# Relicensing Study 3.3.7

# Fish Entrainment and Turbine Passage Mortality Study

# Study Report

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

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# EXECUTIVE SUMMARY

The goal of this study is to assess the potential risk of fish impingement and turbine entrainment at the Northfield Mountain and Turners Falls Projects, and turbine passage survival at the Turners Falls Project. The specific objectives include estimating the potential risk of entrainment, impingement, and turbine mortality loss to resident fish species at the Northfield Mountain Pumped Storage (NMPS) and Turners Falls Projects and conducting a quantitative assessment of the potential impact of entrainment of juvenile American Shad and adult American Eel. This study used qualitative desktop methods to estimate potential entrainment losses of both resident and diadromous species at the Northfield Mountain and Turners Falls Hydroelectric Projects. Resident fish species entrainment risk was qualitatively evaluated based on habitat use relative to project features and the ability of various species to escape intake velocity flow fields.

The risk of entrainment of migratory species was investigated based on results from separate studies conducted by FirstLight of adult American Shad (Study No. 3.3.2), juvenile American Shad (Study No. 3.3.3), and adult American Eel (Study No. 3.3.5) at the Projects using radio telemetry and/or hydroacoustic methods. FirstLight also conducted turbine passage survival studies of juvenile American Shad and adult American Eel at the Turners Falls Project in 2015 to support this study.

An extensive radio telemetry network consisting of 29 monitoring stations throughout the project area was deployed to monitor adult shad movement in 2015. None of the 397 radio/PIT tagged (doubled tagged) adult American Shad were entrained at Northfield Mountain or Station No. 1 during the 2015 monitoring period. Entrainment was observed at Cabot Station. A total of 86 double- tagged shad entered the Cabot power canal during their emigration. Of those, 24 (28.0%) were entrained through Cabot Station and 39 (45.3%) were passed via the downstream bypass (FirstLight, 2016a). Four of the shad that entered the Cabot power canal were subsequently detected in the Cabot tailrace, confirming downstream passage, but their route of passage was unclear (downstream bypass or through Cabot Station) (FirstLight, 2016a). A small number of emigrating fish were attracted to the Station No. 1 forebay but no entrainment was observed (FirstLight, 2016a). Milling was documented within the Cabot Station forebay before fish eventually passed downstream. Approximately 50% of the fish that entered the canal passed within 23 hrs. Only one (4%) of the emigrating fish that entered or were released directly into the power canal upstream of Station No. 1 was attracted to the Station No. 1 forebay (FirstLight, 2016a). During upstream migration many adult shad that entered the Turners Falls Canal were observed milling in the Cabot Station forebay for up to 48 hours before continuing upstream, suggesting the fish were not vulnerable to entrainment or impingement at Cabot Station during their upstream migration. Similarly, fish moving upstream in the canal that entered the Station No. 1 forebay milled around for up to 15 hours before continuing to move upstream through the canal towards Gatehouse, suggesting no entrainment impacts to adult shad during upstream migration due to Station No. 1.

No entrainment of adult shad was documented at the NMPS Project intake/tailrace during the 2015 study (Study No. 3.3.2). Shad were detected at the NPMS intake/tailrace under all operational and diel conditions experienced, i.e. pumping, generation, and non-operation during both daytime and nighttime hours (FirstLight, 2016a). Adult shad were most likely to be detected at the intake/tailrace area at night under pumping operation, with the probability of occurrence declining as pump volume increased. Adult shad were least likely to be detected at the NMPS intake/tailrace area at night during periods of maximum discharge (FirstLight, 2016a). Delay was calculated for those fish that were detected at the NMPS intake/tailrace (n=91). During upstream migration, 50% of the shad detected at the intake left the area and continued their upstream migration within 37.6 hours. During downstream migration delay was shorter, with 50% of the fish exiting the intake/tailrace area within 6.42 hours. These results suggest that operation at NMPS attracts adult shad to the intake/tailrace but that the risk of entrainment is low.

The field studies for the juvenile shad assessment were performed in the fall of 2015 and the final report detailing the methodology and results was submitted to FERC in October 2016. Study No. 3.3.3 assessed juvenile shad emigration through the project area in the fall of 2015 using a combination of radio telemetry and hydroacoustic techniques. Radio tagged juvenile shad (n=218) were released either approximately 1.5 miles upstream of the Northfield Mountain intake/tailrace channel or about 1.25 miles upstream from the Turners Falls Dam and monitored at 13 receiver stations in the project area. In addition, hydroacoustic monitoring systems were deployed at the NMPS Project intake/tailrace, the upper Turners Falls Power Canal (approximately 0.4 miles downstream from Gatehouse), and in the intake of the Cabot Station. The monitoring systems continuously recorded data from August 1 to November 14, 2015. While the hydroacoustics were intended to provide information on the timing, duration and magnitude of juvenile shad outmigration, the locations of the hydroacoustic equipment at the Northfield Mountain intake/tailrace channel and in the power canal did not allow for accurate assessments of the number of juvenile shad in the monitoring areas due to extensive milling behavior. Since that was the case, the estimate of the rate of entrainment of juvenile shad at Northfield Mountain relied on radio telemetry data only; 3.9% (n=3) of the 77 radio tagged juvenile shad that emigrated through the reach of the Connecticut River containing the NMPS Project intake/tailrace were detected in the upper reservoir (FirstLight, 2016b).

Analysis of split beam hydroacoustic data collected at Cabot Station estimated total entrainment of juvenile shad at 1,660,166 during the 2015 study period (FirstLight, 2016b). Juvenile shad exhibited a 95% immediate survival rate after passage through the Unit 2 turbine at Cabot Station and 77% survival at the larger Unit 1 at Station No. 1 (NAI, 2016a). Units 2 and 3 share a common penstock and the turbine passage mortality assessment reported 68% survival.

The adult American Eel assessment was initiated in 2015 and remained ongoing in 2016 as FERC requested a second year of monitoring to assess the annual variation of the seasonal outmigration. The final report is due to FERC in March 2017 and will include a discussion of the adult eel rate of entrainment at each of the intakes associated with the Projects. Although entrainment rates of American Eel in the Project areas are not yet calculated, turbine passage mortality at the Turners Falls Project is not expected to have a substantial impact on downstream migrants. Eels were determined to exhibit a 96% survival rate after passage through the Unit 2 turbine at Cabot Station and 90% survival at the larger Unit 1 at Station No. 1 (NAI, 2016b). Units 2 and 3 share a common penstock and the turbine passage mortality assessment reported only 60% survival. The significance of the low survival to the overall risk of downstream migrants will be better understood following the analysis of radio telemetry data from the Station No. 1 forebay array as part of Study No. 3.3.5.

Overall entrainment risk to resident species is slightly higher at Cabot Station than at Station No. 1. The primary factor that raises the Cabot Station risk level is the proximity of habitat that is attractive to some species. Fringe shoal areas exist upstream from the Cabot intake featuring a limited amount of object cover such as logs and debris, as well as scattered rooted and submerged aquatic vegetation beds. These features are absent from the vicinity of Station No. 1. Although not in the immediate vicinity of the Cabot intake, these habitat pockets may provide shelter for cover-oriented species. Residents of these areas may approach the Cabot intake during localized foraging or exploration movements.

Operation of the Northfield Mountain Project may impact fishes due to entrainment. However, pumping operations generally only occur over a few hours between midnight and 6:00 a.m., thereby limiting impacts to a 6 hour period each night. All species evaluated are at low or moderate risk to entrainment loss at the individual animal level and although intake velocities are generally greater than swimming capabilities of many of the species in the Turners Falls Impoundment, the lack of habitat features likely precludes fish from venturing into the intake/tailrace channel.

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| | |
|---|---|
| CPUE | catch per unit of effort |
| CRWC | Connecticut River Watershed Council |
| cfs | cubic foot/feet per second |
| °C | degrees Celsius |
| EPRI | Electric Power Research Institute |
| FERC | Federal Energy Regulatory Commission |
| FL | fork length |
| FirstLight | FirstLight Hydro Generating Company |
| ft | foot/feet |
| fps | foot/feet per second |
| H | horizontal |
| hp | horsepower |
| in | inch |
| ILP | Integrated Licensing Process |
| kW | kilowatt |
| LMS | Lawler, Matusky, and Skelly Engineers |
| MDF&G | Massachusetts Division of Fish and Game |
| MADFW | Massachusetts Division of Fisheries and Wildlife |
| msl | mean sea level |
| MW | megawatt |
| m | meter |
| mm | millimeter |
| NAI | Normandeau Associates, Inc. |
| NMFS | National Marine Fisheries Service |
| NMPS | Northfield Mountain Pumped Storage |
| NUSCO | Northeast Utilities Service Company |
| No. | number |
| lbs. | pounds |
| PAD | Pre-Application Document |
| PSP | Proposed Study Plan |
| RSP | Revised Study Plan |
| rpm | rotations per minute |
| SD1 | Scoping Document 1 |
| SD2 | Scoping Document 2 |
| SPDL | Study Plan Determination letter |
| TFI | Turners Falls Impoundment |
| TL | total length |
| USGS | United States Geological Survey |
| USFWS | United States Fish and Wildlife Service |
| VY | Vermont Yankee Nuclear Power Plant |
| YOY | young-of-year |

# 1 INTRODUCTION

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

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

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

On August 27, 2013 Entergy Corp. announced that the Vermont Yankee Nuclear Power Plant (VY), located on the downstream end of the Vernon Impoundment on the Connecticut River and upstream of the two Projects, will be closing no later than December 29, 2014. With the closure of VY, certain environmental baseline conditions will change during the relicensing study period. On September 13, 2013, FERC issued its first Study Plan Determination Letter (SPDL) in which many of the studies were approved or approved with FERC modification. However, due to the impending closure of VY, FERC did not act on 19 proposed or requested studies pertaining to aquatic resources. The SPDL for these 19 studies was deferred until after FERC held a technical meeting with stakeholders on November 25, 2013 regarding any necessary adjustments to the proposed and requested study designs and/or schedules due to the impending VY closure. FERC issued its second SPDL on the remaining 19 studies on February 21, 2014, which required FirstLight to consult with United States Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), Massachusetts Division of Fisheries and Wildlife (MADFW), and the Connecticut River Watershed Council (CRWC) following results of the evaluation of downstream passage of juvenile American Shad (Study No. 3.3.3) to address concerns regarding project-related impacts to American Shad eggs and larvae. Subsequently, FirstLight was required to conduct a separate study to assess entrainment of American Shad ichthyoplankton at the Northfield Mountain Project (Study No. 3.3.20), which occurred during late spring and early summer of 2015 and 2016. This allowed the Fish Entrainment and Turbine Passage Mortality Study to proceed in accordance with the RSP.

Normandeau Associates, Inc. (NAI) conducted an evaluation to estimate turbine passage survival of juvenile American Shad and adult American Eel with the use of HI-Z Turb'N tags and mark-recapture methodology during October 2015. Individual reports for the juvenile shad and adult eel survival assessments were prepared under separate covers that detail the study methods and results (NAI, 2016a; 2016b); copies are included in Appendices A and B herein.

In addition, FirstLight has conducted separate studies to assess the entrainment rates of adult American Shad (Study No. 3.3.2), juvenile American Shad (Study No. 3.3.3), and adult American Eel (Study No. 3.3.5) at the Projects using radio telemetry or hydroacoustic methods. An extensive radio telemetry network consisting of 29 monitoring stations throughout the project area was deployed to monitor adult shad movement in 2015. The final report was submitted to FERC in October 2016 and relevant information is discussed in Section 4.2 herein. The field studies for the juvenile shad assessment were performed in the fall of 2015 and the final report detailing the methodology and results was submitted to FERC in October 2016. Pertinent information regarding entrainment rates of juvenile shad are discussed in Section 4.2 herein. The adult American Eel assessment was initiated in 2015 and remains ongoing as FERC requested a second year of monitoring to assess the seasonality of outmigration events. The final report is due to FERC in March 2017 and will include a discussion of the adult eel entrainment at each of the intakes associated with the Projects.

## 1.1 Study Goals and Objectives

The goal of this study is to assess fish impingement, turbine entrainment, and turbine passage survival at the Northfield Mountain and Turners Falls Projects. The specific objectives include:

- Estimating the potential risk of entrainment, impingement, and turbine mortality loss to resident fish species at the Northfield Mountain and Turners Falls Projects by developing a qualitative scale of entrainment risk for resident and migratory fish species.

- Conduct a quantitative assessment of the potential impact of entrainment and turbine mortality of juvenile American Shad and adult American Eel.

## 1.2 Background

Factors that affect the potential for entrainment at a hydroelectric project include engineering, operational and biological characteristics of the site. Influential features include the size and depth of the intake(s), the hydraulic capacity and configuration of the turbine(s), the velocity of water as it enters the intake relative to fish swimming capabilities, the location of the intake relative to fish habitat, and the characteristics of fish species that inhabit the reservoir. Fish impingement at hydroelectric facilities can occur when intake water velocities trap or pin fish against the trashracks. If the fish are unable to escape the flow field and free themselves from the racks, then injuries and/or mortality likely result. Factors that influence the potential for impingement include the size and spacing of trashrack bars; intake velocity at the trashracks; and habitat preferences, sizes (length and width), and swim speed capabilities of fish in the vicinity of the intake.

Entrainment of fish at hydroelectric projects does not necessarily result in injury to the fish. Depending upon the characteristics of the individual units, survival rates of fish through turbines vary, and can be high. Project factors that affect survival rates include the type of turbine, the number of blades, the blade spacing, and the rotation speed of the turbine. Operational factors include how and when the project operates and the type of operation (*e.g*. run-of-river, peaking, pump-storage, etc.). Biological factors affecting entrainment and impingement rates include the species composition, sizes and relative abundance of fish, seasonal and/or diurnal behavior, which in turn may be related to the local habitat, water quality, climatic conditions and position in the watershed of the project. Some species undergo riverwide migrations that must pass the project to complete their life cycles while other species may not move other than for short distances. Passage mortality may be affected by the fish size and body morphology.

Many empirical fish entrainment studies have been conducted and reported on for hydroelectric sites across the United States, more typically for conventional projects similar to the Turners Falls Project. These studies provide order-of-magnitude estimates of annual fish entrainment (FERC, 1995) rather than precise counts. Along with the entrainment data, descriptive information gathered from the various studies includes:

- **Location:** geographical proximity, river basin

- **Project size:** discharge capacity and power production

- **Project operation:** peaking, run-of-river, etc.
- **Biological factors:** fish species composition
- **Impoundment characteristics:** general water quality, impoundment size, flow regime
- **Physical Project characteristics:** trashrack spacing, intake velocity, etc.

Extensive turbine mortality study data exist for a range of turbine types and physical characteristics, which can be compared to the Projects' turbines. These characteristics are commonly attributed to turbine passage mortality (Cramer & Oligher, 1963; Eicher, 1987; Bell, 1991; EPRI, 1992) and include turbine design type, operating head, runner speed, diameter, and peripheral runner velocity.

The Connecticut River is home to riverine species of fish and also serves as a migratory corridor with spawning and rearing habitat for diadromous species such as American Shad, and American Eel. At the Northfield Mountain Project, fish entrained during pumping operations pass from the Connecticut River mainstem through the powerhouse and are discharged to the Upper Reservoir. Although it is probable that fish are able to survive the entrainment process and are discharged to the Upper Reservoir alive, it is also likely that fish succumb to the rapid pressure changes experienced as a fish moves through the pressure shaft. As such, FirstLight assumes the potential for entrainment is restricted to pumping operations.

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

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

Prior entrainment studies conducted at the NMPS Project include a strobe light exclusion efficiency study (Cook *et al*., 1994), a guide net exclusion efficiency study (NUSCO, 1999) and intake netting of shad juveniles in the Upper Reservoir (LMS, 1993a; LMS, 1993b). These studies were conducted to evaluate the impacts of the Northfield Mountain Project operation on anadromous fish species, specifically uprunning adult American Shad and Atlantic Salmon smolts. Methods included radio telemetry, netting, and mark/recapture to investigate entrainment. LMS Engineers (LMS, 1993b) utilized four different assessment methods to estimate the cropping impact of Northfield Mountain on juvenile American Shad passing the intake channel and determined that project operations impacted between 0 and 12.4% of the fish passing upstream of the Project.

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

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

# 2 STUDY AREA

This study area includes the Northfield Mountain and the Turners Falls Projects on the Connecticut River in Northfield, Turners Falls, and Montague, Massachusetts. Key features of the Projects pertaining to fish entrainment are summarized below, followed by a discussion of the fish species that occur in the vicinity of the Projects.

## 2.1 Turners Falls Project

The Turners Falls Project is located on the Connecticut River mainstem (Figure 2.1-1). The project diverts flow from the river into a 2.1 mile-long power canal with a design capacity of approximately 18,000 cubic feet per second (cfs). The upstream portion of the Turners Falls Power Canal is manmade and generally shallow with a mix of substrates including gravel, cobble, small boulder and bedrock. Approximately two-thirds of the way down from the Turners Falls Gatehouse, the canal widens to form a pond-like, low velocity area upstream of the Cabot Station forebay. Here, cover and substrate attractive to fish is lacking. Areas containing attractive substrate are disjunct and low in density within the power canal. Powerhouses along the canal include Station No. 1 and Cabot Station (described below), Cabot Station is operated as peaking station, whereas Station No. 1 is used during periods of low or high river flow. Several entities are permitted to withdraw water from the canal, which subsequently discharge into the bypass reach. Table 2.1-1 lists the canal water users, approximate hydraulic capacity, and FERC project number, as applicable.

### *2.1.1 Station No. 1*

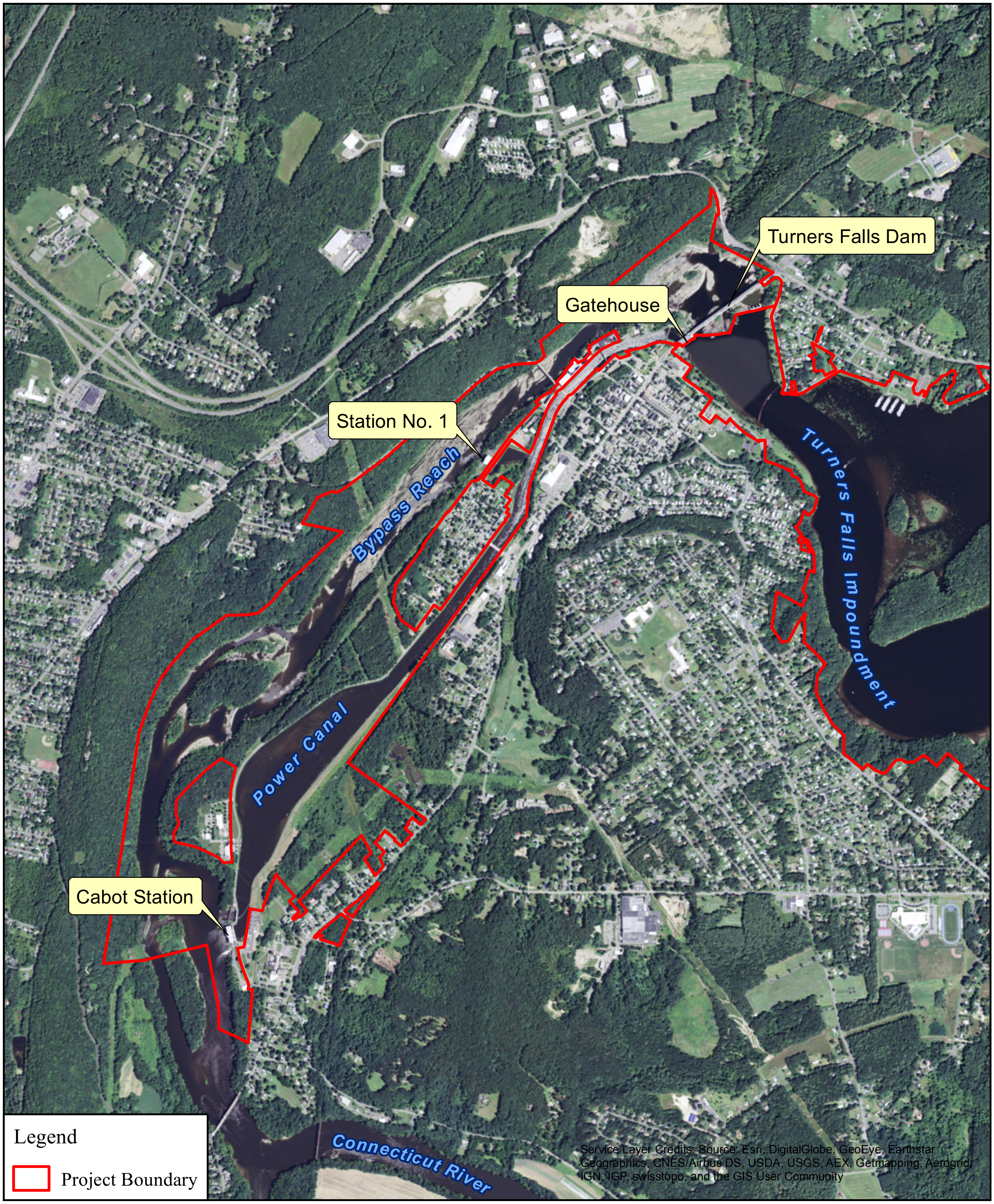
Station No. 1 is located along the west side of the power canal approximately one mile downstream from the Turners Falls Gatehouse. Water is conveyed from the power canal through an approximately 700-feet-long by 100-feet-wide branch canal to the intake for Station No. 1. The entrance to Station No. 1 consists 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 1,813 square feet ($ft^2$). 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 (2,210 cfs), the calculated average approach velocity in front of the trashracks is approximately 1.2 feet per second (fps). More detailed information on velocities was collected for Study No. 3.3.8 Computational Fluid Dynamics (CFD) Study which demonstrated that, under maximum generation flow at Station No. 1, 91% of the rack face had approach velocities of less than 2.0 fps.

Downstream from the trashracks, the intake narrows to four individual 13.125-ft-diameter penstocks that feed the turbines housed in the powerhouse. Penstock 1 feeds Unit 1; Penstock 2 feeds both Units 2 and 3; Penstock 3 feeds both Units 4 and 5; and Penstock 4 feeds Units 6 and 7. Note that penstock 4 bifurcates into pipes leading to Units 6 and 7; Unit 6's penstock was permanently plugged. Station No. 1 operates under a gross head of 43.7 feet, and has an approximate total electrical nameplate capacity and hydraulic capacity of 5,693 kilowatts (kW) and 2,210 cfs, respectively. Table 2.1.1-1 includes information on Station No. 1's generators and turbines. Note that Units 4 and 6 have been inoperable since the last FERC license was issued.

### *2.1.2 Cabot Station*

Cabot Station is located at the downstream terminus of the power canal. The trashrack opening is 217-feet-wide by 31-feet-high, resulting in a gross area of 6,727 $ft^2$. The trashracks are oriented 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. After passing through the trashracks, flow is conveyed through one of six penstocks to turbines housed in the powerhouse. The powerhouse houses six vertical, Francis-type, single runner turbines.

Cabot Station has a total station nameplate capacity of about 62 megawatts (MW) or approximately 10.336 MW/unit. The station has a total hydraulic capacity of approximately 13,728 cfs or 2,288 cfs/unit. At full hydraulic capacity, the calculated approach velocity in front of the trashracks is approximately 2.0 fps. Table 2.1.1-1 includes information on Cabot Station's generators and turbines. More detailed information on velocities was collected for Study No. 3.3.8 Computational Fluid Dynamics (CFD) Study which demonstrated that velocities across the rack were not uniform and, under maximum generation flow, 32% of the rack area had velocities less than 2.0 fps. The highest approach velocities were located in front of penstock no. 6 (the most upstream area of the intake) and nearest to the bottom.




FirstLight Power Resources

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

Relicensing Study 3.3.7

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0 0.25 0.5 1 Miles

Figure 2.1-1: Turners Falls Project Features



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**Table 2.1-1: Entities having rights to withdraw water from the Turners Falls power canal**

| Facility Name | Owner | Approximate Hydraulic Capacity (cfs) | FERC Project No. |
|---|---|---|---|
| Southworth Paper Hydro | Southworth Paper | 113 cfs | N/A |
| Turners Falls Hydro | Turners Falls Hydro, LLC | 288 cfs | 2622 |
| Station No. 1 | FirstLight | 2,210 cfs | 1889 |
| Cabot Station | FirstLight | 13,728 cfs | 1889 |
| United States Geological Survey (USGS) Conte Anadromous Fish Laboratory | USGS | Variable | N/A |

**Table 2.1.1-1: Characteristics of turbines associated with power generation at Northfield Mountain and Turners Falls Developments**

| Unit No. | Runner Diameter (in) | No. of Blades (Buckets) | Runner Type | Hydraulic Capacity (cfs) | Operating Head (ft) | Rotational Speed (rpm) |
|---|---|---|---|---|---|---|
| **Station No. 1** | | | | | | |
| 1 | 48 | 13 | Francis | 560 | 43.7 | 200 |
| 2[1] | 33 | 13 | Francis | 140 | 43.7 | 257 |
| 3 | 42 | 15 | Francis | 500 | 43.7 | 200 |
| 5 | 39 | 13 | Francis | 490 | 43.7 | 200 |
| 7 | 42 | 15 | Francis | 520 | 43.7 | 200 |
| **Cabot Station** | | | | | | |
| 1-6[2] | 136.35 | 13 | Francis | 2,288 | 60 | 97.3 |
| **Northfield Mountain** | | | | | | |
| 1-3[3] | 207 | 7 | Francis | 5,500 (generating)<br>3,200 (pumping) | 790 | 257 |
| 4 | 207 | 7 | Francis | 5,500 (generating)<br>3,200 (pumping) | 745 | 257 |

1 Unit No. 2 is directly connected to a 1,600-amp, 257-rpm, 115-Volt exciter.
2 Unit Nos. 1 through 6 at Cabot Station are identical.
3 Unit Nos. 1 through 3 at Northfield Mountain are identical.

## 2.2 Northfield Mountain Project

The Northfield Pumped Storage Project powerhouse withdraws water from the Connecticut River during pumping operation from the Turners Falls Impoundment (TFI), and is connected to the Upper Reservoir atop the Northfield Mountain through an inclined tunnel (Figure 2.2-1). The reservoir subsequently discharges its storage to the Connecticut River during generation. Connecticut River fishes are potentially subject to entrainment during the pumping portion of the operating cycle, which typically occurs during night hours.

### *2.2.1 Powerhouse Tailrace*

The powerhouse tailrace serves as the intake during pumping and is located inshore from the Connecticut River. An excavated 700-feet-long channel serves as a forebay/tailrace. The channel lacks instream cover, providing limited fish habitat. When operating in a pumping mode, the approximate hydraulic capacity of the station is 15,200 cfs (3,800 cfs/pump). Alternatively, when operating in a generation mode, the approximate hydraulic capacity is 20,000 cfs (5,000 cfs/turbine). Within the underground power plant, there are four reversible Francis type pump turbines; details about each are provided in Table 2.1.1-1.

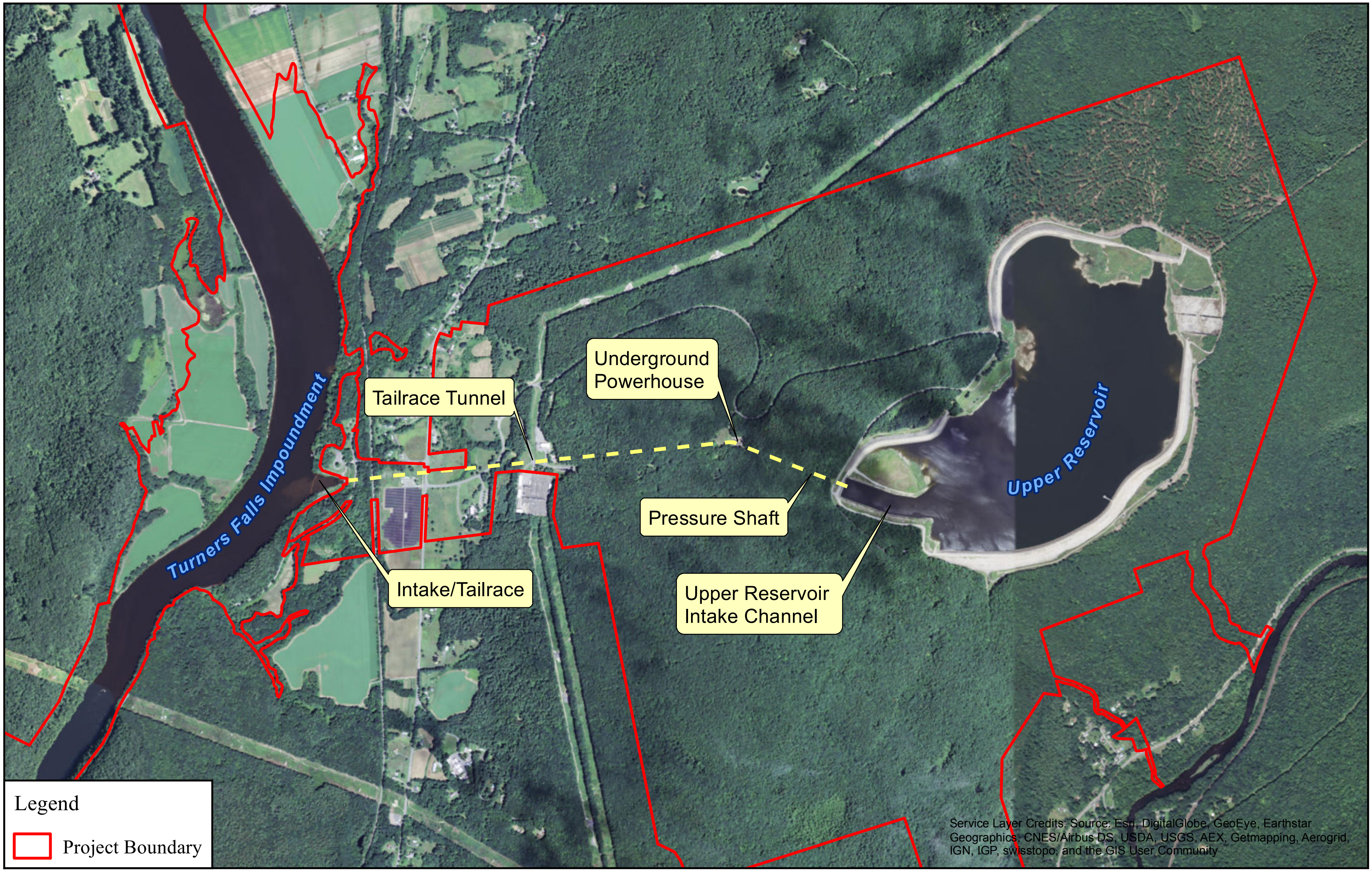
The trashrack opening is trapezoidal in shape and has a gross area opening of 4,400 $ft^2$. The bar thickness is 0.75 inches, with a clear-spacing of 6 inches. Under maximum pumping conditions of 15,200 cfs, the calculated velocity in front of the rack is 3.5 fps. Velocities were field measured in this area as part of Relicensing Study No. 3.3.9 (Northfield 2-D Study). The results indicated that during four units pumping, velocities across the channel were typically 3-4 ft/s. When the barrier net was in place in previous years for reducing entrainment of salmon smolts, only three pumps operate, passing 11,400 cfs and resulting in a calculated intake velocity of 2.6 fps.

### *2.2.2 Upper Reservoir*

The Upper Reservoir is contained by a main dam, three dikes, and a concrete gravity dam with a spillway. Water enters and exits the reservoir via a pressure shaft and intake channel. During pumping operation, water is pumped from the river through the pressure shaft to the Upper Reservoir. During generation, water flows from the Upper Reservoir through the pressure shaft to the powerhouse. The pressure conduit system consists of a reinforced concrete intake portal; a 200 feet long concrete lined transition section; a portal 55 feet wide by 80 feet high; an inclined concrete-lined pressure shaft that connects the intake and manifold shaft (31 feet in diameter, 853 feet long, and inclined 50 degrees from the horizontal); and a concrete-lined manifold formed by branching of the pressure shaft into two 22-foot diameter conduits and then into four 14-foot diameter tunnels which lead to four steel-lined penstocks (340 feet long, diameter decreases from 14 to 9.5 feet).

### *2.2.3 Upper Reservoir Intake Channel*

The intake channel directs water from the Upper Reservoir into the pressure conduit intake. The channel is 1,890 feet long and is excavated in rock with side slopes of 4V:1H. The invert is 130 feet wide at Elevation 828 feet (msl) at the entrance to the intake portal. There is a small dam (submerged) at the upstream end of the intake channel with a stoplog and gate structure. The purpose of this control structure, a low dam between the upper reservoir and intake channel, is to prevent storm water from entering the pressure conduit when the intake channel is dewatered. The submerged dam is 63 feet long with a crest at 900 feet msl. It has two manually operated sluice gates (2.75 feet high by 6 feet wide) and two 18-foot-wide stoplog slots which usually hold eight concrete stop logs (which weigh approximately 3,000 pounds each).




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

Relicensing Study 3.3.7

Figure 2.2-1: Northfield Mountain Project Features

FirstLight Power Resources



Path: W:\gis\studies\3_3_07\Figure2.2-1.mxd

## 2.3 Fish Species in the Study Area

The fish assemblage in the vicinity of the Turners Falls and Northfield Mountain Projects includes both resident species and diadromous fish. Resident species are those that spend their entire life cycles in freshwater and may become vulnerable to entrainment when individuals move into the immediate vicinity of an intake and cannot escape the forces of the intake flow field. Diadromous species are those that use freshwater habitat for portions of their life cycles but also require marine habitat to complete their life cycles. These species undergo downstream and upstream migrations that can expose individuals to the effects of operations as they encounter and attempt to pass project generating facilities. Unlike resident species, diadromous species are only present in the study area seasonally, particularly during migratory runs and rearing; and the lifestages susceptible to entrainment vary by season. For example, adult anadromous fish migrating upstream in search of spawning grounds may be exposed during the spring, whereas juveniles that emigrate downstream following rearing may be exposed during the late summer and fall.

Previous studies suggest that resident and anadromous species may be potentially affected by operations at the Northfield Mountain and Turners Falls Projects (Layzer, 1976; LMS, 1993a; LMS, 1993b). Entrainment dynamics for these species differ at the two Projects because of the configurations of the facilities and methods of operations. Due to the pump-storage operation of the Northfield Mountain Project, Connecticut River fishes are only susceptible to entrainment when water is withdrawn from the river during pumping operations, which occur during night hours, typically during the hours from midnight to 6:00 a.m. Thus, only those fish within the hydraulic zone of influence during the few hours of pumping operations have the potential to be entrained or impinged. By contrast, the Turner Falls Dam acts as a barrier across the width of the river, and those fish not passing over the dam with spill or via the existing downstream fishway adjacent to Cabot Station may be subjected to entrainment at Station No. 1 or Cabot Station.

In support of the Northfield Mountain and Turners Falls Projects' relicensing effort, FirstLight conducted a fish assemblage survey (Study No. 3.3.11 Fish Assemblage Assessment) during 2015 to document the occurrence, distribution, and relative abundance of resident and diadromous fishes within the study area. Surveys were conducted in the TFI during early summer (June-July) and late summer (September); the bypass reach was surveyed in late summer only. A total of 5,908 fish representing 28 species (inclusive of hybrid sunfish) were collected over the course of the survey (Table 2.3-1). During both survey periods (early summer and late summer), Spottail Shiner dominated the collections, followed by Smallmouth Bass, and Yellow Perch; these three species accounted for a combined 74% of the early summer catch and 72% of the late summer catch. Three diadromous species were observed (American Eel, American Shad, and Sea Lamprey) and combined accounted for 0.6% of the early summer catch and 3.2% of the late summer catch. The increase observed in late summer was due to a larger contribution of juvenile shad.

The lifecycle of Sea Lamprey is such that impacts due to entrainment and/or impingement at the Northfield Mountain and Turners Falls Projects are likely negligible. Adults in the marine environment undergo spawning migrations into freshwater rivers where nests are constructed in the mainstem and tributary habitats for egg deposition. There is a risk of adult entrainment and/or impingement during their upstream migration. However, during radio telemetry studies conducted at the Projects in 2015 no entrainment or impingement was documented (FirstLight, 2016c). Subsequent to spawning, adults die and therefore, are not susceptible to mortality due to project operations. Sea Lamprey larvae, or ammocoetes, burrow into muddy, sandy substrate areas after emerging from nests and remain in this sedentary life stage for up to 3-7 years (Moser *et al*., 2007). Upon transformation, individuals leave the substrate and begin movement downstream towards the ocean. The transformers are not susceptible to impingement impacts as their bodies are narrow enough to move through trashracks. Similarly, entrainment impacts are expected to be negligible due to the small size of the transformers.

