TRANSCANADA HYDRO NORTHEAST INC.

ILP Study 21
American Shad Telemetry Study

Final Study Report

In support of Federal Energy Regulatory Commission Relicensing of:

Wilder Hydroelectric Project (FERC Project No. 1892-026)
Bellows Falls Hydroelectric Project (FERC Project No. 1855-045)
Vernon Hydroelectric Project (FERC Project No. 1904-073)

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EXECUTIVE SUMMARY

The goals of this study were to characterize the effects, if any, of TransCanada project operations on behavior, approach routes, passage success, survival, and residency time by adult American Shad (*Alosa sapidissima*) as they move through the Vernon project during both upstream and downstream migration; and to characterize whether project operations affect shad spawning site use and availability, spawning habitat quantity and quality, and spawning activity in the river reaches downstream of Bellows Falls dam to downstream of Vernon dam.

This final study report has been revised in response to stakeholder comments received on the initial study report filed August 1, 2016; to provide additional data and analysis for both upstream entrance efficiency and forays, and for downstream passage as a result of re-processed telemetry data; and to incorporate information from Study 9 – Instream Flow Study (Normandeau, 2016a).

The study was conducted in the spring of 2015 to assess near-field attraction to, and entrance efficiency of the Vernon fish ladder; assess internal efficiency of the Vernon fish ladder; assess upstream migration beyond Vernon dam up to the Bellows Falls project; characterize project operational effects on post-spawn downstream migration route selection, passage efficiency, downstream passage timing/residence, and survival at the Vernon project; identify areas that American Shad use for spawning; assess effects of project operations on identified spawning areas; and quantify spawning activity.

Fish used for this study were collected from the Holyoke fish ladder. One hundred fish were tagged with either a PIT tag or both a radio and PIT tag ("dual-tagged") and were released in Northfield, MA approximately 9.5 river miles downstream of Vernon dam. Additional tagged shad were released farther downstream in a similar study conducted by FirstLight (Kleinschmidt and Gomez and Sullivan, 2016). The sample size of tagged and released adult fish detected in the study area immediately downstream of Vernon was 129, and 96 of those (74.4%) were later detected at the entry to the fish ladder. Of those that entered the fish ladder, 55.2% (N=53) subsequently passed to the Vernon forebay.

The attraction effectiveness of the fish ladder (the proportion of dual-tagged shad within the immediate vicinity of the fish ladder) was 56.3% (95% Confidence Interval [CI] = 51.7-67.2%) based on dual-tagged shad which is within the broad range of attraction effectiveness values (11.0-73.0%) observed at other facilities where similar studies were conducted (e.g., Normandeau, 2008; Normandeau and Gomez and Sullivan, 2012).

Entrance efficiency (the proportion of dual-tagged shad detected within the immediate vicinity of the fish ladder that subsequently entered the ladder) was 73.5% (95% CI = 64.7-82.4%). Internal efficiency of the fish ladder (based on the number of both dual-tagged and PIT-tagged shad that entered the fish ladder and subsequently exited it was 55.2% (95% CI = 50.0-61.5%).

For all forays into the fish ladder, both successful and unsuccessful, residency within the fish ladder from entry to exit ranged in duration from less than 1 minute to 6.4 days. The average duration of foray events for tagged shad that failed to successfully pass upstream was longer than that observed for individuals that successfully passed upstream.

To assess upstream migration above Vernon dam, the subset of individuals successfully passing Vernon from downstream (N=11 of 12 that had retained their radio tag) were supplemented with an additional 54 radio-tagged shad released into the Vernon impoundment. All fish were detected upstream on at least one occasion aside from detection at the monitors located in the Vernon forebay. Eighteen shad migrated to the Bellows Falls tailrace. Fifty-nine shad were later re-located in the Vernon forebay as part of the downstream passage evaluation. Of that total, 17 were not available for downstream passage route determination due to their having been confirmed as mortalities following detection or during removal from the trash racks, or that approached but did not pass downstream of Vernon. Downstream passage was documented for 42 shad, and route selection was determined for 28 shad. The most frequently identified downstream passage route was via the spillway (15 shad) followed by the fish pipe (8 shad), Units 5-8 (3 shad), and Units 9-10 (2 shad). A passage route could not be determined for 14 individuals determined to have passed Vernon based on detections at downstream receivers. Of the individuals known to have passed Vernon, 79% were later detected at monitoring station 1 at Stebbins Island, 60% were detected at Northfield Mountain, and 55% were detected at Turners Falls.

As part of the spawning evaluation, 60 trawl sampling events occurred on 30 nights between May 26 and July 2, 2015 in the Bellows Falls riverine reach, Vernon impoundment, and within the study reach downstream of Vernon dam. One hundred-twenty individual ichthyoplankton net samples were collected and 794 shad eggs and larvae were collected. Of these, 776 (98%) were eggs, nine (1%) were yolk sack larvae, and nine (1%) were post yolk sack larvae. Shad eggs and/or larvae were collected in 46 (38.3%) samples at 31 (51.2%) trawl locations. The developmental stage was determined for each individual shad egg using previously developed stage information for the species (Jones et al., 1978). The majority of the eggs collected (78%) were determined to be stage 1 (blastodisk stage, occurring within 0.5 hours of spawn). For all stage 1 eggs, a back-calculated spawn location was determined using the estimated time from spawn to egg collection along with river flow velocity at the point of collection to determine the approximate distance upstream of the collection point where the egg had likely been spawned. These back-calculated locations were used to identify general spawning areas from the Bellows Falls tailrace downstream to Stebbins Island.

Six general spawning areas were identified, three from the Bellows Falls riverine reach, two from the Vernon impoundment, and one from the Vernon tailrace to Stebbins Island. The potential project effects on shad spawning in each of the six general spawning areas were evaluated using the modeled effects of project operations on three parameters (mean channel velocity, channel width, and thalweg depth) at the upper and lower ends of each general spawning area. A range of discharges from minimum flow to spill flows (including flows at which back-calculated spawning occurred) were evaluated for each general spawning location. In no case did the modeled thalweg depth drop below the literature reported range of water depths for shad spawning activity (i.e., 3-19 ft), even under minimum flow conditions. The difference in wetted channel width decreased between 1 and 39% between the maximum discharges where spawning was observed, to minimum flow conditions but since minimum flow typically occurs less than 1% of the time at each project in May and June, the minimum wetted channel width estimate and potential project effects related to channel width is considered to be very conservative.

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AWS	area weighted suitability
cfs	cubic feet per second
CPUE	catch per unit of effort
CRASC	Connecticut River Atlantic Salmon Commission
CRWC	Connecticut River Watershed Council
°C	degrees Celsius
DO	dissolved oxygen
FERC	Federal Energy Regulatory Commission
FirstLight (FL)	FirstLight Power Resources
ft	Feet or foot
ft/s	feet per second
FWS	U.S. Department of Interior, Fish and Wildlife Service
ILP	Integrated Licensing Process
mg/l	milligrams per liter
µS/cm	micro-siemens per centimeter
NHDES	New Hampshire Department of Environmental Services
NHFGD	New Hampshire Fish and Game Department
NRCS	Natural Resources Conservation Service
Normandeau	Normandeau Associates, Inc.
NTU	Nephelometric Turbidity Units
RSP	Revised Study Plan
SPD	Study Plan Determination
su	standard units
TransCanada (TC)	TransCanada Hydro Northeast Inc.
TU	Trout Unlimited
USGS	U.S. Geologic Survey
VANR	Vermont Agency of Natural Resources
VY	Vermont Yankee Nuclear Power Plant

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1.0 INTRODUCTION

This final study report presents the results of the American Shad Telemetry Study (ILP Study 21) conducted in support of Federal Energy Regulatory Commission (FERC) relicensing efforts by TransCanada Hydro Northeast Inc. (TransCanada) for the Wilder Hydroelectric Project (FERC Project No. 1892), Bellows Falls Hydroelectric Project (FERC No. 1855) and the Vernon Hydroelectric Project (FERC No. 1904). TransCanada has initiated the Integrated Licensing Process (ILP) for these projects in order to extend the term of their operating licenses beyond the current expiration date of April 30, 2019 for each project.

In their study requests, FERC, U.S. Department of the Interior-Fish and Wildlife Service (FWS), New Hampshire Department of Environmental Services (NHDES), New Hampshire Fish and Game Department (NHFGD), Vermont Agency of Natural Resources (VANR), Connecticut River Watershed Council (CRWC), and Trout Unlimited (TU) identified two issues related to potential project effects relative to adult American Shad (*Alosa sapidissima*). One issue concerned upstream and downstream adult American Shad passage success on the Connecticut River, leading stakeholders to request a study of shad migration from FirstLight's Cabot Station to upstream of Vernon dam. The second issue pertained to American Shad spawning behavior, spawning habitat use, areal extent and quality of those spawning areas, and spawning activity in terms of egg deposition in those areas.

Additionally, stakeholders included a request for TransCanada and FirstLight to complete analyses of data collected by USGS on the migration of radio-tagged shad from Turners Falls Project (FERC No. 1889) to Vernon dam and passage efficiency of the Vernon fish ladder.

The Revised Study Plan (RSP) for this study was modified by TransCanada in its December 31, 2013 filing. Modifications were made based on stakeholder agreement during FERC's technical meeting held on November 26, 2013 to discuss impacts of the Vermont Yankee (VY) decommissioning. The following specific changes were made to the RSP.

- a limited review and evaluation of the 2011/2012 USGS data to support this study's design and methodology; and
- temperature tags were no longer needed since their purpose was to record water temperature as shad migrate past Vermont Yankee's thermal discharge.

The RSP for this study was approved without modification by FERC in its February 21, 2014 Study Plan Determination (SPD) except to delay the study until 2015.

This final study report has been revised in response to stakeholder comments received on the initial study report filed August 1, 2016; to provide additional data and analysis for both upstream entrance efficiency and forays, and for downstream passage as a result of re-processed telemetry data; and to incorporate information from Study 9 – Instream Flow Study (Normandeau, 2016a).

2.0 STUDY GOALS AND OBJECTIVES

The goals of this study were to:

- characterize effects, if any, of project operations on behavior, approach routes, passage success, survival, and residency time by adult American Shad as they move through the Vernon project during both upstream and downstream migrations; and

- characterize whether project operations affect American Shad spawning site use and availability, spawning habitat quantity and quality, and spawning activity in the river reaches from downstream of Vernon dam up to the Bellows Falls Project.

The objectives of this study were to:

- assess near-field attraction to, and entrance efficiency of the Vernon fish ladder;
- assess internal efficiency of the Vernon fish ladder;
- assess upstream migration beyond Vernon dam up to the Bellows Falls Project;
- characterize project operational effects on post-spawn downstream migration route selection, passage efficiency, downstream passage timing/residence, and survival related to the Vernon Project;
- identify areas that American Shad use for spawning;
- assess effects (e.g., water velocity, depths, inundation, and exposure of habitats) of project operations on identified spawning areas; and
- quantify spawning activity.

One original objective in the RSP was to assess upstream passage past VY's discharge; but this objective was no longer applicable since VY ceased operation in 2014 and this study was conducted in 2015.

3.0 STUDY AREA

The study area for the passage characterization portion of this study included the Vernon forebay, tailrace, turbines, fish ladders (upstream and downstream), and spillway. The study area for the spawning assessment portion of this study included the Vernon tailrace and impoundment, and the Bellows Falls riverine reach (see Figures 4.3-1 through 4.3-4 below).

4.0 METHODS

4.1 Collection of Test Specimens

This study encompassed three assessments: upstream passage, spawning, and downstream passage. Fish used for the study were collected from two locations, the Holyoke fish ladder and the Vernon fish ladder. Fish collected at Holyoke were equipped with either passive integrated transponders (PIT tags) or radio and PIT tags (dual tags) and released approximately 9.5 miles downstream of Vernon dam in Northfield, Massachusetts. The purpose of this sample group was to assess upstream passage, specifically near-field attraction to the Vernon fish ladder, entrance efficiency of the fish ladder, behavior in the fish ladder, and the internal efficiency of the fish ladder. Behavior in the fish ladder was assessed via PIT technology; near-field attraction to the fish ladder and entrance efficiency of the fish ladder was assessed with radio telemetry; and internal efficiency (i.e., passage success) was assessed with both PIT and radio monitoring methods.

Fish collected at the Vernon fish ladder were equipped with radio tags and released in the Vernon impoundment to assess spawning and downstream migration. These fish supplemented any dual-tagged fish that passed the Vernon project via the fish ladder and were intended to assess upstream migration towards Bellows Falls, spawning activity upstream of Vernon, and subsequent downstream passage at Vernon. The spawning assessment monitored the reach upstream of Vernon dam to the Bellows Falls project and identified spawning areas. The downstream migration assessment characterized project operational effects on post-spawn downstream migration route selection, passage efficiency, downstream passage timing, residence time, and survival related to the Vernon project.

The sample groups for all three Vernon project assessments were supplemented with shad that had been collected at FirstLight's Cabot station, released for studies at Turners Falls similar to this study (Kleinschmidt and Gomez and Sullivan, 2016), and detected at either the most downstream radio telemetry station for this study (in the Vernon tailrace) or in the fish ladder. All FirstLight fish were either PIT tagged or dual tagged.

4.1.1 Holyoke Collection and Tagging

All tagged shad that were released at the Northfield, Massachusetts boat access were collected at the Holyoke fish ladder using the fish lift. Following capture in the fish ladder, shad were lifted via the hopper and diverted into a sorting tank. On each collection day, shad selected for tagging were moved from the sorting tank to the FWS transport truck via sluice. The transport truck was filled with ambient river water and salt was added such that the salinity was approximately 6-11 ppt. A constant flow of dissolved oxygen was supplied to the tank throughout the transport process. Shad were transported from the Holyoke fish ladder to the Pauchaug Brook boat access in Northfield (river mile 132.5). Transport time was slightly over one hour on each date and all fish were released into the river within 3.3 to 4.5 hours after initial loading at Holyoke (Table 4.1-1).

Table 4.1-1. Summary of shad transport from Holyoke, MA to the Northfield, MA release site, May 2015.

Date	10-May	14-May	28-May
Start of Loading Time	12:23	10:40	09:45
Departure Time	12:45	10:56	10:00
Arrival Time	13:50	12:04	11:15
Release Time	16:51	14:00	13:39
Loading to Release Time	4.5 hrs	3.3 hrs	3.9 hrs
Tank Water Temperature at Capture (°C)	14.5	14.0	18.0
Tank Water Temperature at Arrival (°C)	15.3	14.5	18.4
Tank D.O. at Departure (mg/L)	7.0	6.4	N/A[a]
Tank D.O. at Arrival (mg/L)	14.3	7.9	N/A[a]
Release Water Temperature (°C)	16.1	13.4	17.4
Tank Salinity (ppt)	9.6[b]	9.1	9.6[b]
Release Site D.O. (mg/L)	10.7	12.9	9.7
No. of Shad Transported	44	46	25
No. of Shad Dual Tagged	20	20	12
No. Shad PIT Tagged Only	20	20	8

a. D.O. meter experienced problems resulting in invalid data.
b. 60 lbs of salt added to 750 gallon transport tank

Individual shad were netted from the transport truck tank and assessed for tagging suitability (i.e., general well-being, no wounds, abrasions, loss of equilibrium). Individuals deemed unsuitable for tagging were released directly into the Connecticut River following examination. Suitable shad were transferred into a rubber tote outfitted with fine mesh to immobilize the specimen for tagging and to reduce stress. Following determination of gender and length (total and fork), a radio tag was orally inserted into the shad's stomach by means of a cannula, guiding it gently through the esophagus. For all shad collected at the Holyoke fish ladder, a PIT tag was placed below and behind the dorsal fin by making a small (2-mm) incision using a scalpel. The PIT tag was placed horizontally into the incision and gently slid into the specimen's musculature by hand. The tagged shad were then placed into the river. One hundred shad were PIT tagged, 52 of those were also radio tagged.

4.1.2 Vernon Collection and Tagging

Fifty-four shad were collected at the Vernon fish ladder, radio tagged, and released upstream of Vernon at the Old Ferry boat access, Brattleboro, Vermont (river mile 147, approximate 5 miles upstream of Vernon dam) for use in the spawning and downstream migration components of the study. Using the diversion door at the Vernon fish trap, shad were diverted into a separate holding area and not allowed to continue migration through the fish ladder. Once a suitable number of shad were in the trap the trap floor was raised. Shad were netted and placed into the transport truck. Similar to transportation of shad from Holyoke, the transport tank was filled with ambient river water, salted to an approximate concentration of 6-11 ppt and oxygenated with a continuous flow of dissolved oxygen. This process was repeated until the needed number of specimens was captured. At the release site, individual shad were netted from the transport truck tank and assessed for tagging suitability. Methodologies for the determination of tagging suitability as well as the tagging process were identical to those used for shad collected at Holyoke (see Section 4.1.1). Following tagging, shad were placed into the river. Transport time was less than one hour for all dates and all fish were released into the river within 1.4 to 3.4 hours after initial loading at Vernon (Table 4.1-2).

Table 4.1-2. Summary of shad transport from Vernon fish ladder to the Brattleboro, VT release site, May 2015.

Date	17-May	17-May	24-May	30-May
Start of Loading Time	11:35-12:53	15:58	15:00	12:00
Departure Time	13:08	16:23	16:15	12:30
Arrival Time	13:50	17:01	16:47	13:20
Release Time	14:15-15:00	17:20	17:30	14:36
Loading to Release Time	3.4 hrs (max)	1.4 hrs	2.5 hrs	2.6 hrs
Tank Water Temperature at Capture (°C)	13.2 (avg)	15.1	14.2	18.0
Tank Water Temperature at Arrival (°C)	14.2	15.6	16.1	18.7
Tank D.O. at Departure (mg/L)	8.3	12.4 (avg)	11.3	N/A[a]
Tank D.O. at Arrival (mg/L)	9.1	12.4	9.8	N/A[a]
Tank Salinity (ppt)	6.7	8.7	10.9	11.4
Release Water Temperature (°C)	12.7	12.5	14.2	18.8
No. of Shad Transported	13	10	25	20
No. of Shad Radio Tagged	13	7	23	11

a. D.O. meter experienced problems resulting in invalid data.

4.2 Radio Telemetry and PIT Equipment

4.2.1 Radio Tags

Coded VHF radio transmitters (radio tags) purchased from Sigma-Eight Inc. (SEI), Newmarket, Ontario, Canada were used for this study. The radio tags (model number TX-PSC-1-80-M) were digitally encoded and transmitted signals on 5 frequencies (channels): 149.720, 149.780, 149.800, 150.440, and 154.540 MHz. Each radio tag contained a unique pulse train to allow for individual fish identification (codes). Each cylindrical radio tag measured 9.6mm in diameter, 26mm in length, and had a 30cm long whip antenna. The radio tags propagated a signal every 2.0 seconds and had a minimum battery life of approximately 113 days. Additionally, each radio tag was equipped with a motion sensor; if a radio tag became stationary, the rate of the emitted pulse train changed from 2.0 seconds to 9.0 seconds.

4.2.2 PIT Tags

Coded half duplex (HDX) PIT (Passive Integrated Transponder) tags purchased from Oregon RFID (ORFID), Portland, Oregon were used for this study. The HDX PIT tags were encoded by the manufacturer and used 64 data bits. Each cylindrical PIT tag measured 3.65mm in diameter, 32mm long, and weighted 0.8g.

4.2.3 Receivers

TransCanada installed 18 radio-telemetry monitoring stations within the study area. Installed radio-telemetry equipment included Orion receivers, manufactured by Sigma Eight, as well as SRX400 and SRX600 receivers manufactured by Lotek. Receivers were placed following consideration of the detection requirements for the given area of coverage as well as the attributes of the receiver model. The Orion receiver is a broadband receiver capable of monitoring multiple frequencies simultaneously within a 1-MHz band and were most useful for monitoring tagged fish in areas where movement through the monitoring zone can occur quickly (e.g., turbine unit intakes and bypasses). Although Lotek receivers have a greater detection range than Orion receivers, they can only monitor a single frequency at once and require frequency switching which decreases detection efficiency in areas where fish may pass at high rates of speed. As part of monitoring adult shad movements at Vernon, Lotek receivers were used at locations requiring longer range and where the intended detection areas could be characterized by relatively slow transit speeds for tagged fish. All Lotek receivers were programmed to switch frequencies at a 2.1-second interval with a total scan time of 10.5 seconds for the five frequencies used in the study. The CRTO (Continuous Record Time Out) feature within the Lotek receivers was utilized. This feature affects the manner in which the receiver logs and offloads data. When the CRTO value for a Lotek receiver is set to 01:00 (mm:ss), a record for an individual fish ID is initiated at the time of first detection. All subsequent records for that individual within the one minute period are compiled into that single record. At the “time out” of that one minute period, a single data line is produced for that individual that consists of the start date, start time, end date, end time, average signal strength and total number of detections. Should that fish remain present within the detection field following the conclusion of the initial one minute period, a second period starts and generates a new data line for detections occurring during the second minute. The CRTO settings utilized during this study are presented along with descriptions of each monitoring station in Section 4.3. Transmitter detections logged on Orion receivers were all recorded as single events. For any one detection, a unique data line consisting of date, time, tag information, and signal strength was recorded.

Prior to release of fish, background noise levels were determined at the Vernon and Bellows Falls projects during the telemetry calibration process. Background noise is any ambient electromagnetic noise detected by a receiver that is not produced by a radio tag. In general, hydroelectric facilities are noisy electromagnetic environments due to their production and transmission of electricity. Receivers were configured to exclude background noise by utilizing specific features within the receiver's firmware designed for this purpose. Receivers were set to scan each channel for specific time periods depending on location. When a signal was received, the scan program temporarily suspended and the validity of the signal was verified and either logged or rejected. The receiver measured the duration of a preselected number of pulse intervals and if intervals differed significantly, the signal was rejected. All receivers were time synchronized.

HDX PIT readers from ORFID were used to detect and read PIT tags. Due to electromagnetic noise present at Vernon, each half-duplex reader used a tuning box which allowed for the calibration of each PIT antenna to exclude background noise and ensure that quality detections were made. The PIT readers received the signals transmitted by the PIT tags via the antenna, and then filtered, amplified, decoded, and formatted the tag information.

4.2.4 Antennas

Five types of antennas were used, a PIT wire loop antenna and four radio antennas: Laird P1504 four–element Yagi antennas (4-element antenna), Laird PLC1426 six-element Yagi antennas (6-element antenna), Laird PLC 1429 nine-element Yagi antenna (9-element antenna), and custom made underwater antennas (dropper antenna). Yagi antennas are aerial antennas which provide directionality and a relatively large reception range. Dropper antennas, which are deployed vertically within the water column, are omni-directional and provide a relatively limited reception range. They are used to determine discrete movement within a specific location of interest.

The PIT wire loop antennas for PIT readers were used to determine when a fish had passed or came extremely close to discrete areas of passage (within +/-3 ft). All PIT antennas were made from thermoplastic high heat resistant wire (THHN). The purpose of the PIT antenna loop is to create an alternating magnetic field from the reader and then to receive a signal back from the PIT tag. The number of loops within an antenna will coincide with the magnetic field strength of the antenna. Twin-axial communication cable was used from the tuning boxes to the reader.

4.3 Monitoring Locations and Antenna Arrangement

Monitoring stations (PIT and radio) were deployed at 24 locations within the study area and included locations upstream of Stebbins Island, in the Vernon tailrace, fish ladder, spillway, and forebay, and in the Bellows Falls tailrace and Bellows Falls bypassed reach. A description of each stationary monitoring station is provided below and locations are shown graphically in Figures 4.3-1 to 4.3-4.

Monitoring Station 1: Monitoring station 1 was located at the Vermont Yankee water quality station #3, approximately 0.75 miles downstream of Vernon dam and just upstream of Stebbins Island. The station consisted of a Lotek radio receiver (CRTO = 05:00) and aerial antenna oriented towards the east shore and perpendicular to the river channel. Antenna coverage spanned the width of the river and was used to detect radio-tagged shad entry and exit to and from the Vernon study area as well as aid observation of potential spawning habitat around Stebbins Island.

Monitoring Station 2: Monitoring station 2 was installed to provide detection of radio-tagged shad as they entered into the general tailrace area to an approximately distance of 800 feet downstream of Vernon dam. This station consisted of a Lotek radio receiver (CRTO = 10:00) and aerial antenna and was mounted along the western shoreline near the downstream end of the fish ladder.

Monitoring Station 3: Monitoring station 3 was installed to detect radio-tagged shad as they approached the entrance to the upstream fish ladder. It consisted of a single Lotek receiver (CRTO = 05:00) coupled to an aerial antenna and underwater drop antenna, operated via a switcher. The underwater drop antenna was placed in the entrance to the fish ladder and provided detection information for radio-tagged individuals that had passed through the entrance into the fish ladder. The aerial antenna provided coverage of the area immediately outside of the fish ladder entrance out to a distance of approximately 30 feet.

Monitoring Station 4: Monitoring station 4 was installed to detect radio-tagged shad having already passed upstream of monitoring station 3 and moved to a point within the vicinity of the fish ladder counting window. This location consisted of a single Lotek receiver (CRTO = 05:00) and underwater drop antenna.

Monitoring Station 5: This location was installed to detect PIT-tagged shad as they entered the Vernon fish ladder. Monitoring station 5 was located within the first bay of the fish ladder which is split into two entrances side by side with a concrete wall separating them. To provide adequate coverage, two PIT antennas coupled to a multi-antenna PIT reader were deployed. It was determined once all data had been collected that the multi-reader, although calibrated, lacked sensitivity compared to the single readers used at the remaining sites. This resulted in a lower number of PIT-tagged fish detected at the fish ladder entrance versus the number detected at the first bend in the fish ladder (monitoring station 6).

Monitoring Station 6: Monitoring station 6 was installed to detect PIT-tagged shad having already passed upstream of monitoring station 5 and moved to a point near the first bend in the fish ladder adjacent to the public viewing area. This location consisted of a single PIT antenna and reader.

Monitoring Station 7: Monitoring station 7 was installed to detect PIT-tagged shad having already passed upstream of monitoring stations 5 and 6 and moved to a point in the vicinity of the fish ladder counting room. This location consisted of a single PIT antenna and reader.

Monitoring Station 8: Monitoring station 8 was installed to detect PIT-tagged shad having already passed upstream of monitoring stations 5, 6 and 7 and moved to a point upstream of the counting room window where the fish ladder transitions to a vertical slot design. This location consisted of a single PIT antenna and reader.

Monitoring Station 9: Monitoring station 9 was installed to detect PIT-tagged shad as they exited the upstream end of the fish ladder. PIT-tagged shad at this location have already passed upstream of monitoring stations 5, 6, 7 and 8. This location consisted of a single PIT antenna and reader.

Monitoring Station 10: This location was designed to detect radio-tagged shad in the western portion of the Vernon turbine discharge area downstream a distance of ~50 feet and laterally a distance of ~25 feet. It consisted of a single Lotek receiver (CRTO = 05:00) coupled to a pair of aerial antennas mounted to the discharge catwalk and parallel with the river.

Monitoring Station 11: This location was designed to detect radio-tagged shad in the center portion of the Vernon turbine discharge area downstream a distance of ~50 feet and laterally a distance of ~25 feet. It consisted of a single Lotek receiver (CRTO = 05:00) coupled to a pair of aerial antennas mounted to the discharge catwalk and parallel with the river.

Monitoring Station 12: This location was designed to detect radio-tagged shad in the eastern portion of the Vernon turbine discharge area downstream a distance of ~50 feet and laterally a distance of ~25 feet. It consisted of a single Lotek receiver (CRTO = 05:00) coupled to a pair of aerial antennas mounted to the discharge catwalk and parallel with the river.

Monitoring Station 13: Monitoring station 13 detected radio-tagged shad as they moved downstream of the Vernon spillway area, out to a distance of approximately 100 feet. This station was located near the midpoint of the spillway reach and consisted of a single Lotek receiver (CRTO = 10:00) coupled to two aerial antennas controlled by a switchbox.

Monitoring Station 14: This station monitored for outmigrating radio-tagged shad which had entered the forebay area upstream of the Vernon spillway. This station consisted of a single Lotek receiver (CRTO = 10:00) coupled to a series of four aerial antennas spaced evenly over the 600 foot spillway catwalk and calibrated to detect radio tags ~75 feet upstream.

Monitoring Station 15: Monitoring station 15 detected upstream migrating radio-tagged shad having passed monitoring station 22 (see below) at the exit of the upstream fish ladder as well as downstream migrating radio-tagged shad that had entered the forebay area upstream of the Vernon powerhouse. This station consisted of a single Lotek receiver (CRTO = 05:00) coupled to a pair of aerial antennas coupled by a switch box. The first antenna was oriented north-northwest and calibrated to detect shad moving into or out of the forebay. The second antenna was oriented northeast and was calibrated to monitor any radio-tagged shad to the east of the diversion boom.

Monitoring Station 16: This station consisted of a single Orion receiver and four underwater drop antennas and was intended to inform on the outmigration of radio-tagged shad. Dropper antennas were positioned within Units 1, 2, 3, and 4 at a point inside of the trash racks. All four drops were combined to eliminate lost coverage time associated with a receiver switching through the antennas at each individual unit. As a result, detections of a transmitter passing through Units 1-4 were collected as a single data set.

Monitoring Station 17: This station consisted of a single Orion receiver and four underwater drop antennas and was intended to inform on the outmigration of radio-tagged shad. Dropper antennas were positioned within Units 5, 6, 7, and 8 at a point inside of the trash racks. All four drops were combined to eliminate lost coverage time associated with a receiver switching through the antennas at each individual unit. As a result, detections of a transmitter passing through Units 5-8 were collected as a single data set.

Monitoring Station 18: This station consisted of a single Orion receiver and two underwater drop antennas and was intended to inform on the outmigration of radio-tagged shad. Dropper antennas were positioned within Units 9 and 10 at a point inside of the trash racks. The two drops were combined to eliminate lost coverage time associated with a receiver switching through the antennas at each individual unit. As a result, detections of a transmitter passing through Units 9-10 were collected as a single data set.

Monitoring Station 19: Monitoring station 19 detected outmigrating radio-tagged shad as they entered the upstream end of the fish pipe (located between turbine units 4 and 5). This station consisted of a single Orion receiver coupled to an underwater drop antenna.

Monitoring Station 20: Monitoring station 20 detected outmigrating PIT-tagged shad as they exited the downstream end of the fish pipe (located between turbine units 4 and 5). This station consisted of a PIT antenna mounted around the downstream end of the pipe coupled to a reader.

Monitoring Station 21: Monitoring station 21 detected outmigrating radio-tagged shad as they entered the upstream end of the fish tube (located along the western shoreline and adjacent to Unit 10). This station consisted of a single Orion receiver coupled to an underwater drop antenna.

Monitoring Station 22: Monitoring station 22 was installed to detect radio-tagged shad as they exited the upstream end of the Vernon fish ladder. Radio-tagged shad at this location have already passed upstream of monitoring stations 3 and 4. This location consisted of a single Lotek receiver (CRTO = 05:00) and underwater drop antenna.

Monitoring Station 23: This location was installed to determine the presence of radio-tagged shad entering the Bellows Falls tailrace and tailwaters. It consisted of a single Lotek receiver (CRTO = 05:00) and a pair of aerial antennas calibrated to detect fish within the unit discharge area and along the western shoreline just downstream of the powerhouse.

Monitoring Station 24: Monitoring station 24 detected radio-tagged shad as they moved upstream and into the Bellows Falls bypassed reach. It consisted of a single Lotek receiver (CRTO = 05:00) and aerial antenna mounted along the western shoreline of the bypassed reach and oriented perpendicular to the channel. This station was located downstream of the diversion dam.

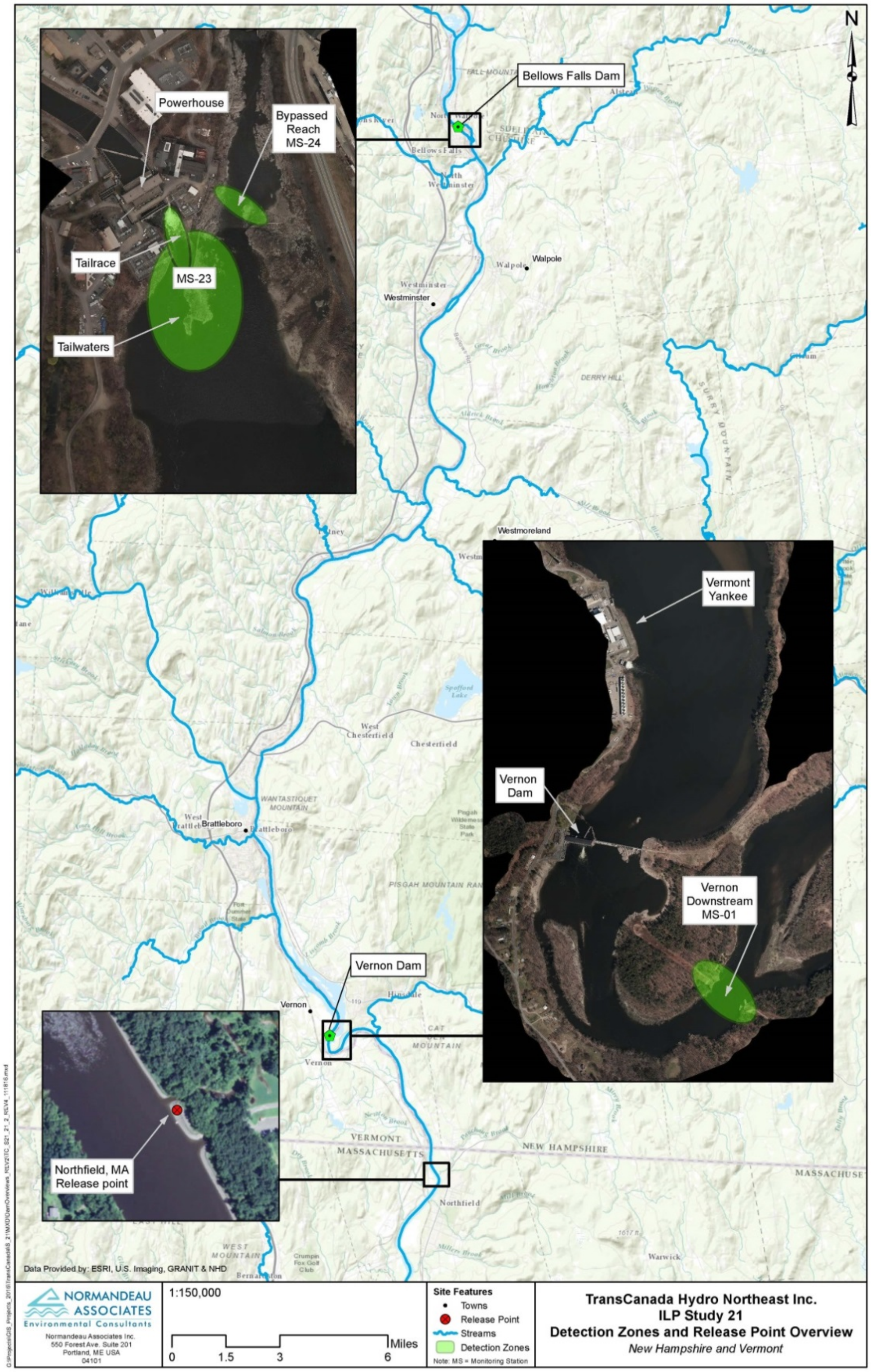

Figure 4.3-1. Detection zones and monitoring stations upstream and downstream of Vernon (MS-xx = Monitoring Station xx).

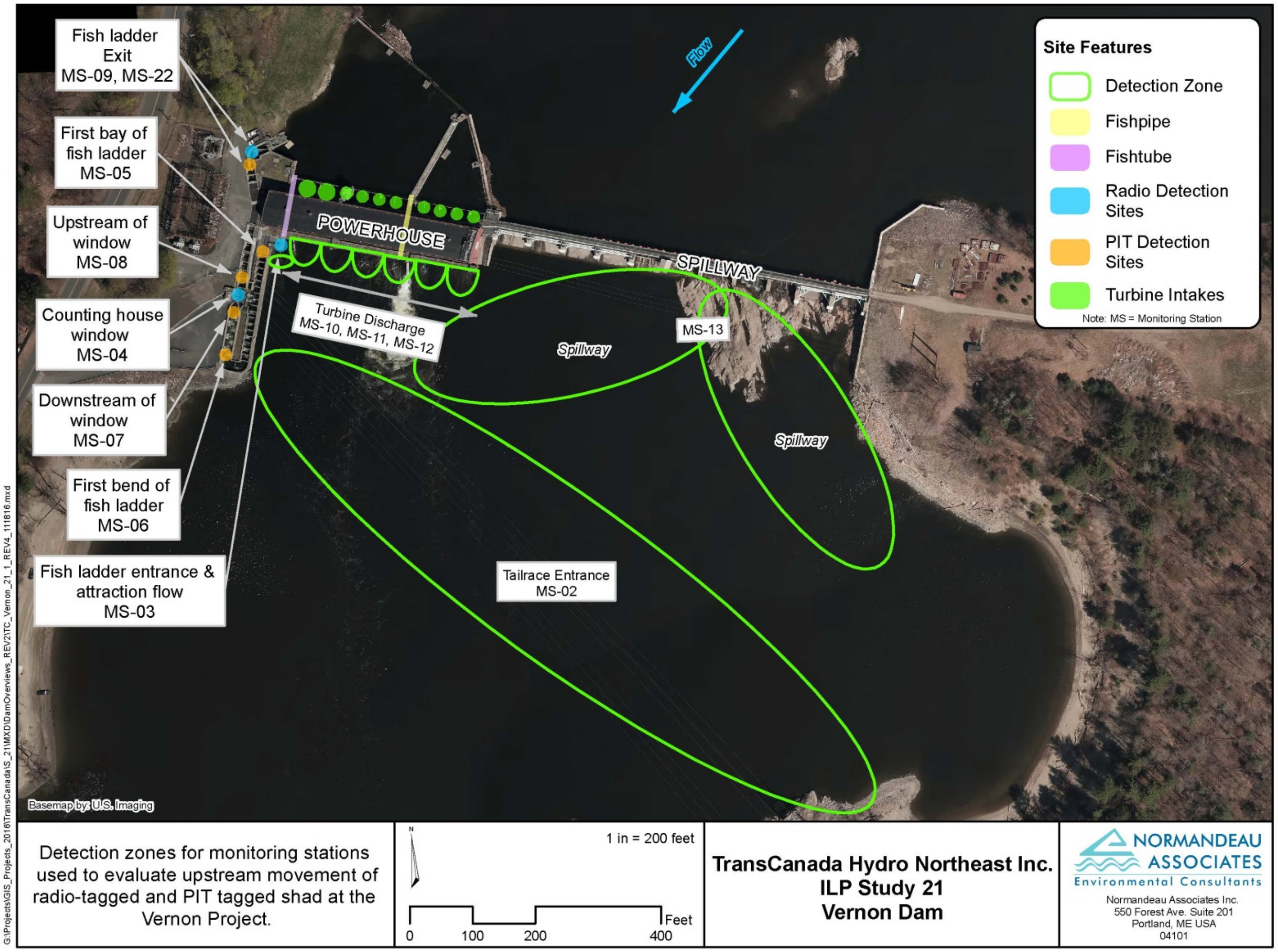

Figure 4.3-2. Tailrace and fish ladder monitoring stations and detection zones used to evaluate upstream movement of shad with radio or PIT tags at Vernon (MS-xx = Monitoring Station xx).

