Relicensing Study 3.3.6

IMPACT OF PROJECT OPERATIONS ON SHAD SPAWNING, SPAWNING HABITAT AND EGG DEPOSITION IN THE AREA OF THE NORTHFIELD MOUNTAIN AND TURNERS FALLS PROJECTS

Study Report

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

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MARCH 2016

EXECUTIVE SUMMARY

FirstLight Hydro Generating Company (FirstLight) is the current licensee of the Northfield Mountain Pumped Storage Project (Northfield Mountain Project, FERC No. 2485) and the Turners Falls Hydroelectric Project (Turners Falls Project, FERC No. 1889). FirstLight has initiated with the Federal Energy Regulatory Commission (FERC, the Commission) the process of relicensing the Northfield Mountain and Turners Falls Projects using the FERC's Integrated Licensing Process (ILP). The current licenses for the Northfield Mountain and Turners Falls Projects were issued on May 14, 1968 and May 5, 1980, respectively, with both set to expire on April 30, 2018. This report documents the results of Study No. 3.3.6 *Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the Area of the Northfield Mountain and Turners Falls Projects*.

Night-time visual and aural surveys were performed in the Connecticut River from the Vernon Dam tailwater (at river kilometer 228.4) to the Route 116 Bridge in Sunderland, Massachusetts to identify shad spawning locations, and to assess spawning activity in the downstream reach (from Cabot Station to the Route 116 Bridge) in relation to operation of the Northfield Mountain and Turners Falls Projects. Initial (Phase 1) surveys to first identify spawning locations in the downstream reach were conducted on five nights between sunset and 01:00 from May 13 to May 21, 2015. Seven spawning events were observed during Phase 1. Although nearly 3.5 decades have passed since previous researchers identified areas of shad spawning downstream of Cabot Station, the 2015 surveys confirmed some of the same areas remain active spawning grounds for shad.

In Phase 2, which was conducted from May 26 to June 22, 2015, the effects of changing generation at Cabot Station on shad spawning activity, as indicated by splash counts, was assessed. Once a spawning event was identified, splash counts were initially recorded over a 15-minute interval and physical habitat parameters (water temperature, dissolved oxygen, pH, conductivity, secchi depth, water depth, and surface velocity) were measured. Notes on behavior were also recorded. Field crews then requested a change in Cabot Station generation (increasing and decreasing generation by one or two units) and subsequently recorded splash counts.

Changes to the wetted areas of the spawning locations in response to the Cabot Station generation changes were also assessed using hydraulic models developed for Study No. 3.2.2 *Hydraulic Study of Turners Falls Impoundment, Bypass Reach, and below Cabot*. Using the existing calibrated hydraulic model of the downstream reach (from the Montague United States Geological Survey Gage to Holyoke Dam) the water surface elevation (WSEL) was computed on an hourly basis at each spawning location for the duration of the shad spawning study. Using the modeling results, wetted areas were impacted by a maximum of 2% during the changes in operations that were assessed. Habitat duration curves were developed to display effects of inundation (increase in WSEL) and exposure (decrease in WSEL) at each of the identified spawning areas due to changes in WSEL due to Project operations and the expected percentage of time the conditions are expected to occur. While it appears that the minimum WSELs estimated by the hydraulic model during the shad spawning period at some of the downstream shad spawning sites constrain the area and depth available for spawning, the habitat duration curves indicate that conditions associated with the minimum WSEL occur infrequently.

Based on observations during the 2015 spawning season, as Cabot Station generation increased, WSEL, velocity and depth also increased at each of the downstream spawning sites. However, photoperiod and time since sunset were more influential on spawning activity than physical changes at spawning sites related to Project operations. In general, spawning activity peaked when photoperiod was 14.8 to 15.0 hours, and over the course of an evening, decreased as time since sunset increased.

In addition to observations of shad spawning in the downstream reach, spawning activity was also documented in the upstream reach of the Turners Falls Impoundment (TFI), near the downstream end of Stebbins Island. Ichthyoplankton tows confirmed shad spawning identified by the visual and aural surveys as eggs were present in each of the samples collected.

Finally, shad spawning activity was identified near the downstream end of the Turners Falls Canal, as well as near the downstream end of Rawson Island in the bypass reach. Spawning activity was only observed at these locations once, later in the season, on June 18, 2015.

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cfs	cubic feet per second
CTDEEP	Connecticut Department of Energy and Environmental Protection
CRASC	Connecticut River Atlantic Salmon Commission
°C	degrees Celsius
DEM	digital elevation model
DO	dissolved oxygen
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Hydro Generating Company
fps	foot/feet per second
ft	foot/feet
GIS	Geographic Information System
GPS	Global Positioning System
H	horizontal
hp	horsepower
ILP	Integrated Licensing Process
ISR	Initial Study Report
km	kilometers
LIDAR	Light Detection and Ranging
m	slope
M	million
MADFW	Massachusetts Department of Fish and Wildlife
mg/L	milligrams per liter
Montague Gage	United States Geological Survey Gage 01170500 Connecticut River at Montague City, MA
msl	mean sea level
MW	megawatts
µs/cm	microsiemens per centimeter
NMFS	National Marine Fisheries Service
No.	number
Northfield Mountain Project	Northfield Mountain Pumped Storage Project
PAD	Pre-Application Document
PSP	Proposed Study Plan
RSP	Revised Study Plan
RKM	river kilometer
SD1	Scoping Document 1
SD2	Scoping Document 2
SE	standard error
SPDL	Study Plan Determination Letter
Turners Falls Project	Turners Falls Hydroelectric Project
TFI	Turners Falls Impoundment
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

USPR	Updated Study Report
V	vertical
VY	Vermont Yankee Nuclear Power Plant
WSEL	water surface elevation
x	mean or average
YOY	young-of-the-year

1 INTRODUCTION

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

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

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

On August 27, 2013, Entergy Corp. announced that the Vermont Yankee Nuclear Power Plant (VY), located on the downstream end of the Vernon Impoundment on the Connecticut River and upstream of the two Projects, will be closing no later than December 29, 2014. With the closure of VY, certain environmental baseline conditions will change during the relicensing study period. On September 13, 2013, FERC issued its first Study Plan Determination Letter (SPDL) in which many of the studies were approved or approved with FERC modification. However, due to the impending closure of VY, FERC did not act on 19 proposed or requested studies pertaining to aquatic resources. The SPDL for these 19 studies was deferred until after FERC held a technical meeting with stakeholders on November 25, 2013 regarding any necessary adjustments to the proposed and requested study designs and/or schedules due to the impending VY closure. FERC issued its second SPDL on the remaining 19 studies on February 21, 2014, which required FirstLight to modify its RSP for Study No. 3.3.6 *Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the Area of the Northfield Mountain and Turners Falls Projects* in consultation with stakeholders. FirstLight filed a modified RSP with its Initial Study Report (ISR). FERC's Determination on Requests for Study Modifications and New Studies issued on January 22, 2015 required further modifications to the RSP to include the power canal in the shad spawning survey area. FERC's determination also acknowledged that water temperature data proposed to be collected as part of the study and as part of Study No. 3.2.1 *Water Quality Study* should be sufficient to compare water temperature values and trends across spawning areas.

On February 4, 2015, a meeting was held with FERC staff, United States Fish and Wildlife Service (USFWS), Massachusetts Department of Fish and Wildlife (MADFW), National Marine Fisheries Service (NMFS), and other non-government stakeholders to discuss the Study No. 3.3.6. Following this meeting, FirstLight developed a more detailed field monitoring plan. On March 18, 2015, FirstLight circulated a modified RSP to the stakeholders. On March 24, 2015, a meeting was held with the same stakeholders to discuss the modified RSP. Based on comments received at this meeting, another version of the RSP was sent to stakeholders on April 8, 2015. A conference call was held with stakeholders on April 22, 2015 and a final RSP was completed on April 27, 2015.

1.1 Background

American Shad (*Alosa sapidissima*) is an anadromous species that spends most of its lifecycle in the ocean, with adults returning to freshwater for spawning. The historical range included nearly the entire Atlantic coast of the United States (from Indian River in Florida up through Maine), with spawning occurring in all accessible rivers and tributaries (Greene *et al.*, 2009), including the Connecticut River. Factors such as overfishing, pollution, climate change, and habitat loss have contributed to a reduction in range and overall population size over the last 170 years (Greene *et al*., 2009). While the latitudinal range within the United States remains generally similar, currently spanning the Atlantic coast from Maine to the St. John's River in Florida (Collette & Klein-MacPhee, 2002), an increase in barriers to migration in rivers has served to reduce the inland range and overall availability of spawning habitat.

Historically, the commercial fishery for American Shad on the Atlantic coast was extensive and lucrative. Catch levels at the end of the 19th century were estimated to be about 66 million pounds (Greene *et al.*, 2009). By 1960, due to factors listed above, the commercial catch reportedly fell to 8 million pounds (Stier & Crance, 1985), and continued to decrease to a minimum of 1.3 million pounds in 1996 (Greene *et al.*, 2009). As the Connecticut River fishery experienced a similar trend in decline, the Connecticut River Atlantic Salmon Commission (CRASC) developed a management plan for American Shad in the Connecticut River in 1992 (CRASC, 1992). An objective of the plan is to achieve and sustain an adult population of 1.5 to 2 million individuals entering the mouth of the Connecticut River annually.

The Turners Falls Dam was the first full mainstem barrier, erected in 1798 at RM 123 (RKM 198), that limited access to upstream spawning areas of the Connecticut River, which were thought to extend as far upstream as the natural barrier of Bellow Falls in Windham County, Vermont at RKM 280. Subsequent construction of the Holyoke Dam at RM 86 (RKM 139), which was initiated in 1848, and the Vernon Dam at RM 142 (RKM 228) in 1908, compounded the issue of upstream access for spawning American Shad that enter the Connecticut River.

Due to the peaking nature of operations of the Turners Falls and Northfield Mountain projects, flow conditions (magnitude, direction, and duration) in the surrounding Connecticut River, particularly downstream of Cabot Station, may potentially affect spawning activity and habitat of American Shad. No previous studies have investigated the relationship between shad spawning behavior, habitat use, and egg deposition as they relate to operation of the Turners Falls and Northfield Mountain Projects. This study was undertaken to gather information on the availability and locations of shad spawning habitat and the effect on spawning activity due to flow changes induced by project operations.

1.1.1 Spawning Habitat Requirements

In the Connecticut River, mature adults begin movement into the river typically during late March or April, reaching Cabot Station in late April or early to mid-May. During the upstream migration, river water temperatures generally range from 12 to 20°C, with spawning occurring from 14 to 23°C (Collette & Klein-MacPhee, 2002). River flow is generally declining from the spring peak during the spawning migration.

Adult shad prefer areas dominated by runs and glides, 3 to 18 ft deep for spawning purposes, and have been observed to spawn over a variety of substrates, but prefer sand and gravel bottom with sufficient water velocity to eliminate silt deposits (Stier & Crance, 1985). In the project area, this type of habitat most closely corresponds to the runs and glides occurring in the reach of the Connecticut River downstream from Cabot Station and to a limited extent, in the bypass reach.

Males typically arrive at the spawning grounds ahead of females. Spawning activity generally occurs after sunset, continuing until midnight or later, and may also occur during the day under low light conditions

(Collette & Klein-MacPhee, 2002). During spawning, a group of shad, which may consist of one female and several males, exhibit behaviors that have been characterized as dashing, darting, circling, and rolling near the surface (Ross *et al.*, 1993). These behaviors lead fish to break the surface of the water, thereby creating a series of splashes.

Female shad broadcast their eggs (about 150,000-500,000 per individual) over a variety of substrates in open water where they are fertilized (Savoy *et al.*, 2004; Greene *et al.*, 2009). After spawning, spent shad swim back downstream during June and July, and may survive to spawn more than once. Fertilized eggs are semi-buoyant and drift downstream with river currents for several kilometers before settling to the bottom (Savoy *et al.*, 2004). Stier and Crance (1985) report optimal egg survival of eggs occurs at water temperatures of 15.5 to 26.0°C, with temperatures above 26.7°C unsuitable for hatching. Shad larvae hatch in three to 12 days, depending on water temperature. The yolk-sac is absorbed in another three to four days, and the larvae are transported by currents into areas of lower velocity, where they begin to feed on plankton. Young-of-the-year (YOY) shad abundance has been shown to be negatively correlated with river flow in June (Crecco & Savoy, 1984), either because of physical displacement of YOY shad into unsuitable habitat, or because of fluctuations in populations of prey organisms that are related to flow.

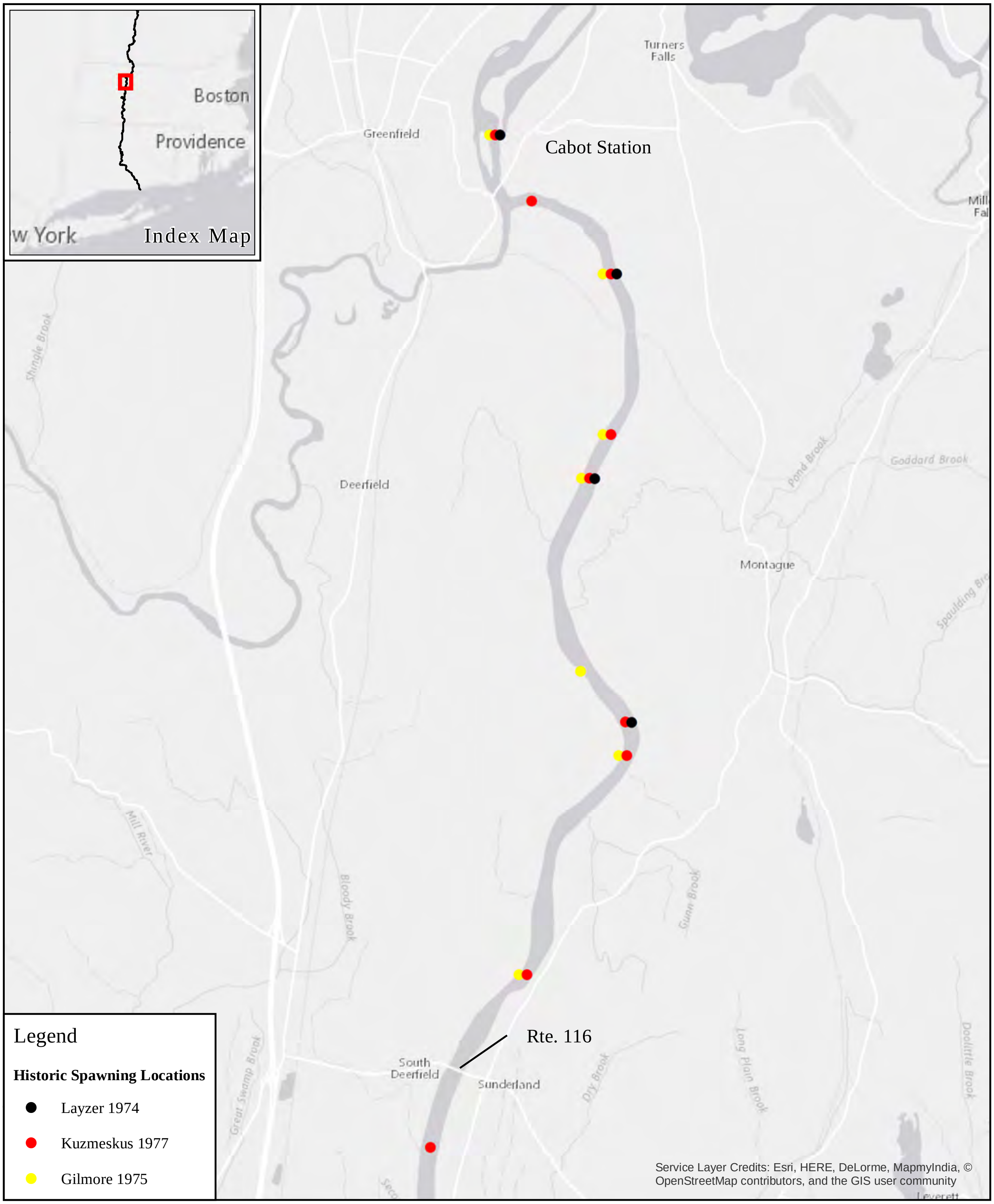
YOY shad are abundant in many river locations throughout the summer and provide a forage base for predatory fish. Although some YOY shad may move downstream at other times, the seaward migration out of the Connecticut River generally occurs in September through October, peaking when water temperature reaches about 9 to 14°C. Most daily movement occurs in evening hours until about 2300 h, but movement can occur around-the-clock (Hartel *et al.*, 2002). The young migrate to areas in the North Atlantic and remain at sea for four to six years before returning to their native river to spawn.

1.1.2 Previously Identified Spawning Locations

The locations of American Shad spawning in the Connecticut River between Holyoke Dam and Turners Falls Dam were identified in previous studies by Layzer (1974), Gilmore (1975 as cited in Kuzmeskus 1977), and Kuzmeskus (1977). Figure 1.1.2-1 depicts the locations of the historical spawning grounds identified in the reach of the Connecticut River spanning from the Cabot Station tailrace to the Route 116 Bridge in Sunderland, Massachusetts. Identification of these sites was based on visual observations and collection of eggs with plankton nets (Layzer, 1974 and Kuzmeskus, 1977).

Little is known about the shad spawning locations in the TFI. Previous adult tagging studies aimed at monitoring movement through the TFI have demonstrated that a portion of shad that successfully pass upstream of the Turners Falls Dam remains within the TFI for the duration of the spawning season (Layzer, 1976), suggesting that spawning is presumably occurring upstream of the dam.

Similarly, shad spawning in the Turners Falls Canal and the bypass reach has not been previously evaluated.



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

Study No. 3.3.6

Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the Area of Northfield Mountain and Turners Falls Project

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Figure 1.1.2-1: Historic Shad Spawning Locations Downstream of Cabot Station

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1.2 Study Goals and Objectives

The goal of the study is to determine if project operations (under the permitted and proposed operational ranges) affect shad spawning site use and availability, spawning habitat quantity and quality, and spawning activity in the river reaches that extends from the base of Vernon Dam to the Route 116 Bridge in Sunderland, Massachusetts.

The specific objectives were identified as:

- Determine areas utilized by shad for spawning by conducting night-time visual and aural observation of spawning activity;
- Identify and define those areas geospatially, and obtain data on physical habitat conditions affected by project operations (e.g., water depth, velocity, discharge, substrate, exposure and inundation of habitats);
- Collect information in order to assess project operation effects on observed spawning activity, under a range of permitted or proposed project operation conditions;
- Quantify effects (e.g., water velocity, depths, inundation, exposure of habitats) of project operation on identified spawning areas for a range of conditions, over the complete period of spawning activity; and
- Verify spawning activity as measured by night-time spawning/splash surveys in areas of spawning activity, and downstream of these areas, to gather data to determine project operation effects (location extent of exposure from changing water levels and flows and on associated habitats from project operations).

2 STUDY AREA

The study was conducted within the Project boundary and generally spanned the area from the Vernon Dam (FERC No. 1904) tailrace to the Route 116 Bridge in Sunderland, Massachusetts. For the purposes of conducting the shad spawning surveys, the study area was divided into three reaches (TFI, canal/bypass, and downstream of Cabot to Route 116 Bridge) (Figure 2.0-1), each of which is described below.

2.1 Impoundment

The TFI extends approximately 20 miles (32.2 kilometers (km)) upstream from the Turner Falls Dam to the Vernon Dam and includes two major tributaries (Ashuelot and Miller Rivers) as well as several smaller tributaries. Both lentic and lotic conditions are present in the TFI. Per the current FERC license, the elevation of the TFI can vary between a minimum of 176.0 ft (msl) to a maximum of 185.0 ft (msl); a 9-ft fluctuation as measured at the Turners Falls Dam.

The upstream reach of the TFI, extending approximately 14.8 miles (23.8 km) from Vernon Dam tailrace to the Northfield Mountain Project tailwater, is located within a broad flood plain and is relatively uniform and generally shallow, with gentle bends. A river channel exists with rock shorelines and lotic conditions. The substrate in this reach is variable ranging from sand to boulders. There are a few narrow islands comprised of alluvial materials such as gravel, cobble and fines. Scour holes and shoals generally are confined to locations downstream of features such as bridge piers and there are few deep pools. Scour holes provide the most extensive cover; object cover in the littoral zone is sparse, and limited to isolated patches of submerged aquatic vegetation (SAV) and clusters of woody debris.

The downstream reach of the TFI extends from the Northfield Mountain Project tailrace approximately 5.2 miles (8.4 km) to the Turners Falls Dam and is dominated by bedrock, which controls much of the stream geometry and substrate features. The geometry of the lower TFI is complex. It is defined by both bedrock and depositional features, and includes a complex of embayment, points, coves, islands, and a wide range of substrates, and features shallow lacustrine littoral habitat with a deeply incised thalweg, in contrast to the riverine habitat found further upstream in the TFI. The lower section of the TFI has several large areas off the channel which are shallow, with SAV and muck bottom habitats characteristic of lentic conditions.

2.2 Canal/Bypass Reach

The Turners Falls Canal is an approximately 2.1 miles (3.4 km) long canal that fills with water from the TFI towards the left (eastern) end of the Turners Falls Dam and extends to the Cabot Station forebay area. The canal supplies water to two hydroelectric power stations (Station No. 1 and Cabot Station) and other water users[1]. The upstream portion of the canal is rectangular in cross-section and engineered with canal walls varying from masonry to concrete to cut-rock faces. The bottom width ranges from 170 ft at the gatehouse to 123 ft at the end of this 3,900-ft reach. The next 3,300-ft reach of the canal has been excavated to a trapezoidal shape with 1.5H:1V slopes on both sides; the canal walls are generally similar to the preceding segment. The remaining segment of the canal (about 4,300 ft upstream of the Cabot Station) is essentially a pond covering about 50 acres.

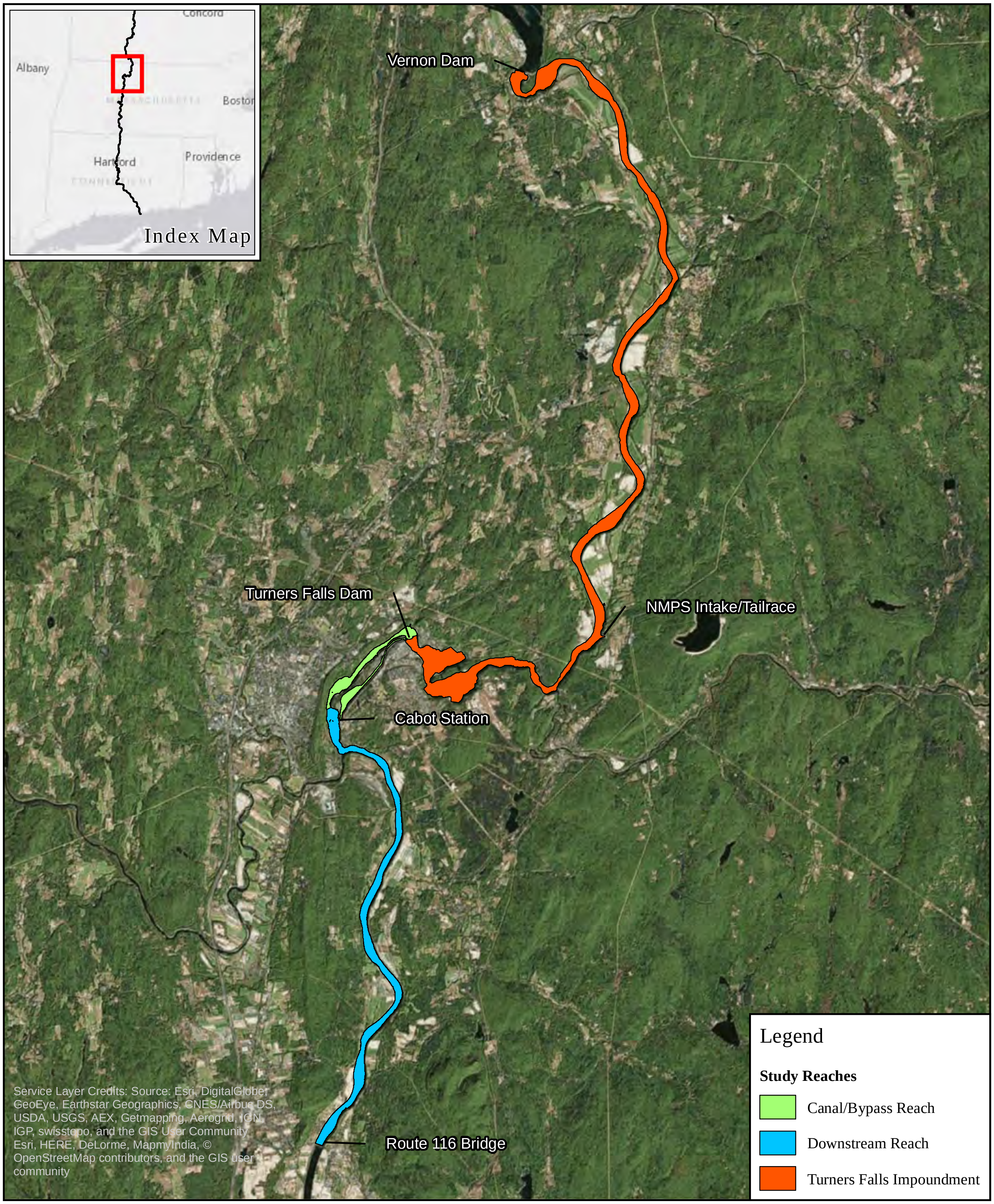
The last 600 ft of the canal, extending from the “pond” to the Cabot Station, was excavated from rock and has earth and concrete walls. It is generally trapezoidal in shape and riprap was added to the earth portions of the graded channel for slope protection.

[1] Other water users include PaperLogic (113 cfs capacity), Turners Falls Hydro, LLC (288 cfs capacity), and the United States Geological Survey Conte Anadromous Fish Laboratory (withdraws can range from 2 to 200 cfs pending time of year).

The 2.7 mi (4.3-km) bypass reach runs nearly adjacent to the canal and extends from the base of Turners Falls Dam to the tailrace of Cabot Station. This reach is low gradient and contains mostly bedrock, boulder, cobble, and gravel substrates; it primarily comprises pool mesohabitat, followed by riffle and backwater types. Flows in the bypass reach are a function of Turners Falls Dam spill during high flow events, Fall River (a tributary to the upstream end of the bypass), Station No. 1 discharges and required flows per the FERC license. Required minimum flows are provided to the bypass reach beginning May 1 annually, continuing until water temperatures fall below 7°C (typically November) to enhance conditions for upstream migratory species and Shortnose Sturgeon. Station No. 1 discharges into the bypass reach approximately 0.9 mi (1.4 km) downstream of the Turners Falls Dam and 1.8 mi upstream of the Cabot Station tailrace.

2.3 Downstream – Cabot to Route 116 Bridge

Downstream of Cabot Station, a low-gradient reach forms a wide flood plain with alluvial-dominated substrates and a meandering channel in many places. Approximately 77% of the 30 mile (48.3-km) reach below the Cabot Station tailrace evaluated by FirstLight (2012a) consisted of run mesohabitat type; presence of glide habitat areas was negligible. Riffle habitat was also extremely uncommon and was most concentrated in the stream reach immediately downstream from the Cabot Station discharge. The Deerfield River enters the Connecticut River just downstream of Cabot Station. This section of the river is subject to fluctuating flow conditions influenced by FirstLight project operations and to a lesser extent peaking operations of hydroelectric facilities on the Deerfield River.



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

Study No. 3.3.6

Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the Area of Northfield Mountain and Turners Falls Project

Figure 2.0-1:
Overview of Study Area

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3 METHODS

The study approach followed the approved RSP and consisted of the following elements: review of historical operations and flow data; identification of spawning areas and assessment of changes in Cabot generation on the spawning activity in the downstream reach, from Cabot Station tailrace to Route 116 Bridge; identification of shad spawning areas in the TFI; identification of shad spawning in the Turners Falls Canal and in the bypass reach; and data analysis.

3.1 Historical Operations and Flow Data

Historic data pertaining to Cabot Station discharge and river flow data were reviewed to provide the basis for determining typical flow regimes during the study period. Operational data (MW output and discharge) from the previous five years of generation were first reviewed to determine how the station has historically operated during the shad spawning season. Historical data from the Montague Gage and the USGS Gage at the Deerfield River (USGS 01170000) near the town of West Deerfield, Massachusetts were reviewed in conjunction with station operational data (Cabot MW output was converted to discharge).

3.2 Spawning Surveys

3.2.1 Downstream Reach – Cabot Station Tailrace to Route 116 Bridge

Field surveys were conducted in two phases at night by boat from May 13 to June 22, 2015; Phase 1 identified locations where shad were actively spawning, and information was collected to evaluate project effects in Phase 2.

Phase 1 Identification of Spawning Areas from Cabot Station to Route 116 Bridge

During the first two weeks of the survey (weeks of May 11th and 18th), Phase 1 field work was conducted to determine if areas that historically supported shad spawning were still active, as well as identify other locations where spawning may occur. For each sampling event, a two-person field crew surveyed the stretch of river between the Cabot Station tailrace and the Route 116 Bridge by boat. The surveys generally commenced at sunset and continued until 01:00 hours the following morning, when conditions permitted. Starting locations were varied to ensure that the results were not biased by visiting the same site at the same time of night every time. The field crews were equipped with 37M lumen spotlights and headlamps to aid in navigation and identification of spawning activity. When the field crew observed surface splashing potentially indicating spawning activity, the boat engine was turned off and spotlights were used to verify that such splashes were made by spawning American Shad. The field crew would also turn off the boat motor periodically as an additional measure to listen for splashes to identify spawning locations. At each location where spawning American Shad were encountered, the general behavior (e.g., darting, circling, rolling, grouping) of the spawning shad was observed and the number of splashes within a 15-minute period was counted as an index of spawning activity.

During each sampled spawning event, the number of splashes heard was recorded by each observer equipped with a tally counter and combined to report an average count. The general surface area over which each spawning event occurred was estimated and recorded with a GPS unit. Additionally, the sample date, start and end time, water temperature (°C), dissolved oxygen (mg/L), pH, conductivity (µs/cm), secchi depth (ft), depth (ft), surface velocity (fps), and predominant substrate type, when visible, were observed and recorded at each spawning location. As surveys were conducted at night, a standardized method of using a flashlight aimed down into the water column was used by crews to record secchi depth.

Phase 2 Assessment of Changes in Cabot Generation on Shad Spawning Activity and Habitat

Between the weeks of May 25th and June 22nd, Phase 2 field surveys were conducted to determine the impacts of flow fluctuations due to changes in generation at Cabot Station on shad spawning locations identified in Phase 1. When shad spawning activity was located by the field crew, behavioral observations and environmental conditions (including splash observations, water quality parameters, depth, surface velocity, predominant substrate type, and location) were recorded using the procedures outlined in Phase 1 above. After documenting conditions, Cabot Station operators were contacted to change operations by bringing on or dropping units. Generation changes of +/- 10 MW (2,288 cfs) and +/- 20 MW (4,576 cfs) were made throughout the study, based on existing river and operational conditions and in consultation with stakeholders. After flow conditions were altered, the field crew waited a minimum of 20 minutes to allow for the new flow rate to stabilize before recording the number of splashes over a 15-minute interval again in the same location. The duration of time between contacting station operators and recording the splash counts after a change in generation varied in accordance with distance downstream from Cabot Station, such that sites closest to Cabot Station were permitted a 20-minute interval, while those further downstream were increasingly scaled towards a one-hour interval.

3.2.2 Turners Falls Impoundment

Beginning the week of May 18th, the TFI was surveyed to identify shad spawning areas using the same methodology as described for the Phase 1 surveys of the downstream reach. In addition, after each observed spawning event, a 1-meter long, 333-micron mesh ichthyoplankton net was towed for 10 minutes, when conditions permitted, to verify spawning activity. A General Oceanics flowmeter was suspended in the center of the net to record the volume of water filtered, although meter malfunction prevented accurate volume measurements in the first few weeks of the study. At the end of the ten-minute tow period, the net was retrieved, and the contents were preserved for subsequent analysis and identification of shad eggs. In the laboratory, a dissecting microscope was used to sort the plankton samples. All eggs were removed and shad identification was conducted in accordance with Jones *et al.* (1978). Eggs with diameters greater than 3.0 mm, no oil globules, and transparent or pink to amber in color were identified as American Shad. Note that larvae and eggs of blueback herring and American shad in the Connecticut River are not easily distinguishable. However, very low numbers of blueback herring pass upstream at the Holyoke Dam, therefore any alosine eggs and larvae were assumed to be American Shad.

3.2.3 Canal/Bypass Reach

Beginning the week of May 18th, the Turners Falls Canal as well as sections of the bypass reach were surveyed to identify shad spawning locations. During each survey event, the crew walked along the length of the canal, to the extent possible, to determine if shad utilize the canal for spawning activities. Due to safety concerns, only three locations (Rock Dam[2], Station No. 1 tailrace, and Plunge Pool near the Spillway Fishway) were visited in the bypass channel during shad spawning surveys. Access to the bypass channel to observe the areas upstream and downstream of Rock Dam was via a well-traveled footpath that leads from Migratory Way to the Bypass Reach where Rock Dam abuts the shore. A pathway leading from Station No. 1 parking lot to the tailrace area was used by the field crew for observations of the Station No. 1 tailrace area during the first week of the study and the Plunge Pool was observed from the Spillway Fishway. The canal and bypass channel surveys identified spawning areas via splash counts consistent with Phase 1 of the downstream surveys.

When spawning shad were observed, splashes were recorded during 15-minute intervals, along with time of day and the approximate location and surface area of the spawning area. Since the observers were shore-bound, water quality, GPS, depth, and surface velocity data at the spawning location were not collected.

[2] Rock Dam is a natural bedrock ledge with a near vertical drop.

3.3 Data Analysis (Impact Evaluation)

3.3.1 Hydraulic Model

Two hydraulic models were developed as part of Study No. 3.2.2 *Hydraulic Study of Turners Falls Impoundment, Bypass Reach and below Cabot*: a) from Vernon Dam to the Turners Falls Dam or the TFI ("TFI model") and b) from the Montague Gage downstream to Holyoke Dam ("below Montague USGS Gage model").

Steady and unsteady calibrated HEC-RAS hydraulic models were developed for both reaches as part of Study No. 3.2.2. For purposes of this report, both hydraulic models were simulated as unsteady—meaning flows vary over time. For Study No. 3.2.2 hourly time step models were developed for both reaches based on observed conditions that occurred from January 1, 2000 through September 30, 2015 for the TFI model and January 1, 2008 to September 30, 2015 for the below Montague USGS Gage model. In the case of the TFI hydraulic model, the flow inputs included: observed Vernon hourly discharges, observed tributary inflow based on USGS gaged flows on the Ashuelot and Millers River, observed Northfield Mountain Project pumped flows/generation flows, and observed water surface elevation (WSEL) at the Turners Falls Dam. In the case of the Montague USGS Gage model, flow data was based on observed flows from the Montague Gage.

The spawning study period extended from May 13 to June 22, 2015. The below Montague USGS Gage model (unsteady mode), was used to estimate the maximum channel depth (ft, WSEL less the thalweg), WSEL, mean channel velocity (fps), flow area (sq. ft) and top width (ft) at the spawning areas under a given flow. These hourly data sets were subsequently used in the analysis described below. The same process was conducted for the TFI hydraulic model.

The hydraulic models were used to determine the WSELs at identified spawning locations in the TFI reach and Montague USGS Gage reach under study period conditions, as well as to determine if any of the spawning areas become exposed under certain operational scenarios. In addition, estimated velocities and depths at the spawning locations in the downstream reach were extracted to assess trends over the study period (see below).

3.3.2 Area of Spawning

The actual wetted area of each spawning location was calculated across the entire range of WSEL values observed at the nearest hydraulic model transect during the study period (May 13 to June 22, 2015). The areas were calculated using one of two methods, depending on the type of data available for each location. Spawning Sites 1, 3, 8, 14, 16, and 20 (Figure 4.2.1-1) in the downstream reach and Site 23[3] in the TFI occurred in areas with full digital elevation models (DEMs) derived from bathymetric and LIDAR surveys. Sites 1, 3, 14, 16 and 20 are located just below the Deerfield River confluence. Bathymetric data were collected in this section as part of the River2D model developed for Study No. 3.3.1 *Instream Flow Studies in Bypass Channel and below Cabot Station*. Bathymetric data for Site 23, located near Stebbins Island in the TFI, were collected for use in the TFI hydraulic model (Study No. 3.2.2).

A computer program using Python script was developed to identify the portion of a DEM within the GPS-delineated boundaries of a spawning location that was less than or equal to a WSEL of interest, and then to calculate the surface area of that portion. This process was repeated for each spawning location for all WSEL values predicted during the shad spawning study period at the closest hydraulic model transect.

The remaining spawning locations in the downstream reach occurred in areas without DEM coverage. For these locations, the wetted surface area at the time of survey was calculated in ArcGIS directly from the GPS-delineated spawning location boundaries. These locations were then matched up with bathymetric

[3] Shad spawning in the TFI was only detected near Stebbins Island, below Vernon Dam.

transects from Study No. 3.3.1, and a distance-based approach was used to calculate wetted surface areas at all other predicted WSEL values. For a given WSEL at a spawning location, a Python script was used to calculate the linear distance along the x-axis of the nearest bathymetry transect that is impacted (exposed or inundated) by the change in WSEL. This impact distance was then multiplied by the length of the spawning location to calculate the area impacted. The impacted area was then subtracted from the area of the spawning location at the time of survey to calculate the wetted surface area of the spawning location at the given WSEL.

3.3.3 Habitat Duration Curves

Habitat duration curves were developed to explore the amount of time during the study period that a given WSEL was equaled or exceeded at each spawning location, as well as explore the amount of spawning habitat that was exposed at each WSEL. As noted above, calibrated hydraulic models of the TFI and the below Montague USGS Gage reach were developed. Using these models and inflows that occurred during the May 13 to June 22, 2015 spawning period, the WSEL at each spawning location was computed on an hourly basis. Using the hourly WSEL at each spawning location over the May 13 to June 22, 2015 period, the maximum, minimum, and median WSELs were computed. Spawning areas calculated as described in Section 3.3.2 above were classified as "exposed" when the wetted spawning area of a location was less than the wetted area at the median WSEL for that location. For each site, a list of WSELs from the hydraulic model and the proportion of exposed area was sorted by WSEL and assigned a rank. The ranks were then divided by the total number of WSELs for each location to calculate the probability of exceedance. Probability of exceedance was plotted versus both WSEL and the proportion of exposed habitat for each site.

