FINAL LICENSE APPLICATION

Volume II of IV

Part 1 - Study Reports
Book 1 of 2

Niagara Hydroelectric Project
(FERC No. 2466)

February 28, 2022

Prepared by:

HDR

Prepared for:

APPALACHIAN POWER
An AEP Company
BOUNDLESS ENERGY

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Appendix A - Bypass Reach Flow and Aquatic Habitat Study Report

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BOUNDLESS ENERGY

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Acronyms and Abbreviations

1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
AEP	American Electric Power
Appalachian or Licensee	Appalachian Power Company
CFR	Code of Federal Regulations
cfs	cubic feet per second
cm	centimeters
FERC or Commission	Federal Energy Regulatory Commission
ft	feet/foot
GIS	Geographic Information System
HSC	Habitat Suitability Criteria
HSI	Habitat Suitability Index
ICM	Integrated Catchment Model
ILP	Integrated Licensing Process
ISR	Initial Study Report
LiDAR	Light detection and ranging
mm	millimeters
NGVD	National Geodetic Vertical Datum of 1929
Project	Niagara Hydroelectric Project
POR	period of record
RSP	Revised Study Plan
SPD	Study Plan Determination
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VDGIF	Virginia Department of Game and Inland Fisheries
VDWR	Virginia Department of Wildlife Resources

1 Project Introduction and Background

Appalachian Power Company (Appalachian or Licensee), a unit of American Electric Power (AEP) is the Licensee, owner, and operator of the 2.4-megawatt run-of-river Niagara Hydroelectric Project (Project) (Project No. 2466), located on the Roanoke River (River Mile 355) in Roanoke County, Virginia.

The Project is currently licensed by the Federal Energy Regulatory Commission (FERC or Commission) under the authority granted to FERC by Congress through the Federal Power Act, 16 United States Code (USC) §791(a), et seq., to license and oversee the operation of non-federal hydroelectric projects on jurisdictional waters and/or federal land. The Project underwent relicensing in the early 1990s, and the current operating license for the Project expires on February 29, 2024. Accordingly, Appalachian is pursuing a subsequent license for the Project pursuant to the Commission's Integrated Licensing Process (ILP), as described at 18 Code of Federal Regulations (CFR) Part 5. In accordance with FERC's regulations at 18 CFR §16.9(b), the licensee must file its final application for a new license with FERC no later than February 28, 2022.

In accordance with 18 CFR §5.11 of the Commission's regulations, Appalachian developed a Revised Study Plan (RSP) for the Project that was filed with the Commission and made available to stakeholders on November 6, 2019. The Commission issued the Study Plan Determination (SPD) on December 6, 2019.

On July 27, 2020, Appalachian filed an updated ILP study schedule and a request for extension of time to file the Initial Study Report (ISR) to account for Project delays resulting from the COVID-19 pandemic. The request was approved by FERC on August 10, 2020, and the filing deadline for the ISR for the Project was extended from November 17, 2020 to January 11, 2021. Appalachian conducted a virtual ISR Meeting on January 21, 2021 and filed the ISR Meeting summary with the Commission on February 5, 2021. Stakeholders provided written comments in response the Appalachian's filling of the ISR meeting summary; these comments were addressed in the Updated Study Report (USR), which was filed December 6, 2021. A USR meeting was held on December 14, 2021 and requests from stakeholders made during the meeting are addressed in this revised USR.

Appalachian has conducted studies in accordance with 18 CFR §5.15, as provided in the RSP and as subsequently modified by FERC. This USR describes the methods and results of the Bypass Reach Flow and Aquatic Habitat Study conducted in support of preparing an application for new license for the Project.

2 Study Goals and Objectives

The objectives of this study are to conduct a flow and habitat assessment for the Project's tailrace and bypass reach using a combination of desktop, field survey, and hydraulic modeling methodologies with the following goals:

- Delineate and quantify aquatic habitats and substrate types within the bypass reach.

- Identify and characterize locations of habitat management interest located within the bypass reach.
- Develop an understanding of surface water travel times and water surface elevation responses for varying Obermeyer sluice gate openings (i.e., varying flow scenarios) in the bypass reach study area to:
  - Demonstrate the efficacy of the existing bypass reach minimum flow requirement (i.e., 8 cubic feet per second [cfs]) on maintaining suitable habitat for aquatic species.
  - Evaluate potential seasonal minimum flow releases in the bypass reach.

3 Study Area

The study area for the Bypass Reach Flow and Aquatic Habitat Study includes the tailrace, bypass reach, and river reach downstream of the Niagara powerhouse to the Blue Ridge Parkway Bridge Figure 3-1.

Figure 3-1. Bypass Reach Flow and Aquatic Habitat Study Area

4 Background and Existing Information

The Niagara bypass reach is approximately 1,500 feet (ft) long, consisting primarily of exposed bedrock and rock outcroppings. License Article 403 established an 8-cfs minimum flow requirement for the bypass reach, but flows can be higher depending on Project inflows and/or spillway sluice gate operations. Under normal operating conditions, the Project uses available flows for powerhouse generation, maintaining the elevation of the Niagara reservoir between elevations of 884.4 and 883.4 ft NGVD[1].

Under Article 403 of the current license, Appalachian is also required to maintain 50 cfs minimum flow release or inflow, whichever is less, downstream of the Project powerhouse. When inflow to the Project exceeds the powerhouse discharge capacity (684 cfs), the excess flows are passed over and through the spillway.

Monthly flow data from the U.S. Geological Survey (USGS) 02056000 Roanoke River at Niagara, VA flow gaging station is provided in Table 4-1. This gage is located immediately downstream of the Project and reports daily average flow data starting in October 1926 through present, providing a 95-year period of record (POR). Monthly mean flow data, along with the 25th and 75th percentile flow data[2] is provided from January 1991 through December 2020 (a 30-year POR[3]) to put recent historic river flows in perspective with the Niagara maximum hydraulic capacity and current minimum downstream flow release requirements.

Based on mean monthly streamflow data, the average flow for this 30-year hydrologic period is 571 cfs. The driest year was 1999 with an average flow of 275 cfs, and the wettest year was 2019 with an average flow of 704 cfs. Table 4-2 provides the percentage of days each month (during the 30-year POR) when Project inflows exceed the powerhouse discharge capacity and excess flows are routed to the bypass reach.

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[1] All elevations are referenced to National Geodetic Vertical Datum of 1929 (NGVD).

[2] A percentile is a value on a scale of one hundred that indicates the percent of a distribution that is equal to or below it. A flow percentile greater than 75 is considered to be wetter than normal; a flow percentile between 25 and 75 is considered normal; and a flow percentile less than 25 is considered to be drier than normal.

[3] The January 1991 – December 2020 POR is reflective of current land use and water use practices and uses more modern data collection and recording methods compared to the 1926 – 1990 POR. The more recent POR also contains a number of dry and wet periods that are sufficient for purposes of evaluating flow regimes relevant to the bypass reach flow and aquatic habitat study goals and objectives.

Table 4-1. USGS 02056000 Roanoke River at Niagara, VA Monthly Flow Statistics, 1991 - 2020

Month	USGS 02056000 Roanoke River at Niagara, VA		
	25th Percentile Flow (cfs)	Mean Monthly Flow (cfs)	75th Percentile Flow (cfs)
Annual	287.1	571.3	761.7
Jan	324.2	671.7	1,013
Feb	341.6	829.2	1,136
Mar	511.6	886.8	1,124
Apr	514.4	826.3	1,128
May	366.5	734.1	903.9
Jun	269.8	588.7	832.9
Jul	224.2	371.6	375.7
Aug	179.2	280.9	326.9
Sep	169.9	384.0	444.1
Oct	160.8	333.0	371.5
Nov	180.6	387.2	655.2
Dec	203.1	562.2	829.5

Table 4-2. Percentage of Days with Spillage > 8 cfs to the Bypass Reach at Niagara

Facility	Niagara Powerhouse Capacity 684 cfs		
Time Period	1991-2020	1999 (dry year)	2019 (wet year)
Annual	24.6	6.3	64.1
Jan	29.5	9.7	61.3
Feb	33.3	0.0	60.7
Mar	46.8	22.6	38.7
Apr	39.9	6.7	10.0
May	28.4	0.0	6.5
Jun	18.3	0.0	46.7
Jul	11.5	9.7	77.4
Aug	12.3	3.2	67.7
Sep	16.6	13.3	100.0
Oct	13.0	0.0	100.0
Nov	20.3	0.0	100.0
Dec	26.1	9.7	100.0

5 Methodology

The U.S. Fish and Wildlife Service (USFWS) and the Virginia Department of Wildlife Resources (VDWR) (formerly the Virginia Department of Game and Inland Fisheries [VDGIF]) requested an instream flow study with the goal of determining the minimum flow, or range of flows to the bypass required to support habitat for a suite of species inhabiting the Roanoke River, including the Roanoke Logperch (*Percina rex)*.

Appalachian's goal in selecting a process for evaluating flows at the Project is to develop a technical basis for systematically evaluating and balancing the needs and priorities of the various flow-related resources. Therefore, the goal of this study is to characterize changes in habitat quantity over a range of flows and operational scenarios. There are several types and combinations of methodologies that could be used to meet the study objectives, ranging from quantitative to qualitative methods. Appalachian believes that the approach used for this study (i.e., development of a 2-dimensional [2-D] flow and habitat model) provides the requested information at an appropriate level of effort. This approach also allows for an assessment of potential Project protection, mitigation, and enhancement measures for the benefit of the range of resources in the bypass reach.

5.1 Literature Review and Desktop Assessment

A literature review of available information was performed to support the study goals, methodologies, and planning for field portions of the study. This task included a review of the hydrologic record for the reach of the Roanoke River in the vicinity of the Project, existing sluice gate operating procedures maintained by Appalachian, existing topographic and geologic maps, and available recent and historical aerial imagery.

Several pieces of information were considered in the field study planning process. First, a desktop analysis of mesohabitat (i.e., pools, riffles, runs, bedrock, shoals) mapping of the bypass reach was completed using high-resolution aerial imagery and topographic contour data. Second, species of interest were determined based on preliminary stakeholder consultation and an evaluation of management objectives (e.g., determine potential habitat availability under different flow regimes using guild curves to represent fish species that are or may be present in the bypass reach, including an evaluation specific to Roanoke Logperch). The life history characteristics and habitat preferences of selected species, as well distribution of mesohabitat types, were considered in the selection of model calibration target flows and locations for field data collection. Desktop mesohabitat mapping results are included in Section 6.3.

5.2 Topography Mapping and Photogrammetry Data Collection

Light detection and ranging (LiDAR) data were collected to support development of comprehensive three-dimensional (3-D) elevation and visual surface layers of the bypass reach. These data were used for desktop mesohabitat mapping as well as to produce a topographic map of the bypass reach. The topographic information was then incorporated as a base layer for subsequent field data collection and hydraulic modeling efforts. LiDAR data collection and digital terrain models are discussed further in the Niagara Reach ICM Model Development Report, which is included in Attachment 1.

5.3 Desktop Mesohabitat Mapping

Using the high-resolution photogrammetry data (see Section 5.2), polygons were drawn in Geographic Information System (GIS) software to encompass the bypass study sites according to substrate size (e.g., sand, gravel, cobble, etc.), cover (e.g., no cover, overhead vegetation, etc.), and mesohabitat types (Table 5-1). If multiple types of cover were present, the most immediate cover type was selected assuming it would have greater influence over aquatic organism behavior (e.g., if instream cover and overhead vegetation both exist, instream cover was selected). While substrate could be composed of several types/sizes, the dominate size class was selected. Mesohabitats were delineated based on typical stream and river morphological, longitudinal sequences (i.e., riffle, run, pool, glide) (Wildland Hydrology 1996) and aerial signatures denoting flow and turbulence at leakage, low-flow, or moderate-flow conditions.

Table 5-1. Desktop Mesohabitat Delineation Codes Used for the Niagara Flow and Aquatic Habitat Study

Substrate-Cover Classifications		
Code	**Cover**	**Substrate**
01	No Cover	and silt or terrestrial vegetation
02	No Cover	and sand
03	No Cover	and gravel
04	No Cover	and cobble
05	No Cover	and small boulder
06	No Cover	and boulder
07	No Cover	and mud or flat bedrock[1] (unsuitable as cover)
08	Overhead vegetation	and terrestrial vegetation
09	Overhead vegetation	and gravel
10	Overhead vegetation	and cobble
11	Overhead vegetation	and small boulder, angled bedrock[3], or woody debris
12	Instream cover	and cobble
13	Instream cover	and small boulder, angled bedrock[3], or woody debris
14	Proximal[2]	and cobble
15	Proximal[2]	and small boulder, angled bedrock[3], or woody debris
16	Instream or proximal[2]	and gravel
17	Overhead, instream, or proximal[2]	and silt or sand
18	Aquatic vegetation	and aquatic macrophytes
Mesohabitat Classifications		
Code	**Mesohabitat Type**	
00	Upland[4]	
01	Pool	
02	Riffle	

Substrate-Cover Classifications	
03	Run
04	Glide
05	Shoal
06	Backwater

[1] Flat bedrock consists of bedrock that is smooth, with or without crater-like divots, or otherwise unsuitable as instream cover.

[2] "Proximal" is defined as within 4.0 ft of suitable cover.

[3] Angled bedrock is angular, jutting or semi-vertical, slab-like bedrock. Angled bedrock was categorized as instream cover, regardless of presence of overhead vegetation.

[4] Upland areas are areas that are inundated during spill events.

5.4 Field Data Collection

5.4.1 Flow and Water Level Assessment

Field data were collected to support development of a 2-D hydraulic model (described in Section 5.5) of Niagara's tailrace and bypass reach. Calibration flows were released into the tailrace and bypass reaches for purposes of collecting water surface elevation, depth, velocity, and wetted area data under four bypass reach and tailrace flow regimes. The model enables a comparison between powerhouse operations (i.e., flow releases into the tailrace areas) and dam operations (i.e., flow releases into the bypass reaches via spillway gates).

To aid calibration and validation of the model, flow data collection was performed under several different steady flow releases into the bypass reach. Eleven water level loggers (Onset® U-20 brand pressure transducers that measure water stage change with high precision) were deployed in the Niagara bypass reach and tailrace prior to the model calibration target flow releases. The instrumentation details document a measured water level with an accuracy of ±0.01 ft. Reference water elevations were collected using a staff gage at each level logger upon installation. Level loggers recorded water surface elevation data at 5-minute intervals providing detail for travel time, and rates of rise estimations used in the model calibration.

The proposed target flow scenarios were designed to allow 2-D hydraulic model simulations capable of evaluating the full operating range of the newly installed Obermeyer trash sluice gate located on the left abutment (looking downstream) of the Niagara dam and spillway (Figure 3-1). The Obermeyer gate is 6.0 ft wide and the discharge rating curve under various forebay and gate invert elevations is provided on Figure 5-1. Data collection for the four target calibration flow scenarios was performed during two separate site visits between June 29 – July 8, 2021. Each scenario was designed to capture a steady calibration flow in the bypass reach. Flow was delivered to the bypass reach through controlled opening of the Obermeyer gate (in addition to normal leakage flow). Total flows in the bypass reach were recorded using a Swoffer® flow meter. In addition to the field data collected during the target calibration flows, a drone was used to capture an aerial imagery orthomosaic of the bypass reach and tailrace at the highest and lowest target calibration flows. These orthomosaic images are presented in Attachment 1.

The Obermeyer gate is capable of providing flow releases of approximately 7 cfs to 287 cfs under the authorized reservoir operating range of 883.4 ft to 884.4 ft, respectively (see Figure 5-1). There are also three 3-ft by 4-ft openings in the dam approximately 15 ft below the crest of the dam. The open ings are sealed with wooden "mud gates" on the upstream face of the dam and steel plates on the downstream face of the dam. To relieve pressure from leakage around the edges of the wooden mud gates, two sluice pipes (each equipped with a valve) are installed in each opening. The valves are normally kept in the open position, providing a combined leakage flow of approximately 1.0 cfs to the bypass reach.

The four target flows in Table 5-2 were selected to support hydraulic model calibration/validation activities and allow model simulations that cover the Obermeyer gate discharge capacity range from 7 cfs up to 287 cfs. Prior to the target flow field data collection activities, water level data loggers (pressure transducers that measure water stage changes) were strategically deployed in the tailrace, bypass, and downstream study reach to record changes in water surface elevation at each of the target flows. The instrumentation remained in place for several weeks afterwards to collect additional water surface elevation and flow travel time data under higher (than target flow) conditions (i.e., during rainfall runoff events). Data collected at higher flows provided additional model calibration data to allow model simulations higher than the Obermeyer gate discharge capacity.

Table 5-2. Niagara Bypass Reach Flow and Aquatic Habitat Study – Proposed Target Flow Scenarios

Niagara Hydroelectric Project				
Open Spillway Crest: 885 ft				
Reservoir Operating Range: 883.4 - 884.4 ft; assume starting Pool Elevation is 883.9 ft				
Volume of Water in Reservoir Operating Range: 56.5 acre-ft				
Obermeyer Gate Dimensions: 6 ft wide; Max & Min Gate Elevations, 885.33 ft / 878.40 ft				
Obermeyer Gate Capacity: 7 - 287 cfs within Reservoir Operating Range				
Powerhouse Discharge Capacity: 684 cfs				
Powerhouse Minimum Discharge Capacity: 100 cfs (either unit operating)				
Obermeyer Gate				
Approximate Gate Invert Elevation* (ft)	Proposed Target Flows (cfs)	Flow Test Duration (hrs)	Volume (acre-ft)	Model Simulation Range (cfs)
883.39	8	8	5	8
882.94	20	8	13	
882.11	50	8	33	
880.74	115	8	76	
				287

Notes: *Assume starting point is midpoint of normal operating range with adequate inflow to maintain pond levels during flow tests. All elevations are referenced to NGVD. Mean monthly flows are from USGS 02056000 Roanoke River at Niagara, Virginia flow gaging station, which is immediately downstream from the Niagara tailrace and bypass reach confluence.

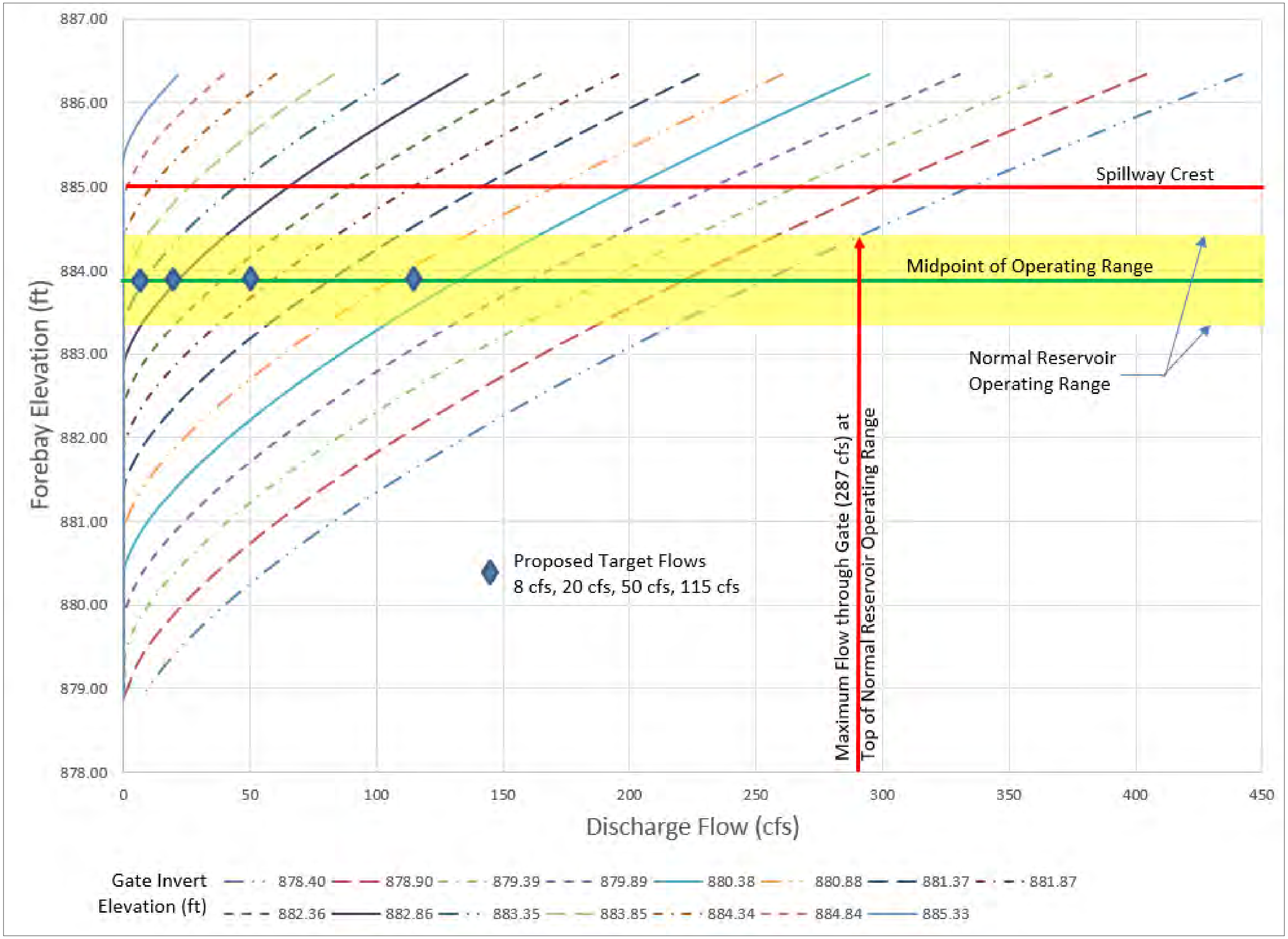

Figure 5-1. Niagara Obermeyer Sluice Gate Rating Curve

5.4.2 Substrate Mapping and Particle Size Distribution

A Wolman pebble count (Wolman 1954) study was performed in the bypass reach to characterize the existing grain size distribution of substrate and evaluate the potential for sediment transport of smaller particle sizes. Two pebble count transects were established near the middle portion of the bypass reach at locations which contained a variety of smaller substrate particle sizes (locations shown on Figure 6-2). Headpins and tailpins were installed at the endpoints of each transect and a tagline was stretched between to provide a visual aid along each transect to reduce location uncertainty between pebble count sampling events. Pebble counts were conducted immediately after each target flow receded. These data were used to characterize the existing surface substrate grain size distribution in the bypass reach and determine if the calibration target flows evaluated have sufficient velocity to mobilize substrate particles in the bypass reach. The Wentworth grain size classification scale (Wentworth 1922) was used to assign size classes to the substrate. Substrate particle sizes were plotted by size class and frequency to determine distributions within the bypass reach study area; plots are shown in Section 6.4.2.

5.5 Hydraulic Model Development

5.5.1 General Model Description

Development of a 2-D hydraulic model was carried out as part of the Bypass Reach Flow and Aquatic Habitat Study. A 2-D model incorporates detailed terrain data obtained by topographic mapping technologies and provides options for building one-dimensional (1-D) and 2-D geometries. It also utilizes a 1-D/2-D model development approach which optimizes the simulation of observed hydraulic behavior for specific project requirements. This study used the Innovyze Infoworks Integrated Catchment Model (ICM) software (version 7.0), which is capable of simulating depth and velocities in a 2-D grid pattern over a wide range of flow conditions.

The advantage of implementing a 2-D model is that it provides more stable results over a wider range of flows than a 1-D model, thus reducing troubleshooting during model development; however, simulation speed is generally slower. The ICM software performs 2-D unsteady flow hydraulic calculations based on conservation of mass and momentum to dynamically route the spillway release flood wave downstream and uses a finite-volume solution algorithm to allow for 2-D cells to be wet or dry and handle a sudden rush of water, subcritical, supercritical, and mixed-flow regimes. For instance, a spillway release is a highly dynamic flood wave that rises and falls quickly; therefore, the 2-D unsteady flow calculation must use the full momentum form of the St. Venant equations (the full momentum equation accounts for the change in velocity both spatially and temporally).

The model geometry is defined by digital terrain model elevation values, user inputs based on Project drawings and survey information, and Manning's roughness coefficient inputs (used to establish terrain roughness) and calculates the flood wave hydrograph resulting from a spillway release based on input gate operation parameters. The ICM is also capable of simulating reservoir inflow and rate of reservoir rise, dynamic gate operations scenarios, release travel times, and rates of rise at locations within and downstream of the bypass reach.

5.5.2 Niagara Bypass Reach ICM Model Development

The morphology of the approximately 1,500-ft-long Niagara bypass reach extending from the dam to the vicinity of the powerhouse tailrace is variable and includes deep and shallow pools, runs, shoals, steep cascades, and side channels with large boulders. This channel variability impacts flow travel times differently at varying flows and is most accurately represented by a 2-D model.

The model used to evaluate the hydraulics of the bypass reach is a fully integrated 2-D hydrodynamic model which facilitates accurate representation of flow paths while enabling complex hydraulics and hydrology to be incorporated into a single model. The Model uses the shallow water equations to develop depth averaged hydraulics results. The 2-D model does not directly model turbulence, but accounts for energy losses due to turbulence due to bed resistance via the Manning's *n* roughness. The modeling domain extends approximately 1,300 ft downstream of the spillway and includes the Niagara tailrace. The domain is modeled with ICM's 2-D surface flooding module. This portion of the modeling extent is known as the 2-D Zone. The Model allows for detailed hydraulic results and provides a reasonable variability in average flow, depth, and velocity from one water column element to the next throughout the modeled area. The Model is considered appropriate for the evaluation of the bypass reach hydraulics. See Attachment 1 (Niagara ICM Model Development Report) for details.

5.6 Aquatic Habitat Evaluation

Activities described above (i.e., literature review and desktop assessment, topographic mapping and photogrammetry, field data collection, and hydraulic model development) were used to develop a flow and aquatic habitat assessment of the Project bypass reach and tailrace. Specifically, for each flow scenario evaluated, incremental changes in depth and wetted area were determined. The water level logger data in combination with the 2-D model results were used to determine rate of rise and fall of water elevation (i.e., water depth) in the tailrace and bypass reach and evaluate flow patterns and hydraulic connectivity under each flow regime evaluated. In addition, substrate and mesohabitat mapping along with the 2-D model depth and velocity simulation results were used in combination with aquatic species habitat suitability criteria (HSC) (i.e., using depth, velocity, and habitat preferences) to evaluate potential available habitat under each modeled flow scenario in the study reach.

5.6.1 Target Species and Habitat Suitability Criteria

Roanoke Logperch was selected as a standalone target species for this study along with a total of eight species-guild representatives, including three shallow-slow, one shallow-fast, two deep-slow, and two deep-fast guilds. Guild representatives were selected from a variety of regionally representative sources, represent a wide range of habitat characteristics, and were selected to represent a wide range of species. In some cases, general non-species-specific criteria were used. In other cases specific species were used to represent a guild category; these include Redbreast Sunfish (*Lepomis auritus*), Silver Redhorse (*Moxostoma anisurum*), and Shorthead Redhorse (*Moxostoma macrolepidotum*) (Table 5-3).

5.6.1.1 Target Species

The Roanoke Logperch is endemic to the Roanoke River basin within North Carolina and Virginia and the Chowan River basin in Virginia. The distribution in the upper Roanoke system extends roughly 1.8 miles downstream of the Niagara Dam upstream into the North Fork Roanoke River and to the South Fork Roanoke River (USFWS 1992). The species predominantly occurs in those portions of the drainage within the Piedmont and Ridge and Valley physiographic provinces. Populations are vulnerable due to limited range and low densities. The Roanoke Logperch is not typically found in reservoirs or other lentic environments.

The Roanoke Logperch is a large darter and can reach a length of about 6 inches. According to USFWS (1992), depending on the different phases of its life history and season, most riverine habitat types are used by this species at some point. During the reproductive period, males are primarily associated with shallow riffles, while spawning females are common in deep runs over gravel and small cobble. Young and juveniles usually occur in slow runs and pools with clean bottoms. Winter habitat of all phases is believed to be under boulders in deep pools (USFWS 1992). Logperch in the Roanoke River have been found primarily in runs, select deep, fast habitats with exposed, silt-free gravel substrate, occasionally in riffles, and rarely in pools. Logperch have been found at a variety of depths and velocities, but consistently in silt-free, loosely embedded substrate (Rosenberger and Angermeier 2003).

5.6.1.2 Guild Species

Redbreast sunfish

As a representative of the deep/slow guild, the Redbreast Sunfish, is a member of the Centrarchidae family. The Redbreast Sunfish is native along the Atlantic slope of the Appalachians from southern Canada to Florida west to the Apalachicola River (Lee et al. 1980). Like most sunfishes, they are opportunistic insectivores that also feed on small fishes as they obtain larger sizes (Levine et al. 1986; Wallace 1984). Superficially, the Redbreast Sunfish resembles most other sunfish, particularly the Bluegill (*Lepomis macrochirus*). However, unlike Bluegill, the Redbreast Sunfish lacks a black blotch on the dorsal fin and has shorter gill rakers. Redbreast Sunfish can be distinguished from all other sunfish, except the Bluegill, by black on the opercular flap that extends to the posterior margin. Adults range from 60-155 millimeter total length (Lee et. al. 1980).

More than any other sunfish, the Redbreast Sunfish dwells almost entirely in lotic environments (Lee et al. 1980; Stauffer et al. 1995). Gravel spawning nests are constructed from spring through summer when water temperatures reach 23°C (Levine et al. 1986; Stauffer et al. 1995).

Redhorse

Representing both shallow/slow (i.e., young-of-year) and deep/fast (i.e., adults) guilds, Catostomidae are members of the genus *Moxostoma*, the redhorses. Specifically, Silver Redhorse (*M. anisurum*) and Shorthead Redhorse (*M. macrolepidotum*) habitat suitability information is included in the guild habitat modeling.

The redhorses are indigenous to the Atlantic slope of the Appalachians, the Mississippi River Drainage, and the Great Lakes Basin. All the redhorses possess subterminal mouths used to forage the streambed for benthic macroinvertebrates. Like other catostomids, they are drab olive bronze dorsally and fade to white ventrally. They possess complete, well developed lateral lines and develop tubercles during breeding. These fish can attain lengths up to 600 millimeters standard length (Lee et al. 1980; Stauffer et al. 1995).

The redhorse can inhabit both lentic and lotic environments, but they prefer medium to large streams and rivers with clear water and assorted rock substrates. While they are usually associated with deep pools and backwaters, they spawn in spring and early summer on coarse gravel (Lee et al. 1980; Stauffer et al. 1995).

5.6.1.3 Habitat Suitability Criteria

HSC define the range of microhabitat variables that are suitable for a particular species and life stage of interest. Variables typically defined with HSC include depth, velocity, instream cover, and bottom substrate. Habitat Suitability Indices (HSI) are the numerical indices that represent the capacity of a given habitat to support a selected fish species (USFWS 1981). HSI values range from 0.0 to 1.0, indicating habitat conditions that are unsuitable to optimal, respectively. HSC provide the biological criteria input to the ICM 2-D model, which combines the physical habitat data and the habitat suitability criteria into a site-wide habitat suitability index (i.e., usable area) over a range of simulation flows. Usable area is defined as the sum of stream surface area within a nodal area model domain or stream reach estimated by multiplying area by habitat suitability variables (most often velocity, depth, and substrate or cover), which range from 0.0 to 1.0 each.

HSI for target species and life stages were obtained from three previous instream flow investigations: (1) Sutton Hydroelectric Project, Elk River, WV (HDR 2010); (2) Smith Mountain Hydroelectric Project, Roanoke River, Va (TRPA & Berger 2007); and (3) Claytor Hydroelectric Project, New River, Va (TRPA & Berger 2008) (Table 5-3). These three recent studies represent the best available sources for regionally applicable species information due to their close proximity to the study location, the similarity in river condition and species community modeled, and the collaborative HSC review process that each underwent. Velocity, depth, and substrate HSI curves for shallow and fast water guilds are shown on Figure 5-2 through Figure 5-5. HSC data tables are included in Attachment 2.

HSI for adult Roanoke Logperch were obtained from Ensign et al. (1998) and Ensign et al. (2000) as provided in Anderson (2016) (Table 5-3). HSI for subadult and young-of-year Roanoke Logperch were developed from data presented in Rosenberger and Angermeier (2003) using the following methods:

1. Frequency of occurrence was measured in BlueBeam Revu (version 20.2.30) for each HSC (i.e., depth, velocity, and substrate) for Roanoke Logperch young-of-year and subadult life stages.
2. Using the frequency of occurrence for HSC as well as available habitat, a measure of habitat preference was calculated (Ensign and Angermeier 1994).
3. Habitat preference values were then scaled to a 0 to 1 index by dividing each preference value by the highest value for that variable (Ensign and Angermeier 1994).

HSI used for Roanoke Logperch are presented in 4 (adult life stage) and Table 5-5 (subadult and young-of-year life stages). Results of the Fish Community Study (results to be submitted to the FERC as supplemental information following completion of the Roanoke Logperch larval drift study in late 2022), specifically Roanoke Logperch snorkel surveys in the Project bypass reach, suggest that the HSI compiled for this analysis adequately represent the preference of Roanoke Logperch in the vicinity of the Project. During summer 2021, 22 adult and 4 subadult Roanoke Logperch were observed in the bypass reach. Of the 22 adults, 17 were found in areas dominated by bedrock, with 8 of those fish observed in areas of 100 percent bedrock. Bedrock comprised 68 percent of the substrate identified in areas of Roanoke Logperch sightings. Boulder, cobble, and gravel were almost e qually distributed at approximately 8 to 11 percent of substrates noted where Roanoke Logperch was observed.

Similarly, three of the four subadult Roanoke Logperch were also in areas dominated by bedrock. These observations are consistent with the HSI from literature and with consideration of substrate availability in the Project bypass reach (i.e., 68.4 percent of the bypass reach is composed of boulder/bedrock, followed by 25.9 percent cobble and only 4.5 percent gravel; see Section 6.3).

Table 5-3. Target Species Habitat and Suitability Criteria Source and Code Table

Species or Guild	Life Stage/ Category	Representative	Source Study	HSC Code
Roanoke Logperch	Adult	--	Ensign et al. 1998 and Ensign et al. 2000	RLPA
	Subadult	--	Rosenberger and Angermeier 2003	RLPSA
	Young-of-Year	--	Rosenberger and Angermeier 2003	RLPYOY
Shallow-Slow Guild	Fine and coarse-mixed substrate (no boulder/bedrock)	Redbreast sunfish spawning	Smith Mountain Hydroelectric Project, Roanoke River, VA	RBSFS
	Fines and small gravel substrate with aquatic vegetation	Silver redhorse Young-of-Year	Sutton Hydroelectric Project, Elk River, WV	SRHAV
	Coarse substrate	Generic shallow-slow guild	Sutton Hydroelectric Project, Elk River, WV	SHSLO
Shallow-Fast Guild	Moderate velocity with coarse substrate	Generic shallow-fast guild	Claytor Hydroelectric Project New River, VA	SHFST
Deep-Slow Guild	Cover	Redbreast sunfish Adult	Smith Mountain Hydroelectric Project, Roanoke River, VA	RBSFA
	No cover	Generic deep-slow guild	Sutton Hydroelectric Project, Elk River, WV	DSLON
Deep-Fast Guild	Slightly weighted for fine substrate, Cover	Silver redhorse adult	Smith Mountain Hydroelectric Project, Roanoke River, VA	SRHAD
	Coarse-mixed substrate	Shorthead redhorse adult	Smith Mountain Hydroelectric Project, Roanoke River, VA	SHRHA

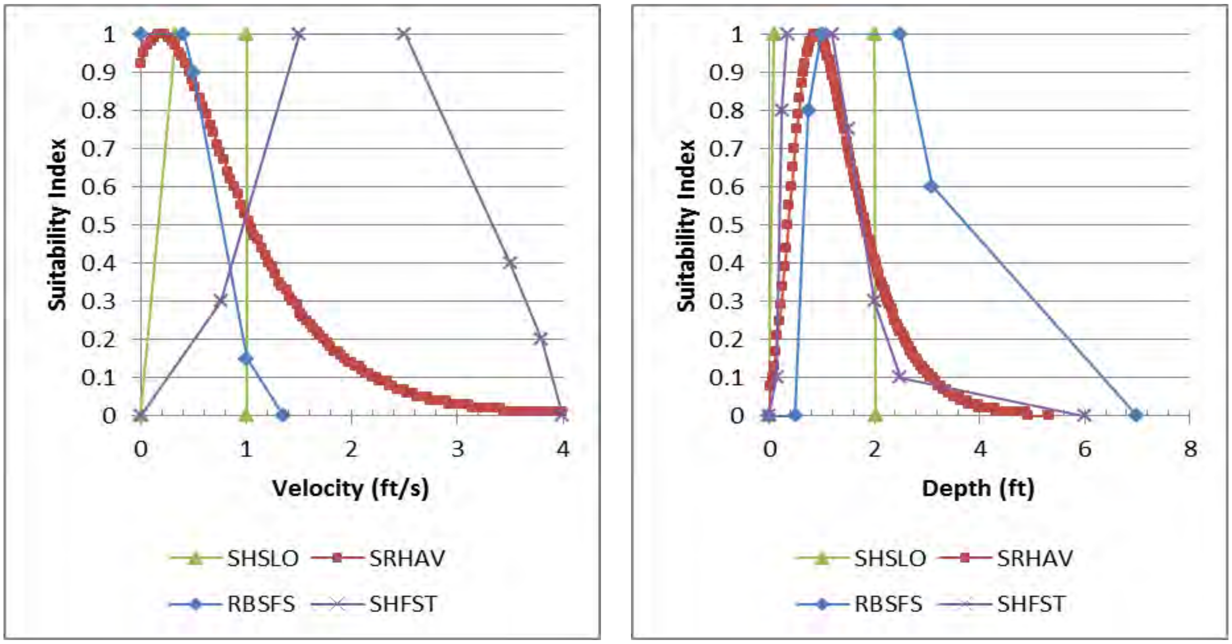

Figure 5-2. Velocity HSC (left) and Depth HSC (right) for Shallow Water Guilds

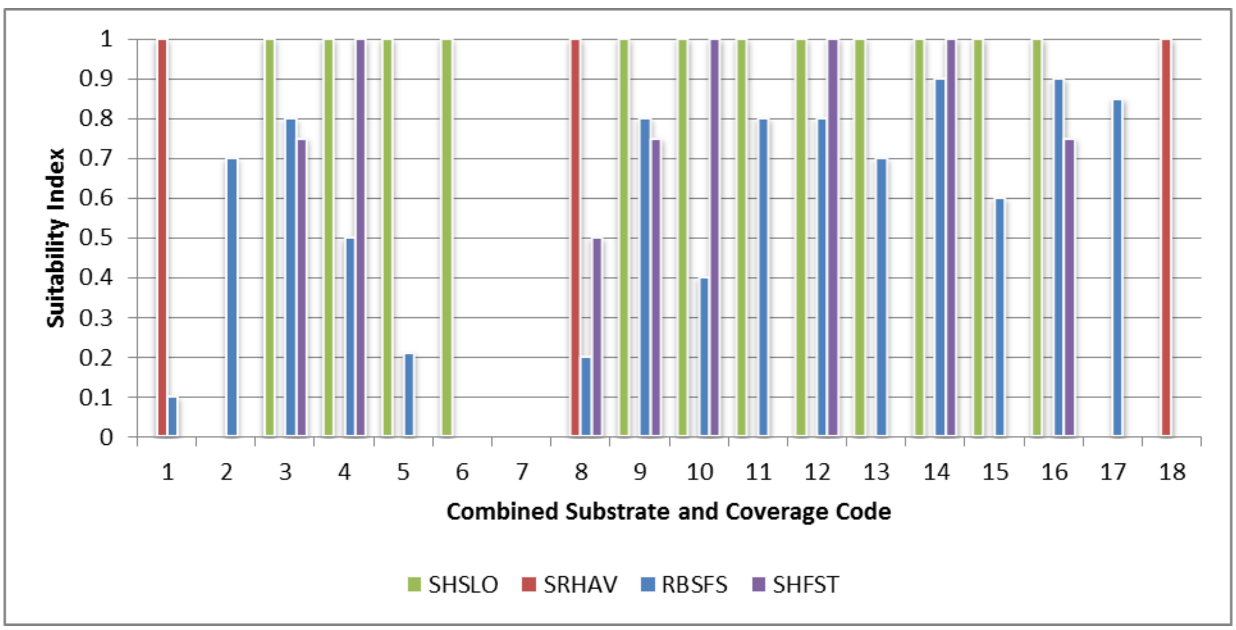

Figure 5-3. Substrate HSC for Shallow Water Guilds

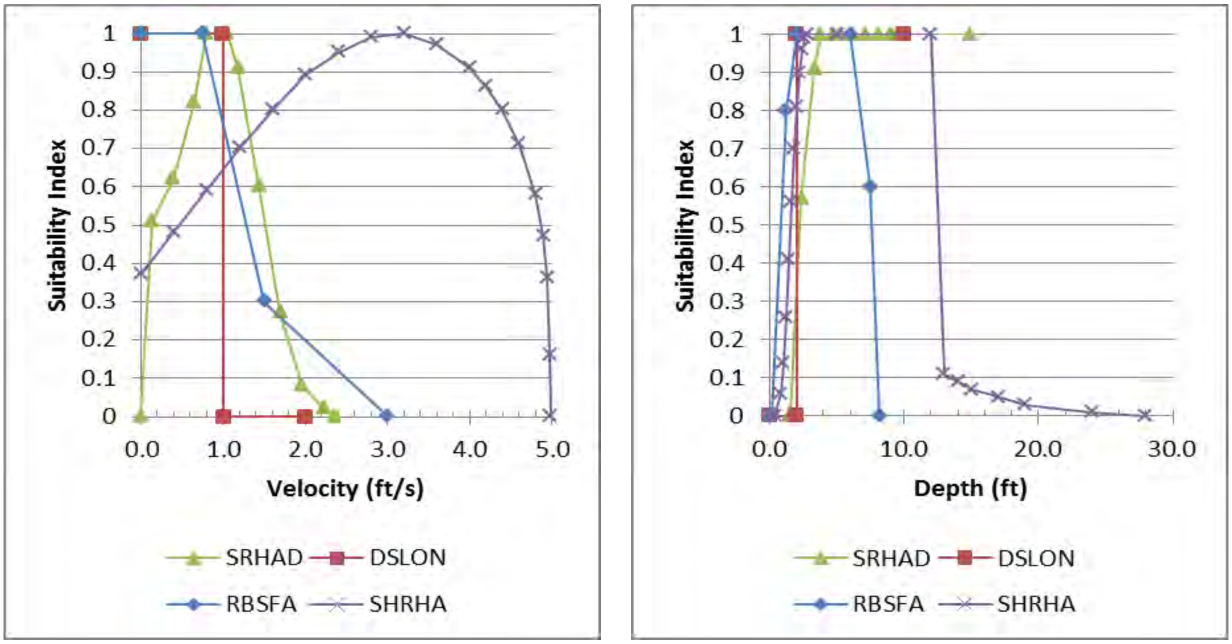

Figure 5-4. Velocity HSC (left) and Depth HSC (right) for Deep Water Guilds

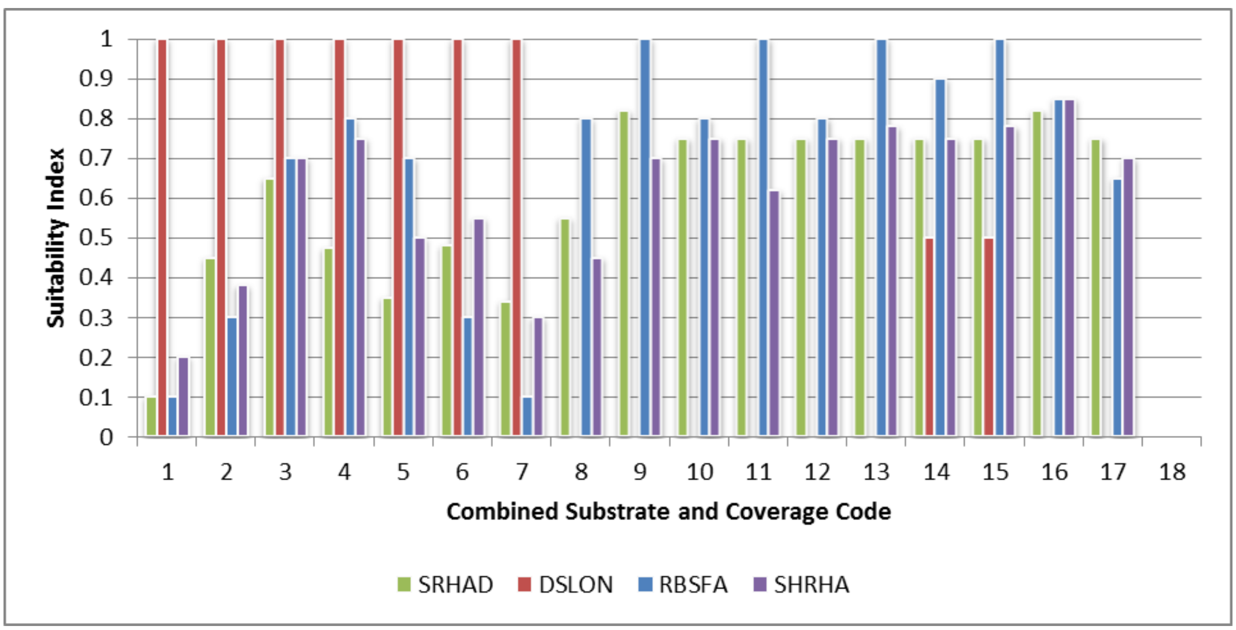

Figure 5-5. Substrate HSC for Deep Water Guilds

Table 5-4. Habitat Suitability Indices for Adult Roanoke Logperch

Habitat Suitability Criteria	Habitat Suitability Index
Mean Velocity (centimeters/second [cm/s])	**Adult**
0-10	0.15
11-20	0.40
21-30	0.81
31-40	0.90
41-50	1.00
51-60	0.73
61-70	0.83
>70	0.49
Depth (cm)	**Adult**
0-10	0
11-20	0.02
21-30	0.15
31-40	0.56
41-50	1.00
51-60	0.63
61-70	0.62
>70	0.21
Substrate	**Adult**
Silt (≤0.06 millimeters [mm])	0
Sand (0.07-2.00 mm)	0
Gravel (3-64 mm)	0.36
Cobble (65-256 mm)	1.00
Boulder/Bedrock (>256 mm)	0.56

Source: Ensign et al. (1998) and Ensign et al. (2000) as cited by Anderson 2016

Table 5-5. Habitat Suitability Indices Developed for Subadult and Young-of-year Roanoke Logperch based on Rosenberger and Angermeier (2003)

Habitat Suitability Criteria	Habitat Suitability Index	
Mean Velocity (cm/s)	**Subadult**	**YOY**
0	0.00	0.27
1-4	0.00	1.00
4-10	1.00	0.09
11-40	0.17	0.00
>41	0.24	0.00
Depth (cm)	**Subadult**	**YOY**
0-15	0.00	0.06
16-30	0.67	1.00
31-50	1.00	0.00
>51	0.25	0.00
Substrate (rank)[1]	**Subadult**	**YOY**
<3	0.00	0.00
4-6	1.00	1.00
7	0.67	0.00
8-9	0.10	0.00

Source: Developed from Rosenberger and Angermeier (2003)
[1]Rankings based on a 9-category Wentworth scale as defined in Lahey and Angermeier (2007): 0-3=organic matter, clay, and silt; 4-6=sand, small gravel, large gravel; 7=cobble; 8-9=boulder and bedrock.
Note: YOY = young-of-year

6 Study Results

6.1 Literature Review and Desktop Assessment Results

The literature review included several key reports and documents, which are included in the references section, as well as USGS and Project flow data as described in Section 5. The aquatic habitat evaluation including life history characteristics and habitat preferences of selected species is provided in Section 5.6. The results of the desktop mesohabitat mapping of the bypass reach, which was completed using high-resolution aerial imagery and topographic contour data, are included in Section 6.3. The 2-D hydraulic model results are included in Attachment 1 and the aquatic habitat model results are provided in Section 6.6.

6.2 Topography Mapping and Photogrammetry Data Collection Results

LiDAR data were collected during a period of relatively low flows in the Niagara bypass reaches to support development of comprehensive 3-D elevation and visual surface layers of the bypass reach. These data were used to support desktop mesohabitat mapping as well as to produce a topographic map of the bypass reach. Digital terrain models are included in the ICM Model Development Report (Attachment 1).

6.3 Desktop Mesohabitat Mapping Results

The habitat mapping codes described in Section 5.3 were used to delineate the Project bypass reach and tailrace (see Figure 6-1). For areas where both overhead cover and instream cover are present, the latter was chosen as it is likely that instream cover has a greater influence on fish habitat selection and behavior because it is in the immediate in-water environment. Habitat types were verified and/or updated in GIS as necessary based on field observations performed during the calibration flow fieldwork in 2021 (i.e., June 29 – July 8, 2021). Substrate-cover and mesohabitat classifications were reviewed by a senior scientist and polygons were processed using quality control procedures to ensure data integrity throughout the aquatic habitat modeling process.

The total area evaluated for the Project bypass reach was 6.87 acres, with an additional 1.01 acres for the tailrace from the powerhouse discharge to the Blue Ridge Parkway bridge. Approximately half of the bypass reach contained instream cover (60.6 percent), followed by overhead cover (27.3 percent) (Table 6-1). The majority of substrate in the bypass consisted of boulder, bedrock, or woody debris (63.2 percent), followed by cobble at 25.9 percent. Much of the bypass was categorized as shoal habitat (32.1 percent), however pools and riffles were also prevalent (24.1 and 15.8 percent, respectively). Approximately 11.3 percent of the bypass was characterized as “upland”, which includes areas that are exposed during the 8 cfs minimum bypass flow requirement, but may be inundated at higher flows (i.e., during rainfall runoff events that result in flow over the Project’s main and auxiliary spillways).

The relatively short tailrace reach was categorized as run mesohabitat type, composed mainly of boulder and bedrock (85.5 percent) with no cover (99.8 percent).

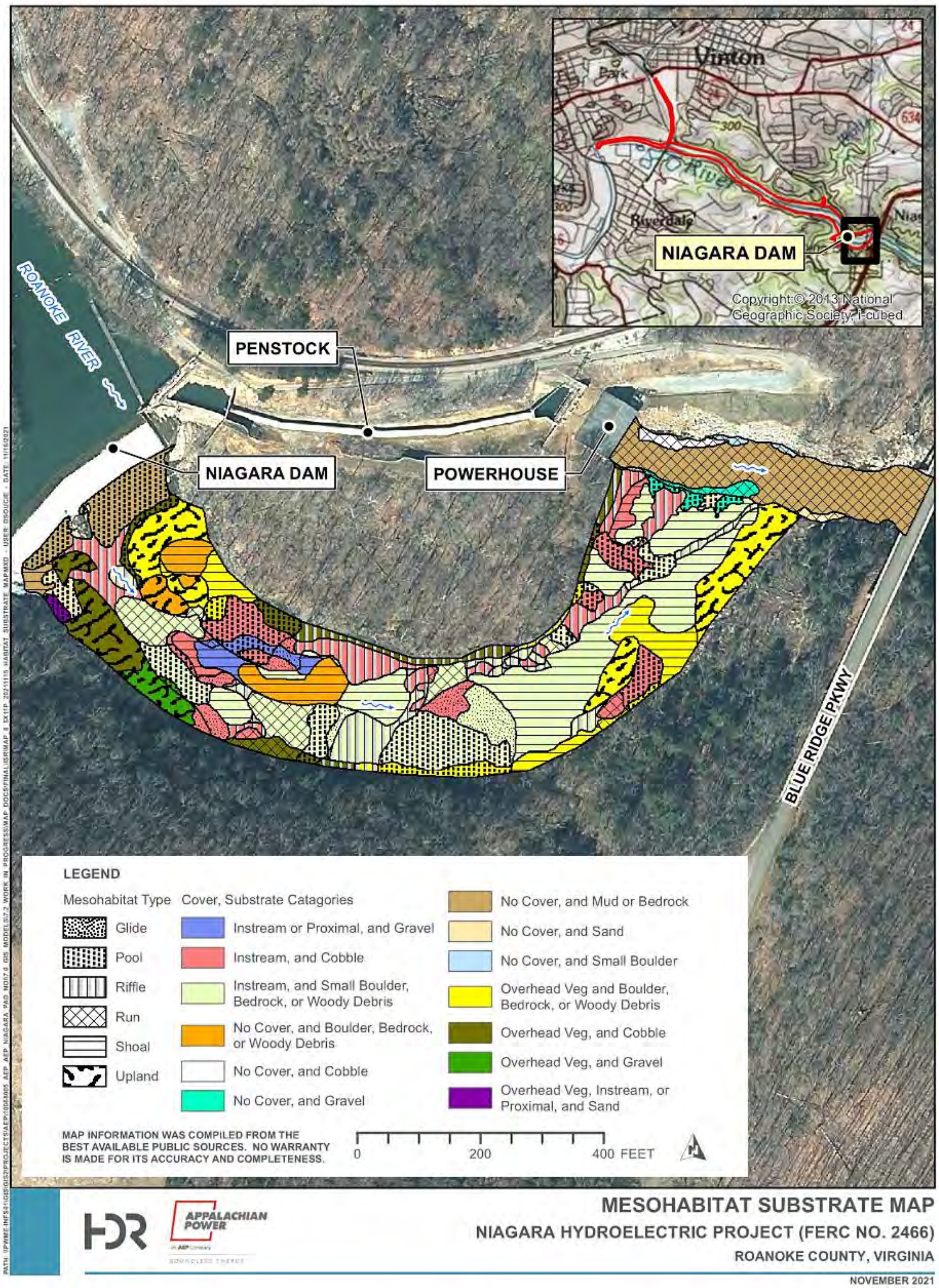

Figure 6-1. Bypass Reach Desktop Habitat Delineation at Niagara Hydroelectric Project

Table 6-1. Summary of Aquatic Habitat Characteristics

Habitat Characteristics	Bypass		Tailrace	
	Area (ac.)	Percent	Area (ac.)	Percent
Cover				
Instream Cover	4.16	60.6	--	--
Overhead Vegetation	1.88	27.3	<0.01	0.2
No Cover	0.83	12.1	1.01	99.8
Total	6.87	100.0	1.01	100.0
Substrate				
Boulder, Bedrock, or Woody Debris	4.34	63.2	0.86	85.5
Cobble	1.78	25.9	0.06	5.5
Mud or Flat Bedrock	0.35	5.2	0.05	4.9
Gravel	0.31	4.5	0.02	2.1
Sand	0.09	1.3	0.02	2.1
Total	6.87	100.0	1.01	100.0
Mesohabitat				
Shoal	2.20	32.1	--	--
Pool	1.65	24.1	--	--
Riffle	1.08	15.8	--	--
Upland	1.08	15.8	--	--
Run	0.49	7.2	1.01	100.0
Glide	0.35	5.1	--	--
Total	6.87	100.0	1.01	100.0

6.4 Field Data Collection Results

6.4.1 Flow and Water Level Assessment Results

Field data collection at the four target calibration flows was conducted during two site visits between June 29 – July 8, 2021. Each target flow was designed to capture a controlled, steady flow in the bypass reach delivered via the Obermeyer trash sluice gate[4]. For each target flow release, depths and velocities were recorded along a fixed transect (shown on Figure 6-2) using a handheld flow meter. The resulting flow was calculated using the depth and velocity data and the actual measured calibration flows are provided in Table 6-2.

Table 6-2. Measured Bypass Reach Flows

Flow Description	Target Calibration Flow (cfs)	Actual Measured Flow (cfs)
Day 1 (Minimum Flow)	8	7
Day 2 (Low Flow)	20	24
Day 3 (Mid Flow)	50	33
Day 4 (High Flow)	115	91

To aid calibration and validation of the ICM 2-D model for the Niagara bypass reach, water surface elevations were collected during the flow releases using Onset U-20 level loggers set to record data at 5-minute intervals (level logger locations provided in Figure 6-2). These data were also used to determine flow travel times in the bypass reach during the flow releases to determine the amount of time required for each flow to stabilize within the study area and also the amount of time it took for each flow to recede once the Obermeyer gate returned to its normal operating position.

Level logger results during the calibration flow fieldwork (i.e., June 29 – July 8, 2021) are provided on Figure 6-3. Summary results/observations pertinent to the Bypass Reach Flow and Aquatic Habitat Study include:

- At lower flows, the main flow path through the bypass reach shifts from river right (looking downstream) near the spillway to river left at approximately the mid-point of the reach.
- Along this main flow path, depths increased approximately 0.32 ft between the minimum flow and low flow, 0.14 ft between the low and mid flows, and 0.46 ft between the mid and high flows. The overall depth increase from the minimum flow to high flow was approximately 0.92 ft.
- Depth increases along the right descending bank (outside the main flow path) were less noticeable as the channel bed elevation is slightly higher along the right bank (which forces flow to the lower left side of the bypass reach channel).

[4] In addition to flows released via the Obermeyer trash sluice gate, a small amount of flow from leakage through the mud gates (estimated at approximately 1.0 cfs) was also included.

- Flow travel times through the approximately 1,500-ft-long bypass reach were approximately 35 minutes for the low and mid model calibration flows and 16 minutes for the high calibration flow.

After the calibration flow field data collection effort, several level loggers were left in place to capture changes in water surface elevations and travel times during naturally occurring rainfall runoff events. These results are presented in Figure 6-4 from June 29 – October 27, 2021. During this period, runoff from Tropical Storms Fred and Ida resulted in bypass reach flows up to approximately 4,400 cfs and 975 cfs, respectively. This period also captured a powerhouse outage from September 7 – 30, 2021 in which all Project inflows were routed through the bypass reach. A peak flow event of approximately 4,775 cfs occurred on September 22, 2021. This flow resulted in a depth increase of approximately 4 – 5 ft in the bypass reach compared to the 7 cfs model calibration flow measurement.

Figure 6-2. Niagara Bypass Reach and Tailrace Flow, Level Logger, and Pebble Count Monitoring Locations

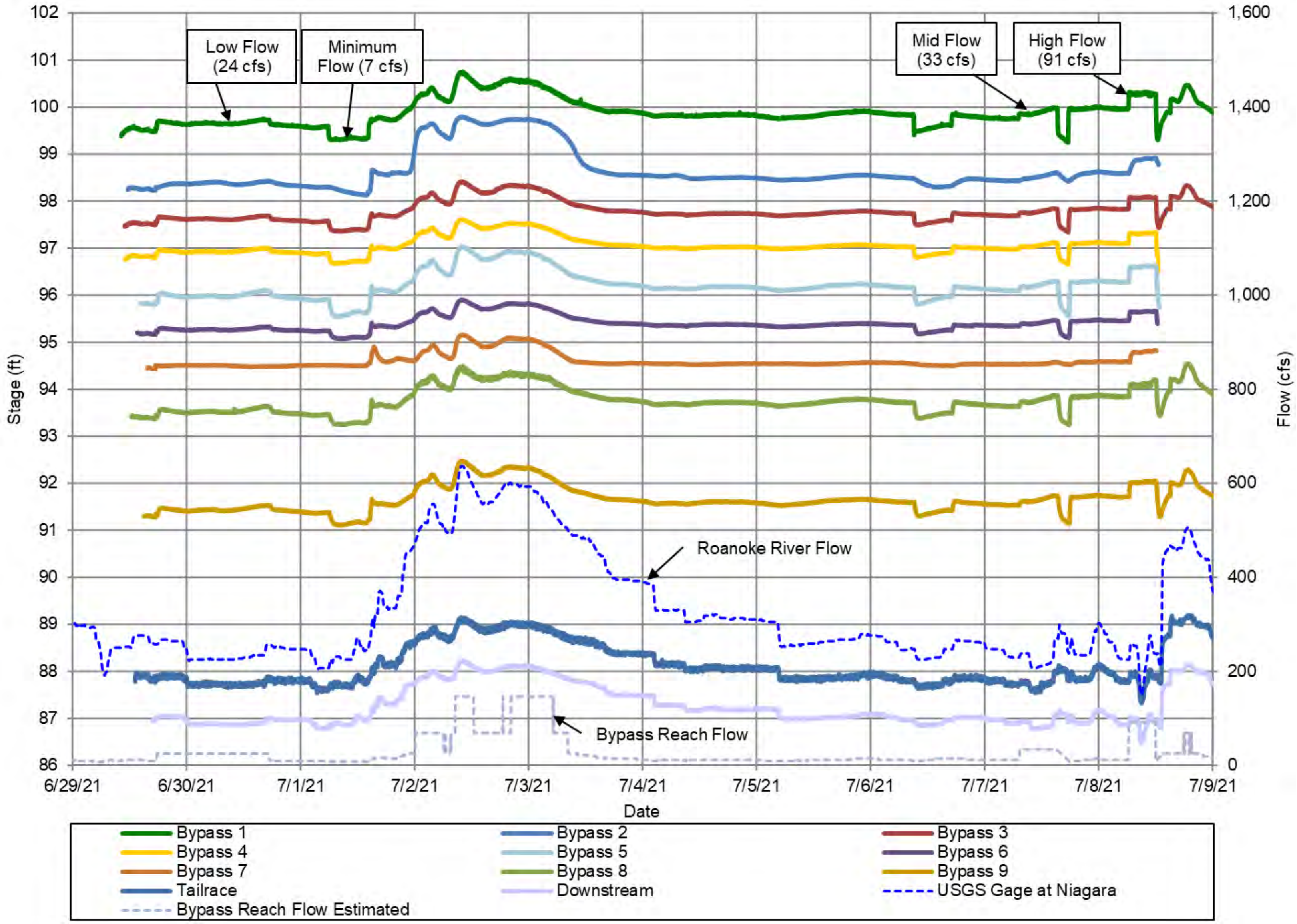

Figure 6-3. Bypass Reach Level Logger and Flow Data during the Calibration Flow Study Period

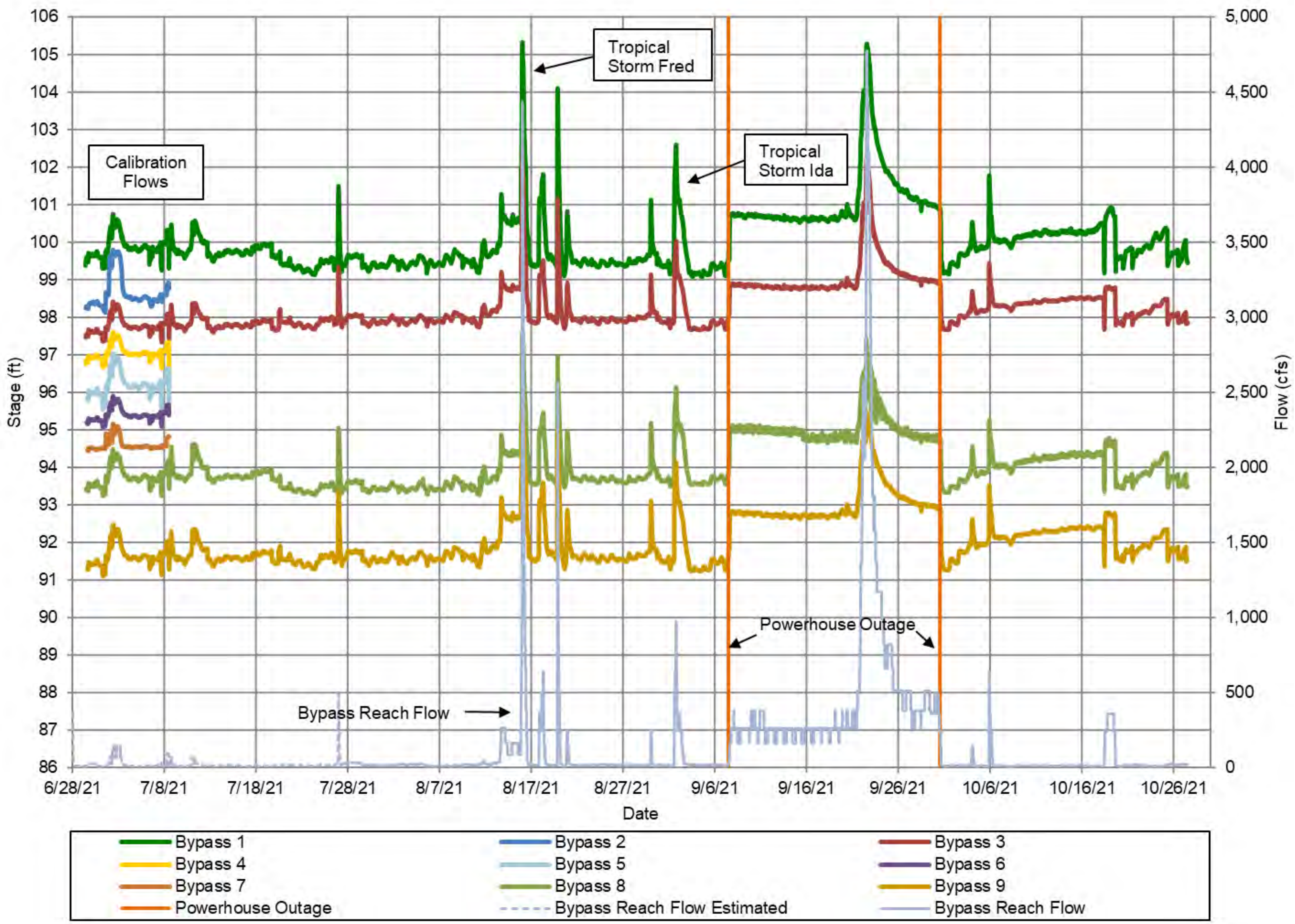

Figure 6-4. Bypass Reach Level Logger and Flow Data during Study Period

6.4.2 Particle Size Distribution Results

To characterize substrate particle size distribution in the bypass reach and evaluate the potential for sediment transport of smaller particle sizes, a Wolman pebble count study was conducted during the model calibration flow fieldwork (June 29 – July 8, 2021). Two pebble count transects were established near the middle portion of the bypass reach at locations which contained a variety of smaller substrate particle sizes (locations shown on Figure 6-2). For each pebble count sampling event, the substrate particle size results are plotted by size class and frequency in Figure 6-5 (upstream transect) and Figure 6-6 (downstream transect).

Both transects are dominated by bedrock, which covers approximately 55 – 75 percent of the transect widths. At the upstream transect, there was a fairly even distribution of particle sizes between 5.7 and 22.6 mm (fine to coarse gravel) as well as particles between 22.6 and 256 mm (coarse gravel to large cobble) recorded after each calibration flow sampling event. At the downstream transect there was a fairly even distribution of particles ranging from 5.7 mm to 180 mm (fine gravel to large cobble) recorded after each flow sampling event. Overall, the individual size class percentages were relatively small (compared to bedrock) and there do not appear to be any noticeable trends attributable to sediment transport over the calibration flow regime (which ranged from 7 – 91 cfs).