**Table 2.3-1: Resident and diadromous fish species documented in the TFI during 2015 surveys**

| Common Name | Scientific Name |
|---|---|
| American Eel | *Anguilla rostrata* |
| American Shad | *Alosa sapidissima* |
| Banded Killifish | *Fundulus diaphanus* |
| Black Crappie | *Pomoxis nigromaculatus* |
| Bluegill | *Lepomis macrochirus* |
| Brown Bullhead | *Ameiurus nebulosus* |
| Chain Pickerel | *Esox niger* |
| Channel Catfish | *Ictalurus punctatus* |
| Common Carp | *Cyprinus carpio* |
| Common Shiner | *Luxilus cornutus* |
| Fallfish | *Semotilus corporalis* |
| Golden Shiner | *Notemigonus crysoleucas* |
| Largemouth Bass | *Micropterus salmoides* |
| Longnose Dace | *Rhinichthys cataractae* |
| Mimic Shiner | *Notropis volucellus* |
| Northern Pike | *Esox lucius* |
| Pumpkinseed | *Lepomis gibbosus* |
| Rock Bass | *Ambloplites rupestris* |
| Rosyface Shiner | *Notropis rubellus* |
| Sea Lamprey | *Petromyzon marinus* |
| Smallmouth Bass | *Micropterus dolomieui* |
| Spottail Shiner | *Notropis hudsonius* |
| Tessellated Darter | *Etheostoma olmstedi* |
| Walleye | *Sander vitreus* |
| White Perch | *Morone americana* |
| White Sucker | *Catostomus commersonii* |
| Yellow Perch | *Perca flavescens* |

# 3 METHODS

The study was conducted in accordance with the approved RSP.

## 3.1 Resident Species

The list of resident species evaluated for potential entrainment risk was based on the species observed in the TFI during the 2015 Fish Assemblage Assessment (Study No. 3.3.11) as listed in Table 2.3-1. Lengths of fish measured during Study No. 3.3.11 were summarized and body width to length ratios were determined based on Smith (1985). Resident fish species entrainment and impingement risk was then qualitatively evaluated based on habitat use relative to project features and the ability of various species to escape intake velocity flow fields.

### *3.1.1 Potential Entrainment and Impingement Risk*

A *Traits Based Assessment* (Cada & Schweizer, 2012) was used to evaluate potential entrainment and/or impingement risk. Known species traits such as habitat preference, life history strategies, behavior morphology and demography were considered to evaluate each major fish species' overall susceptibility to entrainment and/or impingement.

Turners Falls Impoundment resident fish species (*obtained from the 2015 fish assemblage study*) were classified into turbine survival groups; turbine survival for each group and for each turbine set was then characterized by assigning survival rates to fish species resident in the Turners Falls Impoundment based on empirical results reported from independent studies from other similar turbines (Franke, *et al*., 1997). Method details are provided in Section 3.1.2.

It was assumed that the degree to which individuals of each species become entrained or impinged depends upon its physical swimming abilities which dictate the ability of fish to escape involuntary entrainment or impingement. Critical swim speed ($U_{crit}$) is a measure of the ability of a fish to maintain a rate of speed for a certain amount of time (i.e., sustained speed). Sustained speed can be maintained for a number of minutes and allows a fish to maneuver in currents when undertaking localized movements. It is intermediate between cruising speeds (represents movement that can be maintained for long periods of time, such as hours) and darting speed (represents a short, single, targeted effort that is not sustainable; used to escape predator or capture prey). The sustained swim speed for each species at a range of body lengths and acclimation temperatures was generated from literature. For species in which the literature search did not identify a published swim speed, the 10-minute critical sustained swimming speed was estimated as a function of fork length and temperature using the equation derived from Peake (2008) (Equation 1).

$$\boldsymbol{U_{crit} = 0.263 + 0.72\,(FL) + 0.0120(T)} \qquad \textbf{EQUATION 1}$$

Where:

- $U_{crit}$ represents the 10-minute critical sustained swimming speed (cm/s);
- FL represents fork length (cm); and
- T represents acclimation temperature (°C).

The potential for entrainment was assessed through comparison of swim speed capabilities and mean intake velocities at full generation. If the sustained swim speed for an individual was less than the intake velocity, it was assumed that the fish would potentially become entrained (denoted as a minus sign, "-"); a fish with a sustained speed greater than the intake velocity would likely be able to escape (denoted with a plus sign, "+").

The potential for impingement was first assessed though comparison of trashrack spacing and fish body dimensions (length and width). It was assumed that smaller fish with body widths less than the trashrack bar spacing would not be susceptible to impingement. For larger fish with body widths that exceed the trashrack bar spacing, the potential for impingement was assessed by comparison of swim speed capabilities and intake velocity at the trashracks. In general, it was assumed that fish with sustained swim speeds greater than the intake velocity would be able to escape impingement.

### *3.1.2 Turbine Passage Mortality*

The turbine passage mortality assessment focused on Station No. 1 and Cabot Station as it is assumed that any fish entrained during nighttime pumping operations at the Northfield Mountain Project are lost. Both Cabot and Station No. 1 are equipped with Francis turbines (Table 2.1.1-1). Parameters such as head, peripheral runner velocity, hydraulic capacity, rpm, etc., are correlated to entrainment survival (Franke, *et al*., 1997), and vary between the two stations (see Section 2.1 above). The Franke *et al*. (1997) database includes empirical test data for many common resident fish species obtained at independently conducted empirical studies from more than 30 hydroelectric projects with Francis units in North America that can serve as potential source data. However, these sites have a range of physical characteristics; therefore, entrainment survival rate estimates were developed by querying the database to obtain results from a subset of source sites with head, peripheral runner velocity and hydraulic capacity similar to the Cabot and Station No. 1 turbines.

Turners Falls Impoundment resident fish species were classified into turbine survival groups based on phylogenetic families, as most such fish share similar body morphology, scale and skeletal structure, and other biological characteristics that potentially affect turbine survivorship. This allowed pooling of multiple study results. In a few cases where a species present at Turners Falls was not represented in the database, survival rates reported for either juvenile clupeids (a fragile species group), or a similar morphological family (e.g. centrarchid survival data used as a surrogate for White Perch) were substituted as a surrogate. The pool of resulting individual turbine survival results for each fish family were averaged for each turbine set. For purposes of traits based analysis scoring, turbine survival was scored on a scale of 0 (high) (>90%), 1 (good) (80-89%), 2 (moderate) 70-89%) or 3 low (<70%).

## 3.2 Migratory Species

Migratory species in the TFI that were evaluated for entrainment and/or impingement potential include American Shad and American Eel. As mentioned previously, entrainment and/or impingement impacts to Sea Lamprey are considered negligible due to the species lifecycle; therefore, this species was not included in the following analyses.

### *3.2.1 Potential Entrainment and Impingement Risk*

The potential for entrainment and impingement of American Shad and American Eel at the Project intakes was assessed via other studies conducted in support of the FirstLight relicensing efforts. These studies assess entrainment rates at project intakes using a combination of radio telemetry and hydroacoustic techniques.

Study No. 3.3.2 (Evaluate Upstream and Downstream Passage of Adult American Shad) was conducted in spring 2015 during which 793 American Shad were equipped with radio tags and released either just above the Holyoke Dam, in the Turners Falls Power Canal, or upstream of the Turners Falls Dam. Shad were continuously monitored by the fixed receiver stations throughout their upstream and downstream migrations. Data from the monitoring stations located at the Project intakes and tailraces were assessed to determine the number of individual adult shad that were entrained or vulnerable to impingement.

Study No. 3.3.3 assessed juvenile shad emigration through the project area in the fall of 2015 using a combination of radio telemetry and hydroacoustic techniques. Radio tagged juvenile shad (n=218) were released either approximately 1.5 miles upstream of the Northfield Mountain intake/tailrace channel or about 1.25 miles upstream from the Turners Falls Dam and monitored at 13 receiver stations throughout the project area. In addition, hydroacoustic monitoring systems were deployed at the Northfield Mountain intake/tailrace, the upper Turners Falls Power Canal (approximately 0.4 miles downstream from Gatehouse), and in the intake of the Cabot Station. The monitoring systems continuously recorded data from August 1 to November 14, 2015. While the hydroacoustics were intended to provide information on the timing, duration and magnitude of juvenile shad outmigration, the locations of the hydroacoustic equipment at the Northfield Mountain intake/tailrace channel and in the power canal did not allow for accurate assessments of the number of juvenile shad in the monitoring areas due to the milling behavior of shad observed. As such, the estimate of the rate of entrainment of juvenile shad at Northfield Mountain relied on the assessment of radio telemetry data only.

Study No. 3.3.5 (Evaluate downstream passage of American Eel) was conducted to understand emigration of American Eel and determine impacts due to project operations using a combination of hydroacoustic and radio telemetry methods. The hydroacoustic monitoring equipment was deployed in the same locations as described for juvenile shad and the same network of telemetry receivers used for the juvenile shad evaluation monitored the movement of 132 radio tagged eels. The study was initiated in 2015; however, hydroacoustic data collection (required to span 2 years) and analysis of radio telemetry data remains ongoing. As indicated previously, the final report is due to FERC in March 2017 and will include a discussion of entrainment impacts to downstream migrating American Eel.

### *3.2.2 Turbine Passage Mortality*

As indicated previously, empirical studies of turbine passage mortality for juvenile American Shad and adult American Eel was performed by NAI using HI-Z Turb'N Tag and mark/recapture methods in October 2015. Appendices A and B contain the final reports prepared by NAI that detail the methods used to evaluate turbine passage survival at Station No. 1 and Cabot Station.

# 4 RESULTS AND DISCUSSION

## 4.1 Resident Fish

Based on Massachusetts Division of Fish and Game (MDF&G, 1978), Yoder *et al.* (2010), and the recent results of Study No. 3.3.11 (Fish Assemblage Assessment), the fish assemblage in the area of the Projects is dominated by cyprinids, centrarchids, and percids and has remained relatively stable in composition over the decades. Empirical data from other studies (EPRI, 1997; FERC, 1995) suggest that entrainment of such species is dominated by young-of-year (YOY) and juvenile-sized fish during the late summer and fall. Most resident species are littoral, shoreline- and cover-oriented, and due to the paucity of these habitat features in the Northfield Mountain intake/tailrace channel, the likelihood of entrainment or impingement of these fishes is reduced. In addition, these resident species do not typically undertake large river-wide movements that require passing downstream at the Turners Falls Project where they would encounter either the Cabot Station or Station No. 1 intakes. Such fish reside or forage locally within the intake area and encounter velocities that may exceed their sustained swim speed. Some localized movements of individuals, or small schools during foraging or random exploration in the immediate vicinity of the project intake could result in periodic, small-scale entrainment events.

The Traits Based Assessment was performed to determine the vulnerability of species residing in the TFI to entrainment or impingement at the project intakes. Key ecological and biological traits considered in the assessment are summarized in Tables 4.1-1, 4.1-2, and 4.1-3 and discussed by species below.

Table 4.1-4 summarizes key turbine characteristics of the units at Cabot Station and Station No. 1, and potential source study turbines from Franke, *et al*. (1997). Turbine size (indicated by flow volume) ranged from 326 to 4,500 cfs; however, most study sites were 1,600 cfs or less. Head (ft) ranged from 13 to 450 ft with most sites less than 100 ft. Peripheral runner velocity[1], which is the speed of the leading edge of each blade when fish contact the blade ranged from 23 to 111 fps with most sites less than 70 fps.

Cabot and Station No. 1 turbines were qualitatively similar to each other in terms of the parameters of peripheral runner velocity and head, but differed in terms of turbine size (Figure 4.1-1). Since turbine size may affect survival due to the relative dimensions and spacing of components that fish may strike, source data were therefore sorted by turbine size to provide data from sources most similar to Cabot and Station No. 1. For purposes of this analysis source data for Cabot were obtained from turbines with a capacity of approximately 1,000 cfs plus or minus that of Cabot (2,200 cfs). Station No. 1 turbines are smaller (140-560 cfs), data for these turbines was sourced from smaller units (turbines of 1,000 cfs or less).

Tables 4.1-5 and 4.1-6 summarize the source data for Cabot and Station No. 1. Tables 4.1-7 and 4.1-8 summarize estimated turbine survival for resident fish species dwelling in the Turners Falls Impoundment that could potentially be entrained. Estimated survival at Cabot ranged from 65% for ictalurids to 91% for esocids, and generally ranged in the mid 80% for most species. Estimated survival at Station No. 1 ranged from 71% for percids to 95% for banded killifish, and generally ranged in the mid 70-80% range for most species.

[1] Both runner speed and runner diameter collectively contribute to peripheral runner velocity

**Table 4.1-1: Summary of Traits Based Assessment in which plus sign indicates an increased risk to entrainment and minus sign indicates a lower likelihood.**

| Species | Location within TFI | Habitat within Channel | Migration and Movement | Reproductive Strategy | Demography | Recolonization | Sources |
|---|---|---|---|---|---|---|---|
| Yellow Perch | Main channel (+) | Most commonly found in clear water near vegetation; tends to shoal near the shore during spring (-) | Lateral migrations into shallow water, sometimes tributaries (-) | Non-guarders (+) | Medium resilience with minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Cada *et al.*, 2012<br>Page & Burr, 1991 |
| Pumpkinseed | Main channel (+) | Inhabits in or near vegetation cover or brush cover (-) | Lateral migrations into shallow water (-) | Guarders (-) | Medium resilience with minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Page & Burr, 1991<br>Cada *et al.*, 2012 |
| Smallmouth Bass | Main channel (+) | Inhabit shallow rocky areas and flowing pools of rivers, cool flowing streams and reservoirs (+) | Lateral migrations into shallow water (-) | Guarders (-) | Medium resilience with minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Scott & Crossman, 1973 |
| Largemouth Bass | Main channel (+) | Inhabits clear, vegetated lakes, ponds, swamps, and backwaters and pools of creeks and rivers. Usually found over mud or sand and common in impoundments. Prefers quiet, clear water and over-grown banks. (+) | Lateral migrations into shallow water (-) | Guarders (-) | Low resilience with minimum population doubling tie 4.5 - 14 years (+) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Page & Burr, 1991 |
| Bluegill | Main channel (+) | Found frequently in lakes, ponds, reservoirs, and sluggish streams, and prefers deep weed beds | Lateral migrations into shallow water (-) | Guarders (-) | Medium resilience with minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Page & Burr, 1991 |

| **Species** | **Location within TFI** | **Habitat within Channel** | **Migration and Movement** | **Reproductive Strategy** | **Demography** | **Recolonization** | **Sources** |
|---|---|---|---|---|---|---|---|
| Spottail Shiner | Main channel (+) | Found in large rivers or lakes, 3-60 feet dep with sand or gravel bottoms (+) | Lateral migrations into shallow water (-) | Non-guarders (-) | Medium resilience with minimum population doubling time, 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004 Page & Burr, 1991 |
| White Sucker | Main channel (+) | Usually occurs in small, clear, cool creeks and small to medium rivers. May be found at a depth greater than 45 meters (-) | Moves to shallow water to feed (-) | Non-guarders | Low resilience with minimum population doubling tie 4.5 - 14 years (+) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004 Page & Burr, 1991 |
| Walleye | Main channel (+) | Preferred habitat are slightly turbid lakes and rivers. (+) | Lateral migrations into tributary streams (-) | Non-guarders | Low resilience with minimum population doubling tie 4.5 - 14 years (+) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004 Robins *et al.*, 1991 Cada *et al.*, 2012 Page & Burr, 1991 |
| Golden Shiner | Main channel (+) | Prefer relatively clear and quiet water with a great deal of aquatic vegetation in lakes, ponds, or large slow-flowing streams and rivers. (-) | Lateral migration towards spawning areas, occurs in ponds and lakes over vegetation, however feeding occurs at the surface (-) | Non-guarders | Medium resilience with minimum population doubling time, 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004 Page & Burr, 1991 |
| Black Crappie | Main channel (+) | Inhabits lakes, ponds, sloughs, and backwaters of pools of streams. Usually occurs among vegetation over mud or sand, most common in clear water | Lateral migrations into shallow water (-) | Guarders | Medium resilience with minimum population doubling time, 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004 Page & Burr, 1991 Cada *et al.*, 2012 |

| **Species** | **Location within TFI** | **Habitat within Channel** | **Migration and Movement** | **Reproductive Strategy** | **Demography** | **Recolonization** | **Sources** |
|---|---|---|---|---|---|---|---|
| White Perch | Main channel (+) | Primarily found in brackish water but common in pools and other quiet water areas of medium to large rivers, usually over mud (+) | Travel in schools searching for food and forage over a broad area, broadcast spawning occurs over mud (+) | Non-guarders | Low resilience with minimum population doubling time 4.5 - 14 years | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Page & Burr, 1991<br>Cada *et al.*, 2012 |
| Rock Bass | Main channel (+) | Inhabits vegetated brushy stream margins and pools of creeks and small to medium rivers, and rocky and vegetated margins of lakes | Lateral migration to shallow water to spawn, constructs plate-like depression in shallow water | Guarders | Medium resilience with minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Page & Burr, 1991 |
| Brown Bullhead | Main channel (+) | Occurs in pools and sluggish runs over soft substrates in creeks and small to large rivers. Young often found near surface | Lateral migration into shallow water to spawn, preferring sites with some shelter | Guarders | Medium resilience with minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Page & Burr, 1991 |
| Chain Pickerel | Main channel (+) | Inhabits vegetated lakes, swamps, and backwaters and quiet pools of creeks and small to medium rivers. Juveniles lie motionless near shore while larvae hide among vegetation | Lateral migration into marshy areas and shallow bays shortly after ice out; Adults migrate (laterally) into deeper water during winter | Non-guarders | Medium resilience with minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Crossman, 1996 |
| Fallfish | Main channel (+) | Inhabits gravel-bottomed and rubble bottomed pools and runs of small to medium rivers and also lake margins (+) | Lateral spawning migrations preferring quiet water in streams or around shores of lakes with clean gravel bottom | Nesters | Low resilience with minimum population doubling time 4.5 - 14 years (+) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Hartel *et al.*, 2002<br>Page & Burr, 1991 |

| Species | Location within TFI | Habitat within Channel | Migration and Movement | Reproductive Strategy | Demography | Recolonization | Sources |
|---|---|---|---|---|---|---|---|
| Common Carp | Main channel (+) | Hardy and tolerant of a wide variety of conditions but generally prefer large water bodies with slow flowing or standing water and soft sediments. | Lateral spawning migrations into shallow water | Non-guarders | Medium resilience with minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004 Kottelat & Freyhof, 2007 |
| Banded Killifish | Quiet, shallow margins of lakes, ponds, and sluggish streams (+) | Benthopelagic, usually over sand or mud, often near vegetation (-) | Non-migratory, form schools near surface | Non-guarders | High reproductive rates, relatively short population doubling time of less than 15 months (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Cada *et al.*, 2012 Page & Burr, 2011 |
| Channel Catfish | Main channel (+) | Associated with rocky or sandy bottom, but not vegetative areas | Lateral spawning migrations into shallow water | Guarders, nesters | Low resilience with minimum population doubling time 4.5 - 14 years (+) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004 Cada *et al.*, 2012 Hartel *et al.*, 2002 Page & Burr, 1991 |
| Common Shiner | Main channel (+) | Clear, cool, unvegetated areas with swift to moderate current, over gravel to rubble bottom | Non-migratory, but may make upstream movements for spawning | Nesters, guarders | Medium resilience, minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004 Hartel *et al.*, 2002 Cada *et al.*, 2012 Robins *et al.*, 1991 |
| Longnose Dace | Main channel (+) | Swift-flowing riffles with rubble and gravel | Non-migratory, but lateral spawning movements into shallow water | Non-guarders | Medium resilience with minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004 Hartel *et al.*, 2002 Cada *et al.*, 2012 Robins *et al.*, 1991 |

| Species | Location within TFI | Habitat within Channel | Migration and Movement | Reproductive Strategy | Demography | Recolonization | Sources |
|---|---|---|---|---|---|---|---|
| Mimic Shiner | Main channel (+) | Sandy pools of headwaters, creeks and small to large rivers | Non-migratory, but lateral spawning movements into shallow water | Non-guarders | High resilience, minimum population doubling time less than 15 months (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Hartel *et al.*, 2002<br>Cada *et al.*, 2012<br>Page & Burr, 1991 |
| Northern Pike | Main channel (+) | Occurs in clear vegetated lakes, quiet pools and backwaters of creeks and small to large rivers | Lateral spawning movements inshore or to marsh areas | Non-guarders | Low resilience, minimum population doubling time of 4.5-14 years (+) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Hartel *et al.*, 2002<br>Cada *et al.*, 2012<br>Crossman, 1996 |
| Rosyface Shiner | Main channel (+) | Prefers clear, swift large creeks and small rivers with gravel or rubble substrate, usually in or around riffles | Non-migratory, but may make lateral spawning movements | Non-guarders | High resilience, minimum population doubling time less than 15 months (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Cada *et al.*, 2012<br>Page & Burr, 1991 |
| Tessellated Darter | Main channel (+) | Prefer fluvial habitat with firm substrates ranging from pebble to cobble | Non-migratory, but may make lateral spawning movements | Nesters, guarders | Medium resilience, minimum population doubling time 1.4 - 4.4 years (-) | Presence of upstream and downstream passage facilities throughout system, these fish have the ability to recolonize (-) | Werner, 2004<br>Cada *et al.*, 2012<br>Hartel *et al.*, 2002<br>Page & Burr, 1991 |

**Table 4.1-2: Resident fish swim speed analysis at Cabot Station, Station No. 1 and Northfield Mountain intakes.**

*(A minus symbol indicates the fish is unable to escape intake velocities (based on sustained speed) while a plus sign indicates that it can.)*

| Species Name | Fork Length (in) | Acclimation Temperature (°C) | Swim Speed: Sustained (fps) | Swim Speed: Burst (fps) | Source | Entrainment Susceptibility: Northfield Pumping (3.6 fps)* | Entrainment Susceptibility: Station No. 1 (1.2 fps)* | Entrainment Susceptibility: Cabot Station (2.0 fps)* |
|---|---|---|---|---|---|---|---|---|
| Yellow Perch | N/A | N/A | 1.3 | 2.43 | Leavy & Bonner, 2009 | - | + | - |
| Pumpkinseed | 5.00 | 20 | 1.3 | 2.32 | Cooke *et al*., 2009 | - | + | - |
| Smallmouth Bass | 0.87 | 5 | 0.2 | 0.29 | Cooke *et al*., 2009 | - | - | - |
| | 0.87 | 10 | 0.3 | 0.63 | | - | - | - |
| | 0.87 | 15 | 0.5 | 0.91 | | - | - | - |
| | 0.87 | 20 | 0.7 | 1.36 | | - | + | - |
| | 0.87 | 25 | 0.9 | 1.58 | | - | + | - |
| | 0.87 | 30 | 1.0 | 1.82 | | - | + | - |
| | 0.87 | 35 | 0.8 | 1.54 | | - | + | - |
| | 10.31 | 15 | 2.8 | 5.10 | | + | + | + |
| | 12.20 | 17 | 3.7 | 6.75 | | + | + | + |
| Largemouth Bass | 2.28 | 30 | 1.5 | 2.84 | Cooke *et al*., 2009 | - | + | - |
| | 3.39 | 20 | 2.0 | 3.76 | | + | + | + |
| | 4.35 | 5 | 0.6 | 1.16 | | - | - | - |
| | 4.35 | 10 | 1.0 | 1.78 | | - | + | - |
| | 3.82 | 20 | 1.2 | 2.17 | | - | + | - |
| | 3.98 | 5 | 0.7 | 1.21 | | - | + | - |
| | 4.09 | 25 | 1.2 | 2.21 | | - | + | - |
| | 4.80 | 25 | 1.4 | 2.53 | | - | + | - |
| | 6.26 | 6 | 1.0 | 1.83 | | - | + | - |
| | 6.54 | 18 | 1.1 | 2.03 | | - | + | - |
| | 6.69 | 12 | 1.2 | 2.13 | | - | + | - |
| Bluegill | 6.10 | 13 | 1.2 | 2.26 | Cooke *et al*., 2009 | - | + | - |
| | 6.10 | 25 | 1.5 | 2.82 | | - | + | - |
| | 6.10 | 30 | 1.4 | 2.63 | | - | + | - |
| Spottail Shiner | N/A | N/A | 1.6 | 3.03 | Leavy & Bonner 2009 | - | + | - |
| White Sucker | 10.83 | 12 | 2.0 | 3.74 | Peake, 2008 | + | + | + |

| | | | Swim Speed | | | Entrainment Susceptibility | | |
|---|---|---|---|---|---|---|---|---|
| **Species Name** | **Fork Length (in)** | **Acclimation Temperature (°C)** | **Sustained (fps)** | **Burst (fps)** | **Source** | **Northfield Pumping (3.6 fps)*** | **Station No. 1 (1.2 fps)*** | **Cabot Station (2.0 fps)*** |
| Walleye | 21.26 | 5 | 1.7 | 3.14 | Peake *et al.*, 2000 | - | + | - |
| | 21.26 | 10 | 1.8 | 3.30 | | - | + | - |
| | 21.26 | 15 | 1.9 | 3.45 | | - | + | - |
| Golden Shiner | N/A | N/A | 1.6 | 3.03 | Leavy & Bonner 2009 | - | + | - |
| Black Crappie | 1.97 | 6 | 0.3 | 0.61 | Cooke *et al.*, 2009 | - | - | - |
| | 1.97 | 16.5 | 0.5 | 0.97 | | - | - | - |
| | 1.97 | 25.5 | 0.7 | 1.21 | | - | + | - |
| | 3.00 | 15 | 0.5 | 0.82 | | - | - | - |
| | 3.15 | 25 | 0.5 | 0.84 | | - | - | - |
| | 3.15 | 5 | 0.2 | 0.37 | | - | - | - |
| | 3.94 | 6 | 0.4 | 0.67 | | - | - | - |
| | 3.94 | 16.5 | 0.7 | 1.21 | | - | + | - |
| | 3.94 | 25.5 | 0.9 | 1.70 | | - | + | - |
| Black Crappie (cont.) | 5.91 | 6 | 0.3 | 0.61 | | - | - | - |
| | 5.91 | 16.5 | 0.5 | 0.91 | | - | - | - |
| | 5.91 | 25.5 | 1.0 | 1.82 | | - | + | - |
| | 6.50 | 25 | 1.1 | 2.11 | | - | + | - |
| | 7.87 | 6 | 0.5 | 0.91 | | - | - | - |
| | 7.87 | 16.5 | 0.7 | 1.21 | | - | + | - |
| | 7.87 | 25.5 | 1.0 | 1.82 | | - | + | - |
| | 9.84 | 6 | 0.5 | 0.91 | | - | - | - |
| | 9.84 | 16.5 | 0.7 | 1.21 | | - | + | - |
| | 9.84 | 25.5 | 0.8 | 1.52 | | - | + | - |
| White Perch | N/A | N/A | 1.3 | 2.43 | Leavy & Bonner 2009 | - | + | - |
| Rock Bass | N/A | N/A | 1.1 | 1.94 | Leavy & Bonner 2009 | - | + | - |
| Brown Bullhead | N/A | N/A | 2.3 | 4.25 | Leavy & Bonner 2009 | + | + | + |

| Species Name | Fork Length (in) | Acclimation Temperature (°C) | Swim Speed: Sustained (fps) | Swim Speed: Burst (fps) | Source | Entrainment Susceptibility: Northfield Pumping (3.6 fps)* | Station No. 1 (1.2 fps)* | Cabot Station (2.0 fps)* |
|---|---|---|---|---|---|---|---|---|
| Chain Pickerel | 11.22 | 13.5 | 1.0 | 1.83 | Peake, 2008 | - | + | - |
| Fallfish | N/A | N/A | 1.6 | 3.03 | Leavy & Bonner 2009 | - | + | - |
| Common Carp | N/A | N/A | 1.6 | 3.03 | Leavy & Bonner 2009 | - | + | - |
| Banded Killifish | 3 | N/A | 1.1 | 2.04 | Videler, 1993 | - | + | - |
| Channel Catfish | 13 | N/A | 3.1 | 5.72 | Videler, 1993 | + | + | + |
| Common Shiner | 5.5 | N/A | 1.6 | 2.98 | Videler, 1993 | - | + | - |
| Longnose Dace | 3 | N/A | 1.1 | 2.04 | Videler, 1993 | - | - | - |
| Mimic Shiner | 2.2 | N/A | 1.0 | 1.76 | Videler, 1993 | - | - | - |
| Northern Pike | 14 | N/A | 3.3 | 6.07 | Videler, 1993 | + | + | + |
| Rosyface Shiner | 2.4 | N/A | 1.0 | 1.81 | Videler, 1993 | - | + | - |
| Tessellated Darter | 2.1 | N/A | 0.9 | 1.70 | Videler, 1993 | - | + | - |

* Indicates velocity at trashracks.

**Table 4.1-3: Feasibility of impingement based on comparison of mean fish body width and trashrack spacing.**

*Minus sign indicates less susceptible to impingement and plus sign indicates a species is susceptible.*
*TL = total length; BW = body width*

| | Smith 1985 (mm) | | | Measured TL (mm) | | | Estimated BW (mm) | | | Impingement Feasibility | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Common Name** | **TL** | **BW** | **BW:TL** | **Mean** | **Min** | **Max** | **Mean** | **Min** | **Max** | **Northfield (152.4 mm)*** | **Station No. 1 (66.7 mm)*** | **Cabot Station (upper, 23.9 mm)*** | **Cabot Station (lower, 90.5 mm)*** |
| American Eel | 101.5 | 3.8 | 0.037 | 647.1 | 250 | 920 | 24.2 | 9.4 | 34.4 | - | - | + | - |
| American Shad | 122.0 | 16.4 | 0.134 | 88.4 | 67 | 110 | 11.9 | 9.0 | 14.8 | - | - | - | - |
| Banded Killifish | 120.1 | 14.2 | 0.118 | 47.5 | 30 | 67 | 5.6 | 3.5 | 7.9 | - | - | - | - |
| Black Crappie | 133.8 | 13.3 | 0.099 | 223.4 | 87 | 280 | 22.2 | 8.6 | 27.8 | - | - | - | - |
| Bluegill | 126.8 | 16.8 | 0.132 | 159.9 | 30 | 225 | 21.2 | 4.0 | 29.8 | - | - | - | - |
| Brown Bullhead | 123.8 | 20.6 | 0.166 | 340.0 | 325 | 355 | 56.6 | 54.1 | 59.1 | - | - | + | - |
| Chain Pickerel | 116.5 | 10.3 | 0.088 | 431.8 | 410 | 477 | 38.2 | 36.2 | 42.2 | - | - | + | - |
| Channel Catfish | 121.3 | 22.7 | 0.187 | 330.0 | 76 | 622 | 61.8 | 14.2 | 116.4 | - | - | + | - |
| Common Carp | 125.9 | 20.4 | 0.162 | 735.3 | 585 | 930 | 119.1 | 94.8 | 150.7 | - | + | + | + |
| Common Shiner | 124.1 | 13.3 | 0.107 | 37.5 | 30 | 45 | 4.0 | 3.2 | 4.8 | - | - | - | - |
| Fallfish | 124.7 | 16.1 | 0.129 | 139.7 | 56 | 430 | 18.0 | 7.2 | 55.5 | - | - | - | - |
| Golden Shiner | 123.3 | 13.0 | 0.105 | 98.0 | 57 | 212 | 10.3 | 6.0 | 22.4 | - | - | - | - |
| Largemouth Bass | 123.4 | 16.5 | 0.134 | 128.4 | 25 | 410 | 17.2 | 3.3 | 54.8 | - | - | - | - |
| Longnose Dace | 123.3 | 17.2 | 0.139 | 57.0 | 57 | 57 | 8.0 | 8.0 | 8.0 | - | - | - | - |
| Mimic Shiner | 125.5 | 12.7 | 0.101 | 58.4 | 53 | 64 | 5.9 | 5.4 | 6.5 | - | - | - | - |
| Northern Pike | 118.6 | 9.2 | 0.078 | 355.6 | 197 | 780 | 27.6 | 15.3 | 60.5 | - | - | + | - |
| Pumpkinseed | 129.8 | 16.1 | 0.124 | 152.9 | 75 | 205 | 19.0 | 9.3 | 25.4 | - | - | - | - |
| Rock Bass | 124.6 | 19.4 | 0.156 | 142.3 | 32 | 257 | 22.2 | 5.0 | 40.0 | - | - | - | - |
| Rosyface Shiner | 115.3 | 11.0 | 0.095 | 61.0 | 61 | 61 | 5.8 | 5.8 | 5.8 | - | - | - | - |
| Smallmouth Bass | 123.6 | 15.8 | 0.128 | 152.2 | 29 | 470 | 19.5 | 3.7 | 60.1 | - | - | - | - |
| Spottail Shiner | 128.4 | 18.0 | 0.140 | 92.0 | 45 | 165 | 12.9 | 6.3 | 23.1 | - | - | - | - |
| Tessellated Darter | 121.6 | 16.9 | 0.139 | 53.2 | 19 | 85 | 7.4 | 2.6 | 11.8 | - | - | - | - |
| Walleye | 120.2 | 15.0 | 0.125 | 261.5 | 146 | 530 | 32.6 | 18.2 | 66.1 | - | - | + | - |
| White Perch | 123.5 | 17.6 | 0.143 | 109.0 | 109 | 109 | 15.5 | 15.5 | 15.5 | - | - | - | - |
| White Sucker | 121.9 | 17.8 | 0.146 | 117.8 | 35 | 530 | 17.2 | 5.1 | 77.4 | - | - | - | - |
| Yellow Perch | 123.4 | 14.1 | 0.114 | 143.6 | 15 | 360 | 16.4 | 1.7 | 41.1 | - | - | - | - |

* Indicates trashrack spacing.