3.3.4 Statistical Analyses

Statistical analyses were performed with R (R Foundation, 2011). Significance was considered for p-values less than 0.05, unless otherwise noted.

Effects on Spawning Activity

Individual negative binomial models[4] were applied to assess the effects of Cabot Station operations (unit changes and generation output) on splash counts, to serve as a proxy for spawning activity. Before and after splash counts (when generation logs confirmed a change in generation between the before and after counts) were aggregated and averaged to determine if increases and/or decreases in generation (turning on and off 1 or 2 units) affect the number of splashes recorded. As generation output (direct measurement) and discharge (calculated based on output) at Cabot Station are directly correlated, analyses were only performed with one variable (output, MW). In addition, as the duration between, before, and after splash count recordings was generally less than one hour, the effect of potential temperature changes on splash counts before, and after, generation changes was not assessed.

Individual models were developed to explore the effects of generation (MW), river flow (as measured by the Montague Gage), water temperature (as measured by field crews), photoperiod[5] (duration of daylight), and time since sunset (duration from sunset to time of count) on spawning activity throughout the season. Data were transformed using R, and reported estimates are log (ln) transformed.

[4] R MASS package using glm.nb function
[5] Sunset and sunrise information obtained from http://sunrisesunset.willyweather.com/ma/franklin-county/turners-falls.html; accessed January 11, 2016.

Effects on Spawning Habitat

When constructing habitat duration curves, time-stamped model outputs of WSEL, mean channel velocity, and maximum depth (from WSEL to the thalweg) were exported alongside measures of inundation and exposure. The effects of Cabot Station operations on downstream spawning locations were assessed with graphical methods.

4 RESULTS

4.1 Historic Operations and Flow Data

The hydraulic and generation capacity of Cabot Station is 13,728 cfs and 62,016 kW, respectively. The station includes six identical turbines, each with an approximate hydraulic and generation capacity of 2,288 cfs and 10,336 kW, respectively. The frequency and rate of operational changes from the past five years of Cabot Station operations are summarized in Table 4.1-1. These data represent generation and flow records at 30-minute intervals from 8 pm to 2 am, May 1 to June 30 each year. The original dataset consisted of 346 instances of generation changes out of the 3,965 records of 0.5-hr intervals (8% of the time) for the 5-year period. As displayed below, 55% of the changes consisted of increasing or decreasing generation by 10 MW (2,630 cfs) and an additional 20% were 20-MW (5,220 cfs) changes. Few 30-MW (7,886 cfs) or 40-MW (10,440 cfs) changes occurred; therefore, assessment of project impacts to shad spawning was conducted by increasing or decreasing generation at Cabot Station by 10 or 20 MW.

Typical flow during May and June in the Project area was determined from the Montague USGS Gage. The mean daily flow was obtained for the shad spawning period- May 13 to June 22, 2015 (considered provisional by the USGS in 2015), and compared to the long term mean daily flow from 1975-2014[6]. Mean daily flow over the period 1975-2014 ranged from approximately 10,000 to 30,000 cfs during the shad spawning period (Figure 4.1-1). Also shown on Figure 4.1-1 are the shad spawning survey dates. During the 2015 spawning period, mean daily flow ranged from a minimum of 5,380 cfs (May 28) to a maximum of 33,800 cfs (June 3), and averaged 13,995 cfs. River flow in May 2015 was generally lower than the mean long-term daily flow, whereas June 2015 flows were generally higher.

Shown in Figure 4.1-2 is the 15 minute instantaneous flow as measured at the Montague USGS Gage from May 13 to June 22, 2015 along with a) the shad spawning survey dates, and b) a flow line at 18,000 cfs, which is the approximate hydraulic capacity of the power canal. When flows exceed approximately 18,000 cfs both Cabot and Station No. 1 are typically operating at full hydraulic capacity. Thus, the Project has no ability to regulate flow when Montague Gage readings exceed approximately18,000 cfs.

Table 4.1-1: Summary of Historical Generation (MW) and Flow (cfs) Changes at Cabot Station During May and June Based on Operations Data From 2010 Through 2014

Generation Changes (MW)	Discharge Changes (cfs)	2010	2011	2012	2013	2014	Total	% of Total
		No. of MW Decreases						
40 to 30	10,440-7,836	1	2	3	4	5	15	4
30 to 20	7,836-5,220	1	2	3	2	2	10	3
20 to 10	5,220-2,630	5	5	11	5	4	30	9
10 to 0	2,630-0	19	16	9	20	11	75	22
		No. of MW Increases						
0 to 10	0-2,630	25	17	22	32	20	116	33
10 to 20	2,630-5,220	22	5	17	11	14	69	20
20 to 30	5,220-7,836	6	2	3	3	2	16	5
30 to 40	7,836-10,440	3	3	3	3	3	15	4

[6] Although the USGS Gage has been active since 1905, a more recent period was selected to reflect climate change and the development of flood control facilities in the basin above the Turners Falls Dam prior to 1975.

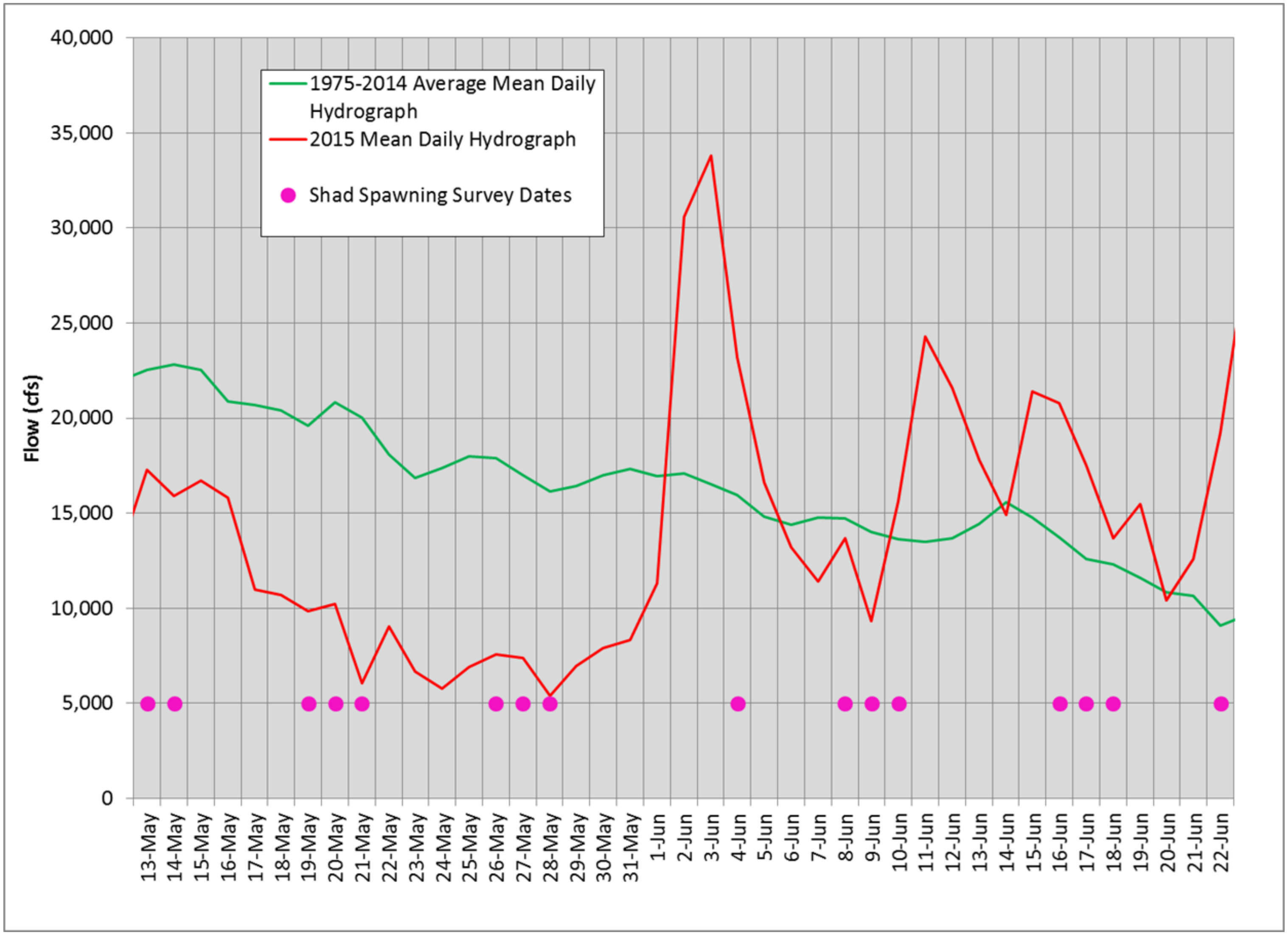


Figure 4.1-1: Connecticut River Mean Daily Flow at Montague USGS Gage from May 13-June 22: Comparison of Long-Term (1975-2014) Versus 2015

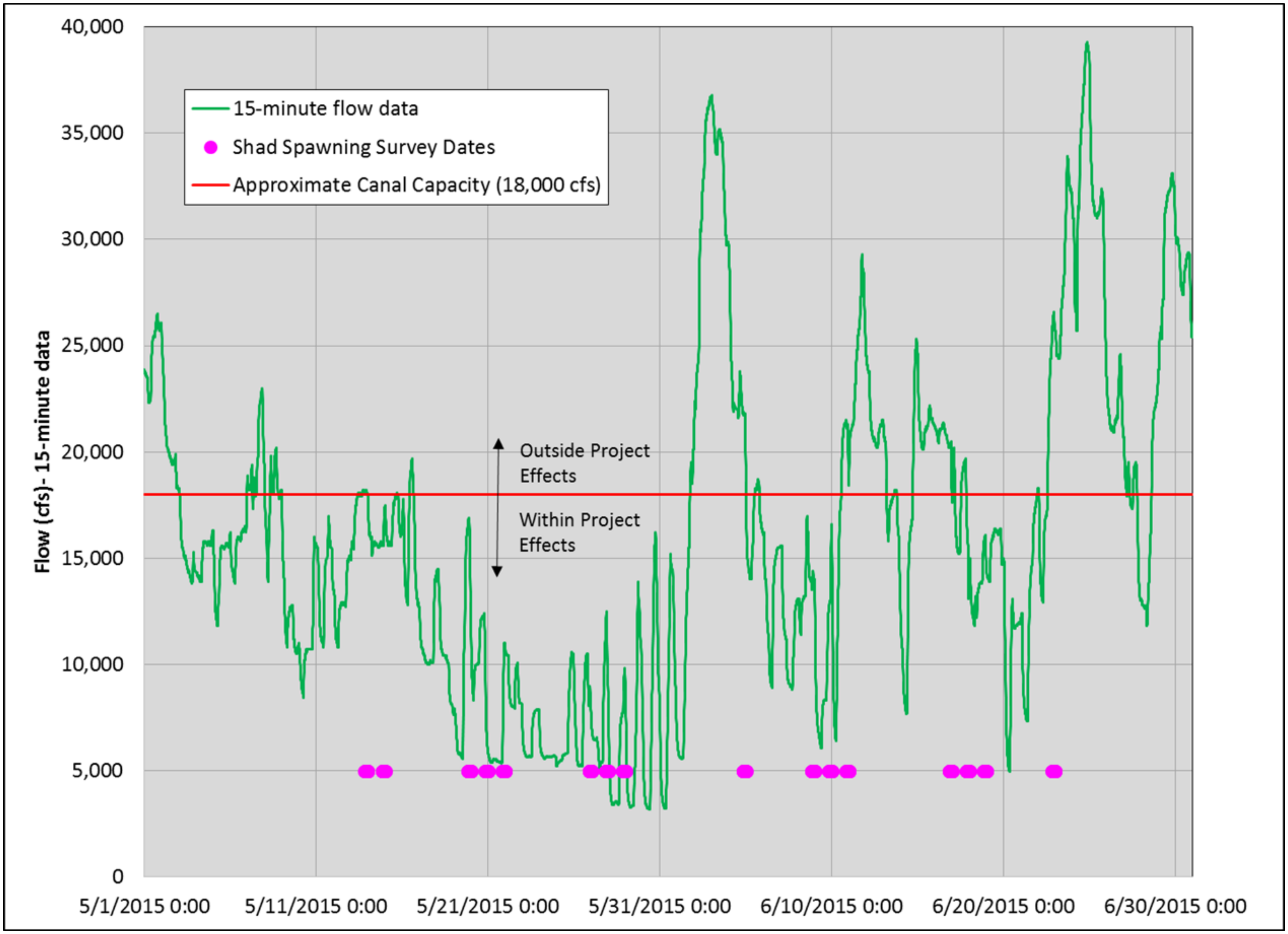


Figure 4.1-2: Connecticut River 15-Minute Instantaneous Flow at Montague USGS Gage from May 13-June 22, 2015

4.2 Spawning Surveys

Field activities for the shad spawning surveys commenced on May 13, 2015 after 10,000 shad had passed the Holyoke Project and continued through June 22, 2015 when upstream movements of shad had ceased and observed spawning activity tapered off. Field surveys were generally conducted 2-3 times a week during the study period. In some instances, high river flows or severe weather prevented surveys from being conducted (Table 4.2-1). FirstLight safety policies prevented field crews from accessing the impoundment when flow exceeded 20,000 cfs.

Table 4.2-1: Summary of Field Sampling Dates and Activities
(I=impoundment; C-B=canal-bypass; D=downstream reach from Cabot Station to Route 116 Bridge)

Week	Survey Date	Reach Surveyed	Comments
Week 1	5/13/2015, 5/14/2015	D	Initial surveys to identify spawning locations in D.
Week 2	5/19/2015, 5/20/2015, 5/21/2015	I, C-B, D	Begin surveys to assess operational changes in D; C-B and I surveys commence.
Week 3	5/26/2015, 5/27/2015, 5/28/2015	I, C-B, D	No I survey on 5/28/2015 due to outboard motor failure.
Week 4	6/4/2015	I, C-B, D	Remaining Week 4 surveys cancelled due to high flows (peak of 36,800 cfs on June 3).
Week 5	6/8/2015, 6/9/2015, 6/10/2015	I, C-B, D	Heavy rain on June 8; delayed start 6/10 due to severe thunderstorm/lightning.
Week 6	6/16/2015, 6/17/2015, 6/18/2015	I, C-B, D	Dense fog substantially reduced visibility on 6/18.
Week 7	6/22/2015	I, C-B, D	High river flows on 6/22 (up to 26,600 cfs) prevented control room from changing operations. Remaining Week 7 surveys cancelled due to high flows.

4.2.1 Downstream Reach

During the study period (May 13 to June 22, 2015), 22 unique spawning observations were documented between Cabot Station and the Route 116 Bridge during Phase 1 and Phase 2 field surveys (Table 4.2.1-1). Surveys typically commenced at sunset and observations of spawning activity were generally between 20:00 and 01:00[7]. Instantaneous discharge from Cabot Station (based on review of 15-minute interval records during the study period) on survey days ranged from 0 to 13,665 cfs[8], indicating generation ranged from zero to maximum output. Station No. 1 operated less frequently than Cabot Station, with discharge ranging from 0 to 2,210[9] cfs.

Identified spawning locations ranged from the Deerfield River confluence (RM 118.6) south to just above Third Island (RM 114.4) (Figure 4.2.1-1). Also shown on Figure 4.2.1-1 are the transects used in HEC-RAS hydraulic model. Spawning was most frequently observed between the Deerfield River confluence

[7] As the surveys spanned two dates, the observation of spawning in the early hours of June 18 at 00:15 was recorded by the field crew that began the survey on the evening of June 17. The following evening, no shad spawning was observed when crews conducted surveys from 20:08 (June 18) to 0:100 (June 19).
[8] Cabot's hydraulic and generating capacity is 13,728 cfs and 62,014 KW. Cabot discharge was indirectly calculated via 1 KWH= 0.2214 cfs (13,728/62,014).
[9] Station No. 1's hydraulic and generating capacity is 2,210 cfs and 5,693 KW. Station No. 1 discharge was indirectly calculated via 1 KWH= 03882 cfs (2,210/5,693).

and the railroad bridge near RM 116.8. The total estimated area of spawning locations identified in the downstream reach was approximately 106 acres (Table 4.2.1-2). The 2015 surveys confirmed shad spawning in the vicinity of the areas identified previously in the 1970s (Figure 4.2.1-2). Field crews recorded spawning behavior as darting and grouping. In general, groups of shad appeared to congregate at a spawning location, with individuals intermittently darting upwards and breaking the water surface, thereby causing splashes. In the downstream reach, the average splash count recorded over a 15-minute interval varied, ranging from 3 to 215.5, with a mean of about 43 splashes.

Discrete water quality, depth and surface velocity measurements recorded for each spawning observation are provided in Table 4.2.1-2. At the times of the surveys, water temperature ranged from 15.8 to 20.2 °C; DO ranged from 9.0 to 13.4 mg/L, pH ranged from 6.2 to 7.4, secchi depth ranged from 5.5 to 9.5 ft, depth measured from 3.3 to 16.0 ft, and surface velocity ranged from 0.1 to 2.8 fps. It should be noted that to safely deploy equipment and accurately collect measurements of physical parameters at the spawning locations, boat crews typically tied off close to the shore to stabilize the boat; therefore, values reported in Table 4.2.1-2 are not necessarily representative of the entire area over which spawning occurred. As such, temperature data recorded at 15-minute intervals over the course of the 2015 spawning survey period was obtained from temperature loggers installed in 2015 as part of Study No. 3.2.1 *Water Quality Monitoring Report*. The temperature loggers referenced in this study- Water Quality Station Nos. 11, 12, and 13 -- are shown in Figure 4.2.1-1. The temperature logger closest to shad spawning locations were plotted as shown in Figures 4.2.1-3, 4.2.1-4, and 4.2.1-5. The discrete temperature measurements collected for each unique spawning event by the field crew at the time of survey are also depicted for reference.

As the spawning surveys were conducted at night, substrate type could not be accurately identified by the field crews; therefore, dominant substrate types at spawning locations were ascertained from data collection efforts related to Study No. 3.3.1 (*Conduct Instream Flow Habitat Assessment in the Bypass reach and below Cabot Station*). All of the identified spawning areas in the downstream reach predominantly consisted of cobble and/or gravel (Table 4.2.1-3). Mesohabitat classifications, also determined as part of Study No. 3.3.1, for the spawning locations were mostly run, with pool-type habitat also present.

Table 4.2.1-1: Summary of Conditions Observed During Shad Spawning Surveys Conducted in the Downstream Reach

Date	Time (EDT)	Location	Cabot Discharge* (cfs)	Station No. 1 Discharge* (cfs)	Instantaneous River Discharge USGS01170500* (cfs)	Average Splash Count (No./15 min.)	Behavior
5/13/2015			13632	0	18200	No shad spawning observed	
5/14/2015	21:15	1	11398	0	15700	36.0	darting, grouping
5/14/2015	20:18	2	11462	0	15700	17.0	darting, grouping
5/19/2015	17:05	3	11274	2194	14600	46.0	darting, grouping
5/19/2015	23:03	4	6875	2194	15700	18.0	darting, grouping
5/20/2015			6923	2210	12400	No shad spawning observed	
5/21/2015	21:51	5	6824	2201	8780	42.0	darting
5/21/2015	22:37	6	6751	1664	10600	107.0	darting, grouping
5/21/2015	23:40	7	6939	1212	11000	29.0	darting, grouping
5/26/2015	20:56	8	2336	0	8310	76.5	darting
5/26/2015	21:34	8	4663	0	8150	69.0	darting
5/26/2015	22:10	9	4614	0	8830	215.5	darting
5/26/2015	22:51	9	2263	0	9000	205.0	darting
5/27/2015	22:50	10	18	1216	11000	37.5	darting
5/27/2015	23:40	10	2227	1208	9240	25.5	darting
5/28/2015	0:15	11	2287	1227	8690	56.0	darting
5/28/2015	0:50	11	18	1242	8190	46.0	darting
5/28/2015	20:46	12	4530	1223	7710	31.5	darting
5/28/2015	22:08	12	6950	1230	9240	14.0	darting
5/28/2015	23:13	13	6976	1212	9760	30.0	darting
5/28/2015	23:57	13	4714	1227	9150	9.5	darting
6/4/2015			13519	2210	23600	No shad spawning observed	
6/8/2015			9142	0	14400	No shad spawning observed	
6/9/2015	20:00	14	9102	0	12500	36.5	darting
6/9/2015	20:43	14	9139	0	12700	22.0	darting
6/9/2015	23:45	15	13665	0	16000	9.5	darting
6/10/2015	0:30	15	9046	0	16200	3.0	darting
6/10/2015	22:29	16	13432	2205	21300	11.0	darting
6/10/2015	23:22	16	8973	2157	20900	11.5	darting
6/10/2015	23:51	17	9153	2194	19400	34.5	darting
6/11/2015	0:27	17	13499	2209	18400	29.0	darting
6/16/2015	22:38	18	13514	2210	20400	72.0	darting
6/16/2015	23:20	18	8987	2210	20400	35.5	darting
6/17/2015	0:24	19	9961	2210	17600	4.5	darting
6/17/2015	0:55	19	13421	2172	18700	4.0	darting

Date	Time (EDT)	Location	Cabot Discharge* (cfs)	Station No. 1 Discharge* (cfs)	Instantaneous River Discharge USGS01170500* (cfs)	Average Splash Count (No./15 min.)	Behavior
6/17/2015	22:20	20	9124	2210	15800	10.5	darting
6/17/2015	23:07	20	4554	2210	15600	17.5	darting
6/17/2015	23:33	21	4585	2210	14100	41.5	darting
6/18/2015	0:15	21	9055	2198	13500	21.5	darting
6/18/2015			3512	0	16100	No shad spawning observed	
6/22/2015	21:59	22	12943	2210	26400	57.5	darting
		Minimum	18	0	7710	3.0	
		Maximum	13665	2210	26400	215.5	
		Average	7646	1329.3	13868	42.6	

* For dates when no shad spawning was observed, the maximum value occurring between 17:00 and 01:00 is reported.

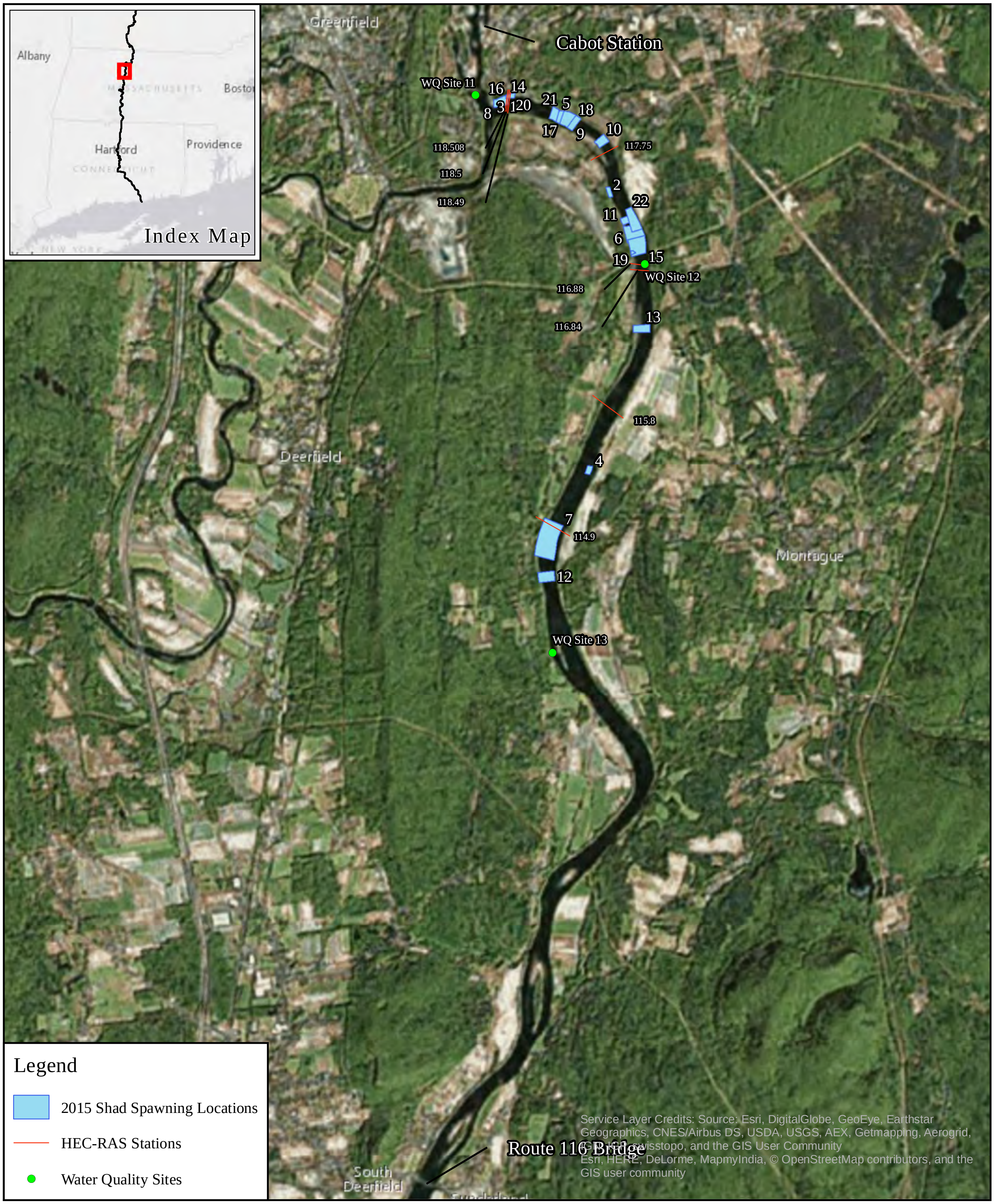
Table 4.2.1-2: Summary of Physical Measurements Recorded During Shad Spawning Surveys Conducted Downstream of Cabot Station

(n/d = no data collected)

Date	Spawning Site ID	Estimated Area (acres)	Water Temp. (°C)	DO (mg/l)	pH	Secchi Depth (ft)	Water Depth (ft)	Surface Velocity (fps)
5/14/2015	1	1.26	16.4	10.0	6.4	9.0	14.1	2.4
5/14/2015	2	1.4	16.4	10.1	6.7	9.0	8.5	2.3
5/19/2015	3	1.21	16.3	13.4	6.2	9.5	12.8	2.3
5/19/2015	4	1.49	16.3	12.7	6.6	n/d	4.3	2.8
5/21/2015	5	7.44	15.8	10.9	6.3	9.0	8.2	1.0
5/21/2015	6	11.21	15.8	11.7	7.0	9.0	6.9	0.5
5/21/2015	7	24.42	15.8	10.6	7.2	n/d	3.3	1.0
5/26/2015	8	4.36	17.7	10.5	6.6	8.3	14.5	0.1
5/26/2015	9	4.68	17.7	10.3	6.6	n/d	6.6	1.1
5/27/2015	10	3.34	18.4	10.1	6.7	7.5	8.0	0.1
5/28/2015	11	3.41	18.8	9.9	6.7	7.5	11.0	0.8
5/28/2015	12	5.49	19.1	9.1	6.9	9.0	14.0	0.8
5/28/2015	13	4.08	18.6	9.4	7.2	n/d	4.0	1.0
6/9/2015	14	0.68	17.3	9.5	6.8	n/d	5.2	0.9
6/9/2015	15	9.15	17.2	9.5	6.5	8.5	9.0	1.0
6/10/2015	16	0.70	18.0	9.2	6.5	6.8	10.0	1.7
6/10/2015	17	4.85	18.3	9.4	7.0	7.5	14.0	1.2
6/16/2015	18	5.05	18.7	9.9	7.4	6.0	10.0	0.7
6/17/2015	19	0.42	18.6	9.1	7.4	6.0	10.0	0.7
6/17/2015	20	1.42	18.9	9.0	7.4	8.0	16.0	0.4
6/17/2015	21	3.10	18.8	9.1	7.4	8.0	10.0	0.2
6/22/2015	22	6.75	20.2	10.0	7.4	5.5	6.0	1.4
	Minimum	0.42	15.8	9.0	6.2	5.5	3.3	0.1
	Maximum	24.42	20.2	13.4	7.4	9.5	16.0	2.8
	Average	4.81	17.7	10.1	6.9	7.9	9.4	1.1

Table 4.2.1-3: Mesohabitat Type and Dominant Substrates for the Spawning Locations identified in the Downstream Reach

Spawning Site ID	Mesohabitat Type	Dominant Substrate(s)
1	Pool/Run	Gravel/Cobble
2	Run	Cobble
3	Pool/Run	Gravel/Cobble
4	Run	Cobble
5	Run	Cobble
6	Run	Cobble
7	Run	Cobble
8	Pool	Gravel
9	Run	Cobble
10	Run	Cobble
11	Run	Cobble
12	Run	Cobble
13	Run	Cobble
14	Pool/Run	Gravel/Cobble
15	Run	Cobble
16	Pool/Run	Gravel/Cobble
17	Run	Cobble
18	Run	Cobble
19	Run	Cobble
20	Pool/Run	Gravel/Cobble
21	Run	Cobble
22	Run	Cobble



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

Study No. 3.3.6

Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the Area of Northfield Mountain and Turners Falls Project

N

0 0.25 0.5 1 Miles

Figure 4.2.1-1: Spawning Locations Identified in the Downstream Reach

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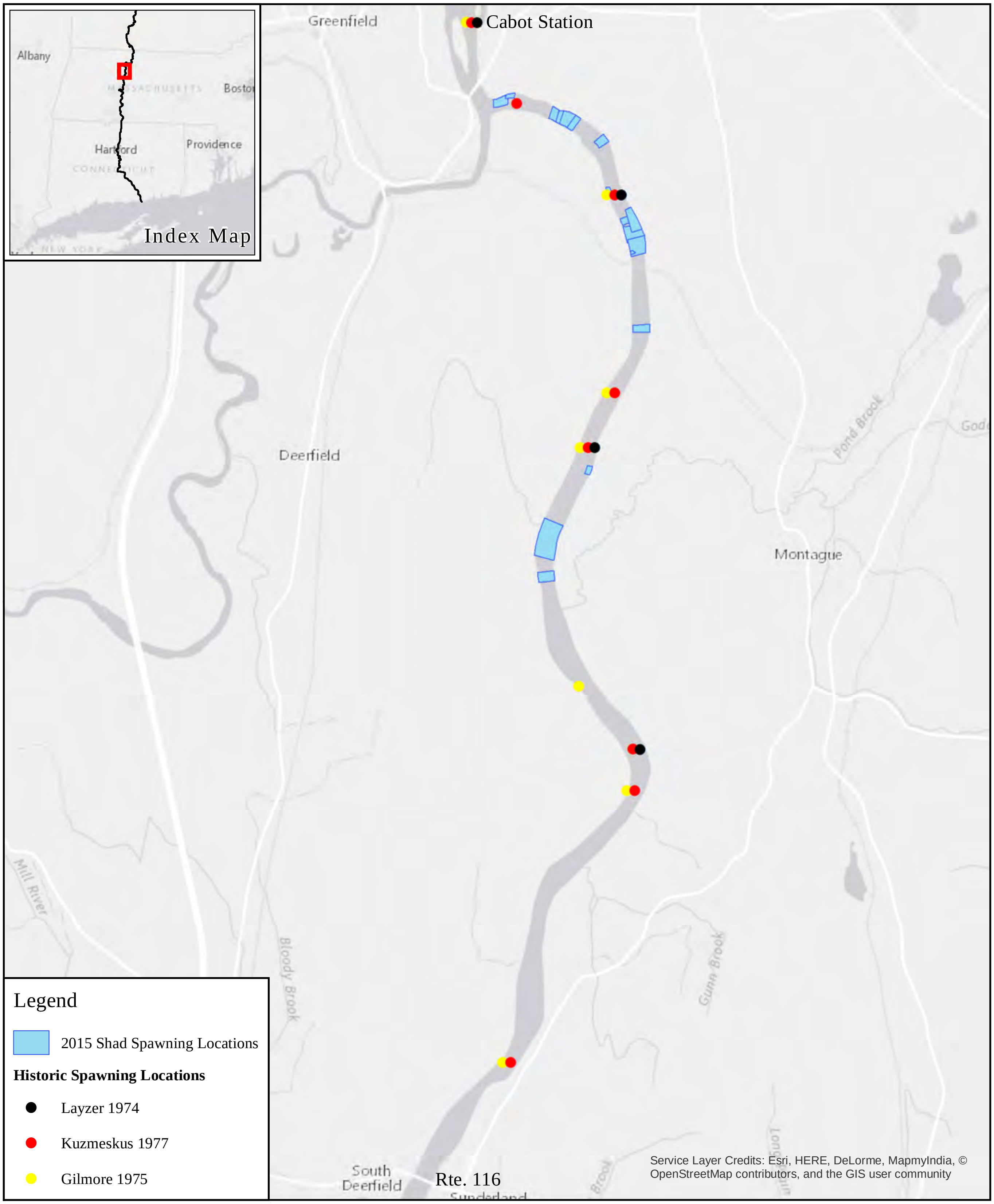

FirstLight GDF SUEZ

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

Study No. 3.3.6
Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the Area of Northfield Mountain and Turners Falls Project

Figure 4.2.1-2:
Spawning Locations Identified in the Downstream Reach in 2015 Surveys, as well as in the 1970s by Previous Researchers

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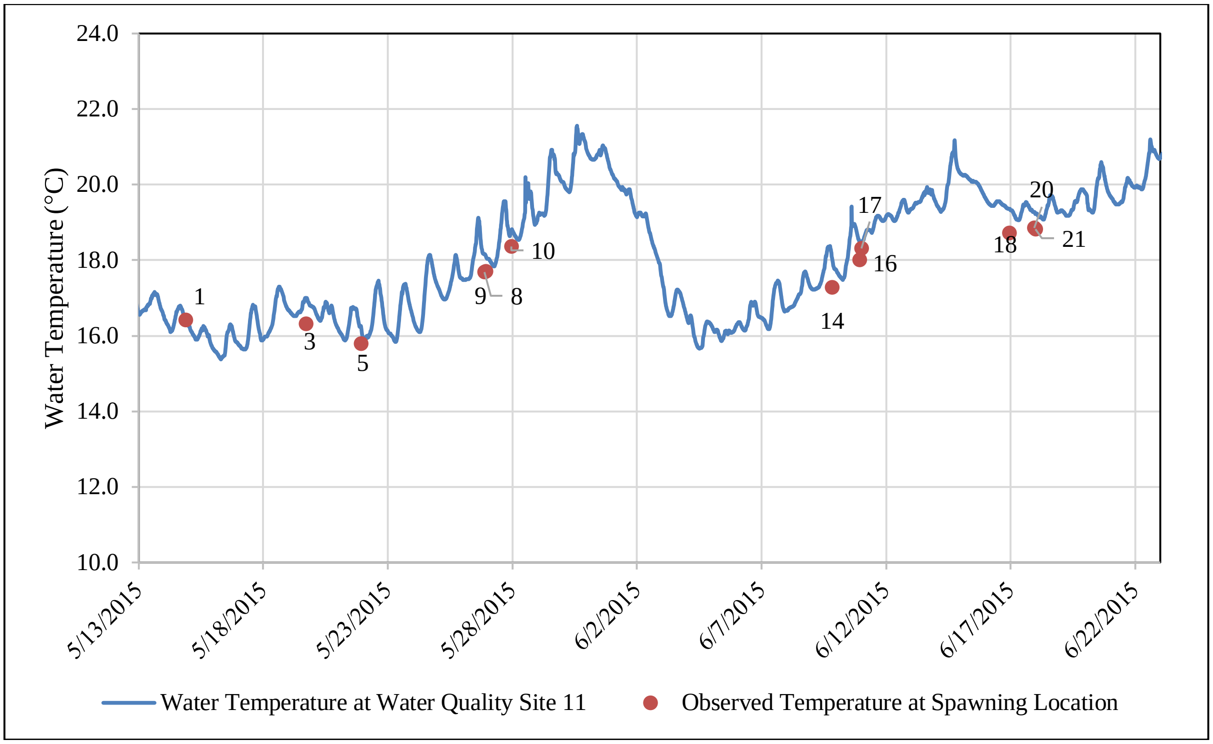


Figure 4.2.1-3: Water Temperature Recorded at Water Quality Site 11 throughout the 2015 Shad Spawning Season

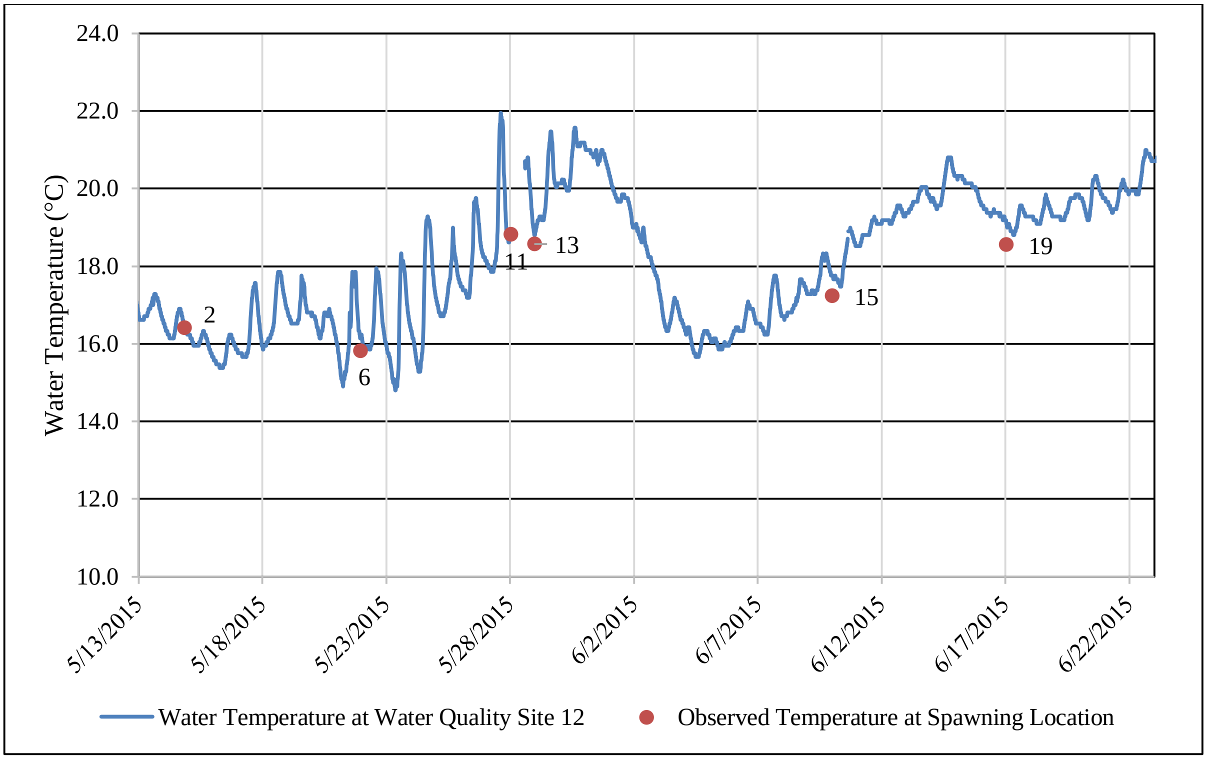


Figure 4.2.1-4: Water Temperature Recorded at Water Quality Site 12 throughout the 2015 Shad Spawning Season

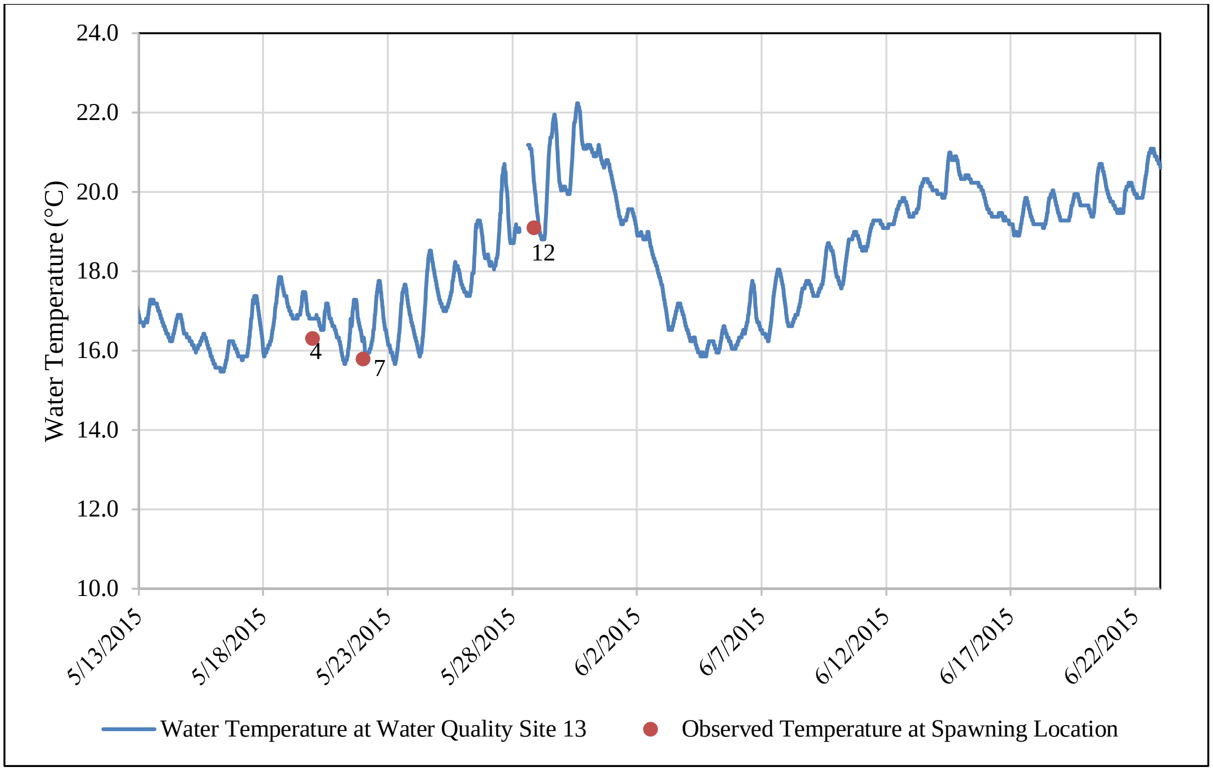


Figure 4.2.1-5: Water Temperature recorded at Water Quality Site 13 throughout the 2015 Shad Spawning Season

4.2.2 Turners Falls Impoundment

Seven unique spawning events were observed in the TFI during field surveys (Table 4.2.2-1). Spawning activity was only observed at one location in the TFI, in the vicinity of the downstream end of Stebbins Island (Figure 4.2.2-1), which is approximately 13.7 RM upstream of the Northfield Mountain Intake. Also shown on Figure 4.2.2-1 are the transects used in HEC-RAS hydraulic model.

