Bypass Reach Flow and Aquatic Habitat Study Report

Niagara Hydroelectric Project (FERC No. 2466)

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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
WUA	weighted useable area

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 (MW) 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 to Appalachian's filing of the ISR meeting summary, which are addressed in this Updated Study Report (USR) along with study methods and results.

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.

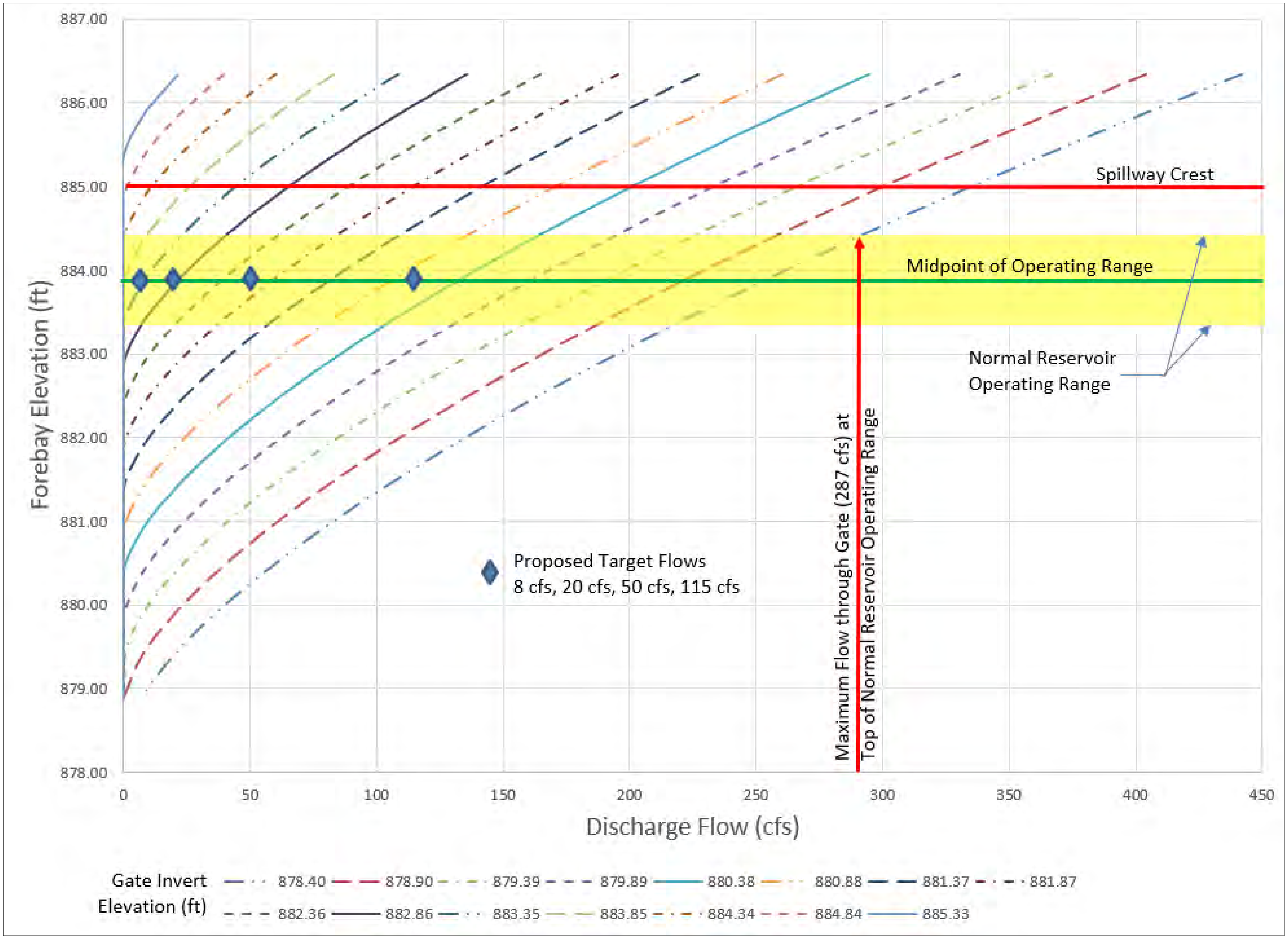


Figure 5-1. Niagara Obermeyer Sluice Gate Rating Curve

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., weighted usable area or WUA) over a range of simulation flows. WUA is defined as the sum of stream surface area within a nodal area model domain or stream reach, weighted 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:

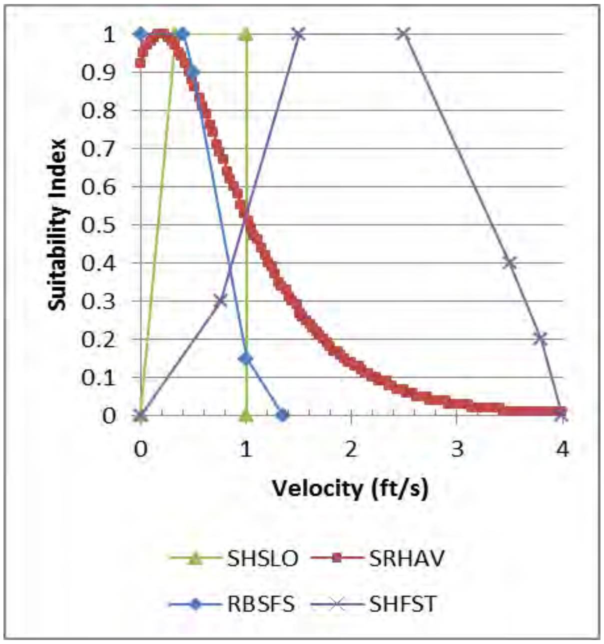
1. Frequency of occurrence was measured in BlueBeam Revu (version 20.2.30) for each HSC (i.e., depth, velocity, and substrate) for Roanoke Logperch young-of-year and subadult life stages.
2. Using the frequency of occurrence for HSC as well as available habitat, a measure of habitat preference was calculated (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 (Appendix C of this USR), 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 equally 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
	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



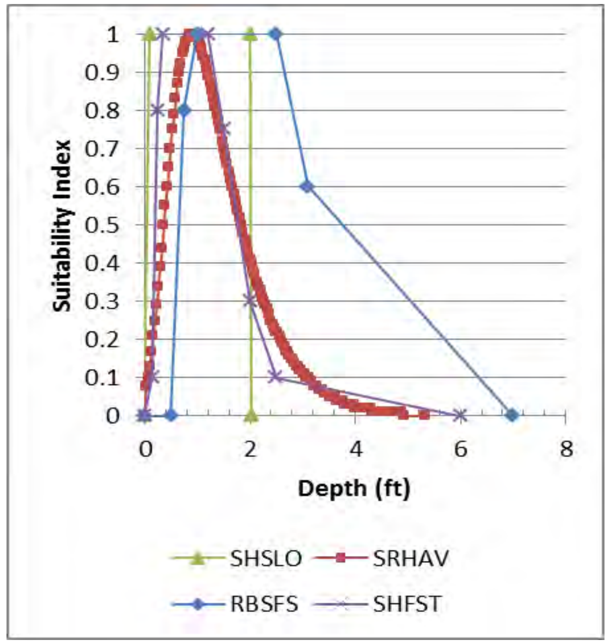


Figure 5-2. Velocity HSC (left) and Depth HSC (right) for Shallow Water Guilds

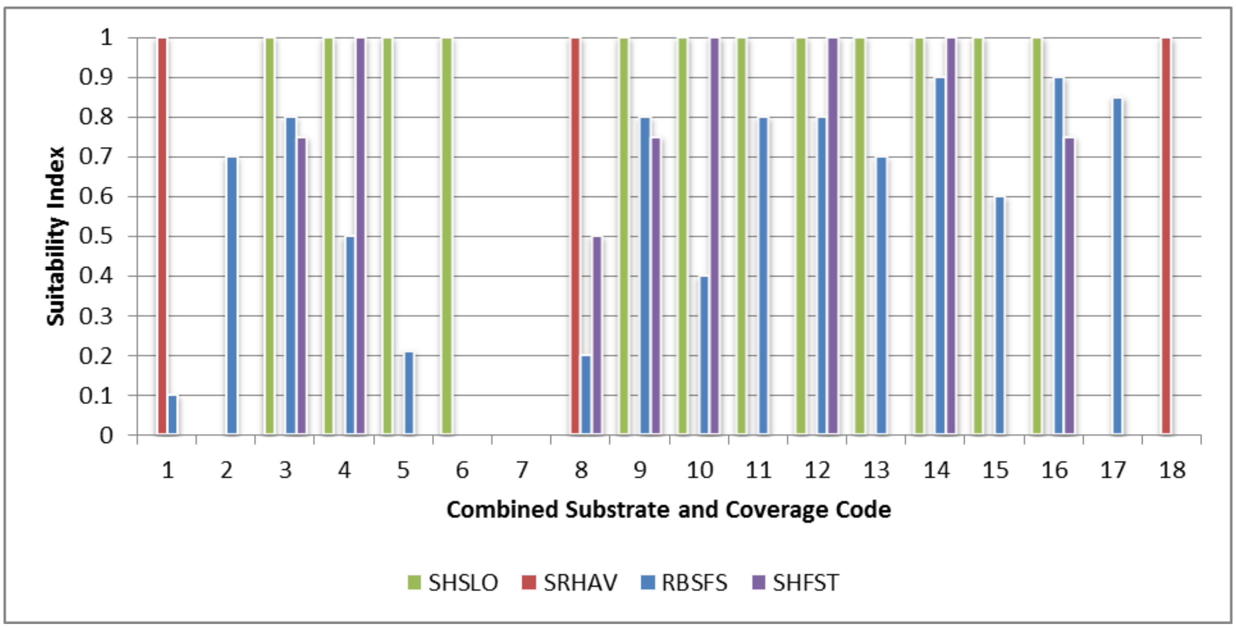
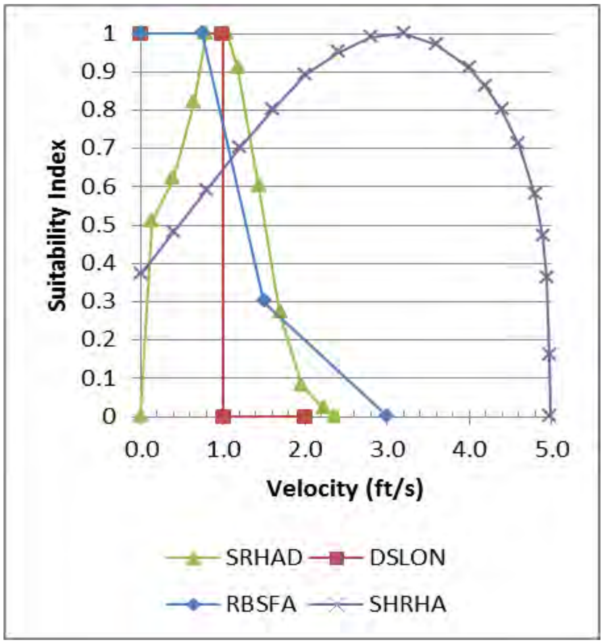