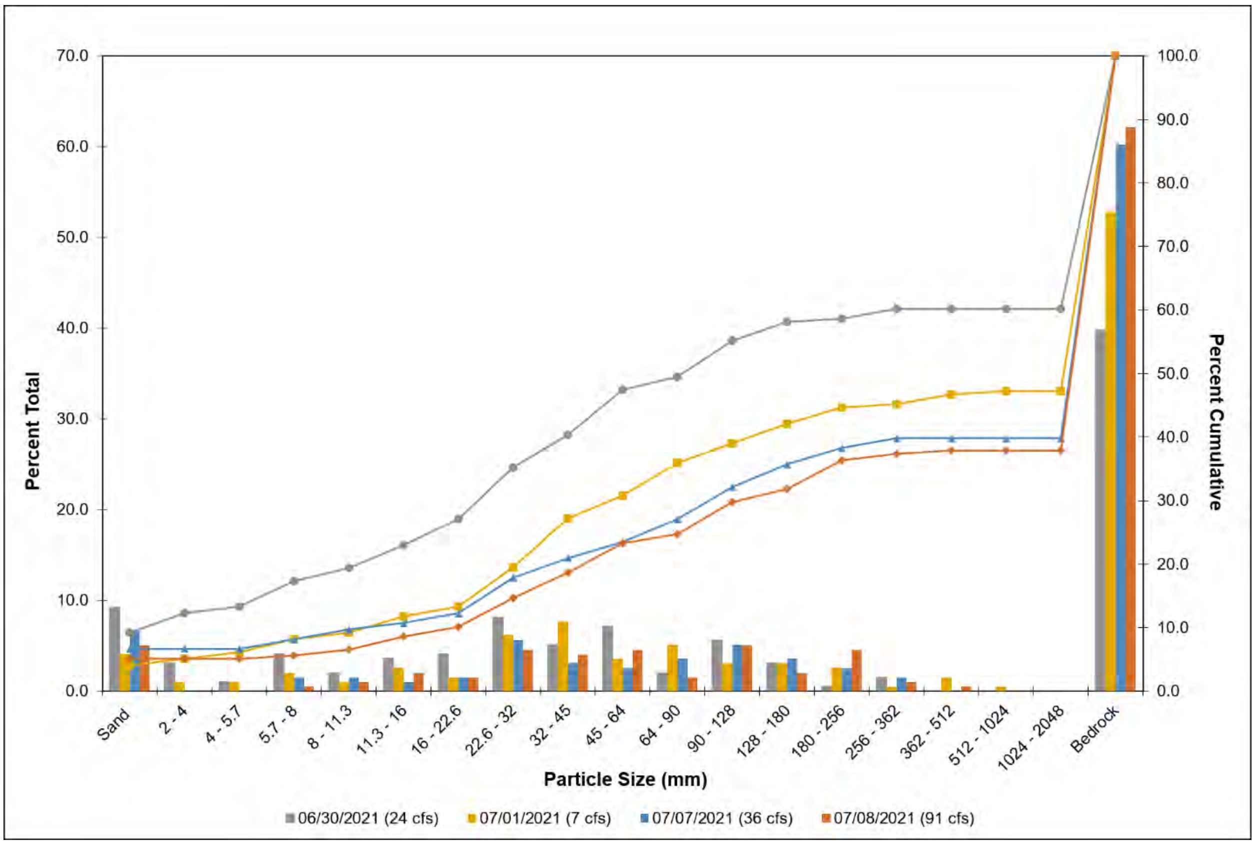

Figure 6-5. Niagara Bypass Reach Pebble Count Particle Size Data after each Model Calibration Flow Release (Upstream Transect)

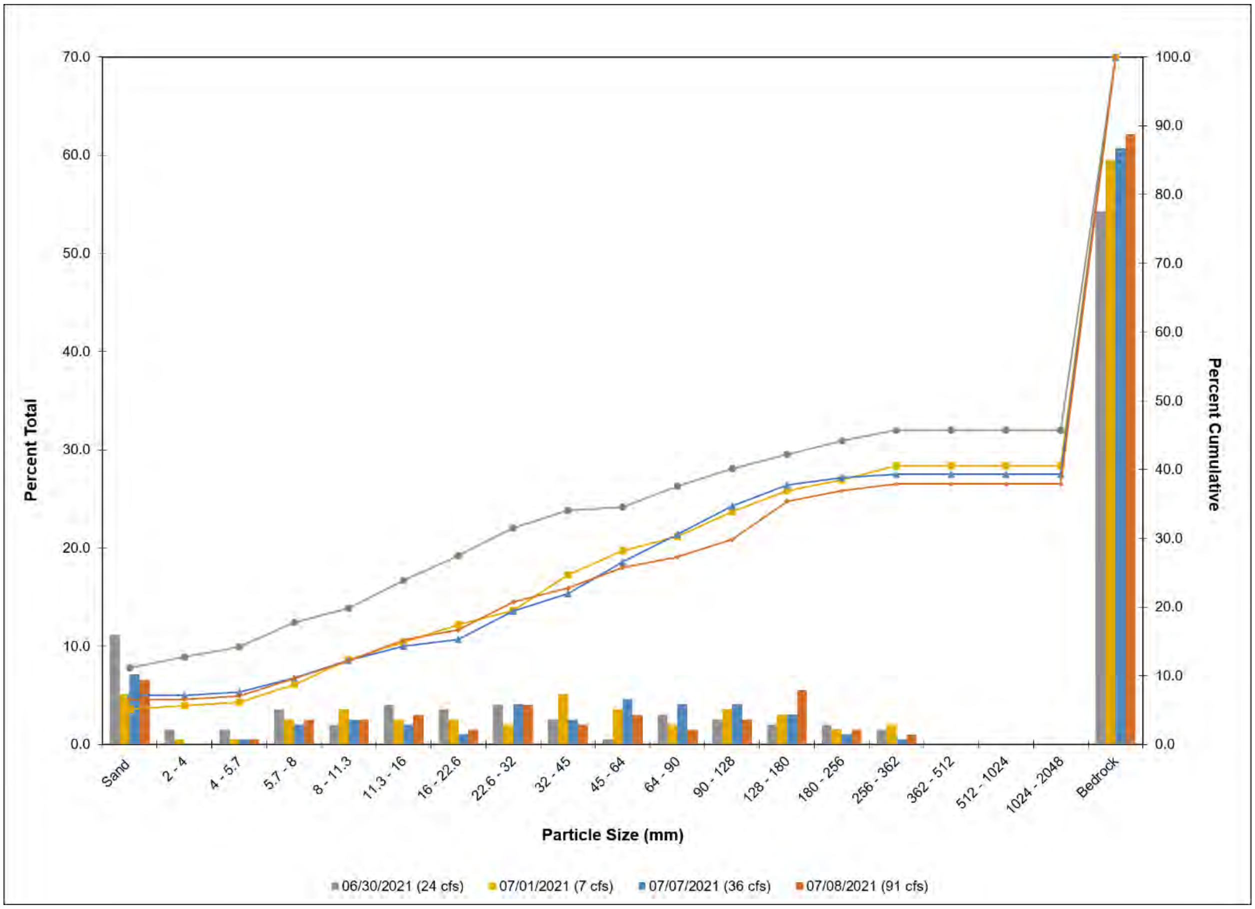

Figure 6-6. Niagara Bypass Reach Pebble Count Particle Size Data after each Model Calibration Flow Release (Downstream Transect)

6.5 Hydraulic Model Results

Results of the modeling effort for the Niagara bypass study area are included in Attachment 1 (Niagara Bypass Reach ICM Model Development Report); this report presents the final 2-D Niagara bypass reach model developed using the ICM software, which was used to predict hydraulic regimes in the bypass reach study area under four different bypass flow scenarios.

To help interpret the aquatic habitat evaluation results (presented in Section 6.6), depth and velocity heat maps are provided in the Niagara ICM report for each of the model calibration flows. These depth and velocity heat maps, along with the substrate and cover information provided in the habitat delineation maps (Section 6.3) form the basis of the habitat modeling results. Coupled with the habitat suitability criteria for each species and life stage (provided in Attachment 2), each of these building blocks (i.e., depth, velocity, substrate, and cover) can be used to determine their respective influence on the overall habitat modeling results.

6.6 Aquatic Habitat Evaluation Results

Habitat suitability maps under each modeled flow scenario are included in Attachment 3. Individual map series are provided for the eight species-guild representatives (i.e., two deep-fast, two deep-slow, one shallow-fast, and three shallow-slow) and Roanoke Logperch (adult, subadult, and young-of-year life stages). Potential available habitat under each modeled flow scenario provided in Table 6-3 is described below. In addition, the amount of usable area in the bypass reach for each guild representative and for Roanoke Logperch (adult, subadult, and young-of-year life stages) over the range of model calibration flows is provided in Figures A4-1 through A4-3 in Attachment 4. These figures can be used to determine how changes in bypass reach flows affect the amount of habitat (in square feet) that is potentially available in the bypass reach between 7 – 91 cfs.

Table 6-3. Measured Bypass Reach Flows

Calibration Flow	Bypass Reach Flow (cfs)	Powerhouse Flow (cfs)
Day 1 (Minimum Flow)	7	225
Day 2 (Low Flow)	24	185
Day 3 (Mid Flow)	33	175
Day 4 (High Flow)	91	218

Deep-Fast Guild

There are several pool areas throughout the Niagara bypass reach and tailrace that provide potential habitat for the Deep-Fast Guild. Over the modeled flow range (7 cfs to 91 cfs), the average velocity increases approximately 0.8 ft/s, however the average depth only increases approximately 0.5 ft. As a result, the amount of potential habitat in the bypass reach is relatively low (compared to the other guilds) but increases linearly as bypass flows increase (see Figure A4-1 in Attachment 4; SRHAD and SHRHA guild representatives).

The two guild representatives for deep-fast are Shorthead Redhorse adult (which prefers coarse-mixed substrate) and Silver Redhorse adult (which prefers finer substrate sizes with cover). Because the bypass reach is comprised mostly of larger substrate sizes, more potential habitat is available for the Shorthead Redhorse adult compared to the Silver Redhorse adult.

Deep-Slow Guild

The Deep-Slow Guild has two categories: “with cover” and “no cover.” Because most of the bypass reach was coded with instream and/or overhead cover, the only area that provides suitable “no cover” habitat is the tailrace downstream from the powerhouse. For the “with cover” guild representative (i.e. Redbreast Sunfish adult), preferred habitat exists throughout the bypass reach. As shown on Figure A4-1 (Attachment 4), the amount of potential habitat for Redbreast Sunfish adult increases fairly rapidly up to 30 cfs. At bypass reach flows higher than 30 cfs, the amount of potential habitat continues to increase, but at a slower rate compared to incremental increases in habitat at flows less than 30 cfs.

Shallow-Fast Guild

Potential available habitat for the Shallow-Fast Guild is along the main flow path in the bypass reach (starting at the outlet of the large pool at the base of the spillway and largely hugging the left descending bank before emptying into the tailrace). As expected (and similar to the Deep-Fast Guild), the amount of potential available habitat is relatively low (compared to the Shallow-Slow

Guild, for example), but increases a small amount as bypass flows increase. The rate of increase in potential available habitat is higher at bypass flows below 30 cfs than bypass flows above 30 cfs (see Figure A4-2 in Attachment 4; SHFST guild representative).

Shallow-Slow Guild

The Shallow-Slow Guild includes three categories: 1) fine- and coarse-mixed substrate sizes with no boulder/bedrock (represented by Redbreast Sunfish spawning), 2) fines and small gravel substrate sizes with aquatic vegetation (represented by Silver Redhorse young-of-year), and 3) coarse substrate (represented by Generic Shallow-Slow Guild). These three guild representatives exhibit some differences in potential available habitat under the four flow scenarios evaluated.

Of the three guild representatives, the Generic Shallow-Slow Guild (i.e., coarse substrate) exhibits the largest overall amount of potential habitat which is available throughout the bypass reach. There are some flow-related differences in the location of available habitat. For example, at lower flows, habitat is available along the main flow path, whereas at higher flows, the main flow path becomes either too deep or too fast. There is no available habitat in the tailrace for the same reason (i.e., too deep/fast). The greatest amount of habitat gain for the Generic Shallow-Slow Guild is for bypass reach flows up to 30 cfs, after which additional increases in habitat start to level off (Figure A4-2 in Attachment 4; SHSLO guild representative).

While slightly lower than for the coarse substrate guild representative, a significant amount of potential habitat is also available for the fine/coarse mixed guild representative, but the magnitude of available habitat is fairly similar between the four modeled flow scenarios (Figure A4-2 in Attachment 4; RBSFS guild representative). The exception being the lower portion of the bypass reach where velocities are too high (along the main flow path) and/or where boulder/bedrock substrate is more prevalent.

The Silver Redhorse young-of-year representative prefers fines and small gravel substrate types and requires instream aquatic vegetation. While there is aquatic vegetation in the bypass reach, it is largely above water at the modeled flow scenarios. Also, while fines and small gravels are present in the bypass reach, there are very few areas where they are considered to be the dominant substrate type; and aquatic vegetation is not co-located in those areas. As a result, model results indicated no available habitat for this guild representative, therefore, a figure was not created.

Roanoke Logperch

Habitat modeling results indicate preferred habitat in the bypass reach for Roanoke Logperch adult life stage primarily along the main flow path which corresponds with the observation data presented in the 2021 Roanoke Logperch Survey performed by EDGE Engineering, Inc. (results to be submitted to the FERC as supplemental information following completion of the Roanoke Logperch larval drift study in late 2022). For adults, the amount of available habitat increases as bypass flows increase, primarily along the main flow path. For the subadult life stage, potential available habitat is along the margins of the main flow path as subadults prefer slightly lower depths and velocities compared to the adult life stage. As a result, potential available habitat for subadults shifts as flow increases. The overall amount of available habitat increases as bypass flows increase, but the rate of increase is lower above approximately 30 cfs (see Figure A4-3 in Attachment 4). Note it is possible that the habitat modeling results for Roanoke Logperch adult and subadult life stages are under-represented. The HSC for bedrock/boulder substrate is 0.56 for the adult life stage and 0.10 for the subadult life stage (see Section 5.6.1.3, Tables 5-4 and 5-5, respectively). Based on field observation data from the 2021 Roanoke Logperch Survey, most of the observations for the adult and subadult life stages occurred in areas dominated by boulder/bedrock substrate. Increasing the habitat suitability for the boulder/bedrock substrate category would likely increase the amount of modeled habitat for these two life stages. Very little habitat is available (at any flow) for the young-of-year life stage which prefers depths less than 1 ft and velocities less than 0.3 ft/s.

7 Summary and Discussion

7.1 Delineate and Quantify Aquatic Habitats and Substrate Types

The Niagara bypass reach is approximately 1,500 ft long with an area of approximately 6.87 acres. A variety of habitat types are available in the bypass reach including shoals, shallow and deep pools, riffles, and runs. Substrate is dominated by larger particle sizes ranging from cobbles and boulders to irregular bedrock. Smaller substrate sizes (sands and gravels) are also present, but at lower percentages compared to the larger substrate sizes. Most of the bypass reach was coded as having cover consisting of instream cover, overhead cover, and proximal cover (i.e., within 4 ft of cover). Approximately 11.3 percent of the bypass was characterized as “upland”, which includes areas that are exposed during the 8 cfs minimum bypass flow requirement, but may be inundated at higher flows (i.e., during rainfall runoff events that result in flow over the Project’s main and auxiliary spillways).

The relatively short tailrace reach downstream from the powerhouse to the Blue Ridge Parkway Bridge was categorized as “run” mesohabitat type, composed mainly of boulder and bedrock (85.5 percent) with no cover (99.8 percent).

7.2 Surface Water Travel Times and Water Surface Elevation Responses

Level logger data collected during the model calibration flow fieldwork (i.e., June 29 – July 8, 2021) were used to determine surface water travel times in the Niagara bypass reach for each flow release. A summary of key findings is provided below:

- The main flow path through the bypass reach shifts from river right (looking downstream) near the spillway to river left at approximately the mid-point of the reach.
- Along this main flow path, depths increased approximately 0.32 ft between the minimum flow and low flow, 0.14 ft between the low and mid flows, and 0.46 ft between the mid and high flows. Overall depth increase from the minimum flow to high flow was approximately 0.92 ft.
- Depth increases along the right descending bank (outside the main flow path) were less noticeable as the channel bed elevation is slightly higher along the right bank (which forces flow to the lower left side of the bypass reach channel).

- Flow travel times through the approximately 1,500-ft-long bypass reach were approximately 35 minutes for the low and mid calibration flows and 16 minutes for the high calibration flow.

7.3 Identify and Characterize Locations of Habitat Management Interest

Habitat model results for the Niagara bypass reach indicate suitable habitat for the four guilds (i.e., Deep-Fast, Deep-Slow, Shallow-Fast, and Shallow-Slow) and the Roanoke Logperch standalone target species under all four modeled flow scenarios. The bypass reach contains shoals, shallow and deep pools, riffles, and runs which offer a variety of habitat types. Model results for species and life stages that prefer larger substrate types (e.g., cobble, boulder, bedrock) with cover (e.g., instream, overhead) generally had larger amounts of potential available habitat. The amount of potential available habitat generally increases as bypass flows increase with most of the incremental gain between the lowest modeled flow (i.e., 7 cfs) and the two middle flows (i.e., 24 – 33 cfs).

Habitat modeling results for the Roanoke Logperch indicate preferred habitat is primarily along the main flow path in the bypass reach, which is in agreement with the observation data presented in the 2021 Roanoke Logperch Survey performed by EDGE Engineering, Inc. The modeling results for the adult and subadult life stages may be under-represented for the bypass reach due to the relatively low suitability values assigned to the larger substrate categories (i.e., boulder/bedrock). Most of the field observations for Roanoke Logperch in the bypass reach listed boulder/bedrock as the prevalent substrate type. Increasing the habitat suitability for the boulder/bedrock substrate category would likely increase the amount of modeled habitat for these two life stages.

7.4 Efficacy of Existing Bypass Reach Minimum Flow Requirement

The minimum calibration flow field measurement was used to set the low end of the 2-D hydraulic model range. Habitat model results from this flow scenario were used to evaluate the efficacy of the existing 8 cfs minimum bypass flow requirement. Suitable habitat is available in the bypass reach at the minimum flow requirement. However, for most of the guilds and the standalone Roanoke Logperch target species, modeled habitat generally increases as bypass flows increase with a significant incremental gain at approximately 30 cfs. At bypass reach flows higher than 30 cfs, available habitat continues to increase for all modeled species and life stages, but generally at a lower rate compared to the incremental habitat gains up to 30 cfs. Between 8 cfs and 30 cfs, water depths increase by approximately 0.2 ft, velocities increase by approximately 0.3 ft/s and the total wetted area increases by approximately 27 percent (see Table 4-2, Attachment 1).

7.5 Evaluate the Impacts of Seasonal Minimum Flows

The purpose of seasonal minimum flow releases to the bypass reach would be primarily to increase spawning habitat for species or guilds using this area, however general habitat availability could also be considered in this context. As described above, a bypass reach flow of approximately 30 cfs would provide a significant incremental increase in overall habitat compared to the existing 8 cfs minimum flow requirement. With respect to spawning habitat, only the Redbreast Sunfish (representing Shallow-Slow Guild with fine- to coarse-substrate sizes with no boulder/bedrock) could be evaluated for this exercise. Spawning Redbreast Sunfish construct nests over silt-free sand and gravel substrates, typically located in calmer areas of pool margins or the lee of large boulders in water less than 3-ft deep (Jenkins and Burkhead 1993). According to the habitat modeling results (Attachment 3), spawning habitat with these characteristics is abundant in the upper half of the bypass reach at the 8 cfs minimum flow requirement, but would increase significantly at bypass reach flows up to approximately 30 cfs; with additional habitat gains tapering off at bypass reach flows higher than 30 cfs (likely due to increased velocities).

HSC information for the Roanoke Logperch spawning life stage was not available for habitat modeling purposes. However, the potential effect of increasing baseflows in the Niagara bypass reach from 8 cfs to 30 cfs indicates an approximate doubling of potential available habitat for the Roanoke Logperch adult and subadult life stages as discussed in Section 6.6.

8 Variances from FERC-Approved Study Plan

The Bypass Reach Flow and Aquatic Habitat Study was conducted in accordance with the FERC-approved RSP.

9 Germane Correspondence and Consultation

No consultation was undertaken for the Bypass Reach Flow and Aquatic Habitat Study.

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Attachment 1

Attachment 1 – Niagara Bypass ICM Development Model Report

Niagara ICM Model Development

Niagara Hydroelectric Project
(FERC No. 2466)

February 28, 2022

Prepared by:

HDR

Prepared for:

Appalachian Power Company

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Contents

Figures

Tables

Acronyms

2-D	2-Dimensional
ADCP	Acoustic Doppler current profiler
AEP	American Electric Power
cfs	cubic feet per second
DTM	Digital Terrain Model
ESRI	Environmental Systems Research Institute
ft	feet/foot
GIS	Geographic Information Systems
ICM	Integrated Catchment Model
Model	2-D Innovyze Infoworks Integrated Catchment Model
LiDAR	Light Detection and Ranging
NAD	North American Datum
NAVD88	North American Vertical Datum of 1988
Project	Niagara Hydroelectric Project
R12 GPS	Trimble® R12 Global Positioning System
STID	Supporting Technical Information Document
TIN	Triangulated Irregular Network
VGIN	Virginia Geographic Information Network
WSEL	Water Surface Elevation

1 Project Background

1.1 Purpose and Scope

This report presents the final results of the 2-Dimensional (2-D) Niagara Bypass Reach Model developed using Innovyze Infoworks Integrated Catchment Model (ICM) software. The 2-D Niagara Bypass Reach ICM (Model) was used to predict hydraulic regimes in the bypass reach under varying flows spilled from the Obermeyer gate. The results of the ICM Model were used in conjunction with habitat analyses presented in the Bypass Reach Flow and Aquatic Study Report (Appendix A) to develop habitat suitability maps under the various flow scenarios. These maps are presented in Appendix A, Attachment 3.

1.2 Study Area

Appalachian Power Company (Appalachian or Licensee) is the Licensee, owner, and operator of the 2.4-megawatt (MW) Niagara Hydroelectric Project (Project) (Federal Energy Regulatory Commission [FERC or Commission] Project No. 2466), located on the Roanoke River (river mile 355) in Roanoke County, Virginia. The Project is operated as a run-of-river hydroelectric facility; there is no appreciable reservoir storage available, and inflows are either used for generation or spilled.

2 Model Development

2.1 Flow Study Field Data Collection

To aid calibration and validation of the Model, phased flow data collection was performed under varying flows. Eleven level loggers (Onset® U-20 brand pressure transducers that measure water stage change with high precision) were deployed in the Niagara Bypass reach and tailrace prior to the target flow releases. The Onset U-20 instrumentation details document a measured water level with an accuracy of ±0.01 feet (ft). Reference water elevations were collected using a staff gage at each level logger when installed. Level loggers recorded water surface elevation data at 5-minute intervals providing detail for travel time, and rates of rise estimations used in the Model calibration. Locations of the deployed level loggers are shown in Figure 2-1.

Four flow tests were performed over two separate trips on June 29th through July 1st and July 6th through July 8th. Each test was designed to capture a specific flow in the bypass reach. Flow was delivered to the bypass reach via leakage and an opening of the Obermeyer Gate. Total flows in the bypass reach were recorded using a Swoffer Flow Meter. The resulting flows are given in Table 2-1. Figure 2-1 shows the flow measurement transect location in the bypass reach.

Table 2-1. Measured Bypass Reach Flows

Test Flow	Bypass Reach Flow (cubic ft per second [cfs])
Day 1 (Minimum Flow)	6.9
Day 2 (Low Flow)	24.0

Test Flow	Bypass Reach Flow (cubic ft per second [cfs])
Day 3 (Mid Flow)	32.5
Day 4 (High Flow)	91.1

In addition to the field data collected during the test flows, a drone was used to capture an aerial imagery orthomosaic of the steady-state flow conditions for the high and minimum test flows in the immediate vicinity of the bypass reach and tailrace. These orthomosaic images are presented in Section 4.

A Trimble® R12 Global Positioning System (R12 GPS) using Static Global Navigation Satellite System positioning with horizontal and vertical accuracies of 3.0 millimeters and 3.5 millimeters, respectively, was used to gather water surface elevation point data at various locations in the bypass reach under the various test flows. The GPS data points are colored by test flow scenario and shown in Figure 2-2.

Steady-state conditions were verified in the field using temporary staff gages. All discharge measurements were made a minimum of three times or until there was less than 5 percent difference between measurements.

After the flow test periods, level logger data was downloaded, and the loggers were redeployed to sample actual flow conditions for an additional three months. Data from this long-term deployment was used to further characterize the hydraulics of the bypass reach under a larger range of flow/spill conditions present outside of each two-day flow study test period (two separate 2-day periods).

The data collection plan enabled correlation of gate openings, flow, and water surface elevations at select locations within the bypass reach. The data was used to enhance understanding of travel times and rates of rise under conditions experienced during the collection period.

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Figure 2-1. Bypass Reach Monitoring Locations

Figure 2-2. R12 GPS Water Surface Elevation Point

2.2 Terrain Data

Light Detection and Ranging (LiDAR) data was collected for the entire Niagara bypass reach from the spillway extending down past the confluence with the tailrace. Bathymetry from the flow test scenarios study was integrated into the LiDAR dataset using a common coordinate system and datum. Coincident with the flow test field effort, HDR used an acoustic doppler current profiler (ADCP) connected to the GPS network to define the bathymetry of the tailrace. Additionally, GPS units were used to measure bathymetry data within the bypass reach. Measured bathymetry datapoints are shown on Figure 2-3.

Note that the pools immediately below the spillway, and on the western edge of the rock outcrop were deemed unsafe for measuring bathymetry data. These locations are also marked on Figure 2-3.

The Niagara powerhouse draft tube invert was defined along the edge of the powerhouse. The invert value of 812.5 ft above mean sea level (National Geodetic Vertical Datum of 1929) was taken from plant drawings presented in the Niagara Supporting Technical Information Document (STID) (DTA, 2005).

The additional bathymetric data was used to describe the channel below the water surface level present at the time LiDAR data was collected. The bathymetry was supplemented in pools by interpolating areas within the pools using professional judgment and field observed depths and elevations.

The Digital Terrain Model (DTM) used in the Niagara Bypass Reach Hydraulic Model was developed by combining the sources of terrain/bathymetry data using professional judgment and field observations. Detailed information on DTM development is presented in Section 3.2.

Figure 2-3. Collected Bathymetry Points

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2.3 Hydraulic Model Development

2.3.1 Conventions and Assumptions

The DTM utilized in the Model was referenced to the North American Vertical Datum of 1988 (NAVD88). The DTM was projected using the Virginia State Plane Coordinate System (i.e., U.S. Survey Foot) and horizontally referenced to the North American Datum (NAD) of 1983.

The ICM Model was developed with the following assumptions:

- In addition to LiDAR data, VGIN provides land cover data at 1-meter resolution. This dataset was used for the model Manning's *n* roughness. Detailed discussion of the Manning's roughness is provided in Section 3.
- Powerhouse outflows were determined using generation data provided by Appalachian. This data is provided in MW and is then converted to flow using the Discharge vs Generator Output curve for Unit 1. This curve is presented in Exhibit A of the Draft License Application document submitted to the FERC October 1, 2021.
- The Niagara tailrace was included in the Model but was not included in the habitat mapping.

2.3.2 Design Inputs

Additional design inputs include:

- Steady state inflow hydrographs of 6.9, 24.0, 32.5, and 91.1 cfs inflows at the Obermeyer gate for the minimum, low, mid, and high flow scenarios, respectively.
- Roughness zones (Manning's *n*-values);
- Initial hydraulic conditions – the bypass reach and tailrace begin the simulation dry and are allowed to fill to steady state conditions.
- Boundary conditions (i.e., 2-D zone boundary, inflow hydrographs, and downstream boundary conditions).

3 Methodology

3.1 ICM Model Development

Innovyze Infoworks ICM Version 11.0 (Innovyze, 2020) was used to evaluate the hydraulics of the bypass reach. The Model is a fully integrated 2-D hydrodynamic model which facilitates accurate representation of flow paths while enabling complex hydraulics and hydrology to be incorporated into a single model. The Model uses the shallow water equations to develop depth averaged hydraulics results. The 2-D model does not directly model turbulence, but accounts for energy losses due to turbulence due to bed resistance via the Manning's *n* roughness. The modeling domain extends approximately 1,300 ft downstream of the spillway and includes the Niagara tailrace. The domain is modeled with ICM's 2-D surface flooding module. This portion of the modeling extent is known as the 2-D Zone. The Model allows for detailed hydraulic results and provides a reasonable variability in average flow, depth, and velocity from one water column element to the next throughout the modeled area. The Model is considered appropriate for the evaluation of the bypass reach hydraulics. See 2.3.2 for design inputs.

3.2 Digital Terrain Model Development

The DTM used in the Model was constructed with data from several sources:

- Site LiDAR data collected by VGIN in 2018; and
- Additional bathymetry measurements collected by HDR in June and July 2021.

LiDAR data points at pools throughout the bypass reach and tailrace were discarded and replaced with bathymetry data in the bypass reach measured using a the R12 GPS unit and in the tailrace measured using a Teledyne Rio Grande® Acoustic Doppler Current Profiler and a Trimble® AG_GPS receiver equipped with an Omnistar® real-time differential GPS correction.

The data sources were converted into triangulated irregular network (TIN) surface files and merged using Environmental Systems Research Institute (Esri™) ArcGIS Pro version 2.8.3 Geographic Information System (GIS) software (Esri 2021). The resulting DTM encompassed the entire study area and was used as the basis for developing the conceptual design for the Hydraulic & Hydrologic analysis and modeling discussed in this report.

Figure 3-1 shows the final DTM used in the Model and the allocation of terrain data. The locations where measured bathymetry was used is shown in Figure 2-3.

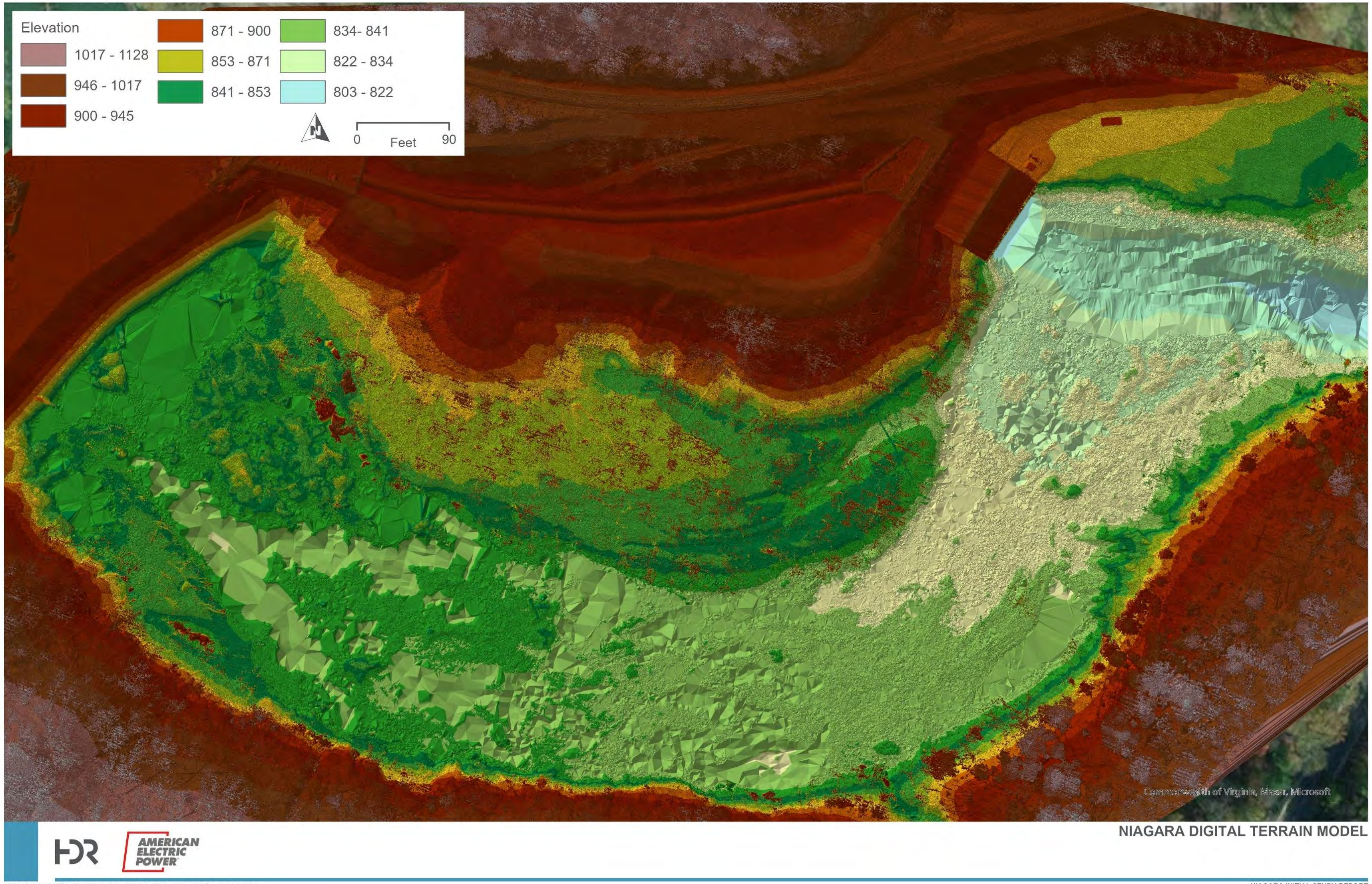

Figure 3-1. Bypass Reach Digital Terrain Model

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3.3 ICM Model

3.3.1 Site Topography

The 2-D Zone defining the Model includes approximately 1,300 ft of the Roanoke River. Figure 3-2 provides a view of the maximum extent of the 2-D Zone.

For the 2-D simulation, ICM subroutines were used to perform a meshing of the 2-D Zone. The 2-D mesh is comprised of an irregular array of triangles. Descriptions of the user input 2-D Zone data fields that are pertinent to this analysis are as follows:

- Maximum triangle area – A measure of mesh resolution used when creating a 2-D mesh; maximum allowable triangle area for areas in the 2-D Zone that are not inside of a secondary mesh zone.
- Minimum element area – Minimum mesh element area used for calculating results. Mesh elements with area less than the minimum area specified are aggregated with adjoining elements until the minimum area is met. This is done for the purpose of calculating results to improve simulation stability and run time.
- Boundary points – Boundary condition for 2-D Zone.
- Terrain-sensitive meshing – Meshing is used to increase the resolution of the mesh in areas that have a large variation in height without increasing the number of elements in relatively flat areas.
- Maximum height variation – The maximum height variation that is permitted within a single triangle. Triangles with a height variation greater than the assigned value are split provided this would not result in a triangle smaller than the Minimum element area.
- Minimum triangle angle – Minimum allowable angle between triangle vertices when creating a 2-D mesh.
- Roughness – Manning's *n* roughness values, used when creating a 2-D mesh. The roughness value assigned to mesh elements in areas in the 2-D Zone that are not in a roughness zone. Roughness values were selected from published tables (Reference 14).

Table 3-1 provides a summary of the selected user input values for the ICM meshing routine as well as the total 2-D Zone area.

A section of the resulting mesh is shown in Figure 3-3. The model mesh contains 98,488 triangles and 98,338 elements. The approximate minimum, maximum, and average element areas are 0.23 sq ft, 6.4 sq ft, and 0.43 sq ft, respectively

Table 3-1. ICM Meshing User Inputs and Area Summary

2D zone Object Properties

Polygon definition

ID	Niagara 2D Zone	
Area (acre)	10.499	#D
Maximum triangle area (ft2)	100.000	
Minimum element area (ft2)	2.500	
Mesh generation		
Boundary points	Vertical Wall	#D
Terrain-sensitive meshing	☒	
Maximum height variation (ft)	0.250	
Minimum angle (degree)	25.00	#D
Roughness (Manning's n)	0.1600	
Apply rainfall etc directly to mes	☐	
Apply rainfall etc	everywhere	#D
Rainfall profile	1	#D
Infiltration surface		#D
Turbulence model		
Rainfall percentage	100.000	#D
Mesh summary	......	
Mesh data	......	

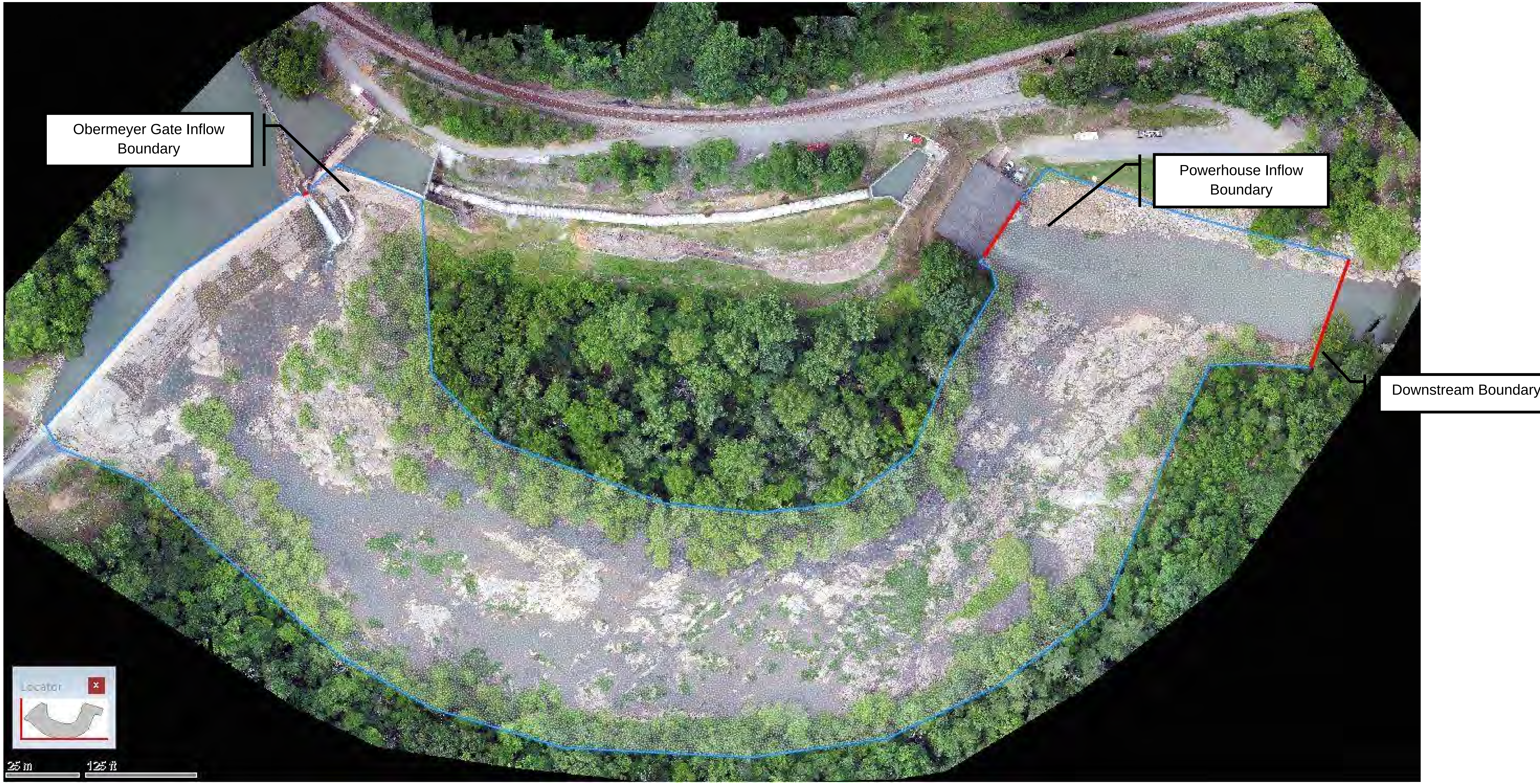

Figure 3-2. Extent of 2-D Zone and ICM Mesh (North is to the Top of the Figure)

Figure 3-3. ICM Mesh Section (North is to the Top of the Figure)

3.3.2 Roughness Zones

Roughness Zones for the 2-D Zone were created in GIS using land cover data provided by VGIN. Roughness Zones were assigned a Manning's *n*-value indicated in Table 3-2 (Chow, 1959). Table 3-2 presents the roughness values used in the model. The land cover is shown in Figure 3-4.

Table 3-2. Manning's *n* Roughness Values

Description	Grid Code	Roughness
Open Water	11	0.040
Developed, Open Space	21	0.040
Developed, Low Intensity	22	0.100
Deciduous Forest	41	0.160
Evergreen Forest	42	0.160
Grassland/Herbaceous	71	0.035

The Manning's *n*-values utilized for this analysis provide a reasonable assessment of current conditions at the project site when evaluating the hydraulics of the bypass reach.

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Figure 3-4. Land Cover Raster for Manning's *n* Roughness

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3.3.3 Initial Hydraulic Conditions

Both the bypass reach and tailrace were set to start the Model run from a dry condition to allow the pools within the bypass reach to fill as they naturally would during a real-life spill event.

3.3.4 Boundary Conditions

The primary 2-D Zone boundary condition (i.e., "vertical wall" Boundary Point settings in Table 4-1) was selected based on the topography at the edge of the 2-D Zone. This boundary condition is considered an impermeable and infinitely high barrier that does not allow water to flow into or out of the 2-D Zone unless specified with another boundary condition.

In addition to the primary 2-D Zone boundary condition, three additional boundary conditions were incorporated into the Model. An upstream boundary condition was defined at the Obermeyer gate where the minimum and inflow hydrographs were applied. A second upstream boundary condition was defined at the powerhouse outlet where the powerhouse flows were introduced. See Section 2 for discussion of the model inflows. The final boundary condition was located at the downstream end of the 2-D Zone on the Roanoke River and allows water to leave the 2-D Zone assuming normal depth. Under this condition it is assumed that slope balances friction forces (normal flow) i.e., depth and velocity are kept constant when water reaches the boundary, so water can flow out of the 2-D Zone without energy losses.

4 Results

The model inputs discussed above were used to set up four scenarios which represent the four test flows. Due to the complexity of the Model and mesh representing the Roanoke River, outputs presented herein are limited to select locations and points of interest.

4.1 Model Calibration and Verification

Field data points collected during the flow testing as well as timing of releases recorded by the level loggers in the bypass reach were used to calibrate and verify the model setup.

4.1.1 Point Water Surface Elevations

Water surface elevations collected by the R12 GPS unit were compared to water surface elevations predicted by the model. Figure 4-1 shows the water surface elevation comparisons for the four test flow scenarios. Field measurement data points are colored by magnitude of percentage difference between field and modeled water surface elevations. Figure 4-2 shows a graphical representation of field vs modeled water surface elevations. Measured field elevations are shown along the Y axis, and modeled elevations along the X axis. A perfect correlation between the measured and modeled elevations would produce a straight, 1:1 slope line and an R^2 correlation value of 1.0. As shown on the figure, the R^2 value of 0.976 indicates there is excellent agreement between the model and the field data. The ranges of difference (i.e., delta) for percentage difference and absolute difference for the four scenarios are presented in Table 4-1.

Table 4-1. Point Water Surface Elevation Comparison

Bypass Reach Flow	Minimum Delta		Maximum Delta		Average Delta	
	Percentage (%)	Magnitude (ft)	Percentage (%)	Magnitude (ft)	Percentage (%)	Magnitude (ft)
Minimum	0.01	0.05	0.24	2.00	0.09	0.73
Low	0.00	0.01	0.11	0.93	0.04	0.32
Mid	0.00	0.01	0.11	0.95	0.04	0.37
High	0.01	0.10	0.09	0.79	0.05	0.42

Figure 4-1. Field vs Modeled Water Surface Elevations

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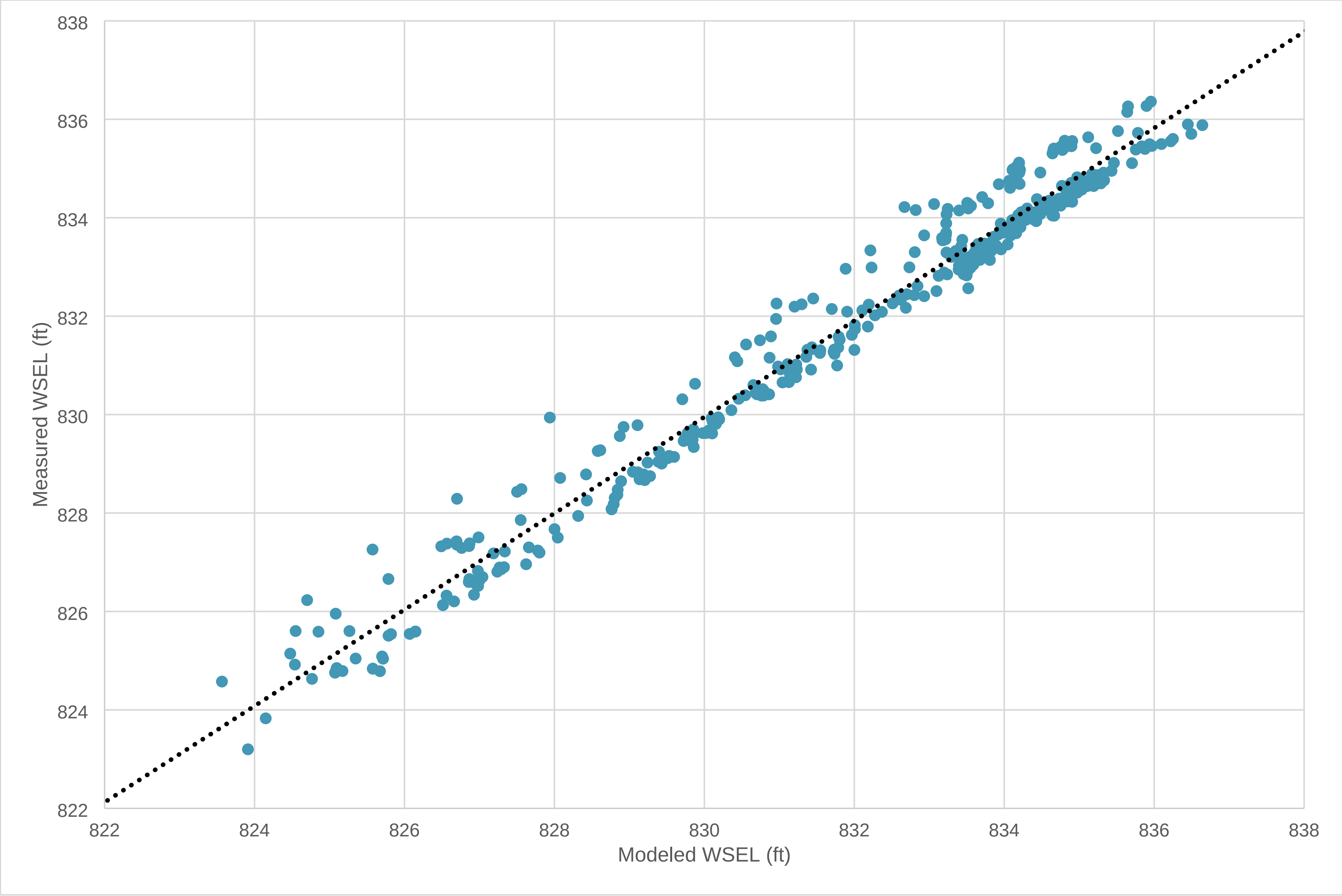

Figure 4-2. Measured vs Modeled Water Surface Elevation Correlation

4.1.2 Wetted Area Comparison

The total wetted area in the bypass reach increases with increasing test flows. Table 4-2 presents the incremental differences predicted by the model of the total bypass reach wetted area between the various test flows.

Table 4-2. Bypass Reach Wetted Area Comparison

Bypass Reach Flow	Total Wetted Area (Acres)	Percent Delta From Minimum	Incremental Area Increase (Acres)
Minimum	2.79	N/A	N/A
Low	3.70	125%	0.91
Mid	3.88	128%	0.18
High	4.63	140%	0.75

Figure 4-3 and Figure 4-4 present model results overlaid onto their respective test flow orthomosaic imagery. These figures provide a view of the model results that can be used as a qualitative check of the Model's agreement with field conditions. For increased detail, only a portion of the bypass reach is presented in these figures. Note these orthomosaic images were only captured during the Low and High flow conditions.

Figure 4-3. Model Results with Orthomosaic Imagery – Low Flow

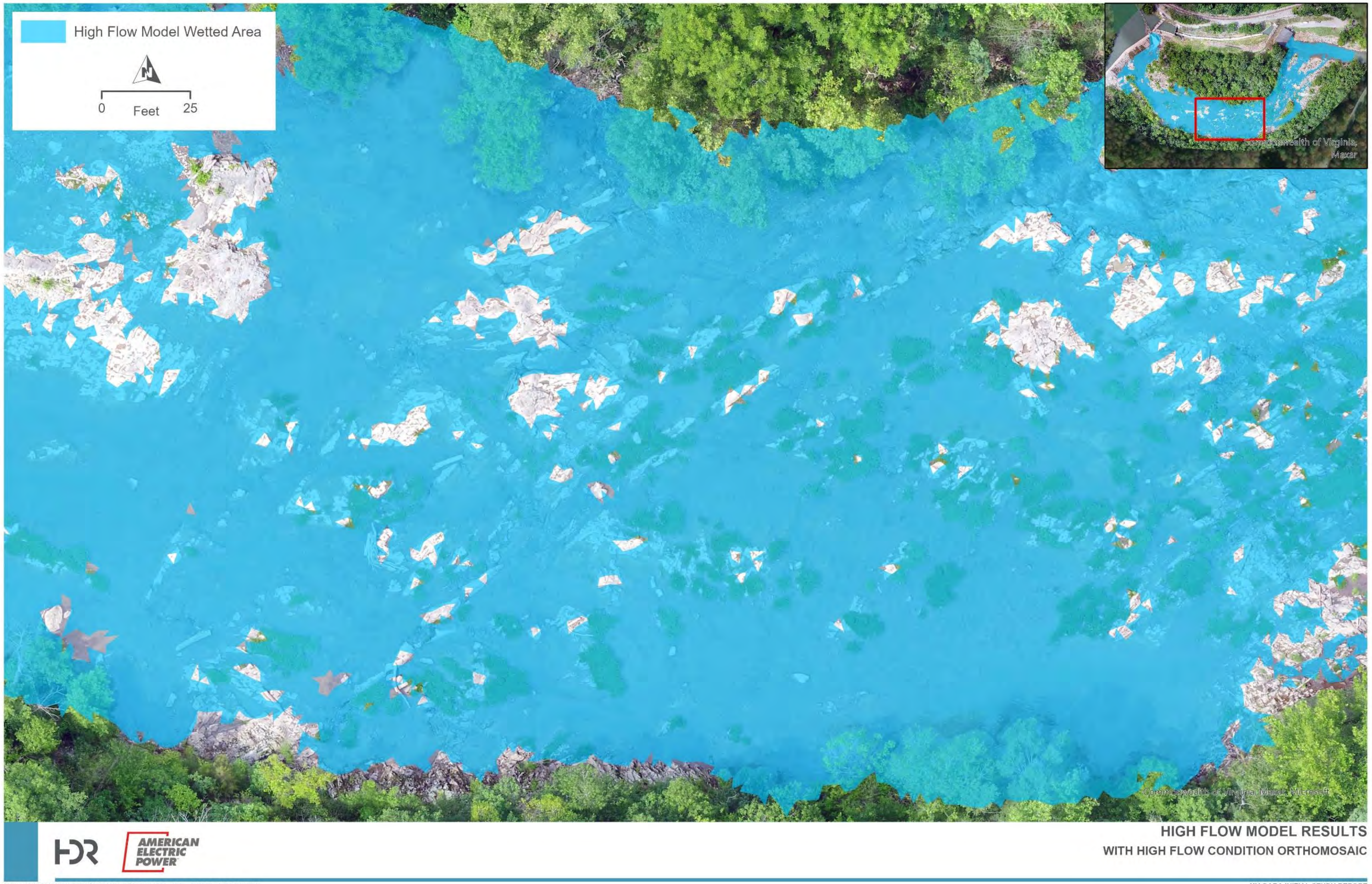

Figure 4-4. Model Results with Orthomosaic Imagery – High Flow

4.1.3 Travel Time

Travel time measures the time it takes an inflow to travel between designated points in the bypass reach. This measurement is a data point used for verifying several model inputs including the Manning's *n* roughness values presented in Section 3.3.2, inflow, and overall bypass reach slope from the LiDAR data/DTM are appropriate for the analysis. Additionally, it provides insight into model hydraulics, specifically the average velocity within the bypass reach. For this analysis, the travel time was measured between the upstream and downstream most level loggers in the bypass reach (NWL BP1, NWL BP9). For reference see Figure 2-1. Table 4-3 presents travel times measured by the level loggers and predicted by the model. As the minimum flow is considered constant, travel times are not measured for that flow condition.

Table 4-3. Bypass Reach Travel Times

Bypass Reach Flow	Level Logger Time (hr:min)	Model Time (hr:min)	Delta (hr:min)
Day 1 (Minimum)	N/A	N/A	N/A
Day 2 (Low)	0:33	0:46	+0:13
Day 3 (Mid)	0:34	0:34	+0:00
Day 4 (High)	0:16	0:15	-0:01

At low flows, the model predicts slightly faster travel times than seen in the field while the opposite is true at higher flows. The small deltas between field and model data confirm the modeling inputs are appropriate and average velocities calculated are representative of field conditions.

4.1.4 Depth and Velocity Maps

Depth and velocity heat maps were generated for the four test flow scenarios. These maps are an useful tool for interpreting the habitat suitability maps presented in the Niagara Bypass Reach Flow and Aquatic Habitat. Depth heat maps are presented in **Error! Reference source not found.** through **Error! Reference source not found.**, and velocity heat maps are presented in **Error! Reference source not found.** through **Error! Reference source not found.**.

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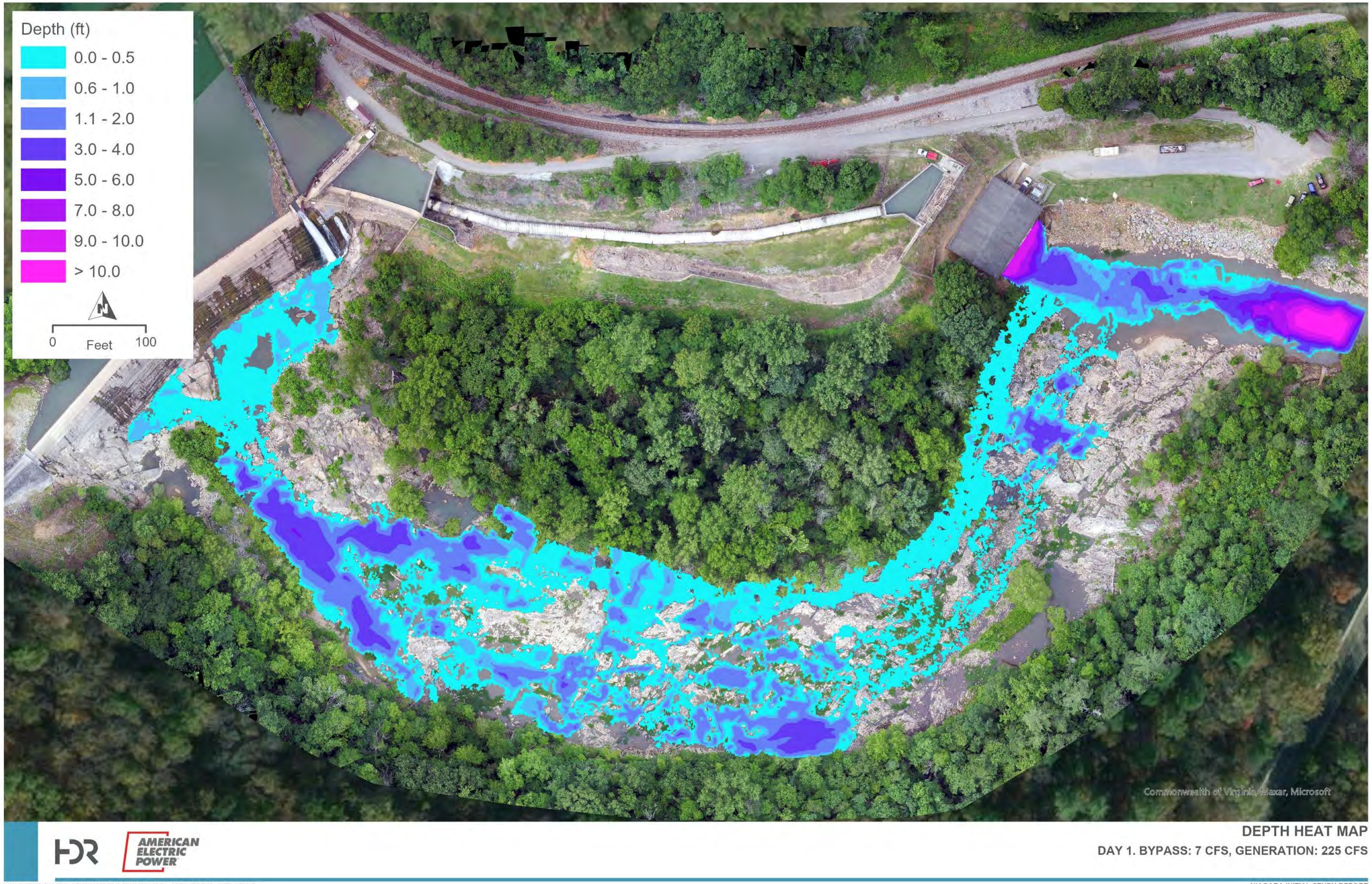

Figure 4-5. Depth Heat Map – Minimum Flow

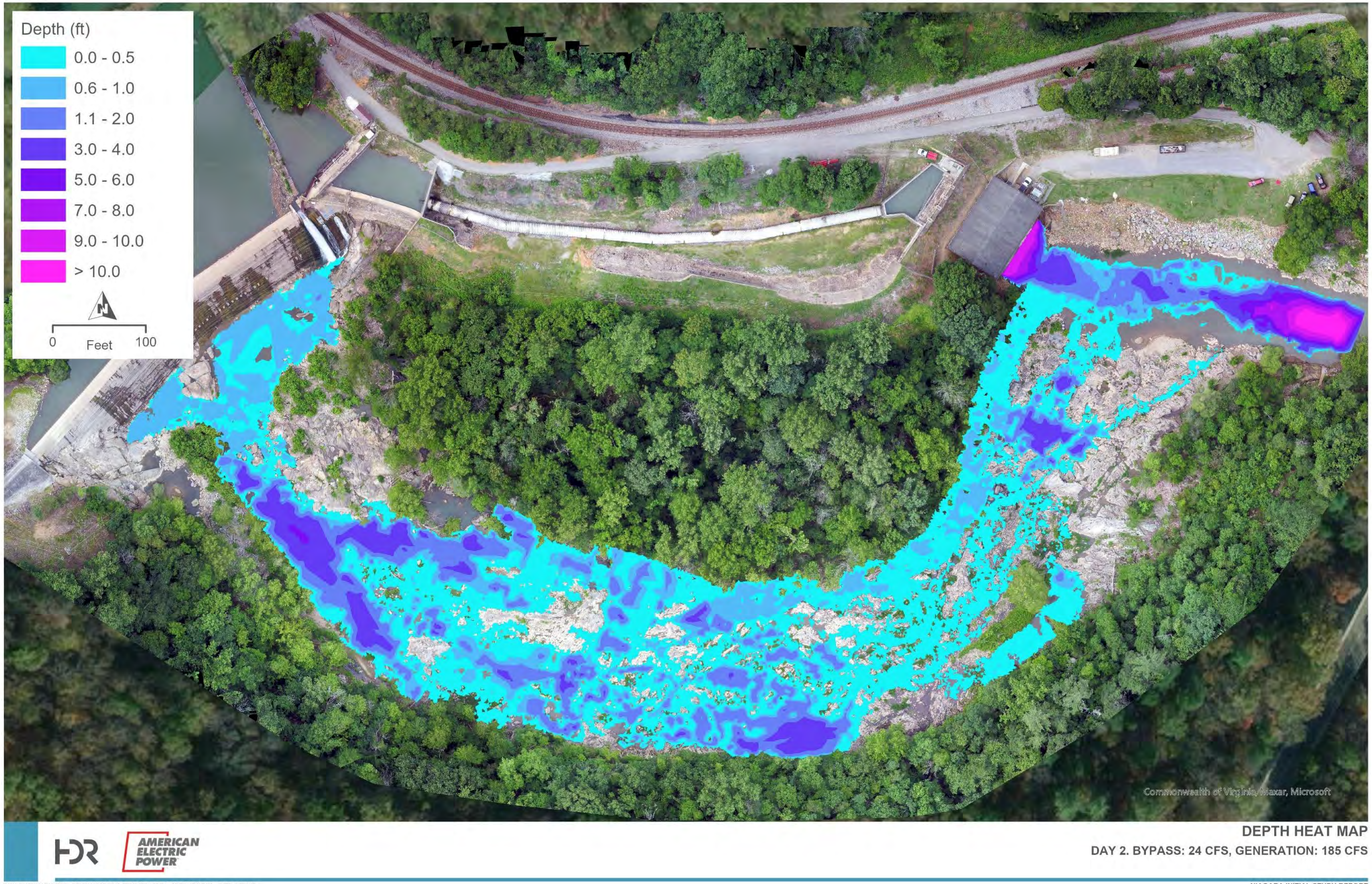

Figure 4-6. Depth Heat Map – Low Flow

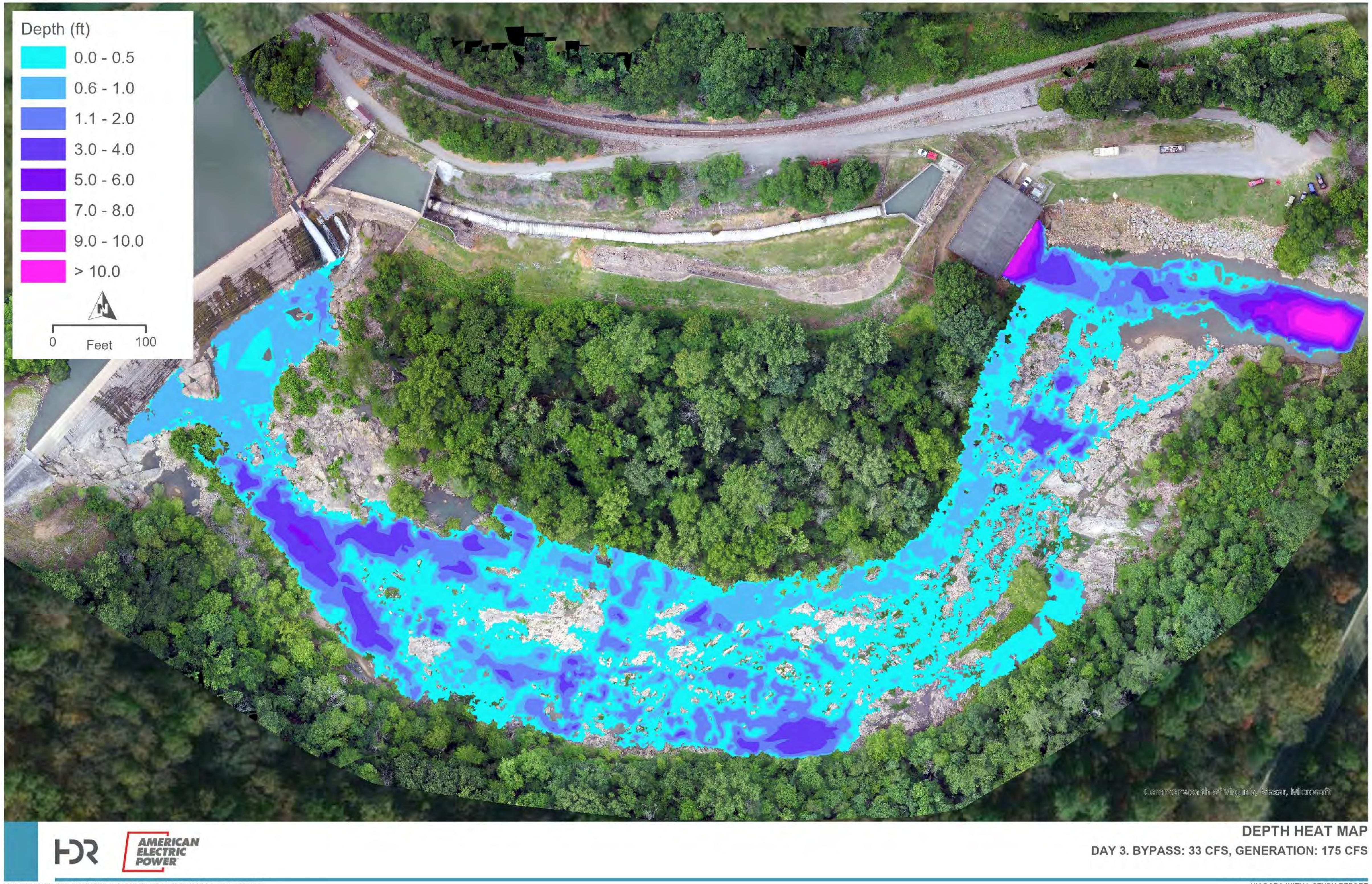

Figure 4-7. Depth Heat Map – Middle Flow

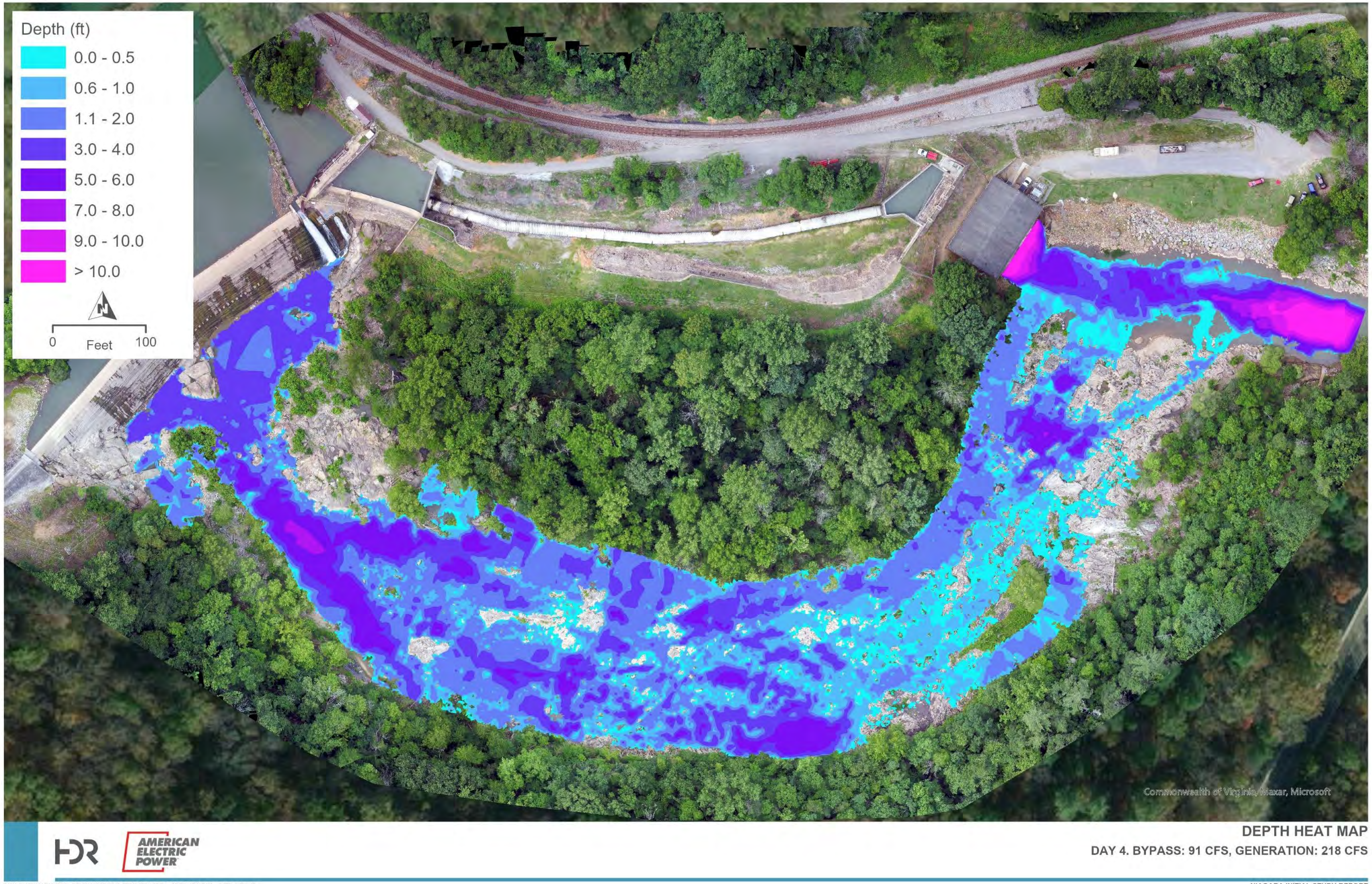

Figure 4-8. Depth Heat Map – High Flow

Figure 4-9. Velocity Heat Map – Minimum Flow

Figure 4-10. Velocity Heat Map – Low Flow

Figure 4-11. Velocity Heat Map – Middle Flow

Figure 4-12. Velocity Heat Map – High Flow

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Attachment 2

Attachment 2 – Habitat Suitability Criteria Tables

Table 1. Shallow Guild HSC Table

Lifestage	Velocity (ft/s)	Velocity (m/s)	Suitability Index	Depth (ft)	Depth (m)	Suitability Index	Channel Index	Suitability Index
	0.0	0.00	1.00	0.0	0.00	0.00	1	0.1
	0.4	0.12	1.00	0.5	0.15	0.00	2	0.7
	0.5	0.15	0.90	0.8	0.23	0.80	3	0.8
	1.0	0.31	0.15	1.0	0.31	1.00	4	0.5
	1.3	0.41	0.00	2.5	0.76	1.00	5	0.21
	--	--	--	3.1	0.95	0.60	6	0
	--	--	--	7.0	2.13	0.00	7	0
	--	--	--	--	--	--	8	0.2
RBSFS	--	--	--	--	--	--	9	0.8
	--	--	--	--	--	--	10	0.4
	--	--	--	--	--	--	11	0.8
	--	--	--	--	--	--	12	0.8
	--	--	--	--	--	--	13	0.7
	--	--	--	--	--	--	14	0.9
	--	--	--	--	--	--	15	0.6
	--	--	--	--	--	--	16	0.9
	--	--	--	--	--	--	17	0.85
	--	--	--	--	--	--	18	0
	0.0	0.00	0.92	0.0	0.00	0.00	1	1
	0.0	0.01	0.95	0.0	0.01	0.08	2	0
	0.1	0.02	0.97	0.1	0.02	0.10	3	0
	0.1	0.03	0.98	0.1	0.03	0.13	4	0
SRHAV	0.1	0.04	0.99	0.1	0.04	0.17	5	0
	0.2	0.05	1.00	0.2	0.05	0.21	6	0
	0.2	0.06	1	0.2	0.06	0.25	7	0
	0.2	0.07	1	0.2	0.07	0.29	8	1
	0.3	0.08	0.99	0.3	0.08	0.34	9	0
	0.3	0.09	0.98	0.3	0.09	0.39	10	0
	0.3	0.10	0.97	0.3	0.10	0.44	11	0
	0.4	0.11	0.95	0.4	0.11	0.5	12	0
	0.4	0.12	0.94	0.4	0.12	0.55	13	0
	0.4	0.13	0.92	0.4	0.13	0.6	14	0
	0.5	0.14	0.9	0.5	0.14	0.65	15	0
	0.5	0.15	0.88	0.5	0.15	0.7	16	0
	0.5	0.16	0.86	0.5	0.16	0.75	17	0
	0.6	0.17	0.83	0.6	0.17	0.79	18	1
	0.6	0.18	0.81	0.6	0.18	0.83	--	--
	0.6	0.19	0.79	0.6	0.19	0.87	--	--
	0.7	0.20	0.76	0.7	0.20	0.90	--	--
	0.7	0.21	0.74	0.7	0.21	0.92	--	--
SRHAV	0.7	0.22	0.71	0.7	0.22	0.95	--	--
	0.8	0.23	0.69	0.8	0.23	0.96	--	--
	0.8	0.24	0.67	0.8	0.24	0.98	--	--
	0.8	0.25	0.64	0.8	0.25	0.99	--	--
	0.8	0.26	0.62	0.8	0.26	1	--	--
	0.9	0.27	0.6	0.9	0.27	1	--	--
	0.9	0.28	0.58	0.9	0.28	1	--	--
	1.0	0.29	0.55	1.0	0.29	1	--	--
	1.0	0.30	0.53	1.0	0.30	0.99	--	--
	1.0	0.31	0.51	1.0	0.31	0.98	--	--
	1.0	0.32	0.49	1.0	0.32	0.97	--	--
	1.1	0.33	0.47	1.1	0.33	0.96	--	--
	1.1	0.34	0.46	1.1	0.34	0.94	--	--
	1.2	0.35	0.44	1.2	0.35	0.93	--	--