Observations generally occurred between 20:00 and 23:00 (EDT), with average splash counts ranging from 5 to 265 over a 15-minute interval. Water temperature ranged from 15.6 to 18.8 C, DO ranged from 9.9 to 11.4 mg/L, pH ranged from 6.4 to 8.2, and secchi depth ranged from 5.0 to 7.5 ft. Water depth at the locations of the measurements ranged from 6.8 to 11.0 ft and surface velocity ranged from 0.1 to 1.6 fps.

Spawning was observed over an approximately 39 acre area at this location. Substrate was dominated by gravel and sand, with mesohabitat classified as a mixture of pool, run, and glide (Normandeau Associates, 2015).

American Shad eggs were identified in all samples that were collected[10] downstream from observed spawning activity. Estimated densities of American Shad eggs in the plankton samples ranged from 7 to 101 eggs per 100 m^3 (Table 4.2.2-2). Two shad larvae were also identified in the samples.

[10] No ichthyoplankton tow was conducted on June 16, 2015 due to severe fog conditions.

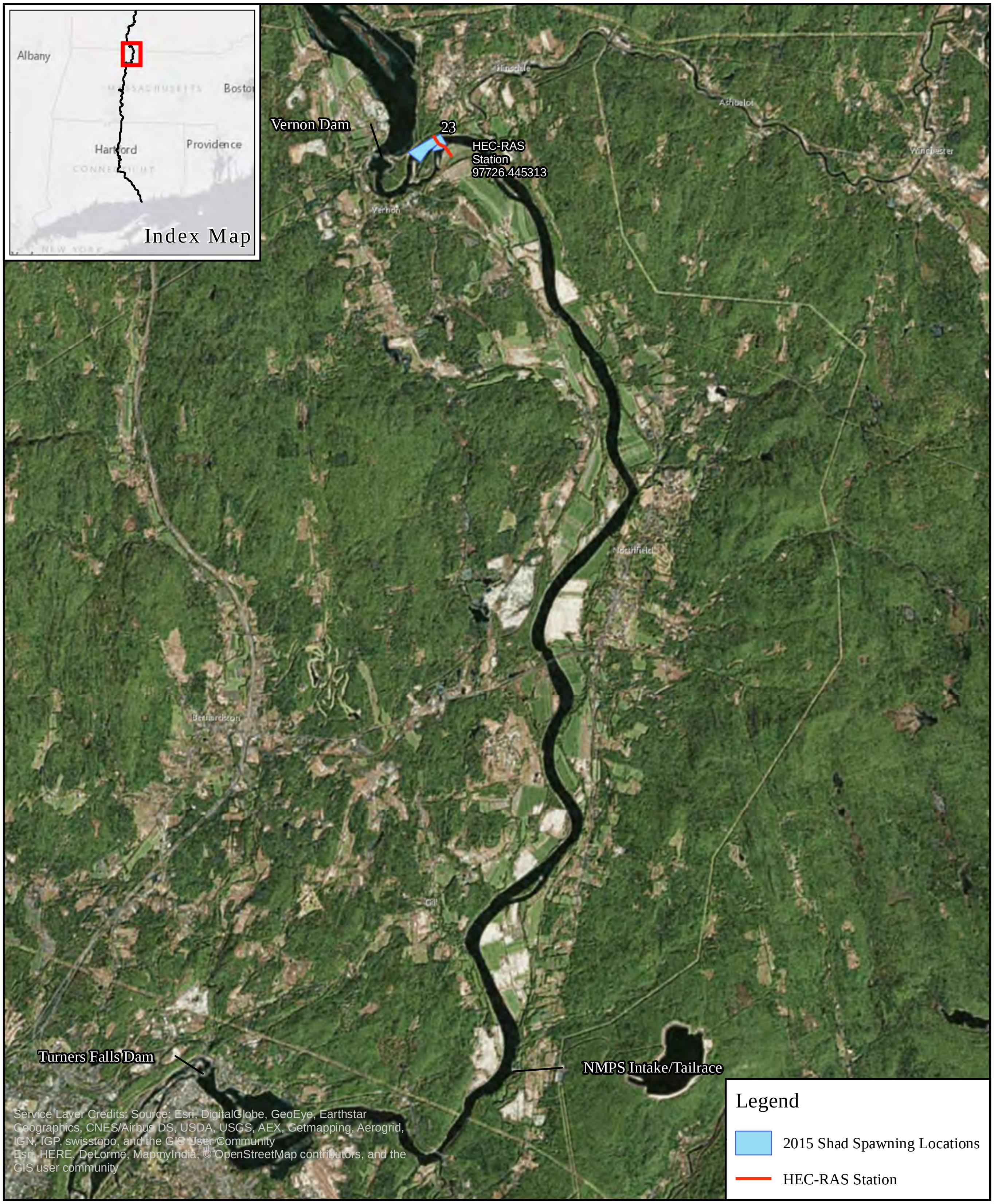
Table 4.2.2-1: Summary of Conditions Observed During Shad Spawning Surveys Conducted in the Turners Falls Impoundment

Date	Time (EDT)	Average Splash Count (No./15 min.)	Water Temp. (°C)	DO (mg/l)	pH	Secchi Depth (ft)	Water Depth (ft)	Surface Velocity (ft/sec)	WSEL NGVD29 (ft)	Vernon Discharge (cfs)	Plankton Tow
5/19/2015	20:33	8	16.4	10.1	7.4	6.8	8.0	0.1	184.39	7944	Yes
5/20/2015	20:21	5	15.6	9.9	7.4	6.0	7.0	1.3	183.16	4345	Yes
5/21/2015			No shad spawning observed								
5/26/2015	20:57	265	17.8	11.4	6.4	5.0	9.5	1.3	183.34	5006	Yes
5/27/2015	22:25	253	18.7	10.5	7.3	6.8	7.5	0.8	182.89	1942	Yes
5/28/2015			No survey conducted due to boat engine failure								
6/4/2015			No shad spawning observed; No other surveys conducted this week due to high flows								
6/8/2015			No shad spawning observed								
6/9/2015			No shad spawning observed								
6/10/2015			No shad spawning observed								
6/16/2015	22:00	56	18.6	10.0	8.17	7.5	11.0		185.31	17535	No
6/17/2015	22:49	24	18.6	9.9	7.38	5.5	7.0	0.06	183.03	8932	Yes
6/18/2015	22:15	89	18.8	10.3	7.55	5.4	6.8	1.6	184.61	13279	Yes
6/22/2015			No shad spawning observed								
	Average	100	17.8	10.3	7.4	6.1	8.1	0.9	183.82	8426	
	Minimum	5	15.6	9.9	6.4	5.0	6.8	0.1	182.89	1942	
	Maximum	265	18.8	11.4	8.2	7.5	11.0	1.6	185.31	17535	

Table 4.2.2-2: Summary of Ichthyoplankton Sample Collections and Contents

Date	Time	Total Sample Volume (m^3)	No. Observed		Density (No./100 m^3)	
			Eggs	Larvae	Eggs	Larvae
5/19/15	20:33	166.9*	13	0	7	-
5/20/15	20:21	166.9*	30	1	17	0.5
5/26/15	20:57	166.9*	103	1	61	0.5
5/27/15	22:25	84.4	86	0	101	-
6/17/15	22:49	240.8	18	0	7	-
6/18/15	22:15	175.4	34	0	19	-

* Estimated due to flow meter malfunction or lack of flow meter during sampling



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

Study No. 3.3.6

Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the Area of Northfield Mountain and Turners Falls Project

N

0 0.75 1.5 3 Miles

Figure 4.2.2-1: Location of Shad Spawning Activity Identified in the TFI

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4.2.3 Canal/Bypass Reach

Shad spawning surveys of the Turners Falls Canal and bypass reach were conducted on 14 nights between May 19 and June 22, 2015, generally from sunset until 01:00. Only one potential spawning event was observed in the canal, occurring during the June 18, 2015 survey, in an area approximately 0.9 acres in size located along Migratory Way, just downstream from where the canal widens (Figure 4.2.3-1; Table 4.2.3-1). An average of 10 splash counts was recorded, but the splashes were distant enough from shore that fish behavior was not identified, and positive identification of the fish making the splashes was not possible. The observation occurred at 00:24, about 3.9 hours after sunset. Note that no water quality measurements were collected in the canal or bypass reach due to safety considerations.

Based on Study Report No. 3.3.18 *Impacts of Turners Falls Canal Drawdown on Fish Migration and Aquatic Organisms*, substrate in this section of the canal is dominated by silt, with SAV also present. Throughout the study period for this reach (May 19 to June 22, 2015), flow in the canal ranged from a minimum of 798 cfs to a maximum of approximately 18,000 cfs and averaged approximately 9,343 cfs. On the date of the shad spawning observation, flow through the canal was above average (approximately 11,000 cfs).

On the same date, a single spawning event was also observed in the bypass reach, over an area approximately 2.7 acres in size located downstream of Rock Dam and near the downstream end of Rawson Island (Figure 4.2.3-1). Spawning activity was more intense in the bypass reach than the canal, with an average of 133 splash counts in a 15-minute period. Time of the observation was 22:17, about 1.8 hours after sunset. Splashes were observed in the tail of the Rock Dam pool down through a run that was present at the time of the survey due to relatively low water levels in the bypass reach. Data collected in support of Study No. 3.3.1 indicate substrate comprised mainly of gravel at the observed spawning area.

Table 4.2.3-1: Summary of Shad Spawning Survey Observations in the Turners Falls Canal and Bypass Reach

Date	Reach	Location	Time (EDT)	Average Splash Count
5/19/2015	No shad spawning observed			
5/20/2015	No shad spawning observed			
5/21/2015	No shad spawning observed			
5/26/2015	No shad spawning observed			
5/27/2015	No shad spawning observed			
5/28/2015	No shad spawning observed			
6/4/2015	No shad spawning observed; No other surveys conducted this week due to high flows			
6/8/2015	No shad spawning observed			
6/9/2015	No shad spawning observed			
6/10/2015	No shad spawning observed			
6/16/2015	No shad spawning observed			
6/18/2015	Canal	24	0:24	10
6/18/2015	Bypass Reach	25	22:17	133
6/22/2015	No shad spawning observed			

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

Study No. 3.3.6

Impact of Project Operations on Shad Spawning, Spawning Habitat and Egg Deposition in the Area of Northfield Mountain and Turners Falls Project

Figure 4.2.3-1:
Location of Shad Spawning Activity Identified in the Turners Falls Canal and Bypass Reach

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4.3 Data Analysis (Impact Evaluation)

The effects of changes in Cabot Station generation (turning on and off 1 or 2 units) on shad spawning activity were assessed during Phase 2 of the downstream reach surveys. A summary of observations pertaining to the following sections is provided in Table 4.3-1.

Table 4.3-1: Summary of Data used for Assessing Effects of Turners Falls Project Operations on Shad Spawning

Date	Instantaneous River Flow Montague USGS Gage (cfs)	Time (EDT)		Site ID	Cabot Generations (MW)		Number of Units		Average Splash Count (No./15 min.)		Area	
		Before	After		Before	After	Before	After	Before	After	Before (acres)	After (% change)
5/26/2015	8,310	20:56	21:34	8	10.5	21.1	1	2	76.5	69	4.36	-0.20%
5/26/2015	8,830	22:10	22:51	9	20.8	10.2	2	1	215.5	205	4.68	+0.19%
5/27/2015	11,000	22:50	23:40	10	0.08	10.1	0	1	37.5	25.5	3.34	-1.99%
5/28/2015	8,690	00:15	00:50	11	10.3	0.08	1	0	56	46	3.41	0%
5/28/2015	7,710	20:46	22:08	12	20.5	31.4	2	3	31.5	14	5.49	+0.12%
5/28/2015	9,760	23:13	23:57	13	31.5	21.3	3	2	30	9.5	4.08	+0.09%
6/9/2015*	9,102	20:00	20:43	14	41.1	41.3	4	4	36.5	22	0.68	+0.25%
6/9-10/2015	13,665	23:45	00:30	15	61.7	40.9	6	4	9.5	3	9.15	+0.14%
6/10/2015	13,432	22:29	23:22	16	60.7	40.5	6	4	11	11.5	0.70	-0.08%
6/10-11/2015	9,153	23:51	00:27	17	41.3	61	4	6	34.5	29	4.85	0%
6/16/2015	13,514	22:38	23:20	18	61	40.6	6	4	72	35.5	5.05	0%
6/17/2015	9,961	00:24	00:55	19	45	60.6	4	6	4.5	4	0.42	0%
6/17/2015	9,124	22:20	23:07	20	41.2	20.6	4	2	10.5	17.5	1.42	-0.04%
6/17-18/2015	4,585	23:33	00:15	21	20.7	40.9	2	4	41.5	21.5	3.10	-0.08%
6/22/2015*	12,943	21:59		22	58.5	58.5	6	6	57.5		6.75	

* No change in generation based on station logs

4.3.1 Spawning Activity

Histograms reveal that the splash counts before and after generation changes were relatively similar with the distributions skewed by relatively few higher counts (Figure 4.3.1-1). The negative binomial model found no statistical difference ($p = 0.302$) in the mean splash counts before (47.6 splashes per 15-minute time period) and after (36.6 splashes per 15-minute time period) changes in generation at Cabot Station.

Cabot Station generation and river flow as measured at the Montague USGS Gage were compared, and as expected, the relationship appeared linear (Figure 4.3.1-2). It should be noted that Cabot Station and Station No. 1 have no ability to regulate flow when the Montague Gage exceeds approximately 18,000 cfs as this represents the hydraulic capacity of the Turners Falls Power Canal. As discharge from the Deerfield River also influences conditions at the Montague USGS Gage, only the effects of Cabot Station generation were analyzed. The effects of water temperature (°C), total output (or production, MW), time-since-sunset (decimal hours), and photoperiod (decimal hours) on splash counts (Figure 4.3.1-3) were assessed with a multiple regression. The y-intercept for the negative binomial model was not significantly different from zero; however, the slope (m) for total Cabot Station output MW ($m=-0.016$; standard error (SE) = 0.007) and time-since-sunset ($m=-0.16$; SE = 0.06) were significant ($p = 0.02$ and $p = 0.005$, respectively). Time–since-sunset had a much larger effect than total Cabot Station output MW, which indicates that splash counts decrease as time-since-sunset increases regardless of Cabot Station generation.

Splash counts measured over time were examined for patterns of change by means of regression analysis. When the relationship between observations close in time is more similar than the relationship of measurements spaced further apart in time, then these data are considered to exhibit positive autocorrelation (Hubert & Fabrizio, 2007). The presence of autocorrelation in splash counts compromises statistical independence of the data, as well as the interpretation of correlation and regression analysis (Hubert & Fabrizio, 2007). A test for autocorrelation was conducted with a Durbin-Watson test (Durbin & Watson, 1950) and was significant ($p < 0.001$), suggesting that the data exhibit serial autocorrelation. Although the data have not been tested for relationships over time with photoperiod as a predictor, splash counts recorded from downstream spawning sites appeared to peak when photoperiod was between 14.8 and 15.0 hours (Figure 4.3.1-3). Incorporating data (splash counts) recorded from the TFI site (Figure 4.3.1-4) provided further evidence of spawning activity peaking when photoperiod was 14.8 to 15 hours in duration, which corresponds to dates between May 20 and May 27, 2015. This suggests that photoperiod may potentially be the driving factor influencing spawning activity.

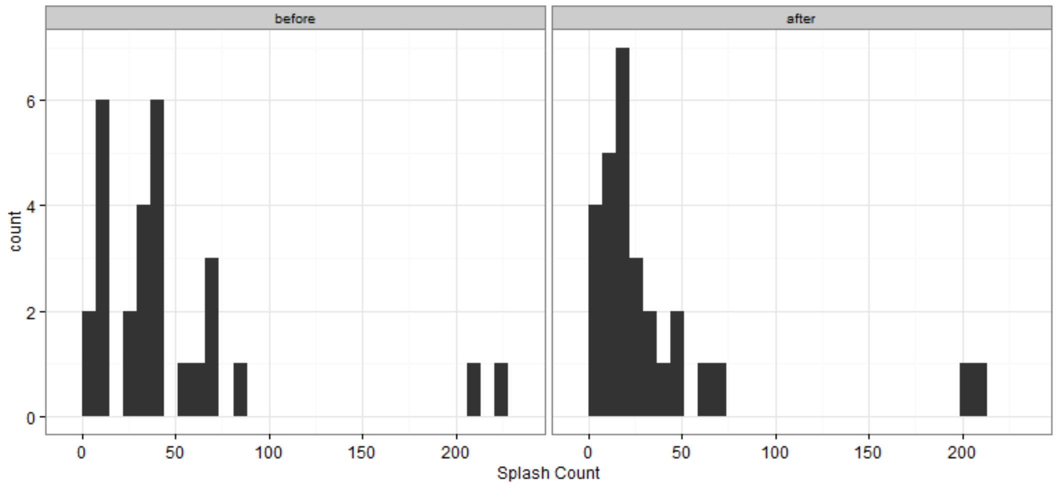

Figure 4.3.1-1: Histogram of Splash Counts (No./15 min.) Recorded Before and After Changes in Cabot Station Generation

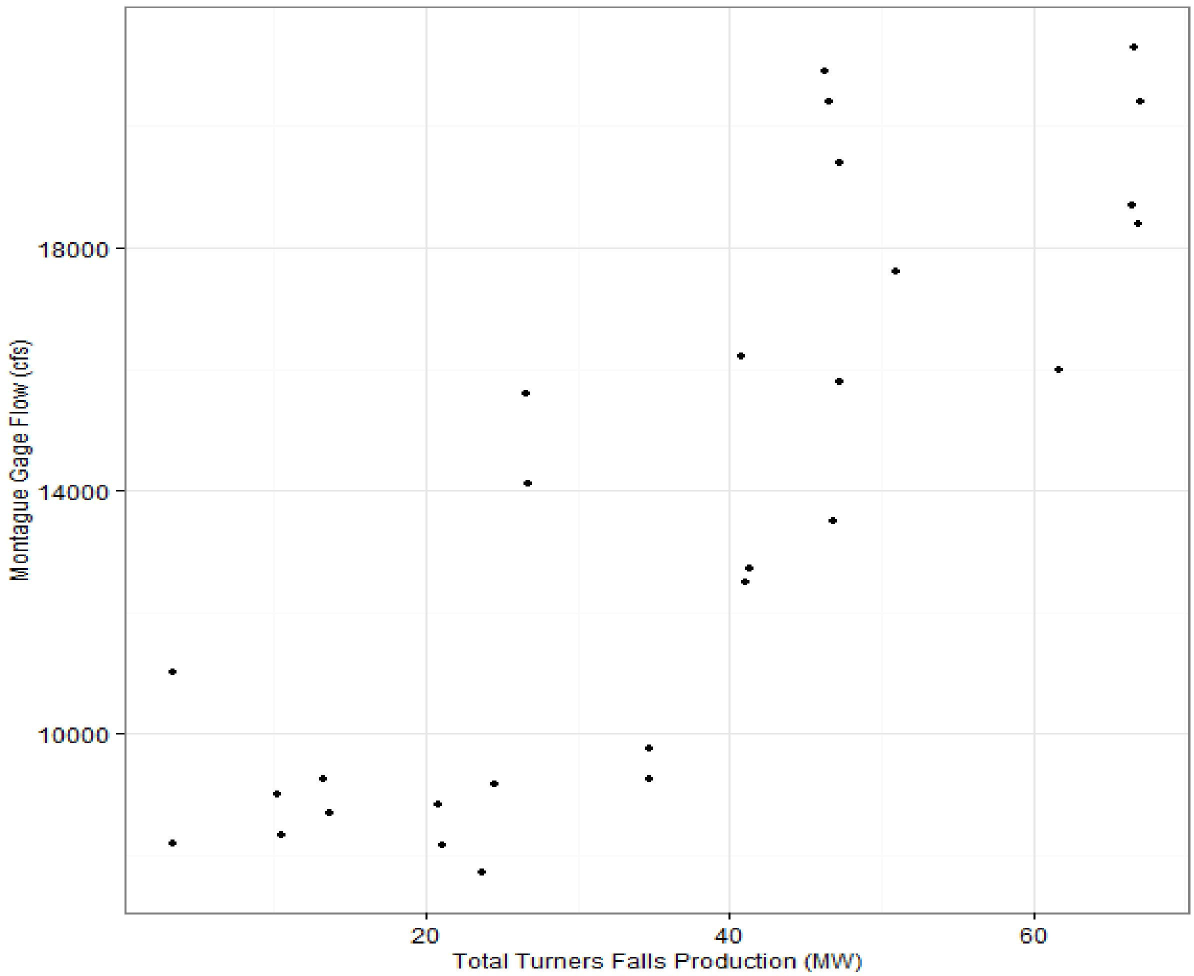

Figure. 4.3.1-2: Montague USGS Gage Flow (cfs) and Cabot Station Output (MW) during the 2015 Study Period

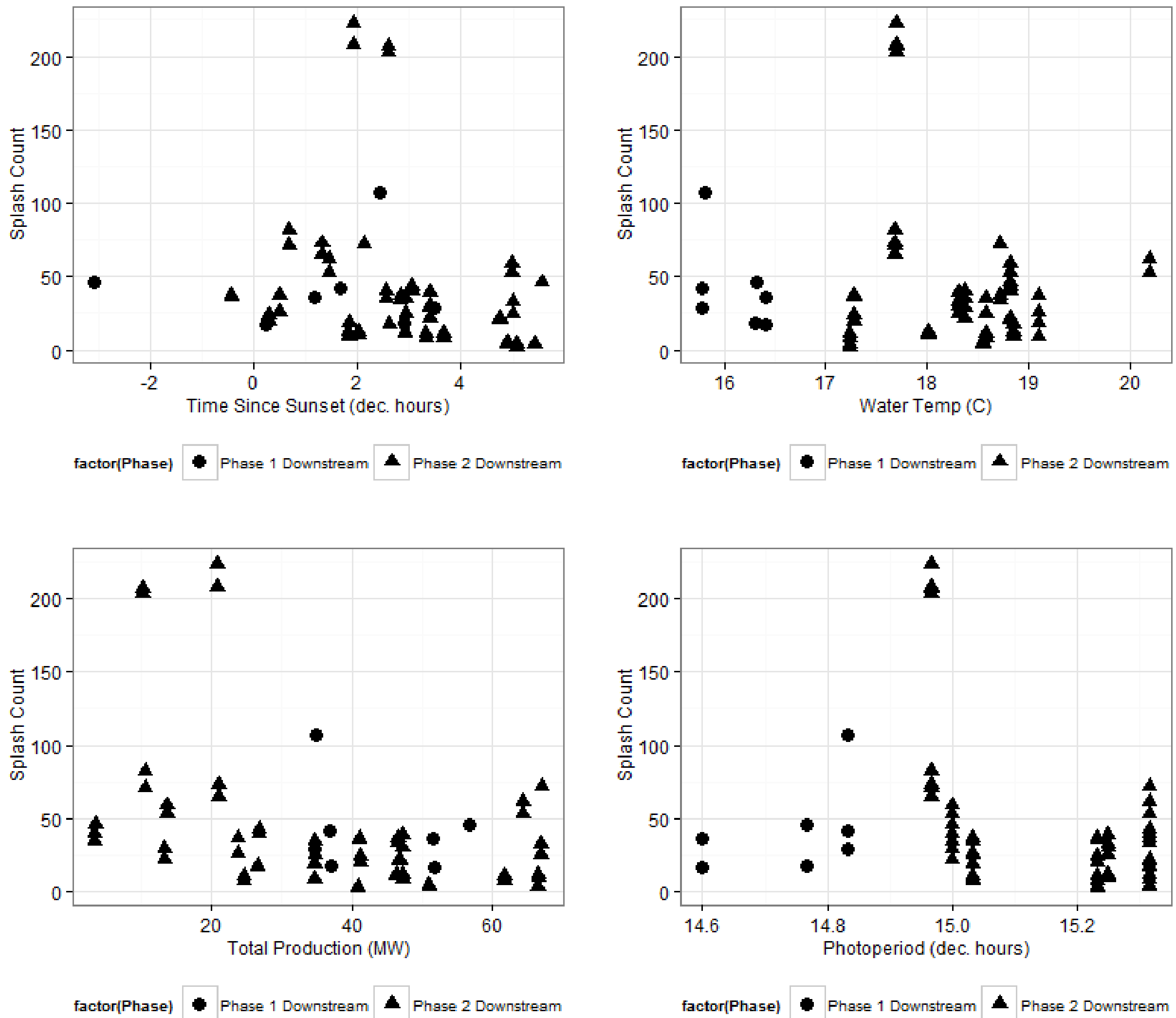

Figure 4.3.1-3: Comparison of Splash Counts (No./15 min) in Relation to Time since Sunset, Water Temperature, Total Production (at Cabot Station), and Photoperiod

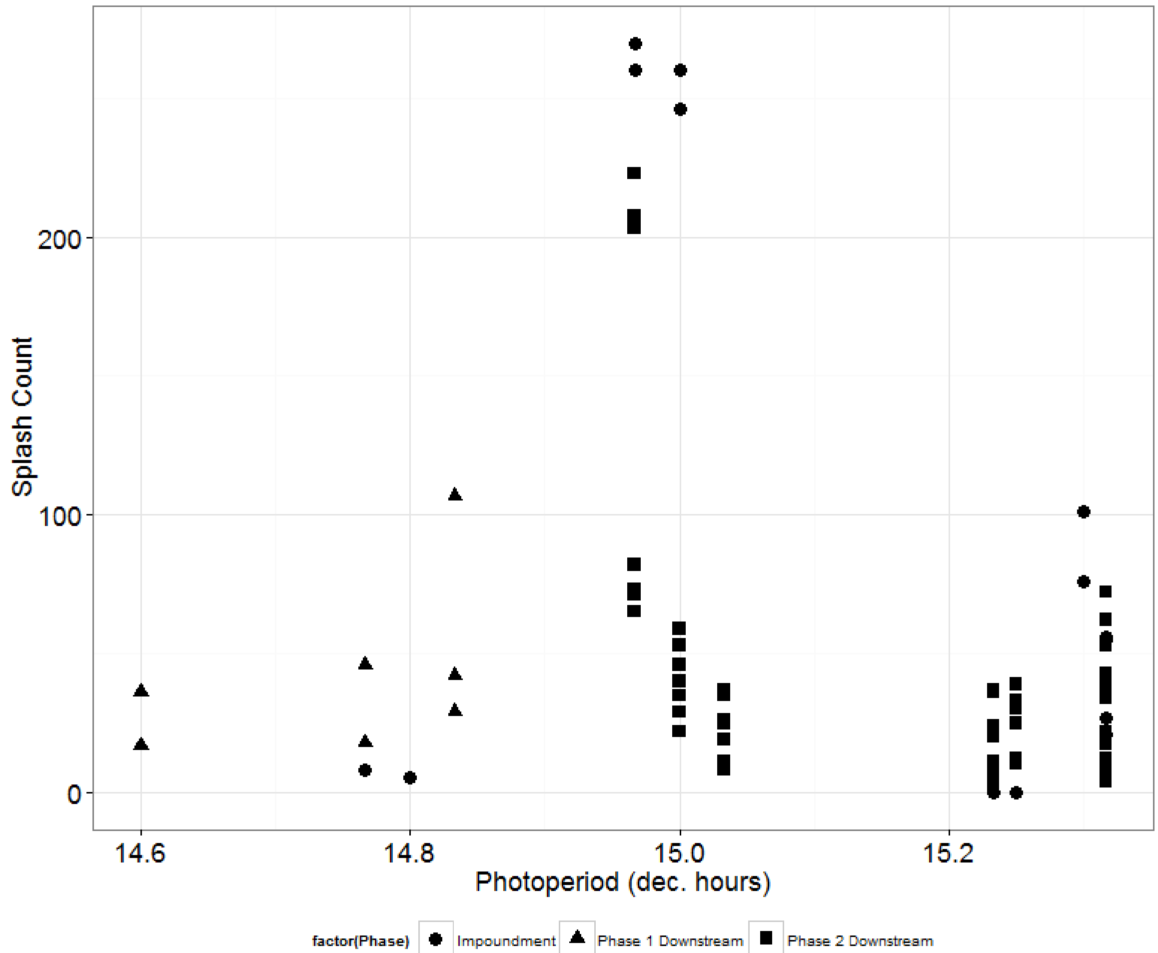

Figure 4.3.1-4: Splash Count (No./15 min.) Data Recorded from the Downstream and Impoundment Spawning Sites in Relation to Photoperiod

4.3.2 Spawning Habitat

In general, changes in area due to increasing or decreasing Cabot Station generation by 1 or 2 units were minimal (Table 4.3-1). The estimated areas (acres) of spawning sites in the downstream reach were impacted by a maximum of approximately 2% (Site 10) during the before and after generation change assessments performed during the study period. The magnitude of area changes at the sites closest to Cabot Station (Sites 8, 14, 16, and 20) was less than Site 10, which is located further downstream. Interestingly, at Site 14, June 9, the estimated area increased despite operation logs indicating no change in generation, suggesting perhaps flow from the Deerfield River could have influenced the WSEL during the "after" assessment, particularly since spill over the dam remained constant during the observed spawning event. There did not appear to be a trend in the direction of the change in area based on unit changes. For example, at Site 8, increasing generation by one unit resulted in a decrease in the spawning area by 0.2%; however, at Site 12, increasing generation by one unit resulted in an increase in the spawning area by 0.12%. No change in area was observed at Site 11 when generation decreased by one unit, and no changes were observed at Site 17, 18, and 19, when generation was increased or decreased by two units.

Appendix A contains elevation maps for Sites 1, 3, 8, 14, 16, 20, and 23 (sites with DEMs available) that depict the wetted surface areas at the minimum, median, maximum and time of observation WSELs. For Site 23, the maximum elevation of the DEM for the TFI site (Site 23) was 183.06 ft (NVGD 1929). Consequently, it was not possible to map the wetted extent of the median or maximum WSEL that occurred throughout the shad spawning season, as they both exceeded this elevation (Figure A-7).

Appendix B displays the same information for those sites where no DEMs were available (Sites 4-7, 9-13, 15, 17-19, 21, and 22). Note that (1) references to right and left are from the perspective of a viewer looking downstream; and (2) the bed profile represents the entire width of the river, with the exception of Site 10, where the profile represents the left channel of Fourth Island. For the downstream sites, differences in area between the minimum and maximum WSELs were generally constrained towards the river bank. None of the downstream sites appears to be vulnerable to complete dewatering or exposure of substrate based on the minimum WSEL observed during the study period.

While it appears that the minimum WSELs at some of the downstream sites constrain the area and depth available for spawning, the habitat duration curves (Appendix C) provide an indication of the percentage of time that condition would be expected to occur. Again the calibrated hydraulic models of the TFI and the reach from the Montague USGS Gage to Holyoke Dam were used to simulate the observed conditions from May 13 to June 22, 2015 on an hourly basis. Thus for each spawning location hourly predicted WSELs were computed on an hourly basis over the shad spawning period. Using the hourly WSEL, elevation duration curves were developed as shown in Appendix C. Also shown on the same plots in Appendix C is the percent of spawning location that was exposed.

For example, at Site 10, it appears that an estimated 100 linear feet of the river bank is exposed at the minimum WSEL (based on the May 13- June 22, 2015 spawning period) as compared to the maximum WSEL (Figure B-7). The habitat duration curve (Figure C-10) indicates that the minimum WSEL exposes about 25% of the width of the available habitat; however, this condition represents the worst-case that is expected to occur based on 2015 data.

For the TFI Site 23 (Figure A-7), spawning was observed in the same area over a range of conditions; however it was not possible to map the wetted extent for conditions when the WSEL exceeded 183.06 ft (the extent of DEM). There is a large gravel bar to the left of Stebbins Island that is exposed under lower WSELs. The channel along the left bank allowed for passage of the survey boat (17-ft skiff with 40-hp outboard) for the range of conditions encountered during the study period.

In terms of project operation effects, it appears that as Cabot Station generation increased, WSEL, velocity, and depth at the spawning locations in the reach downstream also increased during the study period. Shown in Figures 4.3.2-1, 4.3.2-2, and 4.3.2-3 are scatter plots. Again, the Project has no ability to regulate flow when Montague Gage readings exceed approximately 18,000 cfs.