**Table 4.1-4: Comparison of physical and hydraulic characteristics of hydroelectric dams equipped with Francis type turbines.**

| Station | Designed Turbine Flow (cfs) | Runner Speed (rpm) | Head (ft) | Runner Diameter (in) | Peripheral Runner Velocity (fps) |
|---|---|---|---|---|---|
| Shasta, WA | 3,200 | 138.5 | 380 | 184 | 111 |
| Shasta, WA | 3,200 | 138.5 | 380 | 184 | 111 |
| Cushman Plant 2, WA | 800 | 300 | 450 | 83 | 109 |
| Cushman Plant 2, WA (1960) | 800 | 300 | 450 | 83 | 109 |
| Schagticoke, NY | 410 | 300 | 153 | 80 | 105 |
| Colton, NY | 497 | 360 | 265 | 59 | 93 |
| Ruskin, BC | 4,000 | 120 | 130 | 149 | 78 |
| Caldron Falls, WI ( Unit 1) | N/A | 226 | 80 | 72 | 71 |
| Holtwood, PA | 3,500 | 95 | 55 | 164 | 68 |
| E. J. West, NY | 2,700 | 113 | 63 | 131 | 65 |
| Holtwood, PA (U10/single runner) | 3,500 | 94.7 | 62 | 149.5 | 62 |
| Pricket, MI | 326 | 257 | 54 | 53.5 | 60 |
| Hardy, MI (Unit 2) | 510 | 163.6 | 100.2 | 83.75 | 60 |
| Seton Creek, BC | 4,500 | 120 | 150 | 114 | 60 |
| White Rapids, WI | 1,540 | 100 | 29 | 134 | 58 |
| Sandstone Rapids, WI | N/A | 150 | 42 | 87 | 57 |
| Grand Rapids, WI (Unit 4) | 926 | 180 | 28 | 72 | 57 |
| **Cabot** | **2,288** | **97.3** | **60** | **129** | **55** |
| Higley, NY | 675 | 257 | 46 | 48 | 54 |
| Vernon, VT/NH | 1,834 | 74 | 34 | 156 | 50 |
| Holtwood, PA (U3/double runner) | 3,500 | 102.8 | 62 | 112 | 50 |
| **Station No 1 Unit 3** | **500** | **200** | **43.7** | **55** | **48** |
| **Station No 1 Unit 1** | **560** | **200** | **43.7** | **54** | **47** |
| Potato Rapids, WI (Unit 2) | 440 | 135 | 17 | 80 | 47 |
| Potato Rapids, WI (Unit 1) | 500 | 123 | 17 | 84 | 45 |
| Luray, VA | 369 | 164 | 18 | 62.75 | 45 |
| Stevens Creek, SC | 1,000 | 75 | 28 | 135 | 44 |
| **Station No 1 Unit 2** | **140** | **257** | **43.7** | **39** | **44** |
| Minetto, NY | 1,500 | 72 | 17 | 139 | 44 |
| Alcona, MI | 1400 | 90 | 43 | 100 | 39 |
| Alcona, MI | 615 | 90 | 43 | 100 | 39 |
| Rogers, MI (units 1 & 2) | 383 | 150 | 39 | 60 | 39 |
| Grand Rapids, WI (Unit 2) | 645 | 150 | 28 | 58 | 38 |
| **Station No 1 Unit 5** | **570** | **200** | **43.7** | **42** | **37** |
| Five Channels, MI | 1,100 | 150 | 36 | 55 | 36 |
| Five Channels, MI | 675 | 150 | 36 | 55 | 36 |
| Peshtigo, WI (Unit 4) | 460 | 100 | 13 | 80 | 35 |
| **Station No 1 Unit 4** | **490** | **200** | **43.7** | **39** | **34** |
| Grand Rapids, WI (U 1,2,4 comb) | 645 | 90 | 28 | 58 | 23 |

**Table 4.1-5: Physical and hydraulic characteristics of hydroelectric dams equipped with Francis turbines similar to Cabot Station.**

| Station | Designed Turbine Flow (cfs) | Runner Speed (rpm) | Head (ft) | Runner Diameter (in) | Peripheral velocity (fps) |
|---|---|---|---|---|---|
| Caldron Falls, WI (Unit 1) | NA | 226 | 80 | 72 | 71 |
| E. J. West, NY | 2,700 | 113 | 63 | 131 | 65 |
| Five Channels, MI | 1,100 | 150 | 36 | 55 | 36 |
| Holtwood, PA | 3,500 | 95 | 55 | 164 | 68 |
| Holtwood, PA (U3/double runner) | 3,500 | 102.8 | 62 | 112 | 50 |
| Holtwood, PA(U10/single runner) | 3,500 | 94.7 | 62 | 149.5 | 62 |
| Minetto, NY | 1,500 | 72 | 17 | 139 | 44 |
| Sandstone Rapids, WI | NA | 150 | 42 | 87 | 57 |
| Stevens Creek, SC | 1,000 | 75 | 28 | 135 | 44 |
| Vernon, VT/NH | 1,834 | 74 | 34 | 156 | 50 |
| White Rapids, WI | 1,540 | 100 | 29 | 134 | 58 |
| **MEAN** | **2,242** | **114** | **46** | **121** | **55** |
| **Cabot** | **2,288** | **97.3** | **60** | **129** | **55** |

**Table 4.1-6: Physical and hydraulic characteristics of hydroelectric dams equipped with Francis turbines similar to Station No. 1.**

| Station | Designed Turbine Flow (cfs) | Runner Speed (rpm) | Head (ft) | Runner Diameter (in) | Peripheral velocity (fps) |
|---|---|---|---|---|---|
| Alcona, MI | 615 | 90 | 43 | 100 | 39 |
| Five Channels, MI | 675 | 150 | 36 | 55 | 36 |
| Five Channels, MI | 1,100 | 150 | 36 | 55 | 36 |
| Grand Rapids, WI (U 1,2,4 comb) | 645 | 90 | 28 | 58 | 23 |
| Grand Rapids, WI (Unit 2) | 645 | 150 | 28 | 58 | 38 |
| Grand Rapids, WI (Unit 4) | 926 | 180 | 28 | 72 | 57 |
| Hardy, MI (Unit 2) | 510 | 163.6 | 100.2 | 83.75 | 60 |
| Higley, NY | 675 | 257 | 46 | 48 | 54 |
| Luray, VA | 369 | 164 | 18 | 62.75 | 45 |
| Peshtigo, WI (Unit 4) | 460 | 100 | 13 | 80 | 35 |
| Potato Rapids, WI (Unit 1) | 500 | 123 | 17 | 84 | 45 |
| Potato Rapids, WI (Unit 2) | 440 | 135 | 17 | 80 | 47 |
| Pricket, MI | 326 | 257 | 54 | 53.5 | 60 |
| Rogers, MI (Units 1 & 2) | 383 | 150 | 39 | 60 | 39 |
| Stevens Creek, SC | 1,000 | 75 | 28 | 135 | 44 |
| **MEAN** | **618** | **149** | **35** | **70** | **44** |
| **Station No 1 Unit 1** | **560** | **200** | **43.7** | **54** | **47** |
| **Station No 1 Unit 2** | **140** | **257** | **43.7** | **39** | **44** |
| **Station No 1 Unit 3** | **500** | **200** | **43.7** | **55** | **48** |
| **Station No 1 Unit 4** | **490** | **200** | **43.7** | **39** | **34** |
| **Station No 1 Unit 5** | **570** | **200** | **43.7** | **42** | **37** |

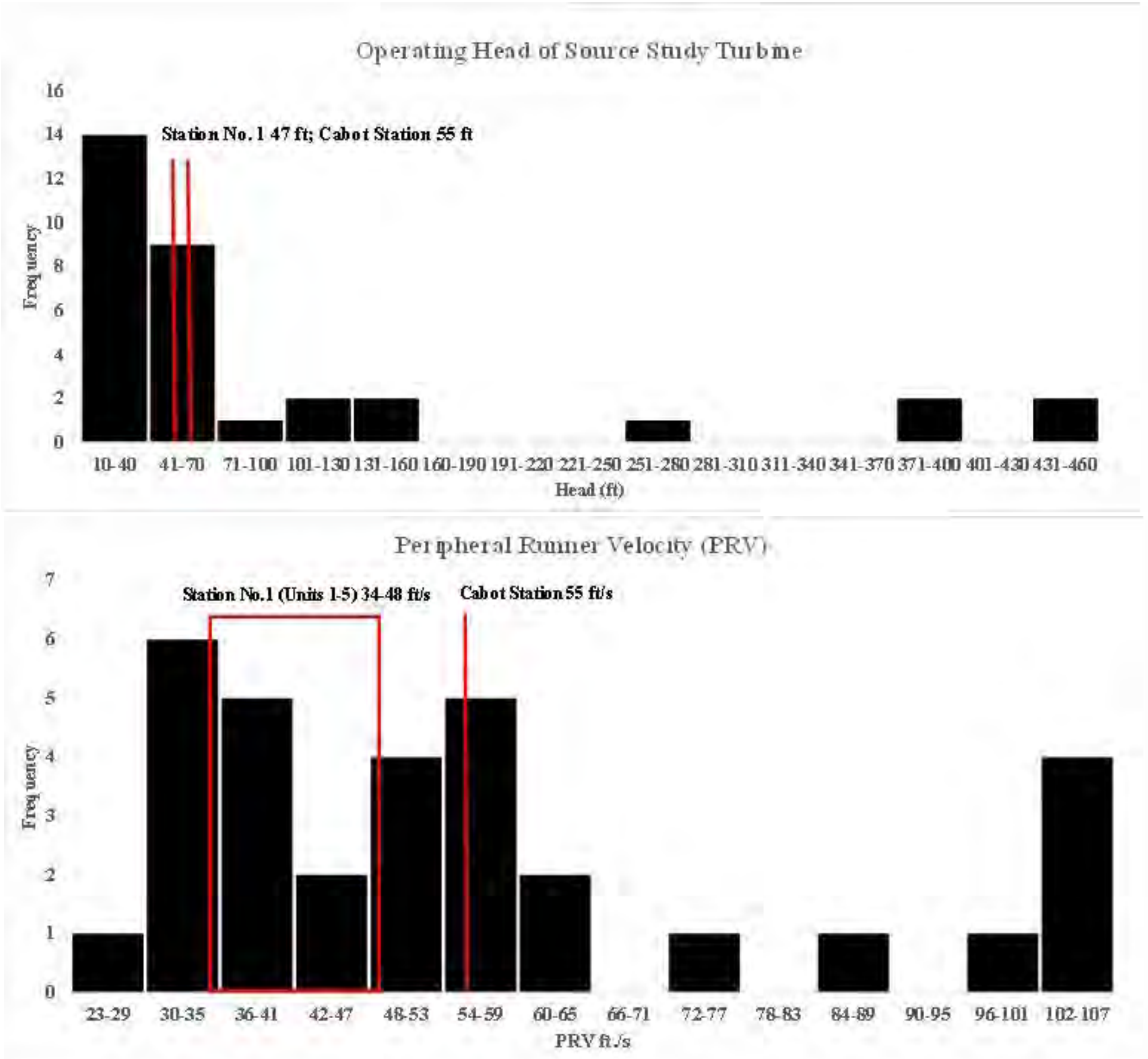



**Figure 4.1-1: Operating head and peripheral runner velocity of 33 cases.**

**Table 4.1-7: Estimated Turbine Survival at Cabot Station**

| Common Name | Scientific Name | Survival Group | % Survival |
|---|---|---|---|
| Banded Killifish* | *Fundulus diaphanus* | Clupeid | 89 |
| Black Crappie | *Pomoxis nigromaculatus* | Centrarchid | 86 |
| Bluegill | *Lepomis macrochirus* | Centrarchid | 86 |
| Brown Bullhead | *Ameiurus nebulosus* | Fusiform | 65 |
| Chain Pickerel | *Esox niger* | Northern Pike | 91 |
| Channel Catfish | *Ictalurus punctatus* | Fusiform | 65 |
| Common Carp | *Cyprinus carpio* | Cyprinid | 71 |
| Common Shiner | *Luxilus cornutus* | Cyprinid | 71 |
| Fallfish | *Semotilus corporalis* | Cyprinid | 71 |
| Golden Shiner | *Notemigonus crysoleucas* | Cyprinid | 71 |
| Largemouth Bass | *Micropterus salmoides* | Centrarchid | 86 |
| Longnose Dace | *Rhinichthys cataractae* | Cyprinid | 71 |
| Mimic Shiner | *Notropis volucellus* | Cyprinid | 71 |
| Northern Pike | *Esox lucius* | Northern Pike | 91 |
| Pumpkinseed | *Lepomis gibbosus* | Centrarchid | 86 |
| Rock Bass | *Ambloplites rupestris* | Centrarchid | 86 |
| Rosyface Shiner | *Notropis rubellus* | Cyprinid | 71 |
| Smallmouth Bass | *Micropterus dolomieui* | Centrarchid | 86 |
| Spottail Shiner | *Notropis hudsonius* | Cyprinid | 71 |
| Tessellated Darter | *Etheostoma olmstedi* | Percid | 74 |
| Walleye | *Sander vitreus* | Percid | 74 |
| White Perch | *Morone americana* | Centrarchid | 86 |
| White Sucker | *Catostomus commersonii* | White Sucker | 88 |
| Yellow Perch | *Perca flavescens* | Percid | 74 |

**Used clupeid group as a surrogate for this species.*

**Table 4.1-8: Estimated Turbine Survival at Station No. 1**

| Common Name | Scientific Name | Survival Group | % Survival |
|---|---|---|---|
| Banded Killifish* | *Fundulus diaphanus* | Clupeid | 95 |
| Black Crappie | *Pomoxis nigromaculatus* | Centrarchid | 86 |
| Bluegill | *Lepomis macrochirus* | Centrarchid | 86 |
| Brown Bullhead | *Ameiurus nebulosus* | Fusiform | 73 |
| Chain Pickerel | *Esox niger* | Northern Pike | 84 |
| Channel Catfish | *Ictalurus punctatus* | Fusiform | 73 |
| Common Carp | *Cyprinus carpio* | Cyprinid | 77 |
| Common Shiner | *Luxilus cornutus* | Cyprinid | 77 |
| Fallfish | *Semotilus corporalis* | Cyprinid | 77 |
| Golden Shiner | *Notemigonus crysoleucas* | Cyprinid | 77 |
| Largemouth Bass | *Micropterus salmoides* | Centrarchid | 86 |
| Longnose Dace | *Rhinichthys cataractae* | Cyprinid | 77 |
| Mimic Shiner | *Notropis volucellus* | Cyprinid | 77 |
| Northern Pike | *Esox lucius* | Northern Pike | 84 |
| Pumpkinseed | *Lepomis gibbosus* | Centrarchid | 86 |
| Rock Bass | *Ambloplites rupestris* | Centrarchid | 86 |
| Rosyface Shiner | *Notropis rubellus* | Cyprinid | 77 |
| Smallmouth Bass | *Micropterus dolomieui* | Centrarchid | 86 |
| Spottail Shiner | *Notropis hudsonius* | Cyprinid | 77 |
| Tessellated Darter | *Etheostoma olmstedi* | Percid | 76 |
| Walleye | *Sander vitreus* | Percid | 76 |
| White Perch | *Morone americana* | Centrarchid | 86 |
| White Sucker | *Catostomus commersonii* | White Sucker | 82 |
| Yellow Perch | *Perca flavescens* | Percid | 76 |

**Used clupeid group as a surrogate for this species.*

### *4.1.1 Percidae*

#### 4.1.1.1 Yellow Perch

*Habitat and Biology* - Yellow Perch are commonly found in or near vegetation in or just offshore of the littoral zone. They tend to concentrate near shore during the spring to broadcast spawn over woody debris or vegetation. At other times, adults in rivers gravitate to nearby deeper water such as pools and deep runs. However, they do not typically undergo extensive riverwide movements. Although they may be found within cover along the littoral zone of the canal and Connecticut River, they are unlikely to be attracted to the immediate vicinity of project intakes as these areas lack shoreline cover and vegetation.

*Likelihood of Entrainment* – Yellow Perch were the second most common species collected in the fish assemblage study at the sampling station in closest proximity to the Northfield pumped storage intake, and thus are considered moderately likely to encounter the Northfield intake. However, entrainment of large numbers of Yellow Perch is unlikely at the canal intakes, due to the lack of preferred habitat in the vicinity of intakes, along with the tendency to perform localized lateral, rather than longitudinal riverine movements. This reduces the likelihood of Yellow Perch encountering the project intakes as local movements are from deeper channels to and from shoreline rather than upstream and downstream; therefore, they would not be expected to attempt to migrate past the intakes, or attempt to move downstream.

*Swim Speed* - The sustained swimming speed for Yellow Perch is lower than the intake velocities at Northfield and Cabot Station but not Station No. 1 (Table 4.1-2). Yellow Perch are potentially relatively vulnerable to involuntary entrainment both at the Northfield Mountain and Cabot Station intakes.

*Likelihood of Impingement* – The estimated body width of Yellow Perch (Table 4.1-3) is less than the trashrack spacing at Northfield, Station No. 1, and the lower portion of the Cabot Station intakes, suggesting impingement of even the larger Yellow Perch is highly unlikely. Due to the rather narrow spacing of the upper portion of the Cabot Station trashracks, it is feasible that Yellow Perch could be impinged on the upper 11-ft section of the intake. However, their habitat preference and predominantly lateral riverine movements minimizes interaction with the Cabot intake.

*Turbine Survival* – Yellow Perch are relatively small, and juveniles and YOY (less than 6 inches TL) comprise most of the individuals potentially subject to entrainment. The mean survival rate from studies at source sites similar to Cabot indicate an estimated survival rate of 74%. The mean survival rate from studies at sites similar to Station No. 1 indicate an estimated survival rate of 76%.

*Potential Impact to Yellow Perch* - Entrainment and impingement losses are expected to affect a few individuals. Adults have high fecundity, and most potential entrainment of the species is expected to be limited to localized YOY and juveniles dwelling in the lower canal. These lifestages experience very high natural mortality rates that eclipse turbine mortality.

#### 4.1.1.2 Walleye

*Habitat and Biology* – Adult and juvenile Walleye are found in the main channel of turbid lakes and rivers, and in non-turbid water bodies such as the Connecticut River, tend to be photophobic, living in deep areas during the day and at varied depths during the night. They prefer firm bottom substrates with gravel or bedrock and may move throughout the water column in search of prey; however, they prefer shoals and drop-offs and are unlikely to be abundant in the vicinity of any of the intakes. None were detected in the fish assemblage study at the sampling station in closest proximity to the NMPS Project intake, and thus are considered unlikely to encounter the intake. During spawning in early spring, Walleye may undergo migrations in search of spawning grounds in shallow rapids, riffles, including tailwater of dams.

*Likelihood of Entrainment* – Walleye may undergo longitudinal pre-spawning migration in the spring that theoretically could pass near intake areas. However, most Walleye in the TFI would be expected to move upstream to fluvial habitat in tributaries and the in the upper riverine-like portion of the TFI rather than downstream to the power canal where the Cabot and Station No. 1 intakes are located. Adults would likely be able to escape intake flows.

*Swim Speed* – Sustained swimming speed for adults exceeds the intake velocity at Station No. 1 but not at Cabot or Northfield (Table 4.1-2). This indicates that adults can readily escape the entrance flows at Station No. 1 but may not be able to escape the Northfield or Cabot Station intakes.

*Likelihood of Impingement* – The estimated body widths of Walleye (Table 4.1-3) in the TFI are less than the trashrack spacing at Northfield, Station No. 1, and the lower portion of the Cabot Station intakes, suggesting impingement of the fishes observed in the TFI is unlikely. Due to the rather narrow spacing of the upper portion of the Cabot Station trashracks, it is feasible that Walleye could be impinged on the upper 11-ft section of the intake.

*Turbine Survival* –The mean survival rate from studies at source sites similar to Cabot indicate an estimated survival rate of 74%. The mean survival rate from studies at sites similar to Station No. 1 indicate an estimated survival rate of 76%. Due to the wide range in length between juveniles and adults, survival may vary by size class; juvenile and YOY may be less sensitive than adults, as they may avoid collisions with runners, gates, etc. more frequently than adults.

*Potential Impact to Walleye* –Impacts are predicted to be low to moderate. Relatively few adults would be expected to enter the intake areas in search of spawning habitat. Impingement does not appear feasible at the Northfield Mountain Project, although there is potential for entrainment should fish enter the intake's hydraulic zone of influence. Adults in the power canal should be able to avoid involuntary entrainment at Station No. 1; adults may or may not be able to escape intake velocity at Cabot Station, or may attempt to pass in search of spawning habitat. Adult fish lost due to entrainment mortality would not contribute to spawning recruitment. Juveniles may be more susceptible to entrainment due to intake velocities, but are likely to experience higher turbine survival rates.

#### 4.1.1.3 Tessellated Darter

*Habitat and Biology* – Tessellated darter is small, benthic species found in the main channel of streams and rivers. They prefer fluvial habitat with firm substrates ranging from pebble to cobble. They make extremely localized foraging movements and do not undergo wide-scale migrations but my make lateral movements for spawning.

*Likelihood of Entrainment* – Likelihood is low; this species does not undergo obligatory migration that would bring it in contact with the Cabot or Station No. 1 intake areas. None were detected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus are considered unlikely to encounter the Northfield intake. Although lateral movement into the Northfield intake/tailrace channel from the main channel is possible, susceptibility to entrainment would only occur for a few hours during the night when pumping operations typically occur.

*Swim Speed* – Sustained swimming speed for Tessellated Darter does not exceeds the intake velocity at Station No., Cabot, or Northfield (Table 4.1-2).

*Likelihood of Impingement* – The estimated body widths of Tessellated Darter (Table 4.1-3) in the TFI are less than the trashrack spacing at all of the project intakes, suggesting impingement is unlikely, even for the largest specimen observed during the field efforts for the Fish Assemblage Assessment (Study No. 3.3.11).

*Turbine Survival* – There are no species-specific turbine survival data for this species; for purposes of this analysis it was included in with other members of the percid family. The mean survival rate from studies at source sites similar to Cabot indicate an estimated survival rate of 74%. The mean survival rate from studies at sites similar to Station No. 1 indicate an estimated survival rate of 76%. Since this dataset includes much larger fish (such as adult Walleye) that would likely have lower survival rates, these estimates are likely conservative for tessellated darter. A smaller species more likely to avoid collisions with runners, gates, etc.

*Potential Impact to Tessellated Darter* –Impacts are predicted to be low. Relatively few fish would be expected to encounter the intakes and their numbers can double in a relatively short time (Table 4.1-1).

### *4.1.2 Centrarchidae*

#### 4.1.2.1 Pumpkinseed

*Habitat and Biology* – Pumpkinseed prefer habitat such as littoral shallow areas with dense vegetative or woody cover. The Northfield Mountain intake/tailrace lacks vegetation and cover; therefore Pumpkinseed are unlikely to interact with the Northfield intake. Although they may be found within cover along the littoral zone of the Turners Falls Power Canal, they are less likely be abundant immediately in front of the Cabot or Station No. 1 intakes as these areas are deeper and lack sufficient cover. This species makes localized foraging movements and does not undergo lengthy migrations; therefore, it is not likely to attempt to move downstream past the Turners Falls intakes.

*Likelihood of Entrainment* – Likelihood is low as this is a sedentary species attracted to dense cover that is absent from intake areas. Very few were detected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus are considered unlikely to encounter the Northfield intake.

*Swim Speed* - Pumpkinseed have a sustained swimming speed that is less than intake velocities at the Northfield Mountain and Cabot Station intakes, but greater than the intake velocity at Station No. 1 (Table 4.1-2).

*Likelihood of Impingement* – The estimated body widths of most Pumpkinseed (Table 4.1-3) in the TFI are less than the trashrack spacing at all of the project intakes, suggesting impingement is unlikely for the majority of individuals observed during the field efforts for the Fish Assemblage Assessment (Study No. 3.3.11). Larger individuals (greater than 193.5 mm) could potentially be impinged on the upper portion of the Cabot Station trashracks; however, individuals are not expected to be in the vicinity of the intake due to lack of preferred habitat.

*Turbine Survival* –The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 86%. The mean survival rate from studies at sites similar to Station No. 1 also indicate a turbine survival rate of 86%. The small size of both adults and juveniles suggest that blade strike probability is expected to be low.

*Potential Impact to Pumpkinseed* – Entrainment and impingement should have minimal impacts as losses would be to a small number of individuals straying from other areas with preferred habitat. The species has relatively high fecundity.

#### 4.1.2.2 Bluegill

*Habitat and Biology*- Bluegill primarily inhabit low velocity main channels of rivers, and in lakes, ponds and reservoirs, but concentrate around weed beds and dense aquatic cover; the species avoids fast moving water and areas lacking object cover. It is therefore unlikely they would be abundant at any of the intakes due to the lack of suitable habitat. The species is highly sedentary, and most local movements are associated with individual short-range diurnal foraging rather than longitudinal migration. Thus, they are not likely to migrate past intakes or attempt to pass downstream of Turners Falls. Adult males are sedentary and territorial during spawning in the spring. As a result, spawning males would be less mobile and at reduced risk to entrainment at that time.

*Likelihood of Entrainment* – Likelihood is low as this is a sedentary species attracted to dense cover that is absent from intake areas. Few were detected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus are considered unlikely to encounter the Northfield intake.

*Swim Speed* – Bluegill are relatively small and have a sustained swimming speed that is lower than intake velocities at the Northfield Mountain and Cabot Station intakes, but greater than Station No. 1 (Table 4.1-2).

*Likelihood of Impingement* – The mean estimated body width of Bluegill (Table 4.1-3) collected in the TFI is less than the trashrack spacing at all of the project intakes, suggesting impingement is unlikely for the majority of individuals observed during the field efforts for the Fish Assemblage Assessment (Study No. 3.3.11). Larger individuals (greater than 181 mm) could potentially be impinged on the upper portion of the Cabot Station trashracks; however, individuals are not expected to be in the vicinity of the intake due to lack of preferred habitat.

*Turbine Survival* - The small size of both adults and juvenile suggest that blade strike probability is expected to be low. The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 86%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 86%.

*Potential Impact to Bluegill* – Entrainment and impingement are expected to have minimal impacts as loss would be to a small number of individuals straying from other areas with more ideal habitat. The species has very high fecundity and most potential entrainment of the species would be expected to be among YOY and juveniles. These lifestages experience very high natural mortality that would eclipse turbine losses.

#### 4.1.2.3 Smallmouth Bass

*Habitat and Biology* – Smallmouth Bass prefer cover-rich rocky substrate, riverine pools, low to moderate gradient streams and cool reservoirs. Cover lacks at the Northfield Mountain intake/tailrace channel and the majority of the Turners Falls Power Canal is comprised of muck, sand, silt and lacks cobble boulder and extensive object cover. Smallmouth Bass are therefore unlikely to be abundant in the vicinity of the project intakes. The species is highly sedentary, and most local movements are associated with individual diurnal foraging and territoriality rather than longitudinal. Thus, they are not likely to migrate or attempt to pass downstream past the Turners Falls Project in large numbers. During the spring spawning season adult males are sedentary, territorial, and guard nests in shallow low velocity areas surrounded by object cover, and as a result would be less mobile and not at risk to entrainment at that time.

*Likelihood of Entrainment* – Smallmouth Bass were the most common species collected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus are considered potentially likely to encounter the Northfield intake. Suitable habitat in the immediate vicinity of intakes lacks significant amounts of cover and the species does not undergo extensive longitudinal excursions, thus entrainment risk is considered low.

*Swim Speed* - Smallmouth Bass swimming speeds vary in accordance with body length (juvenile vs. adult life stages) and water temperature. As temperature and length increase so does the swimming speed (Table 4.1-2). Adults (fish approximately 12 inches or longer) exhibit sustained swimming speeds that exceed the intake velocities at all of the project intakes, suggesting very low potential for entrainment of larger individuals. Smaller (juvenile and YOY) size classes are more susceptible to entrainment because of lower swimming speed, although at higher temperatures, these smaller fish would likely be able to escape the zone of influence at Station No. 1.

*Likelihood of Impingement* – The mean estimated body width of Smallmouth Bass (Table 4.1-3) collected in the TFI is less than the trashrack spacing at all of the project intakes, suggesting impingement is unlikely for the majority of individuals observed during the field efforts for the Fish Assemblage Assessment (Study No. 3.3.11). Larger individuals (greater than 187 mm) could potentially be impinged on the upper portion of the Cabot Station trashracks; however, individuals are not expected to be in the vicinity of the intake due to lack of preferred habitat.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 86%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 86%. Due to the wide range in length between juveniles and adults, survival may vary by size class; juvenile and YOY may be less sensitive than adults, as they may avoid collisions with runners, gates, etc. more frequently than adults.

*Potential Impact to Smallmouth Bass* - Entrainment and impingement should have minimal impacts to Smallmouth Bass as it is expected that impacts would be restricted to a few juvenile and YOY individuals. The species has relatively high fecundity and most potential entrainment of the species would be expected to be among lifestages that experience very high natural mortality that would eclipse turbine losses. The fish assemblage study captured adult, juvenile and YOY lifestages of this species, indicating that these fish are abundant under existing conditions.

#### 4.1.2.4 Largemouth Bass

*Habitat and Biology* - Largemouth Bass prefer vegetated lakes, ponds, swamps, and backwaters as well as pool habitat in slow moving creeks and rivers with dense object cover such as weeds, boulders and submerged logs. The species generally avoids fast moving water and areas lacking object cover; therefore they would not be expected to occur in the Northfield Mountain intake/tailrace channel. Largemouth Bass prefer mud or sand substrates. The species is highly sedentary, and most local movements are associated with individual diurnal foraging and territoriality rather than longitudinal. Largemouth Bass may inhabit the vegetated fringe areas of the power canal, but such habitat does not exist in the vicinity of project intakes. Further, Largemouth Bass are not likely to migrate past intakes or attempt to pass downstream past the Turners Falls Project. Spawning adult males are sedentary, territorial, and guard nests in shallow low velocity areas within object cover and as a result, would be less mobile and at reduced risk to entrainment at that time.

*Likelihood of Entrainment* – No Largemouth Bass were detected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus this species is considered unlikely to encounter the Northfield intake. Habitat in the immediate vicinity of intakes lacks suitable cover, and the species does not undergo extensive longitudinal excursions, thus entrainment risk is considered low.

*Swim Speed* – Largemouth Bass exhibit swim speeds that vary with temperature (Table 4.1-2). In general, when water temperatures are above 20°C, the sustained swimming speed is expected to be greater than the intake velocity at Station No. 1; however, at lower temperatures these fish will not be able to escape the intake flow field at Station No. 1, however during such cooler periods bass become torpid and less inclined to move; therefore, the probability of such fish encountering the velocity fields in front of intakes is low. Regardless of size or water temperature, it appears that Largemouth Bass would not be able to escape the influence of the intakes at Northfield Mountain and Cabot Station, although they are not expected to be in the immediate area of these two intakes due to the lack of preferred habitat.

*Likelihood of Impingement* – The mean estimated body width of Largemouth Bass (Table 4.1-3) collected in the TFI is less than the trashrack spacing at all of the project intakes, suggesting impingement is unlikely for the majority of individuals dwelling in the TFI. Larger individuals (greater than 179 mm) could potentially be impinged on the upper portion of the Cabot Station trashracks; however, individuals are not expected to be in the vicinity of the intake due to lack of preferred habitat.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 86%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 86%. Due to the wide range in length between juveniles and adults, survival may vary by size class; juvenile and YOY may be less sensitive than adults, as they may avoid collisions with runners, gates, etc. more frequently than adults.

*Potential Impact to Largemouth Bass*– Entrainment and impingement should have minimal impacts to Largemouth Bass as loss would be to a small number of individuals straying from other areas with more suitable habitat. The species has relatively high fecundity and most potential entrainment of the species would be expected to be among YOY and juveniles. These lifestages experience very high natural mortality that would eclipse turbine losses.

#### 4.1.2.5 Black Crappie

*Habitat and Biology* – Black Crappie inhabit lakes, ponds and backwaters of pools and streams. They are usually found among vegetation over mud or sand, most commonly in clear water. These habitat preferences suggest Black Crappie could occur in proximity to Cabot Station, but would preclude its presence in the vicinity of the Northfield Mountain intake.

*Likelihood of Entrainment* – The likelihood of entrainment is low at Northfield Mountain due to the lack of preferred habitat in the intake/tailrace channel. Furthermore, this species was not detected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus it is considered unlikely to encounter the Northfield intake. Although Black Crappie may find suitable habitat in the Turners Falls Power Canal, the lack of vegetation in the immediate vicinity of the Station No. 1 and Cabot Station intakes suggests a low likelihood of entrainment.

*Swim Speed* – The Black Crappie was tested at a number of body lengths and acclimation temperatures (Table 4.1-2). The sustained swim speed ranged from 0.5 to 1.1 fps, below all intake velocities.

*Likelihood of Impingement* – The mean estimated body width of Black Crappie (Table 4.1-3) collected in the TFI is less than the trashrack spacing at all of the project intakes, suggesting impingement is unlikely for the majority of individuals dwelling in the TFI. Larger individuals (greater than 240 mm) could potentially be impinged on the upper portion of the Cabot Station trashracks; however, individuals are not expected to be in the vicinity of the intake due to lack of preferred habitat.

*Turbine Survival* - The small size of both adults and juvenile suggest that turbine mortality is expected to be low. The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 86%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 86%.

*Potential Impact to Black Crappie* - Entrainment and impingement should have minimal impacts as loss would be limited to a small number of individuals straying from other areas with better habitat. The species has moderate fecundity. All lifestages experience very high natural mortality that would eclipse turbine losses.

#### 4.1.2.6 Rock Bass

*Habitat and Biology* – The Rock Bass inhabits vegetated stream margins and pools of creeks and small to medium rivers, and the rocky and vegetated margins of lakes. The habitat conditions in front of the Northfield Mountain intake are rocky, but not highly vegetated. While ideal habitat may be present in the lower portion of the Turners Falls Power Canal, habitat in the immediate vicinity of the Cabot Station and Station No. 1 intakes is not expected to attract Rock Bass.

*Likelihood of entrainment* – Rock Bass were the third most common species collected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus are considered moderately likely to encounter the Northfield intake. However, habitat suitability in immediate proximity to all intakes is marginal.

*Swim Speed* – Rock Bass have a low sustained swim speed (1.0 fps), which is less than all intake velocities.

*Likelihood of Impingement* – The mean estimated body width of Rock Bass (Table 4.1-3) collected in the TFI is less than the trashrack spacing at all of the project intakes, suggesting impingement is unlikely for the majority of individuals dwelling in the TFI. Larger individuals (greater than 153 mm) could potentially be impinged on the upper portion of the Cabot Station trashracks; however, individuals are not expected to be in the vicinity of the intake due to lack of preferred habitat.

*Turbine Survival* - The small size of both adults and juvenile suggest that blade strike probability is expected to be low. The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of_86%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 86%.

*Potential Impact to Rock Bass* - Entrainment and impingement should have minimal impacts as loss would be limited to a small number of individuals straying from other areas with better habitat. The species has moderate fecundity. All lifestages experience very high natural mortality that would eclipse turbine losses.

### *4.1.3 Cyprinidae*

#### 4.1.3.1 Spottail Shiner, Common Shiner, Mimic Shiner, Rosyface Shiner, Longnose Dace

*Habitat and Biology* – Shiner species are similar, small, soft-bodied benthic residents of large rivers. Preferred substrate consists of sand or gravel; thus, it is unlikely that they would be abundant in the immediate vicinity of the project intakes. Dace generally prefer lotic conditions with clean fines and gravel substrates. Their local movements are lateral; thus, they are not likely to migrate past the intakes.

*Likelihood of Entrainment* – Likelihood is low as these species are not attracted to habitat characteristic of the intake areas. Shiners may occupy weeded fringes in the lower portion of the Turners Falls Canal but are unlikely to encounter the intake in substantial numbers. Small cyprinid species were uncommon in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus considered unlikely to encounter the Northfield intake.

*Swim Speed* – The sustained swim speeds for these small species are less than the intake velocities for Northfield Mountain and Cabot Station; however, Spottail Shiner and Common Shiner are likely able to escape the hydraulic zone of influence at Station No. 1 (Table 4.1-2).

*Likelihood of Impingement* – The estimated body widths of shiner and dace species observed in the TFI are less than the trashrack spacing at all of the project intakes (Table 4.1-3), suggesting impingement is unlikely for individuals dwelling in the TFI.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 71% for cyprinids overall. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 77%.

*Potential Impact to Cyprinid species* – Entrainment is expected to have minimal impacts as loss would be limited to a small number of individuals straying from other areas with preferred habitat. These species generally have high fecundity, and life stages experience high natural mortality that would eclipse turbine losses. This species group was among the most numerically dominant in both the recent and historic fish assemblage studies, indicating that these fish are abundant under existing conditions.

#### 4.1.3.2 Common Carp

*Habitat and Biology* - Common Carp are tolerant of a wide variety of conditions but generally prefer large water bodies with slow flowing or standing water and soft sediments. These habitat conditions are found in the vicinity of the Northfield Mountain intake/tailrace, as well as within the Turners Falls Power Canal. Their local movements are lateral. Their affinity for slow moving water with soft sediments could place them in local proximity to the Cabot Station intakes.

*Likelihood of Entrainment* – The likelihood of entrainment for adults is low as their large size would preclude passage through the trashracks. However, small juveniles would be susceptible to entrainment as they prefer habitat found within the general vicinity of Northfield Mountain intake/tailrace and Cabot Station. A single adult of this species was detected in the fish assemblage study at the sampling station in closest proximity to the Northfield pumped storage intake, and thus it is considered unlikely to encounter the Northfield intake.

*Swim Speed* – The Common Carp sustained swim speed suggests that this species will be able to escape the intake velocities at Station No. 1, but likely not at Northfield Mountain or Cabot Station intakes.

*Likelihood of Impingement* – The estimated body widths of Common Carp observed in the TFI are greater than the trashrack spacing at the Cabot Station and Station No. 1 intakes (Table 4.1-3), suggesting impingement is feasible for individuals dwelling in the TFI, although they likely would not be subjected to impingement at Station No. 1 due to their swim speed capabilities. The trashrack spacing at the Northfield Mountain intake is large enough such that individuals may be able to fit between the bars, at which point they would become entrained.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 71%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 77%.

*Potential Impact to Carp* –Impacts may be moderate as habitat in the vicinity of the intakes may attract individuals into the zones of influence. The species has moderate fecundity. All young lifestages experience very high natural mortality that would eclipse losses associated with project operations.

#### 4.1.3.3 Fallfish

*Habitat and Biology* – Fallfish inhabit gravel-bottom and rubble bottom pools and runs of small to medium rivers and also lake margins. Similar habitat is found within the Tuners Falls Power Canal, but not in close proximity to Cabot Station or Station No. 1. Local habitat conditions at the Northfield Mountain intake/tailrace channel contain rubble substrate and may attract individuals to the area.

*Likelihood of Entrainment* – The likelihood of entrainment is low to moderate. Fallfish do not prefer habitat characteristics in the immediate vicinity of the Cabot or Station No. 1 intakes. Individuals may be subjected to entrainment at Northfield Mountain, however, only a single specimen of this species was detected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus it is considered unlikely to encounter the Northfield intake.

*Swim Speed* – The sustained swim speed of Fallfish is 1.6 fps. The Fallfish is capable of escaping the influence of the Station No.1 intake, but not Northfield Mountain or Cabot Station.

*Likelihood of Impingement* – The mean estimated body widths of Fallfish observed in the TFI are less than the trashrack spacing at all of the project intakes (Table 4.1-3), suggesting impingement is unlikely for many of the individuals dwelling in the TFI. Larger individuals (greater than 185 mm) could potentially be impinged on the upper portion of the Cabot Station trashracks; however, individuals are not expected to be in the vicinity of the intake due to lack of preferred habitat.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 71%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 77%.