Lifestage	Velocity (ft/s)	Velocity (m/s)	Suitability Index	Depth (ft)	Depth (m)	Suitability Index	Channel Index	Suitability Index
	1.2	0.36	0.42	1.2	0.36	0.91	--	--
	1.2	0.37	0.4	1.2	0.37	0.89	--	--
	1.3	0.38	0.39	1.3	0.38	0.87	--	--
	1.3	0.39	0.37	1.3	0.39	0.85	--	--
	1.3	0.40	0.35	1.3	0.40	0.83	--	--
	1.3	0.41	0.34	1.3	0.41	0.81	--	--
	1.4	0.42	0.33	1.4	0.42	0.79	--	--
	1.4	0.43	0.31	1.4	0.43	0.77	--	--
	1.4	0.44	0.3	1.4	0.44	0.75	--	--
	1.5	0.45	0.29	1.5	0.45	0.72	--	--
	1.5	0.46	0.27	1.5	0.46	0.7	--	--
	1.5	0.47	0.26	1.5	0.47	0.68	--	--
	1.6	0.48	0.25	1.6	0.48	0.66	--	--
	1.6	0.49	0.24	1.6	0.49	0.64	--	--
	1.6	0.50	0.23	1.6	0.50	0.62	--	--
	1.7	0.51	0.22	1.7	0.51	0.6	--	--
	1.7	0.52	0.21	1.7	0.52	0.58	--	--
	1.7	0.53	0.2	1.7	0.53	0.56	--	--
	1.8	0.54	0.19	1.8	0.54	0.54	--	--
	1.8	0.55	0.18	1.8	0.55	0.52	--	--
	1.8	0.56	0.17	1.8	0.56	0.5	--	--
	1.9	0.57	0.17	1.9	0.57	0.48	--	--
	1.9	0.58	0.16	1.9	0.58	0.46	--	--
	1.9	0.59	0.15	1.9	0.59	0.45	--	--
	2.0	0.60	0.14	2.0	0.60	0.43	--	--
	2.0	0.61	0.14	2.0	0.61	0.41	--	--
	2.0	0.62	0.13	2.0	0.62	0.4	--	--
	2.1	0.63	0.13	2.1	0.63	0.38	--	--
SRHAV	2.1	0.64	0.12	2.1	0.64	0.37	--	--
	2.1	0.65	0.11	2.1	0.65	0.35	--	--
	2.2	0.66	0.11	2.2	0.66	0.34	--	--
	2.2	0.67	0.1	2.2	0.67	0.33	--	--
	2.2	0.68	0.1	2.2	0.68	0.31	--	--
	2.3	0.69	0.09	2.3	0.69	0.3	--	--
	2.3	0.70	0.09	2.3	0.70	0.29	--	--
	2.3	0.71	0.09	2.3	0.71	0.28	--	--
	2.4	0.72	0.08	2.4	0.72	0.27	--	--
	2.4	0.73	0.08	2.4	0.73	0.25	--	--
	2.4	0.74	0.07	2.4	0.74	0.24	--	--
	2.5	0.75	0.07	2.5	0.75	0.23	--	--
	2.5	0.76	0.07	2.5	0.76	0.22	--	--
	2.5	0.77	0.06	2.5	0.77	0.22	--	--
	2.6	0.78	0.06	2.6	0.78	0.21	--	--
	2.6	0.79	0.06	2.6	0.79	0.2	--	--
	2.6	0.80	0.05	2.6	0.80	0.19	--	--
	2.7	0.81	0.05	2.7	0.81	0.18	--	--
	2.7	0.82	0.05	2.7	0.82	0.17	--	--
	2.7	0.83	0.05	2.7	0.83	0.17	--	--
	2.7	0.84	0.04	2.7	0.84	0.16	--	--
	2.8	0.85	0.04	2.8	0.85	0.15	--	--
	2.8	0.86	0.04	2.8	0.86	0.15	--	--
	2.9	0.87	0.04	2.9	0.87	0.14	--	--
	2.9	0.88	0.04	2.9	0.88	0.13	--	--
	2.9	0.89	0.03	2.9	0.89	0.13	--	--
	2.9	0.90	0.03	2.9	0.90	0.12	--	--
	3.0	0.91	0.03	3.0	0.91	0.12	--	--

Lifestage	Velocity (ft/s)	Velocity (m/s)	Suitability Index	Depth (ft)	Depth (m)	Suitability Index	Channel Index	Suitability Index
	3.0	0.92	0.03	3.0	0.92	0.11	--	--
	3.1	0.93	0.03	3.1	0.93	0.11	--	--
	3.1	0.94	0.03	3.1	0.94	0.1	--	--
	3.1	0.95	0.03	3.1	0.95	0.1	--	--
	3.1	0.96	0.02	3.1	0.96	0.09	--	--
	3.2	0.97	0.02	3.2	0.97	0.09	--	--
	3.2	0.98	0.02	3.2	0.98	0.08	--	--
	3.3	0.99	0.02	3.3	0.99	0.08	--	--
	3.3	1.00	0.02	3.3	1.00	0.08	--	--
	3.3	1.01	0.02	3.3	1.01	0.07	--	--
	3.3	1.02	0.02	3.3	1.02	0.07	--	--
	3.4	1.03	0.02	3.4	1.03	0.07	--	--
	3.4	1.04	0.02	3.4	1.04	0.06	--	--
	3.4	1.05	0.01	3.4	1.05	0.06	--	--
	3.5	1.06	0.01	3.5	1.06	0.06	--	--
	3.5	1.07	0.01	3.5	1.07	0.05	--	--
	3.5	1.08	0.01	3.5	1.08	0.05	--	--
	3.6	1.09	0.01	3.6	1.09	0.05	--	--
	3.6	1.10	0.01	3.6	1.10	0.05	--	--
	3.6	1.11	0.01	3.6	1.11	0.04	--	--
	3.7	1.12	0.01	3.7	1.12	0.04	--	--
	3.7	1.13	0.01	3.7	1.13	0.04	--	--
	3.7	1.14	0.01	3.7	1.14	0.04	--	--
	3.8	1.15	0.01	3.8	1.15	0.04	--	--
	3.8	1.16	0.01	3.8	1.16	0.03	--	--
	3.8	1.17	0.01	3.8	1.17	0.03	--	--

Lifestage	Velocity (ft/s)	Velocity (m/s)	Suitability Index	Depth (ft)	Depth (m)	Suitability Index	Channel Index	Suitability Index
SRHAV	3.9	1.18	0.01	3.9	1.18	0.03	--	--
	3.9	1.19	0.01	3.9	1.19	0.03	--	--
	3.9	1.20	0.01	3.9	1.20	0.03	--	--
	4.0	1.21	0.01	4.0	1.21	0.03	--	--
	4.0	1.22	0.01	4.0	1.22	0.02	--	--
	4.0	1.23	0.01	4.0	1.23	0.02	--	--
	4.1	1.24	0	4.1	1.24	0.02	--	--
	--	--	--	4.1	1.25	0.02	--	--
	--	--	--	4.1	1.26	0.02	--	--
	--	--	--	4.2	1.27	0.02	--	--
	--	--	--	4.2	1.28	0.02	--	--
	--	--	--	4.2	1.29	0.02	--	--
	--	--	--	4.3	1.30	0.02	--	--
	--	--	--	4.3	1.31	0.02	--	--
	--	--	--	4.3	1.32	0.01	--	--
	--	--	--	4.4	1.33	0.01	--	--
	--	--	--	4.4	1.34	0.01	--	--
	--	--	--	4.4	1.34	0.01	--	--
	--	--	--	4.5	1.36	0.01	--	--
	--	--	--	4.5	1.37	0.01	--	--
	--	--	--	4.5	1.38	0.01	--	--
	--	--	--	4.6	1.39	0.01	--	--
	--	--	--	4.6	1.40	0.01	--	--
	--	--	--	4.6	1.41	0.01	--	--
	--	--	--	4.7	1.42	0.01	--	--
	--	--	--	4.7	1.43	0.01	--	--
	--	--	--	4.7	1.44	0.01	--	--
	--	--	--	4.8	1.45	0.01	--	--

Lifestage	Velocity (ft/s)	Velocity (m/s)	Suitability Index	Depth (ft)	Depth (m)	Suitability Index	Channel Index	Suitability Index
	--	--	--	4.8	1.46	0.01	--	--
	--	--	--	4.8	1.47	0.01	--	--
	--	--	--	4.8	1.48	0.01	--	--
	--	--	--	4.9	1.49	0.01	--	--
	--	--	--	4.9	1.50	0	--	--
	--	--	--	5.3	1.63	0	--	--
SHSLO	0.00	0.00	0	0.00	0.00	0	1	0
	0.33	0.10	1	0.10	0.03	1	2	0
	1.00	0.31	1	2.00	0.61	1	3	1
	1.00	0.31	0	2.03	0.62	0	4	1
	--	--	--	--	--	--	5	1
	--	--	--	--	--	--	6	1
	--	--	--	--	--	--	7	0
	--	--	--	--	--	--	8	0
	--	--	--	--	--	--	9	1
	--	--	--	--	--	--	10	1
	--	--	--	--	--	--	11	1
	--	--	--	--	--	--	12	1
	--	--	--	--	--	--	13	1
	--	--	--	--	--	--	14	1
	--	--	--	--	--	--	15	1
	--	--	--	--	--	--	16	1
	--	--	--	--	--	--	17	0
	--	--	--	--	--	--	18	0
SHFST	0.00	0.00	0	0.00	0.00	0	1	0
	0.76	0.23	0.3	0.15	0.05	0.1	2	0
	1.50	0.46	1	0.25	0.08	0.8	3	0.75
	2.50	0.76	1	0.35	0.11	1	4	1
	3.50	1.07	0.4	1.20	0.37	1	5	0
	3.80	1.16	0.2	1.50	0.46	0.75	6	0
	4.00	1.22	0	2.00	0.61	0.3	7	0
	--	--	--	2.50	0.76	0.1	8	0.5
	--	--	--	6.00	1.83	0	9	0.75
	--	--	--	--	--	--	10	1
	--	--	--	--	--	--	11	0
	--	--	--	--	--	--	12	1
	--	--	--	--	--	--	13	0
	--	--	--	--	--	--	14	1
	--	--	--	--	--	--	15	0
	--	--	--	--	--	--	16	0.75
	--	--	--	--	--	--	17	0
	--	--	--	--	--	--	18	0

Table 2. Deep Guild HSC Table

Lifestage	Velocity (ft/s)	Velocity (m/s)	Suitability Index	Depth (ft)	Depth (m)	Suitability Index	Channel Index	Suitability Index
RBSFA	0.0	0.00	1.00	0.0	0.00	0.00	1	0.1
	0.8	0.23	1.00	0.2	0.06	0.00	2	0.3
	1.5	0.46	0.30	1.2	0.37	0.80	3	0.7
	3.0	0.91	0.00	2.0	0.61	1.00	4	0.8
	--	--	--	6.0	1.83	1.00	5	0.7
	--	--	--	7.5	2.29	0.60	6	0.3
	--	--	--	8.2	2.50	0.00	7	0.1
	--	--	--	--	--	--	8	0.8
	--	--	--	--	--	--	9	1
	--	--	--	--	--	--	10	0.8
	--	--	--	--	--	--	11	1
	--	--	--	--	--	--	12	0.8
	--	--	--	--	--	--	13	1
	--	--	--	--	--	--	14	0.9
	--	--	--	--	--	--	15	1
	--	--	--	--	--	--	16	0.85
	--	--	--	--	--	--	17	0.65
	--	--	--	--	--	--	18	0
DSLON	0.0	0.00	1.00	0.0	0.00	0.00	1	1
	1.0	0.31	1.00	2.0	0.61	0.00	2	1
	1.0	0.31	0.00	2.0	0.61	1.00	3	1
	2.0	0.61	0.00	10.0	3.05	1.00	4	1
	--	--	--	--	--	--	5	1
	--	--	--	--	--	--	6	1
	--	--	--	--	--	--	7	1
	--	--	--	--	--	--	8	0
	--	--	--	--	--	--	9	0
	--	--	--	--	--	--	10	0
	--	--	--	--	--	--	11	0
	--	--	--	--	--	--	12	0
DSLON	--	--	--	--	--	--	13	0
	--	--	--	--	--	--	14	0.5
	--	--	--	--	--	--	15	0.5
	--	--	--	--	--	--	16	0
	--	--	--	--	--	--	17	0
	--	--	--	--	--	--	18	0
SRHAD	0.0	0.00	0.00	0.0	0.00	0.00	1	0.1
	0.1	0.04	0.51	1.5	0.46	0.00	2	0.45
	0.4	0.12	0.62	2.4	0.73	0.57	3	0.65
	0.6	0.20	0.82	3.3	1.02	0.91	4	0.475
	0.8	0.24	1.00	3.8	1.16	1.00	5	0.35
	1.0	0.32	1.00	4.8	1.45	1.00	6	0.48
	1.2	0.36	0.91	5.2	1.59	1.00	7	0.34
	1.4	0.44	0.6	6.2	1.88	1	8	0.55
	1.7	0.52	0.27	7.1	2.18	1	9	0.82
	2.0	0.60	0.08	8.1	2.47	1	10	0.75
	2.2	0.68	0.02	9.0	2.76	1	11	0.75
	2.4	0.719	0	9.5	2.90	1	12	0.75
	--	--	--	15.0	4.56	1	13	0.75
	--	--	--	--	--	--	14	0.75
	--	--	--	--	--	--	15	0.75
	--	--	--	--	--	--	16	0.82
	--	--	--	--	--	--	17	0.75
	--	--	--	--	--	--	18	0
SHRHA	0.0	0.00	0.37	0.0	0.00	0.00	1	0.2
	0.4	0.12	0.48	0.4	0.12	0.00	2	0.38

Lifestage	Velocity (ft/s)	Velocity (m/s)	Suitability Index	Depth (ft)	Depth (m)	Suitability Index	Channel Index	Suitability Index
	0.8	0.24	0.59	0.8	0.24	0.06	3	0.7
	1.2	0.37	0.70	1.0	0.31	0.14	4	0.75
	1.6	0.49	0.80	1.2	0.37	0.26	5	0.5
	2.0	0.61	0.89	1.4	0.43	0.41	6	0.55
	2.4	0.73	0.95	1.6	0.49	0.56	7	0.3
	2.8	0.85	0.99	1.8	0.55	0.7	8	0.45
	3.2	0.98	1	2.0	0.61	0.81	9	0.7
	3.6	1.10	0.97	2.2	0.67	0.9	10	0.75
	4.0	1.22	0.91	2.4	0.73	0.96	11	0.62
	4.2	1.28	0.86	2.6	0.79	0.99	12	0.75
	4.4	1.34	0.8	2.8	0.85	1	13	0.78
	4.6	1.40	0.71	5	1.52	1	14	0.75
	4.8	1.46	0.58	12	3.66	1	15	0.78
	4.9	1.49	0.47	13	3.96	0.11	16	0.85
	5.0	1.51	0.36	14	4.27	0.09	17	0.7
	5.0	1.52	0.16	15	4.57	0.07	18	0
	5.0	1.52	0	17	5.18	0.05	--	--
	--	--	--	19	5.79	0.03	--	--
	--	--	--	24	7.32	0.01	--	--
	--	--	--	28	8.53	0	--	--

Table 3. Roanoke Logperch HSC Table

Lifestage	Velocity (ft/s)	Velocity (cm/s)	Suitability Index	Depth (ft)	Depth (cm)	Suitability Index	Channel Index	Suitability Index
Adult	0.00	0	0.15	0.00	0	0.00	1	0.00
	0.33	10	0.15	0.33	10	0.00	2	0.00
	0.36	11	0.40	0.36	11	0.02	3	0.36
	0.66	20	0.40	0.66	20	0.02	4	1.00
	0.69	21	0.81	0.69	21	0.15	5	0.56
	0.98	30	0.81	0.98	30	0.15	6	0.56
	1.02	31	0.90	1.02	31	0.56	7	0.56
	1.31	40	0.90	1.31	40	0.56	8	0.00
	1.35	41	1.00	1.35	41	1.00	9	0.36
	1.64	50	1.00	1.64	50	1.00	10	1.00
	1.67	51	0.73	1.67	51	0.63	11	0.56
	1.97	60	0.73	1.97	60	0.63	12	1.00
	2.00	61	0.83	2.00	61	0.62	13	0.56
	2.30	70	0.83	2.30	70	0.62	14	1.00
	2.33	71	0.49	2.33	71	0.21	15	0.56
	--	--	--	--	--	--	16	0.36
	--	--	--	--	--	--	17	0.00
	--	--	--	--	--	--	18	0.00
Subadult	0.00	0	0.00	0.00	0.0	0.00	1	0.00
	0.03	1	0.00	0.49	15.0	0.00	2	1.00
	0.16	5	0.00	0.50	15.1	0.67	3	1.00
	0.17	5.1	1.00	0.98	30.0	0.67	4	0.64
	0.33	10	1.00	0.99	30.1	1.00	5	0.10
	0.36	11	0.17	1.64	50.0	1.00	6	0.10
	1.31	40	0.17	1.64	50.1	0.25	7	0.10
	1.35	41	0.24	--	--	--	8	0.00
	--	--	--	--	--	--	9	1.00
	--	--	--	--	--	--	10	0.64
	--	--	--	--	--	--	11	0.10
	--	--	--	--	--	--	12	0.64
	--	--	--	--	--	--	13	0.10

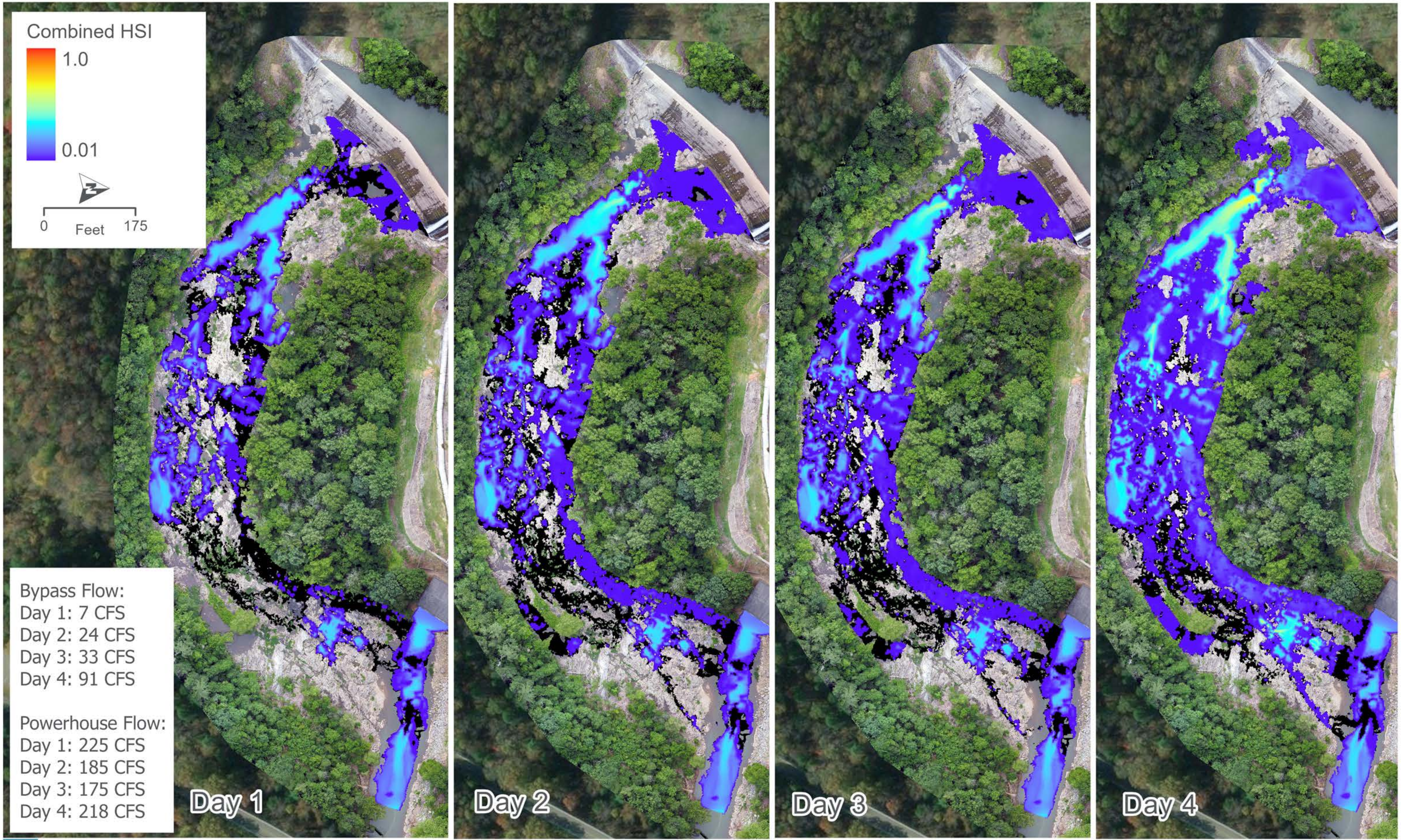
	--	--	--	--	--	--	14	0.64
	--	--	--	--	--	--	15	0.10
	--	--	--	--	--	--	16	1.00
	--	--	--	--	--	--	17	1.00
	--	--	--	--	--	--	18	0.00
Young of Year	0.00	0	0.27	0.00	0.0	0.06	1	0.00
	0.03	1	1.00	0.49	15.0	0.06	2	1.00
	0.16	5	1.00	0.50	15.1	1.00	3	1.00
	0.17	5.1	0.90	0.98	30.0	1.00	4	0.00
	0.33	10	0.90	0.99	30.1	0.00	5	0.00
	0.36	11	0.00	1.64	50.0	0.00	6	0.00
	1.31	40	0.00	1.64	50.1	0.00	7	0.00
	1.35	41	0.00	--	--	--	8	0.00
	--	--	--	--	--	--	9	1.00
	--	--	--	--	--	--	10	0.00
	--	--	--	--	--	--	11	0.00
	--	--	--	--	--	--	12	0.00
	--	--	--	--	--	--	13	0.00
	--	--	--	--	--	--	14	0.00
	--	--	--	--	--	--	15	0.00
	--	--	--	--	--	--	16	1.00
	--	--	--	--	--	--	17	1.00
	--	--	--	--	--	--	18	0.00

Table 3. Target Species Habitat and Suitability Criteria Source and Code Table

Species or Guild	Life Stage/ Category	Representative	Source Study	HSC Code
Roanoke Logperch	Adult	--	Anderson 2016 (Appendix B)	RLPA
	Subadult	--	Rosenberger and Angermeier 2003	RLPSA
	Young-of-Year	--	Rosenberger and Angermeier 2003	RLPYOY
Shallow-Slow Guild	Fine substrate no cover	Redbreast sunfish spawning	Smith Mountain Hydroelectric Project, Roanoke River, VA	RBSFS
	All substrate with aquatic vegetation	Silver redhorse Young of Year	Sutton Hydroelectric Project, Elk River, WV	SRHAV
	Coarse substrate	Generic shallow-slow guild	Sutton Hydroelectric Project, Elk River, WV	SHSLO
Shallow-Fast Guild	Moderate velocity with coarse substrate	Generic shallow-fast guild	Claytor Hydroelectric Project New River, VA	SHFST
Deep-Slow Guild	Cover	Redbreast sunfish Adult	Smith Mountain Hydroelectric Project, Roanoke River, VA	RBSFA
	No cover	Generic deep-slow guild	Sutton Hydroelectric Project, Elk River, WV	DSLON
Deep-Fast Guild	Slightly weighted for fine substrate, Cover	Silver redhorse adult	Smith Mountain Hydroelectric Project, Roanoke River, VA	SRHAD
	Coarse-mixed substrate	Shorthead redhorse adult	Smith Mountain Hydroelectric Project, Roanoke River, VA	SHRHA

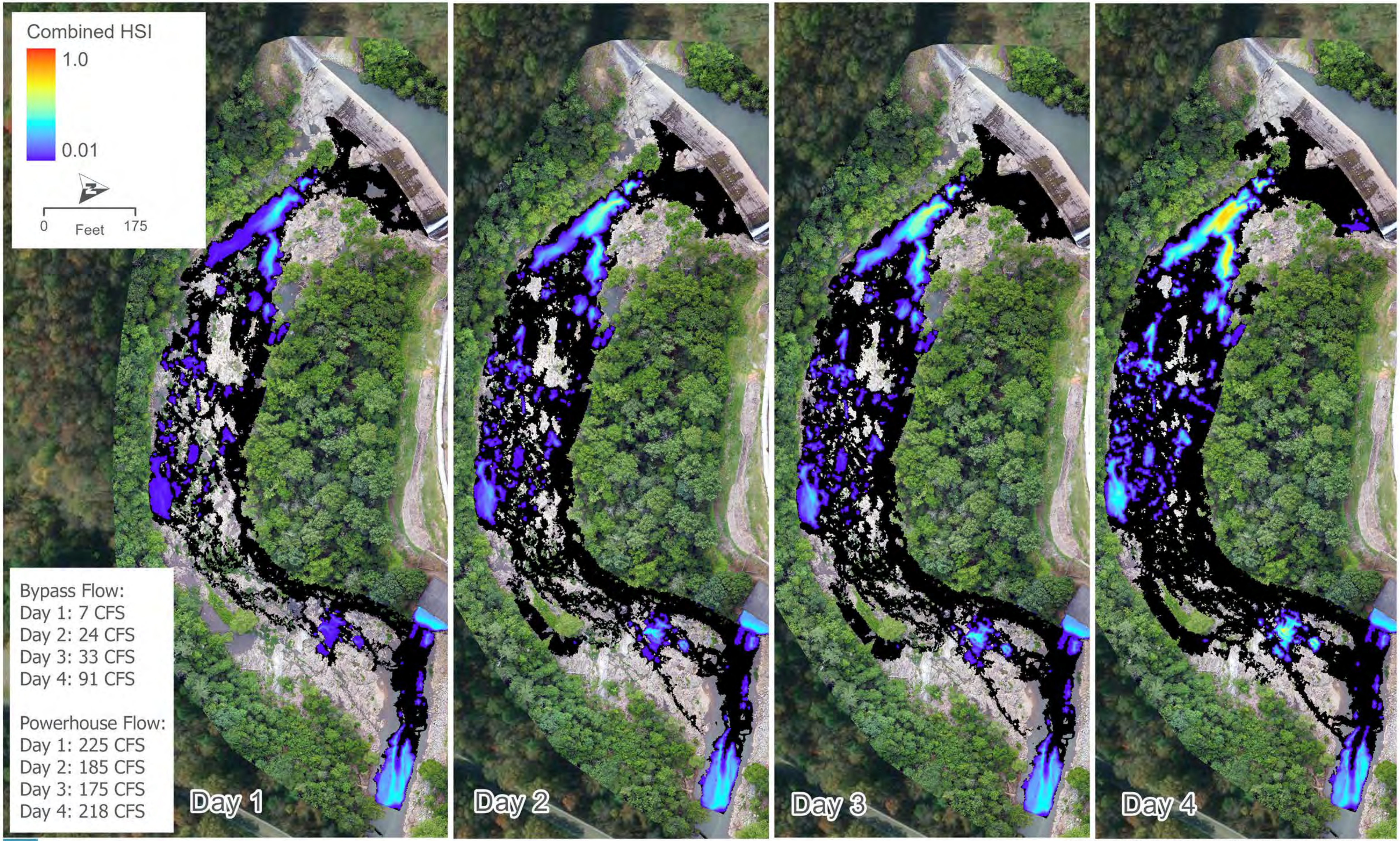
Attachment 3

Attachment 3 – Modeling Results



DEEP-FAST GUILD HABITAT SUITABILITY MAP

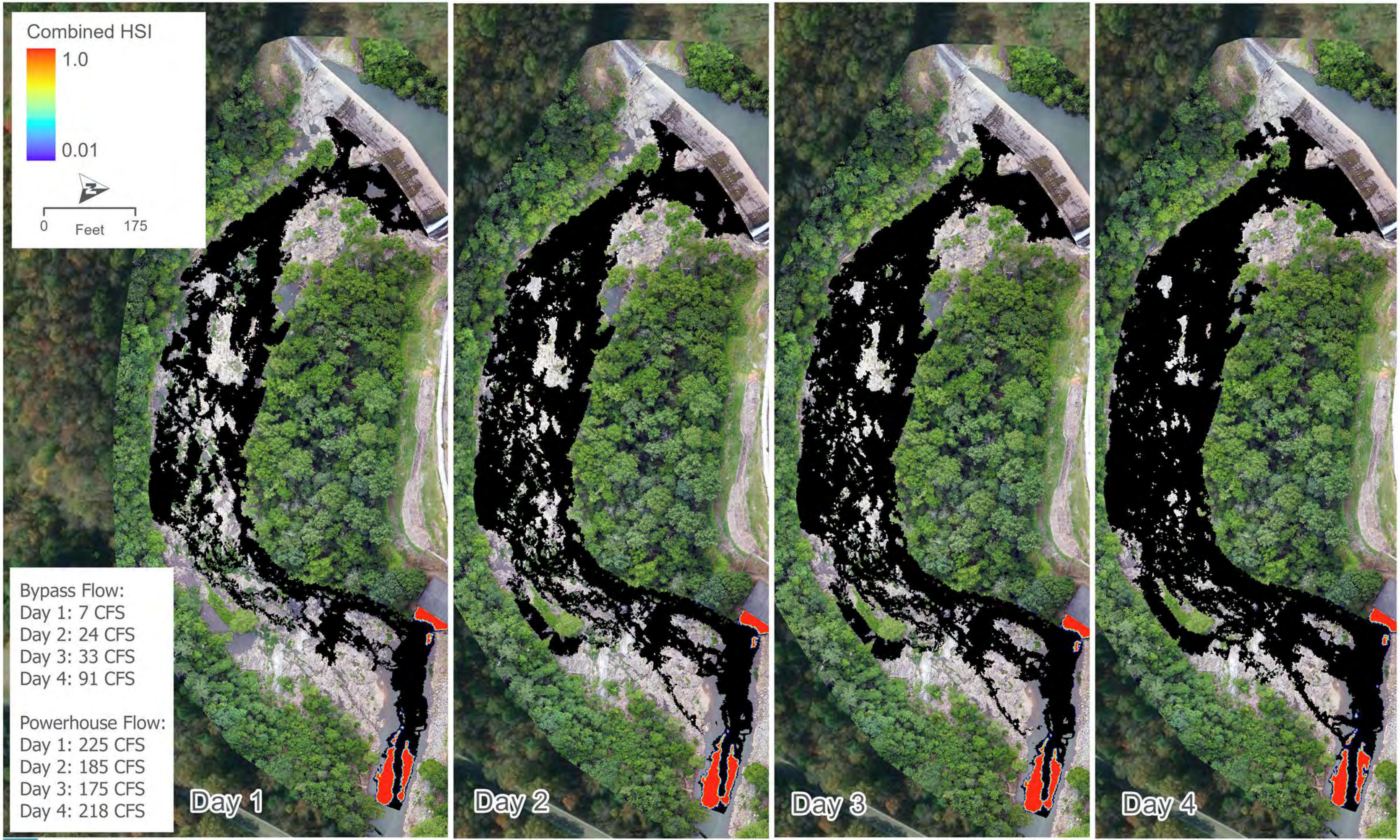
CATEGORY: COARSE-MIXED SUBSTRATE



DEEP-FAST GUILD HABITAT SUITABILITY MAP

CATEGORY: SLIGHTLY WEIGHTED FOR FINE SUBSTRATE, COVER

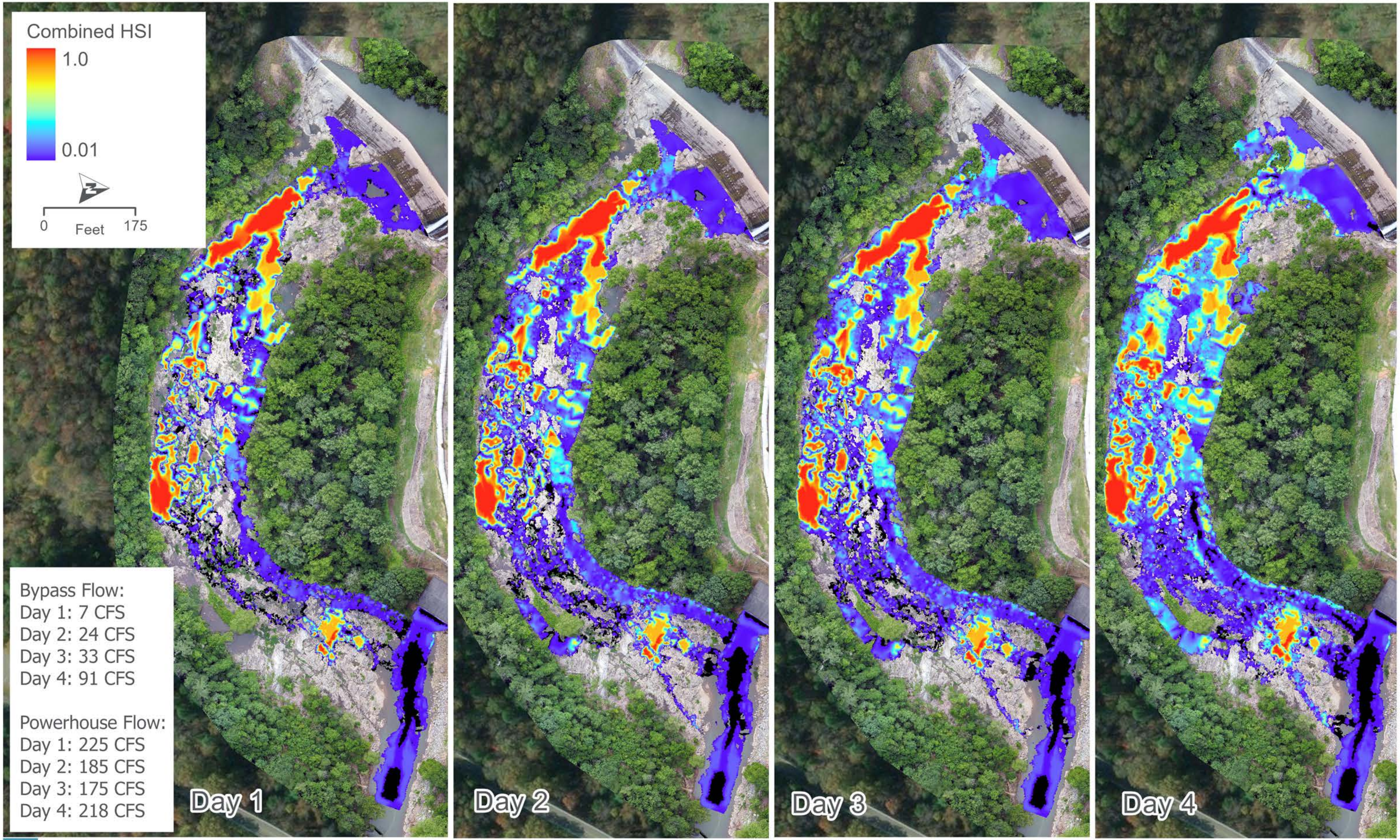
PATH: F:\AEP\RELICENSING_2D_MODELS\NIAGARA\HABITAT\NIAGARA_HABITAT_MAPS.APRX - USER: JDVORAK - DATE: 2/8/2022



HDR AMERICAN ELECTRIC POWER

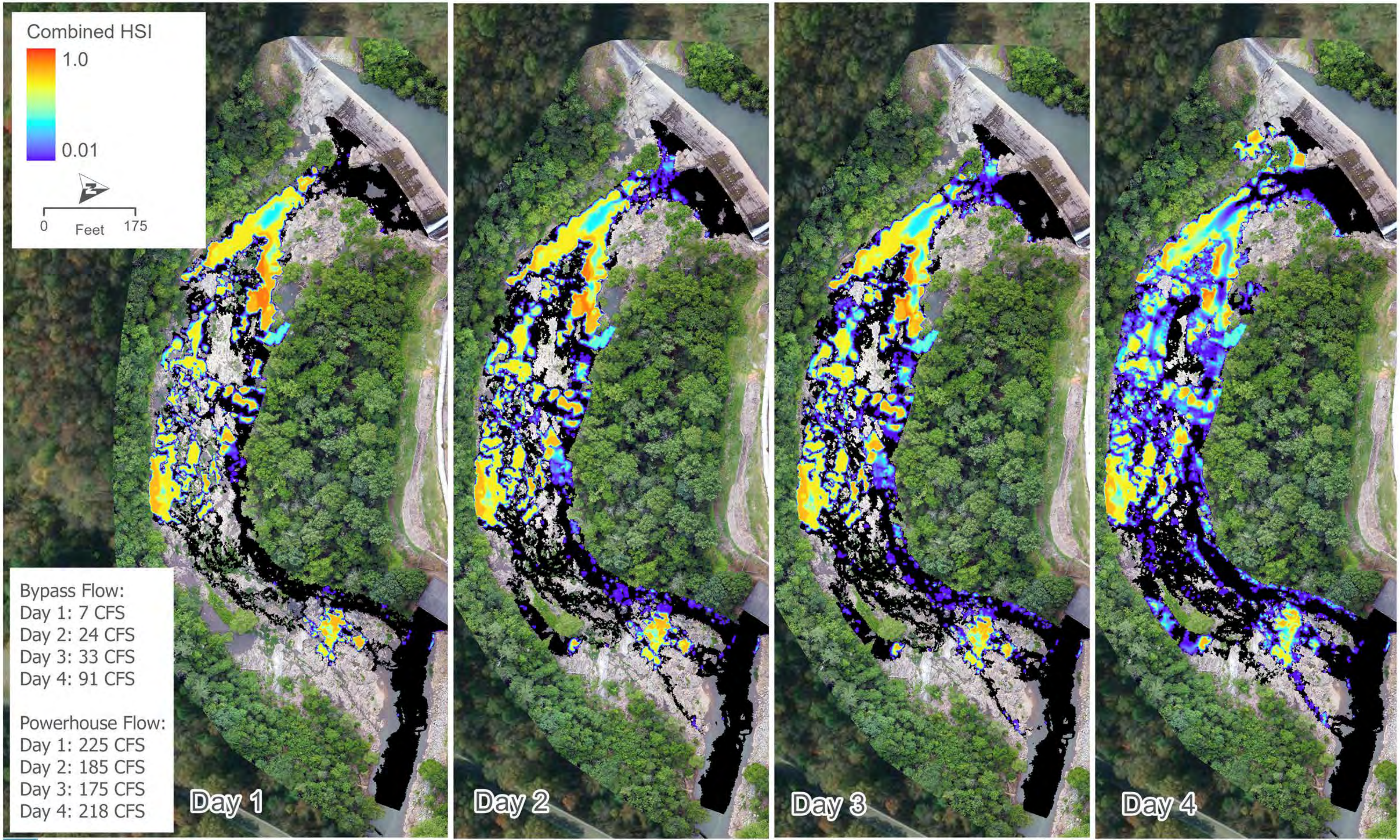
DEEP-SLOW GUILD HABITAT SUITABILITY MAP

CATEGORY: COVER



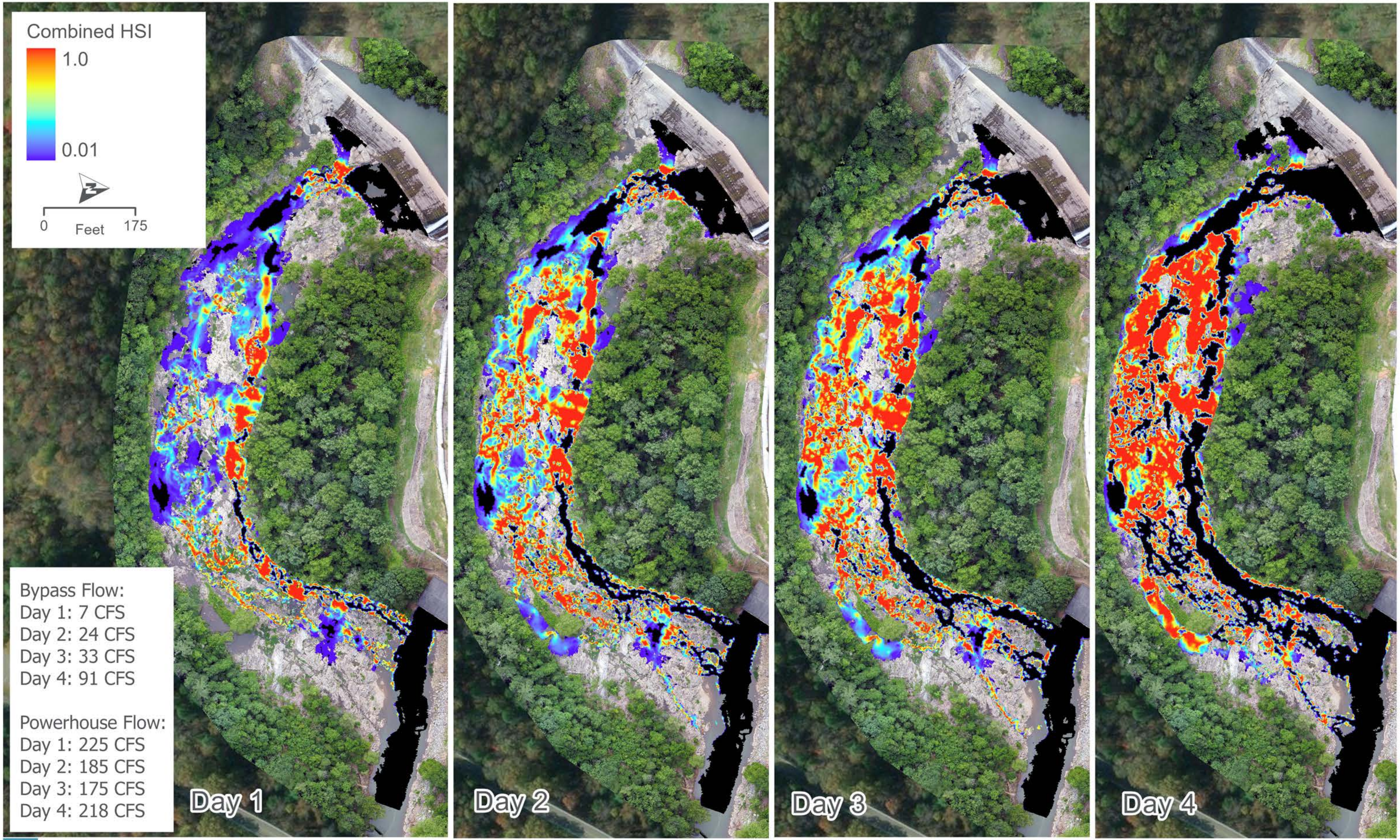
DEEP-SLOW GUILD HABITAT SUITABILITY MAP

CATEGORY: COVER



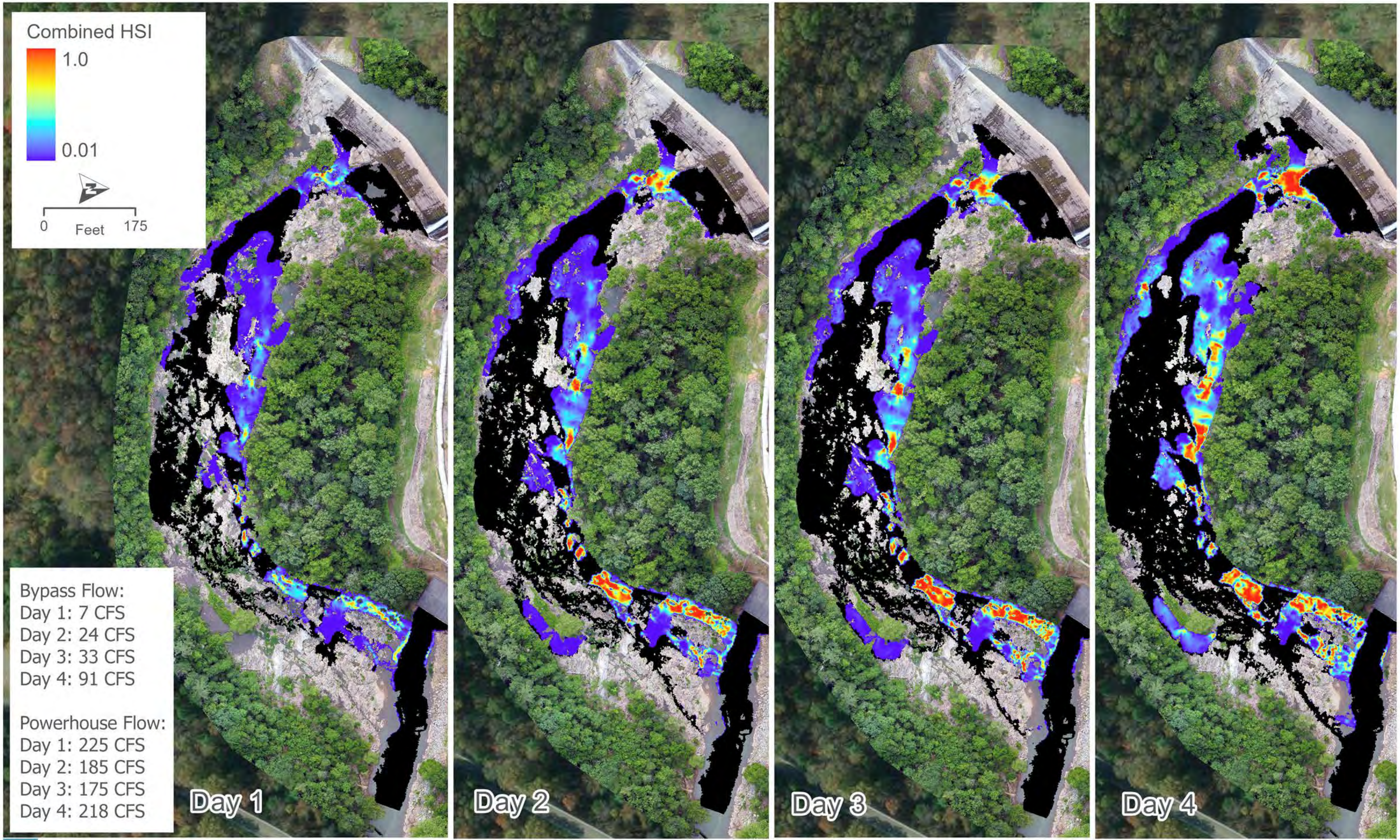
SHALLOW-SLOW GUILD HABITAT SUITABILITY MAP

CATEGORY: FINE SUBSTRATE, NO COVER



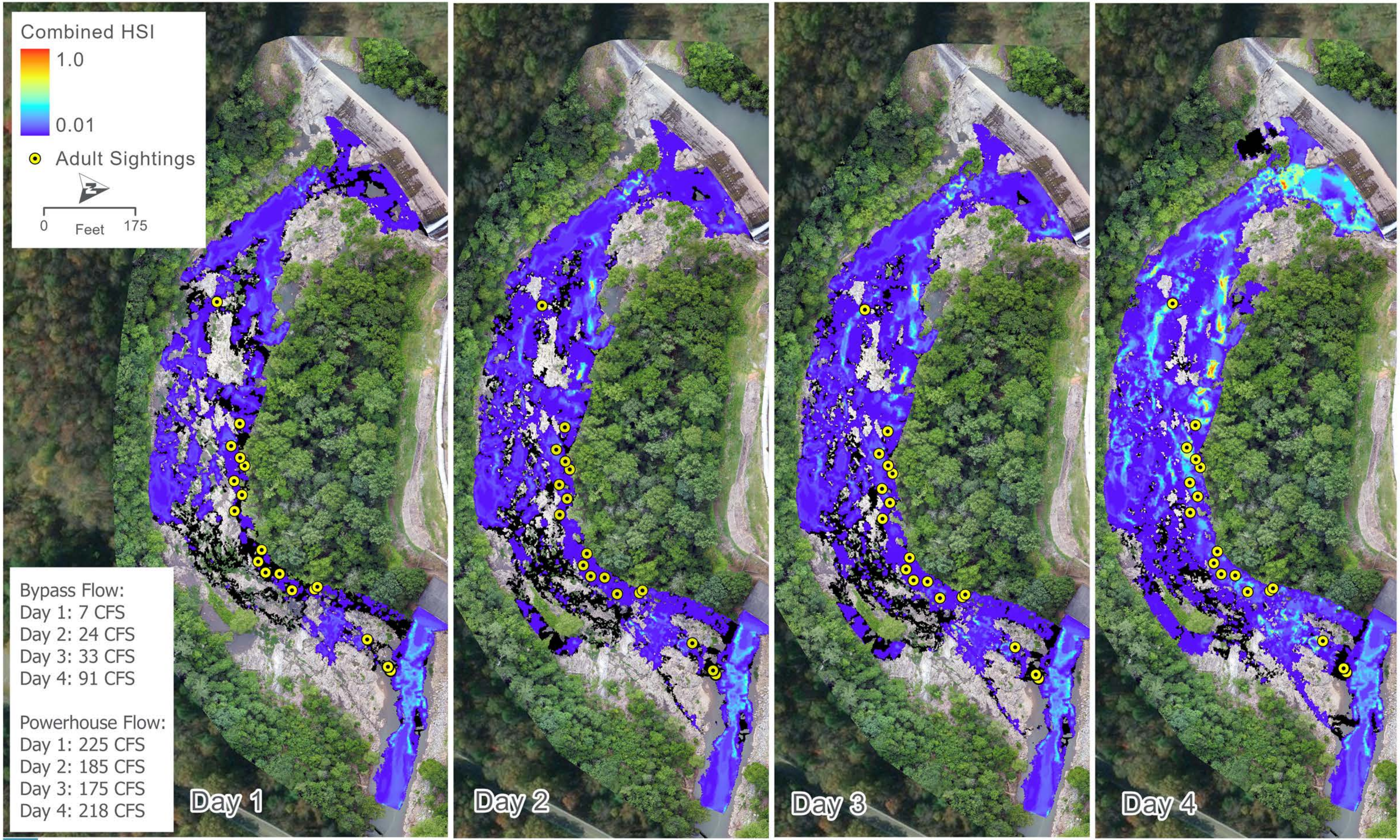
GENERIC SHALLOW-SLOW GUILD HABITAT SUITABILITY MAP

CATEGORY: COARSE SUBSTRATE



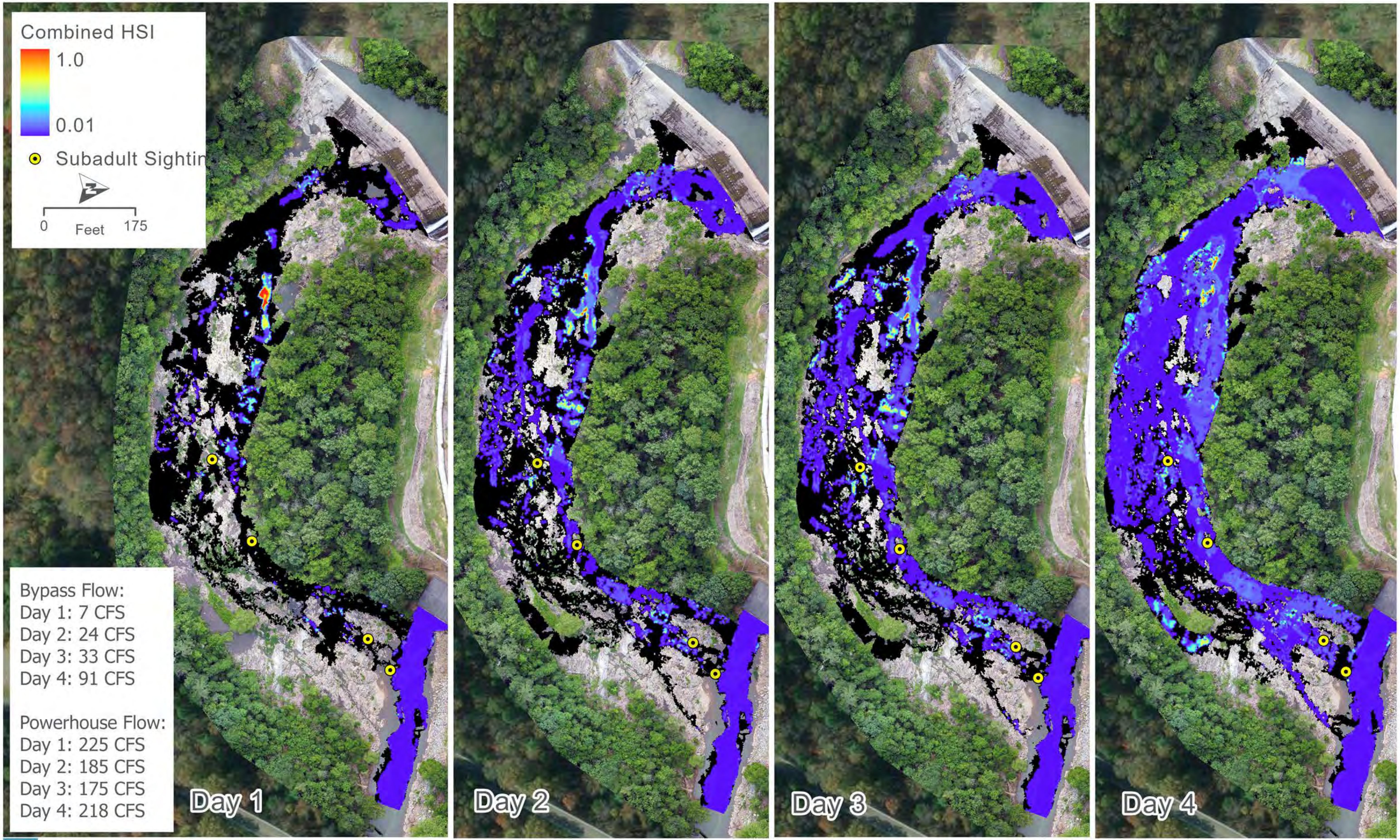
SHALLOW-FAST GUILD HABITAT SUITABILITY MAP

CATEGORY: MODERATE VELOCITY WITH COARSE SUBSTRATE



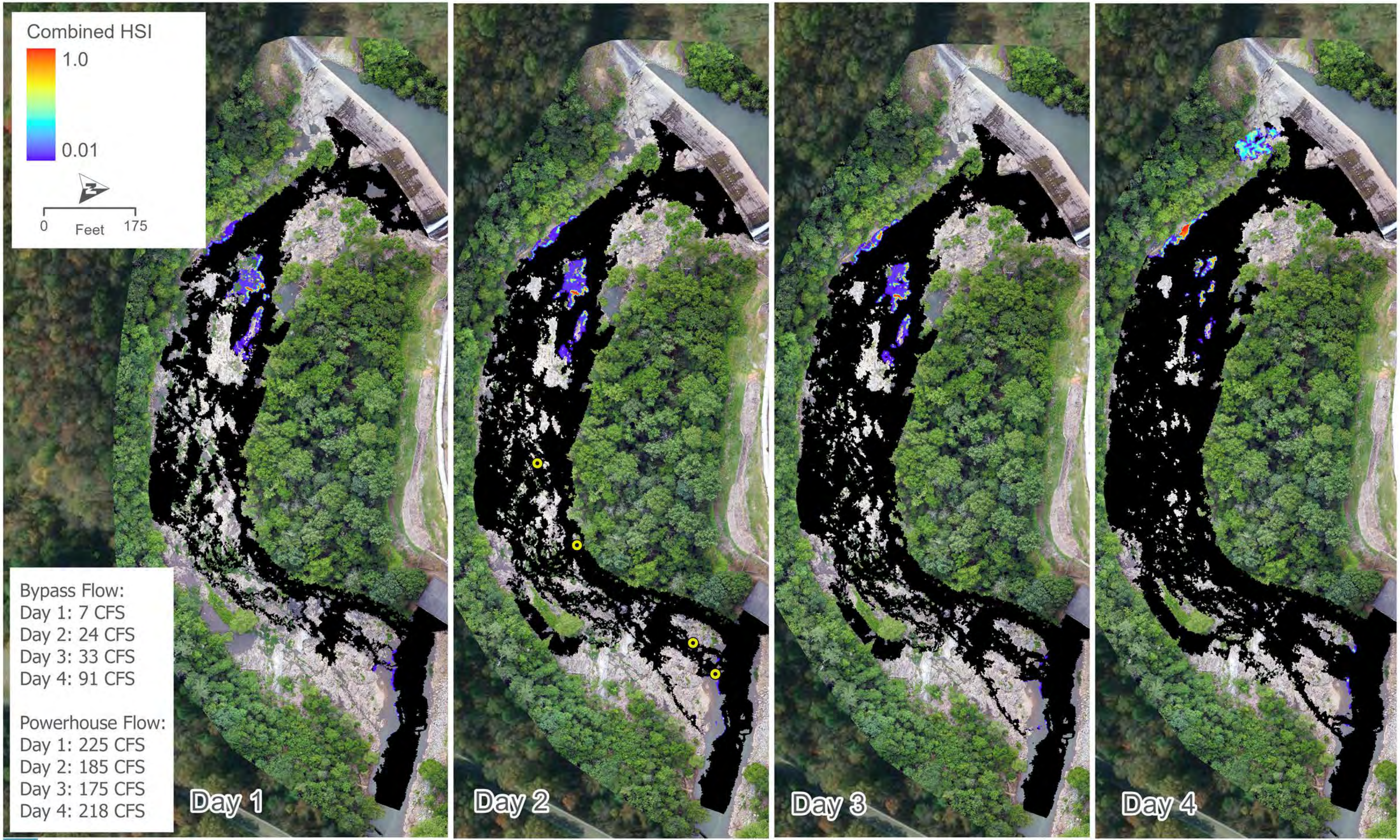
ROANOKE LOGPERCH HABITAT SUITABILITY MAP

LIFESTAGE: ADULT



ROANOKE LOGPERCH HABITAT SUITABILITY MAP

LIFESTAGE: SUBADULT

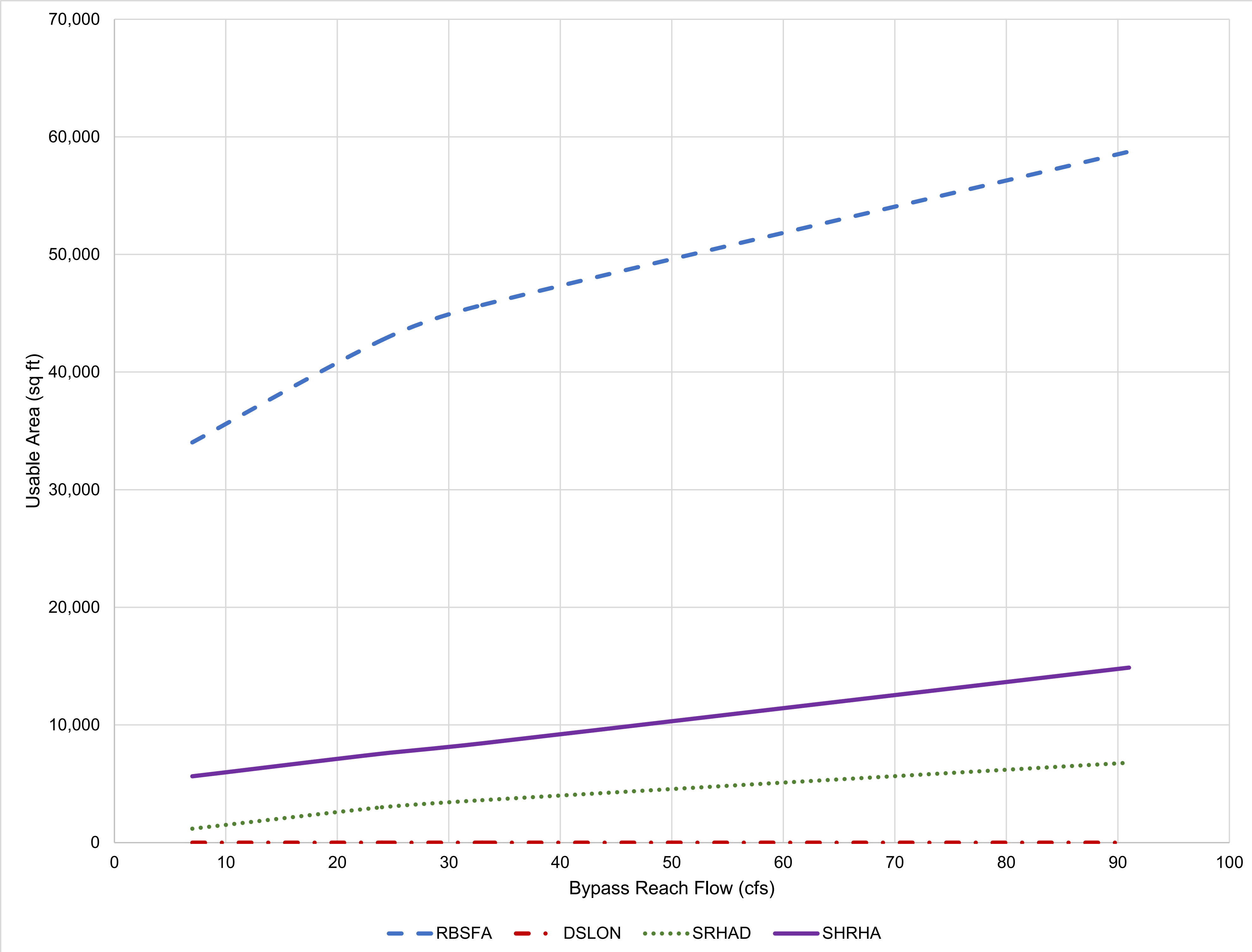


ROANOKE LOGPERCH HABITAT SUITABILITY MAP

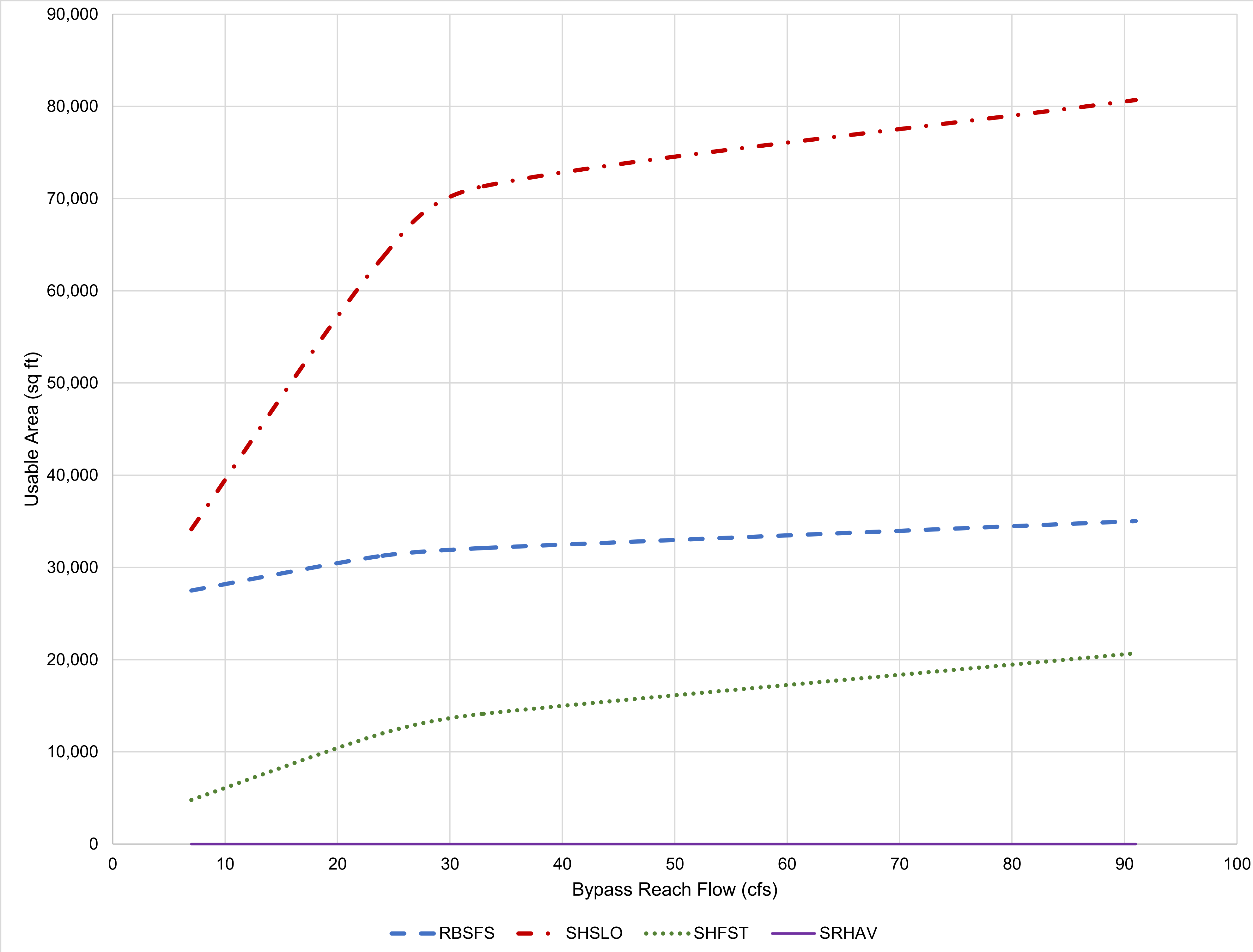
LIFESTAGE: YOUNG-OF-YEAR

Attachment 4

Attachment 4 – Useable Area Figures and Table



70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Usable Area (sq ft)
0
10
20
30
40
50
60
70
80
90
100
Bypass Reach Flow (cfs)
RBSFA
DSLON
SRHAD
SHRHA



90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
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Usable Area (sq ft)
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Bypass Reach Flow (cfs)
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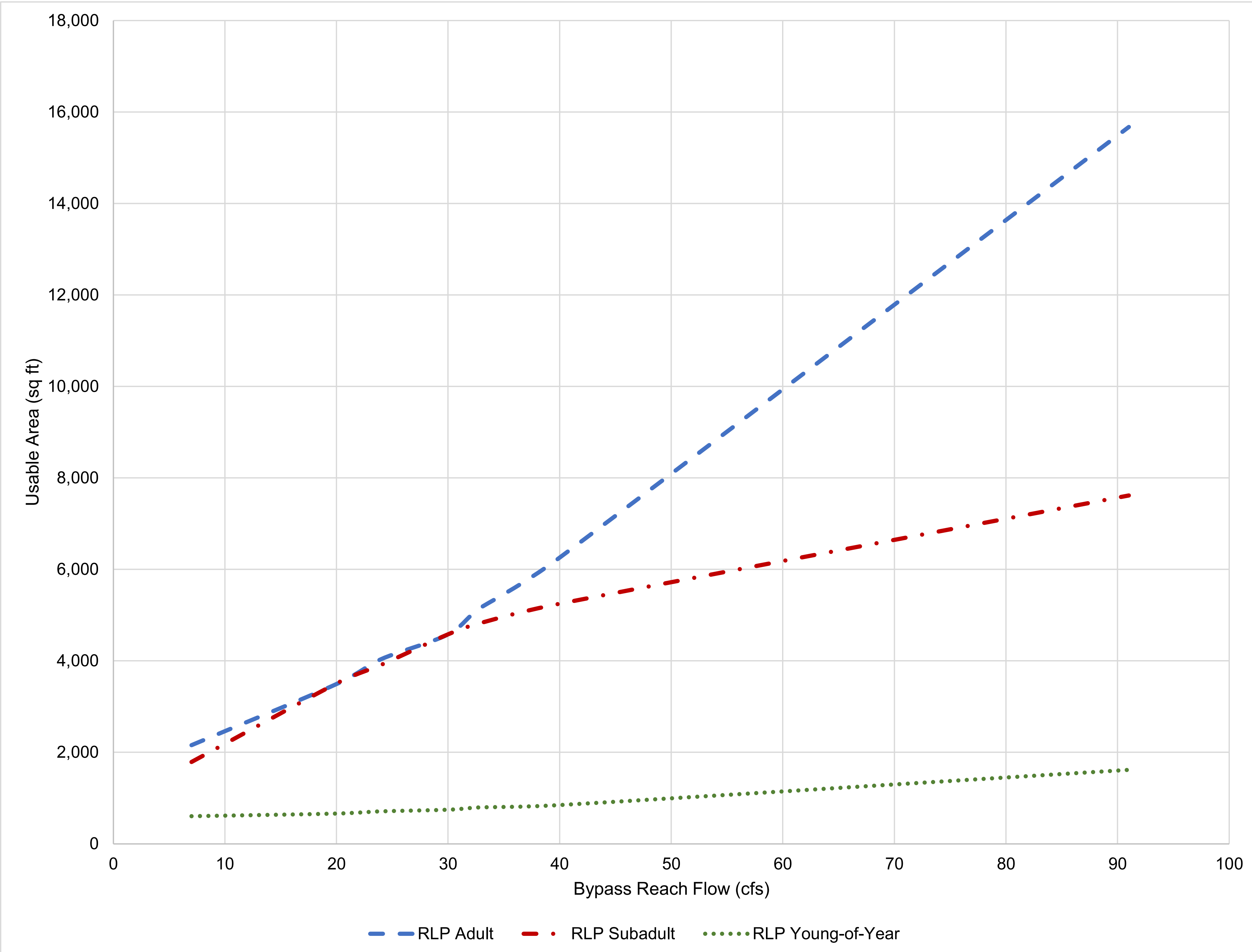
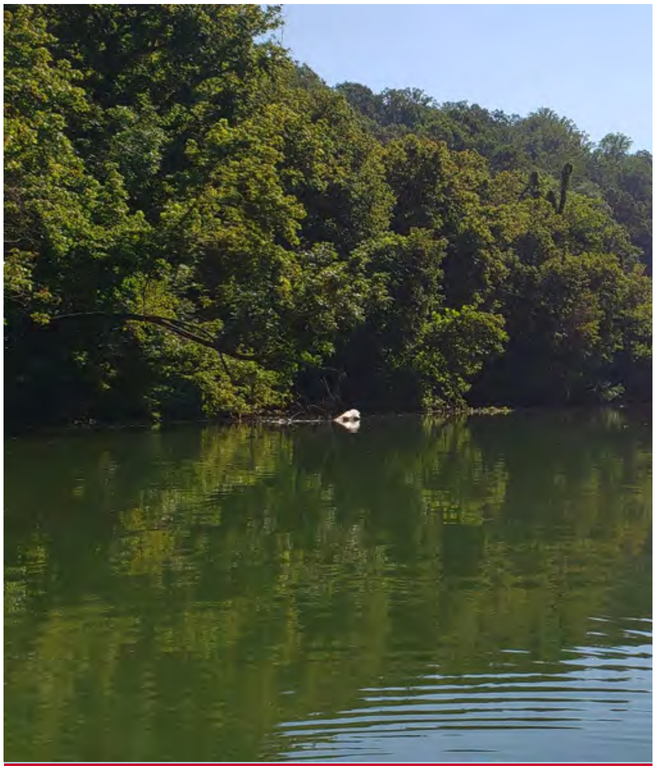
SHSLO
SHFST
SRHAV


18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Usable Area (sq ft)
0
10
20
30
40
50
60
70
80
90
100
Bypass Reach Flow (cfs)
RLP Adult
RLP Subadult
RLP Young-of-Year

Niagara Bypass Reach Aquatic Habitat Modeling Results											
Bypass Flow (cfs)	Roanoke Logperch Usable Area (sq ft)			Shallow Guilds Usable Area (sq ft)				Deep Guilds Usable Area (sq ft)			
	Adult	Subadult	YOY	RBSFS	SRHAV	SHSLO	SHFST	RBSFA	DSLON	SRHAD	SHRHA
7	2,160	1,791	604	27,513	0	34,153	4,799	34,029	0	1,177	5,633
20	3,493	3,507	665	--	--	--	--	--	--	--	--
24	4,037	3,913	711	31,276	0	63,612	12,009	42,730	0	2,998	7,568
30	4,582	4,582	746	--	--	--	--	--	--	--	--
33	5,176	4,833	799	32,105	0	71,360	14,135	45,715	0	3,611	8,445
40	6,261	5,252	847	--	--	--	--	--	--	--	--
91	15,673	7,617	1,619	35,023	0	80,700	20,708	58,754	0	6,795	14,868



Appendix B - Water Quality Study Report

Niagara Hydroelectric Project (FERC No. 2466)

February 28, 2022

Prepared by:

Prepared for:

Appalachian Power Company

Contents

Tables

Figures

Attachments

Acronyms and Abbreviations

°C	degrees Celsius
AEP	American Electric Power
Appalachian or Licensee	Appalachian Power Company
DO	dissolved oxygen
CFR	Code of Federal Regulations
cfs	cubic feet per second
CWA	Clean Water Act
FERC or Commission	Federal Energy Regulatory Commission
ft	feet/foot
mg/l	milligrams per liter
Hydrolab	Hach Hydrolab® MS5
ILP	Integrated Licensing Process
ISR	Initial Study Report
PAD	Pre-Application Document
PM&E	protection, mitigation, and enhancement
Project	Niagara Hydroelectric Project
RSP	Revised Study Plan
SPD	Study Plan Determination
TMDL	total maximum daily load
USGS	U.S. Geological Survey
VAC	Virginia Administrative Code
VDEQ	Virginia Department of Environmental Quality
μS/cm	microsiemens per centimeter

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1 Project Introduction and Background

Appalachian Power Company (Appalachian or Licensee), a unit of American Electric Power (AEP) is the Licensee, owner, and operator of the 2.4-megawatt run-of-river Niagara Hydroelectric Project (Project) (Project No. 2466), located on the Roanoke River (River Mile 355) in Roanoke County, Virginia.