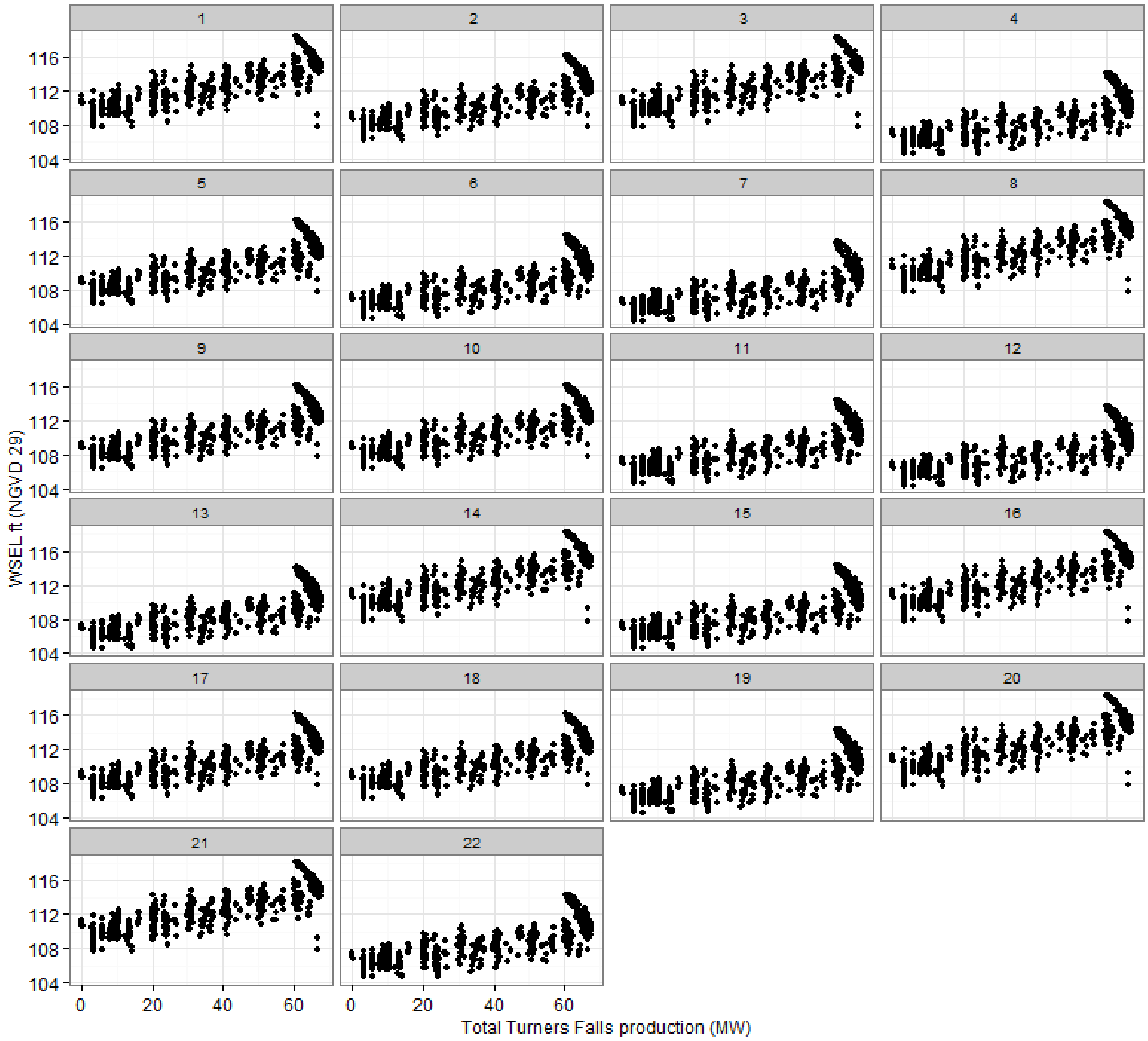

Figure 4.3.2-1. Cabot Station Output and Estimated WSEL at each of the Downstream Spawning Sites Throughout the 2015 Spawning Period

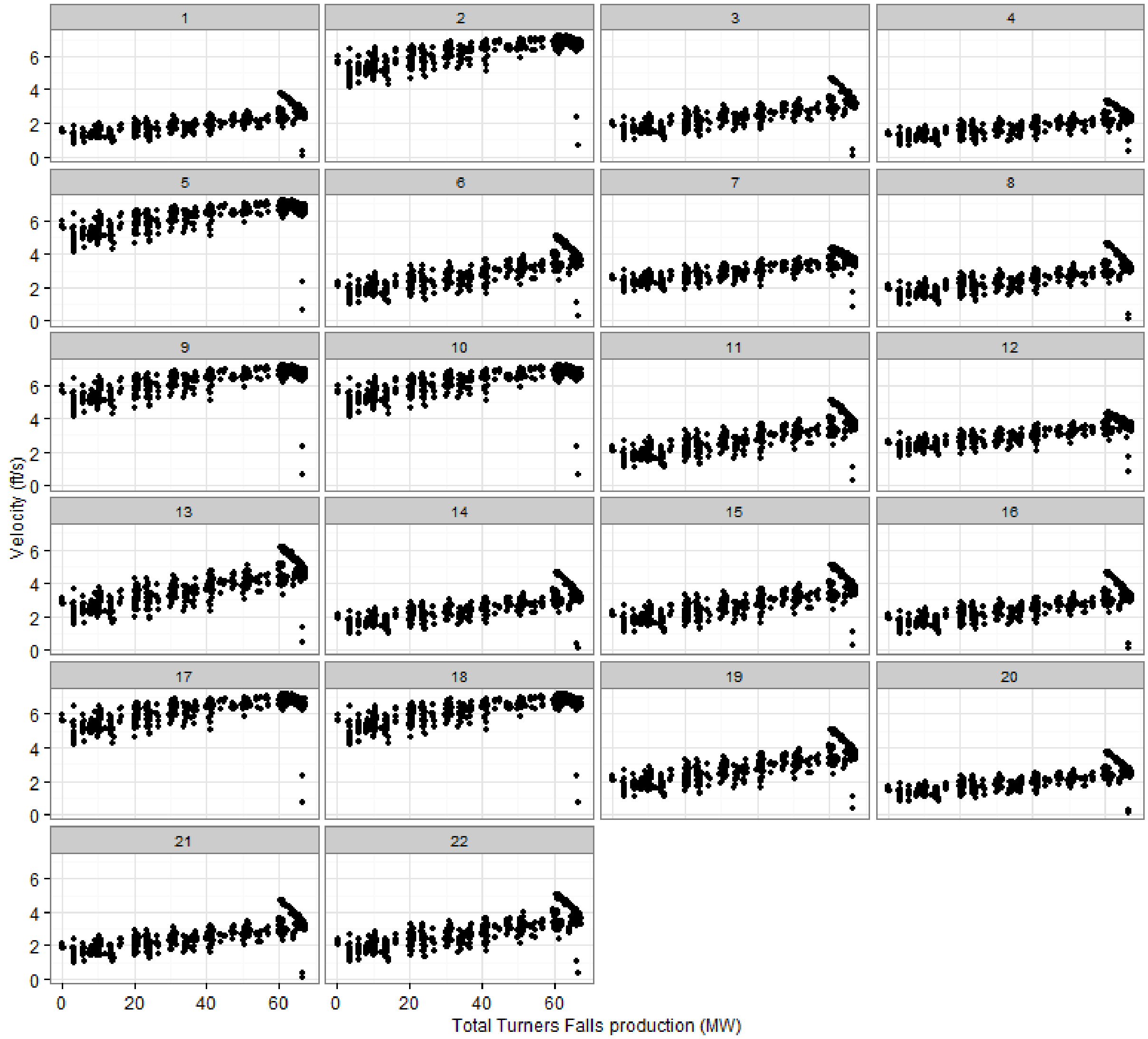

Figure 4.3.2-2. Cabot Station Output and Estimated Mean Channel Velocity at each of the Downstream Spawning Sites Throughout the 2015 Spawning Period

Figure 4.3.2-3. Cabot Station Output and Estimated Maximum Channel Depth at each of the Downstream Spawning Sites Throughout the 2015 Spawning Period

5 DISCUSSION

Shad spawning surveys were conducted within the Project area to determine if Project operations affect shad spawning site use and availability, spawning habitat quantity and quality, and spawning activity in the river reach that extends from the base of Vernon Dam to the Route 116 Bridge in Sunderland, Massachusetts. Results of the 2015 shad spawning surveys conducted from May 13 to June 22, 2015 in relation to the specific objectives identified in Section 1.2 herein are discussed in the following sections.

Spawning Locations

Although nearly 35 years have passed since previous researchers identified areas of shad spawning downstream of Cabot Station, the 2015 surveys confirmed that some of the same general areas remain active spawning grounds for shad. Although no spawning downstream of Third Island was observed during the 2015 surveys, unique areas in the upper portion of the reach were identified. Based on 2015 observations, shad did not appear to utilize the same sites for spawning over the course of the entire spawning season. For example, shad spawning was observed at Sites 2, 4, 10, and 13 only once throughout the survey dates. Since the study plan required surveys to be conducted 2-3 nights per week, it is possible, and perhaps likely, that shad spawning occurred at times when no surveys were conducted, as well as at locations that were not identified by the field crews. As such, the other areas identified by the 1970s researchers (including those downstream of Third Island) may still also be used by shad for spawning, and there are likely additional spawning areas used by shad other than those observed during the 2015 surveys. Layzer (1974) suggested that shad may spawn beneath the water surface, which could have prevented the field crews from being able to identify all spawning activity at the time due to a lack of splashing.

Spawning Activity

Spawning was observed at water temperatures ranging from 15.6 to 20.2°C throughout the study area. Water temperature is reported to be an important factor for spawning (Leggett & Whitney, 1972). Stier and Crance (1985) reported that peak spawning activity occurs between 14 and 21°C, which aligns well with the observations of this study.

Spawning activity was observed downstream of Cabot Station under a variety of operational and environmental conditions. Spawning activity appeared to be most influenced by photoperiod, with peak activity identified when photoperiod ranged between 14.8 and 15.0 hours. Time-since-sunset was also identified as having a greater effect on spawning activity than Cabot Station generation, with results suggesting that spawning activity decreases over the course of a night regardless of Cabot Station operations.

Spawning Habitat

Throughout the 2015 study period, shad spawning areas comprised approximately 106 acres in the downstream reach between Cabot Station and the Route 116 Bridge. Based on the changes in Cabot Station generation that were assessed (increasing and decreasing generation by 1 and 2 units), the surface areas of the downstream spawning sites exhibited little to no changes, with an estimated maximum decrease in spawning area of 2% at Site 10. Considering the range of flow conditions in the Connecticut River throughout the entire 2015 study period, WSELs at the spawning sites in the downstream reach fluctuated by a maximum of 10.7 ft (difference between minimum and maximum WSEL over the course of the entire season), with the WSELs on the surveys dates when shad spawning was observed ranging from 105.7 ft to 115.3 ft (a difference of 9.6 ft). Layzer (1974) reported that although water levels fluctuated up to 6 ft throughout the 1972 spawning period, with corresponding changes in water velocity, shad continued to spawn at these sites. It should be noted that Cabot Station and Station No. 1 have no ability to regulate flow when Montague Gage readings exceed approximately 18,000 cfs as this represents the hydraulic capacity of the Turners Falls Power Canal.

American Shad are broadcast, batch spawners and eggs are semi-buoyant, drifting downstream with river currents for several kilometers before settling to the bottom (Stira, 1976 as cited in Savoy *et al.*, 2004). This suggests that exposure of spawning habitat would not necessarily impact egg deposition, unless eggs spawned upstream drifted into a downstream spawning area. Exposure of habitat at the spawning sites occurs infrequently. In addition, the prolific fecundity and batch spawning strategy of American Shad implies large numbers of eggs are released under a variety of flow conditions to promote survival of at least a portion of those eggs.

The relationships between Cabot Station generation and effects on downstream habitat in terms of WSEL, velocity and depth was determined to be positive, such that as generation increased, WSEL, velocity and depth also increased at each of the downstream spawning sites and vice versa. Measured surface velocities ranged from 0.1 to 2.8 fps, while modeled mean channel velocities ranged from 2.0 to 6.6 fps throughout the 2015 study period. As shad spawning was observed under a range of velocities, it is likely that surface velocity may not be an important factor in site use. Alternatively, Layzer (1974) suggested that water velocity closer to the substrate may be more important than surface velocity for shad spawning as sufficient velocity along the bottom is required to promote egg survival. Water velocity measurements in the field were collected about 1 ft below the surface, generally towards the river banks, and the modeled channel velocities represent mean channel conditions. As such, velocity at the substrate interface remains unknown.

Similarly, the depths of the spawning areas varied at the times of observation as well as throughout the spawning period. Measured depths at spawning locations, which were typically recorded closer to the banks, ranged from 5.5 to 9.5 ft and modeled mean channel depths were estimated to range from 7.0 to 25.2 ft at the downstream spawning sites. With previous research documenting spawning at a variety of depths, it is likely that depth is not a critical factor in site selection for spawning shad. Stier and Crance (1985) indicate the optimum depth range for all life stages (spawning, egg, incubation, larvae, and juvenile) is approximately 4.9 to 20 ft.

While operation of the Turners Falls Project may induce changes at shad spawning sites in the downstream reach, it appears that photoperiod and time since sunset are more influential on spawning activity than physical changes at spawning sites related to project operations. American Shad appeared to spawn over large areas, both longitudinally and laterally, often encompassing a range of conditions. Physical habitat variables, such as depth, velocity, and substrate often vary longitudinally and laterally within rivers, and with spawning documented under a range of physical conditions, temporal variables (time of day or year) appear more influential in terms of predictors of shad spawning.

Shad Spawning in TFI

Shad spawning was documented in the TFI near the downstream end of Stebbins Island. Shad spawning was somewhat sporadic, with spawning observed on 7 of the 14 survey dates. The WSEL at the spawning site ranged from a maximum of 188.3 ft to a minimum of 179.9 ft, during the study period, with spawning observations occurring when WSEL ranged from 182.9 to 185.3 ft. There is a large gravel bar to the left of Stebbins Island that is exposed under lower WSELs. The channel along the left bank allowed for passage of the survey boat (17-ft skiff with 40 hp outboard) under the range of conditions encountered during the study period. Presumably, fish would be able to use this area for spawning or passage upstream to deeper areas (although no shad spawning was observed between the upstream end of Stebbins Island and the base of Vernon Dam).

Shad Spawning in Canal-Bypass Reach

Suspected shad spawning in the Turners Falls canal was documented for the first time, although activity was low in intensity when compared to other sites (average of 10 splash counts over a 15-minute period) and occurred later in the season (June 18). It appears that the canal does not serve as important habitat for shad spawning. Spawning was also documented in the bypass reach, at an area located downstream of Rock

Dam, near the downstream end of Rawson Island for the first time. Spawning activity in the bypass reach was documented on the same night as the spawning activity in the Turners Falls canal, although the intensity, based on splash counts, was nearly ten-fold higher in the bypass reach. As the upstream extent of previous research appears to have been at Cabot Station, it is possible that spawning may have occurred in the bypass reach historically but was not documented. Though spawning was only observed below Rock Dam during one survey event, it was during a low water period. During higher water, spawning may have been occurring in that area or nearby, but was not observed due to a lack of access, turbulence, and the sound of the water flowing over Rock Dam.

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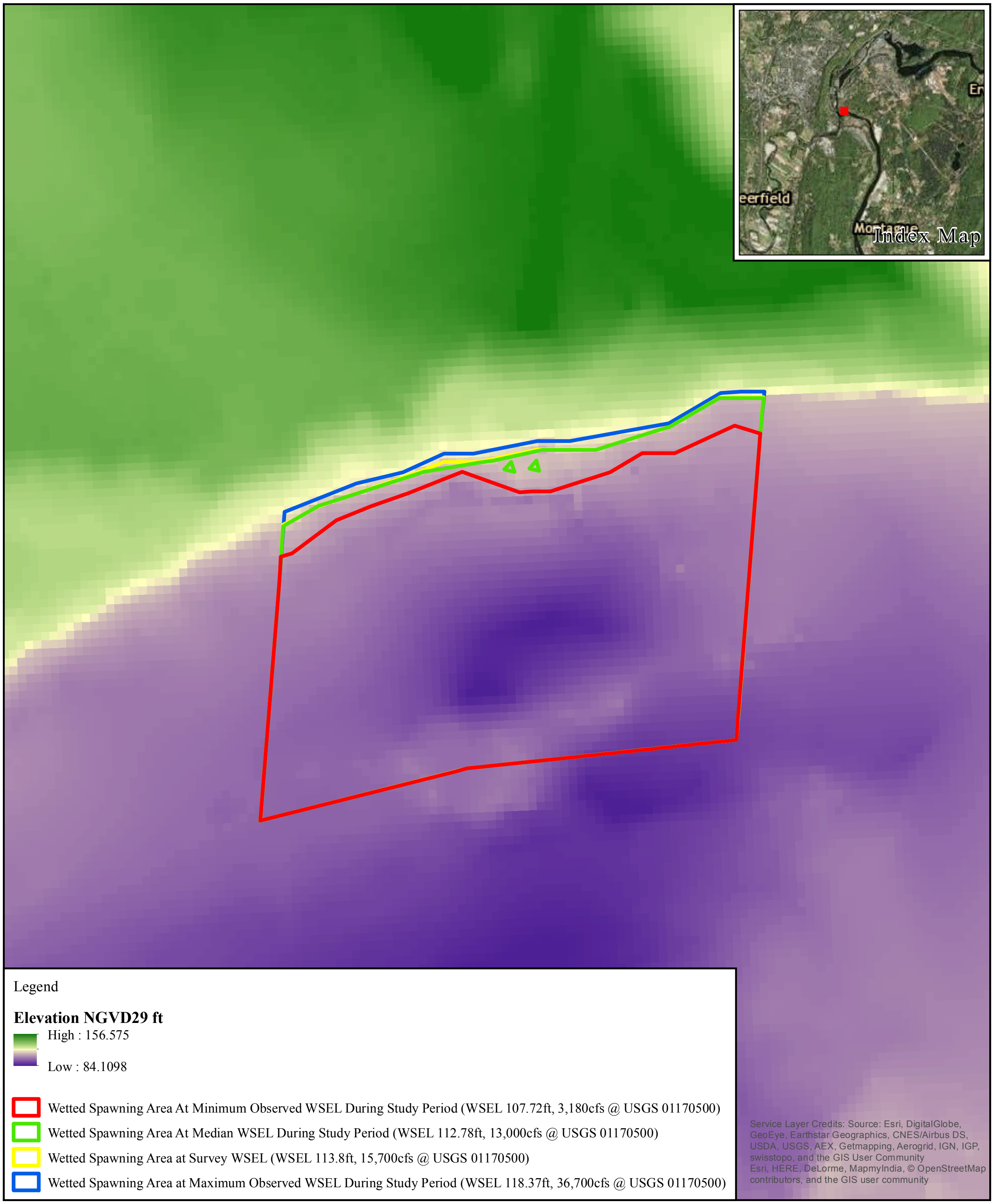
APPENDIX A – WETTED AREA OF SHAD SPAWNING SITES IN DOWNSTREAM REACH AND TFI



FirstLight GDF SUEZ

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

IMPACT OF PROJECT OPERATIONS ON SHAD SPAWNING, SPAWNING HABITAT AND EGG DEPOSITION IN THE AREA OF THE NORTHFIELD MOUNTAIN AND TURNERS FALLS PROJECTS RELICENSING STUDY 3.3.6

N

0 0.0075 0.015 0.03 Miles

Figure A-1: Wetted Extent of Spawning Site 1 at Minimum, Maximum, Median, and Survey Time WSEL During Study Period

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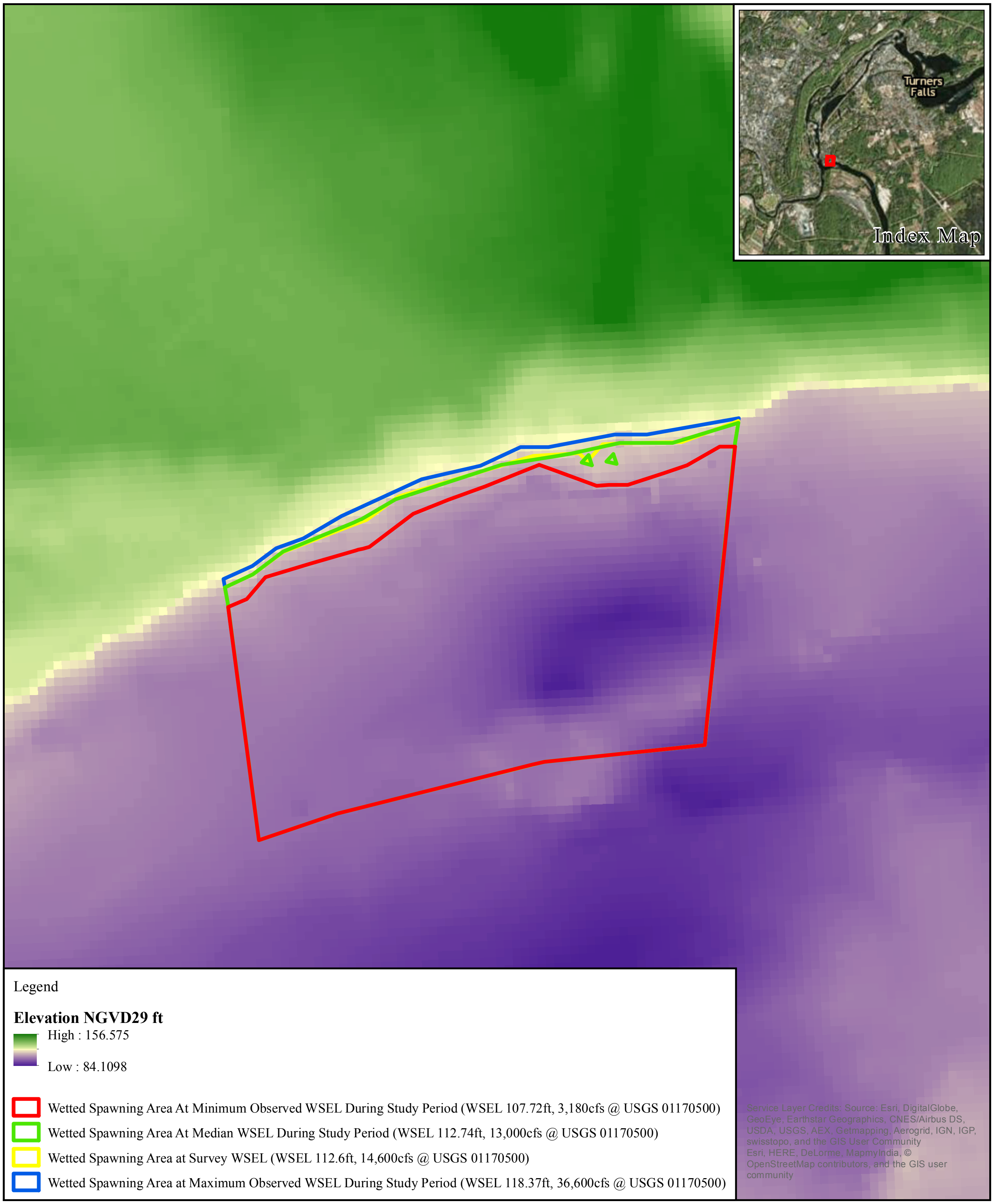


FirstLight™ GDF SUEZ

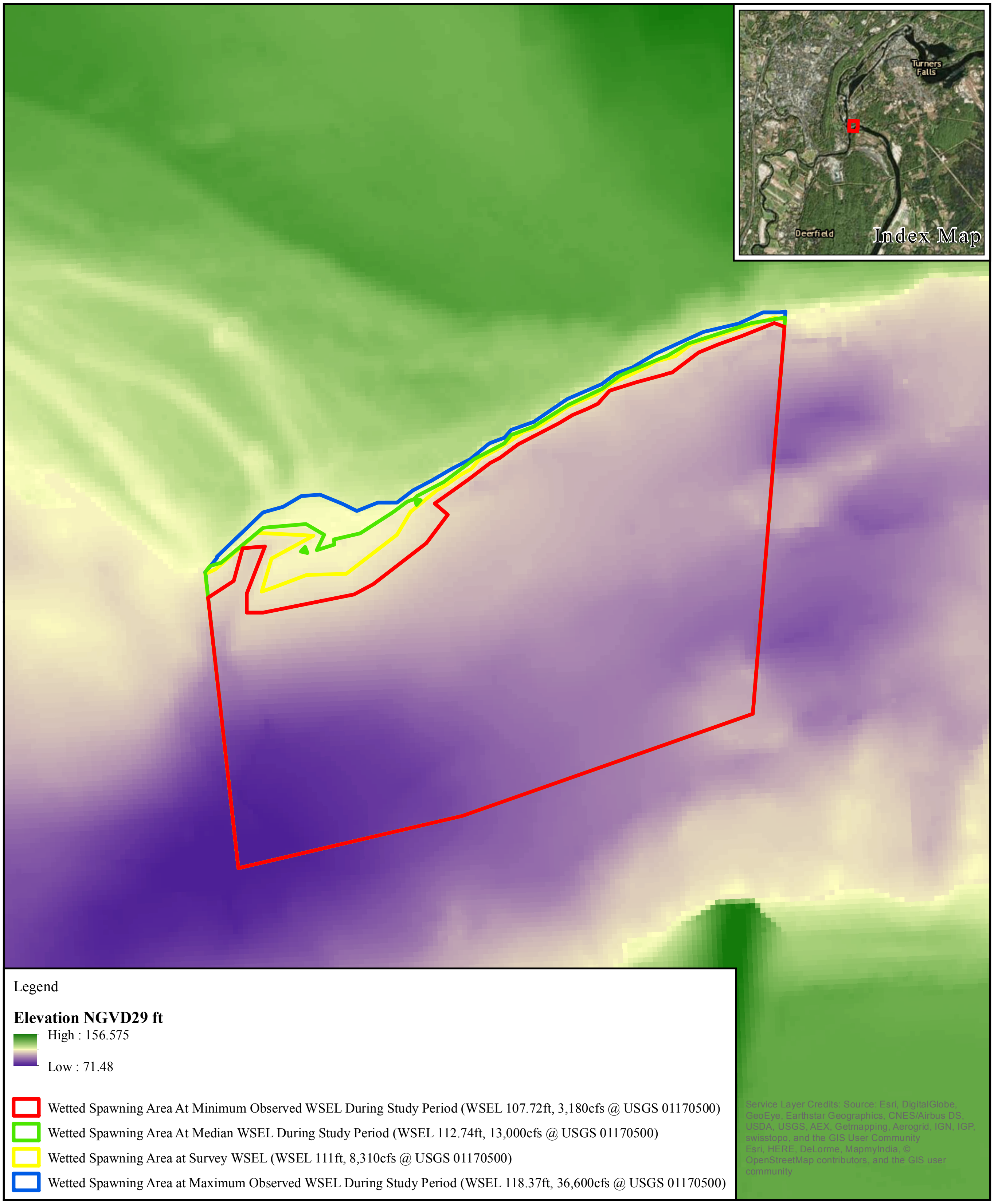
Northfield Mountain Pumped Storage Project (No. 2485) and Turners Falls Hydroelectric Project (No. 1889)

IMPACT OF PROJECT OPERATIONS ON SHAD SPAWNING, SPAWNING HABITAT AND EGG DEPOSITION IN THE AREA OF THE NORTHFIELD MOUNTAIN AND TURNERS FALLS PROJECTS RELICENSING STUDY 3.3.6

N

0 0.0075 0.015 0.03 Miles

Figure A-2: Wetted Extent of Spawning Site 3 at Minimum, Maximum, Median, and Survey Time WSEL During Study Period



FirstLight GDF SUEZ

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

IMPACT OF PROJECT OPERATIONS ON SHAD SPAWNING, SPAWNING HABITAT AND EGG DEPOSITION IN THE AREA OF THE NORTHFIELD MOUNTAIN AND TURNERS FALLS PROJECTS RELICENSING STUDY 3.3.6

N

0 0.0125 0.025 0.05 Miles

Figure A-3: Wetted Extent of Spawning Site 8 at Minimum, Maximum, Median, and Survey Time WSEL During Study Period

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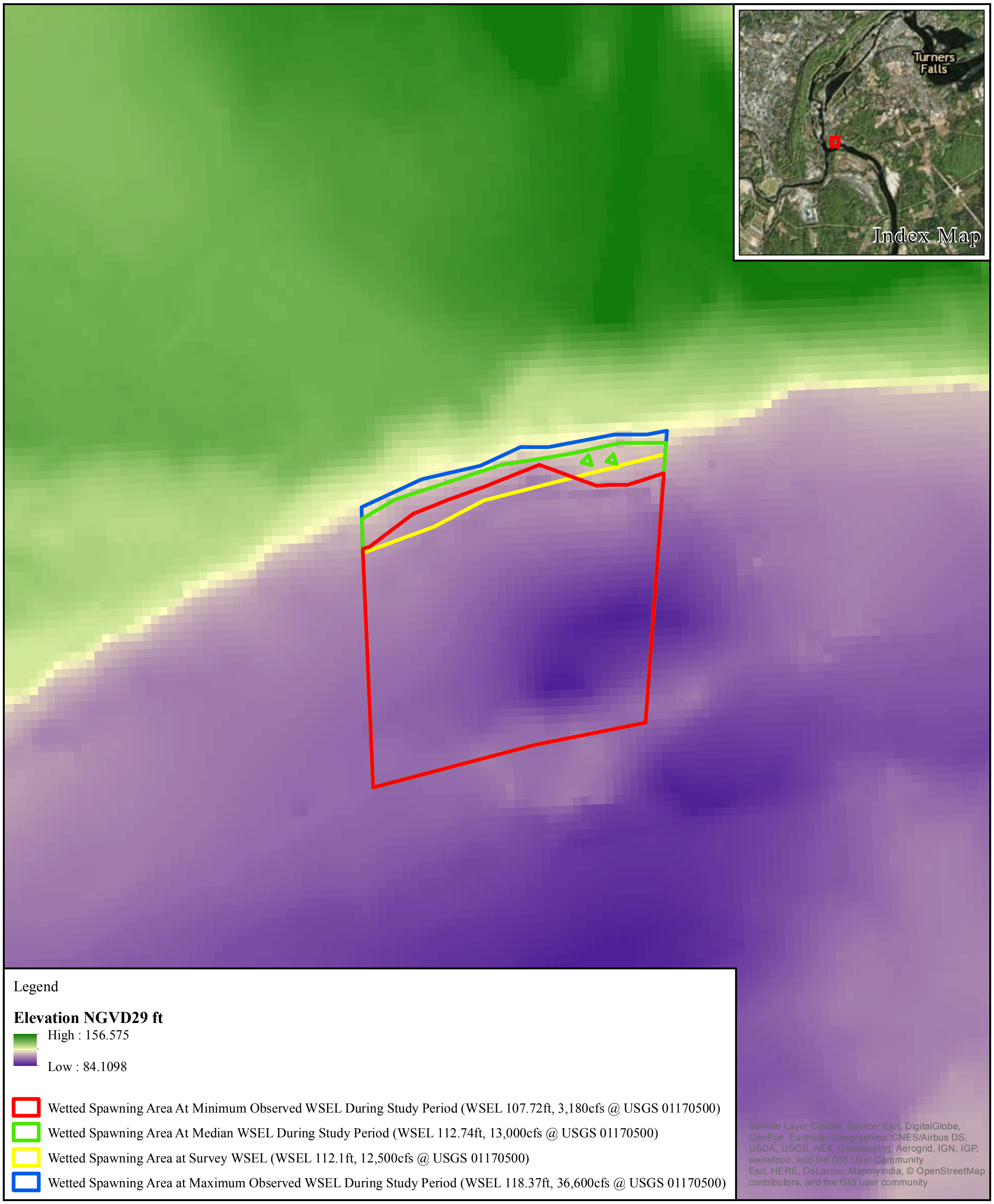

FirstLight GDF SUEZ

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

IMPACT OF PROJECT OPERATIONS ON SHAD SPAWNING, SPAWNING HABITAT AND EGG DEPOSITION IN THE AREA OF THE NORTHFIELD MOUNTAIN AND TURNERS FALLS PROJECTS RELICENSING STUDY 3.3.6

N

0 0.0075 0.015 0.03 Miles

Figure A-4: Wetted Extent of Spawning Site 14 at Minimum, Maximum, Median, and Survey Time WSEL During Study Period

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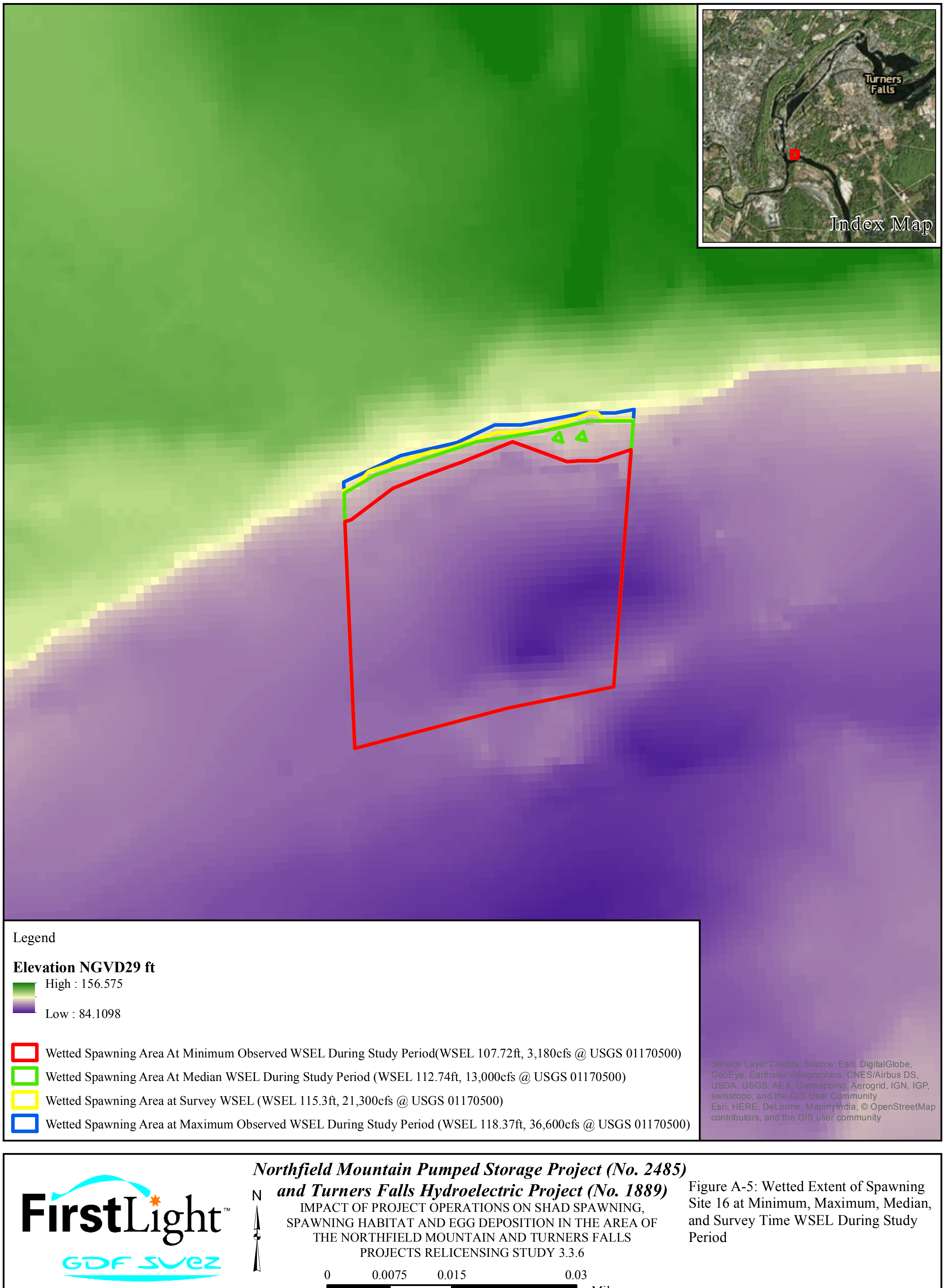

FirstLight GDF SUEZ

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

IMPACT OF PROJECT OPERATIONS ON SHAD SPAWNING, SPAWNING HABITAT AND EGG DEPOSITION IN THE AREA OF THE NORTHFIELD MOUNTAIN AND TURNERS FALLS PROJECTS RELICENSING STUDY 3.3.6

Figure A-5: Wetted Extent of Spawning Site 16 at Minimum, Maximum, Median, and Survey Time WSEL During Study Period

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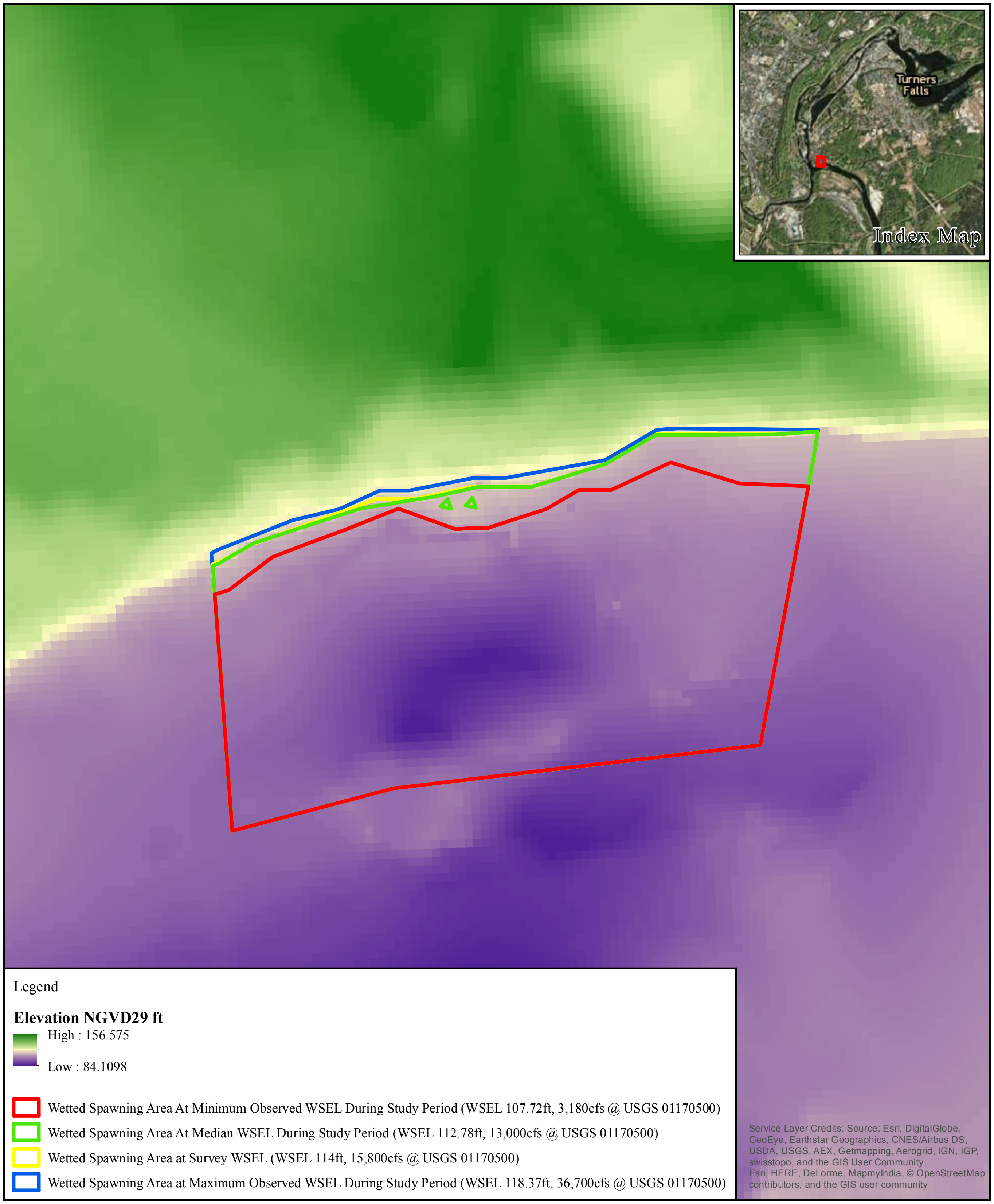