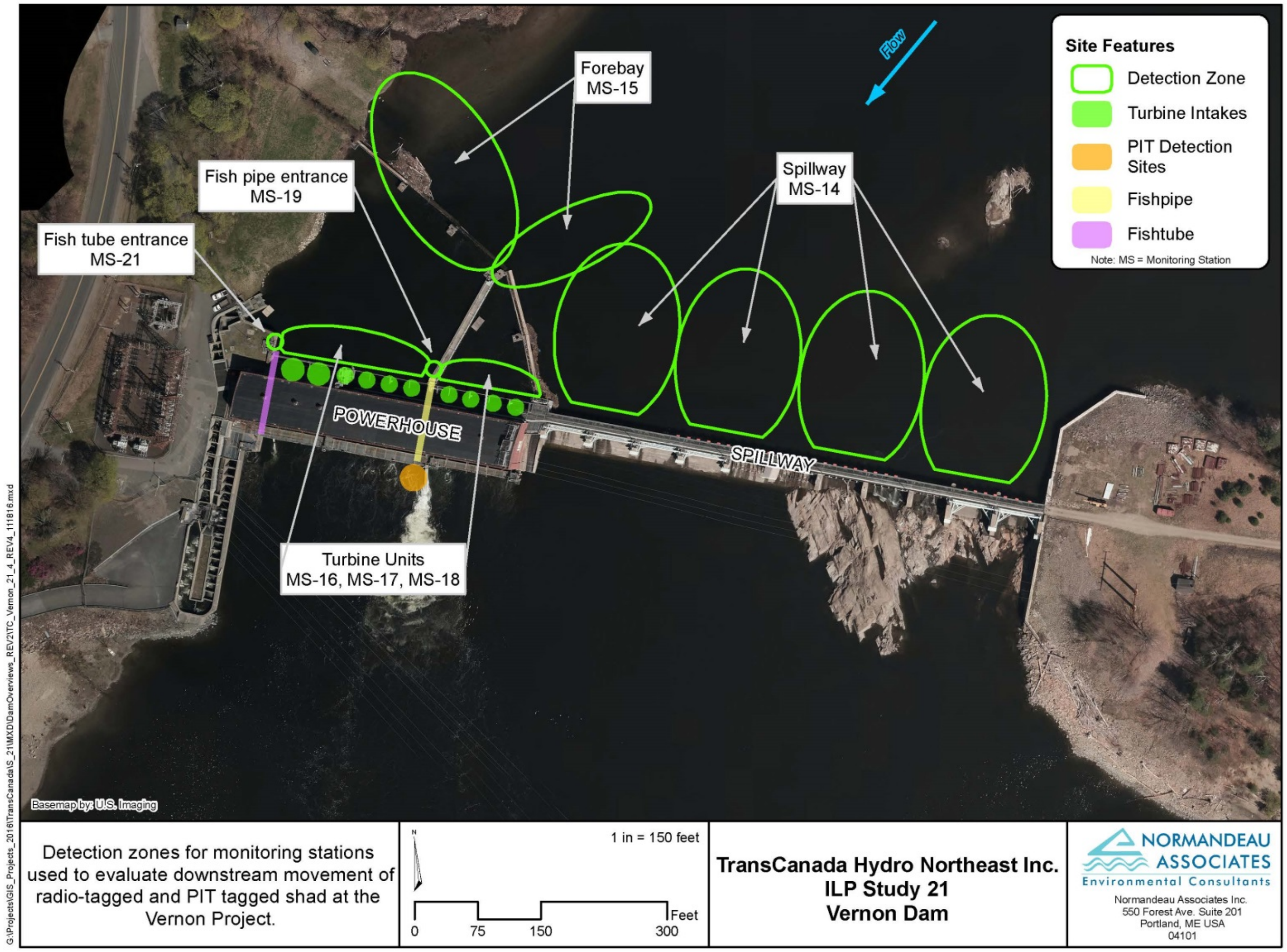

Figure 4.3-3. Forebay monitoring stations and detection zones used to evaluate downstream movement of shad with radio tags at Vernon (MS-xx = Monitoring Station xx).

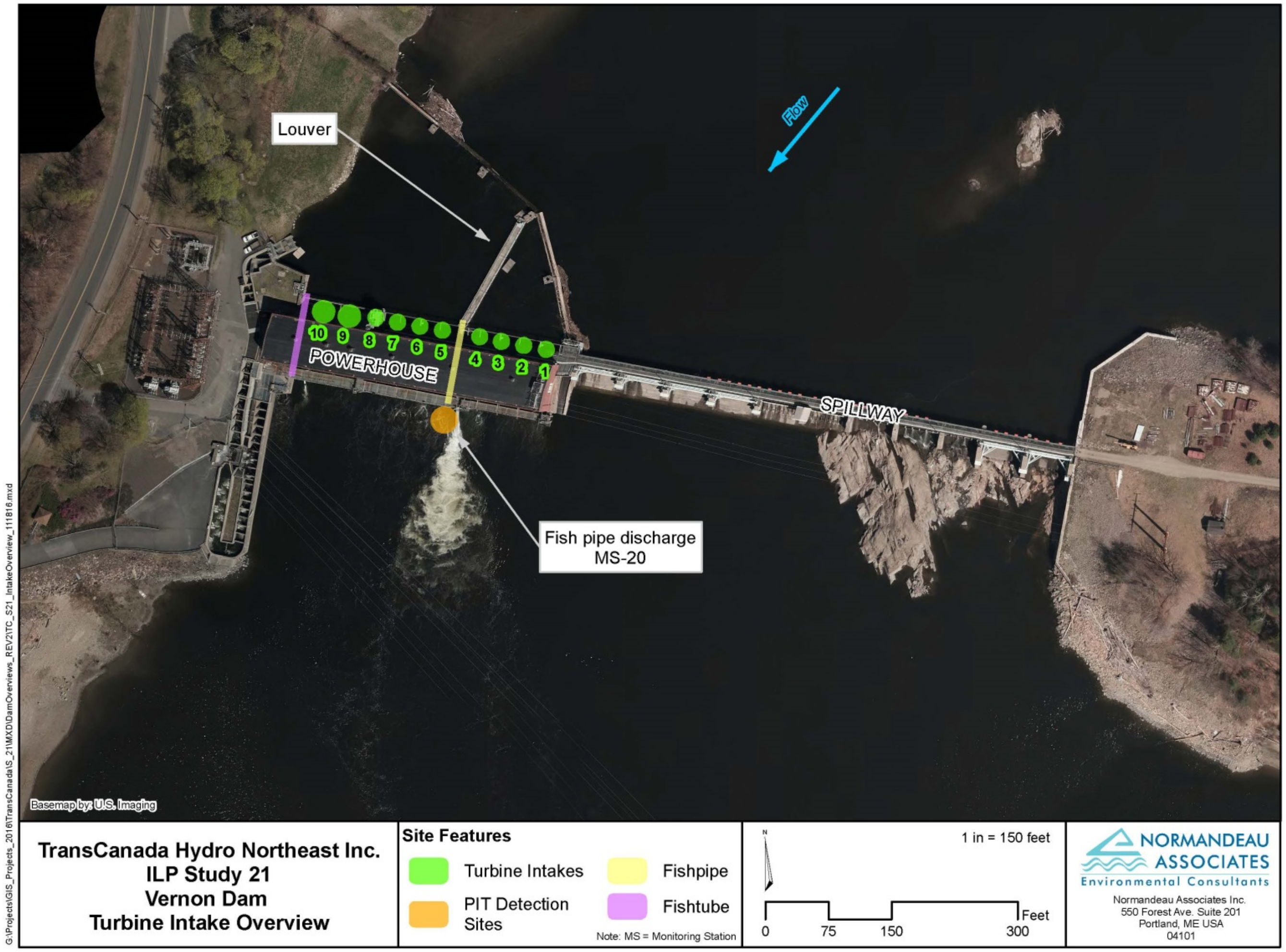

Figure 4.3-4. PIT tag monitoring station on the downstream end of the fish pipe downstream passage route (MS-xx = Monitoring Station xx).

4.4 Data Collection

4.4.1 Stationary Telemetry Data

Dependent on the settings programmed during telemetry set up, data was stored in the stationary receivers as either a single detection, or was compiled for multiple detections over a fixed period of time (i.e., CRTO of 5 or 10 minutes). For locations where multiple detections were compiled into a single record, information included the start date, start time, channel, code, average signal strength, end date, and end time. For locations where detections were recorded as individual events, the download file included date and time of detection, channel, code, signal strength, and antenna (if more than one antenna was connected to receiver). Data was downloaded from stationary receivers three times per week throughout the study period. Back-up copies of all data files were immediately saved to a dedicated flash drive prior to re-initialization of the downloaded receiver. Data was then consolidated into a database for review and verification including examining data for stationary signals.

4.4.2 Manual Telemetry Data

Manual radio tracking by boat was performed for all release groups to supplement data collected from the fixed monitoring stations and to identify areas for potential spawning sampling. The reach downstream of Vernon dam was surveyed every other day to the southern end of Stebbins Island. On occasion, as the study progressed, manual tracking was extended downstream to the release point at Northfield, MA. After radio-tagged shad were released above Vernon dam or had passed via the fish ladder, the approximate 31.8-mile stretch of river between Vernon dam and Bellows Falls dam was surveyed 5 days each week. When radio-tagged shad were located, a GPS coordinate, date, time, and fish status (actively moving or stationary) were recorded to supplement data from the fixed stations.

Fish status was determined based on interpretation of the duration between transmitter pulses. Radio transmitters were equipped with a motion sensor (see Section 4.2.1) which when activated, changed the pulse rate from 2.0 to 9.0 seconds. It should be cautioned that this motion sensor feature is often misinterpreted as a “mortality switch”. The status of a fish (live/dead) does not directly determine which “mode” a transmitter is in. The “no motion” pulse rate is triggered when the switch ceases to achieve a predetermined number of internal contacts within a set period of time. Alternatively, the “motion” pulse rate will be maintained as long as the predetermined number of internal contacts over the set period of time is achieved. The mode that a transmitter is in will be a function of fish behavior (i.e., degree of movement prior to detection) as well as river conditions. A fish that is stationary for a period of time can initiate the “no motion” pulse rate and a transmitter within an individual that is a true mortality can maintain the “motion” pulse rate due to movement of the transmitter by river flows.

4.4.3 Ichthyoplankton Sampling

4.4.3.1 Field Methodologies

Nighttime ichthyoplankton sampling for shad eggs and larvae was conducted over a six-week period from late May to early July with a total of 60 sampling events occurring, generally at two trawl locations each night. All samples were collected with a 0.5-m plankton net (0.5-mm mesh) equipped with a General Oceanics model 2030 flow meter. During each sampling event, two ichthyoplankton nets were fished, one on each side of the boat, for a total of 120 samples. Sampling consisted primarily of the paired nets suspended off the port and starboard side of an anchored boat. However, in some cases, the paired nets were towed behind the boat while in gear moving upstream at headway speed. Sample duration was approximately 30-60 minutes. Nets were fixed at varying depths from surface to mid-depth in the water column depending upon environmental conditions and water depth. Environmental parameters including water temperature, dissolved oxygen, pH, conductivity, and turbidity were measured prior to the collection of each sample. The date, time, location, substrate type, water velocity, water depth, and shad splashes (indicating potential spawning activity) were recorded.

Sample locations were selected based on the presence of radio-tagged adult shad as determined by manual telemetry tracking. Once a fish was located, pertinent site information was recorded and the paired-net ichthyoplankton samples were collected. At the completion of sampling, the nets were pulled and the contents were carefully washed into one-quart jars. The contents of each sample were preserved using 6-8% formalin. Jars were labeled and sealed for delivery to Normandeau's Bedford, NH laboratory for sorting and identification.

The volume of water that was filtered for each sample was measured using the difference in rotor spins by the flow meter. When recording the difference in counts for each sample, a sample volume (m^3) could be calculated by using the following formulas:

A. Distance in meters = $\dfrac{\text{Difference in counts x Rotor constant}^{1}}{999{,}999}$

B. Volume of water filtered (m^3) = $\dfrac{3.14\ (\text{net diameter in } m^2)\ \text{X Distance (m)}}{4}$

4.4.3.2 Laboratory Methodologies

Upon receipt at the Bedford laboratory, shad eggs and larvae were identified and removed from the remainder of the sample. The developmental stage was determined for each individual shad egg using previously developed stage information for American Shad (Jones et al., 1978; Table 4.4-1). The literature

[1] Rotor constant: Standard speed rotor = 26,873; Low speed rotor = 57,560

defined time-since-spawn for each developmental stage is also presented in Table 4.4-1.

Table 4.4-1. Developmental stages of American Shad eggs.

Developmental Stage	Description	Time Since Spawn (hrs)
1	Blastodisk	0.5
2	2 cell stage	1.5
3	4 cell stage	2.0
4	8 cell stage	2.5
5	16 cell stage	3.0
6	Morula	4 to 6
7	Blastopore	6.0
8	Early embryo	38.0
9	Detached tail embryo	48.0

4.5 Data Analysis

4.5.1 Upstream Passage

As stated in the RSP, the determination of nearfield attraction, entrance efficiency, and internal efficiency of the Vernon fish ladder were the primary objectives related to upstream passage. In addition, movement of tagged shad into the study area from downstream release locations, residency time in the project area downstream of Vernon, and movement of tagged shad within the mainstem river from the Vernon dam headpond upstream to the Bellows Falls tailrace were examined.

To evaluate the performance of the Vernon fish ladder the following three metrics were calculated:

- **Nearfield Attraction**: this metric was calculated as the proportion of dual-tagged fish that were detected in the attraction water area immediately outside of the fish ladder (as determined by detection on the aerial antenna associated with monitoring station 3) in relation to the total number of tagged fish available. For this study, “the number of tagged fish available” was defined as the number of dual-tagged shad determined to have moved upstream from downstream release locations and into the detection range of monitoring stations 2, 3 (aerial component only), 10, 11, 12, or 13.
- **Entrance Efficiency**: this metric was calculated as the proportion of dual-tagged fish that entered the fish ladder. Entrance efficiency was calculated using a denominator which represented the total number of dual-tagged shad detected in the attraction water area immediately outside of the fish ladder (i.e., those detected on the aerial antenna associated with monitoring station 3) and a numerator which represented the total number of dual-tagged shad that physically

entered the fish ladder (based on detections at monitoring stations 3 (underwater drop only), 4, 5, 6, 7, 8, 9 or 22).

- **Internal Efficiency**: this metric was calculated as the proportion of the total number of PIT and dual-tagged fish that entered the fish ladder (as determined by detection at monitoring stations 5 or 6[2] for PIT or dual-tagged shad or at the underwater drop antenna at monitoring Station 3 for dual-tagged shad) and were determined to have exited upstream (based on detection at monitoring station 9 for PIT or dual-tagged shad or at the underwater drop antenna at monitoring station 22 for dual-tagged shad). Individuals not remaining upstream of Vernon dam for more than 48 hours following exit from the fish ladder were not considered "successful" and as a result, did not contribute positively to the calculation of internal efficiency.

A 95% confidence interval (CI) was calculated for each of the three upstream fish ladder metrics using a bootstrap sampling procedure (25,000 bootstrap samples randomly drawn with replacement).

In addition to nearfield attraction, entrance efficiency, and internal efficiency, the total residency time downstream of Vernon dam was determined through evaluation of detection information for the subset of dual-tagged shad released by either TransCanada or FirstLight that had moved upstream and into the detection range of monitoring stations 2, 3, 10, 11, 12, or 13. Project operations coinciding with the occurrence of upstream passage at Vernon were examined graphically.

4.5.2 Downstream Passage

As stated in the RSP, the determination of downstream passage timing and residence, post-spawn downstream passage route selection, downstream passage efficiency, and downstream passage survival at Vernon were the primary objectives related to downstream passage of adult shad. Evaluation of downstream passage focused on shad carrying radio-tags. Following the study design outlined in the RSP, the only downstream passage route available to monitor PIT-tagged individuals was the fish pipe (monitoring station 20). As a result, no information on arrival at the Vernon forebay or residency was available for those individuals.

To evaluate downstream passage, detection information from monitoring stations 14 and 15 was used to determine the return of radio-tagged shad to the Vernon forebay as well as their subsequent period of residency prior to downstream passage. Detection information from monitoring stations 13, 16, 17, 18, 19 and 21 was used to inform on the proportion of adult radio-tagged shad which were able to successfully depart the Vernon forebay and arrive downstream. Project operations

[2] Due to the lowered sensitivity of the PIT multi-reader installed at monitoring station 5, the detection probability for shad passing that location was low (see Section 4.3). As a result, detections at monitoring station 6 were used to help inform on the presence of PIT-tagged shad within the fish ladder.

coinciding with the occurrence of downstream passage at Vernon were examined graphically.

Following downstream passage, radio-tagged adult shad were remotely monitored for continued downstream passage by TransCanada at monitoring station 1 (located approximately 0.75 miles downstream of Vernon dam) as well as during manual tracking events conducted within the Turners Falls impoundment. Coincident with this study, FirstLight and its consultants installed and maintained a series of stationary telemetry receivers in the vicinity of Northfield Mountain Pumped Storage and Turners Falls Projects. Passage information collected by FirstLight was obtained and used to inform on the continued downstream movement for each of the radio-tagged shad confirmed to have passed Vernon.

4.5.3 Spawning Surveys

Goals of the spawning surveys included identification of areas used by American Shad for spawning, assessment of the effects of project operations (e.g., water velocity, water depth, inundation and exposure of habitat) on spawning, and quantification of spawning. Potential spawning locations were determined based on the presence of radio-tagged adult shad tracked from downstream of Vernon dam to Bellows Falls dam. Following examination of ichthyoplankton samples collected at those locations, the developmental stage of each collected egg was determined (see Section 4.4.3.2). For all stage 1 eggs, a back-calculated spawn location was determined using the estimated time from spawn to collection along with river velocity at the point of collection to determine the approximate distance upstream of the collection point where the egg was likely spawned. Back-calculated spawning locations were not calculated for eggs older than stage 1 as the water velocity information collected at the time of measurement was less likely to be representative over longer periods of time potentially consisting of varied river flows. Back-calculated spawning locations are presented graphically in Appendix E (geodata). For each of these determined spawning locations, the modeled effects of project operations on three parameters (mean channel velocity, channel width, and thalweg depth) at the upper and lower hydraulic model cross sections bounding each general spawning area were evaluated. Discharges from minimum flow to flows greater than maximum station generating capacity (including flows at which back-calculated spawning occurred) were evaluated for each general spawning location. Average values for each discharge for a range of water surface elevations within the normal operating range of each project are presented in Section 5.5 for each general spawning area. Aquatic substrate/habitat at each determined spawning location was obtained from Studies 7 and 9 and is also provided.

5.0 RESULTS

5.1 Vernon Operations and Connecticut River Conditions

Monitoring of PIT and dual-tagged American Shad was initiated on May 10 and continued until completion of the downstream passage study component on July 7, 2015. Hourly total discharge and river temperature at Vernon dam is presented in Figure 5.2-1. In general, total project discharge was below maximum station generating capacity (17,100 cfs) during May with several spill events occurring during June, 2015. Total discharge exceeded maximum station generating capacity for approximately 0.4% of the study period during May (May 10-May 31; 8 of 2,111 15-min records), 39% of the study period during June (June 1-June 30; 1,110 of 2,880 15-min records) and 46% of the study period during July (July 1-July 7; 307 of 672 15-min records).

Vernon has four 133 rpm single runner vertical Francis units (Units 1-4), two 144 rpm vertical axial flow Kaplan units (Units 5-8), and two 75 rpm single runner vertical Francis units (Units 9-10); hourly discharge values for the duration of the study period are presented in Figures 5.2-2 through 5.2-4. With the exception of Unit 10, which operated continuously throughout the study period, the majority of units had some periods of down time. Figure 5.2-5 presents the release point, timing, and magnitude of spill events at Vernon during the study period. During the study period, spill occurred only via the taintor gates and trash/ice sluice gate. There was no record of spill via the flood gates, flashboard sections, or stanchions. The mean discharge during spill events (reported in 15-minute increments) was 1,217 cfs during May, 6,908 cfs during June, and 6,930 cfs during July. The fish pipe and fish tube, operated as downstream bypasses, were open and passing their maximum discharge (350 and 40 cfs, respectively). The upstream fish ladder operated continuously throughout the study period, passing approximately 65 cfs of fish ladder flow. An additional 200 cfs of attraction water was cycled on for 12-13 hours during daylight hours (generally from 0700 to 1900 or 2000; Figure 5.2-6).

5.2 Tagged Shad Releases

5.2.1 Releases Downstream of Vernon

One hundred adult American Shad were collected from the fish lift facilities at Holyoke dam during May, 2015. Each was PIT-tagged and a subset (N=52) was also radio-tagged ("dual-tagged"). Tagged shad were released on three separate dates at the Pauchaug Brook boat access located in Northfield, MA (Table 5.2-1). Concurrent with this study, FirstLight conducted a similar shad spawning and migration study at their projects located downstream of Vernon dam (Kleinschmidt and Gomez and Sullivan, 2016). FirstLight released 397 dual-tagged shad and 396 PIT-tagged shad in three general areas: Turners Falls impoundment, downstream of Cabot Station, and within the Holyoke impoundment. As agreed during study plan development, upstream passage information for shad from the FirstLight releases would be evaluated for any individuals determined to have entered into the Vernon study area (i.e., detected at monitoring stations 2, 3, 10, 11, 12, or 13 for dual-tagged shad or monitoring stations 5, 6, 7, 8, and 9 for PIT-tagged shad). Tag and release data for shad in the Vernon study area from both studies are included in Appendix A-1 (appendices filed separately in Excel format).

5.2.2 Releases Upstream of Vernon

Fifty-four adult American Shad were captured at the Vernon fish trap, radio-tagged, and released at the Old Ferry boat launch, located in Brattleboro, VT approximately 11.3 river miles upstream of Vernon dam (Table 5.2-2). Releases upstream of Vernon took place over three dates (May 17, 24, and 30) and were intended to supplement the subset of dual-tagged shad successfully ascending the fish ladder and passing Vernon in the evaluation of upstream spawning activity and subsequent downstream passage.

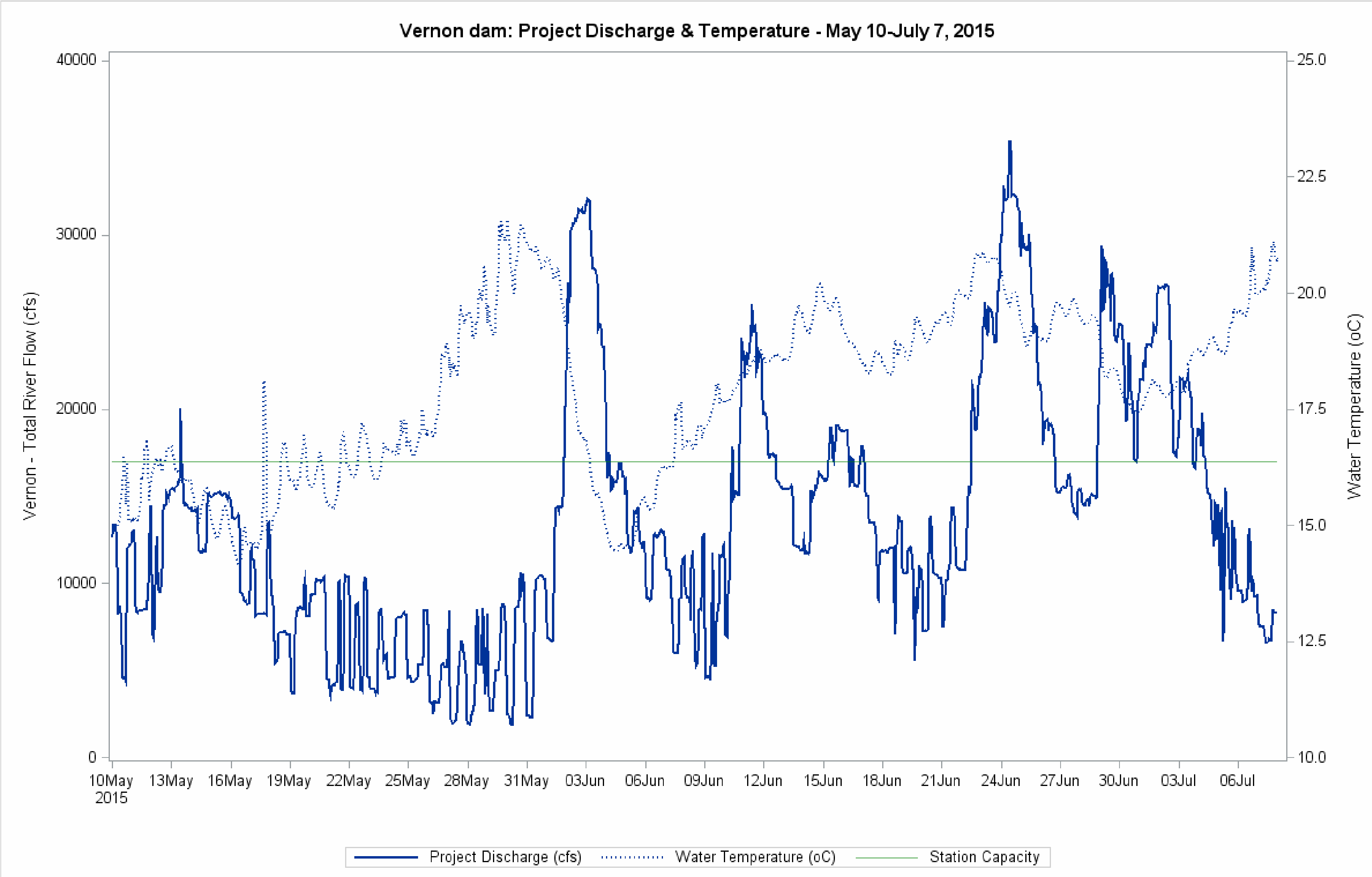

Figure 5.2-1. Project discharge (cfs) and water temperature (^{o}C) at Vernon during the study period, May 10 – July 7, 2015.

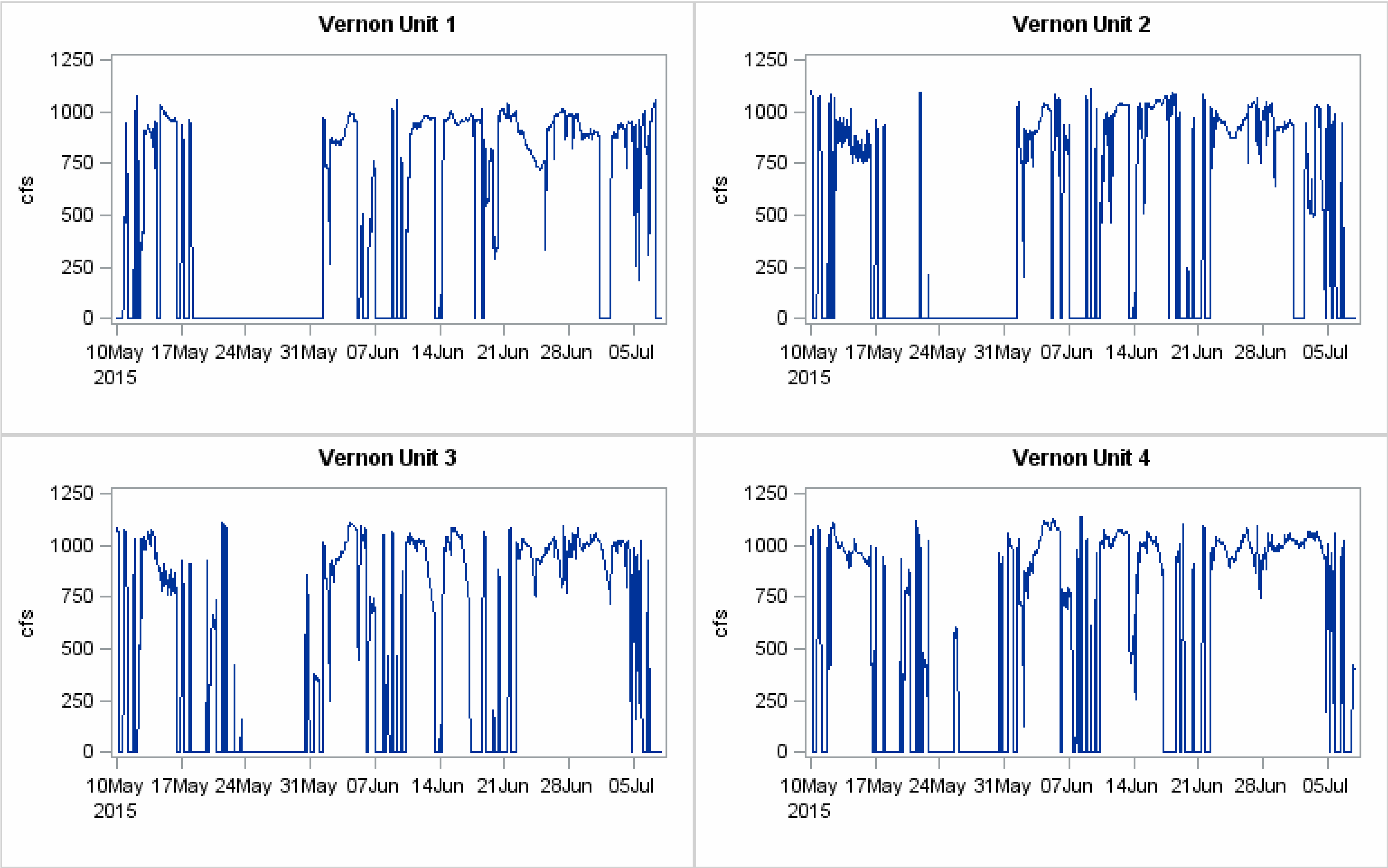

Figure 5.2-2. Hourly discharge for Units 1-4 (133 rpm single runner Francis units) at Vernon during the study period, May 10 – July 7, 2015.

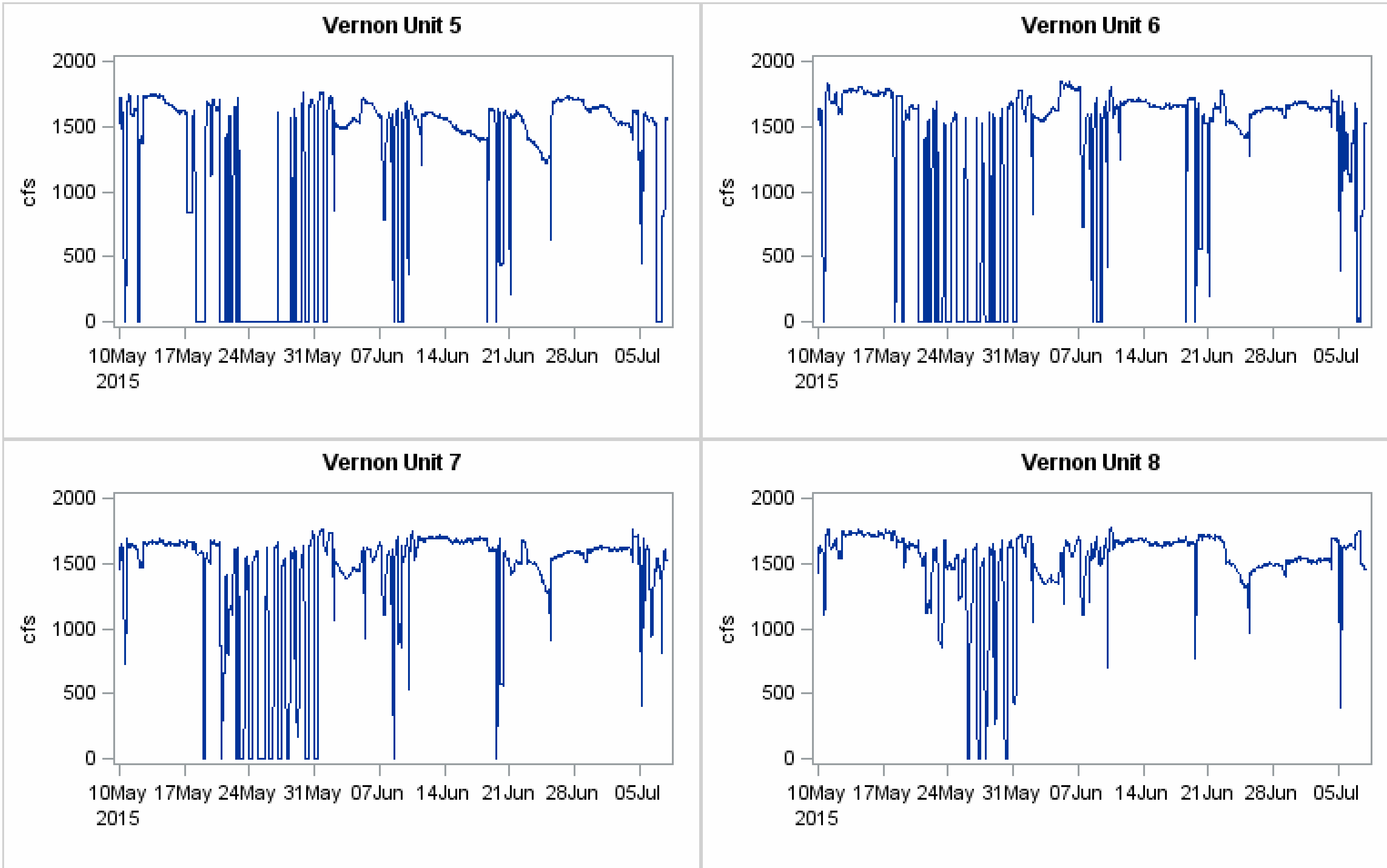

Figure 5.2-3. Hourly discharge for Units 5-8 (144 rpm axial flow Kaplan units) at Vernon during the study period, May 10 – July 7, 2015.

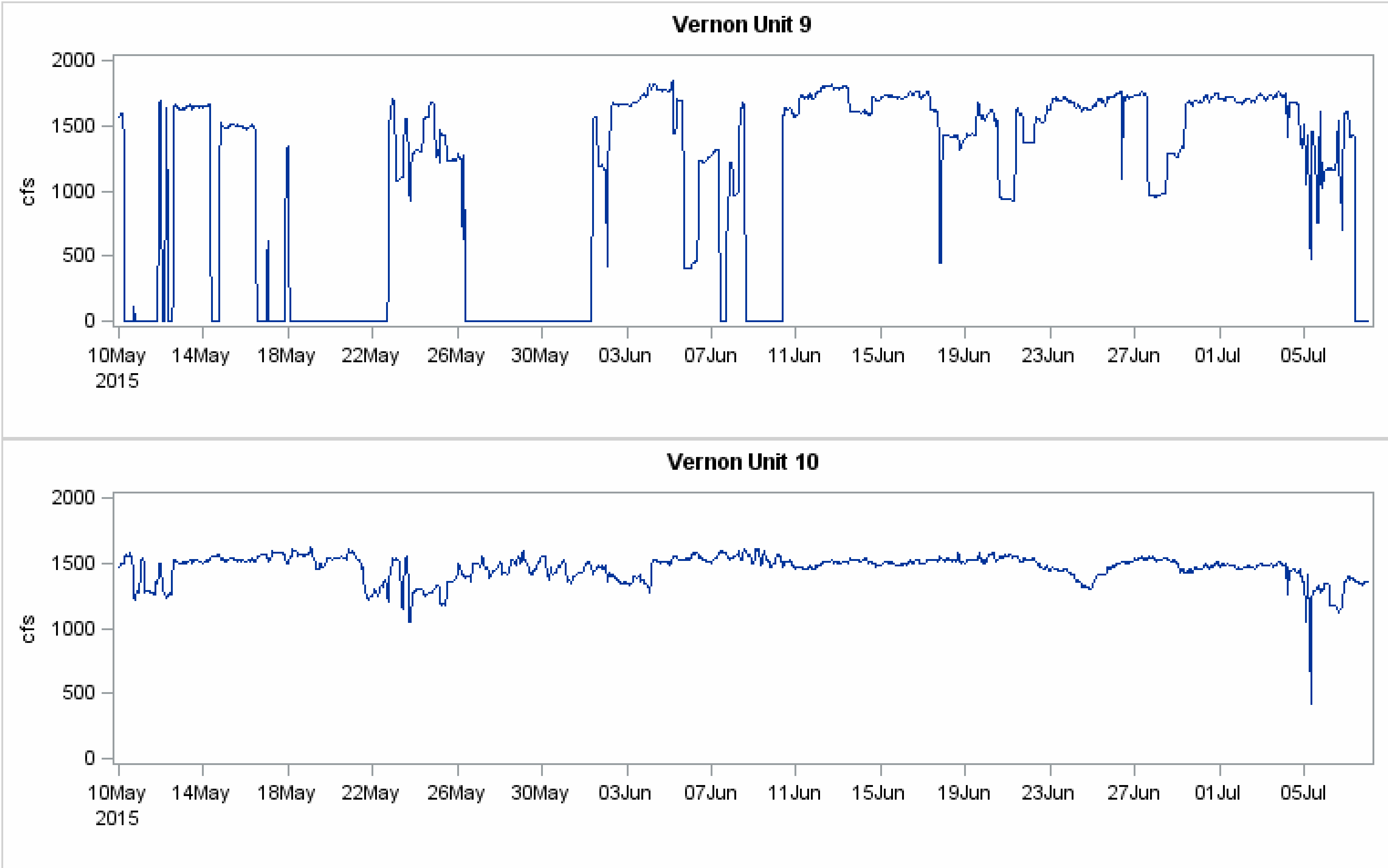

Figure 5.2-4. Hourly discharge for Units 9-10 (75 rpm single runner Francis units) at Vernon during the study period, May 10 – July 7, 2015.

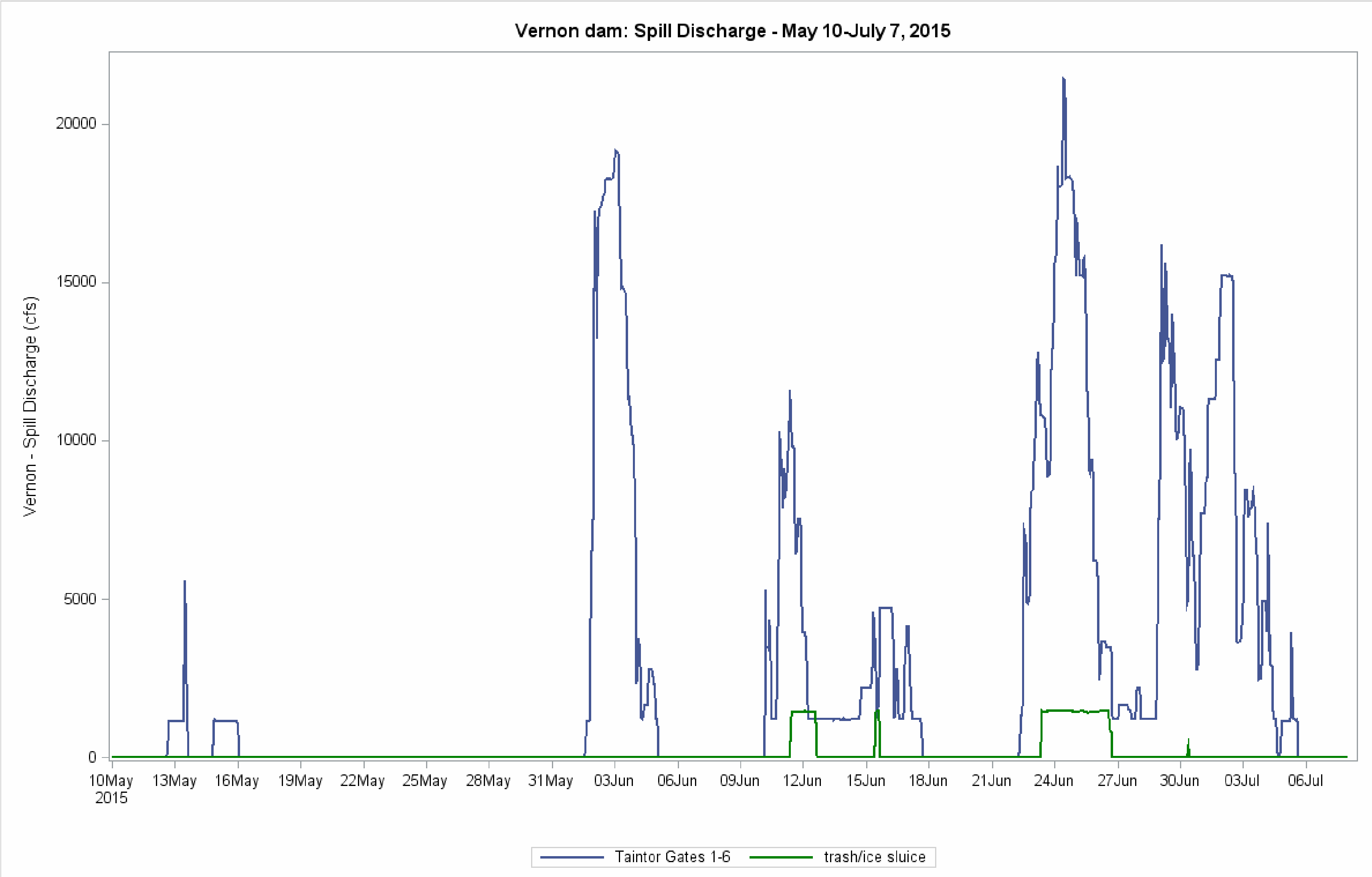

Figure 5.2-5. Spill discharge (cfs) by gate type at Vernon dam during the study period, May 10 – July 7, 2015.

