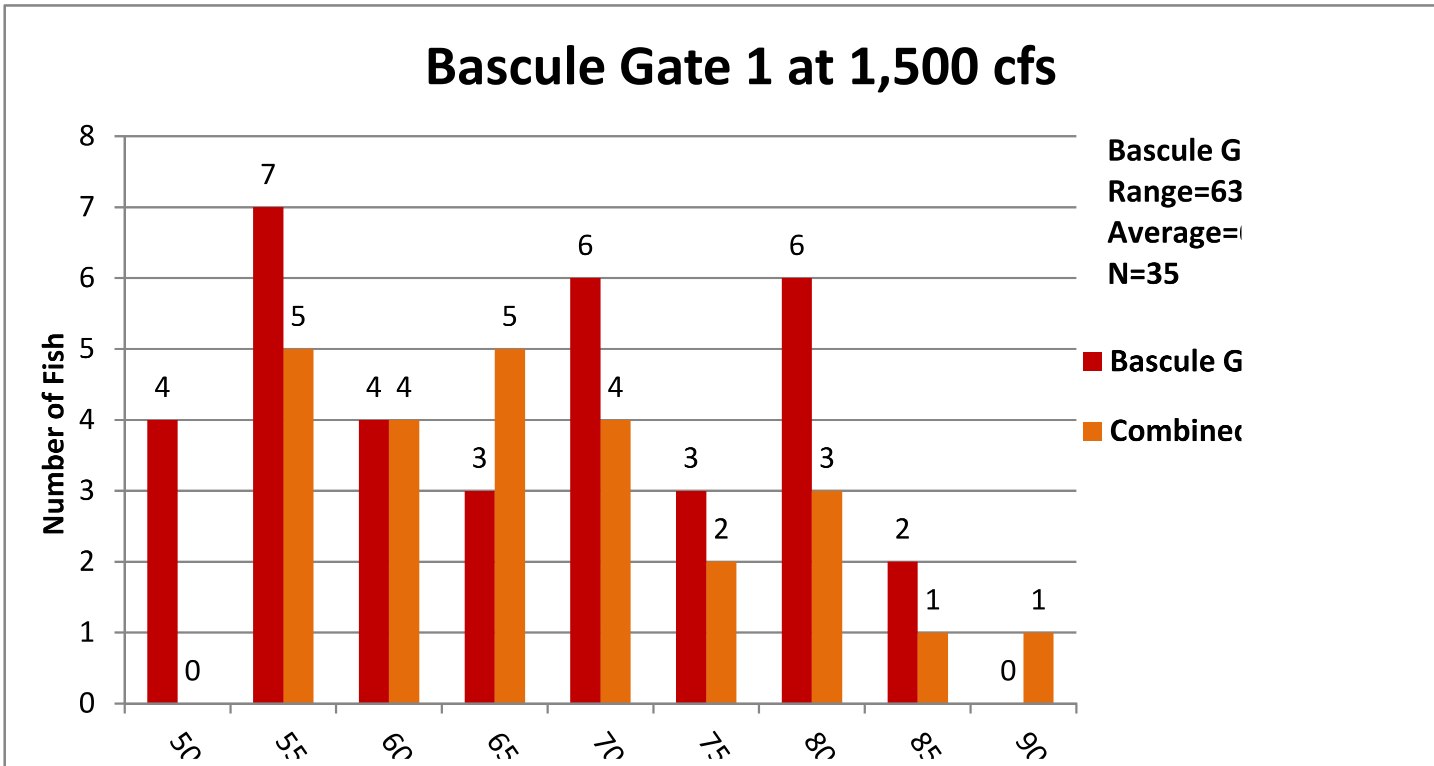

Figure 4-11: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 1 at 1,500 cfs versus combined controls.

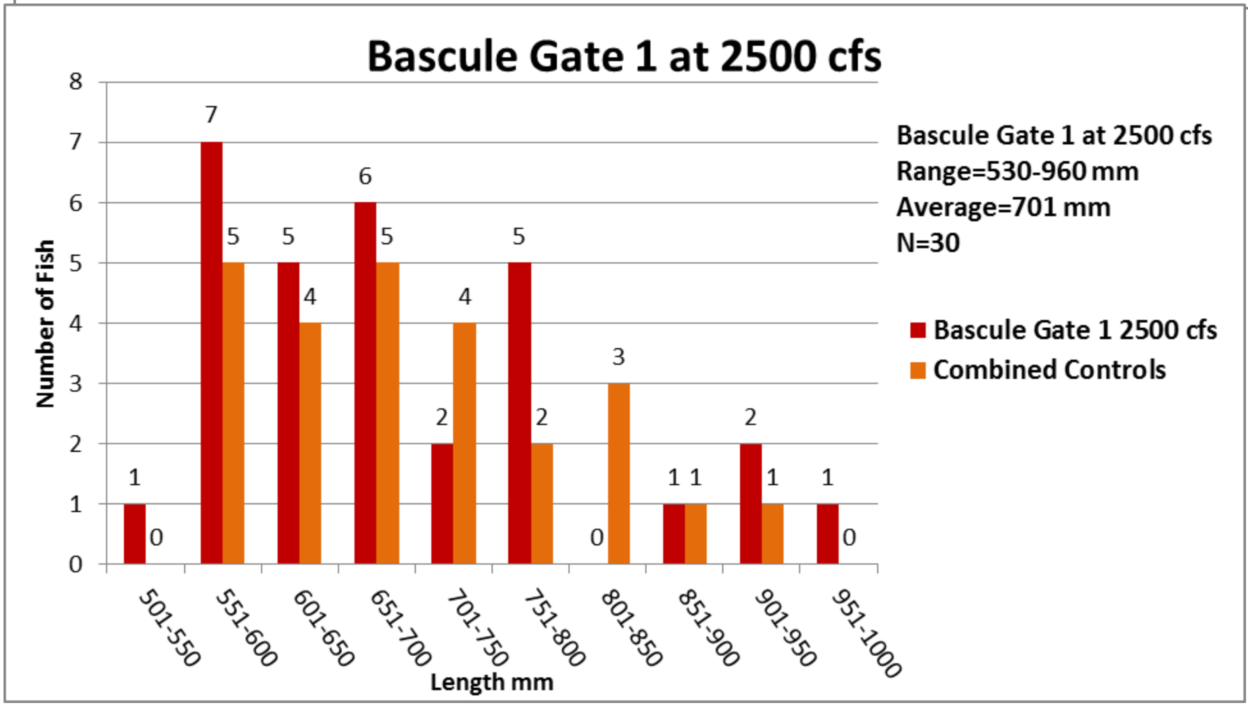

Figure 4-12: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 1 at 2,500 cfs versus combined controls.

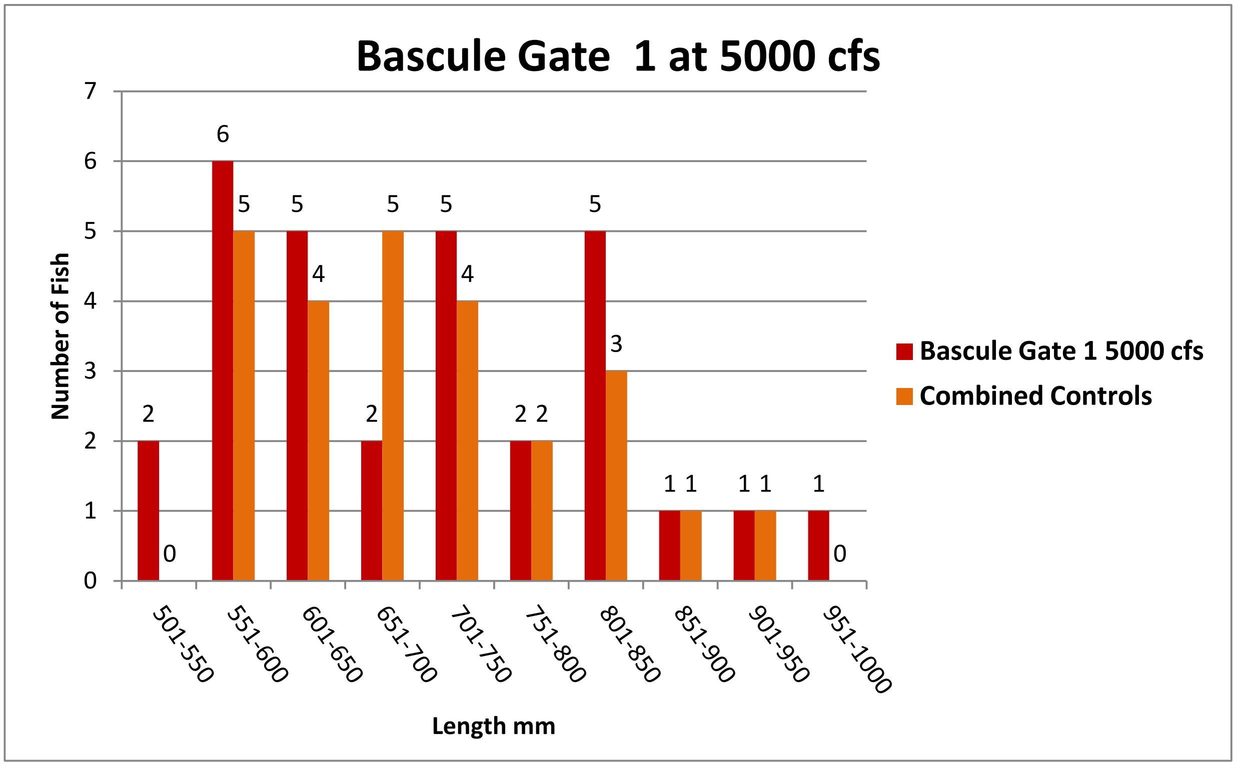

Figure 4-13: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 1 at 5,000 cfs versus combined controls.

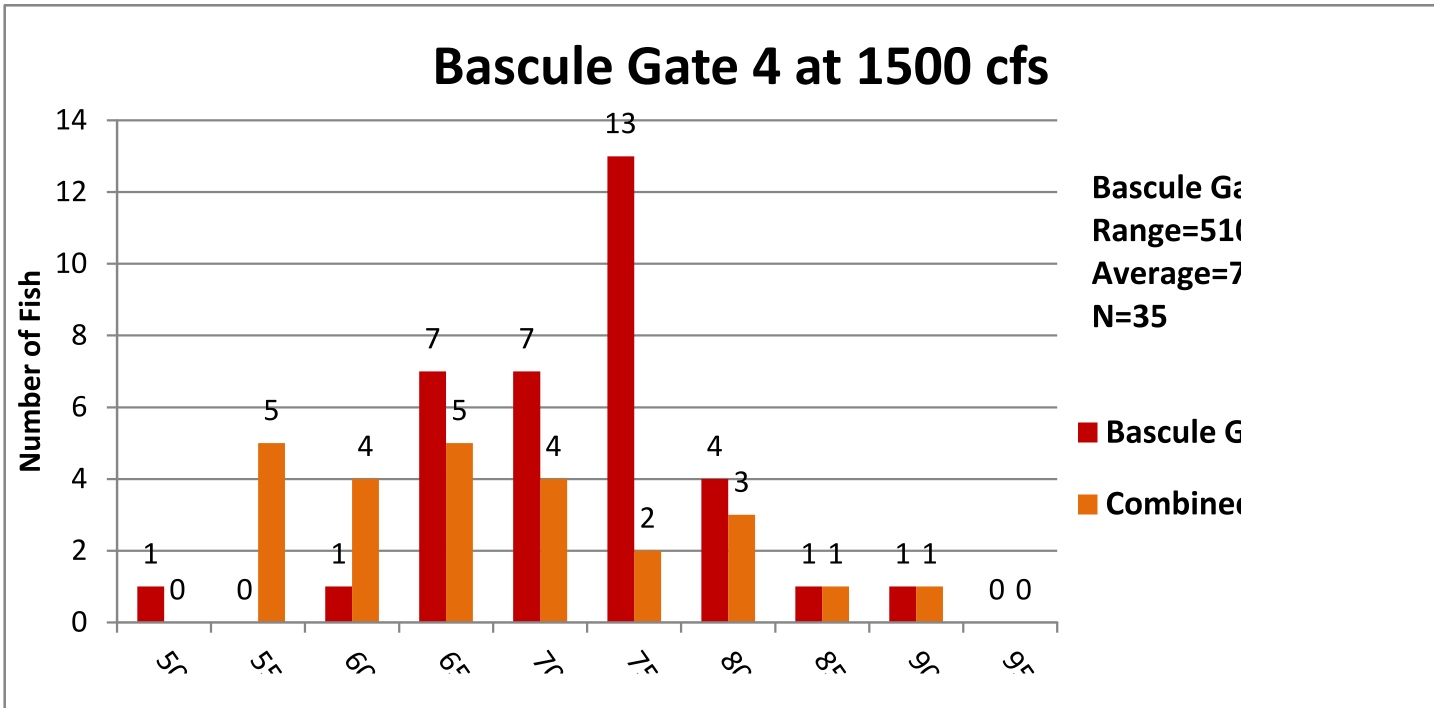

Figure 4-14: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 4 at 1,500 cfs versus combined controls.