FirstLight™ GDF SUEZ

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

IMPACT OF PROJECT OPERATIONS ON SHAD SPAWNING, SPAWNING HABITAT AND EGG DEPOSITION IN THE AREA OF THE NORTHFIELD MOUNTAIN AND TURNERS FALLS PROJECTS RELICENSING STUDY 3.3.6

Figure A-6: Wetted Extent of Spawning Site 20 at Minimum, Maximum, Median, and Survey Time WSEL During Study Period

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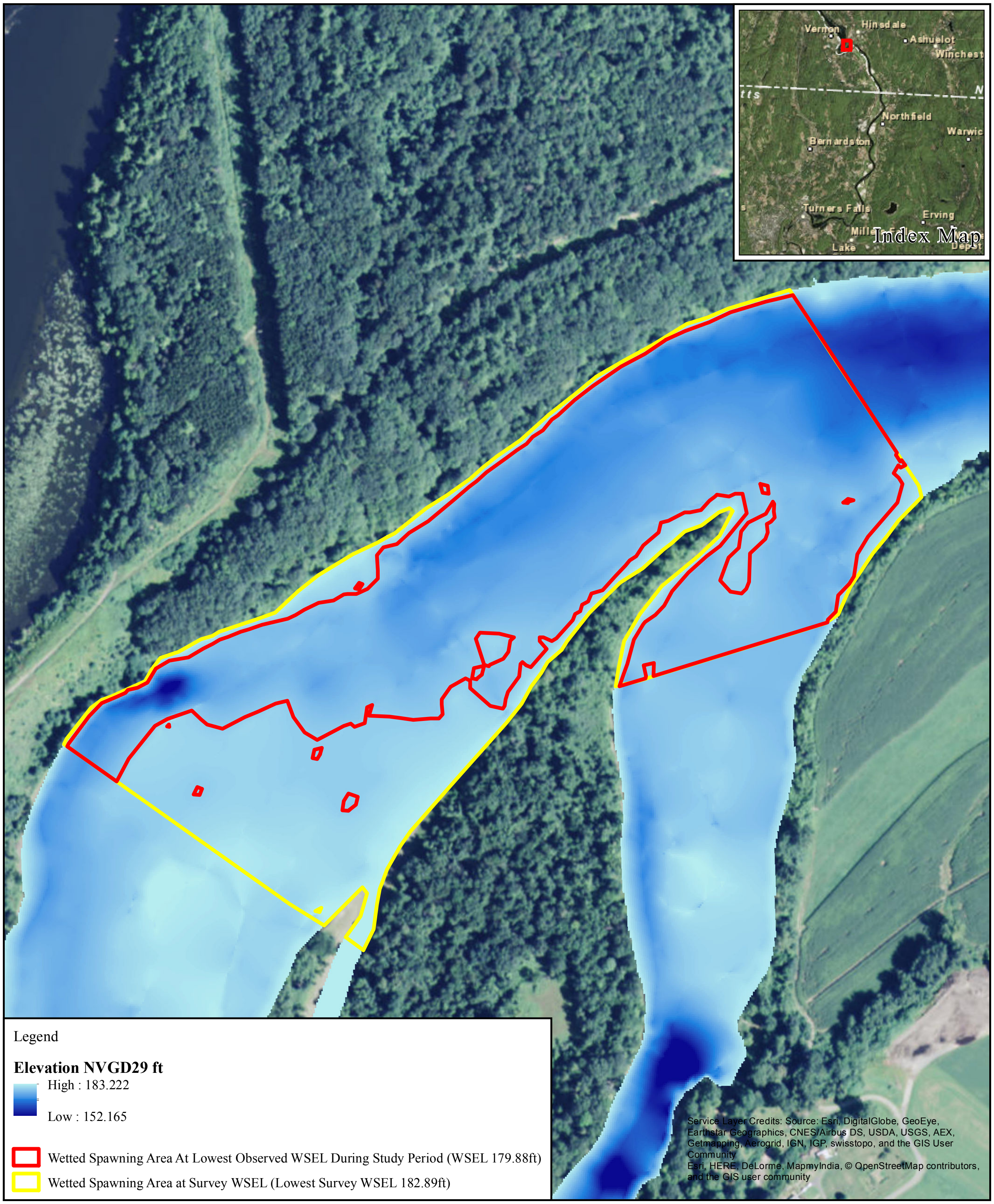

FirstLight™ GDF SUEZ

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

IMPACT OF PROJECT OPERATIONS ON SHAD SPAWNING, SPAWNING HABITAT AND EGG DEPOSITION IN THE AREA OF THE NORTHFIELD MOUNTAIN AND TURNERS FALLS PROJECTS RELICENSING STUDY 3.3.6

N

0 0.035 0.07 0.14 Miles

Figure A-7: Wetted Extent of Spawning Site 23 at Minimum and Lowest Survey Time WSEL During Study Period

Path: W:\gis\studies\3_3_06\maps\Report_Figures\Wetted_Spawning_Areas\SpawnAreaMinMaxWSELsite23.mxd

APPENDIX B – WSEL PLOTS FOR SITES 2, 4-7, 9-13, 15, 17-19, 21-22

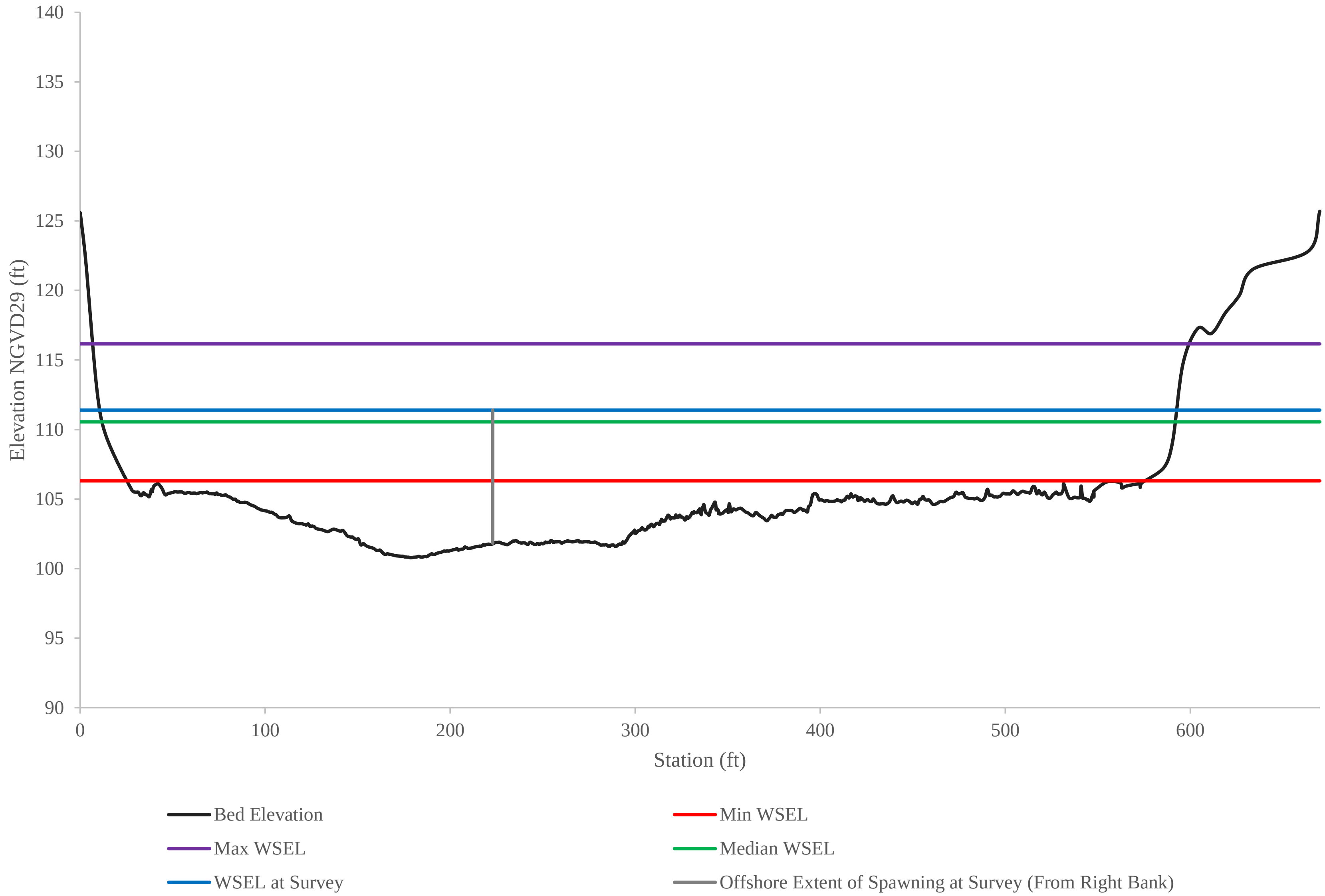

Figure B-1. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 2.

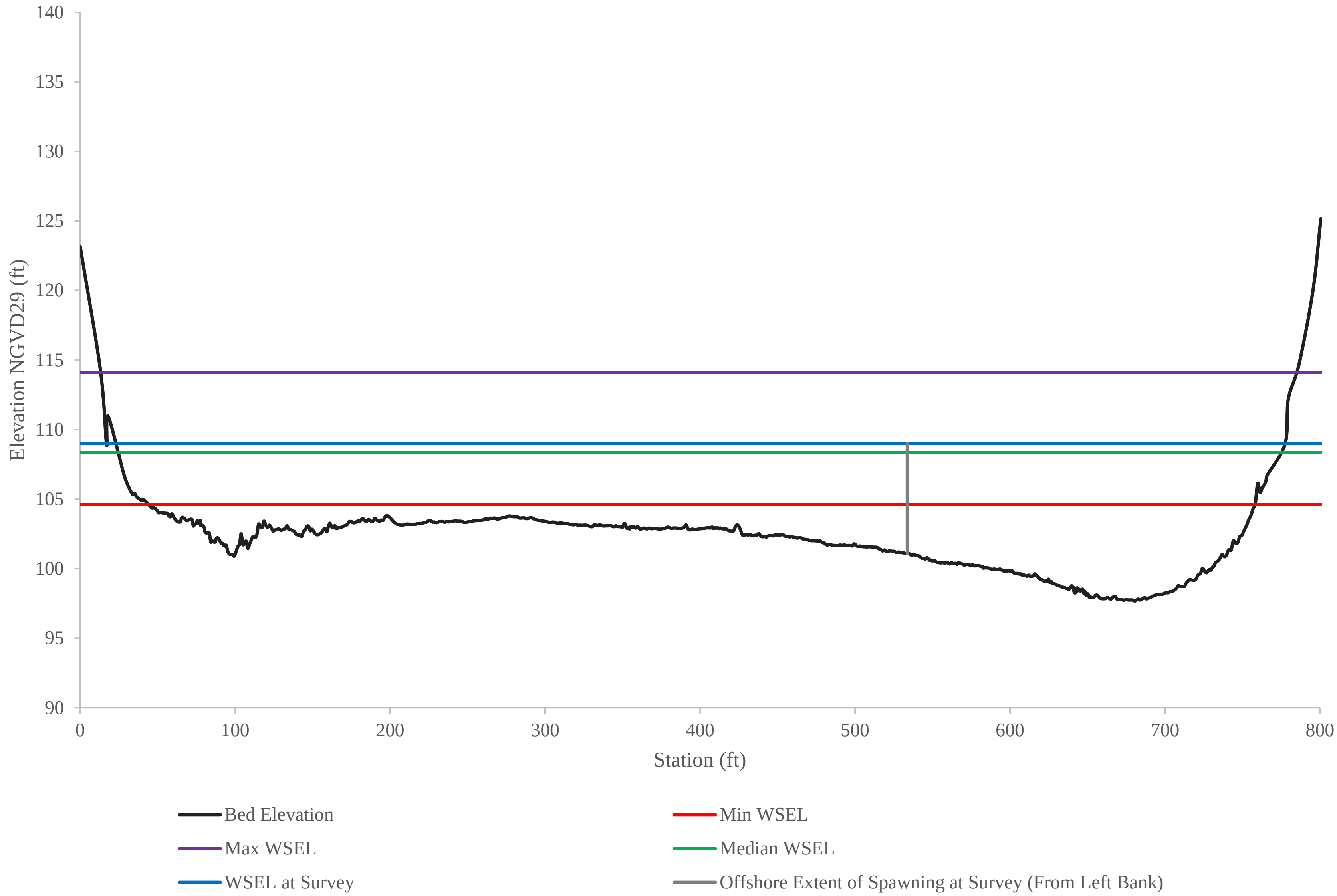

Figure B-2. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 4.

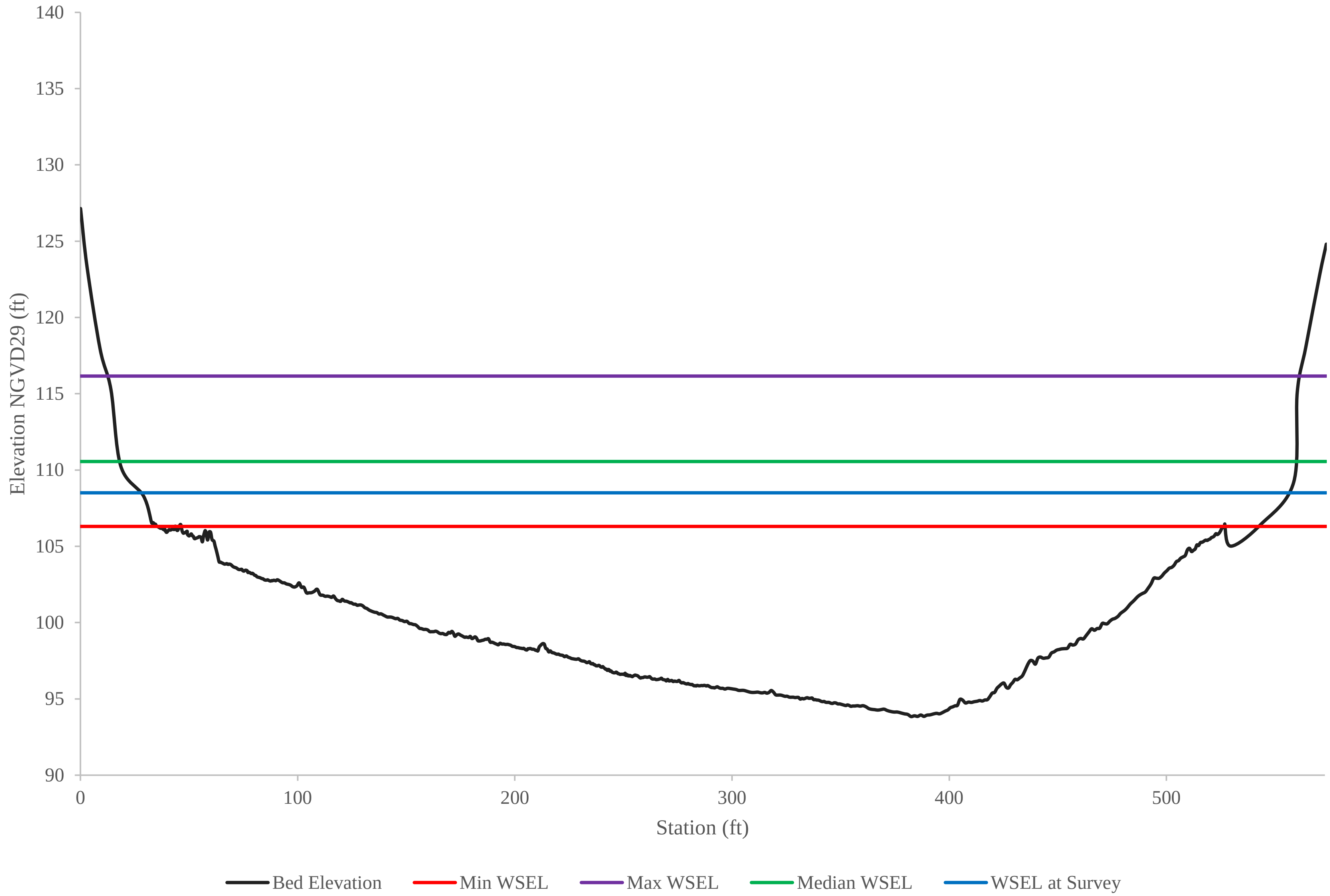

Figure B-3. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 5.

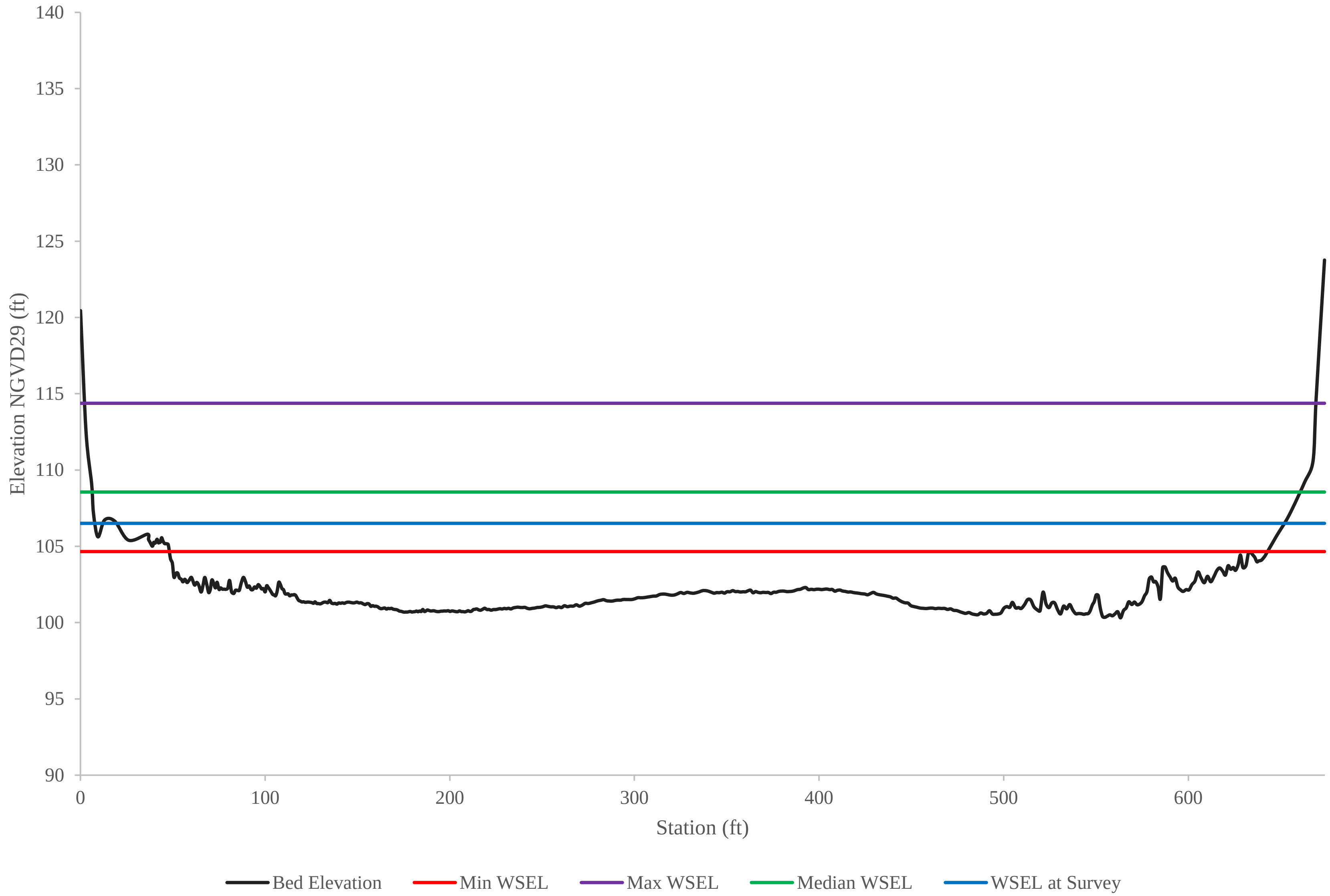

Figure B-4. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 6.

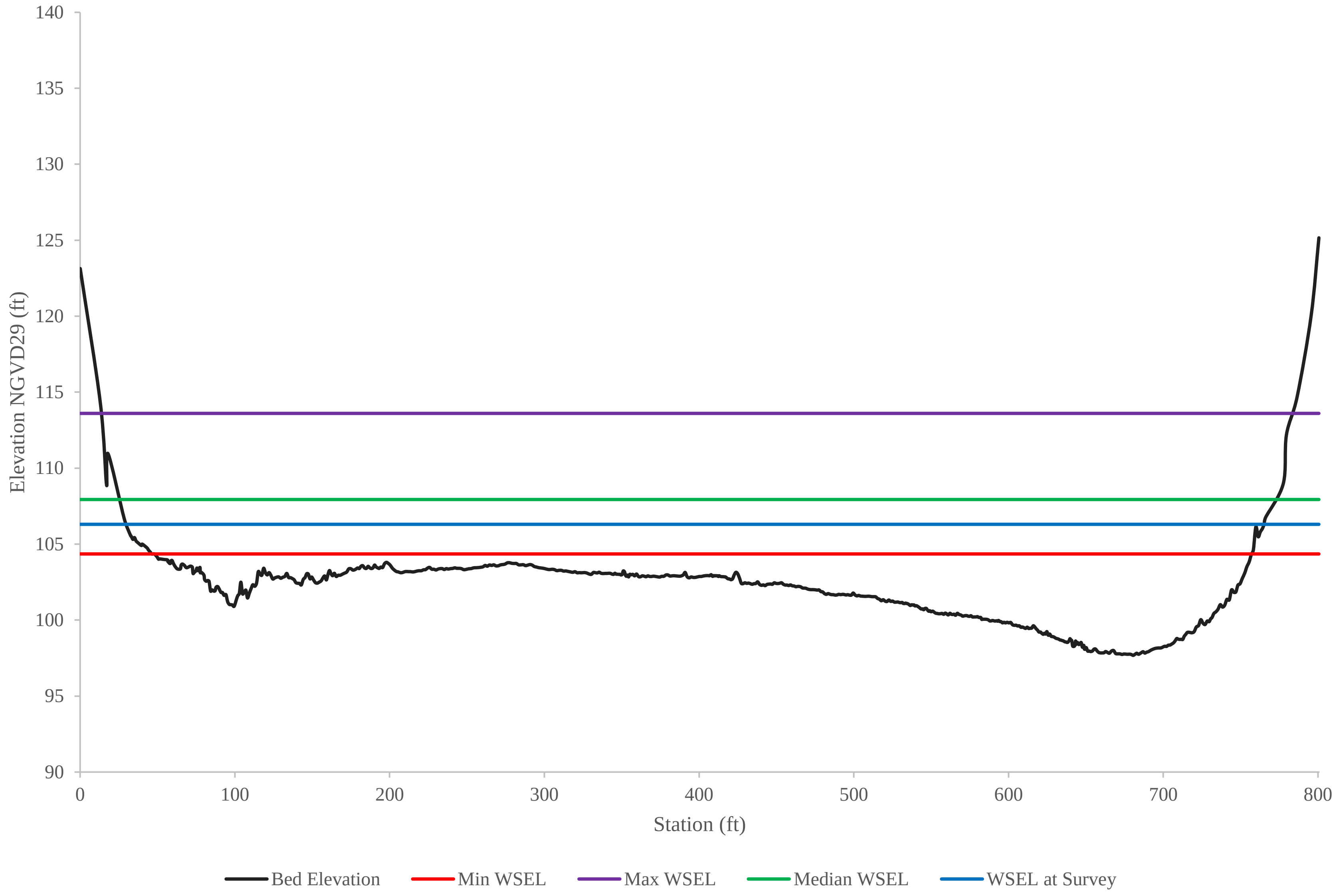

Figure B-5. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 7.

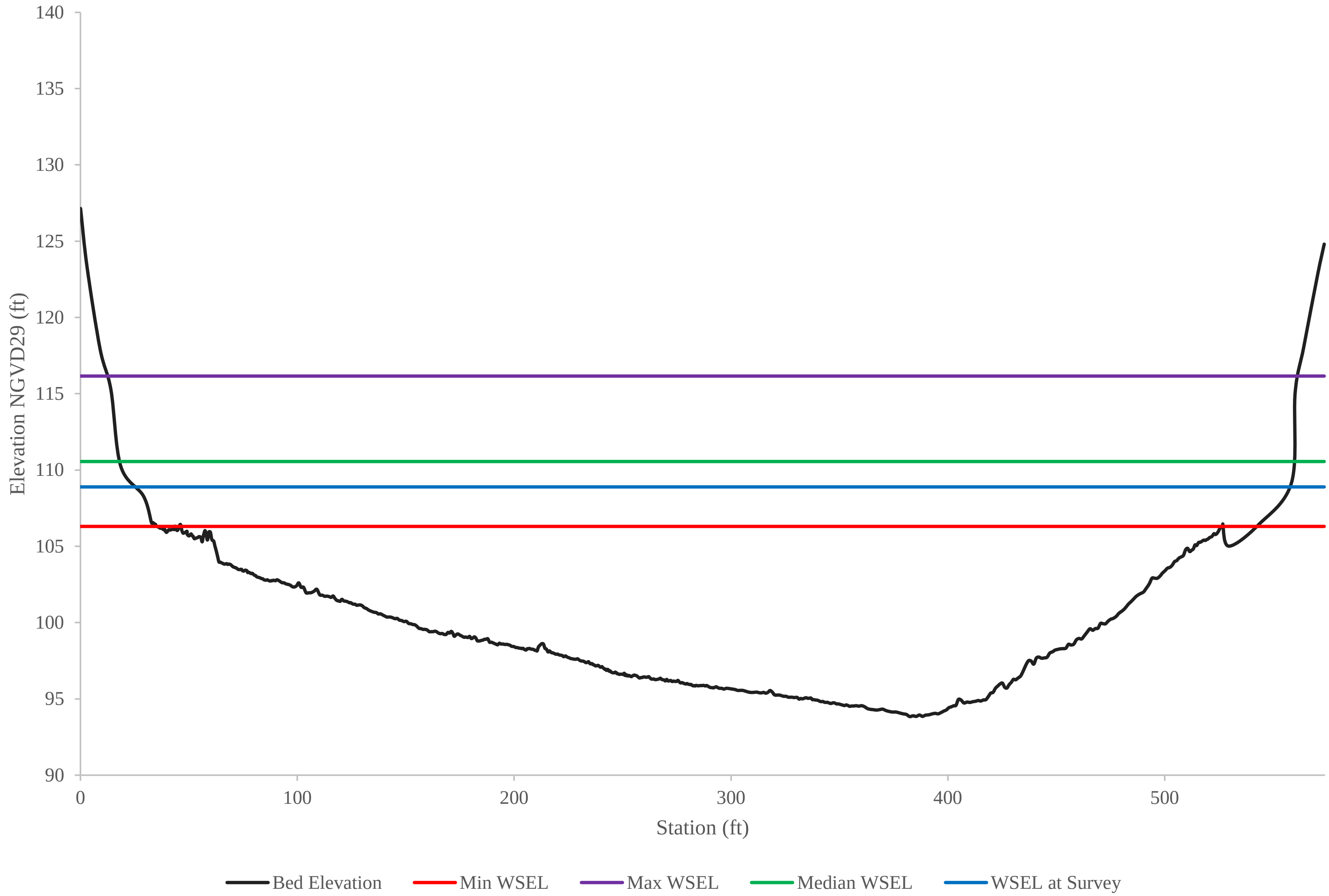

Figure B-6. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 9.

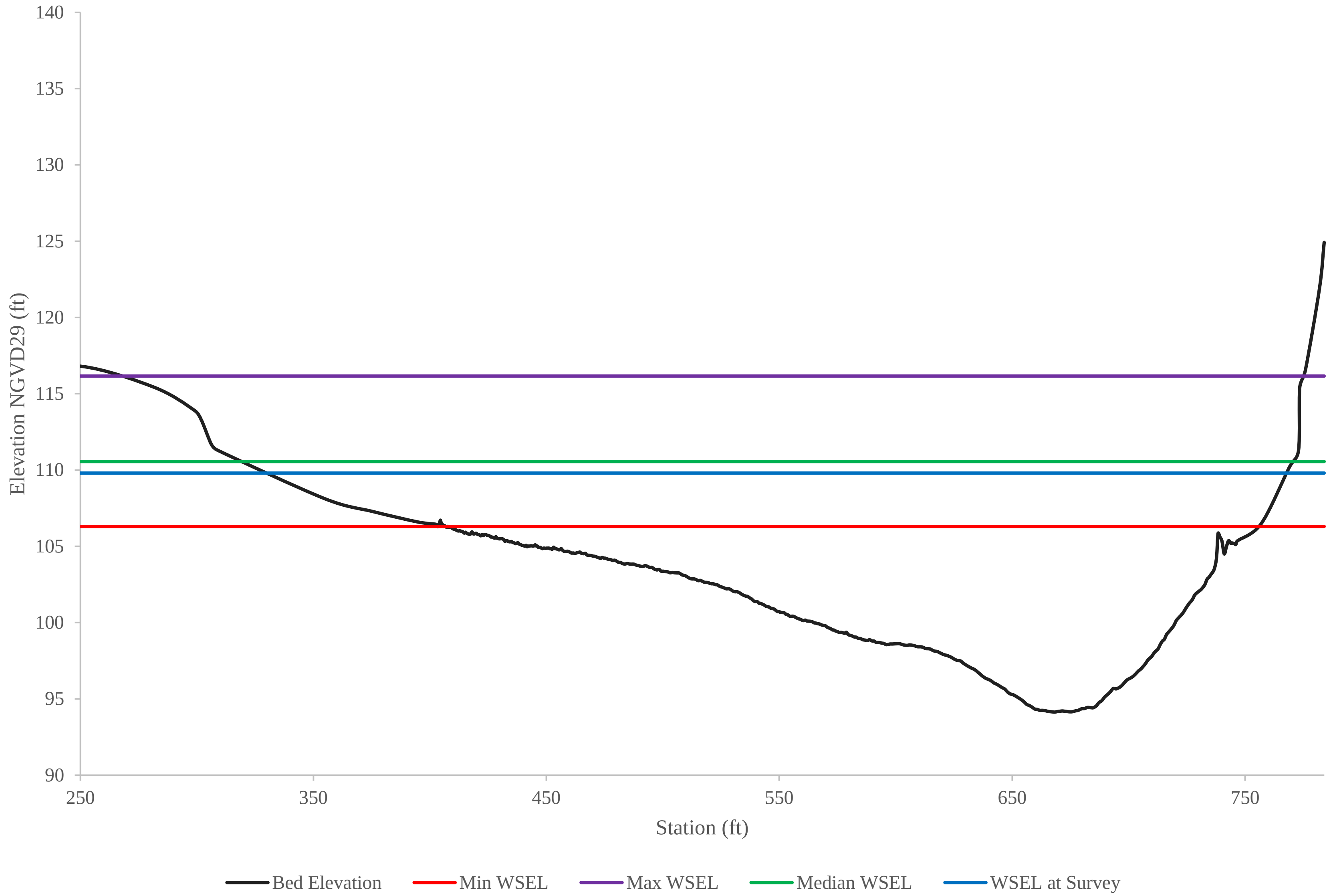

Figure B-7. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 10.

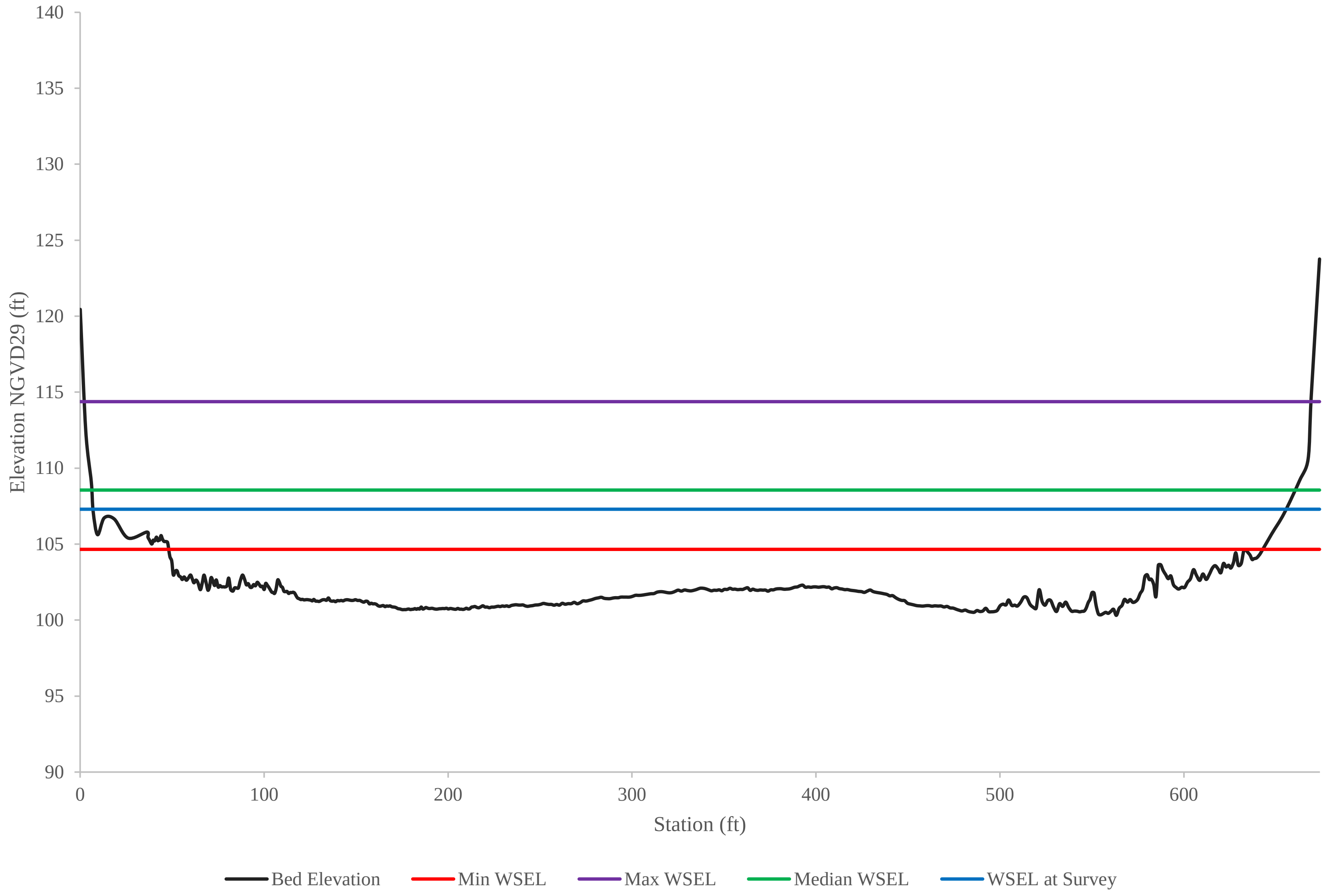

Figure B-8. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 11.

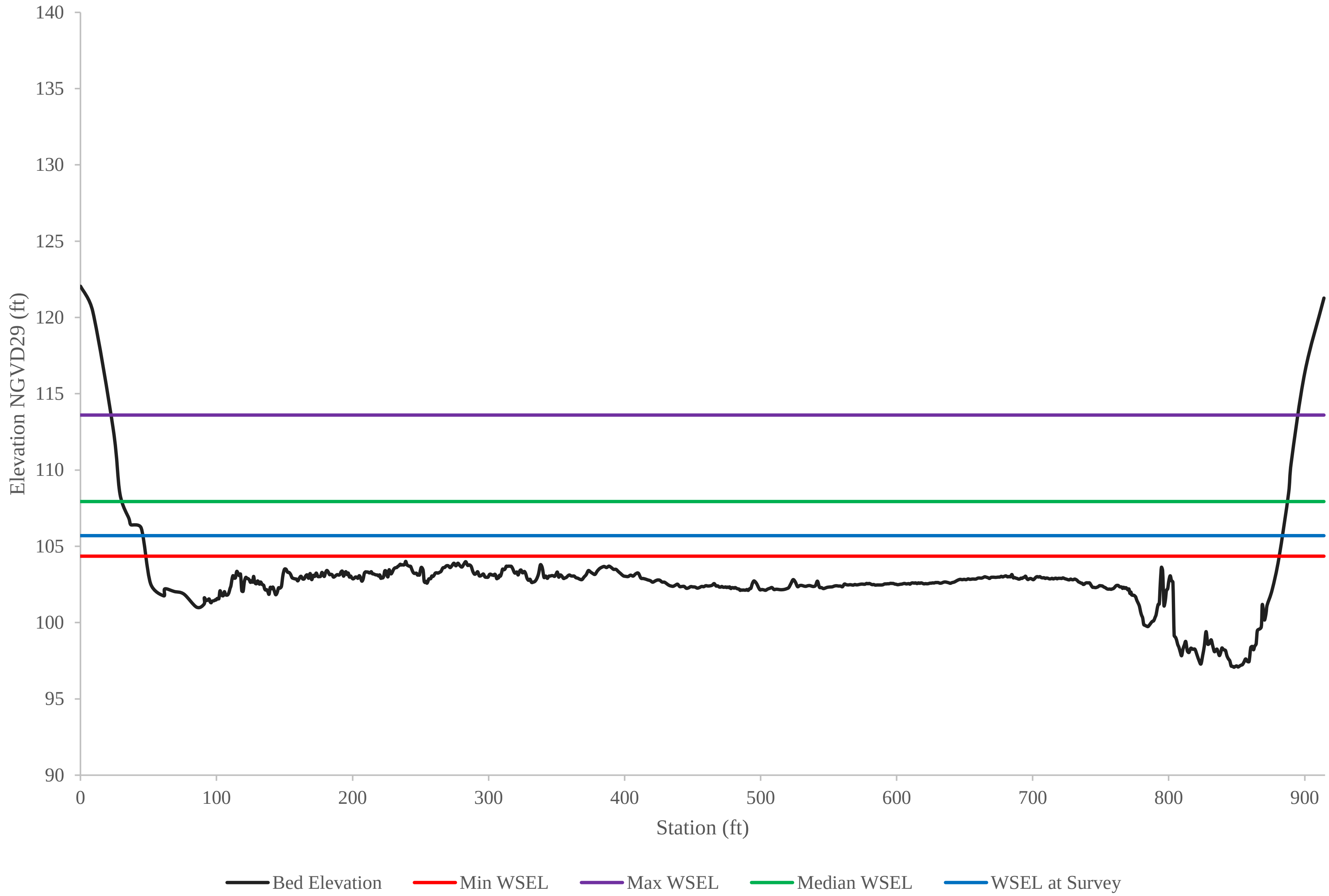

Figure B-9. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 12.

