FINAL STUDY REPORT

INSTREAM FLOW HABITAT ASSESSMENT BELOW CONOWINGO DAM

RSP 3.16

CONOWINGO HYDROELECTRIC PROJECT

FERC PROJECT NUMBER 405

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EXECUTIVE SUMMARY

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt Conowingo Hydroelectric Project (Conowingo Project). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. FERC issued the final study plan determination for the Conowingo Project on February 4, 2010, approving the revised study plan with certain modifications. The final study plan determination required Exelon to conduct an Instream Flow Assessment below Conowingo Dam, which is this report's subject.

An initial study report (ISR) was filed on May 6, 2011, containing Exelon's 2010 study findings. An ISR meeting was held on August 23 and 24, 2011 with resource agencies and interested members of the public. Formal comments on the ISR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

This study's goal is to determine the relationship between flow and aquatic habitat conditions in the Susquehanna River below Conowingo Dam. This required the development of a two-dimensional (depth-averaged) hydraulic and habitat model of the study reach. The study reach extended from the downstream face of Conowingo Dam to the downstream end of Spencer Island, a length of approximately 4.5 miles. The study area also included the spillway portion below Conowingo Dam.

Evaluation species were selected, in consultation with the licensing stakeholders, for analysis from a list of species known to be present in the general study area. In consultation with stakeholders, several species of special concern were selected for detailed analysis, while the remaining target species were analyzed using a habitat guild-type approach. Depth, velocity and substrate Habitat Suitability Indices were developed from previous studies, scientific literature, and the professional judgment of Exelon and stakeholder biologists. In addition, a separate analysis was conducted using the model's hydraulic output to assess habitat for mussels.

The specific hydrodynamic model used was River2D, a two-dimensional (lateral-longitudinal, depth averaged), finite element hydraulic and habitat model. River2D input consisted of a bathymetric/topographic (x,y,z) characterization of the study reach, a roughness parameter and substrate code for each x,y location, inflow discharge, a downstream boundary water surface elevation and target species' Habitat Suitability Indices for depth, velocity and substrate. All input data were based on field data collection, including a bathymetry survey, substrate survey and LIDAR survey. The hydraulic model water surface elevation output was calibrated to +/- 0.15 ft for several flows between 5,000 cfs and 73,000 cfs, including a detailed calibration at 40,000 cfs. Following typical USGS calibration guidelines, model accuracy is usually maintained for a 40% to 250% range around the calibration flow (e.g calibration flow at 10,000 cfs is valid for 4,000 cfs to 25,000 cfs). This allows model production run flows of 2,000 cfs to 182,500 cfs, though the model was not run above 86,000 cfs. Once the model was calibrated, several production runs were conducted, simulating flows of 2,000 cfs, 3,500 cfs, 5,000 cfs, 7,500 cfs, 10,000 cfs, 15,000 cfs, 20,000 cfs, 30,000 cfs, 40,000 cfs, 50,000 cfs, 60,000 cfs, 70,000 cfs, 80,000 cfs and 86,000 cfs. Using the model's hydraulic outputs, several habitat analyses were run, including weighted usable area, persistent habitat and mussel habitat analyses.

Habitat modeling results showed that the target species had a wide range of preferred flows and areas. Many species had divergent flow preferences, with no single flow or flow range providing optimal or near-optimal habitat for all target species. Most life stages of American shad, shortnose sturgeon and striped bass preferred higher flows. Smallmouth bass, macroinvertebrates, and the habitat guilds generally preferred lower flows. The magnitude of available habitat also varied greatly by species. Some species did not appear to have substantial habitat at any of the modeled flows, including shortnose sturgeon (fry, juveniles, adults), smallmouth bass (spawning, fry), ephemeroptera, plecoptera, the shallow-fast and deep-fast guilds.

There were several areas in the river that appeared to provide high-quality habitat for several species and life stages. These areas included downstream of Rowland Island, near the mouths of Octoraro and Deer Creeks, an area southwest of Bird Island, downstream of Snake Island and in-between Robert, Wood and Spencer Islands. The substrates available in these areas (sand, gravel, cobble) were generally finer than those found in the main channel (boulder, bedrock) and were well-suited for many species and life stages.

Habitat persistence analyses were conducted for all immobile life species/life stages. For this analysis, all spawning/incubation and fry life stages were considered immobile, as were all of the macroinvertebrate species and habitat guilds. Persistent habitat analyses showed that more divergent minimum/generation flow pairs had less common, or persistent, habitat. Some species were more sensitive to flow changes than others. Striped bass were less sensitive to flow differences, while macroinvertebrates and smallmouth bass were more sensitive to flow differences.

Mussel habitat analyses were conducted using shear stress thresholds. The analyses showed that higher catch-per-unit-effort rates were associated with areas with lower shear stresses. Results also showed that higher flows tended to increase the area exceeding mussels' preferred shear stress range. Flows over 10,000 cfs had few areas below the low-flow (95% flow exceedance) threshold of 20 dynes/cm^2 (0.042 lb/ft^2), while areas below the high-flow (25% flow exceedance) threshold of 150 dynes/cm^2 (0.313 lb/ft^2) steadily decreased between 10,000 cfs and 86,000 cfs. Relative shear stress (shear stress/critical shear stress) thresholds were also investigated. The large amount of bedrock throughout the study made relative shear stress a somewhat ineffective comparison metric, as bedrock has a very high critical shear stress. The metrics relating mussel development to high-flow and low-flow thresholds were developed for unregulated, smaller streams. Thus, it is not clear how these thresholds would be used to inform flow management decisions in a highly regulated stream.

A habitat time series analysis, as described in task 7 of the RSP, will be released in a subsequent report following the completion of the operations modeling analysis. This report will compare the results of a "baseline" or existing conditions model run to additional operations model production runs that are designed in consultation with the resource agencies.

While the habitat modeling provided estimates of available habitat at various flows, the river flow available is an important consideration in flow and habitat management decisions. There are four hydroelectric projects on the lower Susquehanna River, three of which are main channel peaking hydroelectric plants (Safe Harbor, Holtwood, Conowingo), one of which is a pumped storage project (Muddy Run). All four have the ability to influence the river's flow regime, particularly on a sub-daily scale. The project with the largest hydraulic capacity is Safe Harbor, the farthest upstream project, with a maximum hydraulic capacity of 110,000 cfs. This is greater than the hydraulic capacity of Holtwood (61,460 cfs following expansion construction) and Conowingo (86,000 cfs). Safe Harbor has no minimum flow release requirements as stipulated in its current license, which expires in 2030. Conowingo has a seasonally-varying minimum flow release, and Holtwood will also provide a minimum flow release beginning no later than 2012. Thus, flow management decisions should consider not only the river's unregulated hydrology, but upstream projects' water availability influences, which can greatly impact the lower Susquehanna River's flow management effectiveness.

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ADCP: Acoustic Doppler Current Profiler
CF(I): Compound Function Index
cfs: cubic feet per second
cm: centimeter
CPUE: Catch-Per-Unit-Effort
DEM: Digital Elevation Model
EAV: Emergent Aquatic Vegetation
FERC: Federal Energy Regulatory Commission
ft: foot/feet
GPS: Global Positioning System
HSI: Habitat Suitability Index
IFIM: Instream Flow Incremental Method
ILP: Integrated Licensing Process
kHz: kilohertz
lb: pound
mi: mile
MW: Megawatt
NGO: Non-Government Organization
NGVD: National Geodetic Vertical Datum
PAD: Pre-Application Document
Project: Conowingo Hydroelectric Project
psf: pounds per square foot
PSP: Proposed Study Plan
RSP: Revised Study Plan
RTK: Real-Time Kinematic
SAV: Submerged Aquatic Vegetation
sec: second
SI: Suitability Index
USGS: United States Geological Survey
WSE: Water Surface Elevation
WUA: Weighted Usable Area

1. INTRODUCTION

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt (MW) Conowingo Hydroelectric Project (Project). Exelon is applying for a new license using the FERC's Integrated Licensing Process (ILP). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014.

Exelon filed its Pre-Application Document (PAD) and Notice of Intent with FERC on March 12, 2009. On June 11 and 12, 2009, a site visit and two scoping meetings were held at the Project for resource agencies and interested members of the public. Following these meetings, formal study requests were filed with FERC by several resource agencies. Many of these study requests were included in Exelon's Proposed Study Plan (PSP), which was filed on August 24, 2009. On September 22 and 23, 2009, Exelon held a meeting with resource agencies and interested members of the public to discuss the PSP.

Formal comments on the PSP were filed with FERC on November 22, 2009 by Commission staff, and several resource agencies. Exelon filed a Revised Study Plan (RSP) for the Project on December 22, 2009. FERC issued the final study plan determination for the Project on February 4, 2010, approving the RSP with certain modifications.

The final study plan determination required Exelon to conduct an Instream Flow Assessment below Conowingo Dam, which is this report's subject. This study's goal is to determine the relationship between flow and aquatic habitat conditions in the Susquehanna River below Conowingo Dam.

An initial study report (ISR) was filed on May 6, 2011, containing Exelon's 2010 study findings. A meeting was held on August 23 and 24, 2011 with resource agencies and interested members of the public. Formal comments on the ISR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

2. BACKGROUND

2.1 Project Operation

The Conowingo Project has an installed capacity of 573 MW and a hydraulic capacity of 86,000 cfs. The reservoir, known as Conowingo Pond and formed by Conowingo Dam, extends approximately 14 miles upstream from Conowingo Dam to the lower end of the Holtwood Project tailrace. Conowingo Pond serves many diverse uses including hydropower generation, water supply, industrial cooling water, recreational activities and various environmental resources.

The Conowingo Project license allows for the Conowingo Pond to normally fluctuate between elevation 101.2 to 110.2 NGVD 1929[1]. The following factors also influence the management of water levels within the Conowingo Pond:

- The Conowingo Pond must be maintained at an elevation above 107.2 ft on weekends between Memorial Day and Labor Day to meet recreational needs;
- The Muddy Run Project cannot operate its pumps below elevation 104.7 ft due to cavitation;
- PBAPS begins experiencing cooling problems when the pool elevation drops to 104.2 ft;
- The CWA cannot withdraw water below elevation 100.5 ft;
- The Nuclear Regulatory Commission license for Peach Bottom Atomic Power Station requires the plant to shut down completely at pond elevations of 99.2 ft or below; and
- The City of Baltimore cannot withdraw water when the pond is below elevation 91.5 ft.

The current minimum flow regime below Conowingo Dam was formally established with the signing of a settlement agreement in 1989 between the project owners and several federal and state resource agencies. The established minimum flow regime below Conowingo Dam is the following:

March 1 – March 31 3,500 cfs or natural river flow[2], whichever is less

[1] The datum used in this document is NGVD 1929. The NGVD 1929 datum elevation is 0.7 ft higher than the Conowingo Datum.

[2] As measured at the Susquehanna River at Marietta USGS gage (No. 0157600).

April 1 – April 30	10,000 cfs or natural river flow, whichever is less
May 1 – May 31	7,500 cfs or natural river flow, whichever is less
June 1 – September 14	5,000 cfs or natural river flow, whichever is less
September 15 – November 30	3,500 cfs or natural river flow, whichever is less
December 1 – February 28	3,500 cfs intermittent (maximum six hours off followed by equal amount on)

The downstream discharge must equal these values or the discharge measured at the Susquehanna River at the Marietta United States Geological Survey (USGS) gage (No. 01576000), whichever is less. The Marietta USGS gage is located approximately 35 miles upstream of Conowingo Dam above the Safe Harbor Dam.

During periods of regional drought and low river flow, Exelon has requested and received FERC approval for a temporary variance in the required minimum flow release from the Conowingo Project. Specifically, in the summers of 1999, 2001, 2002, 2005, 2007, and 2010 Exelon has received approval to count the leakage from the Conowingo Project (approximately 800 cfs) as part of the minimum flow discharge.

2.2 Basin Hydrology

The total drainage area of the Susquehanna River basin is 27,510 mi^2, of which 6,270 mi^2 are in south-central New York, 20,950 mi^2 are in central Pennsylvania, and 280 mi^2 are in northeastern Maryland. The drainage area above Conowingo Dam is approximately 27,100 mi^2. Several statistical flow analyses were performed using the Conowingo and Marietta USGS gages as part of Conowingo Study 3.11-Hydrologic Study of the Lower Susquehanna River.

There are three hydroelectric generation projects located between the Marietta gage and Conowingo Dam. The projects are, from upstream to downstream, Safe Harbor Hydroelectric Project, Holtwood Hydroelectric Project and Muddy Run Pumped Storage Project. Safe Harbor and Holtwood are located on the Susquehanna River main stem, while Muddy Run is a pumped storage project that uses Conowingo Pond as the lower reservoir of a two-reservoir system. Conowingo is the fourth and most downstream hydroelectric project on the lower Susquehanna River. The two main stem projects upstream of Conowingo Dam have the ability to heavily influence river flows into Conowingo Pond, and are operated as peaking hydroelectric projects. Safe Harbor is licensed until 2030 and has no minimum flow release obligations, with an estimated hydraulic capacity of 110,000 cfs. Holtwood is also licensed until 2030, but as part of a recent expansion settlement Holtwood has agreed to supply Conowingo with a continuous inflow of 800 cfs or net inflow, and 98.7% of Conowingo's daily volumetric minimum flow requirement. Holtwood's maximum hydraulic capacity is currently approximately 31,500 cfs, and will be 61,460 cfs following the completion of the expansion project, which is expected to be completed in 2012. A detailed flow management timeline is presented in Conowingo Study 3.11: Hydrologic Study of the Lower Susquehanna River.

2.2.1 USGS Gages

There are two USGS flow gages on the lower Susquehanna River. One is located upstream of the hydroelectric stations (Marietta, PA), while one is downstream of all of the hydroelectric stations (Conowingo, MD). No USGS gages exist between the impoundments of Conowingo and Holtwood, or Holtwood and Safe Harbor.

The Marietta, PA USGS Gage No. 10576000 (Marietta) is located on the upper end of the lower Susquehanna River (RM 45), just upstream of the Safe Harbor Dam impoundment. The drainage area at this gage is 25,990 mi^2. The gage has daily average flow data available beginning water year[3] (WY) 1932. As of 4/1/2011, USGS-approved daily average flows range from 10/1/1931 to 12/9/2010 (79+ years). The gage also has 30-min instantaneous flow data, available from 10/1/1985 to 9/30/2009, with no data available for WY 1991 (10/1/1990 – 9/30/1991) (23 years). Marietta is generally considered reflective of the lower Susquehanna River's flow regime absent regulation from peaking hydroelectric projects[4].

The Conowingo, PA USGS Gage No. 01578310 is located on the downstream face of Conowingo Dam (RM 10). The drainage area is 27,100 mi^2. The gage has daily average flow data available beginning 10/1/1967 (WY 1968). As of 4/1/2011, USGS-approved daily average flows range from 10/1/1967 to 1/31/2011 (44+ years). The gage also has 15-min instantaneous flow data[5], available from 2/2/1988 to 9/30/2009, with no data available for WY 1994 (20+ years). The Conowingo gage is immediately downstream of Conowingo Dam, and thus directly reflects Project operations and the influences of the other lower Susquehanna water users.

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[3] Water years begin October 1 and end September 30. For example, WY 1933 is 10/1/1932 to 9/30/1933.

[4] There are several hydroelectric dams, flood control dams, and various other water withdrawals/uses upstream of the Marietta USGS gage in the Susquehanna River and its tributaries.

[5] For consistency with the Marietta gage, all 15-minute Conowingo flow data were converted to 30-min flow data for all analyses

Conowingo sub-daily annual and monthly flow exceedances for the period WY 1988-2009 are shown in Table 2.2.1-1. Annual and monthly flow exceedances were calculated using the full period of record[6] daily flow data for both gages and are shown in Tables 2.2.1-2 and 2.2.1-3.

2.2.2 Unregulated Hydrology Downstream of Conowingo Dam

Major hydrologic influences have existed on the lower Susquehanna River since the late 1920's, predating all flow records downstream of Conowingo Dam. Thus, there are no measurements of unregulated hydrology downstream of Conowingo Dam. However, flow records at the Marietta USGS gage are considered reflective of an unregulated (by peaking hydropower) flow regime. Additionally, the Marietta and Conowingo gages are relatively close in total drainage area, draining 25,990 mi^2 and 27,100 mi^2, respectively. Thus, it is reasonable to assume that the Marietta flow records could be used to estimate the unregulated hydrology downstream of Conowingo Dam.

While a typical drainage area proration is commonly used to relate flow estimates between two gages, this report uses a different method. This study estimated the daily average unregulated river flow hydrology at Conowingo Dam by taking Marietta gage flow and adding the incremental flow estimates between the four hydroelectric projects on the lower Susquehanna. This is consistent with the methodology used in the Susquehanna River operations model described in the Conowingo and Muddy Run Operations Modeling Report (SRBC, 2009).

The operations model determines daily average river flow at the Marietta USGS gage and downstream watersheds by adding flow proportional to the incremental drainage area contributed by each reservoir. Starting at Marietta and going downstream, the model estimates incremental flow input between Marietta and Safe Harbor, Safe Harbor and Holtwood, Holtwood and Conowingo, and inflow from Muddy Run. The operations model uses prorated flows from the Lancaster, PA (USGS Gage No. 01576500) and Manchester, PA (USGS Gage No. 01574000) USGS gages. The specific incremental drainage areas and flow estimates are outlined in Table 2.2.2-1. A comparison between the Marietta USGS gage, Conowingo USGS gage and estimated Conowingo unregulated flows are shown in Figure 2.2.2-1.

The estimated unregulated hydrology was then estimated for the common period of record for the three USGS gages[7] (Marietta, PA, Lancaster, PA and Manchester, PA), which was from WY 1934 to WY

[6] WY 2010 flow data were not used for any (daily or instantaneous) exceedance calculations because WY 2010 USGS-approved instantaneous flow data are not yet available.

2009. The unregulated hydrology was estimated by taking the Marietta USGS gage daily average flow and adding in the daily average incremental flows for the four incremental drainage areas between Marietta and Conowingo (Marietta-Safe Harbor, Safe Harbor-Holtwood, Holtwood-Conowingo, and Muddy Run). Annual and monthly exceedance percentiles were calculated for the estimated daily average unregulated hydrology, which are shown in Table 2.2.2-2.

[7] The Lancaster, PA gage's continuous records began in April 1933. Thus, the first complete WY was 1934 (10/1/1933-9/30/1934).

3. METHODS

The study required the development of a two-dimensional hydraulic and habitat model to examine the project operation's aquatic habitat impacts below Conowingo Dam.

3.1 Study Area

The investigation area for this study encompasses the river reach between Conowingo Dam and the downstream end of Spencer Island, which is approximately 4.5 miles in length. The study area also includes the spillway area below Conowingo Dam (Figure 3.1-1).

3.2 Evaluation Species, Habitat Suitability Indices, and Substrate Coding

3.2.1 Evaluation Species

Evaluation species were selected for analysis from a list of species known to be present in the general study area. In consultation with stakeholders (Appendix A), several species of special concern (American shad, striped bass, shortnose sturgeon, smallmouth bass, Ephemeroptera [mayflies], Plecoptera [stoneflies], and Trichoptera [caddisflies]) were selected for detailed analysis. The remaining target species were analyzed using a habitat guild-type approach. In addition, a separate analysis was conducted using hydraulic model output (e.g., shear stress) to assess mussel habitat.

The guild-type approach was deemed necessary due to the diversity of the species and habitat types encountered in the study area. Additionally, by grouping species into guilds, the number of required Habitat Suitability Index (HSI) curves and resulting model output could be reduced to a manageable level for data organization and interpretation. Table 3.2.1-1 identifies the target species, their respective habitat guilds assignments and species of special concern.

Shown in Table 3.2.1-2 is a monthly periodicity chart, which summarizes when certain species and life stages are expected to be present in the study area.

3.2.2 Habitat Suitability Indices

Aquatic habitat in a river is comprised of both microhabitat and macrohabitat parameters. Microhabitat represents a particular location's physical characteristics within a river, such as slope, width, substrate, cover and the variation of depth and velocity with flow. Macrohabitat refers to broader characteristics impacting fish survival and movement such as food supply, predation and water quality. The following analyses implicitly assume that macrohabitat is suitable throughout the study reach.

Referring to microhabitat characteristics, each species/life stage has a preference for a certain range of depth, velocity, substrate and cover conditions. For example, adult smallmouth bass may prefer higher depths and lower velocities when compared to adult American shad. Over the years, biologists have conducted studies to identify the depth, velocity, and substrate preferences for an array of species and life stages. Using the results of these studies, preference or HSI curves have been developed for depth, velocity, substrate, and in some cases, cover.

Suitability index curves describe the species/life stage preference using a 0 to 1 scale. A suitability index value of 0 indicates no habitat value, while a suitability index value of 1 indicates optimal habitat value. Shown in Figure 3.2.2-1 are juvenile shortnose sturgeon depth, velocity and substrate HSI curves. The optimal depth and velocity for this particular species is 5.0 to 20.0 ft, and 0.20 to 1.50 ft/sec, respectively. Quality habitat ($SI \geq 0.5$), although not optimal, is also available at values outside of these ranges as well.

The HSI values for this study were derived from previous IFIM studies, the scientific literature, and the professional judgment of Exelon and stakeholder biologists. Table 3.2.2-1 is a summary of the species/life stages, as well as the literature source for the HSI. HSI, as agreed to with the stakeholders, for the species and life stages evaluated as part of this study are shown in Appendix B.

The juvenile American shad HSI criteria were modified from those used in this study's ISR, released in May 2011. This process was initiated when Exelon compiled the ISR's habitat results and noticed that the juvenile American shad results appeared to be substantially different than the three other American shad life stages (spawning and incubation, fry and adult). Further investigation into the results revealed a notable difference between the juvenile American shad depth HSI relative to other American shad lifestages. After reviewing the source of the original juvenile American shad depth criteria, new information obtained from the Atlantic Stages Marine Fisheries Commission (Greene et al. 2009) suggested that the original depth HSI may have been inadequate. On June 15, 2011, Exelon, sent a memo outlining the differences between the original and newer HSI depth criteria to stakeholders that were previously involved with HSI discussions. In response to the June 2011 memo, stakeholders proposed alternative depth HSI criteria combining the new and old information sources with their system-specific field observations. As part of an August 2011 stakeholder meeting, Exelon held a discussion with stakeholders to determine the group's overall consensus. It was agreed that an alternative juvenile American shad depth HSI criteria would be adopted as a replacement for the original juvenile American shad depth HSI criteria in this study's ISR. Both juvenile American shad HSI criteria are compared in Figure 3.2.2-2. The results shown in this study report reflect only the updated juvenile American shad depth HSI criteria, as all further references to the original criteria have been removed and replaced with the new criteria.

3.2.3 Substrate Classification

HSI for each of the target species/life stages are based on habitat variables of depth, velocity and substrate. Substrate, like velocity and depth, plays a vital role for fish habitat, particularly as it relates to spawning. While velocity and depth are modeling outputs, substrate was field identified and classified using the classification system shown in Table 3.2.3-1. Substrate refers to the material armoring the channel bed (e.g., sand, gravel, bedrock) and is an important variable, as certain species and life stages of fish prefer different substrate types.

3.3 Hydraulic Model Input Data

Input to the two-dimensional hydrodynamic model consisted of a bathymetric/topographic (x,y,z) characterization of the study reach, a roughness parameter and substrate code for each x,y location, inflow, and a downstream boundary water surface elevation.

3.3.1 Bathymetric, Hydraulic, and Substrate Field Data Collection

Bathymetric and hydraulic data collection followed similar USGS study procedures described in Elliot et al. (2004) and Jacobson et al. (2002). The bathymetric survey was conducted on June 14 to 17, 2010, and was carried out using an 18-ft long Kevlar-hull, jet-propelled vessel equipped with a 1000-kHz Sontek acoustic Doppler current profiler (ADCP), a 200-kHz Odom Hydrotrac single beam echosounder, a RoxAnn Seafloor Classification System and a Trimble real-time kinematic (RTK) global positioning system (GPS) system.

The survey was designed with pre-planned systematic transects orientated from bank to bank approximately perpendicular to flow and spaced 90-150 feet apart over the 4.5 mile study reach (Figure 3.3.1-1). Data collection occurred at a constant flow of approximately 40,000 cfs.

Geo-referenced water surface elevations, bed elevations, and water column velocities were collected using the single beam echo sounder and ADCP linked to an RTK-GPS system. The RTK-GPS equipment provided a three-dimensional position of the echosounder transducer. Thus, the horizontal and vertical position of the echosounder transducer was known for each sonar ping. Subtracting the depth from the transducer elevation for each ping gave an elevation of the river bottom. Since the RTK-GPS equipment provided x, y (horizontal) and z (elevation) data in real time, changes in water level due to standing waves, and turbulence are accounted for.

Substrate data were collected by field teams during August 2010, as part of Conowingo Study RSP 3.17-Downstream EAV/SAV Study, at an approximate 5,000 cfs flow release. During these surveys, the predominant bottom substrate was visually identified (Table 3.2.3-1) and mapped using GPS equipment over the entire study area.

In addition, 15-min water level stage data were collected at six locations[8] along the study reach during the 2010 season (Figure 3.3.1-2). Stage data were collected between flows of approximately 5,000 cfs and 73,000 cfs. Data from three of these stations[9] along with streamflow data measured at the Conowingo USGS gage were used to develop rating curves at all three locations to assist with model calibration.

3.3.2 Topographic Data Collection

Topographic data for streambanks, permanent islands, the Conowingo Dam spillway area, and other above-water features were obtained from LIDAR surveys. LIDAR data was provided in the form of 2-ft contours by Harford County on the Western side of the Susquehanna River. Multipoint-form LIDAR data on the Cecil County (Eastern) side of the Susquehanna River were available through NOAA's Digital Coast website. In addition, Exelon conducted a LIDAR survey of Conowingo Pond on September 18, 2010 as part of Conowingo Study 3.12-Water Level Management Study. During this survey, LIDAR data was also collected (at a flow release of 3,500 cfs) to define the topography of the Conowingo Dam spillway area.

3.4 Hydraulic Model Development, Calibration and Simulation

Hydraulic modeling was performed using River2D modeling software, described in Steffler and Blackburn (2002). River2D is a depth-averaged two-dimensional (lateral-longitudinal), finite element hydraulic and habitat model. It requires input data for a set of spatially-distributed points or "nodes" throughout the study reach. It then creates a linearly-interpolated triangulated mesh from the set of nodes, with each triangle referred to as an "element". River2D solves for mass conservation and momentum balance in two (x,y) dimensions using the St. Venant flow equations. Input data include a digital bathymetric (riverbed topography) map, a stage-discharge relationship or boundary elevation at the

[8] While shown on the map, station 7 was not in the study reach.

[9] Stations 1, 5 and 6 were not used in the rating curve analysis. Station 1 was moved mid-deployment by natural flow events and/or human interference. Stations 5 and 6 were tidally influenced.

downstream end of the study reach, and bed roughness throughout the study reach. Observed water surface elevation data are used for calibration purposes, but are not direct model inputs.

3.4.1 Model Development

Accurate representation of the river bed's physical features is the most crucial factor in successful river flow modeling (Blackburn and Steffler 2002). Generally, elevation transitions in rivers are relatively continuous (except for the toe-of-bank contour), and most features are aligned longitudinally relative to the banks and thalweg. This was not the case for most of the modeled reach, as the lower Susquehanna is primarily a bedrock-controlled channel. The bedrock often transitioned in different angles than the river flowed, and bedrock outcrops were present throughout the reach (Figure 3.4.1-1). Triangulation of the collected bathymetry data occasionally resulted in localized areas of sharp transitions, discontinuities of contours in continuous features. Additional nodes were added when necessary to smooth out irregular features.

A two-dimensional, finite-element computational mesh consisting of linear triangular elements was generated for the study reach, following the procedure described in Bovee et al. (2007). A uniform base mesh (65 ft spacing) was initially applied across the study reach. The mesh was then modified with the primary objective of accurately representing bed structure in the model. This was done by visually assessing the raw bathymetry data, aerial photos and local knowledge of the river. At each node, bed elevation and roughness height were specified, and the model assumed a linear transition between each node. The final mesh contained 37,528 nodes and 75,018 triangulated elements. However, the node size was not uniform throughout the study reach. There was generally denser node spacing in wetted areas, particularly with complex geometry, and sparser node spacing in upland areas that never became wetted.

3.4.2 Model Calibration and Simulation

Concurrent with the collection of bathymetric data, a direct-measurement survey of the water surface profile was conducted for the study reach. The discharge (40,000 cfs) associated with the water surface profile was determined from station operation records. In addition, continuous water surface elevation data were used from the three locations used to create rating curves in Section 3.3.1. Stage data was collected between flows of 5,000 cfs and 73,000 cfs.

With the measured inflow discharge (40,000 cfs) and the measured low-tide outflow water surface elevation as boundary conditions, River2D was run to produce a predicted water surface profile corresponding to the measured profile at the 40,000 cfs discharge. To calibrate the model, adjustments were made to the finite element mesh where increased mesh density was warranted, and the roughness parameter was adjusted upward or downward to alter the resistance to flow provided by friction. For example, if the predicted water surface profile was uniformly lower than the measured profile, roughness height was increased. The increase in resistance caused the velocity to decrease and the depth to increase, thereby raising the elevation of the predicted water surface profile. This procedure was repeated until a reasonable match (+/- 0.15 ft) between the predicted and measured water surface profiles was obtained in the study area.

Water surface elevations were recorded at three point locations throughout the study reach, at flows between 5,000 cfs and 73,000 cfs. Using these data, additional model calibrations were performed at flows of 5,000, 7,500, 10,000, 15,000, 20,000, 60,000 and 73,000 cfs. Following typical USGS calibration guidelines, model accuracy is usually accepted for a 40% to 250% range around the calibration flow (e.g., a calibration flow at 10,000 cfs is valid for 4,000 cfs to 25,000 cfs). Thus, the model is accurate for production run flows of 2,000 cfs to 182,500 cfs, though no flows greater than 86,000 cfs were run.

Following calibration, a series of discharges ranging from 2,000 cfs to 86,000 cfs were simulated. The 14 simulated flows were 2,000 cfs, 3,500 cfs, 5,000 cfs, 7,500 cfs, 10,000 cfs, 15,000 cfs, 20,000 cfs, 30,000 cfs, 40,000 cfs, 50,000 cfs, 60,000 cfs, 70,000 cfs, 80,000 cfs and 86,000 cfs. These discharges were selected to cover the flow range experienced by the study reach due to project operations.

3.5 Habitat Modeling

The calibrated hydraulic model, which predicts velocities and depths over a range of flows, was then combined with a habitat model. The amount of aquatic habitat for a given species/life stage of fish is calculated using the River2D program. Each habitat area is evaluated for its habitat suitability for a particular species/life stage based on the fixed characteristics (substrate) and the variable characteristics of the cell (depth and velocity).

Fish habitat, as used in IFIM procedures, is quantified in terms of a variable known as Weighted Usable Area (WUA). A unit of WUA represents a unit of suitable habitat for the life stage evaluated. The following equation is used to calculate WUA:

$$WUA = \frac{\sum_{i=1}^{n} WUA(i)}{L} \times L_{mac}$$

where: WUA(I) = Weighted Usable Area (i);

n = Total number of nodes;

L = Total length of the study reach; and

L_{mac} = Length of stream, which is represented by the reach, with suitable macrohabitat conditions.

The individual WUA(I) for a node is calculated as follows:

$$WUA(I) = CF(I) \times Area(i)$$

where: Area(i) = Surface area of represented by node(i); and

CF(i) = Compound Function Index for the node area(i)

The Compound Function Index, CF(i), is calculated as follows:

$$CF(i) = SI_V \times SI_D \times SI_S$$

where: SI_V = Suitability Index for Velocity;

SI_D = Suitability Index for Depth; and

SI_S = Suitability Index for Substrate.

The WUA is then computed for each node area. In a given study section or reach, the WUA(i) for all the node areas are summed and expressed in units of square feet. For this analysis it was assumed that L_{mac} was equal to L.

3.6 Habitat Persistence Analysis

Habitat persistence was evaluated to assess the effects of the short-term hydrologic variability created by peaking operations at the Conowingo Project. Habitat persistence was determined as the union of "quality" or "good" habitat ($CF(I) \geq 0.5$) polygon areas between a pair of project flows for a particular species life stage. For example, the available quality habitat polygon areas for striped bass fry at a flow of 5,000 cfs was overlaid with the available quality habitat polygon areas for the same species at a flow of 86,000 cfs. Striped bass fry habitat persistence for that pair of discharges was calculated as the area of overlap between the quality habitat polygons. The habitat persistence analysis was conducted for all immobile target species (macroinvertebrates) and life stages (spawning and fry), including habitat guilds.

3.7 Mussel Habitat Analysis

Several hydraulic parameters are useful in assessing mussel habitat, including water depth, velocity, shear stress, Froude number, Reynolds number, critical shear stress and relative shear stress (Pers. Communication, M. Ashton, 2011). Literature states differing threshold limits above which mussel habitat appears to be compromised. Layzer and Madison (1995) recommend that shear stress not exceed 50 dynes/cm^2 (0.103 psf[10]) over mussel beds. An MDNR interpretation of an Allen and Vaughn (2010) mussel study showed mussel richness and abundance are greatest in areas where shear stress did not exceed 150 dynes/cm^2 (0.31 psf) under high flows (>25% exceedance), nor exceed 20 dynes/cm^2 (0.042 psf) under low flows (<95% exceedance) (Pers. Communication, M. Ashton, 2011). Research also shows that relative shear stress, a unitless ratio of shear stress divided by critical shear stress (the shear stress threshold that initiates sediment transport), is an important parameter for evaluating mussel habitat (Allen and Vaughn, 2010). An MDNR interpretation of Allen and Vaughn (2010) results showed that mussel development is best when relative shear stress is below 0.4 at low flows (<95% exceedance) and below 2.0 at high flows (> 25% exceedance) (Pers. Communication, M. Ashton, 2011). In a modeling study, Morales et al. (2006) concluded that mussel density would be best if relative shear stress did not exceed 1.0 under most flow conditions, and found a maximum tolerance threshold of 1.25.

The hydraulic model output allows each of these parameters to be calculated and mapped over the entire study reach. This allows the model results to be compared to mussel catch-per-unit-effort (CPUE) observations made during Conowingo Study 3.19: Freshwater Mussel Characterization below Conowingo Dam.

3.8 Habitat Time Series

This analysis followed the habitat time series methodology described in Bovee et al. (1998). A habitat time series analysis uses habitat/weighted usable area (WUA) versus discharge relationships to translate a streamflow time series (flow as a function of time) into a habitat time series (habitat as a function of time). Construction of a habitat time series requires two components: 1) a time series of streamflow discharges and 2) a habitat versus discharge relationship.

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[10] For consistency with existing mussel literature, mussel results are expressed in metric units. US Standard units will also be shown where possible. For reference, 1 dyne = 1 g*cm/s^2 = 10^{-5} Newtons (N) = $0.225*10^{-6}$ lb

In this analysis, units of habitat, or WUA, are expressed as the area of habitat within the study area. For every discharge in the streamflow time series, there is a corresponding habitat value from the habitat versus discharge relationship. Thus, the habitat time series was produced by translating hourly discharges from the Conowingo Project into associated WUA values and recording the translated values back to the hourly time step. The translation process is shown in Figure 3.8-1.

The habitat versus discharge relationships for all target species and life stages analyzed in the Conowingo Study 3.16: Instream Flow Habitat Assessment below Conowingo Dam report were merged with the hourly operations model hydrology data reported in the Conowingo Study 3.11 addendum titled "Operations Modeling Baseline and Production Run Report" to yield habitat time series. Developed as part of Conowingo Study 3.11 and Muddy Run 3.2, the model's purpose is to help Exelon and relicensing stakeholders better understand how operational changes at the lower Susquehanna River's four hydroelectric facilities affect the timing of river flows and energy generation. The model takes into account each Project's (Safe Harbor, Holtwood, Muddy Run, and Conowingo) engineering data and operational constraints, such as Conowingo's minimum flow requirement. The production runs were simulated using hydrologic data from Jan 1930 through Dec 2007[11]. Using this model, production runs simulating the Baseline scenario and three alternative operational scenarios have been executed by Exelon. The alternative operating scenarios were developed by relicensing stakeholders and executed by Exelon. The inputs and outputs of each run are described fully in the Conowingo Study 3.11 titled (Operations Modeling Baseline and Production Run Report). Table 3.8-1 summarizes the modeled parameters for the baseline and three alternative scenarios (SRBC-006, SRBC-007 and SRBC-008). The alternative scenarios cover various minimum flows, ramping rates and a run-of-river scenario. Select habitat time series plots (WUA versus time) are presented for each species, along with explanatory text for each species/life stage.

The aggregated habitat time series are presented in the form of monthly habitat duration curves for all target species and life stages. Habitat time series duration curves allows habitat to be depicted over time for the entire analysis period. The habitat time series results may be used to compare alternative flow management scenarios.

[11] The production runs contain results from Jan 1930 through March 2008, but in order to prevent partial-year records skewing any month-by-month analyses, analyses are limited to Jan 1930 – Dec 2007.

4. RESULTS

4.1 Bathymetric and Topographic Mapping

Figure 4.1-1 illustrates the bathymetric and topographic characteristics of the study reach, which is typified by a very irregular stream bottom. The average stream channel slope of the study reach is 0.0007 ft/ft.

4.2 Hydraulic Model

4.2.1 Calibration Results

The hydraulic model was calibrated to the water surface profile collected at 40,000 cfs, following the calibration procedure described in Bovee et al. (2007). The final finite element mesh comprising the study reach contained approximately 37,500 nodes. Calibration to within +/- 0.15 ft (5 cm) of observed water surface elevations at 40,000 cfs was targeted. Table 4.2.1-1 shows the results of the calibration, while Figure 4.2.1-1 shows the error distribution. Most (72%) simulated water surface elevations were within the targeted +/- 0.15 ft threshold and 93% were within +/- 0.25 ft. All of the simulated water surface elevations fell within +/- 0.50 ft of observed water surface elevations.

The model was also calibrated using rating curves developed from water surface elevation data collected at the three continuous water level recorder stations for flows of 5,000 cfs, 20,000 cfs, 60,000 cfs and 80,000 cfs. Table 4.2.1-2 shows the results of this calibration. The predicted water surface elevations computed by the hydraulic model corresponded well with the field measured water surface elevations at the three sites, as the difference between the predicted and measured water surface elevations was within +/- 0.15 ft, except at 5,000 cfs for gage 2, which was within 0.25 ft.

Observed velocities were compared to model velocities at 40,000 cfs across several transects in the study reach. Across each transect, the water velocity profiles has similar shapes as those measured by the ADCP, with low velocities near the banks and higher velocities mid-channel. Flow and velocity distribution between islands and side channels is fairly good. The model tended to be least accurate near water line boundaries (e.g. islands, banks), and was generally better in the main channel. Figure 4.2.1-2 shows the velocity error distribution across the entire study reach.

4.2.2 Simulation Results

The hydraulic model was used to simulate 14 flows in the study reach of 2,000 cfs, 3,500 cfs, 5,000 cfs, 7,500 cfs, 10,000 cfs, 20,000 cfs, 30,000 cfs, 40,000 cfs, 50,000 cfs, 60,000 cfs, 70,000 cfs, 80,000 cfs and 86,000 cfs. Water velocity and depth maps for each simulation flow are shown in Appendix C and Appendix D, respectively.

4.3 Habitat Modeling Results

This section presents the results of the habitat modeling in terms of WUA (habitat) versus flow relationships. Table 4.3-1 summarizes for each species/life stage at what flow the WUA curve (i.e. habitat) peaks, the computed habitat area at maximum WUA flow, the total wetted area of the study reach, and the percentage of total habitat available at the peak WUA. This table puts into perspective how much habitat is available for a given species/life stage relative to the total area of the study reach.

4.3.1 Habitat versus Discharge Relationships

The following sections briefly describe the habitat preferences for each species/life stage based on the HSI curves contained in Appendix B. In addition, the WUA (habitat) versus flow relationships resulting from the habitat modeling are summarized for each species/life stage. Habitat maps showing combined suitability for each species/life stage for each simulated flow are shown in Appendix E.

4.3.1.1 American Shad

Shown in Figure 4.3.1.1-1 are the WUA curves for the spawning & incubation, fry, juvenile and adult life stages of American shad.

Spawning & Incubation: American shad spawning is known to occur in the lower Susquehanna River below Conowingo dam, primarily in the vicinity of Robert, Wood and Spencer Islands. The spawning and incubation HSI curve shows optimal velocities between 1.0 and 3.0 ft/sec (SI=1.0). The optimal depth range for the species/life stage is between 5.0 and 20.0 ft. American shad typically spawn over sand, gravel, and cobble substrates.

The American shad spawning and incubation WUA curve increases to a peak at 40,000 cfs, before declining gradually due to velocities above the optimal range. In general, habitat for the spawning and incubation life stage is reduced in the study reach due to the absence of ideal substrate; however, literature indicates that substrate is not a predictor of spawning and nursery habitat and that it is not important in spawning site selection (Bilkovic et al. 2002; Krauthamer and Richkus 1987). Usable habitat represents approximately 33% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs) there was little habitat throughout the reach, and quality habitat was concentrated southwest of Bird Island. At the peak WUA flow (40,000 cfs), most of the quality habitat is found downstream of Rowland Island, near the mouth of Octoraro Creek, between Robert and Spencer Island and downstream of Snake Island. Additionally, the reach in between Rowland and Spencer islands becomes moderately suitable at 50,000 and 60,000 cfs, then generally declining to the maximum modeled flow of 86,000 cfs. To date, no studies have documented spawning in the Conowingo tailrace.

Fry: American shad eggs are fertilized and eventually sink to the bottom and become wedged under rocks, boulders and fractures or are swept into pools where they hatch. Sand and gravel also provide good substrate as they allow sufficient velocity to prevent the eggs from becoming buried (Greene et al. 2009). Optimal velocities for fry are 0.2 to 1.0 ft/sec (SI=1) and optimal depths are between 5.0 and 20.0 ft (SI=1). American shad fry have optimal preference for silt, sand, gravel, and cobble substrates.

The American shad fry WUA curve increases to a peak at 30,000 cfs, before declining gradually due to velocities above the optimal range. In general, habitat for the fry life stage is reduced in the study reach due to the absence of optimal substrate. As with spawning, substrate is not a good predictor of fry habitat. Greene et al. (2009) found that other factors such as velocity in relation to downstream transport and temperature are more important. Juvenile American shad are sampled annually by MDNR in the upper Chesapeake Bay and Susquehanna Flats to estimate production (SRAFRC 2010). Usable habitat represents approximately 26% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs) there was little habitat throughout the reach, and quality habitat was primarily found southwest of Bird Island, downstream of Robert Island and downstream of Snake Island. At the peak WUA flow (30,000 cfs), most of the quality habitat is found downstream of Rowland Island, near the mouth of Octoraro Creek, between Robert and Spencer Island and downstream of Snake Island. At higher flows (>70,000 cfs) quality habitat was primarily found near the mouth of Octoraro Creek and between Spencer, Wood and Robert Islands.

Juvenile: Juvenile American shad are considered to be more habitat generalists than fry or spawning adults (Greene et al. 2009). Juvenile American shad prefer a velocity between 0.2 and 1.0 ft/sec, with the suitability steadily declining to a SI=0 as velocity increases to 4.5 ft/sec. Optimal depths for juvenile American shad are between 4.90 and 6.60 ft, with a tolerated range of 0 to 50 ft; however, water depth is not considered to be a critical factor in nursery habitat (Krauthamer and Richkus 1987). Silt, sand, gravel and cobble are the preferred substrates for juveniles. Juveniles have historically been sampled on the Susquehanna Flats by MDNR.

The WUA curve for juvenile American shad shows habitat increasing steadily before peaking at a flow of 10,000 cfs, and then gradually decreasing as flow increases. The WUA curve declines due to water velocities and water depths exceeding the preferred range for the species/life stage. In general, habitat for the juvenile life stage is reduced in the study reach due to the absence of optimal substrate. However, Ross et al. (1997) found that there was no overall effect of habitat type on juveniles. This indicated that they utilize a variety of habitats, and that depth and substrate are not driving factors. Ross et al. (1997) did find a positive correlation between percent submersed aquatic vegetation (SAV) and juvenile shad abundance in the upper Delaware River. Useable habitat constitutes approximately 32% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs) there was little habitat throughout the reach, and quality habitat was primarily found downstream of Rowland Island, near the mouth of Octoraro Creek, and west of Bird Island. As flows increased above 30,000 cfs, habitat generally became increasingly fragmented and of lower quality, though habitat became more suitable downstream of Robert Island. At higher flows (>60,000 cfs) there was very little habitat throughout the entire reach, with the exception of near Octoraro Creek's mouth and downstream of Robert Island.

Adult: Adult American shad prefer a velocity between 0.5 and 3.0 ft/sec and the suitability steadily decreases to a SI=0 at a velocity of 5.0 ft/sec. The adult American shad HSI curve shows that adults prefer depths of 5.0 and 20.0 ft and substrates of silt, sand, cobble, and gravel.

The adult American shad WUA curve shows habitat increasing with flow until 40,000 cfs, before peaking and gradually declining at higher flows. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the adult life stage is reduced in the study reach due to the absence of optimal substrate; however, popular literature indicates that substrate is not a predictor of spawning and that it is not important in spawning site selection (Bilkovic et al. 2002; Krauthamer and Richkus 1987). Usable habitat constitutes approximately 36% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs) there was relatively poor habitat throughout the reach, and quality habitat was mostly limited to southwest of Bird Island and near the mouth of Octoraro Creek. At the peak WUA flow (40,000 cfs), there was quality habitat downstream of Rowland Island, near the mouth of Octoraro Creek, southwest of Bird Island, downstream of Snake Island and between Robert, Wood and Spencer Islands. At higher flows (>60,000 cfs) habitat suitability generally declined in the study reach, but the high quality habitat areas remained fairly unaffected by increasing flows.

4.3.1.2 Shortnose Sturgeon

Shown in Figure 4.3.1.2-1 are the WUA curves for the spawning & incubation, fry, juvenile and adult life stages of shortnose sturgeon.

Spawning & Incubation: Shortnose sturgeon use deep channels within the main river to spawn (NMFS 1998). The spawning and incubation HSI curve shows optimal velocities between 1.0 and 3.0 ft/sec (SI=1.0). The optimal depth range for the species/life stage is between 5.0 and 40.0 ft. Shortnose sturgeon typically spawn on cobble substrates, and to lesser extents, gravel, rubble, boulder and ledge substrate.

The shortnose sturgeon spawning and incubation WUA curve increases to a peak at 50,000 cfs, before declining at higher flows. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the spawning and incubation life stage is reduced by the absence of ideal substrate. Useable habitat represents approximately 15% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs) there was relatively poor habitat throughout the reach, with a patch of quality habitat located southwest of Bird Island. At the peak WUA flow (50,000 cfs) there was quality habitat downstream of Rowland Island, near the mouth of Octoraro Creek, southwest of Bird Island, downstream of Sterrit Island and between Robert and Wood Islands. The area just downstream of Rowland Island provides significant spawning habitat from approximately 20,000 cfs through the highest modeled flow of 86,000 cfs. However, at higher flows (>60,000 cfs) habitat quality degraded in most other areas but improved or stayed consistent in some tidally-influenced areas downstream of Deer Creek.

Fry: Shortnose sturgeon that have just hatched are considered to "swim-up" and drift downstream more than any active, directed movement until they are considered fry. At this point they resemble adults and actively migrate downstream (NMFS 1998). Optimal velocities for fry are 0.5 to 1.5 ft/sec (SI=1). Optimal depths are between 5.0 and 40.0 ft (SI=1) as they are generally found in the deepest water within the river channel (NMFS 1998). Shortnose sturgeon fry have optimal preference for sand substrate as they are likely to be found in the tidal section of rivers where this substrate would tend to dominate.

The shortnose sturgeon fry WUA curve increases to a peak at 30,000 cfs, before declining gradually. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the fry life stage is very limited in the study reach, due to the absence of suitable substrate, with useable habitat representing approximately 1% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs) there was relatively poor habitat throughout the reach, with no sizable quality habitat areas. Above 10,000 cfs there was a small patch of quality habitat between Robert and Spencer Islands. This small patch remained relatively constant in size and quality through 86,000 cfs.

The behavior of shortnose sturgeon fry likely preclude them from being found within the study reach. The eggs are demersal and will drift until settled on bottom substrate and the fry drift close to the bottom after hatching until they are large enough for more directed movements. In light of these life history characteristics, the likelihood of shortnose sturgeon fry being present in the area affected by Conowingo Dam is low.

Juvenile: Juvenile shortnose sturgeon are found at the freshwater/saltwater interface in most rivers (NMFS 1998) and prefer a velocity between 0.2 and 1.5 ft/sec, with the suitability steadily declining to a SI=0 as velocity increases to 5.0 ft/sec. Optimal depths for juvenile shortnose sturgeon are between 5.0 and 20.0 ft. Sand and gravel are juveniles' preferred substrates, but they can be found over mud in some rivers as well (NMFS 1998).

The juvenile shortnose sturgeon WUA curve shows habitat increasing steadily before peaking at a flow of 30,000 cfs and then gradually decreasing as flow increases. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the juvenile life stage is very limited in the study reach, due to the absence of suitable substrate, with useable habitat constituting approximately 2% of the overall wetted study area at the peak WUA flow.

At all flows there was relatively poor habitat throughout the reach, though there were patches of quality habitat near the mouth of Octoraro Creek, between Robert and Spencer Islands and downstream of Snake Island.

Given that shortnose sturgeon juveniles are found at the freshwater/saltwater interface in most rivers, which is near the river mouth at Havre de Grace (Conowingo Study 3.20: Salinity and Salt Wedge Encroachment), there is a low likelihood that they will be found within the influence of the Project.

Adult: Adult shortnose sturgeon can be found in the freshwater or freshwater-tidal reaches of a river (NMFS 1998) and prefer a velocity between 0.2 and 1.5 ft/sec, with the suitability steadily decreasing to a SI=0 for a velocity of 5.0 ft/sec. The adult shortnose sturgeon HSI curve shows that adults prefer depths of 5.0 and 20.0 ft and substrates of sand and gravel.

The WUA curve for adult shortnose sturgeon shows habitat increasing steadily before peaking at a flow of 30,000 cfs and then gradually decreasing as flow increases. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the adult life stage is very limited in the study reach, due to the absence of suitable substrate, with useable habitat constituting approximately 2% of the overall wetted study area at the peak WUA flow.

At all flows there was relatively poor habitat throughout the reach, though there were patches of quality habitat near the mouth of Octoraro Creek , between Robert and Spencer Islands and downstream of Snake Island. The area between Robert and Spencer islands is persistent for all flows modeled.

Adult shortnose sturgeon in the warmer climates of its range tend to congregate in deeper water with thermal refugia (NMFS 1998) and may not be within the study reach. There has been documentation of individuals caught in the head of the Chesapeake Bay near the mouth of the Susquehanna River in the early 1980s and again in 1997 (NMFS 1998), but only anecdotal information exists that any have ever been caught in the Susquehanna River historically, even though there is a population present in the nearby Delaware River.

4.3.1.3 Striped Bass

The Chesapeake Bay is considered the epicenter of migratory striped bass abundance and production on the east coast, although there are other estuaries that contribute to the sustainability of the species (Greene et al. 2009). Many individuals are migratory; however, it has been recently discovered that some individuals may be freshwater residents or move between fresh and saltwater (Greene et al. 2009). Shown in Figure 4.3.1.3-1 are the WUA curves for the spawning & incubation, fry, juvenile and adult life stages of striped bass.

Spawning & Incubation: The spawning and incubation HSI curve shows optimal velocities between 1.64 and 3.0 ft/sec (SI=1.0). The optimal depth range for the species/life stage is between 6.0 and 30.0 ft. Striped bass typically spawn on sand, gravel, cobble, boulder and bedrock substrates.

The striped bass spawning and incubation WUA curve increases to a peak at 50,000 cfs, before declining gradually. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the spawning and incubation life stage is good throughout the study reach, with useable habitat representing approximately 77% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs) there was relatively poor habitat throughout the reach, with quality habitat generally confined to the deeper, faster channel downstream of the dam powerhouse and west of Rowland Island. Habitat rapidly improved throughout the reach above 10,000 cfs, with large swaths of optimal habitat throughout the river between 30,000 cfs and 60,000 cfs. At higher flows (>60,000 cfs) habitat quality remained high, but optimal habitat began to become slightly more fragmented.

Fry: Optimal velocities for fry are 1.64 to 3.0 ft/sec (SI=1). Optimal depths are between 6.0 and 10.0 ft (SI=1). Striped bass fry have optimal preference for sand, gravel, cobble, boulder and bedrock substrates.

The striped bass fry WUA curve increases to a peak at 50,000 cfs, before declining gradually. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the fry life stage is good throughout the study reach, with useable habitat representing approximately 76% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs) there was relatively poor habitat throughout the reach, quality habitat generally confined to the deeper, faster channel downstream of the dam powerhouse and west of Rowland Island. Habitat rapidly improved throughout the reach above 10,000 cfs, with large swaths of optimal habitat throughout the river between 40,000 cfs and 60,000 cfs. At higher flows (>60,000 cfs) habitat quality remained high, but optimal habitat became slightly more fragmented.

Juvenile: Juvenile striped bass prefer a velocity between 0.5 and 3.0 ft/sec, with the suitability steadily declining to a SI=0 as velocity increases to 13.1 ft/sec. Optimal depths for juvenile striped bass are between 6.0 and 30.0 ft. Sand, gravel, and cobble are juveniles' preferred substrates; however, they can be found over mud and rock as well (Greene et al 2009).