Figure 5-3. Substrate HSC for Shallow Water Guilds



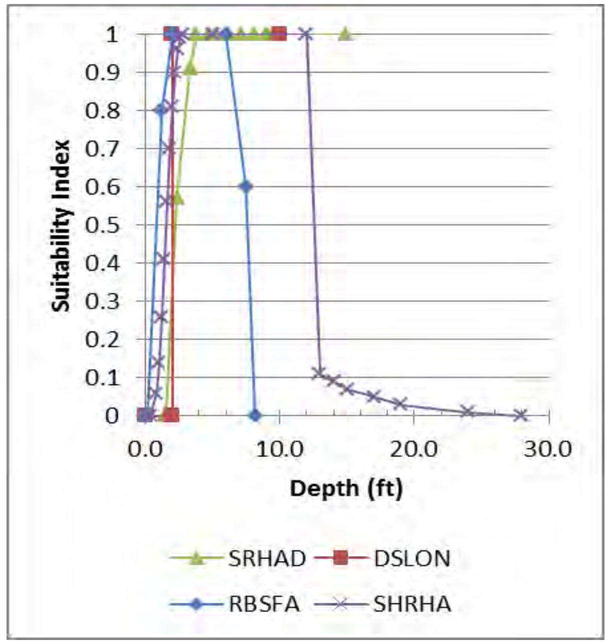


Figure 5-4. Velocity HSC (left) and Depth HSC (right) for Deep Water Guilds

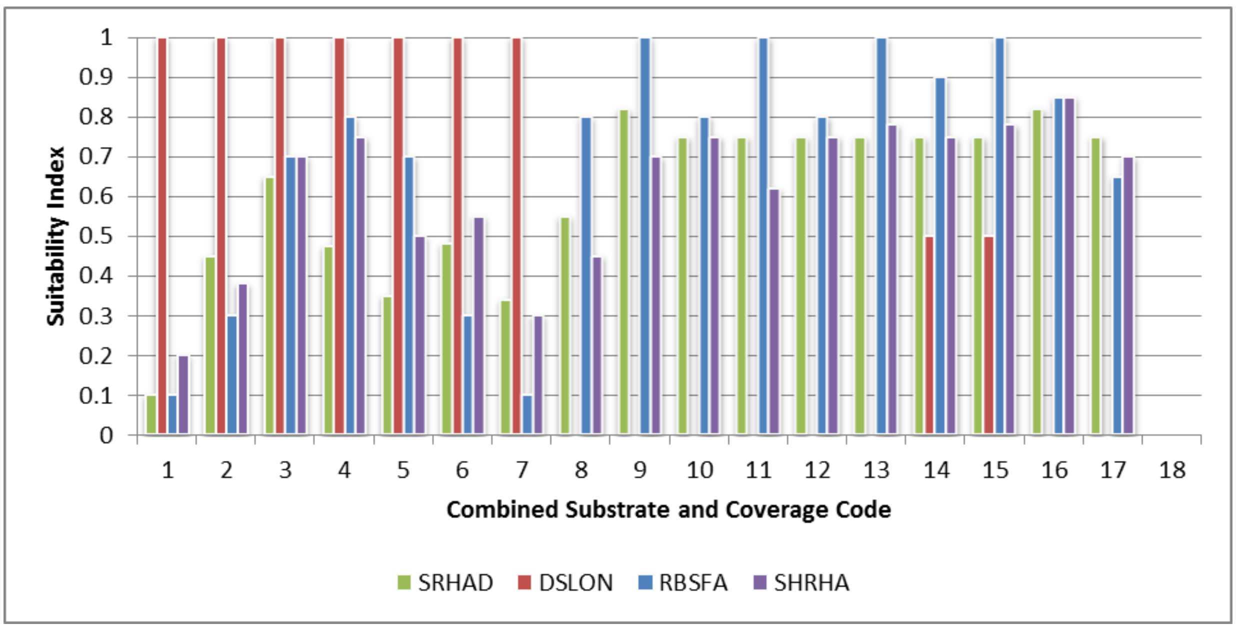


Figure 5-5. Substrate HSC for Deep Water Guilds

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 acre for the tailrace from the powerhouse discharge to the Blue Ridge Parkway bridge. Approximately half of the bypass 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).

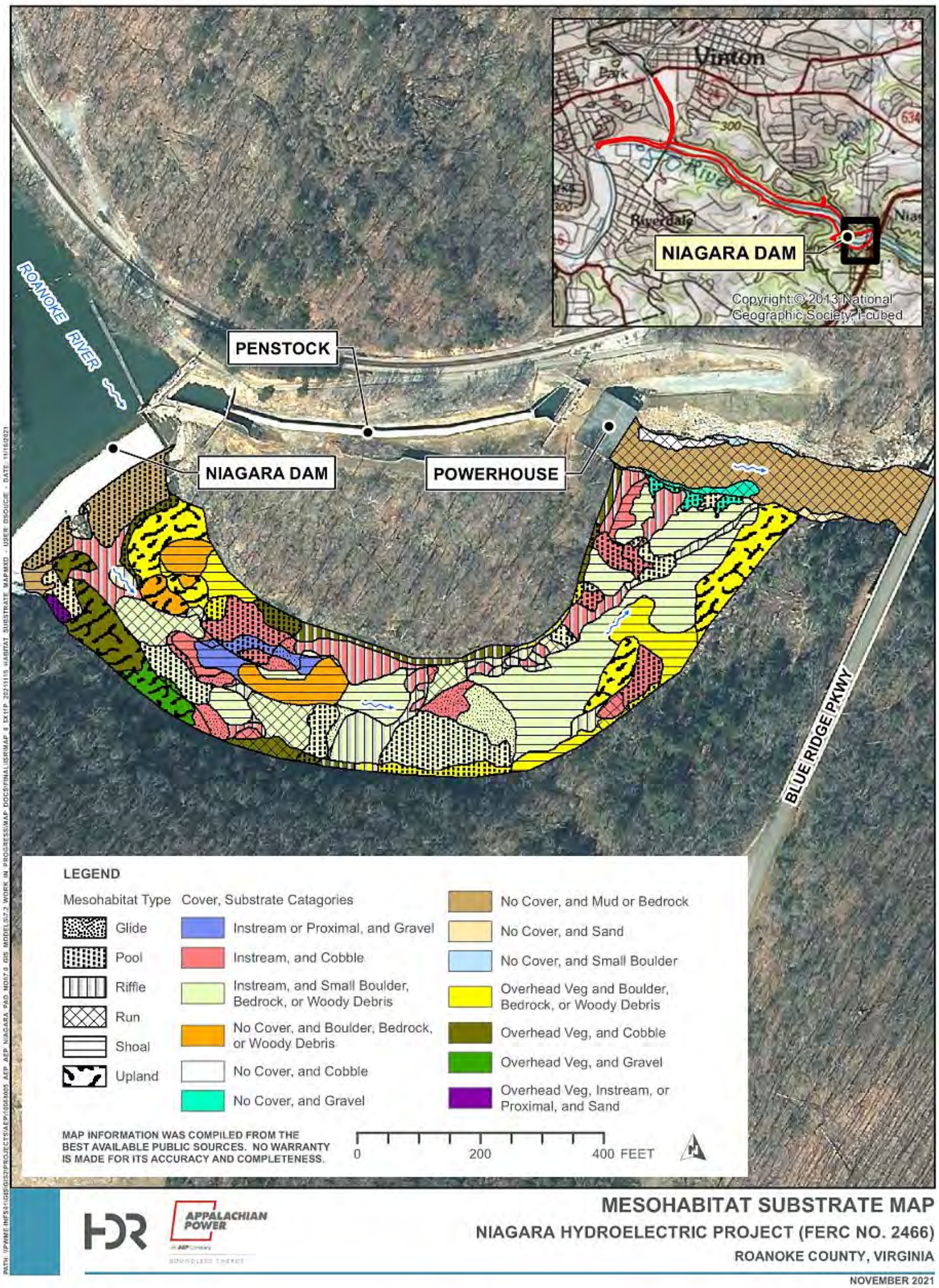


Figure 6-1. Bypass Reach Desktop Habitat Delineation at Niagara Hydroelectric Project

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

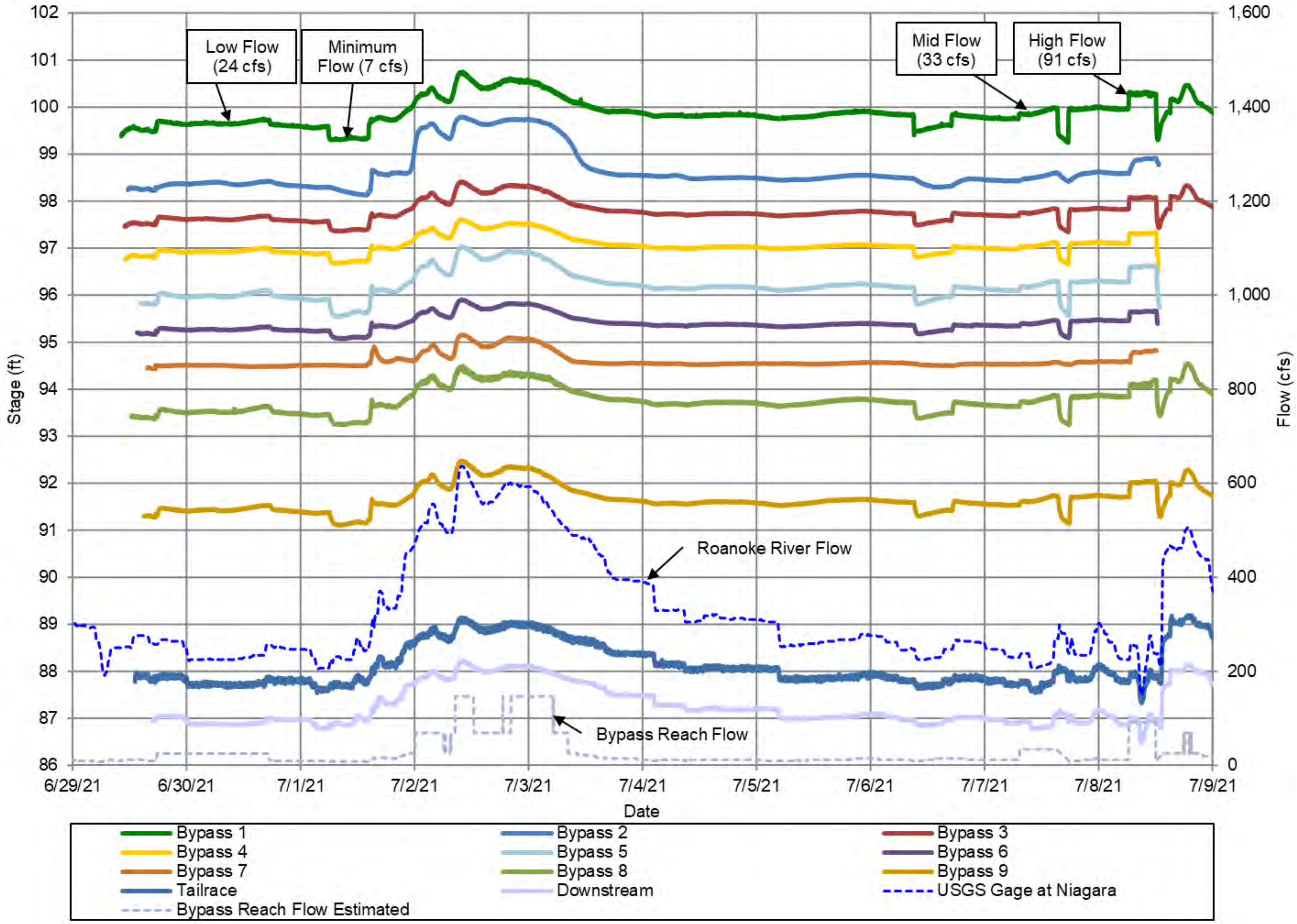


Figure 6-3. Bypass Reach Level Logger and Flow Data during the Calibration Flow Study Period