*Potential Impact to Fallfish* - Entrainment and impingement at Cabot or Station No. 1 should have minimal impacts as loss would be limited to a small number of individuals straying from other areas with more preferred habitat. Due to the habitat conditions at Northfield Mountain intake/tailrace channel and poor swimming performance, Fallfish may be subjected to entrainment during the typical 5-6 hour pumping cycle that occurs each night. The species has very high fecundity. All lifestages experience very high natural mortality that would eclipse project losses.

#### 4.1.3.4 Golden Shiner

*Habitat and Biology* – Golden Shiners prefer clear and quiet water with aquatic vegetation in lakes, ponds, or large, slow flowing streams and rivers. This habitat is not found adjacent to any of the projects' intakes, but it does occur in the lower portion of the Turners Falls Power Canal.

*Likelihood of Entrainment* – The likelihood of entrainment is low since preferred habitat is not located in the immediate vicinity of any of the intakes. No Golden Shiner were detected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and thus this species is considered unlikely to encounter the Northfield intake.

*Swim Speed* – Golden Shiners sustained swim speeds are such that they would only be able to escape the intake velocities exhibited at Station No. 1.

*Likelihood of Impingement* – The mean estimated body widths of Golden Shiner observed in the TFI are less than the trashrack spacing at all of the project intakes (Table 4.1-3), suggesting impingement is highly unlikely for many of the individuals dwelling in the TFI.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 71%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 77%.

*Potential Impact to Golden Shiner* - Entrainment and impingement should have minimal impacts as loss would potentially affect a small number of straying individuals. The species has very high fecundity. All lifestages experience very high natural mortality that would eclipse turbine losses.

### *4.1.4 Catastomidae*

#### 4.1.4.1 White Sucker

*Habitat and Biology* - White Sucker are habitat generalists. They occupy small, clear, cool creeks, large rivers, lakes and impoundments. They prefer cover-rich habitat but may exist in areas with poor cover as well. In rivers they tend to prefer benthic areas where they can bottom feed. It is possible that they would inhabit the power canal area and occur in the vicinity of the Northfield Mountain intake/tailrace. Their movements are localized, except during spring spawning when they may undergo longitudinal migration while seeking riffle habitat.

*Likelihood of Entrainment* – Likelihood is moderate as this species may at times utilize habitat in the intake areas. White Sucker were the third most common species collected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, and as habitat generalists, may be considered moderately likely to encounter the Northfield intake.

*Swim Speed* –The sustained swimming speed for white suckers is reported as 2.0 fps at a fork length of 10.8 inches and acclimation temperature of 12°C (Table 4.1-2). As with all other species, swimming speed increases with body length and temperature. Adult sustained swim speed is higher than the intake velocity at Station No. 1 and Cabot Station, but less than the intake velocities at Northfield Mountain.

*Likelihood of Impingement* – The mean estimated body width of White Sucker observed in the TFI is less than the trashrack spacing at all of the project intakes (Table 4.1-3), suggesting impingement is unlikely for many of the individuals dwelling in the TFI. Larger individuals (greater than 164 mm) could potentially be impinged at Station No. 1 or on the upper portion of the Cabot Station trashracks, although this species tends to remain closer to the bottom.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 88%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 82%. Smaller juvenile and YOY white sucker may be less sensitive than adults, as they may avoid collisions with runners, gates, etc.

*Potential Impact to White Sucker* – Impacts are predicted to be low to moderate. Adults should be able to avoid involuntary entrainment at Station No. 1 and Northfield Mountain; the data indicate that most adults will be able to escape the intake velocity field at Cabot Station. It is possible that a few adults searching for suitable spawning habitat in the spring may undergo localized movements that bring them in incidental contact with intakes and may attempt to pass downstream. Juveniles may be more susceptible to entrainment due to swimming speeds lower than intake velocities. Entrainment and impingement loss would be limited to straying individuals.

### *4.1.5 Esocidae - Northern Pike and Chain Pickerel*

*Habitat and Biology* – Northern Pike and Chain Pickerel inhabit vegetated lakes, swamps, backwaters and quite pools of creeks and rivers. Adults and juveniles tend to lie motionless near shore in littoral vegetation and quiet waters found in isolated pockets of the lower Turners Falls Power Canal; however, areas adjacent to each of the intakes do not provide preferred habitat.

*Likelihood of Entrainment* – The likelihood of entrainment at any of the intakes is low due to an absence of vegetative cover. Neither species was collected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake, thus are considered unlikely to encounter the Northfield intake.

*Swim Speed* – The reported sustained swim speeds of these two species differed in the literature (Table 4.1-2), although the acclimation temperature for Chain Pickerel was low and suggests greater speeds may be achieved at higher temperatures. Northern Pike are strong swimmers and would likely be able to overcome the influence of the intakes.

*Likelihood of Impingement* – The mean estimated body widths of Chain Pickerel and Northern Pike is less than the trashrack spacing at the Northfield Mountain and Station No. 1 intakes, as well as the lower portion of the Cabot Station racks (Table 4.1-3), suggesting impingement is unlikely for many of the individuals dwelling in the TFI. Some individuals greater than 300 mm could potentially be impinged at on the upper portion of the Cabot Station trashracks, although swimming capabilities would likely allow for escape away from the intake.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 91%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 84%.

*Potential Impact to Esocid species* - Entrainment and impingement should have minimal impacts as loss would be limited to a small number of individuals straying from areas of preferred habitat.

### *4.1.6 Ictaluridae*

#### 4.1.6.1 Brown Bullhead

*Habitat and Biology* – Brown Bullhead prefer pools and sluggish runs over soft substrates in ponds, lakes and small to large rivers. Brown Bullhead tend to move into shallow water in areas with cover to spawn and young are often found near the surface. There are isolated pockets of suitable habitat within the power canal upstream of Cabot Station that have the potential for Brown Bullhead presence, but not directly adjacent to any of the intakes.

*Likelihood of Entrainment* – No Brown Bullhead were collected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake. Given the low suitability of habitat directly adjacent to Northfield Mountain and Station No. 1, but presence of suitable areas upstream of Cabot Station, there is a low potential for entrainment at Northfield and a moderate likelihood of entrainment at Station No. 1 or Cabot.

*Swim Speed* – The sustained swim speed of Brown Bullhead is greater than the intake velocity at Station No. 1 and Cabot Station, but not at Northfield Mountain.

*Likelihood of Impingement* – The mean estimated body width of Brown Bullhead observed in the TFI is less than the trashrack spacing at Northfield Mountain, as well as Station No. 1 and the lower portion of the Cabot Station racks (Table 4.1-3), suggesting impingement is unlikely for many of the individuals dwelling in the TFI. Impingement is possible along the upper portion of the Cabot Station intake, especially for younger individuals that tend to be surface oriented.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 65%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of73%.

*Potential Impact to Brown Bullhead* – Very few individuals were collected during the TFI during the field effort for the Fish Assemblage study in 2015. Entrainment and impingement should have minimal impacts due to swim speed capabilities. The species has moderate fecundity. Young lifestages experience very high natural mortality that would eclipse project-related losses.

#### 4.1.6.2 Channel Catfish

*Habitat and Biology* – Channel Catfish inhabit pools and sluggish runs over soft substrates in rivers. They make lateral spawning migrations into shallow water, and do not undergo longitudinal migrations. There are isolated pockets of suitable habitat within the power canal upstream of Cabot Station that have the potential for Channel Catfish presence, but not directly adjacent to any of the intake structures.

*Likelihood of Entrainment* – No Channel Catfish were collected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake. Given the low suitability of habitat directly adjacent to Northfield Mountain and Station No. 1 intakes, but presence of suitable areas upstream of Cabot station in the lower portion of the power canal, there is a low likelihood of entrainment at Northfield Mountain and a moderate likelihood of entrainment at Cabot and Station No. 1.

*Swim Speed* – The sustained swim speed of Channel Catfish is greater than the intake velocity at Station No. 1 and Cabot Station, but not at Northfield Mountain.

*Likelihood of Impingement* – The mean estimated body width of Channel Catfish observed in the TFI is less than the trashrack spacing at Northfield Mountain, as well as Station No. 1 and the lower portion of the Cabot Station racks (Table 4.1-3), suggesting impingement is unlikely for many of the individuals dwelling in the TFI. Impingement is possible along the upper portion of the Cabot Station intake and larger individuals (greater than 128 mm) could potentially be impinged along the lower portion of the Cabot intake and at Station No. 1, although swimming performance may allow for escape.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 65%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 73%.

*Potential Impact to Channel Catfish* - Entrainment and impingement should have minimal impacts as loss would be limited to a small number of individuals straying from areas with preferred habitat. The species has moderate fecundity. Young lifestages experience very high natural mortality that would eclipse turbine losses.

### *4.1.7 Moronidae*

#### 4.1.7.1 White Perch

*Habitat and Biology* - White Perch prefer pools and other quiet areas of medium and large rivers with fine substrates and mud. White Perch are not known to undertake longitudinal migrations but do make localized movements to and from deeper water for foraging and shelter. Potentially suitable habitat is present upstream of the Cabot Station intake.

*Likelihood of Entrainment* – Given the suitability of habitat in the vicinity to the Cabot Station intake, it is possible that White Perch may be entrained at that location. The likelihood of entrainment at the Northfield Mountain and Station No. 1 intakes is considered low as fish would not expect to be in these areas. No White Perch were collected in the fish assemblage study at the station in closest proximity to the Northfield pumped storage intake.

*Swim Speed* – The sustained swimming speed is lower than the intake velocities at Northfield Mountain and Cabot Station; thus, White Perch can only escape intake velocities at Station No. 1.

*Likelihood of Impingement* – The mean estimated body width of White Perch observed in the TFI is less than the trashrack spacing at all of the project intakes, suggesting a very low likelihood of impingement.

*Turbine Survival* - The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 86%. The mean survival rate from studies at sites similar to Station No. 1 also indicate a turbine survival rate of 86%.

*Potential Impact to White Perch* – Very few White Perch individuals were observed during the 2015 field sampling for the Fish Assemblage Assessment and it is unlikely that this species would occur in appreciable numbers in the project area that spans a variety of freshwater habitats.

### *4.1.8 Fundulidae*

#### 4.1.8.1 Banded Killifish

*Habitat and Biology* – Banded Killifish prefer clear and quiet water with aquatic vegetation in lakes, ponds, or slow flowing streams. This habitat is not found adjacent to any of the projects' intakes, but it does occur along the fringes in portions of the lower Turners Falls Power Canal.

*Likelihood of Entrainment* – The likelihood entrainment is low since preferred habitat does not exist in the immediate vicinity of any of the intakes.

*Swim Speed* – Banded Killifish have a low sustained swim speed (1.1 fps), which is less than intake velocities at Station No. 1, Cabot Station, and Northfield Mountain.

*Likelihood of Impingement* – The mean estimated body widths of Banded Killifish observed in the TFI are less than the trash rack spacing at all of the project intakes (Table 4.1-3), suggesting impingement is highly unlikely for many of the individuals dwelling in the TFI.

*Turbine Survival* – No empirical study data are amiable for Banded Killifish, thus study data from a relatively fragile family (clupeid) was used as a surrogate. The mean survival rate from studies at source sites similar to Cabot indicate a turbine survival rate of 89%. The mean survival rate from studies at sites similar to Station No. 1 indicate a turbine survival rate of 95%.

*Potential Impact to Banded Killifish* - Entrainment and impingement should have minimal impacts as loss would potentially affect a small number of straying individuals.

## 4.2 Migratory Species

### *4.2.1 Adult American Shad*

There was no confirmed entrainment of adult shad into the NMPS or Station No. 1, based on data collected from the 29 receiver arrays and 397 radio/PIT tagged adult American Shad during the 2015 monitoring period (Study No. 3.3.2). However, emigrating shad were entrained through Cabot powerhouse. Of the 86 fish that utilized the power canal during emigration, 24 were confirmed to have transitioned from Cabot

Forebay to the Cabot Tailrace without being detected at the downstream bypass (*Adult Shad Report*). Of the 24 fish known to have been entrained into the Cabot Powerhouse, 9 were successfully tracked with mobile tracking and 5 were found dead. Catch-curve mortality estimates described in Miranda and Bettoli (2007) and in Study No. 3.3.2, were used to calculate the daily mortality rates of mobile-tracked fish that passed through project features. The mortality rate for those fish passing via the Cabot powerhouse was 0.02 fish per day, which was comparable to the mortality rate for fish released at Holyoke that did not pass any structure and shad that exited the downstream bypass at Cabot (0.01 fish per day).

During upstream migration many adult shad that entered the Turners Falls Canal were observed milling in the Cabot Station forebay for up to 48 hours before continuing upstream, suggesting these shad are not vulnerable to entrainment or impingement at Cabot Station during their upstream migration. Similarly, fish moving upstream in the canal that entered the Station No. 1 forebay milled around for up to 15 hours before continuing to move upstream through the canal towards Gatehouse, suggesting no entrainment impacts to adult shad during upstream migration due to Station No. 1.

No entrainment of adult shad was documented at NMPS intake/tailrace during the 2015 study (Study No. 3.3.2). However, the study revealed that shad were detected at the NMPS intake/tailrace under all experienced operational and diel conditions, i.e. pumping, generation, and non-operation during both daytime and nighttime hours (FirstLight, 2016a). Adult shad were most likely to be detected at the NMPS Project intake/tailrace area at night under pumping operation, with the probability of occurrence reducing as pump volume increased. Adult shad were least likely to be detected at the NMPS Project intake/tailrace area at night during periods of maximum generation (FirstLight, 2016a). Delay was calculated for those fish that were detected at the Intake (n=91). During upstream migration, 50% of the shad detected at the intake left the area and continued upstream migration within 37.6 hours. During downstream migration, delay was less, with 50% of the fish exiting the intake area within 6.42 hours. These results suggest that the risk of impingement and entrainment is low despite milling in the intake area.

### *4.2.2 Juvenile American Shad*

Analysis of hydroacoustic data collected at the Cabot Station intakes from August 1 to November 14, 2015 suggested 1,660,166 juvenile shad were entrained at Cabot Station. Impacts to these fish are likely far less substantial because of high turbine passage survival; NAI reported a 95.0% immediate survival of juvenile shad passed through the Unit 2 turbine of Cabot Station (NAI, 2016a). The other five generating units at Cabot Station are identical to Unit 2, so similarly high survival is expected at these units as well. The immediate survival rates for the smaller Francis units at Station No. 1 (67.8% and 76.6%) were lower, but radio telemetry results (Study 3.3.3) suggest that a proportionally small number of the shad that enter the canal passed the project through Station No. 1, as evidenced by the fact that of the 16 radio tagged juvenile shad that emigrated through the power canal, only one was detected at the Station No. 1 forebay and was not entrained during the 2015 monitoring study (FirstLight, 2016b).

Determining the rate of entrainment at the NMPS Project was an objective of Relicensing Study 3.3.3 *Evaluate Downstream Passage of Juvenile American Shad*. Hydroacoustic and radio telemetry methods were used to achieve this objective. However, the objective was not fully met due to a high level of milling observed in the hydroacoustic data and poor survival and tag retention for radio-tagged control fish. The study did document the occurrence of entrainment by tagged juvenile shad; of the 77 shad that emigrated through the Connecticut River reach between Shearer Farms (upstream of NMPS intake/tailrace) and Gill banks (downstream of NMPS intake/tailrace) 24 were detected in the NMPS intake/tailrace. Of those 3 (3.9%) were documented as being entrained (FirstLight, 2016b). Thirty two of the shad detected at Shearer Farms passed by the NMPS intake/bypass and continued downstream and were subsequently detected at Gill banks. The remaining 21 fish entered the reach from upstream and were never detected again.

#### *4.2.3 American Eel*

Although entrainment rates of American Eel in the Project areas are not yet calculated, turbine passage mortality at the Turners Falls Project is not expected to have a substantial impact on downstream migrants. Eels were determined to exhibit a 96% immediate survival rate after passage through the Unit 2 turbine at Cabot Station and 90% survival at the larger Unit 1 at Station No. 1 (NAI, 2016b). Units 2 and 3 share a common penstock and the turbine passage mortality assessment reported 60% survival.

### 4.3 Station Impacts

#### *4.3.1 Cabot Station*

Table 4.3.1-1 and Figure 4.3.1-1 summarize the relative risk of entrainment and impingement loss of fish species that reside in the TFI.[2] Most species are at moderate risk to loss at the individual animal level, and none is at a high risk. Species scoring as low-risk included Bluegill, Pumpkinseed and Smallmouth Bass. Entrainment of resident fish is confined to individual movements of a limited number of fish, and therefore, is not expected to materially affect spawning or YOY recruitment. In general, most resident fish entrainment loss has been shown to be dominated by YOY and small juvenile fish that exhibit swimming speeds less than intake velocities (EPRI, 1997). However, turbine survival of smaller fish tends to be relatively high when compared to adults, as smaller fish are less likely to encounter blades, vanes or get caught in shear zones than larger fish (Franke, *et al*., 1997). Natural mortality rates generally exert a more significant effect on YOY and juveniles than does entrainment mortality (Franke, *et al*., 1997; EPRI, 1997).

#### *4.3.2 Station No. 1*

Table 4.3.2-1 and Figure 4.3.2-2 summarize the relative risk of entrainment and impingement loss of fish species resident to the TFI. Five species are at moderate risk to entrainment loss at the individual animal level, and the remainder are at a low risk; none are at a high risk. Entrainment of resident fish is confined to individual movements of a limited number of fish, and therefore is not expected to materially affect spawning or YOY recruitment. In general, most resident fish entrainment loss has been shown to be dominated by YOY and small juvenile fish that exhibit swimming speeds less than intake velocities (EPRI, 1997). However, turbine survival of smaller fish tends to be relatively high when compared to adults, as smaller fish are less likely to encounter blades, vanes and get caught in shear zones than larger fish (Franke, *et al*., 1997). Natural mortality rates generally exert a more significant effect on YOY and juveniles than does entrainment mortality (Franke, *et al*., 1997; EPRI, 1997).

#### *4.3.3 Northfield Mountain*

Table 4.3.3-1 and Figure 4.3.3-1 summarize the relative risk of entrainment and impingement loss of fish species resident to the TFI. All species are at moderate risk to entrainment loss at the individual animal level. It cannot be conclusively determined how many resident fish removed from the river by pumping can return to the ecosystem. Although some may be killed through pumping or generation entrainment, others may survive and be recruited to the storage pond alive, and yet others may return to the river alive. For purposes of this risk assessment, a simplifying assumption was to conservatively assume that all fish entrained into the NMPS Project from the river experience 100% mortality. Entrainment of resident fish is confined to individual movements of a limited number of fish, and therefore entrainment loss is not

[2] Five risk sensitivity categories were scored on a scale from 0 to 3 for each species independently for Northfield Mountain, Cabot and Station No. 1, based on the results from Section 4.1. A category score of 0 indicates no entrainment sensitivity, a 1 reflects “low” probability, 2 reflects “intermediate” probability, and 3 reflects “high” probability. Category scores were then summed to generate a total entrainment risk score on a scale of 0 to 15. Summed scores of 0-5 represent “low” entrainment risk, scores of 6-10 represent “moderate” risk and 11-15 equate to “high” risk.

expected to materially affect spawning or YOY recruitment. In general, most resident fish entrainment loss has been shown to be dominated by YOY and small juvenile fish that exhibit swimming speeds less than intake velocities (EPRI, 1997). However, turbine survival of smaller fish tends to be relatively high when compared to adults, as smaller fish are less likely to encounter blades, vanes and get caught in shear zones than larger fish (Franke, *et al*, 1997). Natural mortality rates generally exert a more significant effect on YOY and juvenile populations than does entrainment mortality (Franke, *et al*., 1997; EPRI, 1997).

**Table 4.3.1-1: Entrainment risk scores for resident species at Cabot Station.**

| Species | Habitat & Biology | Swim Speed | Survival | Likelihood | Population Impact | Risk Score |
|---|---|---|---|---|---|---|
| Banded Killifish | 1 | 2 | 2 | 1 | 0 | 6 |
| Black Crappie | 1 | 2 | 1 | 2 | 0 | 6 |
| Bluegill | 1 | 2 | 1 | 1 | 0 | 5 |
| Brown Bullhead | 1 | 2 | 3 | 2 | 0 | 8 |
| Chain Pickerel | 1 | 2 | 1 | 2 | 0 | 6 |
| Channel Catfish | 1 | 0 | 3 | 2 | 0 | 6 |
| Common Carp | 3 | 2 | 2 | 2 | 0 | 9 |
| Common Shiner | 1 | 2 | 2 | 2 | 0 | 7 |
| Fallfish | 1 | 2 | 2 | 1 | 0 | 6 |
| Golden Shiner | 2 | 2 | 2 | 2 | 0 | 8 |
| Largemouth Bass | 1 | 2 | 1 | 1 | 0 | 5 |
| Longnose Dace | 1 | 2 | 2 | 2 | 0 | 7 |
| Mimic Shiner | 1 | 2 | 2 | 2 | 0 | 7 |
| Northern Pike | 1 | 0 | 0 | 2 | 0 | 3 |
| Pumpkinseed | 1 | 2 | 1 | 1 | 0 | 5 |
| Rock Bass | 1 | 2 | 1 | 2 | 0 | 6 |
| Rosyface Shiner | 1 | 2 | 2 | 2 | 0 | 7 |
| Smallmouth Bass | 1 | 2 | 1 | 1 | 0 | 5 |
| Spottail Shiner | 1 | 2 | 2 | 2 | 0 | 7 |
| Tessellated Darter | 1 | 2 | 2 | 1 | 0 | 6 |
| Walleye | 1 | 2 | 2 | 2 | 0 | 7 |
| White Perch | 2 | 2 | 1 | 2 | 0 | 7 |
| White Sucker | 2 | 0 | 1 | 2 | 0 | 5 |
| Yellow Perch | 1 | 2 | 2 | 1 | 0 | 6 |

| Score | Habitat & Biology | Swim Speed | Survival | Likelihood | Population Impact |
|---|---|---|---|---|---|
| 0 | | greater than intake velocity | 90-100% | | no impact |
| 1 | "unlikely" | equal to intake velocity | 80-90% | "unlikely" | "minimal" |
| 2 | "habitat preference present" | less than intake velocity | 70-80% | "moderate" | may significantly reduce spawning |
| 3 | "very likely" | | <70% | "likely" | may significantly impact YOY |

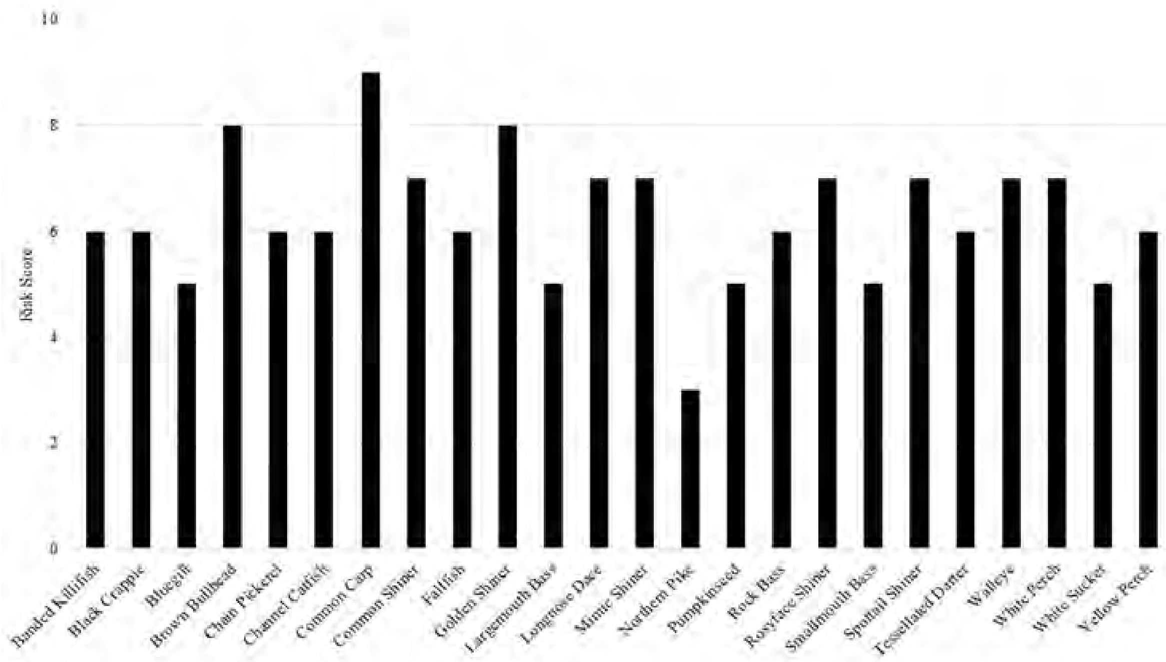



**Figure 4.3.1-1: Resident Fish Species Entrainment Risk at Cabot Station**

**Table 4.3.2-1: Entrainment risk scores for resident species at Station No. 1**

| Species | Habitat & Biology | Swim Speed | Survival | Likelihood | Population Impact | Risk Score |
|---|---|---|---|---|---|---|
| Banded Killifish | 1 | 2 | 1 | 1 | 0 | 5 |
| Black Crappie | 2 | 2 | 1 | 2 | 0 | 7 |
| Bluegill | 1 | 0 | 1 | 1 | 0 | 3 |
| Brown Bullhead | 1 | 0 | 2 | 1 | 0 | 4 |
| Chain Pickerel | 1 | 2 | 1 | 1 | 0 | 5 |
| Channel Catfish | 1 | 0 | 3 | 1 | 0 | 5 |
| Common Carp | 2 | 0 | 2 | 1 | 0 | 5 |
| Common Shiner | 1 | 0 | 2 | 1 | 0 | 4 |
| Fallfish | 1 | 0 | 2 | 1 | 0 | 4 |
| Golden Shiner | 1 | 0 | 2 | 1 | 0 | 4 |
| Largemouth Bass | 1 | 1 | 1 | 1 | 0 | 4 |
| Longnose Dace | 1 | 2 | 2 | 1 | 0 | 6 |
| Mimic Shiner | 1 | 2 | 2 | 1 | 0 | 6 |
| Northern Pike | 1 | 0 | 0 | 1 | 0 | 2 |
| Pumpkinseed | 1 | 0 | 1 | 1 | 0 | 3 |
| Rock Bass | 1 | 2 | 1 | 1 | 0 | 5 |
| Rosyface Shiner | 1 | 2 | 2 | 1 | 0 | 6 |
| Smallmouth Bass | 1 | 1 | 1 | 1 | 0 | 4 |
| Spottail Shiner | 1 | 0 | 2 | 1 | 0 | 4 |
| Tessellated Darter | 1 | 2 | 2 | 1 | 0 | 6 |
| Walleye | 1 | 0 | 2 | 1 | 0 | 4 |
| White Perch | 1 | 0 | 1 | 1 | 0 | 3 |
| White Sucker | 2 | 0 | 1 | 1 | 0 | 4 |
| Yellow Perch | 1 | 0 | 2 | 1 | 0 | 4 |

| Score | Habitat & Biology | Swim Speed | Survival | Likelihood | Population Impact |
|---|---|---|---|---|---|
| 0 | | greater than intake velocity | 90-100% | | no impact |
| 1 | "unlikely" | equal to intake velocity | 80-90% | "unlikely" | "minimal" |
| 2 | "habitat preference present" | less than intake velocity | 70-80% | "moderate" | may significantly reduce spawning |
| 3 | "very likely" | | <70% | "likely" | may significantly impact YOY |

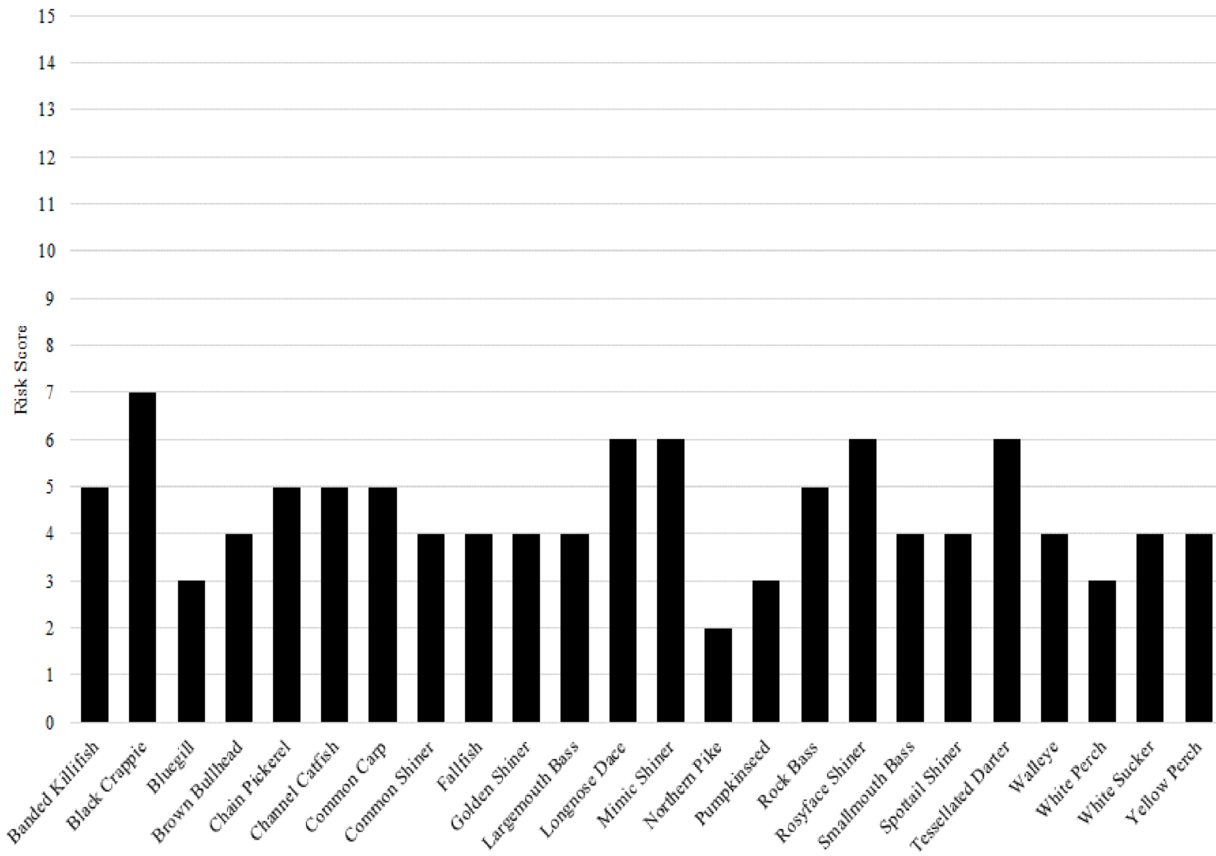



**Figure 4.3.2-1: Resident Fish Species relative Entrainment Risk at Station No. 1.**

**Table 4.3.3-1. Entrainment risk scores for resident species at Northfield Mountain.**

| Species | Habitat & Biology | Swim Speed | Survival | Likelihood | Population Impact | Risk Score |
|---|---|---|---|---|---|---|
| Banded Killifish | 1 | 2 | 3 | 1 | 0 | 7 |
| Black Crappie | 1 | 2 | 3 | 1 | 0 | 7 |
| Bluegill | 1 | 2 | 3 | 1 | 0 | 7 |
| Brown Bullhead | 1 | 2 | 3 | 1 | 0 | 7 |
| Chain Pickerel | 1 | 2 | 3 | 1 | 0 | 7 |
| Channel Catfish | 1 | 2 | 3 | 1 | 0 | 7 |
| Common Carp | 1 | 2 | 3 | 1 | 0 | 7 |
| Common Shiner | 1 | 2 | 3 | 1 | 0 | 7 |
| Fallfish | 1 | 2 | 3 | 1 | 0 | 7 |
| Golden Shiner | 1 | 2 | 3 | 1 | 0 | 7 |
| Largemouth Bass | 1 | 2 | 3 | 1 | 0 | 7 |
| Longnose Dace | 1 | 2 | 3 | 1 | 0 | 7 |
| Mimic Shiner | 1 | 2 | 3 | 1 | 0 | 7 |
| Northern Pike | 1 | 2 | 3 | 1 | 0 | 7 |
| Pumpkinseed | 1 | 2 | 3 | 1 | 0 | 7 |
| Rock Bass | 2 | 2 | 3 | 1 | 0 | 8 |
| Rosyface Shiner | 1 | 2 | 3 | 1 | 0 | 7 |
| Smallmouth Bass | 2 | 2 | 3 | 1 | 0 | 8 |
| Spottail Shiner | 1 | 2 | 3 | 1 | 0 | 7 |
| Tessellated Darter | 1 | 2 | 3 | 1 | 0 | 7 |
| Walleye | 1 | 2 | 3 | 1 | 0 | 7 |
| White Perch | 2 | 2 | 3 | 1 | 0 | 8 |
| White Sucker | 2 | 2 | 3 | 1 | 0 | 8 |
| Yellow Perch | 1 | 2 | 3 | 1 | 0 | 7 |

| Score | Habitat & Biology | Swim Speed | Survival | Likelihood | Population Impact |
|---|---|---|---|---|---|
| 0 | | greater than intake velocity | 90-100% | | no impact |
| 1 | "unlikely" | equal to intake velocity | 80-90% | "unlikely" | "minimal" |
| 2 | "habitat preference present" | slightly less than intake velocity | 70-80% | "moderate" | may significantly reduce spawning |
| 3 | "very likely" | | <70% | "likely" | may significantly impact YOY |

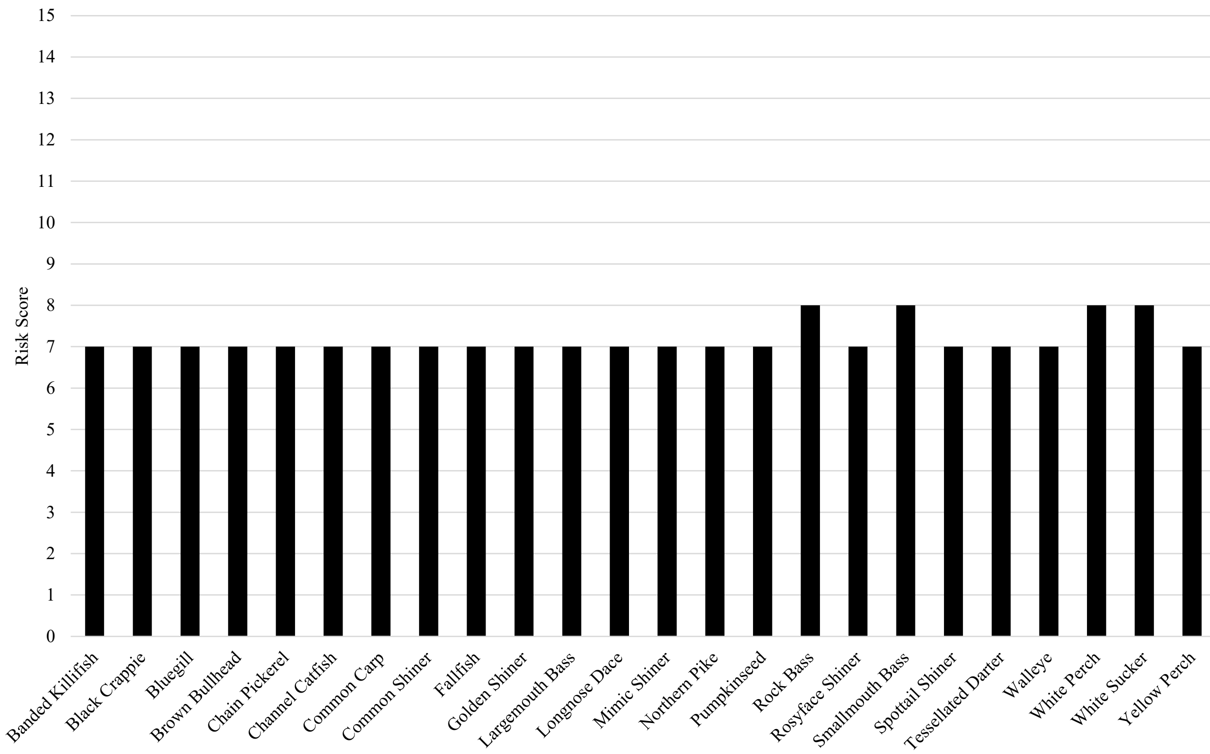



**Figure 4.3.3-1: Resident Fish Species Entrainment Risk at NMPS.**

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

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

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## EXECUTIVE SUMMARY

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

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

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

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

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

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

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

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

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

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## List of Abbreviations

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

# 1.0 INTRODUCTION

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

# 2.0 STUDY GOALS AND OBJECTIVES

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

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

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

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

# 3.0 PROJECT DESCRIPTION

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

## 3.1 Cabot Station and Station No. 1

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

## 3.2 Turners Falls Dam

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

# 4.0 METHODS

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

## 4.1 Source of Shad

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

## 4.2 Study Designs

### 4.2.1 Procedures

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

### 4.2.2 Sample Size Calculations

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

#### 4.2.3 Tagging and Release

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

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

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

### 4.2.4 Juvenile Shad Recapture Methods

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

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

### 4.2.5 Classification of Recaptured Juvenile Shad

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

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

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

#### 4.2.6 Assessment of Juvenile Shad Injuries

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

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

#### 4.2.7 Survival and Malady-Free Estimation

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

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

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

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

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

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

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

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

The estimators associated with the likelihood model are:

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

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

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

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

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

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

Where,

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

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

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

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

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

Direct Survival, 1 and 48 h

Where:

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

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

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

$R_c$ = Number of control shad released;

$a_c$ = Number of control shad alive;

Malady-Free Estimates (MF)

Where:

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

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

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

$c_c$ = Number of control shad recovered without maladies;

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

### 4.2.8 Assignment of Probable Sources of Injury

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

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

## 4.3 Methods Specific to Each Station

### 4.3.1 Cabot Station

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

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

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

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

### 4.3.2 Station No. 1

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

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

### 4.3.3 Bascule Gates

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

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

# 5.0 RESULTS

## 5.1 Recapture Rates

### 5.1.1 Cabot Station Unit 2

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

### 5.1.2 Station No. 1

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

### 5.1.3 Bascule Gates

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

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

## 5.2 Recapture Times

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

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

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

## 5.3 Survival Estimates

### 5.3.1 Cabot Station Unit 2

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

### 5.3.2 Station No. 1

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

### 5.3.3 Bascule Gate 1

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

### 5.3.4 Bascule Gate 4

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

## 5.4 Injury Rate, Types, and Probable Source

### 5.4.1 Cabot Station Unit 2

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

### 5.4.2 Station No. 1

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

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

### 5.4.3 Bascule Gate 1

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

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

#### 5.4.4 Bascule Gate 4

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

### 5.5 Malady Free Estimates

#### 5.5.1 Cabot Station and Station No. 1

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

#### 5.5.2 Bascule Gates

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

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

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

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

# 6.0 ASSESSMENT OF PROJECT EFFECTS

## 6.1 Turbines

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

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

## 6.2 Bascule Gates

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

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

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# Tables

**Table 3-1**

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

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

**Table 3-2**

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

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

**Table 4-1**

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

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

* Table values also applicable for malady-free estimates.