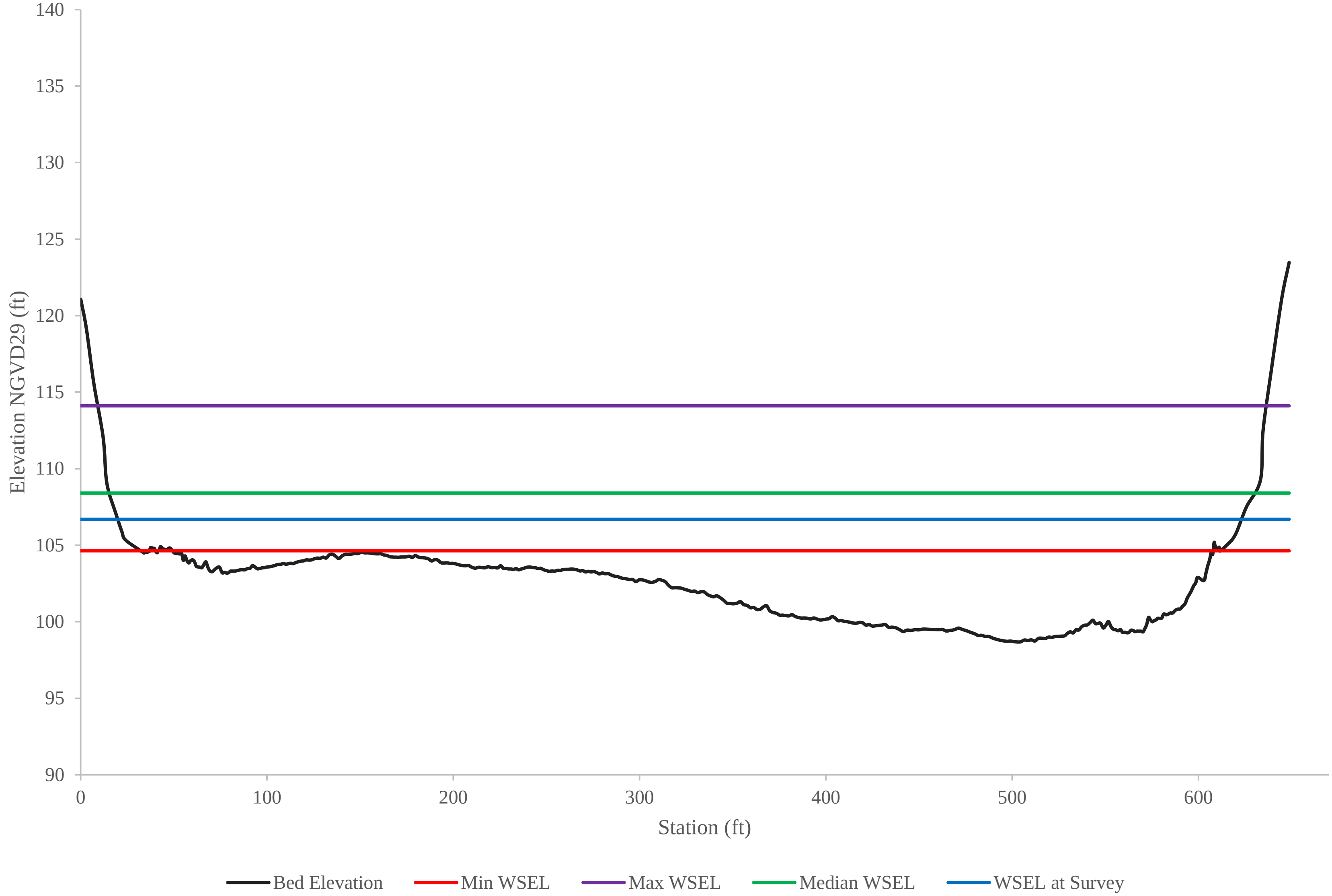

Figure B-10. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 13.

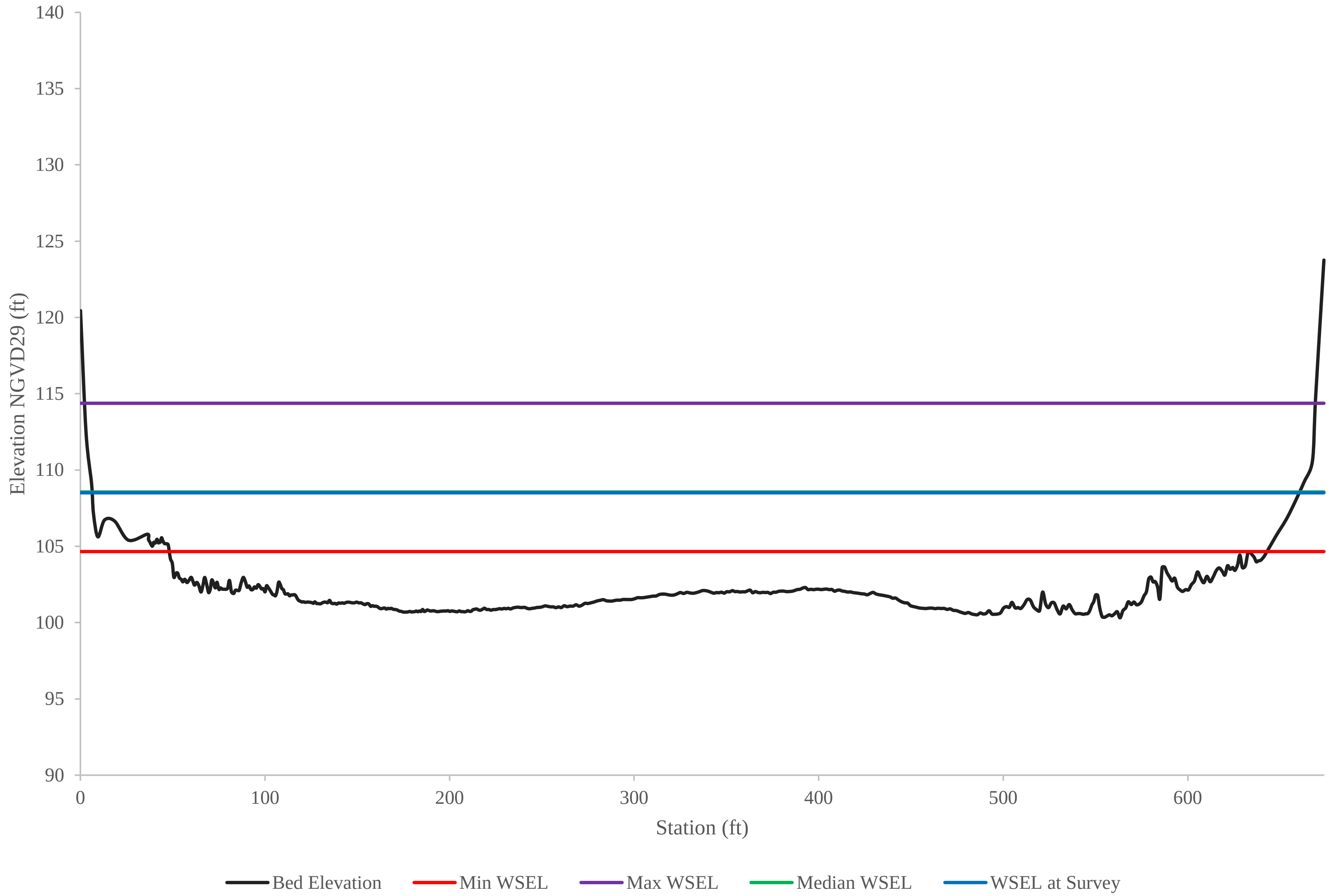

Figure B-11. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 15.

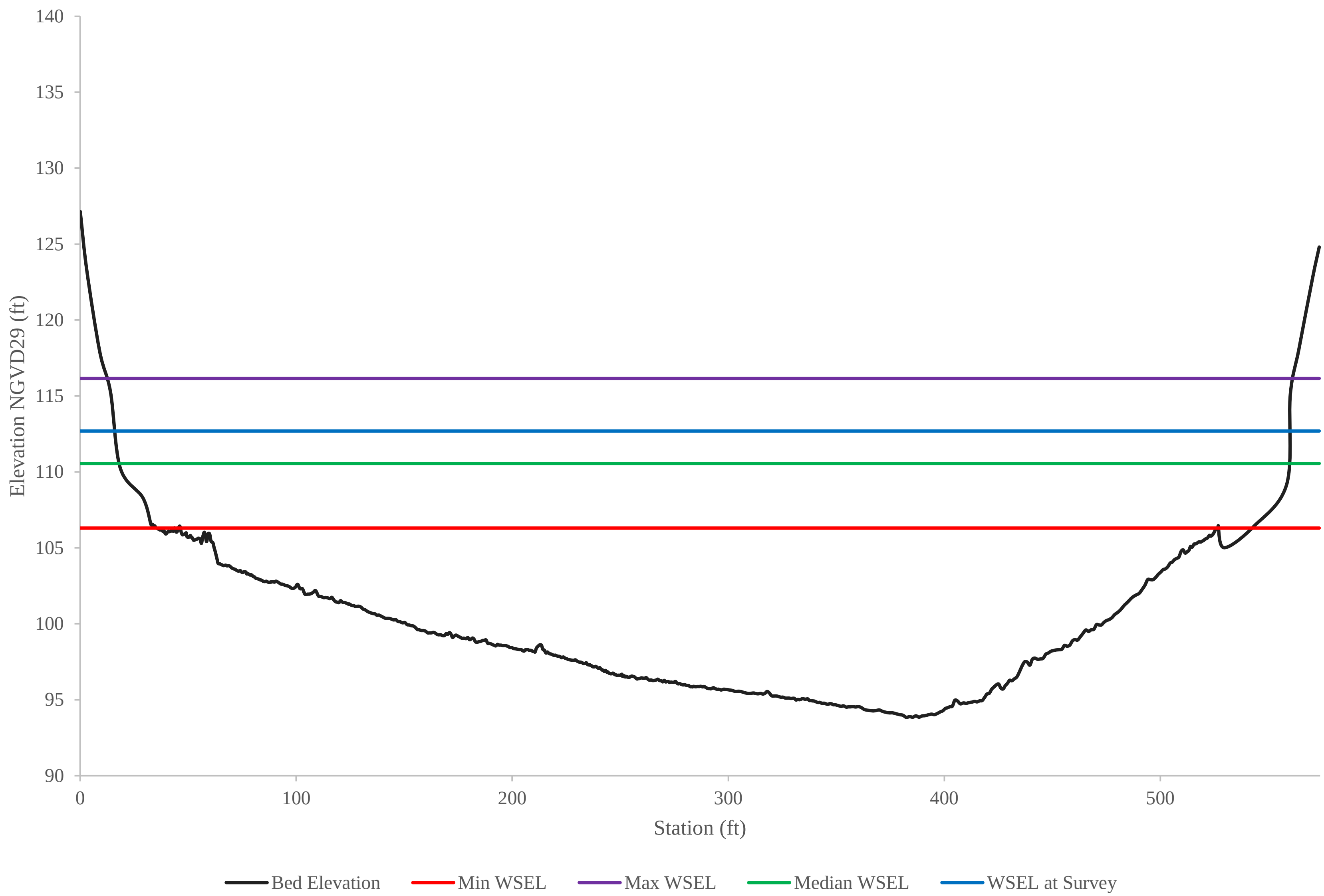

Figure B-12. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 17.

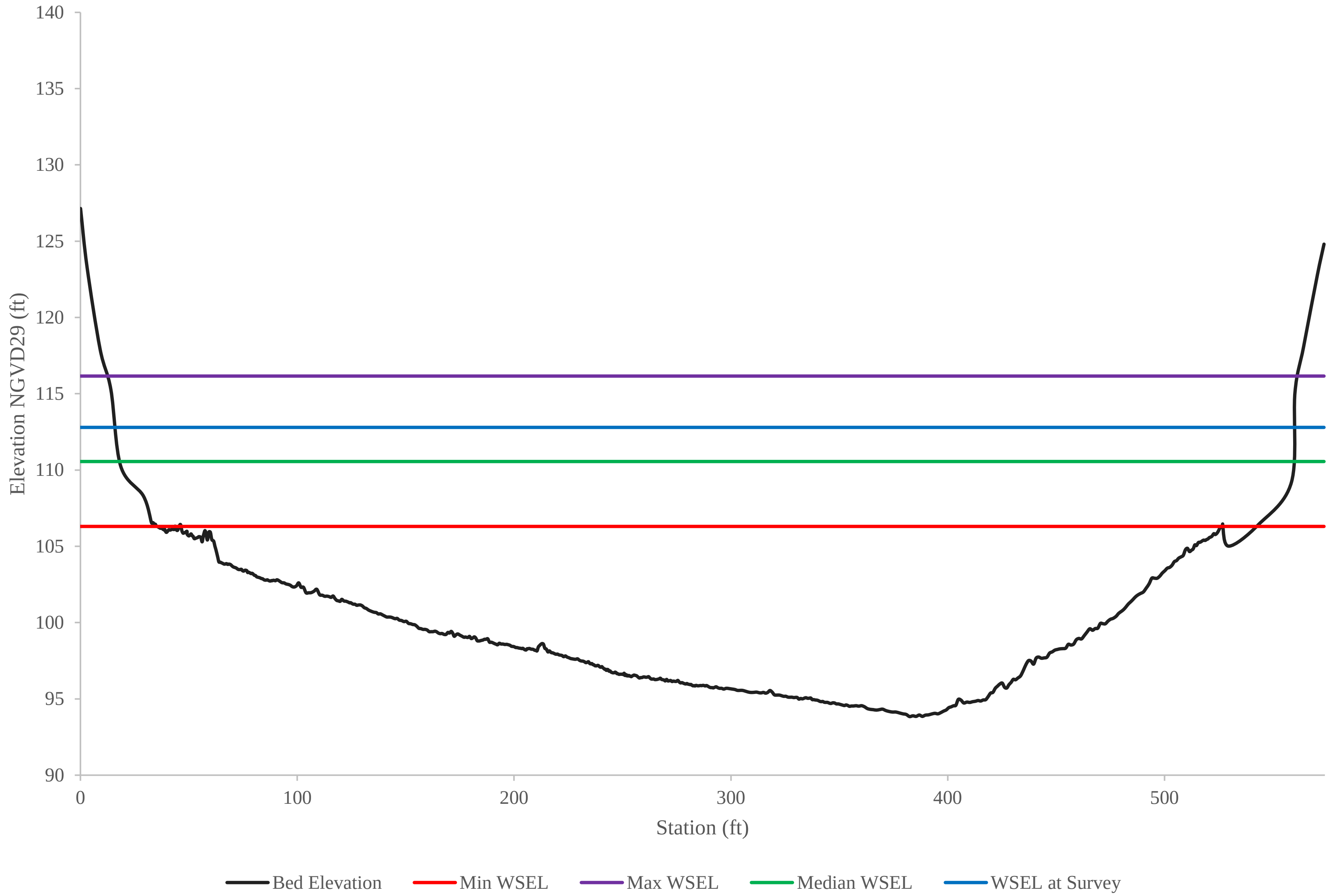

Figure B-13. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 18.

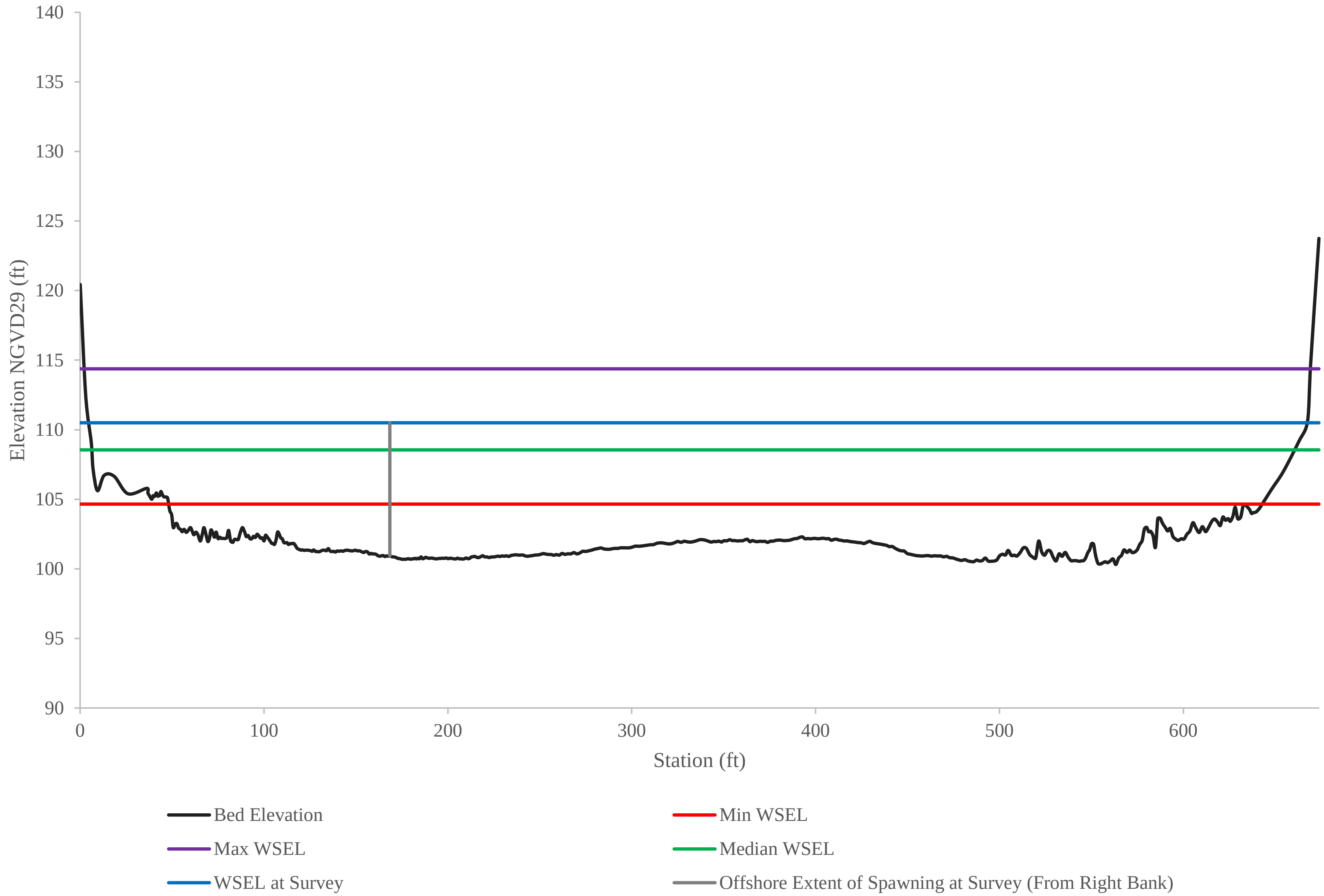

Figure B-14. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 19.

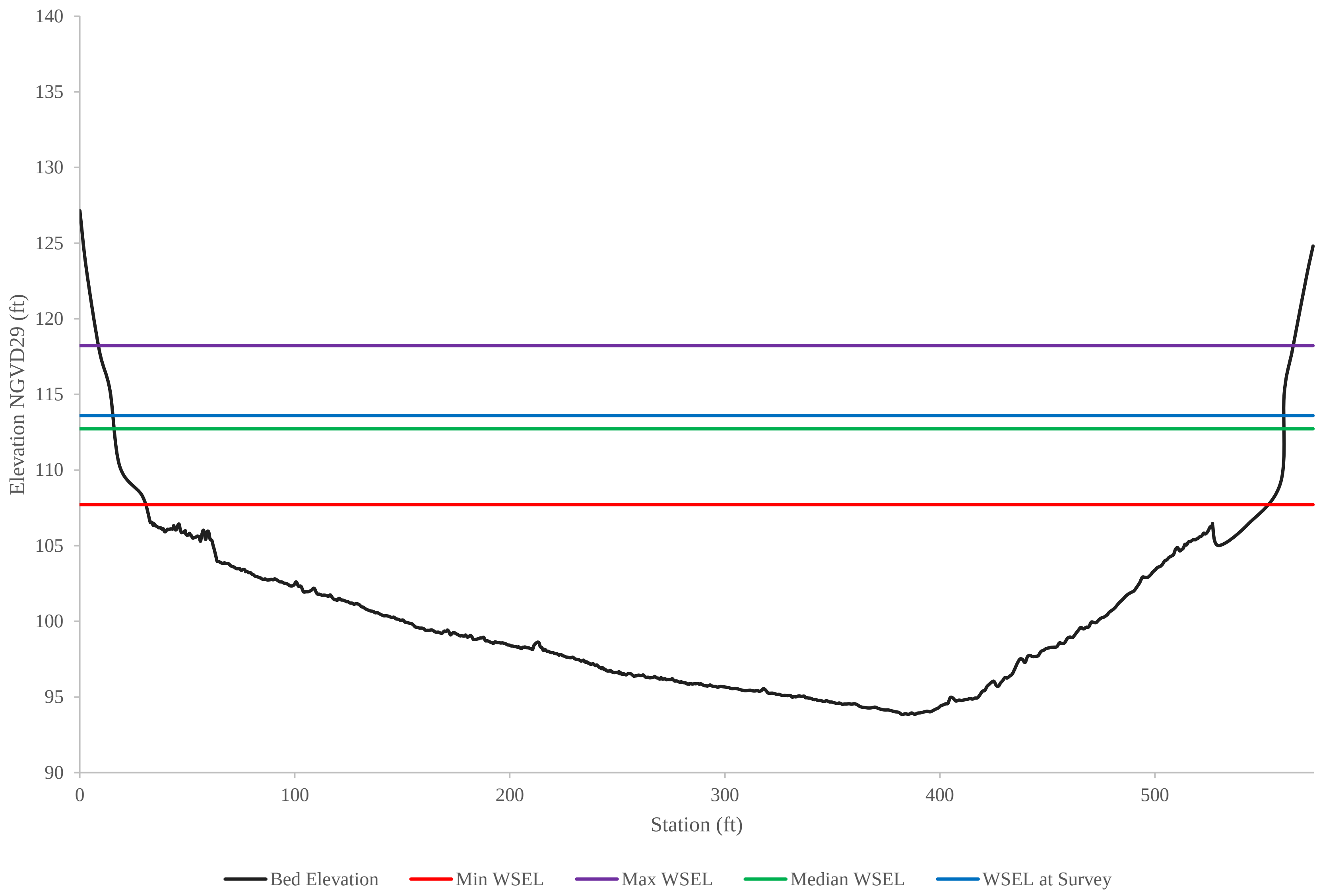

Figure B-15. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 21.

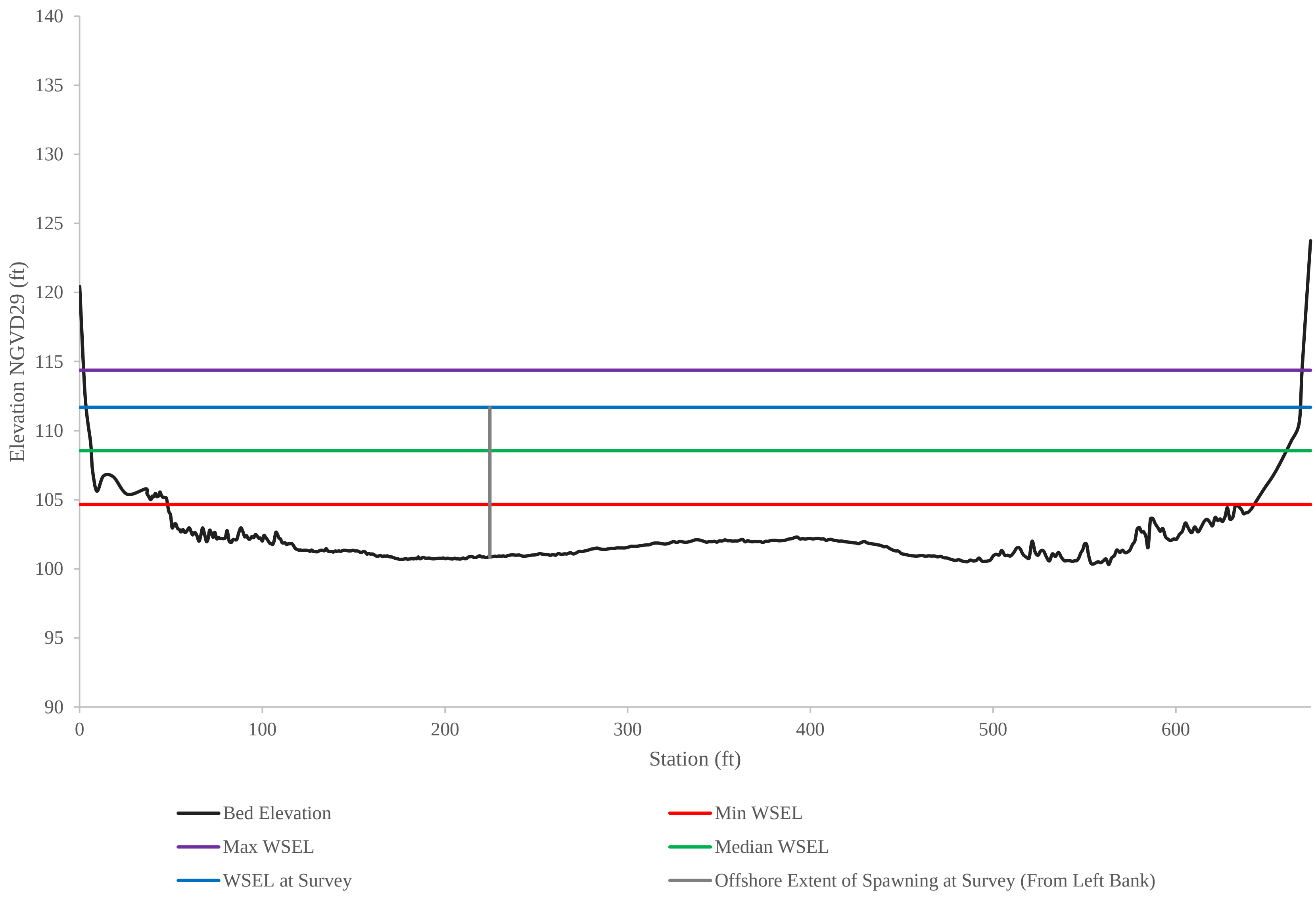

Figure B-16. Minimum, Maximum, Median, and Survey Time WSEL for Spawning Site 22.

APPENDIX C – HABITAT DURATION CURVES

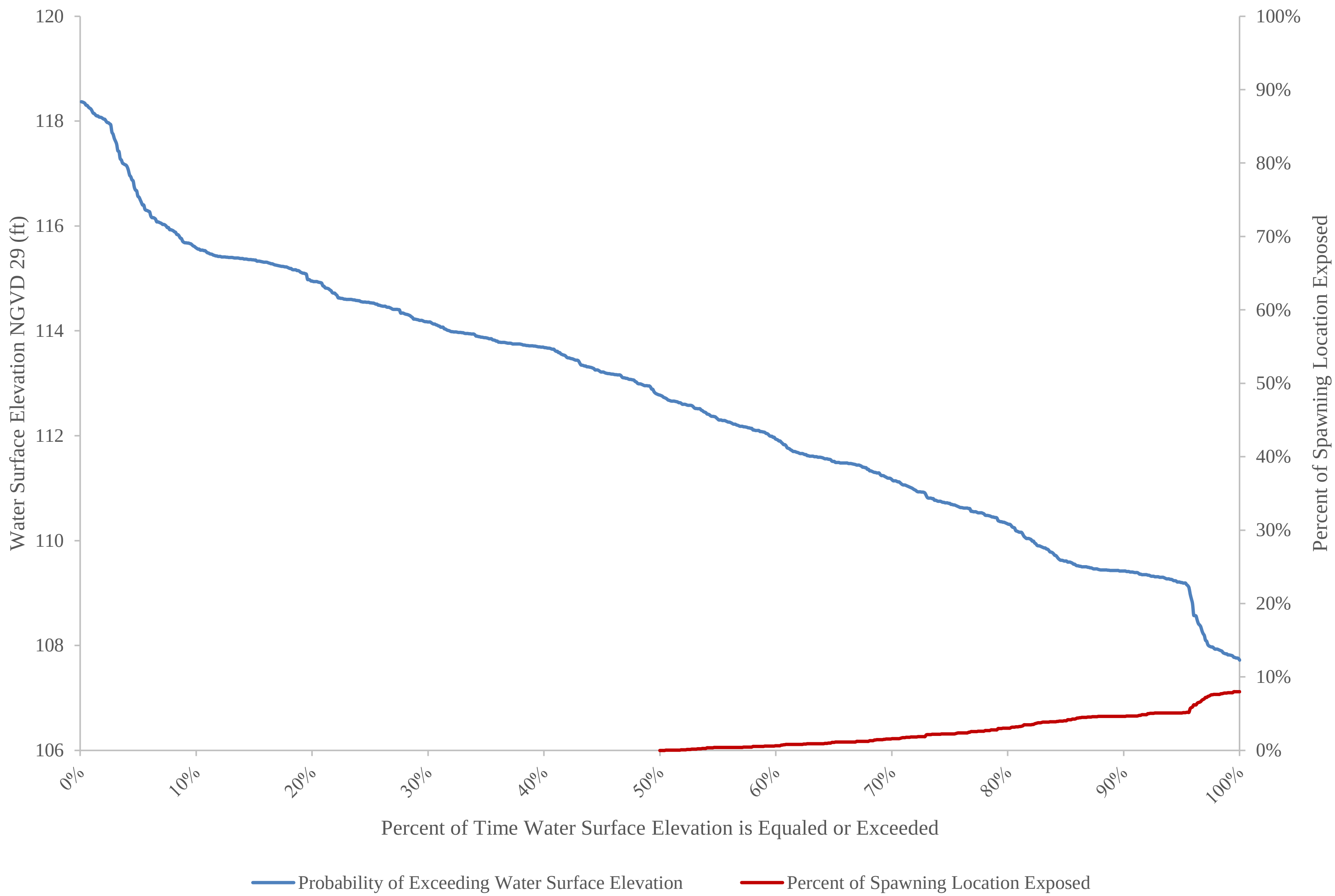

Figure C-1. Habitat Duration Curve for Spawning Site 1.

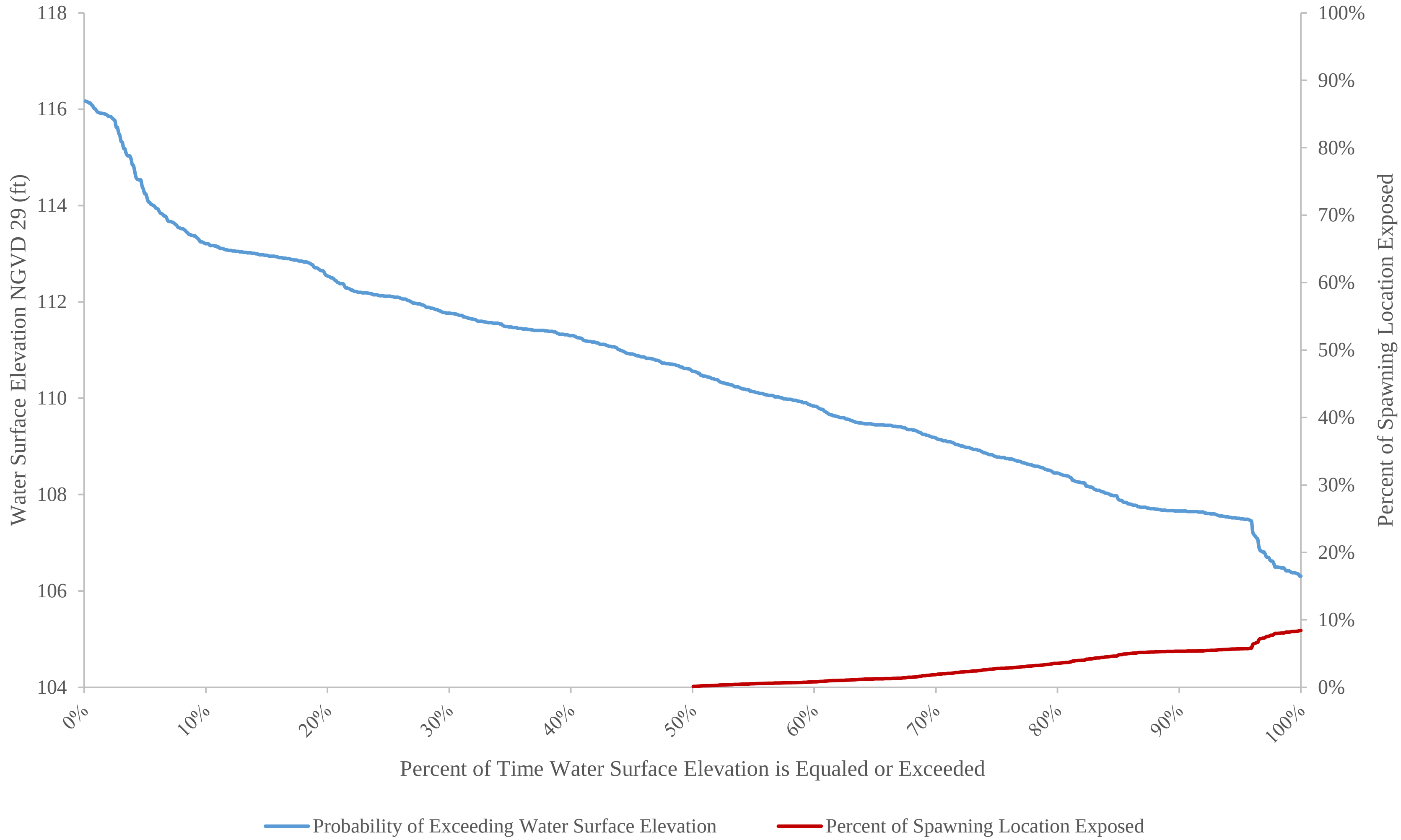

Figure C-2. Habitat Duration Curve for Spawning Site 2.

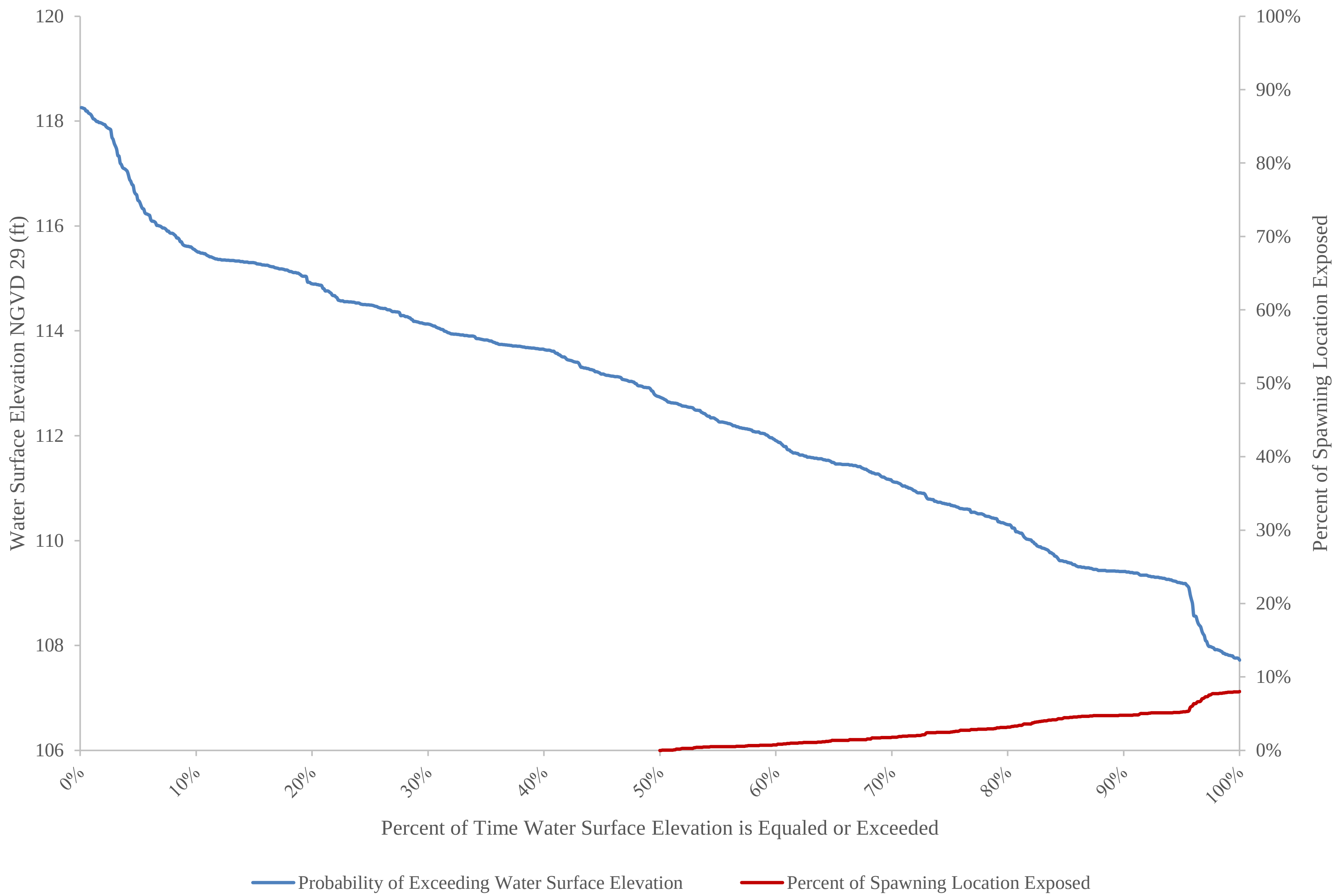

Figure C-3. Habitat Duration Curve for Spawning Site 3.