The WUA curve for juvenile striped bass shows habitat increasing steadily before peaking at a flow of 40,000 cfs, and then gradually decreasing as flow increases. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the juvenile life stage is reduced throughout the study reach due to the absence of ideal substrate. Useable habitat constitutes approximately 42% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs) quality habitat was generally confined to an area southwest of Bird Island. Habitat improved above 10,000 cfs, with quality habitat shifting from southwest of Bird Island to downstream of Rowland Island and between Spencer, Wood and Robert Islands.

Juvenile striped bass are generally found in streams, riverine, estuarine or even freshwater pond habitats, but young-of-the-year juveniles tend to move downstream to higher salinity estuarine areas during their first summer (Greene et al. 2009). Research has indicated that juveniles will use various nearshore areas without requiring specific microhabitats in the summer and move offshore in the fall (Greene et al. 2009). Given these observations, the lower Susquehanna River within the Project influence is not necessarily an important rearing area for striped bass juveniles. Stated another way, substrate is driving the WUA versus flow curve for juvenile striped bass; however, substrate may not be the most important factor influencing where the juveniles may be found at a given time of year.

Adult: Adult striped bass prefer a velocity between 0.9 and 4.0 ft/sec and the suitability steadily decreases to a SI=0 for a velocity of 13.1 ft/sec. The adult striped bass HSI curve shows that adults prefer depths of 6.0 and 30.0 ft and substrates of sand, gravel, cobble, boulder and bedrock.

The WUA curve for adult striped bass shows habitat increasing steadily before peaking at a flow of 80,000 cfs, and then gradually decreasing as flow increases. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat is excellent throughout the study reach, with useable habitat constituting approximately 85% of the overall wetted study area at the peak WUA flow.

At lower flows (<5,000 cfs), quality habitat was generally confined to the deeper, faster channel downstream of the dam powerhouse and west of Rowland Island, though isolated quality habitat patches were present throughout the river. Habitat rapidly improved throughout the reach above 15,000 cfs, with large swaths of optimal habitat throughout the river between 40,000 cfs and 86,000 cfs. At the peak WUA flow (80,000 cfs) the vast majority of the river was optimal habitat, except the channel downstream of the dam powerhouse west of Rowland Island.

4.3.1.4 Smallmouth Bass

The lower Susquehanna River generally does not provide large quantities of quality spawning and fry and juvenile rearing habitat. In spite of this, there is an adult population present below the Conowingo Dam. The population is likely being supported from the passage of fry, juveniles and adults from Conowingo Pond past the station as well as inputs from downstream tributaries. Shown in Figure 4.3.1.4-1 are the WUA curves for the spawning & incubation, fry, juvenile and adult life stages of smallmouth bass.

Spawning & Incubation: The spawning and incubation HSI curve shows optimal velocities between 0.0 and 0.5 ft/sec (SI=1.0). The optimal depth range for the species/life stage is between 2.2 and 4.8 ft. Smallmouth bass typically spawn on gravel substrate, and to a lesser extent, sand substrate.

The smallmouth bass spawning and incubation WUA curve increases to a peak at 5,000 cfs, before declining gradually. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the spawning and incubation life stage is very limited in the study reach, due to the absence of suitable substrate, with useable habitat representing approximately 2% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs), quality habitat generally was confined to a small patch near the mouth of Octoraro Creek and downstream of Robert Island, with only small patches of lower quality habitat in the other parts of the river. Above 10,000 cfs all quality habitat patches slowly degraded until there were only a few small lower quality habitat areas available at 86,000 cfs.

Fry: Optimal velocities for fry are 0.0 to 0.2 ft/sec (SI=1). Optimal depths are between 0.5 and 2.0 ft (SI=1). Smallmouth bass fry have optimal preference for gravel, and to lesser extent, cobble substrate.

The smallmouth bass fry WUA curve peaked at 2,000 cfs, the lowest modeled flow. The habitat declined rapidly between 2,000 cfs and 10,000 cfs, before continuing to decline gradually. In general, habitat for the fry life stage is limited in the study reach, due to the absence of ideal substrate and high water velocities, with useable habitat representing approximately 6% of the overall wetted study area at the peak WUA flow.

There was very little habitat available at any flow throughout the study area. At 30,000 cfs and above there was some lower quality habitat available in the spillway area, but this dissipated at flows above 60,000 cfs.

Juvenile: Juvenile smallmouth bass prefer a velocity between 0.0 and 1.0 ft/sec, with the suitability steadily declining to a SI=0 as velocity increases to 4.92 ft/sec. Optimal depths for juvenile smallmouth bass are between 1.0 and 4.0 ft. Cobble is the preferred substrates for juveniles.

The WUA curve for juvenile smallmouth bass shows habitat increasing steadily before peaking at a flow of 5,000 cfs, and then gradually decreasing as flow increases. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the juvenile life stage is somewhat reduced throughout the study reach due to the absence of ideal substrate. Useable habitat constitutes approximately 39% of the overall wetted study area at the peak WUA flow.

At lower flows (<15,000 cfs), there was habitat found through much of the river, with quality habitat available downstream of Rowland Island, near the mouth of Octoraro Creek and between Spencer, Wood and Robert Islands. As flows increased above 15,000 cfs habitat degraded in all areas, though the spillway and areas around islands provided some lower quality habitat at flows above 40,000 cfs.

Adult: Adult smallmouth bass prefer a velocity between 0.0 and 1.0 ft/sec, and the suitability steadily decreases to a SI=0 for a velocity of 4.92 ft/sec. The adult smallmouth bass HSI curve shows that adults prefer depths of 3.0 and 7.0 ft, and substrates of boulder, and to a lesser extent cobble, gravel, and bedrock.

The WUA curve for adult smallmouth bass shows habitat increasing steadily before peaking at a flow of 15,000 cfs and then gradually decreasing as flow increases. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species/life stage. In general, habitat for the adult life stage is somewhat reduced throughout the study reach due to the absence of ideal substrate. Useable habitat constitutes approximately 42% of the overall wetted study area at the peak WUA flow.

At lower flows (<10,000 cfs), there was habitat found through much of the river, with quality habitat available near the mouths of Octoraro and Deer Creeks and at the upstream edge of Sterret Island. At the peak WUA flow (20,000 cfs) there was quality habitat available near the mouths of Deer and Octoraro Creeks, around the upstream and downstream ends of Sterret Island, between Robert and Wood Island and east of Robert Island. As flows increased above 60,000 cfs, habitat degraded through most of the reach, though quality habitat was still available between Spencer, Wood and Robert Islands.

In light of the fact that little spawning and fry or juvenile rearing habitat exists below Conowingo Dam, the population is likely being supported from Conowingo Pond and downstream tributaries. Any flow management for this species would likely have negligible effects on spawning or fry habitat and not influence the overall population.

4.3.1.5 Macroinvertebrates

Shown in Figure 4.3.1.5-1 are the WUA curves for Ephemeroptera (Mayflies), Plecoptera (Stoneflies), and Trichoptera (Caddisflies).

Ephemeroptera (Mayflies): This group prefers a velocity between 0.3 and 1.0 ft/sec, with the suitability steadily declining to a SI=0 as velocity increases to 3.0 ft/sec. Optimal depths for Ephemeroptera are between 1.6 and 2.3 ft. Cobble, and to a lesser extent, gravel and boulder are the preferred substrates.

The WUA curve for Ephemeroptera shows habitat increasing steadily before peaking at a flow of 5,000 cfs, and then gradually decreasing as flow increases. The WUA curve declines primarily due to both water velocities and water depths exceeding the preferred range for the species. In general, habitat is limited throughout the study reach, due to the absence of ideal substrate. Useable habitat constitutes approximately 9% of the overall wetted study area at the peak WUA flow.

At flows at or below 5,000 cfs habitat was generally poor, but quality habitat was available near the mouths of Octoraro and Deer Creeks and downstream of Rowland Island. As flows increased above 5,000 cfs, habitat quality degraded in the entire river, with nearly all quality habitat eliminated by 20,000 cfs.

Plecoptera (Stoneflies): This group prefers a velocity between 0.3 and 1.0 ft/sec, with the suitability steadily declining to a SI=0 as velocity increases to 3.0 ft/sec. Optimal depths for Plecoptera are between 1.6 and 2.6 ft. Cobble, and to a lesser extent, gravel and boulder are the preferred substrates.

The WUA curve for Plecoptera shows habitat increasing steadily before peaking at a flow of 5,000 cfs, and then gradually decreasing as flow increases. The WUA curve declines primarily due to water velocities and water depths exceeding the preferred range for the species. In general, habitat is limited throughout the study reach, due to the absence of ideal substrate. Useable habitat constitutes approximately 7% of the overall wetted study area at the peak WUA flow.

At flows at or below 5,000 cfs habitat was generally poor, but quality habitat was available near the mouth of Octoraro Creek and downstream of Rowland Island. As flows increased above 5,000 cfs habitat quality degraded in the entire river, with nearly all quality habitat eliminated by 20,000 cfs.

Trichoptera (Caddisflies): This group prefers a velocity between 0.3 and 1.0 ft/sec, with the suitability steadily declining to a SI=0 as velocity increases to 3.0 ft/sec. Optimal depths for Trichoptera are between 1.6 and 3.3 ft. Cobble and boulder are the preferred substrates.

The WUA curve for Trichoptera shows habitat increasing steadily before peaking at a flow of 10,000 cfs and then gradually decreasing as flow increases. The WUA curve declines primarily due to water velocities exceeding the preferred range for the species. In general, habitat is reduced throughout the study reach due to the absence of ideal substrate. Useable habitat constitutes approximately 19% of the overall wetted study area at the peak WUA flow.

At flows at or below 10,000 cfs habitat was generally poor, but there were multiple patches of quality habitat located downstream of Rowland Island, near the mouths of Octoraro and Deer Creeks, upstream and downstream of Sterrit Island, downstream of Snake Island and around the edges of Robert Island. As flows increased above 20,000 cfs habitat quality degraded in the entire river, though quality habitat patches remained between Robert and Wood Islands and near the mouths of Octoraro and Deer Creeks.

4.3.1.6 Habitat Guilds

Shown in Figure 4.3.1.6-1 are the WUA curves for the shallow-slow, shallow-fast, deep-slow, and deep-fast habitat guilds.

Shallow-Slow: For this guild, preferred velocities are between 0.0 and 1.0 ft/sec. The shallow-slow guild HSI curve shows preferred depths of 0.5 and 2.0 ft and substrates of gravel, cobble, boulder, and bedrock.

The shallow-slow guild WUA curve peaked at 2,000 cfs, the lowest modeled flow. The habitat declined rapidly between 2,000 cfs and 15,000 cfs, before remaining roughly constant up to 86,000 cfs. There was a small secondary peak around 40,000 cfs, due to the spillway area becoming initially inundated. The WUA curve declined primarily due to water velocities and water depths exceeding the preferred range for the guild, with useable habitat representing approximately 45% of the overall wetted study area at the peak WUA flow.

There were large amounts of optimal habitat throughout the river channel below flows of 5,000 cfs. At flows above 30,000 cfs high quality habitat was available in the spillway area, with little habitat available elsewhere in the river.

Shallow-Fast: For this guild, preferred velocities are between 0.5 and 1.0 ft/sec. The shallow-fast guild HSI curve shows preferred depths of 0.75 and 1.5 ft and substrates of gravel, cobble, and boulder.

The shallow-fast guild WUA curve peaked at 2,000 cfs, the lowest modeled flow. The habitat declined rapidly between 2,000 cfs and 15,000 cfs, before gradually declining between 15,000 cfs and 86,000 cfs. The WUA curve declined primarily due to water velocities and water depths exceeding the preferred range for the guild and was also limited by a lack of suitable substrate. The useable habitat represented approximately 2% of the overall wetted study area at the peak WUA flow.

The majority of the river was unsuitable habitat for all flows. At flows below 5,000 cfs some quality habitat was available downstream of Rowland Island, near the mouths of Deer and Octoraro Creeks and near Sterrit Island. At flows above 15,000 cfs there was almost no habitat of any quality available in any part of the river.

Deep-Slow: For this guild, preferred velocities are between 0.0 and 1.0 ft/sec. The deep-slow guild HSI curve shows preferred depths of greater than 2.0 ft, and all substrates are considered optimal.

The deep-slow guild WUA curve peaked at 5,000 cfs. The habitat declined rapidly between 5,000 cfs and 30,000 cfs, before gradually declining between 30,000 cfs and 86,000 cfs. The WUA curve declined primarily due to water velocities exceeding the preferred range for the guild, with useable habitat representing approximately 52% of the overall wetted study area at the peak WUA flow.

There is optimal habitat throughout the river channel below flows of 20,000 cfs, though the majority of the habitat is in the tidally-influenced part of the study area downstream of Deer Creek. At flows above 30,000 cfs high quality habitat was primarily limited to the area around Spencer, Wood and Robert Islands, the spillway area and near the mouth of Octoraro Creek. River banks and island edges provided some quality habitat as well at higher flows.

Deep-Fast: For this guild, preferred velocities are between 1.0 and 3.5 ft/sec. The deep-fast guild HSI curve shows preferred depths between 2.5 and 4.0 ft, and gravel and cobble substrates are considered optimal.

The deep-fast guild WUA curve peaked at 20,000 cfs. The habitat declined rapidly between 20,000 cfs and 50,000 cfs, before gradually declining between 50,000 cfs and 86,000 cfs. The WUA curve declined primarily due to water velocities and water depths exceeding the preferred range for the guild and was also limited by a lack of suitable substrate, with useable habitat representing approximately 2% of the overall wetted study area at the peak WUA flow.

The majority of the river was unsuitable habitat for all flows. At flows below 5,000 cfs habitat was extremely limited. At flows above 5,000 cfs there was some quality habitat available downstream of Rowland and Robert Islands, as well as around the mouth of Octoraro Creek. As flows increased above 20,000 cfs the habitat quality degraded, with only very small pockets of habitat left at flows above 50,000 cfs.

4.3.2 Habitat Persistence

Habitat persistence was determined as the intersection of quality habitat polygon areas (combined suitability ≥ 0.5) for all immobile species (macroinvertebrates) and life stages (spawning and fry) for every modeled flow combination. Each flow combination consisted of a low flow matched with an equal or higher flow, to emulate a minimum flow and generation flow combination. Though it was typical for a species' persistent habitat to peak at the same flow as the WUA habitat, this was not necessarily true because the persistent habitat was calculated excluding lower-quality habitat areas (SI < 0.5).

Persistent habitat maps showing each flow pair (3,500 cfs through 40,000 cfs paired with 86,000 cfs) for each species and life stage are located in Appendix F. Persistent habitat tables showing each flow pair for each species and life stage are located in Appendix G.

4.3.2.1 American Shad

The American shad spawning/incubation and fry habitat persistence curves for all modeled flows paired with full generation (86,000 cfs) are shown in Figure 4.3.2.1-1.

Spawning & Incubation:

Generation flows of 86,000 cfs paired with minimum flows below 7,500 cfs produced little American shad spawning and incubation persistent habitat. Increasing the minimum flow above 7,500 cfs resulted in a rapid persistent habitat increase up through a minimum flow of 15,000 cfs, followed by moderate persistent habitat increases above minimum flows of 15,000 cfs. The majority of the persistent habitat (paired with 86,000 cfs) is located downstream of Rowland Island, near the mouths of Deer and Octoraro Creeks, around Sterrit Island, and around Robert Island, though other small patches exist elsewhere.

Fry:

Generation flows of 86,000 cfs paired with minimum flows between 2,000 cfs and 20,000 cfs steadily increased American shad fry persistent habitat, with minimum flows above 20,000 cfs producing more gradual persistent habitat increases. The majority of the persistent habitat (paired with 86,000 cfs) is located downstream of Rowland Island, near the mouth of Octoraro Creek and between Spencer, Wood and Robert Islands, though other small patches exist elsewhere.

4.3.2.2 Shortnose Sturgeon

The shortnose sturgeon spawning/incubation and fry habitat persistence curves for all modeled flows paired with full generation (86,000 cfs) are shown in Figure 4.3.2.2-1.

Spawning & Incubation:

Generation flows of 86,000 cfs paired with minimum flows below 5,000 cfs resulted in little shortnose sturgeon spawning and incubation persistent habitat. Increasing the minimum flow above 5,000 cfs resulted in a rapid persistent habitat increase up through a minimum flow of 20,000 cfs, followed by moderate persistent habitat increases above minimum flows of 20,000 cfs. The majority of the persistent habitat (paired with 86,000 cfs) is located downstream of Rowland Island, but smaller patches exist southwest of Bird Island, near the mouth of Octoraro Creek, around Sterrit Island and downstream of Snake Island.

Fry:

Generation flows of 86,000 cfs paired with minimum flows below 5,000 cfs resulted in little shortnose sturgeon fry persistent habitat. Increasing the minimum flow above 5,000 cfs resulted in a steady persistent habitat increases up through a minimum flow of 86,000 cfs. Overall, there is very little total persistent habitat. The small amount that exists (paired with 86,000 cfs) is found between Robert and Spencer Islands.

4.3.2.3 Striped Bass

The striped bass spawning/incubation and fry habitat persistence curves for all modeled flows paired with full generation (86,000 cfs) are shown in Figure 4.3.2.3-1.

Spawning & Incubation:

Generation flows of 86,000 cfs paired with minimum flows below 7,500 cfs produced little striped bass spawning and incubation persistent habitat. Increasing the minimum flow above 7,500 cfs resulted in a rapid persistent habitat increase up through a minimum flow of 30,000 cfs, followed by gradual persistent habitat increases above minimum flows of 30,000 cfs. The persistent habitat at flows greater than 7,500 cfs (paired with 86,000 cfs) is distributed throughout the entire study area.

Fry:

Generation flows of 86,000 cfs paired with minimum flows below 7,500 cfs produced little striped bass fry persistent habitat. Increasing the minimum flow above 7,500 cfs resulted in a rapid persistent habitat increase up through a minimum flow of 20,000 cfs, followed by gradual persistent habitat increases above minimum flows of 20,000 cfs. The persistent habitat at flows greater than 7,500 cfs (paired with 86,000 cfs) is distributed throughout the entire study area.

4.3.2.4 Smallmouth Bass

The smallmouth bass spawning/incubation and fry habitat persistence curves for all modeled flows paired with full generation (86,000 cfs) are shown in Figure 4.3.2.4-1.

Spawning & Incubation:

Generation flows of 86,000 cfs paired with minimum flows below 10,000 cfs produced a small amount of smallmouth bass spawning and incubation persistent habitat. Increasing the minimum flow above 10,000 cfs resulted in a gradual persistent habitat increase up through a minimum flow of 86,000 cfs. The small amount of persistent habitat was located primarily between Robert and Spencer Islands.

Fry:

Generation flows of 86,000 cfs paired with minimum flows below 7,500 cfs produced little smallmouth bass fry persistent habitat. Increasing the minimum flow above 7,500 cfs resulted in a gradual persistent habitat increase up through a minimum flow of 50,000, followed by rapid persistent habitat increases above minimum flows of 50,000 cfs. The small amount of persistent habitat available was primarily found along the river edges and around islands.

4.3.2.5 Macroinvertebrates

The macroinvertebrate habitat persistence curves for all modeled flows paired with full generation (86,000 cfs) are shown in Figure 4.3.2.5-1, while only the Ephemeroptera and Plecoptera habitat persistence curves are shown in Figure 4.3.2.5-2.

Ephemeroptera (Mayfly):

Generation flows of 86,000 cfs paired with minimum flows below 10,000 cfs produced little Ephemeroptera persistent habitat. Increasing the minimum flow above 10,000 cfs resulted in a gradual persistent habitat increase up through a minimum flow of 50,000 cfs, followed by moderate persistent habitat increases above minimum flows of 50,000 cfs. The small amount of persistent habitat available was primarily found along the river edges and around islands.

Plecoptera (Stonefly):

Generation flows of 86,000 cfs paired with minimum flows at or below 20,000 cfs produced no Plecoptera persistent habitat. Increasing the minimum flow above 20,000 cfs resulted in a gradual persistent habitat increase up through a minimum flow of 60,000 cfs, followed by steady persistent habitat increases above minimum flows of 60,000 cfs. The small amount of persistent habitat available was primarily found along the river edges and around islands.

Trichoptera (Caddisfly):

Generation flows of 86,000 cfs paired with minimum flows resulted in steadily increasing Trichoptera persistent habitat as the minimum flow increased, through 86,000 cfs. Somewhat smaller incremental habitat increases occurred at higher minimum flows. The small amount of persistent habitat available was primarily found downstream of Rowland Island, around the mouth of Octoraro Creek and between Robert, Spencer and Wood Islands.

4.3.2.6 Habitat Guilds

The shallow-slow and shallow-fast habitat persistence curves for all modeled flows paired with full generation (86,000 cfs) are shown in Figure 4.3.2.6-1, and the deep-slow and deep-fast curves are shown in Figure 4.3.2.6-2.

Shallow-Slow:

Generation flows of 86,000 cfs paired with minimum flows between 2,000 cfs and 50,000 cfs resulted in gradual shallow-slow guild persistent habitat increases as minimum flow increased. Increasing the minimum flow above 50,000 cfs resulted in a rapid persistent habitat increase up through a minimum flow of 86,000 cfs. The small amount of persistent habitat available was primarily found along the river edges and around islands.

Shallow-Fast:

Generation flows of 86,000 cfs paired with minimum flows below 70,000 cfs produced no shallow-fast guild persistent habitat. Persistent habitat only marginally increased for minimum flows above 70,000 cfs.

Deep-Slow:

Generation flows of 86,000 cfs paired with minimum flows between 2,000 cfs and 86,000 cfs produced steadily increasing deep-slow guild persistent habitat as minimum flow increased. The small amount of persistent habitat available was primarily found between Spencer, Wood and Robert Islands, the mouths of Deer and Octoraro Creeks, as well as river edges and around islands.

Deep-Fast:

Generation flows of 86,000 cfs paired with minimum flows below 7,500 cfs resulted in a rapid deep-fast guild persistent habitat increase up through a minimum flow of 30,000 cfs, followed by a gradual persistent habitat increase as minimum flows increased between 30,000 cfs and 86,000 cfs. The small amount of persistent habitat available was primarily found along the river edges and around islands.

4.3.3 Mussel Habitat Assessment

Mussel habitat analyses primarily involved comparing mussel CPUE rates from semi-quantitative[12] mussel sampling locations (Conowingo Study 3.19: Freshwater Mussel Characterization Study below Conowingo Dam) to hydraulic parameters and substrate in the study reach (Figure 4.3.3-1).

Several hydraulic parameters are useful in assessing mussel habitat, but recent literature shows that bed shear stress(τ) and relative shear stress[13] (τ_c) are two of the more important metrics (Pers. Comm, M. Ashton, 2011). While River2D directly calculates bed shear velocity, which is easily converted to bed shear stress, the model does not calculate relative shear stress. Relative shear stress (τ_{rel}) is defined as the ratio of bed shear stress to critical shear stress ($\tau_{rel} = \tau/\tau_c$). Thus, to calculate relative shear stress, critical shear stress must also be known.

Critical shear stress is the threshold that bed shear stress must meet or exceed to initiate particle movement and is defined in Allen and Vaughn (2010) as $\tau_c=\theta_c g D_{50}(\rho_s-\rho)$, where θ_c is Shield's parameter (unitless), D_{50} is the median substrate particle size (cm), ρ_s is substrate density (2.65 g/cm^3) [165.4 lb/ft^3][14], and ρ is water density (0.998 g/cm^3) [62.4 lb/ft^3]. Shield's parameter (θ_c) and median particle size (D_{50}) had to be estimated in order to estimate critical shear stress for each substrate type.

Allen and Vaughn (2010) conducted a mussel study that included six sampling sites on the Little River in Oklahoma. They used 0.065 as Shield's parameter, which they listed as appropriate for normally-packed gravel substrate[15]. The lower Susquehanna has a wide range of substrates, so θ_c values from Julien (2010)

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[12] As stated in Conowingo Study 3.19, semi-quantitative mussel sampling consists of only riverbed surface sampling, with no sub-surface sampling, as is done in quantitative mussel sampling.

[13] The "relative shear stress" calculations in this report are comparable to the "entrainment potential" calculations in Conowingo Study 3.15: Sediment Introduction and Transport, and differ in terminology in order to be consistent with each study's respective literature. The equations and methods used in both reports are identical, and the grain size classes are the only difference. The grain size classes in Conowingo Study 3.15 were chosen to be consistent with other sediment transport literature, while this report utilizes the HSI grain size classes described in Table 3.2.3-1 to be consistent with other analyses in this report.

[14] For consistency with existing mussel literature, mussel results will be expressed in SI units. US Standard units will also be shown where possible.

[15] No description of normally-packed gravel was provided.

were used for each substrate type. The θ_c value used in Allen and Vaughn (2010) of 0.065 was noticeably larger than the gravel θ_c listed in Julien (2010) of 0.039. It appears the differences is that the θ_c of 0.065 is only applicable to normally-packed gravel, while a θ_c of 0.039 is a more general estimate for all types of gravel. For this analysis, a θ_c of 0.039 was used because it was more conservative (more sediment transport). The lower θ_c used results in a lower critical shear stress threshold, and thus a more conservative analysis.

D_{50} substrate estimates were categorized using the substrate codes in Table 3.2.3-1, with an additional differentiation between bedrock in the tidal and non-tidal portions of the study reach. With the exception of silt, the median particle size was conservatively estimated as the smallest value of the particle range for that substrate, which would tend to slightly overestimate the amount of sediment moving. For example, gravel ranged from 2 to 64 mm, so the D_{50} was estimated as 2 mm [0.079 inches]. For silt, the particle size was estimated as the "medium silt" size of 0.016 mm [0.0006 inches] as defined in Julien (2010). Though a critical shear stress cannot be accurately estimated for bedrock, it was acknowledged that areas designated as bedrock dominated in the habitat analysis were not composed completely of bedrock and that other sediment types were present. Thus, for bedrock only, all present substrates identified in the 2008 aquatic habitat study were used to create an estimated composite particle size distribution from which the median particle size could be calculated, calculated as:

$$D_{50} = (\%gravel*D_{50gravel}) + (\%cobble*D_{50cobble}) + ([\%boulder+\%bedrock]*D_{50boulder}).$$

Note that bedrock and boulder assumed the same D_{50} for calculation purposes. Additionally, field observations and local knowledge indicate that while the 2008 aquatic habitat study estimated substrate proportions correctly for non-tidal bedrock areas, substrate are slightly finer in tidally-influenced bedrock areas (Pers. Comm., M. Ashton, 2011). To account for this, bedrock was broken into tidal and non-tidal areas, which are shown in Figure 4.3.3-1. The makeup for the bedrock in non-tidal areas was 20% cobble, 15% boulder and 65% bedrock. The makeup for the bedrock in tidal areas was 5% gravel, 25% cobble, 20% boulder and 50% bedrock.

Table 4.3.3-1 shows the substrates used in the mussel analysis, as well as the estimated median particle sizes, Shield's parameter and calculated critical shear stresses for each substrate code.

Hydraulic parameters were matched with the semi-quantitative mussel sampling locations. Appendix H includes tables showing modeled depth, water velocity, Froude number, shear stress and relative shear stress as well as CPUE[16], alewife floater presence/absence, substrate and critical shear stress at each semi-quantitative mussel sampling location for all 14 modeled flows. Each table also highlights where shear stress and relative shear stress thresholds are exceeded for low flows in orange (20 dynes/cm^2 and 0.4, respectively) and high flows in red (150 dynes/cm^2 and 2.0, respectively). While there was a large variability in results, the semi-quantitative mussel surveying locations with the highest CPUE generally had low shear stress and relative shear stress values. A plot of CPUE vs. shear stress at several flows showed that stations with the highest CPUEs tended to have relatively low shear stresses (Figure 4.3.3-2). It also showed that at 3,500 cfs and 5,000 cfs the highest CPUEs were associated with shear stresses lower than 40-60 dynes/cm^2.

To understand the relative amount of area suitable for mussel development at different flows, the area above the low flow and high flow shear stress thresholds were plotted in Figure 4.3.3-3. Maps of shear stress at each modeled flow are shown in Appendix I. The results showed that a moderate to high percentage of the wetted study area exceeded the low flow threshold, while a low to moderate percentage exceeded the high flows. The low flow threshold curve showed a rapid increase in area exceeding 20 dynes/cm^2 between 2,000 cfs and 10,000 cfs, with a moderate increase between 10,000 cfs and 30,000 cfs, followed by a gradual increase between 30,000 and 86,000 cfs. The high flow threshold curve showed a gradual decrease in area exceeding 150 dynes/cm^2 between 2,000 cfs and 5,000 cfs, followed by a graduate increase in area between 5,000 cfs and 10,000 cfs, followed by a steady increase between 10,000 cfs and 86,000 cfs.

4.3.4 Habitat Time Series Analysis

The habitat time series analyses translated each production run's hourly Conowingo Dam outflow time series (Jan 1930 – Dec 2007) into twenty-three individual habitat time series – one hourly time series for each species/lifestage investigated in the Conowingo 3.16 study report. This section shows habitat time series results for all present species each month. Though habitat time series plots were presented for immobile species, we believe the persistent habitat maps and tables presented in this report, when compared to seasonal minimum and maximum flows, are a more effective tool for assessing immobile

[16] All CPUE numbers reflect overall mussel catch numbers, not any specific species

species' habitat. Aggregated results for all species are presented in the form of monthly habitat duration curves. Exelon has provided the raw hourly time series data (flow and habitat) to relicensing stakeholders, along with other production run outputs.

The habitat time series results include several graphs for each month, by species and production run. Each habitat duration curve compares a production run's results to the Baseline results. These curves are presented in Appendix J.

5. STEADY-STATE HABITAT ANALYSIS DISCUSSION

This purpose of this section is to summarize the results presented in Section 4 so that flow regime preferences are compared across all target species or guilds.

5.1 Monthly Analysis of WUA and Persistent Habitat Results

Shown in Table 5.1-1 is the flow that provides the maximum WUA for each species and life stage (second column). The table also depicts the range of flows that provide 90%, 80%, 70% and 60% of the maximum WUA. Based on Table 5.1-1, a series of flows were chosen, and the habitat values as a percentage of maximum habitat were calculated for each species/life stage analyzed. This information is presented in Table 5.1-2.

Habitat as a percentage of maximum WUA was plotted against flow for each species, with daily average flow exceedance percentiles from the Conowingo estimated daily average unregulated flow added for reference (Table 2.2.2-2). Several species/life stages are tolerant of a wide flow range (e.g., American Shad Adult, all Striped Bass life stages), while several prefer narrow flow ranges (e.g., Mayfly, Smallmouth Bass Spawning). Some year-round species' have no preferred flow range overlap (e.g., Striped Bass Adult vs. Deep-Slow Guild), indicating that some species/life stages will be subject to sub-optimal flow conditions regardless of the flow regime.

Based on the discussion relative to species and life stage use in Section 4.2, the estimated unregulated hydrology at Conowingo (Table 2.2.2-2) and the maximum available habitat as a percentage of the study area, we narrowed the list of target species and life stages (Table 3.2.1-2) to those we expect would utilize the lower river and be compatible with its structural habitat and unregulated flow regime. We then analyzed these species and life stages, on a monthly basis, to provide information that could be used in determining a monthly flow schedule.

5.1.1 January

Figure 5.1.1-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in January along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of January these species include:

- Striped bass adults;

- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.1-1 provides the above species' flow preferences and January's median monthly flow.

5.1.2 February

Figure 5.1.2-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in February along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of February these species include:

- Striped bass adults;
- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.2-1 provides the above species' flow preferences and February's median monthly flow.

5.1.3 March

Figure 5.1.3-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in March along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of March these species include:

- Striped bass adults;
- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.3-1 provides the above species' flow preferences and March's median monthly flow.

5.1.4 April

Figure 5.1.4-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in April along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of April these species include:

- American shad spawning;
- American shad adults;
- Striped bass spawning;
- Striped bass fry;
- Striped bass adults;
- Smallmouth bass adults;
- Shortnose sturgeon spawning;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.4-1 provides the above species' flow preferences and April's median monthly flow.

5.1.5 May

Figure 5.1.5-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in May along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of May these species include:

- American shad spawning;
- American shad fry
- American shad adults;
- Striped bass spawning;
- Striped bass fry;
- Striped bass adults;
- Smallmouth bass adults;
- Shortnose sturgeon spawning;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.5-1 provides the above species' flow preferences and May's median monthly flow.

5.1.6 June

Figure 5.1.6-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in June along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of June these species include:

- American shad spawning;
- American shad fry
- American shad adults;
- Striped bass spawning;
- Striped bass fry;
- Striped bass juveniles;
- Striped bass adults;
- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.6-1 provides the above species' flow preferences and June's median monthly flow.

5.1.7 July

Figure 5.1.7-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in July along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of July these species include:

- American shad fry;
- American shad juveniles;

- Striped bass fry;
- Striped bass juveniles;
- Striped bass adults;
- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.7-1 provides the above species' flow preferences and July's median monthly flow.

5.1.8 August

Figure 5.1.8-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in August along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of August these species include:

- American shad juveniles;
- Striped bass juveniles;
- Striped bass adults;
- Smallmouth bass juveniles;
- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.8-1 provides the above species' flow preferences and August's median monthly flow.

5.1.9 September

Figure 5.1.9-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in September along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of September these species include:

- American shad juveniles;
- Striped bass juveniles;
- Striped bass adults;
- Smallmouth bass juveniles;
- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.9-1 provides the above species' flow preferences and September's median monthly flow.

5.1.10 October

Figure 5.1.10-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in October along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of October these species include:

- American shad juveniles;

- Striped bass juveniles;
- Striped bass adults;
- Smallmouth bass juveniles;
- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.10-1 provides the above species' flow preferences and October's median monthly flow.

5.1.11 November

Figure 5.1.11-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in November along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of November these species include:

- American shad juveniles;
- Striped bass juveniles;
- Striped bass adults;
- Smallmouth bass juveniles;
- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.11-1 provides the above species' flow preferences and November's median monthly flow.

5.1.12 December

Figure 5.1.12-1 provides the flow preferences of all target species' that are potentially present below Conowingo Dam in December along with estimated unregulated flow exceedance percentiles from Table 2.2.2-2. We narrowed the broader list of target species down to the following species and lifestages for which there is a relatively high amount of structural habitat available (relative to total wetted area), are expected to be present in the study reach and have some compatibility with the unregulated flow regime. For the month of December these species include:

- Striped bass juveniles;
- Striped bass adults;
- Smallmouth bass juveniles;
- Smallmouth bass adults;
- Trichoptera;
- Members of the shallow-slow guild; and
- Members of the deep-slow guild.

Table 5.1.12-1 provides the above species' flow preferences and December's median monthly flow.

5.2 Mussel Habitat Analysis

The riverbed's primarily high critical shear stress, due to large amounts of boulder and bedrock, made comparing relative shear stresses to mussel catch rates (CPUE) ineffective. As a result, shear stress criteria were primarily used to analyze mussel habitat in the study reach. A plot of mussel CPUE vs. shear stress at various flows showed that stations with the highest CPUE tended to have relatively low shear stresses (Figure 4.3.3-2). Study area shear stresses were compared to low flow and high flow thresholds of 20 dynes/cm^2 and 150 dynes/cm^2, respectively, showing how higher flows reduced optimal mussel habitat availability (Figure 4.3.3-3). Results showed that the percent of the wetted study area exceeding the low flow threshold area rapidly increased between 2,000 cfs and 10,000 cfs and then leveled off, while the percent of the wetted study area exceeding the high flow threshold steadily increased between 10,000 cfs and 86,000 cfs.

The low-flow and high-flow shear stress thresholds predict that significant portions of the study area are not suitable for mussel development, particularly at high flows. While the high-flow shear stress thresholds appear to be related to preventing mussels from being carried downstream by current, the mechanisms driving low-flow shear stress thresholds are not entirely clear. Though Allen and Vaughn (2010) found a relationship between low-flow shear stress and mussel richness and abundance, they stated that better relationships were found with high-flow parameters. Thus, it was not clear whether low-flow shear stress plays a biological role in mussel development, or is simply cross-correlated with shear stresses at higher flows. Layzer and Madison (1995) suggest that adult mussel abundance is controlled at least partially by juvenile tolerances, such that adults are more abundant where juvenile development is best. They implied that adult mussels may be more tolerant of habitat changes than juveniles, but this topic was not investigated in their study. Thus, it is possible that the shear stress thresholds are more descriptive of juvenile habitat preferences than adult mussel tolerances.

Shear stress thresholds of 20 dynes/cm^2, 50 dynes/cm^2 and 150 dynes/cm^2 have all been related to mussel richness and abundance, showing considerable variability associated with what is best for mussel development. In addition to shear stress tolerances' variability in literature, using shear stress thresholds developed with data from other rivers and areas of the country may introduce more uncertainty. Allen and Vaughn's (2010) study was conducted on a river with no peaking hydroelectric influences (flood control only) and the Layzer and Madison (1995) study site was completely unregulated. It is not clear in a highly regulated stream how this information would be used to inform flow management decisions.

Mussel habitat is found exclusively on the riverbed, and in the main-channel is generally found behind small-scale local refugia, such as behind bedrock outcrops and large boulders (Pers. Communication, W. Ettinger). This merits consideration that the hydraulic model, while utilizing a dense mesh relative to the study area, does not capture microhabitat behind individual bed features smaller than the mesh size (20-65 ft). Thus, while the model may be appropriate for identifying hydraulic properties and habitat throughout the reach, the results may underestimate the amount of available mussel habitat. Regardless, the CPUE vs. shear stress plots show that model-predicted shear stress relates fairly well to mussel density, indicating that the model results are moderately capable at identifying large-scale mussel distribution.

5.3 Habitat Conclusions

Habitat analyses for most species were conducted using SI curves, and habitat vs. flow curves were developed. Additionally, mussel habitat and habitat persistence analyses were run. A habitat time series analysis was used to compare various flow management scenarios to Baseline conditions in terms of habitat below Conowingo Dam.

There were several areas in the river that appeared to provide high-quality habitat for many species and life stages. These areas included downstream of Rowland Island, near the mouths of Octoraro and Deer Creeks, an area southwest of Bird Island, downstream of Snake Island and in-between Robert, Wood and Spencer Islands. These areas often provided unique combinations of depth, velocity and substrate, providing refugia for species and life stages that are not well suited for the conditions found in the river's main channel. Other than for striped bass, these areas often proved to be the highest quality habitat found in the river for the target species.

While the habitat modeling provided estimates of available habitat at various flows, the river flow available is an important consideration in flow and habitat management decisions. There are four hydroelectric projects on the lower Susquehanna River, three of which are main channel peaking hydroelectric plants (Safe Harbor, Holtwood, Conowingo), one of which is a pumped storage (Muddy Run). All four have the ability to influence the river's flow regime, particularly on a sub-daily scale. The project with the largest hydraulic capacity is Safe Harbor, the farthest upstream project, with a maximum hydraulic capacity of 110,000 cfs. This is greater than the hydraulic capacity of Holtwood (61,460 cfs following expansion construction) and Conowingo (86,000 cfs). Safe Harbor also has no minimum flow release requirements as stipulated in its current license, which expires in 2030. Conowingo has a seasonally-varying minimum flow release, and Holtwood will also provide a minimum flow release beginning no later than 2012. Thus, it is important to consider not only the river's unregulated hydrology, but upstream projects' water availability influences, which can greatly impact the effectiveness of flow management decisions in the lower Susquehanna River.

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TABLE 2.2.1-1: CONOWINGO WY 1988-2009 30-MIN INSTANTANEOUS FLOW EXCEEDENCE PERCENTILES.

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	909,000	909,000	264,000	415,000	498,000	278,000	461,000	235,000	179,000	619,000	262,000	303,000	295,000
5	119,000	164,000	114,000	173,000	187,000	119,000	84,000	68,900	57,500	73,100	84,800	95,900	140,000
10	85,200	117,000	85,200	132,000	126,000	86,800	69,700	56,500	42,900	55,800	74,900	80,900	99,300
15	78,800	89,200	80,000	104,000	102,000	80,500	62,500	46,100	38,400	42,900	59,400	75,900	83,600
20	72,600	81,100	77,200	87,400	87,900	74,400	54,100	36,500	25,400	33,600	45,700	67,700	80,000
25	66,600	78,800	73,100	82,900	83,800	67,800	47,000	27,900	12,900	24,600	36,300	61,600	76,400
30	59,700	74,060	69,900	79,900	80,500	64,830	39,000	19,200	6,960	11,700	29,950	53,600	70,400
35	49,800	68,100	65,500	77,100	77,700	59,700	32,500	8,310	6,550	6,500	23,500	45,900	65,900
40	40,700	61,900	61,600	74,000	74,200	53,800	27,200	7,060	6,400	6,020	16,200	38,900	59,700
45	32,500	52,400	51,500	71,800	71,600	46,000	23,700	6,700	6,250	5,740	7,080	32,100	51,600
50	24,900	43,200	41,900	69,400	69,000	38,600	16,900	6,450	6,110	5,340	5,050	25,400	42,300
55	16,200	33,200	33,700	65,600	65,955	33,000	8,560	6,300	5,930	5,000	4,690	17,900	33,500
60	9,480	26,000	26,200	60,000	62,500	26,200	7,010	6,200	5,790	4,636	4,600	7,010	26,000
65	6,700	18,700	19,800	49,900	54,700	22,200	6,510	6,020	5,690	4,450	4,540	5,190	18,400
70	6,120	7,881	10,100	39,200	44,200	11,800	6,270	5,880	5,550	4,320	4,450	4,720	7,010
75	5,690	4,770	5,538	30,200	33,100	10,100	6,150	5,790	5,390	4,200	4,370	4,550	4,460
80	5,050	3,960	4,320	23,000	24,500	9,580	5,960	5,650	5,190	3,960	4,250	4,450	3,510
85	4,540	1,520	1,680	7,350	13,600	9,270	5,830	5,500	4,950	3,690	3,880	4,320	1,450
90	4,120	1,110	1,140	5,190	12,400	9,110	5,690	5,290	4,680	3,540	3,760	4,000	1,030
95	3,010	958	950	4,500	11,900	8,800	5,440	4,950	3,840	3,140	3,620	3,650	879
100	257	279	257	1,070	10,000	6,200	4,370	3,070	2,200	1,680	950	748	257

TABLE 2.2.1-2: MARIETTA USGS GAGE (#01576000) DAILY AVERAGE FLOW EXCEEDENCE PERCENTILES (CFS), WY 1932-2009.

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	1,040,000	556,000	446,000	700,000	431,000	450,000	1,040,000	223,000	287,000	545,000	252,000	396,000	348,000
5	118,000	127,000	121,000	188,000	196,050	114,150	67,810	41,800	32,515	43,405	65,090	85,045	114,150
10	84,800	90,990	92,000	148,000	146,000	90,200	51,500	30,430	23,100	26,800	41,000	63,300	83,690
15	67,400	71,200	74,710	123,000	123,000	76,200	43,400	24,800	18,700	20,100	29,490	50,630	70,045
20	56,120	59,920	63,200	108,000	105,000	66,320	37,000	21,600	16,600	16,700	22,860	42,440	59,300
25	47,400	50,100	54,325	95,675	93,900	60,300	31,900	19,400	14,800	13,700	19,000	37,000	51,500
30	40,800	43,500	47,610	85,590	85,400	54,300	29,000	17,300	13,100	11,800	16,090	33,230	45,000
35	35,000	38,205	42,600	77,300	77,800	50,100	26,300	16,000	11,700	10,200	13,605	29,900	40,400
40	30,200	34,000	38,600	70,300	71,840	45,800	23,900	14,400	10,600	9,110	11,700	27,100	36,200
45	26,300	30,435	34,665	64,800	66,800	41,400	21,600	13,300	9,590	8,285	10,400	24,600	32,335
50	23,000	27,000	31,000	59,700	62,700	37,650	19,900	12,300	8,690	7,580	9,495	22,300	29,000
55	20,000	24,000	28,135	54,365	58,755	34,300	18,600	11,300	7,900	6,996	8,680	19,400	25,965
60	17,500	21,500	26,200	48,780	54,300	31,900	17,200	10,400	7,368	6,386	7,908	17,200	23,100
65	15,200	19,400	23,800	44,800	50,100	29,000	15,600	9,490	6,710	5,920	7,090	14,765	21,000
70	13,000	17,500	21,700	41,000	46,100	26,300	14,300	8,750	6,190	5,540	6,451	12,800	19,200
75	11,100	16,000	19,400	37,400	42,200	24,100	13,100	7,983	5,740	5,068	5,743	11,200	17,900
80	9,310	14,500	17,160	32,900	38,340	21,800	12,180	7,210	5,350	4,590	5,150	9,508	16,000
85	7,600	13,000	15,045	28,300	34,100	20,100	11,200	6,397	4,886	4,130	4,640	7,809	13,400
90	6,070	11,170	13,000	24,170	30,700	17,800	9,880	5,530	4,360	3,690	4,080	6,080	11,000
95	4,690	9,081	11,000	18,970	25,095	14,900	8,380	4,629	3,760	3,000	3,650	4,980	8,200
100	1,380	4,000	6,000	6,500	15,300	8,680	4,830	2,580	2,610	1,380	1,450	2,100	3,300

TABLE 2.2.1-3: CONOWINGO USGS GAGE (#01578310) DAILY AVERAGE FLOW EXCEEDENCE PERCENTILES (CFS), WY 1968-2009

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	1,120,000	622,000	470,000	462,000	467,000	235,000	1,120,000	213,000	202,000	662,000	245,000	272,000	357,000
5	121,000	131,000	139,000	184,000	188,050	104,000	80,645	50,575	41,300	56,480	84,690	90,320	129,950
10	85,400	93,980	98,500	139,000	144,000	81,100	59,000	37,500	28,280	35,240	57,170	70,410	98,350
15	70,600	76,140	81,420	119,000	116,150	70,685	49,015	31,985	24,100	26,315	42,285	60,215	80,000
20	60,300	62,160	70,860	102,000	102,200	64,000	42,240	28,080	20,600	22,120	32,480	53,600	71,380
25	52,600	53,775	60,500	88,600	89,175	58,700	37,725	25,500	18,400	19,325	26,825	46,800	64,050
30	46,100	47,800	54,240	81,400	82,700	53,400	33,900	23,170	16,300	17,100	22,700	42,500	57,200
35	40,700	42,800	48,890	73,500	76,870	49,300	31,400	20,665	14,900	14,900	20,265	39,035	52,630
40	35,700	38,060	44,800	68,360	70,900	45,760	28,900	18,900	13,300	13,100	17,460	35,200	47,820
45	31,600	33,955	41,060	63,155	66,545	43,000	26,800	17,355	12,000	11,900	15,355	31,700	43,900
50	27,800	30,250	36,800	58,900	61,800	39,400	24,500	15,700	10,650	10,400	13,800	28,700	40,300
55	24,800	27,600	33,500	54,100	57,700	36,245	22,555	14,400	9,489	8,861	12,100	26,000	36,900
60	21,700	25,040	30,840	50,440	53,900	33,200	20,300	13,100	8,380	7,410	10,900	23,460	33,880
65	19,000	22,635	27,900	46,335	50,500	30,700	18,600	11,800	6,837	6,393	9,690	20,200	31,235
70	16,200	20,800	25,680	42,130	45,470	28,030	17,170	10,400	6,143	5,337	8,320	17,700	28,330
75	13,700	18,700	23,050	38,025	42,000	26,200	15,400	8,373	5,663	4,953	6,890	14,775	25,800
80	11,200	16,240	20,700	34,100	38,200	23,520	13,580	6,946	5,290	4,368	4,912	12,400	22,040
85	8,270	13,200	18,490	30,300	34,500	21,100	11,385	6,152	5,002	3,799	4,460	9,459	18,815
90	5,840	10,210	15,500	24,410	29,690	18,100	8,658	5,421	4,490	3,037	3,750	5,807	13,610
95	4,300	5,465	10,790	18,415	24,485	14,005	6,179	4,527	2,702	1,420	1,212	3,838	7,831
100	269	511	758	287	6,090	5,220	622	269	367	363	295	303	777

TABLE 2.2.2-1: INCREMENTAL RIVER REACHES USED TO ESTIMATE UNREGULATED CONOWINGO FLOW. MARIETTA WATERSHED SIZE IS 25,990 MI^2. CONOWINGO WATERSHED SIZE IS 27,100 MI^2.

River Reach	Incremental Drainage Area (mi^2)	Gage Used to Prorate Flows	Gage Proration Factor (Incr. Drainage Area/ Gage Drainage Area)
Marietta-Safe Harbor	100	Manchester, PA	0.196
Safe Harbor-Holtwood	696	Lancaster, PA	2.148
Muddy Run[17]	9.2	Lancaster, PA	0.029
Holtwood-Conowingo	304.8	Lancaster, PA	0.941
Total	1,110		

[17] Muddy Run is part of the Holtwood-Conowingo incremental reach, but was explicitly broken out in the model separately. The Holtwood-Conowingo incremental drainage areas accounts for this.

TABLE 2.2.2-2: CONOWINGO ESTIMATED DAILY AVERAGE UNREGULATED FLOW EXCEEDANCE PERCENTILES, WY 1934-2009

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	1,058,069	562,718	452,536	706,014	439,768	451,923	1,058,069	226,007	199,595	555,083	254,490	398,881	353,075
5	120,856	131,040	123,979	192,806	199,103	115,402	69,826	43,987	33,750	43,622	67,382	86,033	118,143
10	86,715	94,842	94,961	150,195	148,422	91,444	53,137	31,969	24,026	26,710	42,795	64,234	86,577
15	69,143	73,798	77,813	126,139	123,804	77,387	44,356	26,333	19,583	20,313	30,958	51,860	73,422
20	58,021	61,713	65,481	110,520	105,972	67,626	38,131	22,850	17,346	16,949	23,797	43,386	62,020
25	48,894	52,130	56,367	97,286	95,263	61,351	33,289	20,600	15,498	14,053	19,617	37,692	53,782
30	42,016	44,487	49,905	87,924	86,070	55,435	30,130	18,477	13,616	12,234	16,514	33,764	47,654
35	36,107	39,580	44,625	79,579	78,967	51,125	27,262	16,924	12,238	10,586	14,167	30,522	42,309
40	31,375	35,575	40,560	72,324	72,653	46,637	24,898	15,266	11,043	9,482	12,151	27,877	37,514
45	27,322	31,302	36,222	67,131	67,906	42,553	22,670	14,038	10,142	8,685	10,805	25,271	34,077
50	23,818	27,732	32,617	61,744	63,752	38,768	20,661	13,045	9,201	7,995	9,845	22,927	30,672
55	20,778	24,620	29,506	56,991	59,617	35,025	19,243	12,080	8,339	7,402	9,060	20,143	27,619
60	18,205	21,908	27,159	51,367	55,340	32,630	18,118	11,040	7,748	6,761	8,297	17,690	24,740
65	15,779	19,823	24,738	46,930	50,852	29,504	16,576	10,019	7,119	6,249	7,514	15,447	22,125
70	13,546	17,862	22,601	42,912	46,792	26,976	15,030	9,167	6,515	5,822	6,804	13,455	20,392
75	11,599	16,363	20,002	39,457	43,046	24,650	13,737	8,403	6,049	5,408	6,132	11,633	18,376
80	9,726	14,949	17,750	34,825	38,842	22,390	12,676	7,551	5,662	4,877	5,532	10,127	16,393
85	8,022	13,394	15,741	30,157	35,093	20,506	11,654	6,680	5,166	4,382	4,949	8,387	13,806
90	6,409	11,557	13,551	25,813	31,464	18,070	10,195	5,787	4,582	3,913	4,426	6,598	11,410
95	4,991	9,638	11,264	20,786	25,450	15,319	8,670	4,815	3,872	3,283	3,792	5,542	8,519
100	1,504	4,367	6,083	6,765	15,878	8,959	5,003	2,677	2,692	1,504	2,246	2,192	3,572

TABLE 3.2.1-1: TARGET SPECIES, HABITAT GUILD ASSIGNMENTS, AND SPECIES OF SPECIAL CONCERN. NOTE THAT ALL SPAWNING/INCUBATION AND FRY LIFE STAGES ARE CONSIDERED IMMOBILE.