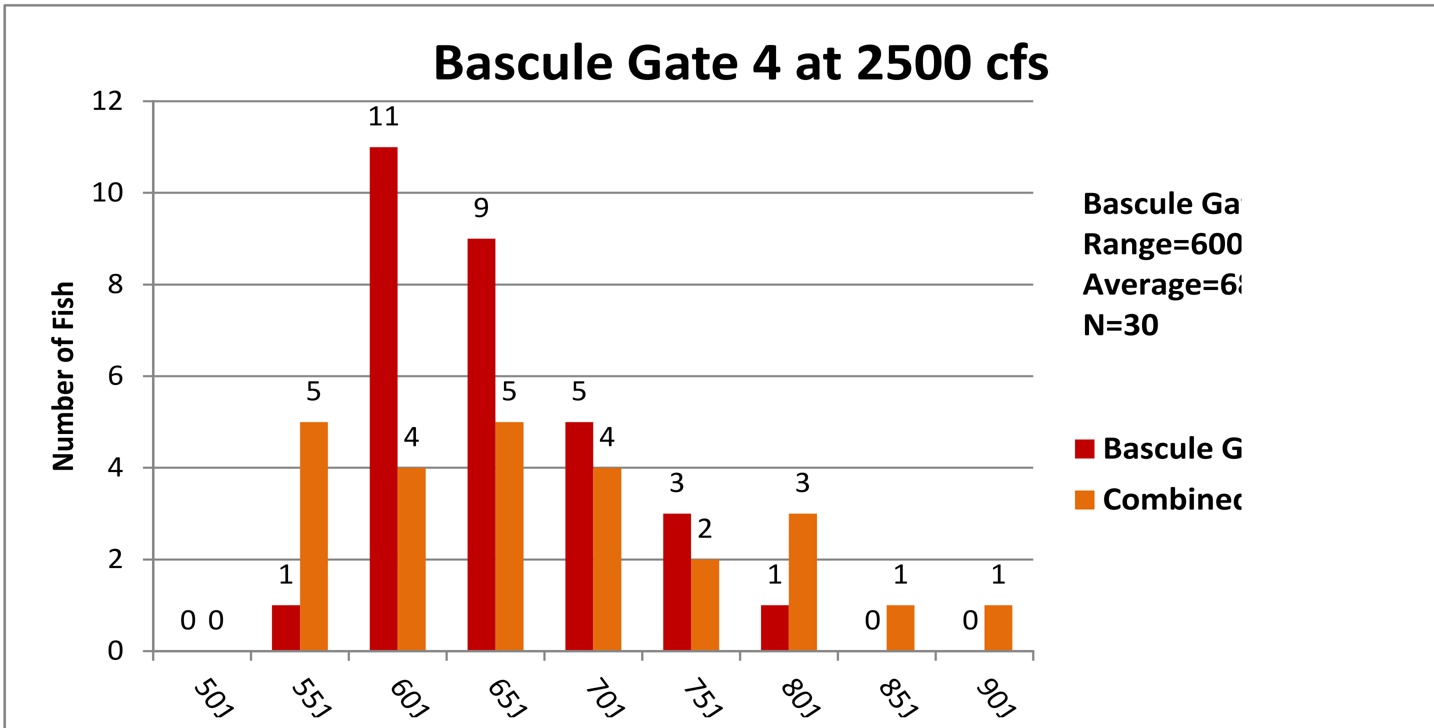

Figure 4-15: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 4 at 2,500 cfs versus combined controls.

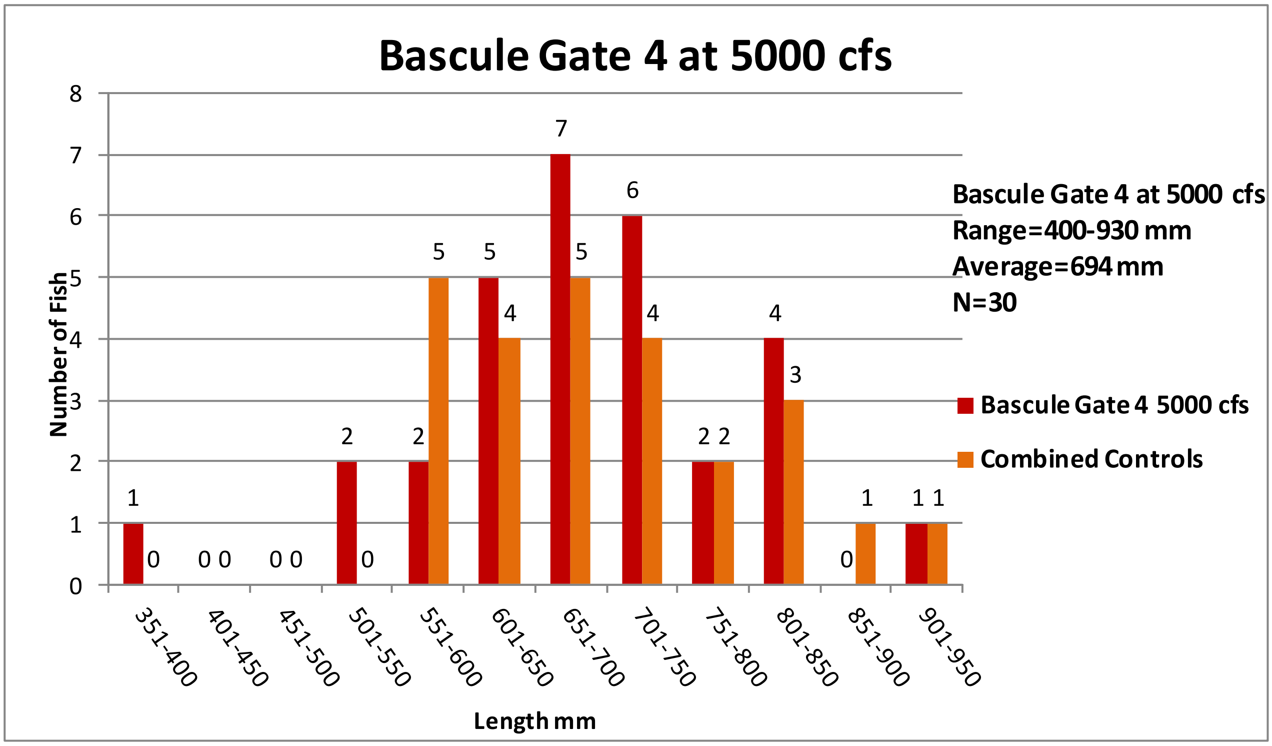

Figure 4-16: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 4 at 5,000 cfs versus combined controls.

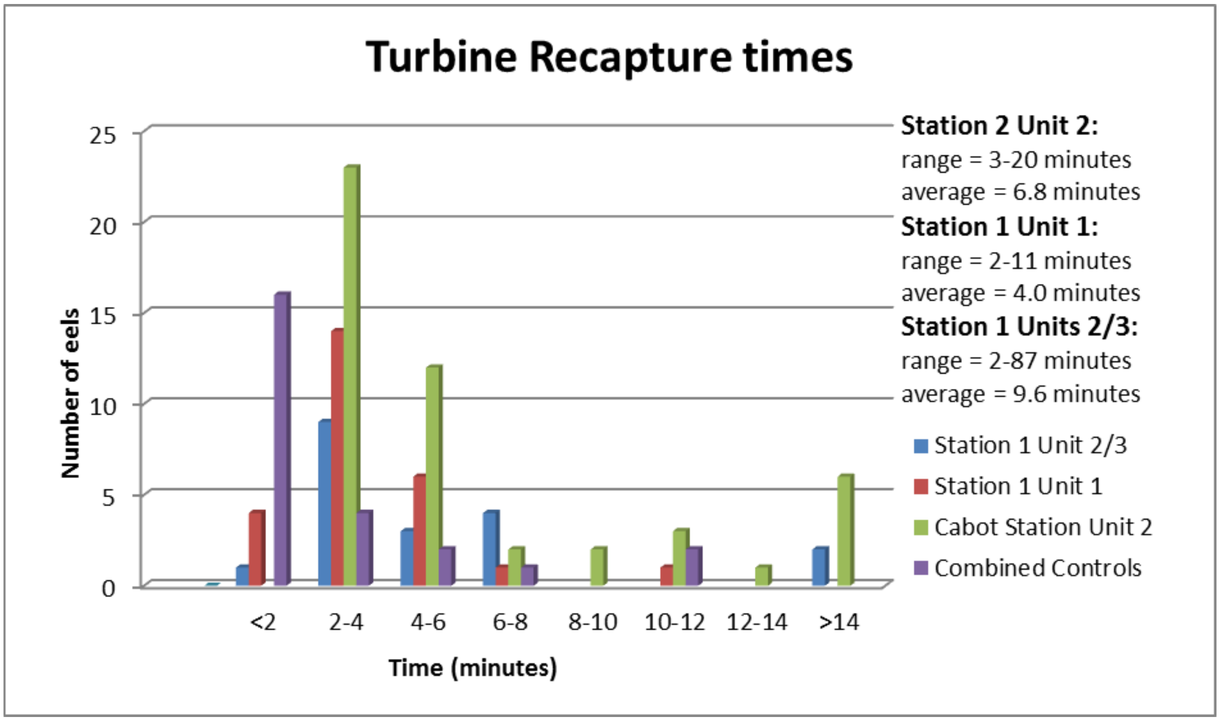

Figure 5-1: Recapture times of fish released through turbine units at Cabot Station and Station 1.

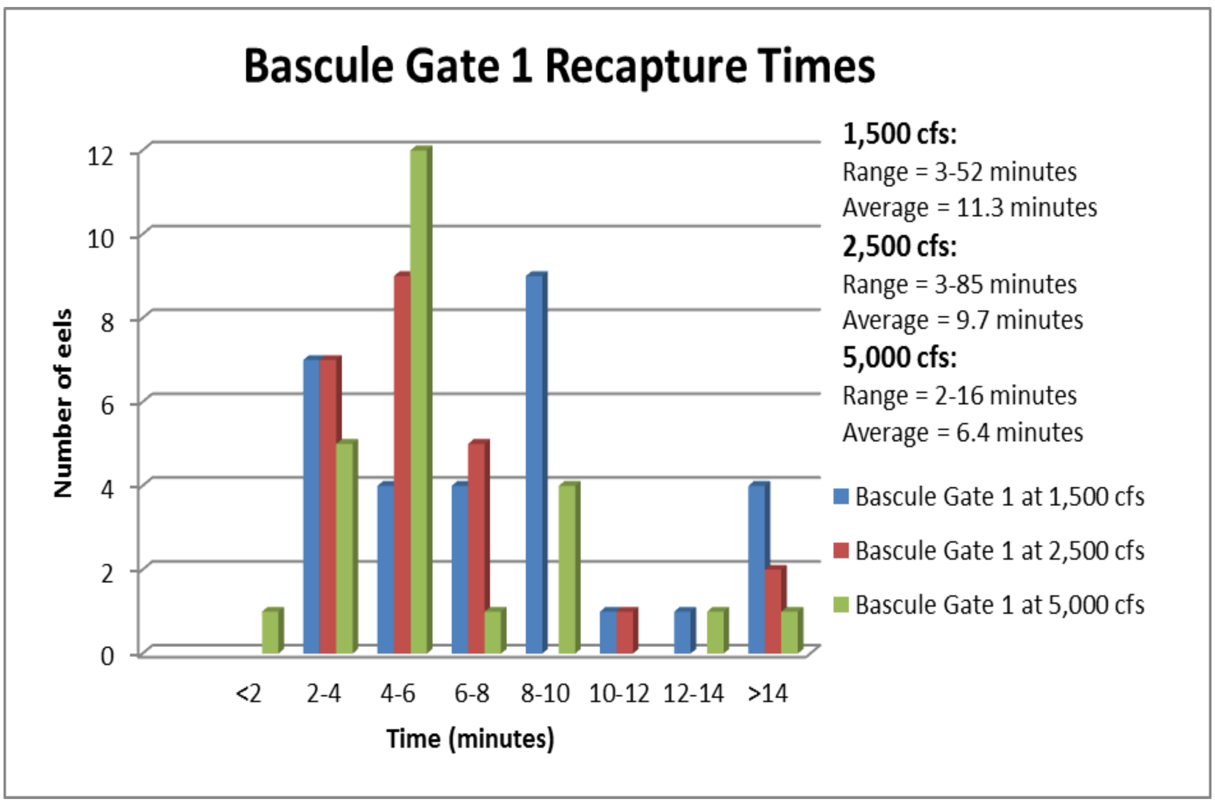

Figure 5-2: Recapture times of fish released at Bascule Gate 1.

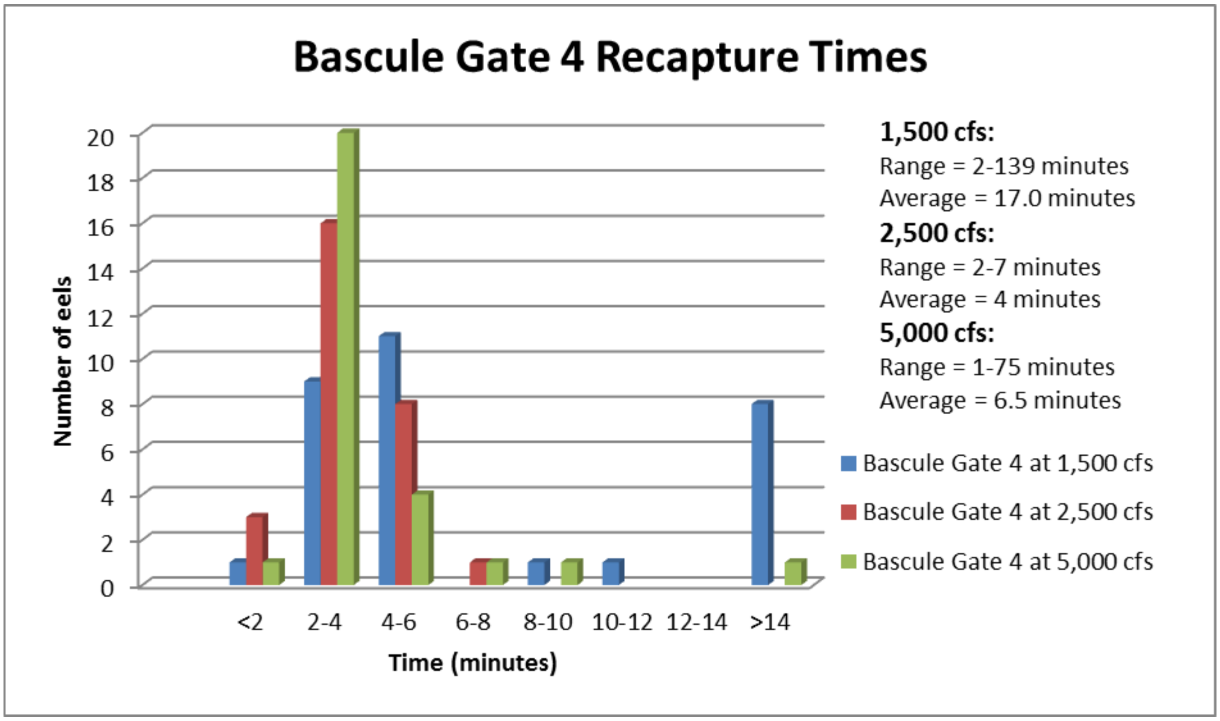

Figure 5-3: Recapture times of fish released at Bascule Gate 4.