**Table 4-2**

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

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

## Table 4-3

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

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

**Table 4-4**

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

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

**Table 5-1**

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

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

* includes dislodged tags and stationary signals

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

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

**Table 5-2**

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

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

*Many fish have multiple injury types.

**Table 5-3**

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

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

*Predator-related injuries not related to passage

**Flesh tear at tag site not related to passage

**Table 5-4**

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

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

*Maladies include both visible injuries and LOE

**Table 5-5**

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

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

**Table 6-1**

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

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

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

* Fork length measurements were recorded

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

# Figures

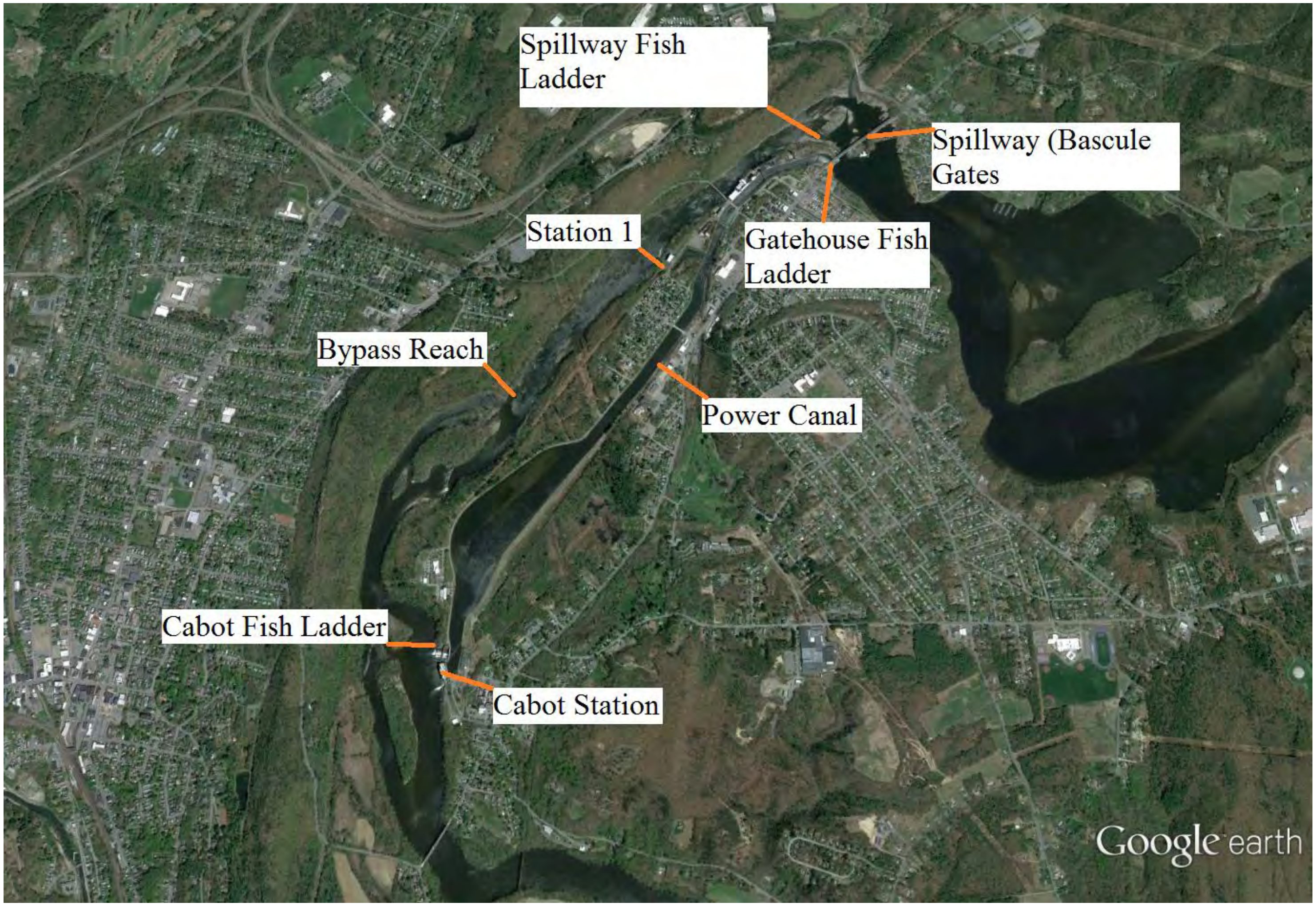


Figure 1-1 Aerial view of the FirstLight study locations.

Figure 3-1 Inside Cabot Station.

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

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

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

Figure 4-2 Electrofishing for juvenile American Shad.

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

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

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

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

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

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

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

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

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

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

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

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


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

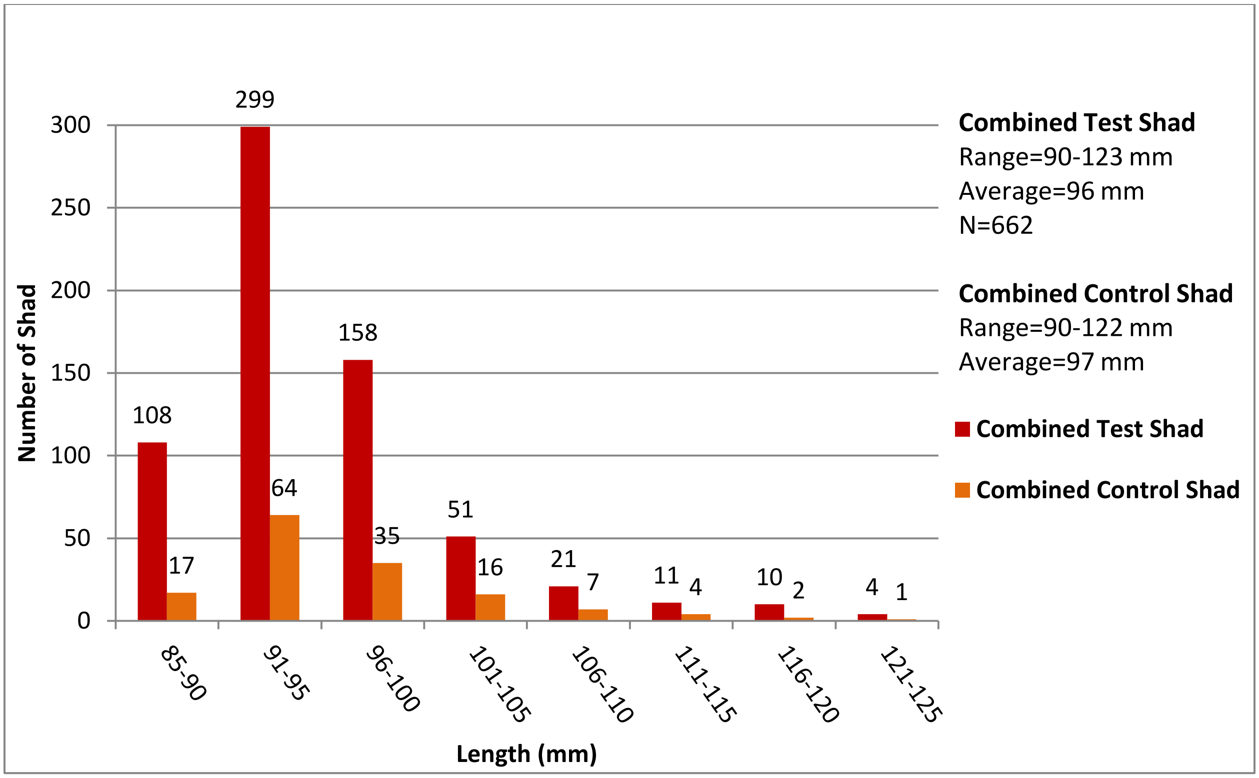


Figure 4-16 Length frequency for HI-Z tagged juvenile American Shad released at Cabot Station Unit 2, Station No. 1, and over Bascule Gates 1 and 4 compared to combined controls.

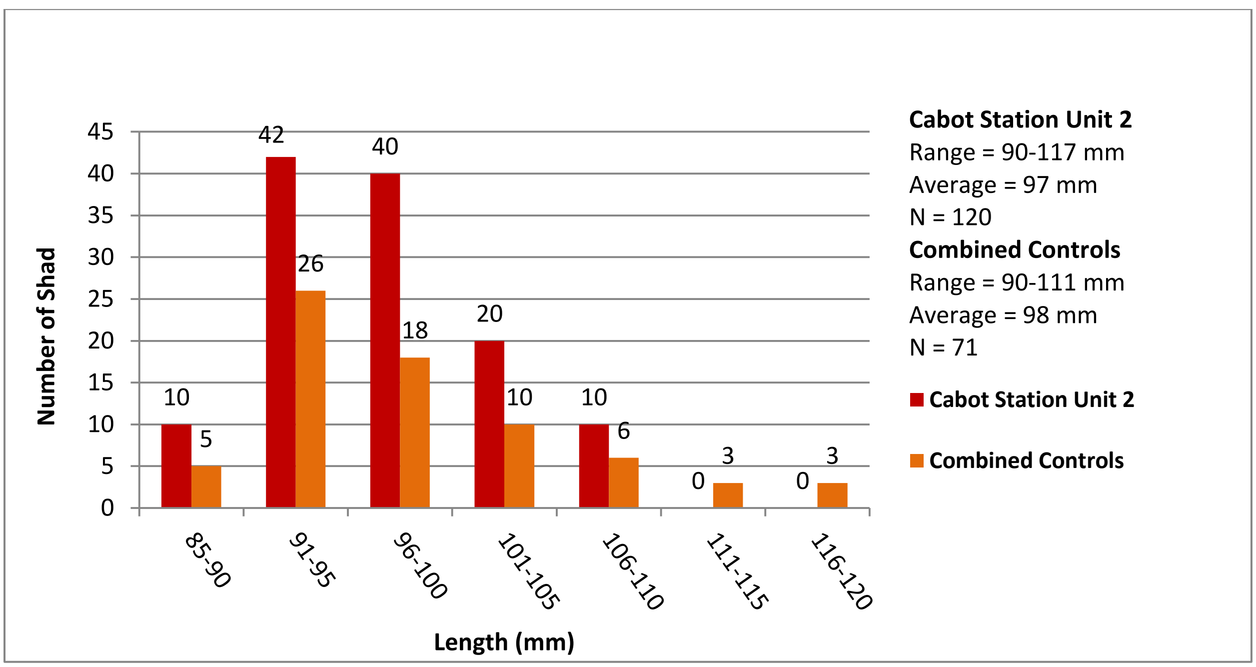


Figure 4-17 Length frequency for HI-Z tagged juvenile American Shad released at Cabot Station Unit 2, versus combined controls.

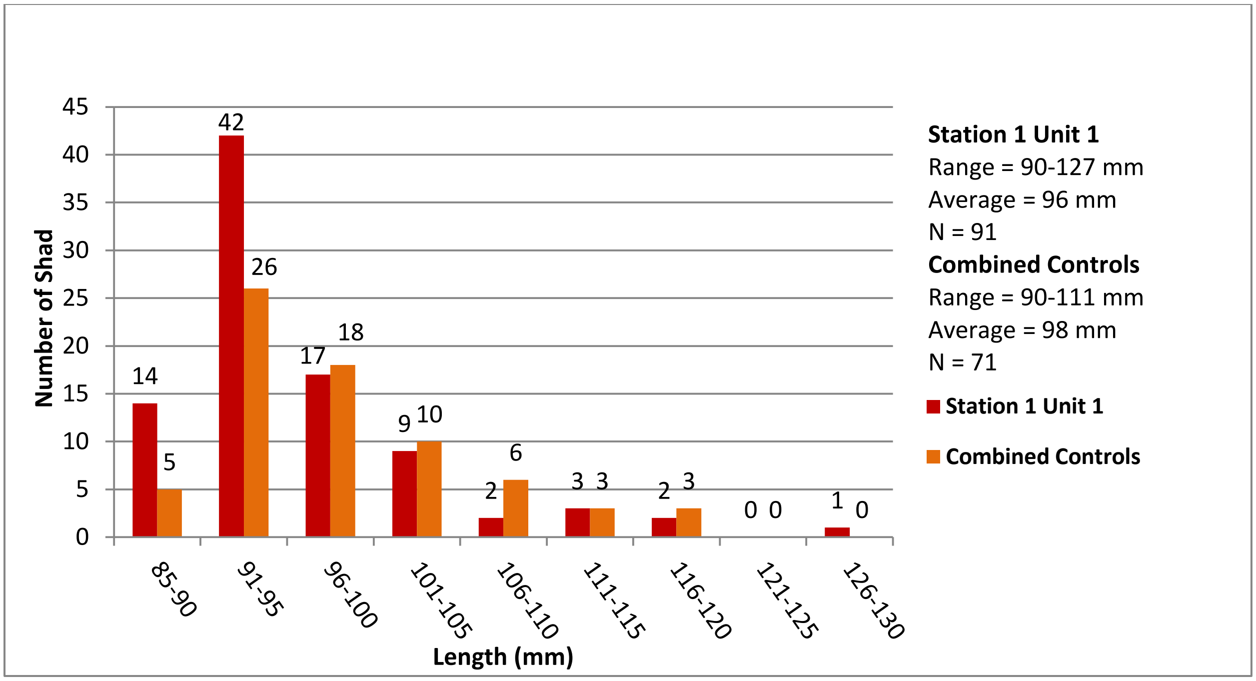


Figure 4-18 Length frequency for HI-Z tagged treatment juvenile American Shad released at Station No. 1 Unit 1 versus combined controls.

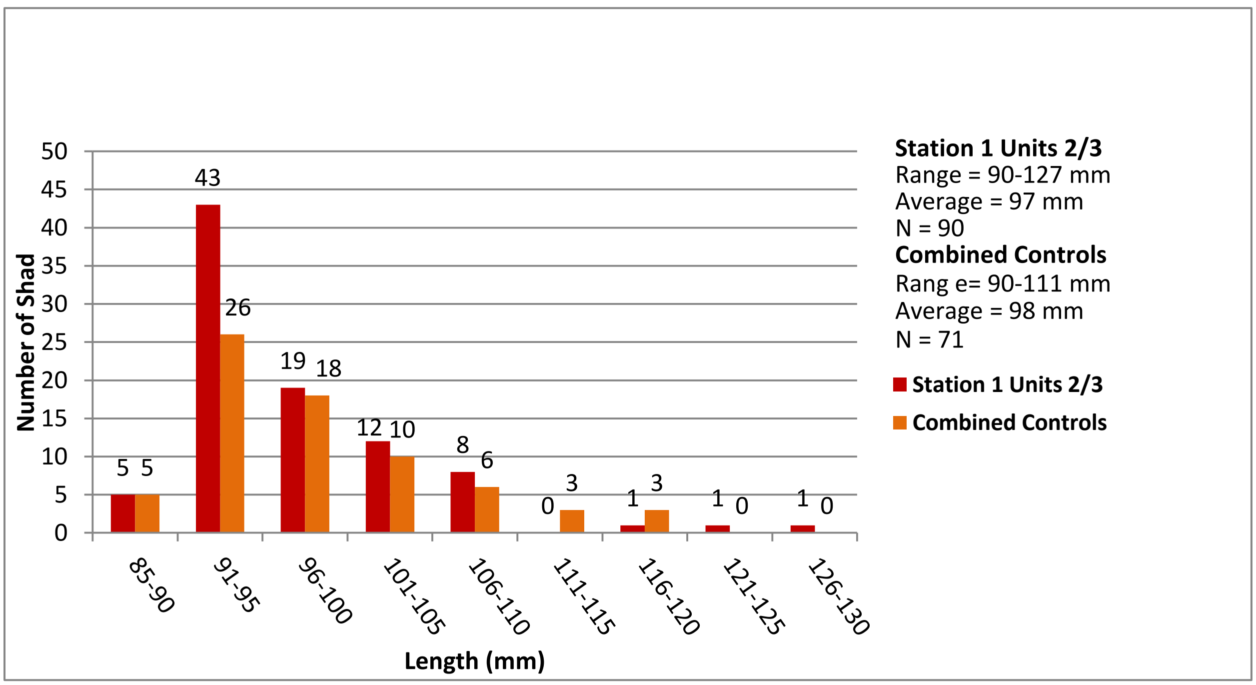


Figure 4-19 Length frequency for HI-Z tagged treatment juvenile American Shad released at Station No. 1 Units 2/3 versus combined controls.

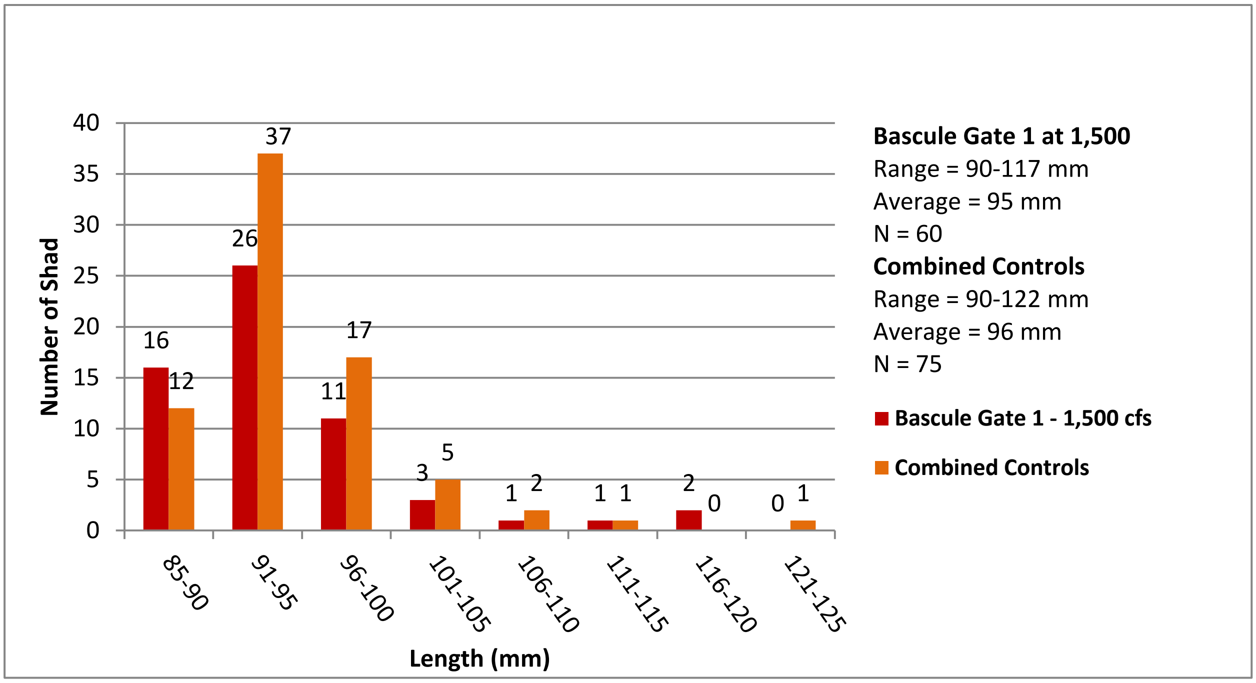


Figure 4-20 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 1 at 1,500 cfs versus combined controls.

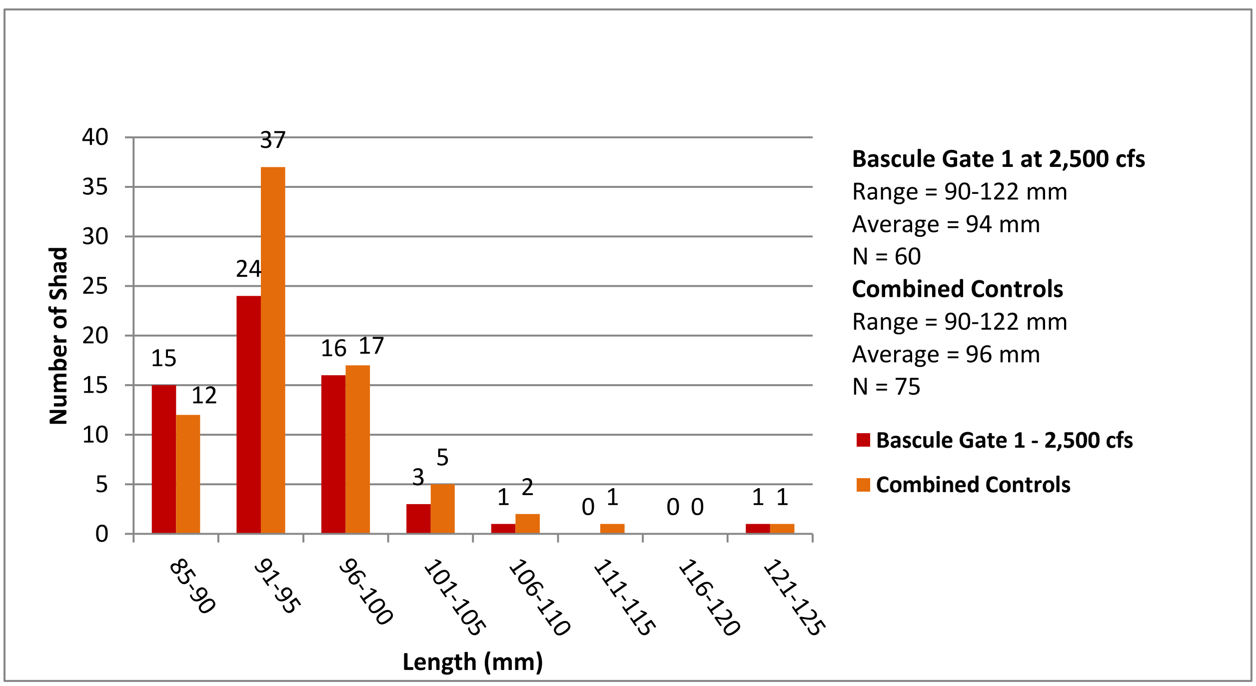


Figure 4-21 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 1 at 2,500 cfs versus combined controls.

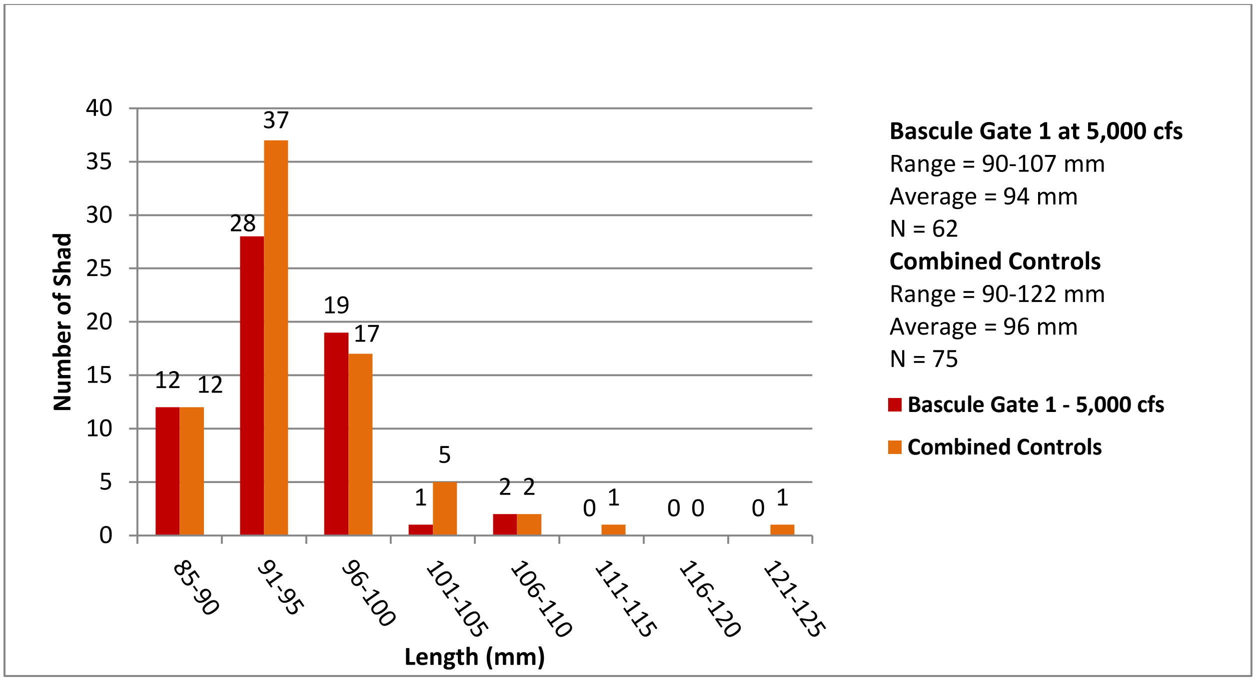


Figure 4-22 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 1 at 5,000 cfs versus combined controls.

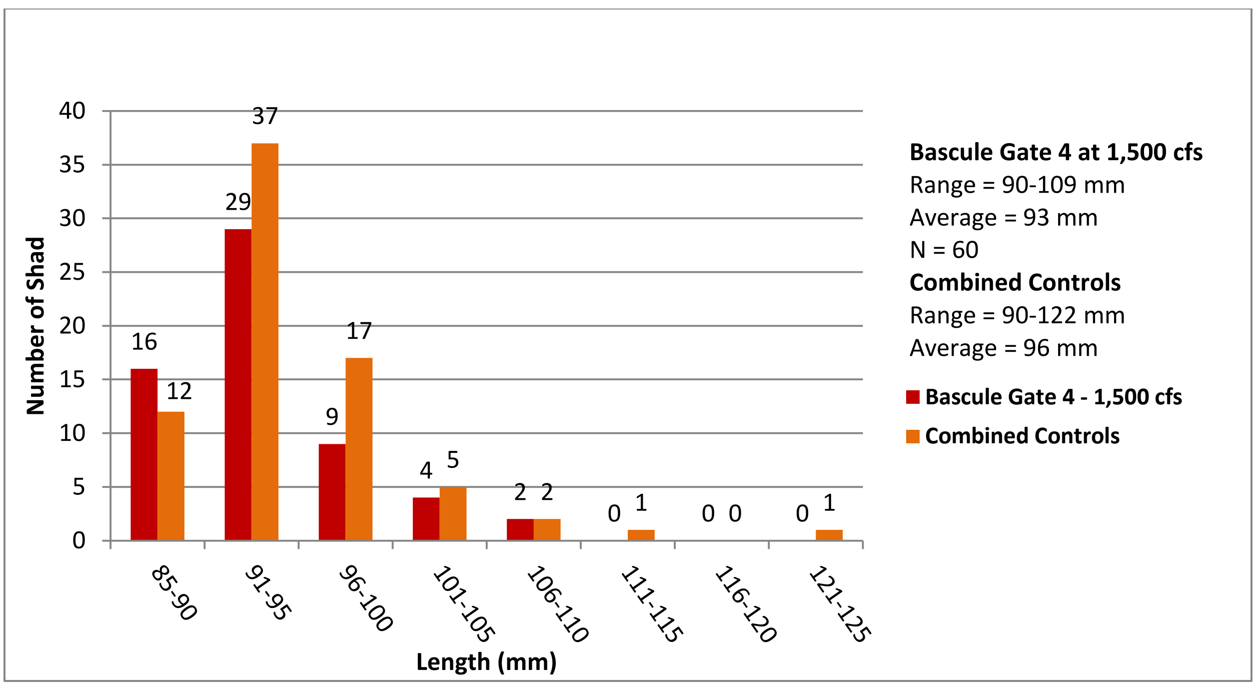


Figure 4-23 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 4 at 1,500 cfs versus combined controls.

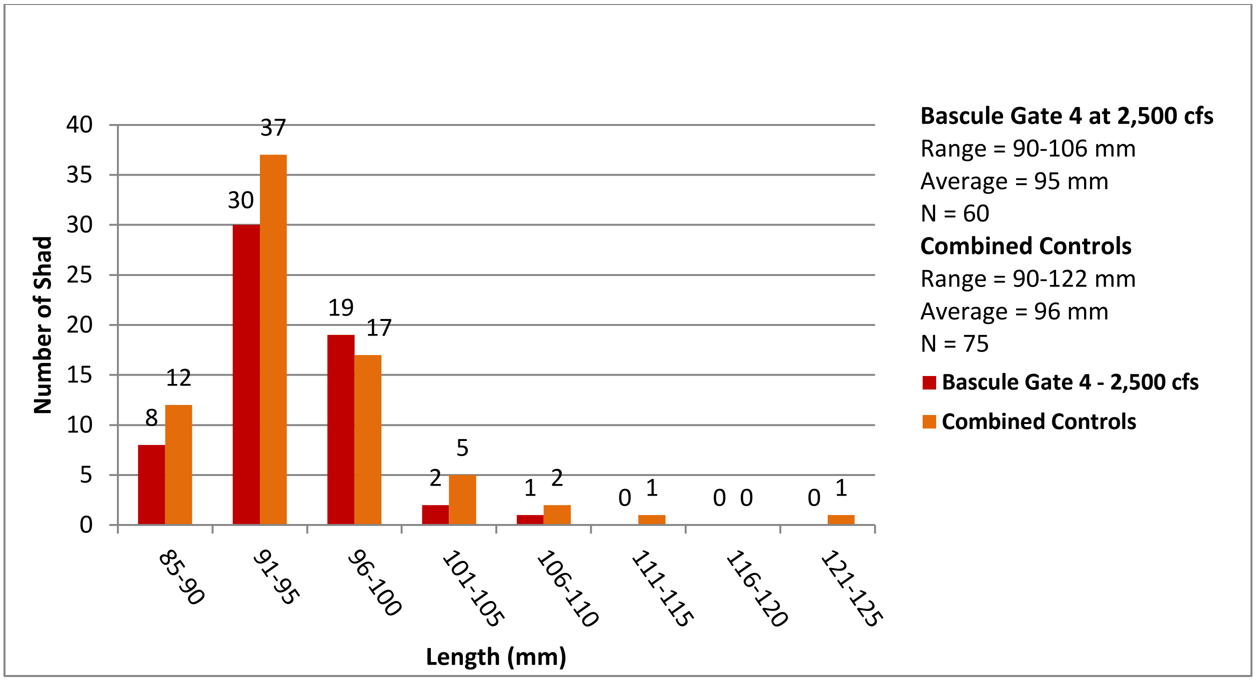


Figure 4-24 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 4 at 2,500 cfs versus combined controls.

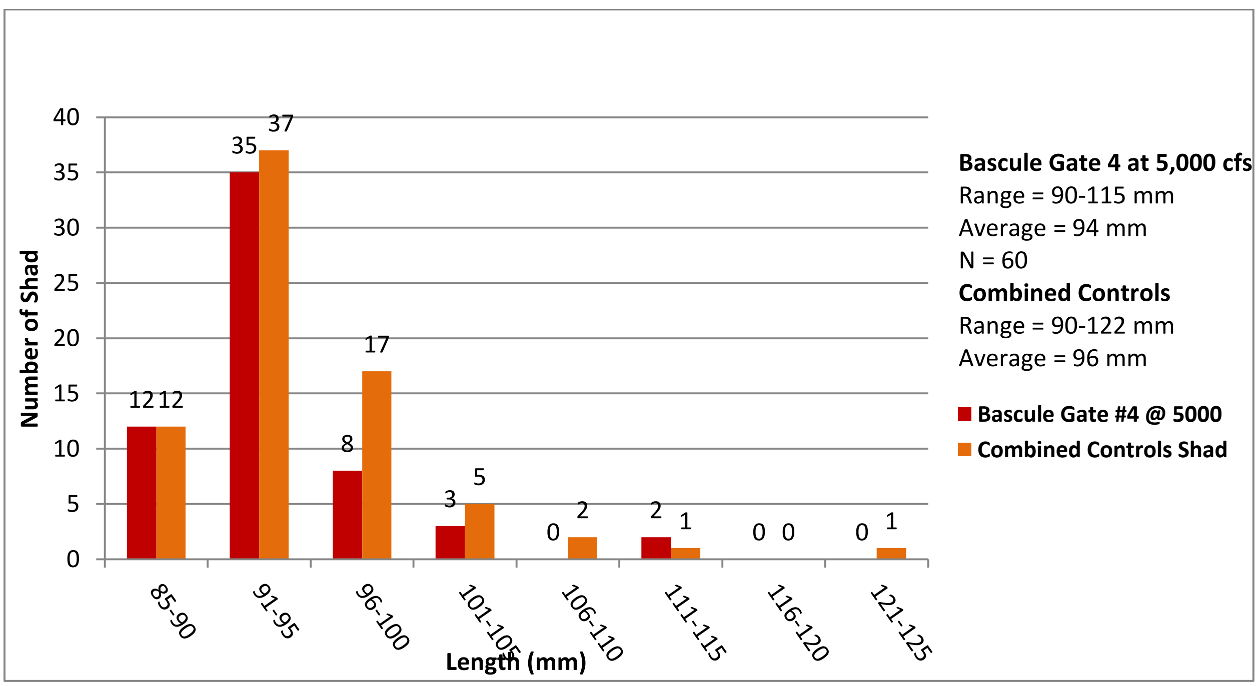


Figure 4-25 Length frequency for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 4 at 5,000 cfs versus combined controls.

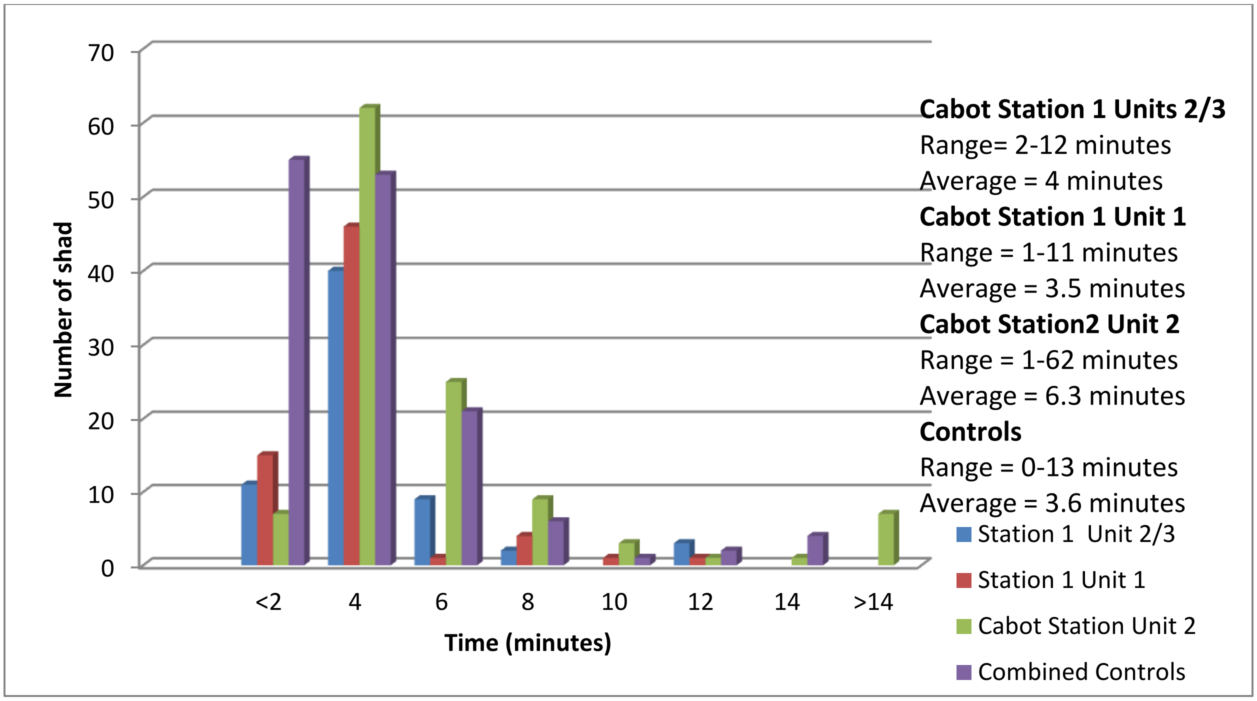


Figure 4-26 Recapture times for HI-Z tagged treatment juvenile American Shad released at Cabot Station Unit 2, Station No. 1 Unit 1, and Station No. 1 Unit 2/3 and combined controls.