A=Adult, J=Juvenile, F=Fry, S=Spawning

	Habitat Guild Assignment			
Target Species	**Shallow-slow (< 2 ft, < 1 ft/s)**	**Shallow-fast (< 2 ft, > 1 ft/s)**	**Deep slow (> 2 ft, < 1 ft/s)**	**Deep-fast (> 2 ft, > 1 ft/s)**
American shad*	F, J		J	A, S
Hickory shad	F		J, S	A
Blueback herring	F, J		A, S	
Alewife	F, J		A, S	
White perch	F, J	S	A, J	S
Yellow perch	F		A, J, S	
Striped bass *	F, J, S		F, J, S	A, S
Largemouth bass	F, J, S		A, F, J, S	
Smallmouth bass *	F		A, F, J, S	
Walleye			A, J, F	S
Shortnose sturgeon *	F	F	A, J, F	A, F, J, S
Atlantic sturgeon			A, J, F	A, F, J, S
American eel***	J		A, J	J
EPT**	√	√	√	√

*Species of special concern for instream flow assessment.
** Ephemeroptera-Plecoptera-Trichoptera
*** Juvenile refers to elver and yellow eels, while adult refers to silver eels

TABLE 3.2.1-2: SEASONAL PERIODICITY OF OCCURRENCE OF TARGET SPECIES IN THE SUSQUEHANNA RIVER BELOW CONOWINGO DAM. ITALICIZED LIFE STAGES ARE CONSIDERED IMMOBILE. HABITAT GUILDS ARE SHOWN IN PARENTHESES.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
American Shad												
Spawning				■	■	■						
Fry					■	■	■					
Juveniles							■	■	■	■	■	
Adults				■	■	■						
Hickory Shad												
Spawning (Deep-Slow)			■	■	■							
Fry(Shallow-Slow)				■	■	■						
Juveniles (Deep-Slow)						■						
Adults (Deep-Fast)			■	■	■							
Blueback Herring												
Spawning (Deep-Slow)				■	■	■						
Fry (Shallow-Slow)					■	■						
Juveniles (Shallow-Slow)							■	■	■	■		
Adults (Deep-Slow)				■	■	■						
Alewife												
Spawning (Deep-Slow)			■	■	■							
Fry (Shallow-Slow)			■	■	■							
Juveniles (Deep-Slow)						■	■	■	■	■		
Adults (Shallow-Slow)				■	■							
White Perch												
Spawning (Shallow-Fast, Deep-Fast)				■	■	■						
Fry (Shallow-Slow)				■	■	■	■					
Juveniles (Shallow-Slow, Deep-Slow)					■	■	■	■	■	■	■	■
Adults (Deep-Slow)	■	■	■	■	■	■	■	■	■	■	■	■
Yellow Perch												
Spawning (Deep-Slow)			■	■								
Fry (Shallow-Slow)				■	■							
Juveniles (Deep-Slow)						■	■	■	■	■	■	■
Adults (Deep-Slow)	■	■	■	■	■	■	■	■	■	■	■	■
Striped Bass												
Spawning				■	■	■						
Fry				■	■	■	■					
Juveniles						■	■	■	■	■	■	■
Adults	■	■	■	■	■	■	■	■	■	■	■	■

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Largemouth Bass												
Spawning (Shallow-Slow, Deep-Slow)					■	■						
Fry (Shallow-Slow, Deep-Slow)						■	■					
Juveniles (Shallow-Slow, Deep-Slow)								■	■	■	■	■
Adults (Deep-Slow)	■	■	■	■	■	■	■	■	■	■	■	■
Smallmouth Bass												
Spawning					■	■						
Fry						■	■					
Juveniles								■	■	■	■	■
Adults	■	■	■	■	■	■	■	■	■	■	■	■
Walleye												
Spawning (Deep-Fast)			■	■								
Fry (Deep-Slow)				■	■	■						
Juveniles (Deep-Slow)						■	■	■	■	■	■	■
Adults (Deep-Slow)	■	■	■	■	■	■	■	■	■	■	■	■
Shortnose sturgeon												
Spawning				■	■							
Fry					■	■	■					
Juveniles/Adults	■	■	■	■	■	■	■	■	■	■	■	■
Atlantic sturgeon												
Spawning (Deep-Fast)				■	■							
Fry (Deep-Slow, Deep-Fast)					■	■	■					
Juveniles/Adults (Deep-Slow, Deep-Fast)	■	■	■	■	■	■	■	■	■	■	■	■
American eel												
Elver (Shallow-Slow, Deep-Slow, Deep-Fast)				■	■	■	■	■	■	■		
Yellow (Shallow-Slow,Deep-Slow,Deep-Fast)	■	■	■	■	■	■	■	■	■	■	■	■
Silver (Deep-Slow)									■	■	■	■
Alewife floater												
Adults/juveniles	■	■	■	■	■	■	■	■	■	■	■	■
Spawning										■	■	■
Larvae			■	■	■							
Eastern elliptio												
Adults/juveniles	■	■	■	■	■	■	■	■	■	■	■	■
Spawning	■	■	■									
Larvae				■	■	■	■	■				
Fingernail clams												
Adults	■	■	■	■	■	■	■	■	■	■	■	■
Spawning/larvae	■	■	■	■	■	■	■	■	■	■	■	■
Ephemeroptera-Plecoptera-Trichoptera												
all life stages	■	■	■	■	■	■	■	■	■	■	■	■

TABLE 3.2.2-1: SOURCES OF HABITAT SUITABILITY INDICES FOR SPECIES OF SPECIAL CONCERN AND HABITAT-BASED GUILDS

	HSC Source		
Species	**Velocity**	**Depth**	**Substrate**
American shad[1, 2, 3]			
Spawning	Stier and Crance 1985.	Stier and Crance 1985.	ASMFC 2009.
Fry	Stier and Crance 1985.	Stier and Crance 1985.	Stier and Crance 1985.
Juvenile	Stier and Crance 1985.	Ross et al 1993. Greene et al. 2009.	Stier and Crance 1985.
Adult	Stier and Crance 1985.	Stier and Crance 1985.	Stier and Crance 1985.
Shortnose Sturgeon [4]			
Spawning	Crance, J.H. 1986.	Crance, J.H. 1986.	Crance, J.H. 1986.
Fry	Crance, J.H. 1986.	Crance, J.H. 1986.	Crance, J.H. 1986.
Juvenile	Crance, J.H. 1986.	Crance, J.H. 1986.	Crance, J.H. 1986.
Adult	Crance, J.H. 1986.	Crance, J.H. 1986.	Crance, J.H. 1986.
Striped bass [5]			
Spawning	Crance, J.H. 1984.	Crance, J.H. 1984.	Crance, J.H. 1984.
Fry	Crance, J.H. 1984.	Crance, J.H. 1984.	Crance, J.H. 1984.
Juvenile	Crance, J.H. 1984.	Crance, J.H. 1984.	Crance, J.H. 1984.
Adult	Crance, J.H. 1984.	Crance, J.H. 1984.	Crance, J.H. 1984.
Smallmouth bass [6, 7, 8]	Aadland and Kuitunen. 2006.	Aadland and Kuitunen. 2006.	Aadland and Kuitunen. 2006.
Adult	North Carolina Department of Water Resources, RMC (1992);	Angermeier (1987), Ross et al (1987), Todd and Rabeni (1989)	North Carolina Department of Water Resources, RMC (1992)
Juvenile	North Carolina Department of Water Resources, RMC (1992)	North Carolina Department of Water Resources, RMC (1992)	North Carolina Department of Water Resources, RMC (1992)
Fry	North Carolina Department of Water Resources, RMC (1992)	North Carolina Department of Water Resources, RMC (1992)	North Carolina Department of Water Resources, RMC (1992)
Spawning	North Carolina Department of Water Resources, RMC (1992)	North Carolina Department of Water Resources, RMC (1992)	North Carolina Department of Water Resources, RMC (1992)
Shallow-slow guild [9]			
(< 2 ft, < 1 ft/sec)	Leonard and Orth (1988); Aadland (1993); Normandeau (2000); Progress Energy (2003); DTA (2005)		
Shallow-fast guild [9]			
(< 2 ft, > 1 ft/sec)	Aadland (1993); Normandeau (2000); Progress Energy (2003); DTA (2005)		
Deep-slow [9]			
(> 2 ft, < 1ft/sec)	Aadland (1993); Normandeau (2000); Progress Energy (2003); DTA (2005)		
Deep-fast [9]			
(> 2 ft, > 1 ft/sec)	Aadland (1993); Normandeau (2000); Progress Energy (2003); DTA (2005)		
EPT [10]	Gore et al. 2001		

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TABLE 3.2.3-1: SUBSTRATE CLASSIFICATION SYSTEM. CLASSIFICATIONS BASED ON PREVIOUS IFIM STUDIES AND THE PROFESSIONAL JUDGMENT OF EXELON AND STAKEHOLDER BIOLOGISTS.

Code	Substrate Type	Size Class (metric)	Size Class (English)
1	Detritus/Organic	NA	NA
2	Mud/soft clay	NA	NA
3	Silt	< 0.062 mm	< 0.00244 in
4	Sand	0.062 - 2 mm	0.00244 - 0.0787 in
5	Gravel	2 - 64 mm	0.0787 - 2.52 in
6	Cobble/rubble	64 - 250 mm	2.52 - 9.84 in
7	Boulder	250 - 4000 mm	9.84 - 157.5 in
8	Bedrock	NA	NA

TABLE 3.8-1: SUMMARY OF MODELED PARAMETERS FOR THE BASELINE AND THREE PRODUCTION RUNS

Run Name	Leakage Credit/Trigger	Hourly Minimum Flow (cfs)	Hourly Maximum Flow (cfs)	Minimum Pond Level (ft NGVD 1929)	Hourly Flow Change (cfs/hr)
Baseline	800 cfs if $Q_{mar} < Q_{FERC} + 1000$ cfs	12/1 – 2/29: 1,750 cfs 3/1 – 3/31: 3,500 cfs 4/1 – 4/30: 10,000 cfs 5/1 – 5/31: 7,500 cfs 6/1 – 9/14: 5,000 cfs 9/15 – 11/30: 3,500 cfs	Year-Round: 86,000	Year-Round: 104.7 Weekends Mem Day to lab Day: 107.2	Conowingo: 40,000 Muddy Run: 15,000
SRBC-006	800 cfs always	1/1 – 1/31: 10,900 2/1 – 2/31: 12,500 3/1 – 3/31: 24,100 4/1 – 4/30: 29,300 5/1 – 5/31: 17,100 6/1 – 6/30: 9,700 7/1 – 7/31: 5,400 8/1 – 8/31: 4,300 9/1 – 9/30: 3,500 10/1 – 10/31: 4,200 11/1 – 11/30: 6,100 12/1 – 12/31: 10,500	4/1 – 11/30: 65,000 12/1 – 3/31: 86,000	Year-Round: 104.7 Weekends Mem Day to lab Day: 107.2	Conowingo: 40,000 Muddy Run: 15,000
SRBC-007	800 cfs always	Marietta flow + intervening inflow	Marietta flow + intervening inflow	Year-Round: 104.7 Weekends Mem Day to lab Day: 107.2	Conowingo: N/A Muddy Run: 15,000
SRBC-008	800 cfs always	3/1 – 6/14: 24,000 6/15 – 9/14: 14,100 9/15 – 2/29: 4,000	4/1 – 11/30: 65,000 12/1 – 3/31: 86,000	Year-Round: 104.7 Weekends Mem Day to lab Day: 107.2	Conowingo: 10,000 Muddy Run: 15,000

TABLE 4.2.1-1: HYDRAULIC MODEL CALIBRATION (40,000 CFS) RESULTS

Range (+/-)	Percentage of Nodes within Range
0.15 ft	72
0.20 ft	85
0.25 ft	93
0.30 ft	96
0.50 ft	100

TABLE 4.2.1-2: HYDRAULIC MODEL CALIBRATION (5,000 CFS, 20,000 CFS, 60,000 CFS AND 80,000 CFS) RESULTS

	Site 2	Site 3	Site 4
Calibration = 5,000 cfs			
Observed WSE (ft)	13.10	9.24	5.38
Predicted WSE (ft)	12.85	9.15	5.28
Difference	-0.25	-0.09	-0.10
Calibration = 20,000 cfs			
Observed WSE (ft)	15.08	10.76	7.22
Predicted WSE (ft)	14.99	10.69	7.31
Difference	-0.09	-0.07	0.09
Calibration = 60,000 cfs			
Observed WSE (ft)	17.88	13.60	10.09
Predicted WSE (ft)	18.01	13.68	10.23
Difference	0.13	0.08	0.14
Calibration = 80,000 cfs			
Observed WSE (ft)	19.23	15.05	11.28
Predicted WSE (ft)	19.25	14.80	11.38
Difference	0.02	0.07	0.10
Refer to Figure 3.3.1-2 to see water level monitor locations			

TABLE 4.3-1: PERCENTAGE OF PEAK WUA RELATIVE TO TOTAL WETTED AREA

Species/Life Stage	Maximum WUA Flow (cfs)	Habitat Area at Maximum WUA Flow (ft^2)	Total Wetted Area at Maximum WUA Flow (ft^2)	% of Available Habitat at Max WUA Flow
American Shad:				
Spawning & Inc.	40,000	24,052,704	72,189,772	33.3
Fry	30,000	17,990,435	68,985,301	26.1
Juvenile	10,000	21,651,763	67,344,789	32.2
Adult	40,000	26,204,622	72,189,772	36.3
Shortnose Sturgeon:				
Spawning & Inc.	50,000	14,048,270	73,143,811	19.2
Fry	30,000	848,538	68,985,301	1.2
Juvenile	30,000	1,431,622	68,985,301	2.1
Adult	30,000	1,431,622	68,985,301	2.1
Striped Bass:				
Spawning & Inc.	50,000	56,216,898	73,143,811	76.9
Fry	50,000	55,545,960	73,143,811	75.9
Juvenile	40,000	30,036,145	72,189,772	41.6
Adult	80,000	63,530,991	75,027,993	84.7
Smallmouth Bass:				
Spawning & Inc.	5,000	1,141,787	66,071,508	1.7
Fry	2,000*	3,611,296	64,268,929	5.6
Juvenile	5,000	26,005,058	66,071,508	39.4
Adult	15,000	36,373,846	68,088,618	53.4
Macroinvertebrates				
Ephemeroptera	5,000	6,052,996	66,071,508	9.2
Plecoptera	5,000	4,432,285	66,071,508	6.7
Trichoptera	10,000	12,751,836	67,344,789	18.9
Habitat Guilds				
Shallow Slow	2,000*	29,171,737	64,268,929	45.4
Shallow Fast	2,000*	1,079,340	64,268,929	1.7
Deep Slow	5,000	34,257,996	66,071,508	51.8
Deep Fast	20,000	1,219,290	68,985,301	1.8

*Indicates that the flow range was limited by the lowest or highest production run flow, thus the true flow range providing this habitat falls outside of the modeled flows and is greater than shown.

TABLE 4.3.3-1: MUSSEL SUBSTRATE CODES AND CORRESPONDING CRITICAL SHEAR STRESS VALUES[18].

Substrate Type	Code	Size Class (metric)	Size Class (English)	Shield's Parameter (θ_c)	Estimated D_{50} (mm)	τ_c (dynes/cm^2)	τ_c (N/m^2)	τ_c (lb/ft^2)
Detritus/Organic	1	NA	NA	NA	NA	NA	NA	NA
Mud/soft clay	2	NA	NA	NA	NA	NA	NA	NA
Silt	3	< 0.062 mm	< 0.00244 in	0.25	0.016	0.65	0.065	0.0014
Sand	4	0.062 - 2 mm	0.00244 - 0.0787 in	0.109	0.062	1.09	0.109	0.0023
Gravel	5	2 - 64 mm	0.0787 - 2.52 in	0.039	2	12.6	1.26	0.026
Cobble/rubble	6	64 - 250 mm	2.52 - 9.84 in	0.052	64	534	53.4	1.11
Boulder	7	250 – 4,000 mm	9.84 - 157.5 in	0.054	250	2,186	219	4.56
Bedrock - US of Robert I.	8a	64-4,000 mm*	2.52 - 157.5 in	0.054	213	1,862	186	3.89
Bedrock - DS of Robert I.	8b	2-4,000 mm**	0.787 - 157.5 in	0.054	191	1,671	167	3.49

* For D_{50} estimations only, bedrock upstream of Robert Island was assumed to contain substrate ranging from cobble/rubble to boulders

** For D_{50} estimations only, bedrock downstream of Robert Island was assumed to contain substrate ranging from gravel to boulders

[18] Field observations and local knowledge indicate that non-dominant substrates are slightly finer in tidally-influenced bedrock-dominated areas than non-tidally influenced bedrock-dominated areas, thus they were broken into two categories for the mussel analysis only..

TABLE 5.1-1: FLOWS PROVIDING PERCENTAGES OF MAXIMUM WEIGHTED USABLE AREA (WUA)

Species/Life Stage	Months Present	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)
American Shad:						
Spawning & Inc.	Apr-Jun	40,000	24,200 – 61,325	18,144 – 72,765	14,472 – 82,757	11,801 – 86,000*
Fry	May-Jul	30,000	14,716 – 43,771	10,703 – 55,000	7,744 – 67,028	5,513 – 80,335
Juvenile	Jul-Nov	10,000	4,011 – 29,062	2,670 – 42,383	2,000* – 52,641	2,000* – 65,469
Adult	Apr-Jun	40,000	25,090 – 69,495	18,332 – 84,715	13,861 – 86,000*	10,166 – 86,000*
Shortnose Sturgeon:						
Spawning & Inc.	Apr-May	50,000	24,234 – 86,000*	16,997 – 86,000*	13,008 – 86,000*	9,872 – 86,000*
Fry	May-Jul	30,000	16,917 – 62,164	11,835 – 79,017	8,546 – 86,000*	6,424 – 86,000*
Juvenile	All	30,000	14,068 – 54,906	9,240 – 77,199	6,228 – 86,000*	4,078 – 86,000*
Adult	All	30,000	14,068 – 54,906	9,240 – 77,199	6,228 – 86,000*	4,078 – 86,000*
Striped Bass:						
Spawning & Inc.	Apr-Jun	50,000	32,730 – 77,550	25,977 – 86,000*	20,450 – 86,000*	16,272 – 86,000*
Fry	Apr-Jul	50,000	34,705 – 76,746	27,846 – 86,000*	22,977 – 86,000*	18,547 – 86,000*
Juvenile	Jun-Dec	40,000	20,968 – 64,890	12,777 – 76,387	7,961 – 86,000*	5,290 – 86,000*
Adult	All	80,000	38,584 – 86,000*	28,570 – 86,000*	21,450 – 86,000*	16,057 – 86,000*
Smallmouth Bass:						
Spawning & Inc.	May-Jun	5,000	2,000* – 8,262	2,000* – 10,853	2,000* – 13,430	2,000* – 16,725
Fry	Jun-Jul	2,000*	2,000* – 2,556	2,000* – 3,111	2,000* – 3,778	2,000* – 4,703
Juvenile	Aug-Dec	5,000	2,000* – 10,552	2,000* – 14,474	2,000* – 18,051	2,000* – 21,757
Adult	All	15,000	6,737 – 24,531	4,623 – 33,522	3,127 – 44,491	2,000* – 58,145
Macroinvertebrates						
Ephemeroptera (Mayfly)	All	5,000	3,190 – 7,823	2,469 – 9,340	2,000* – 11,168	2,000* – 13,235
Plecoptera (Stonefly)	All	5,000	2,000* – 8,067	2,000* – 10,404	2,000* – 13,217	2,000* – 16,828
Trichoptera (Caddisfly)	All	10,000	4,289 – 17,762	3,038 – 23,884	2,000* – 29,890	2,000* – 36,612
Habitat Guilds						
Shallow Slow	All	2,000*	2,000* – 2,726	2,000* – 3,452	2,000* – 4,098	2,000* – 4,740
Shallow Fast	Apr-Jun	2,000*	2,000* – 3,143	2,000* – 4,007	2,000* – 4,743	2,000* – 5,921
Deep Slow	All	5,000	2,703 – 8,574	2,000* – 10,428	2,000* – 12,565	2,000* – 14,702
Deep Fast	All	20,000	14,376 – 22,424	12,866 – 24,848	11,355 – 27,271	9,888 – 26,695

*Indicates that the flow range was limited by the lowest or highest production run flow, thus the true flow range providing this habitat falls outside of the modeled flows and is greater than shown.

TABLE 5.1-2: PERCENTAGE OF THE MAXIMUM WEIGHTED USABLE AREA (WUA) FOR VARIOUS FLOWS

Species/Life Stage	Months Present	Maximum WUA Flow (cfs)	Maximum WUA (ft^2)	3,500 cfs	5,000 cfs	7,500 cfs	10,000 cfs	15,000 cfs	20,000 cfs	40,000 cfs	60,000 cfs	70,000 cfs	80,000 cfs	86,000 cfs
American Shad														
Spawning & Inc.	Apr-Jun	40,000	24,052,704	17.2%	26.3%	40.8%	53.3%	72.0%	84.7%	100.0%	91.1%	82.8%	72.8%	66.7%
Fry	May-Jul	30,000	17,990,453	48.9%	57.6%	69.1%	78.2%	90.7%	97.5%	93.4%	75.6%	67.6%	60.2%	56.1%
Juvenile	Jul-Nov	10,000	21,651,763	87.8%	94.2%	98.4%	100.0%	99.7%	97.3%	82.5%	64.0%	56.7%	49.9%	46.0%
Adult	Apr-Jun	40,000	26,204,622	35.2%	41.4%	51.1%	59.6%	73.1%	83.5%	100.0%	95.1%	89.7%	83.3%	79.1%
Shortnose Sturgeon														
Spawning & Inc.	Apr-May	50,000	14,048,270	24.1%	34.3%	49.0%	60.6%	76.2%	85.7%	99.5%	99.0%	96.6%	93.2%	90.6%
Fry	May-Jul	30,000	848,538	41.7%	52.1%	65.9%	75.7%	87.5%	94.0%	98.9%	91.3%	85.4%	79.4%	77.1%
Juvenile	All	30,000	1,431,622	56.8%	65.2%	75.0%	82.2%	91.8%	96.7%	96.7%	87.7%	83.4%	78.7%	76.6%
Adult	All	30,000	1,431,622	56.8%	65.2%	75.0%	82.2%	91.8%	96.7%	96.7%	87.7%	83.4%	78.7%	76.6%
Striped bass														
Spawning & Inc.	Apr-Jun	50,000	56,216,898	19.1%	24.9%	33.8%	42.1%	56.9%	69.2%	97.2%	97.9%	93.3%	88.9%	84.0%
Fry	Apr-Jul	50,000	55,545,960	13.2%	18.4%	26.9%	35.2%	50.5%	63.9%	96.3%	98.3%	93.8%	88.2%	84.6%
Juvenile	Jun-Dec	40,000	30,036,145	49.8%	58.9%	68.8%	75.4%	83.7%	89.3%	100.0%	93.9%	85.9%	76.6%	71.0%
Adult	All	80,000	63,530,991	18.9%	25.7%	35.9%	44.5%	57.9%	68.0%	91.3%	98.8%	99.7%	100.0%	99.9%
Smallmouth bass														
Spawning & Inc.	May-Jun	5,000	1,141,787	98.4%	100.0%	92.9%	83.3%	63.9%	52.6%	37.1%	29.4%	26.2%	23.8%	22.4%
Fry	Jun-Jul	2,000*	3,611,296	73.0%	56.8%	42.4%	35.4%	27.6%	24.0%	28.7%	25.6%	24.2%	22.2%	22.1%
Juvenile	Aug-Dec	5,000	26,005,058	99.5%	100.0%	96.7%	91.4%	78.7%	64.5%	23.3%	14.1%	13.2%	12.2%	11.7%
Adult	All	15,000	36,373,846	72.9%	82.4%	93.3%	98.9%	100.0%	95.4%	73.6%	58.7%	52.5%	46.7%	43.6%
Macroinvertebrates														
Ephemeroptera	All	5,000	6,052,996	94.3%	100.0%	92.1%	75.7%	51.5%	39.2%	25.1%	18.8%	16.2%	14.4%	13.4%
Plecoptera	All	5,000	4,432,285	99.4%	100.0%	92.5%	81.4%	63.7%	53.7%	36.5%	26.6%	23.1%	20.4%	19.2%
Trichoptera	All	10,000	12,751,836	85.2%	94.3%	100.0%	99.9%	94.4%	86.5%	55.0%	34.6%	28.7%	24.9%	23.1%
Habitat Guilds														
Shallow-Slow	All	2,000*	29,171,737	79.3%	55.9%	27.7%	15.6%	8.3%	7.1%	9.8%	6.5%	5.4%	4.5%	3.8%
Shallow-Fast	Apr-Jun	2,000*	1,079,340	86.9%	66.5%	48.8%	33.9%	19.0%	15.0%	8.5%	7.3%	5.6%	4.1%	4.2%
Deep-Slow	All	5,000	34,257,996	95.4%	100.0%	96.0%	82.0%	58.6%	41.9%	18.9%	18.2%	16.8%	15.5%	15.2%
Deep-Fast	All	20,000	1,219,290	6.0%	14.4%	38.2%	61.0%	94.1%	100.0%	26.7%	6.6%	5.8%	6.0%	5.9%
	* Indicates that the flow range was limited by the lowest production run flow													

TABLE 5.1.1-1: SELECT JANUARY SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
Striped Bass						
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	27,732
Smallmouth Bass						
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	27,732
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	27,732
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	27,732
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	27,732
*Indicates that the flow range was limited by the lowest or highest production run flow						

TABLE 5.1.2-1: SELECT FEBRUARY SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
Striped Bass						
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	32,617
Smallmouth Bass						
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	32,617
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	32,617
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	32,617
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	32,617
*Indicates that the flow range was limited by the lowest or highest production run flow						

TABLE 5.1.3-1: SELECT MARCH SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
Striped Bass						
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	61,744
Smallmouth Bass						
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	61,744
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	61,744
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	61,744
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	61,744
*Indicates that the flow range was limited by the lowest or highest production run flow						

TABLE 5.1.4-1: SELECT APRIL SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
American Shad						
Spawning	40,000	24,200-61,325	18,144-72,765	14,472-82,757	11,801-86,000*	63,752
Adult	40,000	25,090-69,495	18,332-84,715	13,861-86,000*	10,166-86,000*	63,752
Shortnose Sturgeon						
Spawning	50,000	24,234-86,000*	16,997-86,000*	13,008-86,000*	9,872-86,000*	63,752
Striped Bass						
Spawning	50,000	32,730-77,550	25,977-86,000*	20,450-86,000*	16,272-86,000*	63,752
Fry	50,000	34,705-76,746	27,846-86,000*	22,977-86,000*	18,547-86,000*	63,752
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	63,752
Smallmouth Bass						
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	63,752
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	63,752
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	63,752
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	63,752
*Indicates that the flow range was limited by the lowest or highest production run flow						

TABLE 5.1.5-1: SELECT MAY SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
American Shad						
Spawning	40,000	24,200-61,325	18,144-72,765	14,472-82,757	11,801-86,000*	38,768
Fry	30,000	14,716-43,771	10,703-55,000	7,744-67,028	5,513-80,335	38,768
Adult	40,000	25,090-69,495	18,332-84,715	13,861-86,000*	10,166-86,000*	38,768
Shortnose Sturgeon						
Spawning	50,000	24,234-86,000*	16,997-86,000*	13,008-86,000*	9,872-86,000*	38,768
Striped Bass						
Spawning	50,000	32,730-77,550	25,977-86,000*	20,450-86,000*	16,272-86,000*	38,768
Fry	50,000	34,705-76,746	27,846-86,000*	22,977-86,000*	18,547-86,000*	38,768
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	38,768
Smallmouth Bass						
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	38,768
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	38,768
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	38,768
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	38,768
*Indicates that the flow range was limited by the lowest or highest production run flow						

TABLE 5.1.6-1: SELECT JUNE SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
American Shad						
Spawning	40,000	24,200-61,325	18,144-72,765	14,472-82,757	11,801-86,000*	20,661
Fry	30,000	14,716-43,771	10,703-55,000	7,744-67,028	5,513-80,335	20,661
Adult	40,000	25,090-69,495	18,332-84,715	13,861-86,000*	10,166-86,000*	20,661
Striped Bass						
Spawning	50,000	32,730-77,550	25,977-86,000*	20,450-86,000*	16,272-86,000*	20,661
Fry	50,000	34,705-76,746	27,846-86,000*	22,977-86,000*	18,547-86,000*	20,661
Juvenile	40,000	20,968-64,890	12,777-76387	7,961-86,000*	5,290-86,000*	20,661
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	20,661
Smallmouth Bass						
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	20,661
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	20,661
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	20,661
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	20,661
*Indicates that the flow range was limited by the lowest or highest production run flow						

TABLE 5.1.7-1: SELECT JULY SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
American Shad						
Fry	30,000	14,716-43,771	10,703-55,000	7,744-67,028	5,513-80,335	13,045
Juvenile	10,000	4,011-29,652	2,670-42,383	2,000*-52,641	2,000*-65,469	13,045
Striped Bass						
Fry	50,000	34,705-76,746	27,846-86,000*	22,977-86,000*	18,547-86,000*	13,045
Juvenile	40,000	20,968-64,890	12,777-76387	7,961-86,000*	5,290-86,000*	13,045
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	13,045
Smallmouth Bass						
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	13,045
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	13,045
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	13,045
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	13,045

*Indicates that the flow range was limited by the lowest or highest production run flow

TABLE 5.1.8-1: SELECT AUGUST SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
American Shad						
Juvenile	10,000	4,011-29,652	2,670-42,383	2,000*-52,641	2,000*-65,469	9,201
Striped Bass						
Juvenile	40,000	20,968-64,890	12,777-76387	7,961-86,000*	5,290-86,000*	9,201
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	9,201
Smallmouth Bass						
Juvenile	5,000	2,000*-10,552	2,000*-14,474	2,000*-18,051	2,000*-21,757	9,201
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	9,201
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	9,201
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	9,201
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	9,201
*Indicates that the flow range was limited by the lowest or highest production run flow						

TABLE 5.1.9-1: SELECT SEPTEMBER SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
American Shad						
Juvenile	10,000	4,011-29,652	2,670-42,383	2,000*-52,641	2,000*-65,469	7,995
Striped Bass						
Juvenile	40,000	20,968-64,890	12,777-76387	7,961-86,000*	5,290-86,000*	7,995
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	7,995
Smallmouth Bass						
Juvenile	5,000	2,000*-10,552	2,000*-14,474	2,000*-18,051	2,000*-21,757	7,995
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	7,995
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	7,995
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	7,995
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	7,995

*Indicates that the flow range was limited by the lowest or highest production run flow

TABLE 5.1.10-1: SELECT OCTOBER SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
American Shad						
Juvenile	10,000	4,011-29,652	2,670-42,383	2,000*-52,641	2,000*-65,469	9,845
Striped Bass						
Juvenile	40,000	20,968-64,890	12,777-76387	7,961-86,000*	5,290-86,000*	9,845
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	9,845
Smallmouth Bass						
Juvenile	5,000	2,000*-10,552	2,000*-14,474	2,000*-18,051	2,000*-21,757	9,845
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	9,845
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	9,845
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	9,845
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	9,845
*Indicates that the flow range was limited by the lowest or highest production run flow						

TABLE 5.1.11-1: SELECT NOVEMBER SPECIES/LIFE STAGES

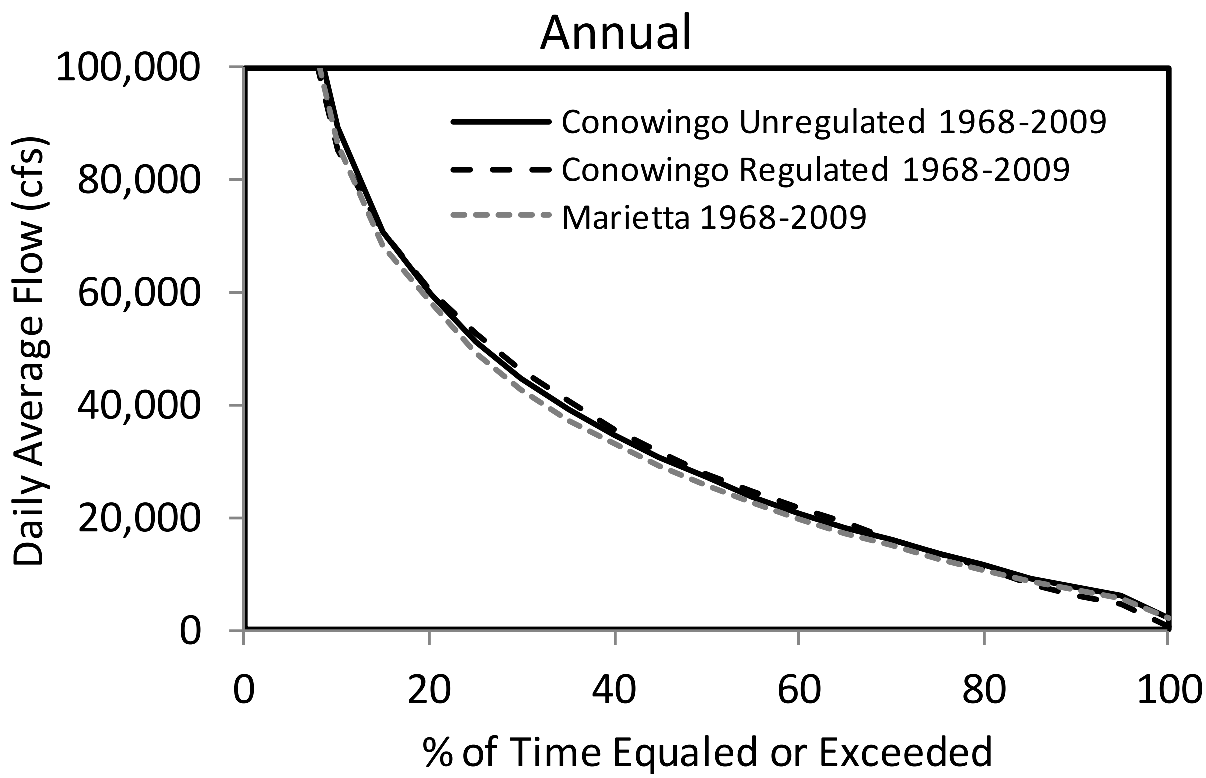
Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
American Shad						
Juvenile	10,000	4,011-29,652	2,670-42,383	2,000*-52,641	2,000*-65,469	22,927
Striped Bass						
Juvenile	40,000	20,968-64,890	12,777-76387	7,961-86,000*	5,290-86,000*	22,927
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	22,927
Smallmouth Bass						
Juvenile	5,000	2,000*-10,552	2,000*-14,474	2,000*-18,051	2,000*-21,757	22,927
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	22,927
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	22,927
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	22,927
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	22,927

*Indicates that the flow range was limited by the lowest or highest production run flow

TABLE 5.1.12-1: SELECT DECEMBER SPECIES/LIFE STAGES

Species/Life Stage	Flow at Maximum WUA (cfs)	Flow Range Providing 90% of Maximum WUA (cfs)	Flow Range Providing 80% of Maximum WUA (cfs)	Flow Range Providing 70% of Maximum WUA (cfs)	Flow Range Providing 60% of Maximum WUA (cfs)	Median Monthly Unregulated Flow (cfs)
Striped Bass						
Juvenile	40,000	20,968-64,890	12,777-76387	7,961-86,000*	5,290-86,000*	30,672
Adult	80,000	38,584-86,000*	28,570-86,000*	21,450-86,000*	16,057-86,000*	30,672
Smallmouth Bass						
Juvenile	5,000	2,000*-10,552	2,000*-14,474	2,000*-18,051	2,000*-21,757	30,672
Adult	15,000	6,737-24,531	4,623-33,522	3,127-44,491	2,000*-58,145	30,672
Macroinvertebrates						
Caddisfly	7,500	4,289-17,762	3,038-23,884	2,150-29,890	2,000*-36,612	30,672
Guilds						
Shallow-Slow	2,000*	2,000*-2,726	2,000*-3452	2,000*-4,098	2,000*-4,740	30,672
Deep-Slow	5,000	2,703-8,574	2,000*-10428	2,000*-12,565	2,000*-14,702	30,672
*Indicates that the flow range was limited by the lowest or highest production run flow						

FIGURE 2.2.2-1: ANNUAL DAILY AVERAGE FLOW DURATION CURVE COMPARISON OF MARIETTA USGS GAGE, CONOWINGO USGS GAGE AND ESTIMATED CONOWINGO UNREGULATED FLOWS. PERIOD OF RECORD: WATER YEAR 1968-2009.



Exelon.

N

0 1,700 3,400 6,800 10,200 Feet

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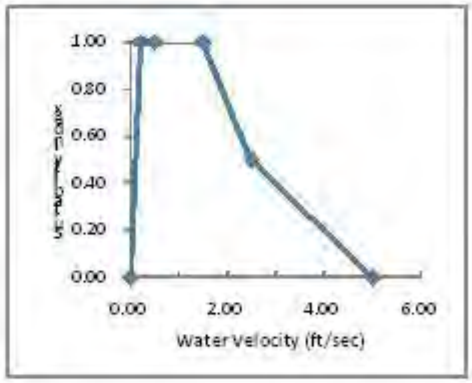
Figure 3.1-1
IFIM Study Area Map. Study Reach Extends From Conowingo Dam to Downstream Tip of Spencer Island

1 inch = 0.56 miles

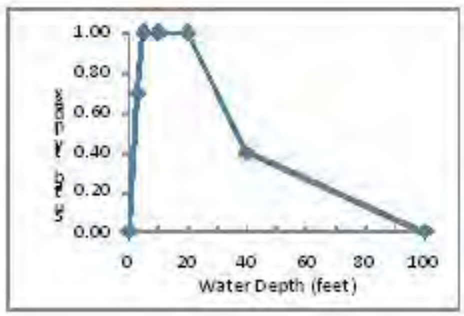
Path: X:\GISMaps\project_maps\study_plan\conowingo\Study_3.16\Figure_3_1_1.mxd

FIGURE 3.2.2-1: SHORTNOSE STURGEON, JUVENILE, HSI CURVES FOR DEPTH, VELOCITY AND SUBSTRATE

Proposed Final	
Velocity	SI Value
0.00	0.00
0.20	1.00
0.50	1.00
1.50	1.00
2.50	0.50
5.00	0.00



Proposed Final	
Depth	SI Value
0.00	0.00
3.00	0.70
5.00	1.00
10.00	1.00
20.00	1.00
40.00	0.40
100.00	0.00



Code	Final SI Value	Type
1	0.00	Detritus/Organic
2	0.40	Mud/soft clay
3	0.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	0.60	Cobble/rubble
7	0.10	Boulder
8	0.00	Bedrock

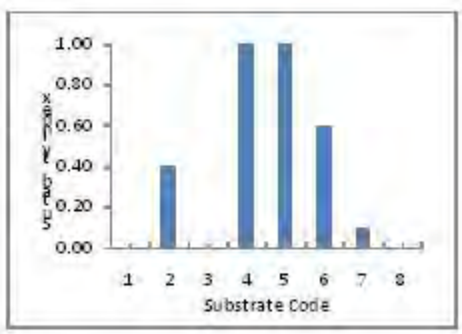


FIGURE 3.2.2-2: COMPARISON OF ORIGINAL AND UPDATED JUVENILE AMERICAN SHAD DEPTH HSI CRITERIA

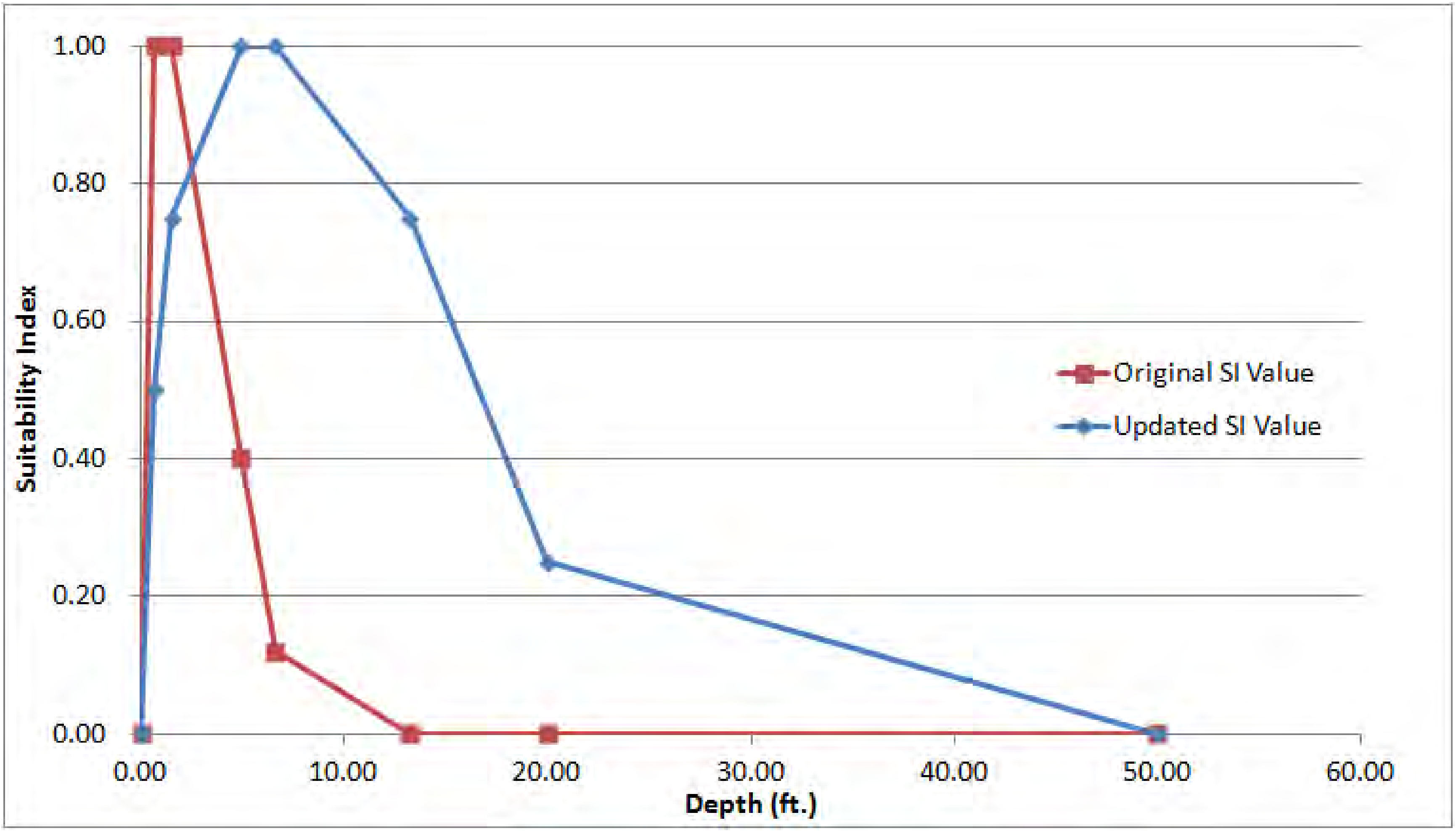


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Figure 3.3.1-1:
Bathymetry Data Collection Transects

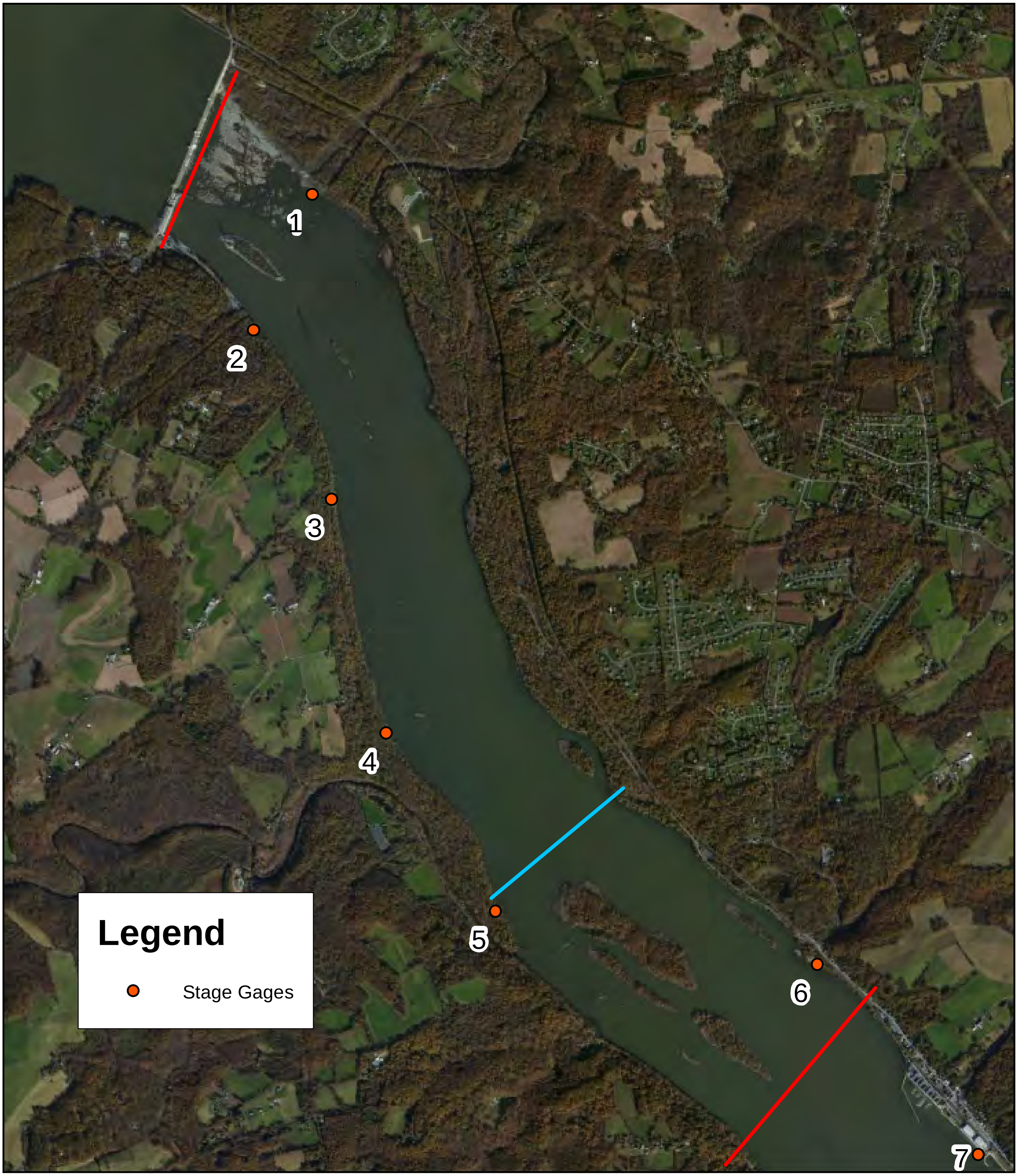
Exelon

N

1 inch = 0.5 miles

0 0.25 0.5 1 Miles

Path: X:\GISMaps\project_maps\study_plan\conowingo\Study_3.16\3.16 Figure 3.3.1-1.mxd



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PROJECT NO. 405

Figure 3.3.1-2
Stage Gages Below Conowingo Dam. The Blue Line Indicates The Approximate Tidal Boundaries.

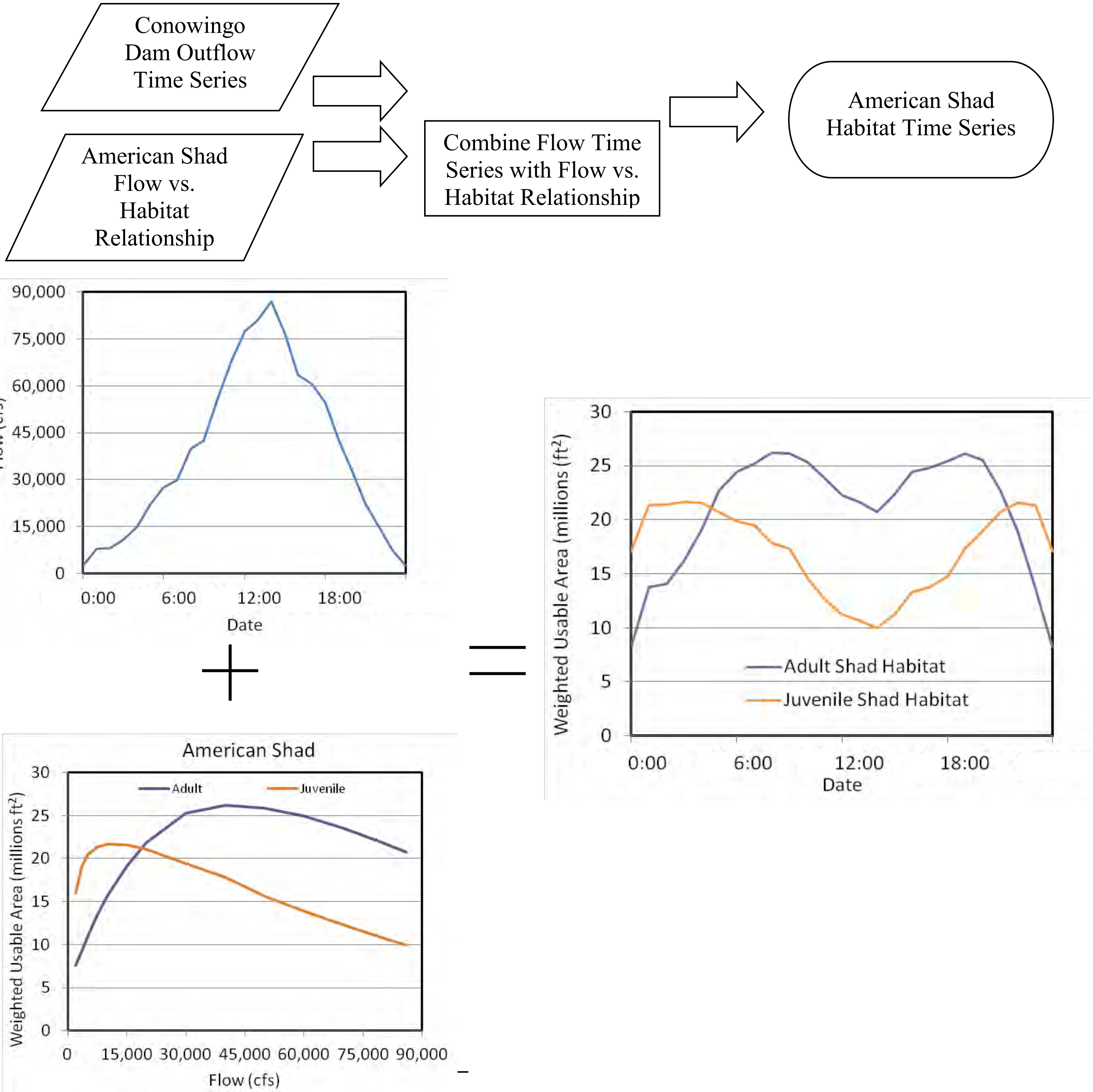
0 1,700 3,400 6,800 10,200 Feet

1 inch = 0.56 miles

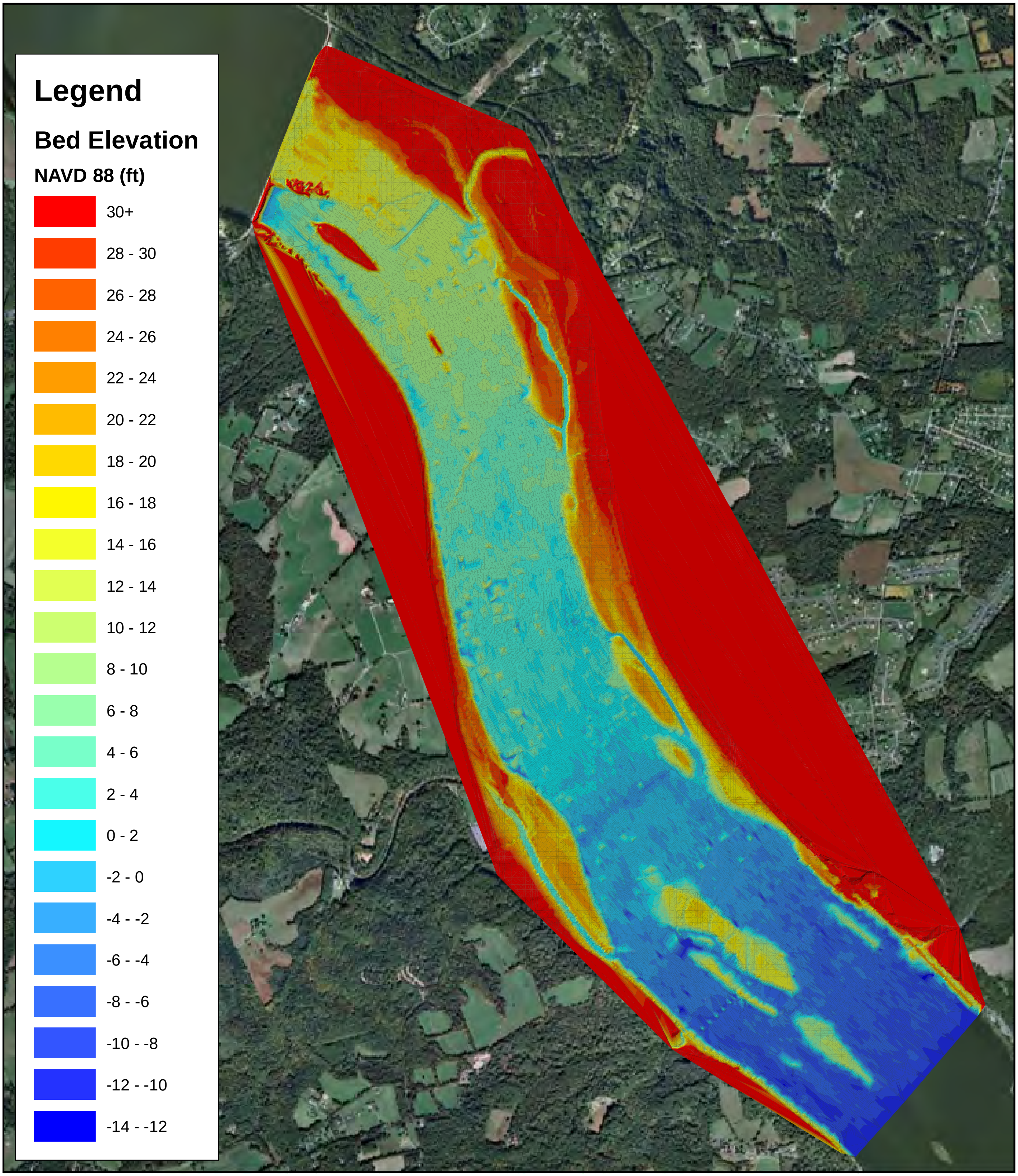
Path: X:\GISMaps\project_maps\study_plan\conowingo\Study_3.16\figure_3_3_1_2.mxd

Figure 3.4.1-1

FIGURE 3.8-1: HABITAT TIME SERIES SCHEMATIC/EXAMPLE[19].