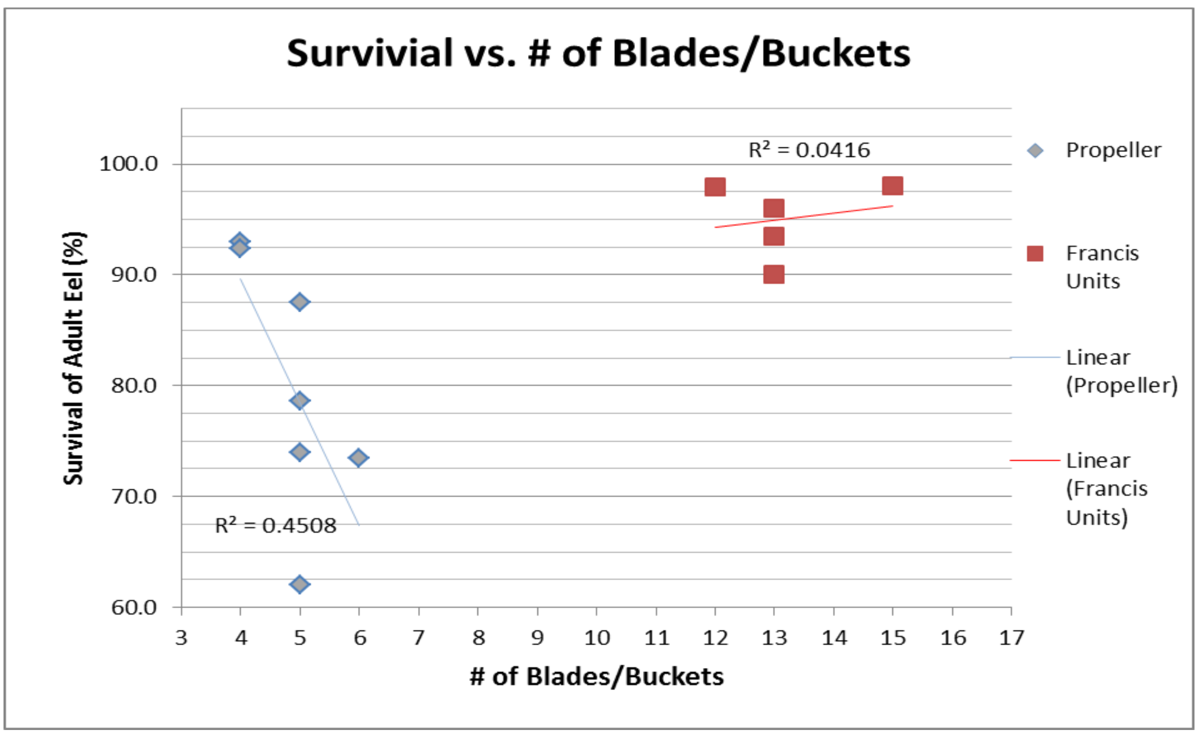

Figure 5-4: Relationship (with trend-lines) between 48h direct survival of HI-Z tagged adult eels passed through propeller and Francis turbines versus number of blades/buckets.

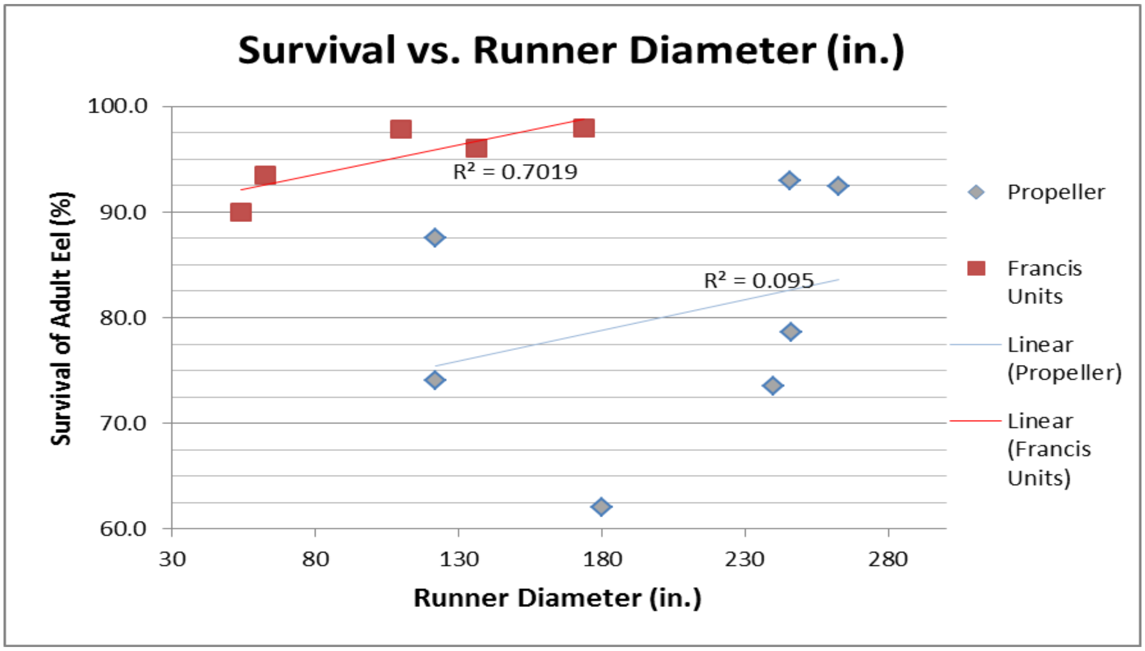

Figure 5-5: Relationship (with trend-lines) between 48h direct survival of HI-Z tagged adult eels passed through propeller and Francis turbines versus runner diameter.

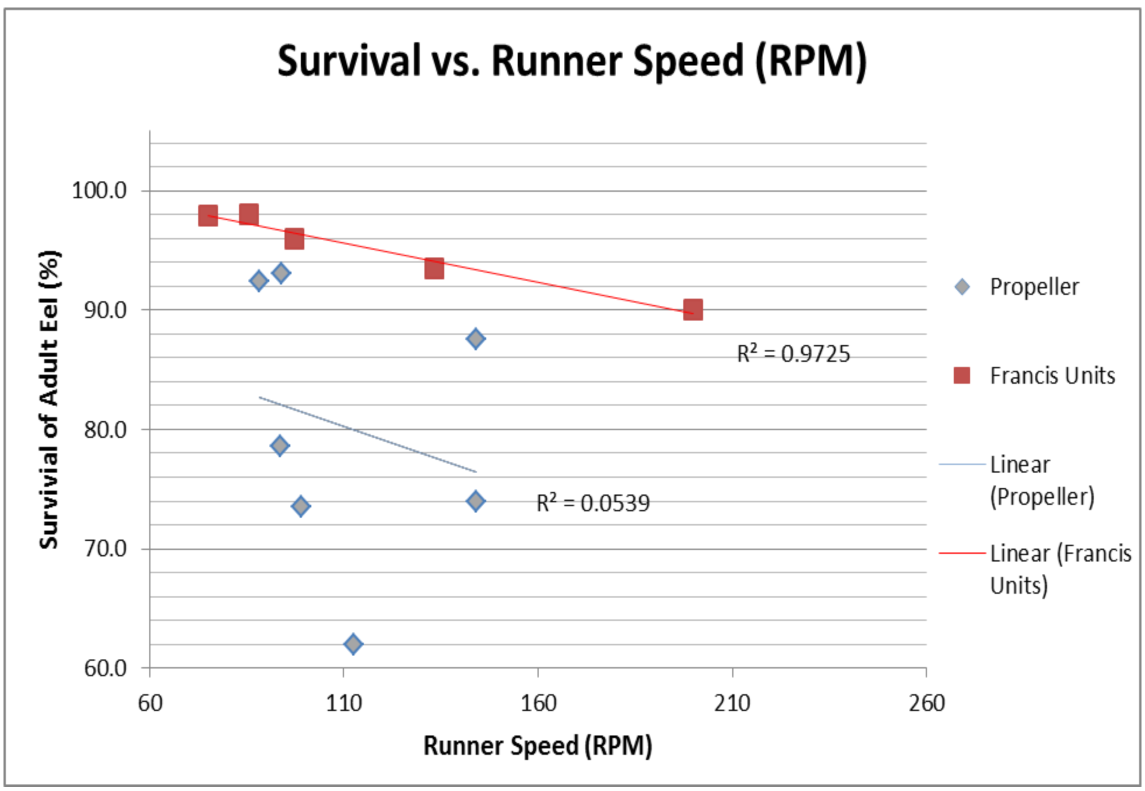

Figure 5-6: Relationship (with trend-lines) between 48h direct survival of HI-Z tagged adult eels passed through propeller and Francis turbines versus runner speed.

Appendix A

Daily Tag / Recapture Data

Appendix Table A

Daily data for recaptured Adult Eels passed through Cabot Station Unit 2, Station 1 Units 1 and 2/3, and over the Bascule Gates 1 and 4 at 1,500, 2,500, and 5,000 cfs, November 2015. Controls released into the tailrace downstream of the treatment sites.

	11/4	11/5	11/6	11/7	11/9	11/10	Totals
Bascule Gates 4: 1500 cfs							
Number released	30	5	--	--	--	--	35
Number alive	27	4	--	--	--	--	31
Number recovered dead	0	0	--	--	--	--	0
Assigned dead	3	1	--	--	--	--	4
Dislodged tags	0	1	--	--	--	--	1
Stationary radio signals	3	0	--	--	--	--	3
Undetermined	0	0	--	--	--	--	0
Held and Alive 1 h	27	4	--	--	--	--	31
Alive 24 h	25	4	--	--	--	--	29
Alive 48h	25	4	--	--	--	--	29
Bascule Gates 4: 2500 cfs							
Number released	30	--	--	--	--	--	30
Number alive	27	--	--	--	--	--	27
Number recovered dead	1	--	--	--	--	--	1
Assigned dead	2	--	--	--	--	--	2
Dislodged tags	0	--	--	--	--	--	0
Stationary radio signals	2	--	--	--	--	--	2
Undetermined	0	--	--	--	--	--	0
Held and Alive 1 h	27	--	--	--	--	--	27
Alive 24 h	27	--	--	--	--	--	27
Alive 48h	27	--	--	--	--	--	27
Bascule Gates 4: 5000 cfs							
Number released	--	30	--	--	--	--	30
Number alive	--	28	--	--	--	--	28
Number recovered dead	--	0	--	--	--	--	0
Assigned dead	--	2	--	--	--	--	2
Dislodged tags	--	0	--	--	--	--	0
Stationary radio signals	--	2	--	--	--	--	2
Undetermined	--	0	--	--	--	--	0
Held and Alive 1 h	--	28	--	--	--	--	28
Alive 24 h	--	28	--	--	--	--	28
Alive 48h	--	28	--	--	--	--	28
Bascule Gates 1: 1500 cfs							
Number released	--	35	--	--	--	--	35
Number alive	--	30	--	--	--	--	30
Number recovered dead	--	0	--	--	--	--	0
Assigned dead	--	4	--	--	--	--	4
Dislodged tags	--	0	--	--	--	--	0

Stationary radio signals	--	4	--	--	--	--	4
Undetermined	--	1	--	--	--	--	1
Held and Alive 1 h	--	30	--	--	--	--	30
Alive 24 h	--	30	--	--	--	--	30
Alive 48h	--	30	--	--	--	--	30
Bascule Gates 1: 2500 cfs							
Number released	--	15	15	--	--	--	30
Number alive	--	11	13	--	--	--	24
Number recovered dead	--	0	0	--	--	--	0
Assigned dead	--	3	1	--	--	--	4
Dislodged tags	--	1	0	--	--	--	1
Stationary radio signals	--	2	1	--	--	--	3
Undetermined	--	1	1	--	--	--	2
Held and Alive 1 h	--	11	13	--	--	--	24
Alive 24 h	--	11	13	--	--	--	24
Alive 48h	--	11	13	--	--	--	24
Bascule Gates 1: 5000 cfs							
Number released	--	--	30	--	--	--	30
Number alive	--	--	25	--	--	--	25
Number recovered dead	--	--	0	--	--	--	0
Assigned dead	--	--	4	--	--	--	4
Dislodged tags	--	--	1	--	--	--	1
Stationary radio signals	--	--	3	--	--	--	3
Undetermined	--	--	1	--	--	--	1
Held and Alive 1 h	--	--	25	--	--	--	25
Alive 24 h	--	--	25	--	--	--	25
Alive 48h	--	--	25	--	--	--	25
Cabot Station 2 Unit 2							
Number released	--	--	--	50	--	--	50
Number alive	--	--	--	49	--	--	49
Number recovered dead	--	--	--	0	--	--	0
Assigned dead	--	--	--	0	--	--	0
Dislodged tags	--	--	--	0	--	--	0
Stationary radio signals	--	--	--	0	--	--	0
Undetermined	--	--	--	1	--	--	1
Held and Alive 1 h	--	--	--	49	--	--	49
Alive 24 h	--	--	--	48	--	--	48
Alive 48h	--	--	--	48	--	--	48
Cabot St. 1: Unit 2/3							
Number released	--	--	--	--	30	--	30
Number alive	--	--	--	--	18	--	18
Number recovered dead	--	--	--	--	1	--	1
Assigned dead	--	--	--	--	10	--	10
Dislodged tags	--	--	--	--	10	--	10
Stationary radio signals	--	--	--	--	0	--	0
Undetermined	--	--	--	--	1	--	1