The Project is currently licensed by the Federal Energy Regulatory Commission (FERC or Commission) under the authority granted to FERC by Congress through the Federal Power Act, 16 United States Code §791(a), et seq., to license and oversee the operation of non-federal hydroelectric projects on jurisdictional waters and/or federal land. The Project underwent relicensing in the early 1990s, and the current operating license for the Project expires on February 29, 2024. Accordingly, Appalachian is pursuing a subsequent license for the Project pursuant to the Commission's Integrated Licensing Process (ILP), as described at 18 Code of Federal Regulations (CFR) Part 5. In accordance with FERC's regulations at 18 CFR §16.9(b), the licensee must file its final application for a new license with FERC no later than February 28, 2022.

In accordance with 18 CFR §5.11 of the Commission's regulations, Appalachian developed a Revised Study Plan (RSP) for the Project that was filed with the Commission and made available to stakeholders on November 6, 2019. The Commission issued the Study Plan Determination (SPD) on December 6, 2019.

On July 27, 2020, Appalachian filed an updated ILP study schedule and a request for extension of time to file the Initial Study Report (ISR) to account for Project delays resulting from the COVID-19 pandemic. The request was approved by FERC on August 10, 2020, and the filing deadline for the ISR for the Project was extended from November 17, 2020 to January 11, 2021. Appalachian conducted a virtual ISR Meeting on January 21, 2021 and filed the ISR Meeting summary with the Commission on February 5, 2021. Stakeholders provided written comments in response the Appalachian's filling of the ISR meeting summary; these comments were addressed in the Updated Study Report (USR), which was filed December 6, 2021. A USR meeting was held on December 14, 2021 and requests from stakeholders made during the meeting are addressed in this revised USR.

Appalachian has conducted studies in accordance with 18 CFR §5.15, as provided in the RSP and as subsequently modified by FERC. This USR describes the methods and results of the Water Quality Study conducted in support of preparing an application for new license for the Project.

2 Study Goals and Objectives

The goals and objectives of the Water Quality Study are to:

- Gather baseline water quality data sufficient to determine consistency of existing Project operations with applicable Virginia state water quality standards and designated uses (Virginia Administrative Code [VAC] Chapter 260).
- Provide data (temperature and dissolved oxygen [DO] concentration) to determine the presence and extent, if any, of temperature or DO stratification in the Niagara impoundment.

- Provide data to support a Virginia Water Protection Permit application (Clean Water Act [CWA] Section 401 Certification).
- Provide information to support evaluation of whether additional or modified protection, mitigation, and enhancement (PM&E) measures may be appropriate for the protection of water quality at the Project.

3 Study Area

The study area for the Water Quality Study includes the Roanoke River within and immediately upstream and downstream of the Niagara Project boundary as shown on Figure 3-1. Appalachian's consultant, HDR Engineering, Inc. (HDR) established eight water quality monitoring locations for approximately three months in 2020:

- One location in the free-flowing section of river upstream of the reservoir and confluence with Tinker Creek;
- One location in Tinker Creek;
- One location in the reservoir downstream of the confluence with Tinker Creek;
- Two locations in the forebay area (one near surface and the other near bottom);
- One location in the tailrace below the powerhouse; and
- Two locations in the bypass reach (upstream location and downstream location).

During the 2020 water quality monitoring period, flows in the bypass reach were higher than normal due to higher than normal Project inflows, damage to the sluice gate hoist operating system, and a powerhouse outage which began on September 8, 2020 and lasted through the end of the study period. While water quality data collected in the bypass reach met Virginia Class IV standards during the 2020 study period, it was recommended that two continuous temperature and DO sondes be re-installed in the bypass reach during the warmest portion of the year in 2021 (i.e., July through October) to record daily fluctuations in temperature and DO under a more typical bypass flow regime. In addition, water quality data (temperature, DO, pH, and specific conductivity) recorded at both the Thirteenth Street Bridge U.S. Geological Survey (USGS) gage (USGS 02055080) and USGS gage at Tinker Creek above Glade Creek (USGS 0205551614) are included in the 2021 water quality monitoring reporting. As a result, during 2021, water quality monitoring was conducted at four monitoring locations by HDR and also reported from the two USGS gages mentioned previously from July through October 2021:

- One location on the Roanoke River at the Thirteenth Street Bridge (USGS 02055080; continuous monitoring) (data collection by others);
- One location at Tinker Creek above Glade Creek (USGS 0205551614; continuous monitoring) (data collection by others);
- One location in the forebay area (i.e., discrete vertical profile data);
- One location in the tailrace below the powerhouse (continuous monitoring); and
- Two locations in the bypass reach: upstream location and downstream location (continuous monitoring).

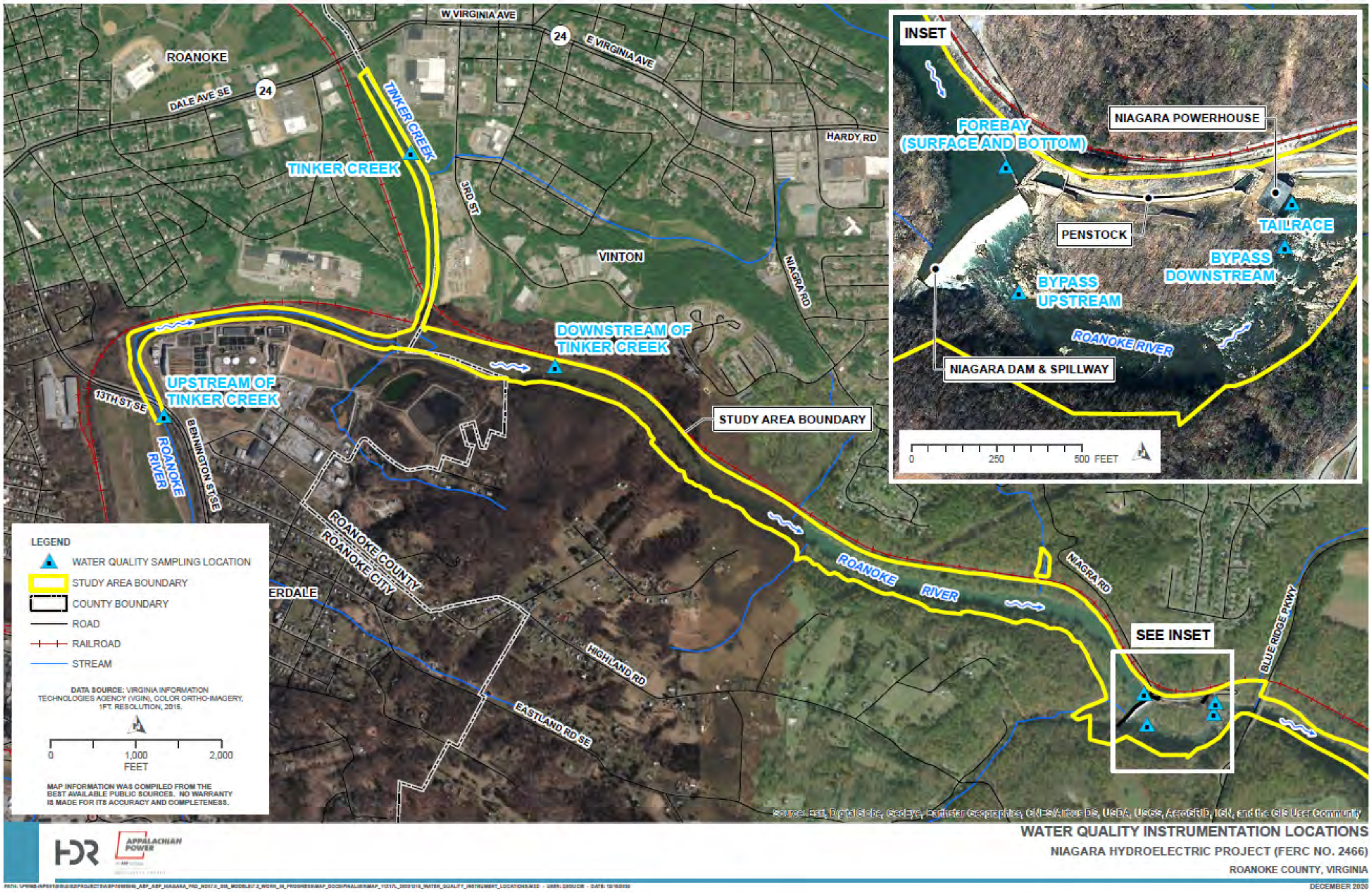

Figure 3-1. Water Quality Study Monitoring Locations

4 Background and Existing Information

Existing relevant and reasonably available information regarding water quality in the Project vicinity was presented in Section 5.3 of the Niagara Pre-Application Document (PAD) (Appalachian 2019). The PAD includes historical water quality data collected by the USGS and the Virginia Department of Environmental Quality (VDEQ) upstream and downstream of the study area. Temperature, DO, pH, and specific conductivity data indicate that inflows to and outflows from the Project meet numeric water quality standards (9VAC25-260-50) required to support designated uses identified at 9VAC25-260-10.

The VDEQ is responsible for carrying out the mandates of the State Water Control Law as well as meeting federal obligations under the CWA (VDEQ 2017a). Waters in the Roanoke River Basin are classified in 9VAC25-260-450. The Roanoke River is designated as Class IV (Mountainous Zone) waters. Tinker Creek is designated as Class VII (Swamp Waters). Numerical criteria for DO, pH, and water temperature for Class IV and VII waters are identified in 9VAC25-260-50 and are summarized in Table 4-1.

Table 4-1. Numeric Water Quality Criteria for Class IV and VII Waters

Parameter	Class IV Standard (Roanoke River)	Class VII (Tinker Creek)
Minimum Instantaneous DO* **	4.0 milligram per liter (mg/l)	*
Daily Average DO	5.0 mg/l	*
pH	6.0 – 9.0	3.7-8.0*
Maximum water temperature	31 degrees Celsius (ºC)	**

*This classification recognizes that the natural quality of these waters may fluctuate outside of the values for DO and pH set forth above as water quality criteria in Class I through VI waters. The natural quality of these waters is the water quality found or expected in the absence of human-induced pollution. Water quality standards will not be considered violated when conditions are determined by the VDEQ to be natural and not due to human-induced sources. The State Water Control Board may develop site specific criteria for Class VII waters that reflect the natural quality of the waterbody when the evidence is sufficient to demonstrate that the site-specific criteria rather than narrative criterion will fully protect aquatic life uses. Virginia Pollutant Discharge Elimination System limitations in Class VII waters shall not cause significant changes to the naturally occurring dissolved oxygen and pH fluctuations in these waters.
** Maximum temperature will be the same as that for Classes I through VI waters as appropriate.
Note: mg/l = milligrams per liter
***The water quality criteria in this section do not apply below the lowest flow averaged (arithmetic mean) over a period of seven consecutive days that can be statistically expected to occur once every 10 climatic years (a climatic year begins April 1 and ends March 31). Site-specific adjustments to these criteria are defined by 9VAC25-260-310 and 9VAC25-260-380 through 9VAC25-260-540.

Due to factors unrelated to Project operations, multiple reaches within the Project boundary were listed as impaired in the 2018 §305(b)/303(d) Water Quality Assessment Integrated Report, including fish consumption advisories (VDEQ 2019). However, the source of impairment is not associated with the Project and it is expected that continued operation of the Project will have no effect on whether these reaches continue to be listed as impaired. Potential sources for water quality impairment include discharges from an upstream wastewater treatment plant, municipal separate storm sewer systems, industrial point source discharge, landfills, municipal areas, individual private treatment systems, sanitary sewer outflows, and wildlife (VDEQ 2019).

Total maximum daily loads (TMDLs) for aquatic life (benthic) use, polychlorinated biphenyls, and bacteria have been developed for the Roanoke River (Berger 2006; Tetra Tech, Inc. 2009; GMU & Berger 2006).

According to the benthic TMDL prepared for the upper Roanoke River (Berger 2006), sediment has been identified as the most probable stressor impacting benthic macroinvertebrates in the biologically impaired segments of the Roanoke River. Excessive sediment loading can negatively impact benthic macroinvertebrates through siltation of habitat, water quality degradation (e.g., decreased light, temperature, and DO concentrations) due to excess sediment in the water column, and bringing invertebrates into contact with other pollutants that enter surface water via adhesion to sediment particles. Potential sources of sediment loading in the watershed include urban stormwater runoff, streambank erosion, and sediment loss from habitat degradation associated with urbanization.

In late July 2017, approximately 165 gallons of Termix 5301, a type of surfactant that is added to herbicide and pesticide products before application, was spilled into Tinker Creek in Cloverdale, Virginia, upstream of the Project. The resulting fish kill was estimated at tens of thousands of fish in Tinker Creek. The fish kill occurred outside of the Project boundary, and no effects have been identified in the mainstem of the Roanoke River (VDEQ 2017b).

5 Methodology

5.1 Data Collection

Continuous temperature and DO monitoring as well as discrete multiparameter water quality sampling were carried out at locations within the study area. Vertical profile data was also collected at the reservoir and forebay monitoring locations (Figure 3-1).

During the initial deployment and subsequent download events, discrete multi-parameter water quality measurements (i.e. spot measurements) of temperature, DO concentration, pH, and specific conductivity were collected at each monitoring location using a Hach Hydrolab® MS5 (Hydrolab). For riverine monitoring locations, Hydrolab water quality data was collected at one location within the water column at a depth similar to the sondes. Profile measurements were collected at 1.0-foot (ft) vertical intervals using the Hydrolab for the two reservoir monitoring locations to record temperature and DO values throughout the water column at the time of the data sonde downloads.

Calibrated Onset® HOBO U26 DO/Temperature Loggers (i.e. sondes) were deployed for continuous in situ measurements and were set to record water temperature and DO at 15-minute intervals. During the 2020 study period, continuous data was collected from July 29 through November 10 and the data sondes were downloaded five times (August 12 and 26, September 22-23, October 21, and November 9-10, 2020). At each of the eight continuous monitoring locations, two data sondes were deployed to provide redundancy. In the forebay, one sonde was deployed near the water surface and a second was deployed near the reservoir bottom to capture temperature and DO stratification. The download schedule was accelerated from monthly to bi-weekly when possible to reduce effects associated with biofouling, which was greater than anticipated at the time of the RSP development. During the 2021 study period, continuous data was collected from June 29 through October 27. At each of the three continuous monitoring locations installed by HDR (i.e., bypass reach upstream, bypass reach downstream, and tailrace), two data sondes were deployed to provide redundancy. The download schedule was roughly every two to three weeks, and the data sondes were downloaded seven times over the monitoring period.

5.2 Data Analysis and Processing

Upon completion of the field data collection effort, data was checked for errors and omissions. Data that more closely matched the discrete measurement readings made in the field during download events were preferentially reported and analyzed for each monitoring location. Note there are several data gaps that occurred during the field data collection period that were the result of biofouling, equipment malfunction, and/or equipment theft. These data gaps did not affect the overall summary results and conclusions of this study report.

Real-time flow data (15-minute) was obtained from the USGS Roanoke River at Niagara Gage (USGS 02056000), which is approximately 500 ft downstream of the Niagara powerhouse and includes the combined flows from the powerhouse and bypass reach. Flows have been recorded since October 1990 at the USGS Roanoke River at Niagara gage and corresponding stage from October 2007 to present.

5.3 Equipment Calibration and Quality Assurance

Prior to the first deployment, Onset HOBO® Model U26 DO/Temperature Loggers were initialized with a new DO sensor cap and calibrated. The Hydrolab multi-parameter water quality sonde was lab calibrated by the manufacturer. Prior to each instantaneous sample collection, the Hydrolab was checked against a suite of standards. A Hydrolab® Surveyor 4a (Surveyor) is the handheld display that connects to the Hydrolab sonde for attended monitoring applications. The Surveyor was sent to the manufacturer for calibration prior to the field deployment. The water quality sensor specifications as specified by the manufacturer are presented in Table 5-1.

Table 5-1. Water Quality Sensor Specifications

Water Quality Sensor Accuracy		
Sensor	Hydrolab® MS5[2]	Onset HOBO® Model U26[3]
Temperature	+/- 0.1°C	+/- 0.2°C
DO[1]	+/- 0.1 mg/l for 0 – 8 mg/l; +/- 0.2 mg/l for greater than 8 mg/l	+/- 0.2 mg/l for 0.0 – 8.0 mg/l; +/- 0.5 mg/l for greater than 8.0 mg/l
Specific conductivity	+/- 0.5 % of reading; +/- 0.001 millisiemens/centimeter	N/A
pH	+/- 0.2 units	N/A

Note:
[1] Hach LDO® - Luminescent Dissolved Oxygen sensor or Onset RDO ® - Rugged Dissolved Oxygen. Both use light to optically measure dissolved oxygen.
[2] Specifications for the Hydrolab® MS5: https://s.campbellsci.com/documents/ca/product-brochures/series_5_br.pdf
[3] Specifications for the Onset HOBO® Model U26: https://www.onsetcomp.com/products/data-loggers/u26-001/

6 Study Results

6.1 Water Temperature

Figure 1-1 and Figure 1-2 in Attachment 1 provide continuous and discrete water temperature data at all water quality locations for 2020 and 2021, respectively. At the time of initial data sonde deployment on July 28-29, 2020, water temperatures were in the 23.5 – 27.4ºC range at the Roanoke River monitoring locations and in the 20 – 25ºC range at the Tinker Creek monitoring location. Water temperatures recorded at the USGS 02055080 (Roanoke River at the Thirteenth Street Bridge in Roanoke) water quality monitoring station (immediately upstream of the reservoir) peaked at 28.7ºC on July 20, 2020; approximately one week prior to initial deployment of the data sondes. Water temperatures generally decreased during the 2020 study period and dropped to approximately 10ºC by early November 2020. Tinker Creek water temperatures were several degrees cooler and exhibited larger daily fluctuations compared to the Roanoke River monitoring locations. The Tinker Creek monitoring location is heavily canopied which may contribute to the cooler temperatures, and the drainage area is relatively small[1] which may contribute to the larger daily fluctuations.

Water temperature measurements during July and August 2021 were slightly higher than during 2020 at all monitoring locations with daily peaks in the 22 – 30ºC range. The diurnal variation in temperature fluctuation at the two bypass reach monitoring locations in 2021 was also greater than 2020. The higher water temperatures and greater diurnal variation in water temperatures were likely the result of lower Project inflows during 2021, particularly in the bypass reach. While 2021 water temperatures were generally higher than in 2020, water temperatures for both years were less than the state maximum water temperature limit of 31ºC.

All discrete temperature data for 2020 and 2021 are included in Tables 2-1 and 2-2 (Attachment 2). Water temperature vertical profile plots for the forebay are presented on Figure 3-1 and 3-2 (Attachment 3). Vertical profile temperature plots for the reservoir are shown on Figure 3-7 (Attachment 3) and vertical profile data are included in Tables 2-3 through 2-6 (Attachment 2). While water temperature varied seasonally, there was no thermal stratification at the reservoir monitoring location during 2020 and no to very weak (i.e., <1.0ºC) thermal stratification at the forebay monitoring location for most of 2020 and 2021. The two exceptions were during the August 12, 2021 and September 15, 2021 download events where the difference between forebay surface and bottom temperatures was approximately 2.7ºC and 3.1ºC, respectively. The stratification observed during the August 12, 2021 download event was mostly in the upper 1 ft of the water column indicating a very warm summer day with solar heating at the water's surface. The September 15, 2021 download event occurred during a powerhouse outage when flows in the forebay area were reduced, thus allowing the water column to thermally stratify.

[1] The drainage area at the Tinker Creek monitoring location is approximately 78 square miles; 66 of which are classified as urban land use, as compared to the Roanoke River drainage area at the Thirteenth Street Bridge monitoring location which is approximately 390 square miles.

6.2 Dissolved Oxygen

Figures 1-3 and 1-4 in Attachment 1 provide continuous and discrete DO concentration data at the upstream water quality monitoring locations (Thirteenth Street Bridge and Tinker Creek) during 2020 and 2021, respectively. All upstream measurements were greater than the 5.0 mg/l daily average DO state standards with typical daily fluctuations in the 2 – 5 mg/l range at both locations. The sharp decline in Tinker Creek DO concentrations the first week of September 2020 was likely the result of a 3-inch rainfall runoff event that occurred at the beginning of that week (see Figure 4-1 of Attachment 4 for rainfall and streamflow data during the 2020 study period). All discrete DO data for 2020 and 2021 are included in Table 2-1 and Table 2-2 of Attachment 2.

Figure 1-5 (Attachment 1) provides continuous and discrete DO concentration data at the Project's forebay and tailrace monitoring locations in 2020. DO values exceeded the 4.0 mg/l instantaneous and 5.0 mg/l daily average standard (9 VAC 25-260-50) except in the Project's forebay on September 8 and 11, 2020. Instantaneous DO concentrations on these dates (recorded at the sonde near the reservoir bottom) were 3.3 mg/l and 3.4 mg/l, respectively. Each occurrence of instantaneous DO concentrations below 4.0 mg/l lasted less than 1.5 hours in duration. Also, both dates coincided with the start of a planned outage at the Niagara plant, which began on September 8, 2020 and continued throughout the end of the monitoring period. Because there was no flow through the powerhouse, instantaneous DO concentrations fluctuated (albeit very short-lived) between the forebay surface and bottom elevations. During these two events, DO concentrations near the surface remained above 5.0 mg/l and as a result, overall DO concentrations in the forebay met the state's DO criteria.[2] Daily fluctuations in DO concentrations were typically in the 1.0 – 2.0 mg/l range at the forebay and tailrace monitoring locations; slightly less than the daily fluctuations at the two upstream monitoring locations. Similar to water temperature profile trends, there was little (i.e., < 0.5 mg/l) difference in DO concentrations between the forebay surface and bottom sonde locations (with the exception of the two events noted above); indicating little to no stratification of DO concentrations throughout the forebay water column. DO concentrations in the tailrace were generally higher (by less than 0.5 mg/l) compared to the surface forebay monitoring location during both periods of generation and non-generation (see data pre- and post- powerhouse outage on September 8, 2020).

Figure 1-6 (Attachment 1) provides continuous and discrete DO measurements at the forebay and tailrace locations for 2021. DO concentrations exceeded the 4.0 mg/l instantaneous and 5.0 mg/l daily average standards throughout the 2021 monitoring period at these two monitoring locations.

Figure 1-7 (Attachment 1) provides continuous and discrete DO concentration data at the bypass reach upstream and downstream monitoring locations for the 2020 study period. Overall magnitude and trends in DO concentrations were very similar between the forebay, tailrace and bypass reach monitoring locations. All measurements were greater than the 5.0 mg/l daily average DO standard with daily fluctuations typically in the 1.5 – 2.5 mg/l range prior to the powerhouse outage that

[2] For a thermally stratified man-made lake or reservoir in Class III, IV, V or VI waters that are listed in 9VAC25-260-187, these dissolved oxygen and pH criteria apply only to the epilimnion of the waterbody. When these waters are not stratified, the dissolved oxygen and pH criteria apply throughout the water column.

occurred on September 8, 2020; after which, daily fluctuations were less than 1.0 mg/l due to the large flow throughput in the bypass reach when generation flows ceased.

Figure 1-8 (Attachment 1) provides continuous and discrete DO concentration data at the bypass reach monitoring locations for 2021. During 2021, continuous and discrete DO concentration data indicated that all values exceeded the 4.0 mg/l instantaneous and 5.0 mg/l daily average standard with the exception of the upper bypass reach monitoring location during the hottest portion of the summer (July/August) when bypass flows were at the 8.0 cubic feet per second (cfs) minimum required release. The upper bypass reach data sonde is located in a slow moving/stagnant pool which at times exhibited DO concentrations less than 4.0 mg/l during nighttime hours on several days in July and August. Hot, relatively dry weather conditions conducive to supersaturation due to photosynthesis during daylight hours and a DO sag during nighttime hours is assumed to be the principal cause; significant biofouling that occurred in these instruments under the lowest monitored flow likely contributed to low DO values. From August 11 – 13, 2021, the bypass flow was increased from 8.0 cfs to approximately 20 cfs due to an operational adjustment associated with the Obermeyer trash sluice gate (see Figure 4-2 in Attachment 4). During this 2-day period, DO concentrations at the upstream bypass reach monitoring location remained above the 4.0 mg/l instantaneous and 5.0 mg/l daily average standard and did not experience a nighttime DO sag. After August 13, 2021, the Obermeyer gate returned to its normal operating mode and DO concentrations in the bypass reach remained above the Virginia standard during the remainder of the 2021 monitoring period. A planned powerhouse maintenance outage occurred from September 7 – 30, 2021, during which time all Project inflow was routed through the bypass reach. This resulted in DO concentrations greater than 8.0 mg/l during the outage. As water temperatures continued to cool during October 2021, DO concentrations in the bypass reach remained high (i.e., > 8.0 mg/l).

DO vertical profile data for the forebay monitoring location are presented in Tables 2-3 and 2-5 (Attachment 2) and on Figures 3-1 and 3-2 (Attachment 3). Vertical profile data for the reservoir is presented in Table 2-4 (Attachment 2) and is shown on Figure 3-7 (Attachment 3). Similar to the water temperature profile data, during 2020 there was no stratification of DO concentrations at the reservoir monitoring location and no to very weak stratification at the forebay monitoring location. During 2021, vertical DO profile measurements during several download events in August and September indicated some degree of DO stratification at the forebay monitoring location; the strongest of which was measured on September 15, 2021 during the powerhouse outage described in Section 6.1. During this download event, DO concentrations ranged from 8.0 mg/l at the surface to 5.0 mg/l near the bottom of the forebay. All DO concentrations measured at the forebay monitoring location in 2021 were greater than 5.0 mg/l at all depths.

6.3 pH

Vertical profile data showing pH is provided in Tables 2-3, 2-4, and 2-6 and presented in Figures 3-3 and 3-4 (forebay location) and Figure 3-8 (reservoir location) of Attachment 3. The range in pH range at both locations during the 2020 and 2021 monitoring periods showed only minor variations (between 7.5 and 8.0) during each discrete sampling event, and there was little to no stratification between the reservoir surface and bottom measurements at both monitoring locations. All discrete pH data for 2020 and 2021 are included in Tables 2-1 and 2-2 (Attachment 2).

Figure 1-9 (Attachment 1) provides continuous pH measurements at the upstream USGS water quality monitoring locations for 2021. The pH at both locations ranged from 7.5 – 8.5, which was slightly higher than the discrete pH measurements at the forebay, tailrace, and bypass reach monitoring locations in 2021, but was within the Virginia standard for pH values.

6.4 Specific Conductivity

While Virginia does not have a state standard for specific conductivity, concentrations between 150-500 microsiemens per centimeter (µS/cm) are generally considered suitable for most fish species (USEPA 2012). Specific conductivity vertical profile data are provided in Attachments 2 and 3. Figure 3-5 and Figure 3-6 show the forebay monitoring location for 2020 and 2021, respectively. Figure 3-9 shows the reservoir monitoring location for 2020. For the 2020 sampling period, conductivity at the forebay monitoring location varied with each sampling event, but concentrations were typically the same from reservoir surface to bottom and ranged from 369 – 435 µS/cm over four sampling events during the study period. Specific conductivity at the reservoir monitoring location also varied with each sampling event and concentrations were typically the same from reservoir surface to bottom, but with a slightly higher (and narrower) range between 411 – 436 µS/cm) over the four sampling events. For 2021, specific conductivity at the forebay monitoring location was slightly higher than in 2020 ranging from 369 – 501 µS/cm over eight sampling events.

Discrete measurements of specific conductivity at the Tinker Creek monitoring location (2020 only) ranged from 461 – 497 µS/cm which is slightly higher than at the Thirteenth Street Bridge monitoring location, which ranged from 319 – 396 µS/cm (see Table 2-2 of Attachment 2 for discrete sampling results). As expected, specific conductivity concentrations at the monitoring locations downstream from these two sampling points fit within these two ranges, the result of blended inflow to the reservoir. All discrete specific conductivity data for 2020 and 2021 are included in Tables 2-1 and 2-2 (Attachment 2).

Figure 1-10 (Attachment 1) provides continuous specific conductivity for the upstream Thirteenth Street Bridge and Tinker Creek monitoring locations during the 2021 study period. Similar to the discrete monitoring results, specific conductivity in Tinker Creek is generally higher than at the Thirteenth Street Bridge monitoring location by approximately 110 µS/cm on average. Sharp declines in specific conductivity at both upstream locations correspond to higher flows during rainfall runoff events.

7 Summary and Discussion

7.1 Consistency with Applicable Virginia State Water Quality Standards

Continuous and discrete water quality data collected during the 2020 study period met Virginia Class IV (Roanoke River) and Class VII (Tinker Creek) water quality standards for temperature (<31 ºC), DO (>4.0 mg/l instantaneous minimum; >5.0 mg/l daily average), and pH (range 6.0 – 9.0 for Class IV and 3.7 – 8 for Class VII) at all monitoring locations during the study period. The continuous monitoring data captured two events when forebay bottom DO concentrations dropped to, or slightly below 4 mg/l for a short period (typically less than 1.5 hours in duration for each event), which was likely the result of a powerhouse outage. Even with these short-lived events, the Project met state water quality criteria throughout the 2020 study period.

Continuous and discrete water quality data collected during the 2021 study period also met Virginia Class IV (Roanoke River) water quality standards with the exception of the DO instantaneous standard (4.0 mg/l) at the upstream bypass reach monitoring location during the hottest portion of the summer (July/August) when bypass flows were at the 8.0 cfs minimum required release. Increasing the bypass reach flow to approximately 20 cfs for a 2-day period in mid-August 2021 reduced nighttime DO sags and resulted in DO concentrations above the Virginia standard. After the 2-day period, the Obermeyer trash sluice gate returned to normal operations and DO concentrations at the upstream monitoring location remained above the Virginia standard for the remainder of the 2021 study period.

7.2 Temperature and Dissolved Oxygen Stratification in the Niagara Impoundment

Continuous and discrete water quality data collected during the 2020 study period indicated little to no thermal or DO stratification at the reservoir and forebay monitoring locations. Water temperatures typically varied less than 1.0ºC from reservoir surface to bottom, and DO concentrations typically varied less than 1.0 mg/l from reservoir surface to bottom. Continuous water temperatures recorded at the USGS Thirteenth Street Bridge water quality monitoring station (immediately upstream of the reservoir) peaked at 28.7ºC on July 20, 2020; approximately one week prior to initial deployment of the data sondes. As a result, water temperatures recorded during this study are representative of both warmer summer months and cooler fall months.

Continuous and discrete water quality data collected during the 2021 study period indicated little to no thermal or DO stratification (forebay location) with the exception of periods of relatively low Project inflow and/or powerhouse outages when thermal and DO stratification in the forebay area was present. The maximum extent of stratification was observed during the September 15, 2021 download event which coincided with a Niagara plant outage (i.e., no powerhouse flows). During this download event, water temperatures ranged from 24.7ºC at the forebay surface to 21.6ºC near the bottom. DO concentrations ranged from 8.0 mg/l near the surface to 5.0 mg/l near the bottom. Even during periods of thermal and DO stratification, Virginia temperature and DO standards were met.

Note that daily water temperature and DO data (minimum, average, and maximum) for both years of the study are presented in tables in Attachment 5.

7.3 Need for Protection, Mitigation, and Enhancement Measures to Protect Water Quality

Water quality in the streams flowing into the Niagara reservoir, the reservoir itself (including the Project's forebay area), tailrace, and bypass reach is consistent with applicable Virginia state water quality standards for temperature, DO, and pH for Class IV (Roanoke River) and Class VII (Tinker Creek) surface waters. While there is no state standard for specific conductivity, concentrations were above 150 µS/cm and less than 550 µS/cm, which is generally considered to be suitable for most fish (USEPA 2012). Appalachian will continue to operate the Project in the existing run-of-river mode with minimum flow releases to the bypass reach over the new license term, for the protection of water quality and other resources. As a result, there is no need for additional PM&E measures to protect water quality at the Project.

7.4 Additional Future Water Quality Data Needs

Water quality data collected during 2020 (higher than normal Project inflows) and 2021 (normal Project inflows) met Virginia Class IV (Roanoke River) and Class VII (Tinker Creek) water quality standards with the exception of the DO 4.0 mg/l instantaneous standard at the upstream bypass reach monitoring location during the hottest portion of the 2021 summer (July/August) when bypass flows were at the 8.0 cfs minimum required release. Increasing the bypass reach flow to approximately 20 cfs reduced nighttime DO sags and resulted in DO concentrations above the Virginia standard. The Niagara forebay area experiences some thermal and DO stratification during periods of relatively low Project inflows and/or powerhouse outages, however, the temperature and DO regime throughout the water column met Virginia temperature and DO standards. Based on these data, Appalachian does not propose additional water quality monitoring at the Project during the new license term.

8 Variances from FERC-Approved Study Plan

Based on the results and findings from the 2020 water quality monitoring period, FERC approved a study modification requiring additional water quality data collection at Niagara in 2021. FERC required that Appalachian conduct continuous monitoring in the bypass reach (two locations) and tailrace (one location) in 2021, as well as the discrete collection of water quality data in the forebay (i.e., vertical profiles), tailrace, and bypass reach. In lieu of reinstalling continuously recording sondes in the upper end of the impoundment, Tinker Creek, and the Roanoke River upstream of the confluence with Tinker Creek, Appalachian proposed, and FERC agreed, to include 2021 water quality data (temperature, DO, pH, and specific conductivity) recorded at both the Thirteenth Street Bridge USGS gage (USGS 02055080) and USGS gage at Tinker Creek above Glade Creek (USGS 0205551614) in the USR. FERC also required that the 2021 water quality monitoring period extend from July through the end of October. The 2021 water quality study incorporated FERC's requirements from the May 10, 2021 determination for study modifications.

9 Germane Correspondence and Consultation

FERC issued a determination on requests for study modifications for the Niagara Project on May 10, 2021. Study modifications included continued collection of water quality parameters at select monitoring locations from July through October 2021. This additional data has been summarized in the USR and correspondence has been added to Attachment 2 (FERC Consultation) of the USR.

10 References

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Attachment 1

Attachment 1 – Continuous Temperature, Dissolved Oxygen, pH, and Specific Conductivity Plots

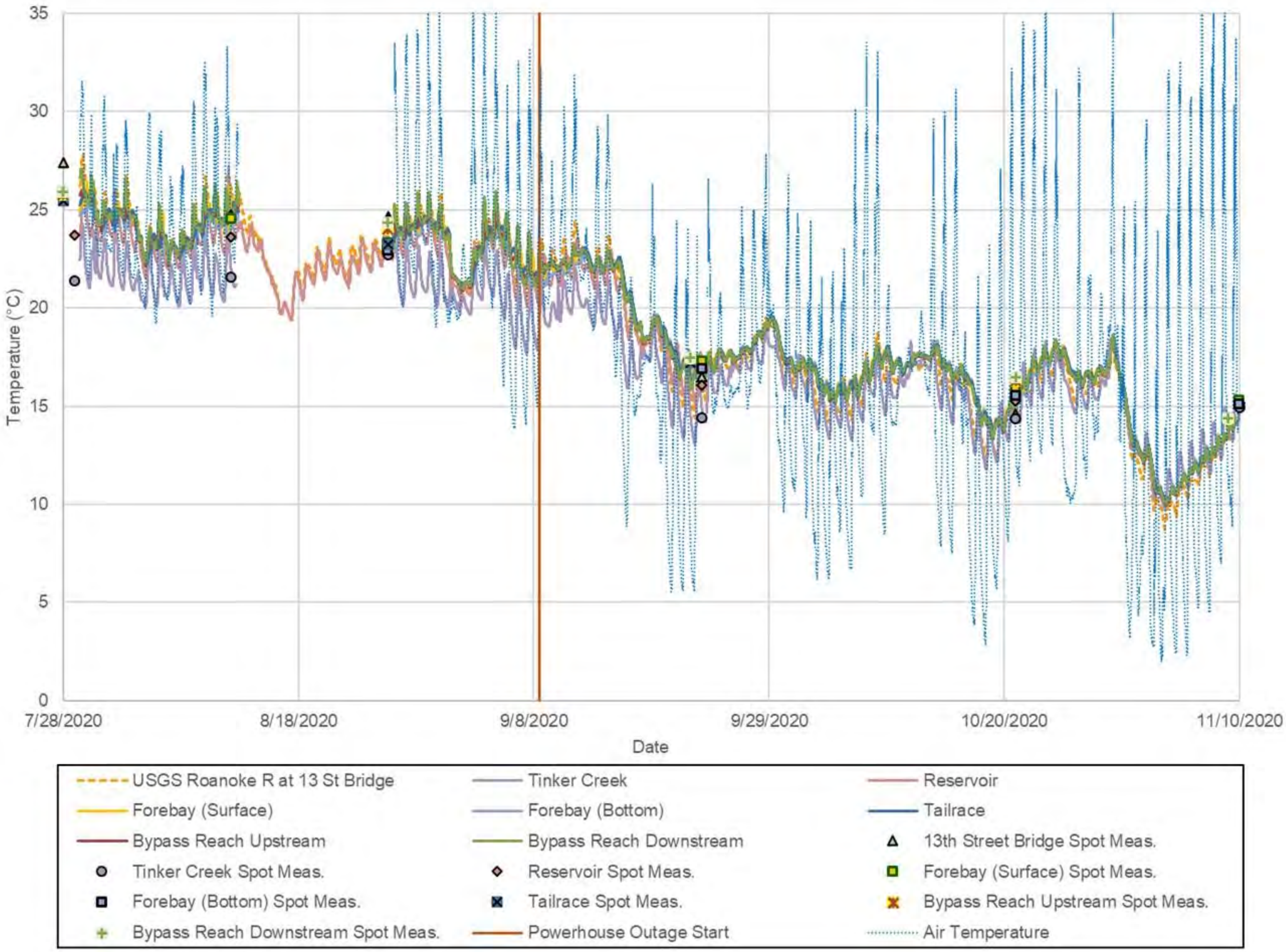

Figure 1-1. Continuous and Discrete Temperature Measurements at All Water Quality Monitoring Locations (2020)

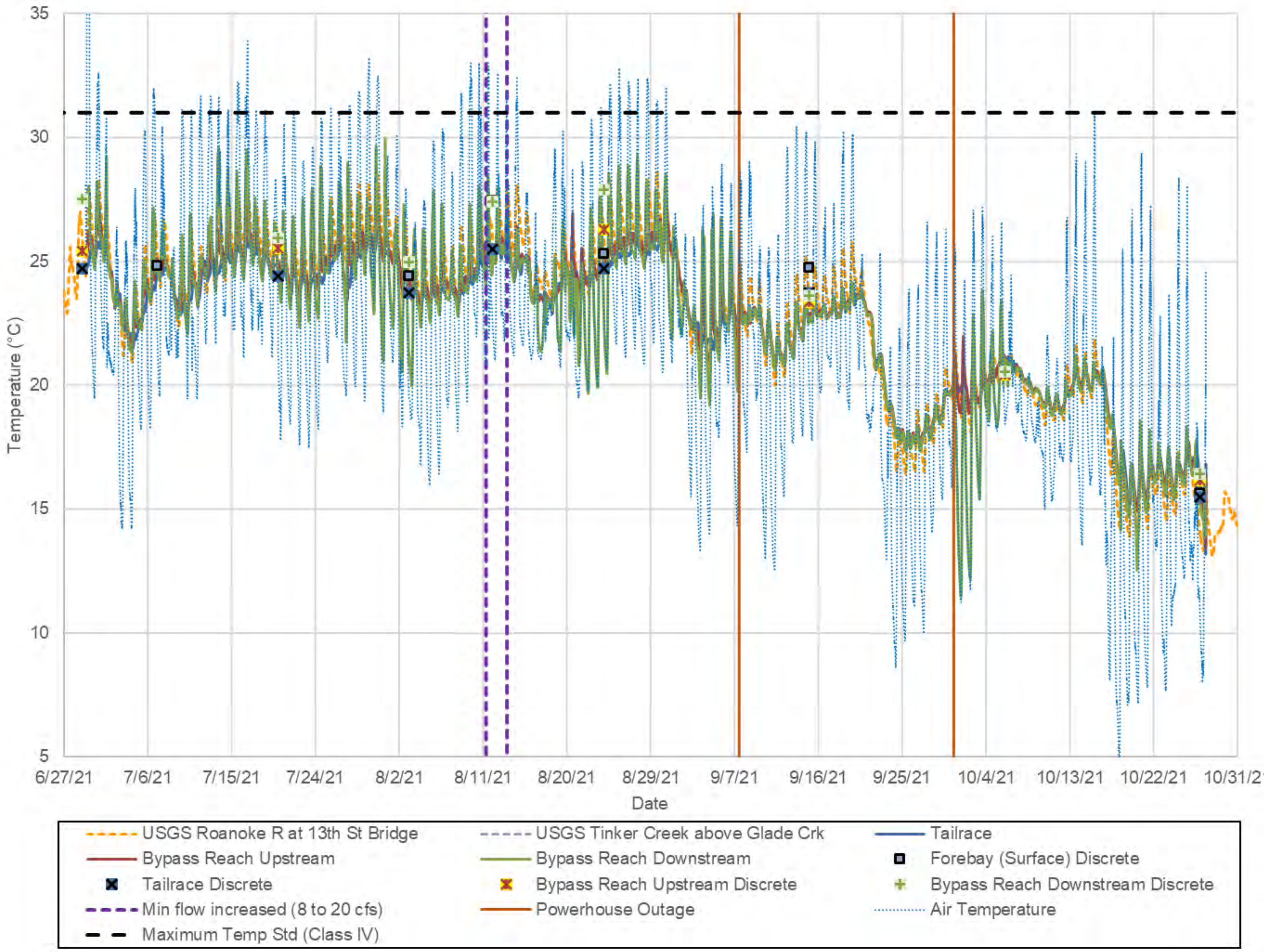

Figure 1-2. Continuous and Discrete Temperature Measurements at All Water Quality Monitoring Locations (2021)

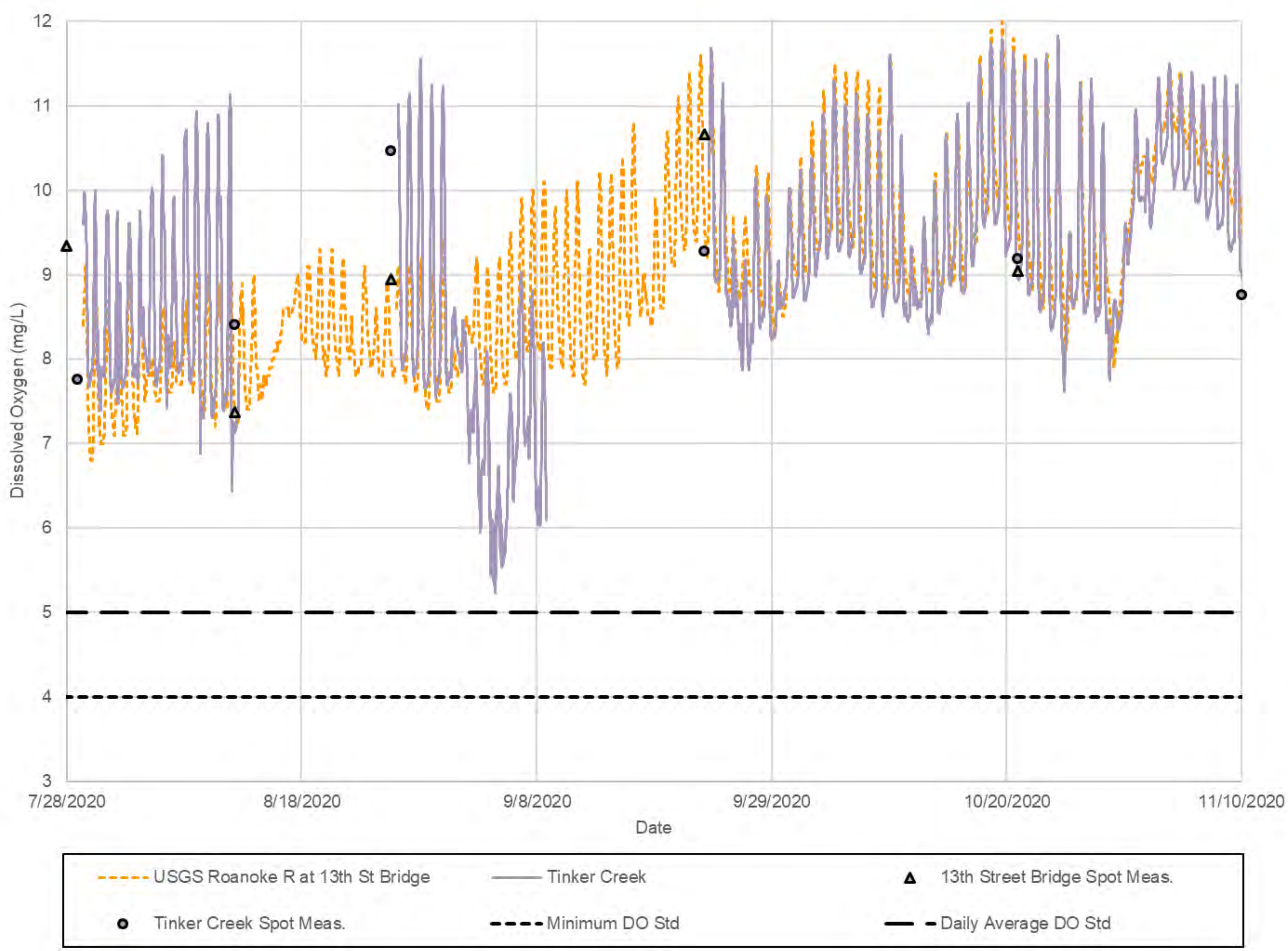

Figure 1-3. Continuous and Discrete Dissolved Oxygen Concentrations at the Upstream Water Quality Monitoring Locations (2020)

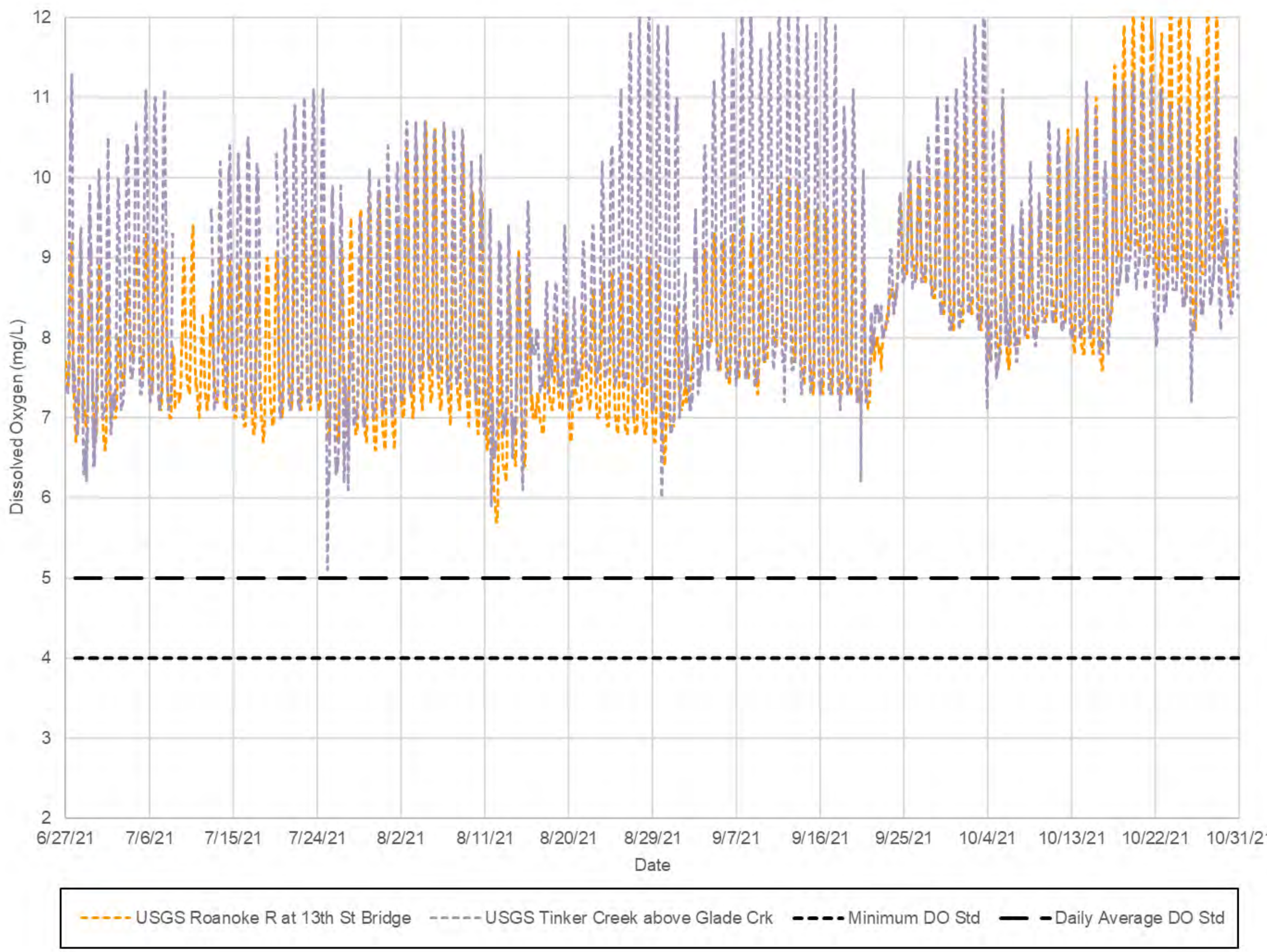

Figure 1-4. Continuous and Discrete Dissolved Oxygen Concentrations at the Upstream USGS Water Quality Monitoring Locations (2021)

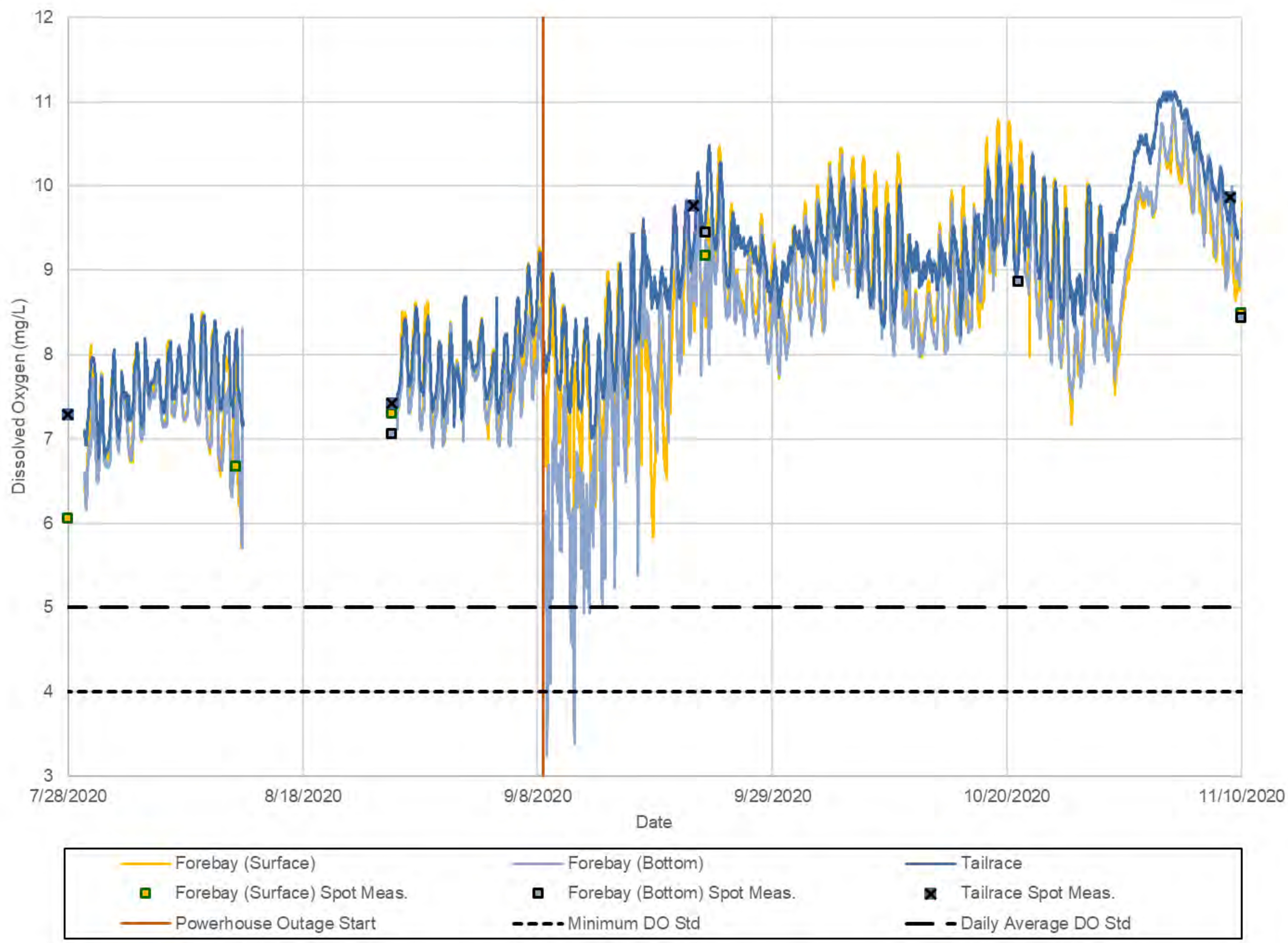

Figure 1-5. Continuous and Discrete Dissolved Oxygen Concentrations at the Forebay and Tailrace Water Quality Monitoring Locations (2020)

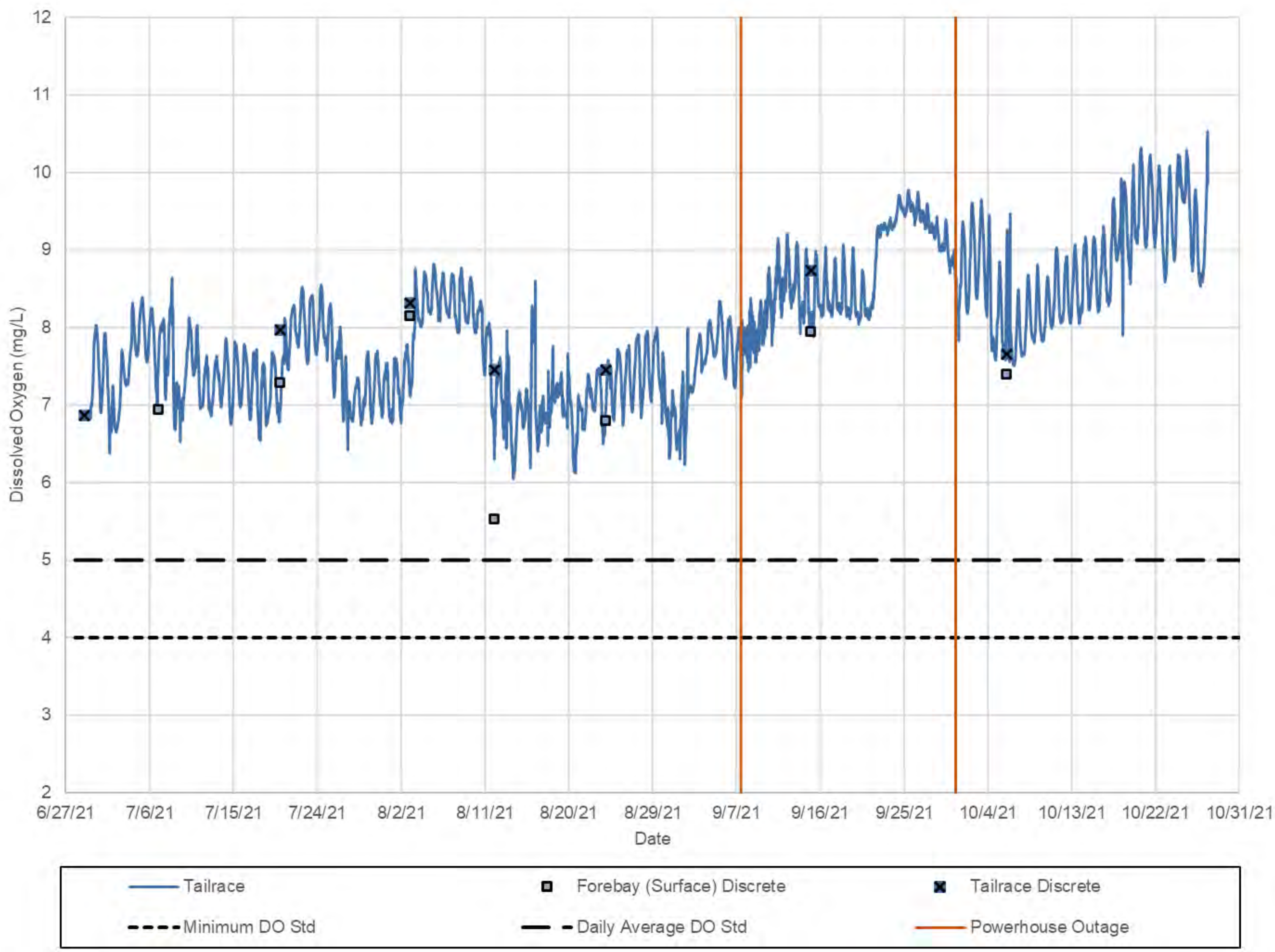

Figure 1-6. Continuous and Discrete Dissolved Oxygen Concentrations at the Forebay and Tailrace Water Quality Monitoring Locations (2021)

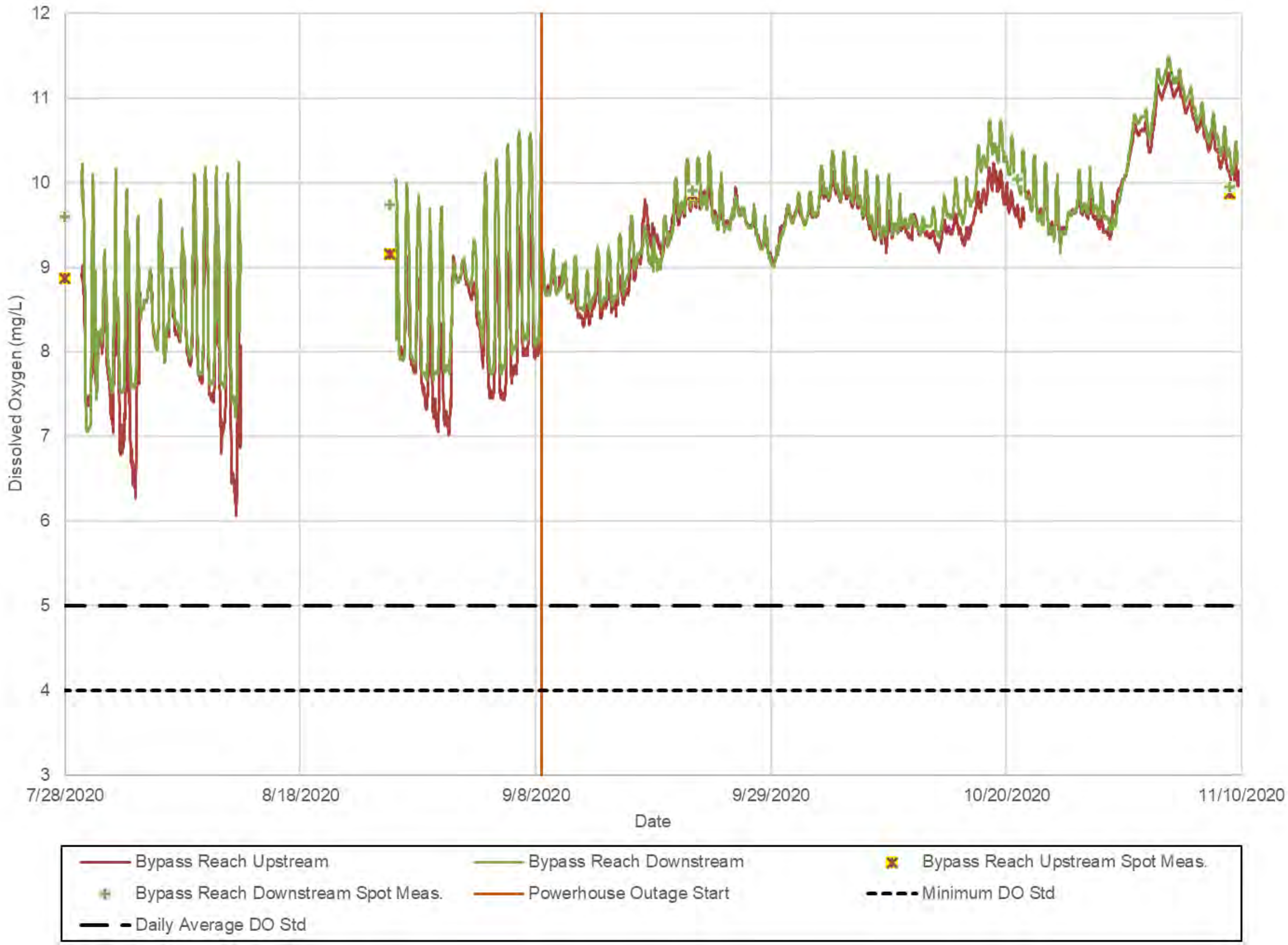

Figure 1-7. Continuous and Discrete Dissolved Oxygen Concentrations at the Bypass Reach Water Quality Monitoring Locations (2020)

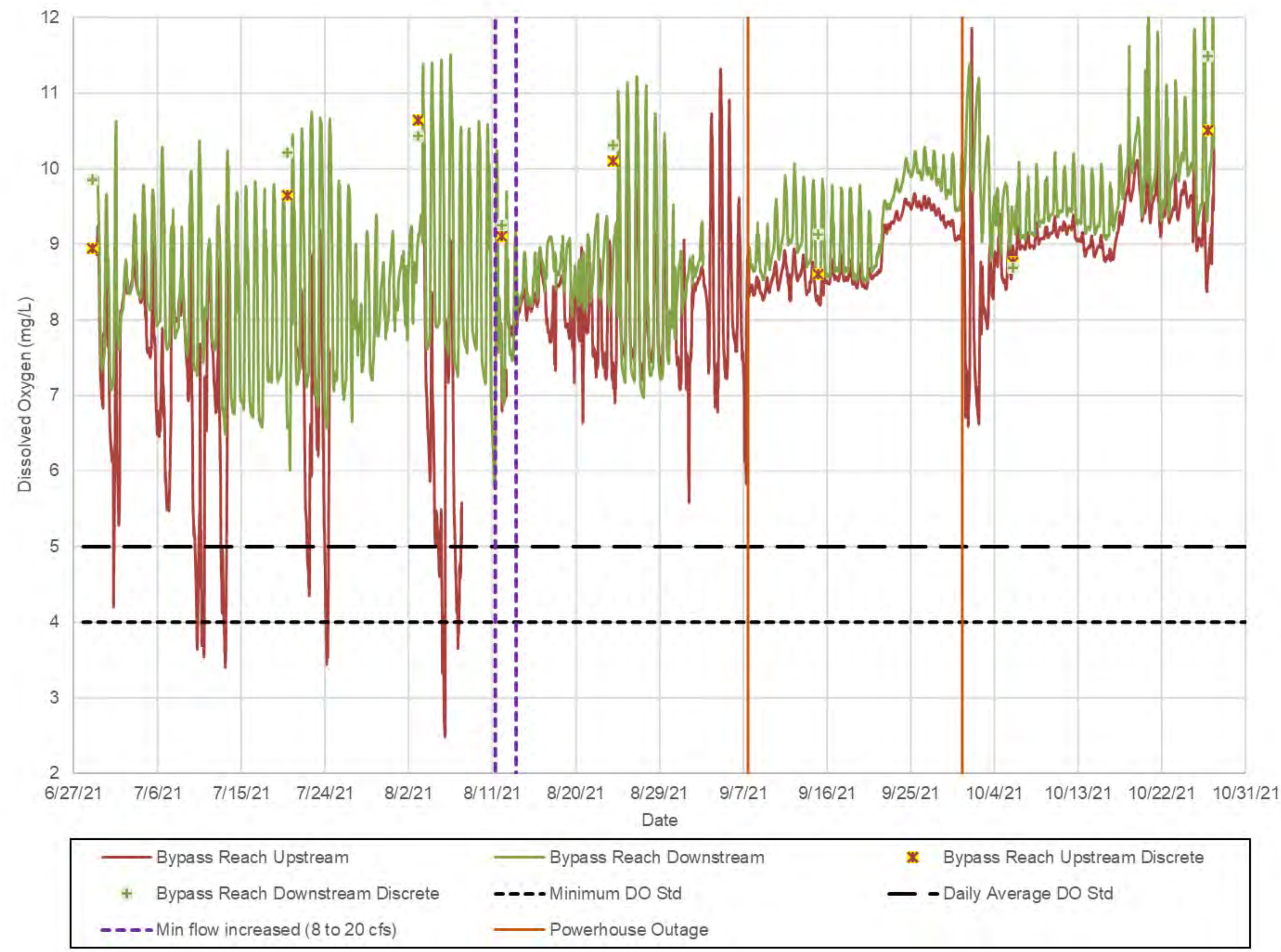

Figure 1-8. Continuous and Discrete Dissolved Oxygen Concentrations at the Bypass Reach Water Quality Monitoring Locations (2021)