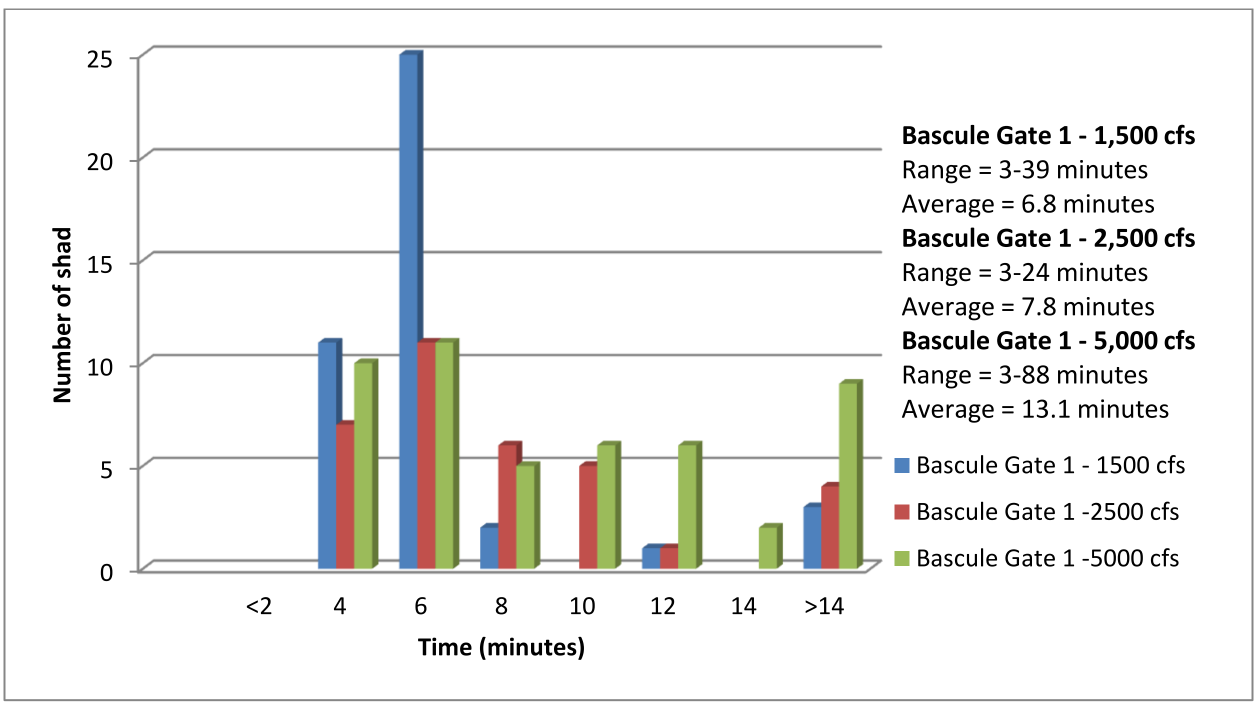


Figure 4-27 Recapture times for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 1 into 1,500, 2,500, and 5,000 cfs conditions.

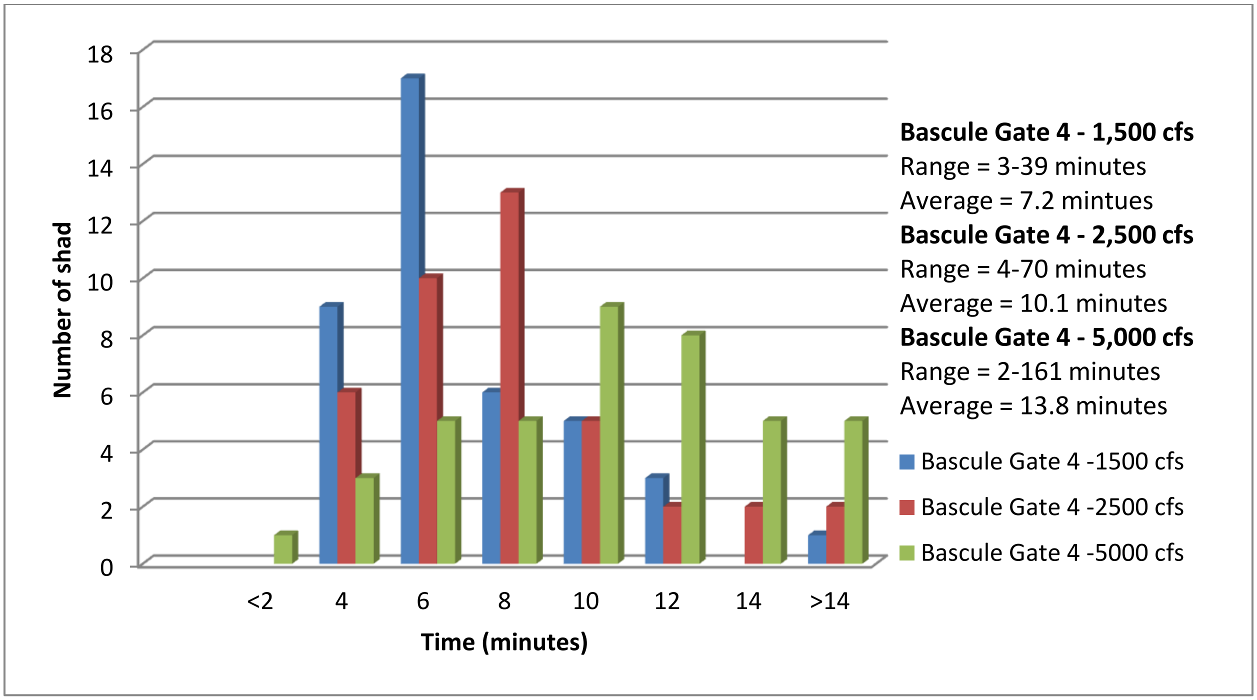


Figure 4-28 Recapture times for HI-Z tagged treatment juvenile American Shad released at Bascule Gate 4 into 1,500, 2,500, and 5,000 cfs conditions.

# APPENDIX A

# INDIVIDUAL FISH DISPOSITION DATA

## Appendix A

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

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

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

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

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

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

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

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|---|---|---|---|---|---|---|---|
| C01 | 91 | 14:42 | 14:44 | *2* | 1 | 1 | A |
| C02 | 90 | 14:43 | 14:44 | *1* | 1 | 1 | A |
| C03 | 90 | 14:45 | 14:49 | *4* | 1 | 1 | A |
| C04 | 94 | 14:47 | | | 0 | 4 | |
| C05 | 97 | 14:49 | 14:53 | *4* | 1 | 1 | A |
| C06 | 93 | 14:49 | | | | | R |
| C07 | 98 | 14:50 | 14:52 | *2* | 1 | 1 | A |
| C08 | 91 | 14:52 | 14:55 | *3* | 1 | 1 | A |
| C09 | 96 | 15:00 | 15:01 | *1* | 1 | 1 | A |
| C10 | 90 | 15:01 | 15:03 | *2* | 1 | 1 | A |
| C11 | 93 | 15:05 | 15:07 | *2* | 1 | 1 | A |

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

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

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

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

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

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

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

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

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

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|---|---|---|---|---|---|---|---|---|---|---|
| 37 | 95 | 13:05 | 13:11 | *6* | 1 | 1 | H | * | | |
| 38 | 90 | 13:07 | 13:13 | *6* | 1 | 1 | H | * | | |
| 39 | 98 | 13:08 | | | 0 | 5 | | | | |
| 40 | 96 | 13:10 | | | 0 | 5 | | | | |
| 41 | 96 | 13:42 | 13:46 | *4* | 1 | 1 | H | * | | |
| 42 | 91 | 13:43 | | | 0 | 5 | | | | |
| 43 | 90 | 13:43 | 13:48 | *5* | 1 | 2 | 9 | B | * | |
| 44 | 100 | 13:44 | 13:52 | *8* | 1 | 1 | H | 5 | * | 9 |
| 45 | 93 | 13:44 | 13:50 | *6* | 1 | 2 | A | * | | |
| 46 | 103 | 13:45 | | | 0 | 5 | | | | |
| 47 | 102 | 13:50 | 14:01 | *11* | 1 | 1 | H | * | | |
| 48 | 91 | 13:51 | | | 1 | 3 | | | | |
| 49 | 95 | 13:52 | 13:59 | *7* | 1 | 1 | H | * | | |
| 50 | 93 | 13:54 | | | 0 | 5 | | | | |
| 51 | 109 | 14:36 | 14:41 | *5* | 1 | 1 | A | | | |
| 52 | 90 | 14:37 | 14:43 | *6* | 1 | 1 | H | * | | |
| 53 | 94 | 14:38 | 14:48 | *10* | 1 | 1 | H | * | 9 | |
| 54 | 91 | 14:39 | 14:43 | *4* | 1 | 1 | H | E | * | |
| 55 | 103 | 14:40 | | | 0 | 5 | | | | |
| 56 | 96 | 14:40 | | | 0 | 5 | | | | |
| 57 | 90 | 14:41 | 14:45 | *4* | 1 | 1 | A | | | |
| 58 | 96 | 14:44 | | | 0 | 5 | | | | |
| 59 | 95 | 14:45 | 14:49 | *4* | 1 | 1 | A | | | |
| 60 | 90 | 14:46 | | | 0 | 5 | | | | |
| 61 | 106 | 14:46 | 14:53 | *7* | 1 | 1 | H | * | | |
| 62 | 102 | 14:47 | | | 0 | 5 | | | | |
| 63 | 93 | 14:48 | | | 0 | 5 | | | | |

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|---|---|---|---|---|---|---|---|---|
| C01 | 98 | 15:48 | 15:50 | *2* | 1 | 1 | A | |
| C02 | 90 | 15:49 | 15:52 | *3* | 1 | 1 | A | |
| C03 | 107 | 15:50 | 15:54 | *4* | 1 | 1 | A | |
| C04 | 104 | 15:50 | 15:53 | *3* | 1 | 1 | H | * |
| C05 | 98 | 15:51 | 15:53 | *2* | 1 | 1 | A | |
| C06 | 95 | 15:51 | 15:55 | *4* | 1 | 1 | A | |
| C07 | 97 | 15:52 | 15:57 | *5* | 1 | 1 | A | |
| C08 | 98 | 15:52 | 15:57 | *5* | 1 | 1 | A | |
| C09 | 94 | 15:55 | 16:03 | *8* | 1 | 1 | A | |
| C10 | 90 | 15:55 | 15:58 | *3* | 1 | 1 | A | |

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|---|---|---|---|---|---|---|---|---|---|
| 1 | 93 | 10:18 | 10:26 | *8* | 1 | 1 | 9 | * | |
| 2 | 101 | 10:18 | | | 0 | 5 | | | |
| 3 | 106 | 10:18 | 10:25 | *7* | 1 | 1 | A | | |
| 4 | 92 | 10:19 | | | 0 | 4 | | | |
| 5 | 94 | 10:19 | | | 0 | 4 | | | |
| 6 | 91 | 10:21 | 10:28 | *7* | 1 | 2 | B | * | |
| 7 | 99 | 10:22 | 10:26 | *4* | 1 | 1 | A | | |
| 8 | 91 | 10:22 | 10:33 | *11* | 1 | 1 | A | | |
| 9 | 94 | 10:23 | | | | | R | | |
| 10 | 91 | 10:23 | | | | | R | | |
| 11 | 98 | 11:09 | 11:16 | *7* | 1 | 2 | G | * | 9 |
| 12 | 91 | 11:10 | 11:19 | *9* | 1 | 2 | 8 | B | * |
| 13 | 91 | 11:10 | 11:18 | *8* | 1 | 2 | F | E | * |
| 14 | 95 | 11:11 | 11:19 | *8* | 1 | 1 | H | W | * |
| 15 | 100 | 11:12 | 11:16 | *4* | 1 | 1 | H | B | * |
| 16 | 98 | 11:13 | 11:18 | *5* | 1 | 1 | A | | |

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

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|---|---|---|---|---|---|---|---|---|---|
| C10 | 104 | 16:04 | 16:08 | *4* | 1 | 1 | H | * | |
| C11 | 91 | 16:02 | 16:04 | *2* | 1 | 1 | A | | |
| C12 | 97 | 16:06 | 16:08 | *2* | 1 | 1 | A | | |
| C13 | 95 | 16:13 | 16:17 | *4* | 1 | 1 | A | | |
| C14 | 92 | 16:13 | 16:16 | *3* | 1 | 1 | A | | |
| C15 | 92 | 16:13 | 16:15 | *2* | 1 | 1 | A | | |
| C16 | 94 | 16:15 | 16:17 | *2* | 1 | 1 | H | * | |

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

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

# APPENDIX B

# DAILY TAG/RECAPTURE DATA

**Appendix B**

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

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

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

**Appendix B**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

# APPENDIX C

# DETAILED FISH INJURY DATA

## Appendix C

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

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

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

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

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10/16/15 | 1A | 074 | dead | 1h | Torn Isthmus | Yes | Yes | Major | Shear |
| 10/16/15 | 1A | 077 | alive | | LOE, Hem. R. pectoral | Yes | No | Major | Mechanical |
| 10/16/15 | 1A | 082 | alive | | LOE | No | No | Minor | Undetermined |
| 10/16/15 | 1A | 085 | dead | 24h | LOE | No | No | Minor | Undetermined |
| 10/16/15 | 1A | C03 | alive | | LOE | No | No | Minor | Undetermined |
| 10/16/15 | 1A | C05* | alive | | LOE | No | No | Minor | Undetermined |
| 10/16/15 | 1A | C12* | alive | | LOE | No | No | Minor | Undetermined |
| 10/16/15 | 1A | C15* | dead | 24h | LOE | No | No | Minor | Undetermined |
| **Date** | **Test Lot** | **Fish ID** | **Live/Dead** | | **Maladies** | **Passage Malady*** | **Photo** | **Malady Severity** | **Probable Cause** |
| | | | | | **Station No. 1 Unit 1** | | | | |
| 10/17/15 | 2A | 005 | dead | 24h | LOE | No | No | Minor | Undetermined |
| 10/17/15 | 2A | 006 | dead | 24h | LOE | No | No | Minor | Shear |
| 10/17/15 | 2A | 008 | dead | 1h | LOE, Hem. R. pectoral | Yes | Yes | Major | Mechanical |
| 10/17/15 | 2A | 010 | alive | | LOE | No | No | Minor | Undetermined |
| 10/17/15 | 2A | 011 | alive | | LOE, Hem. R. eye | Yes | No | Minor | Shear |
| 10/17/15 | 2A | 013 | dead | 48h | LOE | No | No | Minor | Undetermined |
| 10/17/15 | 2A | 020 | alive | | LOE, bulging eyes, Hem behind operc. | Yes | No | Minor | Shear |
| 10/17/15 | 2A | 021 | alive | | LOE | Yes | No | Minor | Shear |
| 10/17/15 | 2A | 023 | dead | 1h | LOE | Yes | No | Major | Undetermined |
| 10/17/15 | 2A | 026 | dead | 24h | LOE | No | No | Minor | Undetermined |
| 10/17/15 | 2A | 032 | dead | 24h | LOE | No | No | Minor | Undetermined |
| 10/17/15 | 2A | 034 | dead | 24h | LOE | No | No | Minor | Undetermined |
| 10/17/15 | 2A | 035 | dead | 24h | LOE | No | No | Minor | Undetermined |
| 10/17/15 | 2A | 036 | dead | 1h | LOE | Yes | No | Major | Undetermined |
| 10/17/15 | 2A | 038 | dead | 1h | R. Eye Missing, R. Operculum, Torn | Yes | Yes | Major | Shear |
| 10/17/15 | 2A | 041 | dead | 1h | Necropsied, no obvious injuries | Yes | No | Major | Undetermined |
| 10/17/15 | 2A | 053 | dead | 24h | Hem, Snout | Yes | Yes | Major | Mechanical |
| 10/17/15 | 2A | 055 | dead | 1h | Decapitated | Yes | Yes | Major | Shear |
| 10/17/15 | 2A | 057 | alive | | LOE | No | No | Minor | Undetermined |

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

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

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

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

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

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

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

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

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

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

| Date | Test Lot | Fish ID | Live/Dead | | Maladies | Passage Malady* | Photo | Malady Severity | Probable Cause |
|---|---|---|---|---|---|---|---|---|---|
| 10/23/2015 | 7 | 046 | dead | 24h | LOE | No | No | Minor | Undetermined |
| 10/23/2015 | 7 | 049 | dead | 24h | Tag Tear, L. Operc. Flare | Yes | Yes | Minor | Shear |
| 10/23/2015 | 7 | 050 | dead | 1h | L. Operc flare, bruise head | Yes | Yes | Major | Shear/Mech |
| 10/23/2015 | 7 | 051 | dead | 24h | LOE, min bruise body | Yes | No | Minor | Mechanical |
| 10/23/2015 | 7 | 052 | dead | 24h | LOE>20% R. Scale loss both sides, hemm dorsal | Yes | Yes | Minor | Mechanical |
| 10/23/2015 | 7 | 053 | dead | 24h | LOE | No | No | Minor | Undetermined |
| 10/23/2015 | 7 | 054 | dead | 24h | LOE>20% R. Scale loss both sides, | Yes | No | Minor | Mechanical |
| 10/23/2015 | 7 | 055 | dead | 24h | LOE, bruise on head | Yes | No | Minor | Mechanical |
| 10/23/2015 | 7 | 056 | alive | | LOE | No | No | Minor | Undetermined |
| 10/23/2015 | 7 | C16* | dead | 24h | LOE | No | No | Minor | Undetermined |

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

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

*control fish

# APPENDIX D

# SURVIVAL AND MALADY-FREE STATISTICAL OUTPUTS

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

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

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


 log-likelihood : -114.7842

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

Z statistic for the equality of equal turbine survivals:
              5.0305

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

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

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

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


 log-likelihood : -166.3047

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

Z statistic for the equality of equal turbine survivals:
              1.2666

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

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

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

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


 log-likelihood : -109.0662

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

Z statistic for the equality of equal turbine survivals:
              2.2715

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

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

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

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


 log-likelihood : -88.9540

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

Z statistic for the equality of equal turbine survivals:
              1.2475

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

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

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

 log-likelihood : -107.1484

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

Z statistic for the equality of equal turbine survivals:
              1.2934

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

Estimating parameters for MODEL #2
fletch finished (1)


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

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

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


 log-likelihood : -109.3749

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

Z statistic for the equality of equal turbine survivals:
              1.2140

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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


Likelihood ratio statistic for equality of recovery probabilities:
       4.4528

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

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

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

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

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

 log-likelihood : -287.6873
```

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

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

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

Estimating parameters for MODEL #2
fletch finished (1)


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

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

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


 log-likelihood : -289.1732

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

Z statistic for the equality of equal turbine survivals:
              0.3967

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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


Likelihood ratio statistic for equality of recovery probabilities:
       2.9717

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

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

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

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

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

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


 log-likelihood : -67.0787
```

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

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

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

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

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

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

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

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


 log-likelihood : -71.3420
```

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

```
Z statistic for the equality of equal turbine survivals:
              1.3532