Held and Alive 1 h	--	--	--	--	18	--	18
Alive 24 h	--	--	--	--	18	--	18
Alive 48h	--	--	--	--	18	--	18
Cabot St. 1: Unit 1							
Number released	--	--	--	--	30	--	30
Number alive	--	--	--	--	26	--	26
Number recovered dead	--	--	--	--	0	--	0
Assigned dead	--	--	--	--	4	--	4
Dislodged tags	--	--	--	--	4	--	4
Stationary radio signals	--	--	--	--	0	--	0
Undetermined	--	--	--	--	0	--	0
Held and Alive 1 h	--	--	--	--	26	--	26
Alive 24 h	--	--	--	--	26	--	26
Alive 48h	--	--	--	--	26	--	26
Bascule Gate Combined Controls							
Number released	5	5	10	--	--	--	20
Number alive	5	5	10	--	--	--	20
Number recovered dead	0	0	0	--	--	--	0
Assigned dead	0	0	0	--	--	--	0
Dislodged tags	0	0	0	--	--	--	0
Stationary radio signals	0	0	0	--	--	--	0
Undetermined	0	0	0	--	--	--	0
Held and Alive 1 h	5	5	10	--	--	--	20
Alive 24 h	5	5	10	--	--	--	20
Alive 48h	5	5	10	--	--	--	20
Cabot Station Combined Controls							
Number released	--	--	--	5	--	--	5
Number alive	--	--	--	5	--	--	5
Number recovered dead	--	--	--	0	--	--	0
Assigned dead	--	--	--	0	--	--	0
Dislodged tags	--	--	--	0	--	--	0
Stationary radio signals	--	--	--	0	--	--	0
Undetermined	--	--	--	0	--	--	0
Held and Alive 1 h	--	--	--	5	--	--	5
Alive 24 h	--	--	--	5	--	--	5
Alive 48h	--	--	--	5	--	--	5

Appendix B

Individual Fish Disposition Data

Appendix Table B

Individual fish disposition data for recaptured Adult Eels passed through Cabot Station Unit 2, Station 1 Units 1 and 2/3, and over the Bascule Gates 1 and 4 at 1,500, 2,500, and 5,000 cfs, November 2015. Controls released downstream of the treatment sites.

Description of codes and details on injured fish are presented in Table 4-4.

	Total		Time								
						No. HI-Z					
Fish	Length		Re-	Re-	Minutes	tags	Survival	Status Codes			
ID	(mm)		leased	covered	at large	recovered	Code	1	2	3	4
	12-Nov-10		Tes tlot 1			Water temp = 9.2°C					
Fish ID	Length	Release	Recovery	Text39	Num Balloons	Survival	Status1	Status2	Status3		Status4
26	800	10:14	10:42	*28*	6	1	A				
27	760	10:18	10:22	*4*	6	1	A				
28	730	10:21	12:40	*139*	6	1	A				
29	725	10:24	10:44	*20*	6	1	A				
30	700	10:27	10:32	*5*	6	1	A				
31	775	11:00	11:03	*3*	6	1	A				
32	700	11:03	11:06	*3*	6	1	A				
33	775	11:07	11:09	*2*	6	1	A				
34	730	11:12	11:16	*4*	6	1	A				
35	700	11:14	11:18	*4*	6	1	A				
36	800	11:17	11:27	*10*	6	1	A				
37	815	11:20	11:25	*5*	6	1	A				
38	790	11:22	11:27	*5*	6	1	A				
39	750	11:25	11:28	*3*	6	1	A				
40	770	11:29	11:32	*3*	6	1	A				
41	830	11:39	12:44	*65*	6	1	A				
42	710	11:42	11:47	*5*	6	1	A				
43	760	11:45	12:38	*53*	6	1	A				
44	800	11:47			0	5					
45	760	11:50	12:56	*66*	6	1	G	*			
46	820	11:53	11:57	*4*	6	1	A				
47	840	11:55	12:01	*6*	4	1	A				
48	730	11:58	12:02	*4*	6	1	A				
49	680	12:00	12:05	*5*	6	1	A				
50	725	12:03	12:08	*5*	6	1	A				
76	775	12:05	12:31	*26*	6	1	A				
77	780	12:08			0	5					
78	760	12:09	12:15	*6*	6	1	A				
79	700	12:12			0	5					

80	705	12:14	12:25	*11*	6	1	A	
81	680	12:54	12:58	*4*	6	1	A	
82	630	12:58			0	5		
83	650	13:03	13:05	*2*	6	1	A	
84	620	13:06	13:10	*4*	6	1	A	
85	700	13:10	13:13	*3*	6	1	A	
86	720	13:14	13:20	*6*	6	1	A	
87	640	13:18	13:21	*3*	6	1	A	
88	625	13:21	13:24	*3*	6	1	A	
89	700	13:25	13:27	*2*	5	1	A	
90	700	13:28	13:31	*3*	6	1	A	
91	640	13:31	13:35	*4*	6	1	A	
92	660	13:47	13:51	*4*	6	1	A	
93	700	13:51	13:55	*4*	4	1	A	
94	710	13:55	13:58	*3*	6	1	A	
95	630	13:57	14:00	*3*	6	1	A	
96	700	14:01	14:08	*7*	5	1	A	
97	790	14:03	14:09	*6*	6	1	A	
98	620	14:07	14:12	*5*	6	1	A	
99	675	14:10			0	5		
100	620	14:13	14:18	*5*	6	1	A	
52	600	14:17	14:21	*4*	6	1	A	
53	610	14:19	14:22	*3*	6	1	A	
54	630	14:22	14:27	*5*	6	1	A	
55	660	14:26	14:28	*2*	6	1	A	
56	740	14:29	14:35	*6*	2	2	7	*
57	780	14:31	14:36	*5*	6	1	A	
58	710	14:34	14:38	*4*	6	1	A	
59	810	14:37	14:42	*5*	6	1	A	
60	780	14:40	14:44	*4*	6	1	A	
61	720	14:43	14:46	*3*	6	1	A	
62	700	15:29	15:31	*2*	6	1	A	
63	650	15:33	15:34	*1*	6	1	A	
64	700	15:39	15:42	*3*	6	1	A	
65	625	15:42	15:44	*2*	6	1	A	
66	600	15:48	15:50	*2*	6	1	A	
441	780	15:07	15:10	*3*	6	1	A	
442	920	15:09	15:16	*7*	6	1	A	
443	740	15:13			0	4		
444	700	15:15	15:27	*12*	6	1	A	
445	650	15:17	15:22	*5*	5	1	A	

446	960	15:20			0	5	
447	760	15:22			0	5	
448	800	15:27	15:32	*5*	6	1	A
449	780	15:30	15:36	*6*	6	1	A
450	670	15:33	15:38	*5*	4	1	A
68	570	15:34	15:40	*6*	4	1	A
69	780	15:37	15:44	*7*	5	1	A
70	610	15:39	15:44	*5*	4	1	A
71	610	15:42			0	3	
72	680	15:45	15:52	*7*	5	1	A
151	650	9:24	9:29	*5*	5	1	A
152	870	9:27			0	3	
153	910	9:30	9:36	*6*	5	1	A
154	680	9:33	9:49	*16*	4	1	A
155	510	9:36	9:42	*6*	4	1	A
156	770	9:49	9:53	*4*	5	1	A
157	400	9:53			0	5	
158	550	9:55	9:58	*3*	4	1	A
159	690	9:57	10:00	*3*	6	1	A
160	740	10:00	10:04	*4*	6	1	A
161	750	10:04	10:08	*4*	5	1	A
162	830	10:06	10:10	*4*	5	1	A
163	550	10:09	10:13	*4*	4	1	A
164	660	10:12	10:15	*3*	4	1	A
165	730	10:14	10:22	*8*	6	1	A
166	720	10:17	10:21	*4*	6	1	A
167	810	10:20	10:25	*5*	6	1	A
168	830	10:24	11:39	*75*	2	1	A
169	600	10:30	10:31	*1*	4	1	A
170	690	10:32	10:41	*9*	5	1	A
171	730	10:52	10:55	*3*	4	1	A
172	740	10:54	10:59	*5*	4	1	A
173	650	10:57	11:00	*3*	4	1	A
174	690	11:00	11:03	*3*	4	1	A
175	660	11:02	11:06	*4*	4	1	A
176	610	11:05	11:08	*3*	4	1	A
177	650	11:09	11:14	*5*	4	1	A
178	640	11:10	11:13	*3*	4	1	A
179	690	11:12	11:16	*4*	4	1	A
180	930	11:16	11:19	*3*	6	1	A
181	600	11:17	11:21	*4*	4	1	A

182	830	11:20	11:25	*5*	5	1	A	
183	610	11:23			0	5		
184	700	11:26	11:29	*3*	4	1	A	
185	760	11:29	11:32	*3*	5	1	A	
186	840	13:13	13:27	*14*	6	1	A	
187	550	13:16	13:28	*12*	4	1	A	
188	580	13:19	13:38	*19*	4	1	A	
189	630	13:21	13:25	*4*	4	1	A	
190	620	13:25	13:34	*9*	4	1	A	
191	530	13:31	13:36	*5*	4	1	A	
192	600	13:33	13:42	*9*	4	1	A	
193	580	13:35			0	5		
194	610	13:38	14:18	*40*	4	1	A	
195	550	13:41	13:48	*7*	4	1	A	
196	850	13:45	13:52	*7*	6	1	A	
197	870	13:49	14:32	*43*	4	1	A	
198	810	13:51			0	5		
199	825	13:57	14:01	*4*	6	1	A	
200	730	14:00	14:09	*9*	5	1	V	*
426	780	14:03			0	4		
427	710	14:07	14:13	*6*	6	1	A	
428	825	14:09	15:01	*52*	6	1	A	
429	780	14:15	14:18	*3*	6	1	A	
430	570	14:17	14:24	*7*	4	1	A	
431	600	14:22	14:26	*4*	4	1	A	
432	560	14:25	14:30	*5*	4	1	A	
433	740	14:27	14:31	*4*	5	1	A	
434	550	14:29	14:38	*9*	4	1	A	
435	600	14:32	14:35	*3*	4	1	A	
436	730	14:36	14:46	*10*	5	1	A	
437	930	14:38	14:44	*6*	7	1	A	
438	840	14:41	14:50	*9*	6	1	A	
439	770	14:43	14:53	*10*	6	1	A	
440	690	14:46	14:55	*9*	5	1	A	
141	710	15:48	15:58	*10*	3	1	A	
142	650	15:50	15:57	*7*	4	1	A	
143	700	15:53	15:57	*4*	5	1	A	
144	750	15:55			0	5		
145	670	15:57			0	5		
146	700	16:20	16:32	*12*	5	1	A	
147	840	16:24	16:26	*2*	6	1	A	

148	920	16:26	16:33	*7*	6	1	A
149	700	16:29	16:31	*2*	6	1	A
150	600	16:33	16:36	*3*	4	1	A
201	700	8:35	8:40	*5*	3	1	A
202	600	8:38	8:45	*7*	4	1	A
203	600	8:41	10:06	*85*	3	1	A
204	600	8:44	8:49	*5*	3	1	A
205	530	8:46	8:52	*6*	3	1	A
206	650	8:49			0	5	
207	640	8:53	8:56	*3*	4	1	A
208	680	8:55	8:59	*4*	4	1	A
209	590	8:58			0	4	
210	600	9:01	9:05	*4*	3	1	A
211	700	9:03	9:28	*25*	4	1	A
212	580	9:08	9:12	*4*	4	1	A
213	750	9:11	9:19	*8*	6	1	A
214	870	9:16	9:20	*4*	7	1	A
215	930	9:21	9:25	*4*	7	1	A
216	840	10:06	10:11	*5*	6	1	A
217	550	10:08	10:18	*10*	3	1	A
218	810	10:11	10:17	*6*	5	1	A
219	800	10:16			0	5	
220	840	10:18			0	5	
221	900	10:24	10:29	*5*	6	1	A
222	600	10:26	10:31	*5*	3	1	A
67	630	10:28	10:33	*5*	4	1	A
224	960	10:32	10:38	*6*	4	1	A
225	830	10:35			0	5	
226	530	10:48	10:54	*6*	3	1	A
227	740	10:49			0	4	
228	660	10:52	10:57	*5*	4	1	A
229	570	10:54	11:07	*13*	3	1	A
230	660	10:56	11:06	*10*	4	1	A
231	650	10:54	11:04	*10*	4	1	A
232	820	11:01	11:05	*4*	5	1	A
233	620	11:03			0	3	
234	590	11:06	11:11	*5*	4	1	A
235	600	11:08	11:14	*6*	4	1	A
236	720	11:10	11:16	*6*	5	1	A
237	910	11:15	11:18	*3*	6	1	A
238	800	11:21	11:30	*9*	4	1	A