[19] American shad juvenile and adult life stages are shown for habitat contrast, even though they do not occur at the same time period.



N

0 1,700 3,400 6,800 10,200 Feet

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PROJECT NO. 405

Figure 4.1-1
Bathymetric and Topographic Map of the Study Reach

1 inch = 0.55 miles

Path: X:\GISMaps\project_maps\study_plan\conowingo\Study_3.16\Figure_4_1_1.mxd

FIGURE 4.2.1-1: HISTOGRAM SHOWING MODEL CALIBRATION ERROR DISTRIBUTION OF 6935 CALIBRATION POINTS

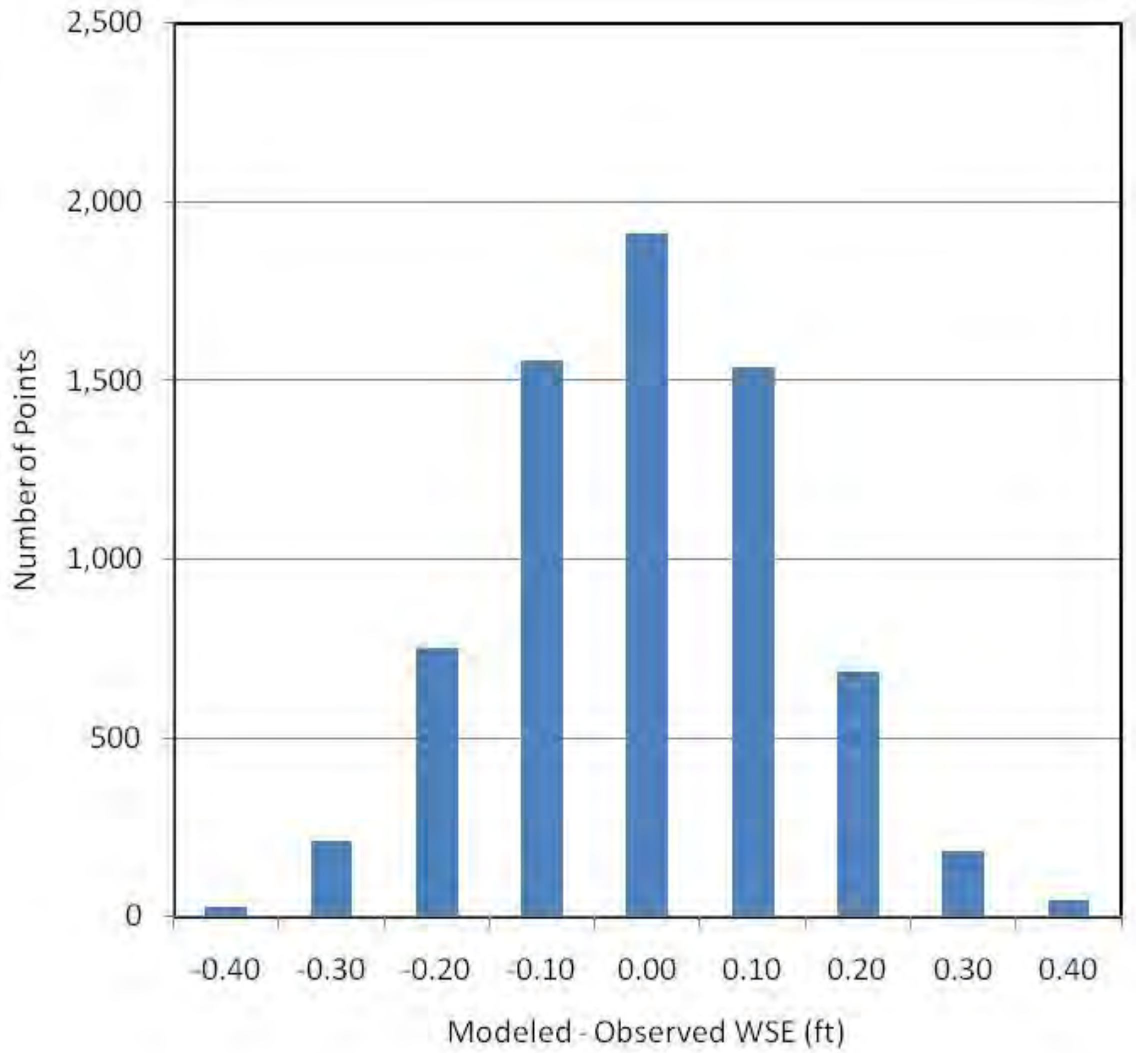


FIGURE 4.2.1-2: HISTOGRAM SHOWING VELOCITY ERROR DISTRIBUTION OF 6935 CALIBRATION POINTS

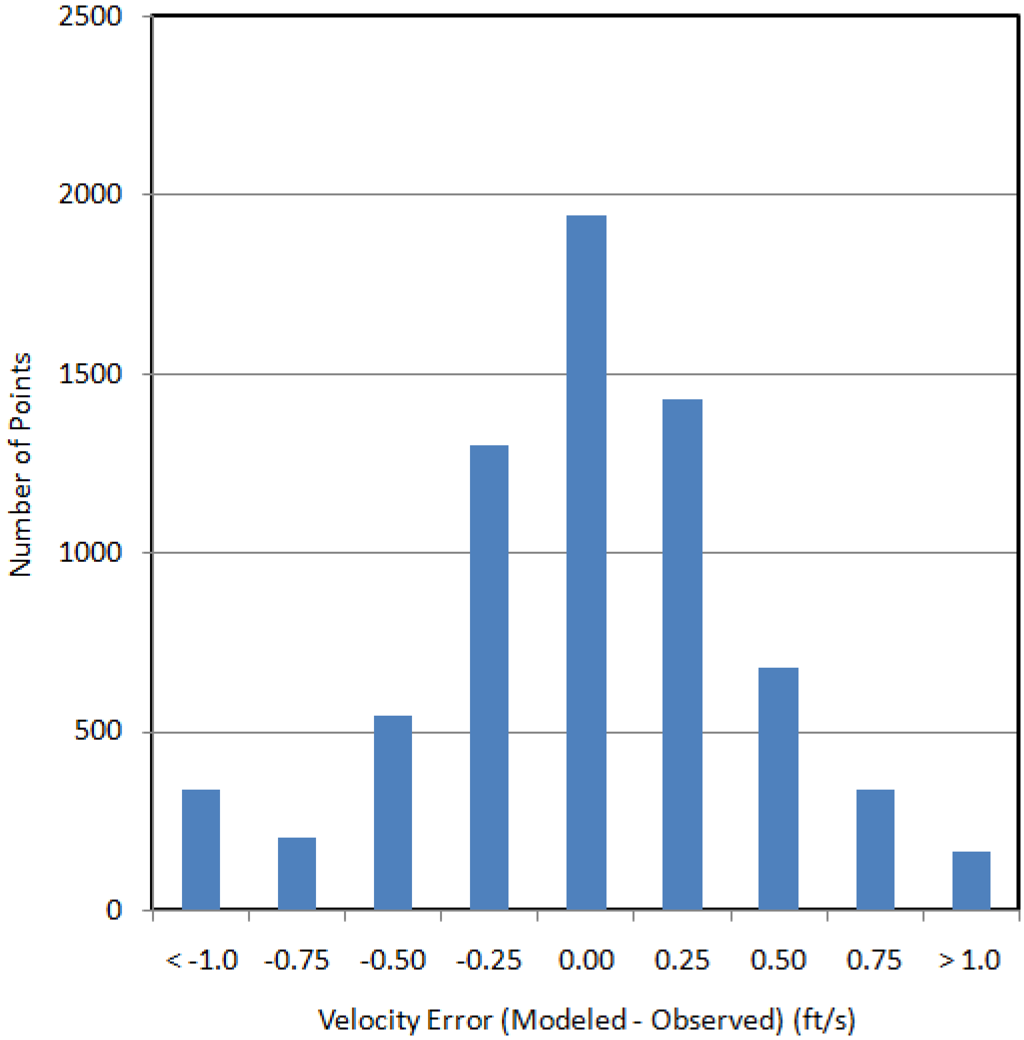


FIGURE 4.3.1.1-1: WUA CURVES FOR THE SPAWNING & INCUBATION, FRY, JUVENILE AND ADULT LIFE STAGES OF AMERICAN SHAD.

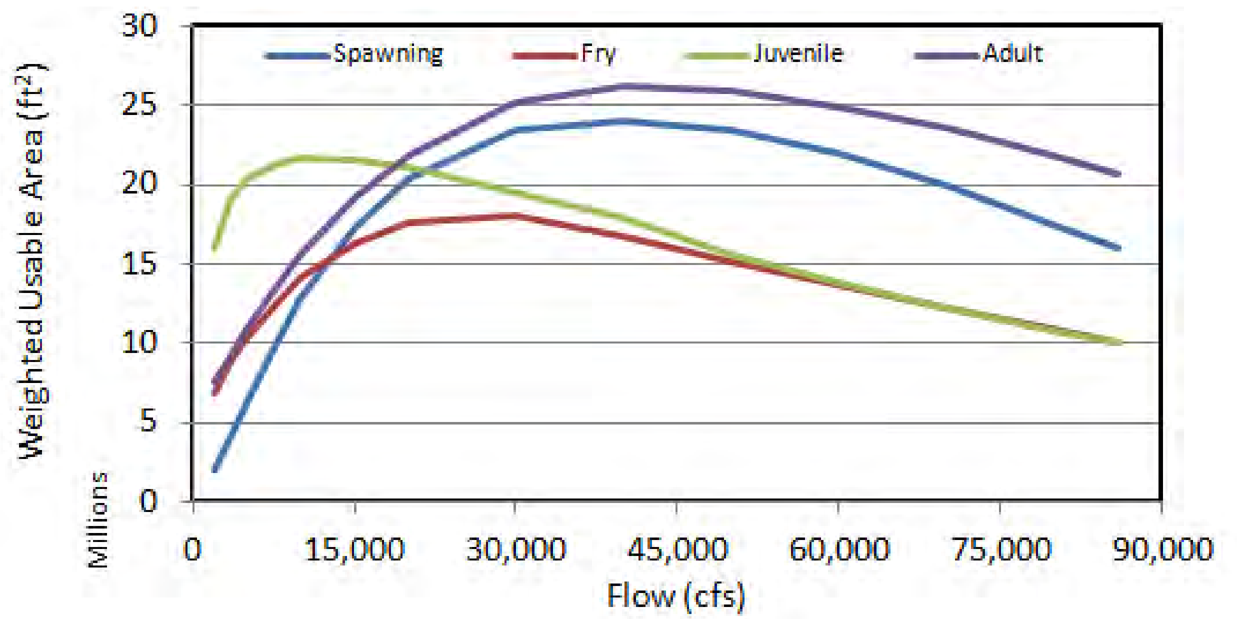
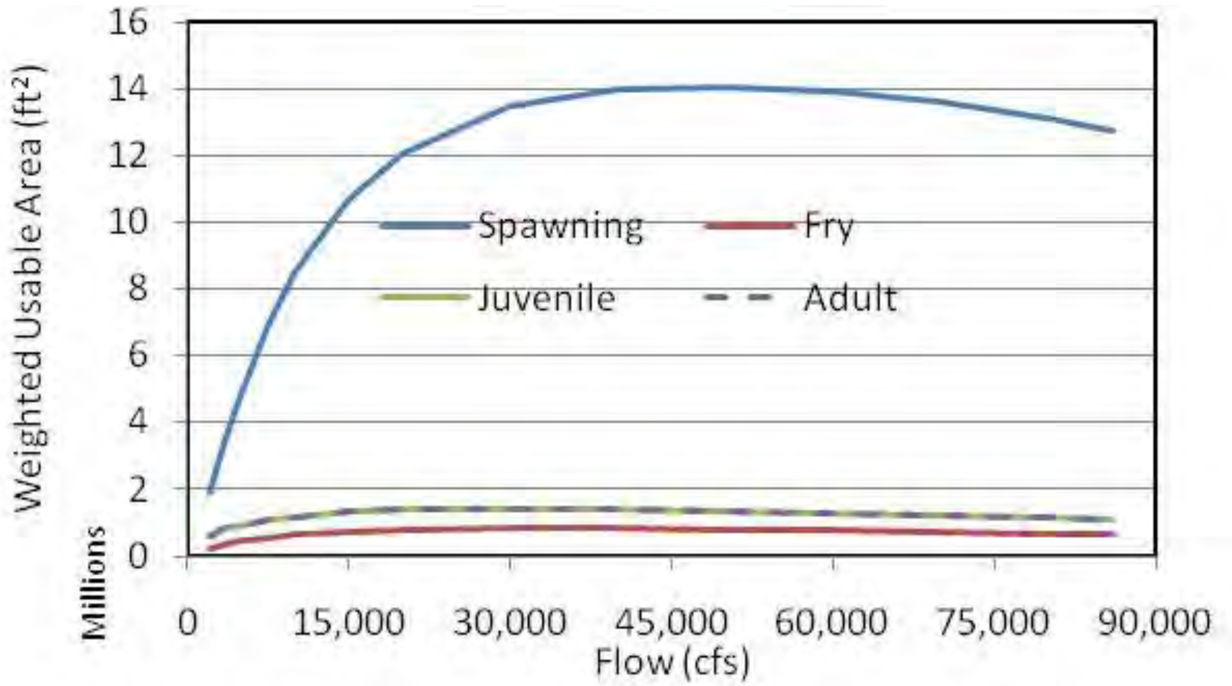


FIGURE 4.3.1.2-1: WUA CURVES FOR THE SPAWNING & INCUBATION, FRY, JUVENILE AND ADULT LIFE STAGES OF SHORTNOSE STURGEON.



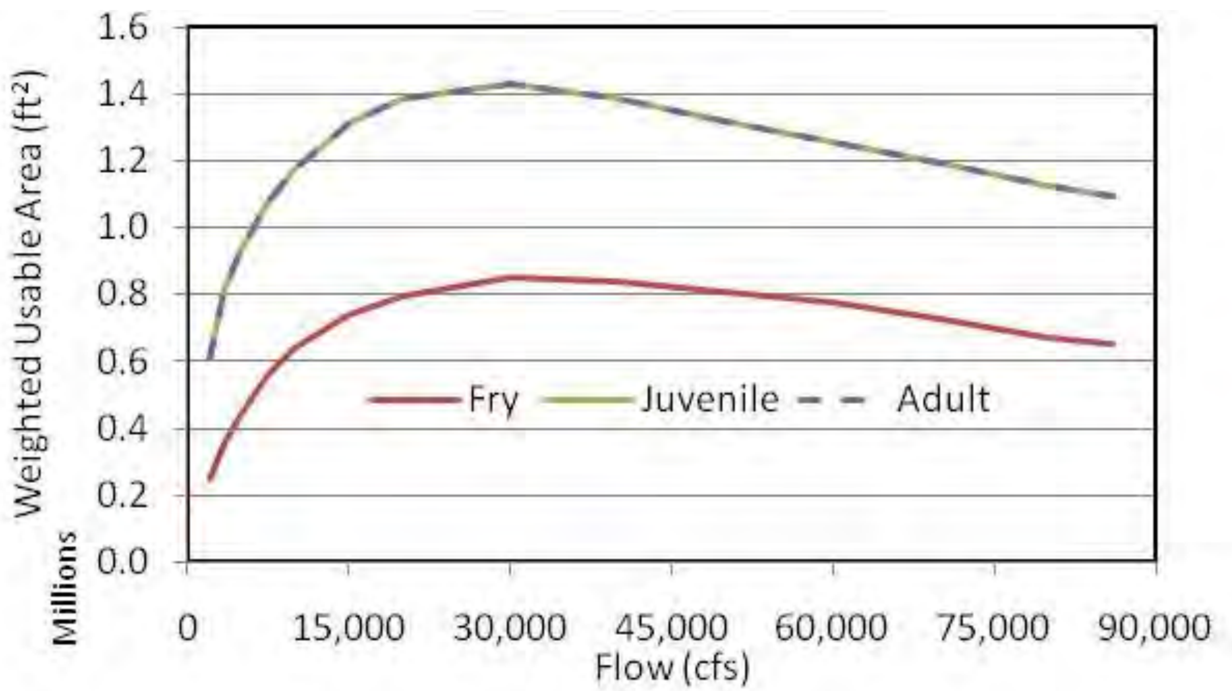


FIGURE 4.3.1.3-1: WUA CURVES FOR THE SPAWNING & INCUBATION, FRY, JUVENILE AND ADULT LIFE STAGES OF STRIPED BASS.

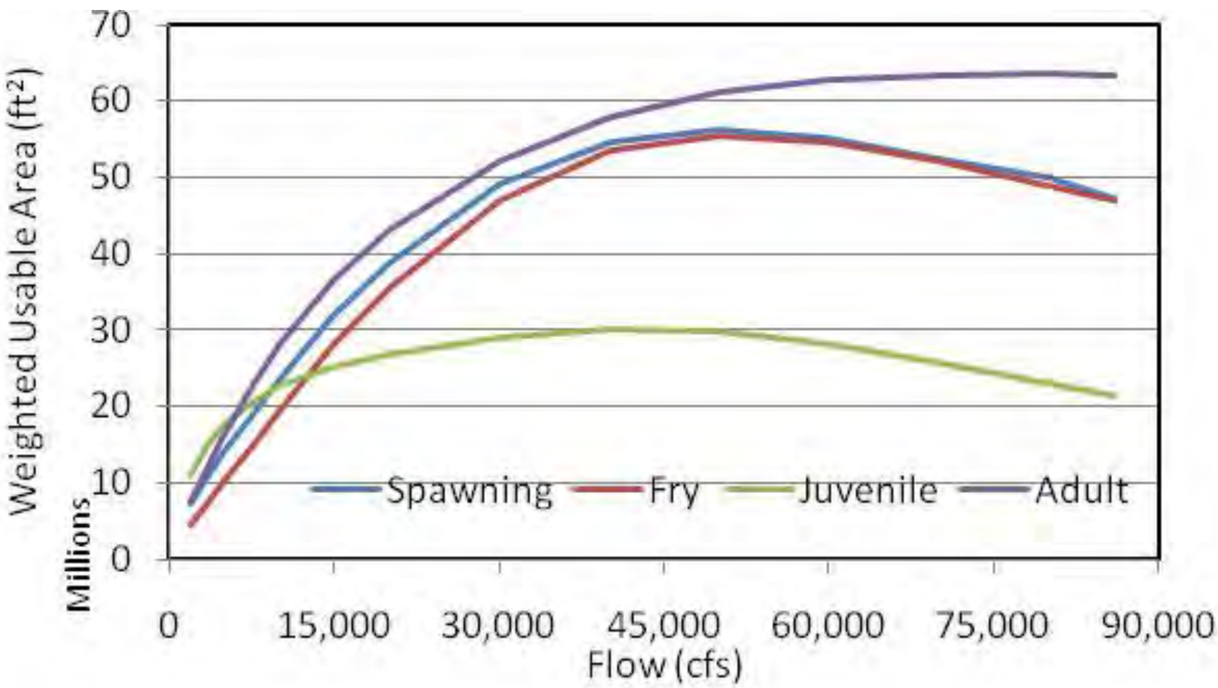
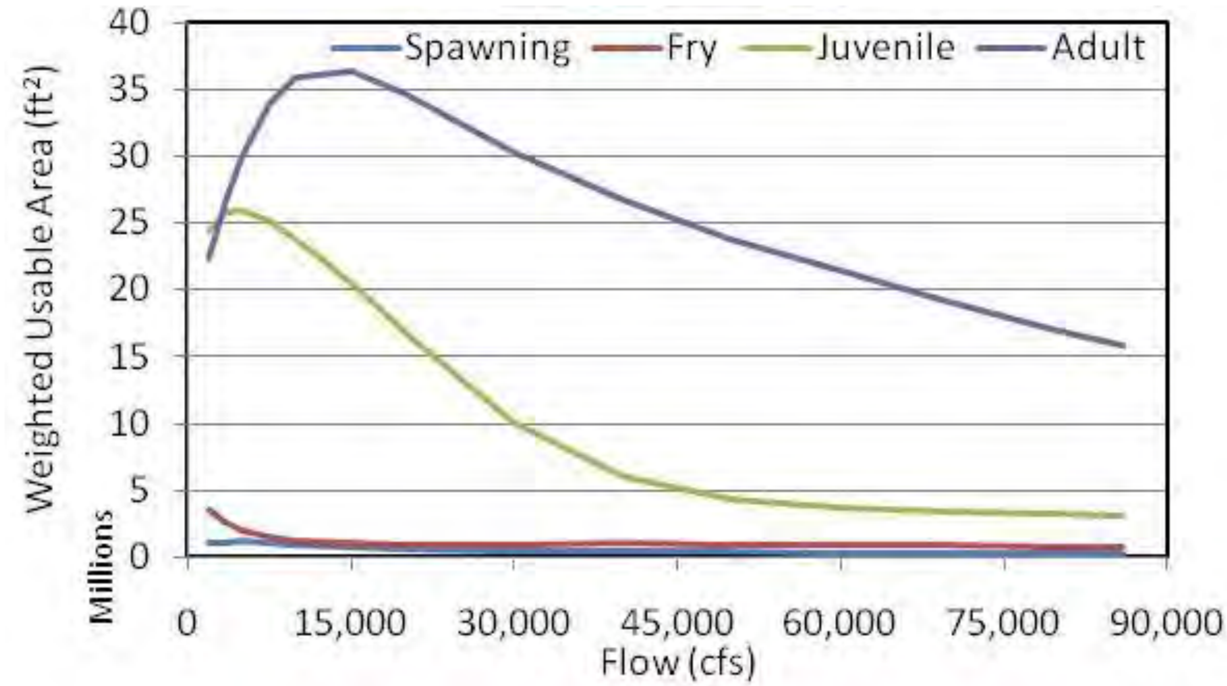


FIGURE 4.3.1.4-1: WUA CURVES FOR THE SPAWNING & INCUBATION, FRY, JUVENILE AND ADULT LIFE STAGES OF SMALLMOUTH BASS.



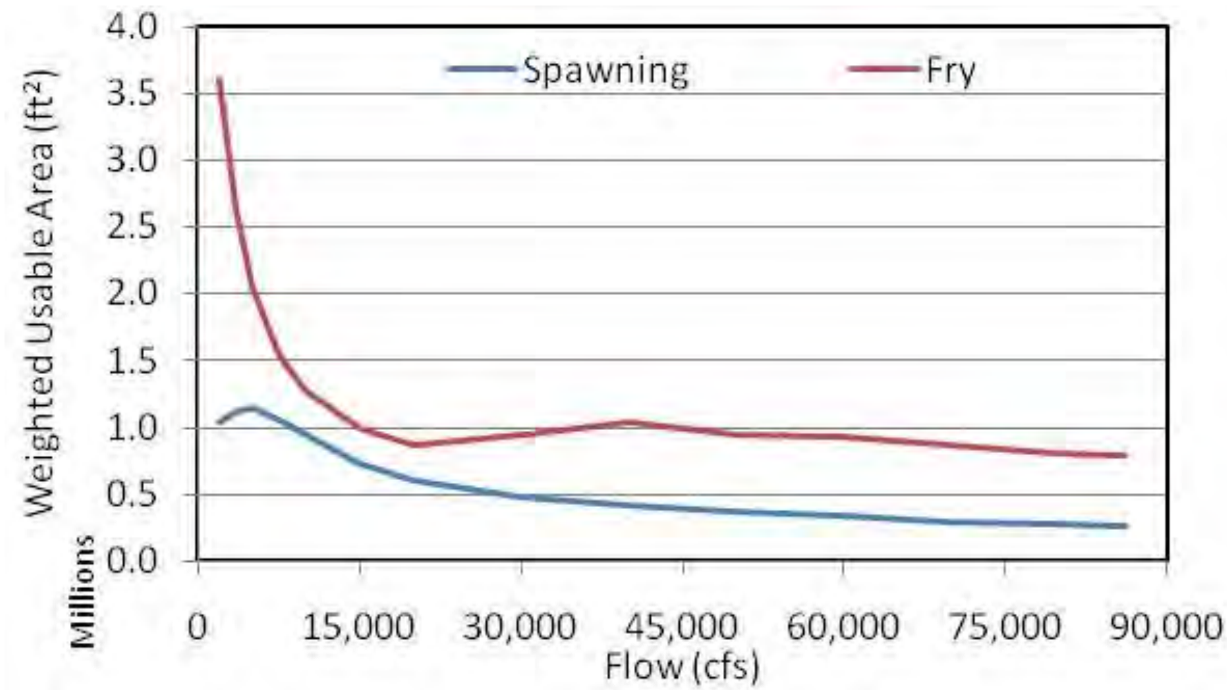


FIGURE 4.3.1.5-1: WUA CURVES FOR EPHEMEROPTERA (MAYFLIES), PLECOPTERA (STONEFLIES), AND TRICHOPTERA (CADDISFLIES).

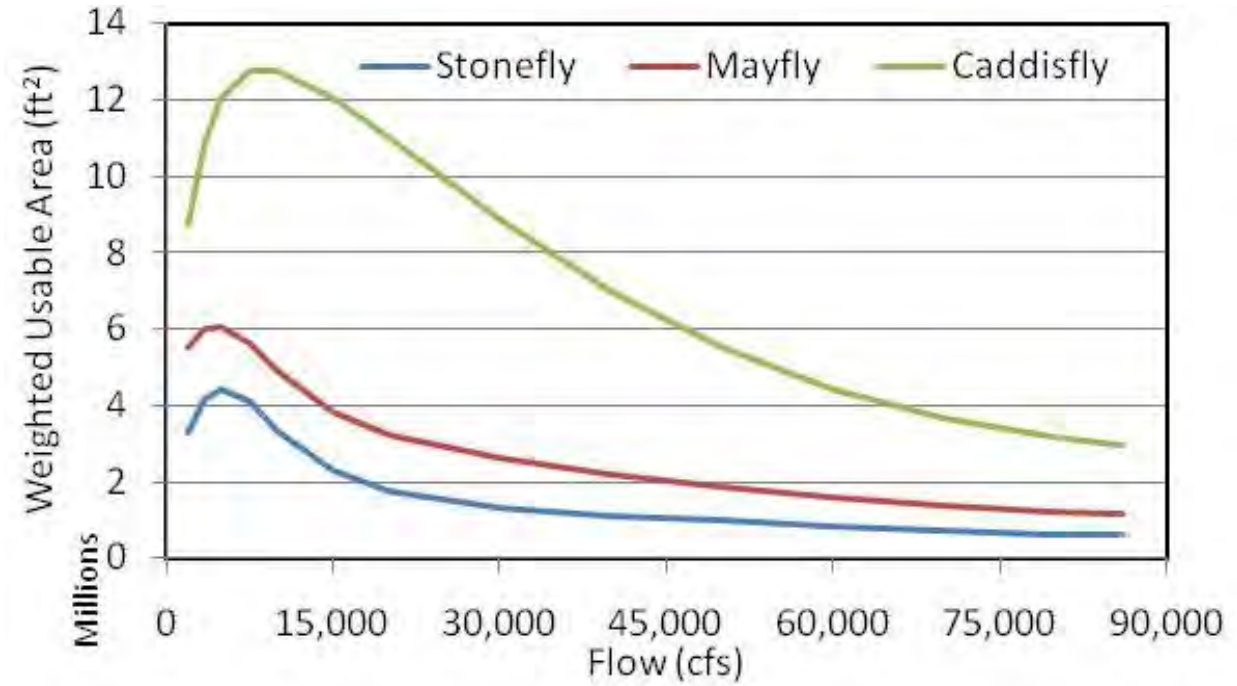
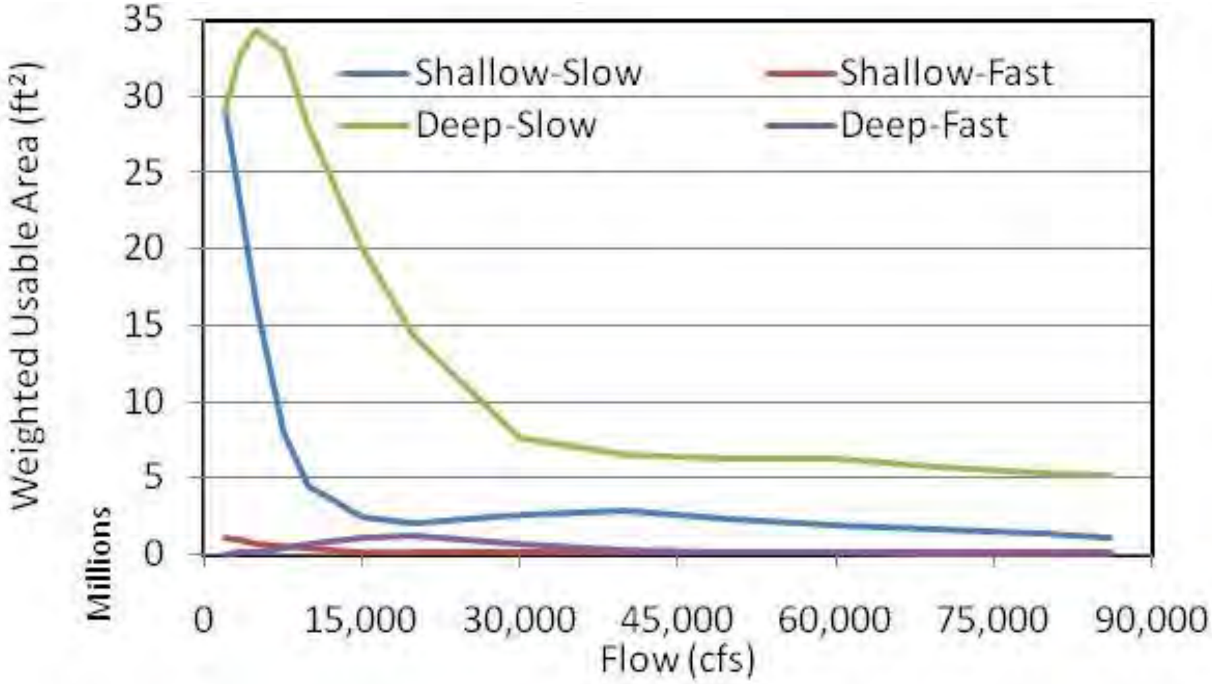


FIGURE 4.3.1.6-1: WUA CURVES FOR THE SHALLOW-SLOW, SHALLOW-FAST, DEEP-SLOW, AND DEEP-FAST HABITAT GUILDS.



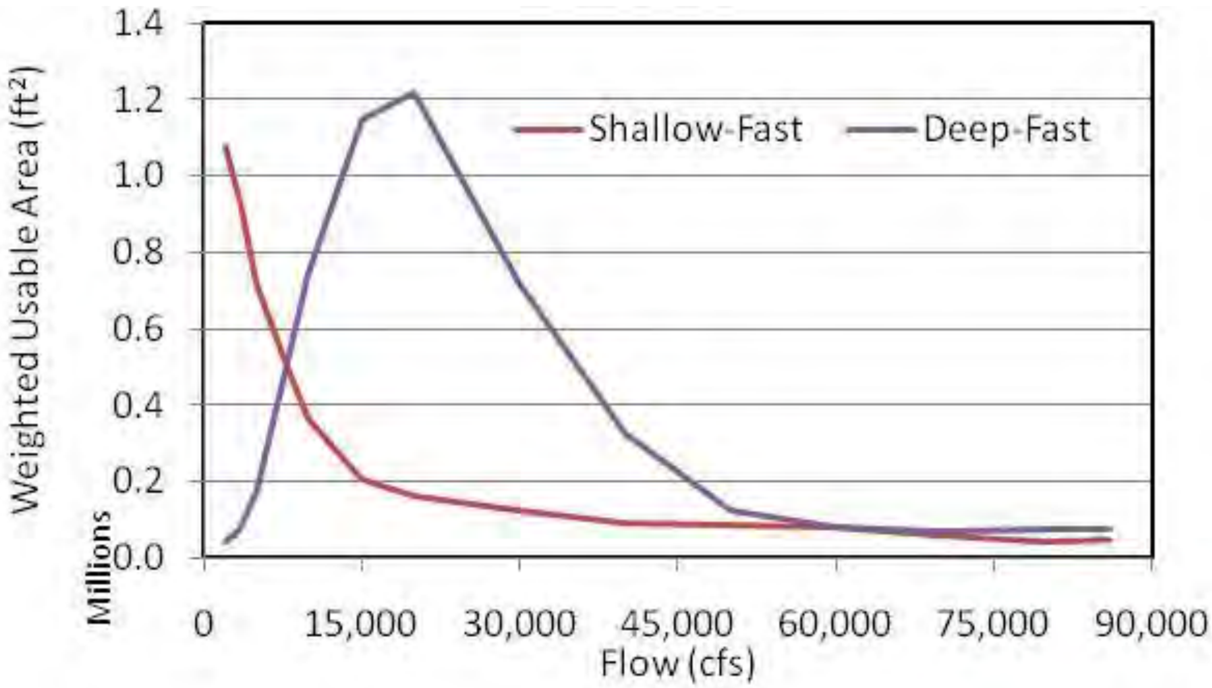


FIGURE 4.3.2.1-1: AMERICAN SHAD PERSISTENT QUALITY HABITAT VERSUS MINIMUM FLOWS PAIRED WITH FULL GENERATION (86,000 CFS)

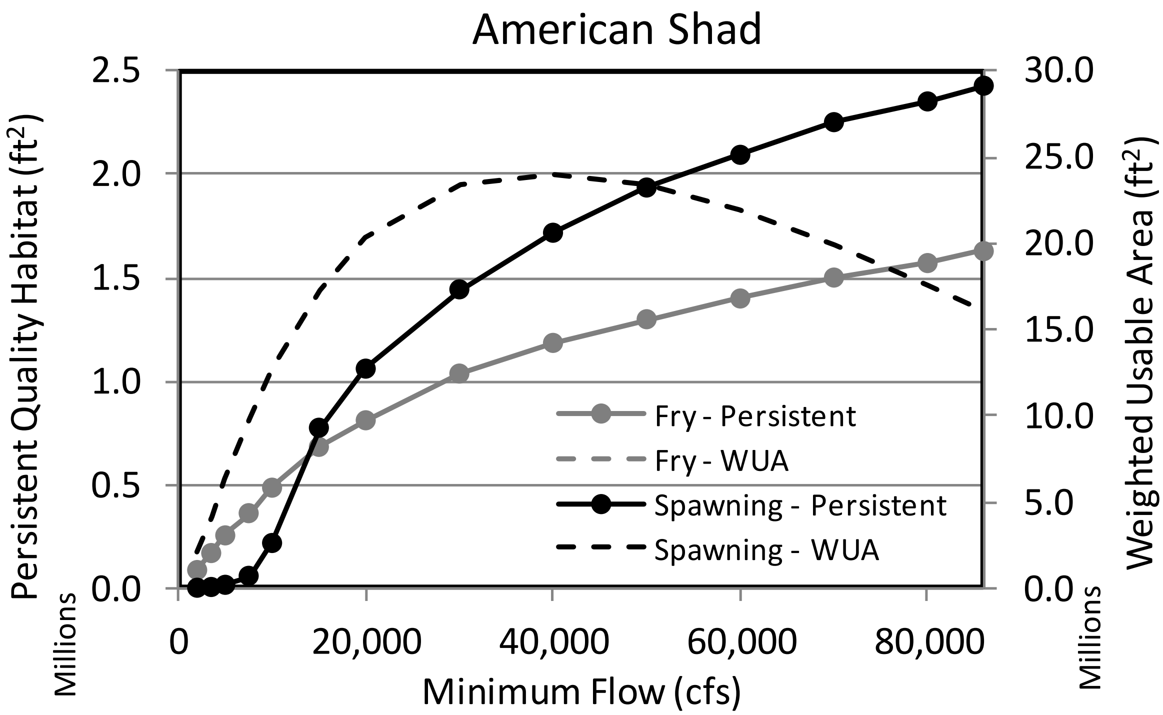


FIGURE 4.3.2.2-1: SHORTNOSE STURGEON PERSISTENT QUALITY HABITAT VERSUS MINIMUM FLOWS PAIRED WITH FULL GENERATION (86,000 CFS)

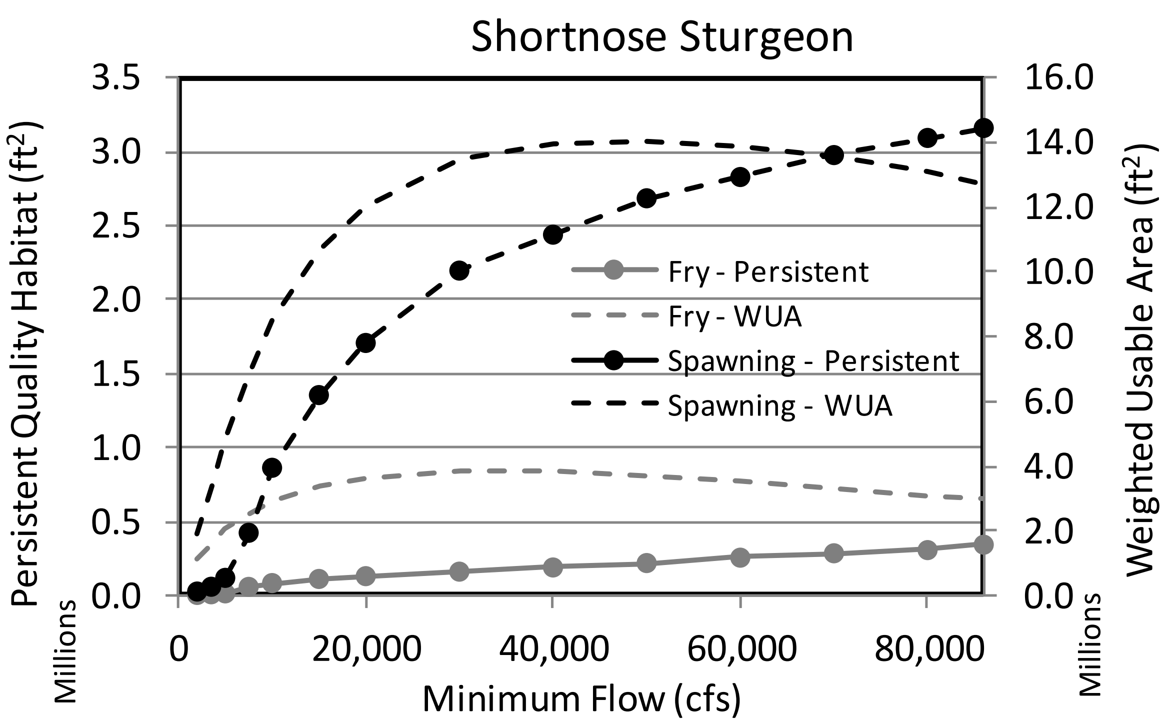


FIGURE 4.3.2.3-1: STRIPED BASS PERSISTENT QUALITY HABITAT VERSUS MINIMUM FLOWS PAIRED WITH FULL GENERATION (86,000 CFS)

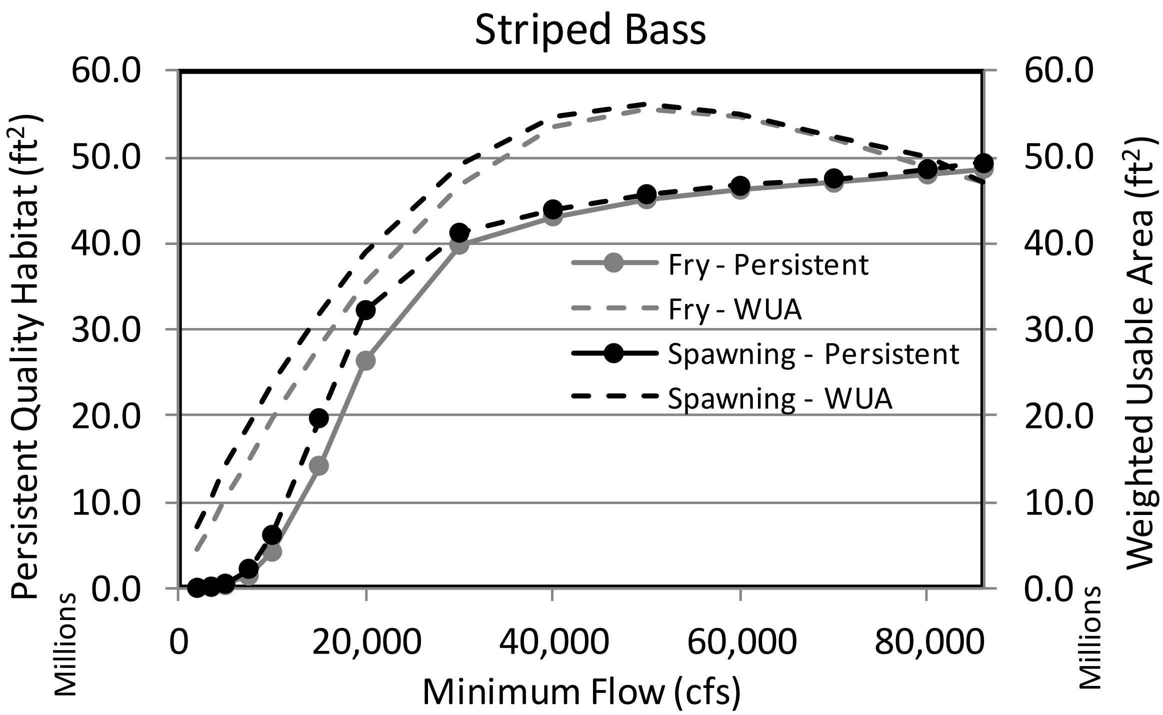


FIGURE 4.3.2.4-1: SMALLMOUTH BASS PERSISTENT QUALITY HABITAT VERSUS MINIMUM FLOWS PAIRED WITH FULL GENERATION (86,000 CFS)

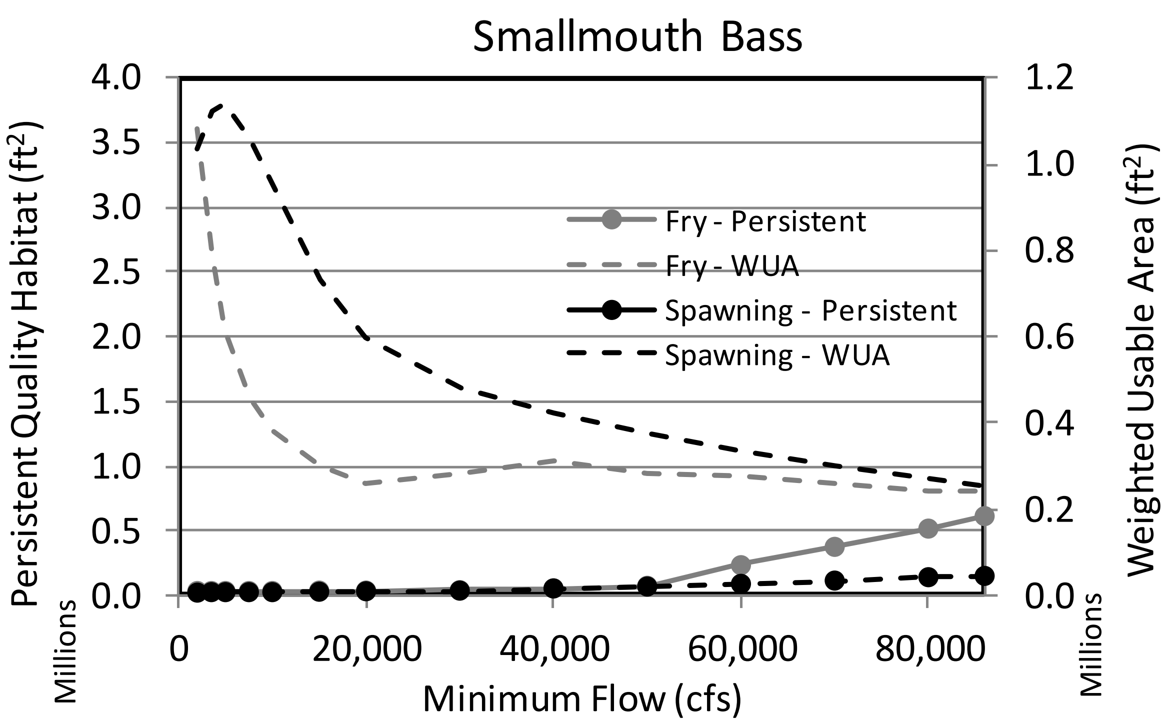


FIGURE 4.3.2.5-1: CADDISFLY PERSISTENT QUALITY HABITAT VERSUS MINIMUM FLOWS PAIRED WITH FULL GENERATION (86,000 CFS)

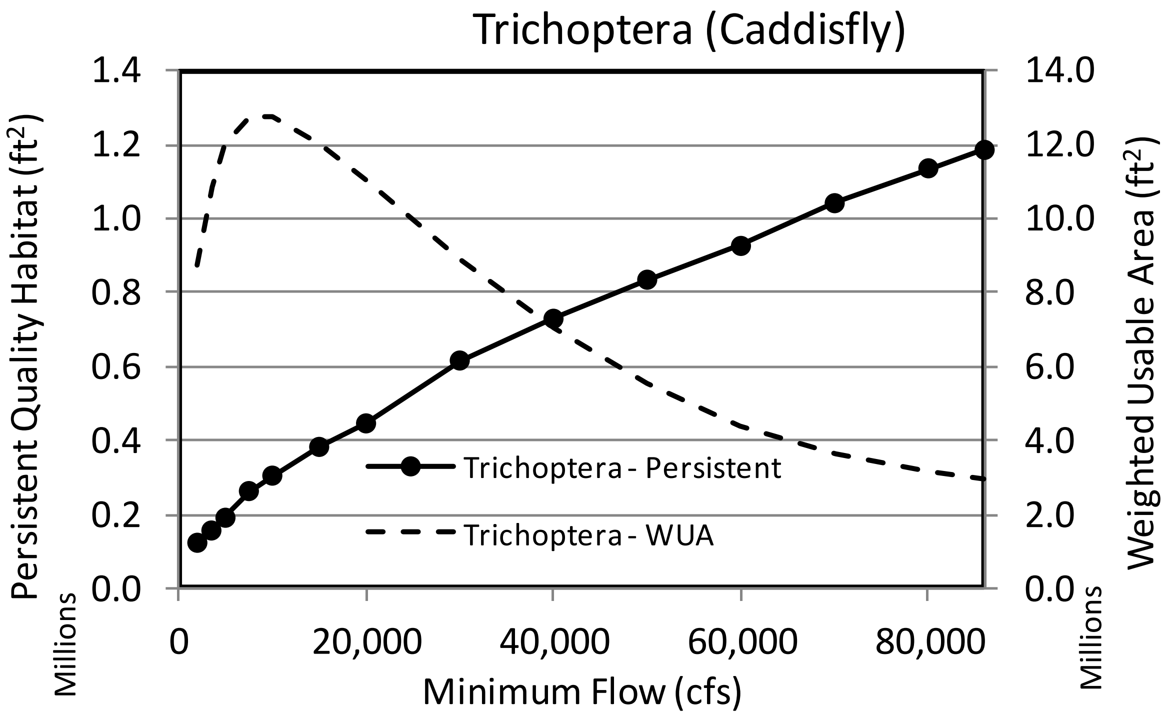


FIGURE 4.3.2.5-2: MAYFLY AND STONEFLY PERSISTENT QUALITY HABITAT VERSUS MINIMUM FLOWS PAIRED WITH FULL GENERATION (86,000 CFS)

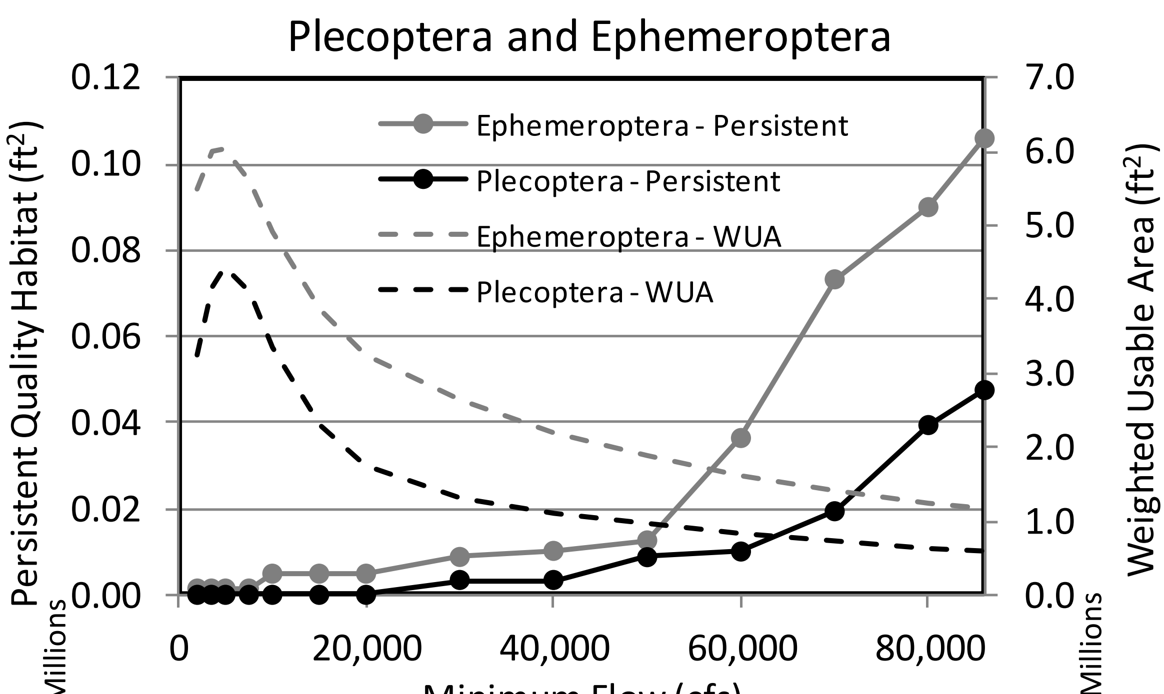


FIGURE 4.3.2.6-1: SHALLOW-FAST, SHALLOW-SLOW GUILD PERSISTENT QUALITY HABITAT VS MINIMUM FLOWS PAIRED WITH FULL GENERATION (86,000 CFS)

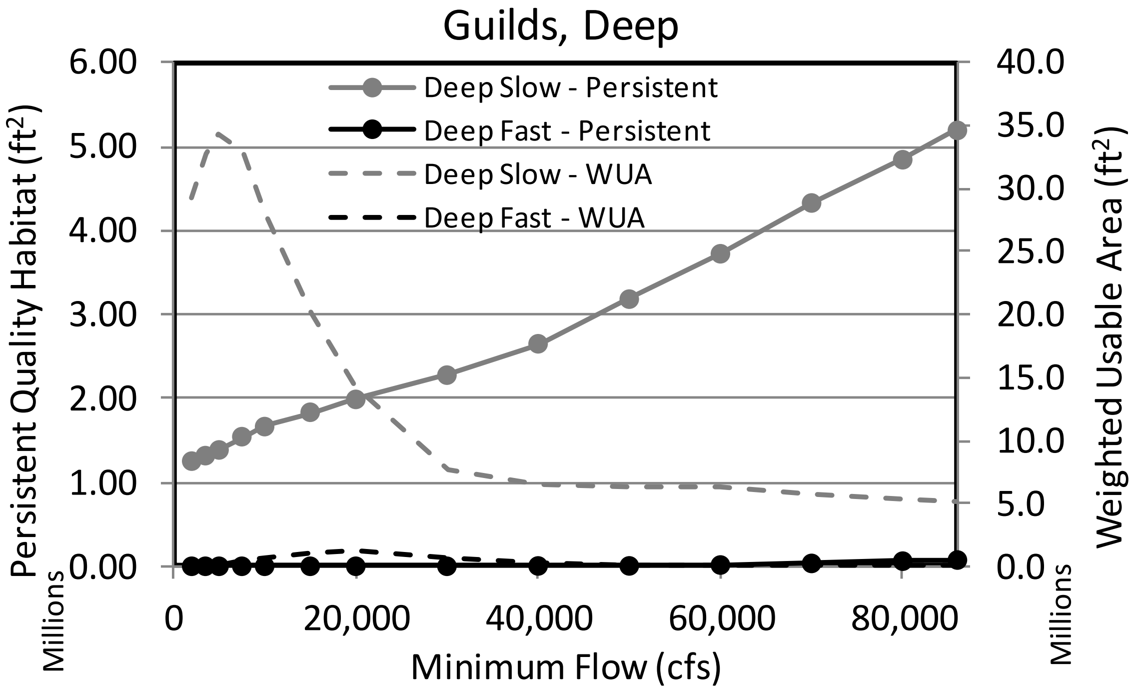
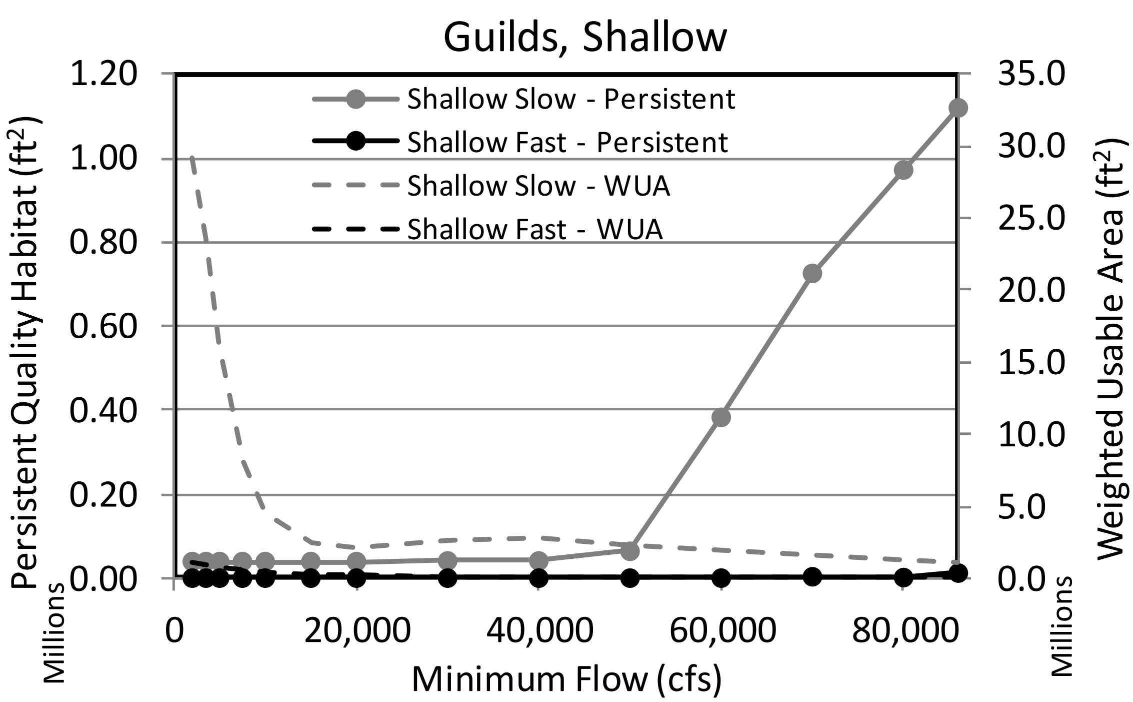
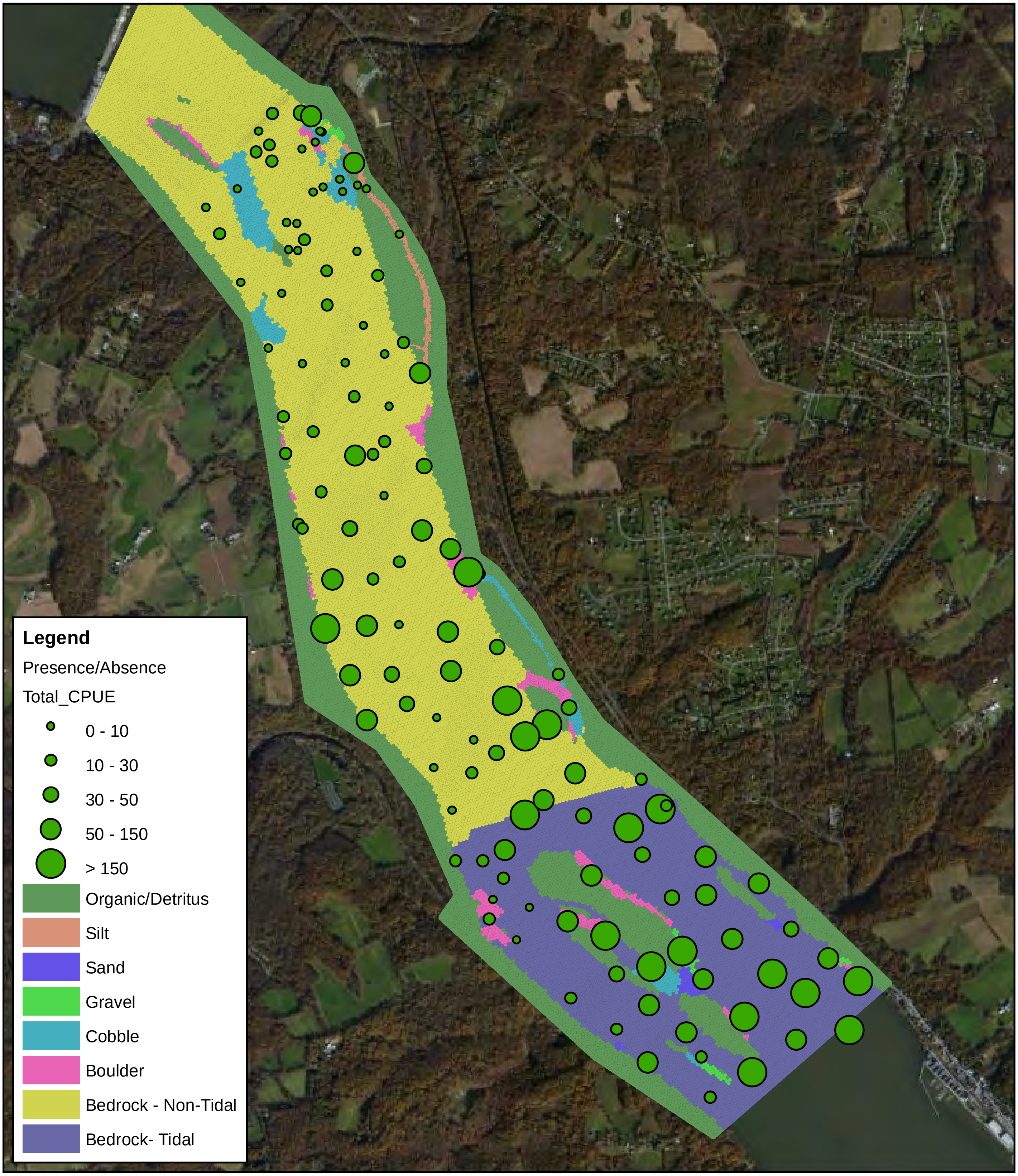


FIGURE 4.3.2.6-2: DEEP-FAST AND DEEP-SLOW GUILD PERSISTENT QUALITY HABITAT VS. MINIMUM FLOWS PAIRED WITH FULL GENERATION (86,000 CFS)





Exelon

N

0 0.25 0.5 1 Miles

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Figure 4.3.3-1: Mussel semi-quantitative survey locations mapped with riverbed substrate.