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

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

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

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


 log-likelihood : -57.0351

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

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

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

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

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

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


 log-likelihood : -72.5360
```

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

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

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

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

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

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


 log-likelihood : -68.2348

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

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

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

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

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

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

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


 log-likelihood : -174.1551

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

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

Compare with quantiles of the normal distribution:

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

Variance-Covariance matrix for estimated probabilities:

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

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

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

# APPENDIX B – DIRECT INJURY AND RELATIVE SURVIVAL OF ADULT AMERICAN EELS AT THE TURNERS FALLS HYDROELECTRIC PROJECT (NAI, 2016b)

# DIRECT INJURY AND RELATIVE SURVIVAL OF ADULT AMERICAN EELS AT THE TURNERS FALLS HYDROELECTRIC PROJECT (NO. 1889)

Prepared for

FirstLight

GDF SUEZ

Prepared by

***NORMANDEAU ASSOCIATES, INC.***


1921 River Road

Drumore, Pennsylvania 17518


July 2016

## EXECUTIVE SUMMARY

The overall goal of this study was to assess whether operations at Cabot Station Unit 2, Station No. 1 (Units 1 and 2/3) and over the Bascule Gates (1 and 4) affects the safe passage of emigrating adult silver-phase American Eels (*Anguilla rostrata*).

FirstLight Hydro Generating Company (FirstLight) is licensed by the Federal Energy Regulatory Commission (FERC or the Commission) to operate the Turners Falls Hydroelectric Project (FERC No. 1889) and the Northfield Mountain Pumped Storage Project (FERC No. 2485). Both Projects utilize water from the Connecticut River to generate hydroelectric power. The current FERC licenses for both Projects expire on April 30, 2018. Every 30-50 years, Licensees are required to relicense their hydroelectric facilities with FERC. Although the Turners Falls Project and Northfield Mountain Pumped Storage Project are currently licensed as separate projects, FirstLight is seeking a single license for both developments. A primary objective of this study was to test 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 was 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 No. 1, and over Bascule Gates 1 and 4 at three treatment discharges of 1,500, 2,500 and 5,000 cfs. Units 2 and 3 of Station No. 1 have a common penstock thus independent survival estimates could not be determined for each unit separately.

Eels used in this study were imported from a commercial fisher in Newfoundland in accordance with state and Federal law and as stipulated in Permit Number 088.15LP issued by Massachusetts Division of Fisheries and Wildlife on October 20, 215. Eels were held at each project in tanks, 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 No. 1 through Unit 1 and Units 2/3 were assessed with 60 treatment fish. The effects of spillway passage through Bascule Gates 1 and 4 were assessed by releasing 95 treatment eels at both locations. Twenty-five (25) control eels were released downstream of the treatment sites.

The treatment eels ranged from 400-960 mm in total 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 No. 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 No. 1 Unit 1, and Station No. 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 No. 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 (48 h) survivals for Cabot Station Unit 2 and Station No. 1 Units 1 and 2/3 were 96.0, 90.0, and 62.1%, respectively. The estimated immediate (48 h) 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 (48 h) 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 No. 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 and loss of equilibrium, were designated a malady-free status. Malady-free estimate rates were adjusted by any maladies incurred by control fish. The adjusted malady-free estimates for recaptured fish at Cabot Station Unit 2, Station No. 1 Unit 1 and Units 2/3, and Bascule Gates 1 and 4 at 1,500, 2,500, and 5,000 cfs were generally greater than 95%, with the exception of Units 2/3 of Station No. 1 (malady-free estimate of 79.0%).

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 No. 1 Unit 1. The study results indicate that adult eels should incur little mortality or injury passing the Francis units except for the smaller units at Station No. 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 of the 190 bascule gate passed eels was likely higher than reported because some of the 20 unrecaptured eels assigned a dead status were likely alive, however the exact status of these unrecaptured eels could not be determined. 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. | Kleinschmidt 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 | Nephelometric 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 Turners Falls Hydroelectric Project (FERC No. 1889) operated by FirstLight Power Resources (FirstLight), 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. Cabot Station Unit 2, Station No. 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 No. 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 and Station No. 1, as well as over the Bascule Gates at three 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 48 h) survival and malady-free rates (eels without visible injuries and no loss of equilibrium) of adult American Eels passing Cabot Station Unit 2, Station No. 1 Units 1 and 2/3, and over the Bascule Gates 1 and 4. Survival and malady-free estimates were to be within ±10%, 90% of the time. Survival and malady-free estimates were to be obtained under typical operational parameters, and Bascule Gates were evaluated at discharges of 1,500, 2,500, and 5,000 cfs.

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

## 3.0 PROJECT DESCRIPTION

The Turners Falls Hydroelectric Project and Northfield Mountain Pumped Storage Project are located on the Connecticut River in the states of Massachusetts (MA), New Hampshire (NH), and Vermont (VT) (Figure 1-1). The Turners Falls Dam is located at approximately river mile 122 (above Long Island Sound) on the Connecticut River in the towns of Gill and Montague, MA. The dam creates an impoundment extending upstream approximately 20 miles to the base of TransCanada's Vernon Hydroelectric Project Dam in VT/NH. A gatehouse at the Turners Falls Dam controls flow into a power canal that supplies two hydroelectric generating facilities: Cabot Station and Station No. 1. Cabot Station is located at the downstream terminus of the power canal and Station No. 1 is located approximately one-third of the way down the power canal. Cabot Station and Station No. 1 discharge into the Connecticut River approximately 0.9 miles downstream of the Turners Falls Dam. Discharge over the Turners Falls Dam is regulated by four Bascule Gates and three tainter gates (Figures 1-1 and 2-1 to 2-3).

### 3.1 Cabot Station and Station No. 1

FirstLight has two hydroelectric facilities located on the power canal, including Cabot Station and Station No. 1. Cabot Station is located at the downstream terminus of the power canal and 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 No. 1 operates under a gross head of approximately 43.7 feet, and has six horizontal Francis turbines with an approximate total electrical capacity and hydraulic capacity of 5,693 kilowatts (kW) and 2,210 cfs, respectively (Table 3-1). Two of the Francis units (Units 2 and 3) tested in this study share a common penstock.

### 3.2 Turners Falls Dams

The Turners Falls Dam consists of two individual concrete gravity dams, referred to as the Gill Dam and Montague Dam, which are connected by a natural rock island known as Great Island. The 630-foot-long Montague Dam is founded on bedrock and connects Great Island to the west bank of the Connecticut River. It includes four bascule type gates and a fixed crest section. When fully upright, the tops of the Bascule Gates are at elevation 185.5 feet mean sea level (msl). The 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 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 the project area. Downstream turbine and Bascule Gate passage survival and injury were assessed with 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

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 for other concurrent eel research projects (e.g., the TransCanada Projects relicensing studies 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. FirstLight and TransCanada consultants jointly prepared and submitted to Massachusetts Department of Fish and Wildlife (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. Kleinschmidt provided additional information on pathogen testing and holding procedures to MDFW and the United States Fish and Wildlife Service (USFWS) in letters dated April 7 and June 6, 2015 and July 16, 2015, respectively. Normandeau provided additional requested information on July 16, 2015. 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 MDFW issued import permits after review of the pathology test reports.

### 4.2 Study Design

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 No. 1. Eels were released upstream of Bascule Gates 1 and 4 at discharges of 1,500, 2,500, and 5,000 cfs, at each gate. 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 48 h 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 parameters measured during the release of treatment adult eels through the turbines and Bascule Gates 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, Inc., 2010, 2011a, and 2011b) 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 any such 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 No. 1, and 30 into Station No. 1 Units 2/3. One hundred ninety eels were released through the bascule gates including, thirty each through Bascule Gates 1 and 4 at 2,500 and 5,000 cfs, and 35 each through 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 Turners Falls Dam. Eels were captured with dip nets and transported in pails or tubs to the tagging sites. Prior to tagging, eels were examined for any injuries and any observed injuries were recorded. If injuries were considered major (see section 4.2.5), the eel was not tagged.

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 4-1 and 4-2).

Eels were individually marked and identified with 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 No. 1, and over Bascule Gates 1 and 4 for treatment eels. The induction system and release hoses were continuously supplied with river water 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 directed eels into the tailrace downstream of the turbines and downstream of the Bascule Gates at the spillway (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 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 (see Section 4.2.4).

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 48 h 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 2011b; Normandeau Associates, Inc. and Skalski, 1998 and 2005; and North/South Consultants Inc. and Normandeau Associates, Inc., 2007 and 2009), 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—eel 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 48 h 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 48 h 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 48 h 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 which conditions and locations provide the safest routes for eel passage.

### 4.2.6 Survival and Malady-Free Estimation

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

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

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

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

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

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

The estimators associated with the likelihood model are:

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

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

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

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

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

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

Where,

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

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

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

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

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

Direct Survival, 1 and 48 h

Where:

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

$R_{Ti}$ = Number of 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 48 h 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 48 h 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 2011b). Passage through gaps between the runner blades and the hub or at the blade tips may result in pinched bodies (Normandeau Associates *et al*., 1995). Contact with the turbine structural components may result in bruising. Injuries likely to be attributed to shear forces for salmonids are decapitation, torn or flared opercula, and hemorrhaged eyes (Dadswell *et al*., 1986). 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.

Ambient river water was continuously supplied to each tank and all eels were held for a minimum of 12-24 h prior to tagging to allow eels time to recover from transport and handling stress. Water temperatures in the holding pools were comparable with river temperature, which was 7.5ºC.

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 No. 1

Eels were transported in a tank by truck from eel holding pools adjacent to the Bascule Gates and delivered to a covered holding pool with a capacity of approximately 300 gal at Station No. 1. This water-level-regulated, covered tank was located near the Station No. 1 intake area. An additional similar sized pool was located in the same area to hold eels for the 48 h post-passage delayed assessment period. As with all scenarios, the transport/holding tank was continuously supplied with aeration and ambient river water. Water temperature in this tank was comparable with river temperature, which was 7.7ºC.

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 (Figure 4-9). The 30 treatment eels released through Units 2/3 ranged in length from 540-800 mm, with the average length of 665 mm (Figure 4-10). Only eels in good physical condition were used for this study.

#### 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 9.1ºC. 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 for Cabot Station, Station No. 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 assigned dead. 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 No. 1

Treatment eels were released through the Francis Units 1 and 2/3 at Station No. 1 on November 9, 2015. Thirty treatment eels were released through  Unit 1 and 30 through 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. For Units 2/3, only 19 (63.3%) of the 30 released eels were recaptured, with eighteen of recaptured eels alive and one 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 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 cfs, 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 (Figure 5-1).

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 No. 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 No. 1 Unit 1, ranged from 2 to 11 minutes and averaged 4 minutes. For Station No. 1 Units 2/3, recapture times ranged from 2 to 87 minutes and averaged 9.6 minutes (Figure 5-2).

### 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 5-3 and 5-4). A few eels became entrapped in underwater boulders and crevices and were not recaptured until the eels escaped after 22 to 139 minutes. Some eels apparently did not escape during the monitoring period which ranged from 1 hour for eels released at the end of the day and up to 5 hours for eels released early in the day.

## 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 48 h of 96%. The precision of the 48 h survival estimates for the Unit 2 eels was within ±4.6%, 90% of the time (Table 5-1).

### 5.3.2 Station No. 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 48 h 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 48 h direct survival rate for Units 2/3 was lower at 62.1%. The precision of the 1 and 48 h 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 dislodged HI-Z inflated balloon tags were retrieved from 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 48 h survival rates at 1,500 cfs were 88.2% (CI 4.0%; Table 5-1). Eel survival (1 and 48 h) 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 48 h. The overall 48 h survival was 86.8% (CI 5.9%). None of the recaptured fish passed through Bascule Gate 1 was dead or died in holding. Overall, 12.6% of the mortality was assigned to eels that were not retrieved; HI-Z tags only on 2% of these fish and a stationary radio signal on the remaining fish (Table 5-1). The survival estimates are likely higher because eels have been recaptured in good condition with missing HI-Z tags and also some of the stationary signals were likely from eels that worked their way into rock crevices before the tags could buoy them to the surface (Figure 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 48 h delayed assessment period (Table 5-1). Survival at 1 and 48 h 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 48 h eel survival at Bascule Gate 4 was 88.4% (CI 5.4%) (Table 5-1). As observed at Bascule Gate 1 the actual survival at Bascule Gate 4 was also likely higher because a portion of the 8% of the non-recaptured eels assigned dead were likely alive.

## 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 48 h assessment period, however, no external or internal injuries were observed (Tables 5-2 to 5-4).

### 5.4.2 Station No. 1

None of the 26 eels recaptured after passage through Station No. 1 Unit 1 was 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 had 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 appeared to recover by 48 h (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 decapitated (Tables 5-1 to 5-3). Injuries were classified as major and strike-induced. The cause of decapitation after passing over a Bascule Gate was 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 No. 1 Unit 1 was 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 No. 1 Units 2/3. Since Units 1 and 3 at Station No. 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% 48 h 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 (48 h) 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 speeds (112.5 and 144 rpm) had generally lower survival (62.0 to 87.5%).

HI-Z tagged adult eels have been passed through seven different Francis Units; this includes the four from the present study (Cabot Station Unit 2, Station No. 1 Units 1 and 2/3). Three of the larger units, including Cabot Station Unit 2, had 13 to 15 buckets, 110 to 174 in diameter, and runner speeds of 75 to 97 rpm (Table 5-6). The 48 h survival for these units was high at 96 to 98%. Two smaller Francis Units, including Station No. 1 Unit 1, with 13 buckets, 54 and 62 in diameters, and 200 and 133 rpms had 90% (Station No. 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 No. 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 speed (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 5-5 to 5-7 and indicate that eels fare best passing large, low speed Francis turbines.

### 5.6.2 Bascule Gates

The passage of adult eels through the Bascule Gates of the Turners Falls Dam 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 salmonids. Survival (48 h) of the adult salmonids (mean lengths 446-716 mm) ranged from 9-100% and injury rates from 0-100%. Survival rates were greater than 96% with injury rates less than 25% for seven of these studies. Low survival and high injury occurred when the adult salmonids 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, shear/pressure forces, season, collision with spill basin structures, depth of transport water "cushion", 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, 2011d, 2013, 2014a, and 2014b; Normandeau Associates, Inc. and Skalski, 2005, 2006a, and 2006b; Normandeau Associates, Inc. *et al*., 1996; Heisey *et al*., 2008a and 2008b). Based on these findings, depth of water discharged over the Bascule Gates and the boulders and concrete in the spill jet path likely have the most impact 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 incur minor mortality (≤4%) or injury (≤4.1%) passing the large Francis units at the Cabot Station. Eels also fare well (approximately 90% survival and little injury) passing the larger of the Francis units at Station No. 1. However, results indicate that the units with a common penstock leading to both a larger and smaller unit inflict up to 40% mortality.