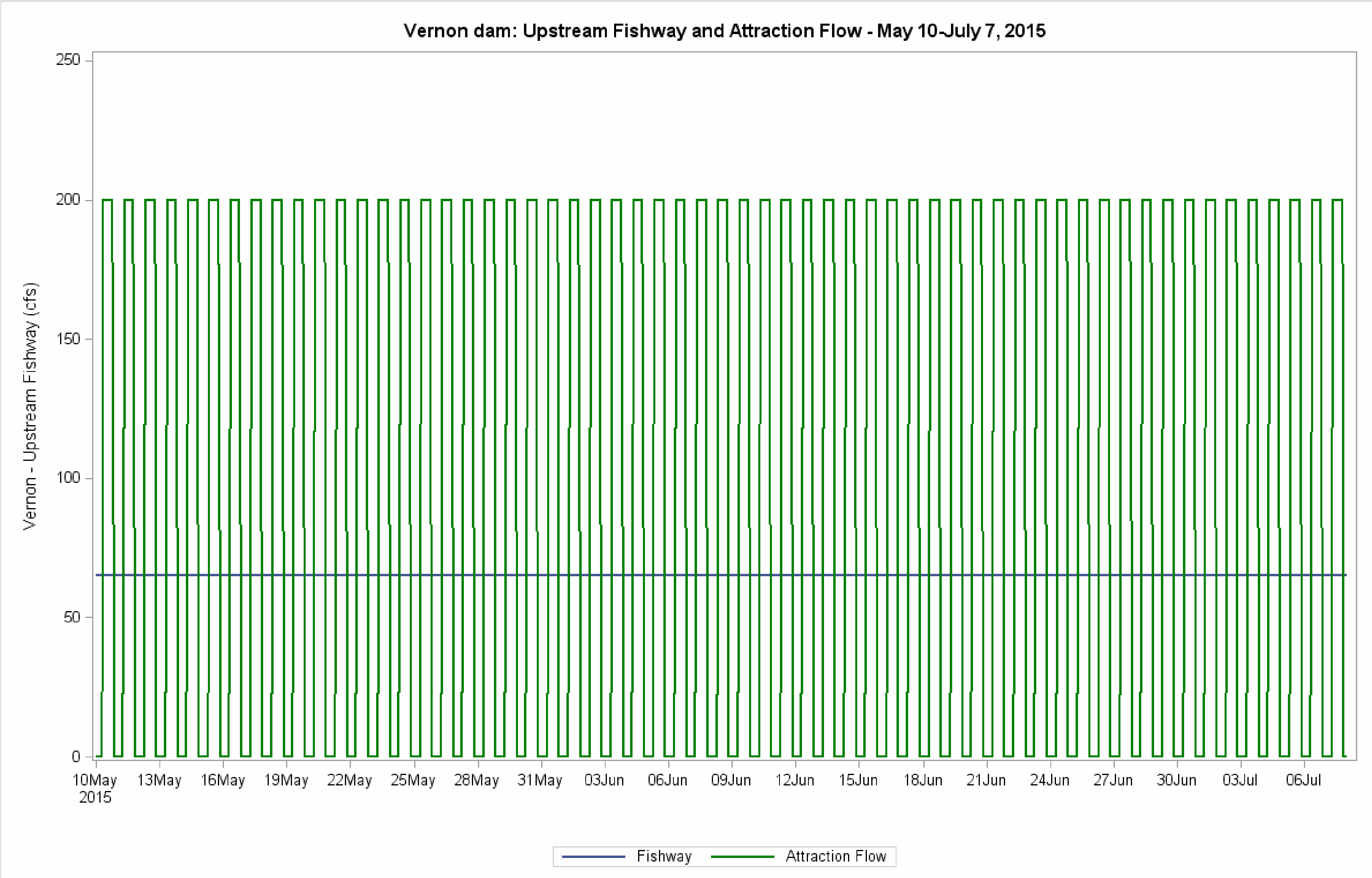

Figure 5.2-6. Upstream fish ladder discharge (cfs) and attraction pump flow (cfs) at Vernon dam during the study period, May 10 – July 7, 2015.

Table 5.2-1. Summary of TransCanada tagged adult American Shad released at the Pauchaug Brook boat access downstream of Vernon dam, spring 2015.

Release Group	Shad Run Segment	Collection Location	Release Date	No. Released	Tag Type	No. Tagged	Sex and No. of Tagged Shad		Release Water Temp. °C
1	Early	Holyoke Fish lift	10-May	40	PIT	20	M	21	16.1
					Radio & PIT	20	F	19	
2	Mid	Holyoke Fish lift	14-May	40	PIT	20	M	26	13.4
					Radio & PIT	20	F	14	
3	Late	Holyoke Fish lift	28-May	20	PIT	8	M	3	17.4
					Radio & PIT	12	F	17	
				Total = 100	**PIT**	**48**	**M**	**50**	
					Radio & PIT	**52**	**F**	**50**	

Table 5.2-2. Summary of TransCanada radio-tagged adult American Shad released at the Old Ferry boat launch upstream of Vernon dam, spring 2015.

Release Group	Shad Run Segment	Collection Location	Release Dates	Number Released	Sex and No. of Tagged Shad		Release Water Temp. °C
1	Early	Vernon Fish Trap	17-May	20	M	16	12.7
					F	4	
2	Mid	Vernon Fish Trap	24-May	23	M	16	14.2
					F	7	
3	Late	Vernon Fish Trap	30-May	11	M	5	18.8
					F	6	
				Total = 54	**M**	**37**	
					F	**17**	

5.3 Upstream Passage

5.3.1 Entry into Study Area

The movement of PIT and dual-tagged shad into the Vernon study area was determined based upon detection at monitoring stations 5, 6, 7, 8, or 9 (PIT-tagged) and monitoring stations 2, 3, 10, 11, 12, and 13 (dual-tagged). Table 5.3-1 presents the proportion of tagged shad from each of the three TransCanada release groups that moved upstream from the Pauchaug Brook boat access to the Vernon study area. When individuals from those three release groups are considered, 36% (36 out of 100) of the tagged shad moved into the Vernon study area (Table 5.3-1). Of that total, 16 individuals were originally PIT-tagged and 20 individuals were originally dual-tagged. Two of the individuals originally radio-tagged as part of the TransCanada releases (ID #s 8-172 and 54-164) shed their radio-tags prior to arrival at Vernon and as a result detection information for those two fish is limited to PIT monitoring stations only. As a result, those two individuals were treated as PIT-tagged fish for all subsequent analyses.

In addition to shad released as part of this study, an additional 41 dual-tagged shad (10.3% of the 397 released at all FirstLight sites) and an additional 52 PIT-tagged shad (13.1% of the 396 released at all FirstLight sites) were detected in the Vernon study area. Note that one of the originally dual-tagged shad released by FirstLight (ID # 54-58) had shed its radio-tag and as a result was treated as a PIT-tagged fish for all subsequent calculations. An additional seven dual-tagged adult shad originally released by FirstLight were determined to have ascended as far upstream as Stebbins Island (based on detection at monitoring station 1) but did not reach the Vernon study area.

As a result, a total of 129 individuals (71 PIT-tagged[3] and 58 dual-tagged) were determined to have entered the Vernon study area and were considered “available” for the calculation of upstream fish ladder performance metrics.

Literature review indicates that a certain proportion of radio-tagged shad will fall back downstream shortly after tag and release with little or no subsequent upstream movement (e.g., Legget, 1976; RMC, 1990; Sprankle, 2005; Olney et al., 2006; Normandeau, 2011; 2012). Depending upon site-specific characteristics and prevailing hydrological conditions, post-tagging stress has consistently been reported to affect migration behavior for up to 40% of American Shad; and can reportedly range widely from less than 10% to 100% (Frank et al., 2009; Barry and Kynard, 1986). Results of this study are therefore generally consistent with expected rates for fall back.

[3] This total includes the three individuals originally dual-tagged that had shed their radio-transmitter prior to arrival at Vernon. Information from those fish was used in metrics where PIT-tagged data was utilized.

Table 5.3-1. Arrival of TransCanada released shad to the Vernon study area as determined based on detection at monitoring stations 5, 6, 7, 8 or 9 (PIT-tagged) and 2, 3, 10, 11, 12, and 13 (dual-tagged).

Release Date	Water Temp °C	No. Released	No. Arrived	Arrival Rate (%)
Dual Tag				
10-May	16.1	20	7	35.0
14-May	13.4	20	7[a]	35.0
28-May	14.2	12	6	50.0
Total		**52**	**20**	**38.5**
PIT Tag				
10-May	16.1	20	7	35.0
14-May	13.4	20	6	30.0
28-May	14.2	8	3	37.5
Total		**48**	**16**	**33.3**
All Tagged Fish				
10-May	16.1	40	14	35.0
14-May	13.4	40	13	32.5
28-May	14.2	20	9	45.0
Total		**100**	**36**	**36.0**

a. Two individuals originally dual-tagged discarded their radio-tags prior to arrival at Vernon and were detected via PIT monitors only.

Table 5.3-2 presents the minimum, maximum, median, and mean travel durations for both PIT and dual-tagged adult shad which was calculated as the difference in time from initial release at the Pauchaug Brook boat access until their initial detection within the Vernon project area. When all individuals are considered, the mean travel duration from release until first detection at Vernon ranged between 26.3 hours to 528.8 hours (22 days, 48 min). When examined between tag types (PIT or dual), the mean travel duration was similar; approximately 8.5 days (Wilcoxon; $z = 0.1029$; $p = 0.9180$).

Table 5.3-2. Minimum, maximum, median, and mean travel duration (in hours) from time of release until arrival in the Vernon project area for PIT and dual-tagged shad, 2015.

Tag Type	N	Min	Max	Median	Mean
Dual	58	26.3	528.8	209.1	210.1
PIT	71	48.0	458.8	192.0	205.4

5.3.2 Downstream Residency

Where detection information was available, the duration of downstream residency time was estimated for dual-tagged adult shad that entered the Vernon study area. Downstream residency was defined as the duration from the initial detection at monitoring station 2, 3, 10, 11, 12, or 13 until either successful upstream passage via the Vernon fish ladder or departure from the study area as indicated by an outgoing detection at monitoring station 1. In some cases, the total duration of downstream residence time for dual-tagged shad was adjusted to reflect short-term movements away from the study area (e.g., a dual-tagged shad detected at monitoring station 2 at 0800 on May 10, then at monitoring station 1 at 1200 on May 10, then back at monitoring station 2 at 0800 on May 11, then monitoring station 1 at 1200 on May 11 would have a downstream residence time of 8 hours).

Table 5.3-3 presents the minimum, maximum, median, and mean downstream residence times for dual-tagged shad. When all individuals are considered, the median downstream residence time was just under two days. There was no statistically significant difference between the mean tailrace residence time observed for dual-tagged shad that successfully passed upstream of Vernon versus those that eventually fell back downstream without passage (Wilcoxon; $z = 0.1884$; $p = 0.8505$). For the 25 dual tagged shad that entered the fish ladder, the duration of time from arrival at the tailrace until entrance into the fish ladder ranged from 1-199 hours (median = 20.8 hours) (Table 5.3-4). Similar to observations for the total tailrace duration, there was no statistically significant difference between the mean duration of time from arrival until entrance at the fish ladder observed for dual-tagged shad that successfully passed upstream of Vernon versus those that eventually fell back downstream without passage (Wilcoxon; $z = -1.916$; $p = 0.8480$). The full list of downstream project area arrival dates, residence times, and eventual fate (by ID and release group) are provided in Appendix A-2.

Table 5.3-3. Minimum, maximum, median, and mean tailrace residence times (in hours) for dual-tagged shad within the study area immediately downstream of Vernon dam, 2015.

Group	N	Min	Max	Median	Mean
Pass	11	4.5	247.8	53.9	75.2
Fallback	47	0.5	413.4	46.5	77.8
All	58	0.5	413.4	46.8	77.3

Table 5.3-4. Minimum, maximum, median, and mean residence times (in hours) for dual-tagged shad from the time of entrance into the study area immediately downstream of Vernon dam until entry into the fish ladder, 2015.

Group	N	Min	Max	Median	Mean
Pass	11	1.0	199.6	20.8	44.4
Fallback	14	1.8	152.5	23.5	38.0
All	25	1.0	199.6	20.8	40.8

Figure 5.3-1 presents the number of dual-tagged shad present in the Vernon downstream study area relative to project discharge. Resident numbers of dual-tagged shad were highest during the second half of May. Numbers dropped steeply during the first few days of June, coinciding with an increase in total discharge. Figure 5.3-2 overlays the downstream residence periods for each upstream migrating shad (indicated by blue, green or red horizontal lines) with the total discharge, presence of spill (i.e., flow conditions exceeding maximum station generating capacity of 17,100 cfs) as well as the operational condition of Units 1-10.

The minimum, maximum, mean, and median total discharge and spill flows (cfs), percentage of the residence time spill conditions occurred, and Units 1-10 operations as encountered by each of the 58 dual-tagged shad for which a downstream residency time was calculated is presented in Table 5.3-5. Similar to observations in Figure 5.3-1, 39 of the 58 shad (67%) with calculated downstream residence times were not present during spill conditions (Table 5.3-5). The table indicates: a) shad that fell back without entering the fish ladder; b) those that made at least one foray into the fish ladder but later fell back and did not ultimately pass upstream; and c) those that made one or more forays into the fish ladder and subsequently passed upstream into the Vernon impoundment.

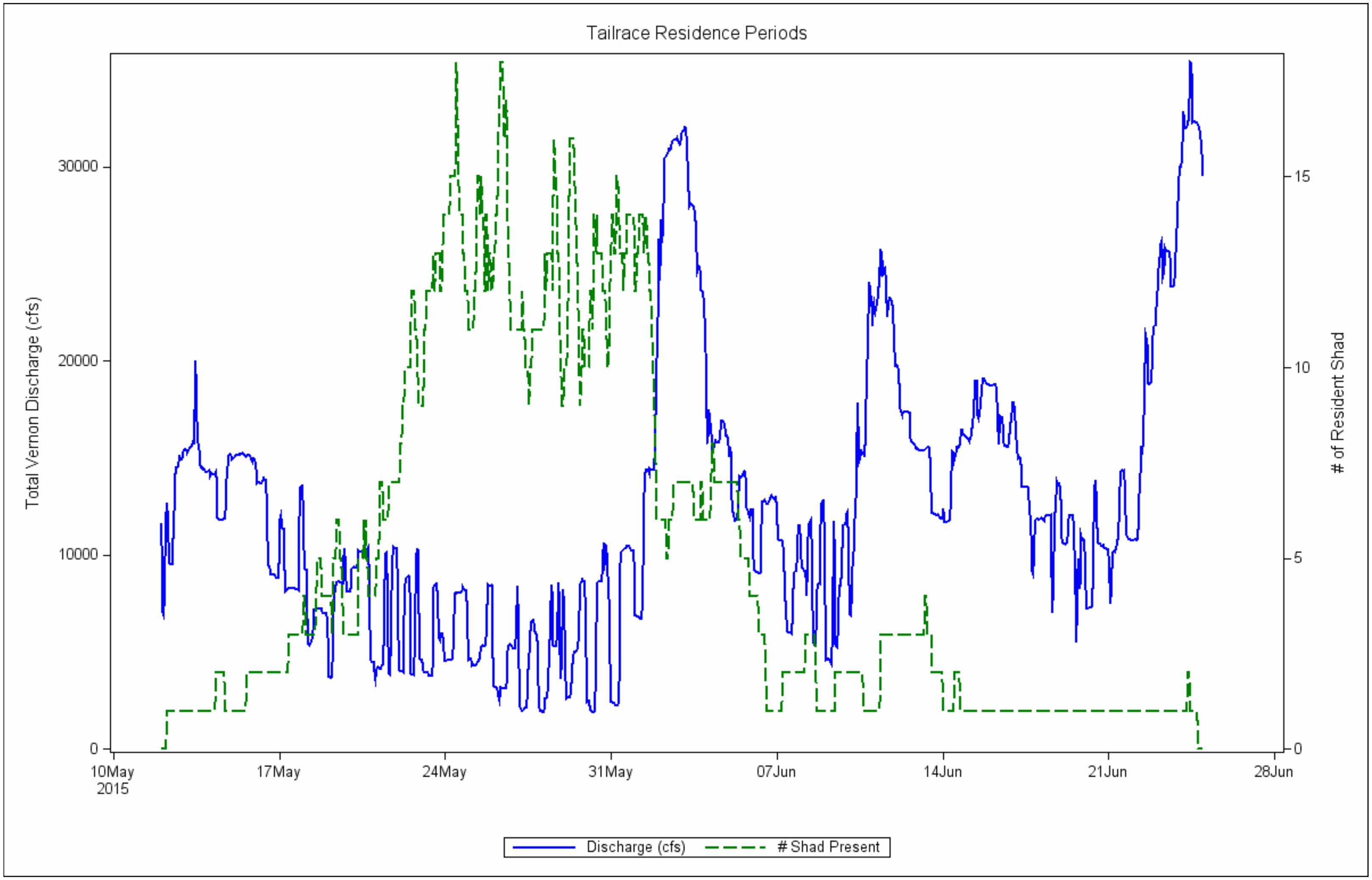

Figure 5.3-1. Detected number of dual-tagged shad resident within the study area downstream of Vernon relative to total project discharge, 2015.

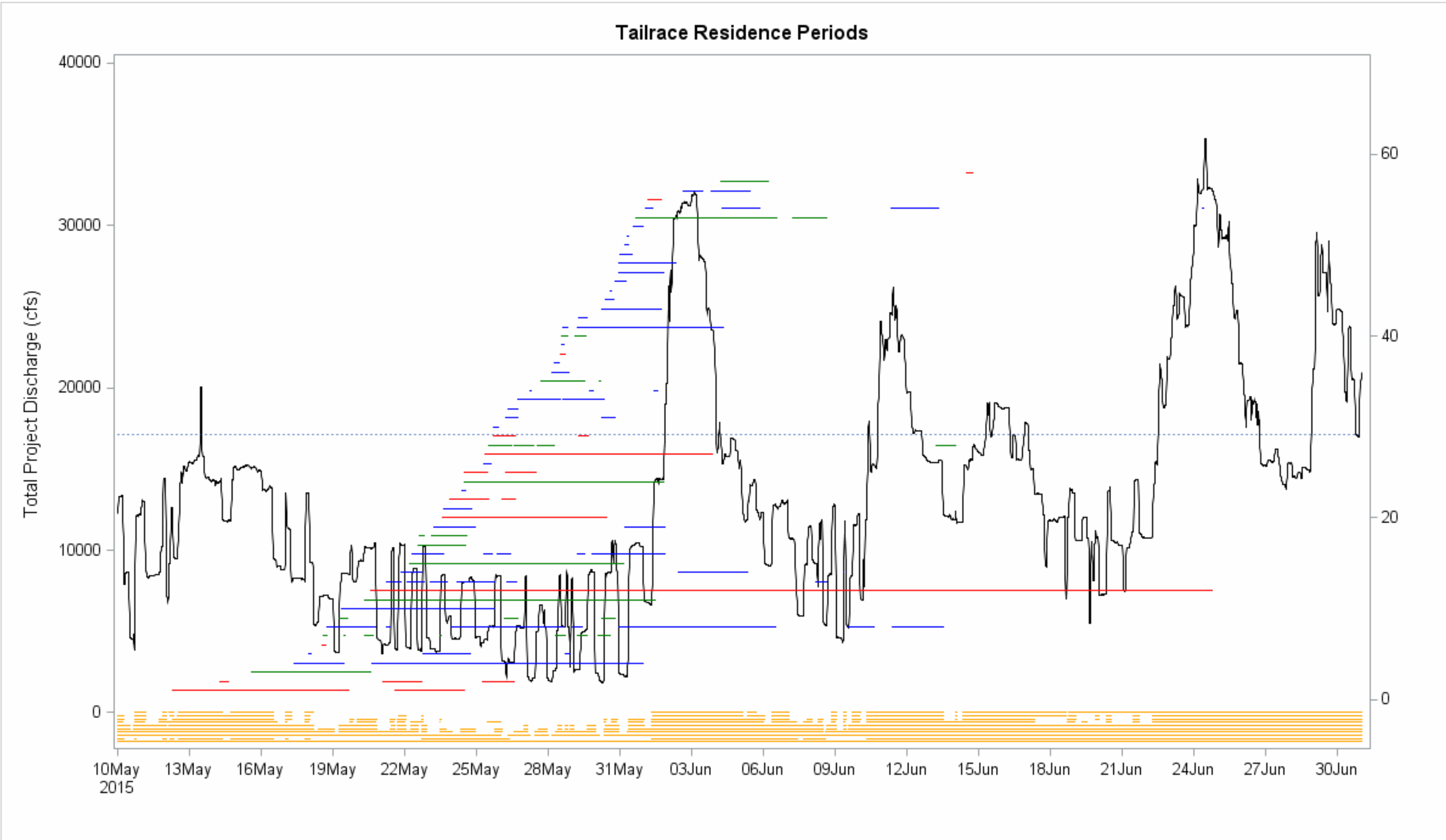

Figure 5.3-2. Temporal distribution of downstream residence times for individual radio-tagged adult shad below Vernon dam. Solid black line = 2015 total project discharge (cfs), dashed blue line = maximum station generating capacity, red lines = downstream residence events resulting in successful passage, green lines = downstream residence events which included at least one attempted foray but no passage, blue lines = downstream residence events with no attempted fish ladder forays, orange lines = operational status of Units 1 (upper) through 10 (lower) where orange = unit on and blank = unit off.

Table 5.3-5. Minimum, maximum, median, and mean total project discharge and spill flows, percentage of time spill present, and percentage of time operating for Units 1-10 for the calculated downstream residence time of radio-tagged shad attempting upstream passage at Vernon.

Fish ID	Initial Date/Time	Final Date/Time	Final Disposition	Downstream Residency	Total Project Discharge				Spill Flow (cfs)					Percentage of Residence Duration with Unit in Operation									
				Hours	Min	Max	Mean	Median	Min	Max	Mean	Median	% of Residence Duration	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1_26	20MAY15:08:09:00	01JUN15:11:47:00	Foray & Fall back	291.6	1855	14372	5966	5291	0	0	0	0	0.0	1.4	3.9	19.1	25.0	31.6	48.2	68.9	93.2	31.6	100.0
1_77	25MAY15:17:20:00	25MAY15:21:51:00	Fall back	4.5	5335	8482	7696	8397	0	0	0	0	0.0	0.0	0.0	0.0	100.0	0.0	88.9	94.4	100.0	100.0	100.0
27_165	12MAY15:06:21:00	24MAY15:11:42:00	Pass	293.4	3671	20016	10086	9384	0	5580	269	0	22.1	41.7	47.7	49.8	52.7	70.0	80.9	88.0	100.0	56.0	100.0
27_166	18MAY15:17:27:00	13JUN15:12:54:00	Fall back	619.5	1873	32048	12005	10115	0	19168	2535	0	35.8	41.1	42.9	53.7	56.2	63.8	75.3	83.4	96.2	58.8	100.0
27_169	23MAY15:15:29:00	24MAY15:19:36:00	Fall back	28.1	4510	8507	6381	5939	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	48.7	69.0	100.0	100.0	100.0
27_170	23MAY15:05:04:00	01JUN15:21:10:00	Fall back	232.1	2234	18327	8096	8043	0	5520	131	0	8.8	16.2	14.9	37.2	35.4	36.0	70.7	78.7	100.0	66.8	100.0
27_171	31MAY15:16:12:00	08JUN15:14:54:00	Foray & Fall back	190.7	5327	32048	16500	14301	0	19168	4809	0	48.1	60.1	64.4	78.1	81.0	94.1	98.4	99.3	100.0	87.6	100.0
27_174	04JUN15:05:15:00	06JUN15:01:27:00	Foray & Fall back	44.2	9075	16884	13858	14085	0	2784	825	0	43.4	64.0	82.0	92.6	90.5	100.0	100.0	100.0	100.0	100.0	100.0
27_175	01JUN15:01:45:00	24JUN15:09:52:00	Fall back	560.1	6650	33581	16565	15781	0	19610	2675	1207	73.4	84.6	87.5	93.8	94.0	94.0	100.0	100.0	100.0	93.8	100.0
27_192	30MAY15:18:15:00	31MAY15:06:33:00	Fall back	12.3	2232	10599	4681	2393	0	0	0	0	0.0	0.0	0.0	22.4	14.3	36.7	38.8	38.8	100.0	0.0	100.0
27_32	20MAY15:13:01:00	24MAY15:17:34:00	Pass	100.6	1855	35382	12591	11266	0	21431	2450	0	38.2	54.0	48.7	52.0	56.7	74.7	80.4	89.0	97.7	71.4	100.0
27_33	17MAY15:09:25:00	31MAY15:23:02:00	Fall back	349.6	1855	13555	6037	5364	0	0	0	0	0.0	2.8	4.3	15.4	20.6	32.8	50.5	70.7	93.8	29.1	100.0
27_46	24MAY15:11:27:00	01JUN15:19:17:00	Foray & Fall back	199.8	1855	14447	6069	5319	0	1127	27	0	2.8	5.8	5.3	18.1	23.3	31.8	50.4	67.8	90.1	28.6	100.0
27_51	22MAY15:04:29:00	31MAY15:03:03:00	Foray & Fall back	214.6	1855	10639	5392	5042	0	0	0	0	0.0	0.0	0.6	5.4	14.8	22.2	40.9	60.0	90.8	41.1	100.0
27_54	22MAY15:07:01:00	01JUN15:21:07:00	Fall back	254.1	1855	18327	6807	6700	0	5520	79	0	5.3	9.7	9.9	30.0	40.1	42.6	56.1	61.9	91.7	41.7	100.0
27_55	29MAY15:06:20:00	29MAY15:15:28:00	Fall back	9.1	2626	5856	4576	4980	0	0	0	0	0.0	0.0	0.0	0.0	0.0	2.8	2.8	100.0	100.0	0.0	100.0
27_58	21MAY15:19:56:00	09JUN15:08:18:00	Fall back	444.4	3785	32048	18805	16490	0	19168	7064	2613	69.6	71.2	77.4	82.3	93.8	89.9	89.9	95.7	100.0	76.6	100.0
27_61	30MAY15:09:07:00	30MAY15:17:46:00	Fall back	8.7	7988	10639	9063	8627	0	0	0	0	0.0	0.0	0.0	48.6	34.3	100.0	100.0	100.0	100.0	0.0	100.0
27_63	25MAY15:06:42:00	25MAY15:15:00:00	Fall back	8.3	4302	5344	4810	4514	0	0	0	0	0.0	0.0	0.0	0.0	45.5	0.0	0.0	0.0	100.0	100.0	100.0
27_85	28MAY15:03:34:00	28MAY15:20:33:00	Fall back	17.0	1938	8621	5245	5295	0	0	0	0	0.0	0.0	0.0	0.0	0.0	36.8	36.8	76.5	100.0	0.0	100.0
27_87	28MAY15:13:00:00	29MAY15:13:48:00	Foray & Fall back	24.8	2626	8621	4682	4989	0	0	0	0	0.0	0.0	0.0	0.0	0.0	12.9	12.9	100.0	100.0	0.0	100.0
27_89	31MAY15:07:33:00	31MAY15:08:01:00	Fall back	0.5	2880	3276	3078	3078	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	0.0	100.0
44_104	14JUN15:11:03:00	14JUN15:17:07:00	Pass	6.1	14918	15596	15333	15483	1195	1205	1200	1200	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
44_172	22MAY15:12:56:00	24MAY15:13:08:00	Foray & Fall back	48.2	3724	10286	5704	4583	0	0	0	0	0.0	0.0	2.6	5.7	10.9	10.9	35.2	46.6	100.0	91.7	100.0
44_53	23MAY15:13:47:00	30MAY15:10:08:00	Pass	164.4	1855	8801	5085	5016	0	0	0	0	0.0	0.0	0.0	1.4	9.0	14.0	36.2	60.4	88.0	40.9	100.0
44_61	24MAY15:09:36:00	24MAY15:13:17:00	Fall back	3.7	7981	8059	8029	8029	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	100.0	100.0
44_82	31MAY15:12:37:00	31MAY15:23:42:00	Fall back	11.1	7960	10447	10219	10325	0	0	0	0	0.0	0.0	0.0	100.0	97.7	100.0	100.0	100.0	100.0	0.0	100.0
44_92	26MAY15:17:37:00	29MAY15:10:44:00	Fall back	65.1	1855	8801	4562	4983	0	0	0	0	0.0	0.0	0.0	0.0	0.0	24.6	35.6	70.1	84.7	0.0	100.0
54_176	21MAY15:05:05:00	08JUN15:15:37:00	Fall back	442.5	2206	11858	6040	5313	0	0	0	0	0.0	0.0	3.4	13.8	28.3	22.9	44.2	59.9	98.2	64.9	100.0
54_179	19MAY15:06:01:00	30MAY15:19:31:00	Foray & Fall back	277.5	1856	10639	6303	7906	0	0	0	0	0.0	0.0	0.0	20.1	16.7	52.8	56.3	65.3	82.6	16.0	100.0
54_20	18MAY15:12:49:00	18MAY15:17:20:00	Pass	4.5	7173	7206	7195	7198	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0	100.0	0.0	100.0
54_41	28MAY15:11:20:00	28MAY15:17:17:00	Fall back	6.0	5279	8534	5949	5331	0	0	0	0	0.0	0.0	0.0	0.0	0.0	33.3	33.3	100.0	100.0	0.0	100.0
54_49	26MAY15:07:00:00	26MAY15:17:49:00	Pass	10.8	3108	5386	3798	3172	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.2	93.0	18.6	100.0
54_50	25MAY15:08:25:00	03JUN15:20:38:00	Fall back	228.2	1855	32048	10793	6775	0	19168	3303	0	24.0	26.6	26.2	37.5	41.9	49.4	60.6	75.8	91.3	37.5	100.0
54_59	25MAY15:16:48:00	29MAY15:16:05:00	Pass	95.3	2206	8482	4744	4212	0	0	0	0	0.0	0.0	0.0	0.0	22.5	3.1	25.6	58.1	78.3	50.4	100.0
54_60	02JUN15:15:07:00	05JUN15:10:45:00	Fall back	67.6	11743	32048	21058	16847	0	19168	7660	2779	85.4	90.8	91.6	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
54_61	26MAY15:04:36:00	30MAY15:19:18:00	Fall back	110.7	1855	10639	5715	4992	0	0	0	0	0.0	0.0	0.0	26.2	21.5	38.3	43.0	57.0	80.4	16.8	100.0
54_82	24MAY15:11:27:00	27MAY15:12:07:00	Pass	72.7	1927	8433	4849	4632	0	0	0	0	0.0	0.0	0.0	0.0	0.0	6.4	27.9	47.9	84.0	50.7	100.0

Fish ID	Initial Date/Time	Final Date/Time	Final Disposition	Downstream Residency	Total Project Discharge				Spill Flow (cfs)					Percentage of Residence Duration with Unit in Operation									
				Hours	Min	Max	Mean	Median	Min	Max	Mean	Median	% of Residence Duration	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
54_89	28MAY15:14:03:00	04JUN15:07:47:00	Fall back	161.7	1855	32048	14898	10421	0	19168	5280	0	43.3	47.2	46.6	63.4	61.6	73.9	79.8	88.9	97.2	47.2	100.0
8_166	18MAY15:13:31:00	30MAY15:14:05:00	Foray & Fall back	288.6	1855	10234	6271	5619	0	0	0	0	0.0	0.0	0.0	26.1	22.3	38.8	52.7	85.6	91.0	3.2	100.0
8_167	14MAY15:06:45:00	31MAY15:15:28:00	Pass	416.7	2206	14415	6371	4990	0	0	0	0	0.0	2.8	20.1	26.4	54.7	35.2	45.6	64.2	91.2	37.7	100.0
8_170	28MAY15:05:19:00	28MAY15:11:00:00	Fall back	5.7	2565	8153	4020	3046	0	0	0	0	0.0	0.0	0.0	0.0	0.0	18.2	18.2	59.1	100.0	0.0	100.0
8_174	30MAY15:13:52:00	30MAY15:15:24:00	Fall back	1.5	8616	9903	9013	8635	0	0	0	0	0.0	0.0	0.0	33.3	33.3	100.0	100.0	100.0	100.0	0.0	100.0
8_175	15MAY15:14:20:00	20MAY15:13:49:00	Foray & Fall back	119.5	3671	15155	9506	8805	0	1153	101	0	9.4	31.0	27.8	42.5	39.7	79.3	92.7	96.7	100.0	24.7	100.0
8_176	30MAY15:05:54:00	01JUN15:16:57:00	Fall back	59.1	1856	14447	8272	8629	0	1127	44	0	5.1	15.3	13.6	57.2	52.5	66.1	81.4	82.6	97.0	15.3	100.0
8_177	30MAY15:22:33:00	02JUN15:08:17:00	Fall back	57.7	2232	30640	12281	10334	0	17855	2843	0	32.0	42.4	40.7	70.1	69.3	71.0	84.4	85.7	100.0	42.4	100.0
8_30	28MAY15:12:49:00	28MAY15:15:28:00	Fall back	2.7	5291	5444	5338	5331	0	0	0	0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	100.0	100.0	0.0	100.0
8_43	27MAY15:15:56:00	30MAY15:04:40:00	Foray & Fall back	60.7	1873	8621	4540	4956	0	0	0	0	0.0	0.0	0.0	0.0	0.0	22.6	38.2	78.0	90.9	0.0	100.0
8_47	30MAY15:23:54:00	31MAY15:11:37:00	Fall back	11.7	2232	10224	4361	2391	0	0	0	0	0.0	0.0	0.0	29.8	29.8	29.8	29.8	36.2	100.0	0.0	100.0
8_48	17MAY15:23:42:00	28MAY15:21:43:00	Fall back	262.0	3567	13555	6324	5715	0	0	0	0	0.0	4.4	4.0	6.6	1.8	17.7	47.8	61.5	100.0	88.9	100.0
8_53	19MAY15:08:38:00	25MAY15:18:46:00	Fall back	154.1	3598	10438	6696	5950	0	0	0	0	0.0	0.0	5.5	25.1	34.0	38.7	54.1	71.0	100.0	48.0	100.0
8_55	22MAY15:14:03:00	24MAY15:14:19:00	Foray & Fall back	48.3	3724	10286	5793	4797	0	0	0	0	0.0	0.0	3.0	6.6	9.6	6.6	37.1	50.9	100.0	93.4	100.0
8_58	30MAY15:22:29:00	01JUN15:19:43:00	Fall back	45.2	2232	14447	8725	10166	0	1205	125	0	12.7	26.0	23.8	61.3	60.2	63.0	80.1	81.8	100.0	26.0	100.0
8_60	27MAY15:05:53:00	01JUN15:13:54:00	Fall back	128.0	1927	14447	10458	8801	0	0	0	0	0.0	48.6	48.6	48.6	48.6	85.7	85.7	85.7	85.7	48.6	100.0
8_61	23MAY15:20:54:00	26MAY15:15:16:00	Pass	66.4	2206	8339	5158	4567	0	0	0	0	0.0	0.0	0.0	0.0	2.8	0.0	28.2	35.2	87.5	88.4	100.0
8_71	01JUN15:03:32:00	01JUN15:17:52:00	Pass	14.3	6650	14447	11485	14194	0	1127	259	0	28.1	70.2	63.2	70.2	71.9	71.9	100.0	100.0	100.0	70.2	100.0
8_83	25MAY15:11:44:00	14JUN15:00:18:00	Foray & Fall back	468.6	1873	15573	6647	5327	0	1203	286	0	24.0	9.0	9.0	9.3	39.6	28.3	48.9	62.9	82.2	50.8	100.0
8_85	31MAY15:05:05:00	01JUN15:07:15:00	Fall back	26.2	2241	3276	2408	2248	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	100.0	0.0	100.0

5.3.3 Nearfield Attraction

An estimate of nearfield attraction to the Vernon fish ladder was obtained based on the movements of dual-tagged shad within the study area. As presented in Table 5.3-6, 34 of the 58 (58.6%) dual-tagged shad available within the Vernon study area were detected by the aerial antenna at monitoring station 3, indicating they were within 30 feet of the entrance to the fish ladder. The 95% confidence interval around the 58.6% estimate of nearfield attraction was calculated as 51.7-67.2%. The 58.6% represents the percentage of dual-tagged adult shad that were detected in the vicinity of the fish ladder entrance. This value is independent of whether or not an individual entered the fish ladder.

Table 5.3-6. Nearfield attraction rate determined for the Vernon fish ladder based on percent of dual-tagged shad entering fish ladder relative to total number of fish available, 2015.

Tag Type	Origin	No. Shad Available[a]	No. Shad Detected near Fish Ladder Entrance[b]	No. Shad with Entry Attempt (min = 1)	Nearfield Attraction Rate (%)
Dual	TC	18	11	8	61.1
	FL	40	23	17	57.5
	Total	58	34	25	58.6

a. Based on detection at monitoring stations 2, 10, 11, 12 or 13.
b. Based on aerial antenna detection at monitoring station 3.

5.3.4 Fish Ladder Forays

For the purposes of this study, a fish ladder "foray" was defined as a single passage attempt by a dual- or radio-tagged shad to ascend the fish ladder. A total of 25 dual-tagged shad (as recorded by the underwater drop antenna associated with monitoring station 3) and 71 PIT-tagged shad (as recorded by monitoring stations 5 or 6) were determined to have moved through the fish ladder entrance. For these 96 individuals, the date and time of that initial detection inside the fish ladder entrance indicated the start of a "foray". Following that initial detection, tagged shad may have turned and departed the fish ladder entrance in a downstream direction, or been recorded at upstream points within the fish ladder prior to either successful passage or termination of the attempt and movement back downstream and out of the fish ladder. Therefore, a single foray could represent a fish that had entered the ladder but then exited the ladder at either the downstream entrance or the upstream exit (i.e., into the impoundment). More than one foray for a single individual would indicate that the fish exited the ladder at the downstream entrance at least one time prior to exiting the ladder at the downstream entrance or the upstream exit for the final time.

A total of 137 individual forays, by the 96 dual- and PIT-tagged shad detected inside the fish ladder entrance were identified and the total number of forays for each tagged individual ranged from a high of 10 to a low of 1 (mean = 1.6; median = 1). The average number of forays ending in failure (i.e., fish that did not ascend the fish ladder and enter the impoundment) was 1.8 (range = 1 to 10) and for forays ending in successful upstream passage was 1.3 (range = 1 to 3). As is regularly observed during radio and PIT tag detection studies, the detection efficiency was less than 100% for the underwater drop antenna associated with monitoring station 3 and the PIT reader and antenna associated with monitoring station 5. As a result, the date and time of initial detection immediately inside the entrance to the fish ladder went unrecorded for 7 of the 37 foray events documented for dual-tagged shad and 31 of the 100 foray events documented for PIT-tagged shad. In those cases, the initial date and time of detection at the PIT reader and antenna installed at the first bend in the lower fish ladder (i.e., monitoring station 6) was used as a surrogate to allow for calculation of a foray duration (i.e., total duration of time for an individual shad foray from entrance until exit at upstream or downstream end of structure). The duration of individual successful passage attempts ranged from 0.9 hours to 99.6 hours (mean = 8.7 hr; median = 3.4 hr; 95% CI = 3.1-14.4 hr). The duration of individual unsuccessful passage attempts ranged from <0.1 to 152.9 hours (mean = 10.2 hr; median = 1.1 hr; 95% CI = 4.6-15.8 hr). The start date/time, end date/time, and resulting duration for each unique foray is presented in Appendix A-3.

Vernon project operations for the 15-minute interval containing the onset of each of the 137 individual foray events are provided in Appendix A-4. Operations at the onset of individual foray events were considered representative of project conditions at the time of approach (i.e. an “approach event”) based on the short duration of time from initial detection within the nearfield area (i.e., detection by the monitoring station 3 aerial antenna) until detection within the entrance of the fish ladder (i.e., detection by the monitoring station 3 underwater drop antenna) observed for dual-tagged shad (median duration = 6 minutes; mean = 51 minutes). This method allowed for the full set of dual- and PIT-tagged adult shad ladder attempts to be evaluated (N = 137). Use of the date and time of first detection at the monitoring station 3 aerial antenna would have limited the evaluation of project operations at the time of fish ladder entrance attraction to the subset of ladder attempts by dual-tagged individuals detected at that location (N = 30). The majority of approach events (93%) were initiated when fish ladder attraction flow was provided (between sunrise and sunset and supplying approximately 200 cfs). In particular, approach events that resulted in a successful upstream foray were generally initiated during periods when attraction flow was provided (94% of successful passage events).

Figures 5.3-3 and 5.3-4 present the distribution of fish ladder approach events (as indicated by detection at the fish ladder entrance via underwater drop or PIT antennas) over the span of the 2015 monitoring period and relative to total project discharge at the time of initiation. Overall, the majority of approach events and corresponding fish ladder forays occurred during flow conditions between 2,500-12,500 cfs (Figure 5.3-4). Total discharge ranged from 2,002 to 14,990 cfs (mean = 5,373 cfs) at the time of approach events resulting in successful upstream forays and from 2,123 to 22,227 cfs (mean = 6,780 cfs) at the time of approach events resulting in unsuccessful upstream forays. Average total discharge at the time of approach did not show a significant difference for events resulting in successful and unsuccessful upstream forays (Wilcoxon; $z = -0.6895$; $p = 0.4905$). When discharge through spill gates is considered (regardless of whether this occurred when flows were greater than maximum station generating capacity), only three approach events occurred under those conditions (Figure 5.3-5). Two of those approach events resulted in successful upstream forays and those individuals approached the fish ladder under spill gate discharge of approximately 1,123 cfs, and 1,198 cfs, respectively. Similarly, a single approach event resulting in an unsuccessful upstream foray was documented for an individual approaching the fish ladder under spill gate discharge of approximately 7,806 cfs. All other approach events were initiated when there was no discharge from spill gates.

The temporal occurrence of initiation times of fish ladder foray events relative to cumulative discharge for Units 1-4, Units 5-8, and Units 9-10 are presented in Figures 5.3-6 through 5.3-8. From April 15 – July 15 (during normal seasonal upstream passage fish ladder operations) operating preference is generally given first to Unit 10, followed by Unit 8 or 7, then Unit 9, Unit 5 or 6, and lastly, Units 1-4. Operations during 2015 followed these guidelines and discharge from Units 1-4 (farthest away from the fish ladder entrance) was lowest during May which coincided with the lower flow portion of the 2015 study period as well as the majority of approach events and corresponding upstream forays within the fish ladder (Figure 5.3-6). The timing of approach events corresponding with successful and unsuccessful upstream forays within the fish ladder occurred over a range of discharge values for Units 5-8 (Figure 5.3-7). Visual examination of Figure 5.3-8 indicates that the majority of approach events which resulted in successful upstream fish ladder foray events took place under periods of lower discharge from Units 9-10. These periods coincided with Unit 10 in operation and Unit 9 offline (Figure 5.2-4). Figure 5.3-9 provides the distribution of initiation times for approach events resulting in successful and unsuccessful fish ladder foray events for 500 cfs increments of discharge from Units 1-4, 5-8, and 9-10. Similar to observations from Figures 5.3-6 through 5.3-8, the greatest number of successful upstream fish ladder foray events occurred during periods when generation was lowest for Units 1-4 and Unit 9 was offline.