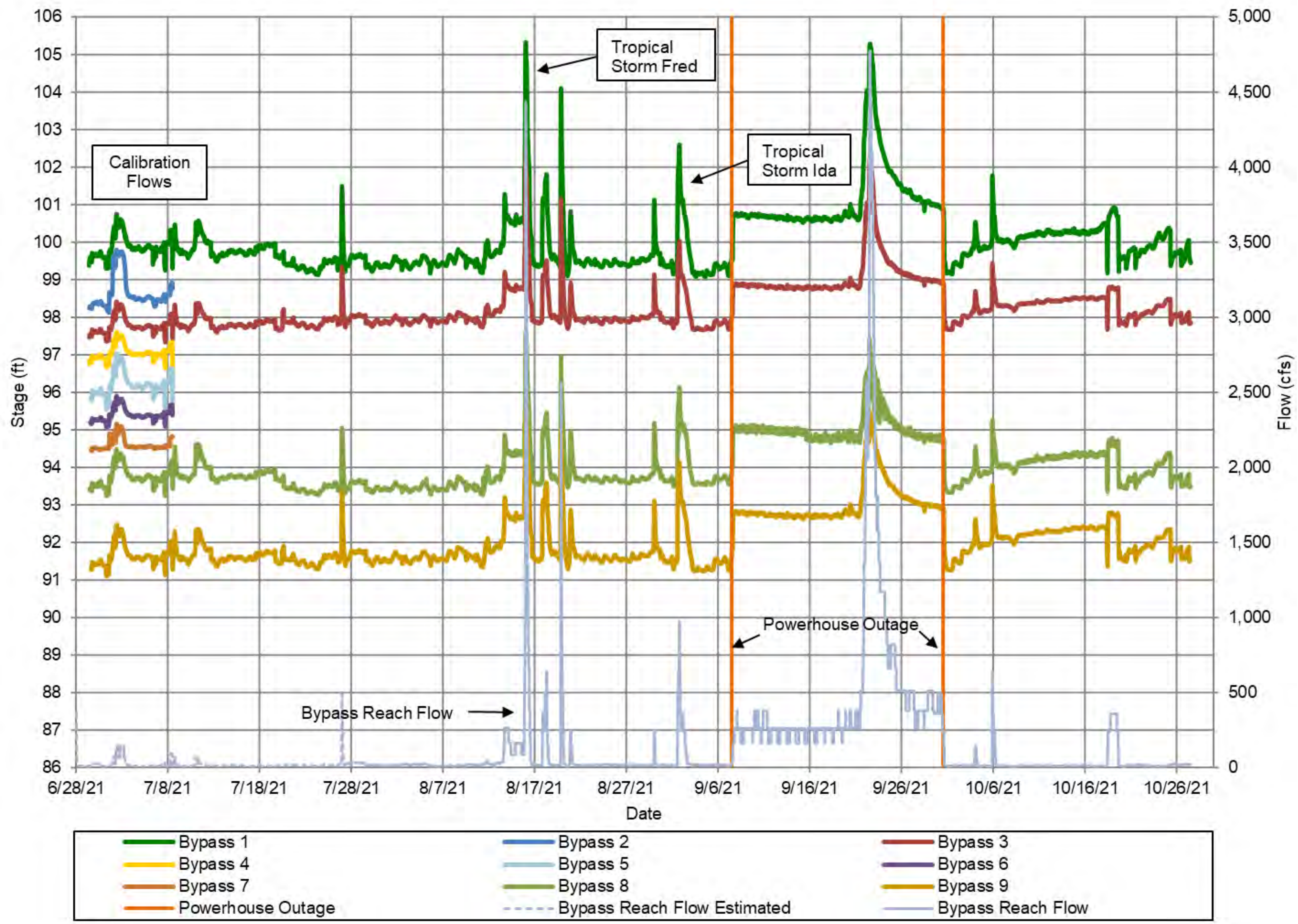


Figure 6-4.. Bypass Reach Level Logger and Flow Data during Study Period

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).

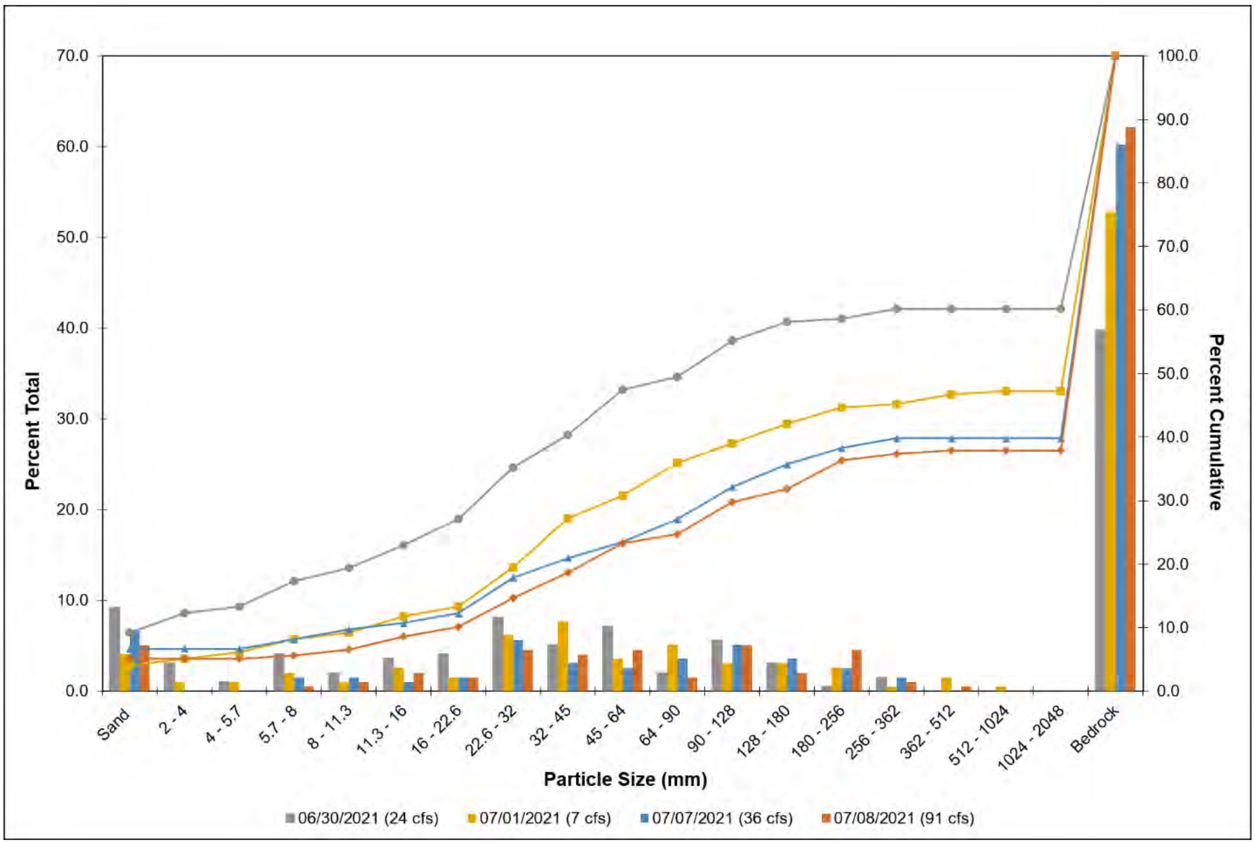


Figure 6-5. Niagara Bypass Reach Pebble Count Particle Size Data after each Model Calibration Flow Release (Upstream Transect)

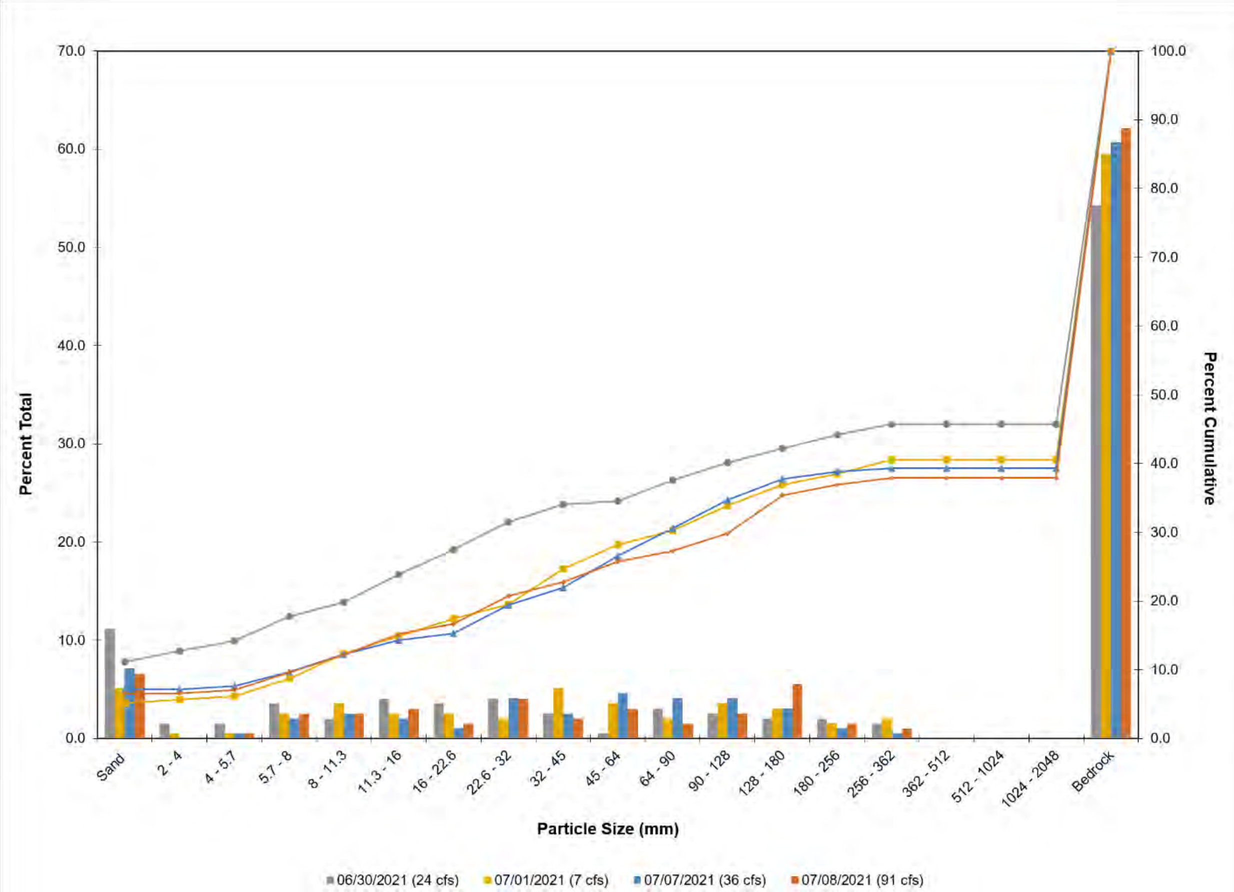


Figure 6-6. Niagara Bypass Reach Pebble Count Particle Size Data after each Model Calibration Flow Release (Downstream Transect)

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.

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.

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 increases a small amount as bypass flows increase.

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. The amount of potential habitat is similar between the 7 cfs, 24 cfs, and 33 cfs modeled scenarios and only slightly higher at the 91 cfs modeled scenario (likely the result of a slightly increased wetted area at the higher flow).

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 increases a small amount as bypass flows increase.

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) all 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).

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 at the four modeled flow scenarios. 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 is not particular about substrate type but requires instream aquatic vegetation. While there is aquatic vegetation in the bypass reach, it is largely above water at the modeled flow scenarios. As a result, potential habitat for this guild representative is very low.

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. (Attachment 2 of Appendix C). For adults, the amount of available habitat generally 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, but the overall amount of available habitat is similar under each of the modeled flow scenarios. 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. (Attachment 2 of Appendix C) . 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 between the minimum calibration flow (i.e., 7 cfs) and the low calibration flow (i.e., 24 cfs). Between these two flow scenarios, water depths increase by approximately 0.2 ft, velocities increase by approximately 0.3 ft/s and the total wetted area increases by approximately 25 percent (see Table 4-2, Attachment 1). While these increases are fairly incremental, habitat results for the Shallow-Fast and Shallow-Slow guilds are noticeable between these two modeled flow scenarios (see Attachment 3).

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. 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 minimum modeled flow (i.e., 7 cfs) and little additional spawning habitat would be gained with increasing flow releases. In fact, slightly less spawning habitat would be available at the highest flow release (91 cfs), likely due to increased flow velocities. As a result, seasonal minimum flows in the Niagara bypass reach would not provide a significant amount of additional available spawning habitat for this species/life stage.