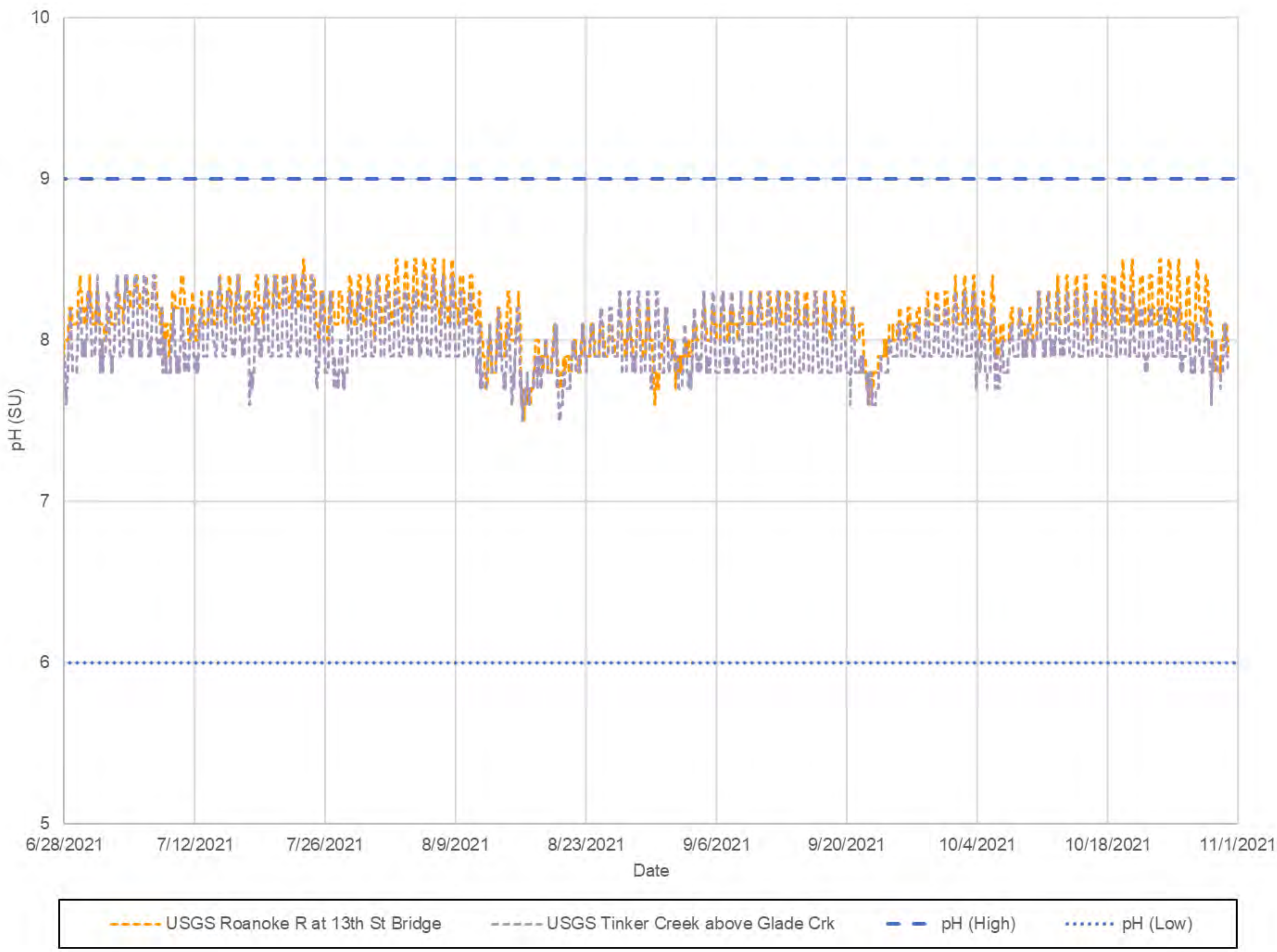

Figure 1-9. Continuous pH Measurements at the Upstream USGS Water Quality Monitoring Locations (2021)

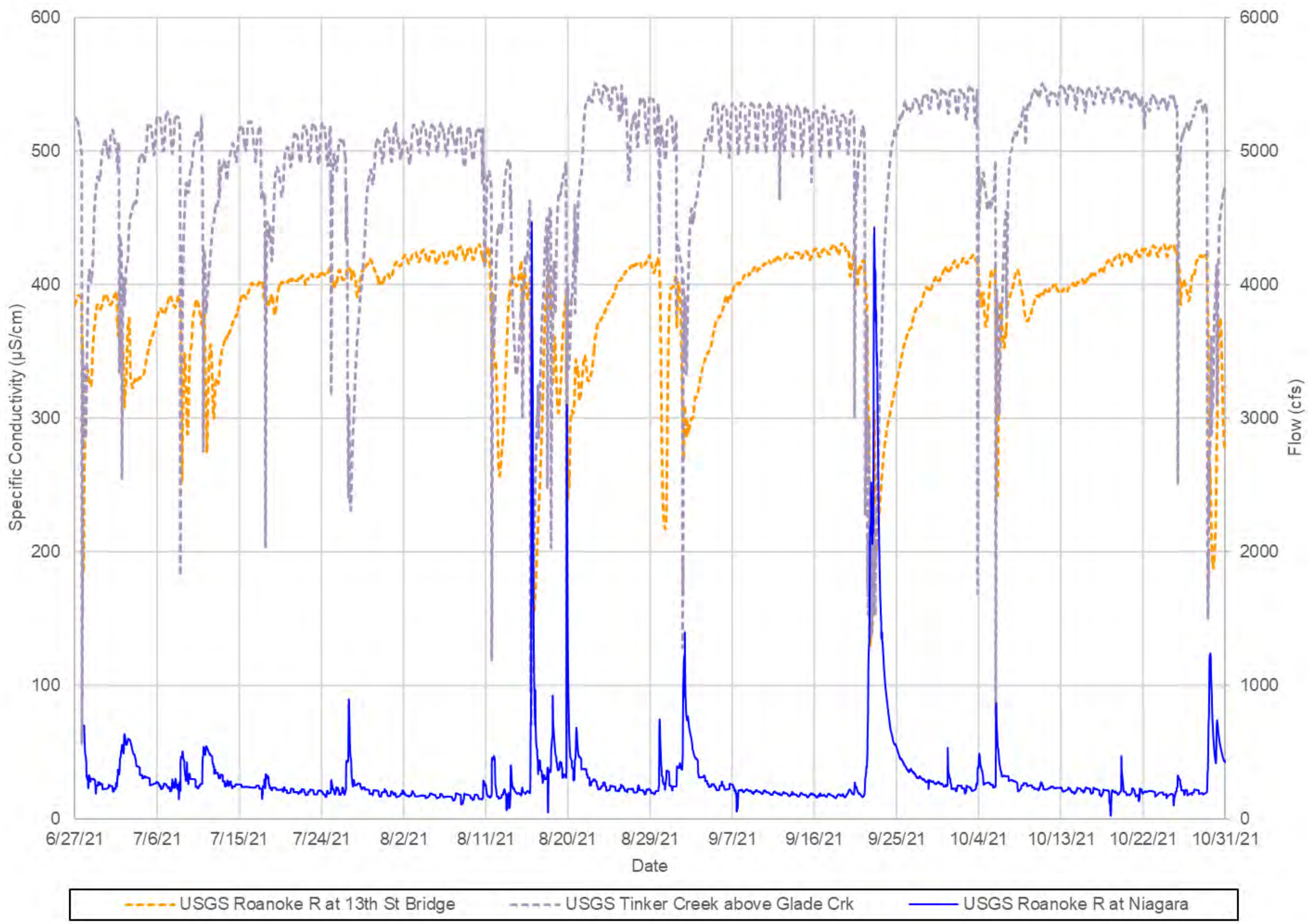

Figure 1-10. Continuous Specific Conductivity Concentrations at the Upstream USGS Water Quality Monitoring Locations (2021)

Attachment 2

Attachment 2 – Discrete Measurement Tables

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Table 2-1. Discrete Measurements at each Water Quality Monitoring Location (2020)

Location	Date	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (SU)	Specific Conductivity (µS/cm)
13th Street Bridge	7/28/2020	27.4	9.3	8.2	396
	8/12/2020	24.7	7.4	8.0	389
	8/26/2020	24.6	9.0	8.3	319
	9/23/2020	16.5	10.7	8.3	NA
	10/21/2020	14.6	9.0	8.0	365
	11/10/2020	15.1	9.5	8.1	339
Tinker Creek	7/29/2020	21.4	7.8	7.8	461
	8/12/2020	21.6	8.4	7.9	479
	8/26/2020	22.7	10.5	8.2	482
	9/23/2020	14.4	9.3	7.9	489
	10/21/2020	14.3	9.2	7.9	497
	11/10/2020	15.0	8.8	7.9	494
Reservoir	7/29/2020	23.7	6.4	7.8	457
	8/12/2020	23.6	6.7	7.7	450
	8/26/2020	24.5	8.1	7.9	392
	9/23/2020	16.1	8.5	7.7	436
	10/21/2020	15.3	NA	7.8	432
	11/10/2020	15.1	8.5	7.8	423
	11/10/2020	15.2	8.7	7.8	411
Forebay	7/28/2020	25.9	6.1	7.6	470
	8/12/2020	24.5	6.7	7.7	439
	8/26/2020	23.3	7.3	7.8	369
	9/23/2020	17.8	9.2	7.9	433
	10/21/2020	16.2	8.9	7.9	435
	11/10/2020	15.3	8.5	7.8	405
Tailrace	7/28/2020	25.5	7.3	7.7	467
	8/12/2020	NA	NA	NA	NA
	8/26/2020	23.2	7.4	7.8	373
	9/22/2020	17.2	9.8	7.8	423
	10/21/2020	NA	NA	NA	NA
	11/9/2020	14.4	9.9	7.9	397
Bypass Reach Upstream	7/28/2020	25.8	8.9	8.1	460
	8/12/2020	NA	NA	NA	NA
	8/26/2020	24.0	9.2	8.2	371
	9/22/2020	17.4	9.9	8.1	427
	10/21/2020	16.3	NA	8.1	432
	11/9/2020	14.3	9.9	8.0	394

Location	Date	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (SU)	Specific Conductivity (µS/cm)
Bypass Reach Downstream	7/28/2020	25.9	9.6	8.2	456
	8/12/2020	NA	NA	NA	NA
	8/26/2020	24.4	9.7	8.3	367
	9/22/2020	17.5	9.9	8.2	425
	10/21/2020	16.5	10.0	8.3	434
	11/9/2020	14.4	10.0	8.0	395

Note:

NA = not available. Instrument was not functioning correctly and/or conditions did not provide a valid reading

Table 2-2. Discrete Measurements at each Water Quality Monitoring Location (2021)

Location	Date	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (SU)	Specific Conductance (µS/cm)
Forebay	6/29/2021	24.6	6.8	7.7	456
	7/20/2021	24.83	7.1	7.7	470
	8/3/2021	24.16	8.1	8.0	491
	8/12/2021	25.7	5.7	7.6	425
	8/24/2021	25.1	6.7	7.7	474
	9/15/2021	23.6	7.8	7.8	501
	10/6/2021	20.4	7.4	7.8	369
	10/27/2021	15.7	8.9	7.9	457
Tailrace	6/29/2021	24.7	6.9	7.6	399
	7/20/2021	24.4	8.0	7.8	464
	8/3/2021	23.75	8.3	7.9	491
	8/12/2021	25.5	7.5	7.6	424
	8/24/2021	24.7	7.5	7.7	470
	9/15/2021	23.7	8.7	8.0	495
	10/6/2021	20.4	7.7	7.8	362
	10/27/2021	15.5	9.6	7.9	457
Bypass Reach Upstream	6/29/2021	25.4	8.9	8.0	390
	7/20/2021	25.5	9.7	8.3	454
	8/3/2021	25.0	10.6	8.3	477
	8/12/2021	27.4	9.1	8.1	415
	8/24/2021	26.3	10.1	8.3	459
	9/15/2021	23.4	8.6	8.1	497
	10/6/2021	20.4	8.8	8.0	368
	10/27/2021	16.2	10.5	8.2	453
Bypass Reach Downstream	6/29/2021	27.5	9.9	8.3	383
	7/20/2021	25.94	10.2	8.4	446
	8/3/2021	25.0	10.4	8.3	475
	8/12/2021	27.4	9.3	8.2	414
	8/24/2021	27.9	10.3	8.5	449
	9/15/2021	23.6	9.1	8.2	496
	10/6/2021	20.5	8.7	8.0	361
	10/27/2021	16.4	11.5	8.3	444

Table 2-3. Forebay Vertical Profile Data (2020)

Depth (ft)	Temperature (°C)				Dissolved Oxygen (mg/L)				pH (SU)				Specific Conductivity (µS/cm)			
	8/26/2020	9/23/2020	10/21/2020	11/10/2020	8/26/2020	9/23/2020	10/21/2020	11/10/2020	8/26/2020	9/23/2020	10/21/2020	11/10/2020	8/26/2020	9/23/2020	10/21/2020	11/10/2020
1	23.3	17.8	16.2	15.3	7.3	9.2	8.9	8.5	7.8	7.9	7.9	7.8	369	433	435	405
2	23.3	17.3	16.0	15.3	7.3	9.2	8.9	8.5	7.8	7.9	7.9	7.7	370	433	435	405
3	23.2	17.1	15.8	15.2	7.3	9.3	8.9	8.5	7.8	7.9	7.9	7.7	374	431	433	406
4	23.0	17.1	15.7	15.1	7.2	9.4	8.9	8.5	7.8	7.9	7.9	7.7	373	430	433	406
5	22.9	17.0	15.7	15.1	7.2	9.4	9.0	8.5	7.8	7.9	7.9	7.7	373	429	432	407
6	22.9	17.0	15.7	15.1	7.1	9.4	9.0	8.4	7.8	7.9	7.9	7.7	374	429	431	407
7	22.9	17.0	15.6	15.1	7.1	9.5	8.9	8.5	7.8	7.9	7.9	7.7	374	428	431	407
8	22.9	16.9	15.5	15.1	7.1	9.5	8.9	8.4	7.8	7.9	7.9	7.7	374	427	431	407
9	--	16.9	15.5	15.1	--	9.5	8.7	8.5	--	7.9	7.8	7.7	--	426	430	407
10	--	16.8	--	15.1	--	9.5	--	8.4	--	7.9	--	7.7	--	426	--	407
11	--	16.8	--	15.1	--	9.5	--	8.4	--	7.9	--	7.7	--	425	--	407

Table 2-4. Reservoir Vertical Profile Data (2020)

Depth (ft)	Temperature (°C)				Dissolved Oxygen (mg/L)				pH (SU)				Specific Conductivity (µS/cm)			
	9/23/2020	10/21/2020	11/10/2020	11/10/2020	9/23/2020	10/21/2020	11/10/2020	11/10/2020	9/23/2020	10/21/2020	11/10/2020	11/10/2020	9/23/2020	10/21/2020	11/10/2020	11/10/2020
1	16.1	15.3	15.1	15.2	8.5	NA	8.5	8.7	7.7	7.8	7.8	7.8	436	432	423	411
2	15.9	15.2	15.1	15.2	8.6	NA	8.6	8.6	7.7	7.8	7.8	7.8	436	432	423	412
3	15.9	15.2	15.1	15.2	8.7	NA	8.6	8.7	7.6	7.8	7.8	7.8	436	432	423	413
4	15.9	15.2	15.1	15.2	8.7	NA	8.6	8.6	7.6	7.8	7.8	7.8	435	432	424	413
5	15.9	15.2	15.1	15.2	8.7	NA	8.5	8.6	7.6	7.8	7.8	7.8	435	432	424	413
6	15.9	15.2	15.1	15.2	8.7	NA	8.5	8.6	7.6	7.5	7.8	7.8	435	432	424	413
6.5	--	--	15.1	--	--	--	8.5	--	--	--	7.8	--	--	--	424	--
7	15.9	15.3	--	15.2	8.8	8.8	--	8.6	7.6	7.7	--	7.8	435	430	--	414
7.5	--	--	--	15.1	--	--	--	8.5	--	--	--	7.8	--	--	--	NA

Table 2-5. Forebay Vertical Profile Data – Temperature and Dissolved Oxygen (2021)

	Temperature (°C)								Dissolved Oxygen (mg/L)							
Depth (ft)	7/7/2021	7/20/2021	8/3/2021	8/12/2021	8/24/2021	9/15/2021	10/6/2021	10/27/2021	7/7/2021	7/20/2021	8/3/2021	8/12/2021	8/24/2021	9/15/2021	10/6/2021	10/27/2021
1	24.8	25.5	24.4	27.4	25.3	24.7	--	15.9	6.9	7.3	8.2	5.5	6.8	8.0	--	9.0
1.5	--	--	--	--	--	--	20.4	--	--	--	--	--	--	--	7.4	--
2	24.6	24.8	24.2	25.7	25.1	23.6	--	15.7	6.8	7.1	8.1	5.7	6.7	7.8	--	8.9
3	24.5	24.6	24.0	25.4	24.9	23.3	20.3	15.6	6.8	7.1	8.0	5.6	6.6	7.5	7.4	8.9
4	24.3	24.5	23.9	25.3	24.7	22.8	20.3	15.5	6.8	7.2	7.9	5.5	6.6	6.9	7.3	8.8
5	24.1	24.4	23.7	25.1	24.4	22.3	20.3	15.5	6.7	7.2	7.5	5.3	6.5	6.6	7.3	8.8
6	24.0	24.3	23.4	25.0	24.1	21.8	20.3	15.5	6.6	7.0	6.9	5.1	5.8	5.5	7.2	8.8
7	23.8	24.3	23.4	24.9	24.0	21.7	20.3	15.4	6.4	7.1	6.6	5.0	5.5	5.4	7.2	8.8
8	23.7	24.3	23.4	24.8	24.0	21.7	20.3	15.4	6.3	7.0	6.6	5.0	5.4	5.3	7.2	8.8
9	23.7	24.3	23.3	--	--	21.6	--	15.4	6.3	7.0	6.6	--	--	5.0	--	8.8
10	23.7	--	--	--	--	--	--	--	6.3	--	--	--	--	--	--	--
10.5	23.7	--	--	--	--	--	--	--	6.2	--	--	--	--	--	--	--

Table 2-6. Forebay Vertical Profile Data – pH and Specific Conductivity (2021)

	pH (SU)								Specific Conductivity (µS/cm)							
Depth (ft)	7/7/2021	7/20/2021	8/3/2021	8/12/2021	8/24/2021	9/15/2021	10/6/2021	10/27/2021	7/7/2021	7/20/2021	8/3/2021	8/12/2021	8/24/2021	9/15/2021	10/6/2021	10/27/2021
1	7.7	7.8	8.0	7.7	7.7	7.8	--	7.9	456	470	490	428	474	500	--	458
1.5	--	--	--	--	--	--	7.8	--	--	--	--	--	--	--	369	--
2	7.7	7.7	8.0	7.6	7.7	7.8	--	7.9	456	470	491	425	474	501	--	457
3	7.7	7.7	8.0	7.6	7.7	7.8	7.7	7.9	455	469	491	423	473	498	369	458
4	7.7	7.7	7.9	7.7	7.7	7.8	7.7	7.9	452	467	491	424	471	497	369	458
5	7.6	7.7	7.9	7.6	7.7	7.8	7.7	7.9	450	465	490	425	468	499	369	458
6	7.6	7.7	7.8	7.6	7.6	7.7	7.7	7.9	449	463	488	431	465	498	369	458
7	7.6	7.7	7.8	7.6	7.6	7.7	7.7	7.9	448	463	486	436	464	498	369	458
8	7.6	7.7	7.8	7.6	7.6	7.7	7.7	7.9	448	462	486	439	464	498	370	458
9	7.6	7.7	7.8	--	--	7.7	--	7.9	448	462	486	--	--	498	--	458
10	7.6	--	--	--	--	--	--	--	448	--	--	--	--	--	--	--
10.5	7.6	--	--	--	--	--	--	--	447	--	--	--	--	--	--	--

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Attachment 3

Attachment 3 – Water Quality Vertical Profile Figures

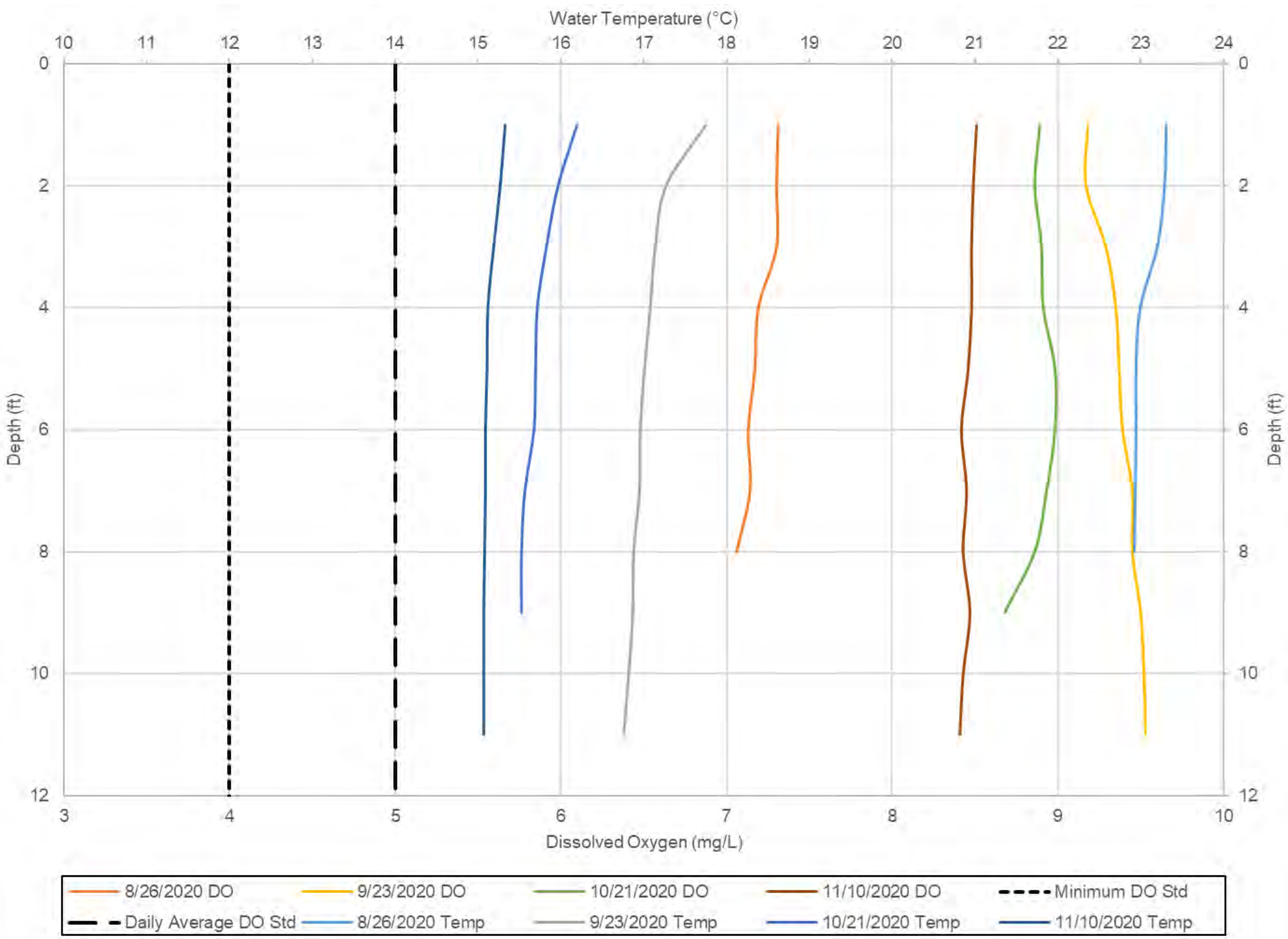

Figure 3-1. Forebay Vertical Profile—Temperature and Dissolved Oxygen Concentration (2020)

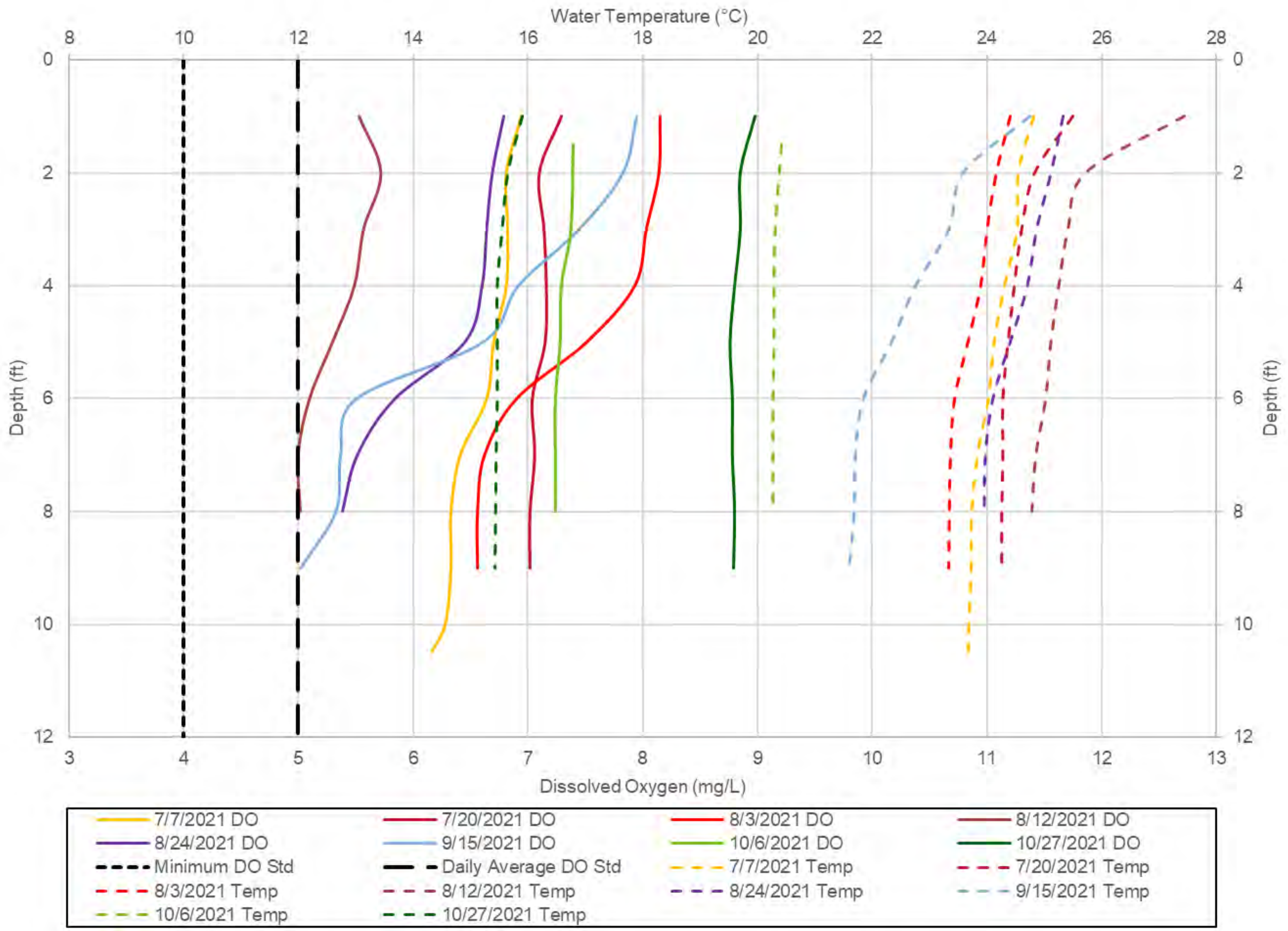

Figure 3-2. Forebay Vertical Profile—Temperature and Dissolved Oxygen Concentration (2021)

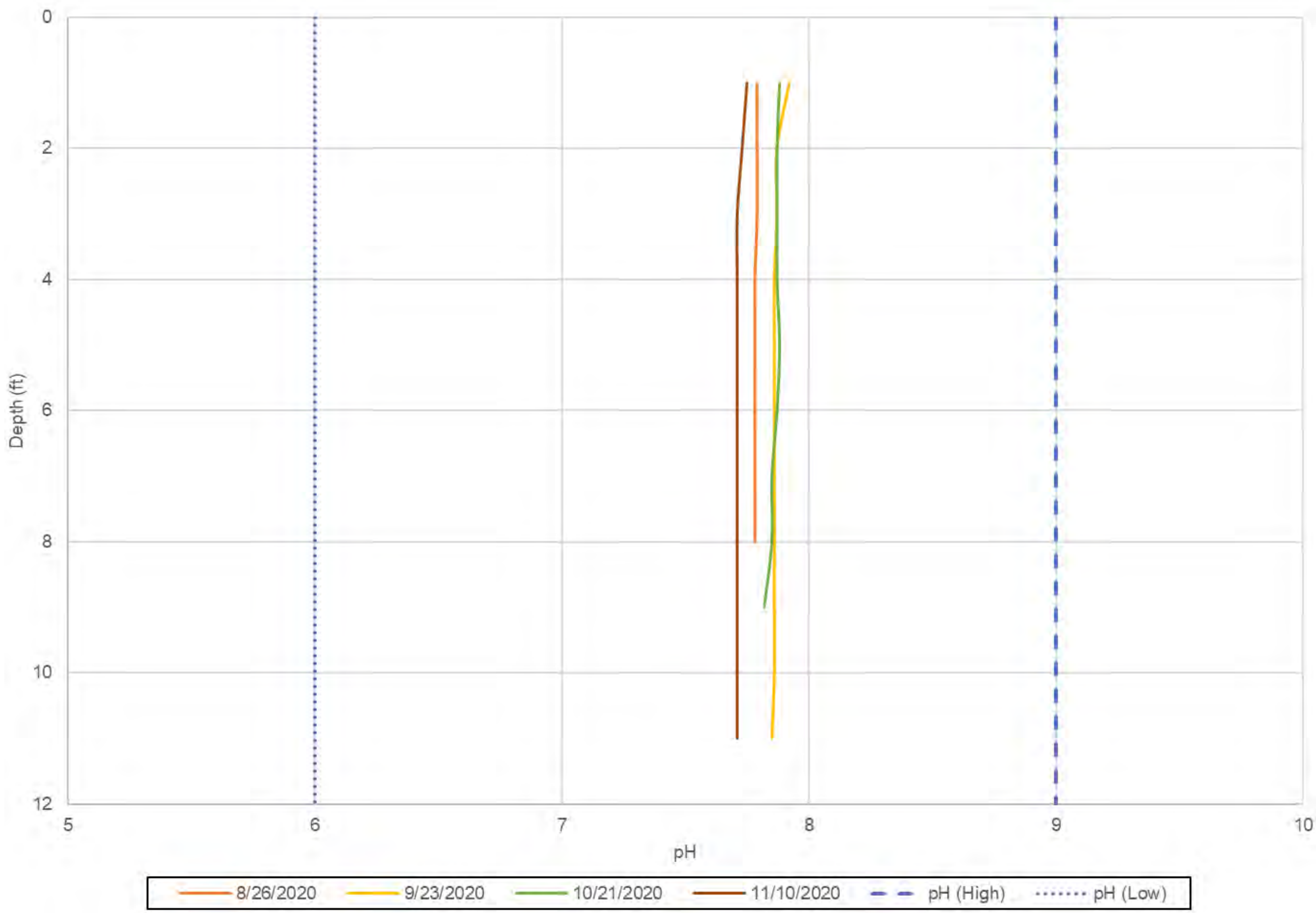

Figure 3-3. Forebay Vertical Profile—pH (2020)

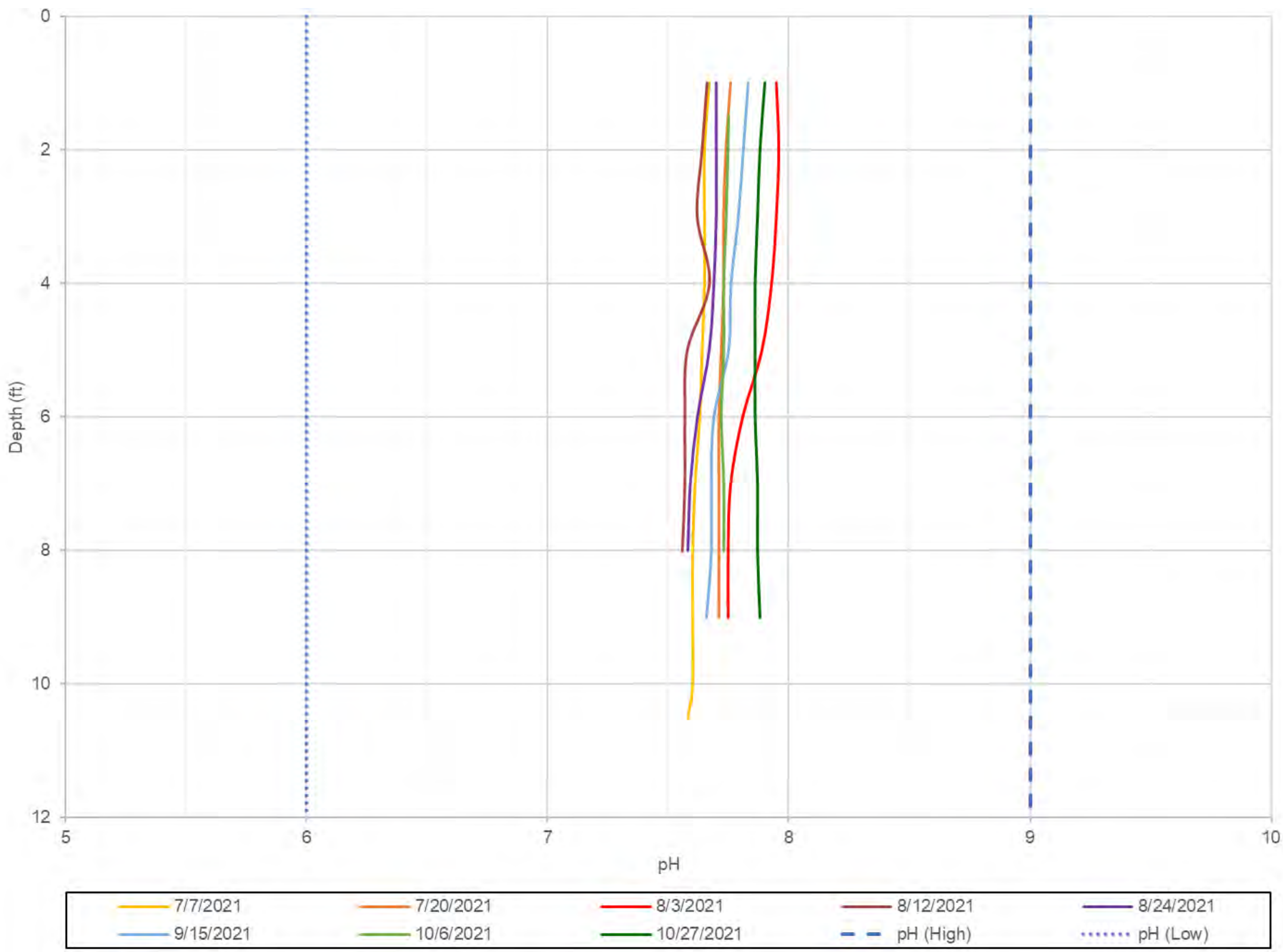

Figure 3-4. Forebay Vertical Profile—pH (2021)

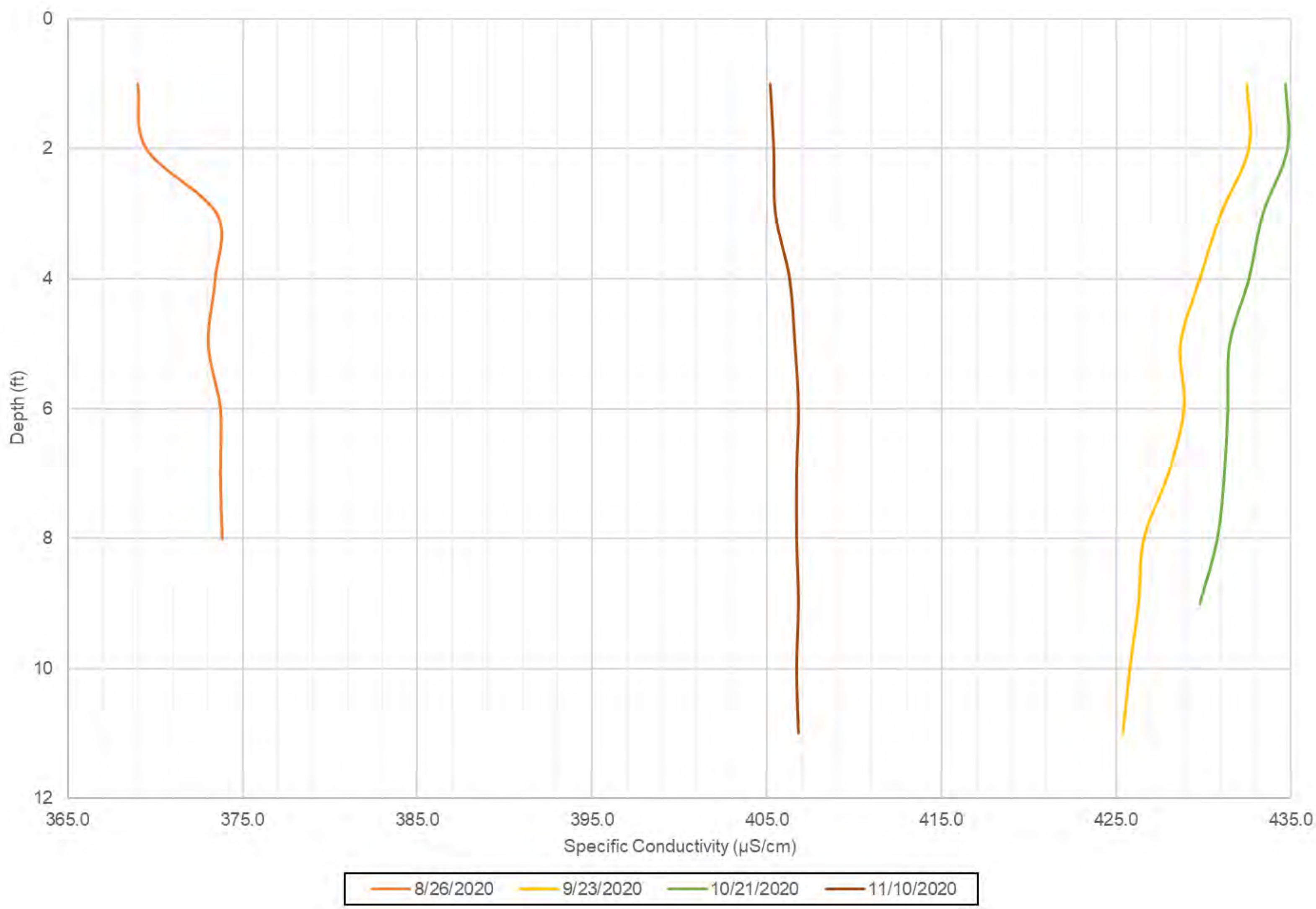

Figure 3-5. Forebay Vertical Profile—Specific Conductivity (2020)

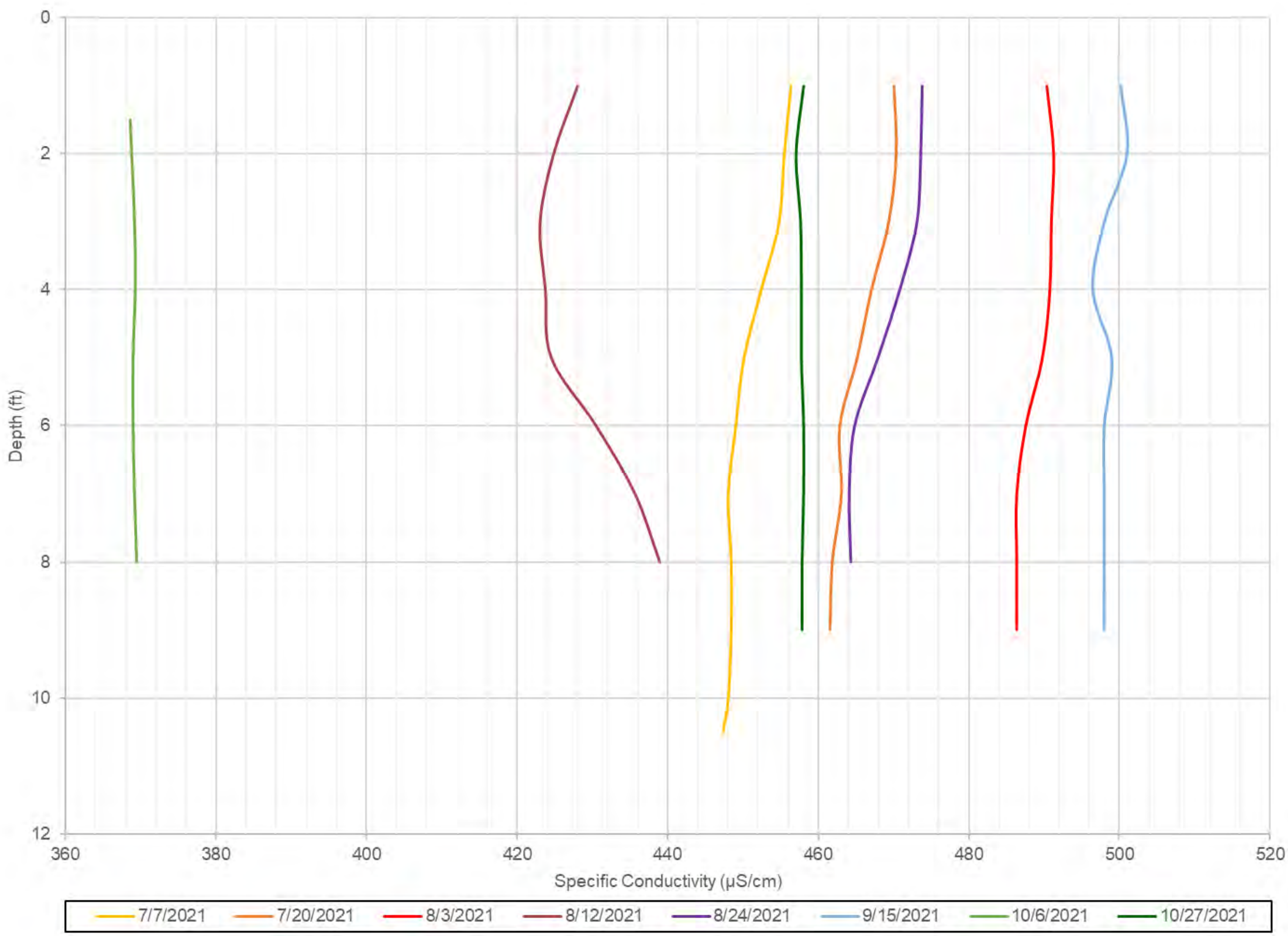

Figure 3-6. Forebay Vertical Profile—Specific Conductivity (2021)

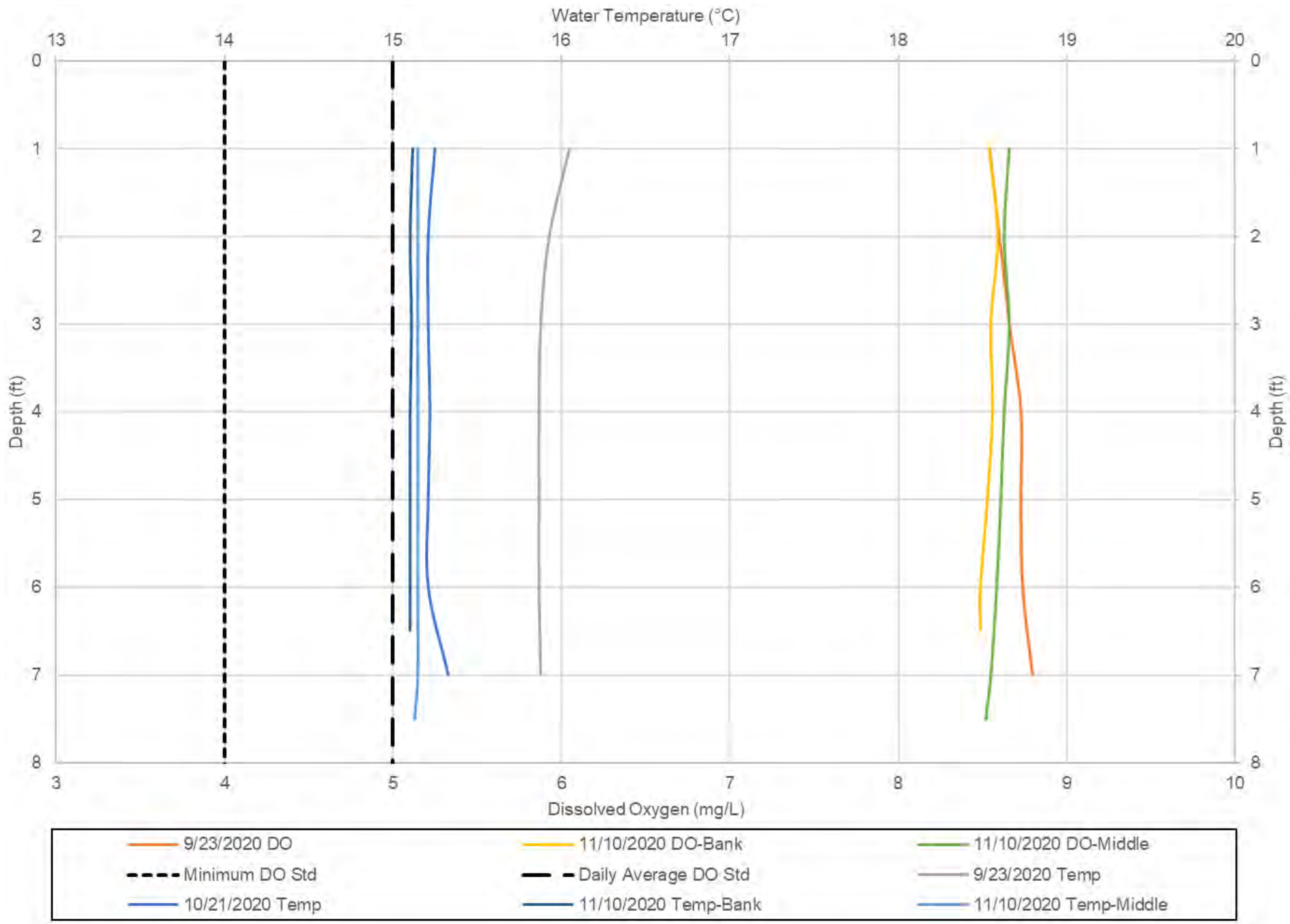

Figure 3-7. Reservoir Vertical Profile—Temperature and Dissolved Oxygen Concentration (2020)

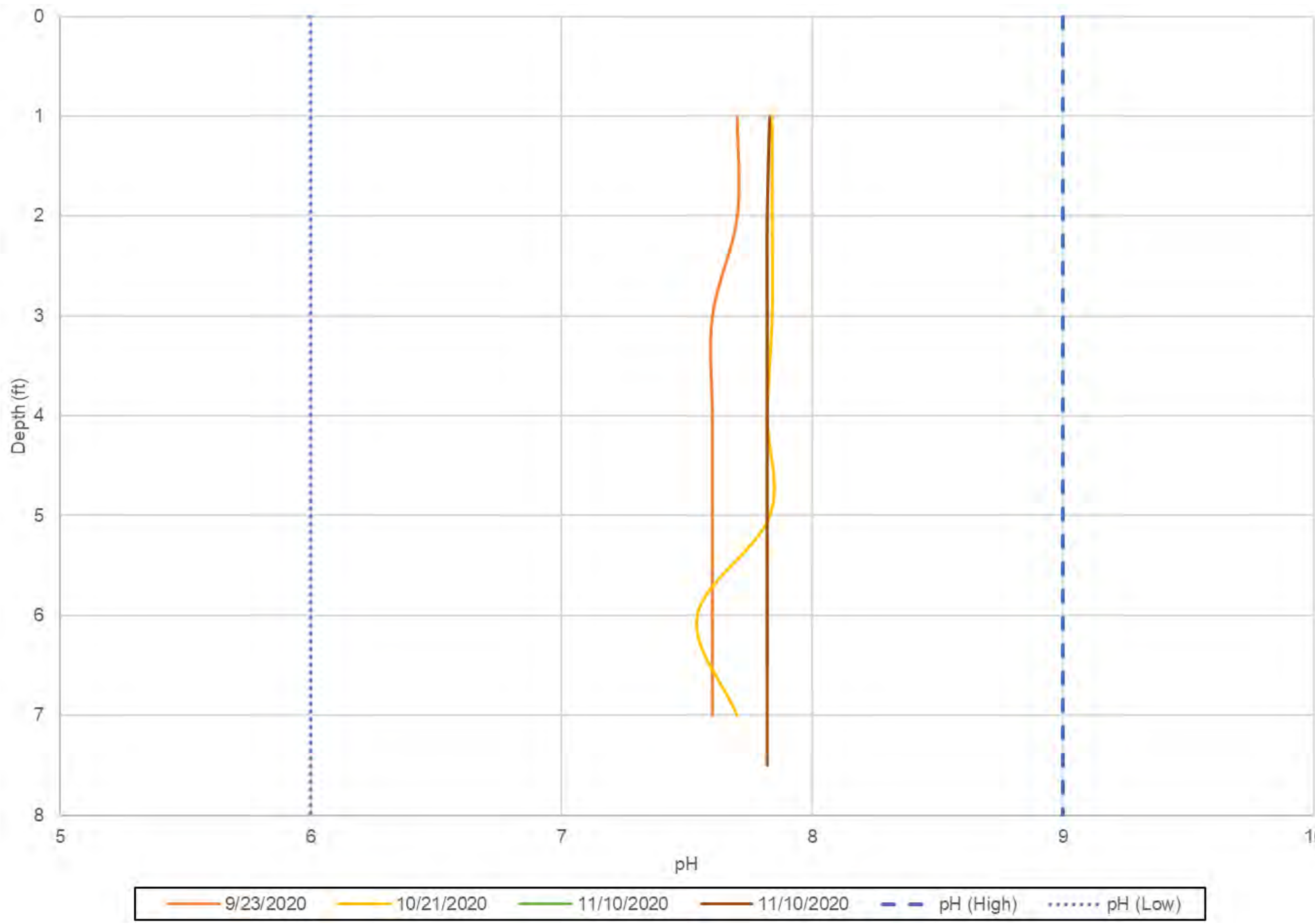

Figure 3-8. Reservoir Vertical Profile—pH (2020)

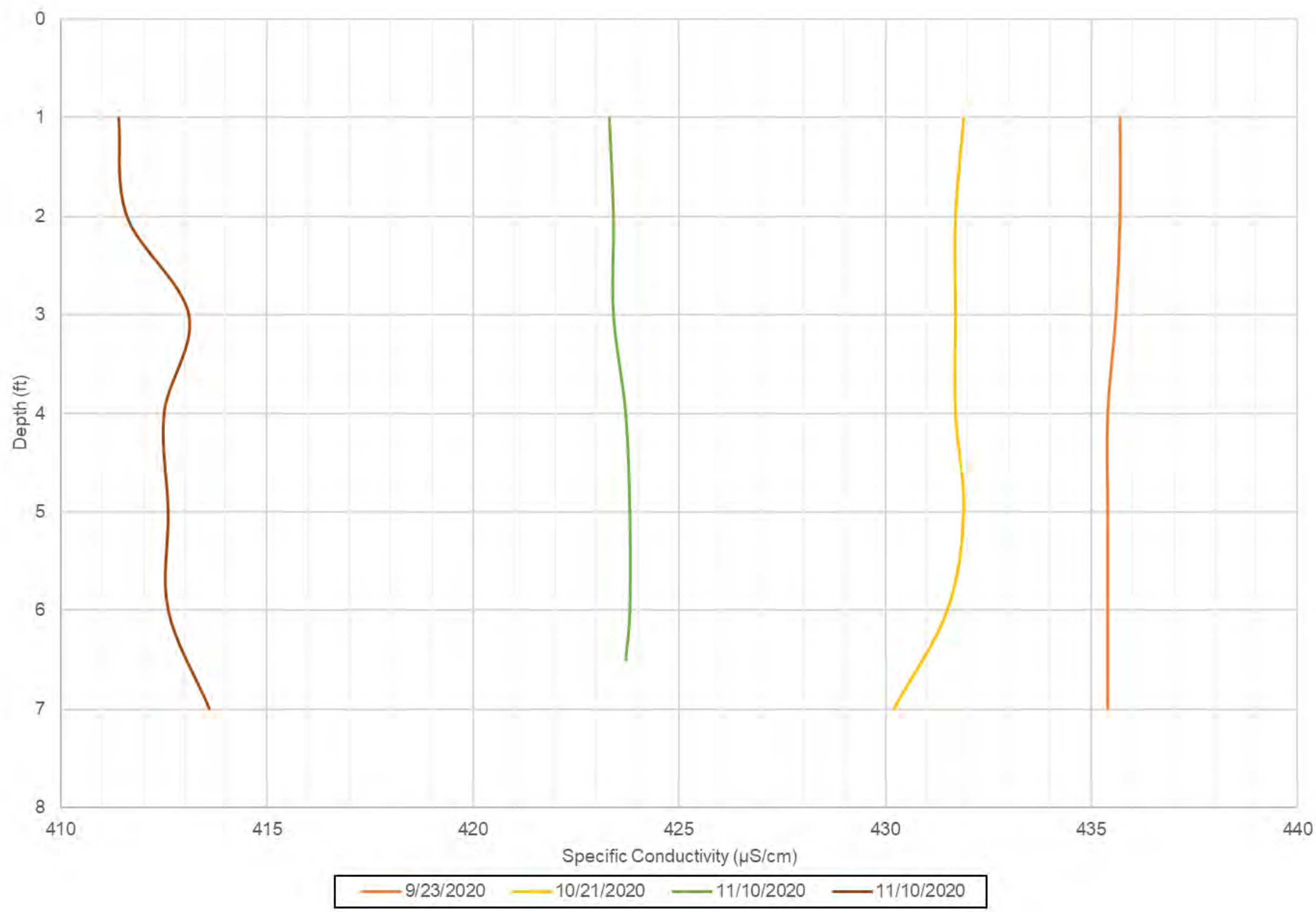

Figure 3-9. Reservoir Vertical Profile—Specific Conductivity (2020)

Attachment 4

Attachment 4 – Estimated Flow and Precipitation Comparison

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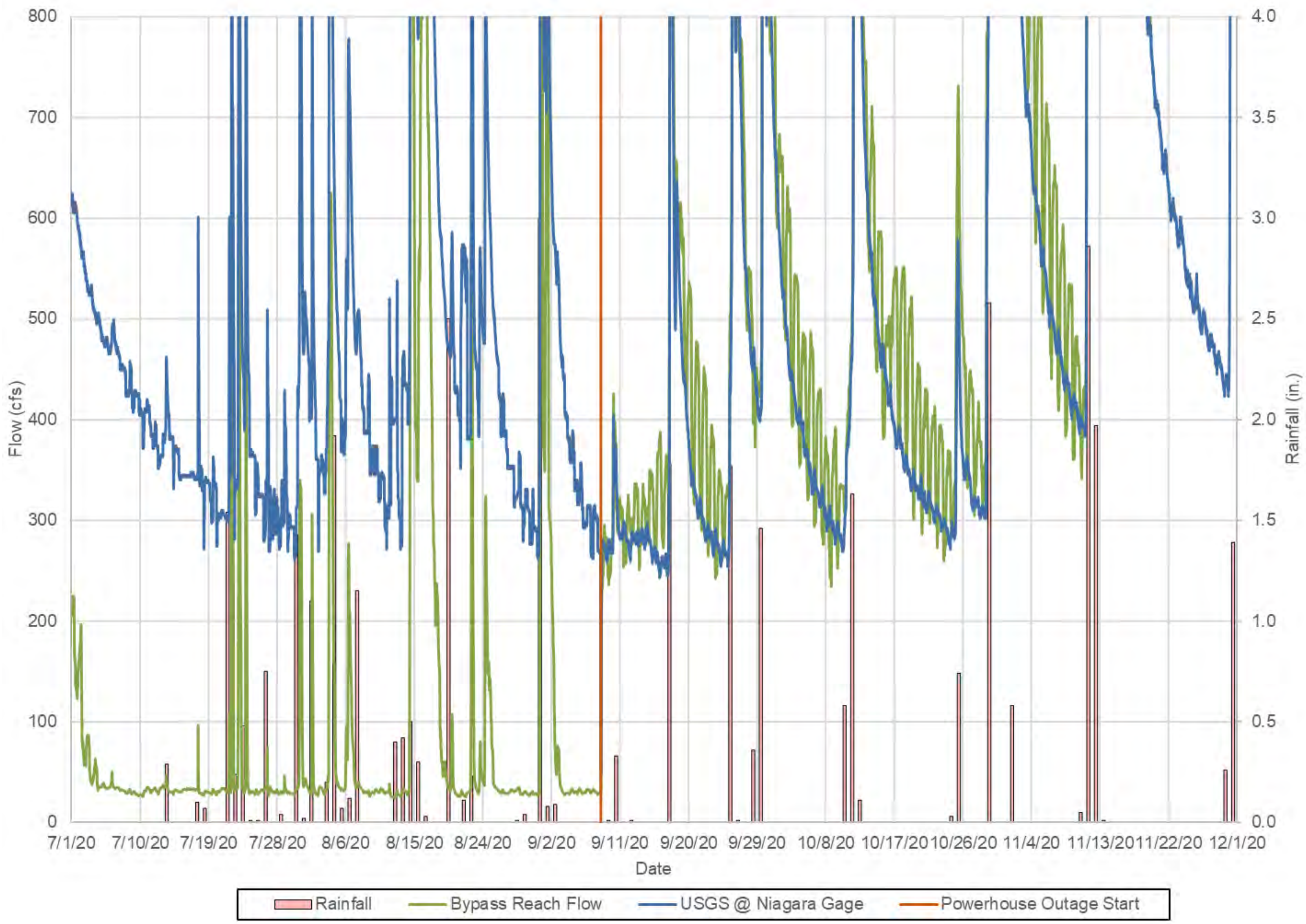

Figure 4-1. Bypass Reach Estimated Flow, Downstream Roanoke River Flow, and Rainfall Comparison (2020)

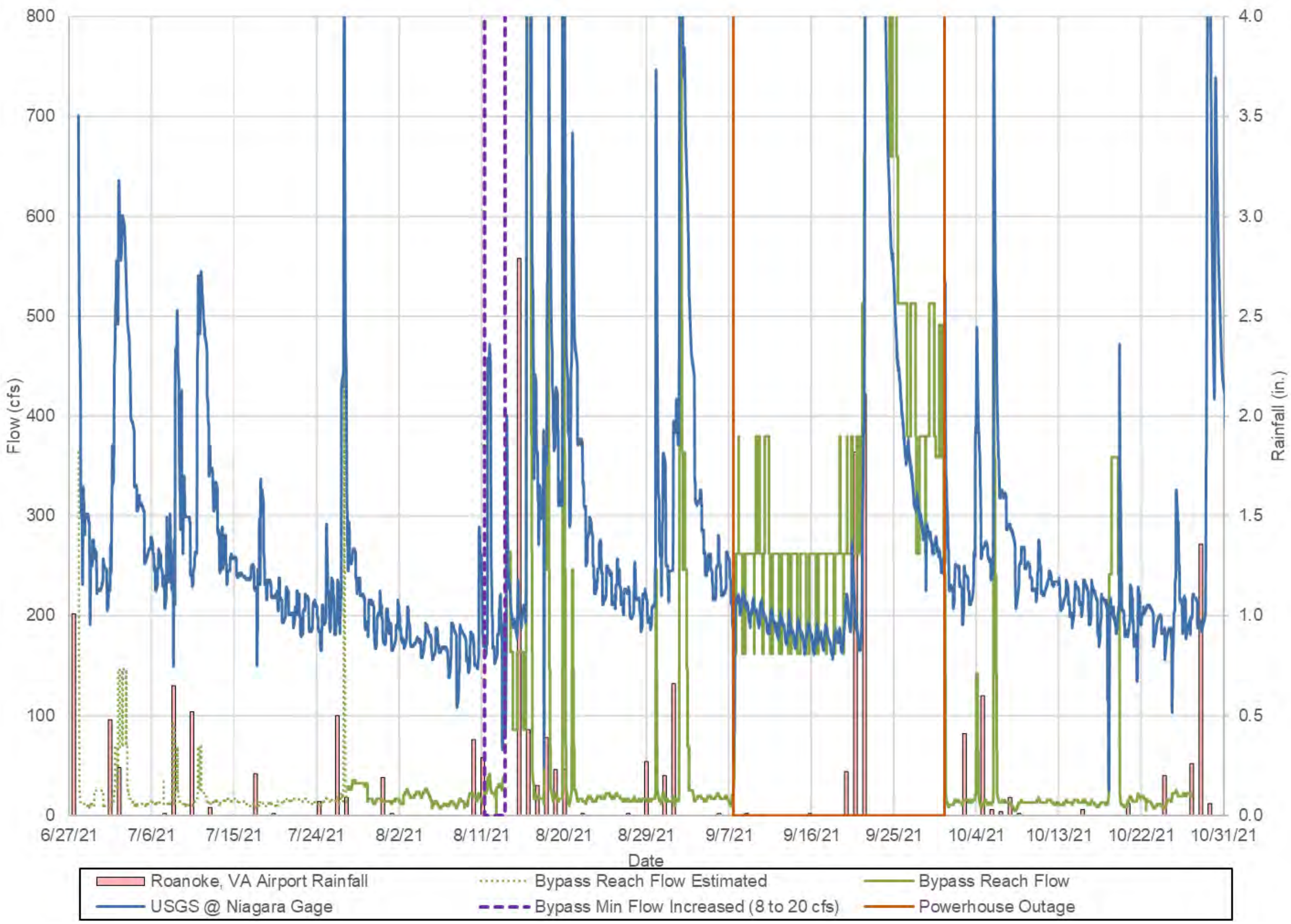

Figure 4-2. Bypass Reach Estimated Flow, Downstream Roanoke River Flow, and Rainfall Comparison (2021)

Attachment 5

Attachment 5 – Daily Water Quality Data Tables

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Table 1. Niagara Upstream Bypass Reach Monitoring Location - Daily Water Quality Data

Bypass Reach: Upstream	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
7/29/2020	7.36	8.18	9.02	25.74	25.89	26.02	78.33	78.59	78.84
7/30/2020	7.36	7.89	9.11	24.52	25.38	25.98	76.14	77.68	78.76
7/31/2020	7.57	8.12	8.69	23.94	24.50	24.92	75.09	76.10	76.86
8/1/2020	6.79	7.71	9.23	24.18	24.62	25.04	75.52	76.32	77.07
8/2/2020	6.64	7.40	8.70	24.54	24.87	25.76	76.17	76.76	78.37
8/3/2020	6.27	7.61	8.70	23.36	24.16	24.72	74.05	75.48	76.50
8/4/2020	8.16	8.61	8.97	22.14	22.92	23.64	71.85	73.26	74.55
8/5/2020	7.94	8.51	9.64	22.96	23.58	24.32	73.33	74.44	75.78
8/6/2020	8.08	8.41	8.83	22.18	23.07	23.56	71.92	73.52	74.41
8/7/2020	7.96	8.46	9.19	22.52	23.03	23.54	72.54	73.46	74.37
8/8/2020	7.71	8.41	9.62	23.00	23.69	24.52	73.40	74.65	76.14
8/9/2020	7.49	8.33	9.63	23.76	24.55	25.66	74.77	76.19	78.19
8/10/2020	6.80	7.98	9.39	24.40	24.80	25.62	75.92	76.65	78.12
8/11/2020	6.45	7.64	9.10	24.26	24.68	25.30	75.67	76.42	77.54
8/12/2020	6.06	6.95	8.57	24.50	25.09	25.76	76.10	77.17	78.37
8/13/2020	-	-	-	-	-	-	-	-	-
8/14/2020	-	-	-	-	-	-	-	-	-
8/15/2020	-	-	-	-	-	-	-	-	-
8/16/2020	-	-	-	-	-	-	-	-	-
8/17/2020	-	-	-	-	-	-	-	-	-
8/18/2020	-	-	-	-	-	-	-	-	-
8/19/2020	-	-	-	-	-	-	-	-	-
8/20/2020	-	-	-	-	-	-	-	-	-
8/21/2020	-	-	-	-	-	-	-	-	-
8/22/2020	-	-	-	-	-	-	-	-	-
8/23/2020	-	-	-	-	-	-	-	-	-
8/24/2020	-	-	-	-	-	-	-	-	-
8/25/2020	-	-	-	-	-	-	-	-	-
8/26/2020	7.99	8.52	9.23	23.84	24.00	24.32	74.91	75.20	75.78
8/27/2020	7.85	8.28	9.12	23.56	23.98	24.76	74.41	75.16	76.57
8/28/2020	7.50	8.06	8.87	23.90	24.27	24.92	75.02	75.68	76.86
8/29/2020	7.22	7.66	8.51	24.00	24.53	25.14	75.20	76.16	77.25
8/30/2020	7.05	7.49	8.34	23.56	24.09	24.76	74.41	75.37	76.57
8/31/2020	7.02	8.06	9.13	21.46	22.79	23.82	70.63	73.02	74.88
9/1/2020	8.77	8.90	9.06	20.86	21.17	21.46	69.55	70.10	70.63
9/2/2020	8.27	8.60	8.82	21.02	21.82	22.82	69.84	71.27	73.08
9/3/2020	7.46	8.13	8.95	22.66	23.39	24.48	72.79	74.11	76.06
9/4/2020	7.45	7.98	9.11	23.44	24.04	24.92	74.19	75.27	76.86
9/5/2020	7.44	8.06	9.17	22.50	23.49	23.98	72.50	74.29	75.16
9/6/2020	7.74	8.39	9.48	21.58	22.41	22.94	70.84	72.35	73.29
9/7/2020	7.92	8.50	9.63	21.48	21.82	22.60	70.66	71.28	72.68
9/8/2020	7.96	8.59	9.53	21.38	21.81	22.76	70.48	71.26	72.97
9/9/2020	8.68	8.79	9.00	21.98	22.15	22.34	71.56	71.87	72.21
9/10/2020	8.65	8.82	9.00	21.90	22.15	22.50	71.42	71.87	72.50
9/11/2020	8.41	8.59	8.80	22.06	22.56	23.06	71.71	72.61	73.51
9/12/2020	8.30	8.42	8.57	22.22	22.72	22.94	72.00	72.89	73.29
9/13/2020	8.39	8.59	8.87	21.84	22.12	22.50	71.31	71.82	72.50
9/14/2020	8.46	8.61	8.82	21.80	22.27	22.88	71.24	72.09	73.18
9/15/2020	8.43	8.67	8.90	21.12	21.96	22.26	70.02	71.52	72.07
9/16/2020	8.66	8.88	9.10	19.40	20.33	21.08	66.92	68.59	69.94
9/17/2020	9.00	9.36	9.80	18.18	18.73	19.32	64.72	65.72	66.78
9/18/2020	9.22	9.37	9.53	18.38	18.84	19.46	65.08	65.91	67.03