Table 5.3-7 provides a summary of unit operations at the time of initiation for each successful and unsuccessful upstream foray. Similar to observations in Figures 5.3-6 through 5.3-8, the majority of approach events resulting in successful forays were initiated when units closest to the fish ladder entrance were operating and those farther away (i.e., Units 1-4) were offline. When all 10 units were in operation, the percentage of approach events resulting in successful fish ladder foray events was low (2 out of 6). When unit operations for the full duration of the study period are considered, all 10 units were in operation for nearly 50% of the time (Table 5.3-8).

Approach events (and corresponding upstream forays within the fish ladder) were initiated over a range of dates from May 16 to June 14 with over half of those occurring between the dates of May 25 and May 29 (Figure 5.3-10). The temporal distribution for approach events resulting in successful and unsuccessful foray attempts did not differ greatly from one another. Successful passage events occurred between May 18 and June 14 and unsuccessful passage events occurred between May 16 and June 11. The peak in occurrence for both successful and unsuccessful events occurred during the same May 25-29 time period. Figure 5.3-11 presents the distribution of times determined for each approach event at the fish ladder resulting in the initiation of an upstream fish ladder foray event. The majority of forays were initiated during the daylight hours (corresponding to times when attraction water pumps were operating).

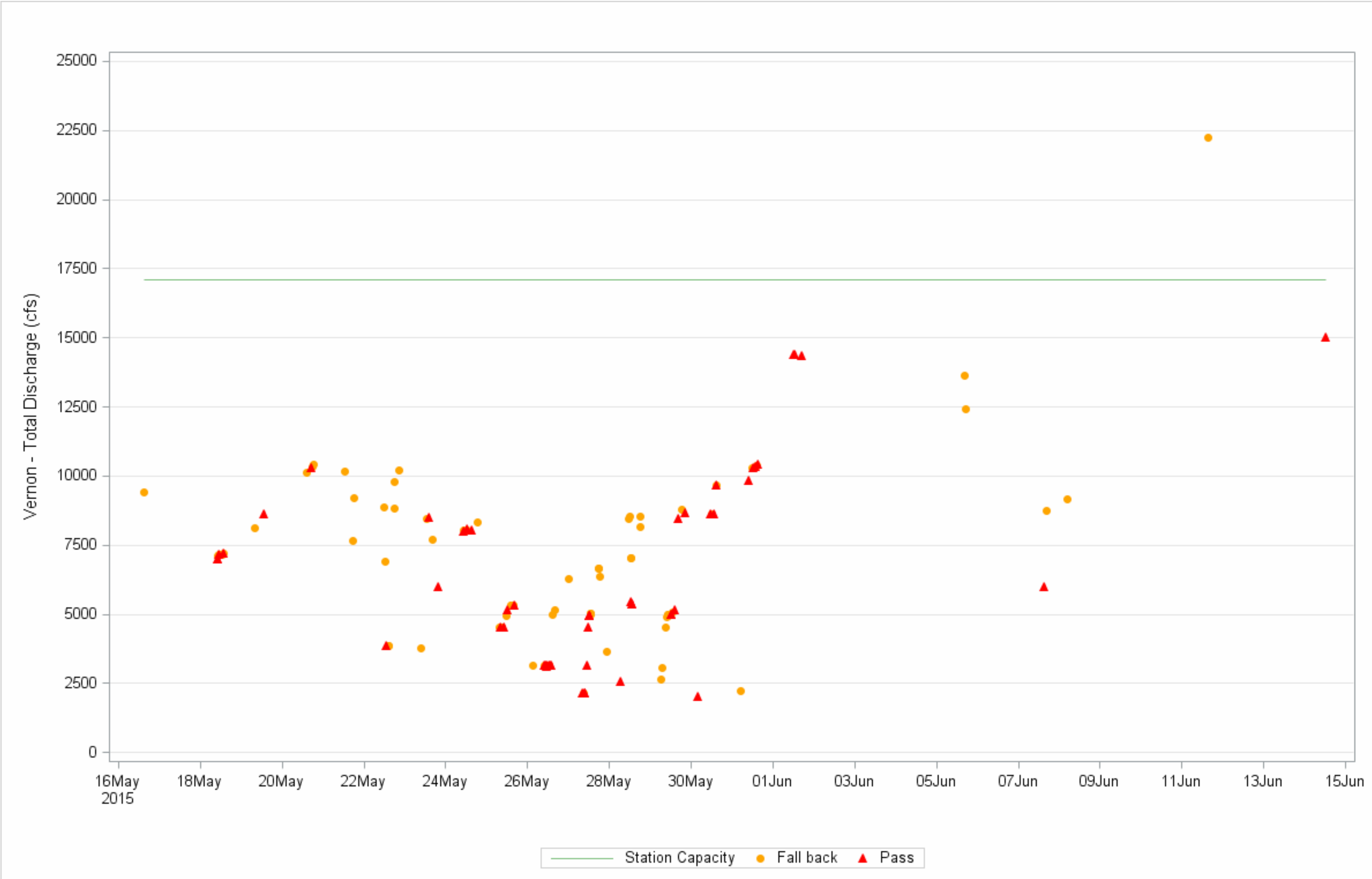

Figure 5.3-3. Timing for the initiation of American Shad approach events to the fish ladder resulting in the initiation of successful and unsuccessful upstream fish ladder foray events at Vernon, relative to total discharge (cfs), 2015 (green line indicates total station capacity).

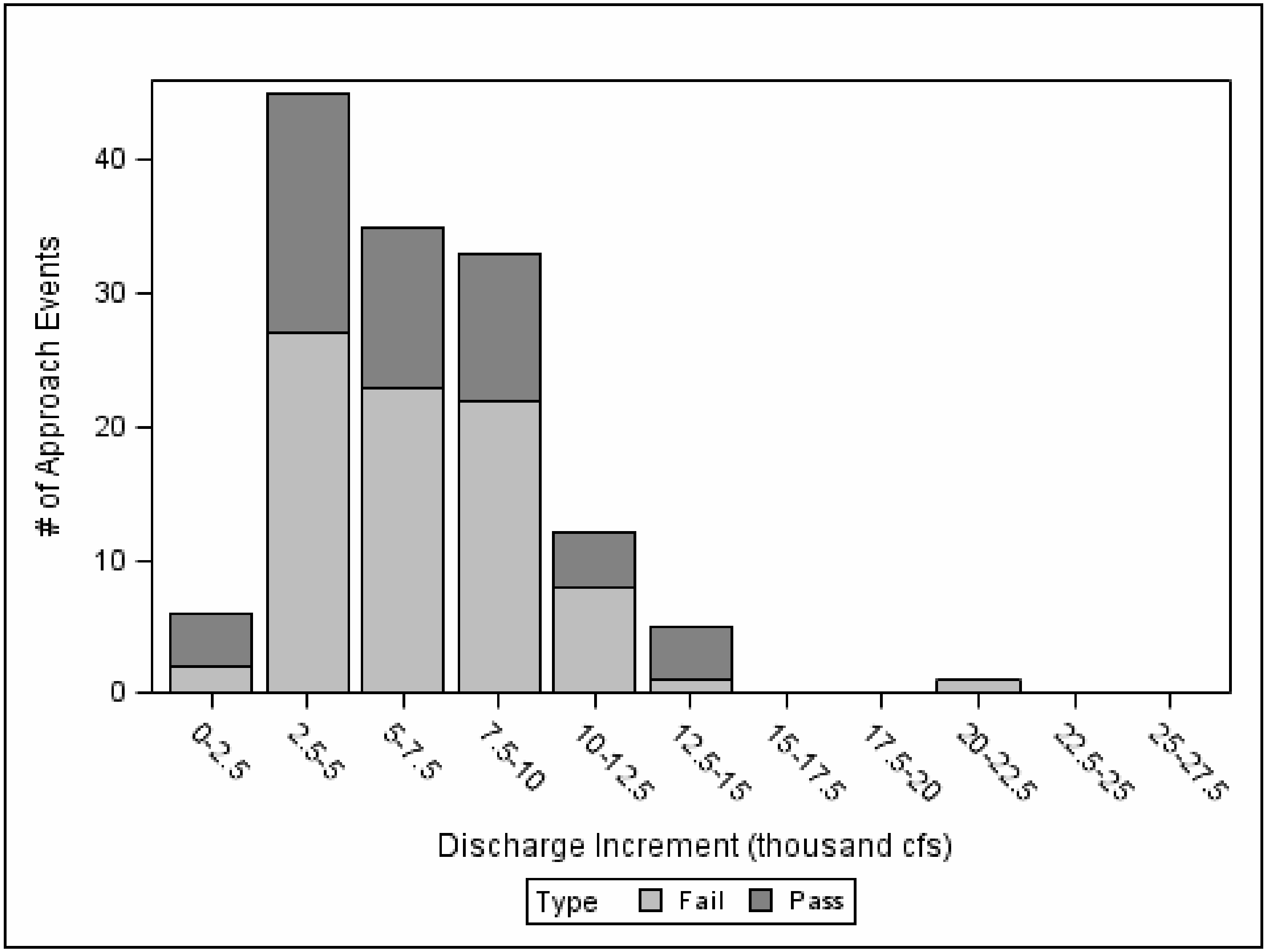

Figure 5.3-4. Frequency distribution of total project discharge (cfs) coinciding with the fish ladder approach events corresponding to successful and unsuccessful upstream American Shad fish ladder forays at Vernon, 2015.

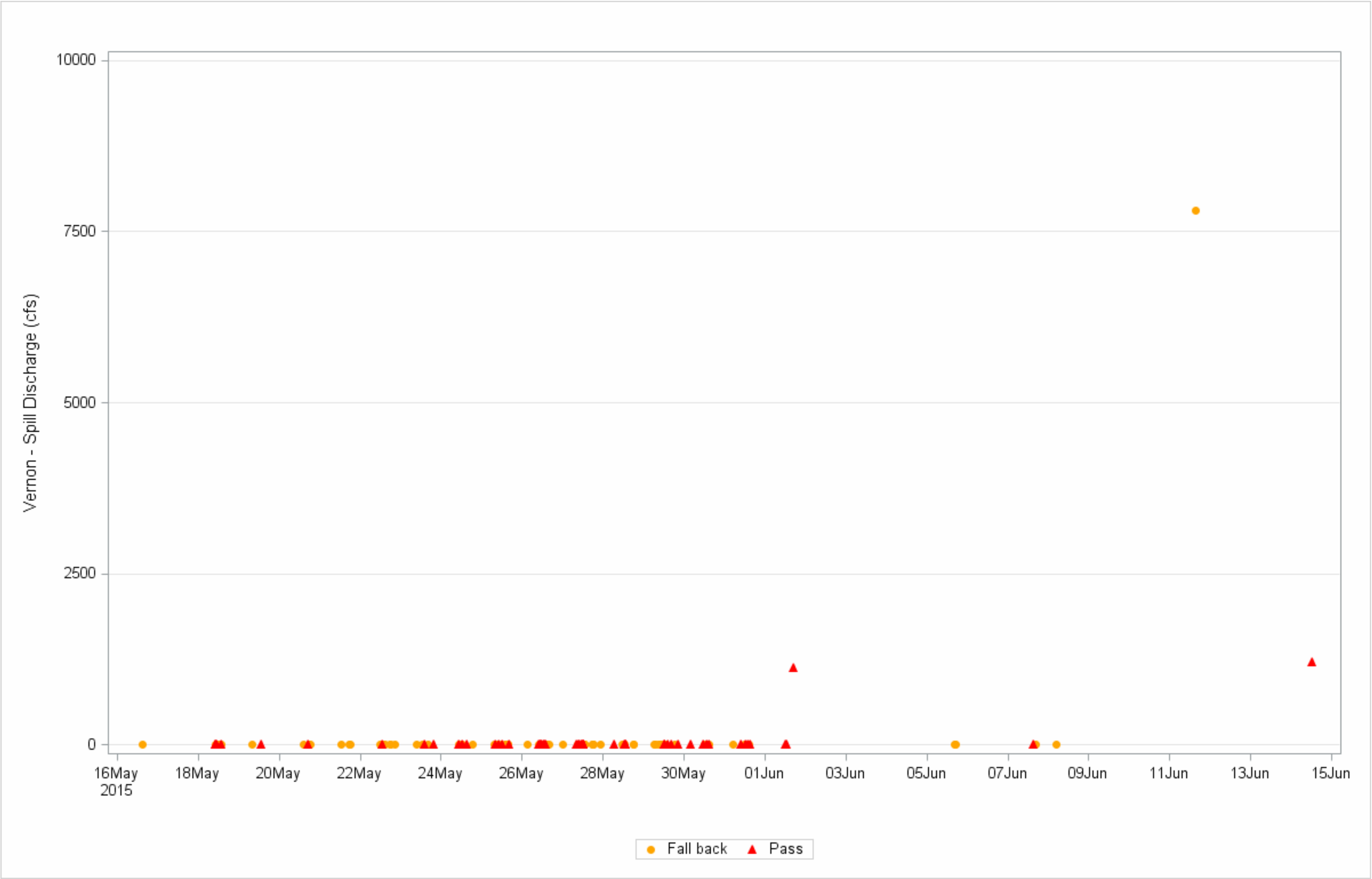

Figure 5.3-5. Timing for the initiation of American Shad approach events to the fish ladder resulting in the initiation of successful and unsuccessful upstream fish ladder foray events at Vernon relative to spill conditions (cfs), 2015.

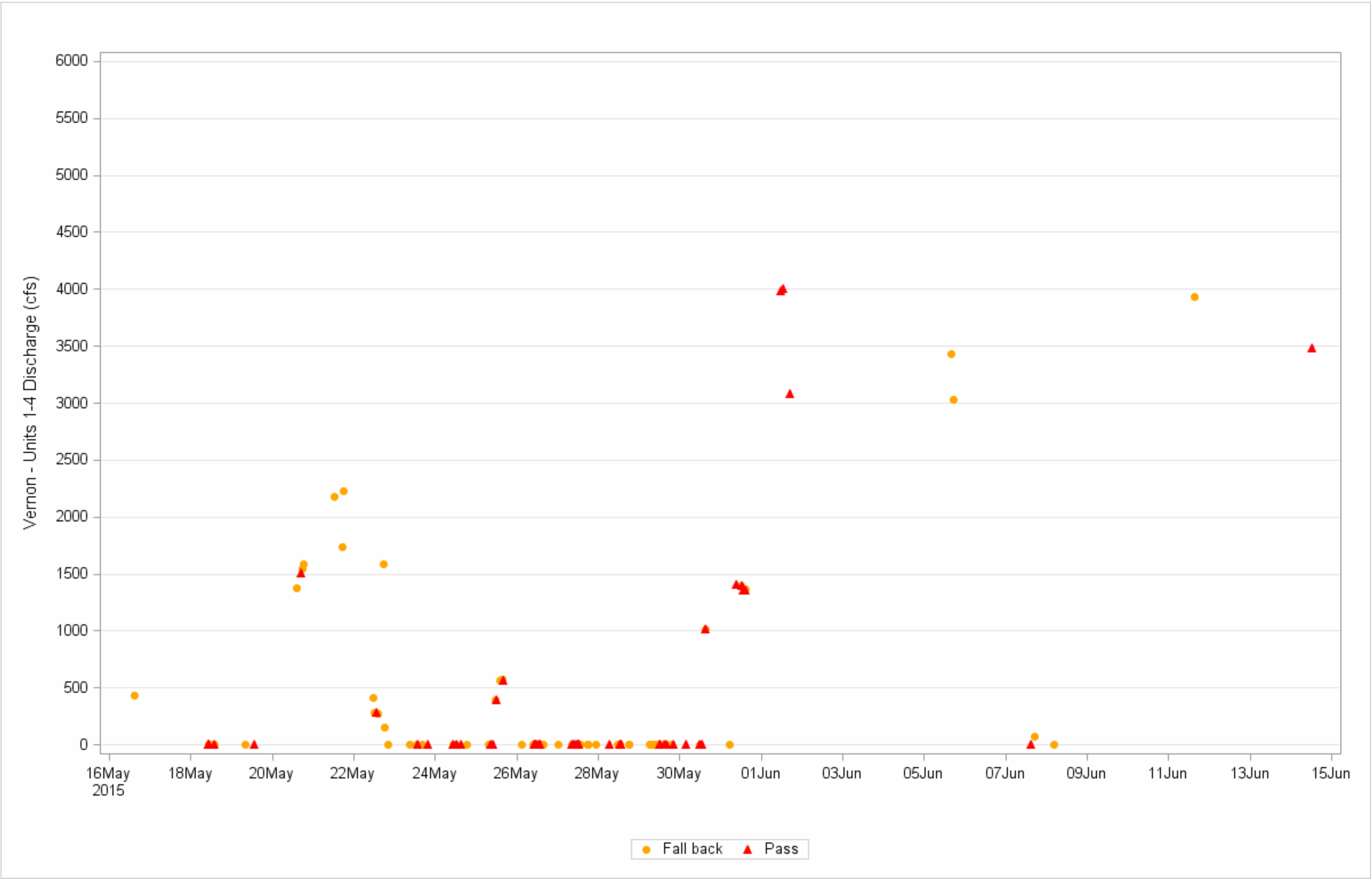

Figure 5.3-6. Timing for the initiation of American shad approach events to the fish ladder resulting in the initiation of successful and unsuccessful upstream fish ladder foray events at Vernon relative to Units 1-4 discharge (cfs), 2015.

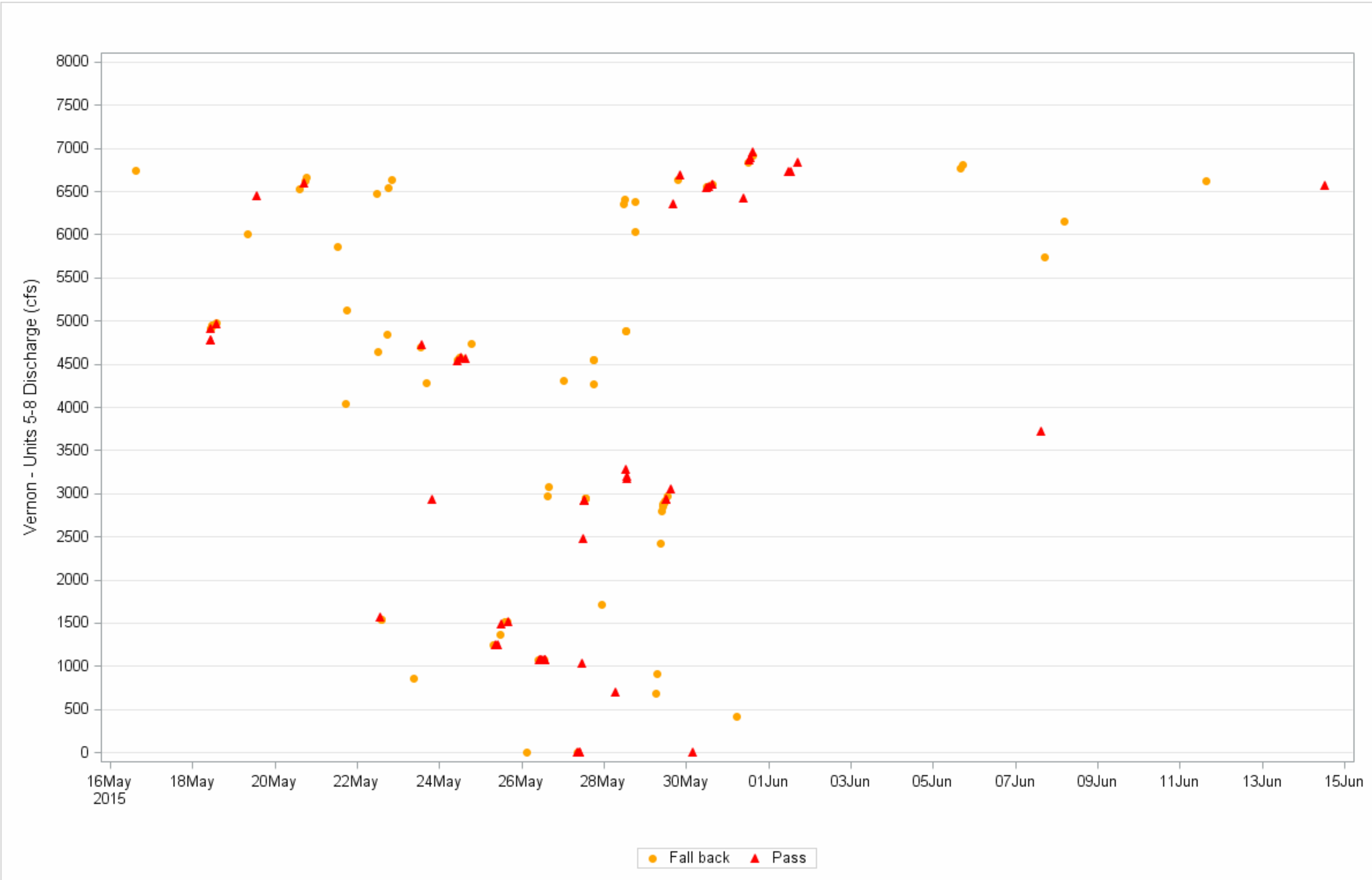

Figure 5.3-7. Timing for the initiation of American Shad approach events to the fish ladder resulting in the initiation of successful and unsuccessful upstream fish ladder foray events at Vernon relative to Units 5-8 discharge (cfs), 2015.

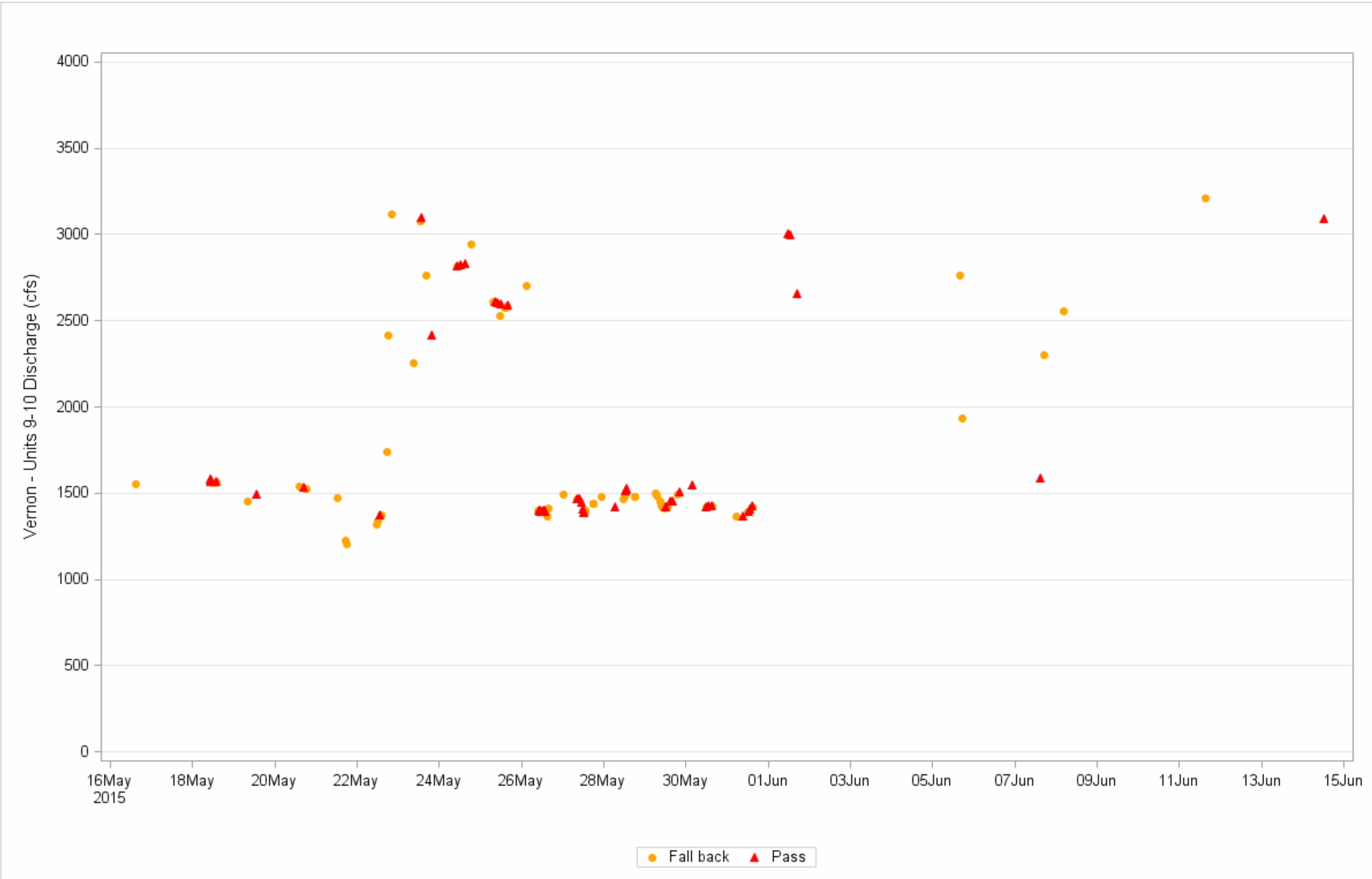

Figure 5.3-8. Timing for the initiation of American Shad approach events to the fish ladder resulting in the initiation of successful and unsuccessful upstream fish ladder foray events at Vernon relative to Units 9-10 discharge (cfs), 2015.

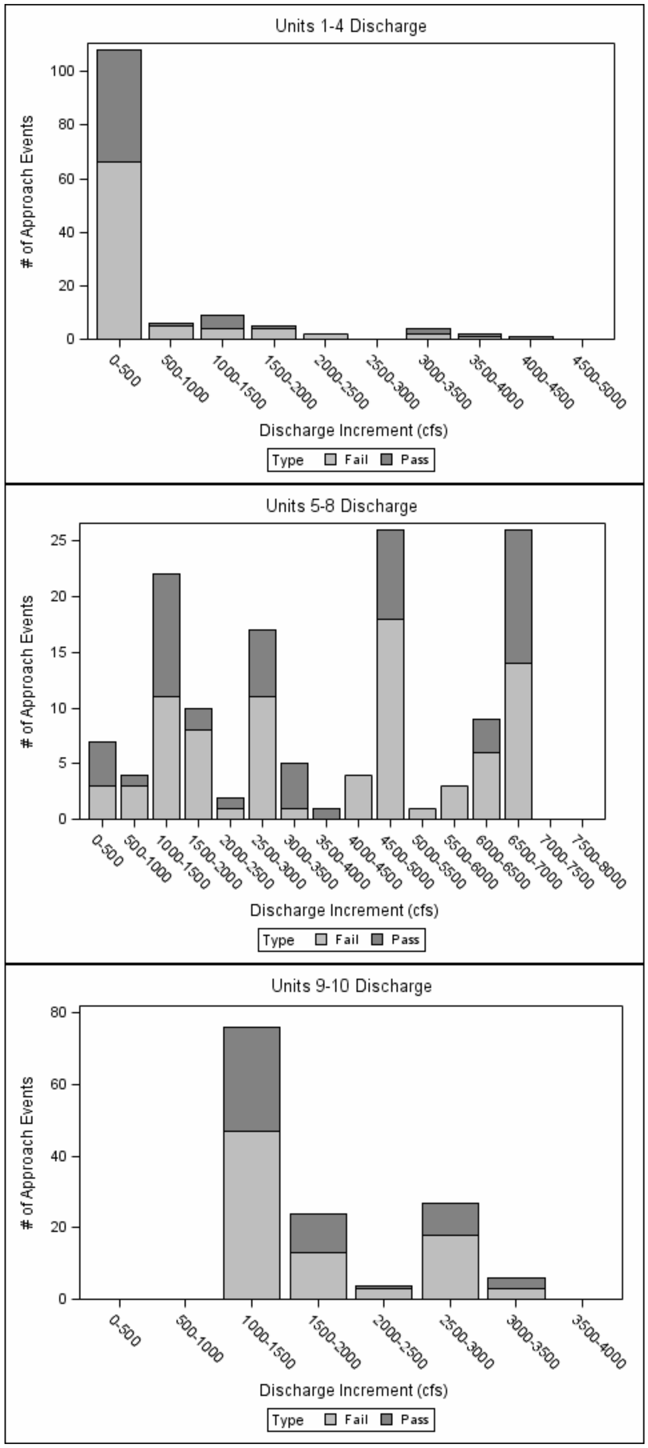

Figure 5.3-9. Frequency distribution of unit discharge (cfs) coinciding with the initiation of successful and unsuccessful American Shad upstream fish ladder forays at Vernon, 2015.

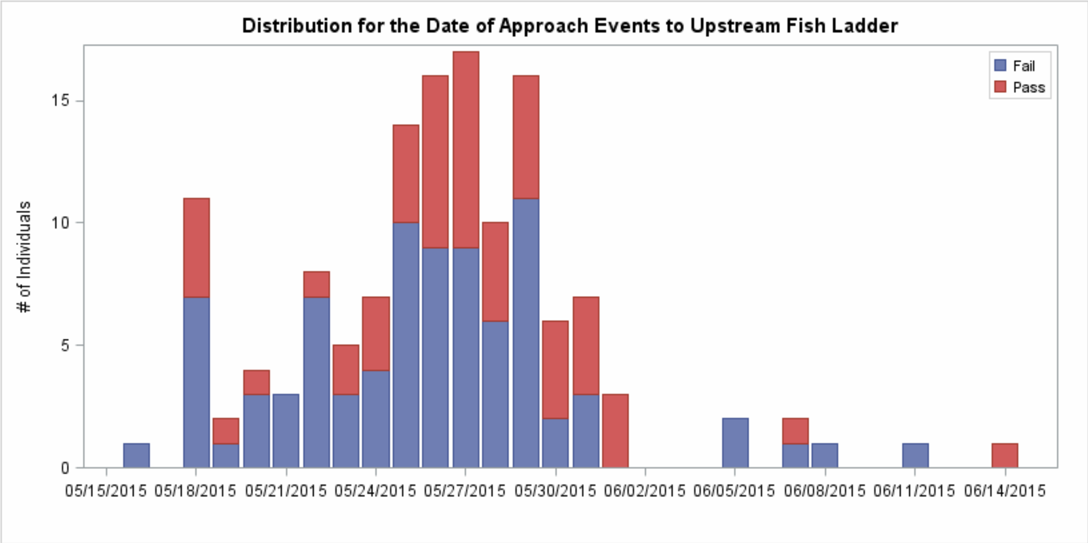

Figure 5.3-10. Distribution of the observed initiation dates for fish ladder approach events resulting in successful and unsuccessful American Shad upstream fish ladder forays at Vernon, 2015.

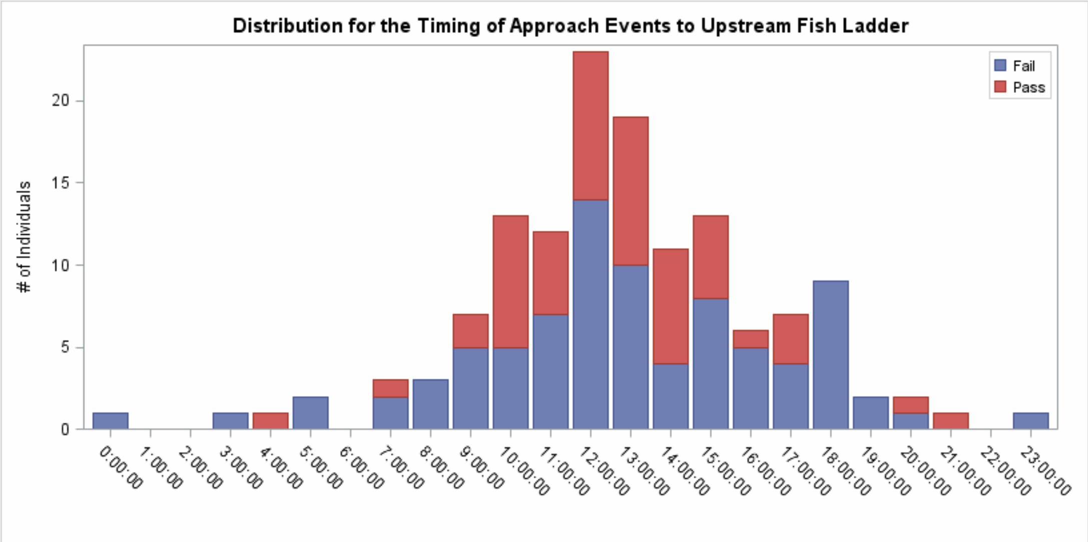

Figure 5.3-11. Distribution of the observed initiation times for fish ladder approach events resulting in successful and unsuccessful American Shad upstream fish ladder forays at Vernon, 2015.

Table 5.3-7. Vernon unit operation sequences, their % occurrence during study period, and associated number of approach events and corresponding successful and unsuccessful upstream American Shad foray events for tagged shad during 2015.

Vernon Unit		Resulting Foray Type		
Status[a]	Availability for Season (%)	Unsuccessful	Successful	Total
0000000001	0.9	1	4	5
0000000011	0.5	1		1
0000000101	2.1	7	8	15
0000000111	2.5	5	2	7
0000001101	5.2	15	10	25
0000001111	0.5		1	1
0000011101	2.4	11	4	15
0000011111	1.5	6	4	10
0000111101	7.8	10	7	17
0000111111	1.3	2		2
0001000101	0.3	2	1	3
0001000111	0.5	6	2	8
0001111101	1.3	3		3
0001111111	2.2	1		1
0011111101	3.8	8	6	14
0110111111	0.2	1		1
0111111101	1.1	1		1
0111111111	1.0	2		2
1111111111	47.8	2	4	6

a. The 10 positions within the column “Status” indicate Units 1 (left) through 10 (right) where 0 = offline and 1 = operational.

Table 5.3-8. Frequency of operational sequences for the Vernon turbine units over the full study period (May 10 – July 7, 2015).

Operational Status[a]	Percentage of Season (%)	Operational Status[a]	Percentage of Season (%)
0000000001	0.90	0011111111	3.20
0000000011	0.48	0100001111	0.02
0000000101	2.10	0100111101	0.02
0000000111	2.54	0100111111	0.02
0000001101	5.16	0110111101	0.05
0000001111	0.53	0110111111	0.18
0000010111	0.02	0111111101	1.15
0000011011	0.02	0111111111	0.97
0000011101	2.38	1000000111	0.04
0000011111	1.48	1000001111	0.48
0000101101	0.02	1000011111	0.44
0000111101	7.84	1000111101	0.26
0000111111	1.32	1000111111	4.91
0001000101	0.26	1001111101	0.14
0001000111	0.48	1001111111	0.51
0001001111	0.02	1010111101	0.02
0001011101	0.11	1010111111	0.04
0001011111	0.44	1011111111	0.46
0001111101	1.32	1100111111	2.10
0001111111	2.17	1101111111	0.18
0010001101	0.02	1110111101	0.49
0010011111	0.07	1110111111	0.83
0010111101	0.41	1111001101	0.02
0010111111	0.16	1111101101	0.02
0011011101	0.11	1111111101	1.57
0011011111	0.02	1111111111	47.78
0011111101	3.76		

a. The 10 positions within the column "Operational Status" indicate Units 1 (left) through 10 (right) where 0 = offline and 1 = operational.

5.3.5 Entrance Efficiency

An estimate of the Vernon fish ladder entrance efficiency was calculated as the percent of all dual-tagged fish determined to have entered the attraction water area immediately outside of the fish ladder (i.e., those detected on aerial antenna associated with monitoring station monitoring station 3) and subsequently entered the fish ladder (Table 5.3-9). When all dual-tagged shad entering the nearfield area of the fish ladder entrance are considered (34 total individuals), entrance efficiency was estimated at 73.5% (95% CI = 64.7-82.4%).

Table 5.3-9. Entrance efficiency rate determined for the Vernon fish ladder based on the proportion of shad passing upstream of the fish ladder entrance relative to the total number detected in the nearfield area immediately outside of the fish ladder, 2015.

Origin	No. Dual-tagged Shad Detected in Nearfield[a]	No. Dual-tagged Shad Detected Entering Fish Ladder[b]	Entrance Efficiency Rate (%)
TC	11	8	72.7
FL	23	17	73.9
Total	34	25	73.5

a. Based on detection at monitoring stations 3 (aerial antenna).

b. Based on detection at monitoring stations 3 (underwater drop antenna) or 4/5 (PIT).

5.3.6 Internal Efficiency

An estimate of the Vernon fish ladder internal efficiency was calculated as the percentage of all PIT and dual-tagged fish that entered the fish ladder, and were subsequently determined to have exited the upstream end and remained upstream of Vernon dam for more than 48 hours (Table 5.3-10). When all tagged shad entering the fish ladder are considered (96 total individuals; 71 PIT-tagged and 25 dual-tagged), 53 subsequently exited and internal efficiency was estimated at 55.2% (95% CI = 50.0-61.5%).

Table 5.3-10. Internal efficiency rate for the Vernon fish ladder based on the proportion of shad reaching and passing the fish ladder exit relative to total number detected at the fish ladder entrance, 2015.

Tag Type	No. Shad Detected Entering Fish Ladder[a]	No. Shad Detected Exiting Fish Ladder[b]	Internal Efficiency Rate (%)
Dual	25	11	44.0
PIT	71	42	59.2
Total	96	53	55.2

a. Based on detection at monitoring stations 3 (underwater drop antenna) and 5 or 6 (PIT).
b. Based on detection at monitoring stations 22 (radio) and 9 (PIT).

5.3.7 Fish Ladder Residency

As noted in Section 5.3.4, a total of 96 tagged shad (71 PIT-tagged and 25 dual-tagged) entered the Vernon fish ladder and made a total of 137 upstream forays within the fish ladder. Figure 5.3-12 presents the percentage of shad ascending the Vernon fish ladder as recorded by stationary monitoring equipment. The majority of unsuccessful forays terminated at points either between the fish ladder entrance and the first bend, or between the points downstream and upstream of the counting window where the fish ladder transitions to a vertical slot configuration.

When considering all forays, successful or unsuccessful, residency within the fish ladder from entry to exit ranged in duration from less than 1 minute to 6 days, 8 hours, 54 minutes. The minimum, maximum, median, and mean durations for successful and unsuccessful within-fish ladder forays are presented in Table 5.3-11. The average duration for the length of these within-fish ladder forays differed significantly for events resulting in successful passage or downstream fall back (Wilcoxon; $z = 2.8834$; $p = 0.0039$). The average duration of foray events for tagged shad that failed to successfully pass upstream was longer than that observed for individuals that successfully passed upstream.

Table 5.3-11. Within-fish ladder foray duration (hours; minimum, maximum, median, and mean) for dual-tagged shad from time of entry to time of upstream passage or downstream exit from the Vernon fish ladder, 2015.

Foray Type	Sample Size (No. of Forays)	Min	Max	Median	Mean
Successful	53	0.9	99.6	3.4	8.8
Unsuccessful	84	<0.1	152.9	1.1	10.2
All	137	<0.1	152.9	2.4	9.6

The minimum, maximum, median, and mean duration of residence in the lower ladder (from the entrance to the counting window) and upper ladder (in the vertical slot section upstream of the counting window to the exit) are presented in Table 5.3-12. The counting house consists of a regulating pool provided with a constant water flow at a constant water surface elevation. Fish are guided by flow and crowder screens through a narrow opening and past the counting window. The counting house forms the transition between the lower and longer ice harbor section of 26 overflow weir pools each 12 inches higher than the last, and the upper and shorter vertical slot section consisting of 25 pools each 6 inches higher than the last. The median time of passage from the entrance to the counting window was approximately 1.1 hours and from the counting window upstream to the exit was approximately 1.4 hours. Appendix A-5 contains a listing of the detection dates and times at each fish ladder monitoring station for all shad determined to have entered the Vernon fish ladder.

Final passage times were identified for 53 individuals as they exited the upstream end of the Vernon fish ladder. Project discharge (cfs) and headpond elevation at the time of exit are presented for each individual shad passing Vernon in Appendix A-6. All shad exiting the fish ladder into the Vernon impoundment did so when total discharge was below maximum station generating capacity (Figure 5.3-13). Although discharge was below maximum station generating capacity, a limited amount of spill at Vernon (~1,000 cfs) was present at the time of fish ladder exit for five shad that passed during early June (Appendix A-6). The average headpond elevation at Vernon for the entire study period was 219.3 ft[4] (range = 218.4-219.9 ft [NGVD29]). Shad exiting the upstream fish ladder into the Vernon impoundment did so at headpond elevations of 218.6-219.9 ft (mean = 219.2 ft).

[4] All elevations are stated in National Geodetic Vertical Datum of 1929 (NGVD29).

Table 5.3-12. Minimum, maximum, median, and mean travel duration (hours) within the lower and upper sections of the Vernon fish ladder (from the entrance to the counting window, and from the counting window to the upstream exit), 2015.