239	630	11:25	11:29	4	3	1	A	
240	650	11:28	11:32	4	4	1	A	
241	750	11:30	11:46	16	4	1	A	
242	730	11:32	11:40	8	1	1	A	
243	600	11:35	11:37	2	4	1	A	
244	750	11:37	11:42	5	5	1	A	
245	600	11:39	11:42	3	4	1	A	
246	750	12:10	12:12	2	4	1	A	
247	600	12:14	12:19	5	5	1	A	
248	650	12:16	12:27	11	4	1	A	
249	830	12:22	12:23	1	6	1	A	
250	750	12:30	12:31	1	6	1	A	
126	780	12:35	12:36	1	6	1	A	
127	900	12:40	12:41	1	6	1	A	
128	810	12:44	12:46	2	6	1	A	
129	560	12:48	12:49	1	4	1	A	
130	600	12:53	12:53	0	4	1	A	
131	600	9:17	9:22	5	6	1	A	
132	650	9:21	9:24	3	3	1	A	
133	775	9:25	9:28	3	6	1	A	
134	610	9:28	9:32	4	5	1	A	
135	630	9:32	9:37	5	5	1	A	
136	780	9:35	9:38	3	5	1	A	
137	600	9:38	9:41	3	5	1	A	
138	630	9:42	9:45	3	5	1	A	
139	815	9:45	9:50	5	6	1	A	
140	690	9:47	9:52	5	4	1	A	
141	625	9:59	10:04	5	5	1	A	
142	610	10:02	10:07	5	6	1	A	
143	670	10:07	10:13	6	4	1	G	*
144	660	10:12	10:15	3	5	1	A	
145	775	10:15			0	5		
146	780	10:19	10:31	12	5	1	A	
147	600	10:22	10:29	7	5	1	A	
148	620	10:24	10:28	4	4	1	A	
149	730	10:27	10:34	7	6	1	A	
150	685	10:39	10:43	4	5	1	A	
376	600	10:52	10:55	3	6	1	A	
377	610	10:57	11:02	5	5	1	A	
378	670	11:00	11:04	4	4	1	A	
379	630	11:03	11:06	3	4	1	A	

380	580	11:05	11:10	*5*	4	1	A	
381	590	11:07	11:11	*4*	4	1	A	
382	800	11:10	11:14	*4*	3	1	G	*
383	770	11:13	11:17	*4*	5	1	A	
384	650	11:16	11:35	*19*	5	1	A	
385	670	11:18	11:27	*9*	4	1	A	
386	775	11:21	11:33	*12*	6	1	A	
387	580	11:37	11:41	*4*	5	1	A	
388	700	11:40	11:43	*3*	2	1	A	
389	650	11:43	12:02	*19*	5	1	A	
390	750	11:46	11:50	*4*	6	1	A	
391	650	11:50	12:05	*15*	1	1	A	
392	700	11:52	11:58	*6*	5	1	A	
393	610	11:55	12:15	*20*	6	1	A	
394	800	11:58	12:14	*16*	3	1	A	
395	790	12:02	12:14	*12*	3	1	A	
397	580	12:09	12:25	*16*	5	1	A	
396	750	12:26	12:36	*10*	3	1	A	
398	800	12:30	12:34	*4*	5	1	A	
399	900	12:33	12:37	*4*	6	1	A	
401	650	12:36	12:40	*4*	4	1	A	
402	775	12:39	12:52	*13*	5	1	A	
403	680	12:42	12:45	*3*	4	1	A	
404	660	12:45	12:48	*3*	5	1	A	
405	610	12:47	12:53	*6*	5	1	A	
406	650	12:50	12:55	*5*	6	1	A	
408	700	13:15	13:20	*5*	6	1	A	
409	750	13:19	13:21	*2*	5	1	A	
410	650	13:22	13:25	*3*	6	1	A	
411	725	13:27	13:29	*2*	6	1	A	
412	775	13:31	13:35	*4*	6	1	A	
451	630	10:31	10:35	*4*	2	1	A	
452	620	10:36	10:43	*7*	2	1	H	*
453	690	10:38	12:05	*87*	2	1	A	
454	630	10:42	10:50	*8*	1	1	A	
455	760	10:46			0	3		
456	670	10:49			0	4		
457	800	10:58	11:13	*15*	5	1	A	
458	605	11:01			0	3		
459	550	11:04	11:11	*7*	4	1	A	
460	540	11:09			0	3		

461	570	11:16	11:21	*5*	2	1	A		
462	650	11:20	11:24	*4*	3	1	A		
463	800	11:23			0	3			
464	740	11:27	11:29	*2*	2	1	A		
465	600	11:29			0	3			
466	590	11:30	11:37	*7*	1	2	H/G	*	
467	600	11:35			0	3			
468	675	11:37	11:41	*4*	2	1	A		
469	560	11:41	11:44	*3*	2	1	V	*	E
470	680	11:44	11:50	*6*	1	1	A		
471	780	11:51			0	3			
472	650	11:54	11:58	*4*	2	1	A		
473	615	11:57	12:00	*3*	3	1	A		
474	725	12:01	12:05	*4*	5	1	A		
475	610	12:02			0	3			
476	760	12:06	12:10	*4*	2	1	A		
477	680	12:08	12:12	*4*	2	1	A		
478	765	12:11	12:16	*5*	2	1	A		
479	730	12:14			0	3			
480	710	12:19			0	3			
481	715	13:02			0	3			
482	680	13:06	13:11	*5*	3	1	A		
483	610	13:08	13:14	*6*	4	1	A		
484	690	13:11	13:14	*3*	6	1	A		
485	630	13:14	13:17	*3*	2	1	A		
486	550	13:16	13:20	*4*	4	1	A		
487	680	13:20			0	3			
488	775	13:25	13:32	*7*	6	1	A		
490	650	13:42	13:44	*2*	2	1	A		
489	600	13:29	13:40	*11*	4	1	A		
491	740	13:45	13:51	*6*	3	1	A		
492	560	13:53	13:56	*3*	4	1	A		
493	580	13:57	14:00	*3*	5	1	A		
494	650	14:03			0	3			
495	560	14:08	14:10	*2*	4	1	A		
496	615	14:13	14:17	*4*	4	1	A		
497	620	14:20	14:22	*2*	6	1	A		
498	600	14:25	14:30	*5*	3	1	A		
499	590	14:28	14:32	*4*	6	1	A		
500	610	14:33	14:36	*3*	6	1	A		
414	675	14:46	14:51	*5*	4	1	A		

415	650	14:51	14:55	*4*	4	1	A
416	580	14:55	14:58	*3*	4	1	A
417	580	14:59	15:02	*3*	3	1	A
418	610	15:01	15:06	*5*	4	1	A
419	620	15:14	15:17	*3*	5	1	A
420	760	15:15			0	3	
421	650	15:21	15:23	*2*	6	1	A
422	710	15:24	15:27	*3*	5	1	A
423	550	15:30	15:33	*3*	6	1	A

Appendix C

Survival and Malady-free Statistical Outputs

One hour survival estimates for adult American Eel passing through Cabot Station Unit 2 and Station 1 Unit 2/3; combining control.
Control 25 released, 25 alive, 0 dead
Unit 2 50 released, 49 alive, 1 dead
Unit 2/3 30 released, 18 alive, 11 dead
==
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9905	(0.0095)	Recovery probability
S2 =	0.9800	(0.0198)	Cabot Station Unit 2 survival
S3 =	0.6207	(0.0901)	Station 1 Unit 2/3 survival

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

Log-likelihood: -29.7992

Tau = 0.9800 (0.0198) Cabot Station Unit 2/Control ratio
Tau = 0.6207 (0.0901) Station 1 Unit 2/3 /Control ratio

Z statistic for the equality of equal turbine survivals: 3.8949

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	0.00008984	0.00000000	0.00000000
0.00000000	0.00000000	0.00039200	0.00000000
0.00000000	0.00000000	0.00000000	0.00811841

Confidence intervals:

	Cabot Unit 2	Station 1 Unit 2/3
90 percent:	(0.9474, 1.0126)	(0.4725, 0.7689)
95 percent:	(0.9412, 1.0188)	(0.4441, 0.7973)
99 percent:	(0.9290, 1.0310)	(0.3887, 0.8527)

==
Likelihood ratio statistic for equality of recovery probabilities: 2.3628

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 adult American Eel passing through Station 1 Unit 2/3 and Station 1 Unit 1; combining control.
Control 25 released, 25 alive, 0 dead
Unit 2/3 30 released, 18 alive, 11 dead
Unit 1 30 released, 27 alive, 3 dead
==
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9882	(0.0117)	Recovery probability
S2 =	0.6207	(0.0901)	Station 1 Unit 2/3 survival
S3 =	0.9000	(0.0548)	Station 1 Unit 1 survival

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

Log-likelihood: -34.4373

Tau = 0.6207 (0.0901) Station 1 Unit 2/3 /Control ratio
Tau = 0.9000 (0.0548) Station 1 Unit 1/Control ratio

Z statistic for the equality of equal turbine survivals: 2.6489

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	0.00013678	0.00000000	0.00000000
0.00000000	0.00000000	0.00811841	0.00000000
0.00000000	0.00000000	0.00000000	0.00300000

Confidence intervals:

	Station 1 Unit 2/3	Station 1 Unit 1
90 percent:	(0.4725, 0.7689)	(0.8099, 0.9901)
95 percent:	(0.4441, 0.7973)	(0.7926, 1.0074)
99 percent:	(0.3887, 0.8527)	(0.7590, 1.0410)

==
Likelihood ratio statistic for equality of recovery probabilities: 1.6410
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 adult American Eel passing through Bascule Gate #1 @ 1500 cfs and Bascule Gate #1 @ 2500 cfs combining control.
Control 25 released, 25 alive, 0 dead
Bascule Gate #1 @ 1500 cfs 35 released, 30 alive, 4 dead
Bascule Gate #1 @ 2500 cfs 30 released, 24 alive, 4 dead
===
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9667	(0.0000)	Recovery probability
S2 =	0.8824	(0.0553)	Bascule Gate #1 @ 1500 cfs survival
S3 =	0.8571	(0.0661)	Bascule Gate #1 @ 2500 cfs survival

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

Log-likelihood: -36.9514

Tau = 0.8824 (0.0236) Bascule Gate #1 @ 1500 cfs/Control ratio
Tau = 0.8571 (0.0449) Bascule Gate #1 @ 2500 cfs/Control ratio

Z statistic for the equality of equal turbine survivals: 0.4967

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:

-0.00320503	0.00107120	0.00000000	0.00000000
0.00107120	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00305312	0.00000000
0.00000000	0.00000000	0.00000000	0.00437318

Confidence intervals:

	BG1 @ 1500 cfs	BG1 @ 2500 cfs
90 percent:	(0.8435, 0.9212)	(0.7832, 0.9310)
95 percent:	(0.8361, 0.9286)	(0.7691, 0.9452)
99 percent:	(0.8215, 0.9432)	(0.7415, 0.9728)

===
Likelihood ratio statistic for equality of recovery probabilities: 2.2796

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 adult American Eel passing through Bascule Gate #1 @ 5000 cfs and Bascule Gate #4 @ 1500 cfs; combining control.
Control 25 released, 25 alive, 0 dead
Bascule Gate #1 @ 5000 cfs 30 released, 25 alive, 4 dead
Bascule Gate #4 @ 1500 cfs 35 released, 31 alive, 4 dead
==
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9889	(0.0110)	Recovery probability
S2 =	0.8621	(0.0640)	Bascule Gate #1 @ 5000 cfs survival
S3 =	0.8857	(0.0538)	Bascule Gate #4 @ 1500 cfs survival

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

Log-likelihood: -29.5671

Tau = 0.8621 (0.0640) Bascule Gate #1 @ 5000 cfs/Control ratio
Tau = 0.8857 (0.0538) Bascule Gate #4 @ 1500 cfs/Control ratio

Z statistic for the equality of equal turbine survivals: 0.2828

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	0.00012209	0.00000000	0.00000000
0.00000000	0.00000000	0.00410021	0.00000000
0.00000000	0.00000000	0.00000000	0.00289213

Confidence intervals:

	BG1 @ 5000 cfs	BG4 @ 1500 cfs
90 percent:	(0.7567, 0.9674)	(0.7972, 0.9742)
95 percent:	(0.7366, 0.9876)	(0.7803, 0.9911)
99 percent:	(0.6972, 1.0270)	(0.7472, 1.0242)

==
Likelihood ratio statistic for equality of recovery probabilities: 0.9448

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 adult American Eel passing through Bascule Gate #4 @ 2500 cfs and Bascule Gate #4 @ 5000 cfs; combining control.
Control 25 released, 25 alive, 0 dead
Bascule Gate #4 @ 2500 cfs 30 released, 27 alive, 3 dead
Bascule Gate #4 @ 5000 cfs 30 released, 28 alive, 2 dead
===
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	1.0	N/A	Recovery probability
S2 =	0.9000	(0.0548)	Bascule Gate #4 @2500 cfs survival
S3 =	0.9333	(0.0455)	Bascule Gate #4 @5000 cfs survival

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

Log-likelihood: -17.1004

Tau = 0.9000 (0.0548) Bascule Gate #4 @2500 cfs/Control ratio
Tau = 0.9333 (0.0455) Bascule Gate #4 @5000 cfs/Control ratio

Z statistic for the equality of equal turbine survivals: 0.4680

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	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00300002	0.00000000
0.00000000	0.00000000	0.00000000	0.00207405

Confidence intervals:

	BG4 @ 2500 cfs	BG4 @ 5000 cfs
90 percent:	(0.8099, 0.9901)	(0.8584, 1.0083)
95 percent:	(0.7926, 1.0074)	(0.8441, 1.0226)
99 percent:	(0.7590, 1.0410)	(0.8161, 1.0506)

===
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 adult American Eel passing through Bascule Gate #1 combined cfs and Bascule Gate #4 combined cfs; combining control.
Control 25 released, 25 alive, 0 dead
Bascule Gate #1 combined 95 released, 79 alive, 12 dead
Bascule Gate #4 combined 95 released, 86 alive, 9 dead
==
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9814	(0.0092)	Recovery probability
S2 =	0.8681	(0.0355)	Bascule Gate #1 combined survival
S3 =	0.9053	(0.0300)	Bascule Gate #4 combined survival

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

Log-likelihood: -85.1523

Tau = 0.8681 (0.0355) Bascule Gate #1 combined/Control ratio
Tau = 0.9053 (0.0300) Bascule Gate #4 combined/Control ratio

Z statistic for the equality of equal turbine survivals: 0.7988

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	0.00008492	0.00000000	0.00000000
0.00000000	0.00000000	0.00125801	0.00000000
0.00000000	0.00000000	0.00000000	0.00090276

Confidence intervals:

	BG1 Combined	BG4 Combined
90 percent:	(0.8098, 0.9265)	(0.8558, 0.9547)
95 percent:	(0.7986, 0.9377)	(0.8464, 0.9642)
99 percent:	(0.7768, 0.9595)	(0.8279, 0.9826)

==
Likelihood ratio statistic for equality of recovery probabilities: 2.6413

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

Forty-eight hour survival estimates for adult American Eel passing through Station 1 Unit 2 and Station 1 Unit 2/3; combining control.
Control 25 released, 25 alive, 0 dead
Unit 2 50 released, 48 alive, 2 dead
Unit 2/3 30 released, 18 alive, 11 dead
==
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9905	(0.0095)	Recovery probability
S2 =	0.9600	(0.0277)	Cabot Station Unit 2 survival
S3 =	0.6207	(0.0901)	Station 1 Unit 2/3 survival

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

Log-likelihood: -33.2944

Tau = 0.9600 (0.0277) Cabot Station Unit 2/Control ratio
Tau = 0.6207 (0.0901) Station 1 Unit 2/3/Control ratio

Z statistic for the equality of equal turbine survivals: 3.5994

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	0.00008984	0.00000000	0.00000000
0.00000000	0.00000000	0.00076800	0.00000000
0.00000000	0.00000000	0.00000000	0.00811841

Confidence intervals:

	Cabot Unit 2	Station 1 Unit 2/3
90 percent:	(0.9144, 1.0056)	(0.4725, 0.7689)
95 percent:	(0.9057, 1.0143)	(0.4441, 0.7973)
99 percent:	(0.8886, 1.0314)	(0.3887, 0.8527)

==
Likelihood ratio statistic for equality of recovery probabilities: 2.2088

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

Forty-eight hour survival estimates for adult American Eel passing through Station 1 Unit 2/3 and Station 1 Unit 1; combining control.
Control 25 released, 25 alive, 0 dead
Unit 2/3 30 released, 18 alive, 11 dead
Unit 1 30 released, 27 alive, 3 dead
===
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9882	(0.0117)	Recovery probability
S2 =	0.6207	(0.0901)	Station 1 Unit 2/3 survival
S3 =	0.9000	(0.0548)	Station 1 Unit 1 survival

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

Log-likelihood: -34.4373

Tau = 0.6207 (0.0901) Station 1 Unit 2/3/Control ratio
Tau = 0.9000 (0.0548) Station 1 Unit 1/Control ratio

Z statistic for the equality of equal turbine survivals: 2.6489

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	0.00013678	0.00000000	0.00000000
0.00000000	0.00000000	0.00811841	0.00000000
0.00000000	0.00000000	0.00000000	0.00300000

Confidence intervals:

	Station 1 Unit 2/3	Station 1 Unit 1
90 percent:	(0.4725, 0.7689)	(0.8099, 0.9901)
95 percent:	(0.4441, 0.7973)	(0.7926, 1.0074)
99 percent:	(0.3887, 0.8527)	(0.7590, 1.0410)

===

Likelihood ratio statistic for equality of recovery probabilities: 1.6410

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

Forty-eight hour survival estimates for adult American Eel passing through Bascule Gate #1 @ 1500 cfs and Bascule Gate #1 @ 2500 cfs; combining control.
Control 25 released, 25 alive, 0 dead
Bascule Gate #1 @ 1500 cfs 35 released, 30 alive, 4 dead
Bascule Gate #1 @ 2500 cfs 30 released, 24 alive, 4 dead
==
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9667	(0.0000)	Recovery probability
S2 =	0.8824	(0.0553)	Bascule Gate #1 @1500 cfs survival
S3 =	0.8571	(0.0661)	Bascule Gate #1 @2500 cfs survival

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

Log-likelihood: -36.9514

Tau = 0.8824 (0.0236) Bascule Gate #1 @1500 cfs/Control ratio
Tau = 0.8571 (0.0449) Bascule Gate #1 @2500 cfs/Control ratio

Z statistic for the equality of equal turbine survivals: 0.4967

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:

-0.00320503 0.00107120 0.00000000 0.00000000
0.00107120 0.00000000 0.00000000 0.00000000
0.00000000 0.00000000 0.00305312 0.00000000
0.00000000 0.00000000 0.00000000 0.00437318

Confidence intervals:

	BG1 @ 1500 cfs	BG1 @ 2500 cfs
90 percent:	(0.8435, 0.9212)	(0.7832, 0.9310)
95 percent:	(0.8361, 0.9286)	(0.7691, 0.9452)
99 percent:	(0.8215, 0.9432)	(0.7415, 0.9728)

===
Likelihood ratio statistic for equality of recovery probabilities: 2.2796

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

Forty-eight hour survival estimates for adult American Eel passing through Bascule Gate #1 @ 5000 cfs and Bascule Gate #4 @ 1500 cfs combining control.
Control 25 released, 25 alive, 0 dead
Bascule Gate #1 @ 5000 cfs 30 released, 25 alive, 4 dead
Bascule Gate #4 @ 1500 cfs 35 released, 29 alive, 6 dead
===
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	Estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9889	(0.0110)	Recovery probability
S2 =	0.8621	(0.0640)	Bascule Gate #1 @5000 cfs survival
S3 =	0.8286	(0.0637)	Bascule Gate #4 @1500 cfs survival

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

Log-likelihood: -33.1638

Tau = 0.8621 (0.0640) Bascule Gate #1 @5000 cfs/Control ratio
Tau = 0.8286 (0.0637) Bascule Gate #4 @1500 cfs/Control ratio

Z statistic for the equality of equal turbine survivals: 0.3709

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	0.00012209	0.00000000	0.00000000
0.00000000	0.00000000	0.00410021	0.00000000
0.00000000	0.00000000	0.00000000	0.00405831

Confidence intervals:

	BG1 @ 5000 cfs	BG4 @ 1500 cfs
90 percent:	(0.7567, 0.9674)	(0.7238, 0.9334)
95 percent:	(0.7366, 0.9876)	(0.7037, 0.9534)

99 percent: (0.6972, 1.0270)   (0.6645, 0.9926)

===

Likelihood ratio statistic for equality of recovery probabilities: 0.5218

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

Forty-eight hour survival estimates for adult American Eel passing through Bascule Gate #4 @ 2500 cfs and Bascule Gate #4 @ 5000 cfs; combining control.
Control 25 released, 25 alive, 0 dead
Bascule Gate #4 @ 2500 cfs 30 released, 27 alive, 3 dead
Bascule Gate #4 @ 5000 cfs 30 released, 28 alive, 2 dead

===

RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	1.0	N/A	Recovery probability
S2 =	0.9000	(0.0548)	Bascule Gate #4 @2500 cfs survival
S3 =	0.9333	(0.0455)	Bascule Gate #4 @5000 cfs survival

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

Log-likelihood: -17.1004

Tau =   0.9000 (0.0548)   Bascule Gate #4 @2500 cfs/Control ratio
Tau =   0.9333 (0.0455)   Bascule Gate #4 @5000 cfs/Control ratio

Z statistic for the equality of equal turbine survivals: 0.4680

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	0.00000000	0.00000000	0.00000000
0.00000000	0.00000000	0.00300002	0.00000000
0.00000000	0.00000000	0.00000000	0.00207405

Confidence intervals:

	BG4 @ 2500 cfs	BG4 @ 5000 cfs
90 percent:	(0.8099, 0.9901)	(0.8584, 1.0083)

95 percent: (0.7926, 1.0074) (0.8441, 1.0226)
99 percent: (0.7590, 1.0410) (0.8161, 1.0506)
==
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

Forty-eight hour survival estimates for adult American Eel passing through Bascule Gate #1 combined cfs and Bascule Gate #4 combined cfs; combining control.
Control 25 released, 25 alive, 0 dead
Bascule Gate #1 combined 95 released, 79 alive, 12 dead
Bascule Gate #4 combined 95 released, 84 alive, 11 dead
==
RESULTS FOR REDUCED MODEL (EQUAL LIVE/DEAD RECOVERY)

	estim.	std.err.	
S1 =	1.0	N/A	Control group survival
Pa = Pd	0.9814	(0.0092)	Recovery probability
S2 =	0.8681	(0.0355)	Bascule Gate #1 Combined survival
S3 =	0.8842	(0.0328)	Bascule Gate #4 Combined survival

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

Log-likelihood: -89.4357

Tau = 0.8681 (0.0355) Bascule Gate #1 Combined/Control ratio
Tau = 0.8842 (0.0328) Bascule Gate #4 Combined/Control ratio

Z statistic for the equality of equal turbine survivals: 0.3327

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	0.00008492	0.00000000	0.00000000
0.00000000	0.00000000	0.00125801	0.00000000
0.00000000	0.00000000	0.00000000	0.00107771

Confidence intervals:
BG1 Combined BG4 Combined

90 percent: (0.8098, 0.9265)   (0.8302, 0.9382)
95 percent: (0.7986, 0.9376)   (0.8199, 0.9486)
99 percent: (0.7768, 0.9595)   (0.7997, 0.9687)
==
Likelihood ratio statistic for equality of recovery probabilities: 1.9727

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

APPENDIX C– RECAPTURE HISTORIES OF THE 170 FISH USED IN CJS ANALYSIS

Statistical Methods & Results

Methods

Data Management

Data management consisted of removing false positive detections from the recaptures database. 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). True positives and true negatives are valid data points which indicate the presence or absence of a tagged fish. A false positive is a detection of a fish's presence when it is not there, while a false negative is a non-detection of a fish that is there. 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 fish that weren't there, or they can increase measures of delay when a fish has already passed. False positives are different from false negatives, which bias statistics in other ways. Inclusion of false negatives may negatively bias statistics because there is no way to know if a fish's absence from a receiver was because it truly wasn't there or if it was just not recaptured. The CJS model accounts for a receiver's recapture rate and removes this bias from rates of survival (successful passage) while the MSM model and time to event only include data from known detection histories. To remove the bias from false positives, they must be removed from the dataset prior to analysis as there are no statistical techniques available to remove bias from the estimate. For the purposes of this study, potential false positive reduction methods relied upon a few metrics, some of them arbitrary, including power floors, reliance on consecutive detections in series, logical errors in site progression and subjective opinion. We rely upon data and quantitative insight to reduce the amount of subjectivity in the analysis. Therefore, a probabilistic method for false positive data reduction was sought.

Bayes Rule is a rigorous method for interpreting evidence in the context of previous experience or knowledge (Stone, 2013). Bayes Rule cannot guarantee the correct answer, but rather provides the probability that each alternative answer (either true or false positive) is correct. Bayes theorem updates conditional probabilities (probability of a record being true positive given some data), and is particularly useful when evaluating diagnostic tests (false positives and false negatives).

Specifically, Bayes Rule calculates the posterior probability, or the probability of our hypothesis occurring given some information about its present state. The prior probability is estimated by looking at how often each class (true or false positive) occurs in the training dataset, while the likelihood is estimated from the histogram of the values of each predictor (observed data) in the training dataset given each hypothesis (true or false positive) (Marsland, 2009). A kernel density function was fit for continuous predictors while qualitative predictors replied upon a multinomial probability distribution. The Naïve Bayes algorithm relied upon a simplifying assumption that all predictor variables are conditionally independent of each other given the state of the record (true or false). Therefore, the probability of getting a particular string of predictor variables given that the record is true or false is equal to the product of each individual feature probability. The constructed Naïve Bayes classifier was nothing more than a database application designed to keep track of which feature gives evidence to which class (Richert & Pedro-Coehlo, 2013). However, there were circumstances where a particular feature variable level did not occur for a given detection class in the feature dataset (e.g., false positive detection with very high power and many consecutive hits in series), meaning that the likelihood for that feature given a detection class is zero. When multiplied together, the posterior probability was zero and uninformative. Therefore, the Naïve Bayes classifier used add-one smoothing, which simply adds 1 to all histogram counts (Richert & Pedro-Coehlo, 2013). The underlying assumption here is that even if the feature value was not seen in the training dataset for a particular detection class, the resultant likelihood probability would be close to zero allowing for an informative posterior.

The training dataset consists of known true and false positive detections. By sacrificing study tags and placing them at strategic locations throughout the study area for the duration of the study, beacon tags give the algorithm information on what a known true positive detection looks like. On the other hand, known false positive detections are generated by the telemetry receivers themselves, and consist of detections coded towards tags that were not present in the list of tags released for the study.