### 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 high, 86.8 and 88.4%. These estimates are likely conservative and survival of the 190 bascule gate passed eels was likely higher since some of the 20 eels assigned as 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 Turners Falls Hydroelectric Project where fish passage survival tests were conducted.**

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

**Table 4-1**
**Average discharge through Bascule Gates 1 and 4, Cabot Station Unit 2, and Station No. 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 | 2494.22 |
| **11/5/15** | **Bascule Gate #4: 1500 cfs*** | N/A | 1576 |
| **11/5/15** | **Bascule Gate #4: 5000 cfs*** | N/A | 5024.38 |
| **11/5/15** | **Bascule Gate #1: 1500 cfs*** | N/A | 1478.86 |
| **11/5/15** | **Bascule Gate #1: 2500 cfs*** | N/A | 2563.25 |
| **11/6/15** | **Bascule Gate #1: 2500 cfs*** | N/A | 2539 |
| **11/6/15** | **Bascule gate #1: 5000 cfs*** | N/A | 4975.33 |
| **11/7/15** | **Cabot Station: Unit 2**** | 10.28 | 2273.67 |
| **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

***Output and discharge for all units combined at Station No. 1

**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 No. 1 Unit 1 and Units 2/3, and over Bascule Gates 1 and 4 at Turners Falls, MA November 2015. Controls released downstream of treatment sites.**

| | Water Temperature (°C) | Bascule Gate 4 | | | Bascule Gate 1 | | | Cabot Station Unit 2 | Station No. 1: Unit 2/3 | Station No. 1: Unit 1 | Combined Controls |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1,500 cfs | 2,500 cfs | 5,000 cfs | 1,500 cfs | 2,500 cfs | 5,000 cfs | | | | |
| **Date** | | | | | | | | | | | |
| 11/4/15 | 8.7 | 30 | 30 | | | | | | | | 5 |
| 11/5/15 | 7.3 | 5 | | 30 | 35 | 15 | | | | | 5 |
| 11/6/15 | 9.3 | | | | | 15 | 30 | | | | 10 |
| 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 48 hours 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 | | | | Combined Controls |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1,500 cfs | 2,500 cfs | 5,000 cfs | BG 1 Combined | 1,500 cfs | 2,500 cfs | 5,000 cfs | BG 4 Combined | |
| 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 | 86 | 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 No. 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.**

| Date | Test Lot | Fish ID | Live/Dead | Dead at | Maladies | Passage Malady* | Photo | Malady Severity | Probable Cause |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Bascule Gate 4 at 1,500 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 2,500 cfs** | | | | |
| 11/4/2015 | 8E | 56 | dead | 1h | Decapitated | Yes | Yes | Major | Mechanical |
| | | | | | **Bascule Gate 1 at 1,500 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 No. 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 |

*Observed injury and LOE attributed to passage route

**Table 5-3**

**Summary of visible injury types and injury rates observed on recaptured adult American Eels passed through Cabot Station Unit 2, Station No. 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 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 No. 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 No. 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 No. 1 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 @ 1,500 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 @ 2,500 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 @ 5,000 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 @ 1,500 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 @ 2,500 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 @ 5,000 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 No. 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. 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 Unit 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 No. 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 No. 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: 1,500 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: 2,500 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: 5,000 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: 1,500 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: 2,500 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: 5,000 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 No. 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 the treatment sites. Proportions are given in parentheses.**

| | Cabot Station: Unit 2 | Station No. 1: Unit 1 | Station No. 1: Units 2/3 | Bascule Gate 1 | | | | Bascule Gate 4 | | | | Combined Controls (Cabot Station & Bascule Gates) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1,500 cfs | 2,500 cfs | 5,000 cfs | BG 1 Combined | 1,500 cfs | 2,500 cfs | 5,000 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 No. 1 (Unit 1)** | ***2015*** | ***Connecticut*** | ***Francis*** | **13** | **200.0** | **54.25 (2 runners)** | **43.7** | **2.0***** | ***present study*** |
| **Station No. 1 (Unit 2)**** | ***2015*** | ***Connecticut*** | ***Francis*** | **13** | **257.0** | **38.9** | **43.7** | **2.0***** | ***present study*** |
| **Station No. 1 (Unit 3)**** | ***2015*** | ***Connecticut*** | ***Francis*** | **15** | **200.0** | **55.3 (2 runners)** | **43.7** | **2.0***** | ***present study*** |
| ***Vernon*** | ***2015*** | ***Connecticut*** | ***Francis*** | ***13*** | ***133.3*** | ***62.5*** | ***35*** | **1.0** | **Draft** |
| ***Vernon*** | ***2015*** | ***Connecticut*** | ***Francis*** | ***12*** | ***75*** | ***110*** | ***34*** | **1.4** | **Draft** |
| ***Vernon*** | ***2015*** | ***Connecticut*** | ***Kaplan*** | ***5*** | ***144*** | ***122*** | ***32*** | **1.2** | **Draft** |
| ***Vernon*** | ***2015*** | ***Connecticut*** | ***Kaplan*** | ***5*** | ***144*** | ***122*** | ***32*** | **1.7** | **Draft** |
| ***Bellows Falls*** | ***2015*** | ***Connecticut*** | ***Francis*** | ***15*** | ***85.7*** | ***174*** | ***57*** | **3.3** | **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 No. 1 (Unit 1)** | ***American*** | **636** | **30** | **86.7** | **90.0** | **6.2** | **0.0** | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ***eel*** | | | | | | | |
| **Station No. 1 (Unit 2)** Station No. 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
***Discharge for all Station No. 1 units combined

# FIGURES

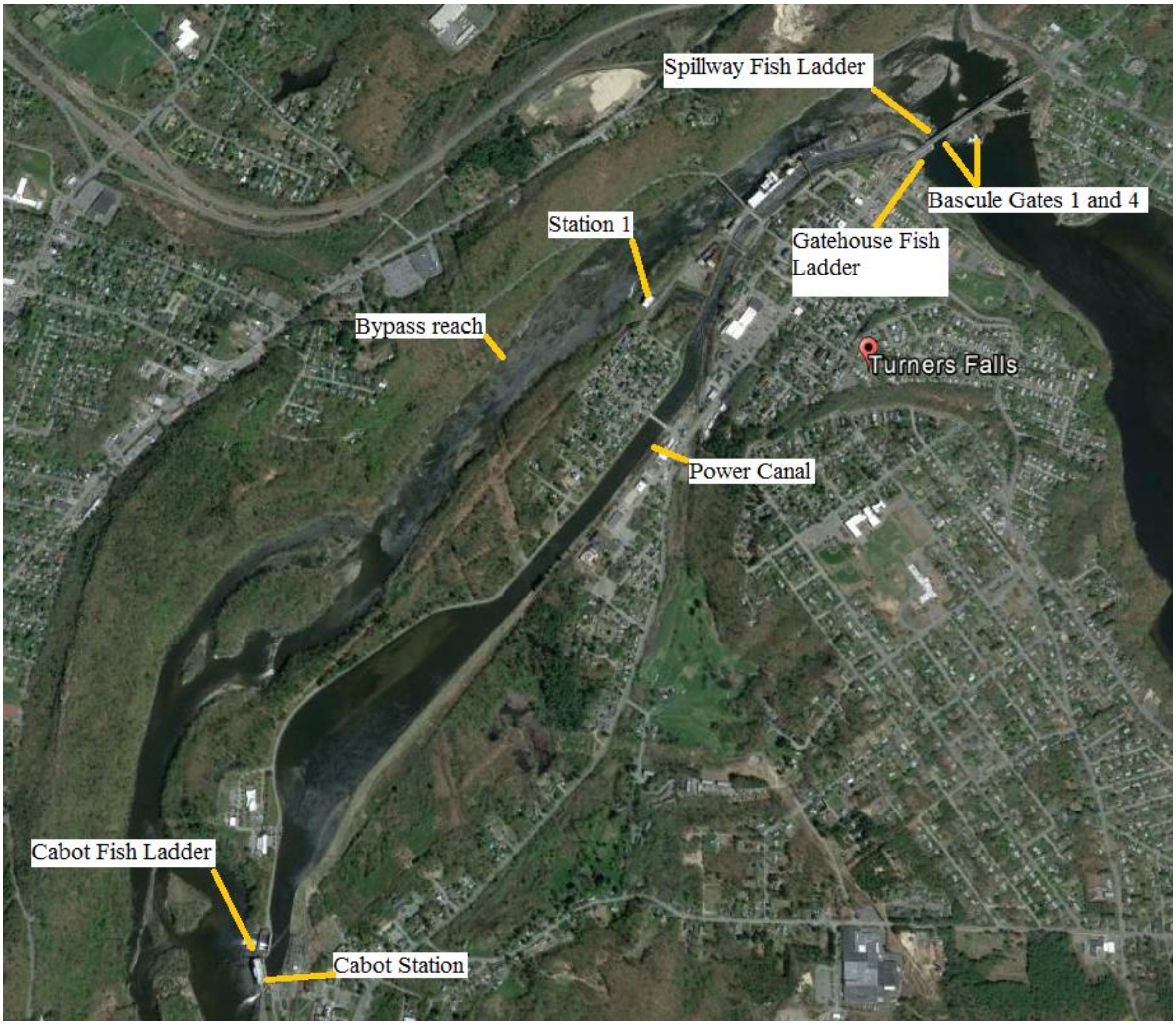


**Figure 1-1: Aerial view of the First Light study locations.**

**Figure 2-1: Inside Cabot Station.**

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

**Figure 2-3: Downstream of Bascule Gate 4 at 5,000 cfs.**

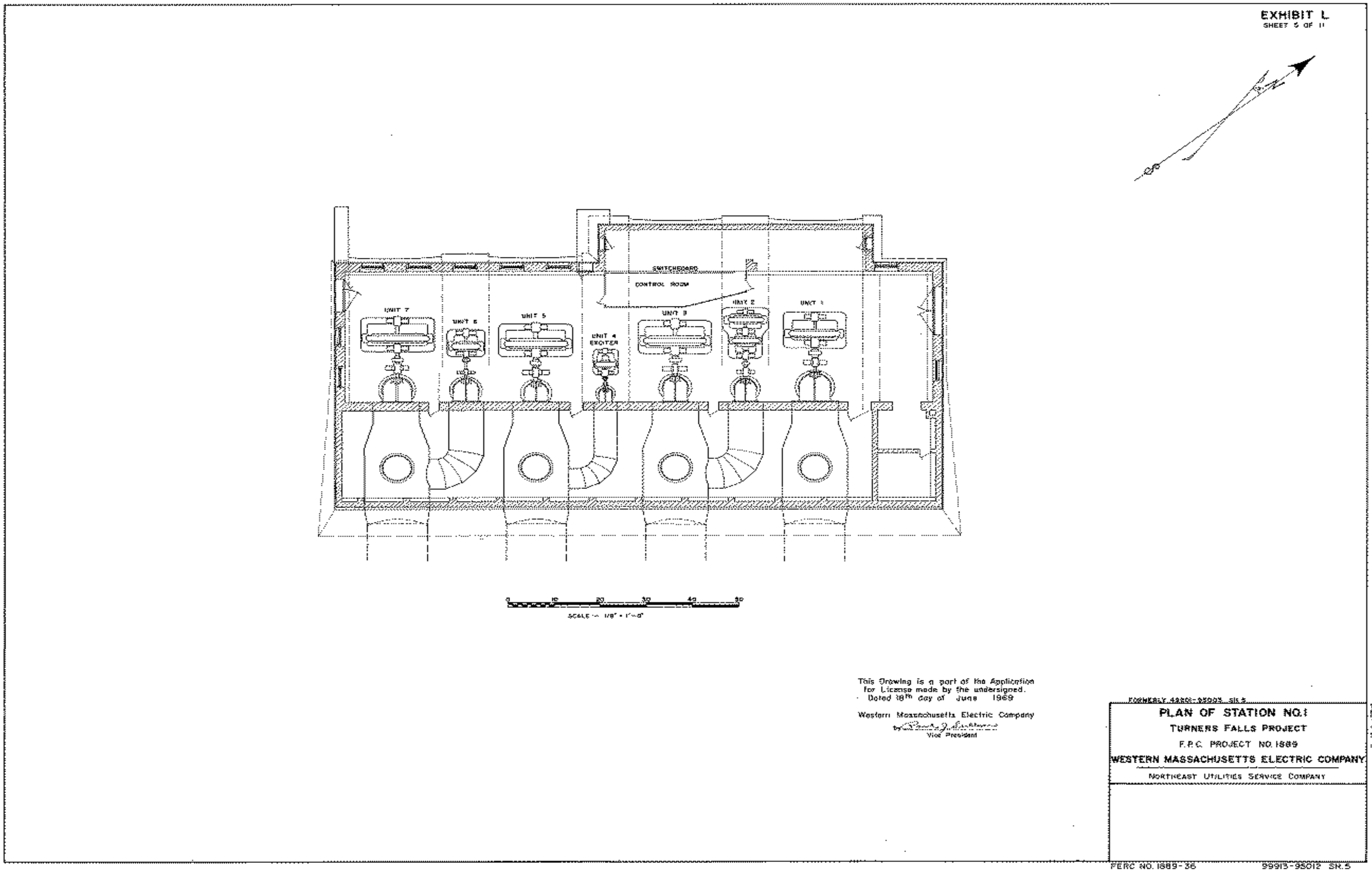


**Figure 3-1: Shared penstocks at Station No. 1. Unit 1 is shown at the far right and Units 2/3 are second and third from right with a common penstock.**

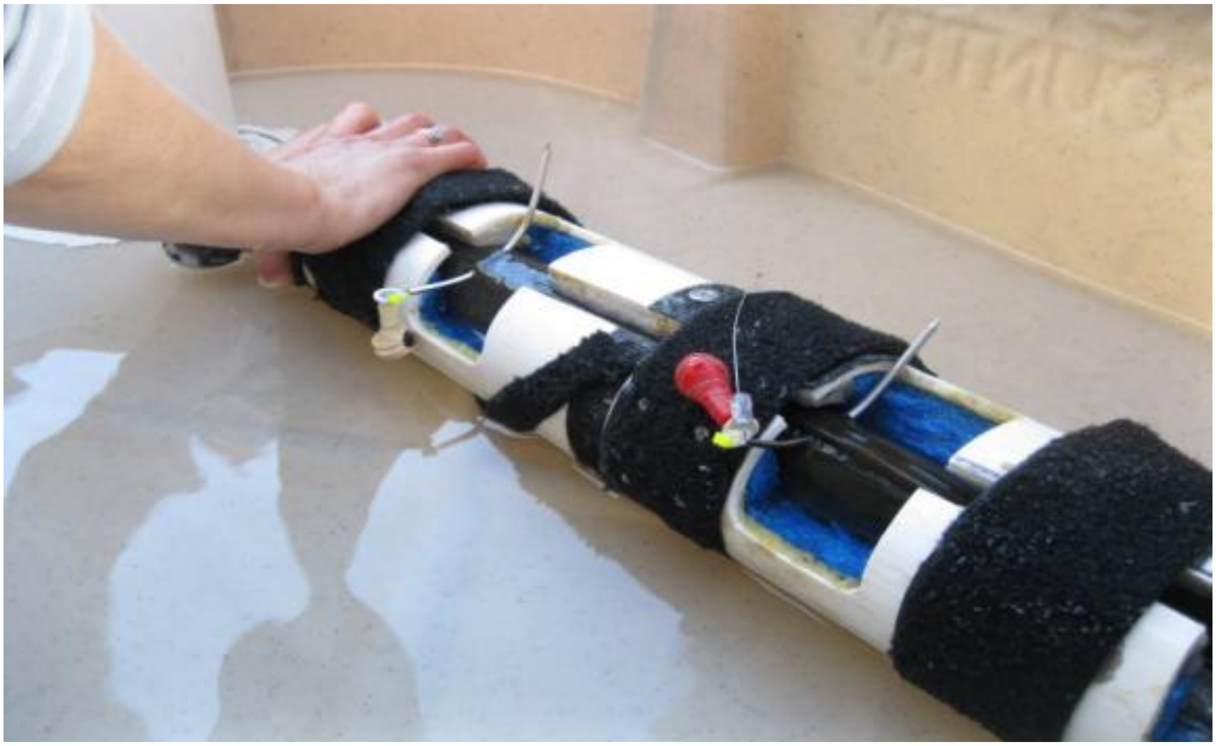

**Figure 4-1: Three to six HI-Z balloon tags attached with a small cable tie through the musculature at two or three locations along the eel's back via a curved cannula needle. Radio tags attached in combination with one of the HI-Z tags to aid in tracking released eels.**

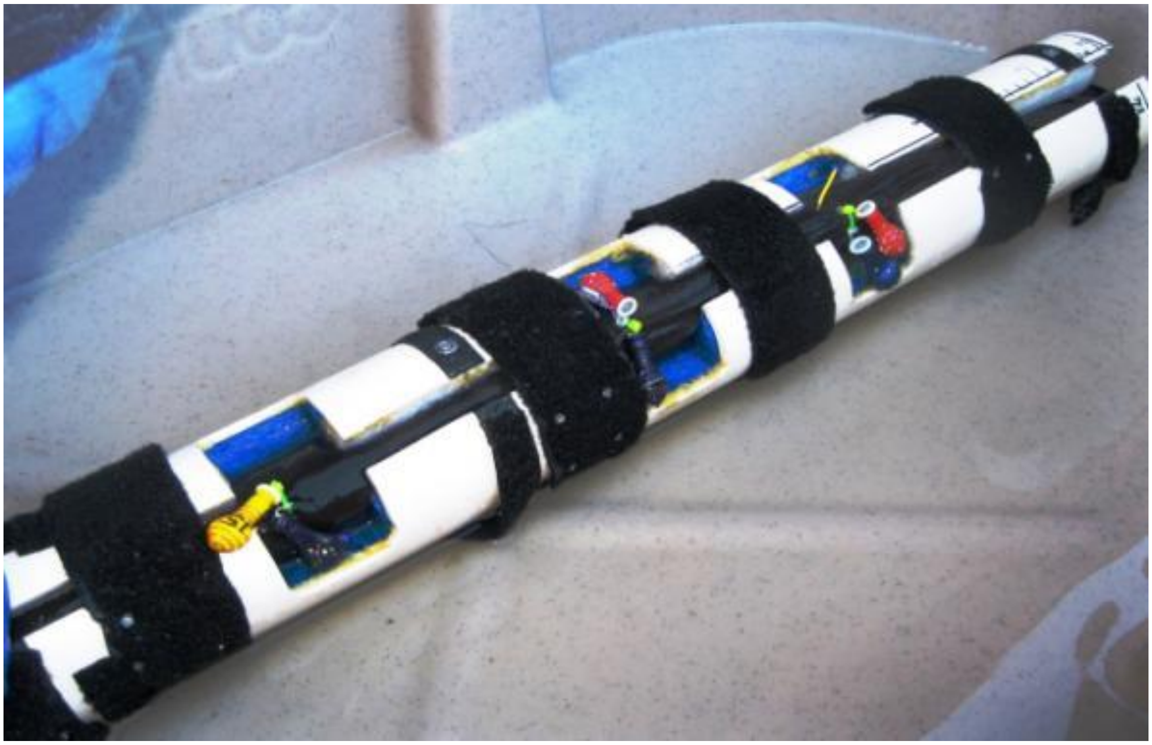

**Figure 4-2: Specially designed eel restraining device used to aid in HI-Z tagging adult American Eels.**

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

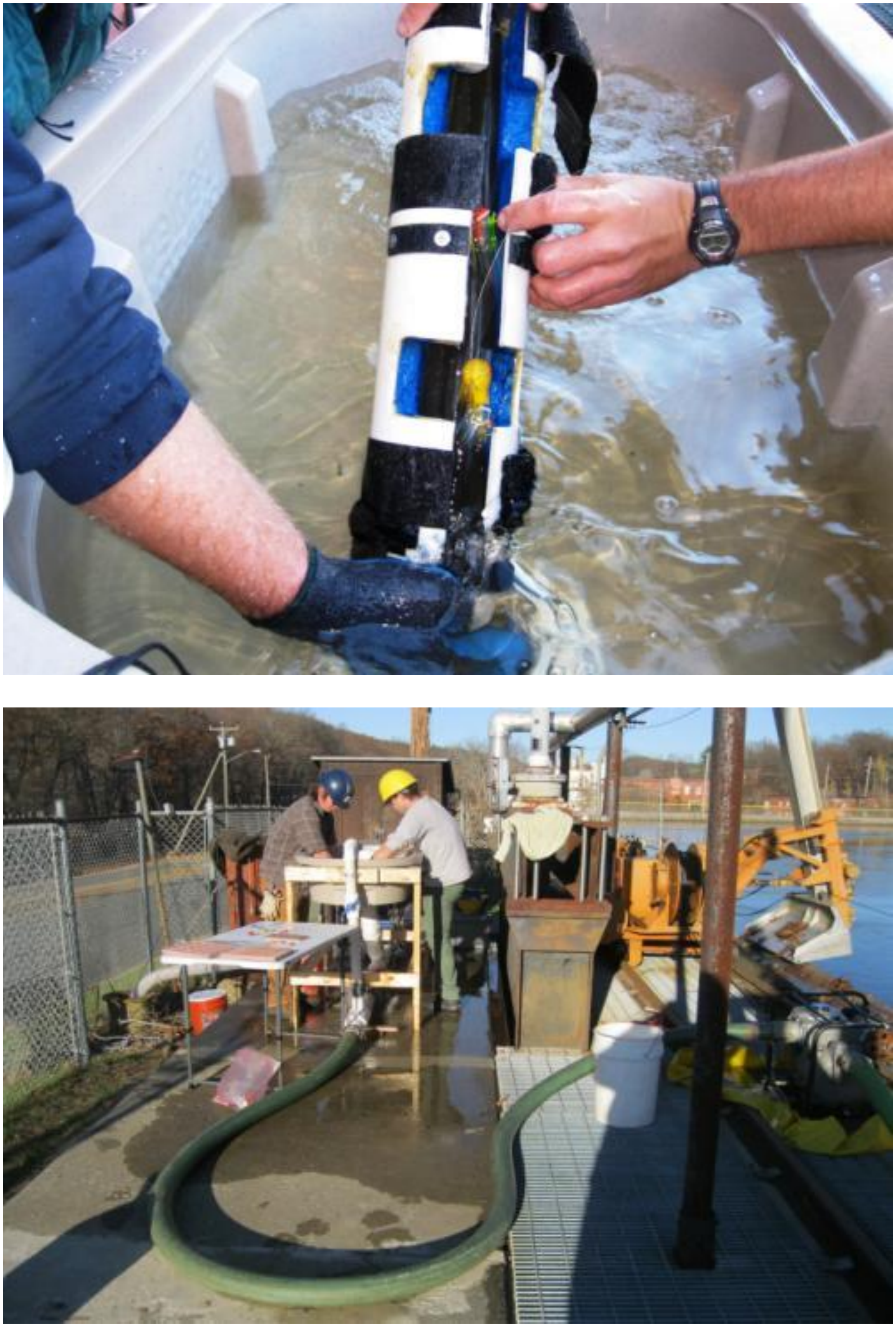

**Figure 4-4: Adult eels released through an induction apparatus. The induction system and release hose supplied with river water by a 3-inch trash pump that transported eels quickly to the desired release point.**

**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.**

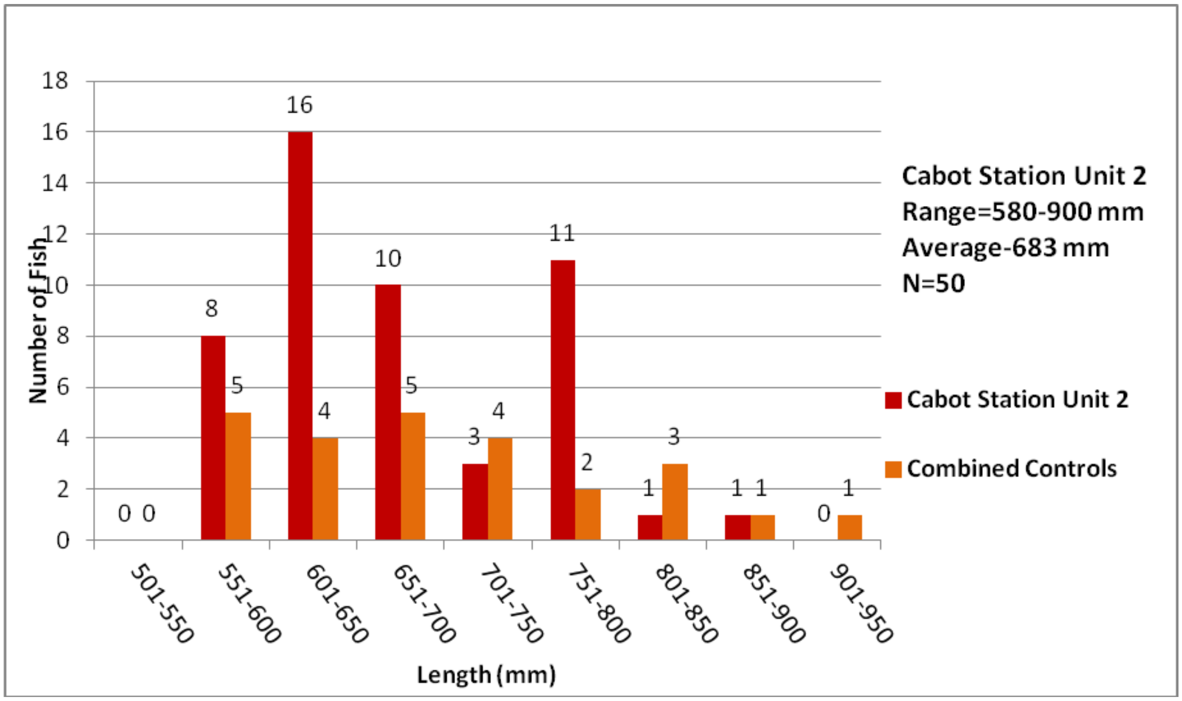


**Figure 4-8: Length frequency for HI-Z tagged adult American Eels released at Cabot Station Unit 2 versus combined controls.**

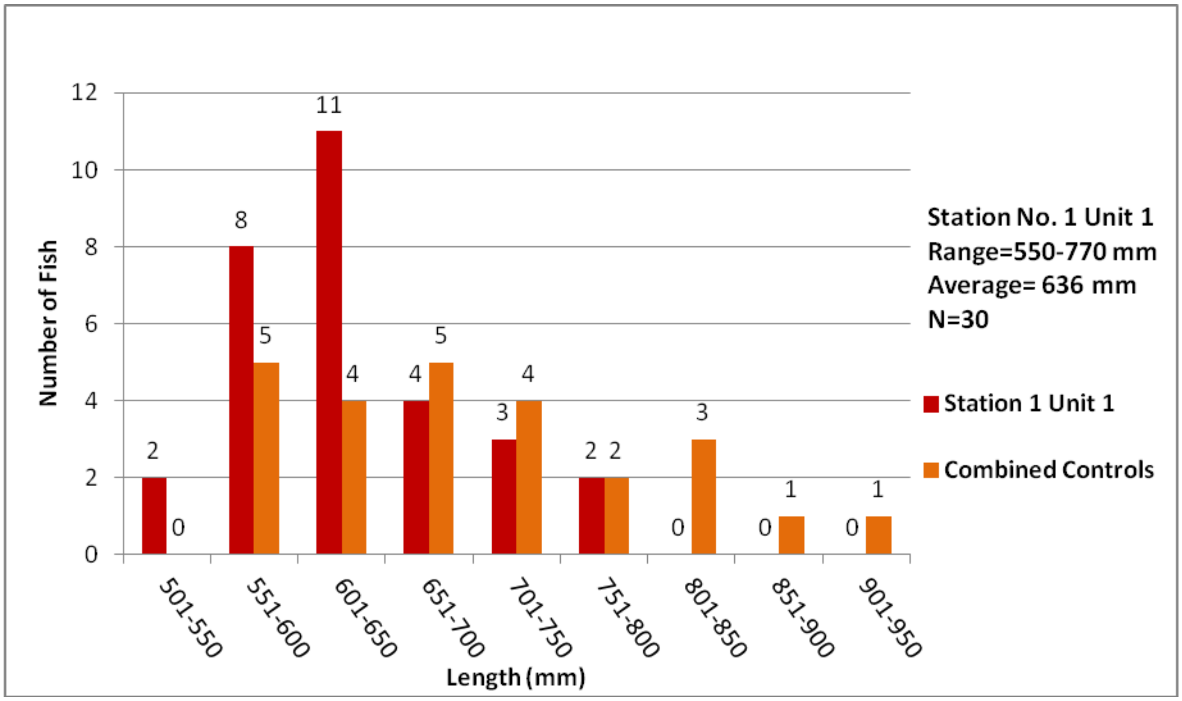


**Figure 4-9: Length frequency for HI-Z tagged treatment adult American Eels released at Station No. 1 Unit 1 versus combined controls.**

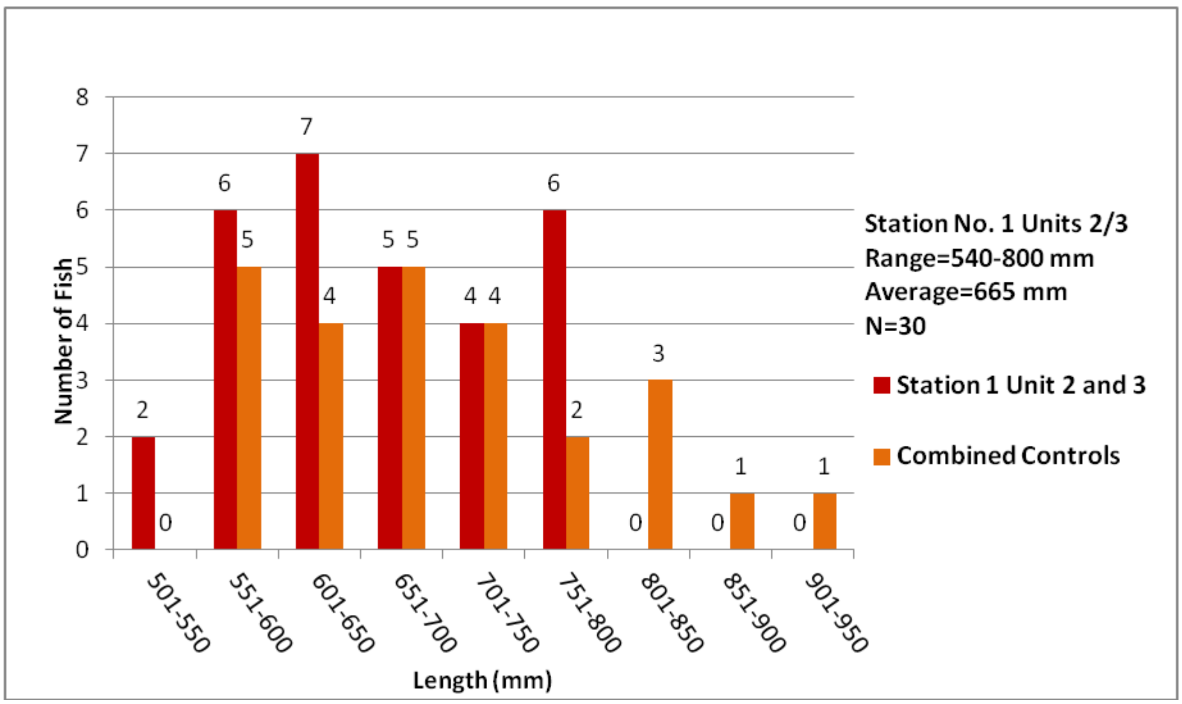


**Figure 4-10: Length frequency for HI-Z tagged treatment adult American Eels released at Station No. 1 Units 2/3 versus combined controls.**

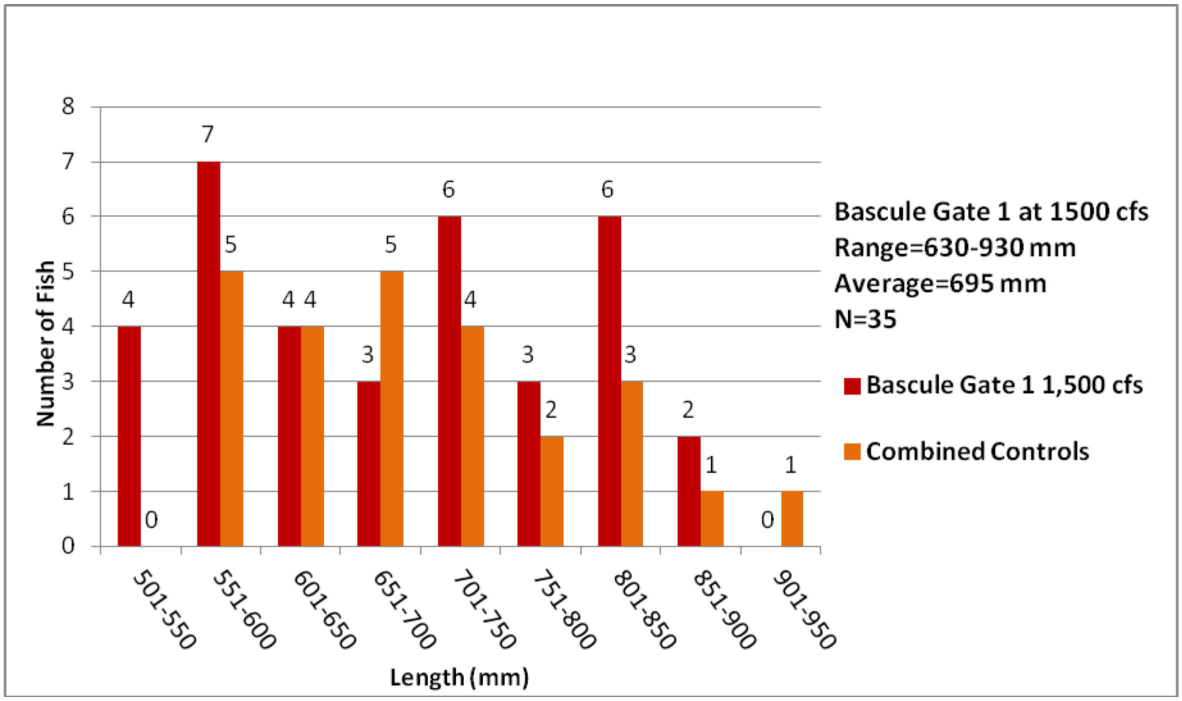


**Figure 4-11: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 1 at 1,500 cfs versus combined controls.**

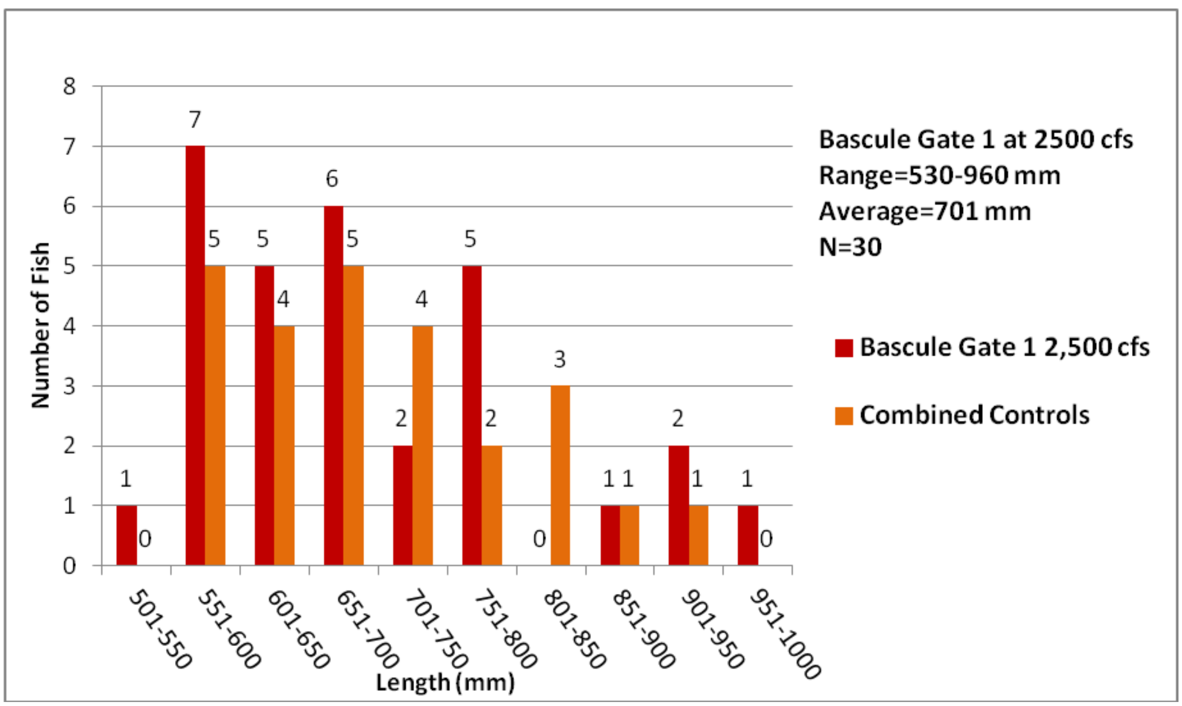


**Figure 4-12: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 1 at 2,500 cfs versus combined controls.**

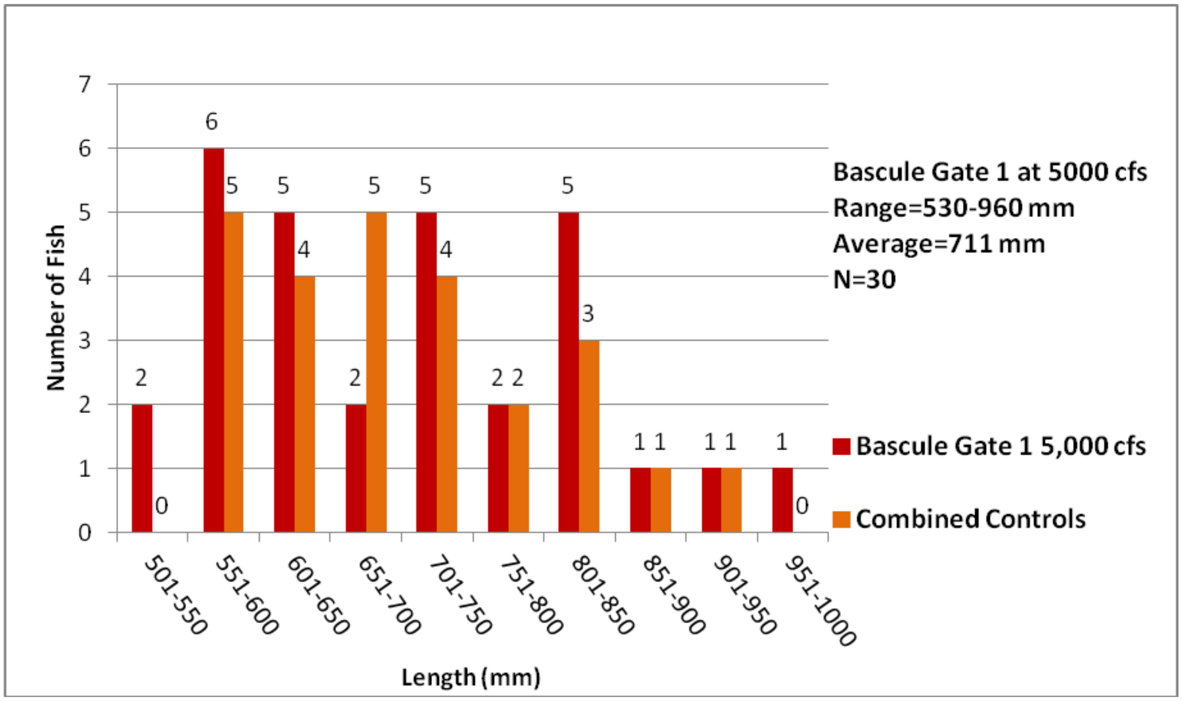


**Figure 4-13: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 1 at 5,000 cfs versus combined controls.**

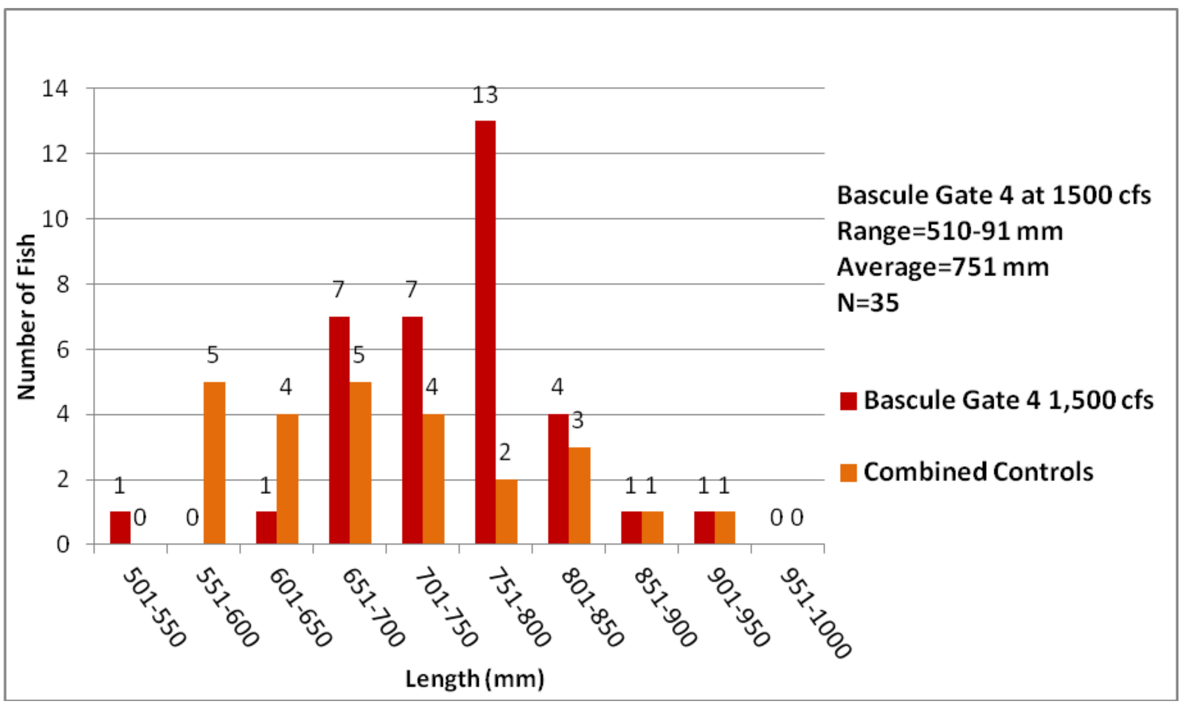


**Figure 4-14: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 4 at 1,500 cfs versus combined controls.**

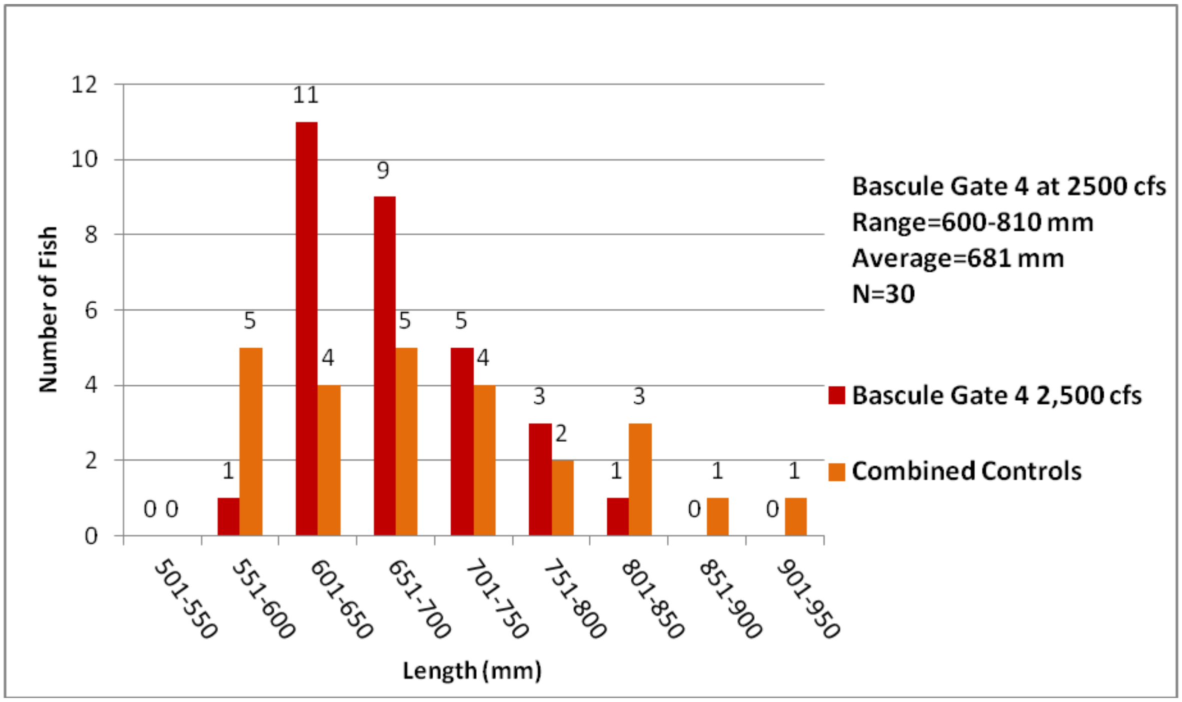


**Figure 4-15: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 4 at 2,500 cfs versus combined controls.**

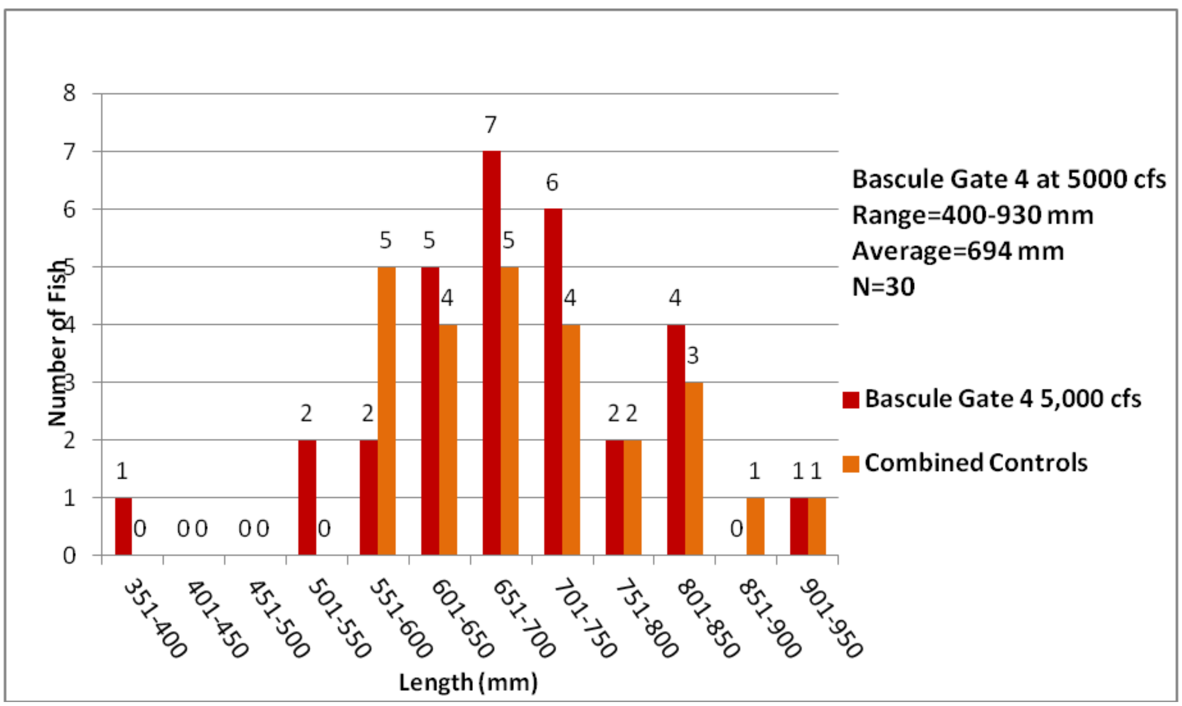


**Figure 4-16: Length frequency for HI-Z tagged treatment adult American Eels released at Bascule Gate 4 at 5,000 cfs versus combined controls.**

**Figure 5-1: Fish recapture crew searching for eels hiding among boulders and in rock crevices downstream of the bascule gates when spill was temporarily curtailed.**

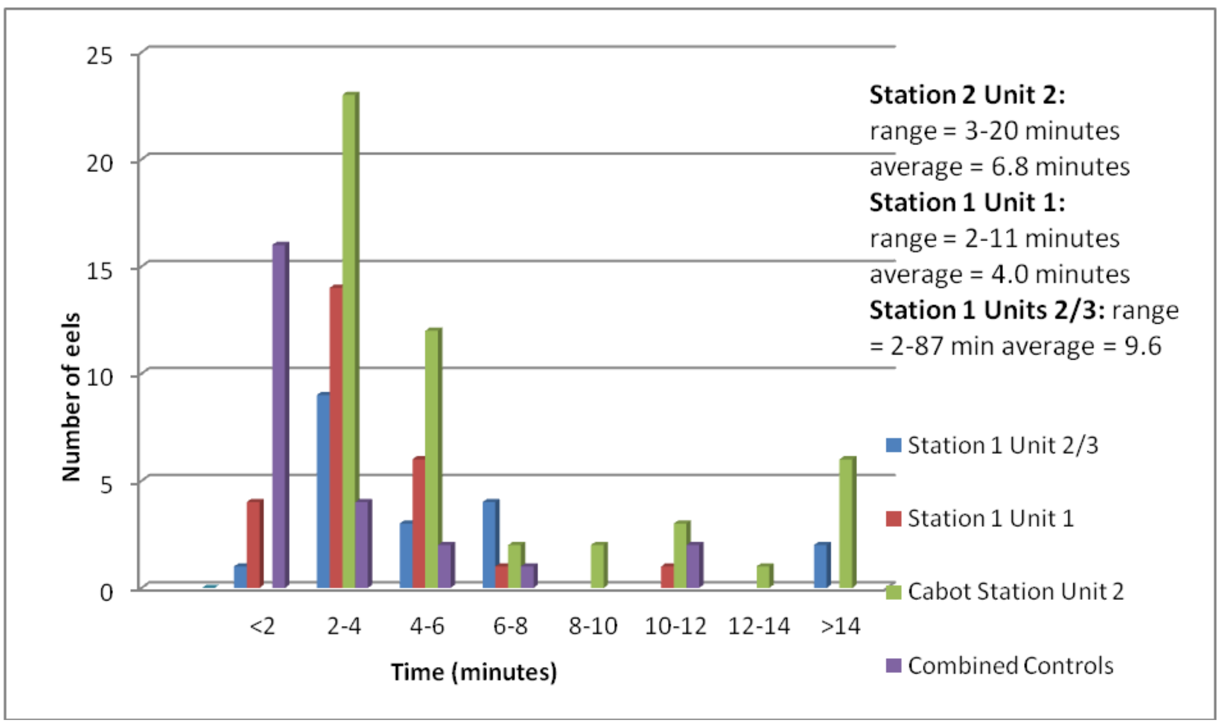


**Figure 5-2: Recapture times of fish released through turbine units at Cabot Station and Station No. 1.**

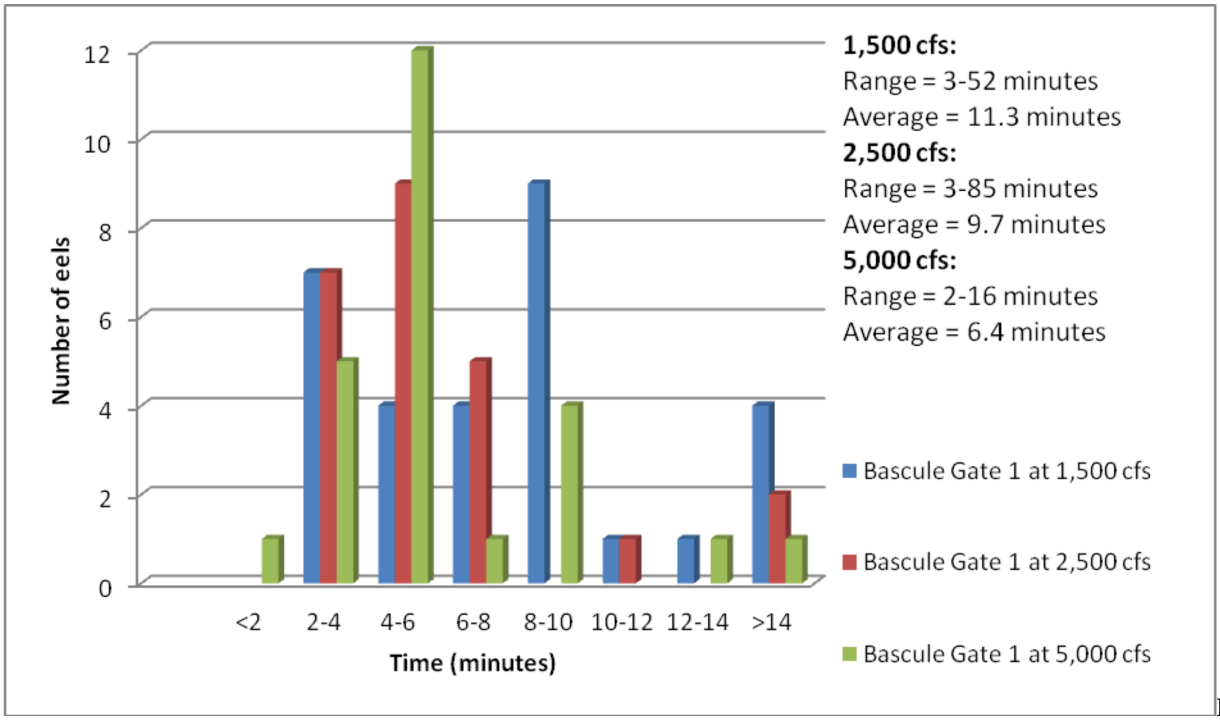


**Figure 5-3: Recapture times of fish released at Bascule Gate 1.**

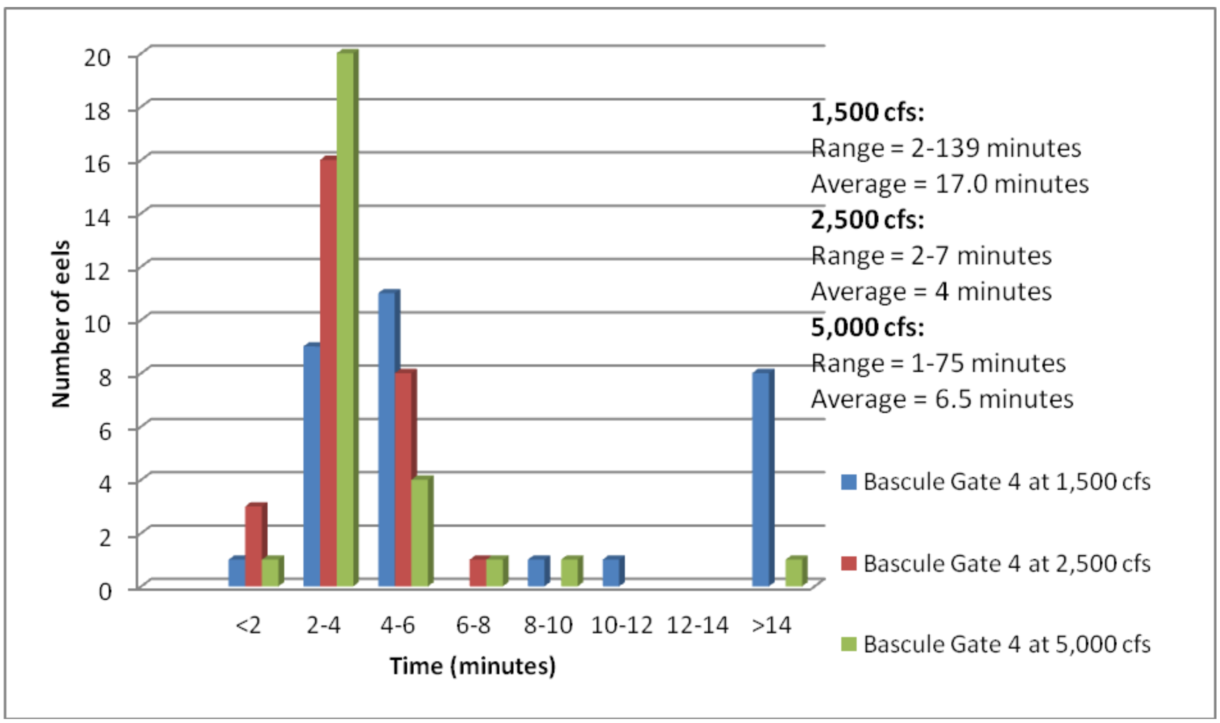


**Figure 5-4: Recapture times of fish released at Bascule Gate 4.**

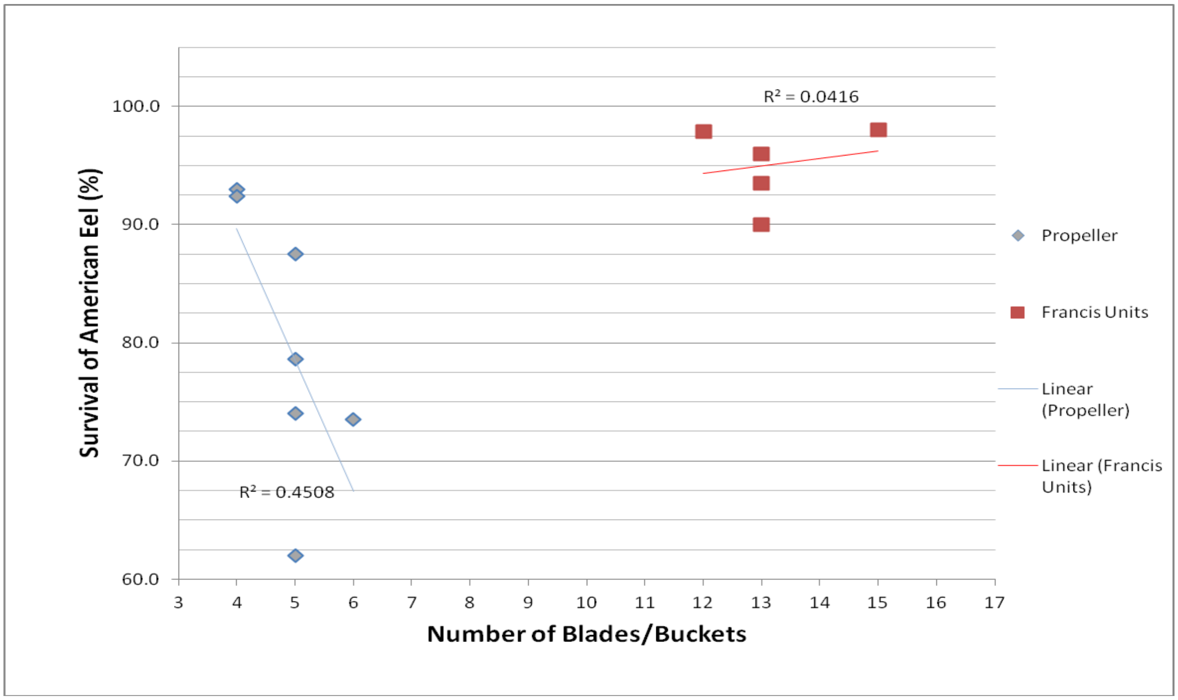


**Figure 5-5: Relationship (with trend-lines) between 48h direct survival of HI-Z tagged adult eels passed through propeller and Francis turbines versus number of blades/buckets.**

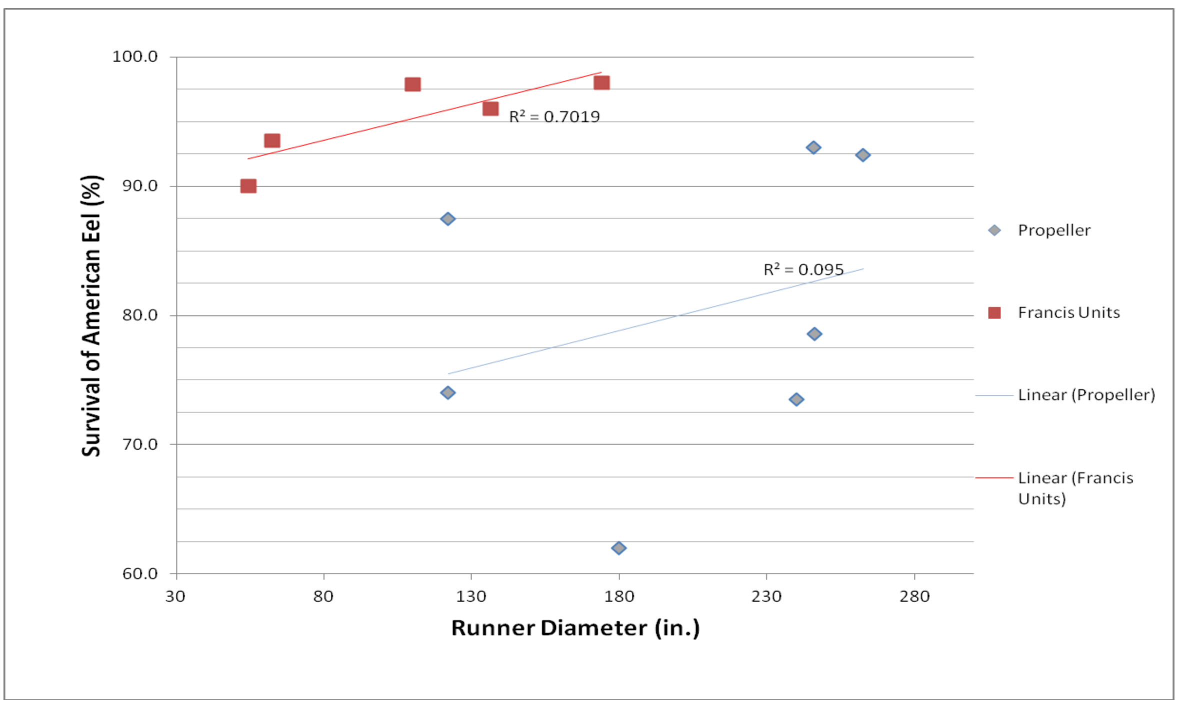


**Figure 5-6: Relationship (with trend-lines) between 48h direct survival of HI-Z tagged adult eels passed through propeller and Francis turbines versus runner diameter.**

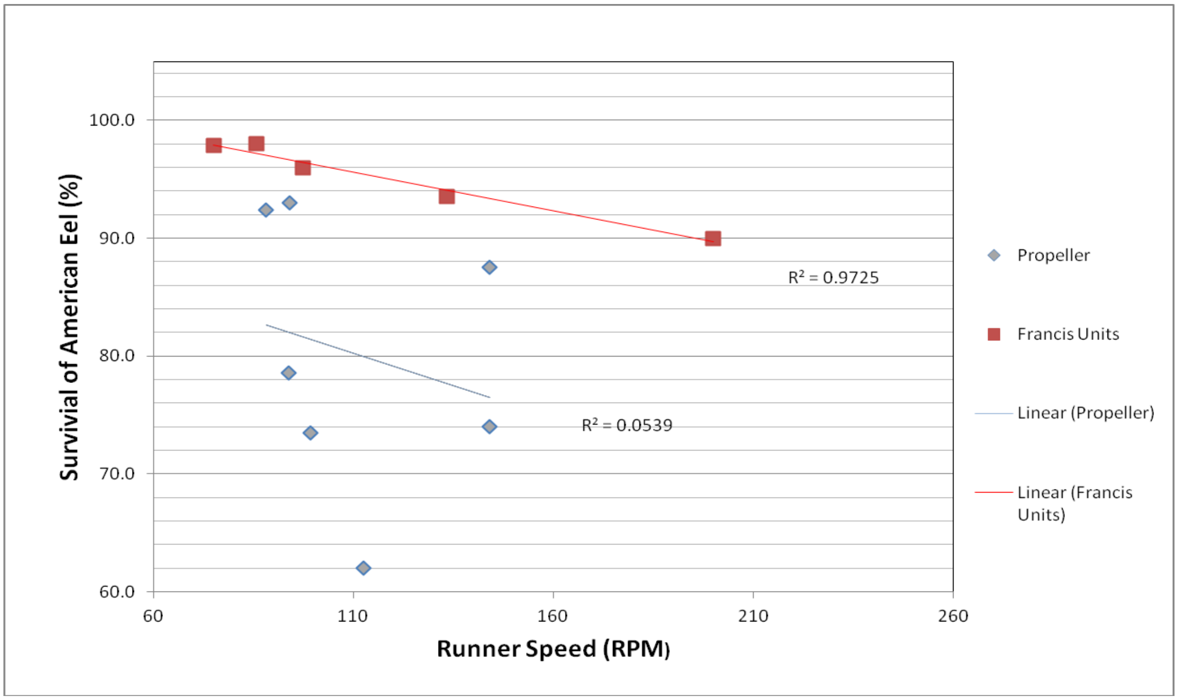


**Figure 5-7: Relationship (with trend-lines) between 48h direct survival of HI-Z tagged adult eels passed through propeller and Francis turbines versus runner speed.**

# Appendix A

# Daily Tag/Recapture Data

## Appendix A

**Daily data for recaptured Adult Eels passed through Cabot Station Unit 2, Station No. 1 Units 1 and 2/3, and over 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: 1,500 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: 2,500 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: 5,000 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: 1,500 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: 2,500 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: 5,000 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: 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 |
| **Station No. 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 |
| **Station No. 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 B

**Individual fish disposition data for recaptured Adult Eels passed through Cabot Station Unit 2, Station No.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.**

| Fish ID | Total Length (mm) | Time Re-leased | Time Re-covered | Minutes at large | No. HI-Z tags recovered | Survival Code | Status Codes |
|---|---|---|---|---|---|---|---|
| **4-Nov-15** | | | **Bascule Gate 4 @1,500 cfs** | | | **Water temp = 8.6°C** | |
| 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 |
| **4-Nov-15** | | | **Bascule Gate 4 @2,500 cfs** | | | **Water temp = 9.2°C** | |
| 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 |
| **4-Nov-15** | | | **Controls** | | | **Water temp = 9.2°C** | |
| 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 |
| **5-Nov-15** | | **Bascule Gate 1 @ 2,500 cfs** | | | | **Water temp = 7.3°C** | |
| 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 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **5-Nov-15** | | **Bascule Gate 4 @1,500 cfs** | | | | **Water temp = 7.3°C** | |
| 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 |
| **5-Nov-15** | | **Bascule Gate 4 @5,000 cfs** | | | | **Water temp = 7.3°C** | |
| 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 |
| **5-Nov-15** | | **Bascule Gate 1 @ 1,500 cfs** | | | | **Water temp = 7.3°C** | |
| 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 | |
| **5-Nov-15** | | | **Control** | | | **Water temp = 7.3°C** | |
| 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 |
| **6-Nov-15** | | | **Bascule Gate 1 @ 2,500 cfs** | | | **Water temp = 9.3°C** | |
| 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 |
| **6-Nov-15** | | | **Bascule Gate 1 @ 5,000 cfs** | | | **Water temp = 9.3°C** | |
| 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 |
| **6-Nov-15** | | | **Controls** | | | **Water temp = 9.3°C** | |
| 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 |
| **7-Nov-15** | | | **Cabot Unit 2** | | | **Water temp = 9.4°C** | |
| 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 |
| **7-Nov-15** | | | **Control** | | | **Water temp = 9.4°C** | |
| 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 |
| **9-Nov-15** | | | **Station No.1 Unit-2/3** | | | **Water temp = 8.5°C** | |
| 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 |
| 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 | |
| **9-Nov-15** | | **Station No.1 Unit 1** | | | | **Water temp = 8.5°C** | |
| 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 No. 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 No. 1 Unit 2/3 survival |

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

Log-likelihood: -29.7992

**Tau = 0.9800 (0.0198) Cabot Station Unit 2/Control ratio**
**Tau = 0.6207 (0.0901) Station No. 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 |

Confidence intervals:

| | Cabot Unit 2 | Station No. 1 Unit 2/3 |
|---|---|---|
| 90 percent: | (0.9474, 1.0000) | (0.4725, 0.7689) |
| 95 percent: | (0.9412, 1.0000) | (0.4441, 0.7973) |
| 99 percent: | (0.9290, 1.0000) | (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 No. 1 Unit 2/3 and Station No. 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 No. 1 Unit 2/3 survival |
| S3 = | 0.9000 | (0.0548) | Station No. 1 Unit 1 survival |

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

Log-likelihood: -34.4373

**Tau = 0.6207 (0.0901) Station No. 1 Unit 2/3 /Control ratio**
**Tau = 0.9000 (0.0548) Station No. 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 |

Confidence intervals:

| | Station No. 1 Unit 2/3 | Station No. 1 Unit 1 |
|---|---|---|
| 90 percent: | (0.4725, 0.7689) | (0.8099, 0.9901) |
| 95 percent: | (0.4441, 0.7973) | (0.7926, 1.0000) |
| 99 percent: | (0.3887, 0.8527) | (0.7590, 1.0000) |

====================================================
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 at 1,500 cfs and Bascule Gate 1 at 2,500 cfs combining control.**

Control 25 released, 25 alive, 0 dead
Bascule Gate 1 @ 1,500 cfs 35 released, 30 alive, 4 dead
Bascule Gate 1 @ 2,500 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 @ 1,500 cfs survival |
| S3 = | 0.8571 | (0.0661) | Bascule Gate 1 @ 2,500 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 @ 1,500 cfs/Control ratio**
**Tau = 0.8571 (0.0449) Bascule Gate 1 @ 2,500 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 |

Confidence intervals:

| | BG1 @ 1,500 cfs | BG1 @ 2,500 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 @ 5,000 cfs and Bascule Gate 4 @ 1,500 cfs; combining control.**

Control 25 released, 25 alive, 0 dead
Bascule Gate 1 @ 5,000 cfs 30 released, 25 alive, 4 dead
Bascule Gate 4 @ 1,500 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 @ 5,000 cfs survival |
| S3 = | 0.8857 | (0.0538) | Bascule Gate 4 @ 1,500 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 @ 5,000 cfs/Control ratio**
**Tau = 0.8857 (0.0538) Bascule Gate 4 @ 1,500 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 |

Confidence intervals:

| | BG1 @ 5,000 cfs | BG4 @ 1,500 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, 1.0000) | (0.7472, 1.0000) |

==================================================
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 @ 2,500 cfs and Bascule Gate 4 @ 5,000 cfs; combining control.**

Control 25 released, 25 alive, 0 dead
Bascule Gate 4 @ 2,500 cfs 30 released, 27 alive, 3 dead
Bascule Gate 4 @ 5,000 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 @2,500 cfs survival |
| S3 = | 0.9333 | (0.0455) | Bascule Gate 4 @5,000 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 @2,500 cfs/Control ratio**
**Tau = 0.9333 (0.0455) Bascule Gate 4 @5,000 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 |

Confidence intervals:

| | BG4 @ 2,500 cfs | BG4 @ 5,000 cfs |
|---|---|---|
| 90 percent: | (0.8099, 0.9901) | (0.8584, 1.0000) |
| 95 percent: | (0.7926, 1.0000) | (0.8441, 1.0000) |
| 99 percent: | (0.7590, 1.0000) | (0.8161, 1.0000) |

====================================================
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 |

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 Cabot Unit 2 and Station No. 1 Unit 2/3; combining control.**

Control 25 released, 25 alive, 0 dead
Cabot Unit 2 50 released, 48 alive, 2 dead
Station No. 1 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 No. 1 Unit 2/3 survival |

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

Log-likelihood: -33.2944

**Tau = 0.9600 (0.0277) Cabot Station Unit 2/Control ratio**
**Tau = 0.6207 (0.0901) Station No. 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 |

Confidence intervals:

| | Cabot Unit 2 | Station No. 1 Unit 2/3 |
|---|---|---|
| 90 percent: | (0.9144, 1.0000) | (0.4725, 0.7689) |
| 95 percent: | (0.9057, 1.0000) | (0.4441, 0.7973) |
| 99 percent: | (0.8886, 1.0000) | (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 No. 1 Unit 2/3 and Station No. 1 Unit 1; combining control.**

Control 25 released, 25 alive, 0 dead
Station No. 1 Unit 2/3 30 released, 18 alive, 11 dead
Station No. 1 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 No. 1 Unit 2/3 survival |
| S3 = | 0.9000 | (0.0548) | Station No. 1 Unit 1 survival |

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

Log-likelihood: -34.4373

**Tau = 0.6207 (0.0901) Station No. 1 Unit 2/3/Control ratio**
**Tau = 0.9000 (0.0548) Station No. 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 |

Confidence intervals:

| | Station No. 1 Unit 2/3 | Station No. 1 Unit 1 |
|---|---|---|
| 90 percent: | (0.4725, 0.7689) | (0.8099, 0.9901) |
| 95 percent: | (0.4441, 0.7973) | (0.7926, 1.0000) |
| 99 percent: | (0.3887, 0.8527) | (0.7590, 1.0000) |

=====================================================
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 @ 1,500 cfs and Bascule Gate 1 @ 2,500 cfs; combining control.**

Control 25 released, 25 alive, 0 dead
Bascule Gate 1 @ 1,500 cfs 35 released, 30 alive, 4 dead
Bascule Gate 1 @ 2,500 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 @1,500 cfs survival |
| S3 = | 0.8571 | (0.0661) | Bascule Gate 1 @2,500 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 @1,500 cfs/Control ratio**
**Tau = 0.8571 (0.0449) Bascule Gate 1 @2,500 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 |

Confidence intervals:

| | BG1 @ 1,500 cfs | BG1 @ 2,500 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 @ 5,000 cfs and Bascule Gate 4 @ 1,500 cfs combining control.**

Control 25 released, 25 alive, 0 dead
Bascule Gate 1 @ 5,000 cfs 30 released, 25 alive, 4 dead
Bascule Gate 4 @ 1,500 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 @5,000 cfs survival |
| S3 = | 0.8286 | (0.0637) | Bascule Gate 4 @1,500 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 @5,000 cfs/Control ratio**
**Tau = 0.8286 (0.0637) Bascule Gate 4 @1,500 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 |

Confidence intervals:

| | BG1 @ 5,000 cfs | BG4 @ 1,500 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, 1.0000) | (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 @ 2,500 cfs and Bascule Gate 4 @ 5,000 cfs; combining control.**

Control 25 released, 25 alive, 0 dead
Bascule Gate 4 @ 2,500 cfs 30 released, 27 alive, 3 dead
Bascule Gate 4 @ 5,000 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 @2,500 cfs survival |
| S3 = | 0.9333 | (0.0455) | Bascule Gate 4 @5,000 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 @2,500 cfs/Control ratio**
**Tau = 0.9333 (0.0455) Bascule Gate 4 @5,000 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 |

Confidence intervals:

| | BG4 @ 2,500 cfs | BG4 @ 5,000 cfs |
|---|---|---|
| 90 percent: | (0.8099, 0.9901) | (0.8584, 1.0000) |
| 95 percent: | (0.7926, 1.0000) | (0.8441, 1.0000) |
| 99 percent: | (0.7590, 1.0000) | (0.8161, 1.0000) |

=====================================================
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 |

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