Foray Type	No. Forays	Min	Max	Median	Mean
Lower Fish Ladder					
Successful[a]	52	0.1	97.3	1.1	4.1
Unsuccessful	84	<0.1	152.9	0.3	5.8
All	136	<0.1	152.9	0.8	5.2
Upper Fish Ladder					
Successful[a]	52	0.5	93.5	1.4	4.8
Unsuccessful	19	<0.1	64.2	4.4	13.0
All	71	<0.1	93.5	1.7	7.0

a. Date-time of presence at the counting window was not recorded for one of the 53 individuals that successfully passed.

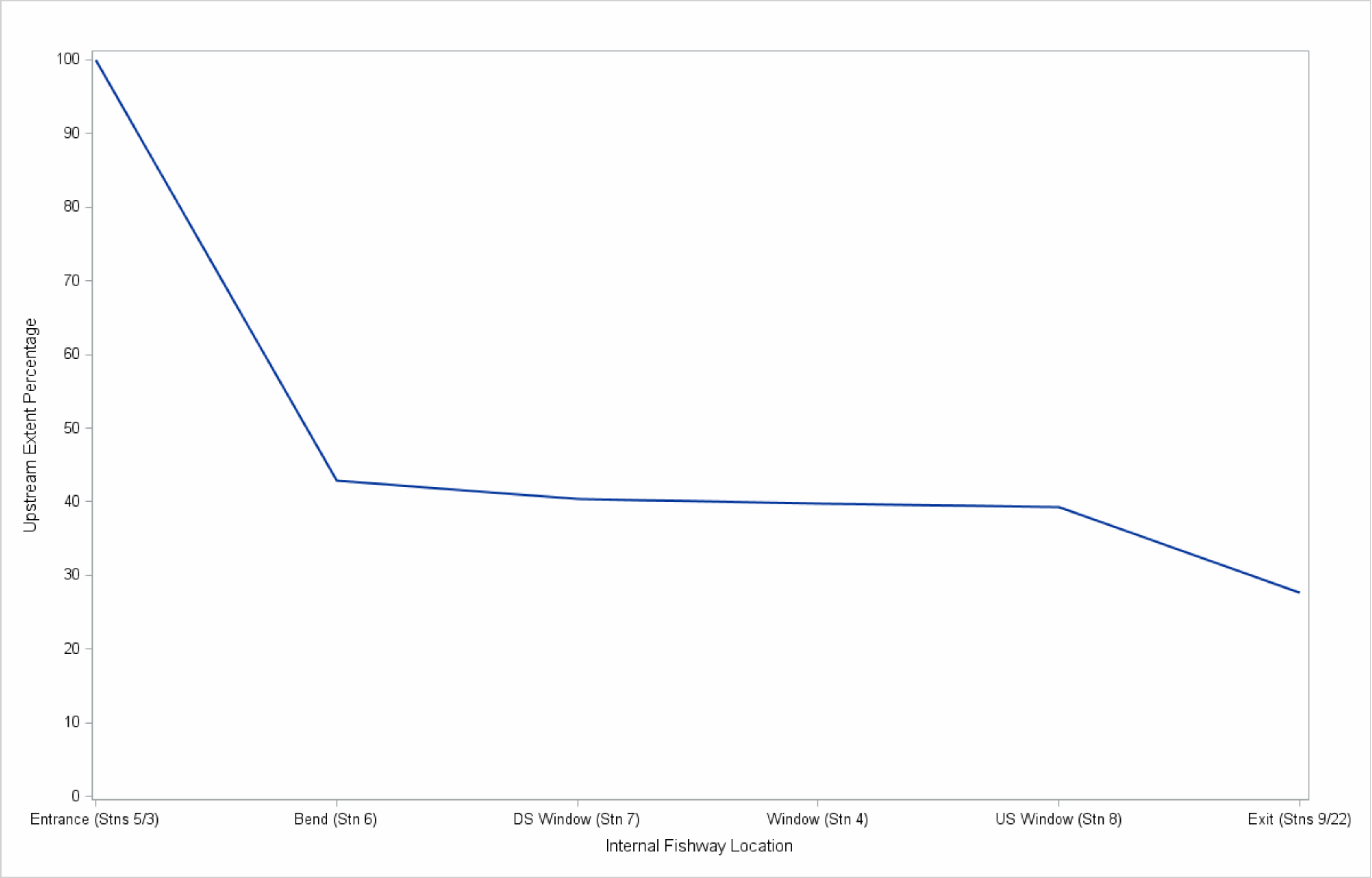

Figure 5.3-12. Upstream extent of foray events within the Vernon fish ladder, 2015.

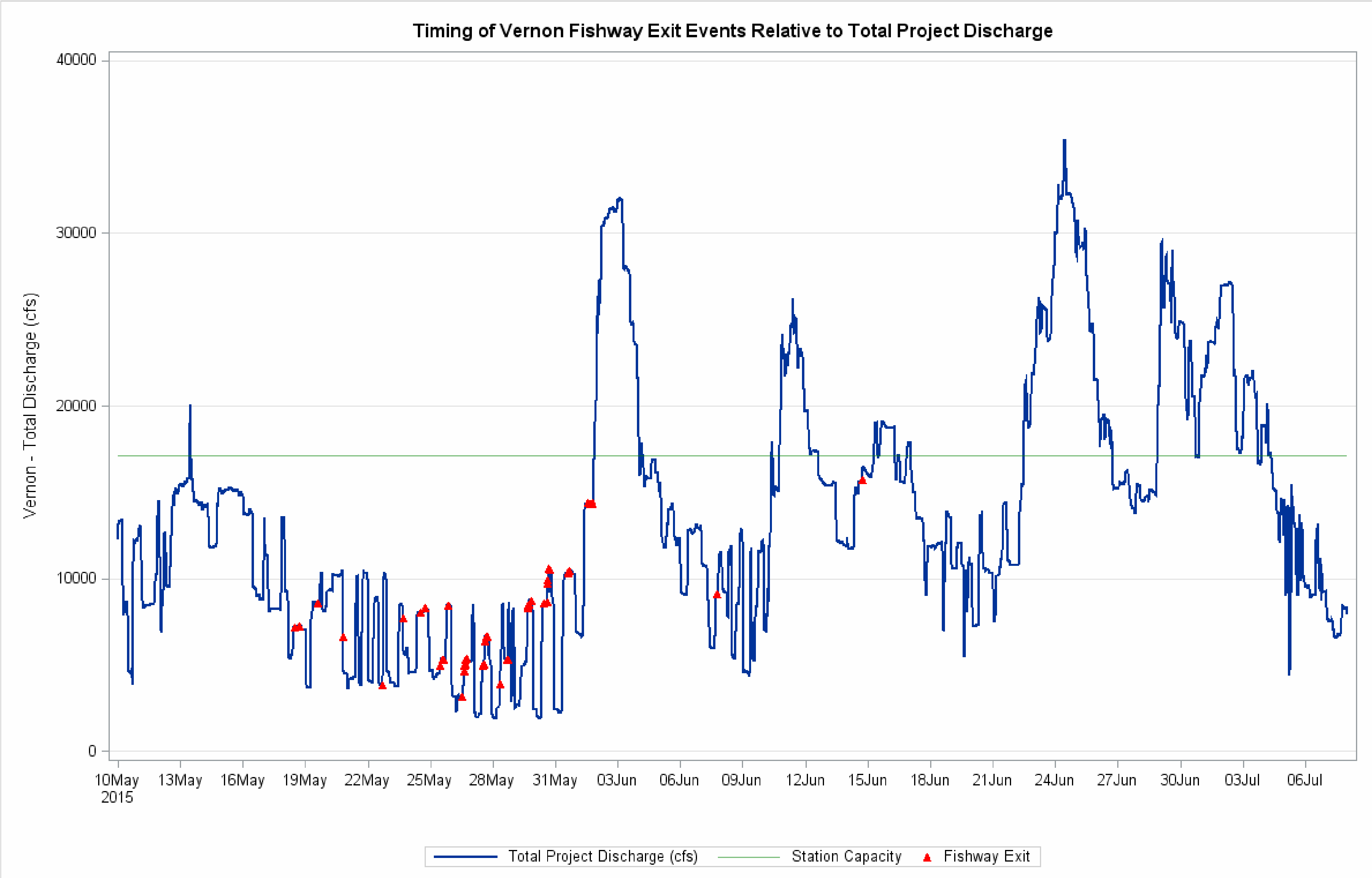

Figure 5.3-13. Timing for the entrance of radio-tagged adult shad into the Vernon headpond following successful passage through the upstream fish ladder relative to total discharge (cfs), 2015.

5.3.8 Upstream Movement Evaluation

As described in the RSP, upstream migration of radio-tagged adult shad through the Vernon impoundment to Bellows Falls dam was evaluated during the 2015 field study. Sixty-five shad were available for monitoring upstream of Vernon dam. Of these, 54 were collected at the Vernon fish ladder trapping facility, tagged, and purposely released upstream of Vernon dam. The remaining 11 individuals volitionally passed upstream through the fish ladder and moved into the Vernon impoundment (one of the 12 dual-tag fish that passed the fish ladder lost its radio tag and was therefore unable to be tracked). Excluding detections at the stationary receivers on the upstream side of Vernon dam, all fish were detected within the Vernon impoundment on at least one occasion. Figure 5.3-14 (and Appendix C-3) identifies all manual tracking detections throughout the study period. Eighteen (27.7%) of the 65 shad monitored for the upstream assessment migrated to the Bellows Falls tailrace. Travel time to Bellows Falls ranged from 20 hours, 23 minutes to over 23 days; with a median travel time of 5 days, 16 hours, 29 minutes. Fifteen of the shad that reached Bellows Falls had been collected at Vernon and three had been collected at Holyoke. All but four of the shad reaching Bellows Falls subsequently passed downstream of Vernon dam.

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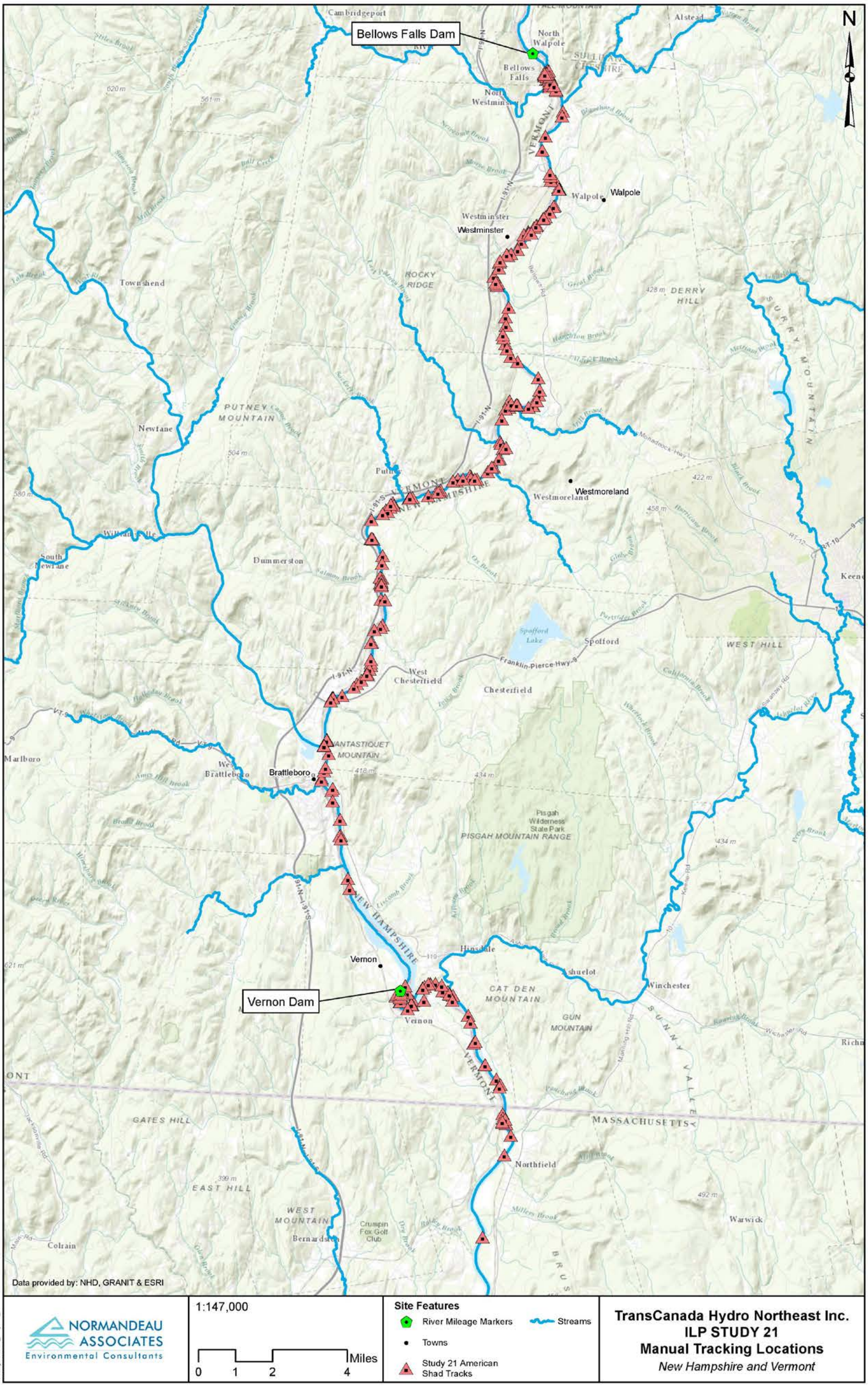

Figure 5.3-14. Adult shad manual tracking locations, 2015.

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5.4 Downstream Passage

Downstream passage at Vernon was evaluated based on detections of the 65 radio-tagged adult shad that were released into the Vernon impoundment or had successfully passed the Vernon fish ladder.

5.4.1 Return Timing and Forebay Residency

Figure 5.4-1 shows the distribution of entrance dates into the reach upstream of Vernon with the largest contributions associated with the intentional release groups which took place on May 17, 24, and 30. Entrance dates for volitionally passed radio-tagged shad occurred from May 18 to June 14, 2015.

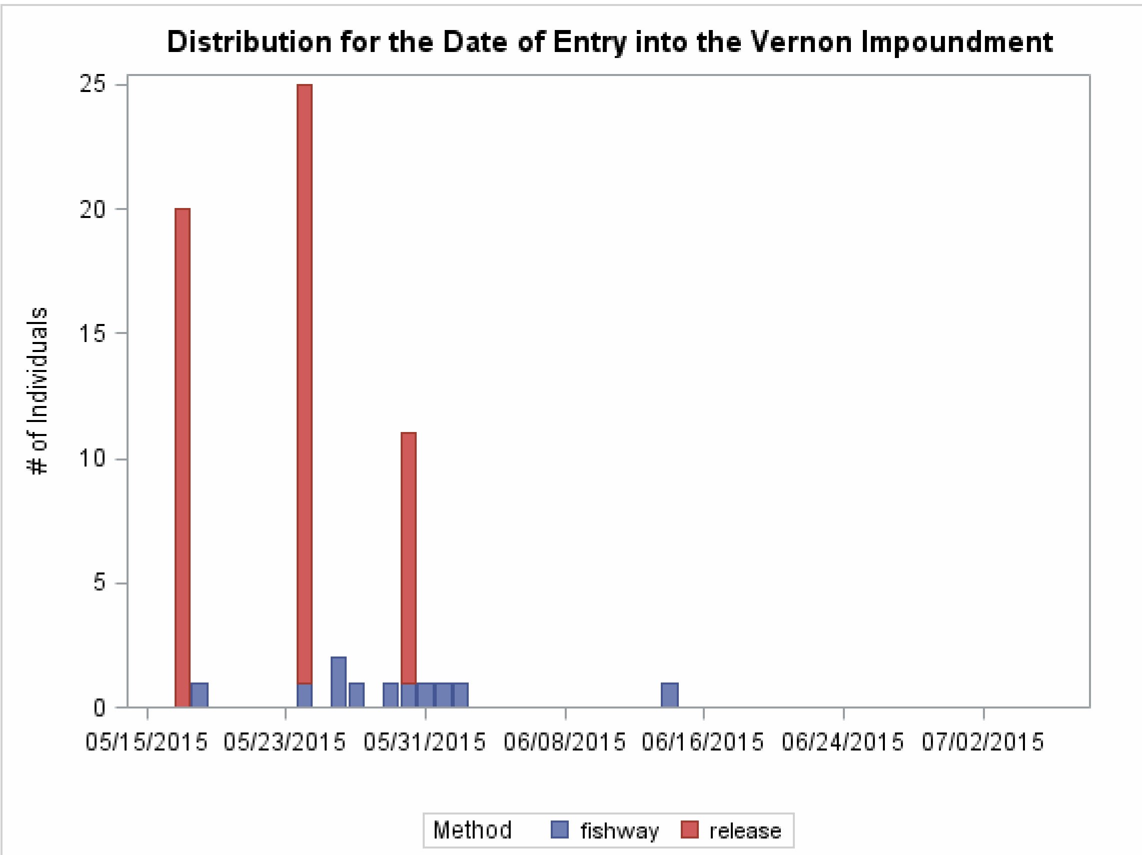

Figure 5.4-1. Distribution of release/passage dates for radio-tagged shad entering the Vernon impoundment, 2015.

The duration of time from release upstream of Vernon or from volitional upstream passage through the Vernon fish ladder to the subsequent "return" detection in the Vernon forebay ranged from 20 hours, 51 minutes to 39 days, 12 hours; with a median time of 12 days, 7 hours, 54 minutes. Of the 65 radio-tagged adult shad, 91% (59 of the 65) were determined to have returned to the Vernon forebay following a period of time upstream of the dam (i.e., in the Vernon impoundment or Bellows Falls riverine reach). The remaining six individuals initially moved upstream of Vernon dam but did not return downstream (those having a known release upstream and manual detections at points upstream of Vernon but had no stationary detections at receivers in the forebay area, no detected passage route, and no downstream detections).

Of the 59 individuals returning to Vernon, 15% (9 of the 59) were determined to be mortalities following removal from project trash racks. As it could not be determined if those individuals died following return to Vernon dam or had drifted downstream following mortality upstream they were excluded from further analysis. The time series of detections for one additional shad when all TransCanada and FirstLight detections were merged appeared conflicting and as a result that individual was dropped from further analysis.

For the remaining 49 individuals, a forebay residency time could be determined for 39 individuals[5]. Forebay residency was defined as the duration of time from initial detection in the forebay following a period of upstream residence (as defined by detection at monitoring stations 14 and 15) until the last detection indicating downstream passage (as defined by detection at monitoring stations 13, 16, 17, 18, 19 and 21). Radio-tagged shad returned to the forebay area between May 18 and July 3, 2015 (Figure 5.4-2). The majority of return events occurred during June with minor peaks in the daily number of downstream migrants coinciding with peaks in the mean daily discharge. Forebay residency ranged from several minutes to greater than 21 days (Table 5.4-1).

When examined by passage route for the 28 shad with a known passage route, the median forebay residency time was shortest for those passing via the fish pipe and higher for those passing via Units 5-8 and Units 9-10. River and operational conditions varied over the full duration of forebay residence time for an individual shad. Figure 5.4-3 overlays forebay residence times with total project discharge (cfs) and operational condition of Units 1-10. It should be noted that one of the 15 that passed via the spillway did so when spill gates were not open; as did four of the eight shad that passed via the fish pipe, two of the three that passed via Units 5-8, both shad that passed via Units 9-10, and five of the 14 that passed via unknown routes.

For each of the 39 radio-tagged shad with a calculated forebay residency time, Table 5.4-2 shows the minimum, maximum, mean, and median total project discharge and spill flows (cfs) during residency, and the percent of residency time during which spill occurred and Units 1-10 operated. Individual radio-tagged adult shad with relatively short forebay residence times (i.e., ≤12 hrs) were generally

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[5] Detection information for 3 of the 49 shad returning to the Vernon forebay was not collected at monitoring stations 14 or 15. Passage for those individuals was determined based on detections on the downstream side of the project. An additional seven individuals that approached Vernon did not successfully pass. These fish had a known release upstream and one or more detections only on receivers from the upstream forebay area. They did not have detections at any downstream locations (TC or FL) or any manual detections (NAI or KA) to indicate they successfully passed.

associated with periods when discharge exceeded maximum station generating capacity (i.e., during spill).

Table 5.4-1. Forebay residency duration (minimum, maximum, mean and median) for radio-tagged shad prior to downstream passage at Vernon, 2015.

Downstream Passage Route	Forebay Residency			
	Min	Max	Mean	Median
Fish Pipe	1m	2d 10h 9m	9h 34m	36m
Spill	1m	21d 15h 17m	4d 1h 20m	11h 56m
Units 5-8	9h 15m	10d 3h 52m	3d 18h 19m	17h 49m
Units 9-10	14m	2d 8h 8m	1d 4h 11m	1d 4h 11m
Unknown	5m	11d 9h 5m	3d 15h 58m	1d 18h 53m
All	1m	21d 15h 17m	3d 2h 37m	11h 56m

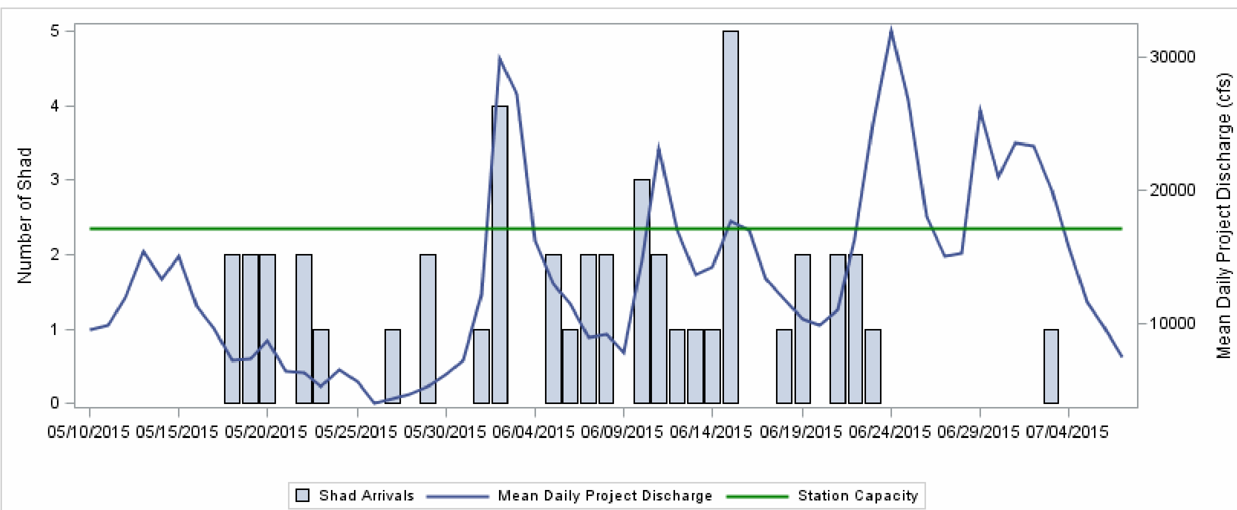

Figure 5.4-2. Distribution of forebay entry dates for radio-tagged shad approaching the Vernon dam during their downstream migration relative to mean daily project discharge (cfs), 2015.

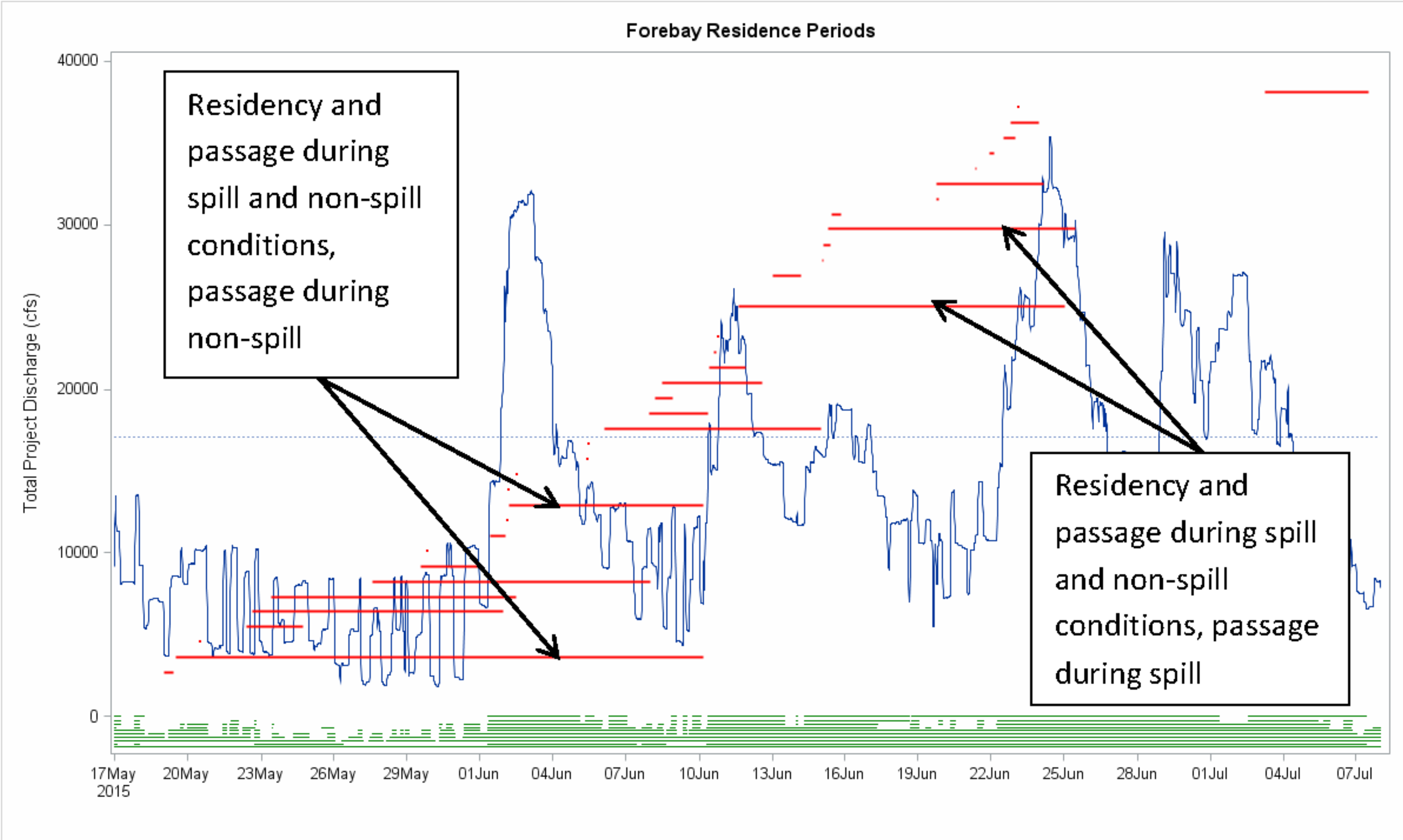

Figure 5.4-3. Temporal distribution of forebay residence times for radio-tagged adult shad emigrating past Vernon dam. Solid blue line = total project discharge (cfs), dashed blue line = maximum station generating capacity, red lines = forebay residence times for radio-tagged shad, green lines = operational status of Units 1 (upper) through 10 (lower) where green = unit on and blank = unit off.

Table 5.4-2. Minimum, maximum, median, and mean total discharge and spill flows; percentage of time spill was present, and each unit (1-10) operated during the calculated forebay residence time of radio-tagged shad passing downstream of Vernon, 2015.

Fish ID	Date/Time of Arrival	Date/Time of Passage	Passage Route	Forebay Residency	Total Discharge (cfs)				Spill Flow (cfs)					Percentage of Residence Duration with Unit in Operation									
				Duration (hrs)	Min	Max	Mean	Median	Min	Max	Mean	Median	% of Residence Duration	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
8_189	19-May-00:53:27	19-May-10:08:50	Units 5-8	9.26	3,671	8,606	5,620	3,895	0	0	0	0	0	0	0	0	0	49	51	57	100	0	100
44_192	19-May-12:53:42	10-Jun-04:10:55	Spill	519.29	1,855	32,048	9,861	8,433	0	19,168	1,620	0	16	26	29	42	47	59	68	82	96	50	100
44_191	20-May-13:12:14	20-May-13:26:43	Fish Pipe	0.24	10,158	10,158	10,158	10,158	0	0	0	0	0	0	0	100	100	100	100	100	100	0	100
44_193	22-May-08:51:18	24-May-16:59:31	Units 9-10	56.14	3,724	10,286	6,043	5,523	0	0	0	0	0	0	2	5	17	17	44	54	100	86	100
54_196	22-May-15:01:34	01-Jun-23:29:16	Unknown	248.46	1,855	20,360	6,197	5,313	0	7,688	106	0	4	6	6	17	22	29	48	64	92	42	100
8_187	23-May-09:08:23	02-Jun-11:38:31	Spill	242.50	1,855	30,897	7,370	5,511	0	17,855	913	0	9	11	11	22	26	33	52	69	92	41	100
8_61	27-May-14:00:31	07-Jun-23:06:17	Unknown	273.10	1,855	32,048	12,752	10,652	0	19,168	3,078	0	31	43	46	58	61	76	83	91	97	56	100
8_194	29-May-13:44:17	31-May-23:40:06	Unknown	57.93	1,855	10,639	6,854	8,604	0	0	0	0	0	0	0	42	38	64	67	71	93	0	100
27_182	29-May-19:59:00	29-May-20:05:55	Unknown	0.12	8,639	8,639	8,639	8,639	0	0	0	0	0	0	0	0	0	100	100	100	100	0	100
8_192	01-Jun-10:26:53	02-Jun-01:40:02	Unknown	15.22	14,124	26,303	16,779	14,406	0	17,239	3,672	1,124	77	100	100	100	100	100	100	100	100	100	100
44_198	02-Jun-03:08:40	02-Jun-03:22:26	Spill	0.23	25,882	25,882	25,882	25,882	13,077	13,077	13,077	13,077	100	100	100	100	100	100	100	100	100	100	100
27_184	02-Jun-05:09:17	10-Jun-03:46:40	Spill	190.62	4,320	32,048	15,081	12,597	0	19,168	3,840	0	36	59	63	71	75	93	93	99	100	77	100
54_205	02-Jun-05:12:04	02-Jun-05:17:47	Unknown	0.10	29,563	29,563	29,563	29,563	16,439	16,439	16,439	16,439	100	100	100	100	100	100	100	100	100	100	100
44_194	02-Jun-12:50:12	02-Jun-12:52:57	Spill	0.05	31,075	31,075	31,075	31,075	18,156	18,156	18,156	18,156	100	100	100	100	100	100	100	100	100	100	100
27_32	05-Jun-10:16:51	05-Jun-10:31:28	Spill	0.24	14,043	14,043	14,043	14,043	0	0	0	0	0	100	100	100	100	100	100	100	100	100	100
54_201	05-Jun-12:00:36	05-Jun-12:22:36	Unknown	0.37	13,993	13,993	13,993	13,993	0	0	0	0	0	100	100	100	100	100	100	100	100	100	100
27_188	06-Jun-03:29:21	15-Jun-00:40:07	Unknown	213.18	4,320	26,200	13,514	12,697	0	12,420	2,012	1,190	55	60	60	65	77	94	94	99	100	78	100
44_202	07-Jun-21:58:10	10-Jun-08:07:25	Fish Pipe	58.15	4,320	14,016	8,754	8,920	0	5,305	279	0	8	29	28	43	36	78	78	98	100	29	100
44_195	08-Jun-03:26:53	08-Jun-21:16:40	Units 5-8	17.83	5,327	12,643	8,696	8,558	0	0	0	0	0	8	8	35	33	82	82	93	100	61	100
8_167	08-Jun-10:30:24	12-Jun-14:21:00	Spill	99.84	4,320	26,200	14,834	15,216	0	12,420	3,521	2,642	59	71	71	73	69	87	87	99	100	59	100
44_200	10-Jun-09:01:45	11-Jun-21:33:27	Spill	36.53	14,809	26,200	21,258	22,826	1,190	12,420	7,328	8,822	100	100	100	100	100	100	100	100	100	100	100
54_182	10-Jun-16:24:36	10-Jun-16:25:12	Fish Pipe	0.01	15,095	15,095	15,095	15,095	1,203	1,203	1,203	1,203	100	100	100	100	100	100	100	100	100	100	100
8_161	10-Jun-18:30:57	10-Jun-18:34:38	Spill	0.06	17,532	17,532	17,532	17,532	3,656	3,656	3,656	3,656	100	100	100	100	100	100	100	100	100	100	100
27_165	11-Jun-07:16:15	11-Jun-07:25:07	Fish Pipe	0.15	24,609	24,609	24,609	24,609	10,522	10,522	10,522	10,522	100	100	100	100	100	100	100	100	100	100	100
54_82	11-Jun-14:25:51	25-Jun-01:34:19	Spill	323.14	5,484	35,382	16,440	15,421	0	22,903	3,870	1,202	65	93	74	66	71	100	100	100	100	100	100
44_168	12-Jun-04:07:02	12-Jun-04:43:22	Fish Pipe	0.61	17,545	17,783	17,664	17,664	3,139	3,400	3,270	3,270	100	100	100	100	100	100	100	100	100	100	100
54_20	13-Jun-00:33:12	14-Jun-04:23:53	Unknown	27.84	11,677	15,573	13,337	12,151	1,184	1,203	1,193	1,194	100	47	47	48	100	100	100	100	100	100	100
27_190	15-Jun-00:48:04	15-Jun-02:26:44	Spill	1.64	15,856	16,000	15,939	15,950	2,183	2,192	2,188	2,189	100	100	100	100	100	100	100	100	100	100	100
27_191	15-Jun-02:53:44	15-Jun-09:35:21	Spill	6.69	15,852	19,093	17,077	16,715	2,188	4,700	2,953	2,524	100	100	100	100	100	100	100	100	100	100	100
8_186	15-Jun-06:32:02	25-Jun-10:24:32	Units 5-8	243.88	5,484	35,382	17,103	14,953	0	22,903	4,852	1,201	54	98	73	62	61	99	99	100	100	100	100
8_188	15-Jun-10:38:32	15-Jun-20:22:07	Unknown	9.73	17,013	19,075	18,284	18,695	2,662	4,708	3,913	4,264	100	100	100	100	100	100	100	100	100	100	100

Fish ID	Date/Time of Arrival	Date/Time of Passage	Passage Route	Forebay Residency	Total Discharge (cfs)				Spill Flow (cfs)					Percentage of Residence Duration with Unit in Operation									
				Duration (hrs)	Min	Max	Mean	Median	Min	Max	Mean	Median	% of Residence Duration	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
27_186	19-Jun-17:32:25	19-Jun-20:46:46	Fish Pipe	3.24	8,116	11,100	9,381	9,202	0	0	0	0	0	100	23	23	0	100	100	100	100	100	100
8_163	19-Jun-18:31:17	24-Jun-04:52:50	Unknown	106.36	7,209	32,857	16,138	13,629	0	20,153	4,311	0	42	100	59	60	54	100	100	100	100	100	100
54_184	21-Jun-09:14:02	21-Jun-09:28:16	Units 9-10	0.24	11,015	11,086	11,050	11,050	0	0	0	0	0	100	0	0	0	100	100	100	100	100	100
44_196	21-Jun-22:26:02	22-Jun-03:01:06	Fish Pipe	4.58	10,756	10,788	10,769	10,767	0	0	0	0	0	100	0	0	0	100	100	100	100	100	100
54_185	22-Jun-12:56:51	23-Jun-00:53:41	Spill	11.95	18,740	22,982	20,585	20,852	4,786	9,519	6,858	6,845	100	100	100	100	100	100	100	100	100	100	100
8_195	22-Jun-19:58:08	23-Jun-23:12:28	Spill	27.24	19,685	28,325	24,556	24,649	6,099	15,277	11,137	11,260	100	100	100	100	100	100	100	100	100	100	100
8_193	23-Jun-03:40:19	23-Jun-03:41:46	Spill	0.02	25,085	25,085	25,085	25,085	11,581	11,581	11,581	11,581	100	100	100	100	100	100	100	100	100	100	100
8_191	03-Jul-05:30:53	07-Jul-12:52:59	Unknown	103.37	4,340	22,027	13,079	12,850	0	8,352	1,788	1,081	53	98	63	69	68	87	93	100	100	98	100

5.4.2 Route Selection and Passage Efficiency

Of the 59 radio-tagged adult shad subsequently located in the Vernon forebay following upstream migration, seven approached the dam but did not pass, nine were found dead on the trash racks, and one was excluded from analysis due to data conflicts. The remaining 42 (71.2%) passed downstream. A definitive passage route could not be determined for 14 individuals (33%) passing downstream of Vernon. For those with known routes, the majority were determined to have passed via the spillway (36%) and through the fish pipe (19%) with the remainder using turbine units 5-10. No outmigrating shad were determined to have passed via Units 1-4, nor via the smaller fish tube located along the western shoreline, adjacent to Unit 10 (Table 5.4-3; Appendix B).

Turbine unit operations at the time of passage for each of the 42 individuals are summarized in Table 5.4-4 and Appendix B. The majority of downstream passage events occurred when all 10 units were in operation which occurred during nearly 50% of the study period (Table 5.3-8 above). The temporal pattern of downstream passage events relative to total discharge and spill discharge is presented in Figure 5.4-4. Peaks in downstream passage events generally coincided with peaks in both total discharge and spill. The timing of downstream passage events appeared to be fairly uniform in distribution with no strong pattern in diel timing when examined by route selection (Figure 5.4-5). This is likely a function of a relatively small sample size.

It should be noted that five individuals carrying only PIT-tags were detected passing downstream via the fish pipe. These individuals passed downstream of Vernon during the same time period as radio-tagged shad (Table 5.4-5). The total period of travel and residence in the Connecticut River upstream of Vernon (potentially including the forebay, Vernon impoundment, and Bellows Falls riverine reach) ranged between 9 and 34 days for these five individuals. PIT-tagged shad were not included in the evaluation of downstream route selection. Due to the inability to detect PIT-tagged shad as they returned to the forebay, it was not possible to calculate residence within the forebay for those individuals. With regard to route selection, only the fish pipe had PIT-tag coverage. As a result, inclusion of PIT-tagged individuals in the assessment of route selection along with the radio-tagged individuals would bias the overall route distribution as detection efficiency for PIT tagged fish at all routes other than the fish pipe was equal to zero (due to lack of coverage). As a result, any PIT tagged individuals passing via spill, the fish tube, or Units 1-10 would not be represented.

Table 5.4-3. Final disposition and downstream passage routes of dual-tagged adult American Shad at Vernon dam, 2015.

Final Disposition	Downstream Passage Route	Number	% of Number Passed
Did not return from upstream	-	6	-
Approached but did not pass	-	7	-
Mortality on trash racks	-	9	-
Excluded due to data conflicts	-	1	-
Passed downstream of Vernon	Turbine Units 1-4	0	0.0
	Turbine Units 5-8	3	7.1
	Turbine Units 9-10	2	4.8
	Fish tube	0	0.0
	Fish pipe	8	19.0
	Spillway	15	35.7
	Unknown	14	33.3
Subtotal (approaching Vernon)		**59**	-
Subtotal (passing Vernon)		**42**	-
Total		**65**	-

Table 5.4-4. Vernon unit operation sequences (and % occurrence during study period) with associated number of downstream passage events for radio-tagged shad, 2015.

Vernon Unit		Total Downstream Passage Events
Status[a]	Percent Occurrence (%)	
0000011111	1.48	1
0000111101	7.84	5
0001111111	2.17	1
0010111101	0.41	1
0011111101	3.76	1
0011111111	3.20	1
0111111111	0.97	1
1000111111	4.91	2
1110111111	0.83	1
1111111101	1.57	1
1111111111	47.78	27

a. The 10 positions within the column “Operational Status” indicate Units 1 (left) through 10 (right) where 0 = offline and 1 = operational.

Table 5.4-5. Duration of time from completion of upstream passage at Vernon to completion of downstream passage (as determined by monitoring station 20) for PIT-tagged shad passing Vernon via the fish pipe, 2015.

Shad ID	Upstream Passage Date	Downstream Passage Date	Total Time Upstream of Vernon (dd:hh:mm)
314-772	5/26/2015	6/23/2015	27:17:06
314-926	5/27/2015	7/1/2015	34:09:42
315-110	5/29/2015	6/8/2015	10:03:36
314-702	5/30/2015	6/17/2015	18:04:28
315-22	5/30/2015	6/8/2015	9:03:59

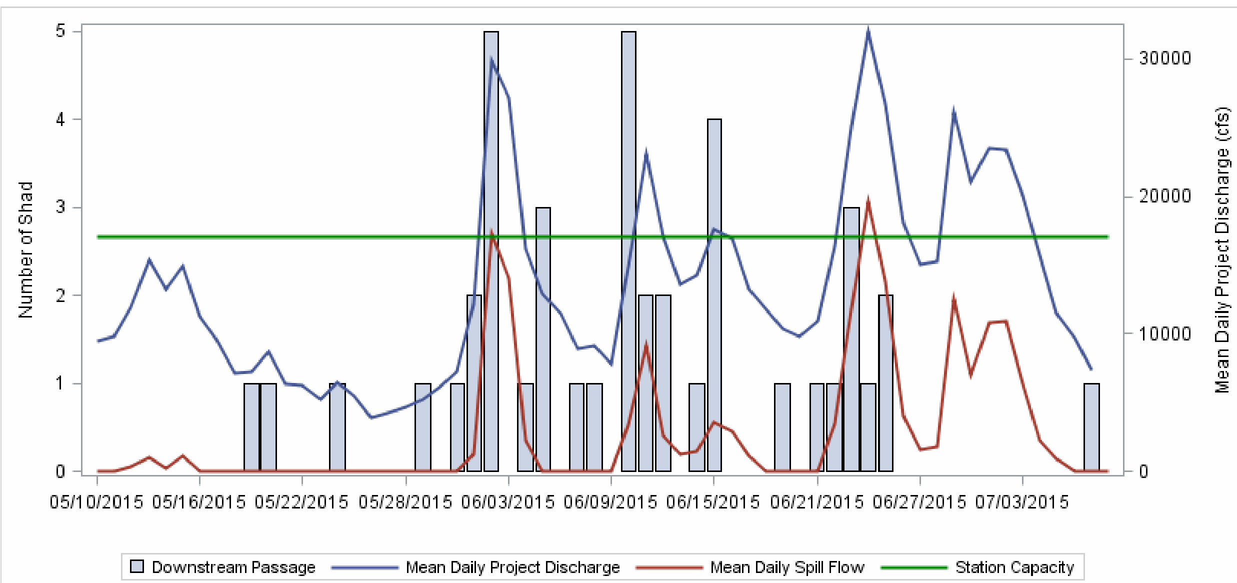

Figure 5.4-4. Distribution of downstream passage dates for radio-tagged shad at Vernon dam relative to mean daily project discharge (cfs) and project spill (cfs), 2015.