1 inch = 0.5 miles

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FIGURE 4.3.3-2: MUSSEL SEMI-QUANTITATIVE SURVEY LOCATIONS' CATCH-PER-UNIT-EFFORT (NUMBER OF MUSSELS PER HOUR) VS. SHEAR STRESS AT 3,500 CFS, 5,000 CFS, 40,000 CFS AND 86,000 CFS.

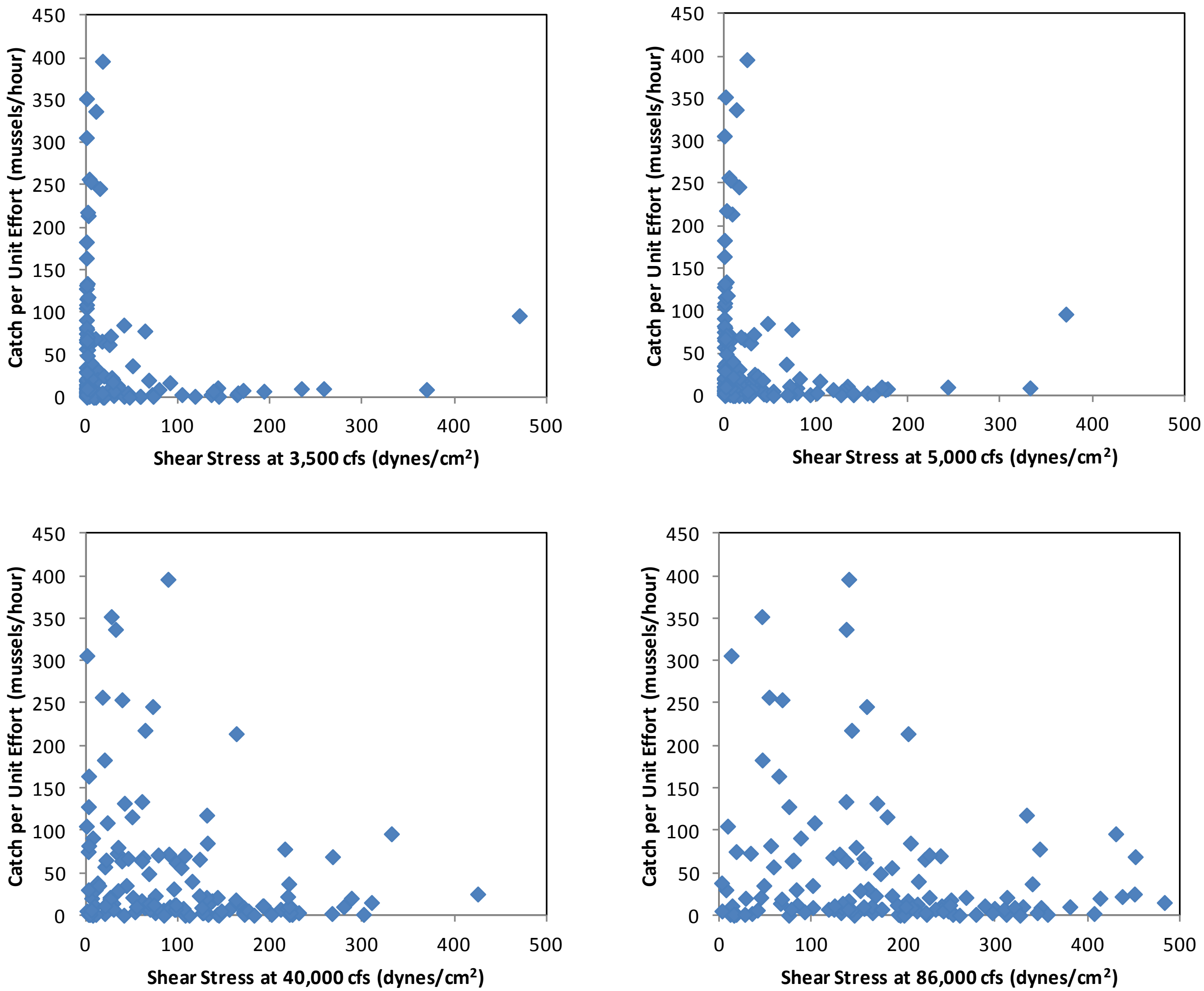


FIGURE 4.3.3-3: PERCENTAGE OF WETTED STUDY AREA THAT DOES NOT EXCEED THE MUSSEL LOW-FLOW THRESHOLD (20 DYNES/CM^2) AND HIGH-FLOW THRESHOLD (150 DYNES/CM^2).

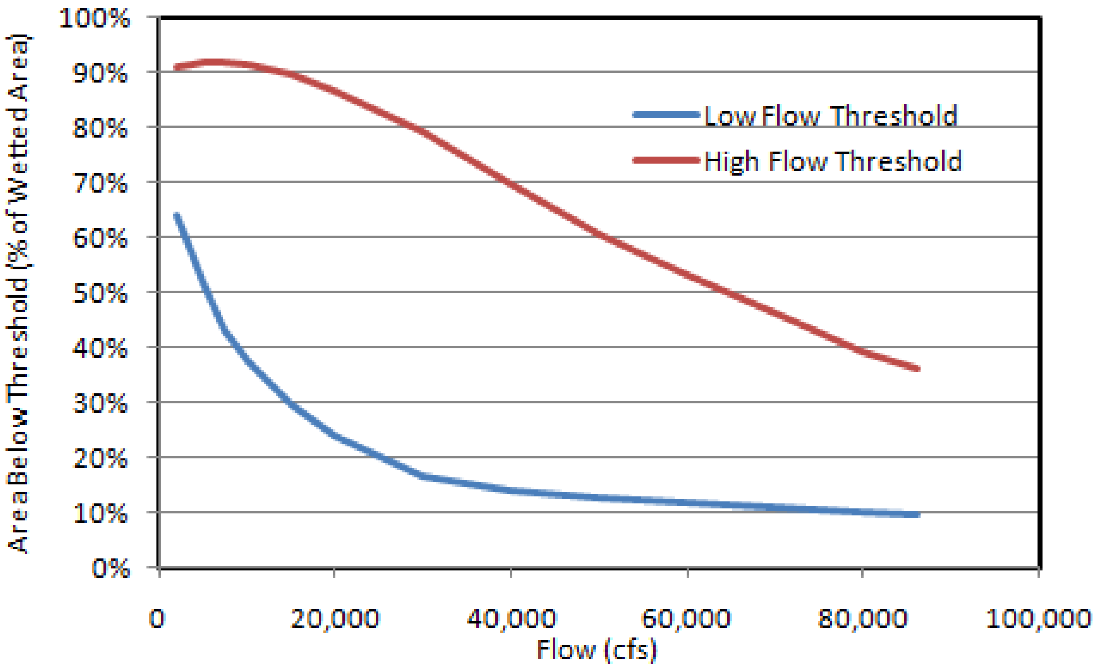


FIGURE 5.1.1-1: JANUARY FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

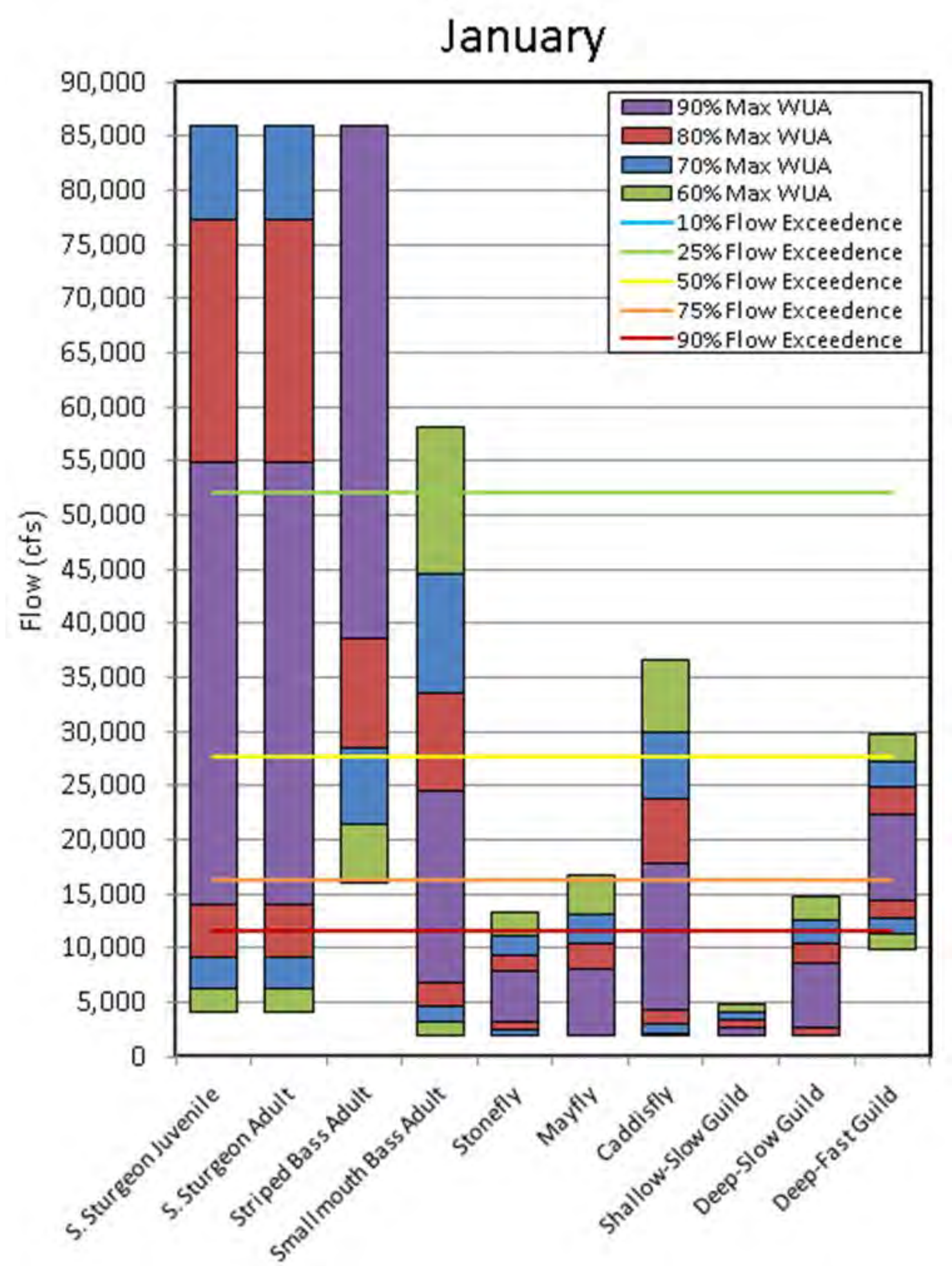


FIGURE 5.1.2-1: FEBRUARY FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

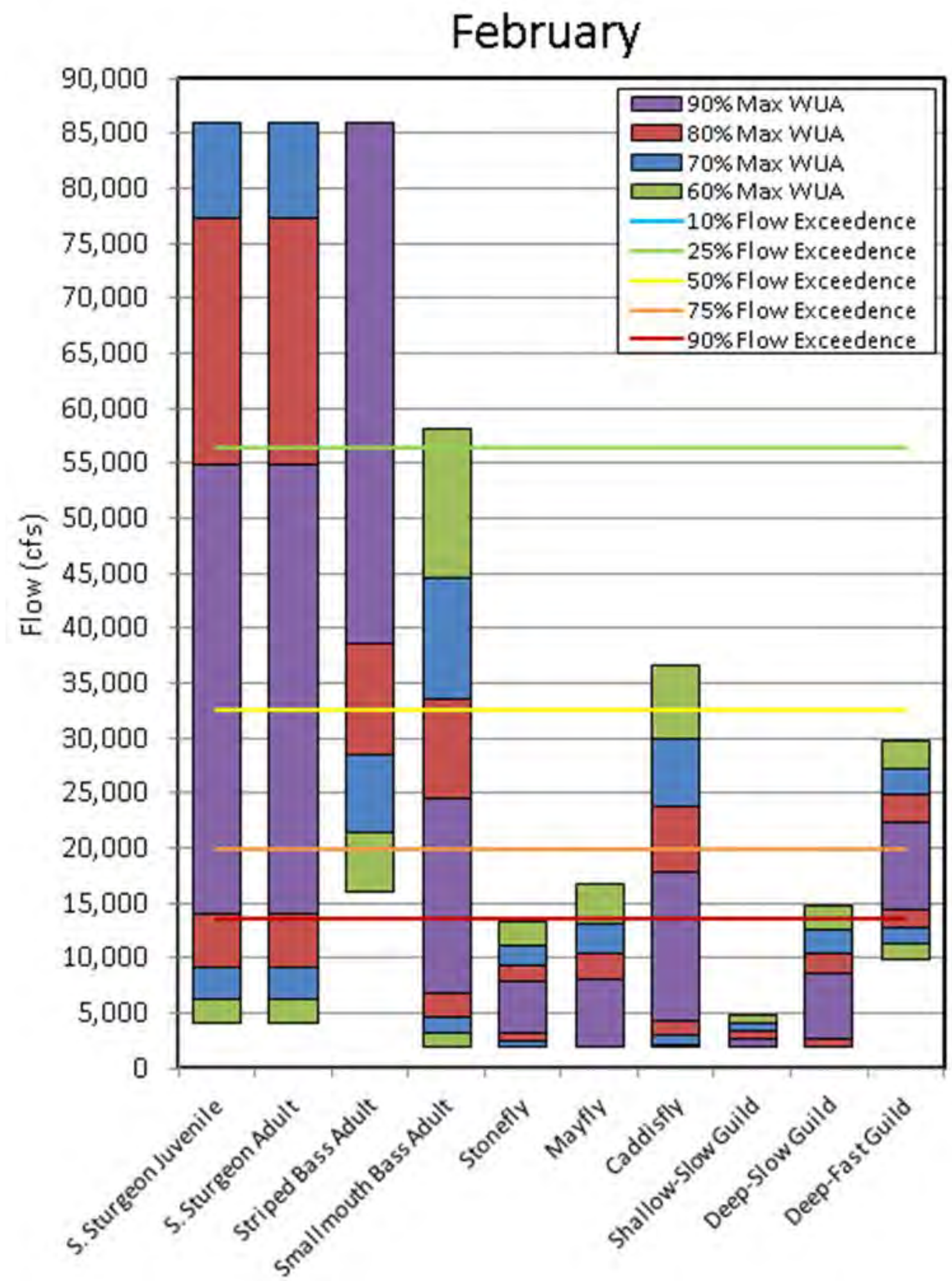


FIGURE 5.1.3-1: MARCH FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

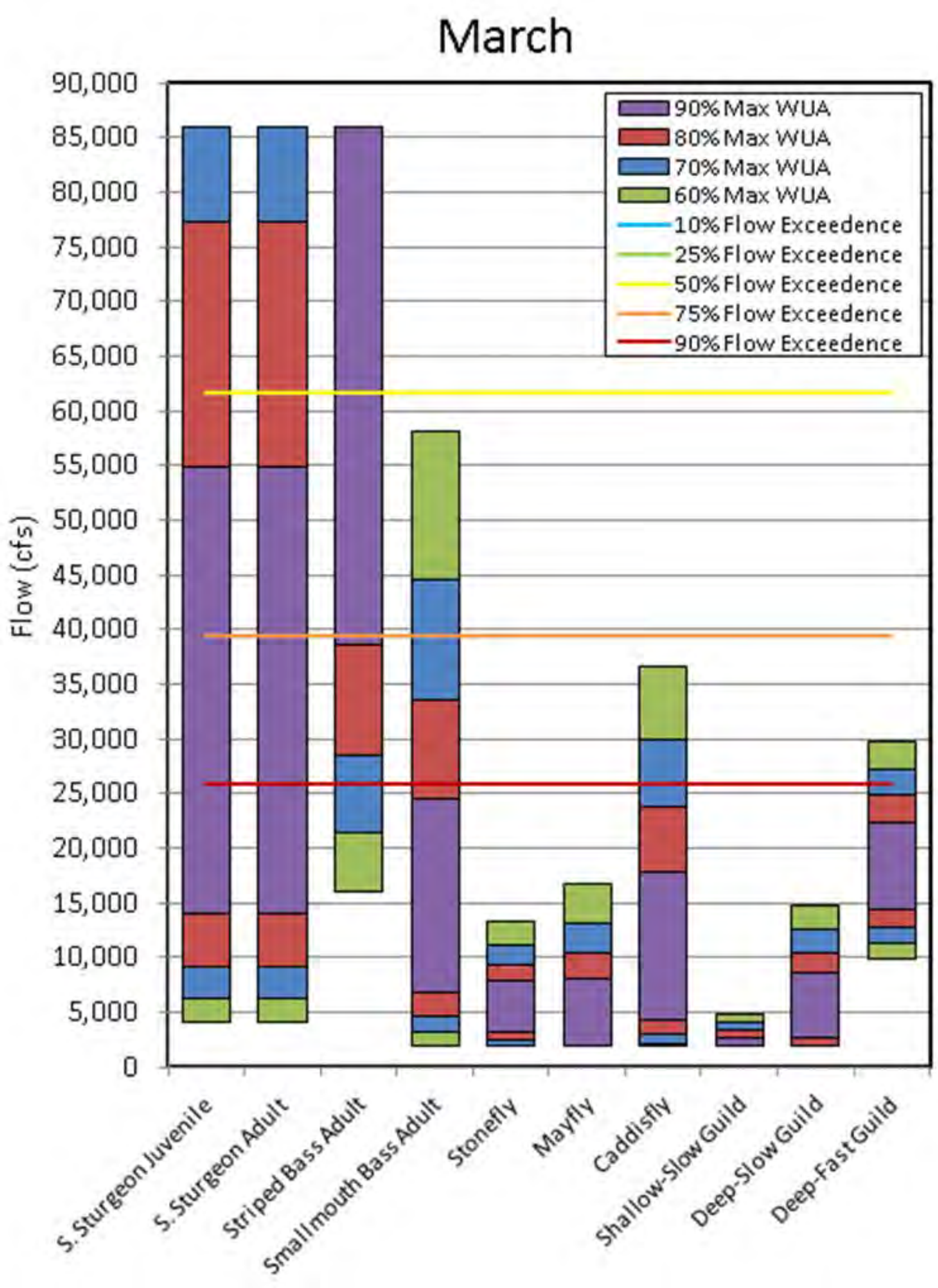


FIGURE 5.1.4-1: APRIL FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

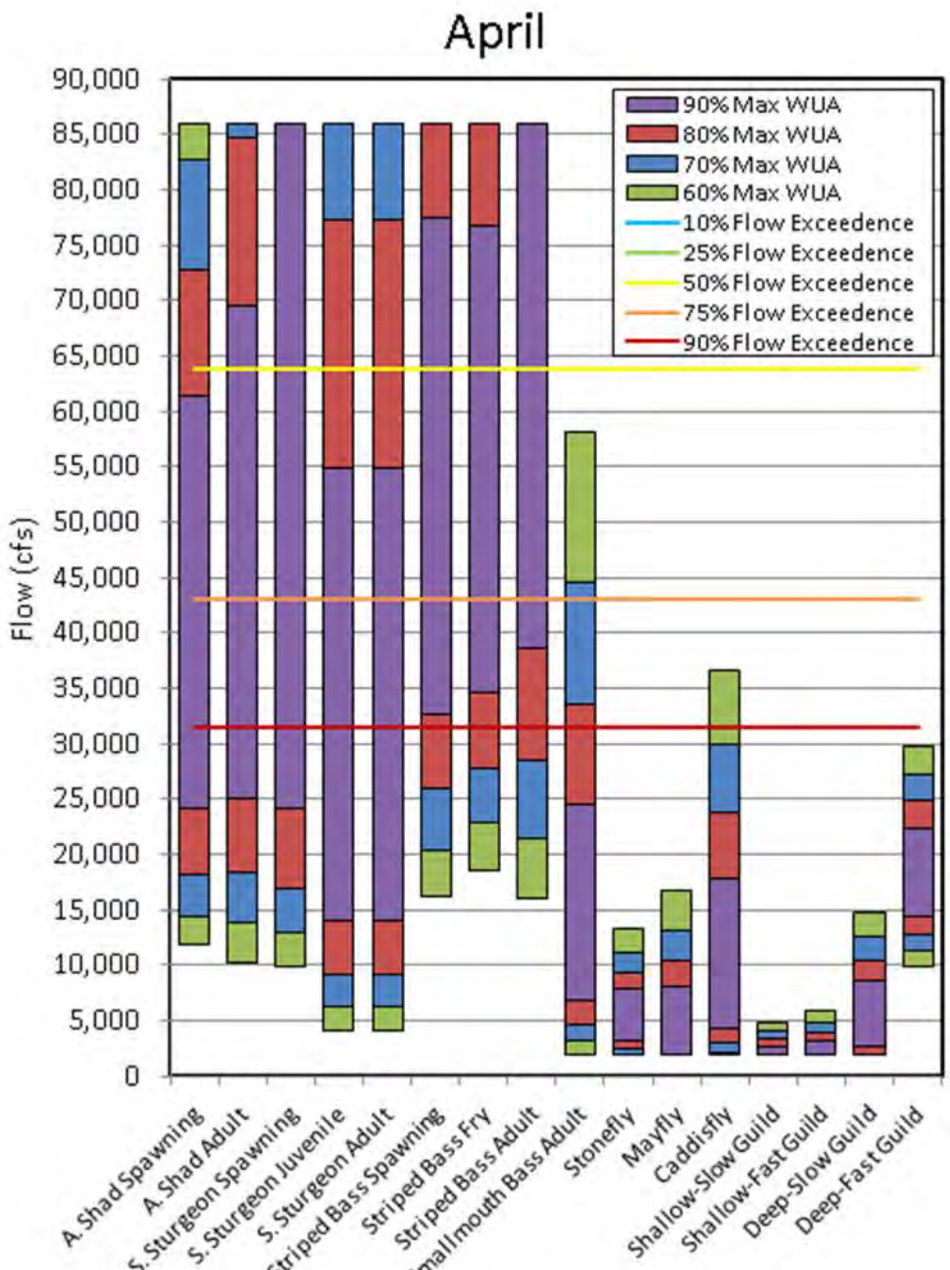


FIGURE 5.1.5-1: MAY FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

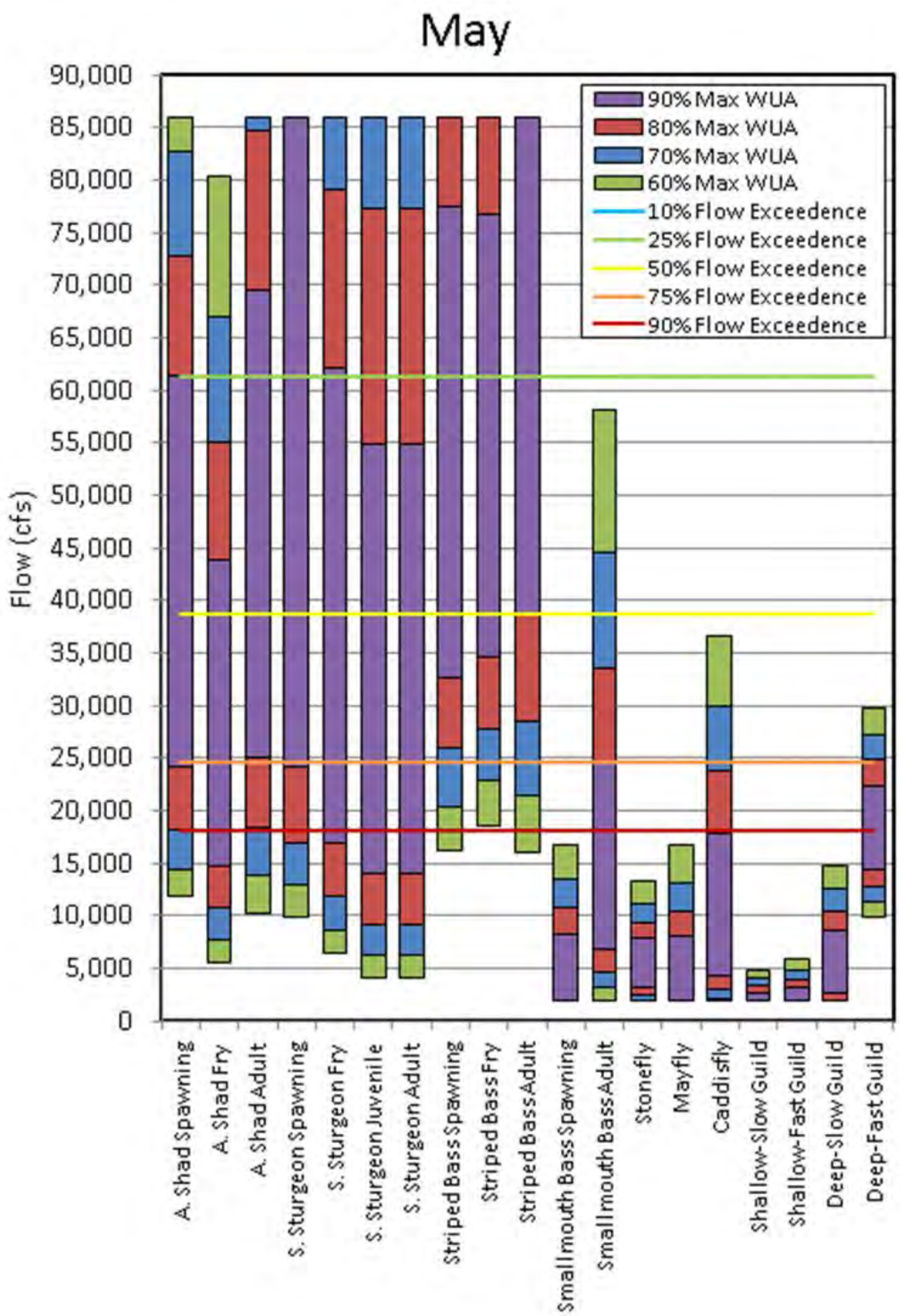


FIGURE 5.1.6-1: JUNE FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

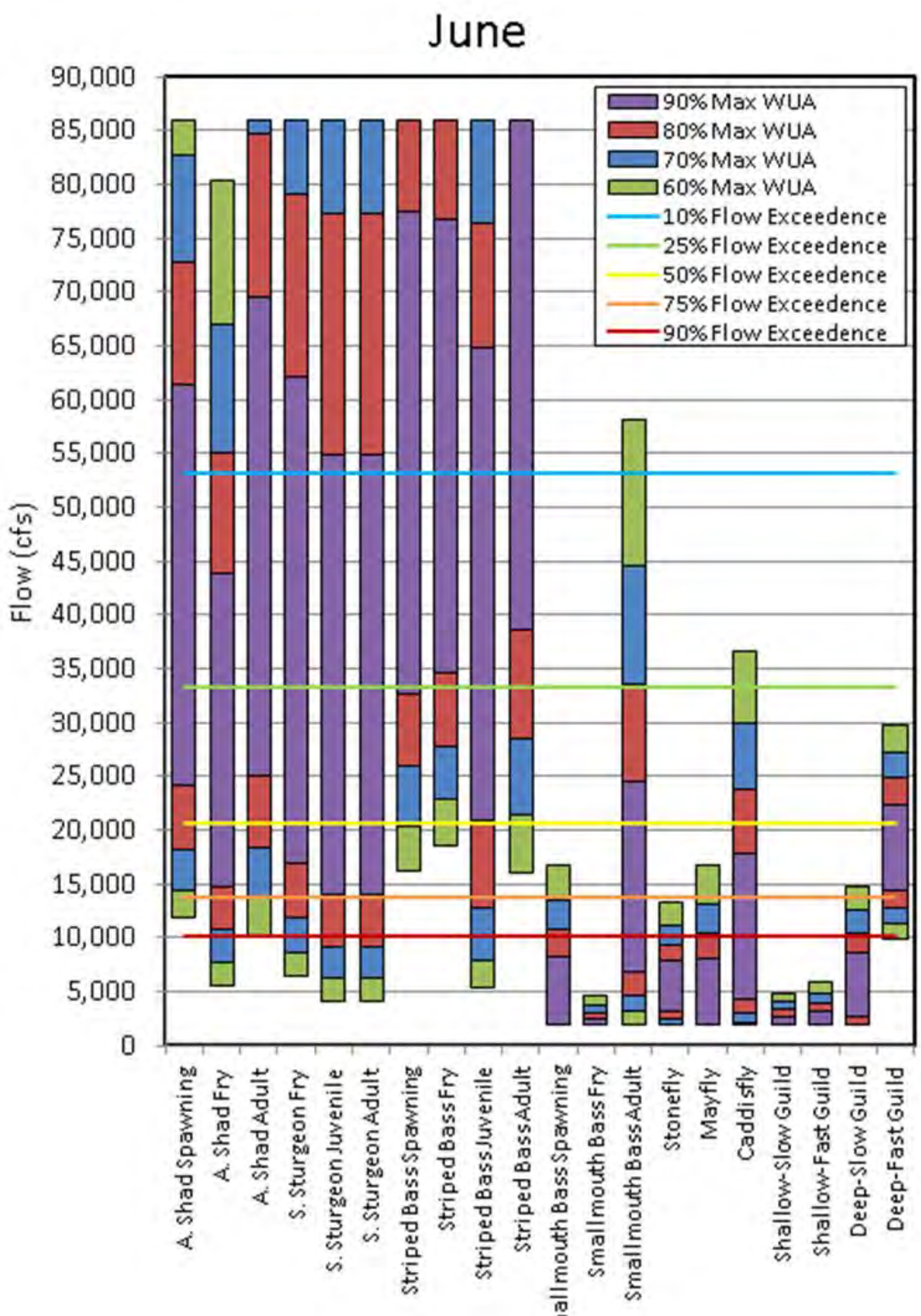


FIGURE 5.1.7-1: JULY FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

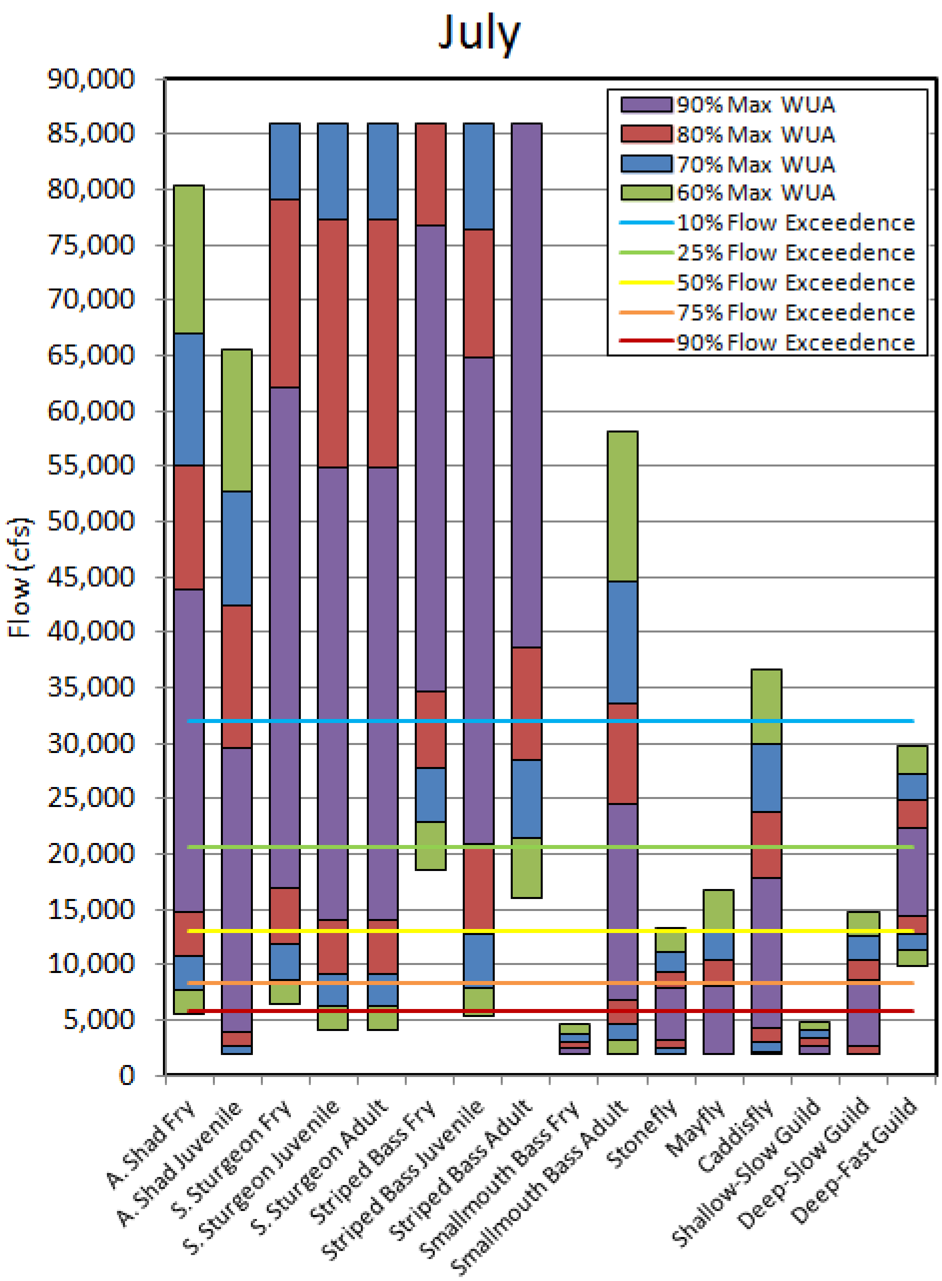


FIGURE 5.1.8-1: AUGUST FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

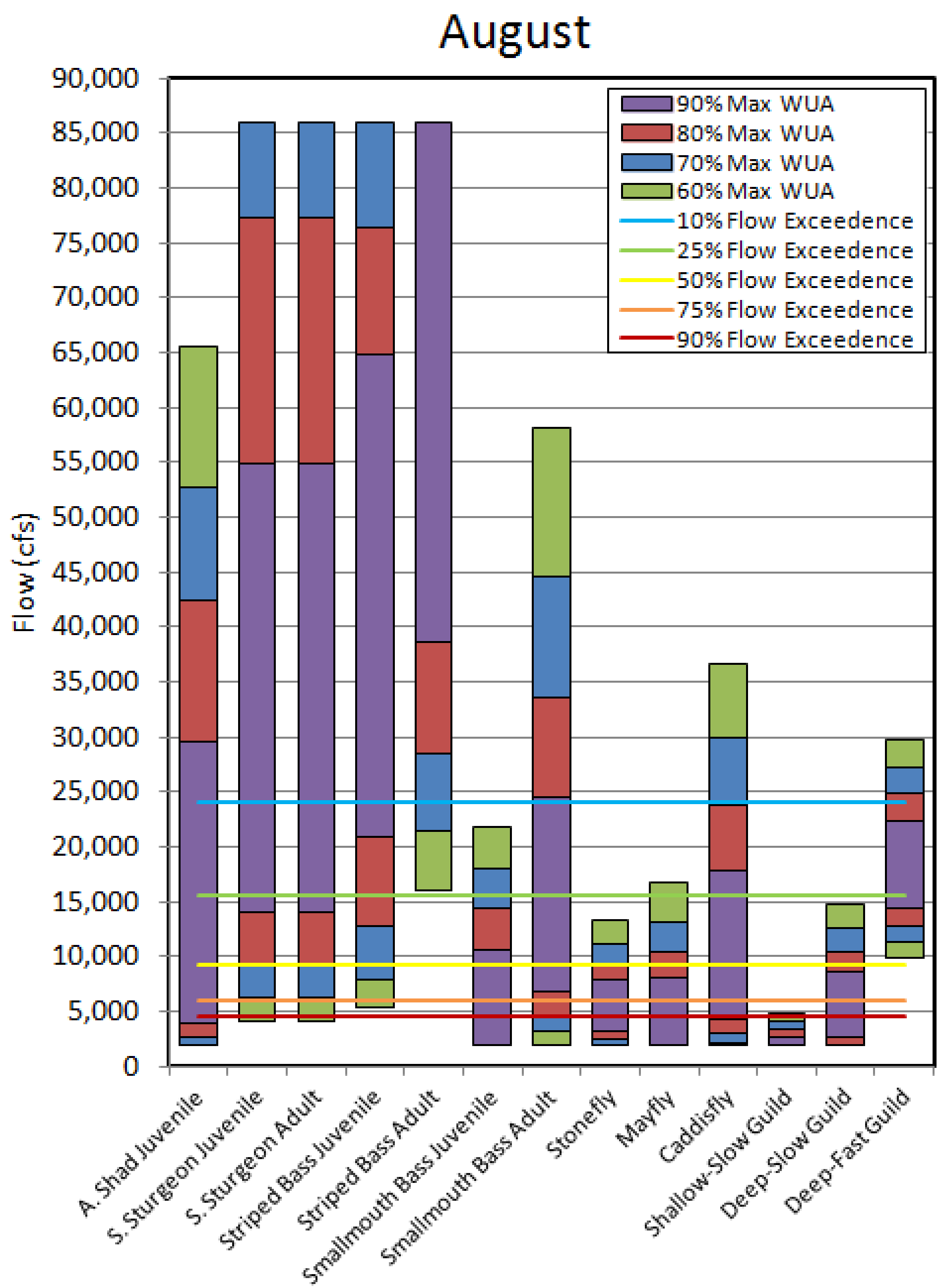


FIGURE 5.1.9-1: SEPTEMBER FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

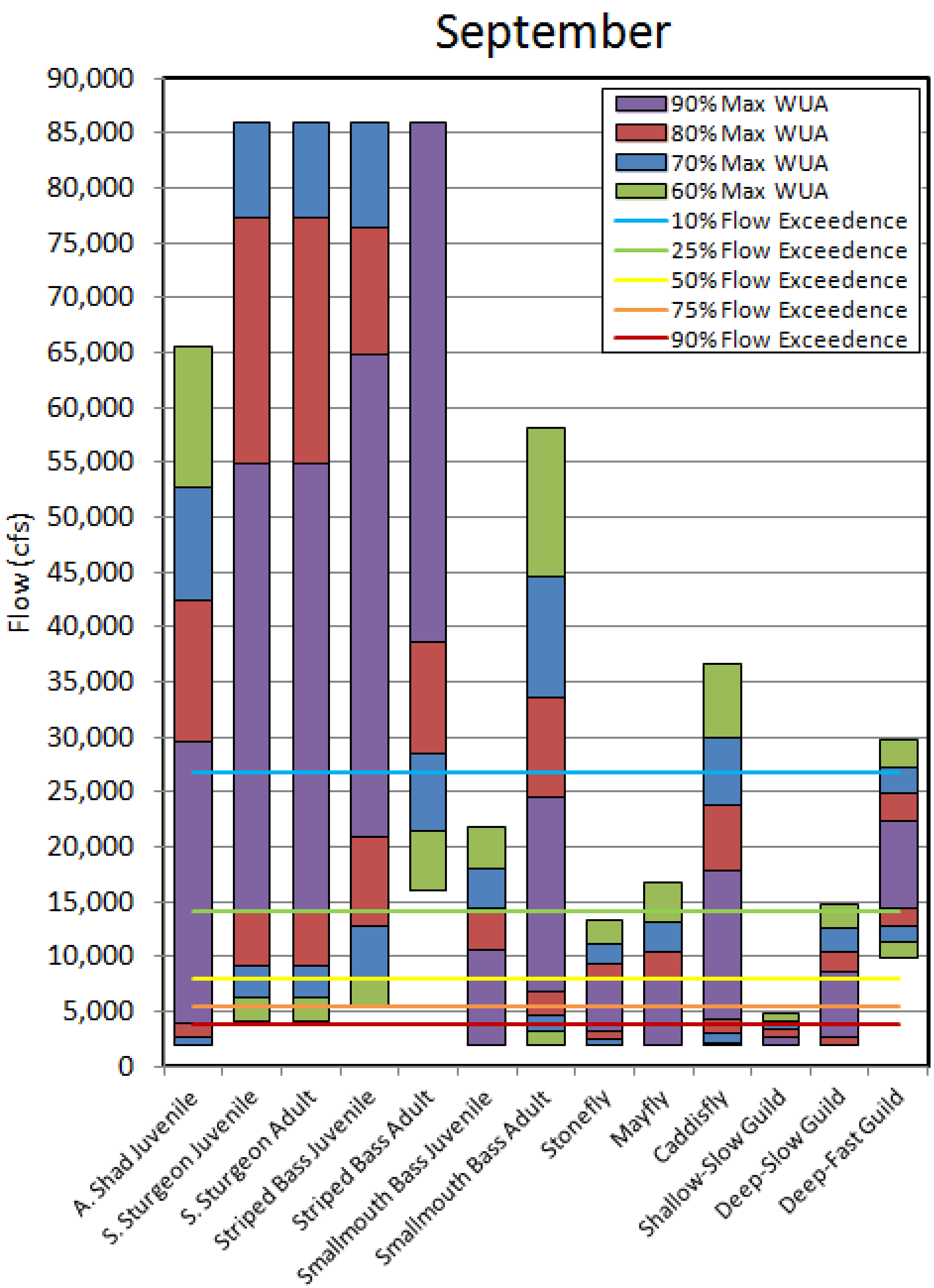


FIGURE 5.1.10-1: OCTOBER FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

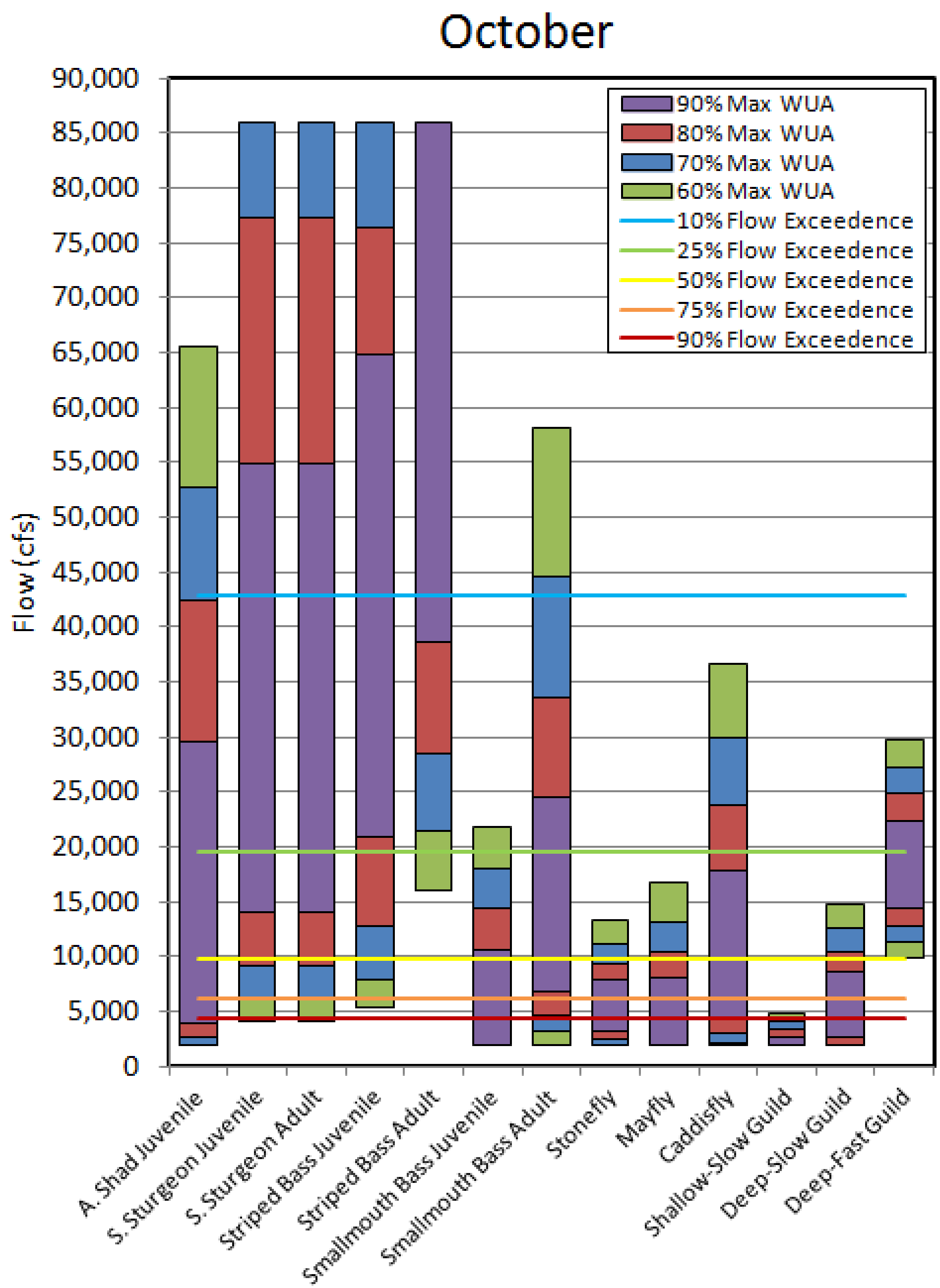


FIGURE 5.1.11-1: NOVEMBER FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD WY 1934-2009.