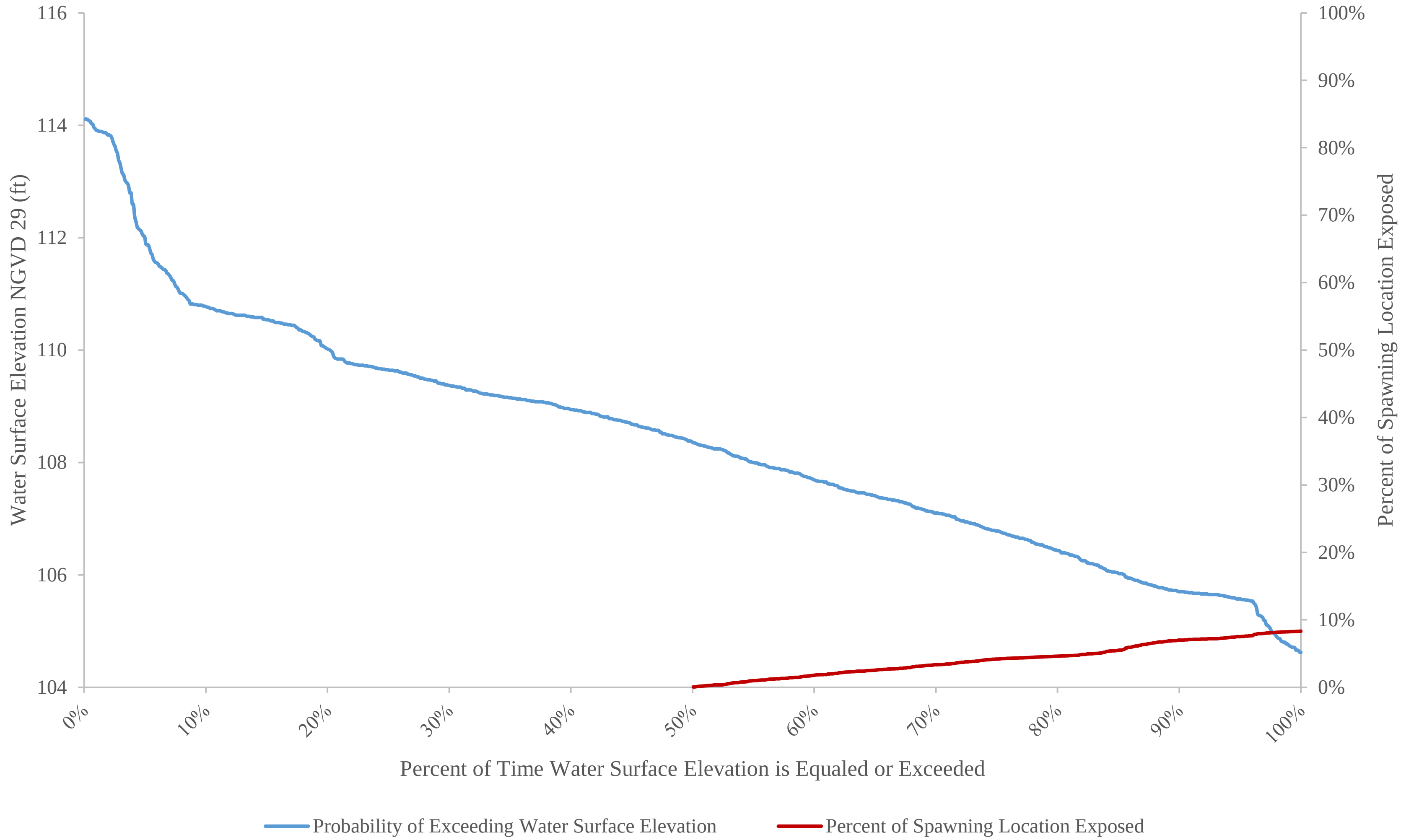

Figure C-4. Habitat Duration Curve for Spawning Site 4.

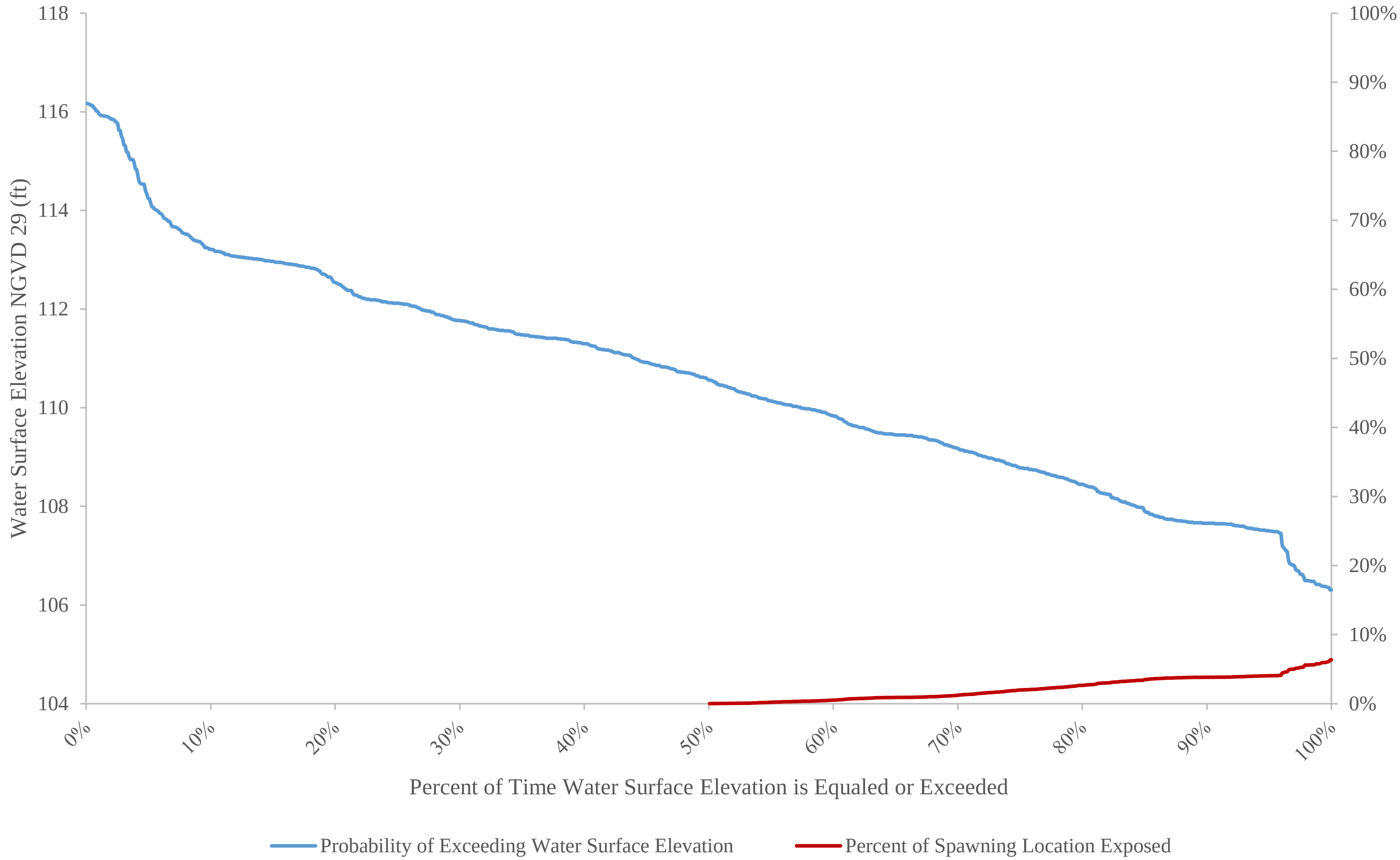

Figure C-5. Habitat Duration Curve for Spawning Site 5.

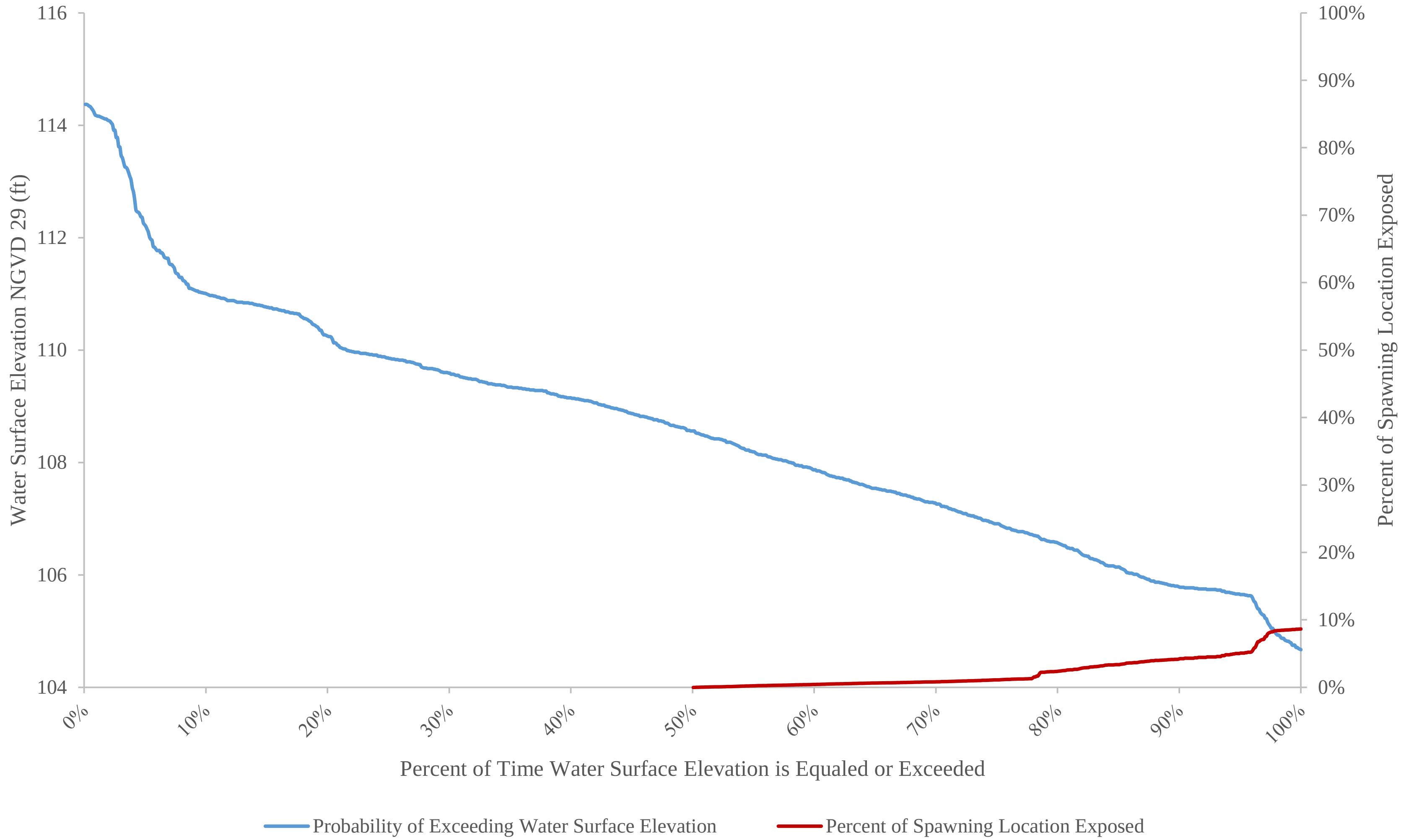

Figure C-6. Habitat Duration Curve for Spawning Site 6.

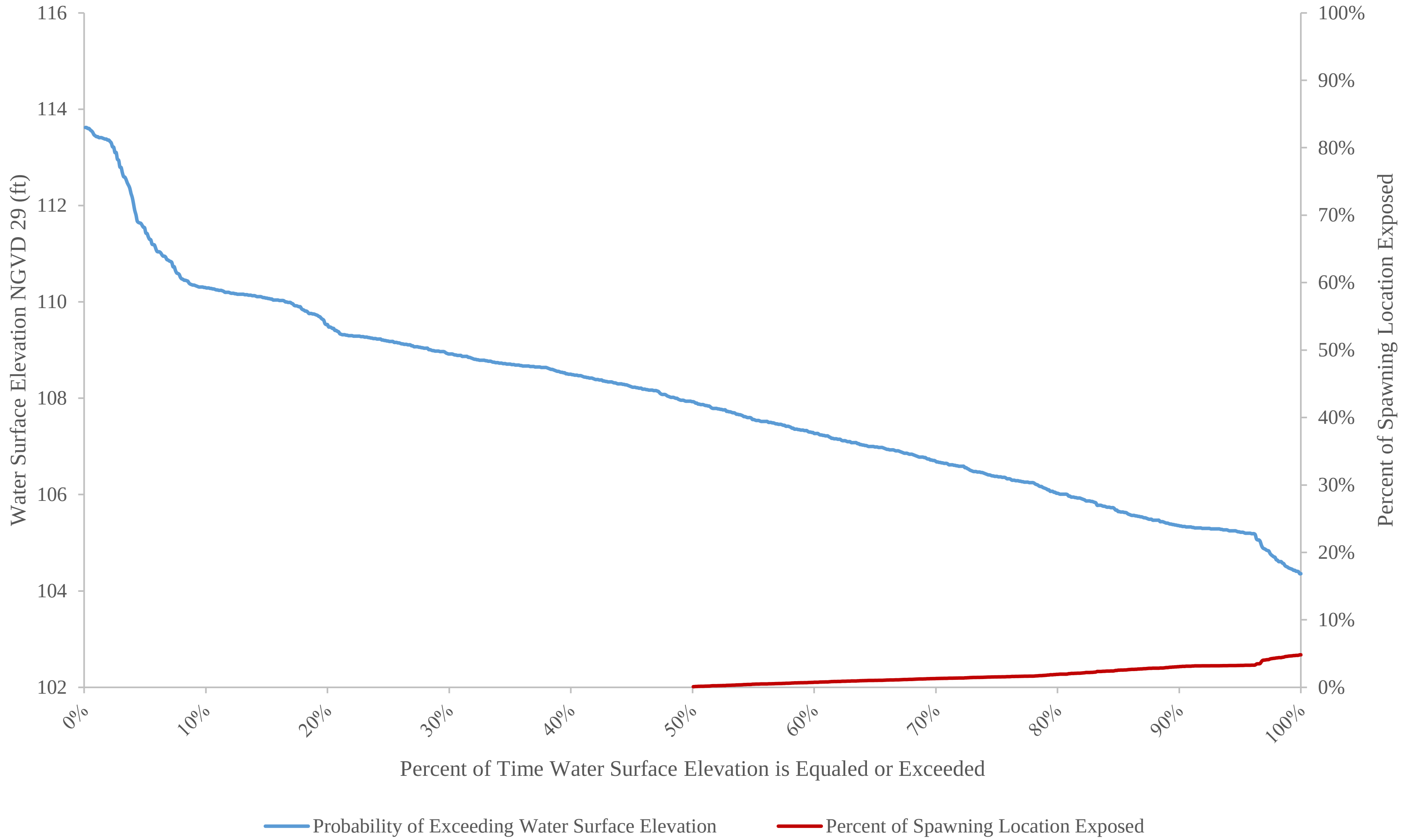

Figure C-7. Habitat Duration Curve for Spawning Site 7.

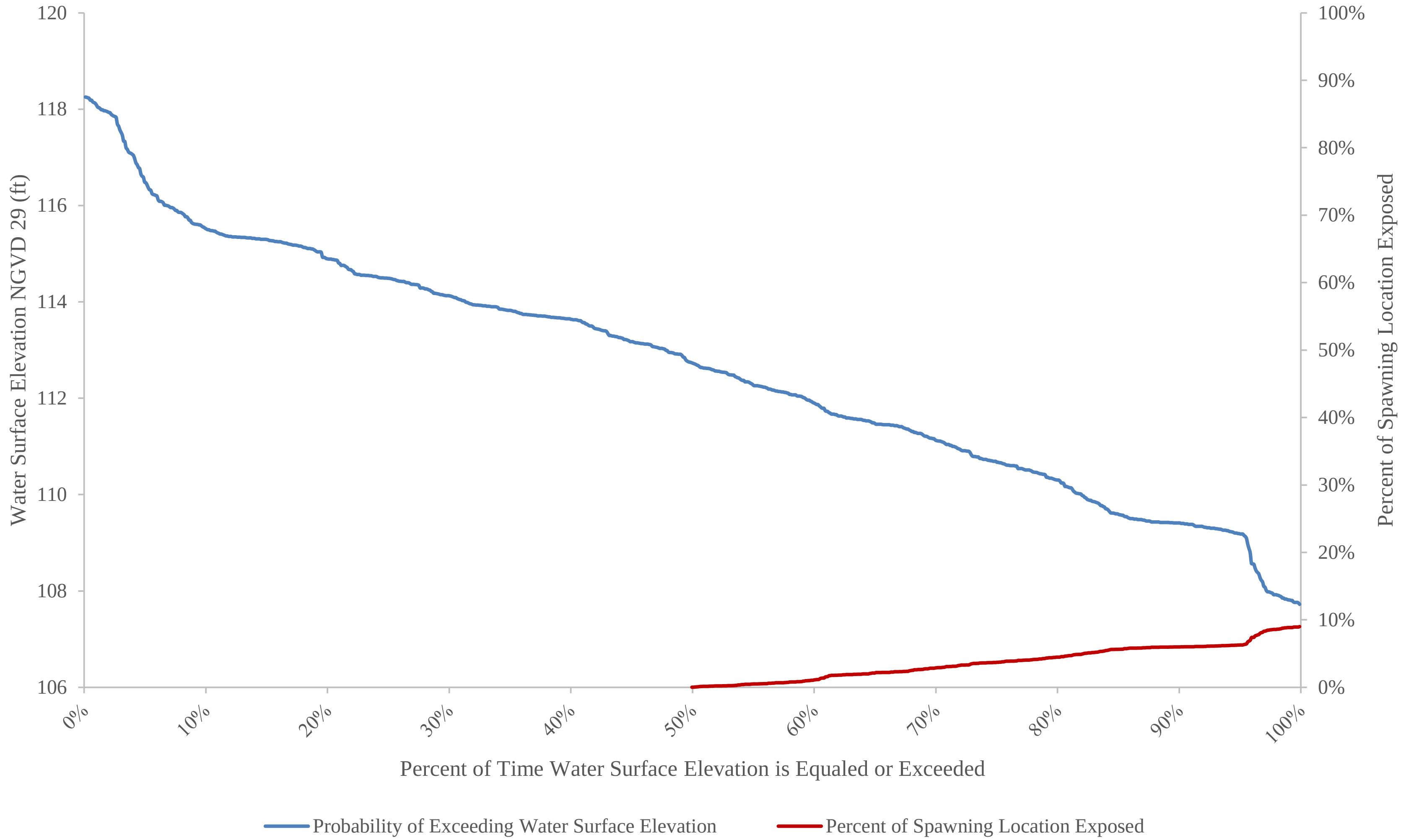

Figure C-8. Habitat Duration Curve for Spawning Site 8.

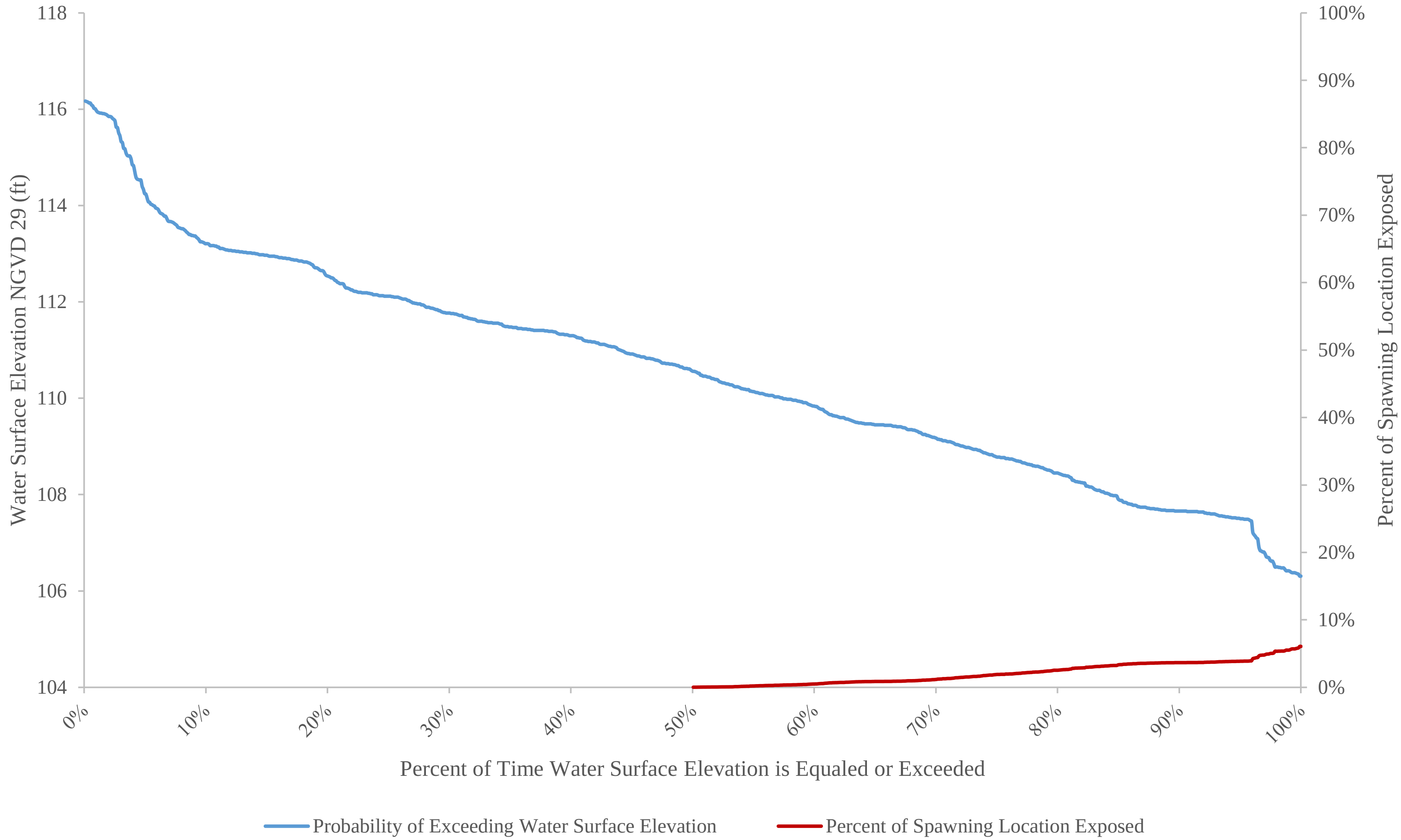

Figure C-9. Habitat Duration Curve for Spawning Site 9.

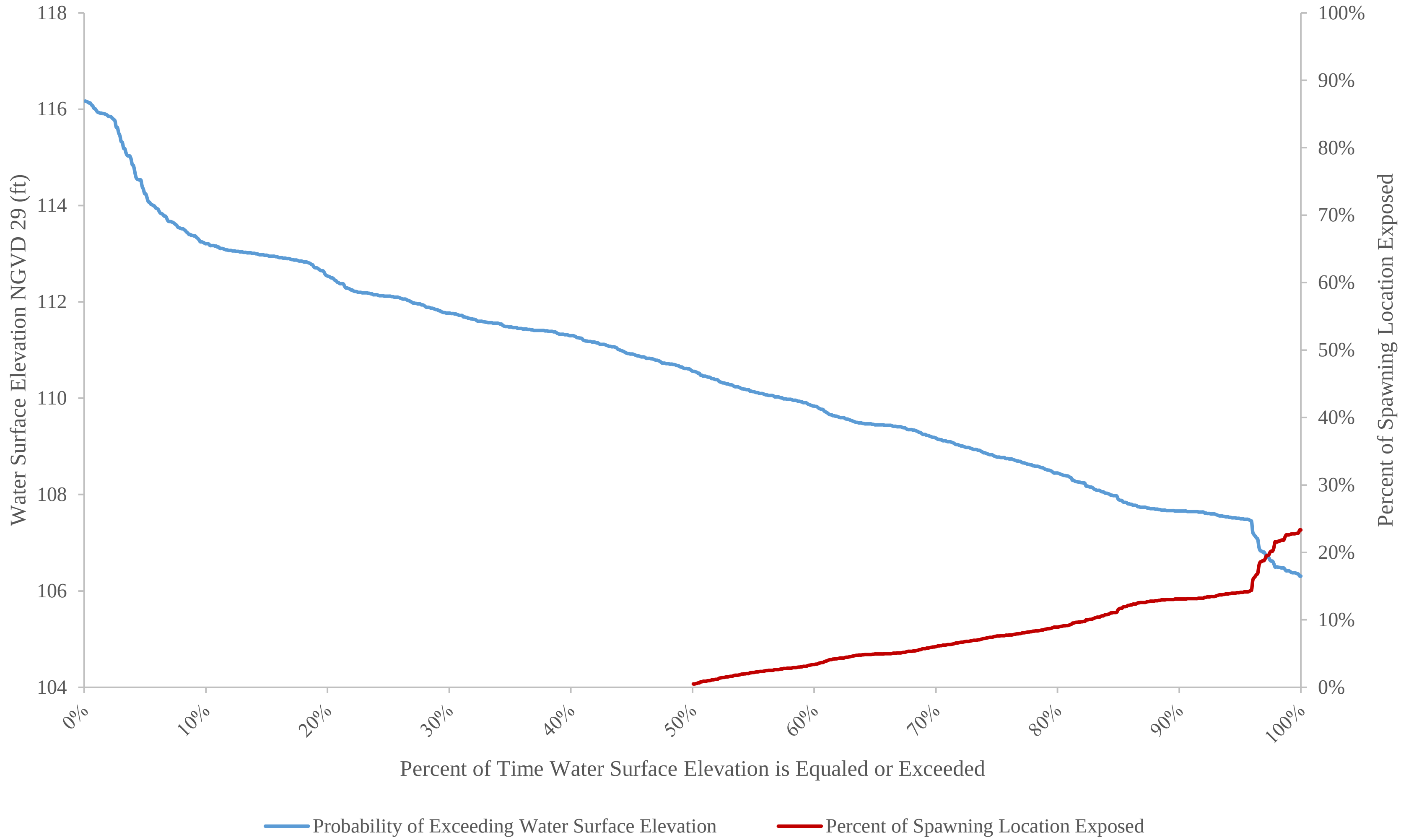

Figure C-10. Habitat Duration Curve for Spawning Site 10.

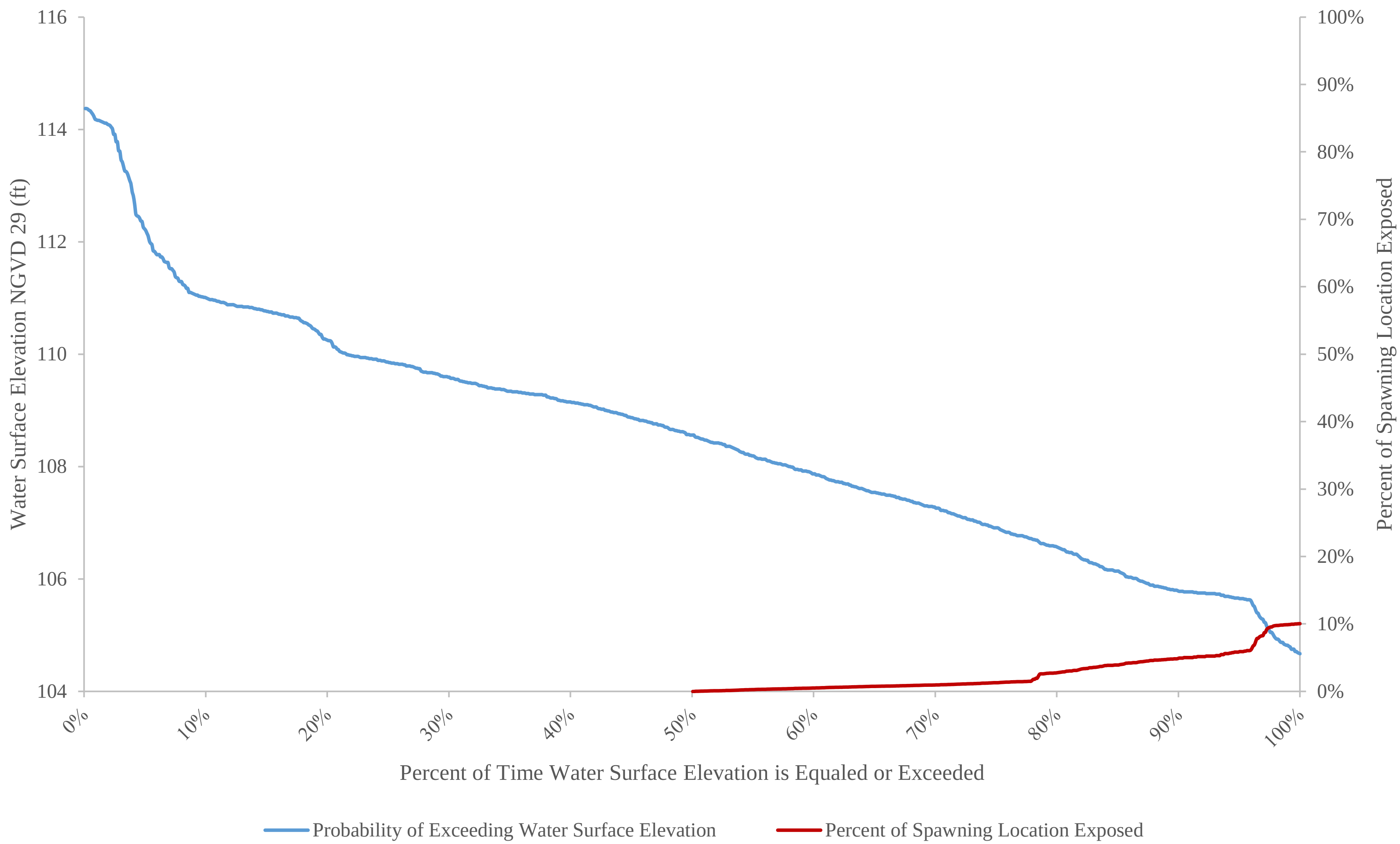

Figure C-11. Habitat Duration Curve for Spawning Site 11.

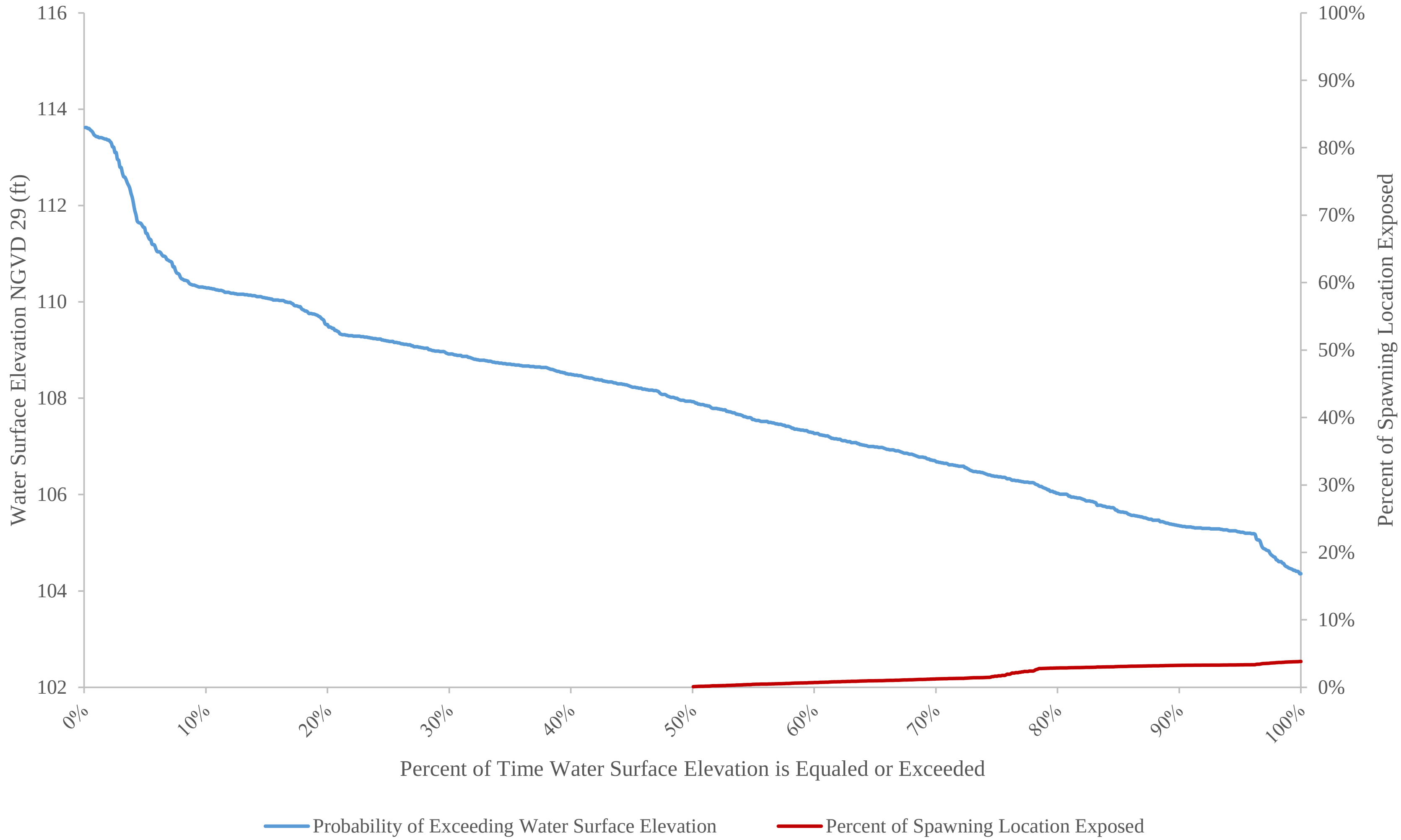

Figure C-12. Habitat Duration Curve for Spawning Site 12.

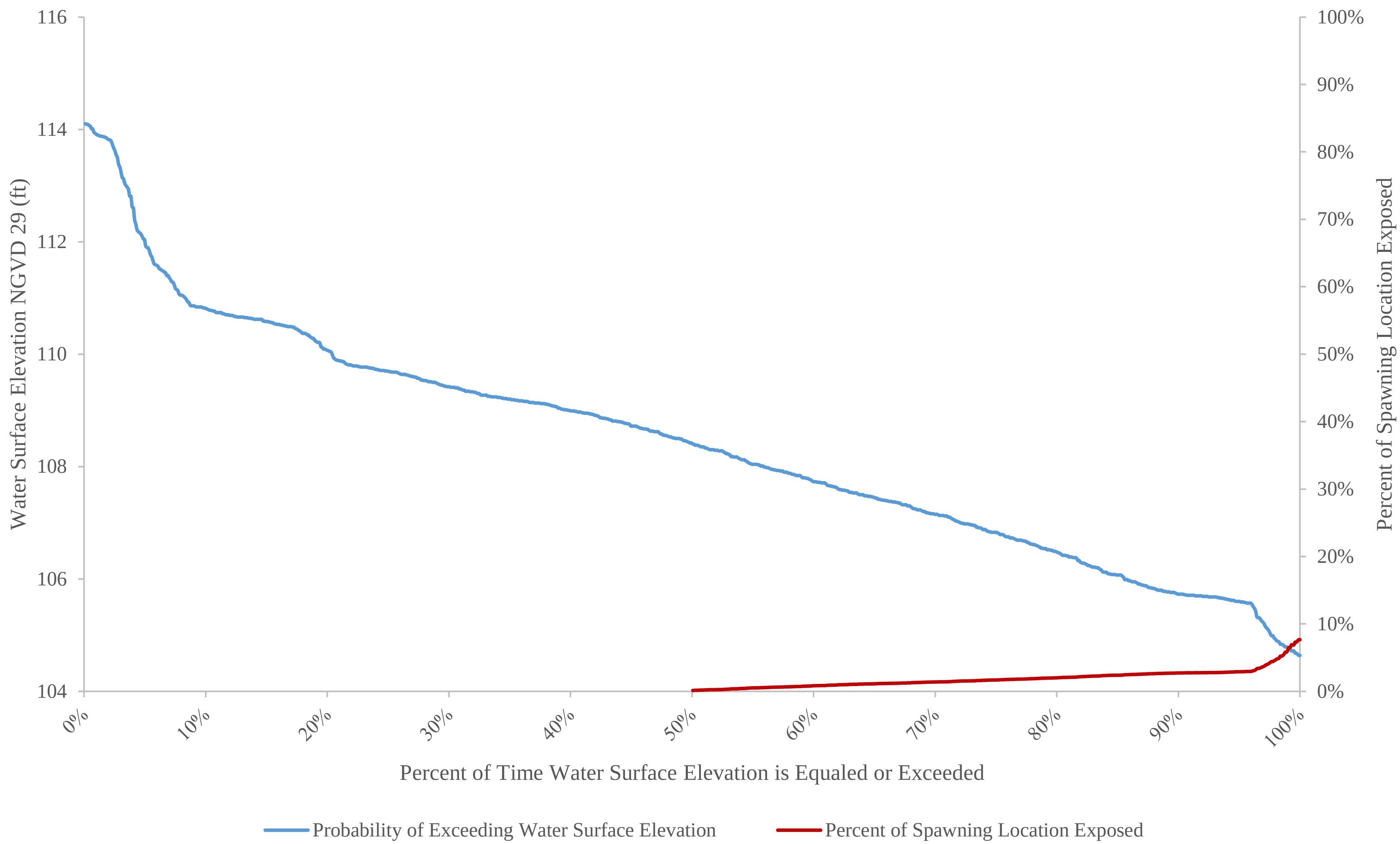

Figure C-13. Habitat Duration Curve for Spawning Site 13.