Bypass Reach: Upstream	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
9/19/2020	9.12	9.27	9.42	17.98	18.72	19.46	64.36	65.70	67.03
9/20/2020	9.39	9.62	9.90	16.44	17.43	18.04	61.59	63.37	64.47
9/21/2020	9.59	9.77	10.00	15.96	16.72	17.06	60.73	62.10	62.71
9/22/2020	8.92	9.32	9.87	15.86	16.50	17.24	60.55	61.70	63.03
9/23/2020	9.58	9.78	9.98	15.76	16.78	17.56	60.37	62.20	63.61
9/24/2020	9.47	9.60	9.80	16.74	17.45	17.86	62.13	63.41	64.15
9/25/2020	9.50	9.64	9.95	17.16	17.44	17.74	62.89	63.40	63.93
9/26/2020	9.50	9.62	9.76	17.32	17.61	17.92	63.18	63.71	64.26
9/27/2020	9.30	9.46	9.59	17.66	18.02	18.60	63.79	64.43	65.48
9/28/2020	9.12	9.26	9.42	18.46	18.78	19.20	65.23	65.81	66.56
9/29/2020	9.05	9.21	9.49	17.98	19.04	19.48	64.36	66.26	67.06
9/30/2020	9.48	9.59	9.71	17.10	17.37	17.96	62.78	63.27	64.33
10/1/2020	9.50	9.64	9.74	16.54	16.90	17.36	61.77	62.43	63.25
10/2/2020	9.50	9.61	9.72	16.74	16.97	17.34	62.13	62.55	63.21
10/3/2020	9.59	9.81	9.97	15.54	16.16	16.96	59.97	61.08	62.53
10/4/2020	9.78	9.93	10.13	15.16	15.52	16.04	59.29	59.94	60.87
10/5/2020	9.77	9.89	10.08	15.28	15.68	16.00	59.50	60.22	60.80
10/6/2020	9.69	9.81	9.97	15.32	15.86	16.32	59.58	60.55	61.38
10/7/2020	9.45	9.64	9.82	15.50	16.43	17.10	59.90	61.58	62.78
10/8/2020	9.27	9.46	9.71	16.24	17.25	17.88	61.23	63.06	64.18
10/9/2020	9.18	9.44	9.67	16.76	17.39	17.82	62.17	63.29	64.08
10/10/2020	9.41	9.48	9.63	16.60	16.97	17.32	61.88	62.55	63.18
10/11/2020	9.32	9.46	9.63	16.60	17.10	17.64	61.88	62.77	63.75
10/12/2020	9.37	9.43	9.51	17.44	17.52	17.60	63.39	63.53	63.68
10/13/2020	9.21	9.34	9.43	17.32	17.59	18.06	63.18	63.67	64.51
10/14/2020	9.18	9.41	9.56	16.74	17.20	18.06	62.13	62.96	64.51
10/15/2020	9.38	9.48	9.64	16.14	16.54	17.02	61.05	61.76	62.64
10/16/2020	9.25	9.38	9.54	16.04	16.48	17.02	60.87	61.67	62.64
10/17/2020	9.51	9.73	9.91	14.00	15.11	16.06	57.20	59.21	60.91
10/18/2020	9.74	9.99	10.23	13.34	14.04	14.54	56.01	57.26	58.17
10/19/2020	9.74	9.96	10.15	13.34	13.95	14.20	56.01	57.11	57.56
10/20/2020	9.59	9.73	10.00	13.78	14.72	15.22	56.80	58.49	59.40
10/21/2020	9.47	9.71	10.00	14.74	15.69	16.24	58.53	60.25	61.23
10/22/2020	9.60	9.77	9.97	15.90	16.80	17.32	60.62	62.24	63.18
10/23/2020	9.44	9.62	9.86	16.74	17.36	17.82	62.13	63.25	64.08
10/24/2020	9.36	9.49	9.71	17.16	17.70	18.24	62.89	63.85	64.83
10/25/2020	9.43	9.55	9.68	16.58	17.29	17.90	61.84	63.13	64.22
10/26/2020	9.62	9.70	9.85	15.96	16.38	16.64	60.73	61.48	61.95
10/27/2020	9.56	9.64	9.81	15.98	16.40	16.64	60.76	61.52	61.95
10/28/2020	9.41	9.49	9.61	16.10	16.63	16.88	60.98	61.94	62.38
10/29/2020	9.33	9.59	9.90	16.52	17.45	18.52	61.74	63.41	65.34
10/30/2020	9.90	10.05	10.30	14.68	16.10	17.16	58.42	60.97	62.89
10/31/2020	10.30	10.54	10.70	12.72	13.37	14.64	54.90	56.06	58.35
11/1/2020	10.35	10.55	10.74	12.06	12.52	12.92	53.71	54.53	55.26
11/2/2020	10.50	10.92	11.16	10.54	11.10	12.50	50.97	51.98	54.50
11/3/2020	11.00	11.15	11.30	9.92	10.26	10.78	49.86	50.47	51.40
11/4/2020	10.83	11.04	11.20	10.46	10.78	11.46	50.83	51.40	52.63
11/5/2020	10.62	10.83	10.98	11.08	11.45	12.08	51.94	52.61	53.74
11/6/2020	10.42	10.62	10.80	11.62	12.02	12.60	52.92	53.64	54.68
11/7/2020	10.29	10.45	10.66	12.14	12.55	12.98	53.85	54.59	55.36
11/8/2020	10.10	10.24	10.45	12.82	13.23	13.66	55.08	55.81	56.59
11/9/2020	8.94	9.97	10.23	13.72	14.02	14.24	56.70	57.23	57.63

Table 2. Niagara Downstream Bypass Reach Monitoring Location - Daily Water Quality Data

Bypass Reach: Downstream	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
7/29/2020	7.05	8.63	10.22	25.78	26.44	27.10	78.40	79.60	80.78
7/30/2020	7.06	8.02	10.10	24.56	25.57	26.80	76.21	78.02	80.24
7/31/2020	7.73	8.35	9.21	24.20	24.71	25.50	75.56	76.48	77.90
8/1/2020	7.51	8.15	10.17	24.28	24.73	25.36	75.70	76.52	77.65
8/2/2020	7.51	8.30	9.93	24.64	25.13	26.56	76.35	77.23	79.81
8/3/2020	7.57	8.34	9.61	23.42	24.24	24.72	74.16	75.64	76.50
8/4/2020	8.21	8.61	8.96	22.26	23.08	24.00	72.07	73.54	75.20
8/5/2020	7.87	8.56	9.80	23.06	23.79	25.34	73.51	74.83	77.61
8/6/2020	8.12	8.50	8.98	22.28	23.14	23.56	72.10	73.66	74.41
8/7/2020	8.03	8.57	9.46	22.62	23.21	24.00	72.72	73.78	75.20
8/8/2020	7.73	8.61	10.10	23.04	23.88	25.28	73.47	74.98	77.50
8/9/2020	7.61	8.57	10.19	23.88	24.77	26.14	74.98	76.59	79.05
8/10/2020	7.61	8.43	10.19	24.40	24.98	26.28	75.92	76.96	79.30
8/11/2020	7.41	8.38	10.11	24.20	24.94	26.06	75.56	76.89	78.91
8/12/2020	7.23	8.25	10.24	24.52	25.25	26.46	76.14	77.46	79.63
8/13/2020	-	-	-	-	-	-	-	-	-
8/14/2020	-	-	-	-	-	-	-	-	-
8/15/2020	-	-	-	-	-	-	-	-	-
8/16/2020	-	-	-	-	-	-	-	-	-
8/17/2020	-	-	-	-	-	-	-	-	-
8/18/2020	-	-	-	-	-	-	-	-	-
8/19/2020	-	-	-	-	-	-	-	-	-
8/20/2020	-	-	-	-	-	-	-	-	-
8/21/2020	-	-	-	-	-	-	-	-	-
8/22/2020	-	-	-	-	-	-	-	-	-
8/23/2020	-	-	-	-	-	-	-	-	-
8/24/2020	-	-	-	-	-	-	-	-	-
8/25/2020	-	-	-	-	-	-	-	-	-
8/26/2020	7.91	8.83	10.04	23.82	24.42	25.30	74.88	75.96	77.54
8/27/2020	7.91	8.60	9.99	23.60	24.25	25.40	74.48	75.65	77.72
8/28/2020	7.74	8.45	9.86	23.90	24.53	25.84	75.02	76.15	78.51
8/29/2020	7.67	8.22	9.69	24.00	24.72	25.90	75.20	76.50	78.62
8/30/2020	7.73	8.35	9.72	23.56	24.27	25.36	74.41	75.69	77.65
8/31/2020	7.74	8.39	9.07	21.52	22.77	23.76	70.74	72.99	74.77
9/1/2020	8.83	8.94	9.11	20.96	21.24	21.52	69.73	70.23	70.74
9/2/2020	8.40	8.87	9.33	21.10	21.96	23.00	69.98	71.53	73.40
9/3/2020	7.76	8.69	10.12	22.64	23.75	25.68	72.75	74.75	78.22
9/4/2020	7.73	8.60	10.28	23.36	24.34	25.96	74.05	75.81	78.73
9/5/2020	7.78	8.74	10.45	22.24	23.63	24.86	72.03	74.53	76.75
9/6/2020	8.03	8.95	10.61	21.46	22.60	24.24	70.63	72.67	75.63
9/7/2020	8.08	8.98	10.58	21.20	22.07	23.92	70.16	71.72	75.06
9/8/2020	8.08	8.84	10.64	21.12	21.86	23.60	70.02	71.35	74.48
9/9/2020	8.67	8.83	9.21	22.00	22.19	22.50	71.60	71.95	72.50
9/10/2020	8.63	8.81	9.07	21.96	22.20	22.54	71.53	71.96	72.57
9/11/2020	8.52	8.73	9.13	22.08	22.61	23.24	71.74	72.70	73.83
9/12/2020	8.48	8.61	8.97	22.28	22.76	22.96	72.10	72.98	73.33
9/13/2020	8.53	8.80	9.24	21.88	22.19	22.60	71.38	71.94	72.68
9/14/2020	8.55	8.79	9.24	21.84	22.32	22.96	71.31	72.18	73.33
9/15/2020	8.64	8.90	9.40	21.14	22.00	22.38	70.05	71.61	72.28
9/16/2020	8.81	9.13	9.61	19.44	20.38	21.10	66.99	68.68	69.98
9/17/2020	9.08	9.26	9.49	18.24	18.79	19.38	64.83	65.83	66.88
9/18/2020	8.96	9.12	9.35	18.42	18.91	19.48	65.16	66.03	67.06

Bypass Reach: Downstream	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
9/19/2020	8.98	9.30	9.60	18.00	18.79	19.50	64.40	65.81	67.10
9/20/2020	9.33	9.68	10.06	16.48	17.50	18.04	61.66	63.51	64.47
9/21/2020	9.64	9.89	10.28	16.02	16.79	17.30	60.84	62.22	63.14
9/22/2020	9.70	9.92	10.29	15.88	16.56	17.64	60.58	61.81	63.75
9/23/2020	9.53	9.87	10.36	15.80	16.84	17.74	60.44	62.32	63.93
9/24/2020	9.42	9.62	10.12	16.76	17.50	17.94	62.17	63.49	64.29
9/25/2020	9.44	9.60	9.84	17.24	17.50	17.80	63.03	63.50	64.04
9/26/2020	9.47	9.60	9.73	17.36	17.69	17.98	63.25	63.84	64.36
9/27/2020	9.25	9.48	9.75	17.74	18.09	18.64	63.93	64.57	65.55
9/28/2020	9.08	9.27	9.60	18.52	18.85	19.22	65.34	65.93	66.60
9/29/2020	9.00	9.16	9.40	18.04	19.10	19.54	64.47	66.38	67.17
9/30/2020	9.38	9.57	9.74	17.28	17.45	18.02	63.10	63.40	64.44
10/1/2020	9.50	9.66	9.88	16.58	16.98	17.40	61.84	62.57	63.32
10/2/2020	9.50	9.67	9.89	16.76	17.05	17.40	62.17	62.69	63.32
10/3/2020	9.62	9.90	10.20	15.58	16.23	16.96	60.04	61.22	62.53
10/4/2020	9.82	10.04	10.38	15.20	15.60	16.04	59.36	60.08	60.87
10/5/2020	9.79	10.00	10.36	15.30	15.75	16.18	59.54	60.35	61.12
10/6/2020	9.74	9.94	10.31	15.32	15.93	16.52	59.58	60.68	61.74
10/7/2020	9.52	9.75	10.15	15.52	16.51	17.30	59.94	61.71	63.14
10/8/2020	9.34	9.60	10.08	16.24	17.32	18.08	61.23	63.18	64.54
10/9/2020	9.37	9.60	10.10	16.82	17.43	17.98	62.28	63.38	64.36
10/10/2020	9.40	9.54	9.87	16.66	17.04	17.42	61.99	62.66	63.36
10/11/2020	9.46	9.53	9.62	16.68	17.16	17.70	62.02	62.89	63.86
10/12/2020	9.38	9.48	9.59	17.50	17.59	17.66	63.50	63.66	63.79
10/13/2020	9.36	9.51	9.72	17.38	17.67	18.06	63.28	63.80	64.51
10/14/2020	9.35	9.60	9.86	16.76	17.27	18.06	62.17	63.08	64.51
10/15/2020	9.57	9.73	10.06	16.20	16.62	17.04	61.16	61.91	62.67
10/16/2020	9.51	9.74	10.07	16.04	16.53	17.08	60.87	61.76	62.74
10/17/2020	9.79	10.13	10.44	14.00	15.18	16.06	57.20	59.33	60.91
10/18/2020	10.18	10.42	10.74	13.38	14.11	14.54	56.08	57.40	58.17
10/19/2020	10.23	10.41	10.74	13.38	14.03	14.44	56.08	57.25	57.99
10/20/2020	9.99	10.21	10.56	13.80	14.79	15.46	56.84	58.62	59.83
10/21/2020	9.80	10.01	10.39	14.78	15.76	16.48	58.60	60.36	61.66
10/22/2020	9.54	9.82	10.32	15.92	16.86	17.56	60.66	62.35	63.61
10/23/2020	9.38	9.67	10.23	16.76	17.42	18.08	62.17	63.36	64.54
10/24/2020	9.17	9.53	10.10	17.18	17.76	18.42	62.92	63.97	65.16
10/25/2020	9.38	9.53	9.66	16.62	17.33	17.90	61.92	63.20	64.22
10/26/2020	9.65	9.80	10.16	16.02	16.46	16.84	60.84	61.62	62.31
10/27/2020	9.63	9.78	10.19	16.02	16.46	16.82	60.84	61.64	62.28
10/28/2020	9.57	9.68	10.00	16.14	16.70	17.00	61.05	62.05	62.60
10/29/2020	9.43	9.55	9.78	16.58	17.52	18.60	61.84	63.54	65.48
10/30/2020	9.76	10.03	10.35	14.74	16.16	17.26	58.53	61.09	63.07
10/31/2020	10.36	10.66	10.80	12.78	13.44	14.70	55.00	56.19	58.46
11/1/2020	10.52	10.71	10.87	12.14	12.59	12.96	53.85	54.66	55.33
11/2/2020	10.69	11.10	11.34	10.60	11.16	12.54	51.08	52.09	54.57
11/3/2020	11.17	11.33	11.49	10.00	10.33	10.84	50.00	50.59	51.51
11/4/2020	10.95	11.19	11.34	10.50	10.85	11.50	50.90	51.53	52.70
11/5/2020	10.72	10.97	11.14	11.12	11.52	12.10	52.02	52.73	53.78
11/6/2020	10.52	10.74	10.95	11.66	12.09	12.62	52.99	53.77	54.72
11/7/2020	10.44	10.60	10.83	12.20	12.63	13.02	53.96	54.73	55.44
11/8/2020	10.30	10.42	10.66	12.86	13.30	13.70	55.15	55.95	56.66
11/9/2020	10.09	10.26	10.49	13.76	14.09	14.34	56.77	57.36	57.81

Table 3. Niagara Tailrace Monitoring Location - Daily Water Quality Data

Tailrace	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
7/29/2020	6.93	7.22	7.75	25.26	25.64	25.90	77.47	78.16	78.62
7/30/2020	6.76	7.52	7.97	24.64	25.36	25.84	76.35	77.64	78.51
7/31/2020	6.78	7.15	7.80	23.94	24.39	24.94	75.09	75.91	76.89
8/1/2020	7.01	7.49	8.06	24.22	24.63	25.06	75.60	76.33	77.11
8/2/2020	7.22	7.44	7.85	24.44	24.80	25.02	75.99	76.63	77.04
8/3/2020	7.15	7.68	8.19	23.50	24.25	24.96	74.30	75.66	76.93
8/4/2020	7.50	7.72	7.93	22.18	22.77	23.60	71.92	72.98	74.48
8/5/2020	7.30	7.61	8.04	23.04	23.44	23.84	73.47	74.20	74.91
8/6/2020	7.46	7.81	8.16	22.24	23.12	23.68	72.03	73.62	74.62
8/7/2020	7.54	7.80	8.30	22.54	22.95	23.44	72.57	73.30	74.19
8/8/2020	7.50	7.91	8.48	23.04	23.53	24.12	73.47	74.36	75.42
8/9/2020	7.34	7.90	8.47	23.66	24.31	24.84	74.59	75.76	76.71
8/10/2020	7.33	7.83	8.40	24.50	24.75	25.02	76.10	76.55	77.04
8/11/2020	7.26	7.89	8.27	24.26	24.50	24.80	75.67	76.11	76.64
8/12/2020	7.15	7.61	8.30	24.54	25.02	25.40	76.17	77.03	77.72
8/13/2020	-	-	-	-	-	-	-	-	-
8/14/2020	-	-	-	-	-	-	-	-	-
8/15/2020	-	-	-	-	-	-	-	-	-
8/16/2020	-	-	-	-	-	-	-	-	-
8/17/2020	-	-	-	-	-	-	-	-	-
8/18/2020	-	-	-	-	-	-	-	-	-
8/19/2020	-	-	-	-	-	-	-	-	-
8/20/2020	-	-	-	-	-	-	-	-	-
8/21/2020	-	-	-	-	-	-	-	-	-
8/22/2020	-	-	-	-	-	-	-	-	-
8/23/2020	-	-	-	-	-	-	-	-	-
8/24/2020	-	-	-	-	-	-	-	-	-
8/25/2020	-	-	-	-	-	-	-	-	-
8/26/2020	7.38	7.81	8.23	23.34	23.74	23.94	74.01	74.73	75.09
8/27/2020	7.62	8.02	8.42	23.48	23.86	24.12	74.26	74.95	75.42
8/28/2020	7.51	8.01	8.57	23.94	24.18	24.38	75.09	75.53	75.88
8/29/2020	7.32	7.82	8.46	24.14	24.51	24.78	75.45	76.12	76.60
8/30/2020	7.26	7.69	8.16	23.74	24.17	24.40	74.73	75.50	75.92
8/31/2020	7.15	7.81	8.25	21.60	22.96	24.04	70.88	73.32	75.27
9/1/2020	7.23	8.00	8.69	20.94	21.31	21.58	69.69	70.35	70.84
9/2/2020	7.81	7.99	8.37	21.06	21.62	22.96	69.91	70.92	73.33
9/3/2020	7.46	7.77	8.41	22.76	23.29	23.98	72.97	73.92	75.16
9/4/2020	7.30	7.69	8.68	23.56	23.99	24.32	74.41	75.18	75.78
9/5/2020	7.55	7.92	8.25	22.88	23.65	24.16	73.18	74.56	75.49
9/6/2020	7.98	8.33	8.68	21.80	22.53	23.06	71.24	72.56	73.51
9/7/2020	8.20	8.61	9.06	21.64	21.88	22.12	70.95	71.39	71.82
9/8/2020	7.78	8.47	9.21	21.62	22.01	25.80	70.92	71.62	78.44
9/9/2020	7.61	8.29	8.96	21.92	22.23	22.40	71.46	72.02	72.32
9/10/2020	7.31	7.93	8.57	22.02	22.20	22.38	71.64	71.97	72.28
9/11/2020	7.32	7.79	8.42	22.14	22.58	23.06	71.85	72.65	73.51
9/12/2020	7.00	7.78	8.43	22.58	22.90	23.08	72.64	73.21	73.54
9/13/2020	7.06	7.63	8.24	22.08	22.30	22.56	71.74	72.15	72.61
9/14/2020	7.56	8.16	8.85	21.98	22.38	22.92	71.56	72.29	73.26
9/15/2020	7.59	8.29	9.08	21.72	22.29	22.60	71.10	72.12	72.68
9/16/2020	7.50	8.47	9.44	19.78	20.73	21.68	67.60	69.32	71.02
9/17/2020	8.17	8.96	9.61	18.34	18.97	19.74	65.01	66.15	67.53
9/18/2020	8.55	8.76	9.03	18.42	18.94	19.50	65.16	66.08	67.10

Tailrace	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
9/19/2020	8.53	8.80	9.04	18.24	19.02	19.58	64.83	66.23	67.24
9/20/2020	8.67	9.16	9.77	16.94	17.82	18.22	62.49	64.07	64.80
9/21/2020	9.00	9.39	9.83	16.48	17.04	17.46	61.66	62.67	63.43
9/22/2020	9.32	9.72	10.16	16.16	16.72	17.38	61.09	62.10	63.28
9/23/2020	9.24	9.81	10.48	16.02	16.84	17.56	60.84	62.32	63.61
9/24/2020	8.82	9.60	10.29	16.90	17.50	17.90	62.42	63.50	64.22
9/25/2020	8.79	9.30	9.68	17.38	17.58	17.86	63.28	63.65	64.15
9/26/2020	9.17	9.30	9.43	17.42	17.73	18.02	63.36	63.92	64.44
9/27/2020	8.95	9.16	9.39	17.82	18.12	18.56	64.08	64.62	65.41
9/28/2020	8.63	8.99	9.40	18.58	18.87	19.16	65.44	65.97	66.49
9/29/2020	8.45	8.83	9.11	18.24	19.19	19.58	64.83	66.55	67.24
9/30/2020	8.86	9.10	9.53	17.40	17.57	18.20	63.32	63.63	64.76
10/1/2020	9.15	9.32	9.48	16.74	17.07	17.42	62.13	62.73	63.36
10/2/2020	8.95	9.25	9.53	16.90	17.19	17.44	62.42	62.94	63.39
10/3/2020	9.14	9.45	9.78	15.74	16.43	17.06	60.33	61.57	62.71
10/4/2020	9.34	9.67	10.09	15.34	15.74	16.14	59.61	60.33	61.05
10/5/2020	9.22	9.67	10.10	15.38	15.85	16.14	59.68	60.53	61.05
10/6/2020	8.68	9.39	9.99	15.48	16.03	16.38	59.86	60.85	61.48
10/7/2020	8.59	9.24	9.97	15.58	16.49	17.10	60.04	61.69	62.78
10/8/2020	8.32	8.99	9.73	16.30	17.32	17.96	61.34	63.17	64.33
10/9/2020	8.33	8.99	9.79	17.18	17.63	18.08	62.92	63.74	64.54
10/10/2020	8.52	9.29	10.02	16.76	17.14	17.46	62.17	62.85	63.43
10/11/2020	8.78	9.14	9.43	16.74	17.18	17.64	62.13	62.92	63.75
10/12/2020	8.80	9.02	9.30	17.58	17.65	17.70	63.64	63.76	63.86
10/13/2020	8.77	9.00	9.24	17.48	17.73	18.08	63.46	63.91	64.54
10/14/2020	8.82	9.06	9.34	16.90	17.43	18.14	62.42	63.37	64.65
10/15/2020	8.25	9.10	9.53	16.46	16.73	17.12	61.63	62.11	62.82
10/16/2020	8.65	9.07	9.55	16.22	16.68	17.06	61.20	62.02	62.71
10/17/2020	8.92	9.39	9.67	14.24	15.44	16.22	57.63	59.80	61.20
10/18/2020	9.24	9.66	10.20	13.66	14.33	14.72	56.59	57.79	58.50
10/19/2020	9.06	9.67	10.37	13.60	14.12	14.36	56.48	57.42	57.85
10/20/2020	8.93	9.52	10.23	13.86	14.76	15.24	56.95	58.58	59.43
10/21/2020	9.08	9.54	10.01	14.86	15.68	16.28	58.75	60.23	61.30
10/22/2020	8.90	9.59	10.38	15.98	16.80	17.26	60.76	62.23	63.07
10/23/2020	8.65	9.32	10.11	16.90	17.43	17.84	62.42	63.37	64.11
10/24/2020	8.42	9.18	10.05	17.32	17.80	18.18	63.18	64.03	64.72
10/25/2020	8.38	9.00	9.73	16.84	17.47	17.94	62.31	63.45	64.29
10/26/2020	8.34	8.66	8.95	16.20	16.64	16.82	61.16	61.95	62.28
10/27/2020	8.63	9.27	10.01	16.16	16.55	16.80	61.09	61.80	62.24
10/28/2020	8.42	9.09	9.77	16.26	16.74	17.02	61.27	62.13	62.64
10/29/2020	8.45	9.22	9.57	16.64	17.55	18.66	61.95	63.58	65.59
10/30/2020	9.54	9.73	9.99	14.94	16.28	17.32	58.89	61.30	63.18
10/31/2020	9.95	10.32	10.60	12.92	13.60	14.90	55.26	56.48	58.82
11/1/2020	10.27	10.47	10.62	12.26	12.67	13.00	54.07	54.81	55.40
11/2/2020	10.40	10.82	11.09	10.74	11.31	12.70	51.33	52.36	54.86
11/3/2020	11.00	11.07	11.12	10.12	10.42	10.84	50.22	50.75	51.51
11/4/2020	10.80	10.95	11.12	10.60	10.91	11.46	51.08	51.64	52.63
11/5/2020	10.40	10.64	10.91	11.22	11.58	12.02	52.20	52.85	53.64
11/6/2020	10.02	10.30	10.64	11.80	12.16	12.54	53.24	53.89	54.57
11/7/2020	9.81	10.03	10.33	12.38	12.70	12.92	54.28	54.86	55.26
11/8/2020	9.56	9.85	10.22	12.94	13.36	13.58	55.29	56.04	56.44
11/9/2020	8.83	9.62	10.30	13.62	14.12	14.32	56.52	57.41	57.78

Table 4. Niagara Forebay Bottom Monitoring Location - Daily Water Quality Data

Forebay: Bottom	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
7/29/2020	6.17	6.57	6.97	24.72	24.88	25.00	76.50	76.79	77.00
7/30/2020	6.49	7.06	7.75	24.54	25.00	25.56	76.17	77.00	78.01
7/31/2020	6.66	6.95	7.76	23.68	24.17	24.94	74.62	75.51	76.89
8/1/2020	6.84	7.36	7.92	24.04	24.47	25.02	75.27	76.04	77.04
8/2/2020	6.74	7.10	7.62	24.08	24.49	25.00	75.34	76.09	77.00
8/3/2020	6.99	7.47	8.15	23.46	24.16	24.92	74.23	75.50	76.86
8/4/2020	7.35	7.56	7.83	22.08	22.51	23.54	71.74	72.53	74.37
8/5/2020	7.14	7.37	7.81	22.64	23.07	23.72	72.75	73.53	74.70
8/6/2020	7.26	7.62	8.11	22.18	23.04	23.64	71.92	73.46	74.55
8/7/2020	7.21	7.48	8.02	22.36	22.72	23.40	72.25	72.90	74.12
8/8/2020	7.16	7.60	8.38	22.92	23.21	23.80	73.26	73.78	74.84
8/9/2020	6.89	7.41	8.31	23.42	23.86	24.56	74.16	74.96	76.21
8/10/2020	6.63	7.22	8.17	24.06	24.48	25.06	75.31	76.06	77.11
8/11/2020	6.31	6.99	7.61	23.68	24.13	24.52	74.62	75.44	76.14
8/12/2020	5.70	6.67	8.31	24.08	24.75	25.40	75.34	76.55	77.72
8/13/2020	-	-	-	-	-	-	-	-	-
8/14/2020	-	-	-	-	-	-	-	-	-
8/15/2020	-	-	-	-	-	-	-	-	-
8/16/2020	-	-	-	-	-	-	-	-	-
8/17/2020	-	-	-	-	-	-	-	-	-
8/18/2020	-	-	-	-	-	-	-	-	-
8/19/2020	-	-	-	-	-	-	-	-	-
8/20/2020	-	-	-	-	-	-	-	-	-
8/21/2020	-	-	-	-	-	-	-	-	-
8/22/2020	-	-	-	-	-	-	-	-	-
8/23/2020	-	-	-	-	-	-	-	-	-
8/24/2020	-	-	-	-	-	-	-	-	-
8/25/2020	-	-	-	-	-	-	-	-	-
8/26/2020	7.11	7.59	8.13	22.96	23.20	24.32	73.33	73.76	75.78
8/27/2020	7.30	7.77	8.40	23.16	23.55	24.10	73.69	74.38	75.38
8/28/2020	7.10	7.69	8.44	23.64	23.91	24.26	74.55	75.05	75.67
8/29/2020	6.89	7.52	8.40	24.04	24.39	24.66	75.27	75.90	76.39
8/30/2020	6.92	7.42	8.02	23.50	23.92	24.34	74.30	75.05	75.81
8/31/2020	7.24	7.80	8.37	21.54	22.89	24.02	70.77	73.20	75.24
9/1/2020	6.98	7.66	8.03	20.86	21.23	21.54	69.55	70.22	70.77
9/2/2020	7.69	7.84	8.24	20.98	21.39	22.86	69.76	70.51	73.15
9/3/2020	7.18	7.53	8.32	22.66	23.02	23.90	72.79	73.43	75.02
9/4/2020	6.91	7.34	7.87	23.42	23.72	24.06	74.16	74.69	75.31
9/5/2020	6.92	7.43	7.86	22.86	23.44	24.16	73.15	74.19	75.49
9/6/2020	7.26	7.81	8.24	21.46	22.26	23.08	70.63	72.07	73.54
9/7/2020	7.46	7.97	8.46	21.06	21.57	21.98	69.91	70.83	71.56
9/8/2020	3.26	6.83	8.56	21.10	21.52	21.80	69.98	70.73	71.24
9/9/2020	4.11	6.22	7.72	21.10	21.59	21.84	69.98	70.86	71.31
9/10/2020	4.59	6.51	7.63	21.70	21.83	22.02	71.06	71.29	71.64
9/11/2020	3.39	5.83	6.85	21.84	22.15	22.34	71.31	71.88	72.21
9/12/2020	4.93	5.90	6.60	22.24	22.49	22.72	72.03	72.48	72.90
9/13/2020	5.02	6.82	7.91	21.76	22.00	22.28	71.17	71.60	72.10
9/14/2020	5.24	7.23	8.46	21.74	21.99	22.16	71.13	71.59	71.89
9/15/2020	6.46	7.52	8.59	21.38	22.04	22.26	70.48	71.67	72.07
9/16/2020	5.41	8.01	9.44	19.28	20.40	21.36	66.70	68.72	70.45
9/17/2020	5.38	8.48	9.45	18.24	18.82	19.30	64.83	65.87	66.74
9/18/2020	6.84	7.82	8.83	18.44	18.80	19.64	65.19	65.84	67.35

Forebay: Bottom	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
9/19/2020	6.97	8.12	9.00	18.28	18.90	19.64	64.90	66.03	67.35
9/20/2020	7.76	8.71	9.73	16.74	17.54	18.38	62.13	63.57	65.08
9/21/2020	8.13	9.02	9.68	16.20	16.77	17.30	61.16	62.19	63.14
9/22/2020	7.75	9.04	9.90	15.98	16.48	16.88	60.76	61.66	62.38
9/23/2020	7.90	8.99	9.75	15.94	16.55	17.00	60.69	61.78	62.60
9/24/2020	8.42	9.18	9.93	16.62	17.19	17.46	61.92	62.95	63.43
9/25/2020	8.37	8.81	9.44	17.24	17.51	17.82	63.03	63.52	64.08
9/26/2020	8.24	8.64	9.17	17.36	17.65	18.02	63.25	63.77	64.44
9/27/2020	8.20	8.59	9.43	17.72	17.97	18.70	63.90	64.34	65.66
9/28/2020	7.89	8.49	9.52	18.50	18.68	19.06	65.30	65.63	66.31
9/29/2020	7.76	8.38	9.25	18.14	19.11	19.54	64.65	66.40	67.17
9/30/2020	7.94	8.48	9.33	17.16	17.50	18.10	62.89	63.49	64.58
10/1/2020	8.40	8.85	9.65	16.60	16.98	17.50	61.88	62.57	63.50
10/2/2020	8.22	8.74	9.62	16.90	17.12	17.50	62.42	62.81	63.50
10/3/2020	8.26	8.96	9.85	15.74	16.27	17.22	60.33	61.28	63.00
10/4/2020	8.89	9.35	10.24	15.20	15.56	16.28	59.36	60.01	61.30
10/5/2020	8.82	9.39	10.37	15.38	15.70	16.12	59.68	60.26	61.02
10/6/2020	8.76	9.29	10.08	15.46	15.79	16.26	59.83	60.41	61.27
10/7/2020	8.55	8.95	9.48	15.52	16.20	16.42	59.94	61.17	61.56
10/8/2020	8.19	8.79	9.48	16.20	17.06	17.54	61.16	62.71	63.57
10/9/2020	7.98	8.73	9.69	16.86	17.42	17.82	62.35	63.35	64.08
10/10/2020	8.31	8.85	9.69	16.62	16.96	17.24	61.92	62.53	63.03
10/11/2020	8.07	8.47	9.08	16.64	17.11	17.70	61.95	62.80	63.86
10/12/2020	7.97	8.27	8.71	17.48	17.55	17.66	63.46	63.60	63.79
10/13/2020	8.06	8.44	9.47	17.38	17.67	18.32	63.28	63.80	64.98
10/14/2020	8.00	8.57	9.44	16.90	17.29	18.32	62.42	63.12	64.98
10/15/2020	8.14	8.80	9.81	16.18	16.52	17.28	61.12	61.73	63.10
10/16/2020	8.26	8.70	9.62	16.32	16.62	17.10	61.38	61.91	62.78
10/17/2020	8.62	9.12	9.74	14.24	15.27	16.36	57.63	59.49	61.45
10/18/2020	8.76	9.45	10.25	13.54	14.12	14.80	56.37	57.42	58.64
10/19/2020	9.31	9.59	10.47	13.56	13.89	14.34	56.41	57.01	57.81
10/20/2020	8.92	9.58	10.28	13.74	14.55	14.80	56.73	58.18	58.64
10/21/2020	8.72	9.31	10.00	14.64	15.41	15.70	58.35	59.74	60.26
10/22/2020	8.19	9.04	9.86	15.66	16.43	16.68	60.19	61.58	62.02
10/23/2020	7.90	8.71	9.55	16.62	17.11	17.34	61.92	62.79	63.21
10/24/2020	7.85	8.52	9.38	17.00	17.52	17.74	62.60	63.53	63.93
10/25/2020	7.49	8.17	9.46	16.78	17.41	18.02	62.20	63.34	64.44
10/26/2020	7.62	8.04	8.71	16.06	16.38	16.78	60.91	61.48	62.20
10/27/2020	7.90	8.69	9.68	16.10	16.40	16.74	60.98	61.52	62.13
10/28/2020	7.97	8.52	9.26	16.22	16.62	16.88	61.20	61.92	62.38
10/29/2020	7.69	8.29	9.44	16.56	17.49	18.58	61.81	63.47	65.44
10/30/2020	8.20	8.83	9.24	14.84	16.21	17.24	58.71	61.18	63.03
10/31/2020	9.19	9.68	10.04	12.86	13.52	14.80	55.15	56.34	58.64
11/1/2020	9.75	9.89	9.99	12.12	12.62	13.08	53.82	54.72	55.54
11/2/2020	9.66	10.15	10.75	10.64	11.27	12.68	51.15	52.29	54.82
11/3/2020	10.30	10.54	10.98	10.02	10.38	10.94	50.04	50.69	51.69
11/4/2020	10.11	10.45	10.86	10.60	10.89	11.62	51.08	51.60	52.92
11/5/2020	9.67	10.18	10.80	11.28	11.56	12.26	52.30	52.82	54.07
11/6/2020	9.28	9.92	10.63	11.76	12.12	12.82	53.17	53.81	55.08
11/7/2020	9.15	9.69	10.37	12.28	12.62	13.10	54.10	54.71	55.58
11/8/2020	8.78	9.46	10.24	12.94	13.26	13.74	55.29	55.88	56.73
11/9/2020	8.82	9.27	10.00	13.80	14.11	14.52	56.84	57.39	58.14
11/10/2020	7.27	8.76	9.70	14.56	15.03	15.32	58.21	59.05	59.58

Table 5. Niagara Forebay Surface Monitoring Location - Daily Water Quality Data

Forebay: Surface	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
7/29/2020	6.31	6.87	7.87	24.94	25.29	25.62	76.89	77.52	78.12
7/30/2020	6.63	7.37	8.12	24.64	25.49	26.42	76.35	77.88	79.56
7/31/2020	6.70	7.08	7.79	23.84	24.36	24.94	74.91	75.85	76.89
8/1/2020	6.85	7.42	8.02	24.22	24.69	25.42	75.60	76.45	77.76
8/2/2020	6.72	7.20	7.93	24.44	24.93	25.60	75.99	76.88	78.08
8/3/2020	6.97	7.58	8.16	23.48	24.32	25.02	74.26	75.78	77.04
8/4/2020	7.39	7.62	7.90	22.14	22.69	23.56	71.85	72.85	74.41
8/5/2020	7.15	7.51	8.16	22.70	23.34	24.90	72.86	74.02	76.82
8/6/2020	7.27	7.68	8.17	22.22	23.14	23.78	72.00	73.66	74.80
8/7/2020	7.20	7.55	8.14	22.48	22.85	23.48	72.46	73.14	74.26
8/8/2020	7.17	7.73	8.48	22.98	23.54	25.32	73.36	74.37	77.58
8/9/2020	6.82	7.62	8.50	23.66	24.34	25.62	74.59	75.81	78.12
8/10/2020	6.55	7.33	8.17	24.24	24.85	25.66	75.63	76.73	78.19
8/11/2020	6.34	7.45	8.07	23.80	24.60	26.26	74.84	76.29	79.27
8/12/2020	5.72	6.74	8.19	24.80	25.32	25.62	76.64	77.58	78.12
8/13/2020	-	-	-	-	-	-	-	-	-
8/14/2020	-	-	-	-	-	-	-	-	-
8/15/2020	-	-	-	-	-	-	-	-	-
8/16/2020	-	-	-	-	-	-	-	-	-
8/17/2020	-	-	-	-	-	-	-	-	-
8/18/2020	-	-	-	-	-	-	-	-	-
8/19/2020	-	-	-	-	-	-	-	-	-
8/20/2020	-	-	-	-	-	-	-	-	-
8/21/2020	-	-	-	-	-	-	-	-	-
8/22/2020	-	-	-	-	-	-	-	-	-
8/23/2020	-	-	-	-	-	-	-	-	-
8/24/2020	-	-	-	-	-	-	-	-	-
8/25/2020	-	-	-	-	-	-	-	-	-
8/26/2020	7.33	7.82	8.51	23.22	24.02	25.24	73.80	75.23	77.43
8/27/2020	7.32	7.96	8.50	23.60	24.06	25.00	74.48	75.31	77.00
8/28/2020	7.13	7.92	8.62	23.80	24.30	25.22	74.84	75.75	77.40
8/29/2020	6.94	7.70	8.62	24.10	24.59	24.86	75.38	76.26	76.75
8/30/2020	6.93	7.55	8.13	23.74	24.27	24.64	74.73	75.69	76.35
8/31/2020	7.29	7.85	8.39	21.56	22.95	24.10	70.81	73.31	75.38
9/1/2020	7.19	7.75	8.12	20.92	21.27	21.56	69.66	70.28	70.81
9/2/2020	7.79	7.98	8.42	21.02	21.56	23.00	69.84	70.82	73.40
9/3/2020	7.00	7.62	8.43	22.72	23.32	24.58	72.90	73.98	76.24
9/4/2020	6.99	7.49	8.06	23.56	24.06	25.06	74.41	75.31	77.11
9/5/2020	7.12	7.64	8.07	22.88	23.80	24.20	73.18	74.84	75.56
9/6/2020	7.30	8.10	8.55	21.88	22.64	23.10	71.38	72.75	73.58
9/7/2020	7.51	8.38	9.08	21.22	21.98	22.74	70.20	71.56	72.93
9/8/2020	5.99	8.05	9.27	21.30	21.74	22.20	70.34	71.12	71.96
9/9/2020	6.96	8.03	8.98	21.42	22.09	22.34	70.56	71.76	72.21
9/10/2020	6.45	7.63	8.59	21.84	22.01	22.18	71.31	71.61	71.92
9/11/2020	6.10	7.35	7.91	22.04	22.42	22.84	71.67	72.35	73.11
9/12/2020	6.16	7.42	8.29	22.42	22.86	23.10	72.36	73.14	73.58
9/13/2020	6.19	7.01	7.72	21.90	22.11	22.38	71.42	71.80	72.28
9/14/2020	6.27	7.86	8.99	21.88	22.20	22.52	71.38	71.96	72.54
9/15/2020	6.65	8.00	9.08	21.50	22.22	22.54	70.70	71.99	72.57
9/16/2020	6.59	7.98	9.37	19.46	20.54	21.46	67.03	68.98	70.63
9/17/2020	6.71	8.14	9.53	18.28	18.90	19.42	64.90	66.01	66.96
9/18/2020	5.84	7.02	8.30	18.46	18.90	19.66	65.23	66.02	67.39

Forebay: Surface	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
9/19/2020	6.54	7.30	8.35	18.28	18.99	19.66	64.90	66.18	67.39
9/20/2020	8.00	8.40	8.99	16.76	17.71	18.40	62.17	63.88	65.12
9/21/2020	7.99	8.85	9.49	16.28	16.97	17.42	61.30	62.55	63.36
9/22/2020	8.28	9.06	9.84	16.08	16.67	17.18	60.94	62.00	62.92
9/23/2020	8.33	9.18	9.76	15.98	16.80	17.66	60.76	62.23	63.79
9/24/2020	8.60	9.50	10.47	16.86	17.51	17.82	62.35	63.52	64.08
9/25/2020	8.39	9.04	9.79	17.28	17.58	17.86	63.10	63.65	64.15
9/26/2020	8.41	8.77	9.31	17.40	17.69	18.04	63.32	63.84	64.47
9/27/2020	8.48	8.81	9.62	17.78	18.05	18.76	64.00	64.48	65.77
9/28/2020	8.27	8.77	9.67	18.54	18.79	19.26	65.37	65.82	66.67
9/29/2020	7.72	8.52	9.33	18.18	19.17	19.58	64.72	66.50	67.24
9/30/2020	8.12	8.63	9.52	17.24	17.54	18.16	63.03	63.58	64.69
10/1/2020	8.43	8.99	9.81	16.70	17.04	17.54	62.06	62.67	63.57
10/2/2020	8.55	8.93	9.92	16.96	17.18	17.52	62.53	62.92	63.54
10/3/2020	8.29	9.18	10.01	15.76	16.37	17.24	60.37	61.47	63.03
10/4/2020	8.78	9.45	10.29	15.32	15.68	16.32	59.58	60.23	61.38
10/5/2020	8.94	9.57	10.45	15.54	15.82	16.18	59.97	60.48	61.12
10/6/2020	8.82	9.48	10.34	15.54	15.95	16.32	59.97	60.70	61.38
10/7/2020	8.66	9.45	10.35	15.68	16.47	16.80	60.22	61.65	62.24
10/8/2020	8.34	9.19	10.17	16.40	17.33	17.72	61.52	63.19	63.90
10/9/2020	8.38	9.10	10.04	16.94	17.62	18.02	62.49	63.71	64.44
10/10/2020	8.45	9.34	10.38	16.66	17.09	17.42	61.99	62.77	63.36
10/11/2020	8.23	8.69	9.43	16.68	17.17	17.72	62.02	62.91	63.90
10/12/2020	7.97	8.36	8.89	17.52	17.59	17.68	63.54	63.66	63.82
10/13/2020	8.24	8.67	9.56	17.42	17.72	18.34	63.36	63.90	65.01
10/14/2020	8.05	8.71	9.82	16.94	17.36	18.34	62.49	63.26	65.01
10/15/2020	8.26	8.96	9.94	16.32	16.64	17.30	61.38	61.95	63.14
10/16/2020	8.29	8.91	10.00	16.32	16.69	17.16	61.38	62.04	62.89
10/17/2020	8.33	8.95	9.79	14.26	15.36	16.38	57.67	59.65	61.48
10/18/2020	8.94	9.54	10.57	13.58	14.27	14.88	56.44	57.69	58.78
10/19/2020	9.42	9.93	10.78	13.58	14.08	14.40	56.44	57.34	57.92
10/20/2020	9.10	9.89	10.77	13.96	14.76	14.96	57.13	58.57	58.93
10/21/2020	8.84	9.64	10.54	14.90	15.65	16.04	58.82	60.17	60.87
10/22/2020	7.98	9.29	10.35	16.06	16.77	17.02	60.91	62.18	62.64
10/23/2020	8.07	9.05	10.11	16.90	17.33	17.56	62.42	63.20	63.61
10/24/2020	7.84	8.92	10.09	17.32	17.74	17.98	63.18	63.94	64.36
10/25/2020	7.17	8.32	10.00	16.82	17.50	18.10	62.28	63.50	64.58
10/26/2020	7.74	8.13	8.70	16.10	16.49	16.82	60.98	61.68	62.28
10/27/2020	8.23	9.01	10.03	16.12	16.51	16.78	61.02	61.72	62.20
10/28/2020	8.10	8.82	9.76	16.24	16.72	16.96	61.23	62.10	62.53
10/29/2020	7.52	8.26	9.39	16.58	17.53	18.60	61.84	63.55	65.48
10/30/2020	7.98	8.66	9.09	14.88	16.25	17.28	58.78	61.25	63.10
10/31/2020	9.03	9.56	9.95	12.90	13.57	14.84	55.22	56.43	58.71
11/1/2020	9.70	9.83	9.93	12.16	12.67	13.12	53.89	54.80	55.62
11/2/2020	9.63	10.12	10.74	10.72	11.32	12.72	51.30	52.37	54.90
11/3/2020	10.15	10.46	10.90	10.06	10.44	10.98	50.11	50.78	51.76
11/4/2020	10.03	10.34	10.79	10.66	10.94	11.66	51.19	51.70	52.99
11/5/2020	9.69	10.10	10.69	11.32	11.62	12.30	52.38	52.91	54.14
11/6/2020	9.47	9.85	10.58	11.80	12.17	12.88	53.24	53.91	55.18
11/7/2020	9.10	9.56	10.24	12.32	12.68	13.22	54.18	54.82	55.80
11/8/2020	8.92	9.32	10.10	12.98	13.34	13.88	55.36	56.01	56.98
11/9/2020	8.64	9.09	9.88	13.88	14.20	14.78	56.98	57.56	58.60
11/10/2020	7.74	8.76	9.81	14.84	15.14	15.38	58.71	59.25	59.68

Table 6. Niagara Tinker Creek Monitoring Location - Daily Water Quality Data

Tinker Creek	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
7/29/2020	7.67	9.07	9.98	22.12	23.42	24.30	71.82	74.15	75.74
7/30/2020	7.41	8.30	10.00	21.04	22.13	23.96	69.87	71.84	75.13
7/31/2020	7.39	8.43	9.76	21.50	22.38	23.80	70.70	72.29	74.84
8/1/2020	7.47	8.16	9.75	21.10	22.38	25.90	69.98	72.28	78.62
8/2/2020	7.66	8.43	9.61	20.94	21.93	23.40	69.69	71.47	74.12
8/3/2020	7.72	8.38	9.76	20.42	21.14	21.86	68.76	70.06	71.35
8/4/2020	7.71	8.64	10.04	20.06	21.23	23.02	68.11	70.21	73.44
8/5/2020	7.42	8.66	10.42	20.06	21.18	22.66	68.11	70.12	72.79
8/6/2020	7.83	8.53	9.92	20.60	21.17	22.26	69.08	70.10	72.07
8/7/2020	7.75	8.93	10.72	20.06	21.15	22.54	68.11	70.07	72.57
8/8/2020	6.89	8.81	10.94	20.24	21.48	23.22	68.43	70.66	73.80
8/9/2020	7.31	8.58	10.79	20.90	22.19	24.02	69.62	71.94	75.24
8/10/2020	7.31	8.65	10.89	20.60	21.63	22.80	69.08	70.94	73.04
8/11/2020	6.44	8.30	11.13	20.32	22.09	27.24	68.58	71.76	81.03
8/12/2020	7.13	7.33	7.93	21.06	21.33	21.80	69.91	70.40	71.24
8/13/2020	-	-	-	-	-	-	-	-	-
8/14/2020	-	-	-	-	-	-	-	-	-
8/15/2020	-	-	-	-	-	-	-	-	-
8/16/2020	-	-	-	-	-	-	-	-	-
8/17/2020	-	-	-	-	-	-	-	-	-
8/18/2020	-	-	-	-	-	-	-	-	-
8/19/2020	-	-	-	-	-	-	-	-	-
8/20/2020	-	-	-	-	-	-	-	-	-
8/21/2020	-	-	-	-	-	-	-	-	-
8/22/2020	-	-	-	-	-	-	-	-	-
8/23/2020	-	-	-	-	-	-	-	-	-
8/24/2020	-	-	-	-	-	-	-	-	-
8/25/2020	-	-	-	-	-	-	-	-	-
8/26/2020	7.88	9.47	11.01	21.26	22.52	23.26	70.27	72.53	73.87
8/27/2020	7.81	9.12	11.15	20.16	21.45	23.16	68.29	70.62	73.69
8/28/2020	7.66	9.06	11.56	20.54	21.58	23.20	68.97	70.84	73.76
8/29/2020	7.58	8.76	11.26	20.80	21.52	22.86	69.44	70.74	73.15
8/30/2020	7.55	8.93	11.23	20.10	21.19	22.82	68.18	70.15	73.08
8/31/2020	7.69	8.11	8.62	19.98	20.56	21.52	67.96	69.01	70.74
9/1/2020	6.78	7.93	8.46	19.70	20.21	20.66	67.46	68.37	69.19
9/2/2020	5.95	7.17	8.12	19.66	20.78	22.52	67.39	69.40	72.54
9/3/2020	5.45	6.87	8.10	20.40	21.50	23.16	68.72	70.70	73.69
9/4/2020	5.23	5.90	6.73	20.54	21.55	22.92	68.97	70.79	73.26
9/5/2020	5.58	6.55	7.59	19.42	20.48	21.76	66.96	68.86	71.17
9/6/2020	6.53	7.70	9.03	17.92	19.35	21.16	64.26	66.83	70.09
9/7/2020	6.22	7.49	8.81	17.66	19.12	21.04	63.79	66.42	69.87
9/8/2020	6.03	6.88	8.20	17.84	19.32	21.26	64.11	66.78	70.27
9/9/2020	-	-	-	19.04	19.58	20.28	66.27	67.24	68.50
9/10/2020	-	-	-	19.30	20.41	21.42	66.74	68.74	70.56
9/11/2020	-	-	-	19.68	20.68	22.04	67.42	69.22	71.67
9/12/2020	-	-	-	19.76	20.23	20.66	67.57	68.41	69.19
9/13/2020	-	-	-	19.04	19.97	21.30	66.27	67.95	70.34
9/14/2020	-	-	-	19.16	20.07	21.46	66.49	68.13	70.63
9/15/2020	-	-	-	17.84	19.01	19.74	64.11	66.22	67.53
9/16/2020	-	-	-	15.92	17.07	18.34	60.66	62.73	65.01
9/17/2020	-	-	-	16.40	17.11	18.12	61.52	62.80	64.62
9/18/2020	-	-	-	17.30	18.02	19.32	63.14	64.43	66.78

Tinker Creek	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
9/19/2020	-	-	-	15.80	16.91	17.64	60.44	62.44	63.75
9/20/2020	-	-	-	13.94	15.33	16.94	57.09	59.59	62.49
9/21/2020	-	-	-	13.34	14.76	16.54	56.01	58.57	61.77
9/22/2020	-	-	-	13.06	14.68	16.66	55.51	58.42	61.99
9/23/2020	8.91	10.51	11.68	14.20	15.62	17.46	57.56	60.11	63.43
9/24/2020	8.78	9.63	11.27	15.66	16.23	17.08	60.19	61.21	62.74
9/25/2020	8.39	8.77	9.47	16.06	16.62	17.76	60.91	61.91	63.97
9/26/2020	7.87	8.40	9.18	16.72	17.30	18.08	62.10	63.14	64.54
9/27/2020	7.97	8.91	10.15	16.84	17.52	18.52	62.31	63.53	65.34
9/28/2020	8.26	8.94	9.93	17.16	17.93	19.06	62.89	64.28	66.31
9/29/2020	8.23	8.58	9.16	17.20	17.90	18.58	62.96	64.22	65.44
9/30/2020	8.64	9.18	10.02	15.84	16.59	17.32	60.51	61.87	63.18
10/1/2020	8.69	9.24	10.23	15.40	16.33	17.62	59.72	61.40	63.72
10/2/2020	8.70	9.37	10.39	15.16	16.05	17.06	59.29	60.88	62.71
10/3/2020	9.04	9.79	10.92	13.84	14.86	16.08	56.91	58.74	60.94
10/4/2020	9.22	10.04	11.30	13.34	14.51	15.92	56.01	58.12	60.66
10/5/2020	9.21	9.85	11.00	13.90	14.84	16.20	57.02	58.72	61.16
10/6/2020	9.01	9.89	11.15	13.30	14.75	16.54	55.94	58.55	61.77
10/7/2020	8.62	9.58	10.90	14.24	15.64	17.44	57.63	60.15	63.39
10/8/2020	8.50	9.30	10.69	15.50	16.43	17.90	59.90	61.57	64.22
10/9/2020	8.57	9.73	11.61	14.54	15.64	16.76	58.17	60.15	62.17
10/10/2020	8.52	9.11	10.65	15.42	15.89	16.90	59.76	60.60	62.42
10/11/2020	8.45	8.76	9.33	15.98	16.82	18.32	60.76	62.28	64.98
10/12/2020	8.36	8.89	9.68	17.02	17.25	17.50	62.64	63.04	63.50
10/13/2020	8.30	8.98	10.09	16.30	17.27	18.32	61.34	63.08	64.98
10/14/2020	8.54	9.41	10.66	14.82	15.86	17.06	58.68	60.55	62.71
10/15/2020	8.79	9.62	10.90	14.08	15.42	16.98	57.34	59.75	62.56
10/16/2020	8.78	9.55	11.04	14.30	15.50	15.96	57.74	59.90	60.73
10/17/2020	9.11	10.15	11.49	12.58	13.60	14.70	54.64	56.47	58.46
10/18/2020	9.56	10.39	11.75	11.78	12.95	14.36	53.20	55.30	57.85
10/19/2020	9.22	10.32	11.79	12.14	13.46	15.18	53.85	56.23	59.32
10/20/2020	8.96	10.00	11.64	13.18	14.51	16.24	55.72	58.13	61.23
10/21/2020	8.76	9.77	11.52	14.16	15.49	17.24	57.49	59.88	63.03
10/22/2020	8.59	9.64	11.55	15.02	16.24	17.92	59.04	61.24	64.26
10/23/2020	8.34	9.52	11.62	15.38	16.60	18.26	59.68	61.88	64.87
10/24/2020	8.14	9.46	11.83	15.72	16.78	18.04	60.30	62.20	64.47
10/25/2020	7.61	8.64	9.51	15.22	16.30	17.46	59.40	61.34	63.43
10/26/2020	8.54	9.48	11.28	14.60	15.48	16.72	58.28	59.86	62.10
10/27/2020	8.45	9.44	11.32	14.84	15.62	16.62	58.71	60.12	61.92
10/28/2020	8.31	9.17	10.79	15.34	15.79	16.40	59.61	60.42	61.52
10/29/2020	7.75	8.39	8.70	16.02	17.63	18.56	60.84	63.74	65.41
10/30/2020	8.34	8.97	9.62	14.38	16.29	17.96	57.88	61.31	64.33
10/31/2020	9.35	10.09	10.96	12.52	13.20	14.32	54.54	55.76	57.78
11/1/2020	9.55	9.98	10.61	12.24	12.77	13.62	54.03	54.99	56.52
11/2/2020	9.67	10.50	11.33	10.30	10.96	12.24	50.54	51.72	54.03
11/3/2020	10.02	10.71	11.50	9.70	10.66	11.78	49.46	51.19	53.20
11/4/2020	10.00	10.52	11.37	10.42	11.43	12.70	50.76	52.57	54.86
11/5/2020	9.87	10.46	11.40	10.86	11.91	13.20	51.55	53.43	55.76
11/6/2020	9.66	10.27	11.24	11.44	12.43	13.84	52.59	54.38	56.91
11/7/2020	9.54	10.22	11.33	11.56	12.73	14.18	52.81	54.91	57.52
11/8/2020	9.29	10.05	11.35	12.32	13.46	14.98	54.18	56.22	58.96
11/9/2020	9.03	9.85	11.25	13.24	14.20	15.60	55.83	57.56	60.08
11/10/2020	7.69	8.76	10.14	14.58	14.77	14.88	58.24	58.59	58.78

Table 1. Niagara Upstream Bypass Reach Monitoring Location - Daily Water Quality Data

Bypass Reach: Upstream	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
6/29/2021	6.95	8.21	9.24	25.24	25.83	26.28	77.43	78.50	79.30
6/30/2021	6.27	7.62	8.87	25.08	25.94	26.86	77.14	78.69	80.35
7/1/2021	4.20	6.20	8.25	24.44	25.55	27.44	75.99	77.98	81.39
7/2/2021	8.03	8.34	8.52	23.10	23.65	24.48	73.58	74.57	76.06
7/3/2021	8.36	8.55	8.87	21.84	22.59	23.46	71.31	72.66	74.23
7/4/2021	7.56	8.30	9.66	21.52	22.23	23.22	70.74	72.01	73.80
7/5/2021	6.48	7.61	9.03	22.54	23.31	24.26	72.57	73.96	75.67
7/6/2021	5.55	6.72	7.89	23.64	24.32	25.14	74.55	75.77	77.25
7/7/2021	5.47	7.17	9.34	24.48	25.00	25.68	76.06	76.99	78.22
7/8/2021	7.73	8.18	8.75	23.42	24.34	25.06	74.16	75.82	77.11
7/9/2021	5.13	6.89	8.99	23.02	23.51	24.56	73.44	74.32	76.21
7/10/2021	3.54	4.61	7.68	22.78	23.78	24.82	73.00	74.80	76.68
7/11/2021	3.57	7.54	8.71	23.22	24.23	25.22	73.80	75.61	77.40
7/12/2021	4.12	6.56	8.79	24.38	25.02	26.00	75.88	77.03	78.80
7/13/2021	3.40	4.86	8.78	24.32	25.28	26.28	75.78	77.51	79.30
7/14/2021	-	-	-	24.98	25.57	26.64	76.96	78.03	79.95
7/15/2021	-	-	-	24.82	25.68	26.92	76.68	78.22	80.46
7/16/2021	-	-	-	24.72	25.88	27.52	76.50	78.59	81.54
7/17/2021	-	-	-	25.12	25.67	26.48	77.22	78.21	79.66
7/18/2021	-	-	-	24.50	25.32	26.54	76.10	77.57	79.77
7/19/2021	-	-	-	24.52	25.07	25.98	76.14	77.12	78.76
7/20/2021	7.60	8.35	9.32	23.84	24.72	25.70	74.91	76.50	78.26
7/21/2021	5.37	7.28	8.39	23.50	24.43	25.50	74.30	75.97	77.90
7/22/2021	4.35	6.32	8.86	23.28	24.30	25.82	73.90	75.74	78.48
7/23/2021	4.77	7.08	9.19	23.46	24.40	25.40	74.23	75.92	77.72
7/24/2021	3.44	4.65	7.59	23.84	24.67	25.90	74.91	76.41	78.62
7/25/2021	-	-	-	24.72	25.22	25.96	76.50	77.39	78.73
7/26/2021	-	-	-	24.52	25.73	26.78	76.14	78.31	80.20
7/27/2021	-	-	-	23.28	24.67	25.96	73.90	76.41	78.73
7/28/2021	-	-	-	24.96	25.65	26.48	76.93	78.17	79.66
7/29/2021	-	-	-	25.32	26.15	27.14	77.58	79.06	80.85
7/30/2021	-	-	-	25.32	26.17	27.14	77.58	79.11	80.85
7/31/2021	-	-	-	25.02	25.54	26.14	77.04	77.98	79.05
8/1/2021	-	-	-	24.90	25.22	25.62	76.82	77.39	78.12
8/2/2021	-	-	-	23.82	24.60	25.72	74.88	76.28	78.30
8/3/2021	6.84	8.26	9.76	23.46	24.01	24.58	74.23	75.21	76.24
8/4/2021	5.00	6.34	8.36	22.88	23.66	24.28	73.18	74.59	75.70
8/5/2021	2.48	4.54	8.01	23.08	23.97	25.52	73.54	75.14	77.94
8/6/2021	5.08	7.48	9.05	23.46	24.12	25.00	74.23	75.41	77.00
8/7/2021	3.65	4.48	5.58	23.66	24.07	24.46	74.59	75.33	76.03
8/8/2021	-	-	-	23.20	23.88	24.68	73.76	74.99	76.42
8/9/2021	-	-	-	23.98	24.50	25.56	75.16	76.09	78.01
8/10/2021	-	-	-	24.54	25.25	26.20	76.17	77.45	79.16
8/11/2021	7.43	7.77	7.96	24.52	25.38	26.74	76.14	77.68	80.13
8/12/2021	6.79	7.52	8.50	25.20	25.68	26.82	77.36	78.23	80.28
8/13/2021	7.79	8.03	8.33	25.14	25.83	26.76	77.25	78.49	80.17
8/14/2021	7.99	8.23	8.42	24.22	25.06	26.42	75.60	77.10	79.56
8/15/2021	8.11	8.23	8.49	24.56	25.04	25.30	76.21	77.08	77.54
8/16/2021	7.83	8.44	8.86	23.32	23.65	24.64	73.98	74.58	76.35
8/17/2021	7.33	7.94	8.47	23.40	23.53	23.74	74.12	74.35	74.73
8/18/2021	7.90	8.37	8.58	22.96	23.62	24.40	73.33	74.51	75.92
8/19/2021	7.17	8.00	8.55	23.74	24.46	25.34	74.73	76.04	77.61

Bypass Reach: Upstream	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
8/20/2021	6.64	7.96	8.96	23.96	24.71	26.94	75.13	76.48	80.49
8/21/2021	7.51	8.05	8.74	23.68	24.40	25.52	74.62	75.92	77.94
8/22/2021	7.24	7.85	8.81	24.02	24.61	25.36	75.24	76.31	77.65
8/23/2021	7.18	7.89	9.05	24.22	24.91	25.76	75.60	76.85	78.37
8/24/2021	6.90	8.09	9.69	24.56	25.19	25.84	76.21	77.34	78.51
8/25/2021	7.51	8.27	9.75	25.16	25.68	26.30	77.29	78.22	79.34
8/26/2021	7.36	8.28	9.76	25.30	25.82	26.28	77.54	78.47	79.30
8/27/2021	7.21	7.96	9.56	25.60	26.02	27.06	78.08	78.84	80.71
8/28/2021	7.44	8.07	9.16	25.10	25.66	26.08	77.18	78.19	78.94
8/29/2021	7.28	7.96	9.05	25.80	26.03	26.36	78.44	78.86	79.45
8/30/2021	7.40	8.03	8.68	25.20	26.31	27.56	77.36	79.35	81.61
8/31/2021	7.08	7.78	9.06	24.70	25.44	25.94	76.46	77.80	78.69
9/1/2021	5.58	7.79	8.65	23.08	23.84	24.66	73.54	74.91	76.39
9/2/2021	8.33	8.54	8.69	22.06	22.50	23.04	71.71	72.50	73.47
9/3/2021	6.84	8.59	10.73	21.04	22.38	24.58	69.87	72.29	76.24
9/4/2021	6.78	8.57	11.32	20.98	22.18	24.28	69.76	71.92	75.70
9/5/2021	7.22	8.37	10.91	21.76	22.78	24.26	71.17	73.00	75.67
9/6/2021	7.47	8.20	9.61	22.48	23.18	24.26	72.46	73.72	75.67
9/7/2021	5.83	7.86	8.86	21.60	22.64	24.84	70.88	72.76	76.71
9/8/2021	8.31	8.42	8.57	22.50	22.75	22.96	72.50	72.94	73.33
9/9/2021	8.26	8.39	8.56	22.20	22.85	23.14	71.96	73.12	73.65
9/10/2021	8.39	8.57	8.77	21.44	21.98	22.80	70.59	71.56	73.04
9/11/2021	8.27	8.68	8.92	20.76	21.26	21.72	69.37	70.27	71.10
9/12/2021	8.25	8.65	8.94	20.80	21.45	22.30	69.44	70.61	72.14
9/13/2021	8.33	8.58	8.86	21.18	22.05	23.10	70.12	71.68	73.58
9/14/2021	8.25	8.48	8.77	21.92	22.56	23.28	71.46	72.60	73.90
9/15/2021	8.19	8.41	8.65	22.70	22.97	23.46	72.86	73.34	74.23
9/16/2021	8.47	8.58	8.80	22.68	22.98	23.12	72.82	73.36	73.62
9/17/2021	8.51	8.60	8.86	22.76	22.99	23.38	72.97	73.38	74.08
9/18/2021	8.47	8.58	8.79	22.76	23.10	23.62	72.97	73.57	74.52
9/19/2021	8.42	8.52	8.73	23.14	23.46	23.86	73.65	74.22	74.95
9/20/2021	8.41	8.53	8.68	23.32	23.57	23.74	73.98	74.43	74.73
9/21/2021	8.57	8.67	9.04	21.30	22.72	23.32	70.34	72.90	73.98
9/22/2021	9.05	9.22	9.30	20.44	20.93	21.26	68.79	69.68	70.27
9/23/2021	9.28	9.35	9.44	18.96	19.38	20.40	66.13	66.88	68.72
9/24/2021	9.37	9.52	9.60	17.84	18.16	18.94	64.11	64.69	66.09
9/25/2021	9.46	9.55	9.67	17.38	17.74	18.22	63.28	63.94	64.80
9/26/2021	9.45	9.54	9.64	17.42	17.83	18.18	63.36	64.10	64.72
9/27/2021	9.38	9.47	9.60	17.50	18.13	18.60	63.50	64.63	65.48
9/28/2021	9.22	9.32	9.47	17.90	18.59	19.06	64.22	65.47	66.31
9/29/2021	9.05	9.21	9.32	18.50	19.21	19.74	65.30	66.57	67.53
9/30/2021	6.71	8.80	9.65	19.40	20.06	21.20	66.92	68.11	70.16
10/1/2021	6.59	8.30	11.86	18.88	19.90	22.00	65.98	67.82	71.60
10/2/2021	6.62	7.73	8.77	18.86	19.67	20.76	65.95	67.41	69.37
10/3/2021	7.88	8.37	8.99	19.32	19.88	20.58	66.78	67.78	69.04
10/4/2021	8.49	8.84	9.41	19.92	20.32	20.72	67.86	68.58	69.30
10/5/2021	8.40	8.68	9.08	20.36	20.84	21.24	68.65	69.51	70.23
10/6/2021	8.79	8.97	9.23	20.38	20.73	21.08	68.68	69.32	69.94
10/7/2021	8.93	9.00	9.16	20.28	20.60	20.80	68.50	69.09	69.44
10/8/2021	8.94	9.05	9.29	19.78	20.11	20.28	67.60	68.20	68.50
10/9/2021	9.07	9.12	9.23	19.38	19.73	19.86	66.88	67.51	67.75
10/10/2021	9.09	9.19	9.37	19.00	19.38	19.82	66.20	66.88	67.68
10/11/2021	9.13	9.21	9.30	18.88	19.22	19.58	65.98	66.59	67.24
10/12/2021	9.04	9.19	9.39	18.90	19.42	20.00	66.02	66.96	68.00

Bypass Reach: Upstream	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
10/13/2021	8.84	9.00	9.16	19.68	20.25	20.98	67.42	68.46	69.76
10/14/2021	8.83	8.95	9.11	19.92	20.33	20.84	67.86	68.59	69.51
10/15/2021	8.77	8.94	9.12	19.86	20.24	20.62	67.75	68.43	69.12
10/16/2021	8.78	8.85	8.99	19.30	20.21	20.62	66.74	68.38	69.12
10/17/2021	9.00	9.27	9.51	17.02	18.38	19.26	62.64	65.08	66.67
10/18/2021	9.52	9.71	10.61	15.92	16.62	17.78	60.66	61.92	64.00
10/19/2021	9.30	9.81	10.11	14.82	15.76	16.82	58.68	60.37	62.28
10/20/2021	9.28	9.61	10.43	14.90	16.03	17.62	58.82	60.85	63.72
10/21/2021	9.10	9.59	10.30	15.28	16.22	17.30	59.50	61.20	63.14
10/22/2021	9.28	9.46	10.08	16.14	16.67	17.32	61.05	62.01	63.18
10/23/2021	9.32	9.49	9.94	15.92	16.47	17.28	60.66	61.64	63.10
10/24/2021	9.49	9.65	9.83	15.46	16.30	16.82	59.83	61.34	62.28
10/25/2021	8.91	9.45	10.04	16.12	16.89	17.70	61.02	62.41	63.86
10/26/2021	8.37	8.98	9.54	15.90	16.85	17.54	60.62	62.32	63.57
10/27/2021	8.69	9.19	10.25	13.46	15.30	16.34	56.23	59.54	61.41

Table 2. Niagara Downstream Bypass Reach Monitoring Location - Daily Water Quality Data