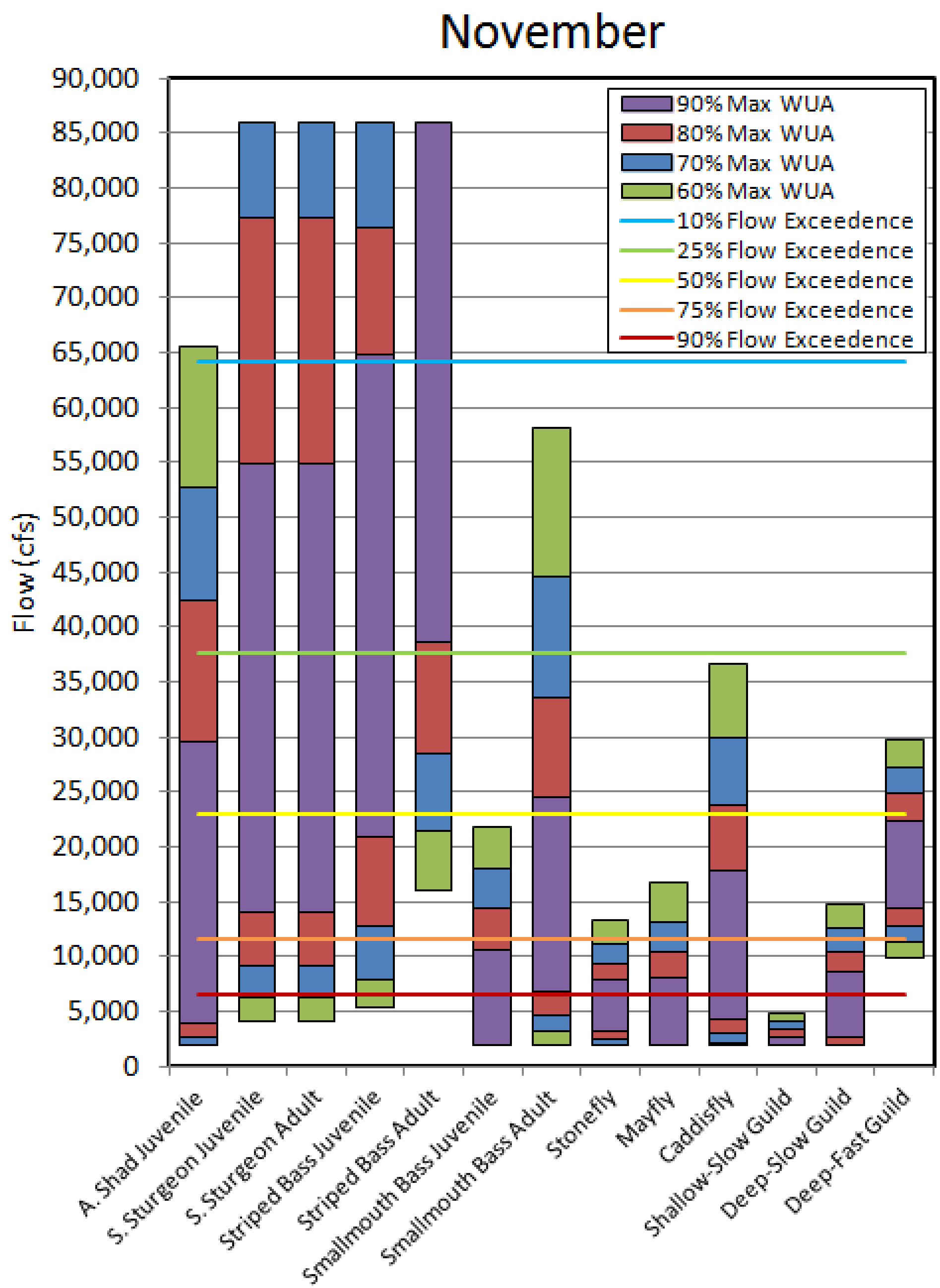
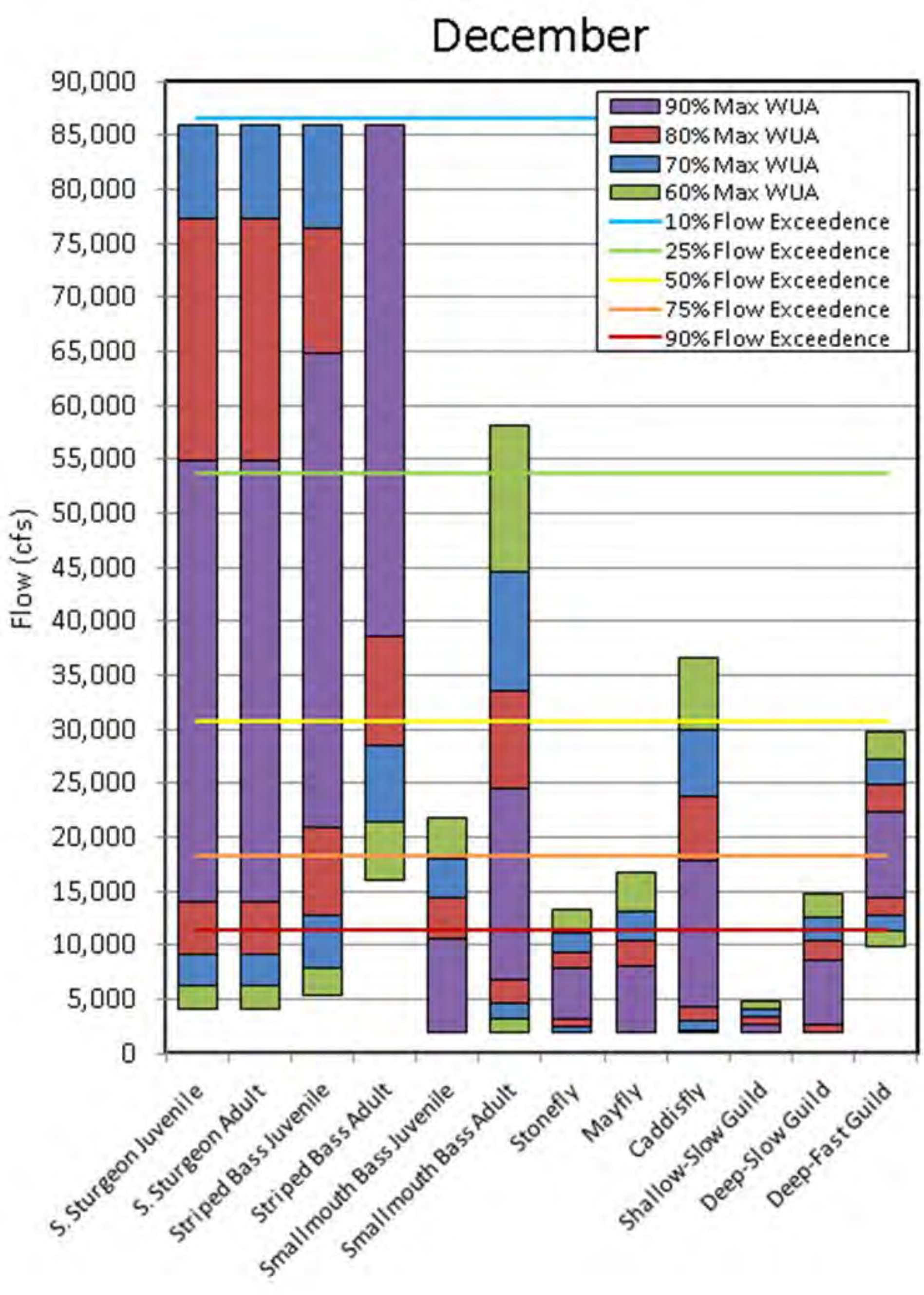


FIGURE 5.1.12-1: DECEMBER FLOW VS. HABITAT COMPARISON. FLOW EXCEEDANCES ARE FROM CONOWINGO ESTIMATED UNREGULATED FLOWS, PERIOD OF RECORD 1934-2009.



APPENDIX A- HABITAT SUITABILITY INDICES CONSULTATION

MEMORANDUM

December 9, 2010

TO: Larry Miller (USFWS), Andy Shiels (PFBC), Mike Hendricks (PFBC), Jim Richenderfer (SRBC), Andrew Dehoff (SRBC), Julie Crocker (NOAA), Shawn Seaman (MDNR), Bob Sadzinski (MDNR), Steve Schreiner (Versar Inc.), Bill Richkus (Versar Inc.), Jim Spontak (PaDEP), Janet Norman (USFWS), Jeremy Miller (PaDEP), John Smith (FERC), Mark Bryer (The Nature Conservancy), John Seebach (American Rivers), Don Pugh (American Rivers), Keith Whiteford (MDNR), Tyler Shenk (SRBC), John Balay (SRBC), Josh Treneski (PFBC), Matt Ashton (MDNR), Jessica Pruden (NMFS)

FROM: Gomez and Sullivan Engineers

Re: **Proposed Final Habitat Suitability Criteria Selection for the Instream Flow Habitat Assessment below Conowingo Dam (RSP 3.16). Conowingo Hydroelectric Project, FERC No. 405, Relicensing.**

INTRODUCTION

On August 19, 2010, Exelon sponsored a meeting with the stakeholders to discuss the initial habitat suitability curves, periodicity chart and habitat assignment guilds. Subsequently, further changes were made to specific curves after discussions with sub-groups. Specifically, the additional changes were made to the striped bass, shortnose sturgeon and smallmouth bass curves. This purpose of this memo is present to the group the proposed final periodicity table, habitat guild assignment and habitat suitability criteria for target species to be analyzed within the Instream Flow Habitat Assessment Study for the Conowingo Hydroelectric Project.

PROPOSED FINAL HABITAT SUITABILITY CURVES

There were several modifications proposed at the August meeting to the individual HSI curves of American shad, shortnose sturgeon, striped bass and smallmouth bass as well as the removal of the mussels and community macroinvertebrate curves from the analysis. The analysis of the mussels will be incorporated into the hydraulic analysis. The mussel habitat analysis will rely on output from the 2-dimensional hydraulic model, which is the basis for the instream flow study. Specifically, modeled hydraulic parameters, such as bottom shear stress, depth, and average column velocity, will be analyzed for specific areas of interest (i.e., known mussel bed locations) in the study reach, to determine the habitat impacts of the existing and alternative flow regimes.

Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), or EPT, curves were added to take the place of the community macroinvertebrate curve, as was discussed at the meeting. The EPT curves were developed from Gore et al. 2001. The Gore (2001) document provides a correlation between habitat suitability criteria for fish and the diversity of the macroinvertabrate community. The paper developed habitat suitability criteria for the EPT community that is commonly used during instream flow evaluations.

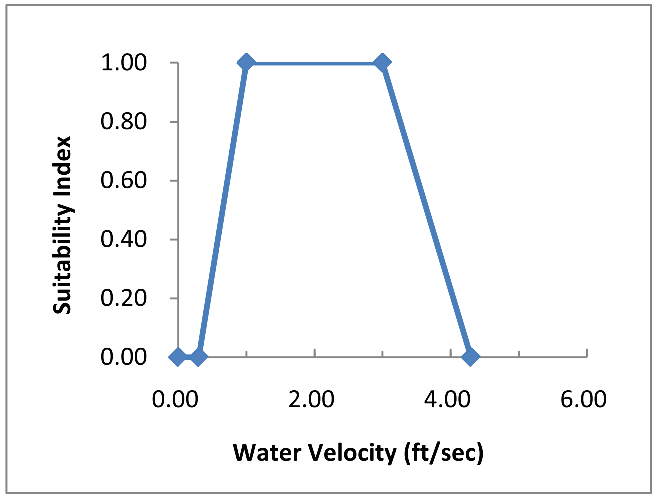
Further changes to the striped bass curves were made following discussions with Bob Sadzinski and Eric Durell of MDNR. The shortnose sturgeon curves were modified after a conference call with Don Pugh (American Rivers) and Jessica Pruden (NMFS). Smallmouth bass curves were further modified after information was provided by Mike Hendricks (PFBC). All of the information provided during the August 19 meeting and the subsequent discussions has been used to develop curves for the current analysis. Any changes made since the meeting are plotted on the same graph as the original curve so that the group can view the changes.

The appendices at the end of this memo provide a proposed final set of habitat suitability criteria, habitat guild assignment and periodicity table for review. All references used in the development of the curves are provided in Appendix D. Please review the information and respond with comments by December 24, 2010.

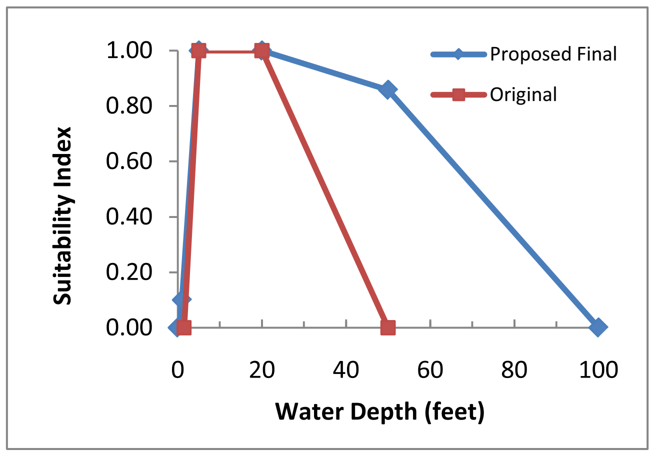
Appendix A- Revised Habitat Suitability Criteria

Species: American Shad
Lifestage: Spawning

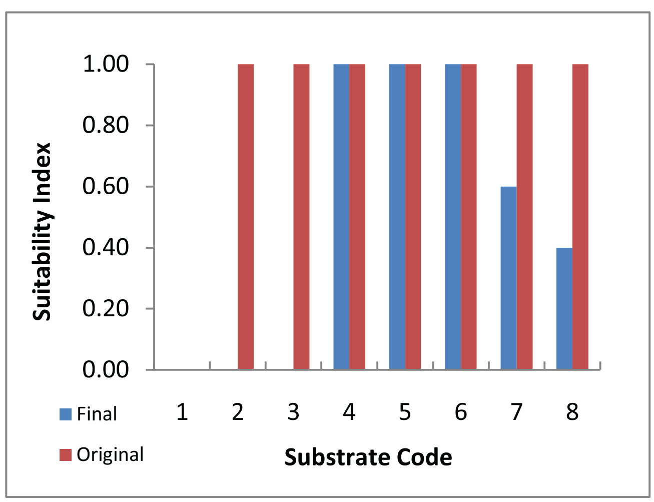
Velocity	SI Value
0.00	0.00
0.30	0.00
1.00	1.00
3.00	1.00
4.30	0.00



Proposed Final		Original	
Depth	SI Value	Depth	SI Value
0.00	0.00	1.50	0.00
1.00	0.10	5.00	1.00
5.00	1.00	20.00	1.00
20.00	1.00	50.00	0.00
50.00	0.86		
100.00	0.00		

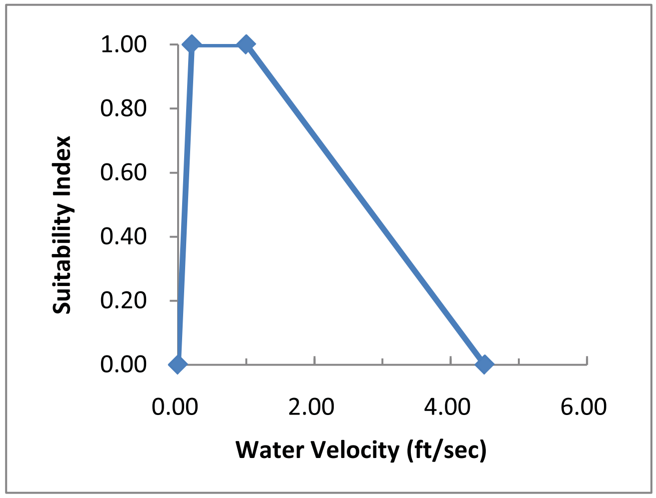


Code	Final SI Value	Original SI Value	Type
1	0.00	0.00	Detritus
2	0.00	1.00	Mud
3	0.00	1.00	Silt
4	1.00	1.00	Sand
5	1.00	1.00	Gravel
6	1.00	1.00	Cobble
7	0.60	1.00	Boulder
8	0.40	1.00	Bedrock

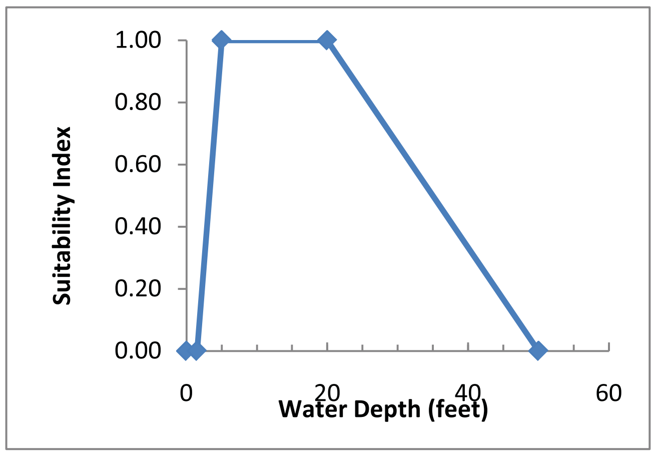


Species: American Shad
Lifestage: Fry

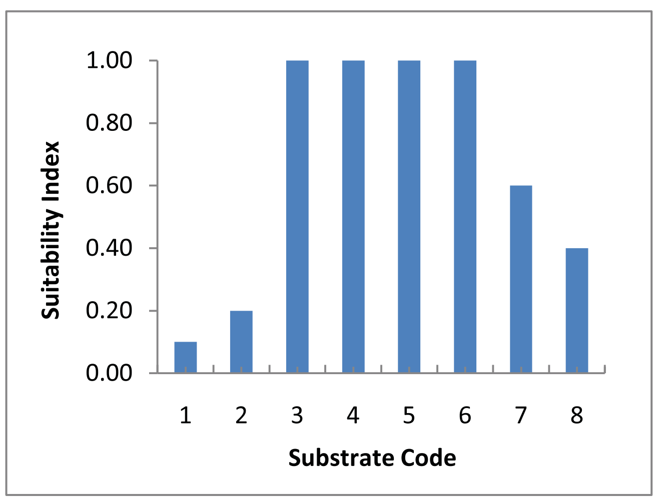
Velocity	SI Value
0.00	0.00
0.20	1.00
1.00	1.00
4.50	0.00



Depth	SI Value
0.00	0.00
1.50	0.00
5.00	1.00
20.00	1.00
50.00	0.00

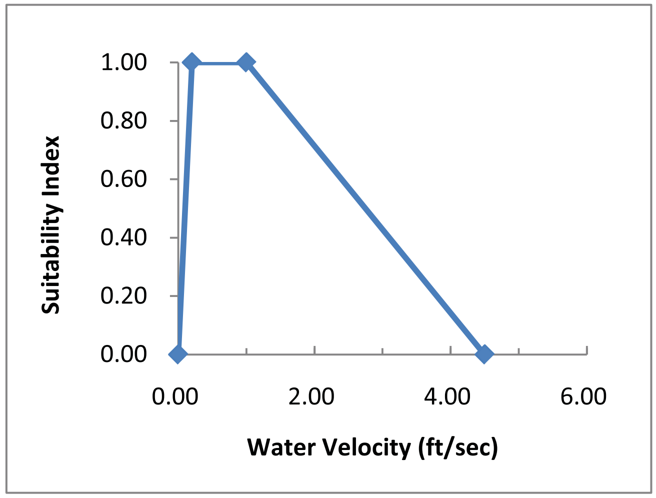


Code	SI Value	Type
1	0.10	Detritus/Organic
2	0.20	Mud/soft clay
3	1.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	1.00	Cobble
7	0.60	Boulder
8	0.40	Bedrock

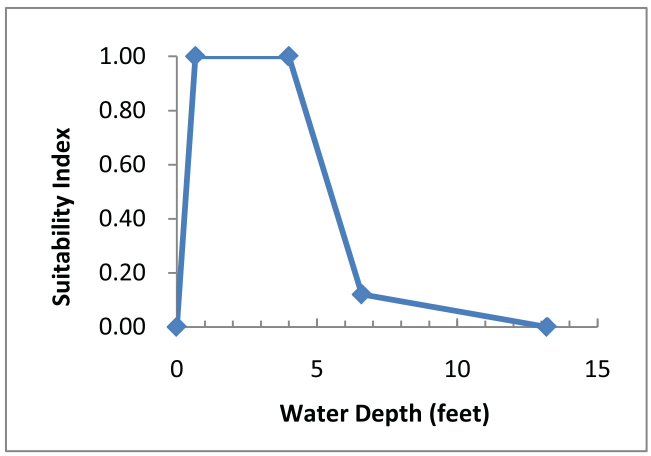


Species: American Shad
Lifestage: Juvenile

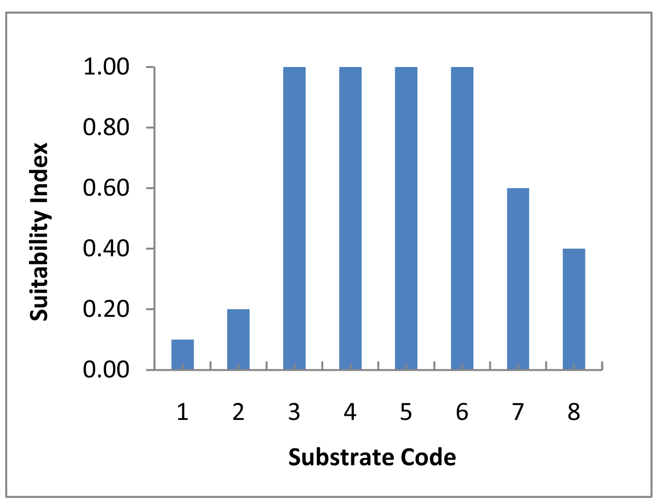
Velocity	SI Value
0.00	0.00
0.20	1.00
1.00	1.00
4.50	0.00



Depth	SI Value
0.00	0.00
0.66	1.00
3.99	1.00
6.60	0.12
13.20	0.00

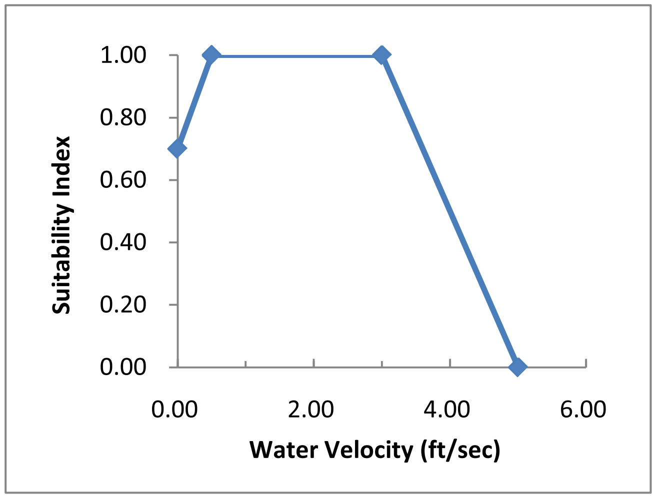


Code	SI Value	Type
1	0.10	Detritus/Organic
2	0.20	Mud/soft clay
3	1.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	1.00	Cobble
7	0.60	Boulder
8	0.40	Bedrock

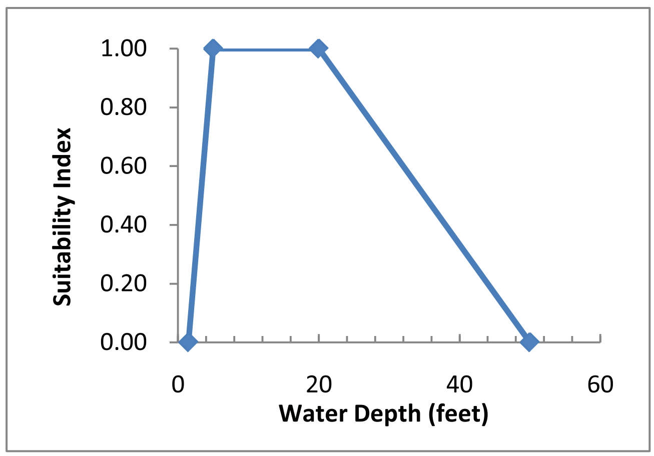


Species: American Shad
Lifestage: Adult

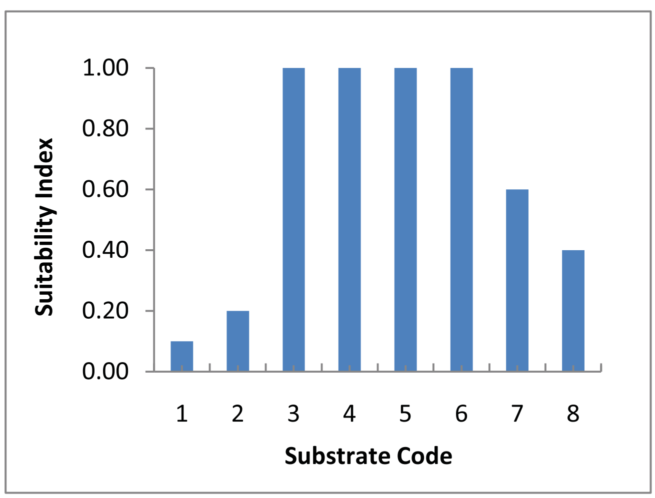
Velocity	SI Value
0.00	0.70
0.50	1.00
3.00	1.00
5.00	0.00



Depth	SI Value
0.00	0.00
1.50	0.00
5.00	1.00
20.00	1.00
50.00	0.00

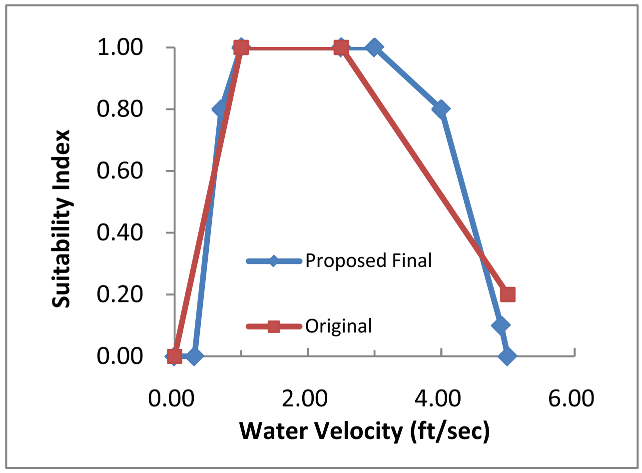


Code	SI Value	Type
1	0.10	Detritus/Organic
2	0.20	Mud/soft clay
3	1.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	1.00	Cobble
7	0.60	Boulder
8	0.40	Bedrock

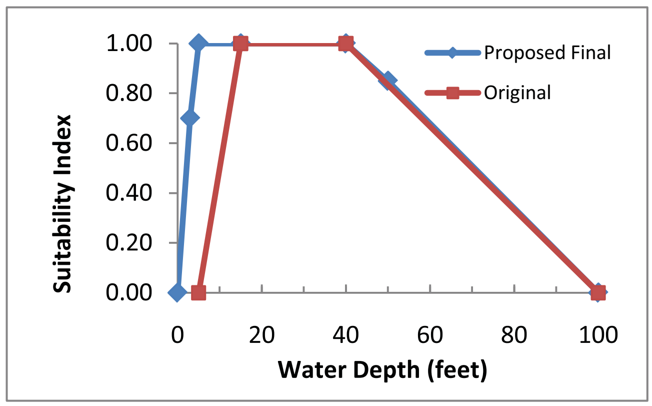


Species: Shortnose Sturgeon
Lifestage: Spawning

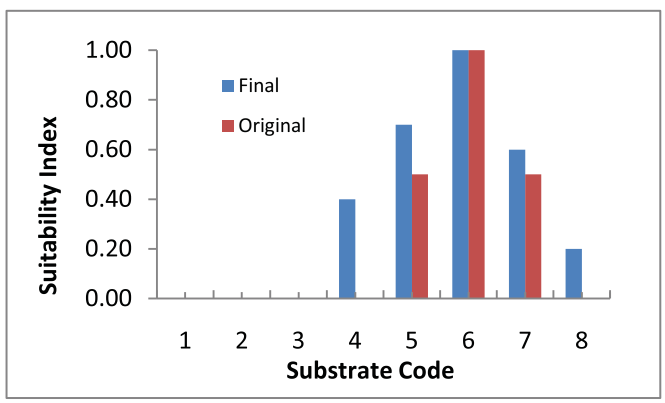
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	0.00	0.00	0.00
0.30	0.00	1.00	1.00
0.70	0.80	2.50	1.00
1.00	1.00	5.00	0.20
2.50	1.00		
3.00	1.00		
4.00	0.80		
4.90	0.10		
5.00	0.00		



Proposed Final		Original	
Depth	SI Value	Depth	SI Value
0.00	0.00	5.00	0.00
3.00	0.70	15.00	1.00
5.00	1.00	40.00	1.00
15.00	1.00	100.00	0.00
40.00	1.00		
50.00	0.85		
100.00	0.00		

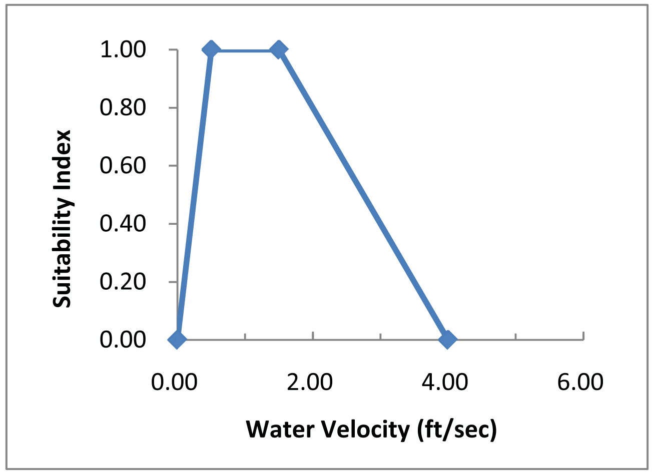


Code	Final SI Value	Original SI Value	Type
1	0.00	0.00	Detritus/Organic
2	0.00	0.00	Mud/soft clay
3	0.00	0.00	Silt
4	0.40	0.00	Sand
5	0.70	0.50	Gravel
6	1.00	1.00	Cobble/rubble
7	0.60	0.50	Boulder
8	0.20	0.00	Bedrock

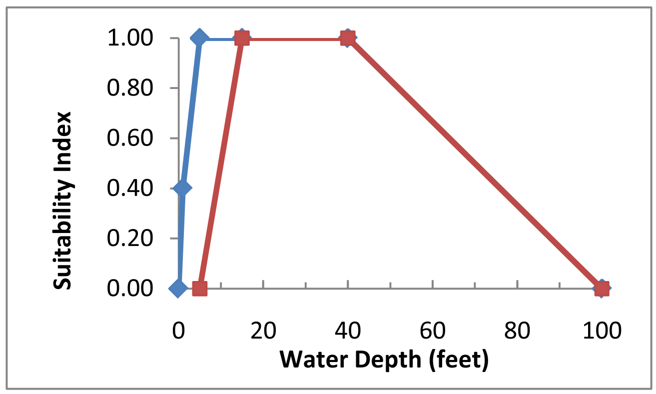


Species: Shortnose Sturgeon
Lifestage: Fry

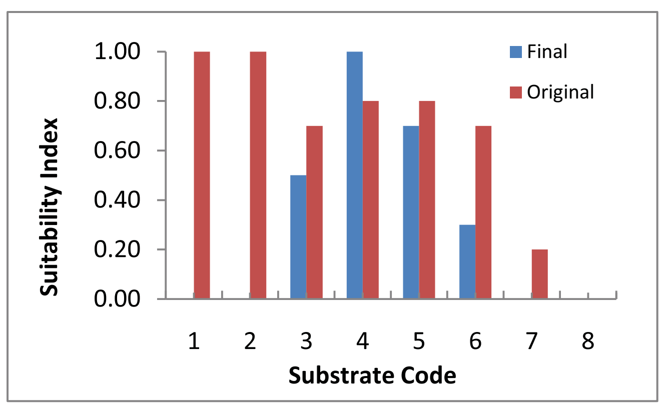
Velocity	SI Value
0.00	0.00
0.50	1.00
1.50	1.00
4.00	0.00



Proposed Final		Original	
Depth	SI Value	Depth	SI Value
0.00	0.00	5.00	0.00
1.00	0.40	15.00	1.00
5.00	1.00	40.00	1.00
15.00	1.00	100.00	0.00
40.00	1.00		
100.00	0.00		

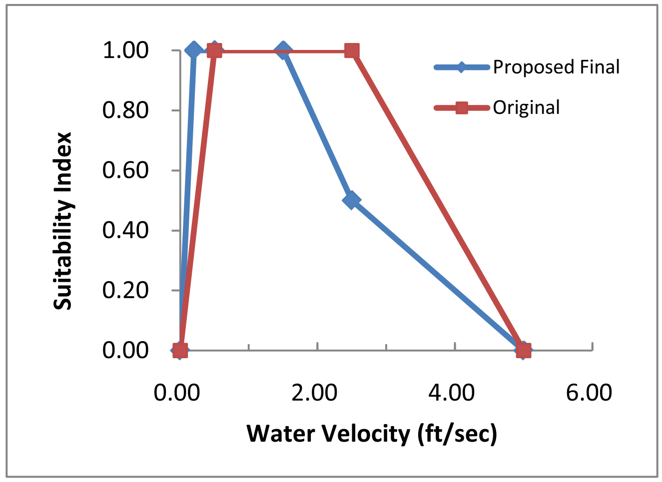


Code	Final SI Value	Original SI Value	Type
1	0.00	1.00	Detritus/Organic
2	0.00	1.00	Mud/soft clay
3	0.50	0.70	Silt
4	1.00	0.80	Sand
5	0.70	0.80	Gravel
6	0.30	0.70	Cobble/rubble
7	0.00	0.20	Boulder
8	0.00	0.00	Bedrock

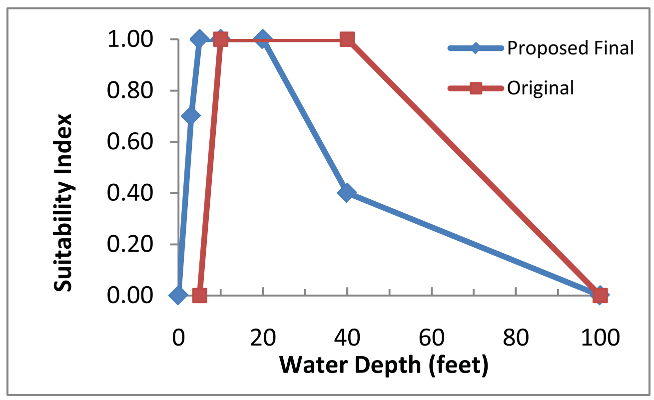


Species: Shortnose Sturgeon
Lifestage: Juveniles

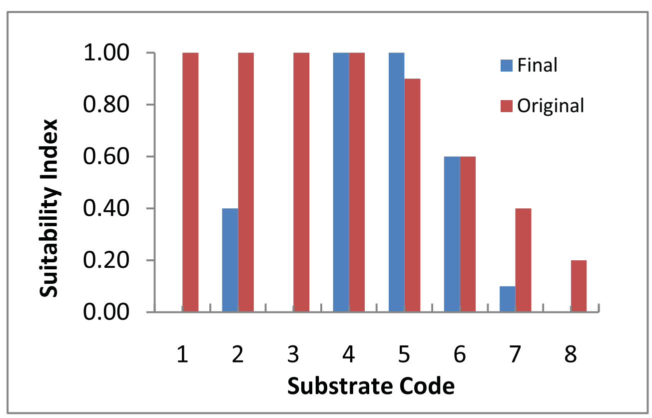
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	0.00	0.00	0.00
0.20	1.00	0.50	1.00
0.50	1.00	2.50	1.00
1.50	1.00	5.00	0.00
2.50	0.50		
5.00	0.00		



Proposed Final		Original	
Depth	SI Value	Depth	SI Value
0.00	0.00	5.00	0.00
3.00	0.70	10.00	1.00
5.00	1.00	40.00	1.00
10.00	1.00	100.00	0.00
20.00	1.00		
40.00	0.40		
100.00	0.00		

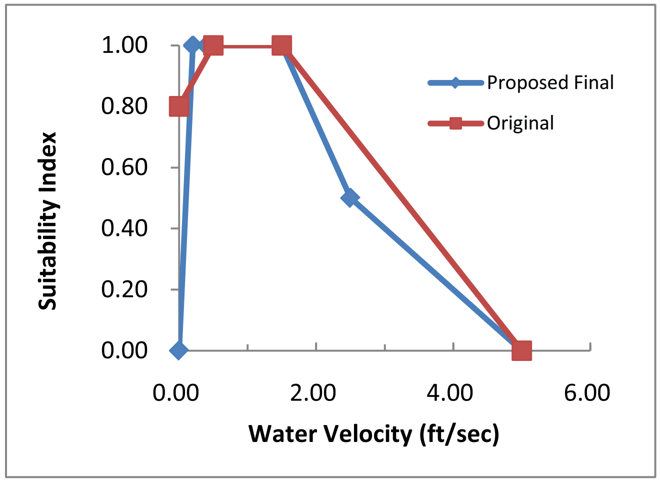


Code	Final SI Value	Original SI Value	Type
1	0.00	1.00	Detritus/Organic
2	0.40	1.00	Mud/soft clay
3	0.00	1.00	Silt
4	1.00	1.00	Sand
5	1.00	0.90	Gravel
6	0.60	0.60	Cobble/rubble
7	0.10	0.40	Boulder
8	0.00	0.20	Bedrock

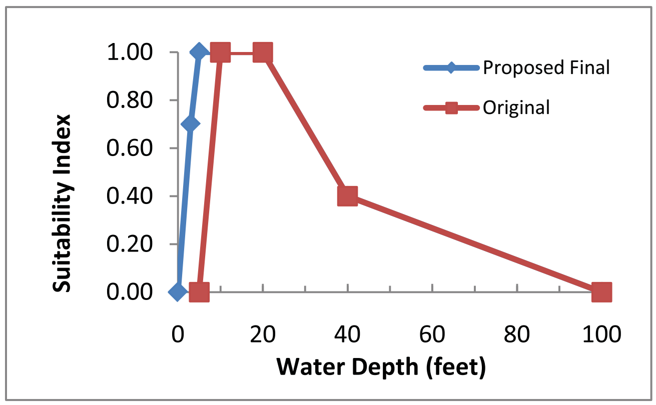


Species: Shortnose Sturgeon
Lifestage: Adults

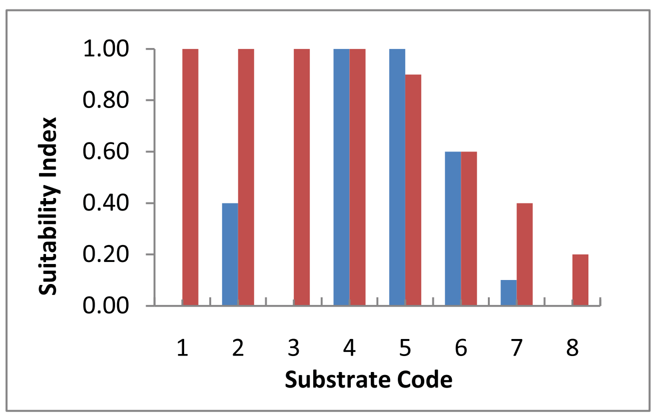
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	0.00	0.00	0.80
0.20	1.00	0.50	1.00
0.40	1.00	1.50	1.00
0.50	1.00	5.00	0.00
1.50	1.00		
2.50	0.50		
5.00	0.00		



Proposed Final		Original	
Depth	SI Value	Depth	SI Value
0.00	0.00	5.00	0.00
3.00	0.70	10.00	1.00
5.00	1.00	20.00	1.00
10.00	1.00	40.00	0.40
20.00	1.00	100.00	0.00
40.00	0.40		
100.00	0.00		

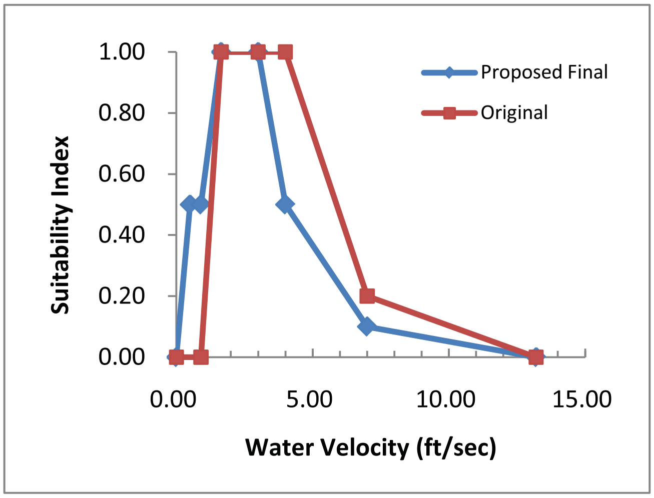


Code	Final SI Value	Original SI Value	Type
1	0.00	1.00	Detritus/Organic
2	0.40	1.00	Mud/soft clay
3	0.00	1.00	Silt
4	1.00	1.00	Sand
5	1.00	0.90	Gravel
6	0.60	0.60	Cobble/rubble
7	0.10	0.40	Boulder
8	0.00	0.20	Bedrock

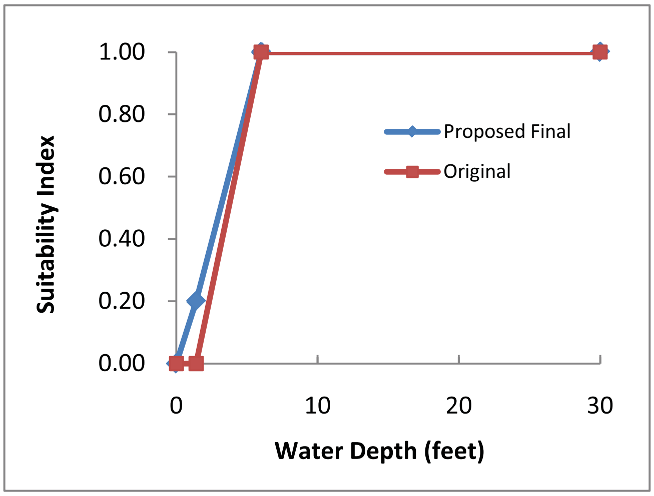


Species: Striped Bass
Lifestage: Spawning

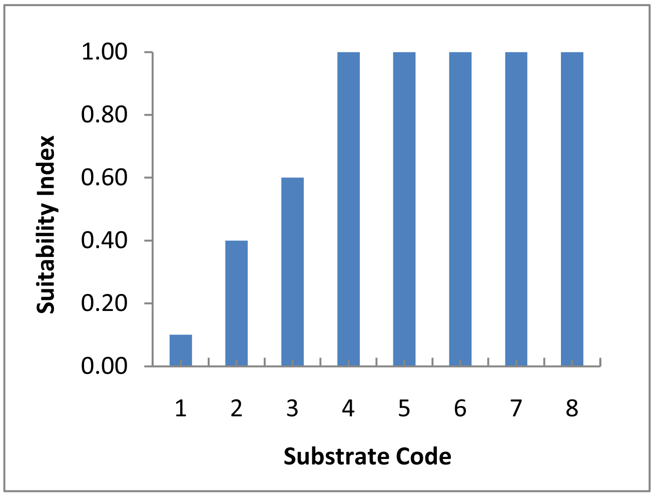
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	0.00	0.00	0.00
0.50	0.50	0.90	0.00
0.90	0.50	1.64	1.00
1.64	1.00	3.00	1.00
3.00	1.00	4.00	1.00
4.00	0.50	7.00	0.20
7.00	0.10	13.20	0.00
13.20	0.00		



Proposed Final		Original	
Depth	SI Value	Depth	SI Value
0.00	0.00	0.0	0.00
1.40	0.20	1.4	0.00
6.00	1.00	6.0	1.00
30.0	1.00	30.0	1.00

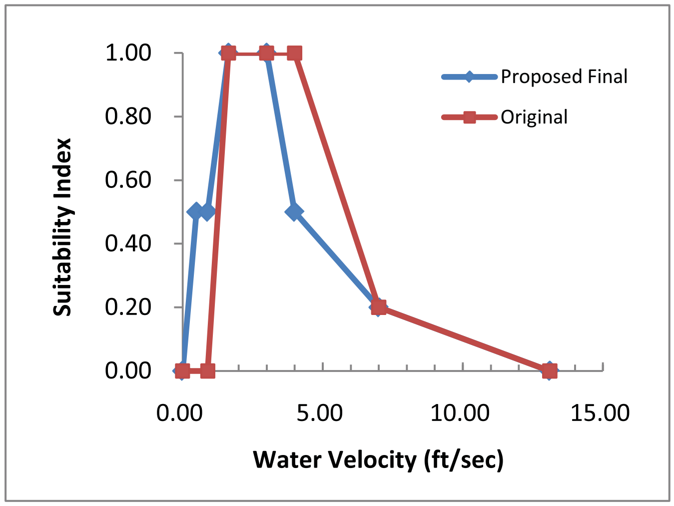


Code	SI Value	Type
1	0.1	Detritus/Organic
2	0.4	Mud/Soft Clay
3	0.6	Silt
4	1.0	Sand
5	1.0	Gravel
6	1.0	Cobble
7	1.0	Boulder
8	1.0	Bedrock

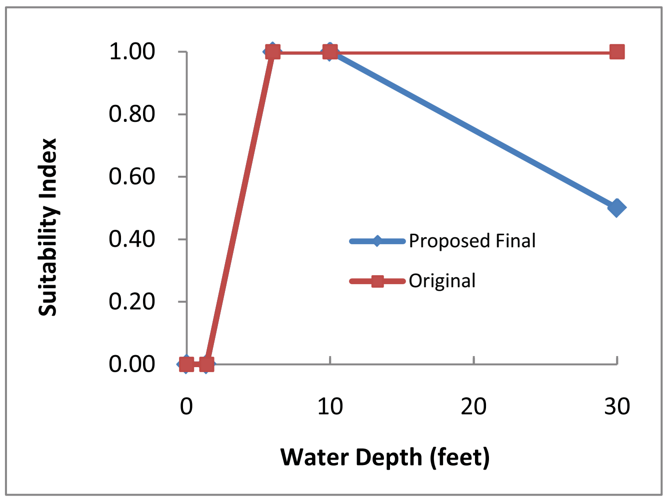


Species: Striped Bass
Lifestage: Fry

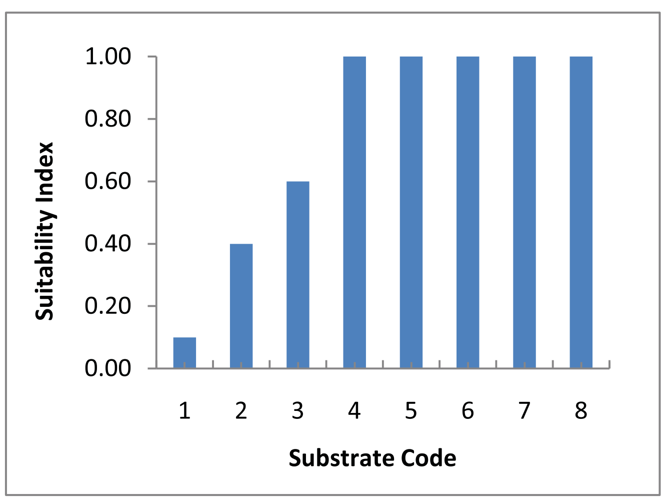
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	0.00	0.00	0.00
0.50	0.50	0.90	0.00
0.90	0.50	1.64	1.00
1.64	1.00	3.00	1.00
3.00	1.00	4.00	1.00
4.00	0.50	7.00	0.20
7.00	0.20	13.10	0.00
13.10	0.00		



Proposed Final		Original	
Depth	SI Value	Depth	SI Value
0.00	0.00	0.0	0.00
1.40	0.00	1.4	0.00
6.00	1.00	6.0	1.00
10.0	1.00	10.0	1.00
30.0	0.50	30.0	1.00

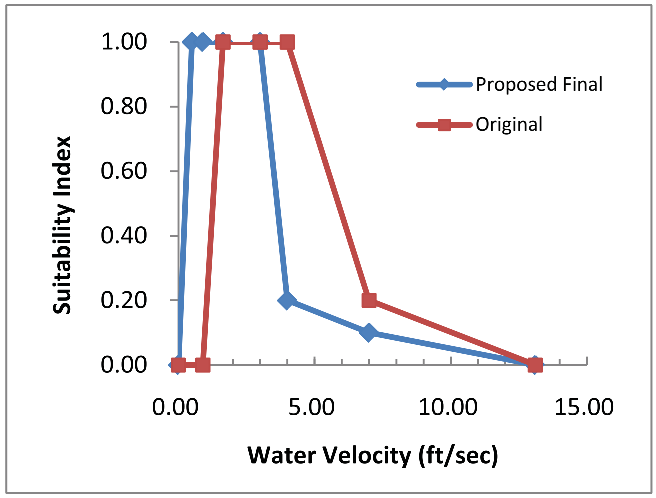


Code	SI Value	Type
1	0.1	Detritus/Organic
2	0.4	Mud/Soft Clay
3	0.6	Silt
4	1.0	Sand
5	1.0	Gravel
6	1.0	Cobble
7	1.0	Boulder
8	1.0	Bedrock

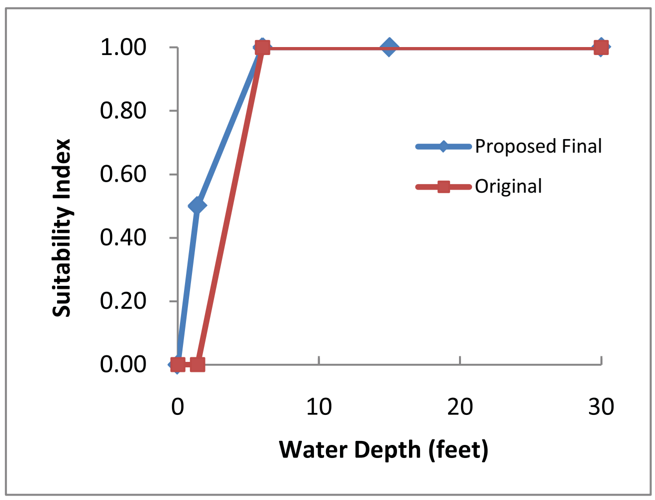


Species: Striped Bass
Lifestage: Juvenile

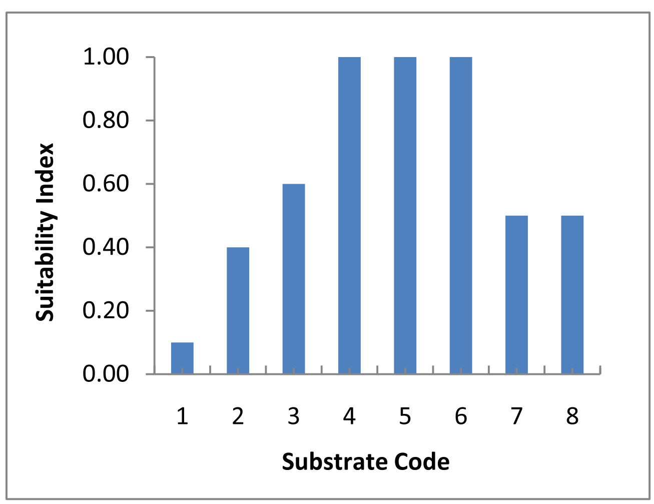
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	0.00	0.00	0.00
0.50	1.00	0.90	0.00
0.90	1.00	1.64	1.00
1.64	1.00	3.00	1.00
3.00	1.00	4.00	1.00
4.00	0.20	7.00	0.20
7.00	0.10	13.10	0.00
13.10	0.00		



Proposed Final		Original	
Depth	SI Value	Depth	SI Value
0.00	0.00	0.0	0.00
1.40	0.50	1.4	0.00
6.00	1.00	6.0	1.00
15.0	1.00	30.0	1.00
30.0	1.00		

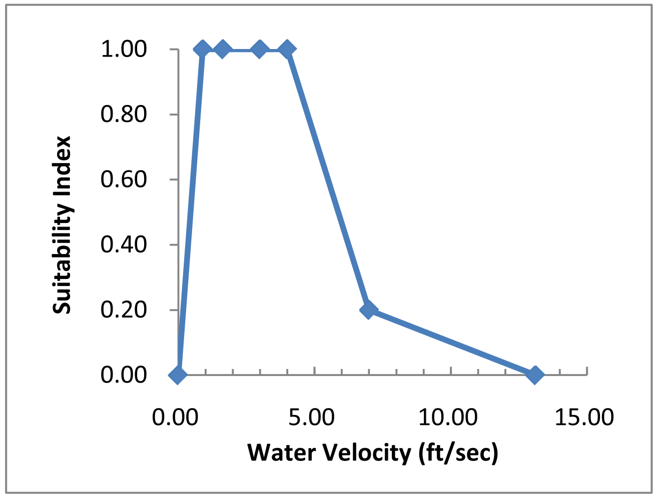


Code	SI Value	Type
1	0.1	Detritus/Organic
2	0.4	Mud/Soft Clay
3	0.6	Silt
4	1.0	Sand
5	1.0	Gravel
6	1.0	Cobble
7	0.5	Boulder
8	0.5	Bedrock

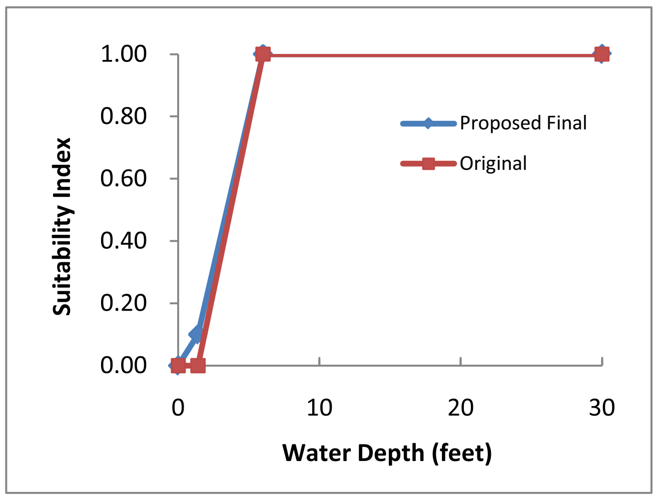


Species: Striped Bass
Lifestage: Adult

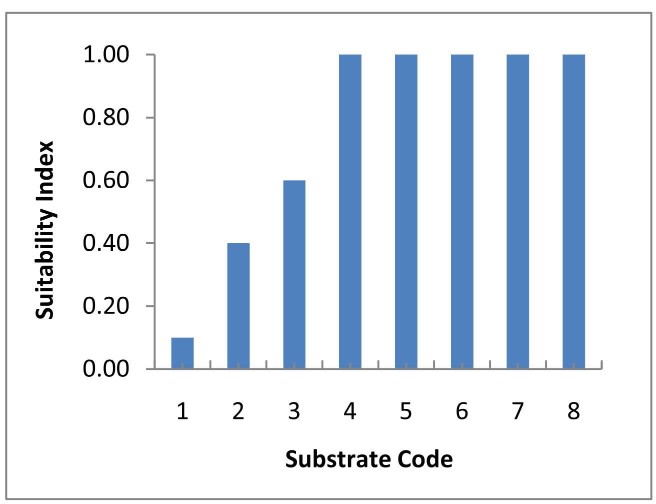
Velocity	SI Value
0.00	0.00
0.90	1.00
1.64	1.00
3.00	1.00
4.00	1.00
7.00	0.20
13.10	0.00



Proposed Final		Original	
Depth	SI Value	Depth	SI Value
0.00	0.00	0.0	0.00
1.40	0.10	1.4	0.00
6.00	1.00	6.0	1.00
30.0	1.00	30.0	1.00