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 for general habitat availability for Roanoke Logperch (as well as the other guild representatives) was 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.

10 References

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Attachment 1

Attachment 1 – Niagara Bypass Reach ICM Development Model

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Niagara Bypass Reach ICM Model Development

Niagara Hydroelectric Project (FERC No. 2466)

December 6, 2021

Prepared by:

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.

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Figure 2-3. Collected Bathymetry Points

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.

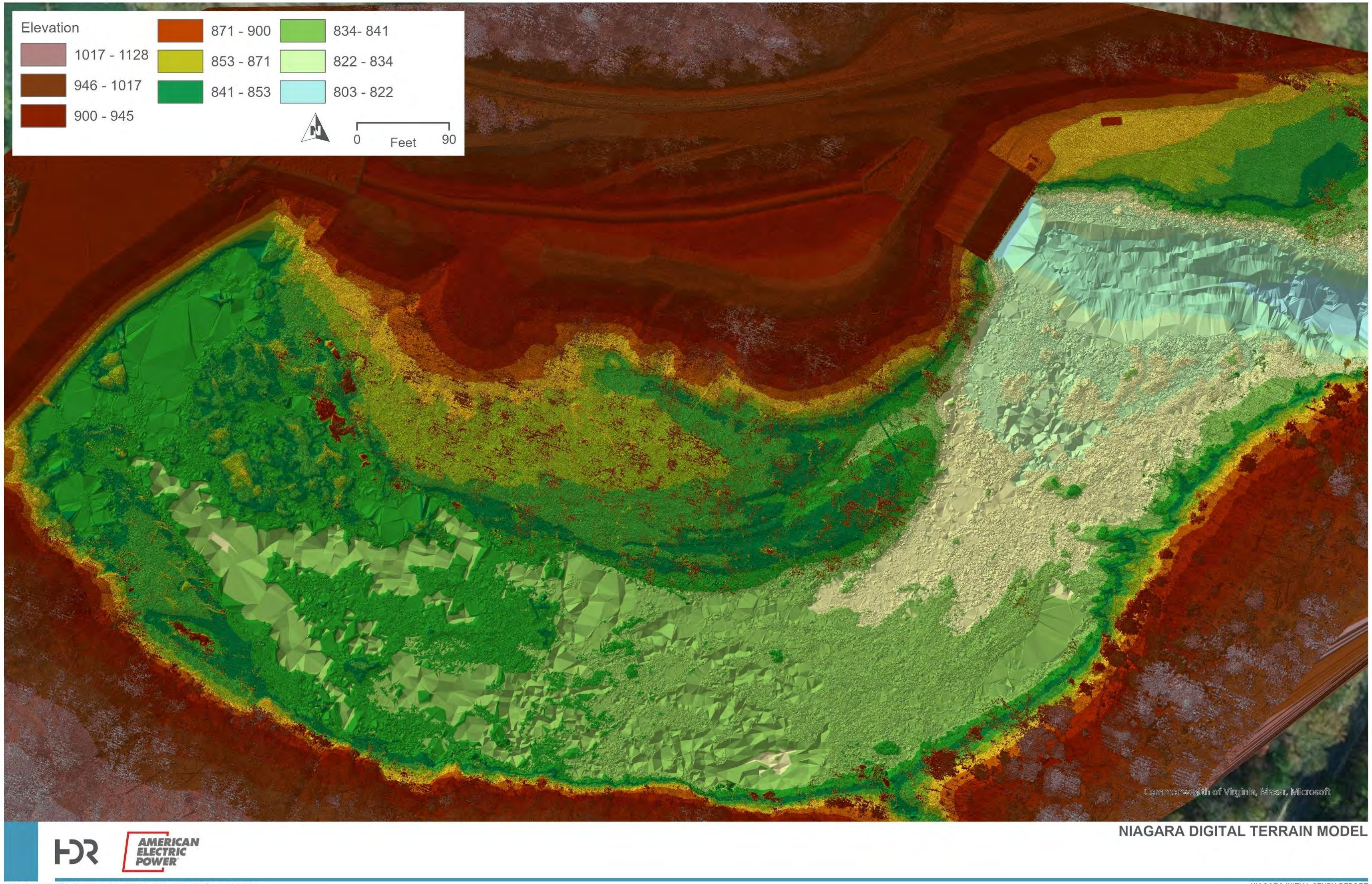

Figure 3-1. Bypass Reach Digital Terrain Model

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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

Property	Value		
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	...		

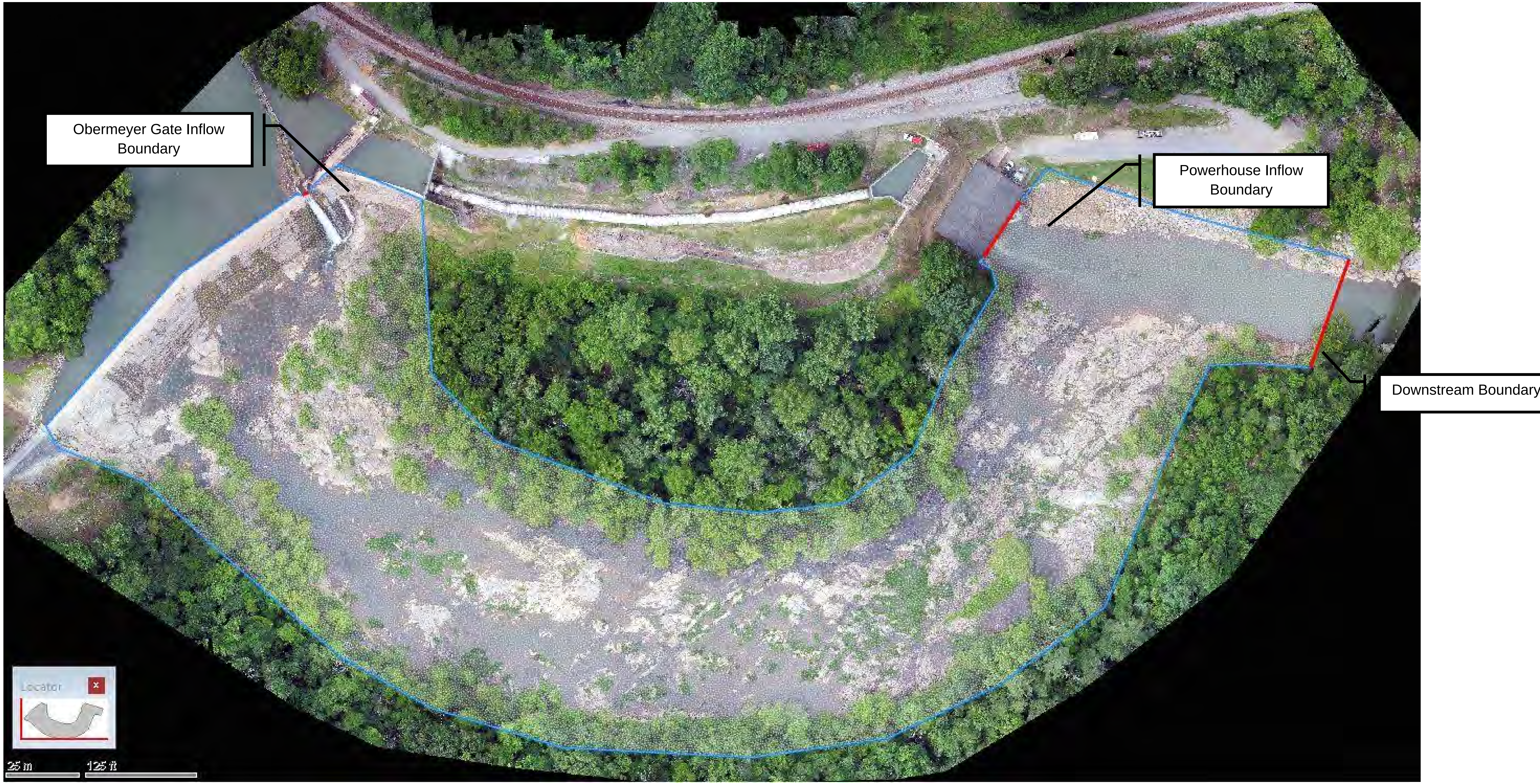

Figure 3-2. Extent of 2-D Zone and ICM Mesh (North is to the Top of the Figure)

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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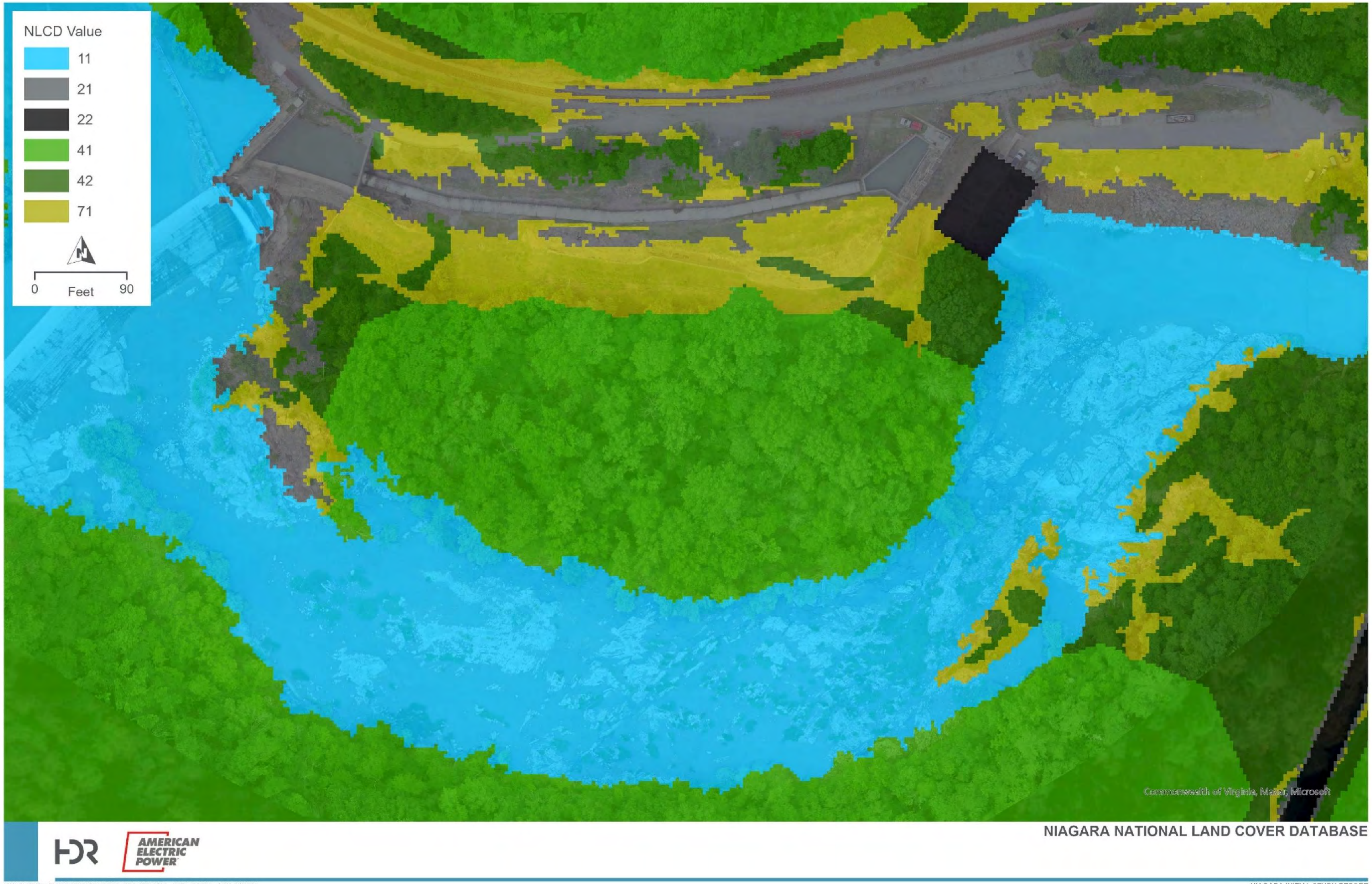