Bypass Reach: Downstream	Min. Do mg/L	Ave. DO mg/L	Max. DO mg/L	Min. T °C	Ave. T °C	Max. T °C	Min. T °F	Ave. T °F	Max. T °F
6/29/2021	7.38	8.57	9.89	25.42	26.76	28.04	77.76	80.16	82.47
6/30/2021	7.09	8.15	9.66	24.68	26.16	28.24	76.42	79.09	82.83
7/1/2021	7.07	8.07	10.63	24.32	25.73	29.24	75.78	78.31	84.63
7/2/2021	7.92	8.38	8.80	23.16	23.64	24.34	73.69	74.55	75.81
7/3/2021	8.34	8.72	9.39	21.56	22.70	23.52	70.81	72.85	74.34
7/4/2021	8.18	8.79	9.78	21.28	22.38	24.22	70.30	72.29	75.60
7/5/2021	7.92	8.68	9.72	22.26	23.50	25.04	72.07	74.31	77.07
7/6/2021	7.63	8.68	10.29	23.38	24.76	27.18	74.08	76.57	80.92
7/7/2021	7.61	8.22	9.46	24.22	25.07	26.24	75.60	77.12	79.23
7/8/2021	7.80	8.23	9.23	23.20	24.33	25.12	73.76	75.79	77.22
7/9/2021	7.33	8.40	9.97	22.70	23.86	26.08	72.86	74.94	78.94
7/10/2021	7.26	8.42	10.37	22.06	24.14	26.92	71.71	75.45	80.46
7/11/2021	7.65	8.34	9.07	23.24	24.33	25.24	73.83	75.79	77.43
7/12/2021	6.81	8.24	9.51	24.30	25.39	26.80	75.74	77.69	80.24
7/13/2021	6.49	8.03	10.24	23.78	26.06	29.58	74.80	78.91	85.24
7/14/2021	6.75	7.88	9.69	24.38	25.91	28.74	75.88	78.63	83.73
7/15/2021	6.81	7.92	9.77	24.36	26.05	28.64	75.85	78.90	83.55
7/16/2021	6.67	7.85	9.83	24.24	26.43	29.52	75.63	79.58	85.14
7/17/2021	6.58	7.78	9.73	24.82	25.89	27.58	76.68	78.61	81.64
7/18/2021	7.17	8.10	9.80	24.22	25.47	27.44	75.60	77.84	81.39
7/19/2021	6.57	8.00	9.63	24.30	25.14	26.54	75.74	77.26	79.77
7/20/2021	6.02	8.12	10.45	23.34	24.81	27.04	74.01	76.66	80.67
7/21/2021	7.13	8.46	10.53	23.08	24.73	26.82	73.54	76.52	80.28
7/22/2021	7.05	8.63	10.75	22.34	24.59	27.52	72.21	76.26	81.54
7/23/2021	6.85	8.49	10.67	22.58	24.85	27.96	72.64	76.72	82.33
7/24/2021	6.57	8.28	10.66	22.70	25.16	28.84	72.86	77.28	83.91
7/25/2021	7.01	8.10	9.84	24.50	25.58	27.40	76.10	78.05	81.32
7/26/2021	6.65	8.07	9.78	24.52	26.06	28.22	76.14	78.91	82.80
7/27/2021	7.31	8.08	9.00	21.72	25.39	28.98	71.10	77.70	84.16
7/28/2021	7.23	8.09	9.17	24.26	25.81	27.68	75.67	78.46	81.82
7/29/2021	7.20	8.02	9.39	24.46	25.82	27.58	76.03	78.47	81.64
7/30/2021	7.75	8.26	8.76	22.88	25.74	29.68	73.18	78.33	85.42
7/31/2021	7.85	8.51	9.17	20.96	24.60	29.96	69.73	76.29	85.93
8/1/2021	7.73	8.48	8.91	22.32	24.26	26.46	72.18	75.66	79.63
8/2/2021	7.95	8.76	9.24	20.52	23.43	27.30	68.94	74.18	81.14
8/3/2021	7.61	9.34	11.38	19.98	22.86	26.32	67.96	73.15	79.38
8/4/2021	7.62	9.00	11.40	22.34	23.97	26.34	72.21	75.15	79.41
8/5/2021	7.66	9.12	11.44	22.52	24.53	27.86	72.54	76.15	82.15
8/6/2021	7.40	8.99	11.51	22.82	24.53	27.34	73.08	76.15	81.21
8/7/2021	7.25	8.42	10.55	23.44	23.97	25.44	74.19	75.15	77.79
8/8/2021	7.56	8.63	10.53	22.78	24.04	25.66	73.00	75.28	78.19
8/9/2021	7.35	8.67	10.63	23.72	24.87	27.32	74.70	76.77	81.18
8/10/2021	6.59	8.32	10.59	24.22	25.63	28.04	75.60	78.13	82.47
8/11/2021	5.78	7.64	10.24	24.06	25.50	28.44	75.31	77.91	83.19
8/12/2021	6.88	7.86	9.70	24.90	25.79	27.98	76.82	78.43	82.36
8/13/2021	7.46	8.14	9.19	25.02	25.82	27.12	77.04	78.47	80.82
8/14/2021	8.20	8.45	8.90	24.16	24.99	26.30	75.49	76.98	79.34
8/15/2021	8.18	8.44	8.89	24.48	24.96	25.20	76.06	76.93	77.36
8/16/2021	8.37	8.76	9.03	21.74	23.49	24.68	71.13	74.27	76.42
8/17/2021	8.40	8.89	9.10	21.36	22.37	23.76	70.45	72.26	74.77
8/18/2021	8.37	8.69	9.11	22.34	23.64	25.12	72.21	74.56	77.22
8/19/2021	8.05	8.64	9.08	21.36	23.78	26.62	70.45	74.80	79.92

Bypass Reach: Downstream	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
8/20/2021	8.12	8.52	8.90	22.04	23.74	24.98	71.67	74.74	76.96
8/21/2021	8.17	8.65	9.14	20.78	23.04	24.92	69.40	73.47	76.86
8/22/2021	8.27	8.79	9.40	19.66	23.19	27.18	67.39	73.75	80.92
8/23/2021	8.12	8.70	9.37	19.90	23.91	28.08	67.82	75.05	82.54
8/24/2021	7.34	9.04	11.03	20.46	24.48	28.56	68.83	76.06	83.41
8/25/2021	7.17	8.59	11.14	24.74	26.09	28.88	76.53	78.96	83.98
8/26/2021	7.08	8.68	11.22	24.88	26.34	28.88	76.78	79.41	83.98
8/27/2021	6.97	8.26	11.10	25.12	26.24	29.28	77.22	79.23	84.70
8/28/2021	7.26	8.48	10.73	24.70	26.04	28.24	76.46	78.88	82.83
8/29/2021	7.21	8.34	10.47	25.48	26.27	27.90	77.86	79.29	82.22
8/30/2021	7.44	8.25	9.52	23.72	26.13	28.54	74.70	79.04	83.37
8/31/2021	8.08	8.49	8.91	21.84	24.17	26.42	71.31	75.51	79.56
9/1/2021	8.46	8.66	8.85	22.06	23.11	24.20	71.71	73.60	75.56
9/2/2021	-	-	-	21.57	22.50	23.20	70.82	72.50	73.75
9/3/2021	-	-	-	19.47	22.66	26.39	67.05	72.79	79.50
9/4/2021	-	-	-	19.28	22.56	26.88	66.71	72.60	80.38
9/5/2021	-	-	-	21.00	23.25	26.78	69.79	73.85	80.21
9/6/2021	-	-	-	22.14	23.60	26.20	71.86	74.49	79.15
9/7/2021	-	-	-	19.76	22.33	24.93	67.56	72.19	76.88
9/8/2021	8.60	8.79	9.29	22.46	22.76	23.14	72.43	72.96	73.65
9/9/2021	8.53	8.75	9.27	22.12	22.82	23.22	71.82	73.08	73.80
9/10/2021	8.78	9.06	9.60	21.30	21.96	22.98	70.34	71.53	73.36
9/11/2021	8.92	9.27	9.91	20.62	21.25	21.92	69.12	70.25	71.46
9/12/2021	8.89	9.29	10.07	20.76	21.49	22.50	69.37	70.68	72.50
9/13/2021	8.70	9.18	9.89	21.10	22.07	23.34	69.98	71.72	74.01
9/14/2021	8.56	9.04	9.85	21.82	22.56	23.58	71.28	72.62	74.44
9/15/2021	8.56	8.93	9.86	22.56	22.94	23.64	72.61	73.29	74.55
9/16/2021	8.56	8.90	9.78	22.66	22.92	23.24	72.79	73.26	73.83
9/17/2021	8.61	8.90	9.75	22.70	22.99	23.60	72.86	73.38	74.48
9/18/2021	8.54	8.94	9.75	22.70	23.13	23.92	72.86	73.63	75.06
9/19/2021	8.52	8.89	9.78	23.02	23.48	24.16	73.44	74.26	75.49
9/20/2021	8.50	8.78	9.44	23.26	23.56	23.84	73.87	74.40	74.91
9/21/2021	8.68	8.88	9.34	21.28	22.65	23.24	70.30	72.77	73.83
9/22/2021	9.36	9.51	9.58	20.42	20.89	21.26	68.76	69.60	70.27
9/23/2021	9.59	9.72	9.86	18.88	19.36	20.38	65.98	66.85	68.68
9/24/2021	9.77	9.97	10.14	17.76	18.12	18.86	63.97	64.62	65.95
9/25/2021	9.89	10.02	10.23	17.34	17.73	18.12	63.21	63.92	64.62
9/26/2021	9.85	10.02	10.29	17.34	17.82	18.32	63.21	64.07	64.98
9/27/2021	9.78	9.96	10.24	17.38	18.13	18.78	63.28	64.63	65.80
9/28/2021	9.60	9.82	10.18	17.82	18.57	19.20	64.08	65.42	66.56
9/29/2021	9.44	9.76	10.20	18.42	19.21	19.78	65.16	66.58	67.60
9/30/2021	9.31	9.82	10.62	14.50	19.06	20.84	58.10	66.30	69.51
10/1/2021	9.69	10.48	11.38	11.46	15.55	19.76	52.63	60.00	67.57
10/2/2021	9.03	10.14	11.20	12.16	17.24	22.86	53.89	63.03	73.15
10/3/2021	8.78	9.66	10.43	15.40	19.27	23.84	59.72	66.69	74.91
10/4/2021	8.87	9.34	9.74	18.58	20.23	22.20	65.44	68.41	71.96
10/5/2021	8.95	9.44	9.81	18.32	20.38	23.44	64.98	68.68	74.19
10/6/2021	9.08	9.40	10.09	19.96	20.66	21.02	67.93	69.18	69.84
10/7/2021	9.07	9.29	9.90	20.20	20.56	20.70	68.36	69.00	69.26
10/8/2021	9.11	9.39	10.06	19.72	20.08	20.32	67.50	68.15	68.58
10/9/2021	9.28	9.45	9.89	19.32	19.68	19.88	66.78	67.43	67.78
10/10/2021	9.36	9.57	10.22	18.90	19.35	19.92	66.02	66.83	67.86
10/11/2021	9.37	9.59	10.03	18.76	19.18	19.66	65.77	66.52	67.39

Bypass Reach: Downstream	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
10/12/2021	9.26	9.58	10.20	18.82	19.43	20.18	65.88	66.98	68.32
10/13/2021	9.14	9.45	10.04	19.58	20.25	21.22	67.24	68.44	70.20
10/14/2021	9.13	9.40	10.00	19.76	20.29	21.08	67.57	68.51	69.94
10/15/2021	9.07	9.42	10.06	19.74	20.23	20.94	67.53	68.41	69.69
10/16/2021	9.06	9.30	9.81	19.12	20.11	20.66	66.42	68.19	69.19
10/17/2021	9.32	9.73	10.31	16.90	18.27	19.06	62.42	64.88	66.31
10/18/2021	9.81	10.11	11.62	14.12	16.45	17.74	57.42	61.61	63.93
10/19/2021	9.36	10.17	10.68	14.68	15.66	16.86	58.42	60.19	62.35
10/20/2021	9.57	10.32	12.07	12.52	15.57	18.58	54.54	60.02	65.44
10/21/2021	9.31	10.14	11.81	14.84	16.18	18.20	58.71	61.13	64.76
10/22/2021	9.37	9.95	11.11	16.04	16.61	17.70	60.87	61.90	63.86
10/23/2021	9.78	10.17	11.17	15.52	16.34	17.52	59.94	61.41	63.54
10/24/2021	9.90	10.26	10.95	15.36	16.28	17.18	59.65	61.30	62.92
10/25/2021	9.25	10.23	11.85	16.00	16.92	18.34	60.80	62.45	65.01
10/26/2021	9.30	10.09	12.21	15.18	16.50	17.80	59.32	61.71	64.04
10/27/2021	9.63	10.43	12.37	13.82	14.77	16.26	56.88	58.58	61.27

Table 3. Niagara Tailrace Monitoring Location - Daily Water Quality Data

Tailrace	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
6/29/2021	6.82	7.08	7.58	24.80	25.22	25.60	76.64	77.40	78.08
6/30/2021	6.90	7.53	8.03	25.14	25.52	25.88	77.25	77.94	78.58
7/1/2021	6.38	7.27	7.93	24.50	25.32	25.90	76.10	77.57	78.62
7/2/2021	6.65	6.94	7.66	23.10	23.67	24.60	73.58	74.61	76.28
7/3/2021	7.25	7.45	7.72	21.96	22.49	23.70	71.53	72.49	74.66
7/4/2021	7.63	7.91	8.32	21.48	21.91	22.28	70.66	71.44	72.10
7/5/2021	7.55	7.96	8.39	22.30	22.89	23.70	72.14	73.20	74.66
7/6/2021	6.92	7.74	8.25	23.58	23.88	24.60	74.44	74.98	76.28
7/7/2021	7.07	7.75	8.11	24.44	24.64	24.84	75.99	76.35	76.71
7/8/2021	6.68	7.63	8.64	23.48	24.29	24.80	74.26	75.72	76.64
7/9/2021	6.53	7.10	7.62	22.86	23.15	23.52	73.15	73.67	74.34
7/10/2021	7.38	7.72	8.13	22.92	23.44	24.18	73.26	74.20	75.52
7/11/2021	6.95	7.34	8.03	23.14	23.95	24.84	73.65	75.11	76.71
7/12/2021	6.86	7.19	7.64	24.22	24.69	25.16	75.60	76.44	77.29
7/13/2021	6.97	7.32	7.63	24.48	24.77	25.22	76.06	76.59	77.40
7/14/2021	6.75	7.29	7.86	24.94	25.19	25.50	76.89	77.34	77.90
7/15/2021	6.97	7.38	7.82	24.92	25.27	25.66	76.86	77.48	78.19
7/16/2021	6.81	7.33	7.78	24.88	25.40	25.98	76.78	77.71	78.76
7/17/2021	6.54	7.21	7.72	25.16	25.40	25.76	77.29	77.71	78.37
7/18/2021	6.73	7.13	7.54	24.54	24.96	25.36	76.17	76.92	77.65
7/19/2021	6.78	7.29	7.68	24.58	24.79	24.94	76.24	76.62	76.89
7/20/2021	6.93	7.57	8.12	24.32	24.58	24.98	75.78	76.25	76.96
7/21/2021	7.67	8.02	8.29	23.64	24.24	24.90	74.55	75.63	76.82
7/22/2021	7.53	8.07	8.52	23.78	24.12	24.76	74.80	75.42	76.57
7/23/2021	7.55	8.03	8.42	23.84	24.14	24.36	74.91	75.44	75.85
7/24/2021	7.77	8.09	8.55	24.10	24.31	24.50	75.38	75.76	76.10
7/25/2021	7.10	7.77	8.31	24.52	24.77	25.04	76.14	76.59	77.07
7/26/2021	6.79	7.51	8.01	24.62	25.32	25.64	76.32	77.58	78.15
7/27/2021	6.42	6.97	7.63	23.36	24.07	25.12	74.05	75.33	77.22
7/28/2021	6.74	7.08	7.35	25.00	25.26	25.60	77.00	77.47	78.08
7/29/2021	6.76	7.21	7.69	25.34	25.75	26.22	77.61	78.34	79.20
7/30/2021	6.84	7.29	7.70	25.40	25.79	26.34	77.72	78.42	79.41
7/31/2021	6.79	7.16	7.54	25.22	25.38	25.76	77.40	77.69	78.37
8/1/2021	6.77	7.21	7.61	24.94	25.06	25.24	76.89	77.10	77.43
8/2/2021	6.77	7.38	7.78	23.96	24.37	24.90	75.13	75.87	76.82
8/3/2021	7.11	7.97	8.76	23.62	23.83	24.18	74.52	74.90	75.52
8/4/2021	8.01	8.35	8.72	23.12	23.50	23.82	73.62	74.30	74.88
8/5/2021	8.17	8.47	8.82	23.34	23.64	24.06	74.01	74.56	75.31
8/6/2021	8.08	8.38	8.71	23.60	23.80	24.06	74.48	74.83	75.31
8/7/2021	8.00	8.36	8.69	23.64	23.91	24.10	74.55	75.04	75.38
8/8/2021	7.93	8.32	8.77	23.28	23.62	24.04	73.90	74.51	75.27
8/9/2021	7.93	8.27	8.65	23.84	24.12	24.48	74.91	75.41	76.06
8/10/2021	7.39	8.02	8.35	24.20	24.76	25.40	75.56	76.56	77.72
8/11/2021	6.56	7.55	8.06	24.44	25.06	25.82	75.99	77.11	78.48
8/12/2021	6.30	7.15	7.61	25.06	25.43	25.94	77.11	77.77	78.69
8/13/2021	6.23	6.96	7.96	24.92	25.51	26.44	76.86	77.92	79.59
8/14/2021	6.05	6.72	7.18	24.28	24.68	25.18	75.70	76.43	77.32
8/15/2021	6.19	6.86	7.57	24.48	24.94	25.26	76.06	76.89	77.47
8/16/2021	6.40	7.27	8.60	23.32	23.62	24.84	73.98	74.52	76.71
8/17/2021	6.48	6.85	7.44	23.28	23.48	23.66	73.90	74.27	74.59

Tailrace	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
8/18/2021	6.89	7.17	7.76	22.88	23.45	23.78	73.18	74.21	74.80
8/19/2021	6.70	7.09	7.66	23.80	24.24	24.92	74.84	75.63	76.86
8/20/2021	6.12	6.68	7.42	23.94	24.31	24.80	75.09	75.76	76.64
8/21/2021	6.68	6.92	7.22	23.58	24.07	24.62	74.44	75.32	76.32
8/22/2021	6.92	7.14	7.40	23.96	24.30	24.60	75.13	75.74	76.28
8/23/2021	6.50	7.06	7.48	24.32	24.61	24.90	75.78	76.29	76.82
8/24/2021	6.80	7.20	7.58	24.62	24.86	25.30	76.32	76.74	77.54
8/25/2021	6.73	7.33	7.72	25.14	25.32	25.68	77.25	77.58	78.22
8/26/2021	6.91	7.36	7.77	25.20	25.45	25.80	77.36	77.81	78.44
8/27/2021	6.83	7.47	7.91	25.44	25.73	25.96	77.79	78.32	78.73
8/28/2021	7.04	7.49	7.95	25.10	25.36	25.64	77.18	77.65	78.15
8/29/2021	7.08	7.61	8.00	25.44	25.72	26.06	77.79	78.29	78.91
8/30/2021	6.31	6.92	7.68	25.30	25.95	26.64	77.54	78.70	79.95
8/31/2021	6.30	6.76	7.19	24.70	25.33	25.68	76.46	77.60	78.22
9/1/2021	6.23	7.00	7.99	23.16	23.81	24.64	73.69	74.87	76.35
9/2/2021	7.16	7.42	7.85	22.30	22.53	23.14	72.14	72.56	73.65
9/3/2021	7.42	7.67	8.05	21.50	21.95	22.54	70.70	71.52	72.57
9/4/2021	7.62	7.83	8.09	21.44	21.77	22.24	70.59	71.19	72.03
9/5/2021	7.34	7.88	8.34	22.14	22.43	22.96	71.85	72.38	73.33
9/6/2021	7.22	7.73	8.14	22.46	22.89	23.60	72.43	73.21	74.48
9/7/2021	7.11	7.76	8.10	22.50	22.87	23.84	72.50	73.17	74.91
9/8/2021	7.44	7.90	8.38	22.46	22.79	23.22	72.43	73.03	73.80
9/9/2021	7.55	7.94	8.35	22.18	22.83	23.22	71.92	73.10	73.80
9/10/2021	7.77	8.28	8.78	21.28	21.99	22.94	70.30	71.58	73.29
9/11/2021	8.10	8.55	9.15	20.64	21.30	21.94	69.15	70.34	71.49
9/12/2021	8.25	8.67	9.22	20.76	21.51	22.52	69.37	70.73	72.54
9/13/2021	7.92	8.56	9.10	21.08	22.08	23.34	69.94	71.75	74.01
9/14/2021	8.00	8.39	9.02	21.78	22.60	23.58	71.20	72.68	74.44
9/15/2021	7.88	8.38	8.99	22.54	22.95	23.66	72.57	73.32	74.59
9/16/2021	8.14	8.44	9.04	22.74	22.94	23.28	72.93	73.29	73.90
9/17/2021	8.14	8.41	8.90	22.72	23.01	23.54	72.90	73.42	74.37
9/18/2021	8.14	8.44	9.07	22.72	23.17	23.94	72.90	73.70	75.09
9/19/2021	8.11	8.41	9.03	23.00	23.49	24.14	73.40	74.28	75.45
9/20/2021	8.04	8.31	8.74	23.28	23.57	23.84	73.90	74.43	74.91
9/21/2021	8.10	8.34	8.90	21.34	22.68	23.28	70.41	72.83	73.90
9/22/2021	8.90	9.25	9.35	20.48	20.95	21.36	68.86	69.72	70.45
9/23/2021	9.19	9.30	9.42	18.94	19.42	20.44	66.09	66.96	68.79
9/24/2021	9.34	9.54	9.71	17.84	18.18	18.92	64.11	64.73	66.06
9/25/2021	9.43	9.57	9.77	17.38	17.79	18.14	63.28	64.02	64.65
9/26/2021	9.32	9.50	9.75	17.40	17.87	18.34	63.32	64.17	65.01
9/27/2021	9.22	9.38	9.60	17.40	18.17	18.82	63.32	64.70	65.88
9/28/2021	8.98	9.20	9.43	17.88	18.60	19.24	64.18	65.49	66.63
9/29/2021	8.70	9.05	9.39	18.48	19.25	19.84	65.26	66.65	67.71
9/30/2021	7.83	8.58	9.00	19.60	20.02	20.68	67.28	68.04	69.22
10/1/2021	8.18	8.72	9.37	19.64	19.95	20.34	67.35	67.91	68.61
10/2/2021	8.37	8.96	9.61	19.24	19.53	19.96	66.63	67.15	67.93
10/3/2021	8.14	8.94	9.65	19.26	19.67	20.06	66.67	67.41	68.11
10/4/2021	7.58	8.18	9.45	19.74	20.18	20.38	67.53	68.32	68.68
10/5/2021	7.58	8.12	8.85	20.32	20.74	20.98	68.58	69.33	69.76
10/6/2021	7.51	7.90	9.47	20.36	20.69	21.16	68.65	69.25	70.09
10/7/2021	7.63	7.91	8.49	20.28	20.62	20.86	68.50	69.11	69.55
10/8/2021	7.79	8.16	8.68	19.76	20.13	20.28	67.57	68.24	68.50
10/9/2021	7.82	8.16	8.81	19.38	19.74	19.90	66.88	67.52	67.82
10/10/2021	7.87	8.23	8.66	19.02	19.35	19.62	66.24	66.84	67.32

Tailrace	Min. Do *mg/L*	Ave. DO *mg/L*	Max. DO *mg/L*	Min. T *°C*	Ave. T *°C*	Max. T *°C*	Min. T *°F*	Ave. T *°F*	Max. T *°F*
10/11/2021	8.06	8.46	9.03	18.92	19.20	19.50	66.06	66.56	67.10
10/12/2021	8.05	8.41	8.92	18.90	19.35	19.76	66.02	66.83	67.57
10/13/2021	8.05	8.52	9.07	19.56	20.17	20.84	67.21	68.31	69.51
10/14/2021	8.20	8.65	9.17	19.98	20.32	20.80	67.96	68.57	69.44
10/15/2021	8.20	8.68	9.17	19.86	20.19	20.60	67.75	68.34	69.08
10/16/2021	8.27	8.74	9.31	19.40	20.21	20.54	66.92	68.38	68.97
10/17/2021	8.32	9.04	9.67	17.16	18.45	19.36	62.89	65.20	66.85
10/18/2021	7.90	9.35	9.92	16.28	16.74	17.38	61.30	62.14	63.28
10/19/2021	8.56	9.23	10.10	15.06	15.84	16.54	59.11	60.52	61.77
10/20/2021	9.03	9.63	10.32	15.18	15.94	16.82	59.32	60.69	62.28
10/21/2021	9.03	9.61	10.23	15.44	16.14	16.72	59.79	61.04	62.10
10/22/2021	8.66	9.44	10.09	16.14	16.60	17.10	61.05	61.89	62.78
10/23/2021	8.59	9.33	10.09	16.06	16.50	17.04	60.91	61.69	62.67
10/24/2021	8.86	9.71	10.23	15.46	16.27	16.84	59.83	61.28	62.31
10/25/2021	8.73	9.63	10.29	16.14	16.78	17.40	61.05	62.21	63.32
10/26/2021	8.53	9.06	9.78	16.04	16.93	17.30	60.87	62.47	63.14
10/27/2021	8.59	9.26	10.53	13.18	15.20	16.82	55.72	59.36	62.28

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Appendix C - Fish Community Study Report - To be Submitted by Nov. 30, 2022

Niagara Hydroelectric Project (FERC No. 2466)

February 28, 2022

Prepared by:

Prepared for:

Appalachian Power Company

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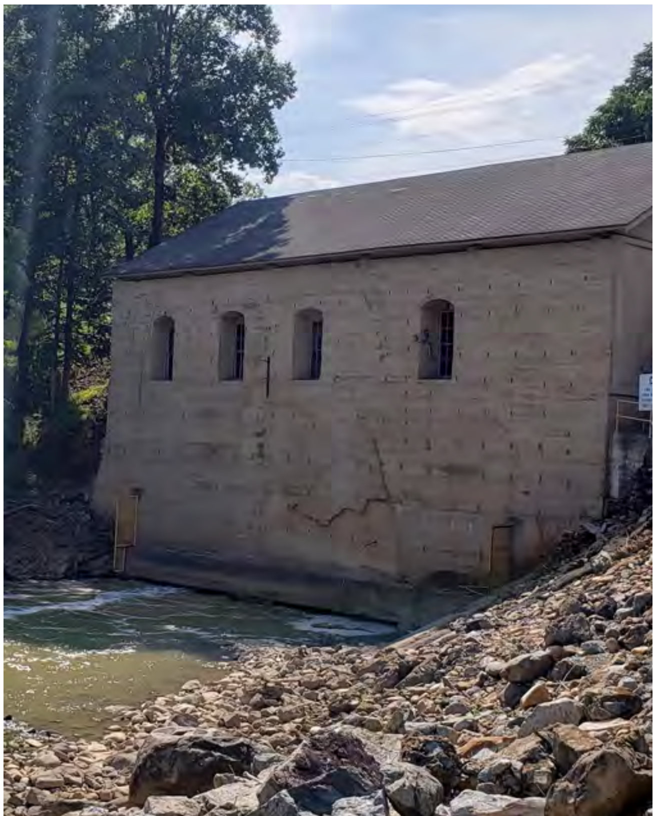

Appendix D - Benthic Aquatic and Mussel Community Report

Niagara Hydroelectric Project (FERC No. 2466)

February 28, 2022

Prepared by:

Edge Engineering and Science, LLC

Prepared for:

Appalachian Power Company

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Niagara Hydroelectric Project
(FERC Project No. 2466)

2020-2021 Benthic Aquatic Resources Survey Results, Virginia

February 28, 2022

Prepared for:

AMERICAN ELECTRIC POWER
BOUNDLESS ENERGY

Niagara → HDR2020-0002

Prepared by:

EDGE ENGINEERING & SCIENCE
further insight.

Edge Engineering and Science, LLC
Cincinnati, Ohio

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LIST OF ACRONYMS

AEP	American Electric Power – Client
Appalachian	Appalachian Power Company
CFS	Cubic feet per second
CPUE	Catch per unit effort
DO	Dissolved oxygen
EDGE	Edge Engineering and Science, LLC
FERC	Federal Energy Regulatory Commission
HDR	HDR, Inc. – Client
ISR	Initial Study Report
LDB	Left descending bank
NRSA	National Rivers and Streams Assessment
Project	Niagara Dam Hydroelectric Project
RDB	Right descending bank
RSP	Revised Study Plan
SAV	Submerged aquatic vegetation
TOYR	Time-of-year restriction
USFWS	U.S. Fish and Wildlife Service
USR	Updated Study Report
VAC	Virginia Administrative Code
VDCR	Virginia Department of Conservation and Recreation
VDEQ	Virginia Department of Environmental Quality
VDWR	Virginia Department of Wildlife Resources (formerly VDGIF)
VISAC	Virginia Invasive Species Advisory Committee

1.0 INTRODUCTION

The Niagara Hydroelectric Project (Project) is a 2.4-megawatt hydroelectric generating facility located at river mile 355 of the Roanoke River in Roanoke County, Virginia. Appalachian Power Company (a unit of American Electric Power; AEP) is pursuing a new license from the Federal Energy Regulatory Commission (FERC) for the Project as their existing license (FERC Project No. 2466) expires in 2024. Aquatic biological studies were completed to support their existing FERC license and results of these studies are ultimately used as a record and reference for current relicensing efforts. The Roanoke River, along with the approximately 2-mile-long reservoir resulting from the Niagara Dam, harbors a diverse community of aquatic biota; thus, aquatic biological studies are required to survey and document the contemporary community of organisms present within the Project area (Figure 1). The Roanoke River and lower reaches of tributary streams are included in the Project area. The information gained from these studies will document the current conditions of macroinvertebrate and mussel abundance, diversity, and distribution in the vicinity of the Project.

Study scoping with state and federal agencies resulted in the development and approval of a Project-specific Revised Study Plan (RSP) that identified four objectives for Project studies (AEP 2019) pertaining to benthic aquatic species.

Goals and Objectives

1) Collect a baseline of existing macroinvertebrate and crayfish communities in the vicinity of the Project
2) Confirm the presence or absence of mussels within the study area
3) Characterize the mussel community composition (if present), abundance, and distribution within the study area
4) Determine presence/probable absence of federally or state-listed species within the study area

In accordance with the RSP, field sampling efforts were necessary to satisfy each of the four objectives. Satisfaction of all objectives was not able to be accomplished during the 2020 calendar year due to delays resulting from unforeseeable circumstances including the COVID-19 global pandemic; therefore, an Initial Study Report (ISR) was submitted on January 11, 2021. This report serves as the Update Study Report (USR) now that all field sampling efforts within the RSP have been completed.

2.0 METHODS

The RSP provided guidance on the biological sampling framework for the Project that included macroinvertebrates, crayfish, and freshwater mussels. Macroinvertebrate and crayfish sampling employ a variety of methods to target representative habitat at 10 sites throughout the Project area. Mussel sampling targeted representative habitat at 13 sites throughout the Project area. The methods, number and location of sample sites, and seasonality were developed to document a comprehensive representation of the Project area and to correlate with previous sampling efforts (Appalachian and AEP 1991) for comparison. Replication of fall 2020 macroinvertebrate and crayfish methods and sites occurred in spring 2021, both during the sample index period defined by Virginia Department of Environmental Quality (VDEQ) Biological Monitoring Program Quality Assurance Project Plan (VDEQ 2008).

2.1 Macroinvertebrate and Crayfish Community

Macroinvertebrate and crayfish surveys, detailed in the RSP, include two temporally independent efforts (one survey in fall and one survey in spring). Specific sampling dates within these timeframes are determined based on factors including (but not limited to) weather conditions, water temperatures, river flows and reservoir elevations, and safety of field staff and the public. Sampling methods were derived from National Rivers and Streams Assessment (NRSA) Field Operations Manual (USEPA 2019) and VDEQ (2008) and include quantitative and qualitative sampling methods that target different habitats. Within the constraints of the Project's objectives and geographic limits, quantitative sampling targets riffle/run habitats and qualitative sampling targets available microhabitats in pools. A variety of sampling techniques were used to sample macroinvertebrates using quantitative and qualitative methods as described in subsequent sections. Five sample sites were located upstream of Niagara Dam (two quantitative and three qualitative) and five sites were downstream of Niagara Dam (three quantitative and two qualitative). Site naming conventions are as follows: Location-Seasonality-Method-Site Number. For example, NFQT1 = Niagara Fall Quantitative Site 1, NFQL3 = Niagara Fall Qualitative Site 3, and NSQL3 = Niagara Spring Qualitative Site 3.

The sampling methods used to quantify macroinvertebrates only allows for the determination of presence of crayfish. To assess the crayfish community in the Project area, additional kick samples and seining efforts were performed following benthic macroinvertebrate sampling to ensure all crayfish habitat had been covered and that a broad representation of crayfish species available at each site was documented. The exact abundance of crayfish was not recorded because methods used are not crayfish specific and simply provide presence data.

2.1.1 Quantitative Sampling

Sampling for benthic macroinvertebrates and crayfish occurred at five riffle/run sites (i.e., quantitative; NFQT and NSQT site names) along 100-meter transects following guidelines defined by USEPA (2019) and VDEQ (2008). Upon arrival at riffle/run sites (Figures 1-6), transects were delineated in riffle/run habitat and the start and endpoint coordinates were recorded. Site photos were taken in four directions (upstream, downstream, left descending bank [LDB], and right descending bank [RDB]; all 90 degrees to one another) and substrate, and field conditions were recorded (e.g., time, date, temperature, precipitation, cloudy/overcast, etc.). At each sample site, habitat characteristics (e.g., substrate, estimated water velocity, depth, and instream cover) and water quality parameters (e.g., pH, water temperature, dissolved oxygen [DO], and conductivity) were measured and recorded. Multiple points for habitat and water quality measurements were taken if there was large variation within a single site. Sampling effort (e.g., time, number of samples) were also recorded during each sampling event.

Starting at the downstream end of the transect and moving upstream, all riffle/run habitats were candidates for sampling throughout the reach. Sampling was conducted holding the D-frame net on the bottom of the stream perpendicular to flow and kicking substrate to agitate and dislodge organisms, allowing them to flow into the net. A single kick consists of disturbing the substrate upstream of the net by kicking with the feet and/or by using the hands to dislodge the cobble/boulder for 30-90 seconds. For example, a single sample was a composite of six kick sets, each disturbing approximately 0.33 m^2 above the dip net for a duration of 30-90 seconds and totaled an area comprising 2 m^2. The composited sample was washed by running clean stream water through the net 2-3 times and then transferred to a sieve (500 µm) if needed. For QA/QC measures, replicate sampling was conducted at one quantitative site within close proximity (not in the same locations as the first set of samples) of the initial sampling area. This replicate sample was completed downstream of Niagara Dam (one from fall 2020 and one from spring 2021) and was included in data analysis.

2.1.2 Qualitative Sampling

Benthic macroinvertebrates and crayfish were also sampled at five qualitative sites (i.e., multi-habitat; NFQL and NSQL site names) along 100-meter transects following guidelines defined by USEPA (2019) and VDEQ (2008). At pool sites (Figure 1 and Figures 7-11), transects were delineated in near-shore pool habitats and the start and endpoint coordinates were recorded. Site photos, field conditions, habitat characteristics, and water quality parameters were recorded in the same manner as quantitative sites (see Section 2.1.1). In addition, a Secchi disk reading was taken at each sample site at the time of sampling to assess water transparency. Multiple points for habitat and water quality measurements were taken if there was large variation within a single site.

A canoe was necessary to collect qualitative samples along each of the transects starting at the downstream end and moving upstream. Sampling was conducted by performing 20 jabs with a D-frame net into suitable, stable habitats (snags, vegetation, banks, and substrate). A single jab consists of forcefully thrusting the net into a microhabitat for a linear distance of 1.0 meter, followed by 2-3 sweeps of the same area to collect dislodged organisms for 20-90 seconds per jab, sweep, or kick. Multiple types of habitat were sampled in rough proportion to their frequency within the reach. Unique habitat types (i.e., those consisting of less than 5 percent of stable habitat within the sampling reach) were not sampled. Sampling effort was proportionally allocated (20 jabs/sweeps/kicks) to shore-zone and bottom-zone, 20-90 seconds per jab, sweep, or kick. Samples were cleaned and transferred to the sieve bucket at least every five jabs; or more often as necessary. At one qualitative site, replicate sampling was conducted within the initial sampling area in close proximity (not in the same locations as the first set of samples). This replicate sample was completed upstream of Niagara Dam (one from fall 2020 and one from spring 2021) and was included in data analysis. All samples were preserved and processed in the same manner as quantitative methods (see Section 2.1.1).

2.1.3 Laboratory Processing

All field samples were preserved in 95% ethanol, placed in labeled jars, and sent to Civil & Environmental Consultants, Inc. (CEC) for processing and identification to the lowest practicable taxonomic level. Laboratory processing was performed in accordance with the VDEQ standard operating procedures “Methods for Laboratory Sorting and Subsampling of Benthic Macroinvertebrate Samples” (VDEQ 2008). Photo vouchers were taken of all unique or rare species collected. At the completion of the study, a summary of species and numbers collected will be provided to the Virginia Department of Wildlife Resources (VDWR) in compliance with the scientific collection permit specifications.

2.1.4 Data Analysis

The Virginia Stream Condition Index (VSCI) (Burton and Gerritsen 2003) was employed to investigate the impairment of the Roanoke River within the Project area using eight metrics of the macroinvertebrate community. These metrics include (1) Total Taxa, (2) EPT Taxa (*Ephemeroptera* [mayflies], *Plecoptera* [stoneflies], and *Trichoptera* [caddisflies]), (3) Percent Ephemeroptera, (4) Percent Plecoptera plus Trichoptera less Hydropsychidae, (5) Percent Scrapers, (6) Percent Chironomidae, (7) Percent Top Two Dominant taxa, and (8) the Hilsenhoff Biotic Index (HBI). For the purposes of this study, and in agreement with VDEQ methods, all VSCI scores were calculated at family-level taxonomy. “Reference” conditions are a collection of aspects shared by streams deemed unimpaired within the region. The results of the VSCI scores determine the level of impairment at a specific site with scores over 80 indicating “reference” conditions, scores between 60 and 79 indicating “similar to reference” conditions, and scores below 60 indicating “impaired” conditions. The site VSCI scores were also used to make qualitative comparisons of overall reach conditions between different Project areas (i.e., upstream of Niagara Dam and downstream of Niagara Dam).

2.2 Mussel Habitat and Community

Mussel habitat and community study survey efforts included one season of sampling (fall 2020). The survey was developed following the Draft Freshwater Mussel Guidelines for Virginia (USFWS and VDGIF 2018) using habitat (e.g., water depth, substrate, stream flow) dependent methods, which included snorkeling, viewscope, and/or Surface Supply Air. Transect surveys occurred in pool habitats and included searching all habitat along the entire length. Abbreviated surveys occurred at mixed habitat sites and involved searching for mussels in suitable habitat throughout each site. Sampling dates were chosen within the approved survey window and occurred during relatively low-flow and high-visibility conditions. A variety of search techniques were used to survey for mussels at transect and abbreviated sites as described in subsequent sections. Eleven sites were upstream of Niagara Dam (eight transect and three abbreviated) and two sites were downstream of Niagara Dam (both abbreviated). The site naming convention for transect sites is ‘T’ followed by site number and for abbreviated sites is ‘UNIO’ followed by site number/descriptor. For example, UNIO-WC is the abbreviated site in Wolf Creek.

2.2.1 Transects

Freshwater mussel surveys in the impounded areas of the Project consisted of searches performed along eight linear transects that extended across the stream channel (varying from approximately 30 to 75 meters long) and perpendicular to stream flow. Due to safety concerns, no transect searches were performed in the 500-meter reach immediately upstream of Niagara Dam. Transects were placed approximately every 500 meters in the Niagara Dam impoundment and the free-flowing reach near the upstream extent of the Project area. Upon arrival at sites T-1 through T-8 (Figure 1 and Figures 12-19), transects were delineated and the start and endpoint coordinates were recorded. Site photos were taken in four directions (90 degrees to one another), and substrate and field conditions were documented (e.g., time, date, temperature, precipitation, cloudy/overcast, etc.). At each sample site, habitat characteristics (e.g., substrate, estimated water velocity, depth, and instream cover) and water quality parameters (e.g., pH, water temperature, DO, and conductivity) were measured and recorded. A Secchi disk reading was taken at each reservoir sample site at the time of sampling. Transects were subdivided into 10-meter intervals and data (i.e., substrate composition, mussel occurrence) was recorded for each interval.

Commercial divers approved by AEP and HDR conducted the mussel surveys at Niagara under the direction of an EDGE mussel biologist, working under Virginia Scientific Collecting Permit No. 068630 (Appendix A). Divers searched transects using Surface Supply Air methods at an approximate rate of one minute per square meter in heterogeneous substrates. All efforts were made to locate mussels including wafting substrates, searching through aquatic vegetation, and turning cobble, boulder, and woody debris. Additionally, divers wafted sediment and raked substrates with their fingertips to uncover buried mussels.

2.2.2 Abbreviated

Sampling for freshwater mussels also involved surveying five abbreviated sites outside the impounded area. (Figure 1 and Figures 20-24). Upon arrival, sites were delineated, and the start and endpoint coordinates were recorded. Site photos, field conditions, habitat characteristics, and water quality parameters were recorded in the same manner as quantitative sites, as described in Section 2.2.1. Multiple data points, for habitat and water quality measurements, were taken if there was large variation within a single site.

Abbreviated mussel searches were completed throughout the assigned survey reach using viewscopes, snorkeling, and Surface Supply Air methods. Surveyors targeted habitat(s) suitable for the occurrence of freshwater mussels and searched those areas at an approximate rate of one minute per square meter in heterogeneous substrates. All efforts were made to locate mussels as described in Section 2.2.1.

Located mussels were placed in mesh bags and retained in the water for subsequent processing that included species identifications, enumerations, and length measurements. Photographs of representative taxa were taken. No live mussels were retained or injured during survey related activities. Fresh dead (empty valves) and weathered shells were retained as voucher specimens and will be deposited at malacological museums at 1) Marshall University in Huntington, West Virginia, 2) Ohio State University in Columbus, Ohio, 3) Carnegie Museum of Natural History in Pittsburgh, Pennsylvania, or 4) will provided to the United States Fish and Wildlife Service (USFWS), VDWR, and/or appropriate state agency upon request.

2.3 Deviations from Revised Study Plan

2.3.1 COVID-19 Delays

Initially, macroinvertebrate and crayfish surveys were proposed for completion in spring and fall 2020; however, the COVID-19 pandemic, and subsequent restrictions on non-essential travel and safety considerations for field staff, prohibited spring 2020 field efforts. As a result, AEP requested and was granted an extension to accommodate the change in schedule as the USFWS, VDWR, VDEQ, and Virginia Department of Conservation and Recreation (VDCR) all concurred with adaptable schedule revisions. EDGE was contracted and given notice to proceed with fieldwork at the beginning of September 2020. Thus, spring macroinvertebrate and crayfish sampling was completed during spring 2021. Mussel surveys were scheduled for and successfully completed during the 2020 field season

2.3.2 Weather Delays

Periodic delays associated with weather and stream flow conditions plagued the fall of 2020. Average annual rainfall for Roanoke, Virginia (collected at this station since 1981) is approximately 105 centimeters (U.S. Climate Data 2021) and, as of December 1, 2020, Roanoke already accumulated over 157 centimeters of rain (National Weather Service 2020). Sampling efforts were completed at the assumed 2020 baseflow, which was likely around 150-200 cubic feet per second (cfs) during the sampling period. The 47 percent increase in average precipitation made it difficult to sustain contiguous field sampling efforts and did not allow the Roanoke River to reach average annual baseflow throughout the sampling period at the study location. Spring 2021 flows more closely matched average flows during the sampling period.

2.3.3 Time-of-Year Restrictions

Virginia time-of-year restrictions (TOYR) for the protection of the state and federally endangered Roanoke Logperch (*Percina rex*) extend from March 15 through June 30 each year. The VDWR and USFWS were consulted in advance of the spring 2021 field data collections to receive their concurrence that the proposed methodology and timing of macroinvertebrate sampling were appropriate to avoid impacts to the endangered Roanoke Logperch during the TOYR. Concurrence to perform the sample collection with the proposed methodology during the TOYR was received at the end of May 2021, but the delay resulted in sample collection occurring outside of the spring index period.

3.0 RESULTS

Study samples were collected as closely as possible to the locations proposed in the RSP. Upon arrival at each proposed sample location, field biologists delineated the sample transect or area in the nearest location exhibiting the target habitat type (i.e., riffles, pools, etc.) using habitat-specific sampling methodologies. No notable or significant changes were made to proposed sampling locations for macroinvertebrate and crayfish or mussel survey efforts.

3.1 Macroinvertebrate and Crayfish Community

Macroinvertebrate samples were collected from ten sites between September 15 and 16, and on October 5, 2020, during the fall sample index period (September 1 – November 30) defined by VDEQ (2008). Although spring 2021 sampling occurred three days beyond the spring sample index period (March 1 – May 31) defined by VDEQ (2008), the impacts of the delay described in Section 2.3.3 were deemed negligible. Sampling was performed by EDGE's state and federally permitted astacologist under Virginia Scientific Collecting Permit No. 070705 (see Appendix A). There were differences in habitat type and substrates observed between sites (Appendix B); however, differences in sampling dates, time of day, and low number of intra- and inter-site samples do not facilitate statistical comparison of physiochemical properties between sites. Results of physiochemical data collected at sample sites met the state water quality standards established for the New River, indicating that water quality within the Project area is capable of supporting macroinvertebrate communities. Additional water quality data are provided in the Water Quality Study Report presented in the Project USR.

3.1.1 Upstream of Niagara Dam

The substrate at the quantitative macroinvertebrate site at the Tinker Creek, upstream of Niagara Dam, generally consisted of sand (45%), gravel (35%), cobble (18%), and boulder (2%) (Figure 2), and habitat structure consisted of occasional boulders, rootwads and undercut banks particularly along the LDB. Bedrock (35%), boulder (20%), cobble (25%), gravel (10%), and sand (10%) were the dominant substrates at the Roanoke River site (Figure 3), and habitat structure consisted of shallow sheets of bedrock riffles and glides with an overlay of other smaller substrates and occasional patches of submerged aquatic vegetation (SAV) were present as well as filamentous algae. Appalachian Brook Crayfish (*Cambarus bartoni bartoni*) and Ozark Crayfish (*Faxonius ozarkae*) were collected in Tinker Creek and Atlantic Slope Crayfish (*Cambarus longulus*) and Ozark Crayfish were collected in the mainstem Roanoke River. The Appalachian Brook Crayfish and Atlantic Slope Crayfish are both native to the Roanoke River whereas Ozark Crayfish is considered an invasive species. Water quality parameters (temperature, pH, velocity, and conductivity) remained relatively consistent between the two quantitative sites upstream of Niagara Dam, with exception of DO, which was generally higher at the Roanoke River site than the Tinker Creek site (Appendix C), and velocities which were highly variable within and among sites.

The substrate at qualitative macroinvertebrate sites upstream of Niagara Dam generally consisted of bedrock (60%), cobble (30%), and silt (10%) with large quantities of leaf packs, rootwads, and snags along the shore at the upstream most site within the impounded area. The other two sites in the impounded area upstream of Niagara Dam were dominated by sand (60%) and silt (40%) substrates and with large quantities of leaf packs and snags occurring along the steeply sloping shoreline. Two species of invasive crayfish (Ozark Crayfish and Red Swamp Crayfish [*Procambarus clarkii*]) were collected from the sample sites in the impounded area, with zero crayfish being captured at the downstream most site in the impoundment (Figure 9). Water quality parameters (temperature, pH, DO, velocity, and conductivity) remained relatively consistent within the impoundment, but DO was generally the lowest in the middle of the impoundment.

A total of 38 macroinvertebrate taxa were collected upstream of Niagara Dam from two quantitative sites and three qualitative sites. The average VSCI score for riffle/run sites and pool sites sampled upstream of Niagara Dam in fall 2020 were 48.1 and 34.7, respectively, with all five sites scoring below 60 (Appendix C). The average VSCI score for riffle/run sites and pool sites sampled upstream of Niagara Dam in spring 2021 were 44.1 and 20.6, respectively, with all five sites scoring below 60 (Appendix C). However, a quantitative site (NF/NSQT2) in the mainstem of the Roanoke River in this Project area had HBI value indicating “Good” water quality in fall and spring and one qualitative site (NSQL3) had an HBI value indicating “Excellent” water quality in spring based on the tolerance of the macroinvertebrate community.

3.1.2 Downstream of Niagara Dam

The substrate at the three quantitative macroinvertebrate sites downstream of Niagara Dam generally consisted of bedrock (40%), slab boulder (20%), cobble (20%), and gravel (20%); and habitat structure consisted of shallow riffles and glides with smooth bedrock overlain with small, mixed substrates with sporadic patches of SAV and filamentous algae. One native species (Atlantic Slope Crayfish [*Cambarus longulus*]) and three invasive species (Ozark Crayfish, Virile Crayfish [*Faxonius virilis*], and the Red Swamp Crayfish) were collected at quantitative sites downstream of the Niagara Dam. Water quality parameters (temperature, pH, DO, velocity, and conductivity) remained relatively consistent between the quantitative sites in the reach downstream of Niagara Dam.

The substrate at the two qualitative macroinvertebrate sites downstream of Niagara Dam generally consisted of bedrock (40%), cobble (40%), gravel (10%), and sand (10%) with a moderate amount of rootwads along the shoreline. Based on depth and flow velocity, both sites were best characterized as run habitats. Two species of invasive crayfish were captured at these qualitative sites (Ozark Crayfish and Virile Crayfish), and water quality parameters (temperature, pH, DO, velocity, and conductivity) remained relatively consistent.

A total of 45 macroinvertebrate taxa were collected downstream of Niagara Dam from three quantitative sites and two qualitative sites. The average VSCI score for riffle/run sites and pool sites sampled downstream of Niagara Dam in fall 2020 were 39.0 and 42.8, respectively, with all five sites scoring below 60 (Appendix C). The average VSCI score for riffle/run sites and pool sites sampled downstream of Niagara Dam in spring 2021 were 38.1 and 41.1, respectively, with all five sites scoring below 60 (Appendix C). However, one quantitative site (NFQT6) and one qualitative site (NFQL8) in this Project area had HBI value indicating “Good” water quality in fall and one quantitative site (NSQT10) had an HBI value indicating “Good” water quality in spring 2021 based on the tolerance of the macroinvertebrate community.

3.2 Mussel Habitat and Community

Mussel survey efforts were completed during optimal weather and riverine conditions between October 6-8, 2020, following methods defined in the RSP and derived from the Draft Freshwater Mussel Guidelines for Virginia (USFWS and VDGIF 2018). Survey efforts were performed by EDGE's state permitted malacologist and a commercial dive team under Virginia Scientific Collecting Permit No. 068630 (see Appendix A).

Unionids were mostly absent throughout all 13 survey reaches. Survey efforts along eight transects located in the Niagara Dam impoundment totaling 430 square meters resulted in the collection of zero live or deadshell specimens. Abbreviated surveys at five locations, with a cumulative search effort of 1,335 minutes, resulted in the collection four live unionids representing one species, Eastern Elliptio (*Elliptio complanata*). The Eastern Elliptio is native to the Roanoke River system and a common species in Atlantic Slope mussel assemblages. Additionally, a single Notched Rainbow (*Villosa constricta*) was observed as weathered deadshell material during quantitative macroinvertebrate and crayfish surveys near the Tinker Creek site. No live mussels or deadshell were collected downstream of Niagara Dam. The invasive Asiatic Clam (*Corbicula fluminea*) was noted at all sites. The highest density of Asiatic Clams in the Project area was noted in Tinker Creek. Asiatic Clams appeared in relatively even densities between sites within the mainstem Roanoke River (above and below Niagara Dam), with slightly higher densities observed where suitable mollusk habitat was present. Asiatic Clams were noted at the mouth of Wolf Creek but did not persist upstream beyond the confluence with the Roanoke River. Representative site and mussel photos are provided in Appendix B. Results of physiochemical data collected at sample sites met the state water quality standards established for the Roanoke River, indicating that water quality within the Project area is capable of supporting macroinvertebrate communities. Additional discussions regarding water quality will be provided in the Project-specific USR water quality study report.

3.2.1 Upstream of Niagara Dam

Abbreviated mussel sites were located in riffle/run habitat upstream of the Niagara Dam, with one site in Tinker Creek and one in the mainstem of the Roanoke River. The Tinker Creek site consisted of riffle/run complexes (Figure 21). During the survey effort, the streamflow was low and clear with a maximum depth of approximately 1.5 meters and an average depth of 0.2 meters. The average stream width at this site was approximately 15 meters. The riffles and thalweg of Tinker Creek were dominated by unstable, mobile sand (65%), gravel (25%), and silt (10%). A small area (~25 square meters) around the Tinker Creek Canoe Launch provided the only coarse substrate (i.e., large, stable cobble) in the stream. Two hundred and forty (240) minutes of qualitative search effort was expended and yielded two live and approximately 12 weathered deadshell Eastern Elliptio specimens, with CPUE of 0.5 individuals per hour and an approximate qualitative density of 0.0018 individuals per square meter. Both live individuals were old and all deadshell specimens were represented by older individuals, suggesting a lack of recruitment. Additionally, a Notched Rainbow was observed as weathered deadshell material during quantitative macroinvertebrate and crayfish surveys near this site in Tinker Creek.

The site was strongly influenced by anthropogenic impacts and featured heavy trash deposits, human feces, and combined sewer outfalls. During high flow events, the stream likely experiences elevated water velocities and unnatural sediment transport as it drains downtown Roanoke with a watershed dominated by impermeable surfaces. However, stable substrates suitable for mussel colonization were present in pockets behind woody debris and along the lateral stream margins. The Tinker Creek site likely supports a minimal population of freshwater mussels that may be greatly degraded due to anthropogenic impacts and a lack of recruitment.

The Roanoke River site consists of several riffle-run complexes and one long pool (Figure 20). During survey efforts, the streamflow was relatively low and clear with a maximum depth of approximately 1.5

meters and an average depth of 0.5 meter. The average stream width at this site was approximately 33 meters. Substrate composition was a heterogeneous mixture of sand (30%), gravel (30%), cobble (25%), and bedrock (10%) with some silt (5%) deposits along the stream margins. Survey efforts included 360 minutes of qualitative searches using snorkel and view scope methods and resulted in the collection of two live Eastern Elliptio (Appendix C). This sampling location resulted in a CPUE of 0.33 individuals per hour with an approximate qualitative density of 0.000148 individuals per square meter. However, both individuals were collected within 3 meters of each other in sand/silt substrates near flow refugia along the LDB. With an abundance of two and a species richness of one, the UNIO-1 site likely supports a minimal population of highly localized freshwater mussels that persist in low densities. No state or federally listed mussels were found.

Wolf Creek is a small tributary that empties into the impounded portion of the Roanoke River along the LDB and consisted of high-gradient riffle/run complexes (Figure 22). The maximum depth was approximately 1.0 meter with an average depth of 8 centimeters. The average stream width at this site was approximately five meters. Substrate composition was dominated by unconsolidated sand (70%) with small pea gravel (25%) and some cobble (5%) present. Survey efforts began at the Wolf Creek confluence with the Roanoke River and extended approximately 500 meters upstream. One hundred and thirty-five (135) minutes of qualitative search efforts yielded no live individuals or deadshell specimens. The stream featured excellent riparian zone coverage but was heavily impacted by unstable sand deposits, likely the result of upstream urban activity. The small stream size (approximately 13 square kilometer drainage area) and unstable substrates provided poor habitat for freshwater mussel colonization.

All mussel transect sites were placed within the impounded section of the Roanoke River and consequently categorized as pool habitats. Substrate composition varied from bedrock to silt, with a general longitudinal pattern observed in substrate sizes that decreased in the downstream direction towards Niagara Dam (Figure 1; T). Transect sites had relatively similar habitat features and all resulted in zero live mussels; therefore, are discussed collectively and in generality.

The Niagara impoundment was surveyed with eight bank-to-bank transects spaced 500 meters apart totaling 430 square meters of search area (averaging approximately 54 meters per transect) (Figures 12-19). Survey efforts yielded zero live freshwater mussels or deadshell specimens. Longitudinal variation in depth and substrate sizes were observed between the upper and lower portions of the impoundment. Water depth along transects 1-3, in the upper portion of the reach, averaged approximately one meter across the channel; water depth along the lower transects (Transects 6-8) averaged approximately two meters, and depth along the middle transects averaged between one and two meters. Substrate composition in the upper impoundment was dominated by coarse materials such as gravel and bedrock and gradually transitioned to less coarse and homogenous substrates such as deep silt and sand deposits at downstream transects. The upper transects had high visibility, shallow stream banks, and a lack of fine sediments. The downstream transects had steep sloping banks, less visibility, and numerous woody debris deposits.

Although the thalweg was typically inundated with thick, mobile silt deposits, the riverine margins were characterized by stable, presumably suitable, unionid habitat. However, no live or deadshell freshwater mussels were encountered, including silt-tolerant species (e.g., Paper Pondshell [*Utterbackia imbecillis*]) which are common in the stable banks of impoundments throughout the Atlantic Slope.

3.2.2 Downstream of Niagara Dam

Downstream of Niagara Dam, one abbreviated mussel site was located in the Bypass Reach and another was located downstream below the tailrace. The Bypass Reach site occurs directly downstream of Niagara Dam and primarily consisted of heavily braided riffle/run habitats and plunge pools (Figure 23). The maximum depth was approximately 1.0 meter with an average depth of 15 centimeters at the time of surveys. The average stream width at this site was approximately 55 meters. The survey area was dominated by scoured bedrock (50%), cobble (40%), and gravel (10%) with very little suitable unionid habitat available. Survey efforts began at the Niagara Pumphouse and extended approximately 315 meters upstream to the base of the Niagara Dam (Figure 23). Three hundred and thirty (330) minutes of qualitative search efforts yielded no live individuals or deadshell specimens. The entire reach is heavily impacted by strong flows from the Niagara Dam; and although minimum flow requirements maintain a wetted channel, portions of the reach may go dry during periods of low flow. Although riverine conditions exhibited high DO and cool temperatures, this site was highly unsuitable for unionid colonization due to large areas of smooth bedrock, heavy scouring and periodic turbulent velocities.

The tailrace site occurs downstream of Niagara Pumphouse and primarily consisted of deep, swift bedrock runs (Figure 24). The maximum depth was approximately 2.5 meters with an average depth of 1.0 meter. The average stream width at this site was approximately 25 meters. The site was dominated by bedrock (90%) substrate in the thalweg with gravel (5%) and sand (5%) along the shorelines. Survey efforts began 500 meters downstream of the Niagara Powerhouse and extended approximately 500 meters downstream. Two hundred and seventy (270) minutes of qualitative search effort yielded no live individuals or deadshell specimens. Although riverine conditions exhibited high DO and cool water temperatures, the entire reach is heavily impacted by strong flows from the Niagara Dam and deeply scoured into swift chutes of bedrock.

4.0 DISCUSSION

4.1 Macroinvertebrate and Crayfish Community

Benthic macroinvertebrate and crayfish species diversity and abundance can be used as indicators of water quality, as these organisms serve as a food resource for fish and other fauna in the riverine community. A healthy stream generally includes habitat diversity and limited pollution, often indicated by a high VSCI metric score, which indicates the presence of an abundance and diversity of pollution intolerant taxa. VDEQ (2017) conducted macroinvertebrate sampling in the Roanoke River downstream of Niagara Dam and demonstrated low diversity and presence of few sensitive taxa overall; despite presence of some optimal habitat. There is no site-specific reference information available for crayfish in the vicinity of the Project; however, Virginia is known to harbor approximately 33 species of crayfish. Several species currently found in Virginia include non-indigenous and/or invasive species such as the Red Swamp Crayfish, Rusty Crayfish (*Faxonius rusticus*), and Virile Crayfish (VDGIF 2018; VISAC 2018).

VSCI scores recorded at each site were greater on average in the fall than in the spring. The average VSCI scores upstream and downstream of Niagara Dam indicated “impaired” conditions during the fall and spring samples. Upstream of Niagara Dam had an overall average VSCI score of 33.8 whereas downstream of Niagara Dam had an overall average VSCI score of 39.7. Zero sites within either Project area, during either season, resulted in a VSCI score above the threshold of “similar to reference” conditions (60). During both seasonal collections, the lowest VSCI scores were recorded upstream of Niagara Dam and the highest were recorded downstream of Niagara Dam, which indicates less impairment as you move downstream through the project area. This trend likely results from the impacts of point and non-point source pollution from the Roanoke River watershed.

Although the species composition varied, four of five species of crayfish were present above and below Niagara Dam. There were zero crayfish captured at the one qualitative site upstream of Niagara Dam. Above the dam there were two native and two invasive species and below the dam there was one native species and three invasive species. The Appalachian Brook Crayfish (i.e., native) was only collected in Tinker Creek. The invasive Ozark Crayfish and Red Swamp crayfish were collected both above and below the dam, whereas the Virile Crayfish was only collected below the dam (however there are records of Virile Crayfish above the Project in the Roanoke River [Foltz, unpublished data]). Native species were collected at three of the 10 sampled sites while invasive species were collected at eight of the 10 sampled sites. The invasive Ozark Crayfish was collected at all sites where crayfish were present, as one of five sites above the dam resulted in zero crayfish.

4.2 Mussel Habitat and Community

The presence of a diverse and abundance freshwater mussel community can also serve as a biological indicator of a healthy stream because of their typical intolerance to fine sediments and water pollution. The presence of certain invasive mollusks (i.e., Asiatic Clam) can also indicate potentially degraded stream health. Asiatic clams have not been previously identified in the Project area; however, little to no recent mussel surveys have been completed in the vicinity of the Project. A geographic search on VDWR's Fish and Wildlife Information Service and communications with USFWS identified potential occurrence of seven mussel species that may occur in the Project vicinity, including the Atlantic Pigtoe (*Fusconaia masoni*, proposed for federal listing), the Green Floater (*Lasmigona subviridis*, state threatened) and James Spinymussel (*Parvaspina collina*, federally and state endangered). No evidence of these aforementioned species was encountered during 2020 mussel surveys.

Site-specific survey results were presented for abbreviated mussel surveys in Section 3.2.1. Two Eastern Elliptio mussels were collected near one another at the most upstream site in the Roanoke River project area (UNIO-1). Two live Eastern Elliptio mussels and approximately 12 deadshell specimens, were collected in Tinker Creek (UNIO-2). Although these two sites offer minimal suitable mussel habitat, they are likely the most productive within the Project area. Although the measured water quality parameters appear suitable (Appendix C), with high DO and cool temperatures, the habitat at many sites was unsuitable for unionid colonization due to heavy scouring and bedrock substrates and may be impaired due to other water quality issues that were not assessed as part of this study. Anthropogenic impacts to the Roanoke River upstream and within the Project area, along with a dearth of suitable habitat, appear to support marginal populations exhibiting a lack of recruitment and strong presence of invasive Asiatic Clams throughout. The lack of suitable habitat and depauperate unionid community suggests the probable absence of federally or state-listed species within the study area.

This report provides results based on the completion of the study objectives: 1) Collect a baseline of existing macroinvertebrate and crayfish communities in the vicinity of the Project, 2) Confirm the presence or absence of mussels within the study area, 3) Characterize the mussel community composition (if present), abundance, and distribution within the study area, 4) Determine presence/probable absence of federally or state-listed species within the study area.