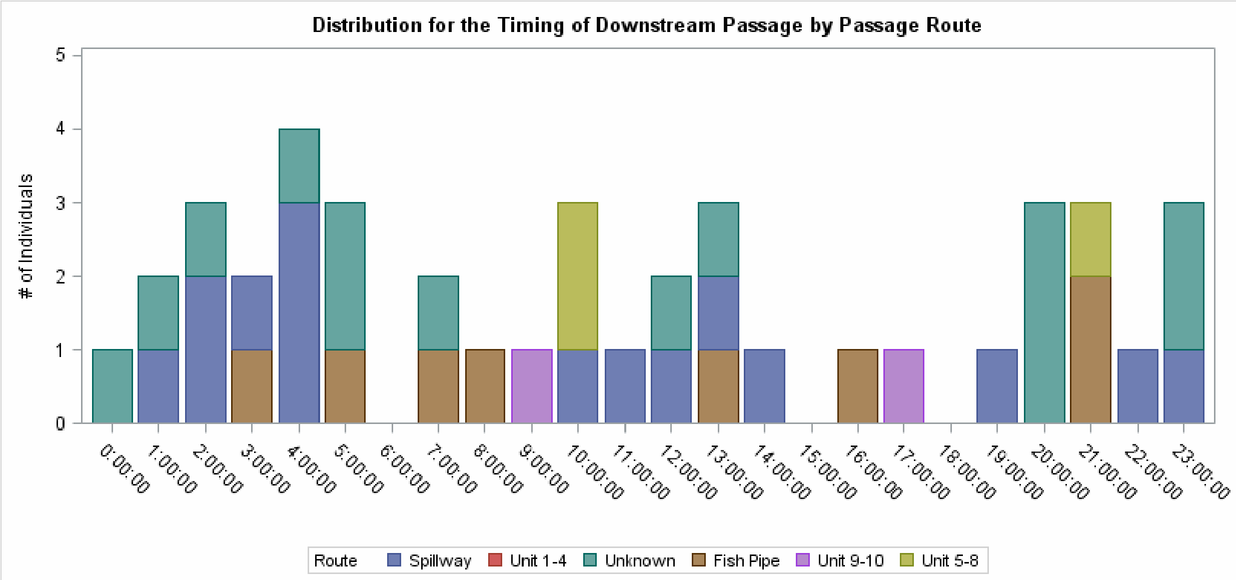

Figure 5.4-5. Distribution of the observed downstream passage times for radio-tagged shad at Vernon, 2015.

5.4.3 Downstream Passage Survival

The downstream progress of the 42 radio-tagged individuals known to have passed Vernon was evaluated based on a review of telemetry data collected as part of this study and for the FirstLight monitoring associated with the concurrent study at Northfield Mountain and Turners Falls. For each individual passing Vernon, the time series of stationary telemetry data was reviewed and detections were noted for the following locations:

- TC monitoring station 1 – receiver operated by TransCanada and located approximately 0.75 miles downstream of Vernon just upstream of Stebbins Island;
- Northfield Mountain[6] – compilation of receivers operated by FirstLight and located in the vicinity of Northfield Mountain located approximately 15 miles downstream of Vernon; and
- Turners Falls – compilation of receivers operated by FirstLight and located in the vicinity of Turners Falls, the bypass reach and canal located approximately 20 miles downstream of Vernon.

[6] Stationary telemetry data in the vicinity of Northfield Mountain and Turners Falls was provided by FirstLight. For this analysis, Northfield Mountain was defined as the composite of detections from Stations T24-T27 and Turners Falls was defined as the composite of detections from Stations T11, T12 (E/W), T13-T15, and T17-T23.

Determination of the degree of downstream progress for adult shad following passage at Vernon is potentially influenced by factors including: injury and mortality associated with dam passage, natural mortality (i.e., predation, post-spawn effects, and body condition), and incidental tag loss. Considering these factors, the downstream progress for adult shad following passage at Vernon is shown by passage route in Table 5.4-6. Of the 42 individuals known to have passed Vernon, 79% were detected at the Stebbins Island monitoring station (MS-1), 60% were detected at Northfield Mountain (NMPS), and 55% were detected at Turners Falls. Although comparisons among known passage routes are limited by sample size, individuals passing Vernon via Units 9-10 and via the fish pipe showed a higher degree of downstream progress as indicated by detection at Turners Falls, (100%, and 75%, respectively) than individuals passing via spill (60%), or Units 5-8 (33%).

Table 5.4-6. The number of adult shad detected by radio telemetry monitoring at Stebbins Island, Northfield Mountain, and Turners Falls following downstream passage at Vernon dam (by passage route), 2015.

Passage Route	No. Passing Vernon	Stebbins Island		Northfield Mountain		Turners Falls	
		No.	Percent Detected (%)	No.	Percent Detected (%)	No.	Percent Detected (%)
Fish Pipe	8	7	88	6	75	6	75
Spill	15	14	93	10	67	9	60
Units 5-8	3	1	33	1	33	1	33
Units 9-10	2	2	100	2	100	2	100
Unknown	14	9	64	6	43	5	36
Total	**42**	**33**	**79**	**25**	**60**	**23**	**55**

5.5 Spawning Surveys

5.5.1 Sampling Effort

Spawning surveys were conducted on 30 nights between May 26 and July 2, 2015. Sampling locations were selected based on the presence of radio-tagged shad throughout the study area from Bellows Falls dam to downstream of Vernon dam. A total of 120 ichthyoplankton net samples were collected including 32 in the Bellows Falls riverine reach, 54 in the Vernon impoundment, and 34 in the Vernon riverine reach (Table 5.5-1; Appendix C-1; and Appendix E [spawning geodata]). The spatial distribution of sample locations and substrate/habitat within the study is presented in Figures 5.5-1 through 5.5-7. For each sampling location, the date and time of visitation, water quality parameters, substrate type, average channel depth, and water velocity were collected. Water temperature ranged from 11.7°C in the first week of June to 21°C in the third week of June. All pH measurements were within the more stringent New Hampshire state standard, between 6.5 and 8.0

standard units (su) for Class B waters (Vermont's standard is 6.5 - 8.5 su). Turbidity ranged from less than 1 NTU to 37.9 NTU with 78% of all measurements less than 10 NTU and 16% of all measurements less than 20 NTU. Conductivity ranged from 10 to 170 µS/cm, with 51% of measurements less than 100 µS/cm, and 49% of measurement between 100 and 170 µS/cm. DO ranged from 5.8 to 13.8 mg/l with one measurement on May 26 at Site 21-002 (in the Vernon impoundment near Dummerston, VT) lower than Vermont's 6.0 mg/l standard, but within New Hampshire's 5.0 mg/l instantaneous standard.

Benthic habitat in each area sampled was generally homogeneous and consisted primarily of gravel/cobble sand, silt, clay, or occasionally, boulder. Figures 5.5-1 through 5.5-7 illustrate ichthyoplankton sampling locations, locations where egg and/or larvae were and were not collected, substrate type in impoundment locations, and mesohabitat type in riverine locations. In sample locations where substrate was not visible, benthic habitat was categorized based on aquatic habitat mapping conducted for ILP Study 7 (Normandeau, 2015). Shad eggs or larvae were collected in all substrate types sampled with the exception of woody debris (only two samples were taken over woody debris). Tracking of radio-tagged shad and the subsequent ichthyoplankton sampling to identify spawning activity occurred most frequently over gravel-cobble substrates.

Additionally, visual and audible observations related to spawning (e.g., splash counts) were also recorded. Much of the time few to no splashes were noted. When splashes were documented the average count was low at 2-3 splashes per one minute of observation. Observations related to splash count are summarized in Appendix C-1. A full listing of sample location characteristics is provided in Appendices C-1, C-2, and D.

Table 5.5-1. Number of shad spawning ichthyoplankton samples collected by date and river reach, 2015.

Sampling Date	River Reach					
	Bellows Falls Riverine		Vernon Impoundment		Vernon Riverine	
	No. of Locations	No. of Samples	No. of Locations	No. of Samples	No. of Locations	No. of Samples
5/26/2015			1	2		
5/27/2015			2	4		
5/28/2015			2	4		
5/29/2015	2	4				
5/31/2015					2	4
6/1/2015					1	2
6/2/2015			2	4		
6/3/2015					2	4
6/4/2015	1	2	1	2		
6/5/2015					2	4
6/9/2015			3	6		
6/10/2015			2	4		
6/11/2015					2	4
6/13/2015	3	6				
6/14/2015	2	4				
6/15/2015					2	4
6/16/2015			2	4		
6/17/2015	1	2	1	2		
6/19/2015					2	4
6/20/2015	1	2	1	2		
6/22/2015			2	4		
6/23/2015			2	4		
6/24/2015			2	4		
6/25/2015	1	2	1	2		
6/26/2015	1	2	1	2		
6/27/2015					2	4
6/29/2015	1	2	1	2		
6/30/2015	2	4				
7/1/2015					2	4
7/2/2015	1	2	1	2		
All Dates	**16**	**32**	**27**	**54**	**17**	**34**

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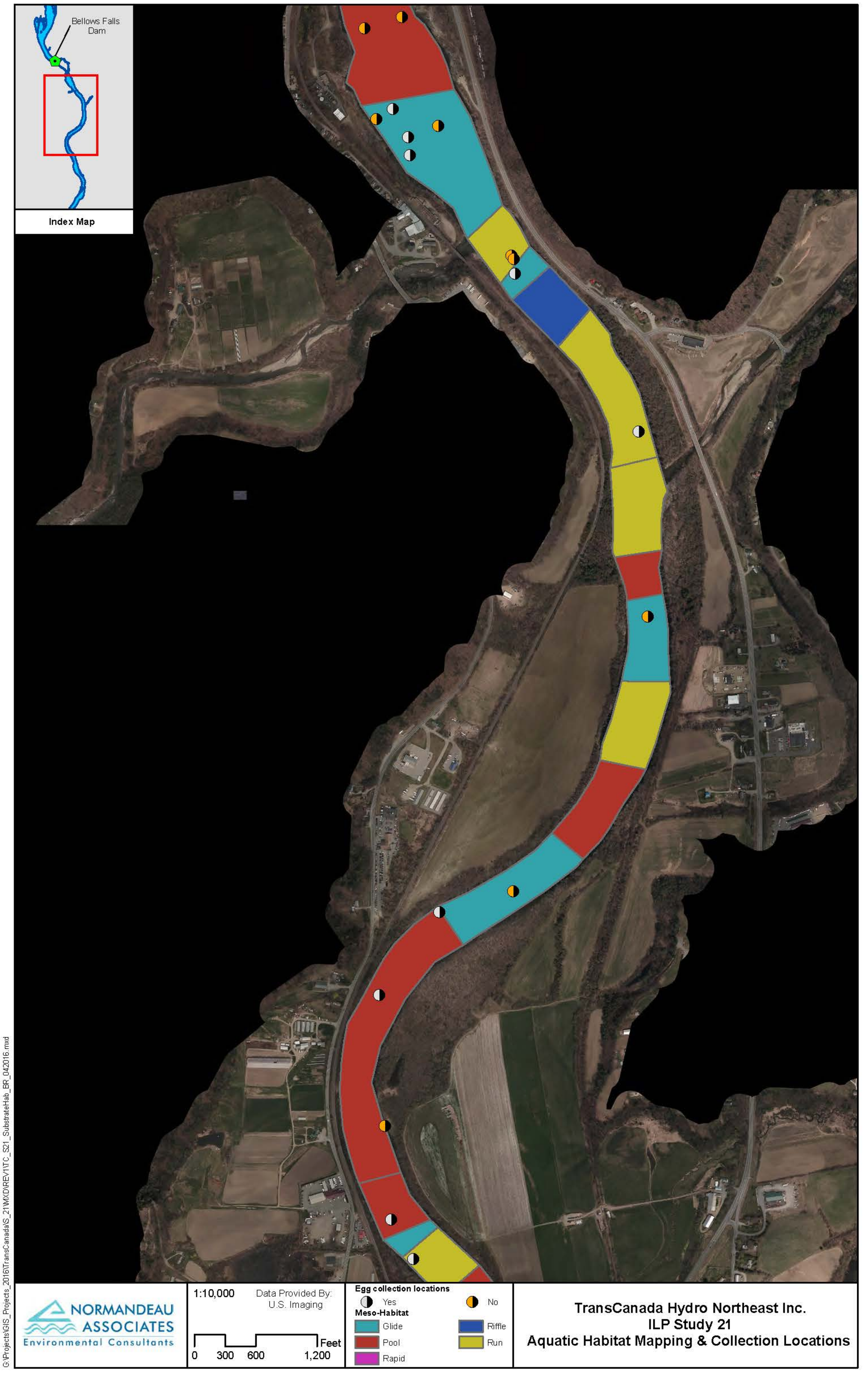

Figure 5.5-1. American Shad ichthyoplankton sampling locations, upper Bellows Falls riverine reach.

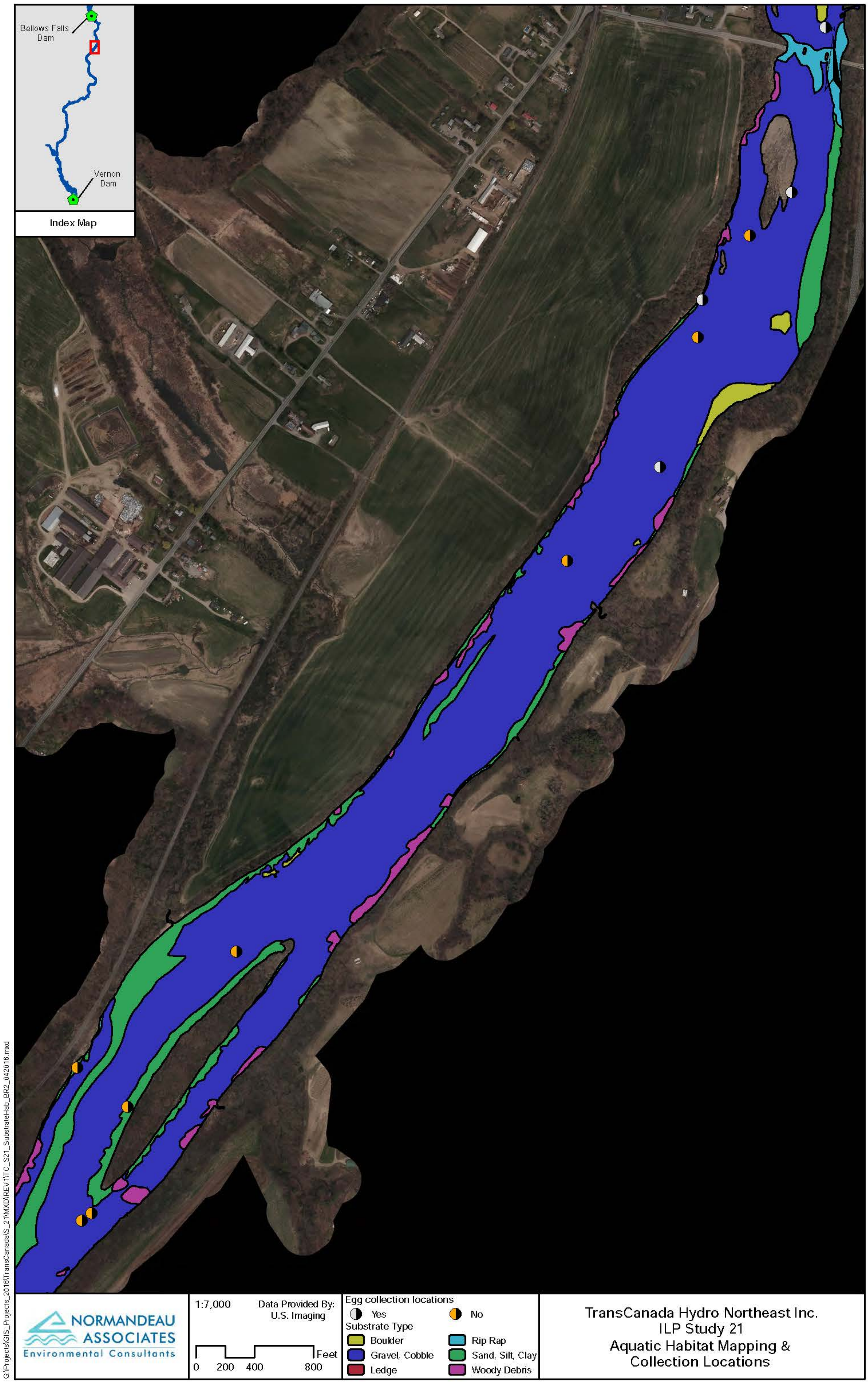

Figure 5.5-2. American Shad ichthyoplankton sampling locations, lower Bellows Falls riverine reach.

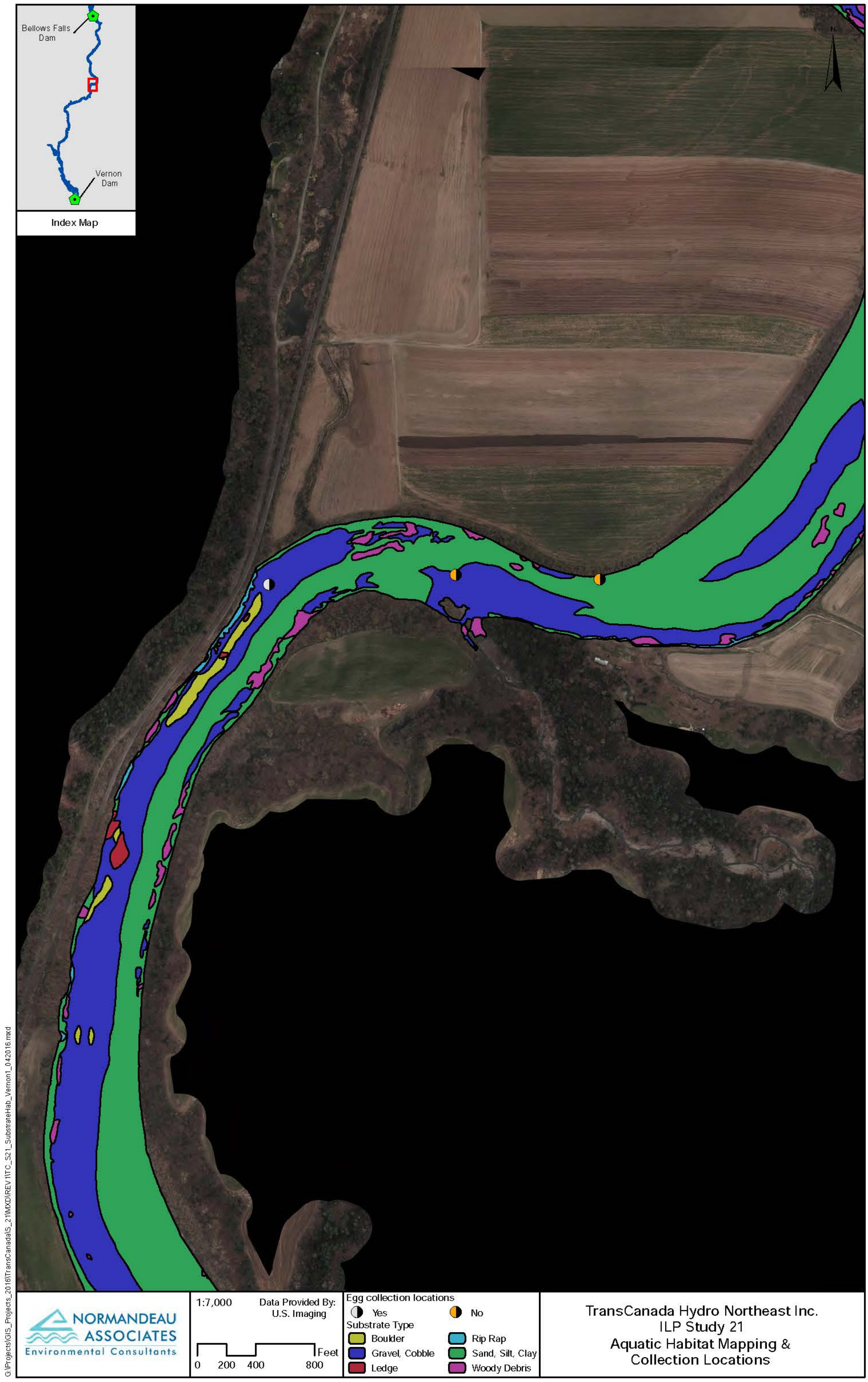

Figure 5.5-3. American Shad ichthyoplankton sampling locations, upper Vernon impoundment.

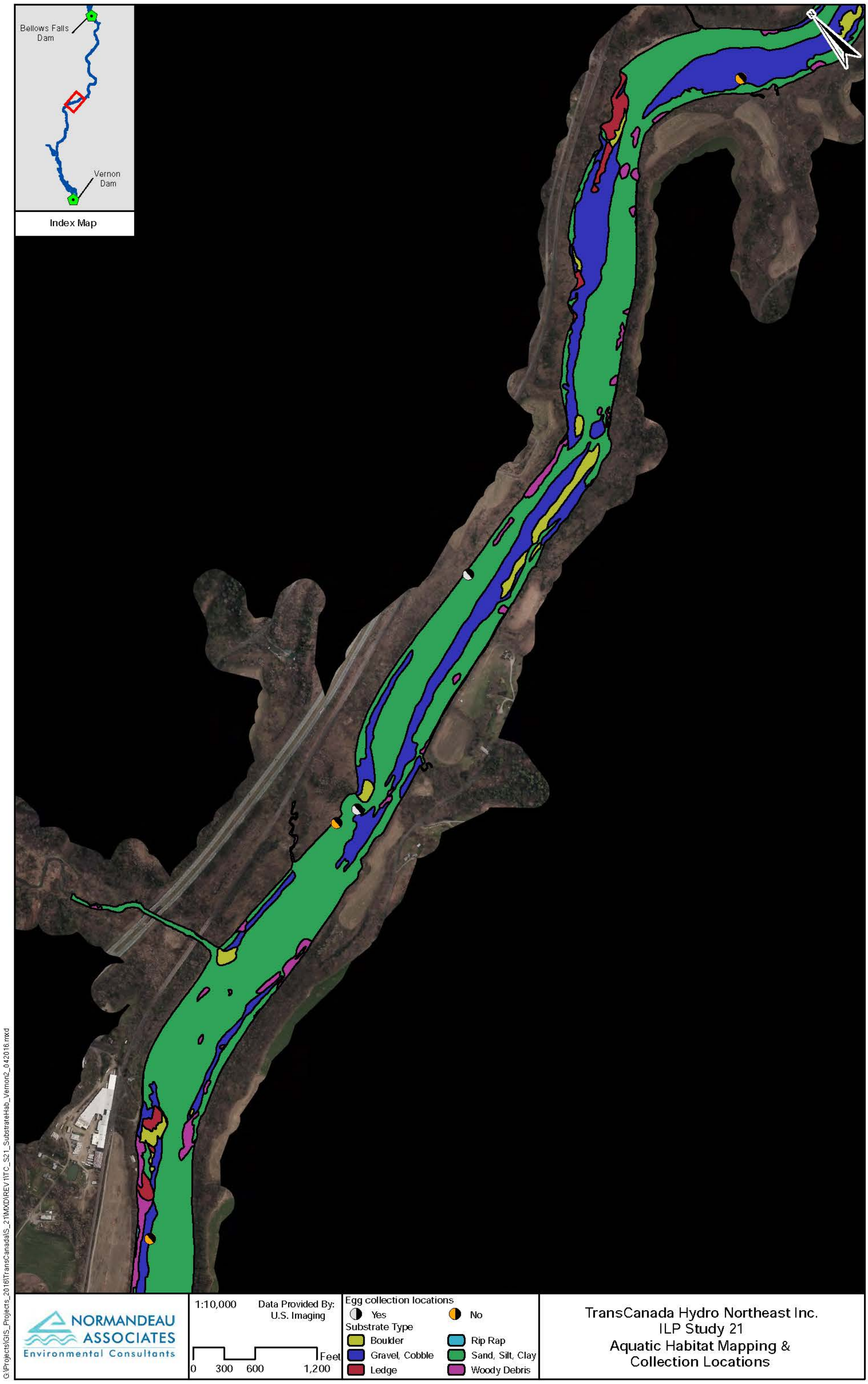

Figure 5.5-4. American Shad ichthyoplankton sampling locations, upper-middle Vernon impoundment.

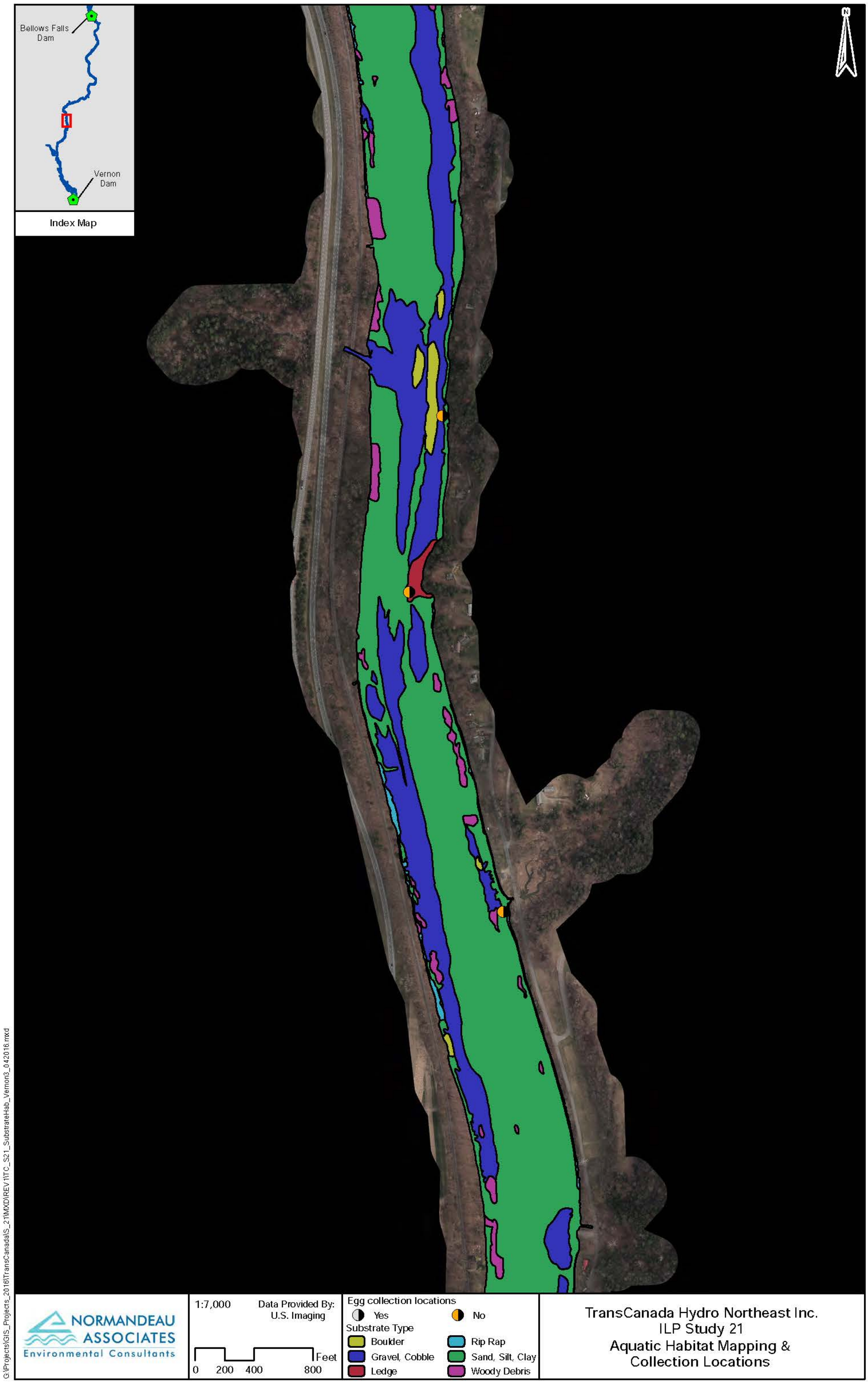

Figure 5.5-5. American Shad ichthyoplankton sampling locations, lower-middle Vernon impoundment.

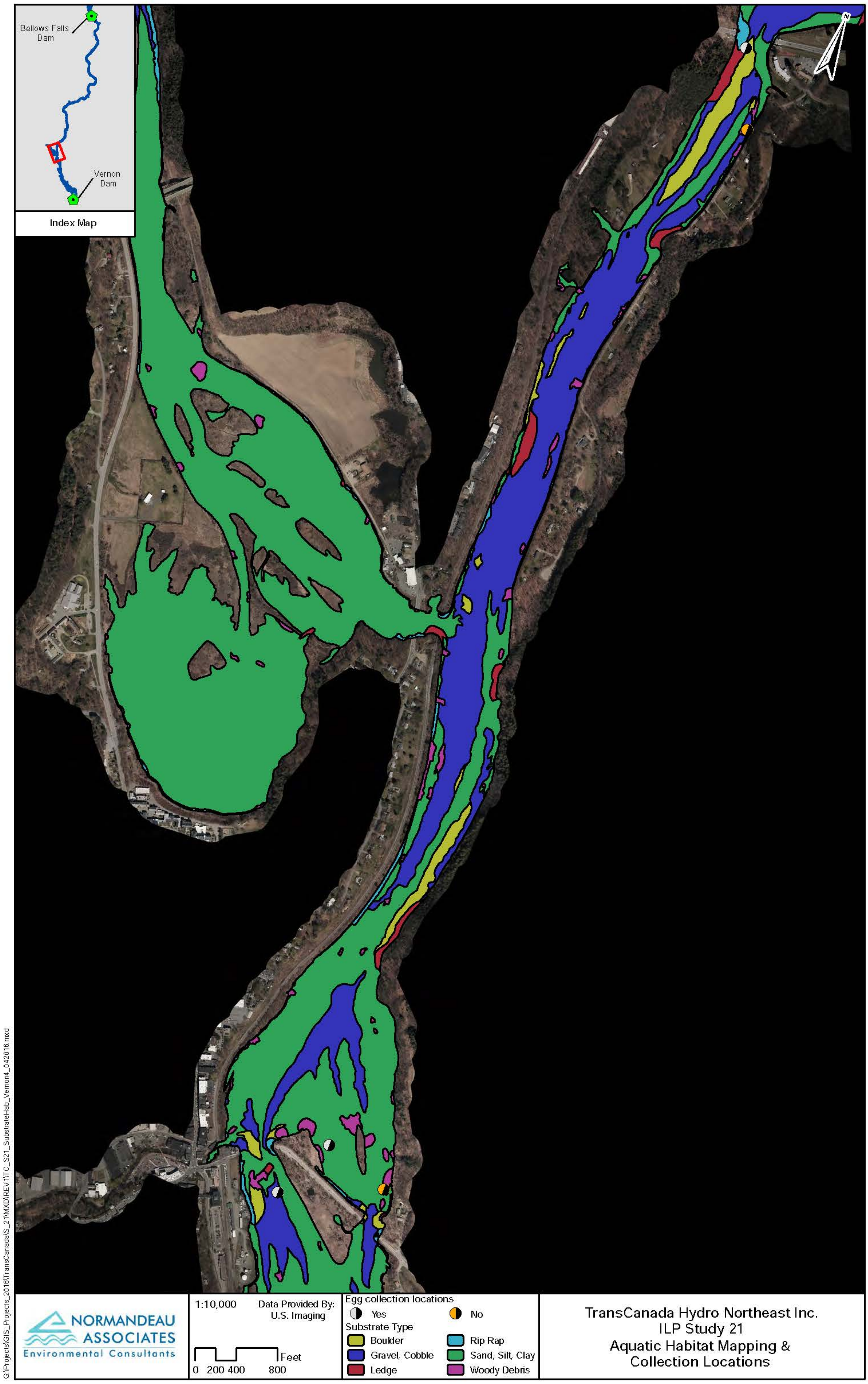

Figure 5.5-6. American Shad ichthyoplankton sampling locations, lower Vernon impoundment.

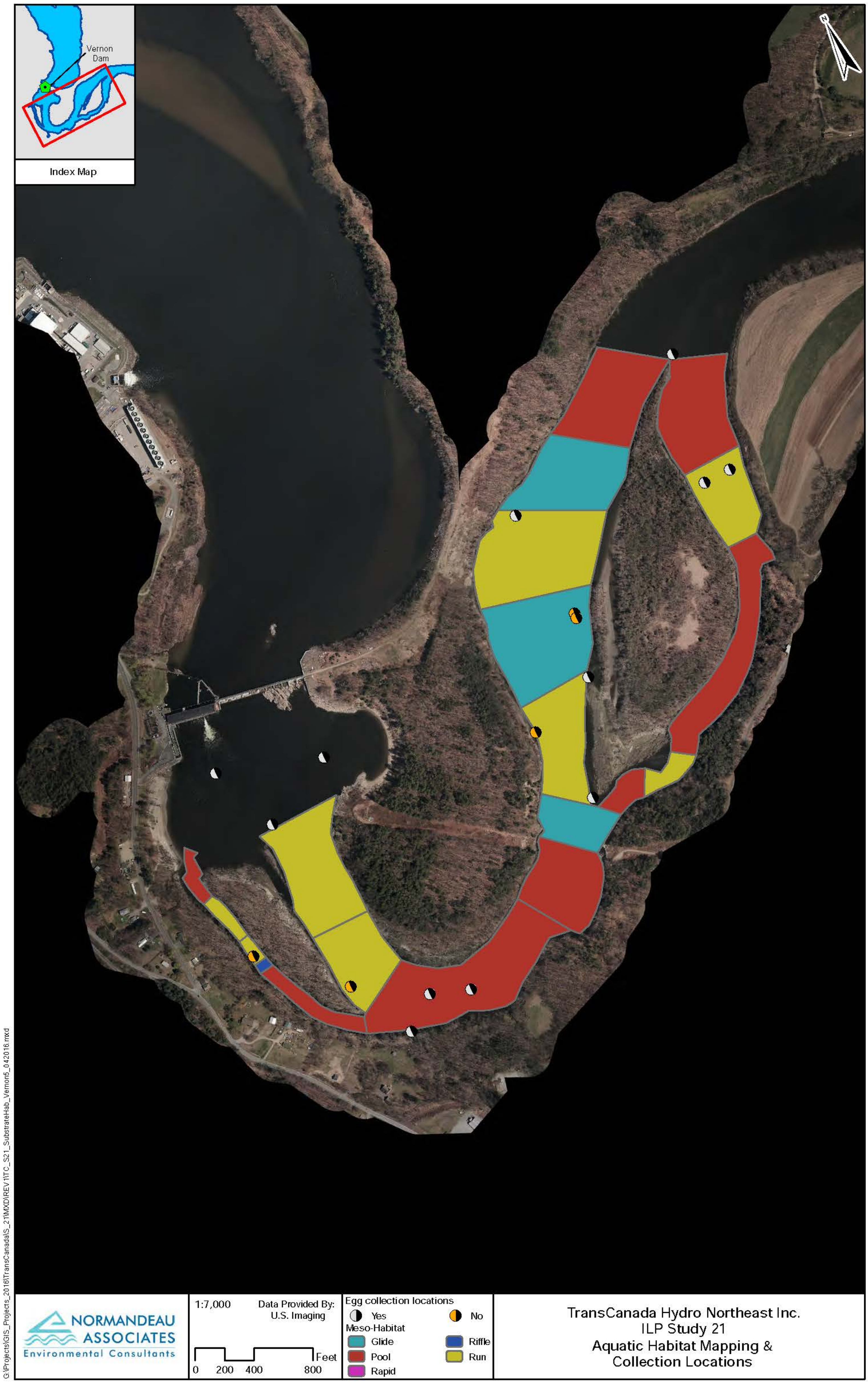

Figure 5.5-7. American Shad ichthyoplankton sampling locations, Vernon riverine reach.

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5.5.1.1 Quantification of Shad Ichthyoplankton Catch

Approximately 38% (46 of 120) of the ichthyoplankton samples contained American Shad eggs or larvae. Overall, 794 eggs and larvae were collected at 31 of the 60 sampling locations (Table 5.5-2). The majority of eggs and larvae were contained in samples collected in the Vernon riverine reach (46.3%) and the Bellows Falls riverine reach (48.6%) with far fewer eggs or larvae collected in the Vernon impoundment (5.1%).

As described in Section 4.4.3.2, collected eggs were examined and a developmental stage was assigned. The majority of eggs collected (608 of 776; 78%) were determined to be stage 1 (blastodisk stage), which occurs within 0.5 hours of spawn (Table 5.5-3). Eggs classified as stages 2 through 9 were also collected but in lower abundance. American Shad yolk-sac and post yolk-sac larvae were observed in low numbers, with each lifestage representing 1% of the total catch. Figure 5.5-8 presents example images of shad egg developmental stage classifications obtained during sample processing.

Table 5.5-2. Number of sampling locations and total catch of American Shad eggs and larvae by river reach, 2015.

River Reach	Sampling Locations		No. of Eggs	No. of Larvae
	Number	Percent with Catch (%)		
Bellows Falls riverine	16	62.5	267	2
Vernon impoundment	27	37.0	151	6
Vernon riverine	17	70.6	358	10

Table 5.5-3. American Shad egg and larval counts by sample, river reach and collection date, 2015.