Figure 3-4. Land Cover Raster for Manning's *n* Roughness

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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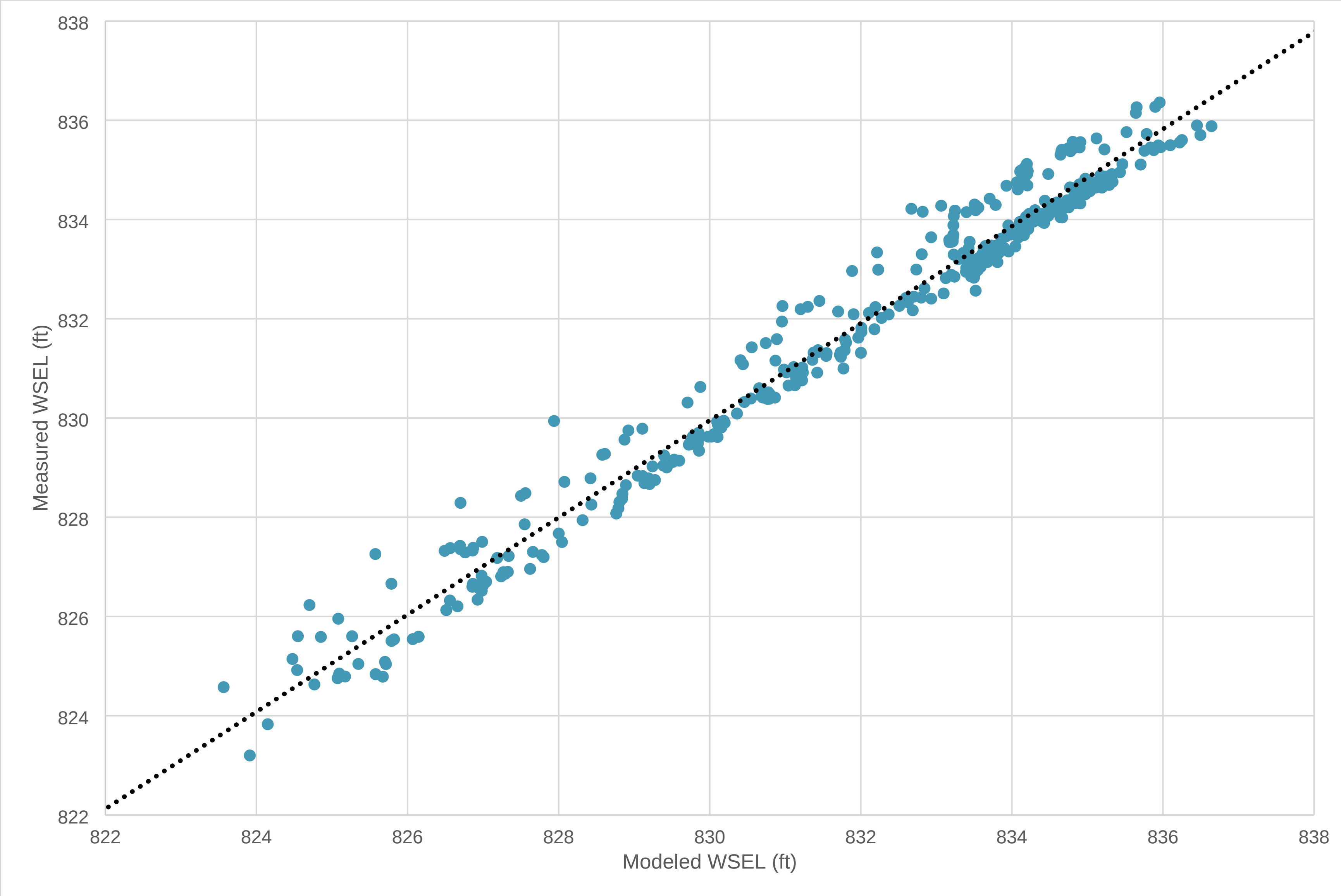

Figure 4-2. Measured vs Modeled Water Surface Elevation Correlation

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

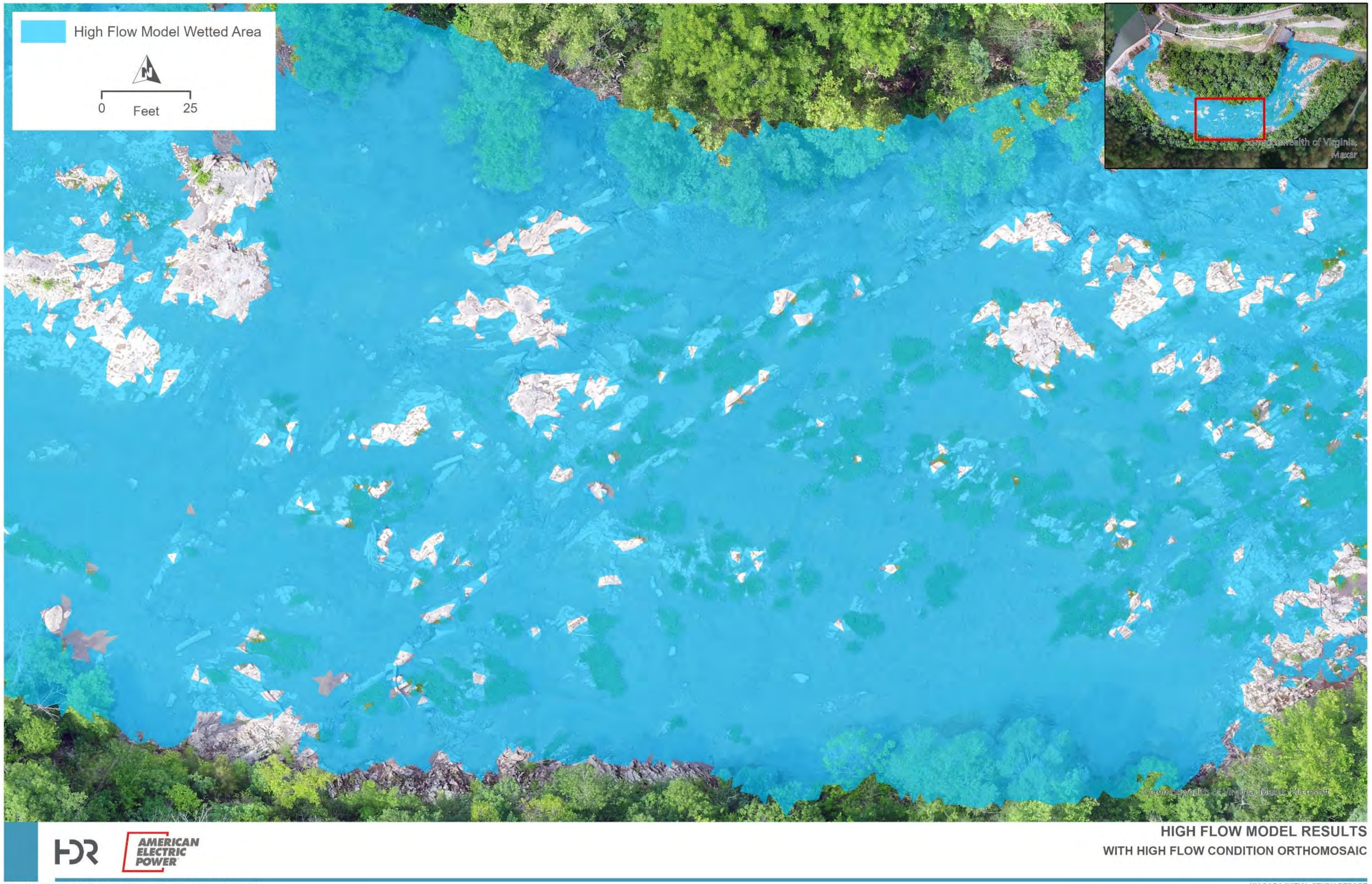

Figure 4-4. Model Results with Orthomosaic Imagery – High Flow

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.

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Attachment 2

Attachment 2 – Habitat Suitability Criteria Tables

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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
RBSFS	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
	--	--	--	--	--	--	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
SRHAV	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
	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
SRHAV	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	--	--
	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