Following the completion of the study, a number of predictor features were calculated for each received line of data. Predictor features include a detection history of pulses, the consecutive record hit length, hit ratio, miscode ratio, consecutive detection, detection in series, and power. The pulse detection history is a string of 1's and 0's that looked forwards and backwards in time from the current detection in series, and identifies whether or not a pulse from that particular tag was detected. For example, if a particular tag had a 3 second burst rate, the algorithm will look 3 seconds forward and backward in time, query the entire dataset and return 1 if it was detected or 0 if it was not. The algorithm looks forward and backward for a user defined set of detection intervals. Consecutive detection length and hit ratio are derived from this detection history. Consecutive detection length simply counts the number of detections in series, while hit ratio is the ratio of the count of heard detections to the length of the detection history string (Table 3.2.5-1).

Note from Table 3.2.5-1 that both detection history events are considerably different, but they have the same hit ratios. However, the derived consecutive record length features are not the same. The hit ratio counts the number of correctly assigned detections to the total number of detections within a user defined set of time. The hypothesis behind this predictor stipulates that a detection is more likely to be true when there are less miscoded detections. Consecutive detections, and detections in series are binary in nature and quite similar, but the consecutive detection feature was stricter. For consecutive detection to return as true, either the previous or next detection must occur within the next pulse. Detections in series allows the previous or next detection to occur at intervals greater than the first pulse, however recaptures need to be in series. For example, if the pulse rate is 3 seconds and the next consecutive detection was missed, series hit would return true if the next recorded transmission occurred on the 6th or 9th second. In other words, the pulse rate must be a factor of the difference in time between the present detection and next detection for a series hit to return true. The last predictor, power, is hypothesized to be higher for true detections than false positives.

Following the algorithmic data reduction, quality assurance and control (QAQC) procedures were conducted for each receiver, and consisted of randomly selecting 50 American Eel and checking for systematic errors. Type I and II errors were identified, and reasoning 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, this 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.

Following algorithm QAQC, data reduction procedures were carried out with MS Access Query (SQL) methods. If the time stamp of the recapture occurred before the fish was released, then a recapture was deemed false positive. Further, if the calculated hit ratio for any detection was less than 10%, meaning only 1 "heard" detection within a (+/-5) series of detections, the record was deemed as false positive regardless of the posterior probability. Following SQL data reduction, site specific information was exported and aggregated into a system wide recaptures database. The recapture history of each specimen could then be examined through space and time with a three-dimensional (3D) visual inspection tool (Figure 3.2.5-1). After assessing each fish with the visual inspection tool, stationary and mobile tracking data were analyzed.

Cormack-Jolly-Seber Open Population Mark Recapture

Mark recapture survival analysis is typically used to assess passage through fish ladders (Perry *et al.*, 2013). Use of the term "survival" is standard for mark recapture analysis, which is predominantly used to assess the actual survival of marked animals over time. Survival simply means successful passage, it should not convey mortality. Given that the temporal and spatial horizon is very short for those stretches studied with Mark Recapture techniques (on the order of hours to less than 1,000 feet), mortality was not tested using a mark recapture framework, nor were any animals found to have died within the stretches of river assessed with Mark Recapture techniques. However, we maintain Mark Recapture theory terminology for this section, therefore survival always refers to the successful passage of a fish from one receiver to the next. It does not refer to the probability that a fish will die along the way. To estimate survival parameters in the field under natural or anthropogenic conditions, one must follow individually marked animals through time (Lebreton *et al.*, 1992). However, it is rarely possible to follow all individuals of an initial sample over time (Lebreton *et al.*, 1992) as is evident by varying recapture rates at each telemetry receiver location. Open population mark recapture models allow for change (emigration and mortality) during the course of a study (Armstrup *et al.*, 2005). The Cormack Jolly Seber (CJS) model is based solely on recaptures of marked animals and provides estimates of survival and capture probabilities only (Armstrup *et al.*, 2005). The CJS model has the following assumptions:

- Every marked animal present in the population at time (t) has the same probability of recapture (p_t),
- Every marked animal in the population immediately after time (t) has the same probability of surviving to time (t+1),
- Marks are not lost or missed,
- All samples are instantaneous, relative to the interval between occasion (t) and (t+1), and
- Each release is made immediately after the sample (Cooch & White 2006).

An animal that has not been observed for some time may have survived and escaped recapture by chance or for biological reasons its recapture might occur if the study were to continue (Lebreton *et al.*, 1992). With this binary state of nature in mind, the presence and absence of animals at each location along a telemetry network is encoded with a string of 1s or 0s denoting presence and absence respectively. To properly assess survival with variability in recapture, more parameters are required.

Under the assumption of independence of fates and identity of individuals, the observed detection history strings are an observation of a multinomial probability distribution (Lebreton *et al.*, 1992). The method of maximum likelihood estimation will be used to estimate the parameters in the model (Lebreton *et al.*, 1992). The statistical likelihood is the product of the probability of observing a particular detection history given release over those capture histories actually observed (Lebreton *et al.*, 1992). More than one animal may have the same recapture history, therefore the number observed in each recapture history appears as an exponent in its corresponding probability likelihood statement (Lebreton *et al.*, 1992). MARK uses the profile likelihood estimation of variance to construct the confidence intervals (Cooch & White, 2006). Consequently, the shape of the log-likelihood function estimated by the maximum likelihood procedure provides information on the precision of the estimators (Lebreton *et al.*, 1992). Profile likelihood intervals have better coverage with small samples and because the distribution of estimators are often very non-normal and the parameter space has boundaries [0, 1] (Lebreton *et al.*, 1992).

Following Lebreton et al (1992) and Cooch & White (2006), the following model creation and selection procedure was followed for analysis of survival through projects:

- Build a global model compatible with the biology of the species studied and with the design of the study,
- Assess model fit using appropriate goodness of fit (GOF) measures,

- Select a more parsimonious model using Akaikes Information Criteria (AIC) to limit number of formal tests,
- Test for the most important biological questions by comparing this model with neighboring ones using likelihood ratio tests, and
- Obtain maximum likelihood estimates of model parameters with estimates of precision.

The first step is to build a saturated model, which is loosely defined as the model where the number of parameters equals the number of data points or data structures (Cooch & White 2006). The saturated model estimated a survival (ϕ) between each facility location and recapture (p) probability at each facility relocation location (Figure 3.2.6.1-1). It is not possible to differentiate between the final survival (ϕ_5) and recapture station (p_4) because it is not known if an animal died or was simply not recaptured at the final telemetry station. Following the creation of the saturated model, goodness of fit testing was performed.

Next, Goodness of Fit (GOF) procedures tested the assumptions underlying the models we are trying to fit to the data. GOF is a necessary first step to ensure that the most general model adequately fits the data (Cooch & White 2006). To accommodate for lack of fit, we needed a measure of how much extra binomial noise (variation) is in the data, this is known as the variance inflation factor or $\hat{c}$ (Cooch & White 2006). The internal MARK program RELEASE assessed goodness of fit for CJS model and consists of two important tests, Test 2 and 3. Test 2 deals with those animals known to be alive between time t and t+1 and tests the assumption that all marked animals should be equally detectable at location t+1 independent of whether or not they were captured at occasion t. Test 3 tests the assumption that all marked animals alive at t have the same probability of surviving to t+1. If the resultant χ^2tests are significant, the assumptions are violated. Further, if the overall GOF test proves significant, it is necessary to assume the assumptions are violated. If the assumptions were violated, the Median-$\hat{c}$ procedure within MARK estimated the variance inflation factor and the models were adjusted accordingly. After adjustment or non-significant GOF, a series of reduced models were created: reduced survival and individual recapture (ϕ.p(t)), individual survival and reduced recapture(ϕ(t)p.)), reduced time and reduced recapture(ϕ.p.).

Following model creation, model selection starts with comparing AIC values and then computing Likelihood Ratio Tests. Model selection is important as parsimony is desired. Therefore, models relating sample data and population parameters should contain enough parameters to account for all of the significant variation (Lebreton *et al*., 1992). An important tradeoff exists between the number of parameters in the model and sampling variance (Lebreton *et al*., 1992). The goal in model selection is to identify a biologically meaningful model that explains the variability in the data but excludes unnecessary parameters. The AIC is a measure of the relative quality of statistical models for a given set of data and provides a means for model selection. The lower the AIC, the more parsimonious the model (best fit with fewest parameters). However, the AIC value should not be the deciding factor, especially when hypothesis testing is available with other techniques. The likelihood ratio test compares a restricted model nested within the full model. If the likelihood ratio test is significant, there is evidence to suggest for variance in survival between stations. Once the final model was chosen, MARK provides estimates of critical survival (ϕ) and recapture (p) ratios.

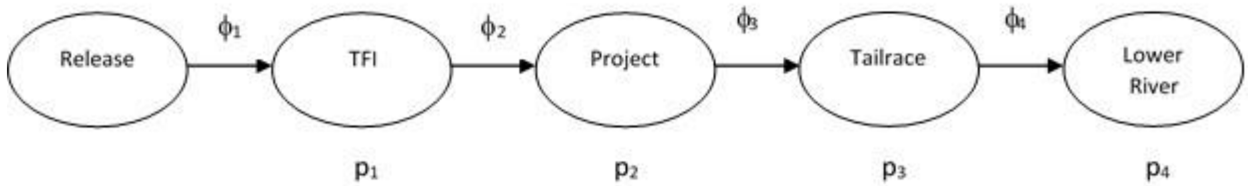

Figure 3.2.6.1-1. Graphical schematic of the MARK model to assess through project survival showing estimable parameters. Survival probabilities (ϕ_i) are assessed between stations while recapture rates (p_i) are measured at a station.

Competing Risks Assessment

A multi-state model is used to understand situations where a tagged animal transitions from one state to the next (Crowson *et al*., 2016). For our purposes, 'transition' simply means that a fish was detected in one location and eventually moves to another location. In traditional time-to-event modeling, the standard survival curve (Kaplan-Meier) can be thought of as a simple multi-state model with two states (alive and dead) and one transition between those two states (Crowson *et al*., 2016). For our purposes, these two states are staging and passing. The curve simply depicts the probability that a tagged fish remains within the staging location after a certain amount of time. However, for many of our locations we have more than two end states. For example, those fish emigrating through the canal can pass via the bypass sluiceway, Cabot Station powerhouse, or through the Station No. 1 powerhouse. Competing risks generalize the standard survival analysis of a single endpoint (as described above) into an investigation of multiple first event types (Allignol *et al*., 2011). Competing risks are the simplest multi-state model, where events are envisioned as transitions between states (Allignol *et al*., 2011), or movement from the staging site to a passing site. For competing risks, there is a common initial state for all models that all tagged fish move from (Allignol *et al*., 20111). For example, with the assessment of time to passage over Turners Falls Dam (TFD), our common initial state is the being present in the impoundment. When assessing entrainment at NMPS, our common initial state is being present within the intake area. When fish pass into the bypass reach or the canal, they enter an absorbing state. The baseline hazard is measured with the Nelson-Aalen cause specific cumulative incidence function. One can think of the hazard as the probability of experiencing an event (passage) within the next time unit conditional on still being in the initial state (Allignol *et al*., 2011). For example, with regards to route of passage choice at the TFD, the hazard is the instantaneous probability that a fish will move from the impoundment to the canal (or bypass reach) in the next unit of time. The Nelson-Aalen $\hat{A}(t)$ is computed with (Allignol *et al*., 2011):

$$\hat{A}(t) = \sum_{k=1}^{K} \frac{number\ of\ individuals\ observed\ to\ transition\ into\ state\ i\ at\ t_k}{number\ of\ individuals\ at\ risk\ just\ prior\ to\ t_k}$$

Where t is a time of interest, K is the number of event times for fish entering state i, and k is an event time, or the duration an animal took to transition from the impoundment into a passing state. This formula is simple, it counts the number of individuals to experience the event of interest (i.e. passage into the canal from the impoundment) at event time $t_k$divided by the number of individuals still in the impoundment just prior to t_k. The sum term simply adds the probability across all discrete event times K. Therefore, the end probability is cumulative, and represents the probability that an animal will move from the impoundment into an absorbing state i. If we lose track of an animal, it is not censored at its last event time, rather it enters an unknown state. By attributing each tagged animal to a state at all times, we are ensured our final probabilities match empirical expectations. In other words, if 50 out of 100 eels transitioned into the canal, and 25 of 100 transitioned into the bypass reach, and we lost track of 25, the Nelson-Aalen cumulative incidence estimators will result in 50% transitioning into the canal, 25% transitioning into the bypass reach and 25% transitioning into an unknown state. Animals are only censored if they are still being tracked within the staging site until the end of study. If we happen to lose track of a fish before the end of the study, they enter an unknown state. After computing the Nelson-Aalen estimators for each route of passage (competing event), and plotting the survival function (Kaplan-Meier) for those fish still remaining in the impoundment, one would generate the probability

Following the computation of cause-specific Nelson-Aalen estimators, an assessment of delay was performed using Cox Proportional Hazards regression analysis for each separate event. Crowson, Atkinson, & Therneau (2016) state that a common mistake with competing risks is to use the Kaplan-Meier survival curve separately on each event type while treating other event types as censored. When this occurs, the probability of transitioning into the absorbing state of interest is positively biased, and the reason why competing risk curves may sum > 1.0. When analyzed in the framework proposed by Crowson, Atkinson, & Therneau (2016), each separate Cox model ignores the other absorbing events and assesses the cause-specific transition. Here, rates depend only on the set of subjects who are at risk (fish in staging state) at a given moment. The Cox models for each competing risk assessment were fit in a procedure analogous to multiple regression modeling, where individual time-dependent covariates were added in an iterative fashion constructing ever more complex models. Model quality was assessed with the omnibus likelihood ratio test statistic, the null hypothesis of which states that the model is not better than chance. If this statistic is rejected at the $\alpha = 0.05$ level, then the model is considered to be better than chance, and we observe the estimated hazard ratio associated with the covariate of interest and its significance. If the covariate is significant at the $\alpha = 0.05$ level, then we conclude that the estimated hazard ratio is significant, and interpret the results. Our statistic of interest is the hazard ratio, which is the ratio of the hazard rates corresponding to the conditions described by two levels of an explanatory variable (for example day vs night, or rain (in) vs no rain). Hazards are the instantaneous probability that a marked animal will experience the event of interest (i.e. passage into the canal) in the next period of time. For example, if our event of interest is passage into the canal, and our dependent covariate is rain in inches. The hazard ratio is the immediate probability of transitioning into the canal after one inch of rain over the immediate probability of transitioning into the canal with no rain. If the hazard ratio is > 1.0, this means the probability of transitioning into the canal during a rain event is higher than transitioning during dry conditions. The fish is more likely to transition during these times. When the hazard ratio is greater than 1, a unit increase in the covariate (i.e. rain) would increase the instantaneous risk (hazard) of the event occurring and delay is reduced. One would conclude that the population appears to experience less delay when the hazard ratio is > 1.0. If the hazard ratio is < 1.0 than the instantaneous risk decreases, and the proportion to have experienced the event at time (t) decreases, thus delay is incurred. The "best" model minimized AIC scores and/or had a significant omnibus statistic ($p < 0.05$) and informative hazard estimate (HR $\neq$ 1.0).