5.0 LITERATURE CITED

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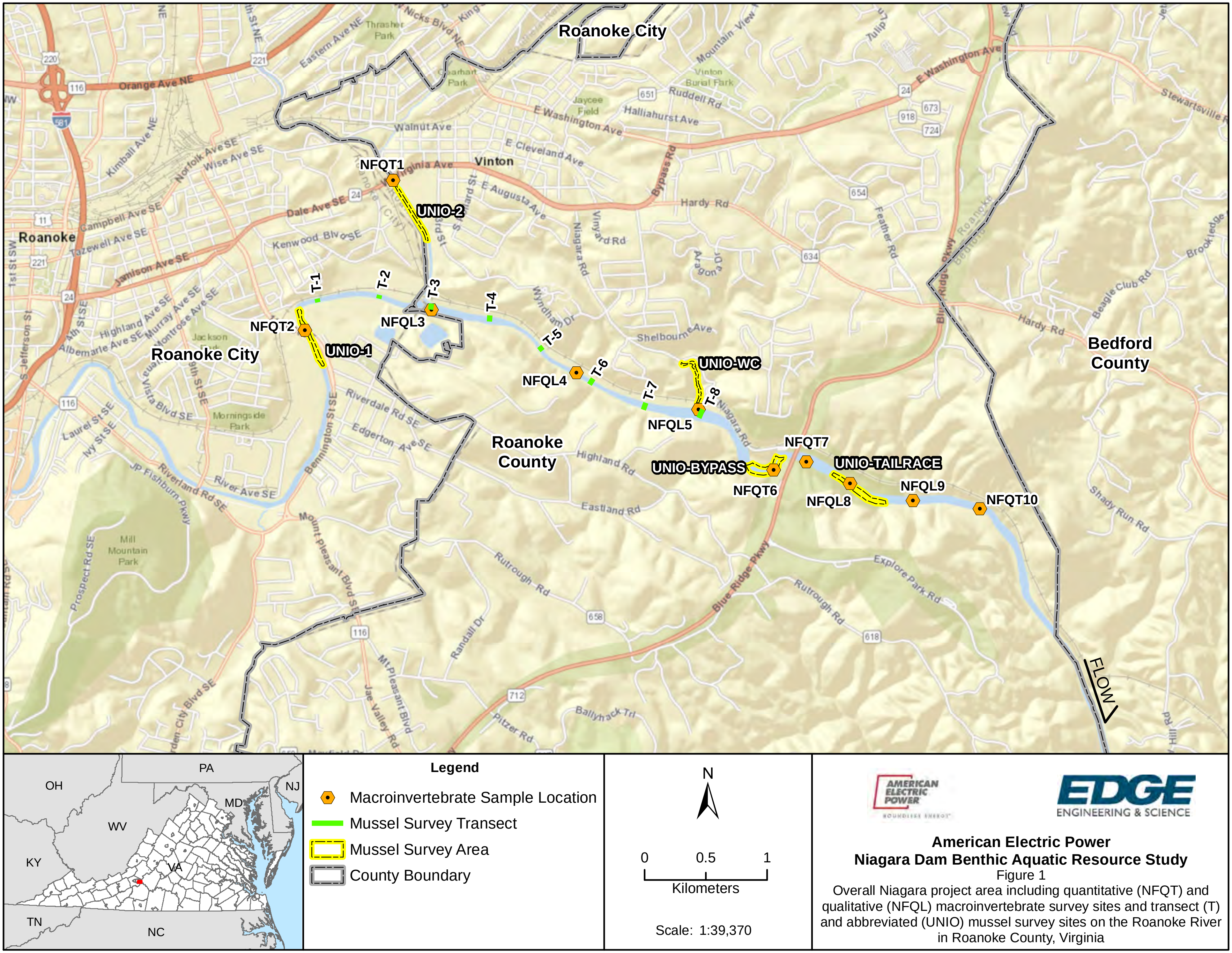
Figures



American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 1
Overall Niagara project area including quantitative (NFQT) and qualitative (NFQL) macroinvertebrate survey sites and transect (T) and abbreviated (UNIO) mussel survey sites on the Roanoke River in Roanoke County, Virginia

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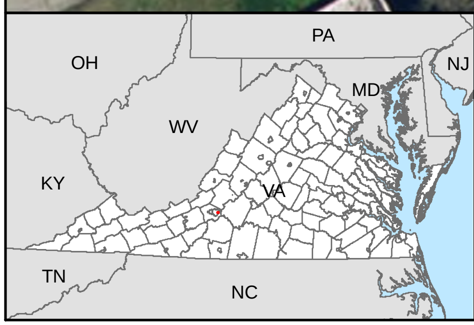

Legend

- Macroinvertebrate Sample Location
- Macroinvertebrate Survey Transect

N

0 15 30

Meters

Scale: 1:1,181

American Electric Power

Niagara Dam Benthic Aquatic Resource Study

Figure 2

Quantitative macroinvertebrate and crayfish 100-meter survey extent in riffle/run habitat in Roanoke County, Virginia

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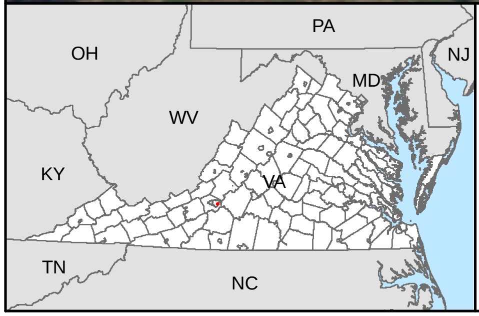


Legend

- Macroinvertebrate Sample Location
- Macroinvertebrate Survey Transect

N

0 15 30

Meters

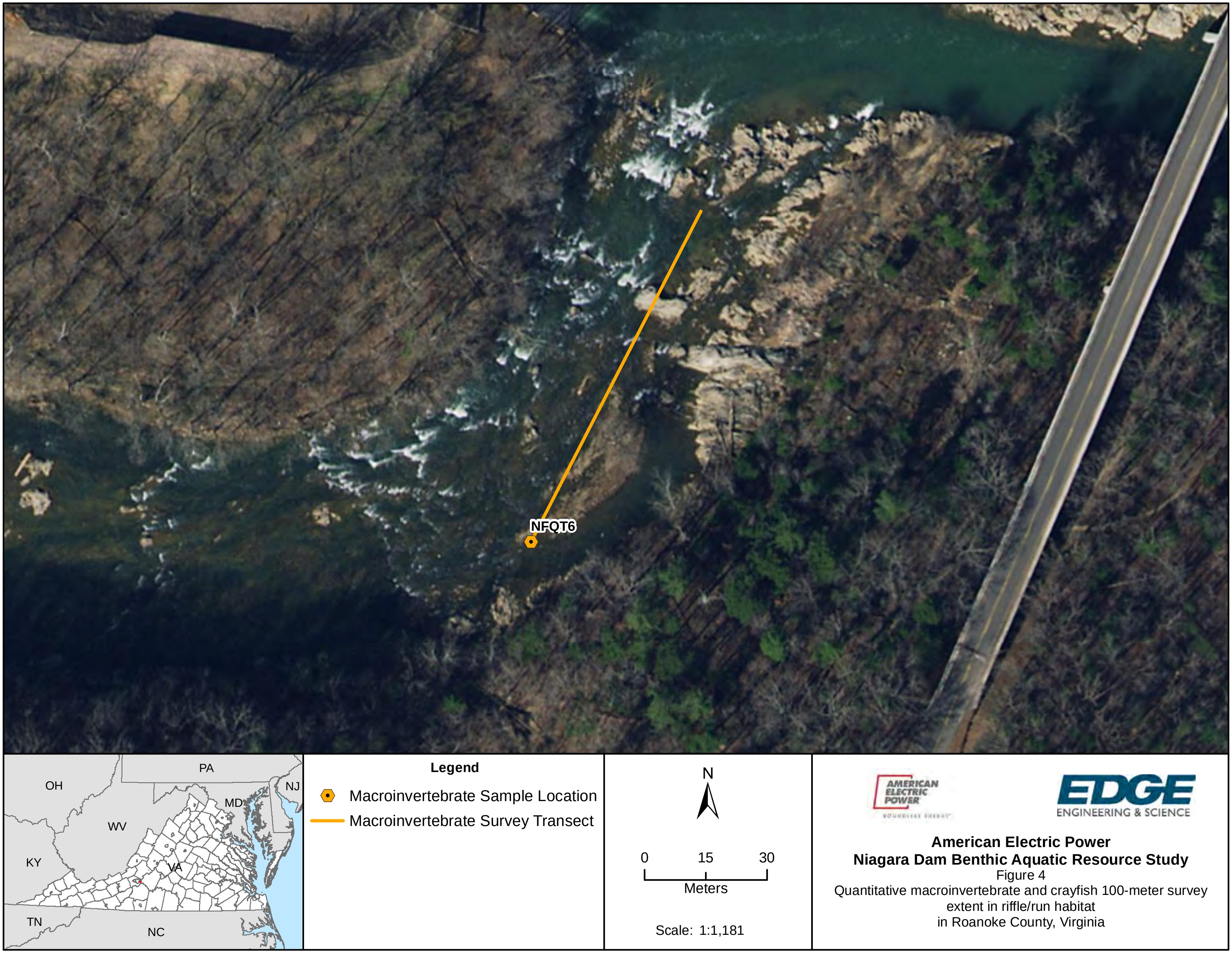
Scale: 1:1,181

AMERICAN ELECTRIC POWER

EDGE ENGINEERING & SCIENCE

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 3
Quantitative macroinvertebrate and crayfish 100-meter survey extent in riffle/run habitat in Roanoke County, Virginia

D:\PROJECTS\HDR\HDR2020-0002 Niagara Dam Relicensing\GIS\MXD\MacroInvtbrts\Report_Figs\20201124_Sbmtl\HDR2020-0002_McroInvbrts_Fig2_24_20210317.mxd



Legend

- Macroinvertebrate Sample Location
- Macroinvertebrate Survey Transect

N

0 15 30

Meters

Scale: 1:1,181

AMERICAN ELECTRIC POWER

EDGE ENGINEERING & SCIENCE

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 4
Quantitative macroinvertebrate and crayfish 100-meter survey extent in riffle/run habitat in Roanoke County, Virginia

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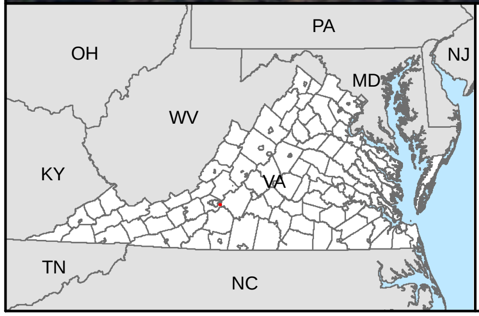

Legend

- Macroinvertebrate Sample Location
- Macroinvertebrate Survey Transect

N

0 15 30

Meters

Scale: 1:1,181

EDGE ENGINEERING & SCIENCE

American Electric Power

Niagara Dam Benthic Aquatic Resource Study

Figure 5

Quantitative macroinvertebrate and crayfish 100-meter survey extent in riffle/run habitat in Roanoke County, Virginia

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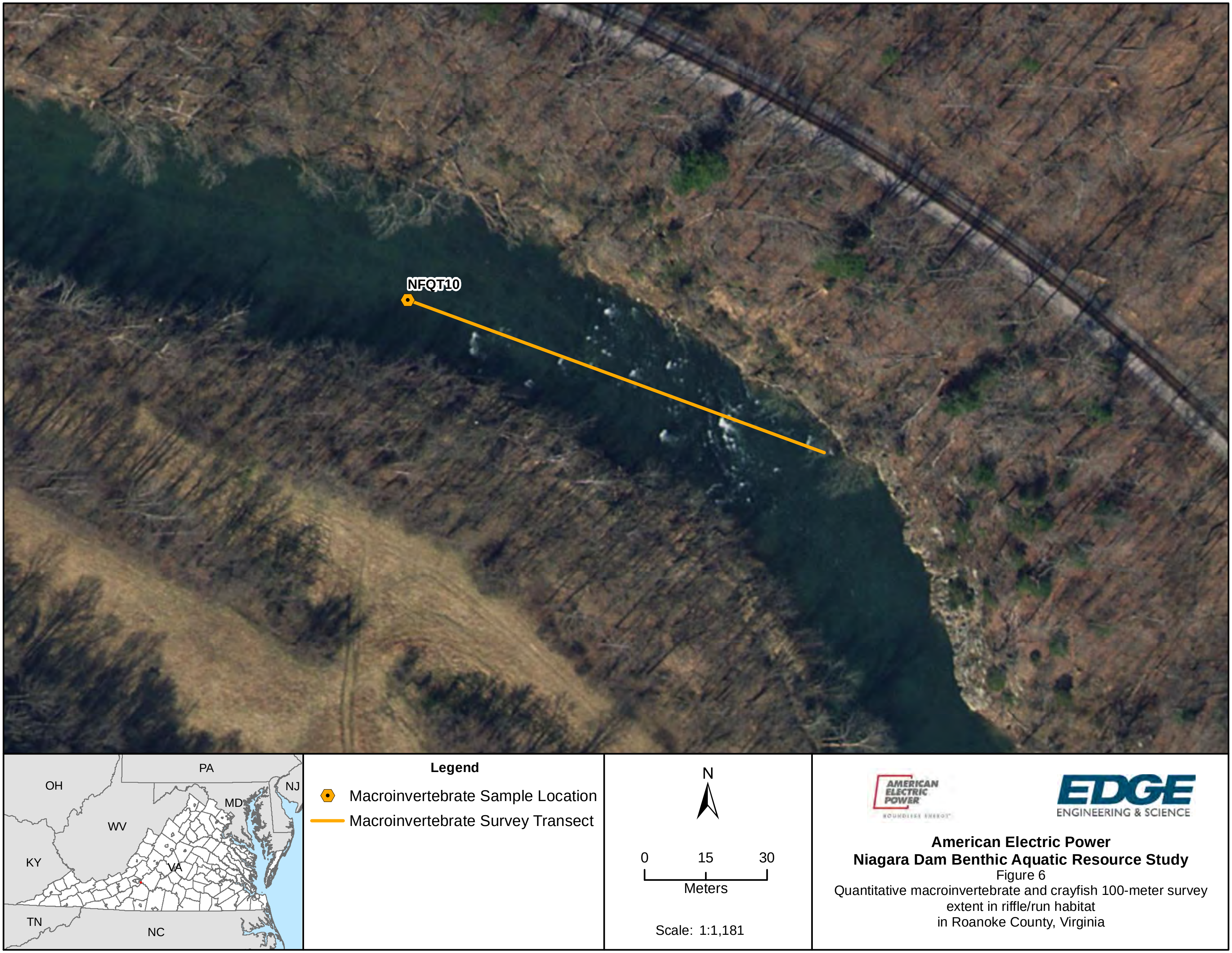

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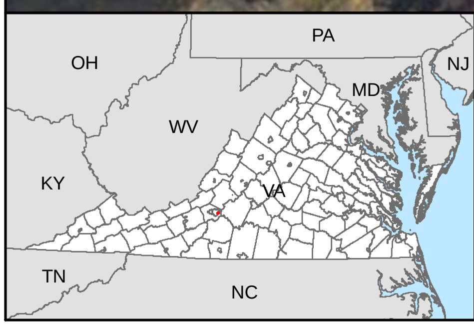

Legend

- Macroinvertebrate Sample Location
- Macroinvertebrate Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 7
Qualitative macroinvertebrate and crayfish 100-meter survey extent
in mixed habitat
in Roanoke County, Virginia

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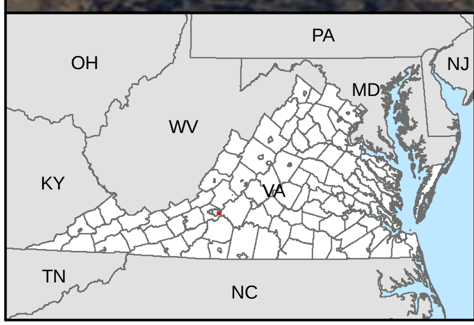

Legend

- Macroinvertebrate Sample Location
- Macroinvertebrate Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 8
Qualitative macroinvertebrate and crayfish 100-meter survey extent
in mixed habitat
in Roanoke County, Virginia

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Legend

- Macroinvertebrate Sample Location
- Macroinvertebrate Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

AMERICAN ELECTRIC POWER

EDGE ENGINEERING & SCIENCE

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 9
Qualitative macroinvertebrate and crayfish 100-meter survey extent
in mixed habitat
in Roanoke County, Virginia

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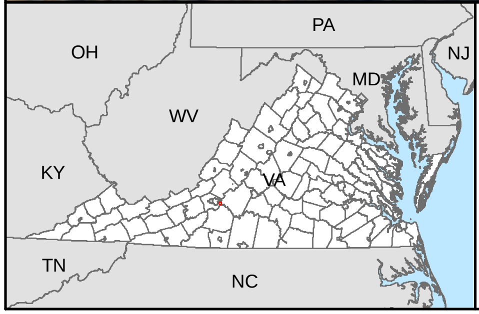

Legend

- Macroinvertebrate Sample Location
- Macroinvertebrate Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 10
Qualitative macroinvertebrate and crayfish 100-meter survey extent
in mixed habitat
in Roanoke County, Virginia

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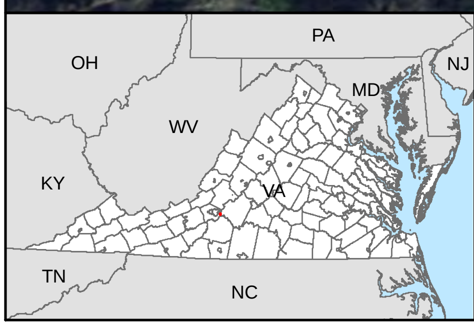

Legend

- Macroinvertebrate Sample Location
- Macroinvertebrate Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 11
Qualitative macroinvertebrate and crayfish 100-meter survey extent
in mixed habitat
in Roanoke County, Virginia

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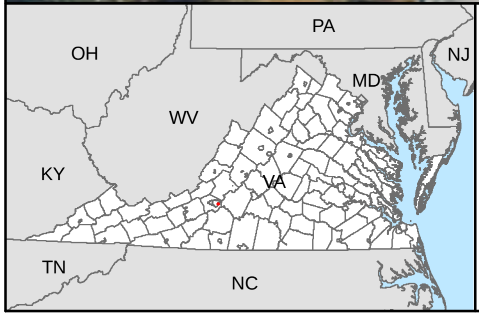

Legend

Mussel Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 12
Transect mussel survey extent in pool habitat
in Roanoke County, Virginia

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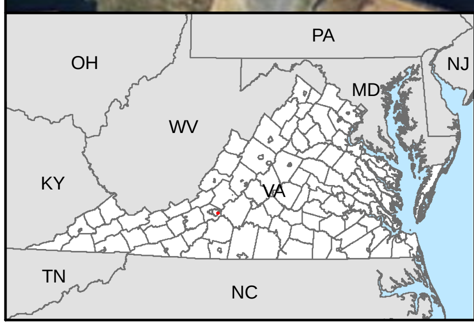

Legend

Mussel Survey Transect

N

0 15 30

Meters

Scale: 1:1,181

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American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 13
Transect mussel survey extent in pool habitat
in Roanoke County, Virginia

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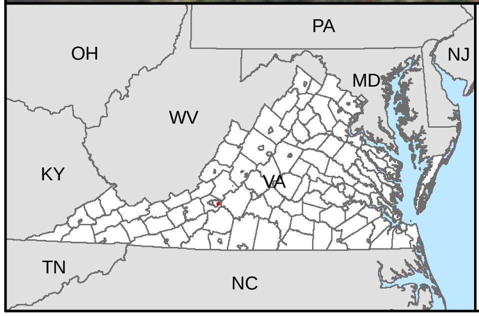

Legend

Mussel Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 14
Transect mussel survey extent in pool habitat
in Roanoke County, Virginia

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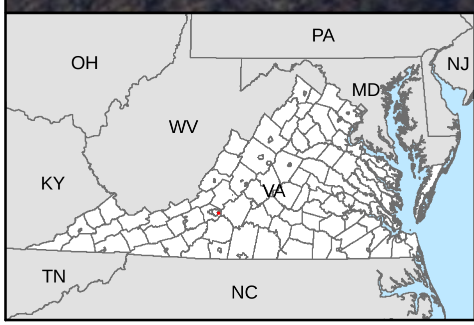

Legend

Mussel Survey Transect

N

0 15 30

Meters

Scale: 1:1,181

American Electric Power

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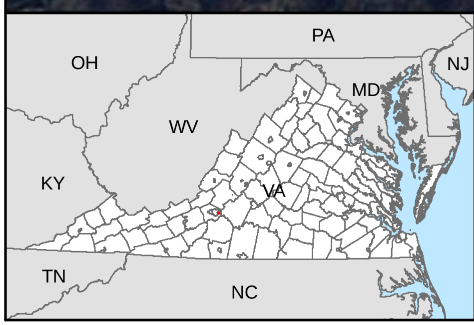
Figure 15

Transect mussel survey extent in pool habitat in Roanoke County, Virginia



Legend

Mussel Survey Transect

N

0 15 30

Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 16
Transect mussel survey extent in pool habitat
in Roanoke County, Virginia

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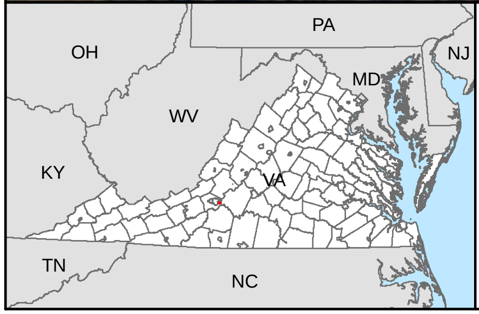


Legend

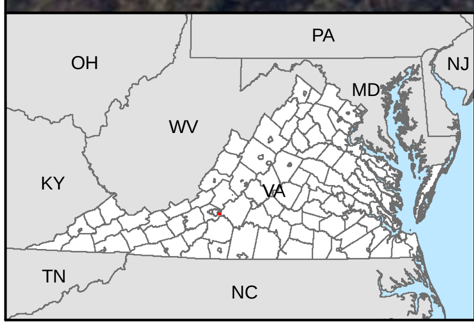
Mussel Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 17
Transect mussel survey extent in pool habitat
in Roanoke County, Virginia



Legend

Mussel Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 18
Transect mussel survey extent in pool habitat
in Roanoke County, Virginia

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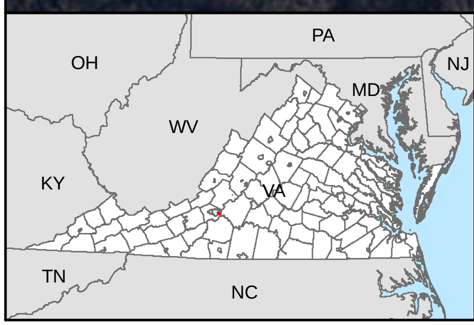

Legend

Mussel Survey Transect

N

0 15 30
Meters

Scale: 1:1,181

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 19
Transect mussel survey extent in pool habitat
in Roanoke County, Virginia

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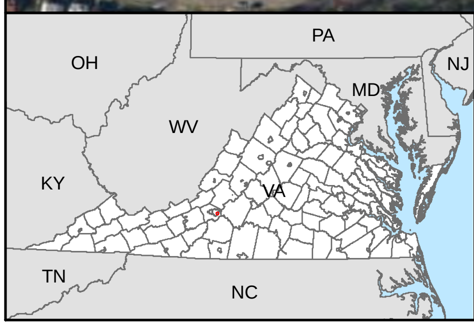


Legend

Mussel Survey Area

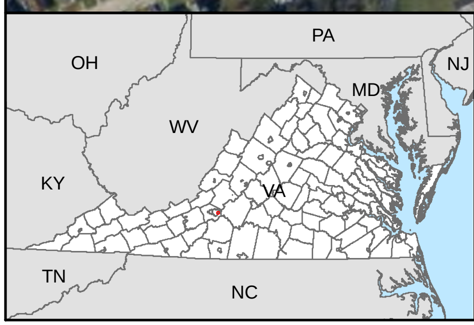
N

0 50 100
Meters

Scale: 1:3,937

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 20
Abbreviated mussel survey extent in mixed habitat
in Roanoke County, Virginia

D:\PROJECTS\HDR\HDR2020-0002 Niagara Dam Relicensing\GIS\MXD\MacroInvtbrts\Report_Figs\20201124_Sbmtl\HDR2020-0002_McroInvbrts_Fig2_24_20210317.mxd



Legend

Mussel Survey Area

N

0 50 100
Meters

Scale: 1:3,937

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 21
Abbreviated mussel survey extent in mixed habitat
in Roanoke County, Virginia

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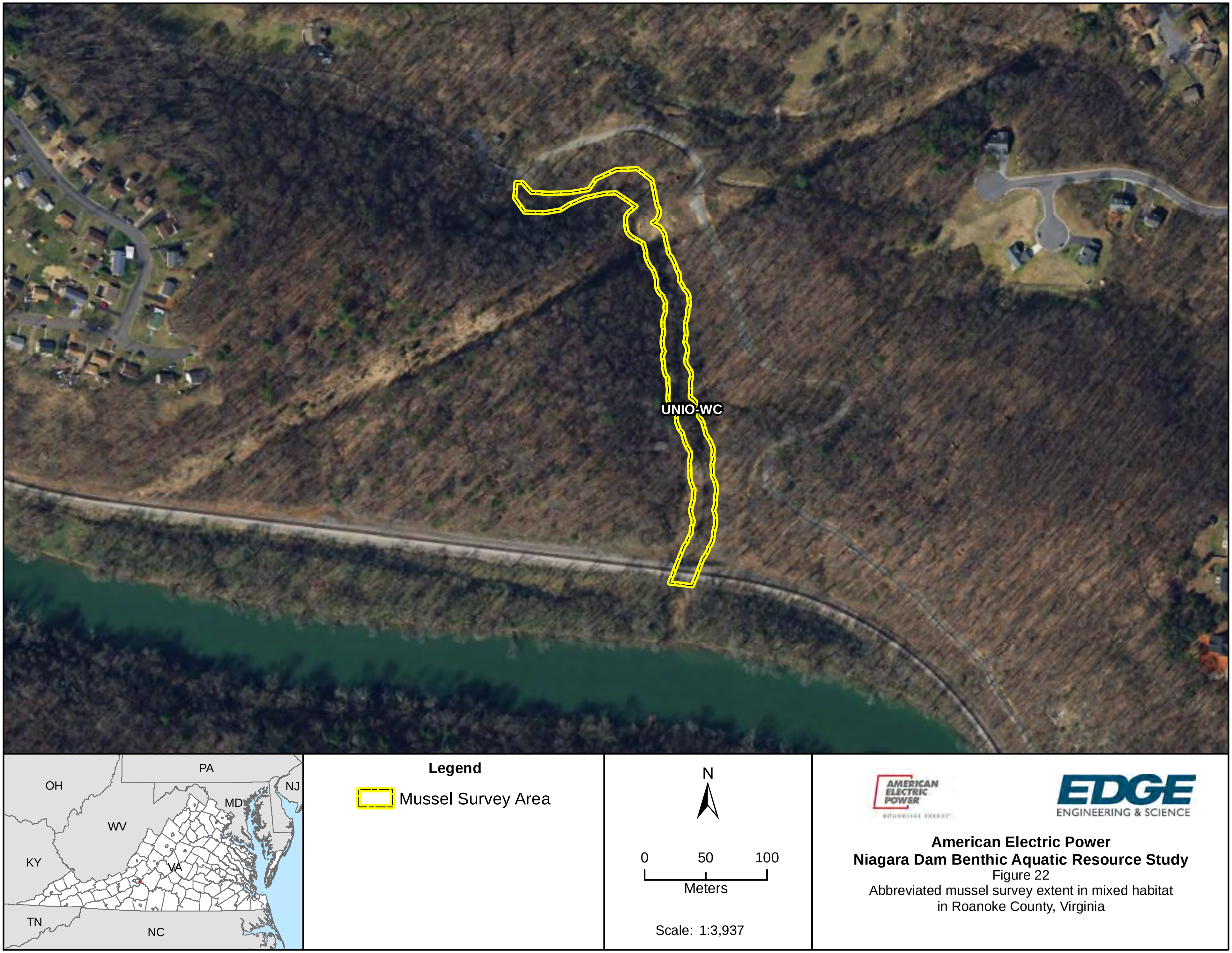

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 22
Abbreviated mussel survey extent in mixed habitat
in Roanoke County, Virginia

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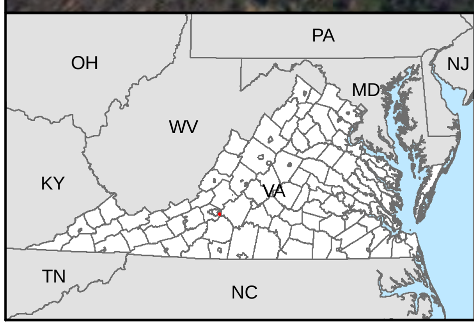

Legend

Mussel Survey Area

N

0 50 100

Meters

Scale: 1:3,937

American Electric Power
Niagara Dam Benthic Aquatic Resource Study
Figure 23
Abbreviated mussel survey extent in mixed habitat
in Roanoke County, Virginia

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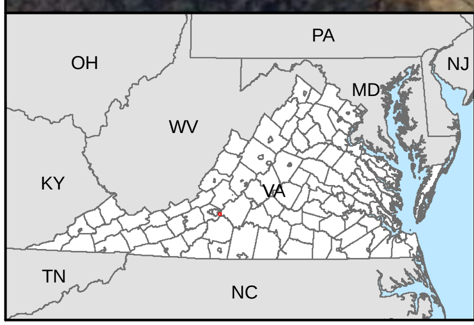

Legend

Mussel Survey Area

N

0 50 100
Meters

Scale: 1:3,937

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Niagara Dam Benthic Aquatic Resource Study
Figure 24
Abbreviated mussel survey extent in mixed habitat
in Roanoke County, Virginia

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Appendix A

SCIENTIFIC COLLECTION PERMITS

Virginia Department of Game and Inland Fisheries
7870 Villa Park Drive, P.O. Box 90778, Henrico, VA 23228-0778
(804) 367-1000 (V/TDD)
Under Authority of § 29.1-412, § 29.1-417, & § 29.1-418 of the Code of Virginia

Scientific Collection Permit

Permit Type: **Renewal** | Fee Paid: **$40.00** | VADGIF Permit No. **068630**

Permittee: **Casey D Swecker**
Address: **4005 Ponder Drive**
Cincinnati, OH 45245
Email: **cdswecker@edge-es.com**

Home:
Office: **(304) 633-5808**
City/County: **Out of State**

Business: **Edge Engineering and Science, LLC**
4005 Ponder Drive
Cincinnati, OH 45245
City/County: **Out of State**

Contract Species Surveys/Research/Relocation

Authorized Collection Methods: By Hand/Dip Nets/Electrofishing/Gill Nets-Trawl Nets/Seine Nets/Snorkel/View Scope/Aquatic Kick Samples/Scuba/Nets-Traps (Fyke/Hoop/D-Frame)/Hooka (Third Lung)
All methods which are part of the project(s) outlined in the submitted and approved proposal.
Authorized Waterbodies: Blackwater River/New River/Banister River/Sandy River/North Fork Roanoke River/Little Creek/Crooked Creek/Roanoke River/Sinking Creek/North Fork Holston River/Mill Creek
Authorized Marking Techniques: N/A

SPECIAL CONDITIONS: It is recommended that the fish relocation best management practices be utilized while collecting fish for this project. Permittee is exempt from standard condition #11 (game fish creek limit) during gillnet sampling on the New River above Byllesby Dam.

PERMIT AMENDMENT 9/1/2020: The amendment changes the following: Principal Permittee & Authorized Subpermittees Affiliation FROM: ESI to Edge Engineering and Science, LLC
This amendment deletes the following:
Authorized Subpermittees: Kyle McGill/Greg Anderson/Robert Paul/Brandon Yates/Keith Gibbs/Kyle Price/Brandon Bassinger/Tyler Slagle
This amendment adds the following: Permittee is exempt from standard condition #11 (game fish creek limit) during gillnet sampling on the New River above Byllesby Dam.

Permittee MUST notify VDGIF a minimum of 7 days prior to each sampling event. Notification must be made via email to: collectionpermits@dgif.virginia.gov

Report Due: 31 January 2021, 31 January 2022

ANNUAL REPORTS MUST BE SUBMITTED VIA: https://vafwis.dgif.virginia.gov/collection_permits/

STANDARD CONDITIONS ATTACHED APPLY TO THIS PERMIT.

Authorized Counties / Cities:
Augusta
Bath
Brunswick
Buckingham
Carroll
Cumberland
Dinwiddie
Franklin
Giles
Greensville
Highland
Montgomery
Nelson
Nottoway
Pittsylvania
Prince Edward
Pulaski
Roanoke
Scott
Southampton
Radford
Statewide

Virginia Department of Game and Inland Fisheries

7870 Villa Park Drive, P.O. Box 90778, Henrico, VA 23228-0778
(804) 367-1000 (V/TDD)
Under Authority of § 29.1-412, § 29.1-417, & § 29.1-418 of the Code of Virginia

Scientific Collection Permit

Permit Type: **Renewal** Fee Paid: **$40.00** VADGIF Permit No. **068630**

Authorized Species:

Description	ID Number	Scientific Name
Aquatic Insects		
Aquatic Invertebrates (excluding aquatic mollusks)		
Crayfish		
Freshwater Fish		
Freshwater Mussels		
Spiny Riversnail		***Io fluvialis***

Annual Report Due End of Each Year

Authorized Sub-Permittees:
See Attached Sheet

Approved by: [signature]

Applicants may appeal permit decisions within 30 days of issuance. The appeal must be in writing to the Director, Department of Game and Inland Fisheries.

Title: **Randall T. Francis - Permits Manager** **Date: 4/21/2020**

20 Permit Effective **4/21/2020** through **12/31/2021** **21**

Virginia Department of Game and Inland Fisheries

7870 Villa Park Drive, P.O. Box 90778, Henrico, VA 23228-0778
(804) 367-1000 (V/TDD)

Under Authority of § 29.1-412, § 29.1-417, & § 29.1-418 of the Code of Virginia

Scientific Collection Permit

Permit Type: **Renewal** FeePaid: **$40.00** VADGIF Permit No. **068630**

Authorized Sub-Permittees:

Dr. Tom Jones, Edge Engineering & Science, LLC
John Spaeth, Edge Engineering & Science, LLC
Aaron Prewitt, Edge Engineering & Science, LLC
Nancy Scott, Three Oaks Engineering
Adam Benshoff, Edge Engineering & Science, LLC
Dr. Art Bogan, NC Museum of Natural Sciences
Tom Dickinson, Three Oaks Engineering
Nathan Howell, Three Oaks Engineering
David Foltz, Edge Engineering & Science, LLC
Jonathan Studio, Edge Engineering & Science, LLC
Doug Locy, Edge Engineering & Science, LLC
Alyssa Brady, Edge Engineering & Science, LLC
Cody Parks, Three Oaks Engineering
Lizzy Stokes, Three Oaks Engineering
Tim Savage, Three Oaks Engineering
Mitchell Kriege, Edge Engineering & Science, LLC

Virginia Department of Game and Inland Fisheries

7870 Villa Park Drive, P.O. Box 90778, Henrico, VA 23228-0778
(804) 367-1000 (V/TDD)
Under Authority of § 29.1-412, § 29.1-417, & § 29.1-418 of the Code of Virginia

Scientific Collection Permit

Permit Type: **New** | Fee Paid: **$40.00** | VADGIF Permit No. **070705**

Permittee: **Jonathan Studio**
Address: **36550 Chester Road, Apt. 4801**
Avon, OH 44011
Email: **jastudio@edge-es.com**

Home:
Office: **(440) 413-4609**
City/County:

Business: **Edge Engineering & Science, LLC**
4005 Ponder Drive
Cincinnati, OH 45245

Niagara Hydroelectric Project/Byllesby-Buck Hydroelectric Project

Authorized Collection Methods: By Hand/Dip Nets/Electrofishing/Gill Nets/Trawl Nets/Nets-Traps (Fyke/Hoop/D-Frame)/Seine Nets/Drift Nets
Authorized Waterbodies: Roanoke River/Tinker Creek/New River
Authorized Marking Techniques: N/A

SPECIAL CONDITIONS: No electrofishing in Roanoke Logperch TOYR unless requested and approved by both USFWS and DWR. Mussels may not be targeted and any inadvertently collected must be returned to the point-of-capture after the individual is identified (if ID is possible).

Permittee MUST notify DWR within the 7 day period prior to each sampling event. Notification must be made via email to: collectionpermits@dwr.virginia.gov

Report Due: 31 January 2022, 31 January 2023

ANNUAL REPORTS MUST BE SUBMITTED VIA: https://vafwis.dgif.virginia.gov/collection_permits/

STANDARD CONDITIONS ATTACHED APPLY TO THIS PERMIT.

Authorized Counties / Cities:
Carroll
Roanoke

Authorized Species:

Description	ID Number	Scientific Name
Aquatic Insects		
Crayfish		
Freshwater Fish		
Other Aquatic Invertebrates		

Annual Report Due End of Each Year

Authorized Sub-Permittees:
See Attached Sheet

Approved by: [signature]

Applicants may appeal permit decisions within 30 days of issuance. The appeal must be in writing to the Director, Department of Game and Inland Fisheries.

Title: **Randall T. Francis - Permits Manager**

Date: 3/2/2021

Virginia Department of Game and Inland Fisheries
7870 Villa Park Drive, P.O. Box 90778, Henrico, VA 23228-0778
(804) 367-1000 (V/TDD)
Under Authority of § 29.1-412, § 29.1-417, & § 29.1-418 of the Code of Virginia

Scientific Collection Permit

Permit Type:	**New**	Fee Paid:	**$40.00**	VADGIF Permit No.	**070705**

20

Permit Effective **3/2/2021** through **12/31/2022**

22

Virginia Department of Game and Inland Fisheries

7870 Villa Park Drive, P.O. Box 90778, Henrico, VA 23228-0778
(804) 367-1000 (V/TDD)

Under Authority of § 29.1-412, § 29.1-417, & § 29.1-418 of the Code of Virginia

Scientific Collection Permit

Permit Type: **New** FeePaid: **$40.00** VADGIF Permit No. **070705**

Authorized Sub-Permittees:

Sarah Messer, Edge Engineering & Science, LLC
John Spaeth, Edge Engineering & Science, LLC
Aaron Prewitt, Edge Engineering & Science, LLC
Adam Benshoff, Edge Engineering & Science, LLC
David Foltz, Edge Engineering & Science, LLC
Mitchell Kriege, Edge Engineering & Science, LLC
Alyssa Jones, Edge Engineering & Science, LLC
David Ford, Edge Engineering & Science, LLC
Tim Brust, Edge Engineering & Science, LLC

Appendix B

REPRESENTATIVE PHOTOGRAPHS

NFQT1 - Downstream
Quantitative Macroinvertebrate Sample Site

NFQT2 - Downstream
Quantitative Macroinvertebrate Sample Site

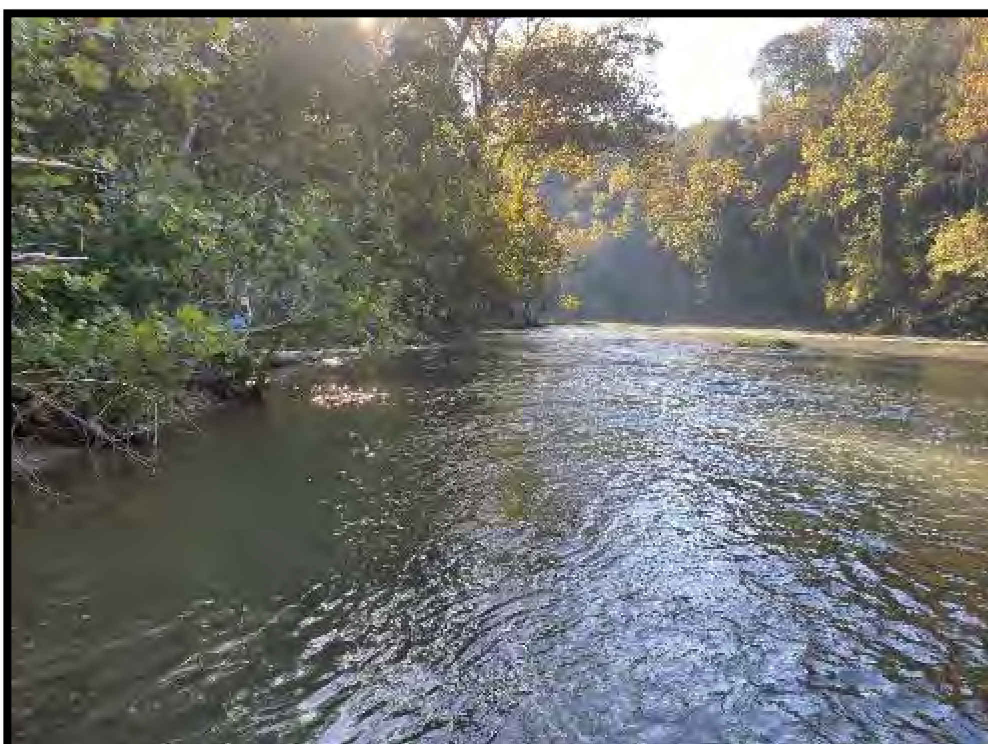
NFQL3 - Upstream
Qualitative Macroinvertebrate Sample Site

NFQL4 - Upstream
Qualitative Macroinvertebrate Sample Site

NFQL5 - Upstream
Qualitative Macroinvertebrate Sample Site

NFQT6 - Upstream
Quantitative Macroinvertebrate Sample Site

NFQT7 - Upstream
Quantitative Macroinvertebrate Sample Site



NFQL8 - Downstream
Qualitative Macroinvertebrate Sample Site

NFQL9 - Upstream
Qualitative Macroinvertebrate Sample Site

NFQT10 - Upstream
Quantitative Macroinvertebrate Sample Site

The single specimen collected was too small for detailed voucher photo.

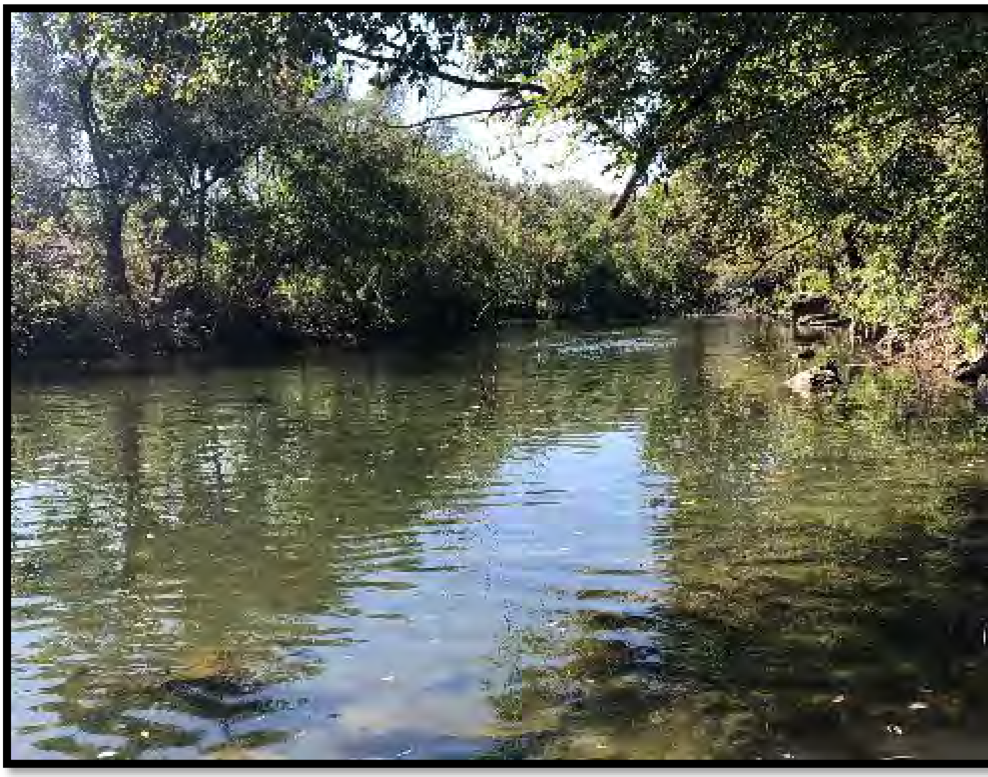
Appalachian Brook Crayfish
(*Cambarus bartoni bartoni*)

Atlantic Slope Crayfish
(*Cambarus longulus*)

Ozark Crayfish
(*Faxonius ozarkae*)

Virile Crayfish
(*Faxonius virilis*)

Red Swamp Crayfish
(*Procambarus clarkii*)



T-1 - Upstream
Mussel Transect Sample Site

T-2 - Downstream
Mussel Transect Sample Site

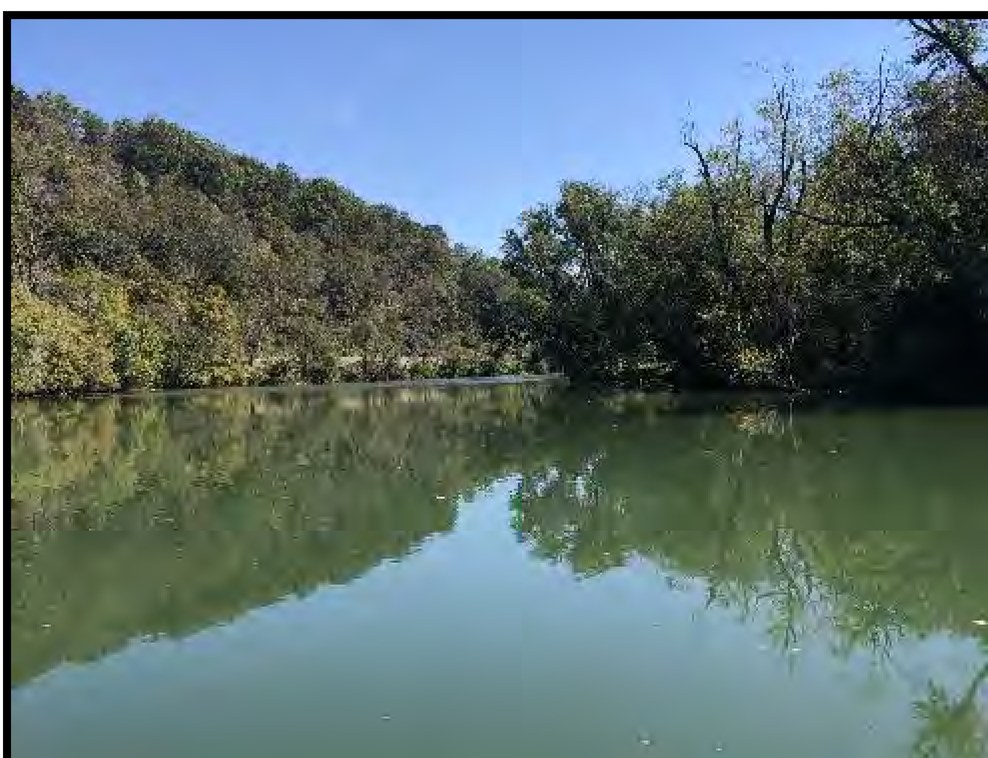
T-3 - Downstream
Mussel Transect Sample Site

T-4 - Downstream
Mussel Transect Sample Site

T-5 - Downstream
Mussel Transect Sample Site

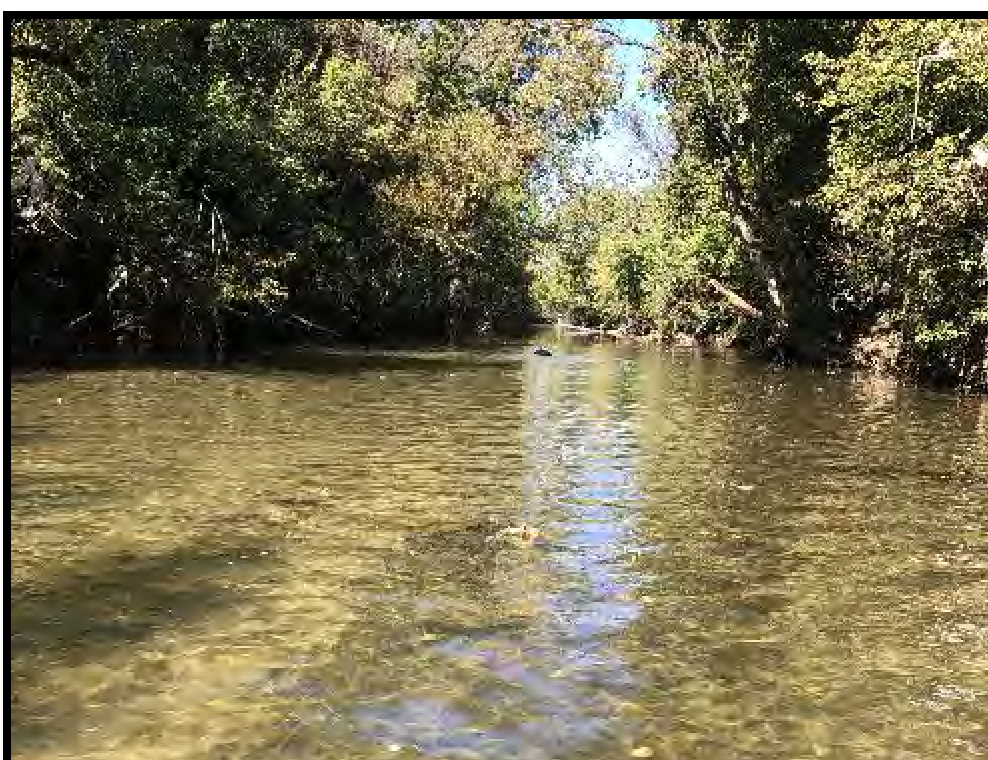
T-6 - Downstream
Mussel Transect Sample Site

T-7 - Downstream
Mussel Transect Sample Site



T-8 - Downstream
Mussel Transect Sample Site

UNIO-1 - Downstream
Mussel Abbreviated Sample Site



UNIO-2 - Upstream
Mussel Abbreviated Sample Site

UNIO-WC - Upstream
Mussel Abbreviated Sample Site

UNIO-Bypass - Upstream
Mussel Abbreviated Sample Site

UNIO-Tailrace - Upstream
Mussel Abbreviated Sample Site

Eastern Elliptio
(*Elliptio Complanata*)

Notched Rainbow
(*Villosa constricta*)

Appendix C

RAW DATA

TAXON	Number of Organisms per Taxon per Subsample											
	Tinker Creek	Roanoke River Samples and Collection Dates										
	NFQT1	NFQT2	NFQL3	NFQL4 - ORIGINAL	NFQL4 - REPLICATE	NFQL5	NFQT6 - ORIGINAL	NFQT6 - REPLICATE	NFQT7	NFQL8	NFQL9	NFQT10
	9/15/2020	9/15/2020	9/15/2020	9/16/2020	9/16/2020	9/16/2020	9/16/2020	9/16/2020	9/16/2020	10/5/2020	10/5/2020	10/5/2020
PLATYHELMINTHES (flatworms)												
TURBELLARIA												
Planariidae	1		1				9	3		1		1
ANNELIDA (segmented worms)												
HIRUDINEA (leeches)[1]			1						1			
OLIGOCHAETA (aquatic worms)	3		2	2	8	1			2		3	3
ARTHROPODA (arthropods)												
HYDRACARINA (water mites)	1			1	1					2		1
CRUSTACEA (crayfish, scuds, aquatic sow bugs)												
AMPHIPODA (scuds, sideswimmers)												
Crangonyctidae												
Crangonyx sp.			19	1	1				2			
Talitridae												
Hyalella sp.			2			3						
ISOPODA (aquatic sow bugs)												
Asellidae												
Caecidotea sp.			11	1	1	1			2			
DECAPODA (crayfish)												
Cambaridae												
Faxonius sp.	1		3								1	
INSECTA (insects)												
EPHEMEROPTERA (mayflies)												
Baetidae (small minnow mayflies)												
Acentrella sp.		1										
Baetis flavistriga												1
Baetis intercalaris	2											2
Baetis spp.	3	2								2		
Neocloeon sp.				1								
Plauditus sp.		1							1			3
Heptageniidae (flatheaded mayflies)												
Stenacron sp.		1							1			
Isonychiidae (brushlegged mayflies)												
Isonychia sp.		1										
Leptohyphidae (little stout crawlers)[2]												
Tricorythodes sp.									2		1	
TRICHOPTERA (caddisflies)												
Glossosomatidae (saddlecase makers)										2		
Hydropsychidae (common net-spinners)												
Ceratopsyche morosa												1
Cheumatopsyche spp.	7	16						1		18	2	24
Hydropsyche spp.		3	1				1		1	15	6	34
Potamyia flava		1										
Hydroptilidae (micro-caddisflies)										1		
Hydroptila sp.	1		1	1	2		5	4				
Leptoceridae (long-horned caddisflies)				2								
Philopotamidae (fingernet caddisflies)												
Chimarra sp.	4	2					1					
Polycentropodidae (trumpetnet and tubemakers)												
Polycentropus sp.				1		1						

TAXON	Number of Organisms per Taxon per Subsample											
	Tinker Creek	Roanoke River Samples and Collection Dates										
	NFQT1	**NFQT2**	**NFQL3**	**NFQL4 - ORIGINAL**	**NFQL4 - REPLICATE**	**NFQL5**	**NFQT6 - ORIGINAL**	**NFQT6 - REPLICATE**	**NFQT7**	**NFQL8**	**NFQL9**	**NFQT10**
	9/15/2020	9/15/2020	9/15/2020	9/16/2020	9/16/2020	9/16/2020	9/16/2020	9/16/2020	9/16/2020	10/5/2020	10/5/2020	10/5/2020
Psychomyiidae (net tube-making caddisflies)												
Psychomyia flavida											2	
COLEOPTERA (aquatic beetles)												
Curculionidae (weevils)											1	
Dryopidae (long-toed water beetles)												
Helichus sp.								1				
Elmidae (riffle beetles)												
Ancyronyx sp.			1	3	4							
Dubiraphia sp.	1								4		1	
Gonielmis sp.		5	1									
Macronychus sp.				2	1			1			4	
Microcylloepus sp.		28	1			1		1			1	
Optioservus sp.	1	3	1				2				3	
Stenelmis sp.	15	3	4				1	2		1	1	1
Hydrophilidae (water scavenger beetles)												
Berosus sp.									2			
Psephenidae (water penny beetles)												
Ectopria sp.												1
Psephenus herricki	1									1	3	1
ODONATA (dragonflies, damselflies)												
ANISOPTERA (dragonflies)												
Corduliidae (green-eyed skimmers)												
Epicordulia sp.				2								
Neurocordulia sp.			1									
Gomphidae (clubtails)												
Stylogomphus sp.												1
Macromiidae (cruisers)												
Macromia sp.											1	
ZYGOPTERA (damselflies)												
Coenagrionidae (narrow-winged damselflies)												
Argia sp.	1	2	5	5	5	1			5		7	
Enallagma sp.			16	10	6	25					1	
DIPTERA (true flies)												
Ceratopogonidae (biting midges)												
Atrichopogon sp.				2								
Probezzia sp.					1							
Chironomidae (A)[3] - (midges)	66	7	10	59	71	64	29	9	80	18	49	20
Simuliidae (blackflies)												
Simulium sp.	2	3										
Tipulidae (crane flies)												
Tipula sp.	1			1		1		1				
LEPIDOPTERA (aquatic moths)												
Pyralidae (pyralid moths)												
Petrophila sp.											5	12
HEMIPTERA (water bugs)												
Gerridae (water striders)									1			
MOLLUSCA												
GASTROPODA (snails, limpets)												
Ancylidae (limpets)			1	4	2						2	

TAXON	Number of Organisms per Taxon per Subsample											
	Tinker Creek	**Roanoke River Samples and Collection Dates**										
	NFQT1	**NFQT2**	**NFQL3**	**NFQL4 - ORIGINAL**	**NFQL4 - REPLICATE**	**NFQL5**	**NFQT6 - ORIGINAL**	**NFQT6 - REPLICATE**	**NFQT7**	**NFQL8**	**NFQL9**	**NFQT10**
	9/15/2020	9/15/2020	9/15/2020	9/16/2020	9/16/2020	9/16/2020	9/16/2020	9/16/2020	9/16/2020	10/5/2020	10/5/2020	10/5/2020
Lymnaeidae (pond snails)						3						
Planorbidae (ram's horn snails)			7	1	7	1						
Pleuroceridae (pleurocerid snails)	8	29	3				63	88	1	49		4
Physidae (bladder snails)			10	3		4		1				
BIVALVIA (clams or bivalves)												
Corbiculidae (Asian clam)		5						3	6	3	8	1
Sphaeriidae (fingernail clams)	1								1	1		
TOTAL NUMBER OF TAXA	**19**	**18**	**22**	**19**	**13**	**12**	**8**	**12**	**16**	**13**	**20**	**17**
TOTAL NUMBER OF ORGANISMS	**120**	**113**	**102**	**102**	**110**	**106**	**111**	**115**	**112**	**114**	**102**	**111**

[1] - Class Hirudinea (leeches) is now classified as Class Clitellata

[2] - Family Leptohyphidae previously named Family Tricorythidae

[3] - Chironomidae Group (A) includes all chironomid taxa except those that are highly tolerant of organic pollution, which are placed in Group (B). All identified Chironomidae specimens in all subsamples were assigned to Group A.

TAXON	Number of Organisms per Taxon per Subsample											
	Tinker Creek	Roanoke River Samples and Collection Dates										
	NSQT1	NSQT2	NSQL3	NSQL4 - ORIGINAL	NSQL4 - REPLICATE	NSQL5	NSQT6 - ORIGINAL	NSQT6 - REPLICATE	NSQT7	NSQL8	NSQL9	NSQT10
	6/4/2021	6/3/2021	6/4/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/4/2021	6/4/2021
PLATYHELMINTHES (flatworms)												
TURBELLARIA												
Planariidae	2				1		3	8		2	4	3
ANNELIDA (segmented worms)												
HIRUDINEA (leeches)[1]			3									
OLIGOCHAETA (aquatic worms)	2		22	9	4	1	2		3		1	2
ARTHROPODA (arthropods)												
HYDRACARINA (water mites)	4	3					4	1				2
CRUSTACEA (crayfish, scuds, aquatic sow bugs)												
AMPHIPODA (scuds, sideswimmers)												
Crangonyctidae												
Crangonyx sp.	2		34						2		1	
Talitridae												
Hyalella sp.			1									
ISOPODA (aquatic sow bugs)												
Asellidae												
Caecidotea sp.			8	2					1			
DECAPODA (crayfish)												
Cambaridae												
Faxonius sp.			3						2	10	1	1
INSECTA (insects)												
EPHEMEROPTERA (mayflies)												
Baetidae (small minnow mayflies)												
Acentrella sp.		5										
Baetis flavistriga	8	4						1				9
Baetis intercalaris	3	1										1
Baetis spp.	1									1	1	
Heterocloeon sp.		2										
Labiobaetis sp.										1		
Neocloeon sp.									1	1		
Plauditus sp.		5										6
Ephemerellidae (spiny crawler mayflies)												
Eurylophella spp.										2		
Heptageniidae (flatheaded mayflies)												
Leucrocuta sp.		1										
Maccaffertium spp.		2					1					3
Stenacron sp.		1										
Isonychiidae (brushlegged mayflies)												
Isonychia sp.		1						1				1
PLECOPTERA (stoneflies)												
Leuctridae (rolled-wing stoneflies)												
Leuctra sp.		1										
TRICHOPTERA (caddisflies)												
Brachycentridae (humpless casemakers)												
Brachycentrus sp.												2
Hydropsychidae (common net-spinners)												
Ceratopsyche morosa	1	2										4
Cheumatopsyche spp.	7	8					2	9			6	13
Hydropsyche spp.	3	7					4	8			2	11

TAXON	Number of Organisms per Taxon per Subsample											
	Tinker Creek	Roanoke River Samples and Collection Dates										
	NSQT1	NSQT2	NSQL3	NSQL4 - ORIGINAL	NSQL4 - REPLICATE	NSQL5	NSQT6 - ORIGINAL	NSQT6 - REPLICATE	NSQT7	NSQL8	NSQL9	NSQT10
	6/4/2021	6/3/2021	6/4/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/4/2021	6/4/2021
Hydroptilidae (micro-caddisflies)												
Hydroptila sp.	1						2	1	1	2	3	1
Leucotrichia sp.												1
Leptoceridae (long-horned caddisflies)												
Triaenodes sp.											1	
Psychomyiidae (net tube-making caddisflies)												
Psychomyia flavida		1										
COLEOPTERA (aquatic beetles)												
Elmidae (riffle beetles)												
Dubiraphia sp.			2			1					2	
Macronychus sp.										2		
Microcylloepus sp.		2		1			1	2			3	
Optioservus sp.			2				1	2				
Stenelmis sp.	2	2					1	15				6
Psephenidae (water penny beetles)												
Psephenus herricki											1	
ODONATA (dragonflies, damselflies)												
ANISOPTERA (dragonflies)												
Aeshnidae (darners)										2		
ZYGOPTERA (damselflies)												
Coenagrionidae (narrow-winged damselflies)												
Argia sp.				1	1					2		
Enallagma sp.			1							1		
DIPTERA (true flies)												
Ceratopogonidae (biting midges)												
Atrichopogon sp.					1			1				
Sphaeromias sp.			1									
Chironomidae (A)[2] - (midges)	63	33	23	44	89	89	82	45	97	23	84	12
Chironomidae (B) - (midges)			4	47	6	18			6		2	
Empididae (dance flies)												
Hemerodromia sp.	1									1		
Simuliidae (blackflies)												
Simulium spp.	7	16						1				3
Tipulidae (crane flies)												
Antocha sp.	1							1				3
HEMIPTERA (water bugs)												
Corixidae (water boatmen)						3						
Gerridae (water striders)										11		
Veliidae (broad-shouldered water striders)										3		
MOLLUSCA												
GASTROPODA (snails, limpets)												
Ancylidae (limpets)									4		2	
Lymnaeidae (pond snails)									2			
Planorbidae (ram's horn snails)			2	2	1							
Pleuroceridae (pleurocerid snails)	5	18					13	15		29	1	25
Physidae (bladder snails)	1	1	2	1	2					15		

TAXON	Number of Organisms per Taxon per Subsample											
	Tinker Creek	Roanoke River Samples and Collection Dates										
	NSQT1	NSQT2	NSQL3	NSQL4 - ORIGINAL	NSQL4 - REPLICATE	NSQL5	NSQT6 - ORIGINAL	NSQT6 - REPLICATE	NSQT7	NSQL8	NSQL9	NSQT10
	6/4/2021	6/3/2021	6/4/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/3/2021	6/4/2021	6/4/2021
BIVALVIA (clams or bivalves)												
Corbiculidae							1				1	1
Sphaeriidae (fingernail clams)					1							
TOTAL NUMBER OF TAXA	**18**	**21**	**13**	**7**	**8**	**4**	**13**	**15**	**9**	**17**	**16**	**21**
TOTAL NUMBER OF ORGANISMS	**114**	**116**	**108**	**107**	**106**	**112**	**117**	**111**	**119**	**108**	**116**	**110**

[1] - Class Hirudinea (leeches) is now classified as Class Clitellata

[2] - Chironomidae Group (A) includes all chironomid taxa, except those that are highly tolerant of organic pollution, which are placed in Group (B). The family Chironomidae is counted as one taxon on this table, despite the Group A and Group B designations.

Water quality parameters at quantitative and qualitative sites in fall 2020 (NFQT and NFQL site names, respectively) and spring 2021 (NSQT and NSQL site names). Sites above the dashed line are upstream of Niagara Dam and sites below the dashed line are downstream of Niagara Dam.

Date	Site	Water Temp. (C)	pH	DO (%)	Conductivity (us/cm)	Habitat
9/15/2020	NFQT1	18.5	6.90	75.4	416	Riffle/Run
9/15/2020	NFQT2	21.4	8.40	96.9	390	Riffle/Run
9/15/2020	NFQL3	21.2	7.10	79.2	418	Pool
9/16/2020	NFQL4	19.5	7.10	62.6	405	Pool
9/16/2020	NFQL5	20.4	7.10	75.1	413	Pool
6/4/2021	NSQT1	18.5	8.16	87.5	285	Riffle/Run
6/3/2021	NSQT2	22.6	8.11	115.0	281	Riffle/Run
6/4/2021	NSQL3	20.1	8.08	82.8	258	Pool
6/3/2021	NSQL4	20.3	8.17	76.2	275	Pool
6/3/2021	NSQL5	22.8	8.19	77.4	254	Pool
9/16/2020	NFQT6	20.6	7.20	85.4	402	Riffle/Run
9/16/2020	NFQT7	20.8	8.50	80.4	444	Riffle/Run
10/5/2020	NFQL8	15.6	8.10	98.1	413	Run
10/5/2020	NFQL9	15.9	8.00	104.7	345	Run
10/5/2020	NFQT10	16.1	8.20	105.7	418	Riffle
6/3/2021	NSQT6	21.5	8.21	112.6	258	Riffle/Run
6/3/2021	NSQT7	20.9	8.14	95.1	257	Riffle/Run
6/3/2021	NSQL8	21.1	8.12	98.6	261	Run
6/4/2021	NSQL9	21.9	8.26	102.6	261	Run
6/4/2021	NSQT10	22.2	8.26	115.9	250	Riffle

Raw data used to calculate VSCI scores for fall 2020 macroinvertebrate data (family). Sites above and below the dashed line are upstream and downstream of Niagara Dam, respectively.

Site	Total	Total Taxa	EPT Taxa	% Eph.	% Plec. + Trich. - Hydropsych.	% Scrapers	% Top 2 Dominant	% Chironomidae	HBI
NFQT1	120	16	4	4.17	4.17	22.50	69.17	55.00	**5.21**
NFQT2	113	11	5	5.31	1.77	61.06	60.18	6.19	**4.74**
NFQL3	102	17	2	0.00	0.98	29.41	39.22	9.80	**5.49**
NFQL4 - ORIGINAL	103	17	4	0.97	3.88	13.59	71.84	57.28	**6.03**
NFQL4 - REPLICATE	110	11	1	0.00	1.82	14.55	74.55	64.55	**5.75**
NFQL5	106	11	1	0.00	0.94	8.49	84.91	60.38	**6.59**
NFQT6 - ORIGINAL	110	7	3	0.00	5.45	63.64	83.64	26.36	**4.95**
NFQT6 - REPLICATE	115	10	2	0.00	3.48	84.35	84.35	7.83	**4.49**
NFQT7	112	16	4	3.57	0.00	5.36	76.79	71.43	**5.87**
NFQL8	114	12	4	1.75	2.63	47.37	71.93	15.79	**4.95**
NFQL9	102	14	2	0.98	1.96	14.71	57.84	48.04	**5.76**
NFQT10	111	12	2	5.41	0.00	6.31	71.17	18.02	**5.43**

Site results of VSCI scores for fall 2020 macroinvertebrate data (family). Sites above and below the dashed line are upstream and downstream of Niagara Dam, respectively.

Site	Total	Total Taxa	EPT Taxa	% Eph.	% Plec. + Trich. - Hydropsych.	% Scrapers	% Top 2 Dominant	% Chironomidae	HBI	VSCI Score
NFQT1	120	72.73	36.36	6.80	11.70	43.60	44.56	45.00	70.47	**41.40**
NFQT2	113	50.00	45.45	8.66	4.97	100.00	57.55	93.81	77.30	**54.72**
NFQL3	102	77.27	18.18	0.00	2.75	57.00	87.84	90.20	66.32	**49.95**
NFQL4 - ORIGINAL	103	77.27	36.36	1.58	10.91	26.34	40.69	42.72	58.40	**36.78**
NFQL4 - REPLICATE	110	50.00	9.09	0.00	5.11	28.19	36.78	35.45	62.57	**28.40**
NFQL5	106	50.00	9.09	0.00	2.65	16.45	21.81	39.62	50.08	**23.71**
NFQT6 - ORIGINAL	110	31.82	27.27	0.00	15.32	100.00	23.65	73.64	74.20	**43.24**
NFQT6 - REPLICATE	115	45.45	18.18	0.00	9.77	100.00	22.62	92.17	81.07	**46.16**
NFQT7	112	72.73	36.36	5.83	0.00	10.38	33.55	28.57	60.79	**31.03**
NFQL8	114	54.55	36.36	2.86	7.39	91.80	40.56	84.21	74.30	**49.01**
NFQL9	102	63.64	18.18	1.60	5.51	28.50	60.92	51.96	62.28	**36.57**
NFQT10	111	54.55	18.18	8.82	0.00	12.22	41.66	81.98	67.17	**35.57**

EPT = Ephemeroptera, Trichoptera, and Plecoptera; HBI = Hilsenhoff Biotic Index; VSCI = Virginia stream condition index

Raw data used to calculate VSCI scores for spring 2021 macroinvertebrate data (family). Sites above and below the dashed line are upstream and downstream of Niagara Dam, respectively.

Site	Total	Total Taxa	EPT Taxa	% Eph.	% Plec. + Trich. - Hydropsych.	% Scrapers	% Top 2 Dominant	% Chironomidae	HBI
NSQT1	114	14	3	10.53	0.88	7.89	65.79	55.26	**5.27**
NSQT2	116	12	6	18.97	1.72	23.28	43.97	28.45	**4.98**
NSQL3	108	13	0	0.00	0.00	7.41	52.78	25.00	**2.91**
NSQL4 - ORIGINAL	107	8	0	0.00	0.00	3.74	85.05	85.05	**6.90**
NSQL4 - REPLICATE	106	9	0	0.00	0.00	2.83	89.62	89.62	**6.06**
NSQL5	112	5	0	0.00	0.00	0.89	95.54	95.54	**6.38**
NSQT6 - ORIGINAL	117	10	3	0.85	1.71	16.24	84.82	70.09	**5.47**
NSQT6 - REPLICATE	111	12	4	1.80	0.90	31.53	57.66	40.54	**5.38**
NSQT7	119	10	2	0.84	0.84	5.88	86.55	86.55	**5.90**
NSQL8	108	14	3	4.63	1.85	44.44	48.15	21.30	**5.79**
NSQL9	116	15	4	0.86	3.45	10.34	79.31	74.14	**5.87**
NSQT10	110	16	6	18.18	3.64	32.73	48.18	10.91	**4.71**

Site results of VSCI scores for spring 2021 macroinvertebrate data (family). Sites above and below the dashed line are upstream and downstream of Niagara Dam, respectively.

Site	Total	Total Taxa	EPT Taxa	% Eph.	% Plec. + Trich. - Hydropsych.	% Scrapers	% Top 2 Dominant	% Chironomidae	HBI	VSCI Score
NSQT1	114	63.64	27.27	17.17	2.46	15.30	49.44	44.74	69.53	**36.19**
NSQT2	116	54.55	54.55	30.94	4.84	45.11	80.97	71.55	73.78	**52.04**
NSQL3	108	59.09	0.00	0.00	0.00	14.36	68.24	75.00	100.00	**39.59**
NSQL4 - ORIGINAL	107	36.36	0.00	0.00	0.00	7.24	21.61	14.95	45.63	**15.72**
NSQL4 - REPLICATE	106	40.91	0.00	0.00	0.00	5.48	15.00	10.38	57.99	**16.22**
NSQL5	112	22.73	0.00	0.00	0.00	1.73	6.45	4.46	53.18	**11.07**
NSQT6 - ORIGINAL	117	45.45	27.27	1.39	4.80	31.47	21.93	29.91	66.62	**28.61**
NSQT6 - REPLICATE	111	54.55	36.36	2.94	2.53	61.11	61.19	59.46	67.97	**43.26**
NSQT7	119	45.45	18.18	1.37	2.36	11.40	19.43	13.45	60.31	**21.49**
NSQL8	108	63.64	27.27	7.55	5.20	86.13	74.93	78.70	61.96	**50.67**
NSQL9	116	68.18	36.36	1.41	9.69	20.05	29.90	25.86	60.73	**31.52**
NSQT10	110	72.73	54.55	29.66	10.21	63.42	74.88	89.09	77.81	**59.04**

EPT = Ephemeroptera, Trichoptera, and Plecoptera; HBI = Hilsenhoff Biotic Index; VSCI = Virginia stream condition index

Crayfish observations. Sites above and below the dashed line are upstream and downstream of Niagara Dam, respectively. Shaded species names are invasive.

Site	Appalachian Brook Crayfish	Atlantic Slope Crayfish	Ozark Crayfish	Virile Crayfish	Red Swamp Crayfish
NFQT1	present		abundant		
NFQT2		present	abundant		
NFQL3			present		present
NFQL4			present		
NFQL5					
NFQT6			present		present
NFQT7			abundant		
NFQL8			abundant		
NFQL9			abundant	present	
NFQT10		present	abundant	abundant	

Water quality parameters at mussel sites in fall 2020. Sites above the dashed line are upstream of Niagara Dam and sites below the dashed line are downstream of Niagara Dam.

Date	Site	Water Temp. (C)	pH	DO (%)	Conductivity (us/cm)	Habitat
10/6/2020	T-1	15.8	7.9	96.9	336	Pool
10/6/2020	T-2	16.1	7.7	96.8	390	Pool
10/6/2020	T-3	15.4	7.8	79.2	384	Pool
10/6/2020	T-4	15.0	7.9	94.6	406	Pool
10/6/2020	T-5	14.9	7.9	62.6	399	Pool
10/6/2020	T-6	15.0	7.9	75.0	400	Pool
10/6/2020	T-7	15.2	7.9	96.9	404	Pool
10/6/2020	T-8	15.5	7.9	60.2	402	Pool
10/8/2020	UNIO-1	16.4	8.4	96.9	352	Riffle/Run
10/8/2020	UNIO-2	16.4	8.6	130.3	466	Riffle/Run
10/6/2020	UNIO-WC	16.4	8.0	85.4	213	Riffle/Run
10/7/2020	UNIO-Bypass	16.8	8.4	102.1	409	Riffle/Run
10/7/2020	UNIO-Tailrace	16.7	8.1	103.3	404	Run

Mussel observation in fall 2020. Both sites are upstream of Niagara Dam

Date	Site	Common Name	Species	Length (mm)	Dom. Substrate
10/8/2020	UNIO-1	Eastern Elliptio	*Elliptio complanata*	88.9	Course
10/8/2020	UNIO-1	Eastern Elliptio	*Elliptio complanata*	96.2	Course
10/8/2020	UNIO-2	Eastern Elliptio	*Elliptio complanata*	105.4	Sand
10/8/2020	UNIO-2	Eastern Elliptio	*Elliptio complanata*	73.5	Sand