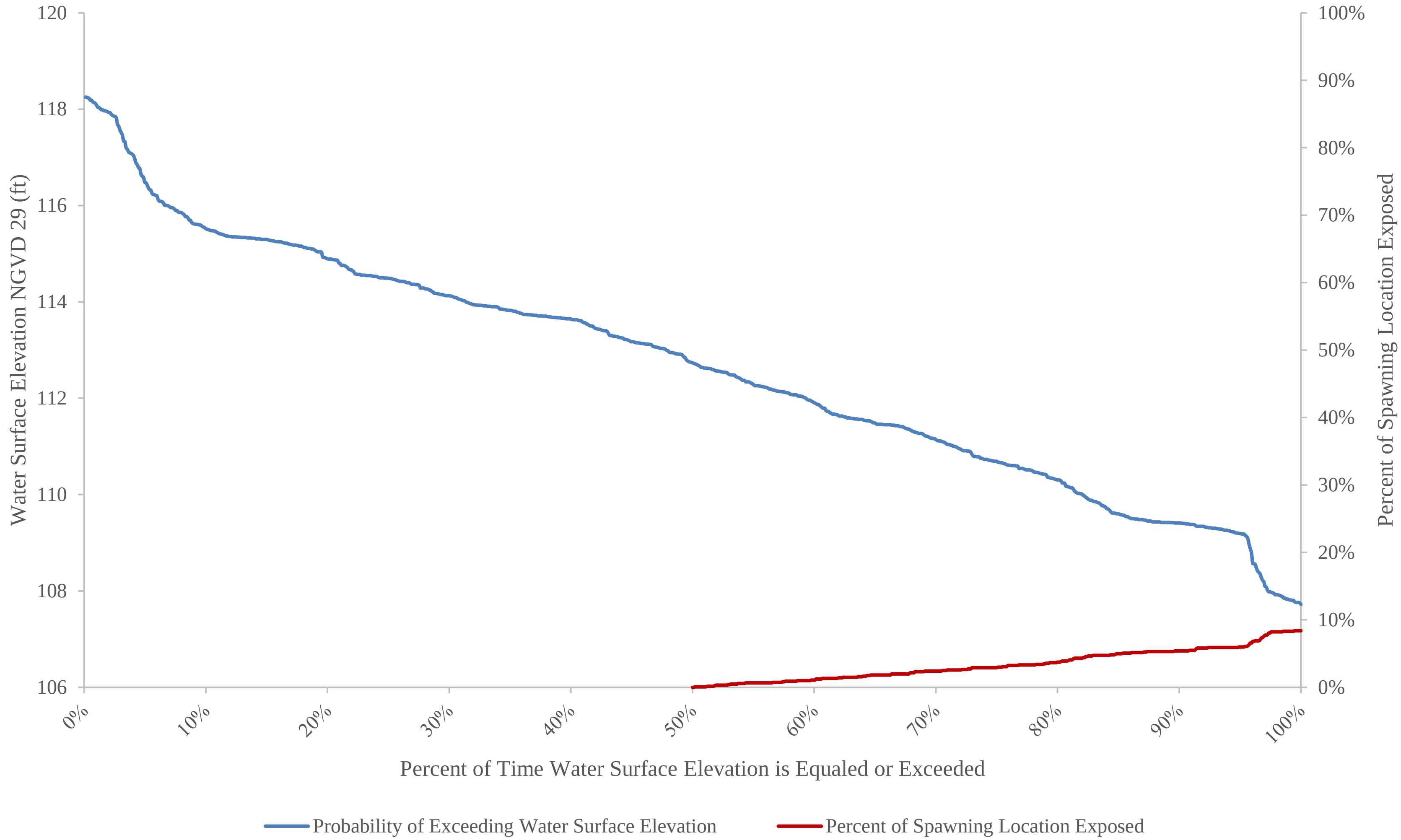

Figure C-14. Habitat Duration Curve for Spawning Site 14.

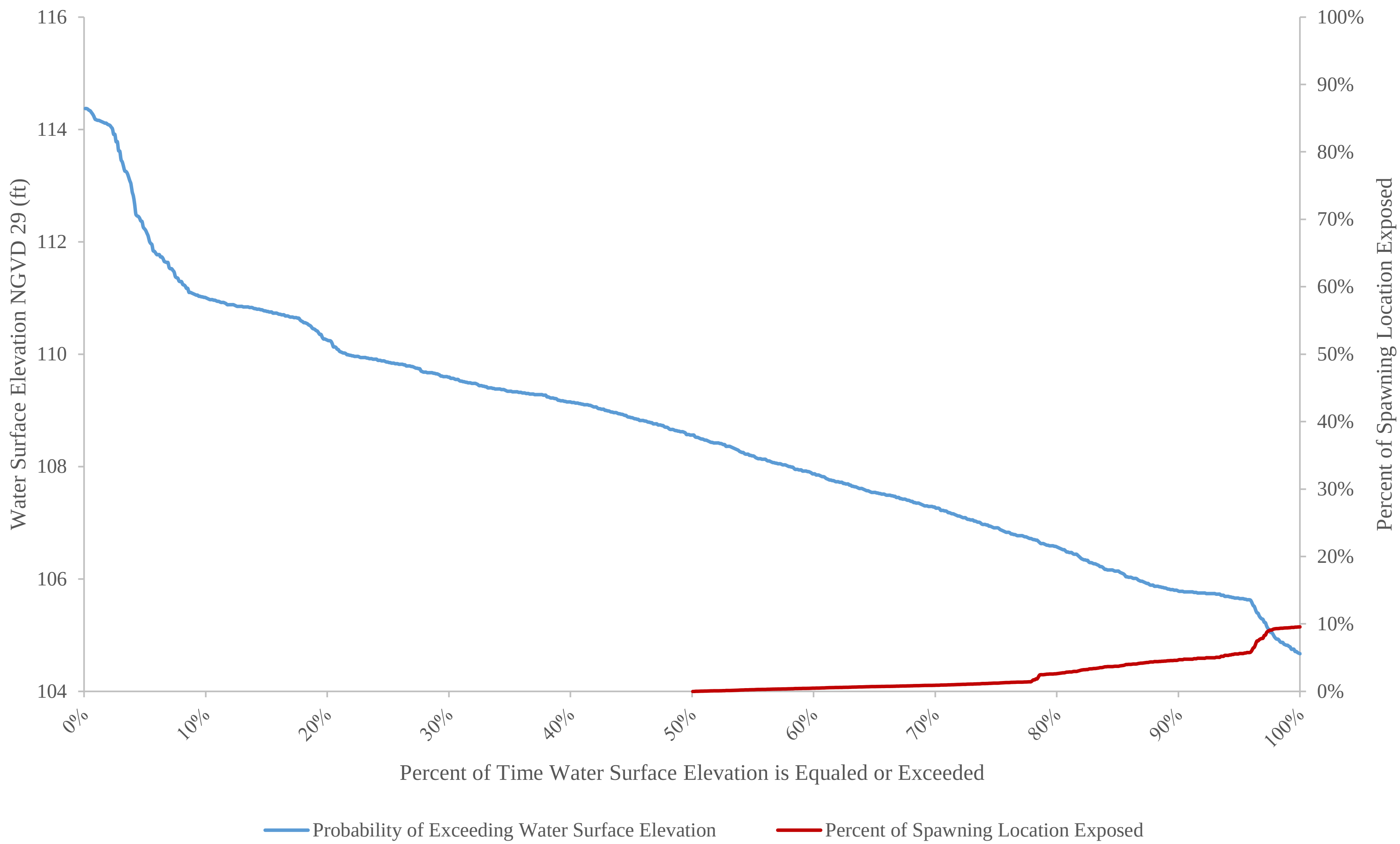

Figure C-15. Habitat Duration Curve for Spawning Site 15.

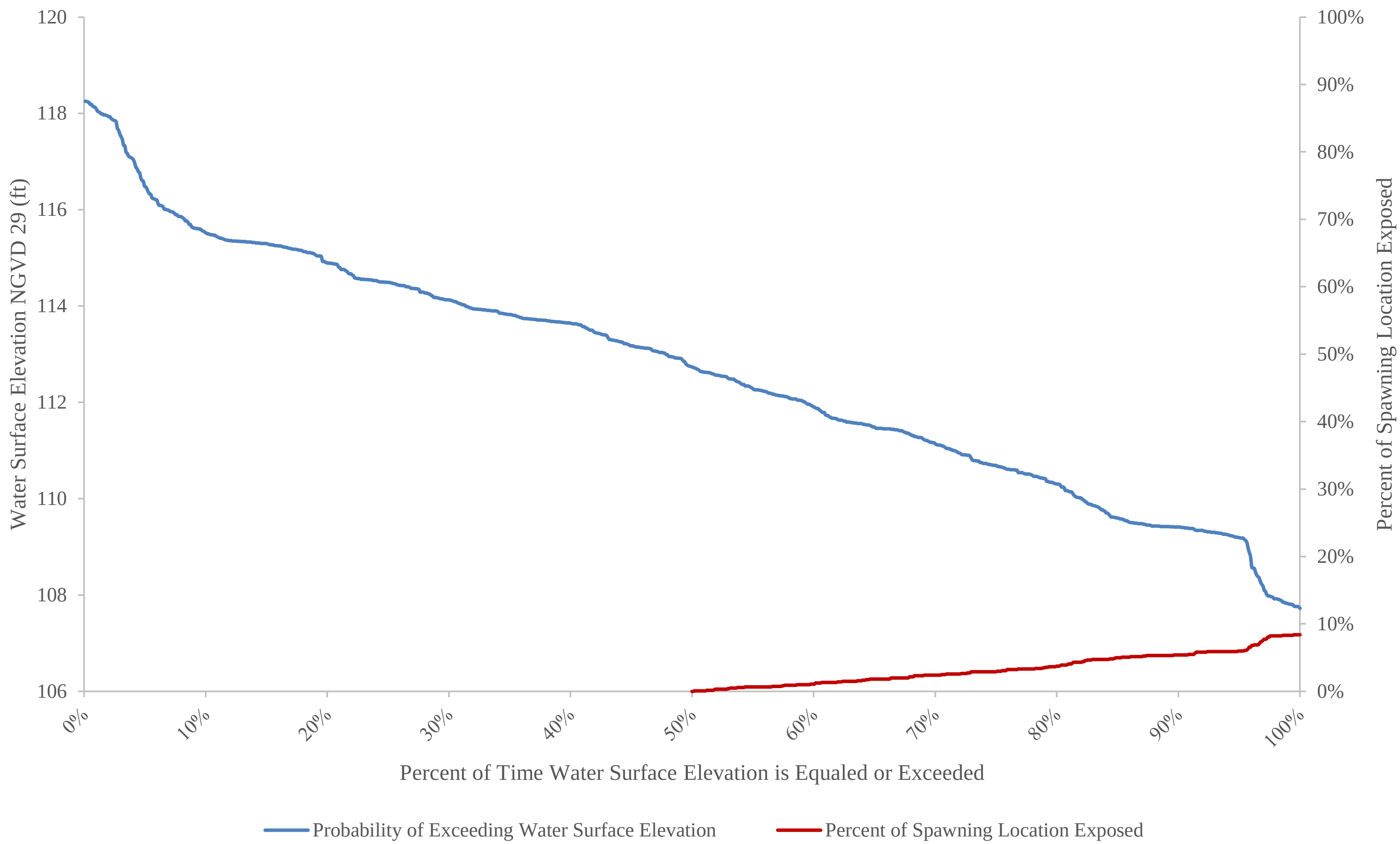

Figure C-16. Habitat Duration Curve for Spawning Site 16.

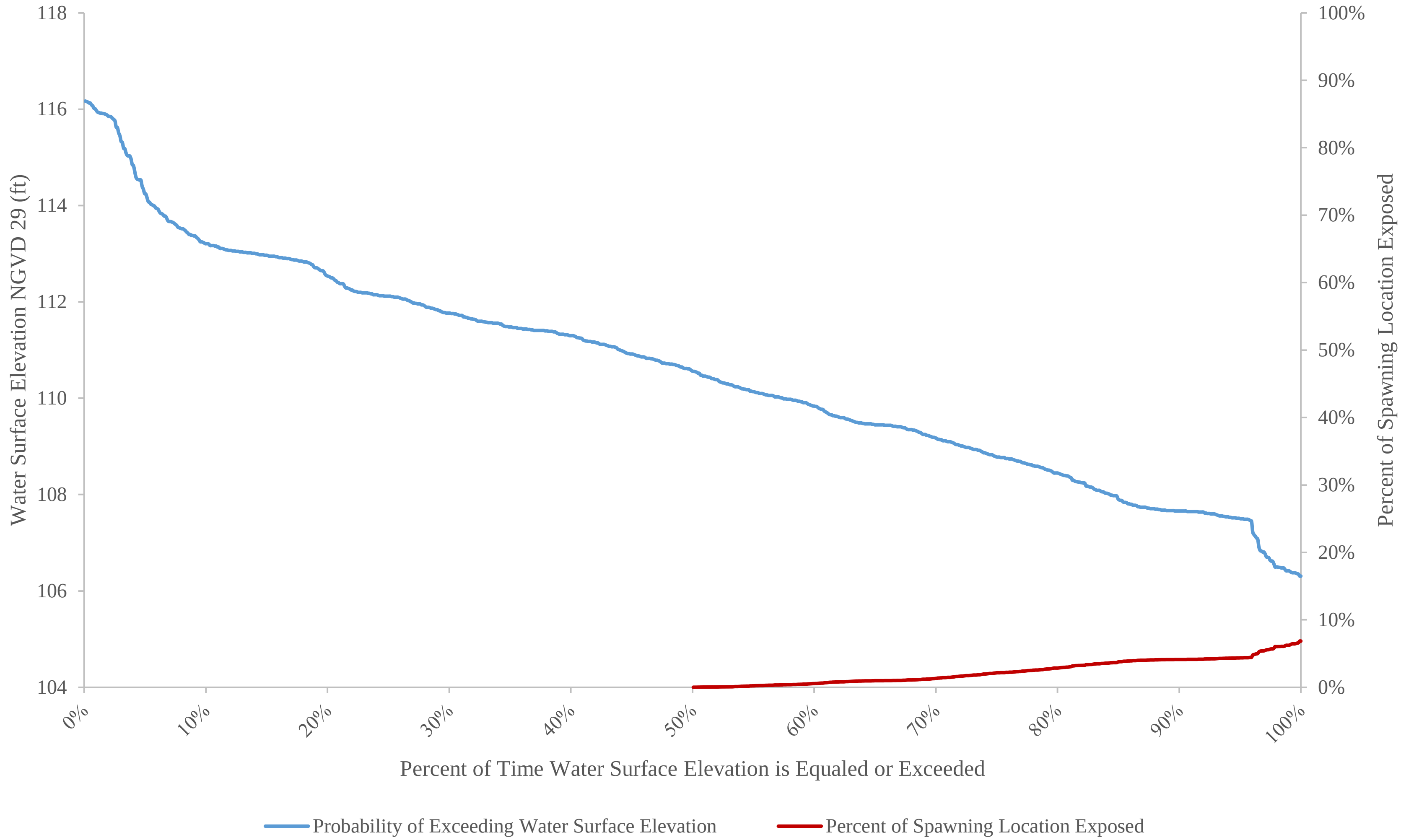

Figure C-17. Habitat Duration Curve for Spawning Site 17.

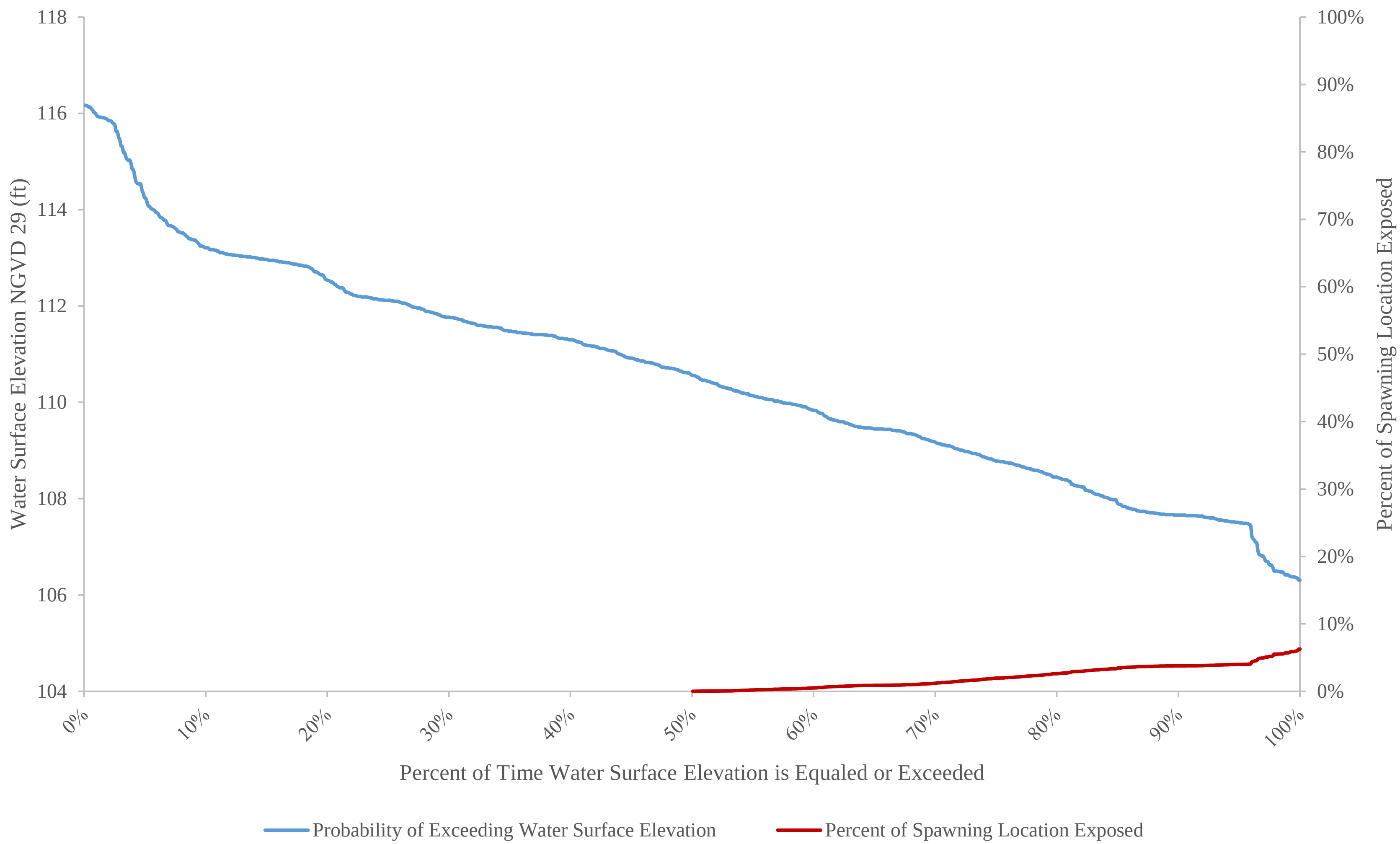

Figure C-18. Habitat Duration Curve for Spawning Site 18.

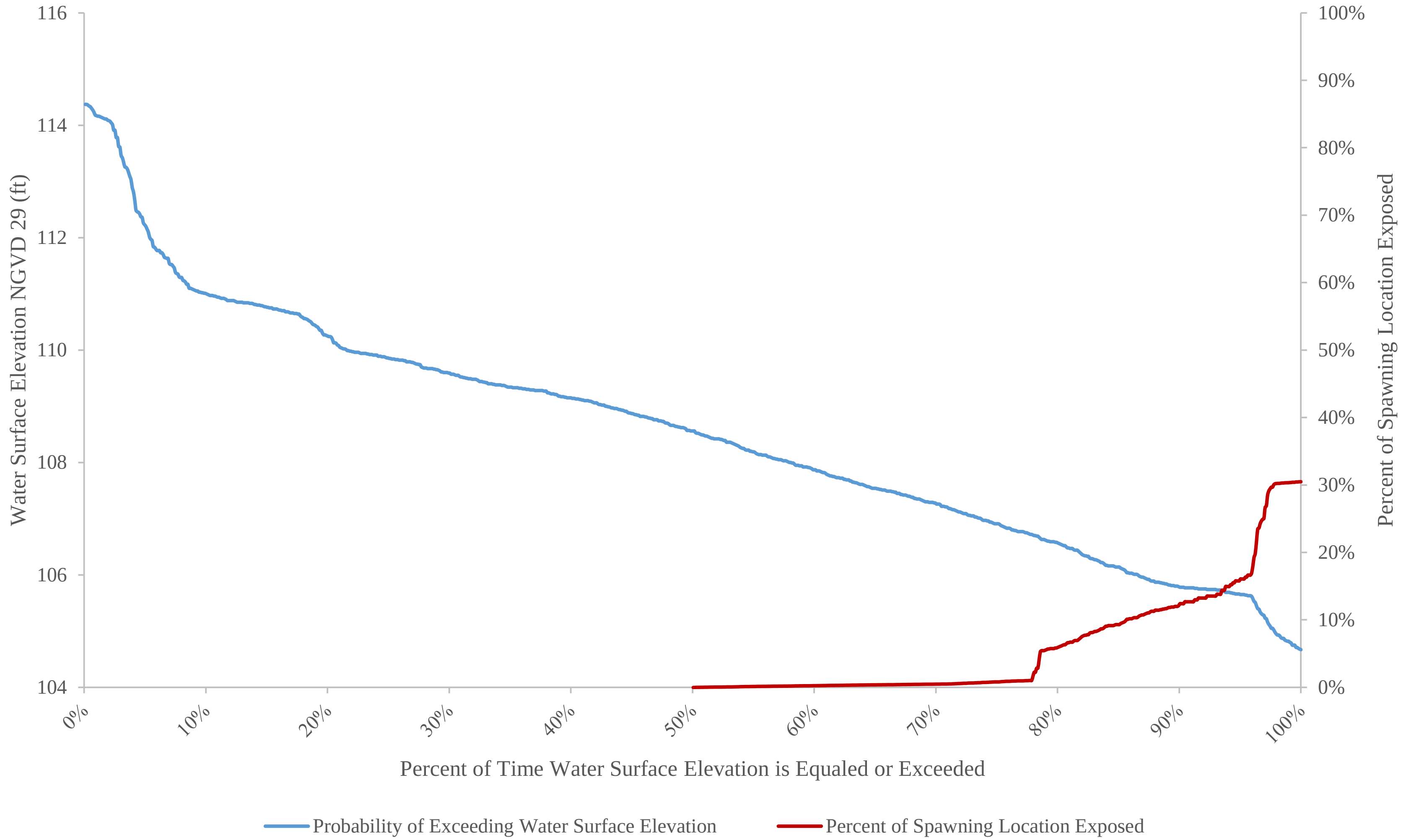

Figure C-19. Habitat Duration Curve for Spawning Site 19.

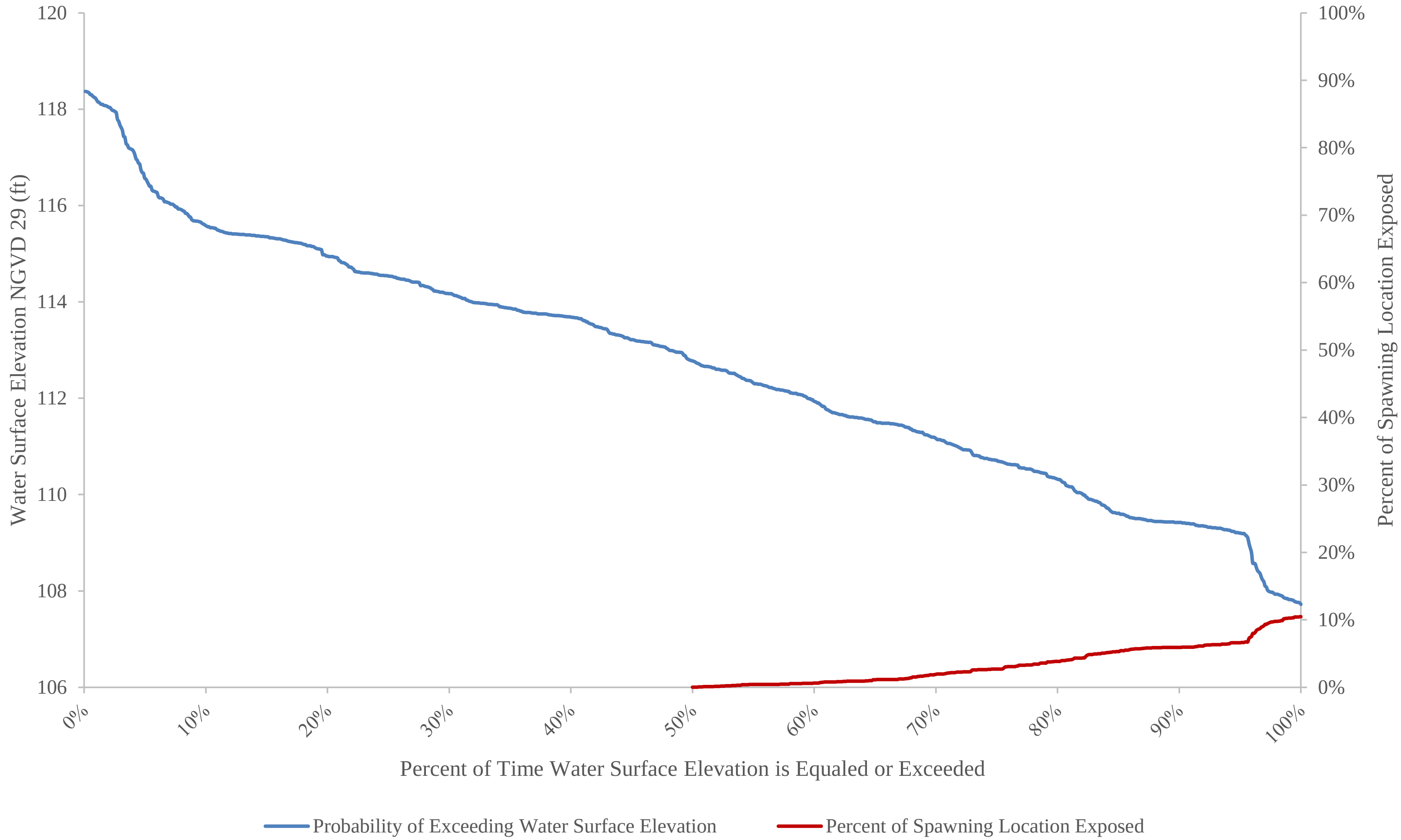

Figure C-20. Habitat Duration Curve for Spawning Site 20.

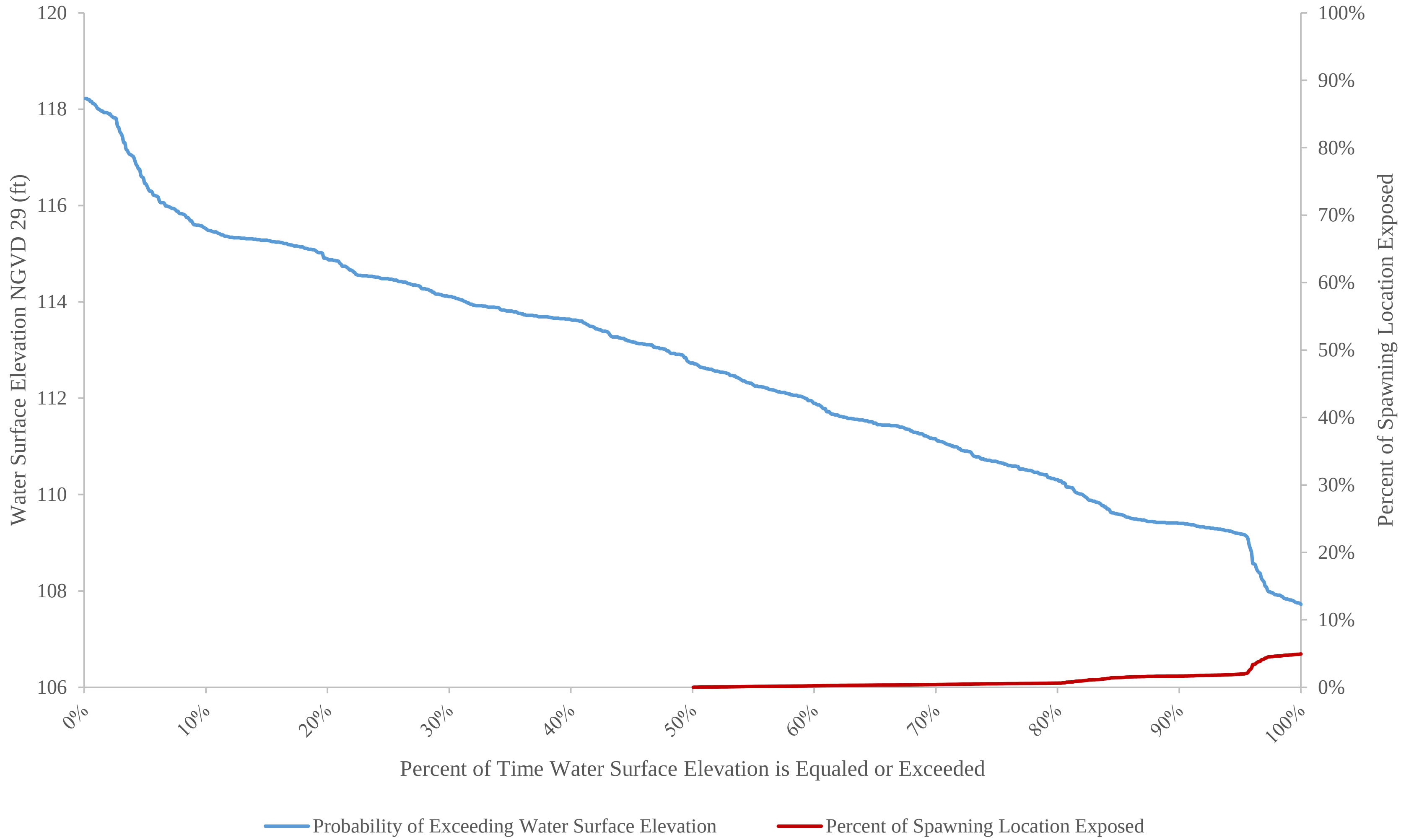

Figure C-21. Habitat Duration Curve for Spawning Site 21.

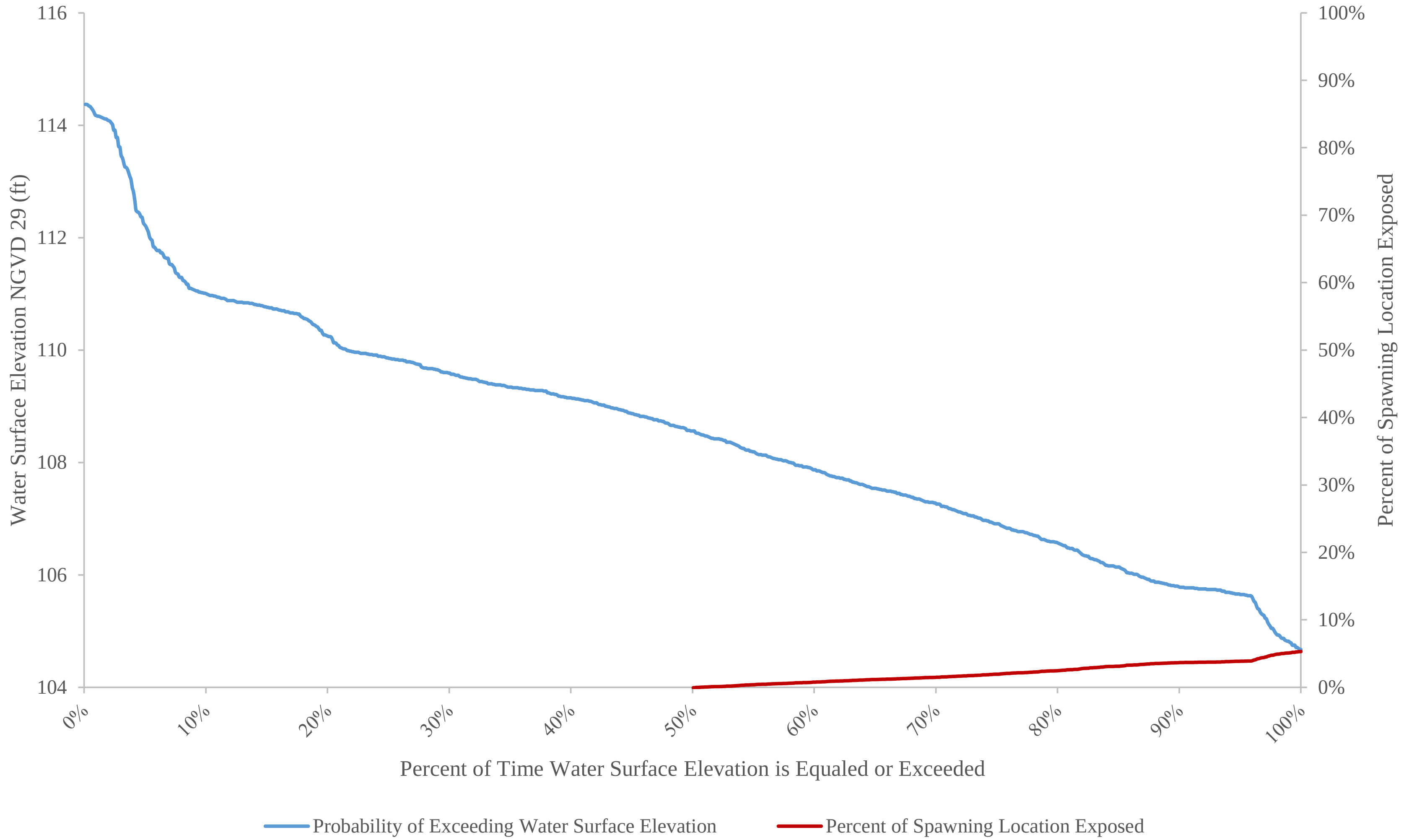

Figure C-22. Habitat Duration Curve for Spawning Site 22.

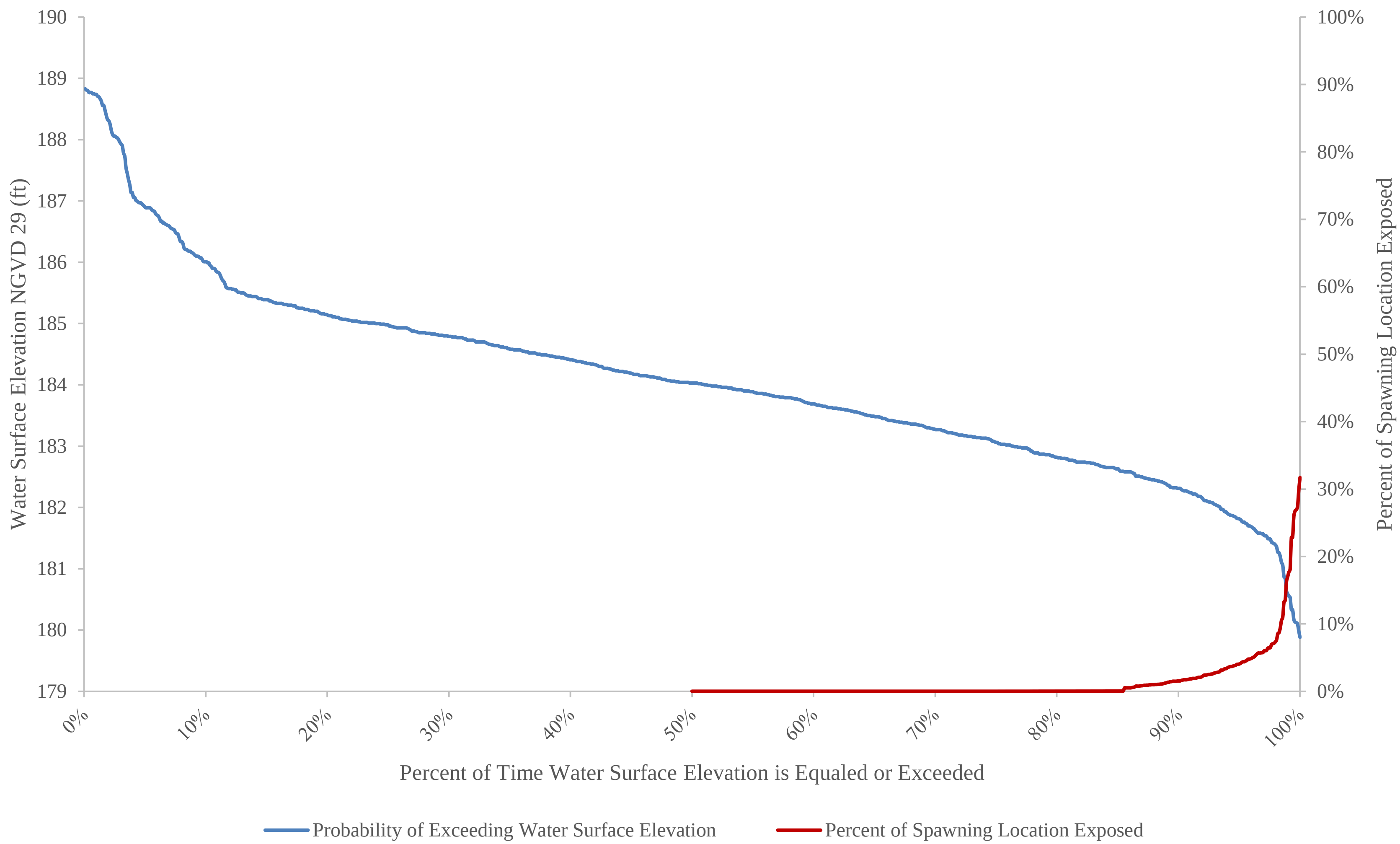

Figure C-23. Habitat Duration Curve for Spawning Site 23.