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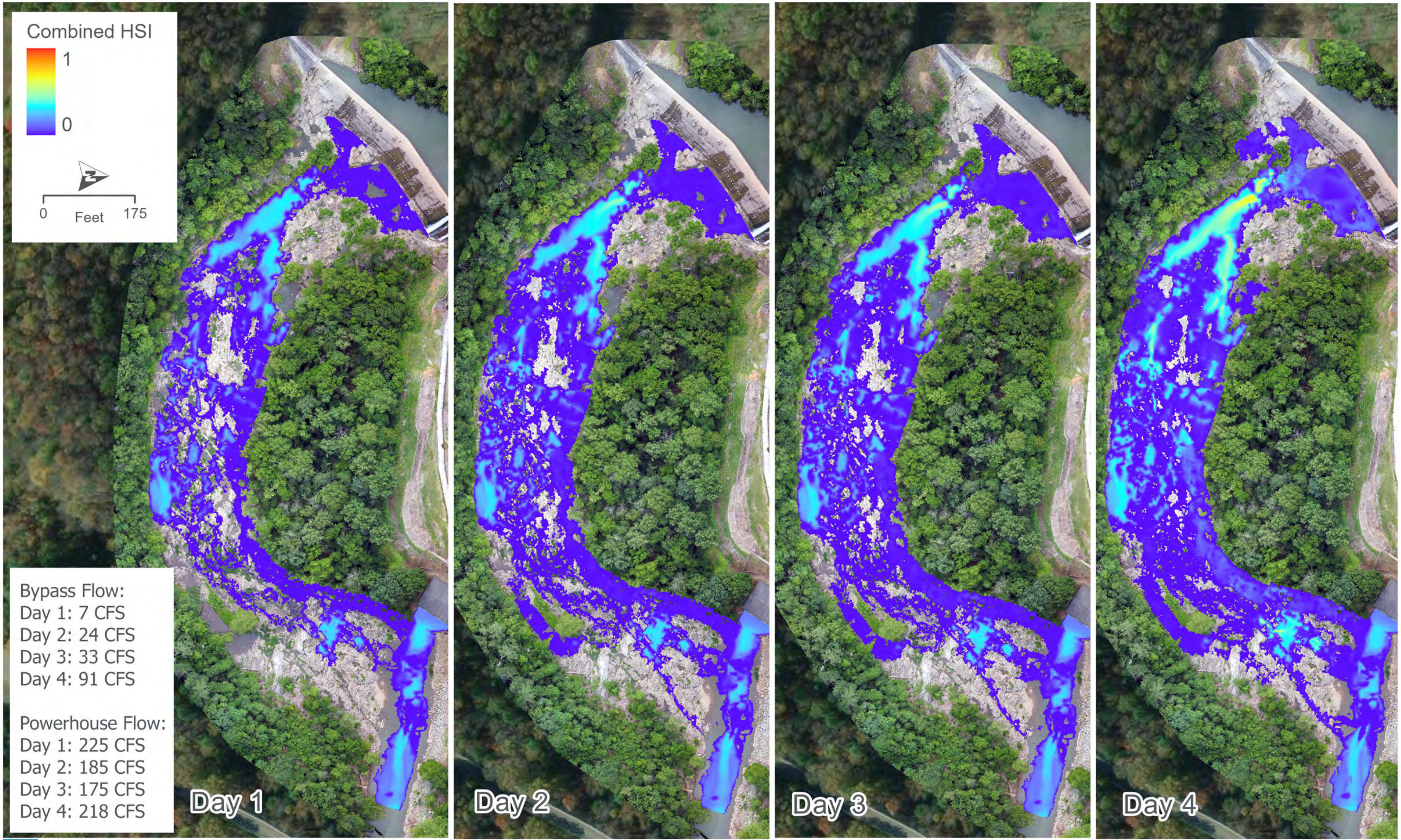
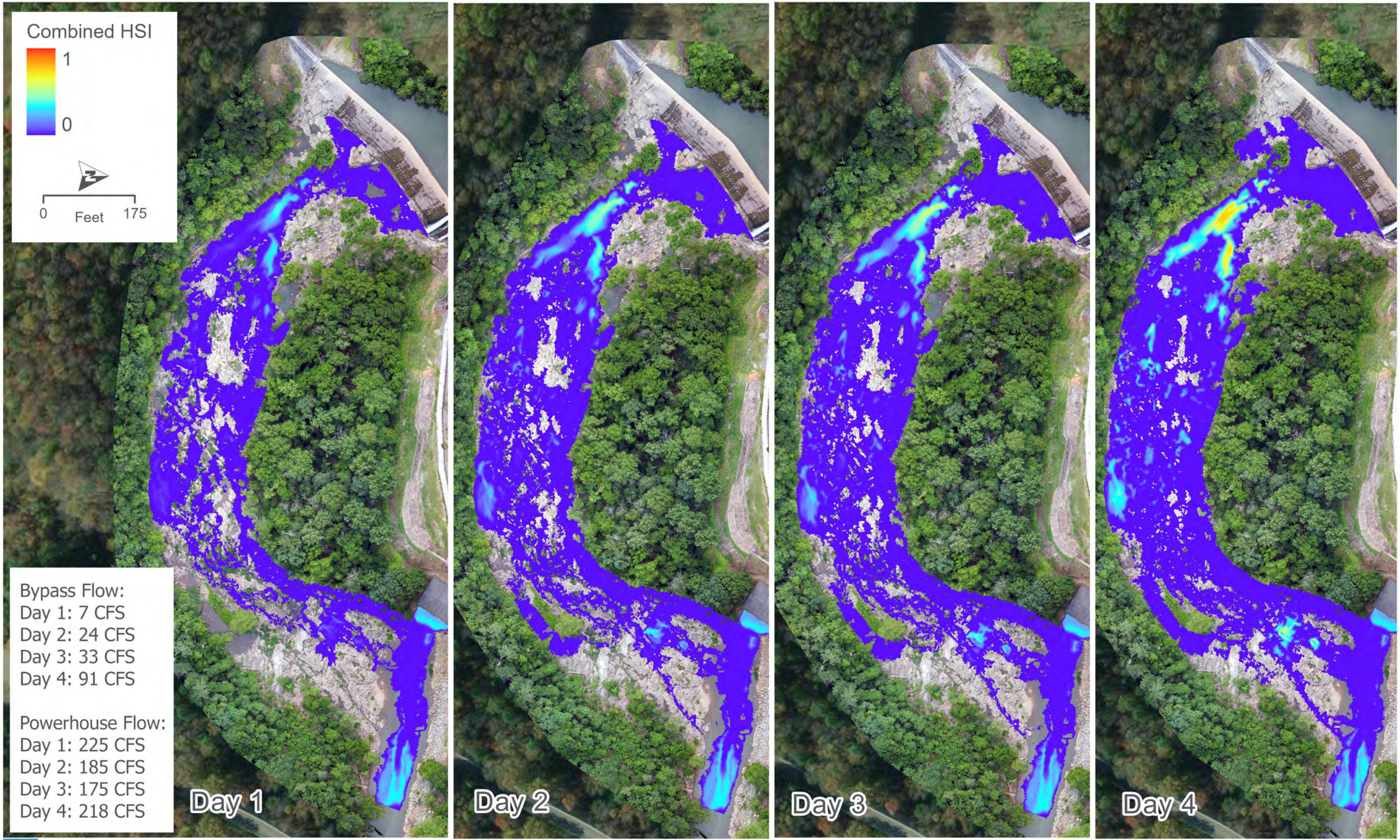


DEEP-FAST GUILD HABITAT SUITABILITY MAP

CATEGORY: COARSE-MIXED SUBSTRATE



DEEP-FAST GUILD HABITAT SUITABILITY MAP

CATEGORY: SLIGHTLY WEIGHTED FOR FINE SUBSTRATE, COVER

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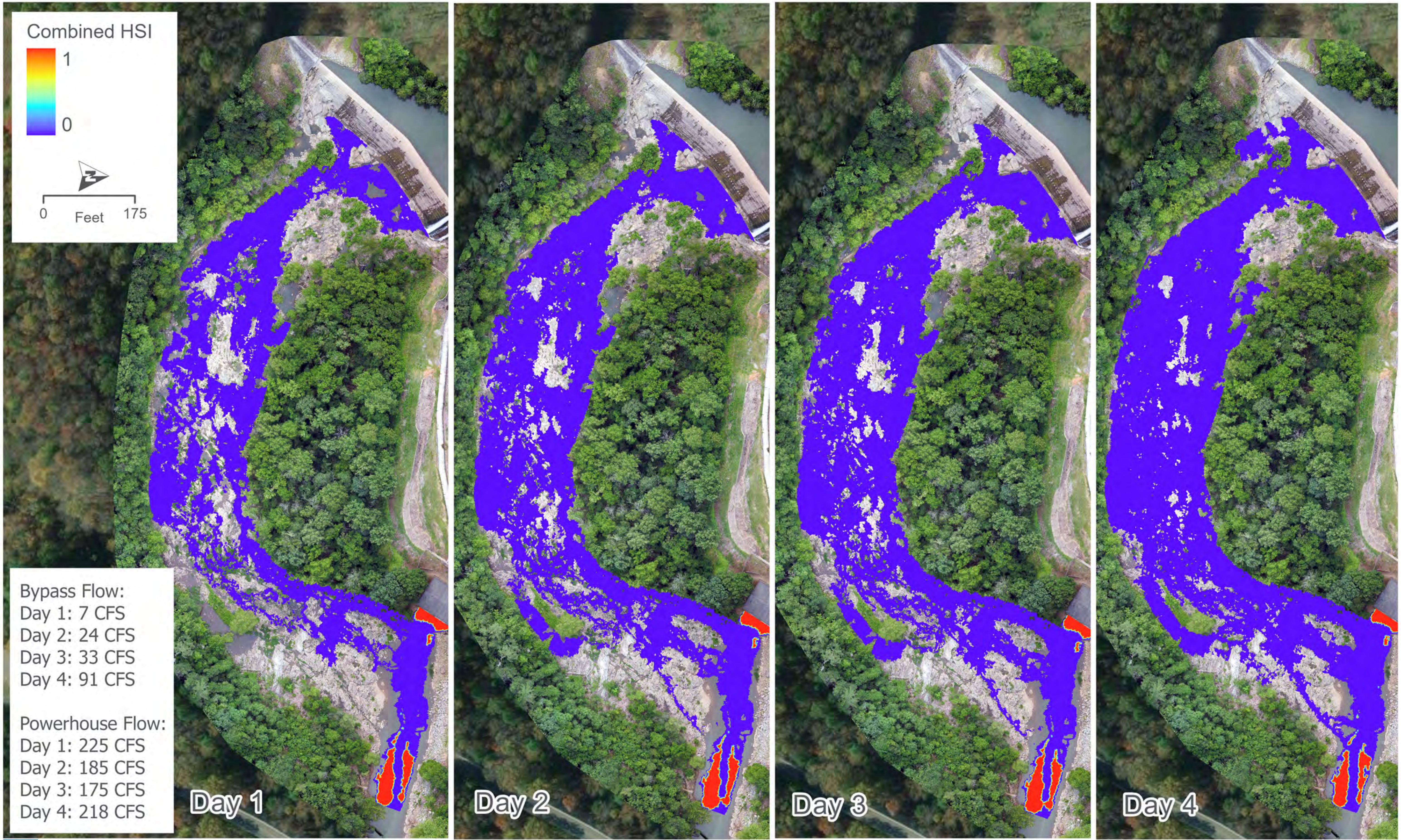
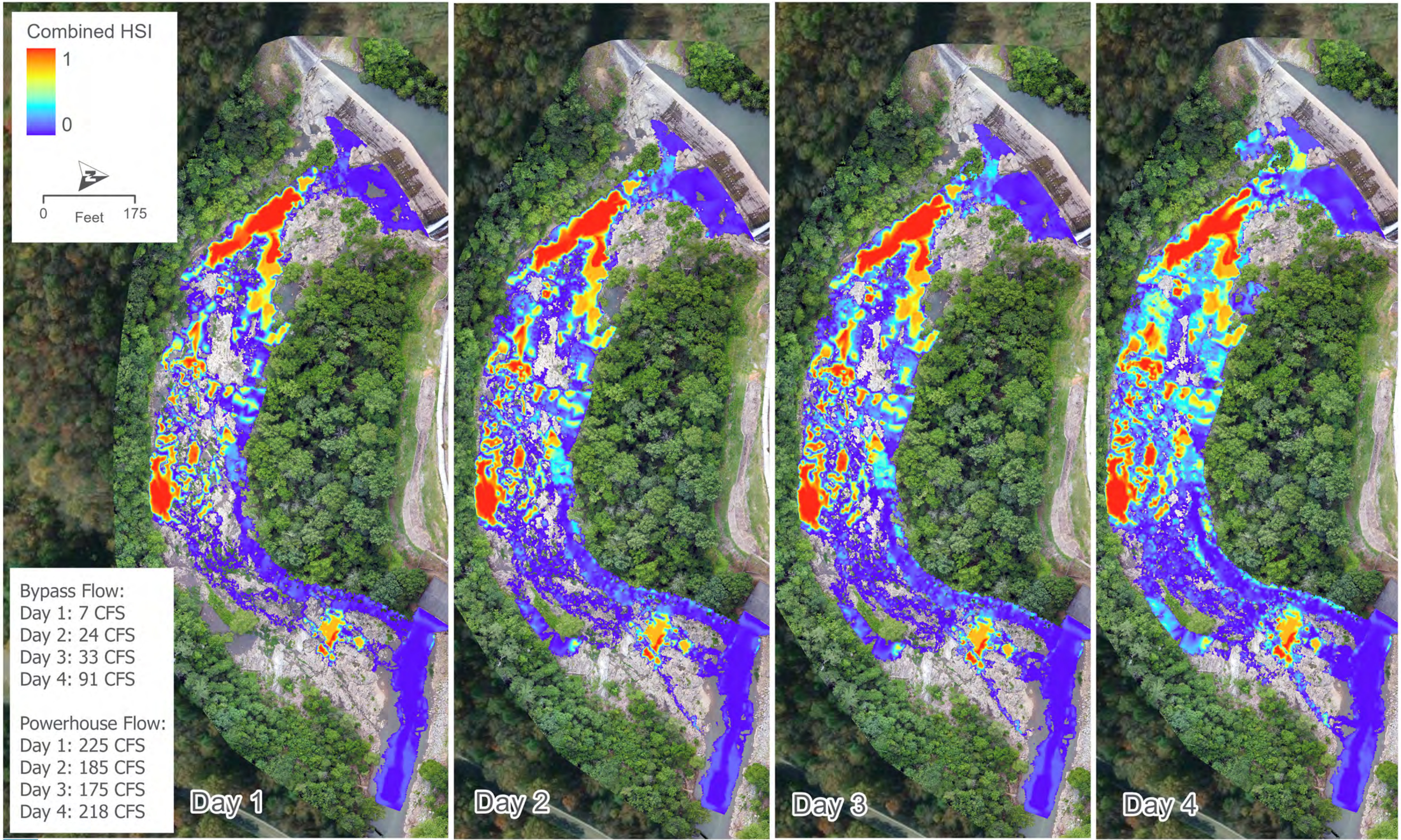