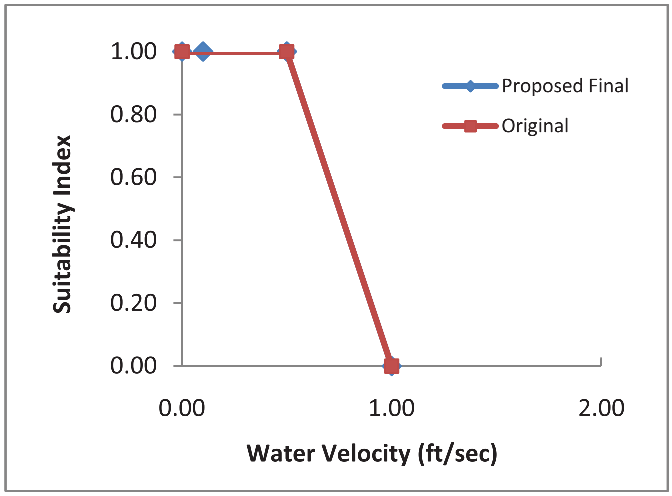


Code	SI Value	Type
1	0.1	Detritus/Organic
2	0.4	Mud/Soft Clay
3	0.6	Silt
4	1.0	Sand
5	1.0	Gravel
6	1.0	Cobble
7	1.0	Boulder
8	1.0	Bedrock

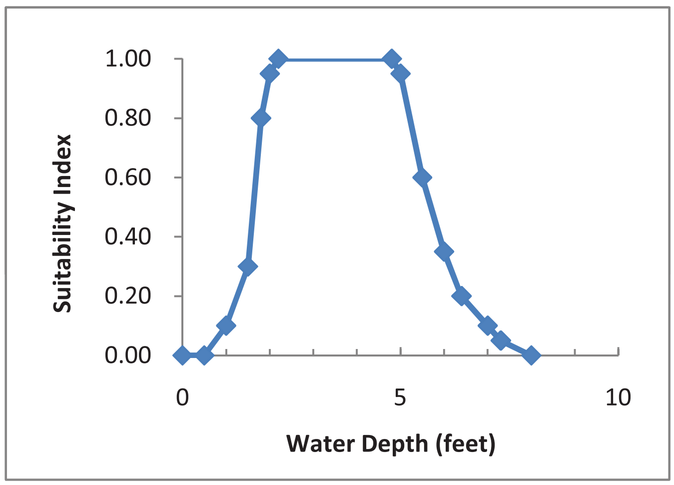


Species: Smallmouth Bass
Lifestage: Spawning

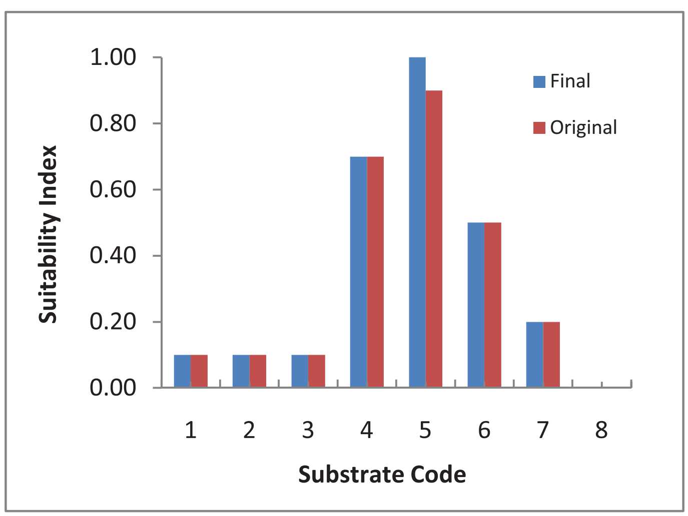
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	1.00	0.00	1.00
0.10	1.00	0.50	1.00
0.50	1.00	1.00	0.00
1.00	0.00		



Depth	SI Value
0.00	0.00
0.50	0.00
1.00	0.10
1.50	0.30
1.80	0.80
2.00	0.95
2.20	1.00
4.80	1.00
5.00	0.95
5.50	0.60
6.00	0.35
6.40	0.20
7.00	0.10
7.30	0.05
8.00	0.00

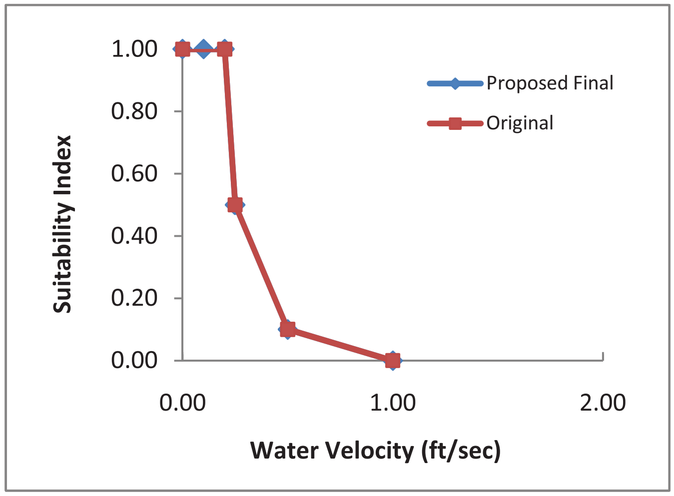


Code	Final SI Value	Original SI Value	Type
1	0.10	0.10	Detritus
2	0.10	0.10	Mud
3	0.10	0.10	Silt
4	0.70	0.70	Sand
5	1.00	0.90	Gravel
6	0.50	0.50	Cobble
7	0.20	0.20	Boulder
8	0.00	0.00	Bedrock

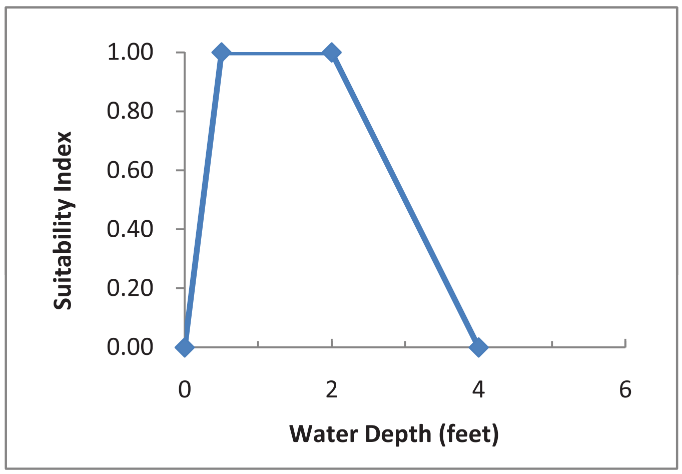


Species: Smallmouth Bass
Lifestage: Fry

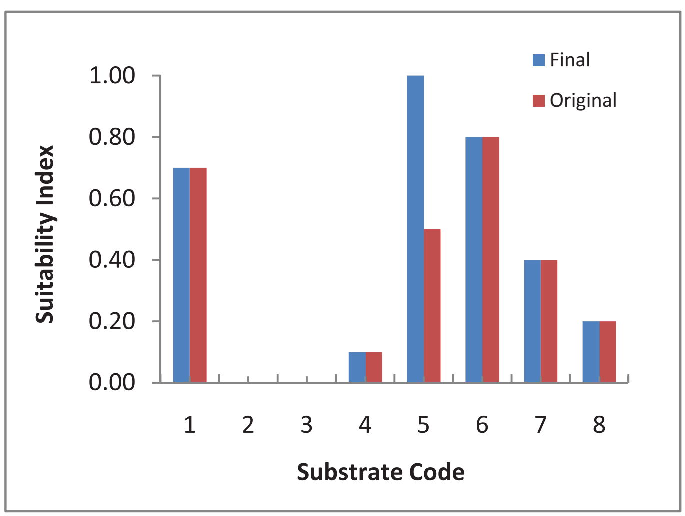
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	1.00	0.00	1.00
0.10	1.00	0.20	1.00
0.20	1.00	0.25	0.50
0.25	0.50	0.50	0.10
0.50	0.10	1.00	0.00
1.00	0.00		



Depth	SI Value
0.00	0.00
0.50	1.00
2.00	1.00
4.00	0.00

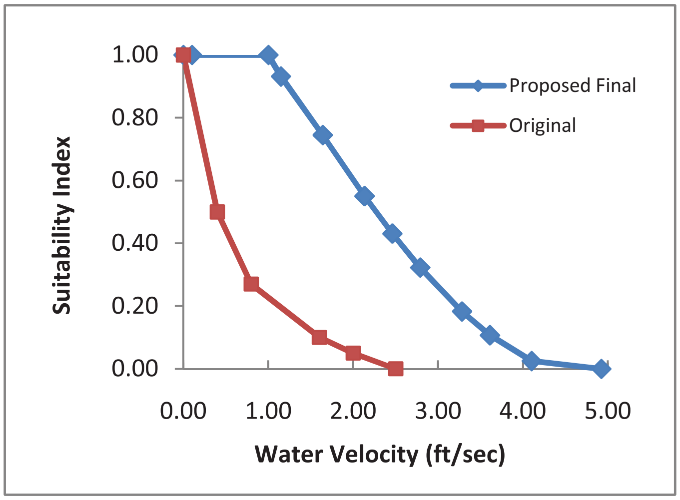


Code	Final SI Value	Original SI Value	Type
1	0.70	0.70	Detritus
2	0.00	0.00	Mud
3	0.00	0.00	Silt
4	0.10	0.10	Sand
5	1.00	0.50	Gravel
6	0.80	0.80	Cobble
7	0.40	0.40	Boulder
8	0.20	0.20	Bedrock

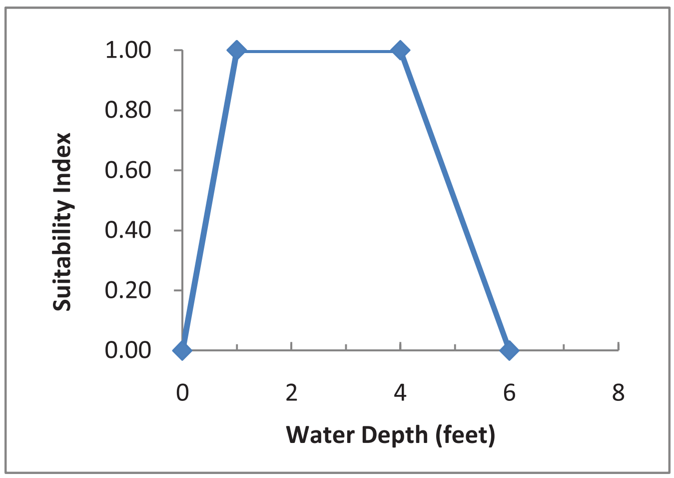


Species: Smallmouth Bass
Lifestage: Juvenile

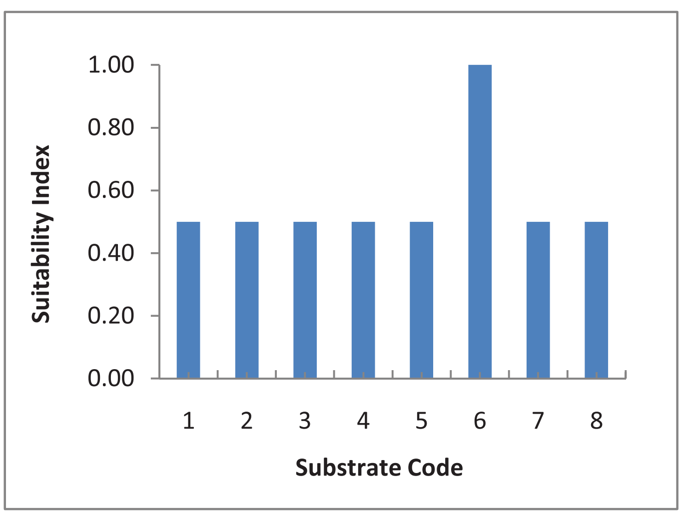
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	1.00	0.00	1.00
0.10	1.00	0.40	0.50
1.00	1.00	0.80	0.27
1.15	0.93	1.60	0.10
1.64	0.75	2.00	0.05
2.13	0.55	2.50	0.00
2.46	0.43		
2.79	0.32		
3.28	0.18		
3.61	0.11		
4.10	0.02		
4.92	0.00		



Depth	SI Value
0.00	0.00
1.00	1.00
4.00	1.00
6.00	0.00

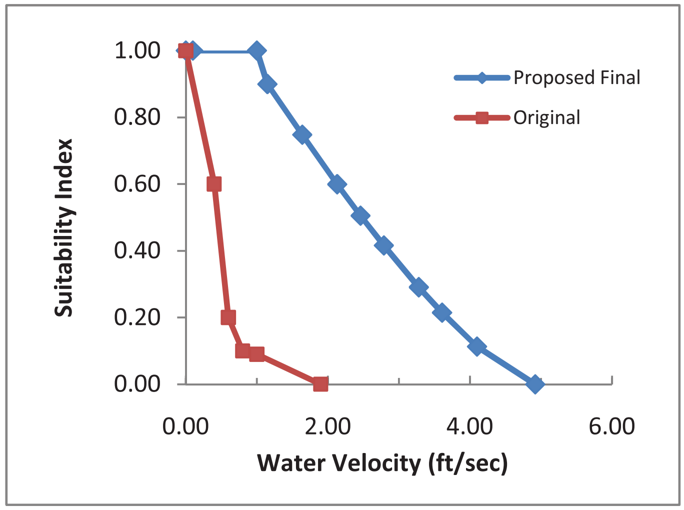


Code	SI Value	Type
1	0.50	Detritus/Organic
2	0.50	Mud/soft clay
3	0.50	Silt
4	0.50	Sand
5	0.50	Gravel
6	1.00	Cobble/rubble
7	0.50	Boulder
8	0.50	Bedrock

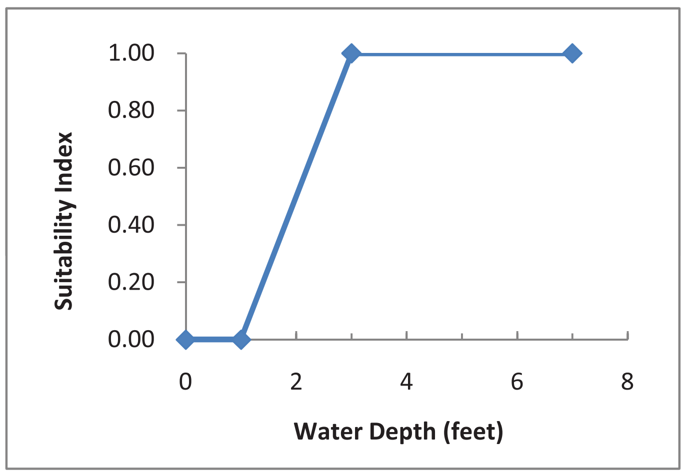


Species: Smallmouth Bass
Lifestage: Adult

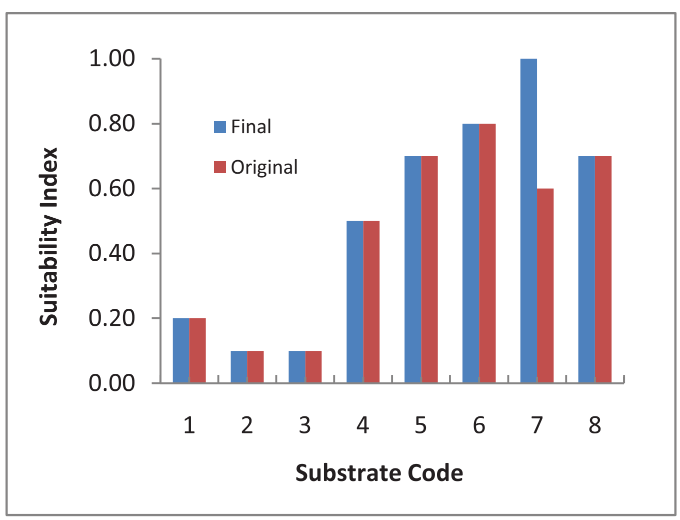
Proposed Final		Original	
Velocity	SI Value	Velocity	SI Value
0.00	1.00	0.00	1.00
0.10	1.00	0.40	0.60
1.00	1.00	0.60	0.20
1.15	0.90	0.80	0.10
1.64	0.75	1.00	0.09
2.13	0.60	1.90	0.00
2.46	0.51		
2.79	0.42		
3.28	0.29		
3.61	0.21		
4.10	0.11		
4.92	0.00		



Depth	SI Value
0.00	0.00
1.00	0.00
3.00	1.00
7.00	1.00



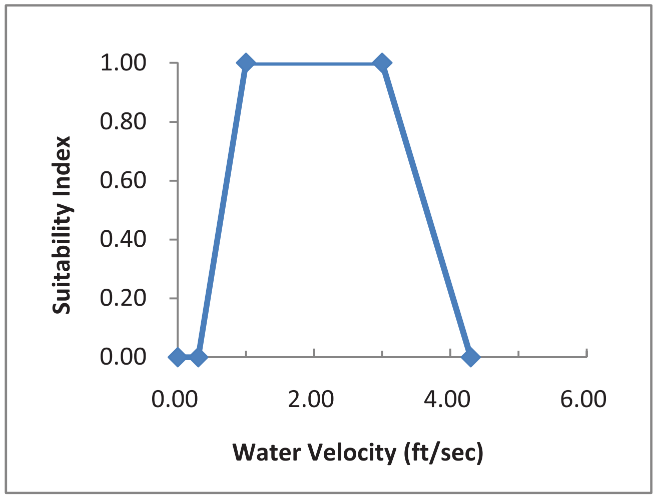
Code	Final SI Value	Original SI Value	Type
1	0.20	0.20	Detritus
2	0.10	0.10	Mud
3	0.10	0.10	Silt
4	0.50	0.50	Sand
5	0.70	0.70	Gravel
6	0.80	0.80	Cobble
7	1.00	0.60	Boulder
8	0.70	0.70	Bedrock



APPENDIX B-HABITAT SUITABILITY INDICES

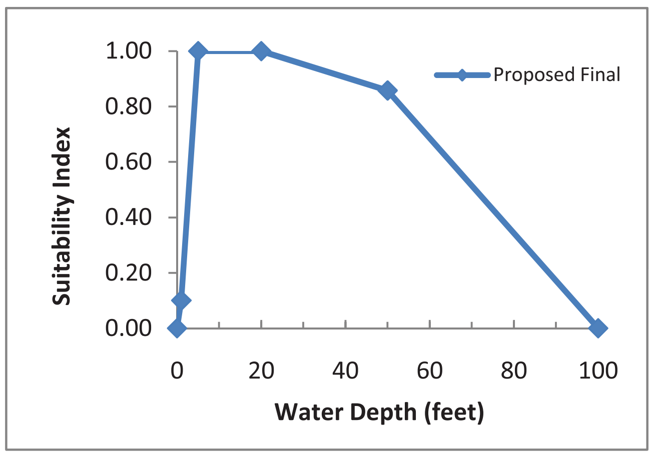
Species: American Shad
Lifestage: Spawning

Velocity	SI Value
0.00	0.00
0.30	0.00
1.00	1.00
3.00	1.00
4.30	0.00

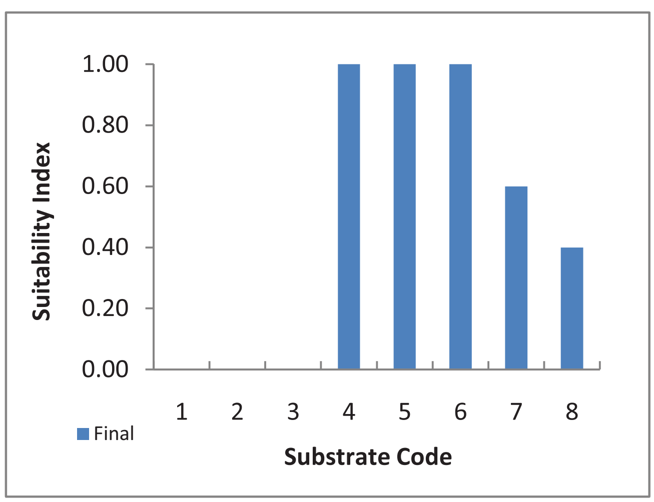


Proposed Final

Depth	SI Value
0.00	0.00
1.00	0.10
5.00	1.00
20.00	1.00
50.00	0.86
100.00	0.00

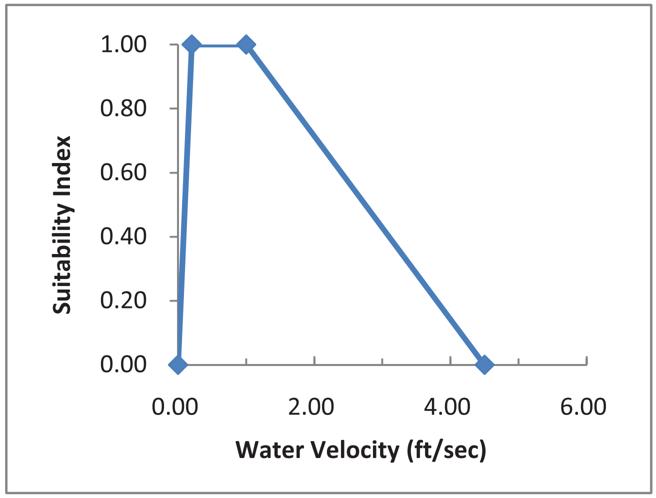


Code	Final SI Value	Type
1	0.00	Detritus
2	0.00	Mud
3	0.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	1.00	Cobble
7	0.60	Boulder
8	0.40	Bedrock

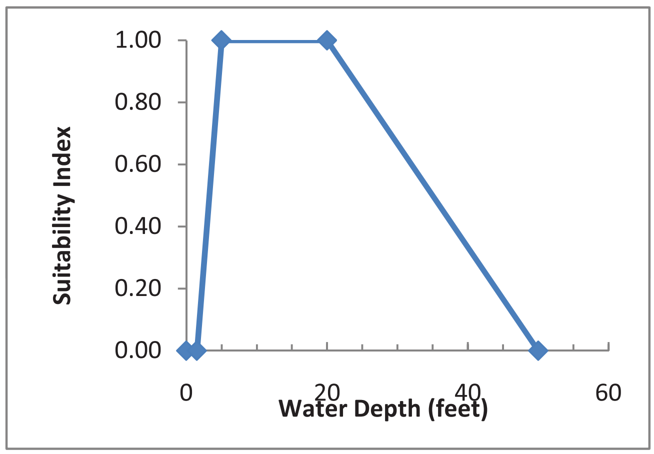


Species: American Shad
Lifestage: Fry

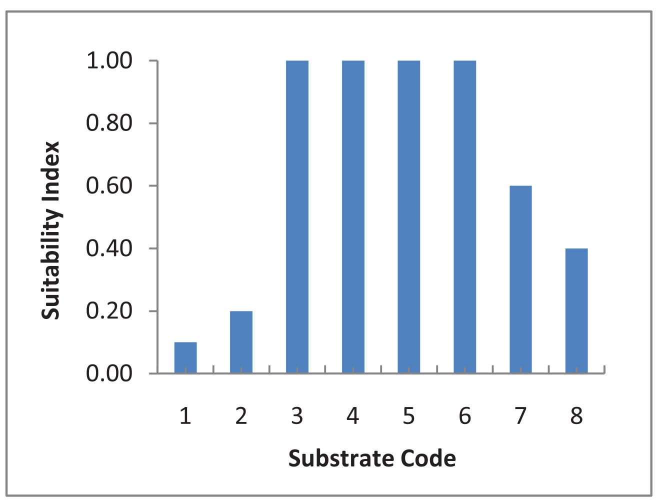
Velocity	SI Value
0.00	0.00
0.20	1.00
1.00	1.00
4.50	0.00



Depth	SI Value
0.00	0.00
1.50	0.00
5.00	1.00
20.00	1.00
50.00	0.00

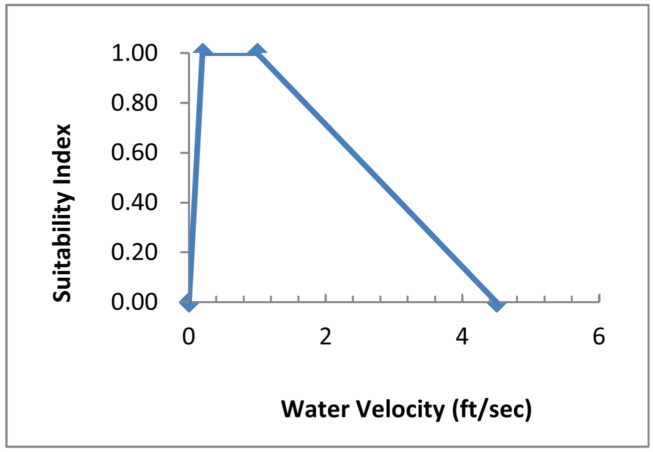


Code	SI Value	Type
1	0.10	Detritus/Organic
2	0.20	Mud/soft clay
3	1.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	1.00	Cobble
7	0.60	Boulder
8	0.40	Bedrock

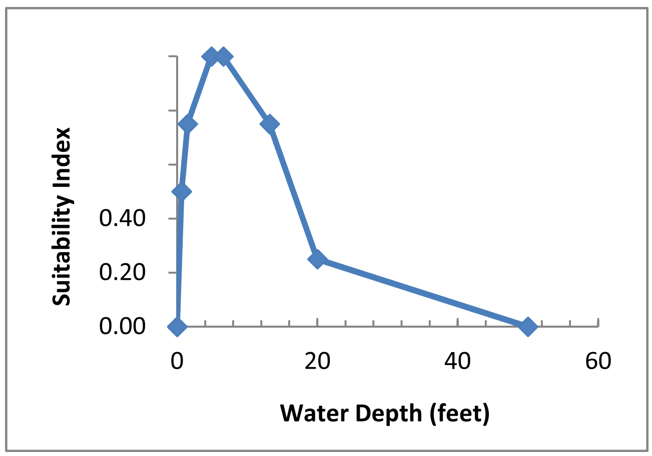


Species: American Shad
Lifestage: Juvenile

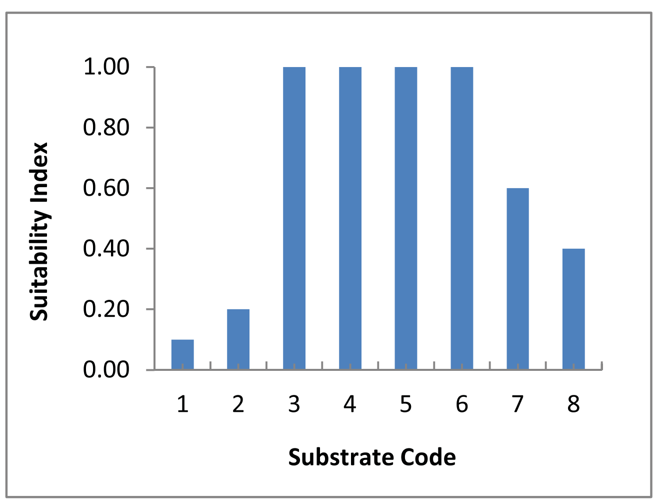
Velocity	SI Value
0.00	0.00
0.20	1.00
1.00	1.00
4.50	0.00



Depth	SI Value
0.00	0.00
0.66	0.50
1.50	0.75
4.90	1.00
6.60	1.00
13.20	0.75
20.00	0.25
50.00	0.00

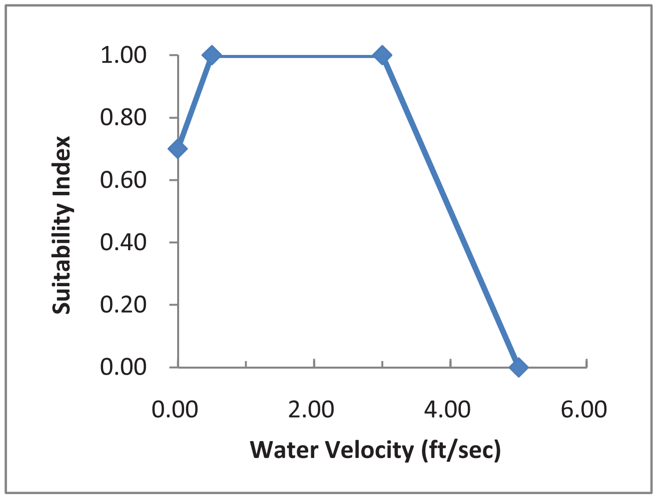


Code	SI Value	Type
1	0.10	Detritus/Organic
2	0.20	Mud/soft clay
3	1.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	1.00	Cobble
7	0.60	Boulder
8	0.40	Bedrock

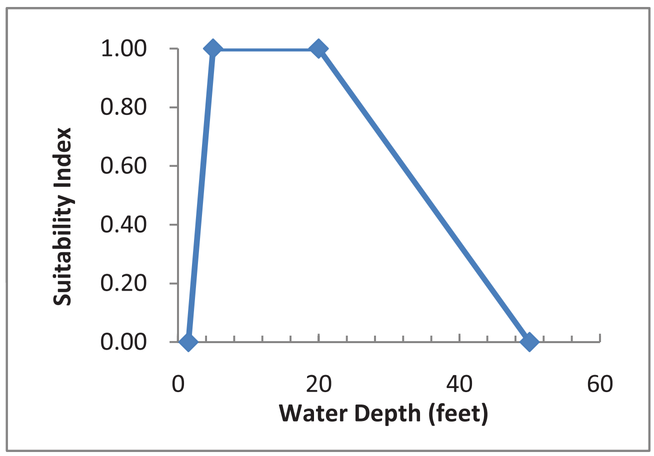


Species: American Shad
Lifestage: Adult

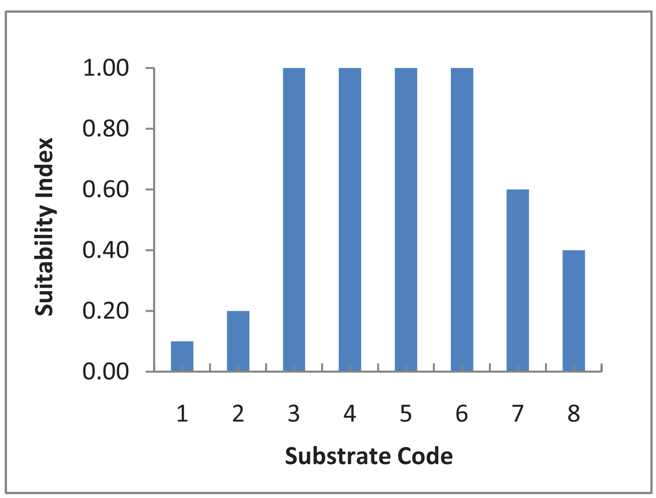
Velocity	SI Value
0.00	0.70
0.50	1.00
3.00	1.00
5.00	0.00



Depth	SI Value
0.00	0.00
1.50	0.00
5.00	1.00
20.00	1.00
50.00	0.00

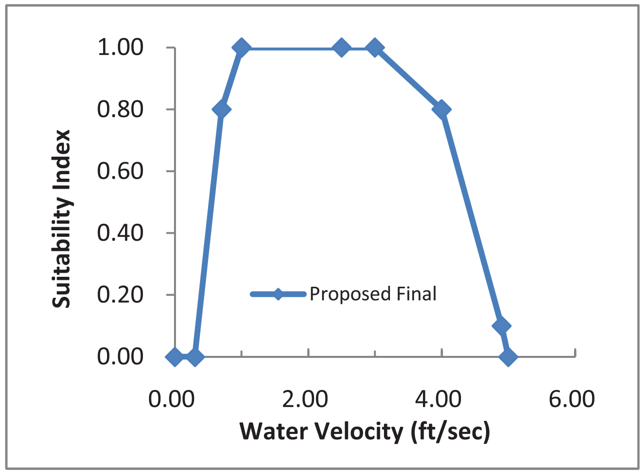


Code	SI Value	Type
1	0.10	Detritus/Organic
2	0.20	Mud/soft clay
3	1.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	1.00	Cobble
7	0.60	Boulder
8	0.40	Bedrock

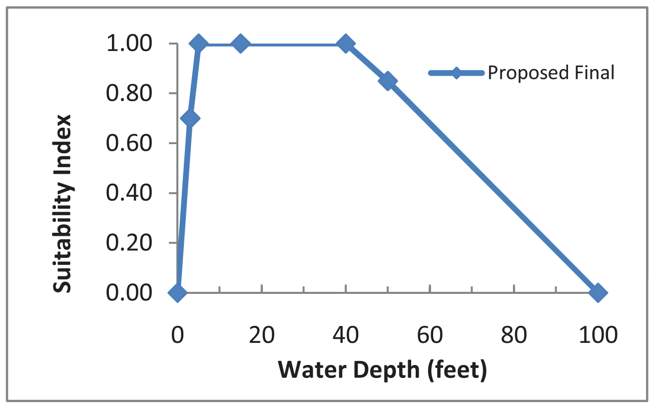


Species: Shortnose Sturgeon
Lifestage: Spawning

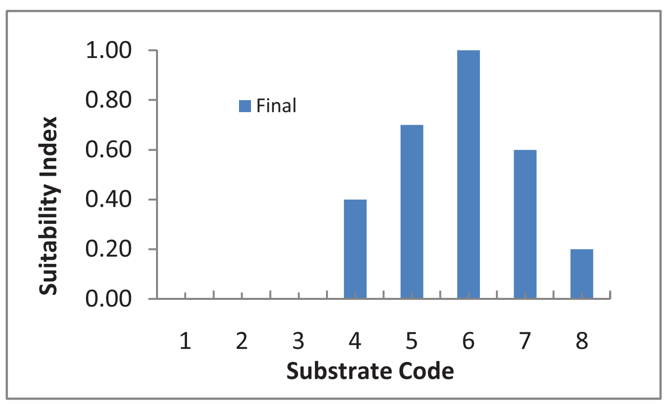
Proposed Final	
Velocity	SI Value
0.00	0.00
0.30	0.00
0.70	0.80
1.00	1.00
2.50	1.00
3.00	1.00
4.00	0.80
4.90	0.10
5.00	0.00



Proposed Final	
Depth	SI Value
0.00	0.00
3.00	0.70
5.00	1.00
15.00	1.00
40.00	1.00
50.00	0.85
100.00	0.00

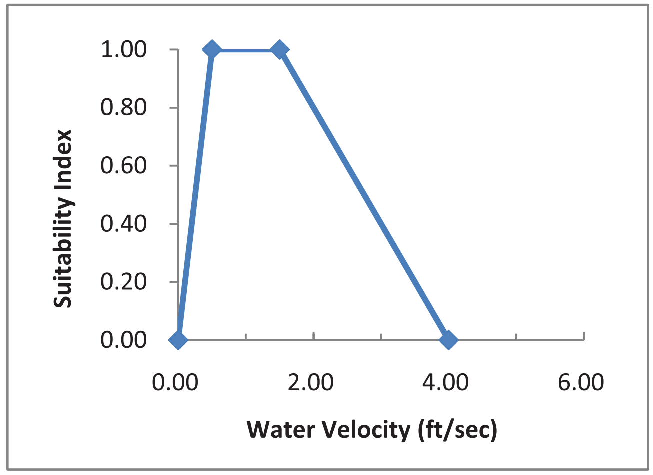


Code	Final SI Value	Type
1	0.00	Detritus/Organic
2	0.00	Mud/soft clay
3	0.00	Silt
4	0.40	Sand
5	0.70	Gravel
6	1.00	Cobble/rubble
7	0.60	Boulder
8	0.20	Bedrock



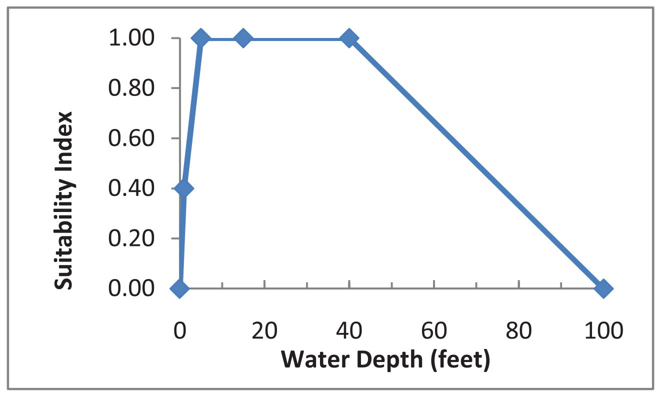
Species: Shortnose Sturgeon
Lifestage: Fry

Velocity	SI Value
0.00	0.00
0.50	1.00
1.50	1.00
4.00	0.00

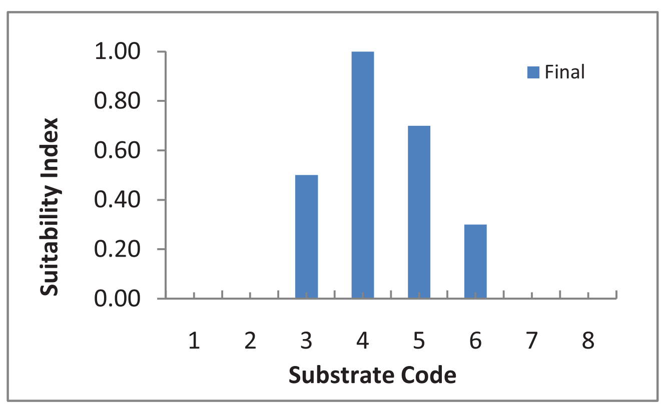


Proposed Final

Depth	SI Value
0.00	0.00
1.00	0.40
5.00	1.00
15.00	1.00
40.00	1.00
100.00	0.00

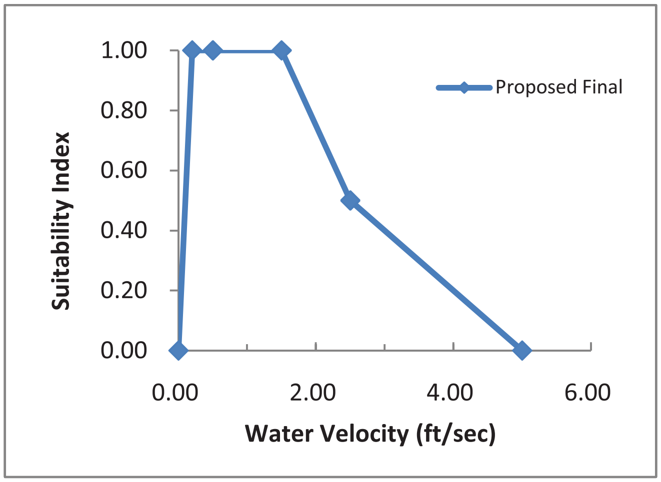


Code	Final SI Value	Type
1	0.00	Detritus/Organic
2	0.00	Mud/soft clay
3	0.50	Silt
4	1.00	Sand
5	0.70	Gravel
6	0.30	Cobble/rubble
7	0.00	Boulder
8	0.00	Bedrock

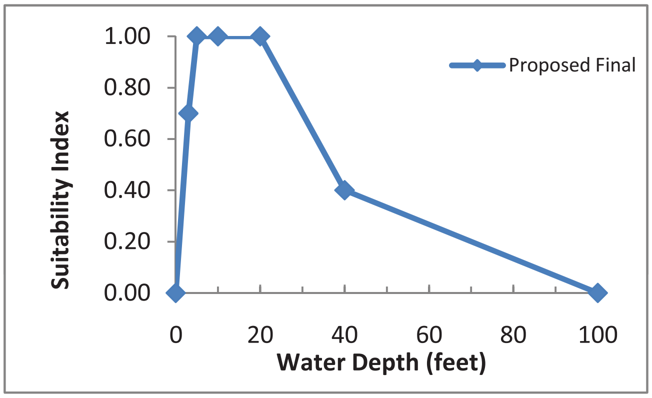


Species: Shortnose Sturgeon
Lifestage: Juveniles

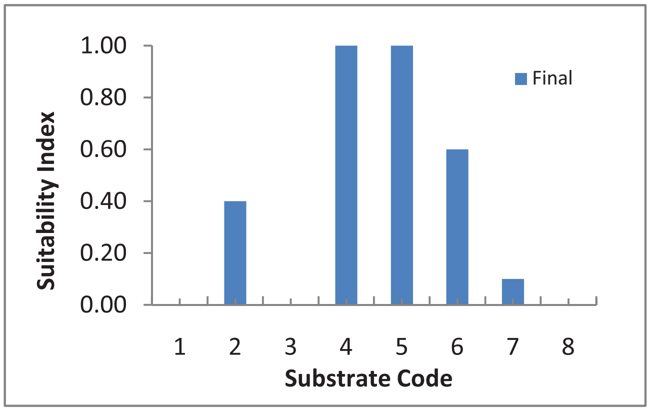
Proposed Final Velocity	SI Value
0.00	0.00
0.20	1.00
0.50	1.00
1.50	1.00
2.50	0.50
5.00	0.00



Proposed Final Depth	SI Value
0.00	0.00
3.00	0.70
5.00	1.00
10.00	1.00
20.00	1.00
40.00	0.40
100.00	0.00

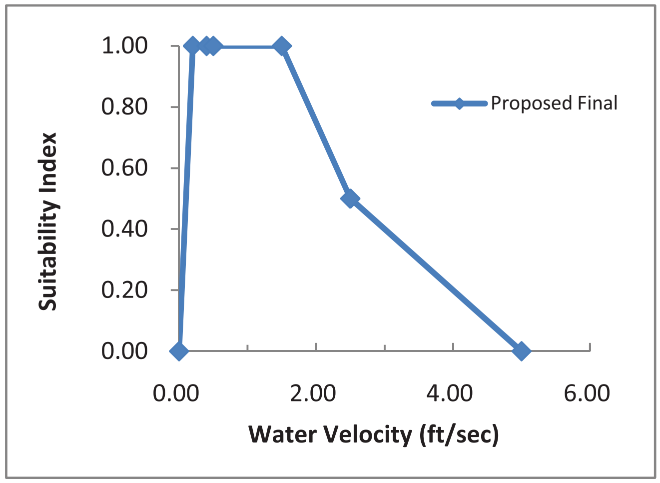


Code	Final SI Value	Type
1	0.00	Detritus/Organic
2	0.40	Mud/soft clay
3	0.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	0.60	Cobble/rubble
7	0.10	Boulder
8	0.00	Bedrock

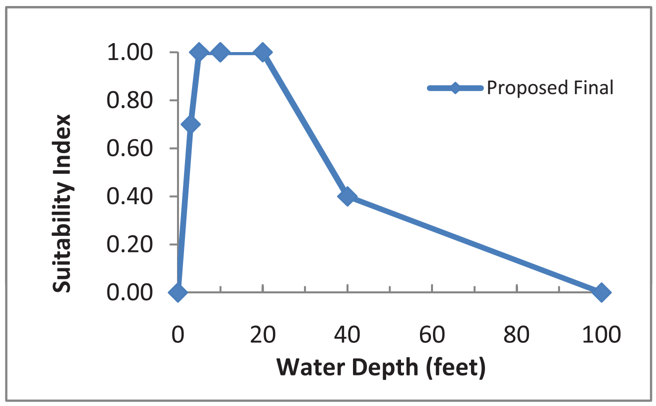


Species: Shortnose Sturgeon
Lifestage: Adults

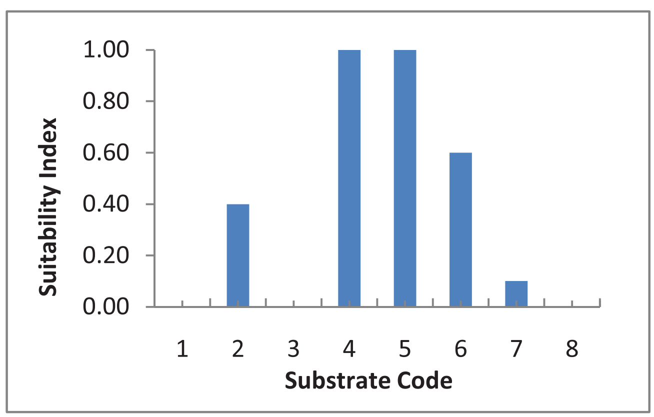
Proposed Final	
Velocity	SI Value
0.00	0.00
0.20	1.00
0.40	1.00
0.50	1.00
1.50	1.00
2.50	0.50
5.00	0.00



Proposed Final	
Depth	SI Value
0.00	0.00
3.00	0.70
5.00	1.00
10.00	1.00
20.00	1.00
40.00	0.40
100.00	0.00

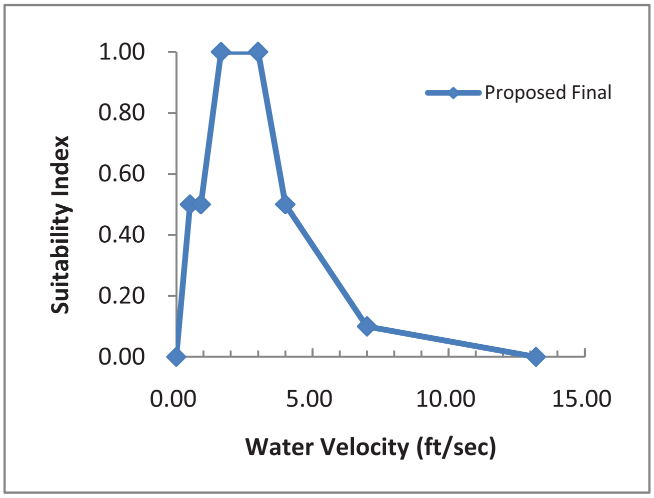


Code	Final SI Value	Type
1	0.00	Detritus/Organic
2	0.40	Mud/soft clay
3	0.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	0.60	Cobble/rubble
7	0.10	Boulder
8	0.00	Bedrock

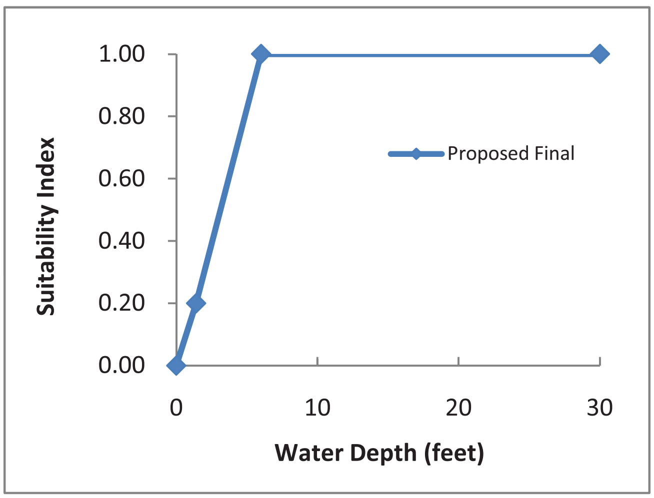


Species: Striped Bass
Lifestage: Spawning

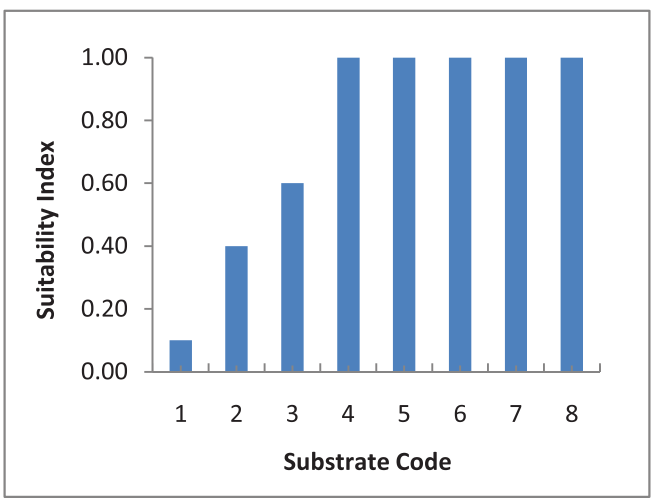
Proposed Final	
Velocity	SI Value
0.00	0.00
0.50	0.50
0.90	0.50
1.64	1.00
3.00	1.00
4.00	0.50
7.00	0.10
13.20	0.00



Proposed Final	
Depth	SI Value
0.00	0.00
1.40	0.20
6.00	1.00
30.0	1.00



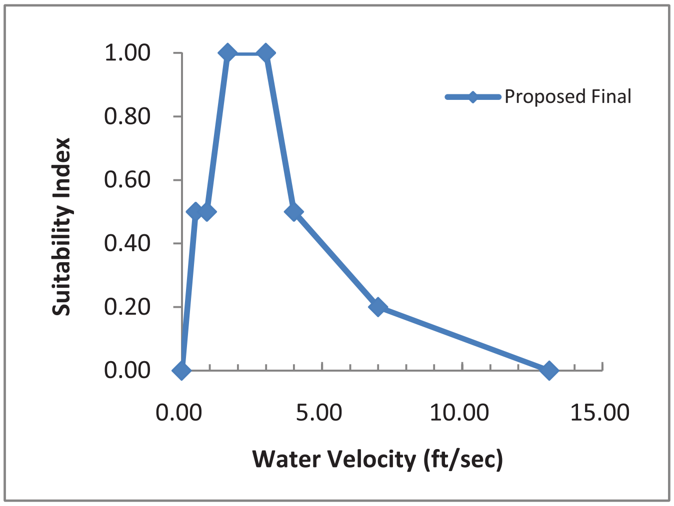
Code	SI Value	Type
1	0.1	Detritus/Organic
2	0.4	Mud/Soft Clay
3	0.6	Silt
4	1.0	Sand
5	1.0	Gravel
6	1.0	Cobble
7	1.0	Boulder
8	1.0	Bedrock



Species: Striped Bass
Lifestage: Fry

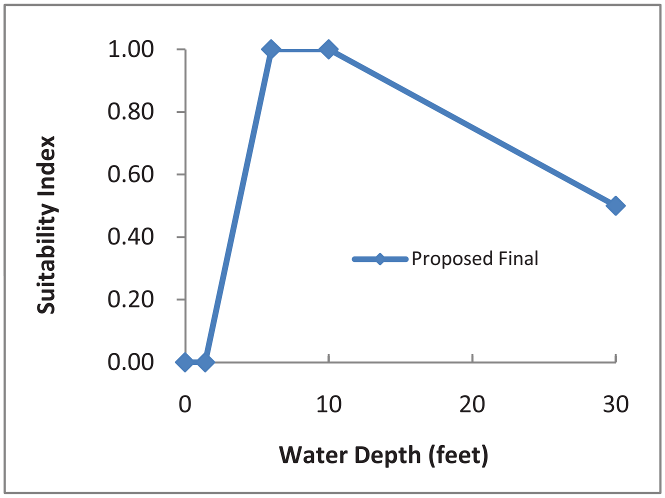
Proposed Final

Velocity	SI Value
0.00	0.00
0.50	0.50
0.90	0.50
1.64	1.00
3.00	1.00
4.00	0.50
7.00	0.20
13.10	0.00

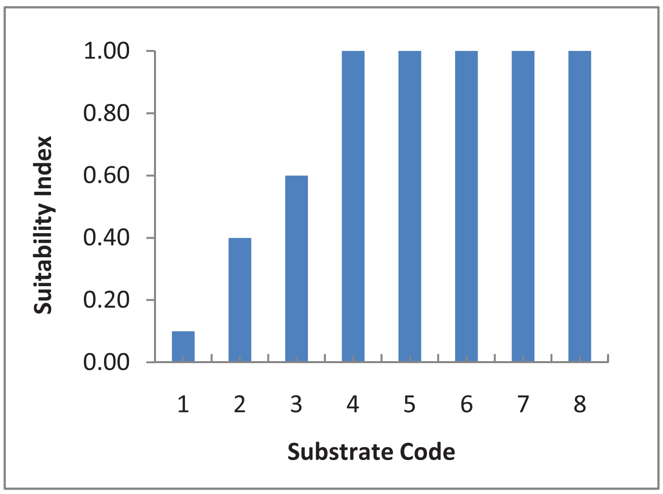


Proposed Final

Depth	SI Value
0.00	0.00
1.40	0.00
6.00	1.00
10.0	1.00
30.0	0.50



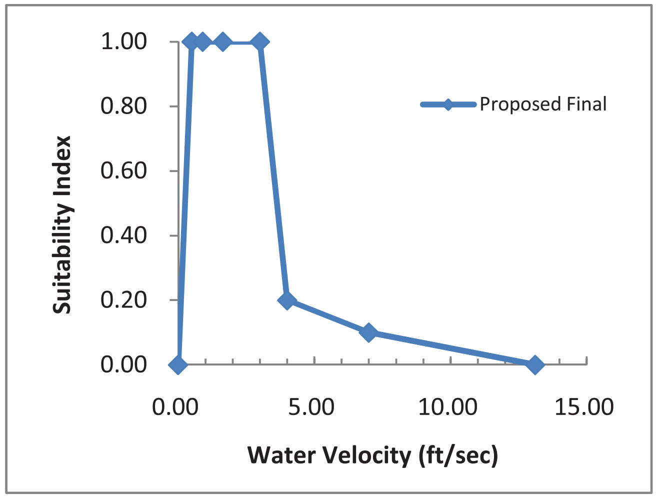
Code	SI Value	
1	0.1	
2	0.4	Mud/Soft Clay
3	0.6	Silt
4	1.0	Sand
5	1.0	Gravel
6	1.0	Cobble
7	1.0	Boulder
8	1.0	Bedrock