Results

Cormack-Jolly-Seber

The following table contains the detection histories of the 170 viable American Eel used in the Cormack-Jolly-Seber (CJS) open population mark recapture model. A value of 1 indicates the fish was recaptured and zero indicates no recapture occurred. For example, a fish with a detection history of 1,1,0,1,0 was recaptured in the impoundment, passed through the project undetected, was recaptured in the Cabot Station tailrace, and then was not recaptured at Montague. The table also identifies the release cohort and its route through the project.

FreqCode	Release	Impoundment	Project	Tailrace	Montague	Route Choice	Release Cohort
149.740 20	1	1	0	1	0	unknown	Lower Impoundment
149.740 21	1	1	0	1	0	unknown	Lower Impoundment
149.740 22	1	1	1	1	0	canal	Upper Impoundment
149.740 23	1	1	1	1	1	canal	Upper Impoundment
149.740 24	1	1	1	0	0	canal	Lower Impoundment
149.740 25	1	0	1	1	0	canal	Lower Impoundment
149.740 26	1	1	1	1	0	canal	Lower Impoundment
149.740 27	1	1	0	0	0	did not pass	Upper Impoundment
149.740 28	1	1	0	1	0	unknown	Upper Impoundment
149.740 29	1	1	1	1	0	canal	Lower Impoundment
149.740 30	1	1	1	1	0	canal	Upper Impoundment
149.740 32	1	0	1	1	1	bypass	Lower Impoundment
149.740 33	1	1	1	0	0	bypass	Lower Impoundment
149.740 34	1	1	1	1	0	bypass	Upper Impoundment
149.740 35	1	1	0	0	0	did not pass	Upper Impoundment
149.740 36	1	1	0	0	0	did not pass	Upper Impoundment
149.740 38	1	1	1	1	0	canal	Lower Impoundment
149.740 39	1	0	0	1	0	unknown	Lower Impoundment
149.740 40	1	1	0	0	0	did not pass	Upper Impoundment
149.740 41	1	1	1	1	0	canal	Upper Impoundment
149.740 42	1	1	1	1	0	canal	Lower Impoundment
149.740 43	1	1	0	0	0	did not pass	Lower Impoundment
149.740 44	1	1	1	1	0	canal	Lower Impoundment
149.740 46	1	1	1	1	0	canal	Lower Impoundment
149.740 48	1	1	1	1	1	canal	Upper Impoundment
149.740 49	1	1	1	1	0	canal	Lower Impoundment
149.740 50	1	1	0	1	0	unknown	Upper Impoundment
149.740 51	1	1	1	1	0	canal	Lower Impoundment
149.740 52	1	1	1	1	0	canal	Lower Impoundment
149.740 53	1	0	1	1	0	canal	Lower Impoundment
149.740 54	1	1	1	1	0	canal	Lower Impoundment
149.740 55	1	1	1	1	0	canal	Lower Impoundment

FreqCode	Release	Impoundment	Project	Tailrace	Montague	Route Choice	Release Cohort
149.740 56	1	1	0	0	0	did not pass	Lower Impoundment
149.740 57	1	1	0	0	0	did not pass	Upper Impoundment
149.740 58	1	1	0	0	0	did not pass	Upper Impoundment
149.740 59	1	1	0	0	0	did not pass	Lower Impoundment
149.740 60	1	1	1	1	0	canal	Upper Impoundment
149.740 61	1	1	0	0	0	did not pass	Lower Impoundment
149.740 62	1	1	1	1	0	canal	Upper Impoundment
149.740 63	1	1	0	0	0	did not pass	Upper Impoundment
149.740 64	1	1	1	1	0	canal	Lower Impoundment
149.740 65	1	1	0	0	0	did not pass	Upper Impoundment
149.740 67	1	1	1	1	0	canal	Lower Impoundment
149.740 68	1	1	1	1	0	bypass	Upper Impoundment
149.740 69	1	0	1	1	0	canal	Lower Impoundment
149.740 70	1	1	1	1	0	canal	Lower Impoundment
149.740 71	1	1	1	1	0	canal	Upper Impoundment
149.740 72	1	1	1	1	0	canal	Upper Impoundment
149.740 73	1	1	0	0	0	did not pass	Lower Impoundment
149.740 74	1	1	0	1	0	unknown	Upper Impoundment
149.740 75	1	1	1	1	0	canal	Upper Impoundment
149.740 76	1	1	1	1	0	canal	Upper Impoundment
149.740 77	1	1	0	0	0	did not pass	Upper Impoundment
149.740 78	1	1	1	1	0	canal	Upper Impoundment
149.740 80	1	1	0	0	0	did not pass	Upper Impoundment
149.740 81	1	1	1	1	0	canal	Upper Impoundment
149.740 82	1	1	1	1	0	canal	Upper Impoundment
149.740 83	1	1	1	1	0	canal	Upper Impoundment
149.740 84	1	1	1	1	0	canal	Upper Impoundment
149.740 85	1	1	0	0	0	did not pass	Upper Impoundment
149.760 20	1	1	0	1	0	unknown	Upper Impoundment
149.760 21	1	1	0	0	0	did not pass	Upper Impoundment
149.760 22	1	1	0	0	0	did not pass	Upper Impoundment
149.760 23	1	1	1	1	0	canal	Lower Impoundment
149.760 24	1	1	0	0	0	did not pass	Upper Impoundment
149.760 25	1	1	1	1	0	station 1	Lower Impoundment
149.760 26	1	1	0	0	0	did not pass	Upper Impoundment
149.760 27	1	1	1	1	1	canal	Lower Impoundment
149.760 28	1	1	1	0	0	canal	Lower Impoundment
149.760 30	1	0	1	1	1	bypass	Lower Impoundment
149.760 32	1	1	1	1	1	canal	Lower Impoundment
149.760 34	1	1	1	1	0	canal	Lower Impoundment

FreqCode	Release	Impoundment	Project	Tailrace	Montague	Route Choice	Release Cohort
149.760 35	1	1	1	1	1	canal	Lower Impoundment
149.760 37	1	1	1	1	1	bypass	Upper Impoundment
149.760 38	1	1	0	1	0	unknown	Upper Impoundment
149.760 39	1	1	1	1	0	canal	Upper Impoundment
149.760 40	1	1	1	1	0	bypass	Upper Impoundment
149.760 42	1	1	1	0	0	bypass	Lower Impoundment
149.760 43	1	1	1	1	0	canal	Upper Impoundment
149.760 44	1	1	1	1	0	canal	Upper Impoundment
149.760 46	1	1	1	1	0	canal	Upper Impoundment
149.760 47	1	1	1	1	0	bypass	Upper Impoundment
149.760 48	1	1	0	1	0	unknown	Upper Impoundment
149.760 49	1	1	0	1	0	canal	Upper Impoundment
149.760 50	1	1	1	1	0	canal	Lower Impoundment
149.760 51	1	1	1	1	1	canal	Lower Impoundment
149.760 53	1	1	0	0	0	did not pass	Lower Impoundment
149.760 55	1	1	0	0	0	did not pass	Upper Impoundment
149.760 56	1	1	0	1	0	canal	Lower Impoundment
149.760 57	1	1	1	1	0	canal	Lower Impoundment
149.760 58	1	1	1	1	0	canal	Lower Impoundment
149.760 59	1	1	0	0	0	did not pass	Lower Impoundment
149.760 60	1	1	1	1	0	canal	Lower Impoundment
149.760 61	1	1	1	1	0	canal	Lower Impoundment
149.760 62	1	1	1	1	0	canal	Lower Impoundment
149.760 63	1	1	1	1	0	canal	Upper Impoundment
149.760 64	1	1	1	1	0	canal	Lower Impoundment
149.760 65	1	1	0	0	0	did not pass	Lower Impoundment
149.760 66	1	1	0	0	0	did not pass	Lower Impoundment
149.760 67	1	1	1	1	0	canal	Upper Impoundment
149.760 68	1	1	1	1	0	canal	Upper Impoundment
149.760 69	1	1	0	0	0	did not pass	Lower Impoundment
149.760 70	1	1	0	0	0	did not pass	Lower Impoundment
149.760 71	1	1	0	0	0	did not pass	Lower Impoundment
149.760 72	1	1	1	1	0	canal	Lower Impoundment
149.760 73	1	1	0	0	0	did not pass	Upper Impoundment
149.760 74	1	1	1	0	0	bypass	Upper Impoundment
149.760 75	1	1	0	0	0	did not pass	Upper Impoundment
149.760 77	1	1	1	0	0	bypass	Upper Impoundment
149.760 78	1	1	0	0	0	did not pass	Upper Impoundment
149.760 79	1	1	0	0	0	did not pass	Upper Impoundment
149.760 80	1	1	0	0	0	did not pass	Upper Impoundment

FreqCode	Release	Impoundment	Project	Tailrace	Montague	Route Choice	Release Cohort
149.760 82	1	1	1	1	0	canal	Upper Impoundment
149.760 83	1	1	1	0	0	canal	Upper Impoundment
149.760 84	1	1	0	0	0	did not pass	Upper Impoundment
149.760 85	1	1	0	0	0	did not pass	Upper Impoundment
150.340 101	1	1	1	1	1	canal	TC
150.340 102	1	1	0	0	0	did not pass	TC
150.340 103	1	1	1	1	0	bypass	TC
150.340 104	1	1	0	0	0	did not pass	TC
150.340 105	1	1	0	0	0	did not pass	TC
150.340 107	1	1	0	0	0	did not pass	TC
150.340 112	1	1	1	0	0	station 1	TC
150.340 128	1	1	0	0	0	did not pass	TC
150.340 129	1	1	1	1	0	canal	TC
150.340 134	1	1	1	1	0	canal	TC
150.340 141	1	1	0	0	0	did not pass	TC
150.340 142	1	1	0	1	0	unknown	TC
150.340 143	1	1	1	1	0	canal	TC
150.340 150	1	1	1	1	0	canal	TC
150.340 153	1	1	1	1	0	canal	TC
150.340 161	1	1	1	1	0	canal	TC
150.340 173	1	1	1	1	0	canal	TC
150.340 181	1	1	1	1	0	canal	TC
150.340 183	1	1	0	0	0	did not pass	TC
150.340 54	1	1	1	1	0	canal	TC
150.340 55	1	1	0	0	0	did not pass	TC
150.340 57	1	1	0	0	0	did not pass	TC
150.360 139	1	1	1	1	0	canal	TC
150.360 140	1	1	1	0	0	canal	TC
150.360 141	1	1	0	1	0	unknown	TC
150.360 156	1	1	0	0	0	did not pass	TC
150.360 158	1	1	0	0	0	did not pass	TC
150.360 164	1	1	1	1	0	canal	TC
150.360 165	1	1	1	1	0	canal	TC
150.360 166	1	1	0	0	0	did not pass	TC
150.360 176	1	1	1	1	0	canal	TC
150.360 177	1	1	0	0	0	did not pass	TC
150.360 184	1	1	1	1	0	canal	TC
150.360 51	1	1	1	1	0	canal	TC
150.360 53	1	1	1	1	0	canal	TC
150.380 102	1	1	1	1	0	canal	TC

FreqCode	Release	Impoundment	Project	Tailrace	Montague	Route Choice	Release Cohort
150.380 108	1	1	0	1	0	unknown	TC
150.380 110	1	1	1	1	0	canal	TC
150.380 112	1	1	1	1	0	canal	TC
150.380 113	1	1	1	1	0	station 1	TC
150.380 118	1	1	1	1	0	canal	TC
150.380 124	1	1	1	1	0	canal	TC
150.380 146	1	1	0	0	0	did not pass	TC
150.380 149	1	1	1	1	0	canal	TC
150.380 150	1	1	1	1	0	canal	TC
150.380 152	1	1	1	1	0	canal	TC
150.380 153	1	1	0	0	0	did not pass	TC
150.380 159	1	1	0	0	0	did not pass	TC
150.380 169	1	1	0	0	0	did not pass	TC
150.380 170	1	1	1	1	0	bypass	TC
150.380 178	1	1	0	0	0	did not pass	TC
150.380 180	1	1	0	0	0	did not pass	TC
150.380 188	1	1	1	1	0	canal	TC
150.380 189	1	1	0	0	0	did not pass	TC