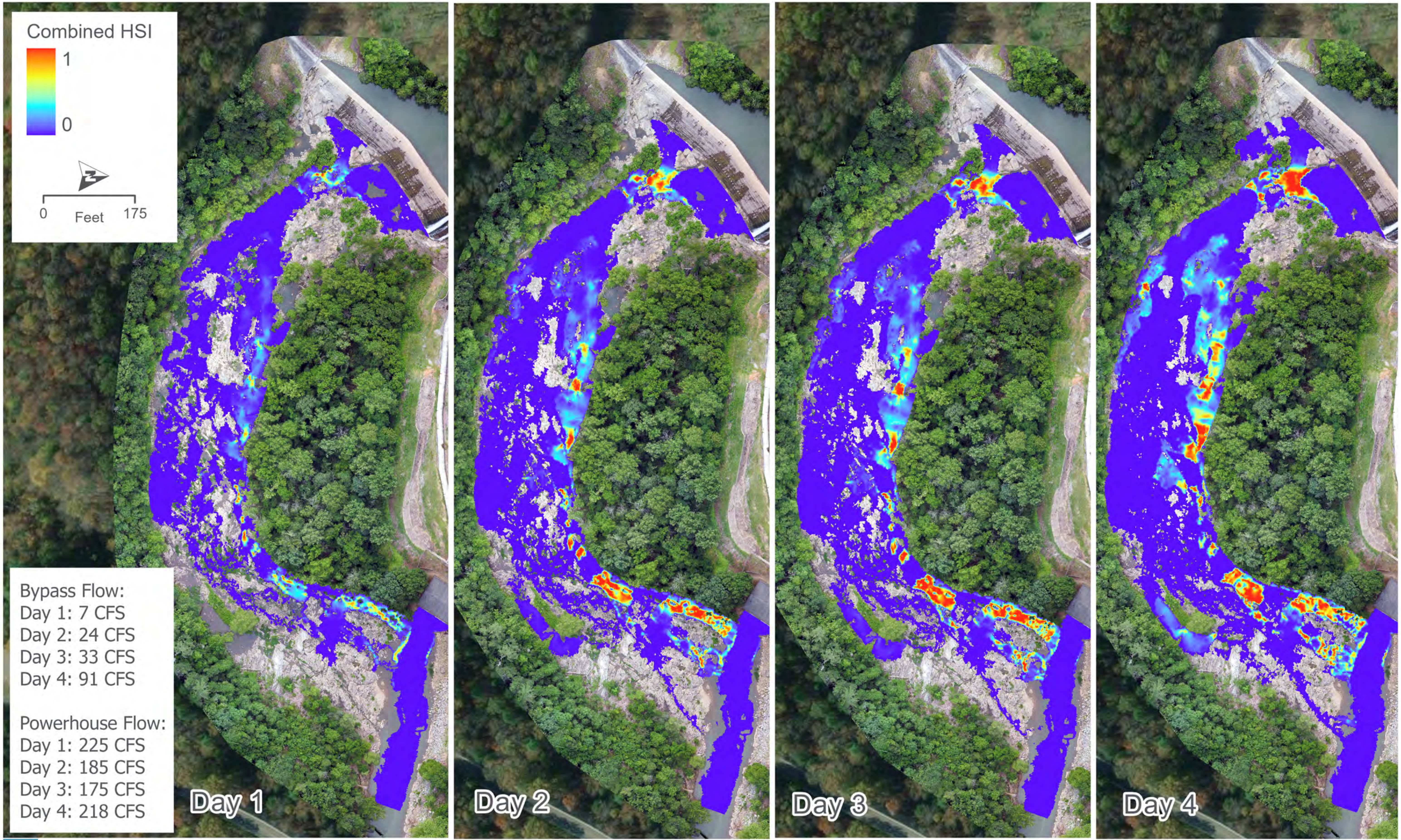
GENERIC DEEP-SLOW GUILD HABITAT SUITABILITY MAP

CATEGORY: NO COVER



DEEP-SLOW GUILD HABITAT SUITABILITY MAP

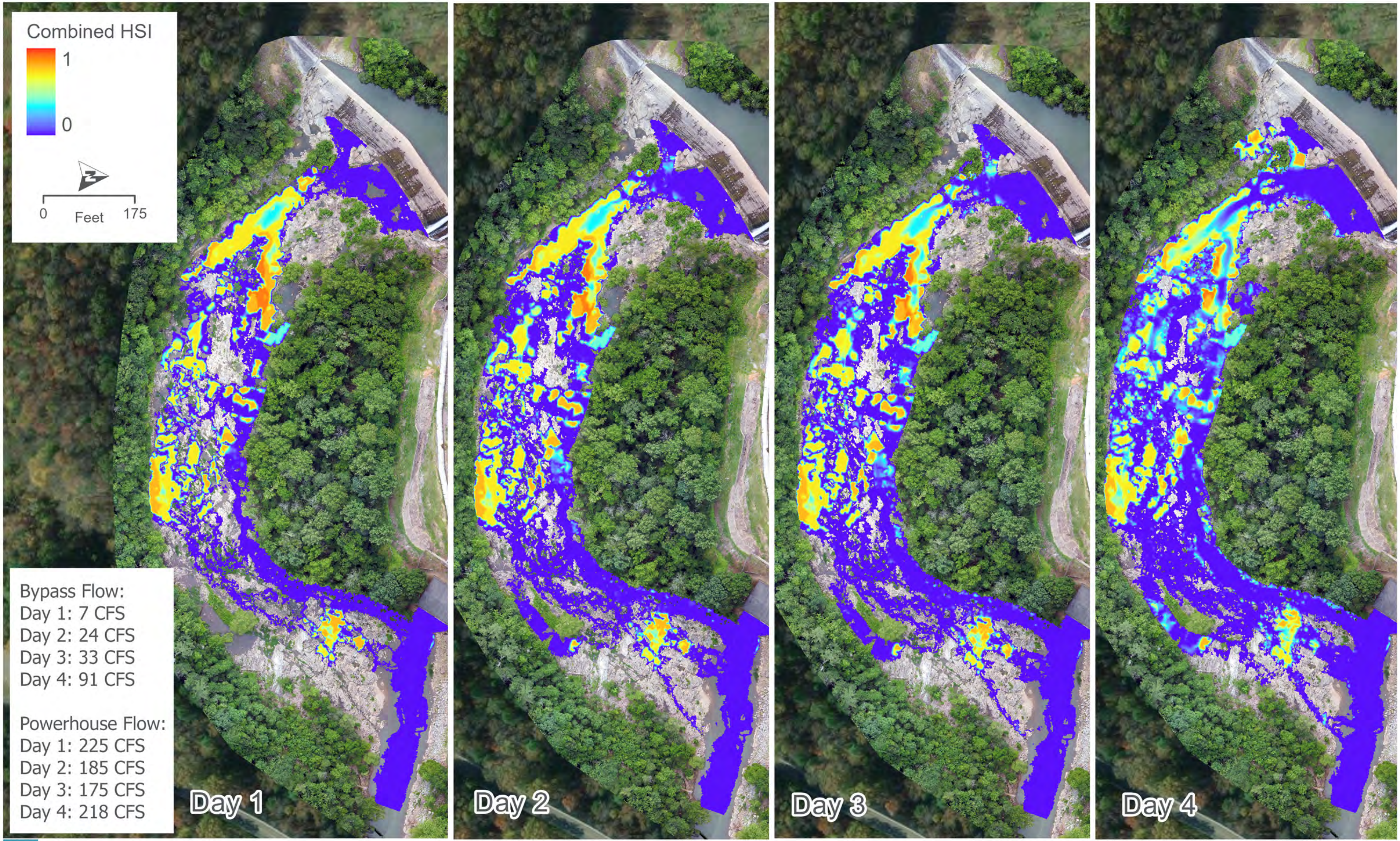
CATEGORY: COVER



HDR AMERICAN ELECTRIC POWER

SHALLOW-FAST GUILD HABITAT SUITABILITY MAP

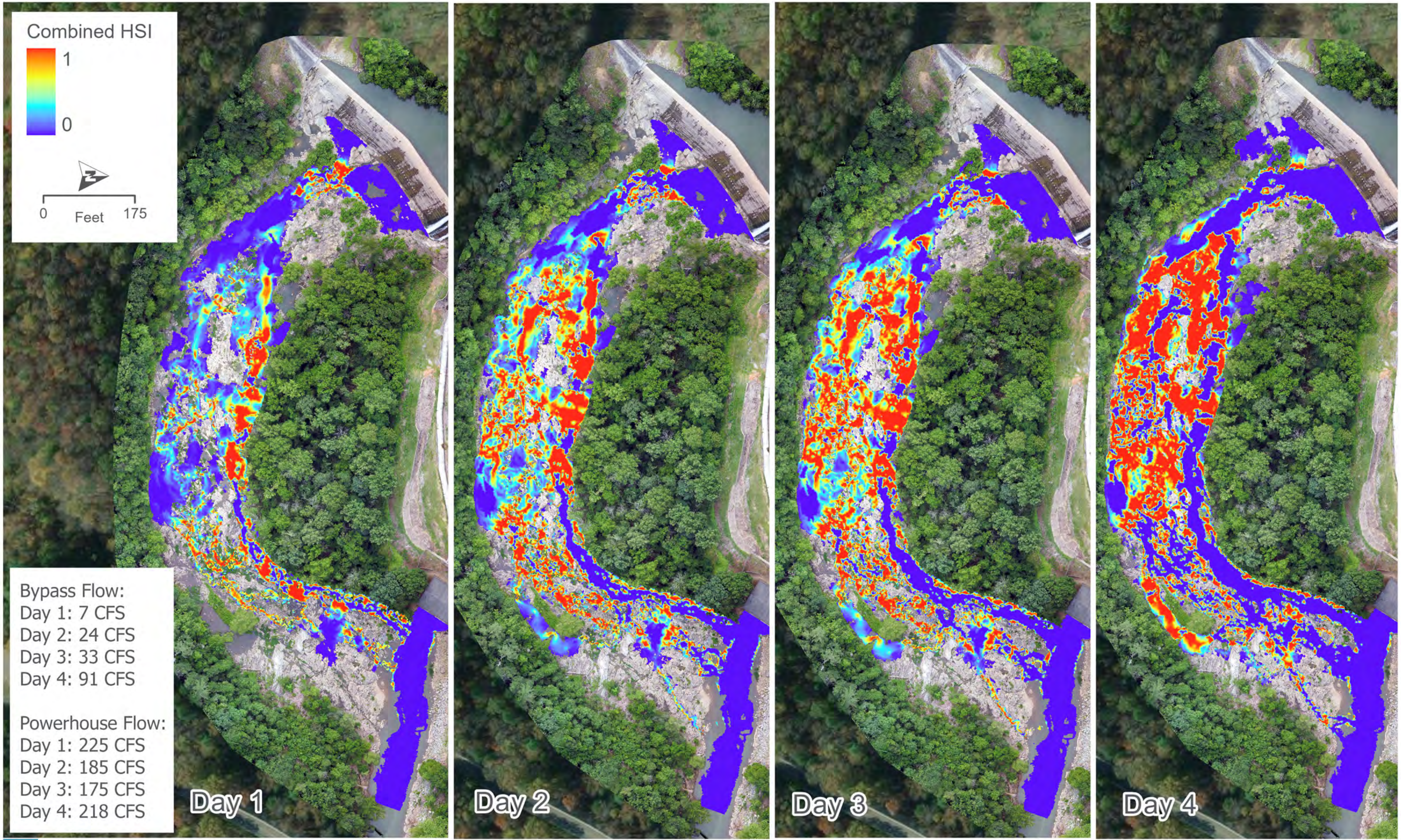
CATEGORY: MODERATE VELOCITY WITH COARSE SUBSTRATE