Date	Geo-reference ID[a]	Reach[b]	Egg and Larval Stage Category[c]											Total
			Stg 1	Stg 2	Stg 3	Stg 4	Stg 5	Stg 6	Stg 7	Stg 8	Stg 9	YSL	PYSL	
5/29/2015	21-013	BFR	2									2		4
5/31/2015	21-017	VR	30		3			6				1		40
5/31/2015	21-018	VR	17						3					20
6/1/2015	21-019	VR	43					1		12	9	1	1	67
6/1/2015	21-020	VR	29					2		5	3	3	3	45
6/3/2015	21-025	VR	2							1				3
6/3/2015	21-026	VR	1											1
6/3/2015	21-027	VR	1											1
6/5/2015	21-033	VR	20											20
6/5/2015	21-034	VR	3											3
6/5/2015	21-035	VR	18							1				19
6/5/2015	21-036	VR	25											25
6/9/2015	21-043	VI	2											2
6/10/2015	21-045	VI								2				2
6/10/2015	21-046	VI	1											1
6/10/2015	21-047	VI						1		1	1			3
6/11/2015	21-049	VR	1											1
6/11/2015	21-051	VR	25											25
6/11/2015	21-052	VR	20									1		21
6/13/2015	21-054	BFR	109											109
6/14/2015	21-059	BFR	2						1	1				4
6/15/2015	21-062	VR	1											1
6/15/2015	21-063	VR	13							2				15
6/15/2015	21-064	VR	17					2						19
6/17/2015	21-070	BFR	1											1
6/17/2015	21-071	BFR	2											2
6/17/2015	21-072	BFR	4											4

Date	Geo-reference ID[a]	Reach[b]	Egg and Larval Stage Category[c]											Total
			Stg 1	Stg 2	Stg 3	Stg 4	Stg 5	Stg 6	Stg 7	Stg 8	Stg 9	YSL	PYSL	
6/19/2015	21-074	VR								1				1
6/19/2015	21-075	VR	37							1	1			39
6/19/2015	21-076	VR	2											2
6/20/2015	21-078	BFR								1				1
6/20/2015	21-080	BFR								1				1
6/22/2015	21-084	VI								3				3
6/23/2015	21-086	VI											2	2
6/23/2015	21-087	VI											2	2
6/23/2015	21-088	VI										1		1
6/24/2015	21-090	BFR											1	1
6/26/2015	21-097	BFR	99	1	13	5		1						119
6/26/2015	21-098	BFR	52		37	26		2						117
6/26/2015	21-099	BFR	1					1						2
6/26/2015	21-100	BFR	1				13							14
6/30/2015	21-110	BFR	1											1
6/30/2015	21-111	BFR	8		2	1								11
6/30/2015	21-112	BFR	10											10
7/2/2015	21-117	BFR		1										1
7/2/2015	21-118	BFR	8											8
All Samples			608	2	55	32	13	16	4	32	14	9	9	794

a. Sample locations are geo-referenced in Appendix C-1, C-2.
b. BFR=Bellows Falls riverine reach, VI = Vernon impoundment, VR=Vernon riverine reach.
c. Stage categories:
Stg 1 = Blastodisk
Stg 2 = 2 cell stage
Stg 3 = 4 cell stage
Stg 4 = 8 cell stage
Stg 5 = 16 cell stage
Stg 6 = Morula
Stg 7 = Blastopore
Stg 8 = Early embryo
Stg 9 = Detached tail embryo
YSL = Yolk sac larvae
PYSL = Post yolk sac larvae

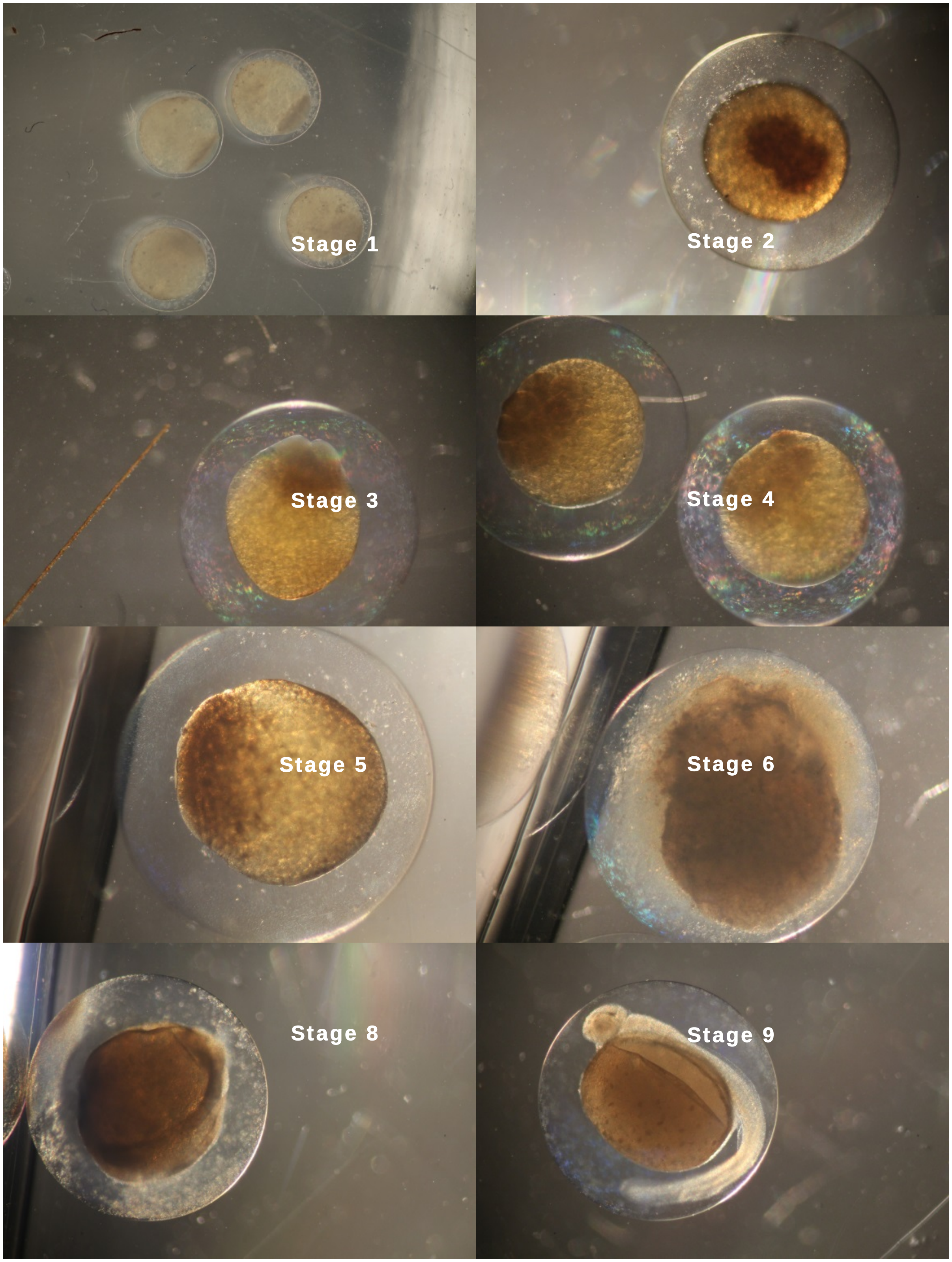

Figure 5.5-8. Example images of American Shad egg stage classifications from trawl collections, 2015.

Distribution of the American Shad ichthyoplankton catch by developmental stage for the three sample reaches (Bellows Falls riverine, Vernon impoundment, and Vernon riverine) showed a greater proportion of stage 1 eggs in the two riverine reaches and a more dispersed distribution of developmental life stage in the impoundment (Figure 5.5-9).

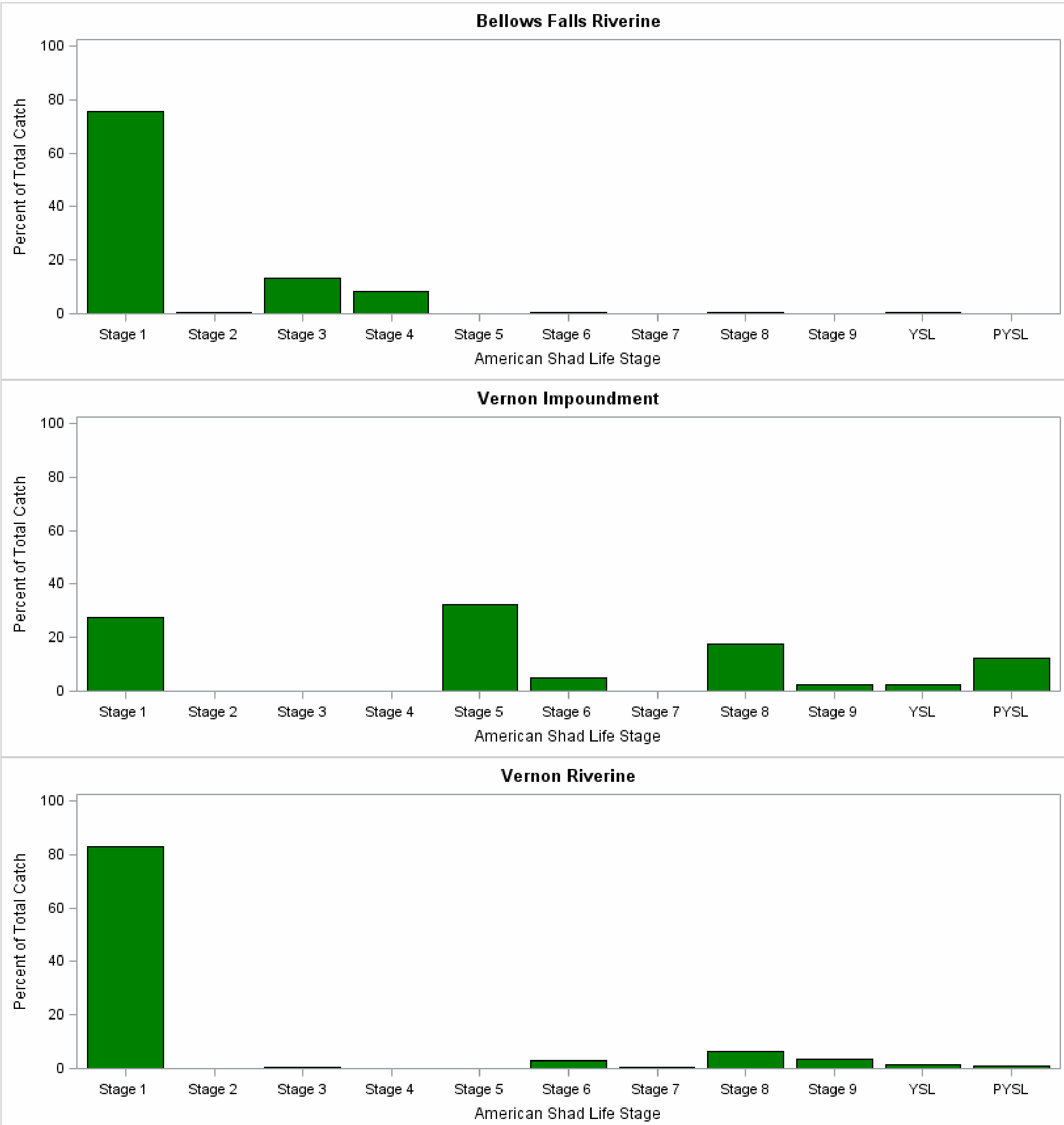

Figure 5.5-9. Life stage contribution to total American Shad ichthyoplankton catch within the Bellows Falls riverine, Vernon impoundment, and Vernon riverine reaches, 2015.

5.5.1.2 Project Operations During the Spawning Season

Project operations during the spawning study period ranged from approximately minimum flow to sustained periods of high flow. Sample days and catch results relative to project operation (average hourly discharge) and water temperature (data from ILP Study 6 [Louis Berger and Normandeau, 2016)]) are shown in Figure 5.5-10 for sample locations downstream of Bellows Falls dam, and Figure 5.5-11 for sample locations downstream of Vernon dam. Details for each sample date and location are presented in Table 5.5-4.

As the figures and table illustrate, sampling occurred over a range of station operating conditions and spill conditions (Appendix C-2). Sustained periods of minimum or low flows are uncommon in the spring. Monthly flow exceedance curves (years 1979 – 2015) indicate that minimum flows at both projects occurred less than 1% of the time during May and June. Flows up to mid-range generating flows at Bellows Falls (approximately 5,000 cfs) occurred only 5% of the time in May and 25% in June. Flows up to mid-range generating flows at Vernon (8,000 cfs) occurred about 16% of the time in May and 46% in June.

No ichthyoplankton were caught downstream of Bellows Falls dam during early June when flows were high and temperatures cool (<15°C). In general, American Shad will enter rivers at temperatures between 13-16°C and spawning activity can slow or cease if water temperatures dip below that range (Munroe, 2002). However, eggs and larvae were collected later in June during a sustained period of high flow and warm temperatures. Downstream of Vernon, ichthyoplankton were collected in early June when flows were high and water temperatures less than 15°C; no ichthyoplankton were collected after June 19. However, no sampling was conducted in that reach between June 20 and June 26 due to sustained high flows throughout that period that prevented safe sampling.

Eggs and larvae were collected throughout the study area and throughout the study period. Collections were more concentrated in the Bellows Falls and Vernon riverine reaches where telemetered shad were mainly concentrated during sampling events. Overall, 20 of the 30 sample dates had collections in locations proximate to samples with no collections during the same time periods (and hence during the same operational periods).

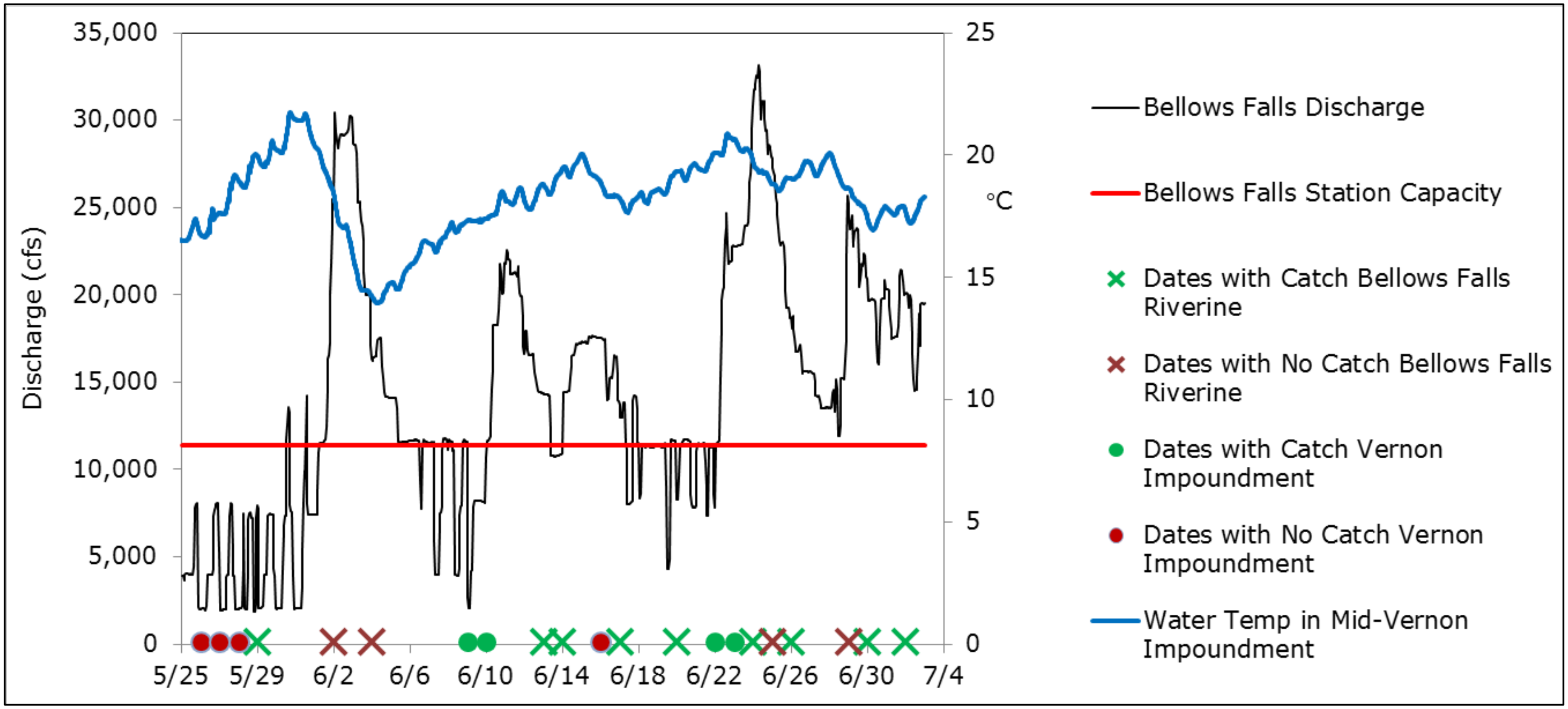

Figure 5.5-10. Bellows Falls discharge, water temperature, and ichthyoplankton catch results downstream of Bellows Falls dam, 2015.

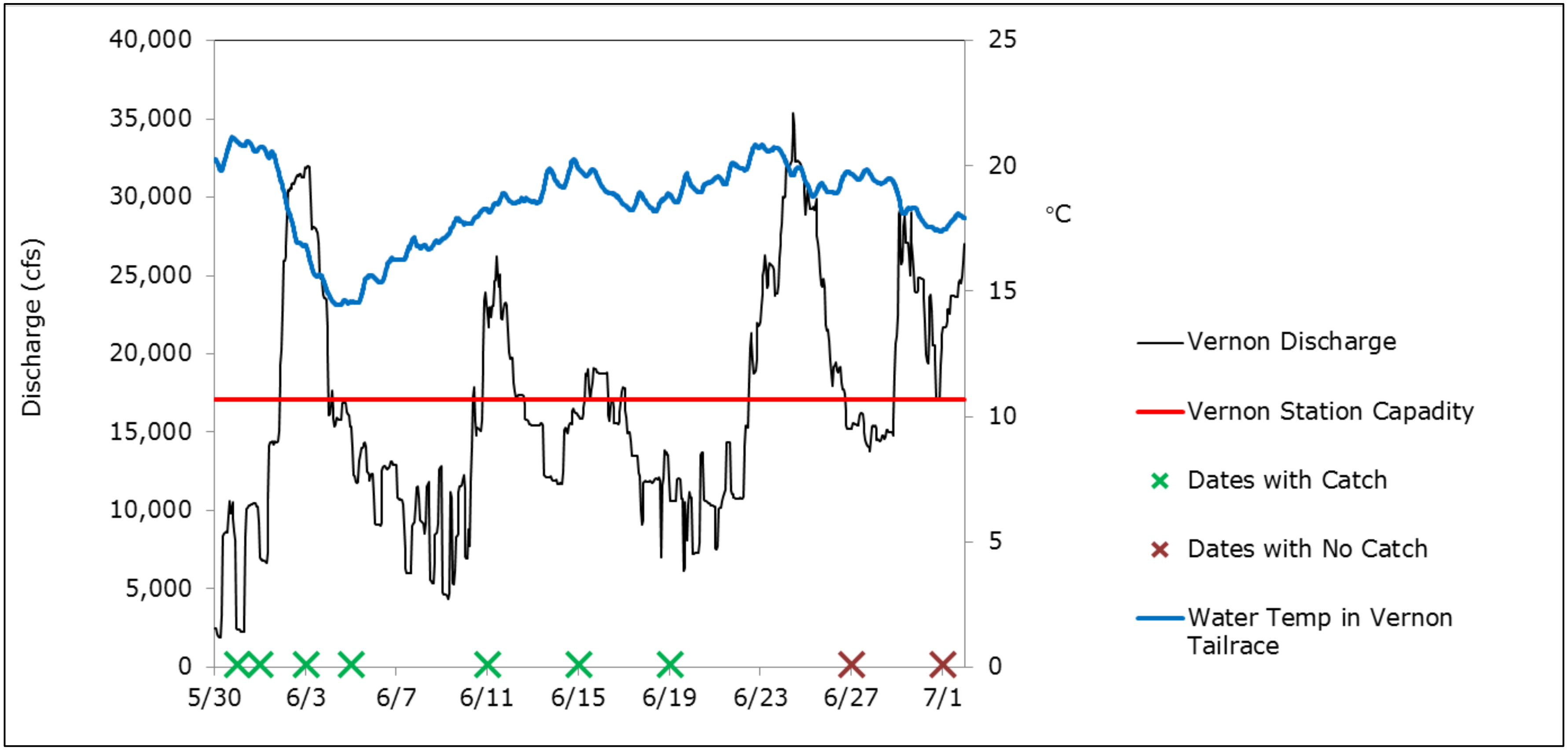

Figure 5.5-11. Vernon discharge, water temperature, and ichthyoplankton catch results downstream of Vernon dam, 2015.

Table 5.5-4. Project discharge at time of ichthyoplankton sampling, 2015.

Trawl Date	Trawl Ending Time	Ichthyoplankton Collected	Project Discharge (cfs) [a, b]	Reach[c]
5/26/2015	**23:17**	**N**	**5335**	**VI**
5/27/2015	**21:15**	**N**	**5182**	**VI**
5/27/2015	**22:02**	**N**	**5182**	**VI**
5/28/2015	**21:35**	**N**	**2071**	**VI**
5/28/2015	**21:45**	**N**	**2071**	**VI**
5/29/2015	**21:00**	**N**	**4082**	**BFR**
5/29/2015	**21:58**	**Y**	**4082**	**BFR**
5/31/2015	**21:02**	**N**	**10235**	**VR**
5/31/2015	**23:00**	**Y**	**9747**	**VR**
6/1/2015	21:26	Y	18807	VR
6/2/2015	21:50	N	31244	VI
6/2/2015	23:29	N	31631	VI
6/3/2015	21:38	Y	23482	VR
6/3/2015	23:07	Y	22522	VR
6/4/2015	20:00	N	14143	BFR
6/4/2015	**21:22**	**N**	**14128**	**VI**
6/5/2015	**21:02**	**Y**	**12041**	**VR**
6/5/2015	**22:19**	**Y**	**12324**	**VR**
6/9/2015	**20:56**	**N**	**8138**	**VI**
6/9/2015	**22:29**	**N**	**8106**	**VI**
6/9/2015	**23:58**	**Y**	**11784**	**VI**
6/10/2015	21:52	Y	23672	VI
6/10/2015	22:54	Y	23537	VI
6/11/2015	21:12	Y	22164	VR
6/11/2015	22:40	Y	20779	VR
6/13/2015	**21:52**	**N**	**10838**	**BFR**
6/13/2015	**22:42**	**N**	**10871**	**BFR**
6/13/2015	**23:38**	**N**	**10912**	**BFR**
6/14/2015	21:34	Y	17232	BFR
6/14/2015	22:19	N	17250	BFR
6/15/2015	21:28	N	18791	VR
6/15/2015	22:09	Y	18791	VR
6/16/2015	21:31	N	17271	VI
6/16/2015	22:48	N	17714	VI
6/17/2015	21:18	N	13799	BFR
6/17/2015	**22:36**	**Y**	**12479**	**VI**
6/19/2015	**21:17**	**N**	**10989**	**VR**
6/19/2015	**22:02**	**Y**	**10989**	**VR**

Trawl Date	Trawl Ending Time	Ichthyoplankton Collected	Project Discharge (cfs) [a, b]	Reach[c]
6/20/2015	**20:31**	**N**	**7860**	**BFR**
6/20/2015	**21:35**	**N**	**7860**	**VI**
6/22/2015	21:27	N	21873	VI
6/22/2015	22:48	N	21798	VI
6/23/2015	22:10	N	26579	VI
6/23/2015	23:28	Y	29184	VI
6/24/2015	21:47	N	28381	VI
6/24/2015	23:20	N	27858	VI
6/25/2015	20:06	N	19239	BFR
6/25/2015	21:34	N	19087	VI
6/26/2015	22:15	Y	15600	BFR
6/26/2015	**23:55**	**Y**	**15605**	**VI**
6/27/2015	**20:00**	**N**	**13901**	**VR**
6/27/2015	**21:20**	**N**	**14932**	**VR**
6/29/2015	20:45	N	22293	BFR
6/29/2015	22:16	N	21105	VI
6/30/2015	21:30	N	20328	BFR
6/30/2015	23:03	Y	20328	BFR
7/1/2015	21:52	N	25395	VR
7/1/2015	23:05	N	25395	VR
7/2/2015	21:35	Y	19495	BFR
7/2/2015	23:13	N	19489	VI

a. 2-hour average project discharge encompassing the hour ending at or after sample effort.
b. Bolded entries indicate discharge was within station generating capacity.
c. BFR= Bellows Falls riverine reach, VI = Vernon impoundment, VR = Vernon riverine reach.

5.5.2 Identification and Characterization of Spawning Areas

American Shad typically spawn in river reaches dominated by broad flats with relatively shallow water (3-19 ft) and moderate currents (1.0-3.2 ft/s) (Munroe, 2002). Fertilized eggs are semi-buoyant and non-adhesive. Following fertilization, shad eggs sink towards the river bottom where an increase in diameter due to water-hardening may cause them to lodge into the bottom substrate. Given current velocities of 0.5 to 2.0 ft/s (0.15 to 0.6 m/s), most shad eggs travel between one and four miles (1.6 and 6.4 km) downstream of their spawning location prior to hatch (Marcy, 1976). Based on the tendency of eggs to drift downstream following fertilization, spawning areas were back-calculated based on the known collection location and river velocity at the time of collection for stage 1 eggs. As described in Section 4.5.3, back-calculated spawning locations were determined for only stage 1 eggs since river flow conditions at the time of collection were more likely to be similar to those at the time of spawn given the short duration of that egg stage (approximately 30 minutes) than would be the case for older stages, and because they were by far the most numerous stage collected. Based upon the back-calculated locations, six general spawning areas were defined (see Figures 5.5-12 to 5.5-17 below):

- Bellows Falls tailrace to downstream of the Saxtons River confluence
- Bellows Falls riverine reach, Cold River confluence to upstream of Mad Brook
- Bellows Falls riverine reach/upper Vernon impoundment, vicinity of Mad Brook confluence
- Vernon impoundment, vicinity of Mill Brook confluence
- Vernon impoundment, upstream of the Rt 119 Bridge in Brattleboro/ Hinsdale
- Vernon tailrace to Stebbins Island

The number of sample dates within each of the general spawning areas and catch results for all ichthyoplankton stages and those identified to stage 1 are presented in Table 5.5-5. At each of the six locations, the majority of dates sampled yielded stage 1 catch. The temporal distribution of sample collections and resulting catch (total and stage 1 only) are presented for each of the six general spawning areas in Table 5.5-6.

When all life stages are considered, total catch of American Shad ichthyoplankton was highest in the general spawning area from the Bellows Falls tailrace downstream to the Saxtons River confluence and from the Vernon tailrace to Stebbins Island (Table 5.5-7). Table 5.5-8 presents the average sample catch by life stage and general spawning area standardized to the number of individuals per hour of net sampling (i.e., catch per unit of effort or CPUE). Although the average CPUE rate for Stage 1 shad eggs appears highest for the Bellows Falls tailrace downstream to the Saxtons River confluence, followed by the Vernon tailrace to Stebbins Island spawning areas, comparison of the log-transformed ($\log_{10}(X+1)$ data for those two spawning areas did not indicate a statistically significant difference ($F = 2.22$; $p = 0.0600$).

Table 5.5-5. Number of dates American Shad ichthyoplankton were sampled, by catch result, within the six identified general spawning areas during 2015.

Catch Results	Number of Collection Dates					
	Bellows Falls Riverine		BF Riverine / Vernon Imp	Vernon Impoundment		Vernon Riverine
	Tailrace - DS of Saxtons River	Cold River - US of Mad Brook	Mad Brook Area	Mill Brook Area	Rt 119 Bridge	Tailrace to Stebbins Island
Ichthyo Absent	3	1	3	1	0	2
Ichthyo Present	5	4	4	1	2	7
Total	8	5	7	2	2	9
Stage 1 eggs present in Catch	4	4	2	1	1	7

Table 5.5-6. Temporal distribution of sampling events and catch of American Shad ichthyoplankton from the six identified general spawning areas during 2015 (Y=yes, N=no).

Date	Bellows Falls Riverine						Vernon Impoundment				Vernon Riverine	
	Tailrace - DS of Saxtons River		Cold River - US of Mad Brook		Mad Brook Area		Mill Brook Area		Rt 119 Bridge		Tailrace to Stebbins Island	
	Catch Present		Catch Present		Catch Present		Catch Present		Catch Present		Catch Present	
	Ichthyo	Stage 1	Ichthyo	Stage 1	Ichthyo	Stage 1	Ichthyo	Stage 1	Ichthyo	Stage 1	Ichthyo	Stage 1
5/26/2015												
5/27/2015							N	N				
5/28/2015												
5/29/2015	N	N	Y	Y								
5/30/2015												
5/31/2015 [a]											Y	Y
6/1/2015											Y	Y
6/2/2015												
6/3/2015											Y	Y
6/4/2015	N	N										
6/5/2015											Y	Y
6/6/2015												
6/7/2015												
6/8/2015												
6/9/2015					N	N	Y	Y				
6/10/2015									Y	Y		
6/11/2015											Y	Y
6/12/2015												
6/13/2015	Y	Y										
6/14/2015			Y	Y								
6/15/2015 [a]											Y	Y
6/16/2015												
6/17/2015			Y	Y	Y	Y						
6/18/2015												
6/19/2015 [a]											Y	Y
6/20/2015	Y	N			Y	N						
6/21/2015												
6/22/2015									Y	N		

Date	Bellows Falls Riverine						Vernon Impoundment				Vernon Riverine	
	Tailrace - DS of Saxtons River		Cold River - US of Mad Brook		Mad Brook Area		Mill Brook Area		Rt 119 Bridge		Tailrace to Stebbins Island	
	Catch Present		Catch Present		Catch Present		Catch Present		Catch Present		Catch Present	
	Ichthyo	Stage 1	Ichthyo	Stage 1	Ichthyo	Stage 1	Ichthyo	Stage 1	Ichthyo	Stage 1	Ichthyo	Stage 1
6/23/2015												
6/24/2015					Y	N						
6/25/2015			N	N	N	N						
6/26/2015	Y	Y			Y	Y						
6/27/2015											N	N
6/28/2015												
6/29/2015	N	N										
6/30/2015	Y	Y	Y	Y								
7/1/2015											N	N
7/2/2015	Y	Y			N	N						

a. Back-calculation of spawning location for these samples indicated spawn occurred just upstream of Vernon dam. Catch by stage for these three samples is included in the Vernon riverine reach subtotal in Tables 5.5-10 and 5.5-11 but these samples were not included in the analysis as it is unlikely that spawning occurred just upstream of Vernon dam.

Table 5.5-7. Total catch of American Shad ichthyoplankton (by stage) within the six identified general spawning areas identified during 2015.

Developmental Stage	Number of Individuals					
	Bellows Falls Riverine			Vernon Impoundment		Vernon Riverine
	Tailrace - DS of Saxtons River	Cold River - US of Mad Brook	Mad Brook Area	Mill Brook Area	Rt 119 Bridge	Tailrace to Stebbins Island
Stage 1	269	23	8	2	1	305
Stage 2	2	0	0	0	0	0
Stage 3	50	2	0	0	0	3
Stage 4	31	1	0	0	0	0
Stage 5	0	0	13	0	0	0
Stage 6	3	0	1	0	0	11
Stage 7	0	1	0	0	0	3
Stage 8	1	1	1	0	5	23
Stage 9	0	0	0	0	0	13
YSL	0	2	0	0	0	6
PYSL	0	0	1	0	0	4
Total	**356**	**30**	**24**	**2**	**6**	**368**

Table 5.5-8. Catch per unit of effort (number/hour) for American Shad ichthyoplankton (by stage) within the six identified general spawning areas during 2015.

Life Stage	Catch per Unit Effort (#/hr)					
	Bellows Falls Riverine			Vernon Impoundment		Vernon Riverine
	Tailrace - DS of Saxtons River	Cold River - US of Mad Brook	Mad Brook Area	Mill Brook Area	Rt 119 BR	Tailrace to Stebbins Island
Stage 1	19.04	2.18	0.69	0.63	0.29	11.51
Stage 2	0.10	0	0	0	0	0
Stage 3	2.60	0.17	0	0	0	0.08
Stage 4	1.62	0.08	0	0	0	0
Stage 5	0	0	0.93	0	0	0
Stage 6	0.16	0	0.08	0	0	0.34
Stage 7	0	0.13	0	0	0	0.08
Stage 8	0.09	0.13	0.07	0	1.00	0.79
Stage 9	0	0	0	0	0	0.41
YSL	0	0.33	0	0	0	0.20
PYSL	0	0	0.07	0	0	0.12
Total	**23.59**	**2.68**	**1.84**	**0.63**	**1.29**	**13.32**

5.5.2.1 Project Operations Assessment

Among the objectives for Study 21 was the assessment of effects of project operations on identified spawning areas. A plan view of each general spawning area was prepared (Figures 5.5-12 to 5.5-17) and includes the location of back-calculated shad egg spawn locations as well as the estimated upper and lower bounds of the area (as defined by cross sections from the hydraulic model from ILP Study 4 (GEI, 2016), numbered white lines in the figures). This analysis is necessarily limited since exact spawning locations were not able to be identified.

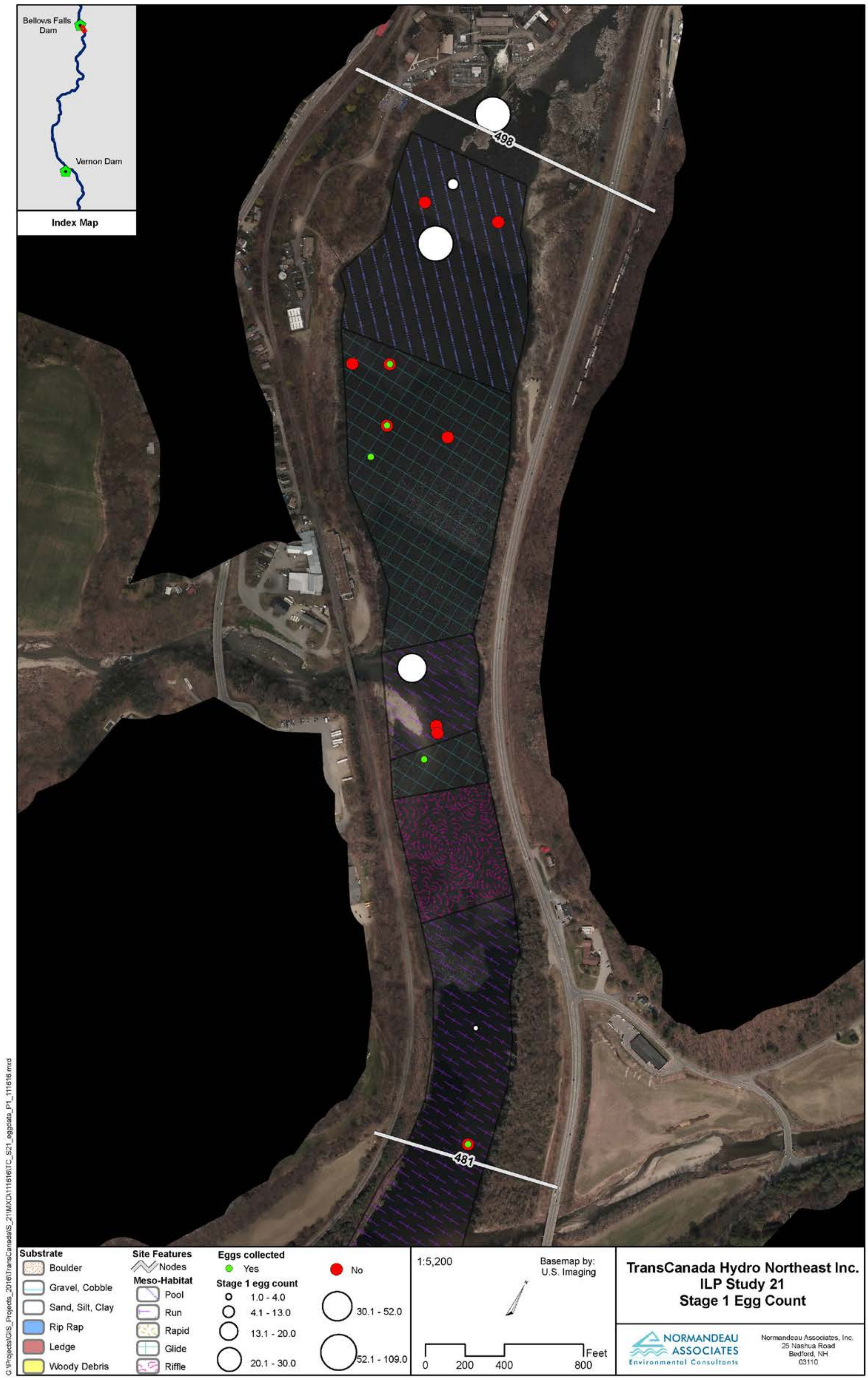

Figure 5.5-12. American Shad egg collections, calculated spawning locations, and substrate/habitat in the Bellows Falls tailrace to downstream of the Saxtons River confluence, 2015.

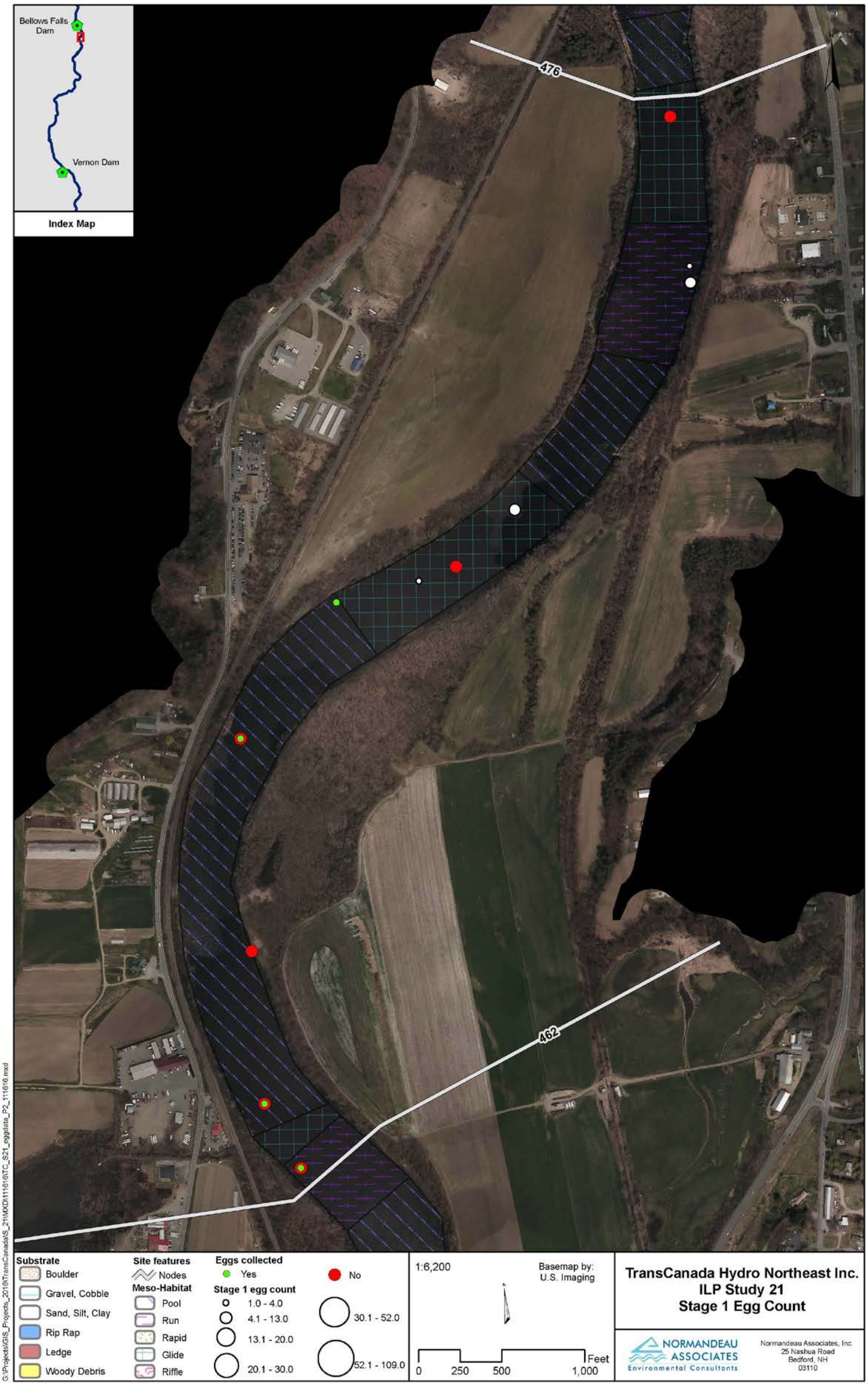

Figure 5.5-13. American Shad egg collections, calculated spawning locations, and substrate/habitat in the Bellows Falls riverine reach from the Cold River confluence to upstream of Mad Brook, 2015.

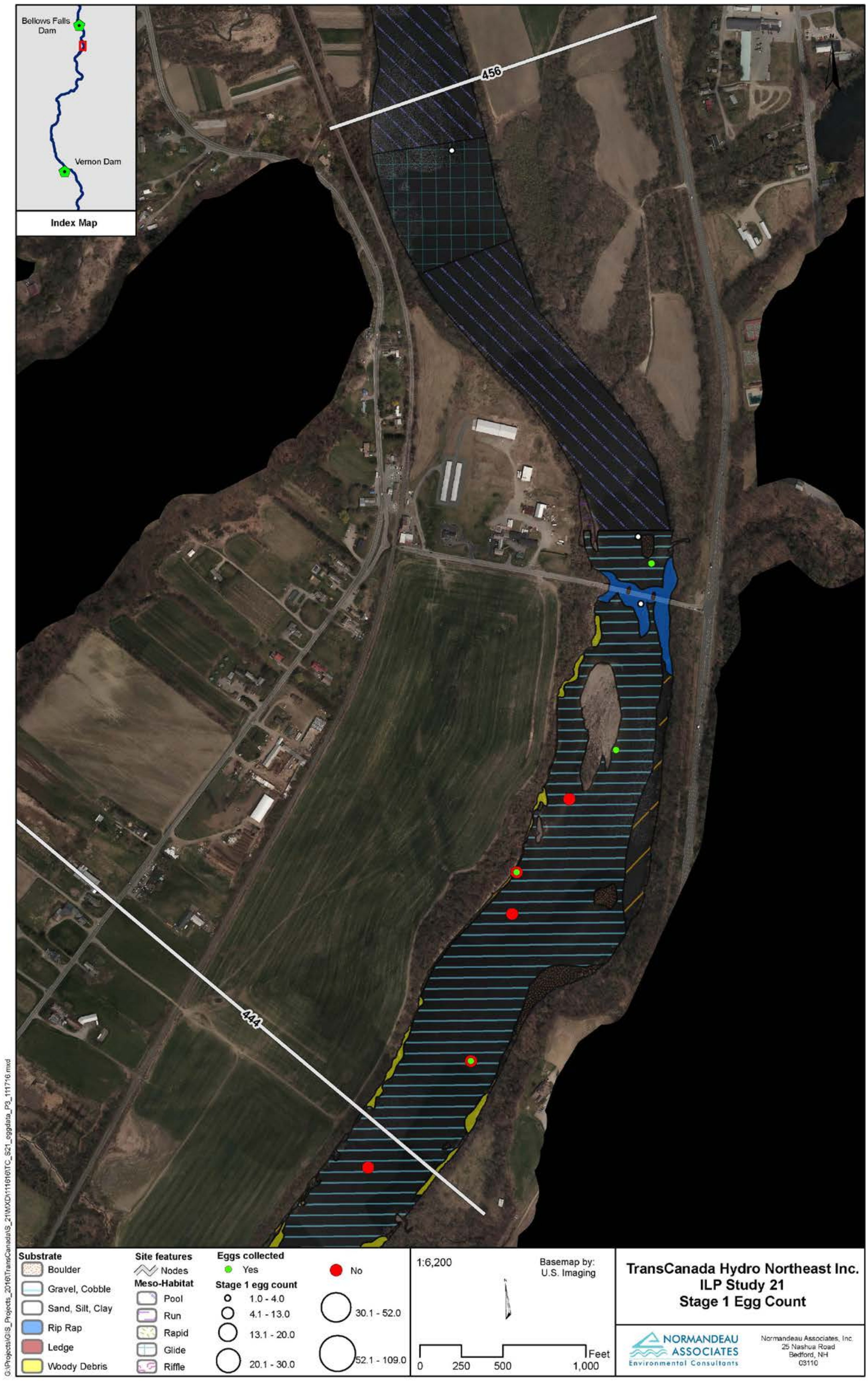

Figure 5.5-14. American Shad egg collections, calculated spawning locations, and substrate/habitat in the Bellows Falls riverine reach, vicinity of Mad Brook confluence, 2015.