HDR AMERICAN ELECTRIC POWER

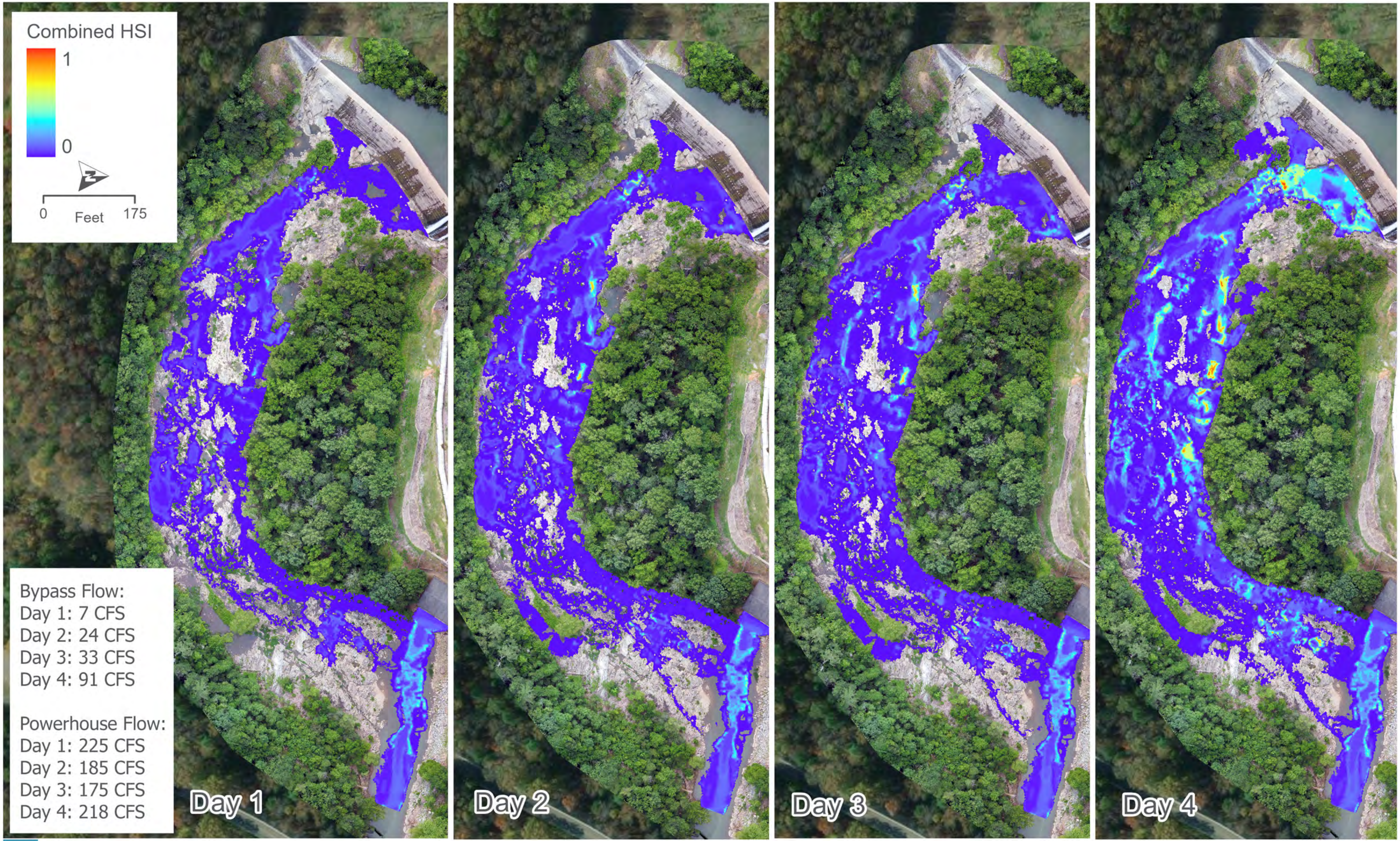
SHALLOW-SLOW GUILD HABITAT SUITABILITY MAP

CATEGORY: FINE AND COARSE-MIXED SUBSTRATE (NO BOULDER/BEDROCK)



GENERIC SHALLOW-SLOW GUILD HABITAT SUITABILITY MAP

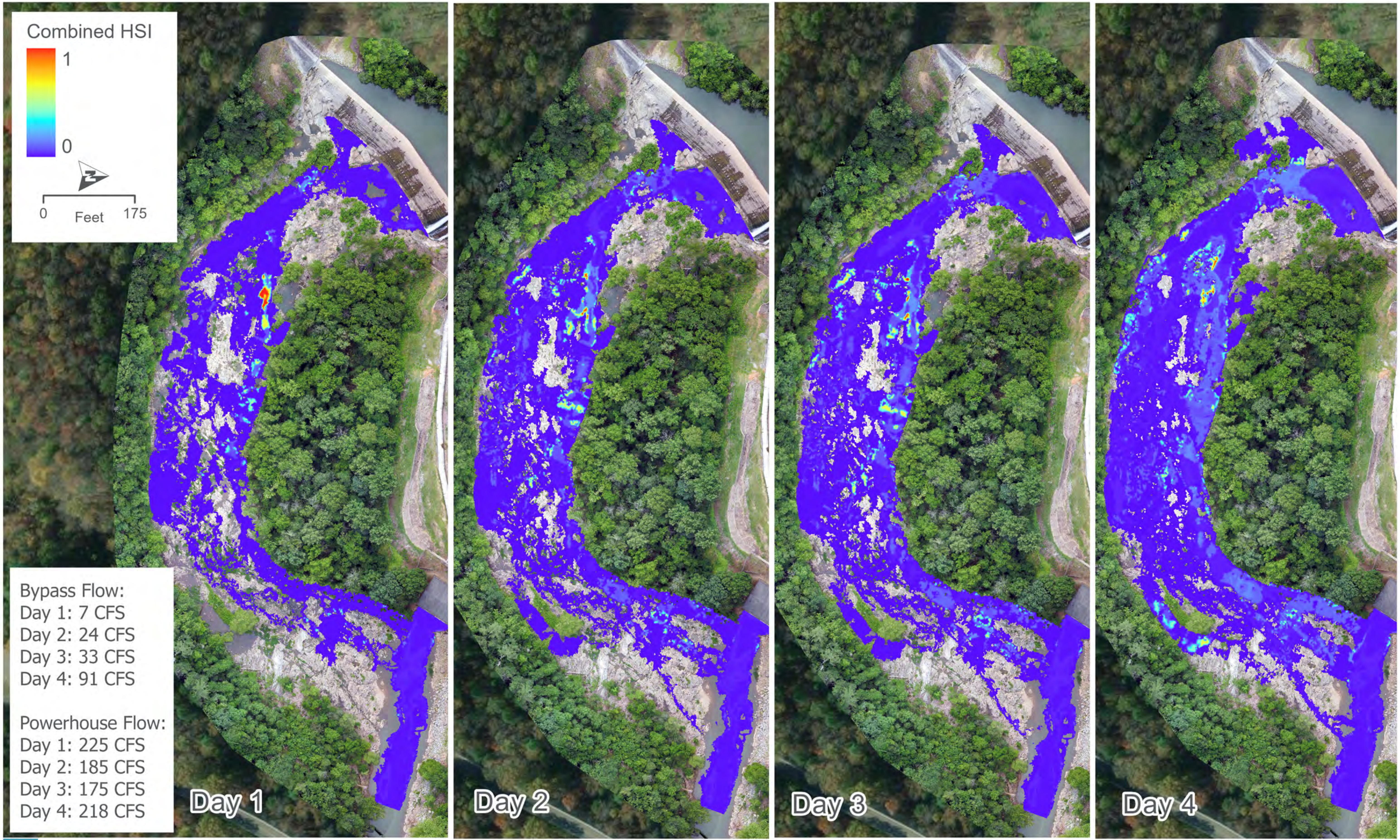
CATEGORY: COARSE SUBSTRATE



HDR AMERICAN ELECTRIC POWER

ROANOKE LOGPERCH HABITAT SUITABILITY MAP

LIFESTAGE: ADULT



ROANOKE LOGPERCH HABITAT SUITABILITY MAP

LIFESTAGE: SUBADULT

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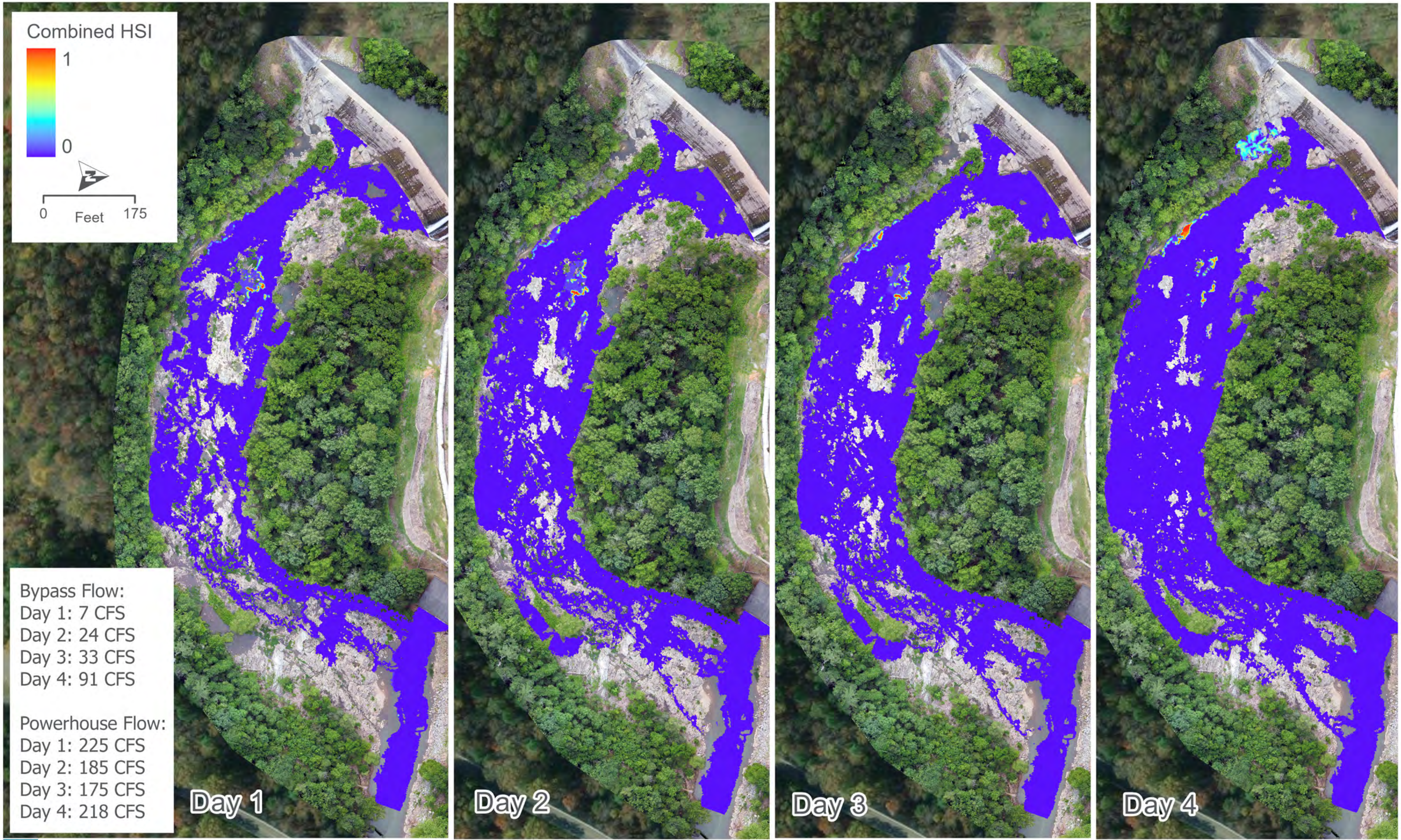

ROANOKE LOGPERCH HABITAT SUITABILITY MAP

LIFESTAGE: YOUNG-OF-YEAR

PATH: F:\AEP\RELICENSING_2D_MODELS\NIAGARA\HABITAT\NIAGARA_HABITAT_MAPS.APRX - USER: JDVORAK - DATE: 11/30/2021