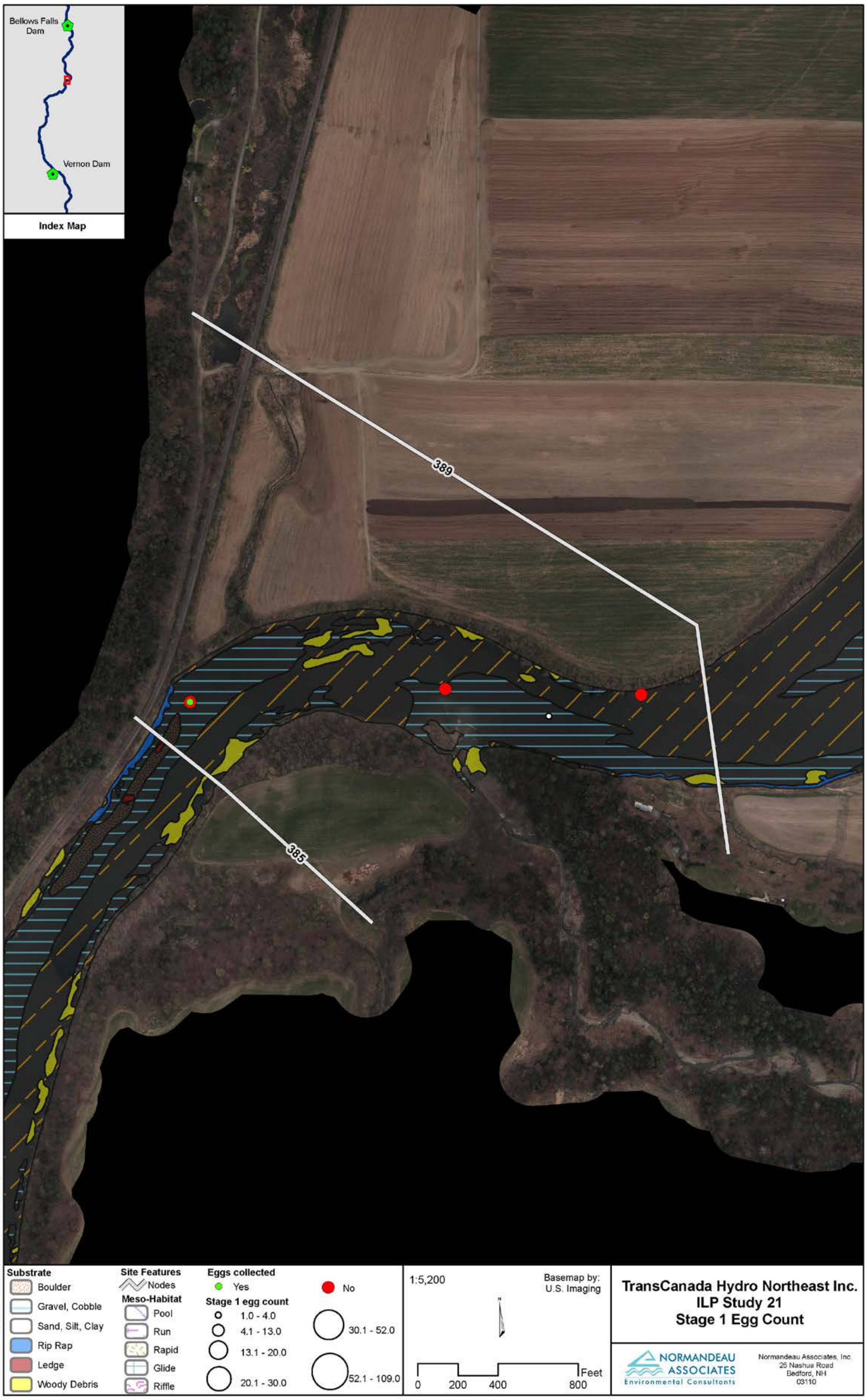

Figure 5.5-15. American Shad egg collections, calculated spawning locations, and substrate/habitat in the Vernon impoundment, vicinity of Mill Brook confluence, 2015.

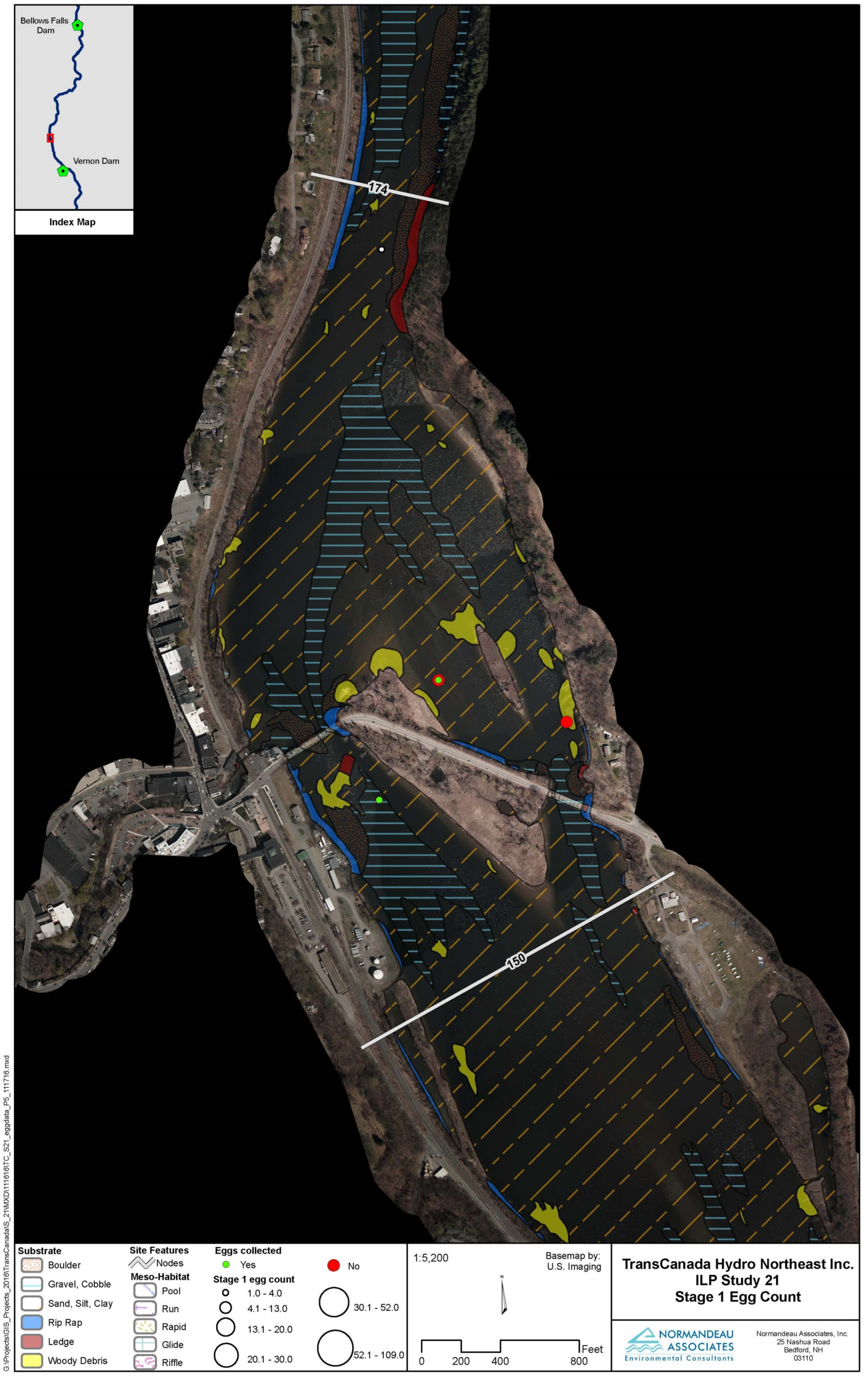

Figure 5.5-16. American Shad egg collections, calculated spawning locations, and substrate/habitat in the Vernon impoundment, vicinity of Route 119 Bridge, 2015.

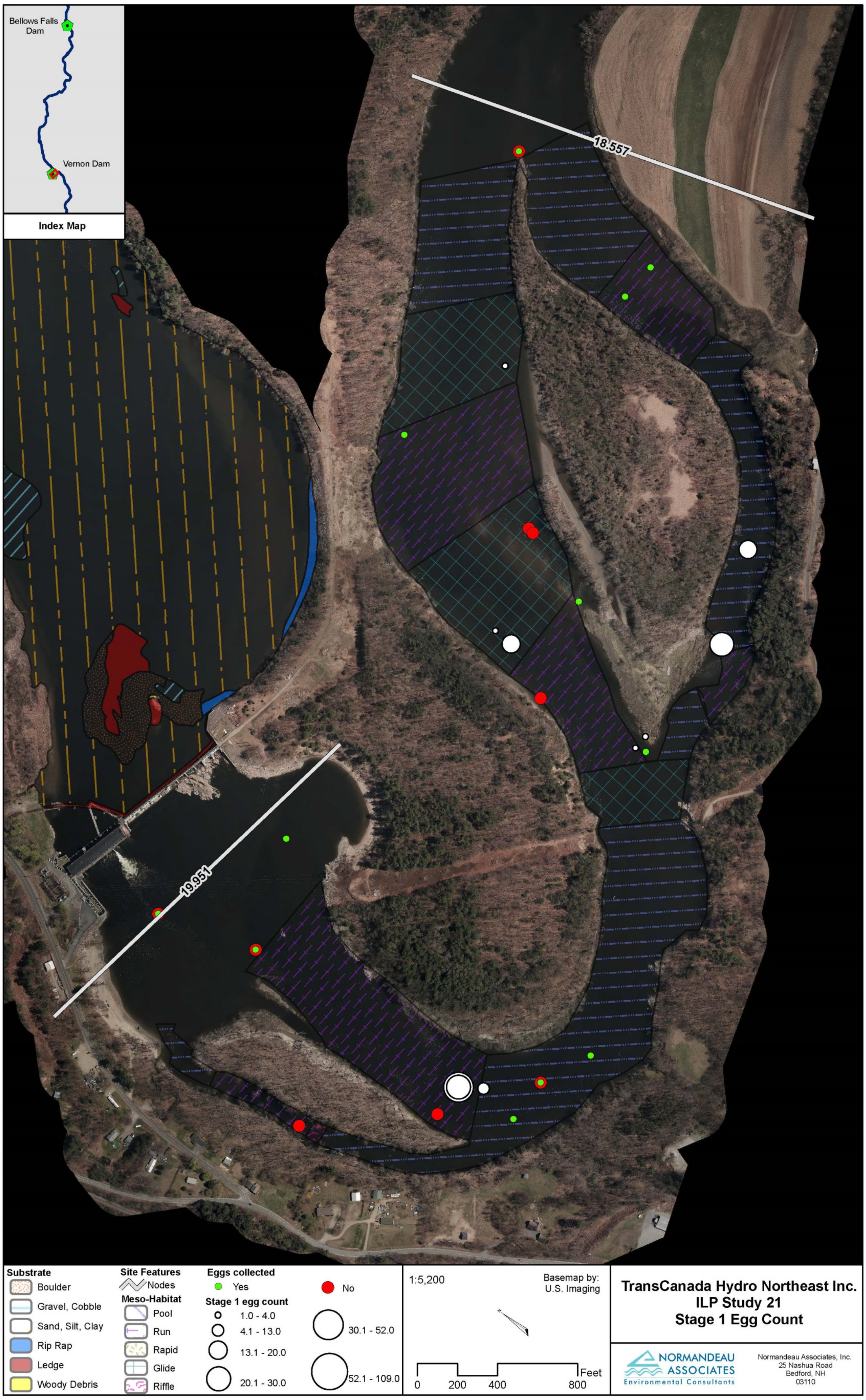

Figure 5.5-17. American Shad egg collections, calculated spawning locations, and substrate/habitat in the Vernon riverine reach, 2015.

For each general spawning area, the effects of project operations on three parameters from the hydraulic model (mean channel velocity, channel width, and thalweg depth) at the upper and lower cross section bounding each general spawning area were evaluated. Discharges from minimum flow to flows greater than maximum station generating capacity, including flows at which back-calculated spawning occurred, were evaluated for each general spawning location.

As part of ILP Study 9 (Normandeau, 2016a), a habitat index expressed as area weighted suitability (AWS; ft^2/ft) for American Shad spawning within the Bellows Falls and Vernon riverine reaches was also determined. As detailed in the Study 9 interim report (Normandeau, 2016a), AWS was calculated for a range of discharge values. For each transect data point identified in Study 9, a combined suitability index (CSI) was calculated by multiplying the individual variable suitability's for depth, velocity, and substrate from the habitat suitability criteria (HSC). This was multiplied by the width each point represents, summed, and multiplied by the transect weighting (as identified in Study 9). The substrate habitat suitability curve describes the suitability of each substrate category, and the substrate suitability at the measurement point is the sum of the suitability for each category multiplied by the percentage of that substrate category at the point. The AWS index does not represent an actual area upstream and downstream, but is based only on points across the stream channel. The only "area" involved in the calculation of AWS is width between points.

The AWS for American Shad spawning over the range of modeled discharges is presented for the Bellows Falls riverine reach in Figures 5.5-18 and for the Vernon riverine reach in Figure 5.5-19. The graphs indicate a loss or gain in AWS over the range of modeled discharges. Area weighted suitability values are not available for the Vernon impoundment as only riverine reaches were evaluated during ILP Study 9. Additional analysis currently being conducted as part of ILP Study 9 will provide more information on habitat suitability than can be presented here.

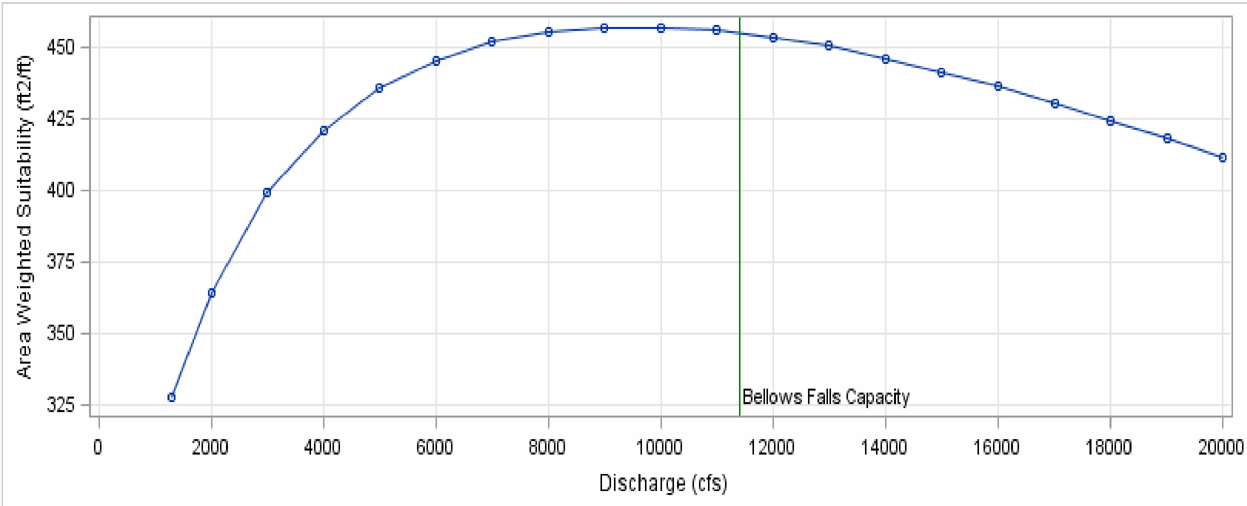

Figure 5.5-18. American Shad spawning area weighted suitability (AWS; ft^2/ft) by discharge for the Bellows Falls riverine reach.

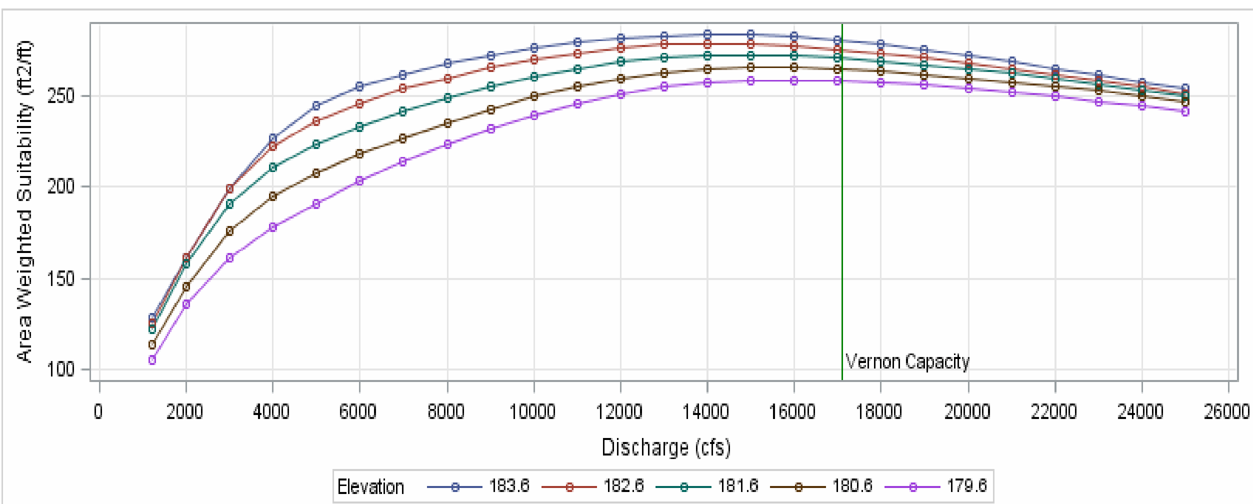

Figure 5.5-19. American Shad spawning area weighted suitability (AWS; ft^2/ft) by discharge for the Vernon riverine reach.

5.5.2.2 Bellows Falls Tailrace to Downstream of the Saxtons River Confluence

Figure 5.5-12 above presents the plan view for the general spawning area stretching from the Bellows Falls tailrace to downstream of the Saxtons River confluence. The area is bounded on the upstream side by hydraulic model cross section 498 and on the downstream side by cross section 481. Changes in the mean column velocity, channel width and thalweg depth for minimum, mid-range, and maximum generation flows as well as at each discharge where stage 1 eggs were collected indicating active spawning, are presented in Table 5.5-9. As would be expected, all three parameters increase with increases in river flow. Predicted water depths at the upper and lower end of the identified spawning area are within the range expected for shad based upon available literature. A change in discharge from the maximum flow condition at which spawning was observed during 2015 (20,000 cfs) to Bellows Falls minimum flow from generation (1,300 cfs) would result in a decrease in channel width of 39% at the upper end and 24% at the lower end of the spawning area. However, the mean thalweg depth would remain within the reported range of values for spawning at both locations under minimum flow conditions. When AWS values for the Bellows Falls riverine reach are considered (Figure 5.5-18), suitability for this spawning area is at its peak for discharges between 9,000-11,000 cfs.

Table 5.5-9. Mean predicted values for mean column velocity, channel width and water depth at the upper and lower ends of the shad spawning area from Bellows Falls tailrace to downstream of Saxtons River confluence.

Reach Bound	Bellows Falls Discharge (cfs)	Mean Velocity (ft/s)	Mean Water Depth (ft)	Mean Channel Width (ft)
Upper, Bellows Falls Tailrace	1,300	3.2	3.8	190.4
	5,000	5.9	6.0	216.7
	11,000 [a]	7.4	8.7	249.9
	15,000 [a]	8.1	10.1	277.4
	20,000 [a]	8.6	11.7	311.6
Lower, DS of Saxtons River	1,300	1.1	7.8	310.7
	5,000	2.0	11.4	392.3
	11,000 [a]	3.0	14.4	399.4
	15,000 [a]	3.5	15.9	402.9
	20,000 [a]	4.0	17.6	406.8

a. Back-calculated spawning occurred at this approximate flow.

5.5.2.3 Bellows Falls Riverine Reach – Cold River Confluence to Upstream of Mad Brook

Figure 5.5-13 above presents the plan view for the general spawning area stretching from the Cold River confluence to upstream of Mad Brook. The area is bounded on the upstream side by hydraulic model cross section 475 and on the downstream side by cross section 462. Changes in the mean column velocity, channel width and thalweg depth for minimum, mid-range, and maximum generation flows as well as each discharge where stage 1 eggs were collected indicating active spawning, are presented in Table 5.5-10. As would be expected, all three parameters increase with increases in river flow. Predicted water depths at the upper and lower end of the identified spawning area are within the range expected for shad based upon available literature. A change in discharge from the maximum flow condition at which spawning was observed during 2015 (20,000 cfs) to Bellows Falls minimum flow from generation (1,300 cfs) would result in a decrease in channel width of 18% at the upper and 19% at the lower end of the spawning area. However, the mean thalweg depth would remain within the reported range of values for spawning at both locations under minimum flow conditions. When AWS values for the Bellows Falls riverine reach are considered, suitability for this spawning area is at its peak for discharges between 9,000-11,000 cfs (Figure 5.5-18).

Table 5.5-10. Mean predicted values for mean column velocity, channel width and water depth at the upper and lower ends of the Bellows Falls riverine spawning area from the Cold River confluence to area upstream of Mad Brook.

Reach Bound	Bellows Falls Discharge (cfs)	Mean Velocity (ft/s)	Mean Water Depth (ft)	Mean Channel Width (ft)
Upper	1,300	1.8	3.1	379.8
	5,000	2.4	6.4	441.0
	7,000 [a]	2.7	7.5	445.8
	9,000 [a]	3.0	8.4	449.2
	11,000	3.3	9.1	451.5
	17,000 [a]	4.0	11.2	457.7
	20,000 [a]	4.2	12.2	460.5
Lower	1,300	1.4	3.5	431.4
	5,000	2.7	5.5	458.5
	7,000 [a]	3.0	6.5	470.5
	9,000 [a]	3.3	7.4	481.5
	11,000	3.5	8.2	491.6
	17,000 [a]	3.9	10.5	519.4
	20,000 [a]	4.1	11.5	534.3

a. Back-calculated spawning occurred at this approximate flow.

5.5.2.4 Bellows Falls Riverine Reach– Mad Brook Confluence

Figure 5.5-14 above presents the plan view for the general spawning area in the vicinity of Mad Brook in the lower Bellows Falls riverine reach, near the Westminster Bridge. The area is bounded on the upstream side by hydraulic model cross section 456 and on the downstream side by cross section 444. Changes in the mean column velocity, channel width and thalweg depth for minimum, mid-range and maximum generation flows as well as each discharge where stage 1 eggs were collected indicating active spawning are presented in Table 5.5-11. As would be expected, all three parameters increase with increases in river flow. Predicted water depths at the upper and lower end of the identified spawning area are within the range expected for shad based upon available literature. A change in discharge from the maximum flow condition at which spawning was observed during 2015 (16,000 cfs) to the upstream minimum flow from Bellows Falls generation (1,300 cfs) would result in a decrease in channel width of 10% at the upper and 7% at the lower end of the spawning area. However, the mean thalweg depth would remain within the reported range of values for spawning at both locations under minimum flow conditions. When AWS values for the Bellows Falls riverine reach are considered, suitability for this spawning area is at its peak for discharges between 9,000-11,000 cfs (Figure 5.5-18).

Table 5.5-11. Mean predicted values for mean column velocity, channel width and water depth at the upper and lower ends of the Bellows Falls riverine reach spawning area in the vicinity of Mad Brook.

Reach Bound	Bellows Falls Discharge (cfs)	Mean Velocity (ft/s)	Mean Water Depth (ft)	Mean Channel Width (ft)
Upper	1,300	0.7	4.3	597.2
	5,000	1.7	6.2	622.2
	11,000	2.4	8.9	649.4
	14,000 [a]	2.6	10.0	660.5
	16,000 [a]	2.7	10.8	667.1
Lower	1,300	0.5	7.5	521.6
	5,000	1.7	8.6	530.4
	11,000	2.6	10.8	547.3
	14,000 [a]	2.9	11.9	554.2
	16,000 [a]	3.1	12.6	558.7

a. Back-calculated spawning occurred at this approximate flow.

5.5.2.5 Vernon Impoundment – Mill Brook Confluence

Figure 5.5-15 above presents the plan view for the general spawning area in the vicinity of Mill Brook in the Vernon impoundment. The area is bounded on the upstream side by hydraulic model cross section 389 and on the downstream side by cross section 385. Changes in the mean column velocity, channel width and thalweg depth for minimum, mid-range and maximum generation flows as well as each discharge where stage 1 eggs were collected indicating active spawning are presented in Table 5.5-12. As would be expected, all three parameters increase with increases in river flow. Although predicted channel thalweg depths at the upper and lower end of the identified spawning area are at the upper extent of the range expected for shad spawning based upon available literature, a range of shallower depths would be available towards the channel margins. A change in discharge from the maximum flow condition at which spawning was observed during 2015 (8,000 cfs) to the upstream minimum flow from Bellows Falls generation (1,300 cfs) would result in a decrease in channel width of 1% at the upper and lower ends of the spawning area.

Table 5.5-12. Mean predicted values for mean column velocity, channel width and water depth at the upper and lower ends of the Vernon impoundment spawning area in the vicinity of Mill Brook.

Reach Bound	Bellows Falls Discharge (cfs)	Mean Velocity (ft/s)	Mean Water Depth (ft)	Mean Channel Width (ft)
Upper	1,300	0.2	21.0	560.0
	5,000	0.8	21.3	562.3
	8,000 [a]	1.2	21.7	565.9
	11,000	1.5	22.2	570.5
Lower	1,300	0.3	18.4	409.9
	5,000	1.0	18.7	411.3
	8,000 [a]	1.5	19.0	413.4
	11,000	2.0	19.5	416.3

a. Back-calculated spawning occurred at this approximate flow.

5.5.2.6 Vernon Impoundment – Route 119 Bridge

Figure 5.5-16 above presents the plan view for the general spawning area upstream of the Route 119 Bridge in the Vernon impoundment near Brattleboro. The area is bounded on the upstream side by hydraulic model cross section 174 and on the downstream side by cross section 150. Changes in the mean column velocity, channel width and thalweg depth for minimum, mid-range and maximum generation flows as well as each discharge where stage 1 eggs were collected indicating active spawning are presented in Table 5.5-13. As would be expected, all three parameters increase with increases in river flow. Although predicted channel thalweg depths at the upper and lower end of the identified spawning area are greater than the range expected for shad spawning based upon available literature, a range of shallower depths would be available towards the channel margins. A change in discharge from the maximum flow condition at which spawning was observed during 2015 (20,000 cfs) the upstream minimum flow from Bellows Falls generation (1,300 cfs) would result in a decrease in channel width of less than 1% at the upper and 2% at the lower end of the spawning area.

Table 5.5-13. Mean predicted values for mean column velocity, channel width and water depth at the upper and lower ends of the Vernon impoundment spawning area upstream of the Route 119 Bridge.

Reach Bound	Bellows Falls Discharge (cfs)	Mean Velocity (ft/s)	Mean Water Depth (ft)	Mean Channel Width (ft)
Upper	1,300	0.1	35.9	405.8
	5,000	0.5	35.9	405.9
	11,000	1.0	36.0	406.3
	20,000 [a]	1.9	36.4	407.4
Lower	1,300	0.1	29.1	1253.4
	5,000	0.3	29.1	1254.4
	11,000	0.6	29.2	1258.6
	20,000 [a]	1.1	29.5	1281.1

a. Back-calculated spawning occurred at this approximate flow.

5.5.2.7 Vernon Tailrace to Stebbins Island

Figure 5.5-17 above presents the plan view for the general spawning area stretching from the Vernon tailrace downstream to Stebbins Island. The area is bounded on the upstream side by hydraulic model cross section 149 and on the downstream side by cross section 119. Changes in the mean column velocity, channel width and thalweg depth for minimum, mid-range and maximum generation flows as well as each discharge where stage 1 eggs were collected indicating active spawning are presented in Table 5.5-14. As would be expected, all three parameters increase with increases in river flow and Turners Falls impoundment water levels. Predicted water depths at the lower end of the identified spawning area are within the range expected for shad based upon available literature. Although predicted channel thalweg depths at the upper end of the identified spawning area are greater than the range expected for shad spawning, a range of shallower depths would be available towards the channel margins.

A change in discharge from the maximum flow condition at which spawning was observed during 2015 (24,000 cfs) to Vernon’s minimum flow from generation (1,600 cfs) would result in a decrease in channel width of 7% at the upper and 3% at the lower end of the spawning area. For the range of elevations considered, suitability for American Shad spawning within the spawning area from the Vernon tailrace to Stebbins Island reaches a peak for discharges between 14,000 and 16,000 cfs (Figure 5.5-19 above).

Table 5.5-14. Mean predicted values for mean column velocity, channel width and water depth at the upper and lower ends of the Vernon riverine spawning area extending from the Vernon tailrace downstream to Stebbins Island.

Reach Bound	Vernon Discharge (cfs)	Mean Velocity (ft/s)	Mean Water Depth (ft)	Mean Channel Width (ft)
Upper, Vernon Tailrace	1,600	0.1	28.0	1453.5
	8,000	0.3	30.2	1494.3
	12,000 [a]	0.4	31.5	1507.0
	16,000 [a]	0.5	32.8	1522.4
	17,000	0.5	33.1	1528.0
	22,000 [a]	0.6	34.6	1559.7
	24,000 [a]	0.7	35.1	1570.2
Lower, Stebbins Island	1,600	0.3	10.1	846.0
	8,000	1.3	11.4	852.2
	12,000 [a]	1.7	12.5	857.2
	16,000 [a]	2.0	13.6	862.4
	17,000	2.1	13.9	863.7
	22,000 [a]	2.3	15.3	870.1
	24,000 [a]	2.4	15.8	872.4

a. Back-calculated spawning occurred at this approximate flow.

6.0 DISCUSSION AND STUDY CONCLUSIONS

This final study report addresses each of the goals and objectives presented in the RSP. In a May 2, 2016 letter to FERC, FWS requested the use of the time-to-event analysis approach first detailed in Castro-Santos and Perry (2012). This analytical method was not discussed during study plan development and as a result the field design deployed during 2015 was not tailored for this type of analysis. Lotek receivers installed to monitor approaching shad during 2015 utilized the CRTO feature which compiled multiple detections for an individual radio-tag within pre-specified time durations and exported that series of records as a single data line. Due to the use of this feature, it was not possible to identify the unique date/time stamp for each individual record within a single CRTO record. CRTO data records collected from aerial antennas in close proximity to one another (e.g., receivers covering the tailrace, discharge, spillway) could overlap in time (i.e., duration from the time of the initial detection to the time of the final detection) with records from an adjacent station.

The loss of time resolution due to the use of CRTO and inability to separate periods of overlap at adjacent stations precluded conducting time-to-event analysis which seeks to identify discrete zones of interest for which the periods of residence of individual fish must be identified, and the entry and exit times from these zones must be clearly identified. To accomplish this, the intervals between successive detections at a specific receiver (and on an individual basis) are reviewed and a threshold duration is derived which will represent the maximum period of time where an individual can go unrecorded at a particular station but is still considered as present (based on the knowledge that transmissions will go undetected for a variety of reasons and as a result, this threshold value will never equal the transmission rate of the tags). Determination of this threshold value was precluded by the use of CRTO which masked the interval duration between successive detections at a particular location. However, data analysis and results of this study are adequate to address the study goals and objectives without the use of time-to-event analysis.

6.1 Upstream Passage and Fish Ladder Utilization

Three metrics were calculated to evaluate the performance of the Vernon fish ladder for upstream passage of American Shad; nearfield attraction, entrance efficiency, and internal efficiency. These upstream performance metrics were based on the subset of tagged shad considered “available” determined by movement into the Vernon study area. For dual-tagged shad, the Vernon study area was defined as the reach of river from the downstream dam face to a point approximately 800 feet downstream at the upstream end of Stebbins Island (monitoring station 1).

This definition resulted in 71 PIT-tagged and 58 dual-tagged adult American Shad (129 total individuals) available for upstream passage evaluation. The median downstream residence time for dual-tagged shad was just under two days. There was no statistically significant difference between the mean tailrace residence time observed for dual-tagged shad that successfully passed upstream of Vernon versus those that eventually fell back downstream without passage. Numbers of dual-tagged shad in the Vernon tailrace peaked during the second half of May, coinciding with controlled river conditions and an absence of spill. The majority of dual-tagged shad for which duration of residence downstream of Vernon was calculated were not present during spill conditions.

The attraction effectiveness of the fish ladder (the proportion of dual-tagged shad within the immediate vicinity of the fish ladder) was 56.3% (95% CI = 51.7-67.2%) based on dual-tagged shad which is within the broad range of attraction effectiveness values (11.0-73.0%) observed at other facilities where similar studies were conducted (e.g., Normandeau, 2008; Normandeau and Gomez and Sullivan, 2012). Entrance efficiency (the proportion of dual-tagged shad detected within the immediate vicinity of the fish ladder that subsequently entered the ladder) was 73.5% (95% CI = 64.7-82.4%). For all forays into the fish ladder, both successful and unsuccessful, residency within the fish ladder from entry to exit ranged in duration from less than 1 minute to 6.4 days. The average duration of foray events for tagged shad that failed to successfully pass upstream was longer than that observed for individuals that successfully passed upstream. In particular, forays that resulted in eventual passage success were generally initiated when attraction water flow was cycled on during daytime hours to supplement fish ladder flow (94% of successful passage events). Average total project discharge at the time of approach did not show a significant difference for events resulting in successful and unsuccessful upstream forays.

Internal efficiency of the fish ladder based on the number of both dual-tagged and PIT-tagged shad that entered the fish ladder and subsequently exited the upstream end and remained upstream of Vernon dam for greater than 48 hours, was 55.2% (95% CI = 50.0-61.5%). The median time of passage from the entrance to the counting window was approximately 1.1 hours and from the counting window upstream to the exit was approximately 1.4 hours.

6.2 Upstream Movement beyond Vernon and Subsequent Downstream Passage

Approximately 28% of shad released above Vernon dam or passed via the fish ladder continued upstream to the Bellows Falls tailrace. The median time to travel from Vernon to the Bellows Falls tailrace was approximately 5.5 days. It is possible that the remaining 72% found suitable spawning habitat in the approximate 31-mile reach between Vernon and Bellows Falls as egg and larval collections occurred at several locations throughout this reach. All but four of the 18 radio-tagged shad that reached Bellows Falls eventually returned to Vernon dam.

Of the radio-tagged adult shad upstream of Vernon, 91% were determined to have returned to the Vernon forebay following a period of time upstream of the dam (i.e., the Vernon impoundment or Bellows Falls riverine reaches). Excluding individuals determined to have died either upstream or within the forebay (as evidenced by detection/collection from trash racks), residency upstream of Vernon prior to downstream passage ranged between several minutes to greater than 21 days. The majority of return events occurred during June with minor peaks in the daily number of downstream migrants coinciding with peaks in the mean daily project discharge. Median forebay residency times varied among individuals using different downstream passage routes, and those with relatively short forebay residence times (i.e., ≤12 hrs) were generally associated with periods when flows exceeded maximum station generating capacity (during spill).

Among individuals where a downstream passage route could be determined, the spillway was the dominant route used, followed by the fish pipe and turbine units. It is not known which spill gates fish used to pass, but tainter gate No. 2 was operated most frequently alone or in combination with tainter gate No. 1; both are located on the eastern end of the spillway, on the opposite end of the spillway from the powerhouse. Tainter gate No. 3 is located about one-third of the distance from the powerhouse to the eastern end of the spillway and the trash/ice sluice is located directly next to the powerhouse. It should be noted that the sample size evaluated for downstream passage routes (28 individuals with known routes) was limited and was a consideration when evaluating effects of project operations on downstream passage. Peaks in downstream passage events generally coincided with peaks in both total discharge and spill. The majority of downstream passage events occurred at times when all 10 turbine units were in operation. The timing of downstream passage events appeared to be fairly uniform in distribution with no strong pattern in diel timing when examined by passage route. Since residence time within the Vernon forebay prior to downstream passage was relatively short (median <12 hours) it can be concluded that the ability to locate downstream routes of passage through the Vernon project did not hinder the timing of the emigration. Of the individuals known to have passed Vernon, 55% were later detected at Turners Falls.

6.3 Spawning – Assessment of Project Effects

Shad are broadcast spawners and eggs are swept downstream and lodge in the substrate. Shad develop quickly from egg to larval stage and it appears that spring river flows and water temperature are determining factors for survival (Savoy et al., 2004). Larvae drift downstream into areas of reduced velocity along shorelines and backwaters. Shad eggs and larvae were found throughout the study area in a variety of substrates, conditions, and flows which indicates that the entire study reach is likely suitable for spawning particularly in the riverine reaches where most eggs and larvae were collected.

Although it was already assumed that American Shad used the area downstream of Vernon to spawn, this study provided the first concerted effort to identify unique spawning areas for the species within the reach of the Connecticut River from the Vernon tailwater upstream to Bellows Falls. In contrast, shad spawning locations lower in the river (i.e., between Holyoke and Turners Falls) have been identified in previous studies (Layzer, 1974; Kuzmeskus, 1977). Within this study, general spawning areas had not been previously evaluated and were identified based on the back-calculated locations of spawn for stage 1 shad eggs collected within ichthyoplankton samples over the duration of the study period. Six general locations were identified and included three within the Bellows Falls riverine reach (the Bellows Falls tailrace to downstream of the Saxtons River, the Cold River to upstream of Mad Brook, and the vicinity of Mad Brook confluence), two within the Vernon impoundment (vicinity of Mill Brook confluence, and vicinity of Route 119 Bridge) and the area downstream of Vernon dam to Stebbins Island. When standardized to the number of individuals per hour of net sampling the average CPUE rate for stage 1 shad eggs was highest for the Bellows Falls tailrace downstream to the Saxtons River confluence followed by the Vernon tailrace to Stebbins Island spawning areas (although the two areas were not significantly different).

During spawning, a female shad may be accompanied by one or several males and the pair or group will swim near the surface, sometimes with their backs exposed, leaving a wake and splashing (Munroe, 2002). For reasons unknown, identification of American Shad spawning (i.e., surface splashing activity) was ineffective within this study's reaches. The RSP specified that observed effects of project operations on spawning activity were to be classified per operational regime observed as:

1. no effect – no observable effect on spawning; viable eggs were collected;

2. moderate effect – observable possible effect on normal spawning activity; spawning may have been hindered but viable eggs were collected; and

3. adverse effect – project operations likely to have prevented successful spawning of shad; no viable eggs were collected.

A direct assessment of operational changes on actively spawning fish during 2015 was not possible due to the lack of an observable response variable (i.e., if splash counts were to be used as a proxy for spawning activity, one would need to have an established baseline of count frequency under a certain condition by which to compare other conditions). As these observations were not available, the potential impact of project effects on shad spawning in each of the six general spawning areas was evaluated using the modeled effects of project operations on three parameters (mean channel velocity, channel width, and thalweg depth) at the upper and lower model cross sections bounding each general spawning area. A range of discharges, from minimum flow to spill flows (including flows at which back-calculated spawning occurred) were evaluated for each general spawning location. For the riverine reaches, estimates of area weighted suitability for American Shad spawning were evaluated over the target range of discharges.

As would be expected mean channel velocity, channel width, and thalweg depth all increased with increases in river flow. Each of the six general spawning areas contained areas with adequate depth and velocity to support shad spawning. In no case did the modeled thalweg depth drop below the literature reported range of water depths for shad spawning activity (i.e., 3-19 ft), even under minimum flow conditions. While the difference in modeled wetted channel width decreased from 1 to 39% between the maximum discharges when spawning was observed, to minimum flow conditions, minimum flows at both projects typically occur less than 1% of the time during May and June so the minimum wetted channel width estimate and potential project effects related to channel width is considered to be very conservative.

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Appendices A – D filed separately in Excel (zipfile) format

Appendix A-1 to A-6: Upstream Passage Data in a single Excel workbook

Appendices B-D in a single Excel workbook

Appendix B: Downstream Passage Data

Appendix C-1 to C-3: Trawl, Spawning, and Manual Tracking Data

Appendix D: Water Quality Data

Appendix E: Spawning geodata filed separately in KMZ and ARC (zipfile) formats