Species: Striped Bass
Lifestage: Juvenile

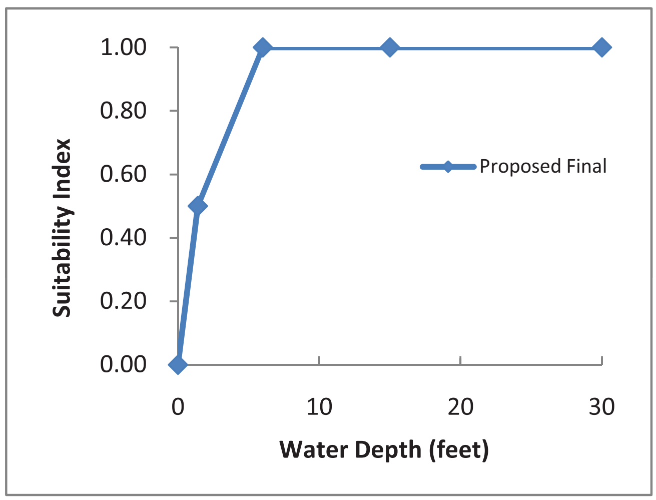
Proposed Final

Velocity	SI Value
0.00	0.00
0.50	1.00
0.90	1.00
1.64	1.00
3.00	1.00
4.00	0.20
7.00	0.10
13.10	0.00

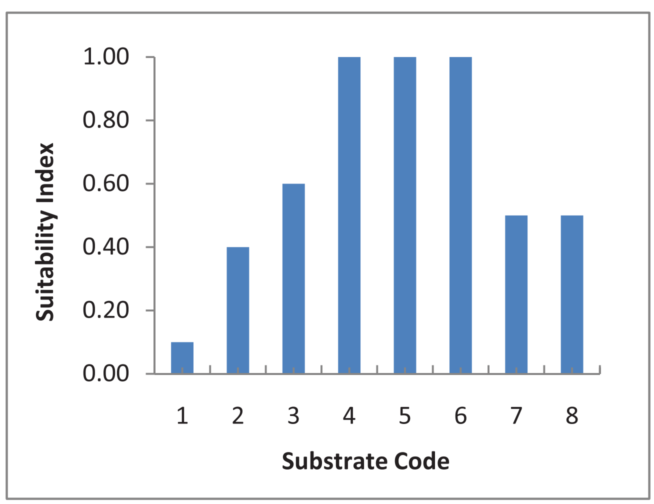


Proposed Final

Depth	SI Value
0.00	0.00
1.40	0.50
6.00	1.00
15.0	1.00
30.0	1.00

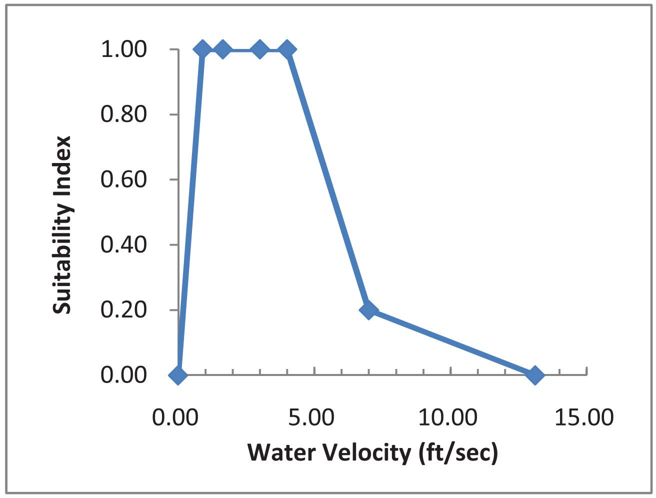


Code	SI Value	Type
1	0.1	Detritus/Organic
2	0.4	Mud/Soft Clay
3	0.6	Silt
4	1.0	Sand
5	1.0	Gravel
6	1.0	Cobble
7	0.5	Boulder
8	0.5	Bedrock



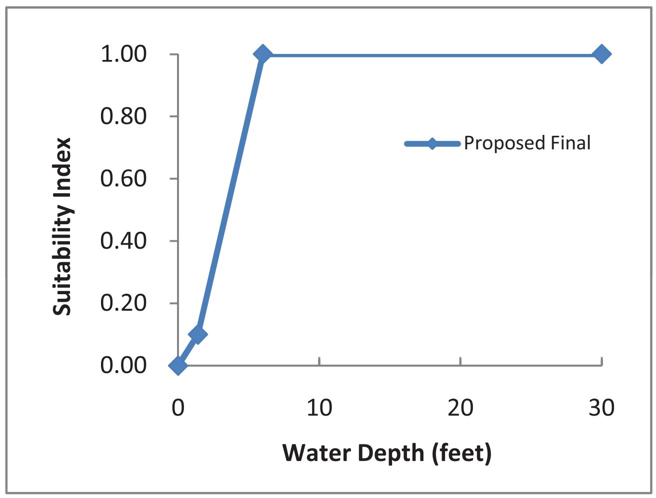
Species: Striped Bass
Lifestage: Adult

Velocity	SI Value
0.00	0.00
0.90	1.00
1.64	1.00
3.00	1.00
4.00	1.00
7.00	0.20
13.10	0.00

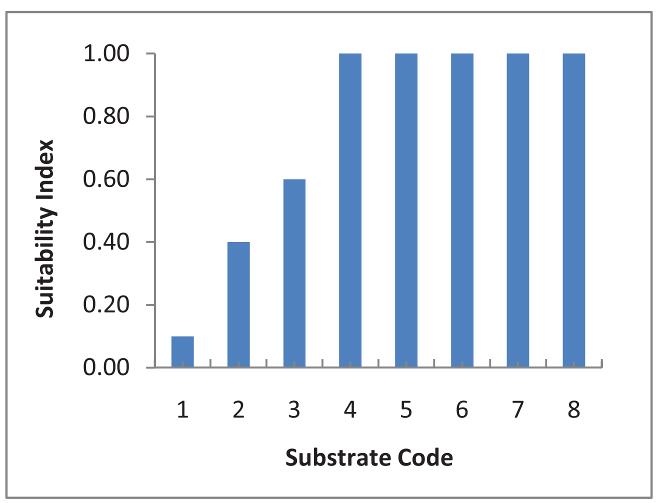


Proposed Final

Depth	SI Value
0.00	0.00
1.40	0.10
6.00	1.00
30.0	1.00

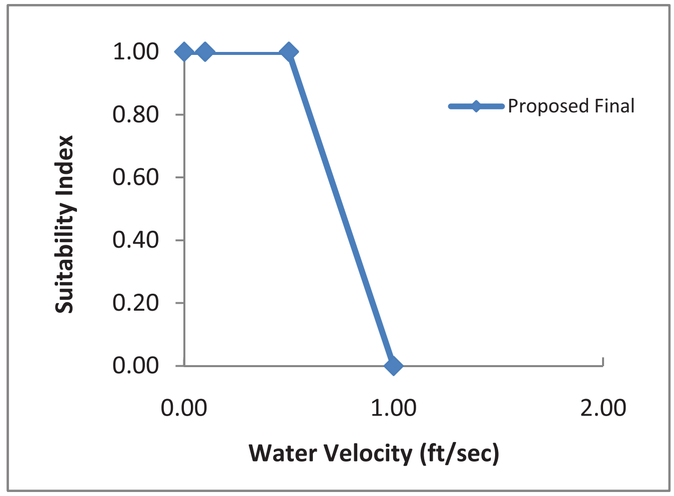


Code	SI Value	Type
1	0.1	Detritus/Organic
2	0.4	Mud/Soft Clay
3	0.6	Silt
4	1.0	Sand
5	1.0	Gravel
6	1.0	Cobble
7	1.0	Boulder
8	1.0	Bedrock

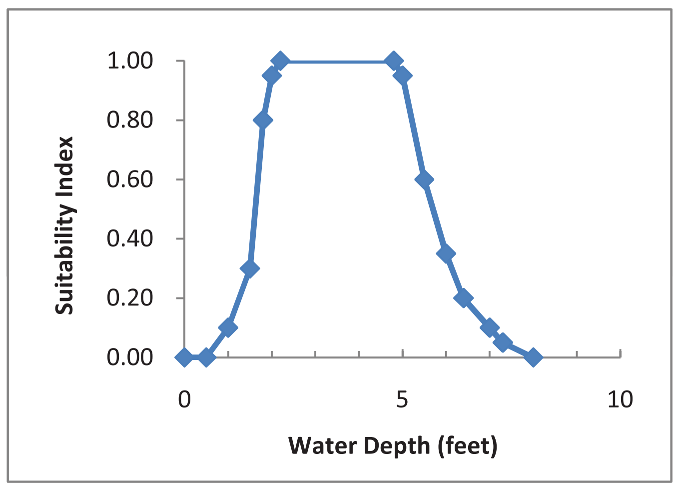


Species: Smallmouth Bass
Lifestage: Spawning

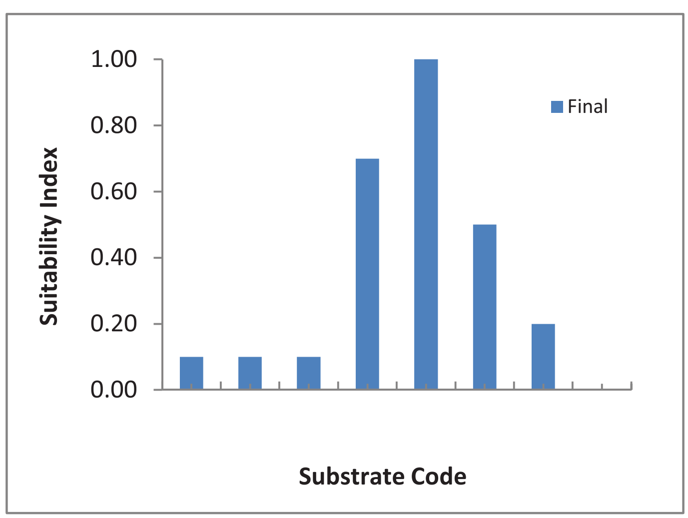
Proposed Final	
Velocity	SI Value
0.00	1.00
0.10	1.00
0.50	1.00
1.00	0.00



Depth	SI Value
0.00	0.00
0.50	0.00
1.00	0.10
1.50	0.30
1.80	0.80
2.00	0.95
2.20	1.00
4.80	1.00
5.00	0.95
5.50	0.60
6.00	0.35
6.40	0.20
7.00	0.10
7.30	0.05
8.00	0.00

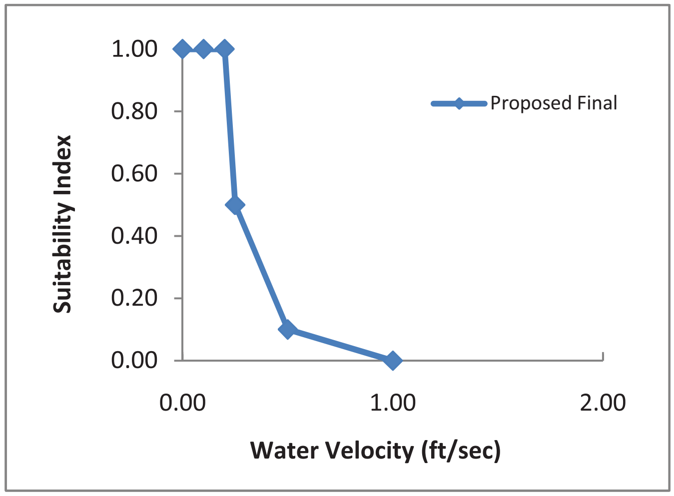


	Final	
Code	SI Value	Type
1	0.10	Detritus
2	0.10	Mud
3	0.10	Silt
4	0.70	Sand
5	1.00	Gravel
6	0.50	Cobble
7	0.20	Boulder
8	0.00	Bedrock

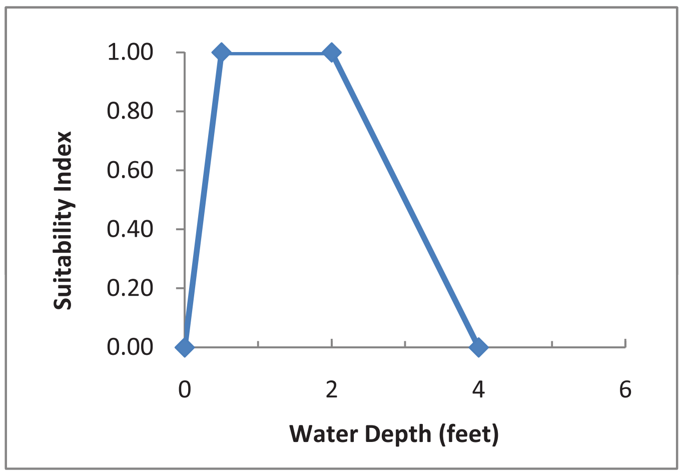


Species: Smallmouth Bass
Lifestage: Fry

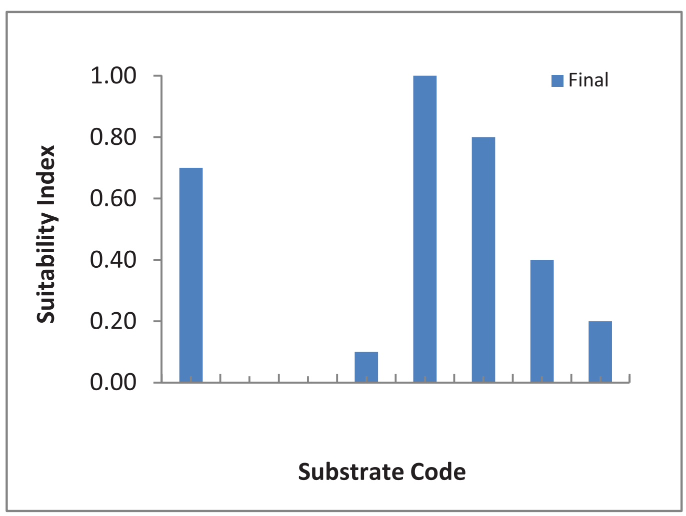
Proposed Final	
Velocity	SI Value
0.00	1.00
0.10	1.00
0.20	1.00
0.25	0.50
0.50	0.10
1.00	0.00



Depth	SI Value
0.00	0.00
0.50	1.00
2.00	1.00
4.00	0.00

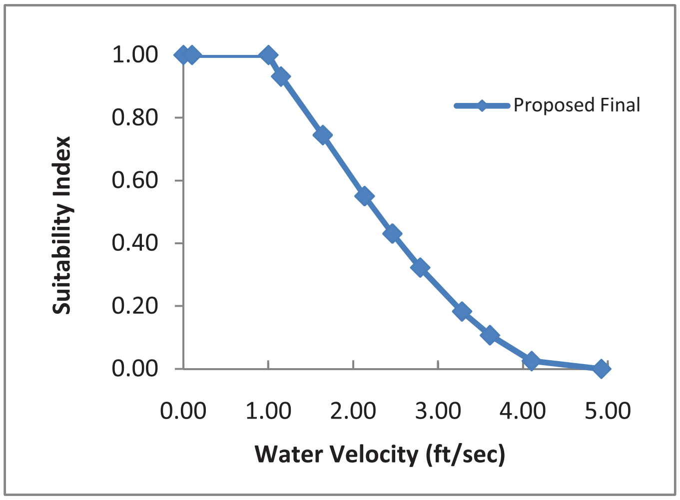


Code	Final SI Value	Type
1	0.70	Detritus
2	0.00	Mud
3	0.00	Silt
4	0.10	Sand
5	1.00	Gravel
6	0.80	Cobble
7	0.40	Boulder
8	0.20	Bedrock

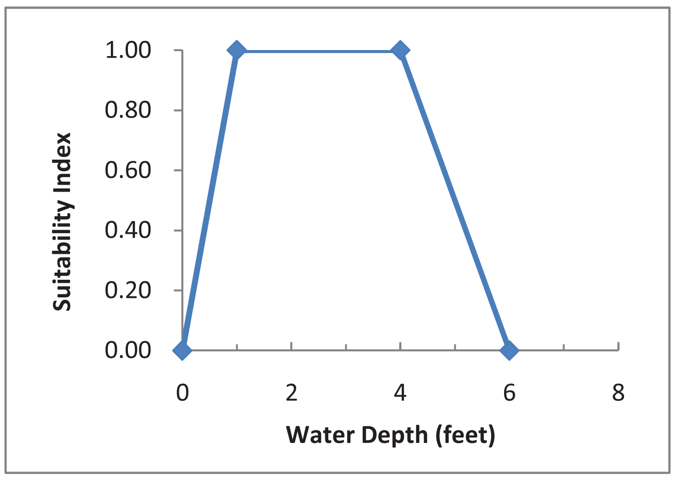


Species: Smallmouth Bass
Lifestage: Juvenile

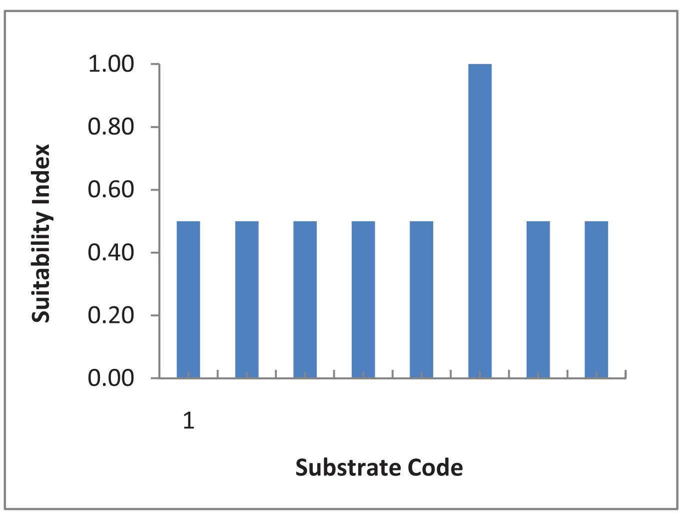
Proposed Final	
Velocity	SI Value
0.00	1.00
0.10	1.00
1.00	1.00
1.15	0.93
1.64	0.75
2.13	0.55
2.46	0.43
2.79	0.32
3.28	0.18
3.61	0.11
4.10	0.02
4.92	0.00



Depth	SI Value
0.00	0.00
1.00	1.00
4.00	1.00
6.00	0.00

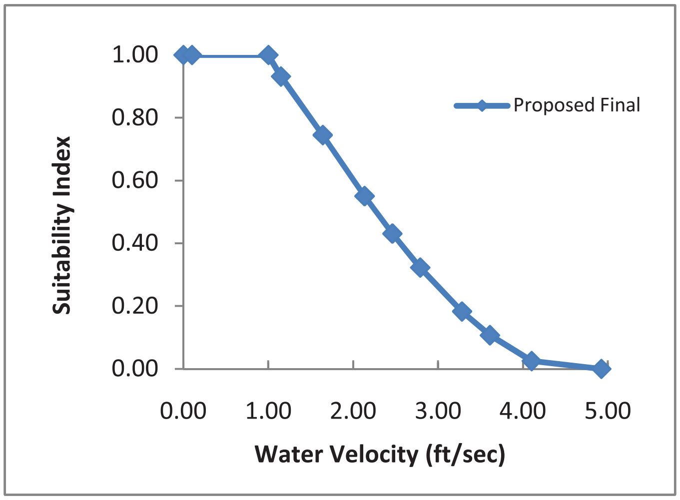


Code	SI Value	Type
1	0.50	Detritus/Organic
2	0.50	Mud/soft clay
3	0.50	Silt
4	0.50	Sand
5	0.50	Gravel
6	1.00	Cobble/rubble
7	0.50	Boulder
8	0.50	Bedrock

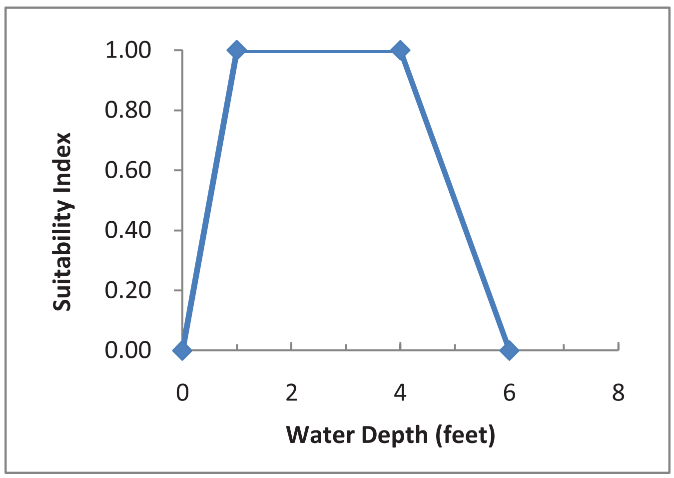


Species: Smallmouth Bass
Lifestage: Juvenile

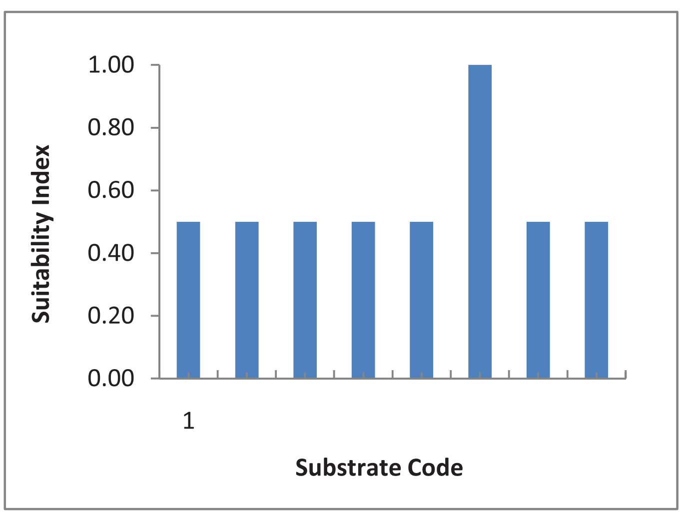
Proposed Final	
Velocity	SI Value
0.00	1.00
0.10	1.00
1.00	1.00
1.15	0.93
1.64	0.75
2.13	0.55
2.46	0.43
2.79	0.32
3.28	0.18
3.61	0.11
4.10	0.02
4.92	0.00



Depth	SI Value
0.00	0.00
1.00	1.00
4.00	1.00
6.00	0.00

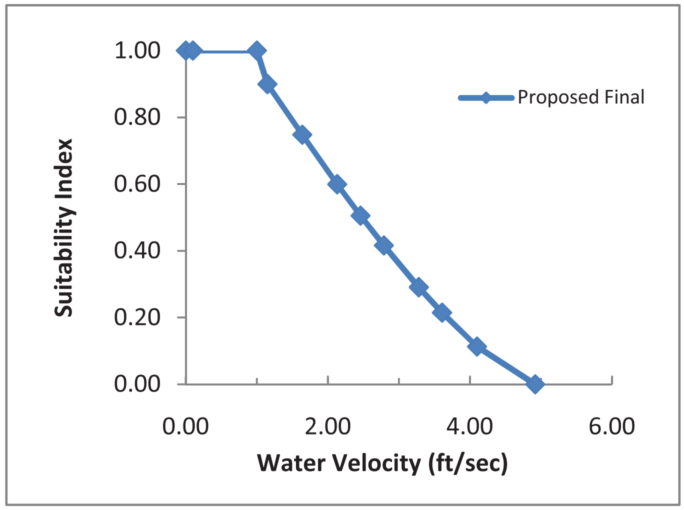


Code	SI Value	Type
1	0.50	Detritus/Organic
2	0.50	Mud/soft clay
3	0.50	Silt
4	0.50	Sand
5	0.50	Gravel
6	1.00	Cobble/rubble
7	0.50	Boulder
8	0.50	Bedrock

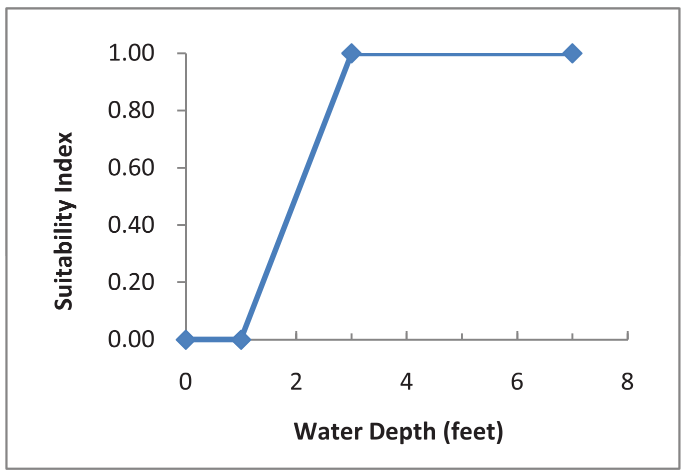


Species: Smallmouth Bass
Lifestage: Adult

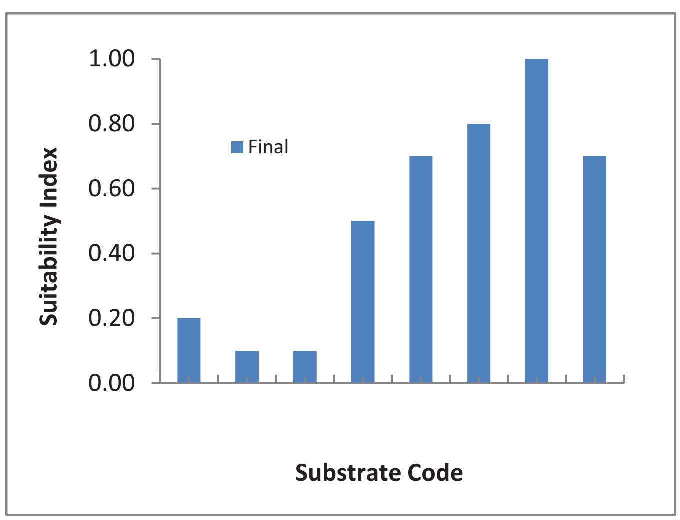
Proposed Final	
Velocity	SI Value
0.00	1.00
0.10	1.00
1.00	1.00
1.15	0.90
1.64	0.75
2.13	0.60
2.46	0.51
2.79	0.42
3.28	0.29
3.61	0.21
4.10	0.11
4.92	0.00



Depth	SI Value
0.00	0.00
1.00	0.00
3.00	1.00
7.00	1.00

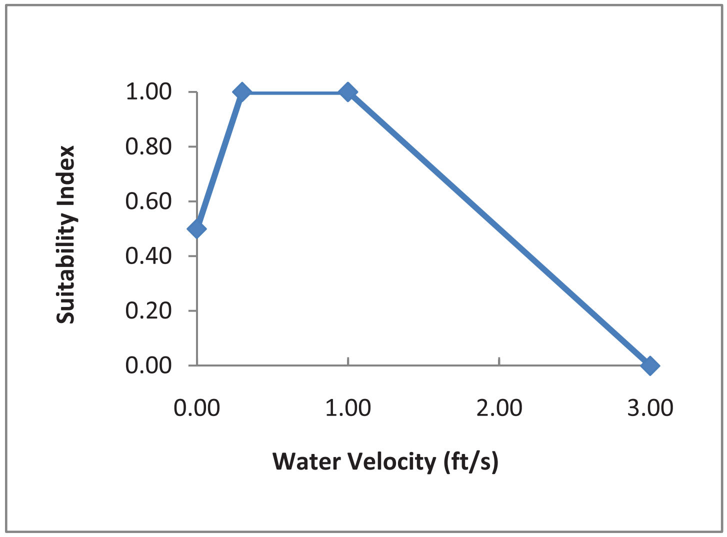


Code	Final SI Value	Type
1	0.20	Detritus
2	0.10	Mud
3	0.10	Silt
4	0.50	Sand
5	0.70	Gravel
6	0.80	Cobble
7	1.00	Boulder
8	0.70	Bedrock

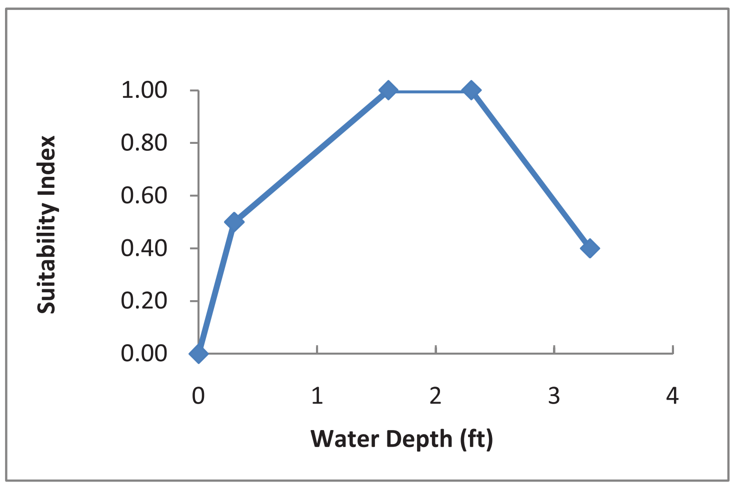


Species: Ephemeroptera (Mayflies)
Lifestage: Community Diversity -Large River

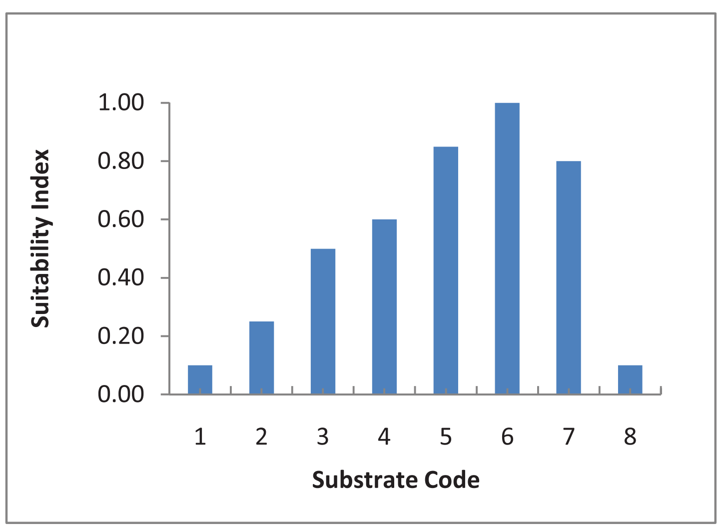
Velocity	SI Value
0.00	0.50
0.30	1.00
1.00	1.00
3.00	0.00



Depth	SI Value
0.00	0.00
0.30	0.50
1.60	1.00
2.30	1.00
3.30	0.40

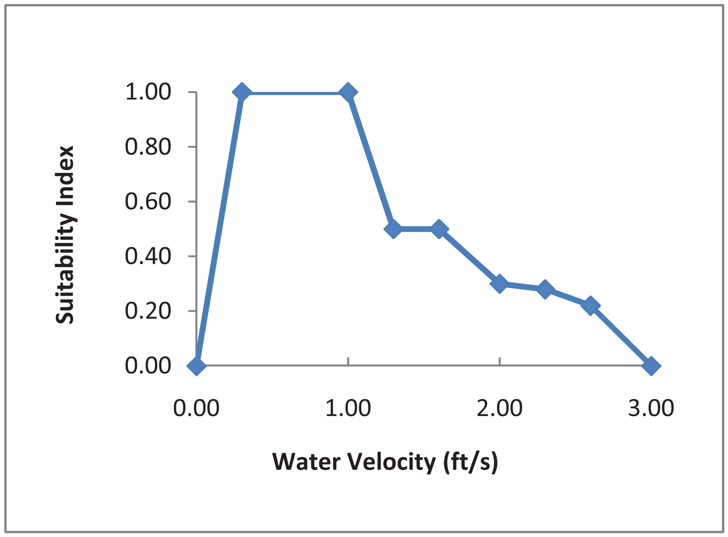


Code	SI Value	Type
1	0.10	Detritus/Organic
2	0.25	Mud/soft clay
3	0.50	Silt
4	0.60	Sand
5	0.85	Gravel
6	1.00	Cobble/rubble
7	0.80	Boulder
8	0.10	Bedrock

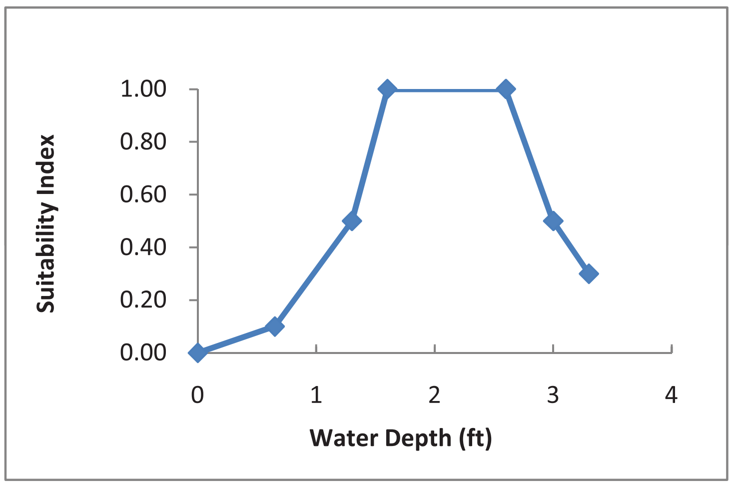


Species: Plecoptera (Stoneflies)
Lifestage: Community Diversity -Large River

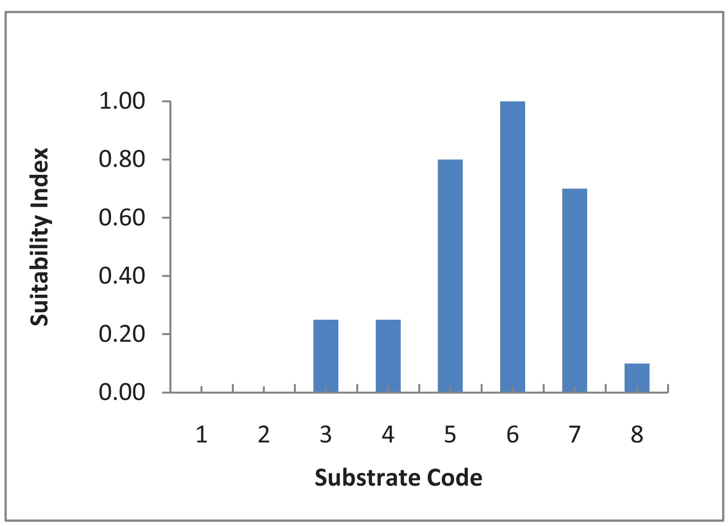
Velocity	SI Value
0.00	0.00
0.30	1.00
1.00	1.00
1.30	0.50
1.60	0.50
2.00	0.30
2.30	0.28
2.60	0.22
3.00	0.00



Depth	SI Value
0.00	0.00
0.65	0.10
1.30	0.50
1.60	1.00
2.60	1.00
3.00	0.50
3.30	0.30

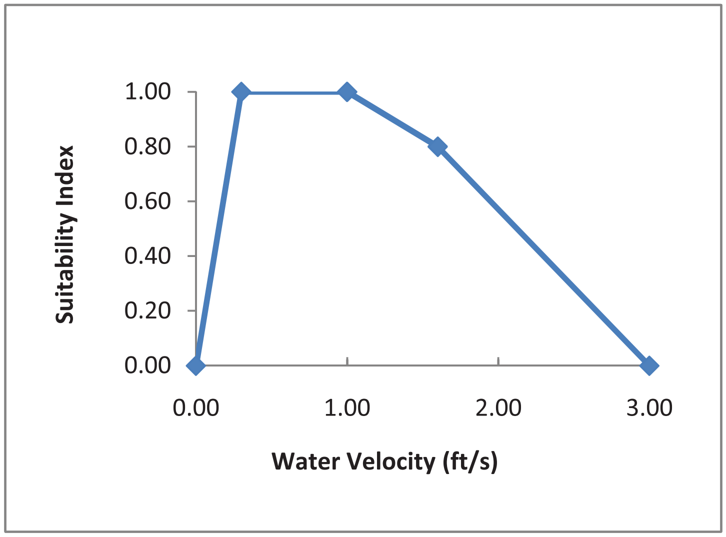


Code	SI Value	Type
1	0.00	Detritus/Organic
2	0.00	Mud/soft clay
3	0.25	Silt
4	0.25	Sand
5	0.80	Gravel
6	1.00	Cobble/rubble
7	0.70	Boulder
8	0.10	Bedrock

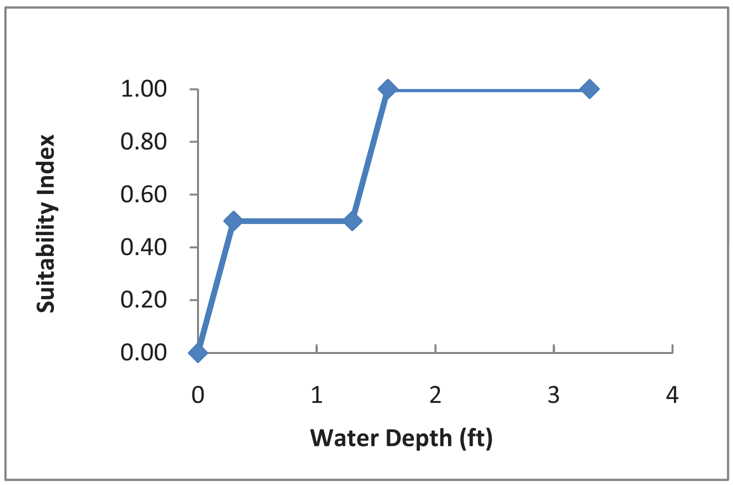


Species: Tricoptera (Caddisflies)
Lifestage: Community Diversity -Large River

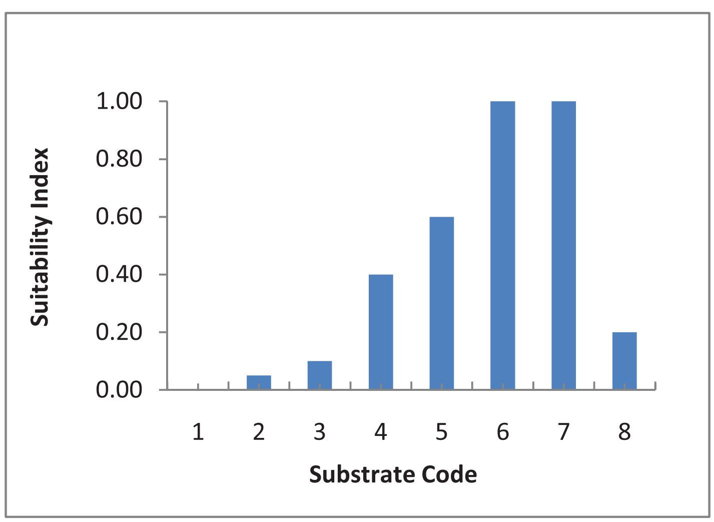
Velocity	SI Value
0.00	0.00
0.30	1.00
1.00	1.00
1.60	0.80
3.00	0.00



Depth	SI Value
0.00	0.00
0.30	0.50
1.30	0.50
1.60	1.00
3.30	1.00

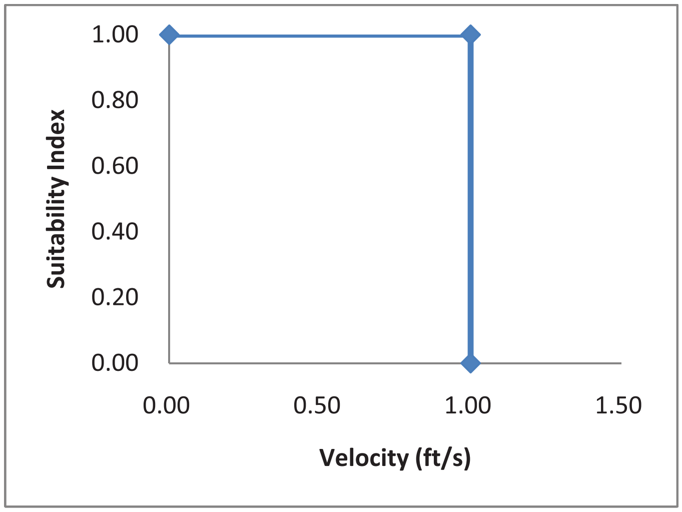


Code	SI Value	Type
1	0.00	Detritus/Organic
2	0.05	Mud/soft clay
3	0.10	Silt
4	0.40	Sand
5	0.60	Gravel
6	1.00	Cobble/rubble
7	1.00	Boulder
8	0.20	Bedrock

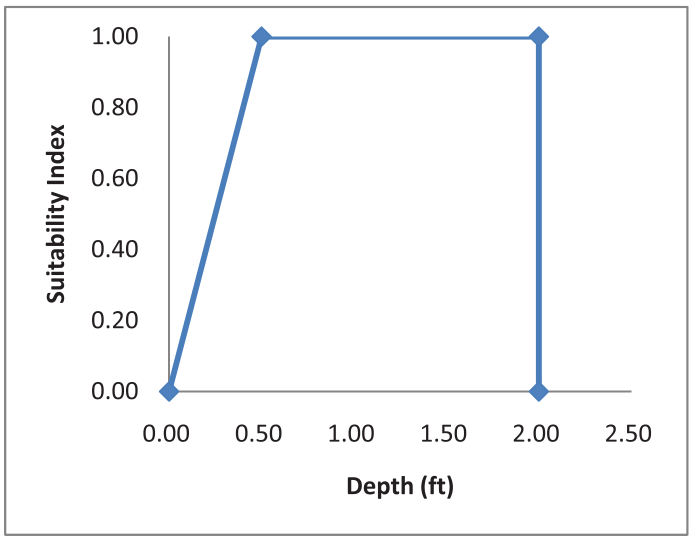


Species: Shallow-Slow Guild

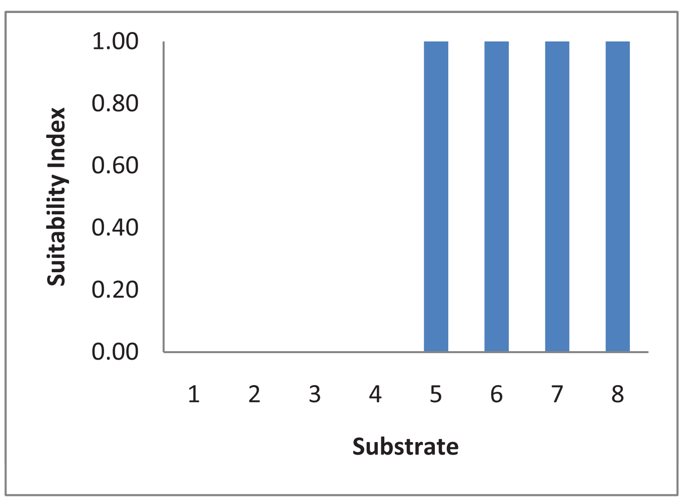
Velocity	SI Value
0.00	1.00
1.00	1.00
1.00	0.00



Depth	SI Value
0.00	0.00
0.50	1.00
2.00	1.00
2.00	0.00

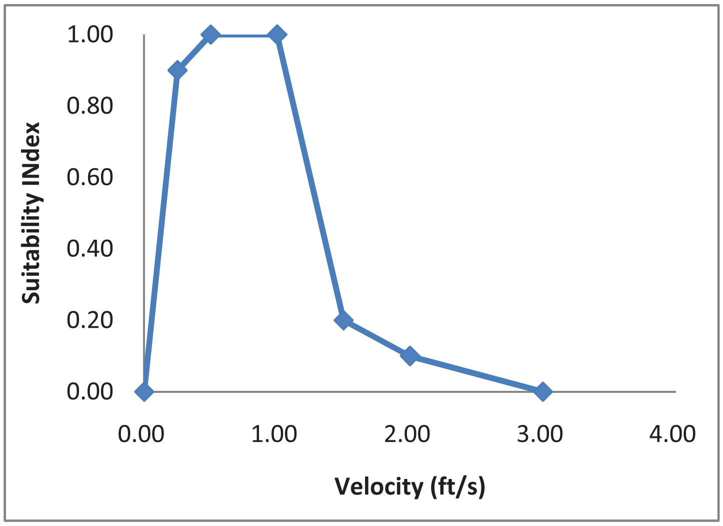


Code	SI Value	Type
1	0.00	Detritus/Organic
2	0.00	Mud/soft clay
3	0.00	Silt
4	0.00	Sand
5	1.00	Gravel
6	1.00	Cobble/rubble
7	1.00	Boulder
8	1.00	Bedrock

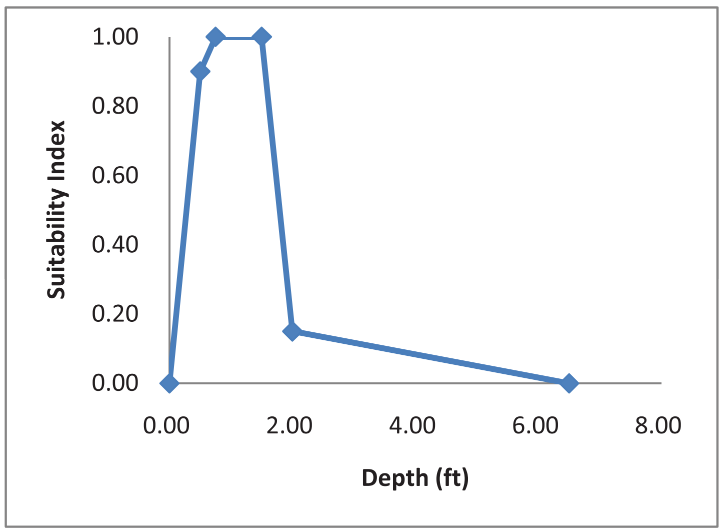


Species: Shallow-Fast Guild

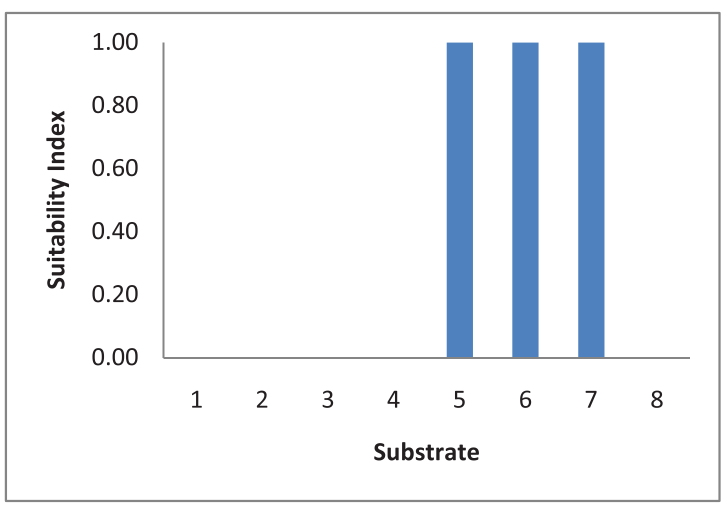
Velocity	SI Value
0.00	0.00
0.25	0.90
0.50	1.00
1.00	1.00
1.50	0.20
2.00	0.10
3.00	0.00



Depth	SI Value
0.00	0.00
0.50	0.90
0.75	1.00
1.50	1.00
2.00	0.15
6.50	0.00

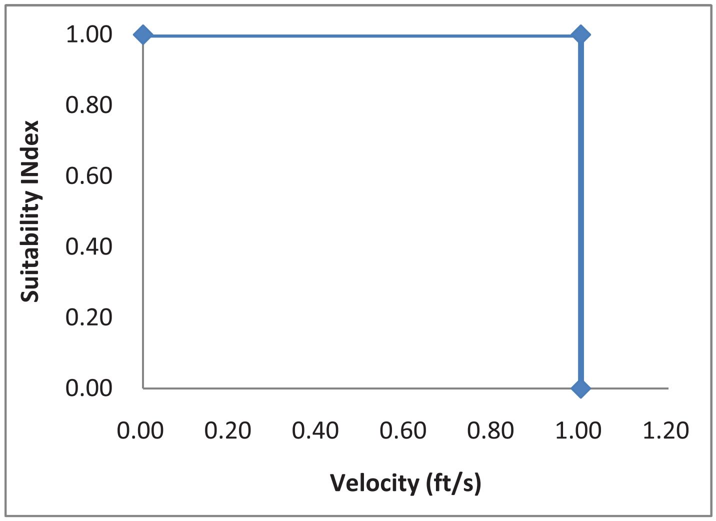


Code	SI Value	Type
1	0.00	Detritus/Organic
2	0.00	Mud/soft clay
3	0.00	Silt
4	0.00	Sand
5	1.00	Gravel
6	1.00	Cobble/rubble
7	1.00	Boulder
8	0.00	Bedrock

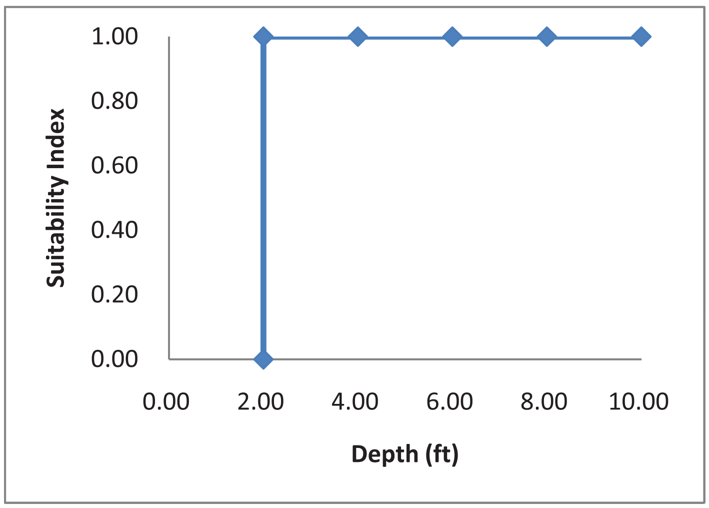


Species: Deep-Slow Guild

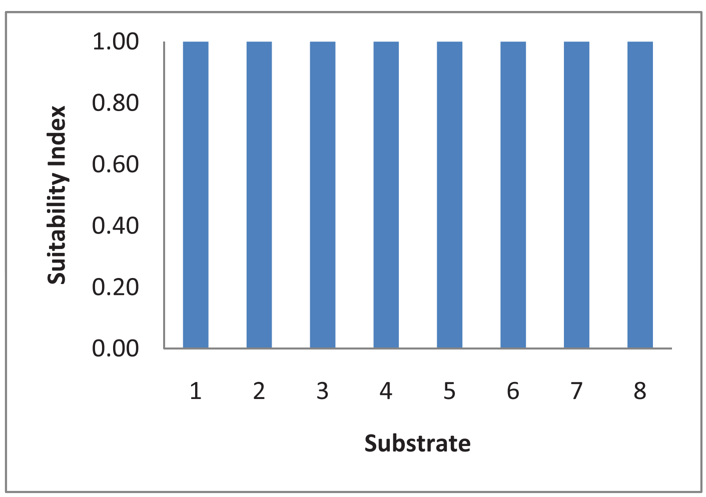
Velocity	SI Value
0.00	1.00
1.00	1.00
1.00	0.00



Depth	SI Value
2.00	0.00
2.00	1.00
4.00	1.00
6.00	1.00
8.00	1.00
10.00	1.00

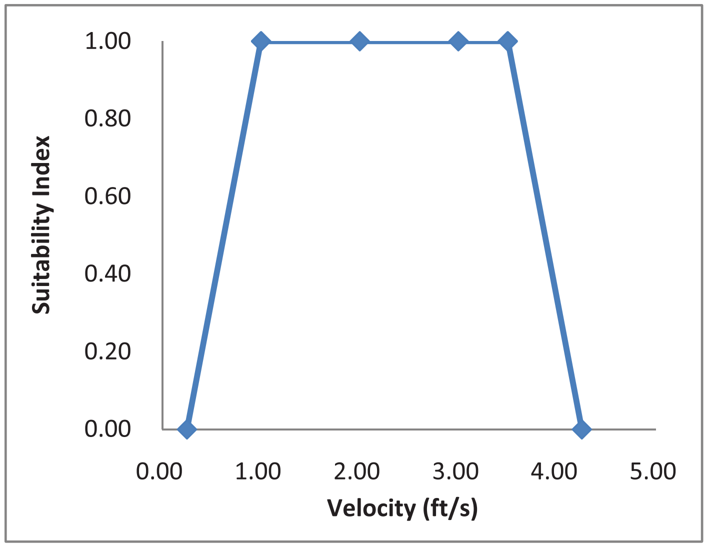


Code	SI Value	Type
1	1.00	Detritus/Organic
2	1.00	Mud/soft clay
3	1.00	Silt
4	1.00	Sand
5	1.00	Gravel
6	1.00	Cobble/rubble
7	1.00	Boulder
8	1.00	Bedrock

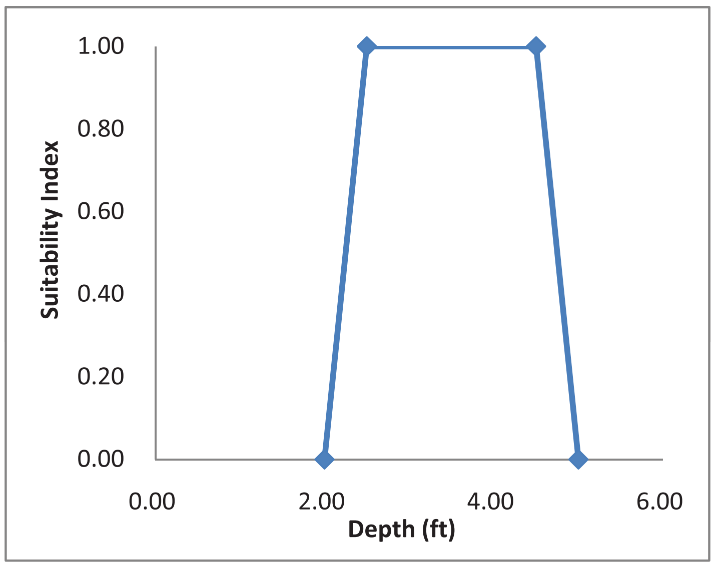


Species: Deep-Fast Guild

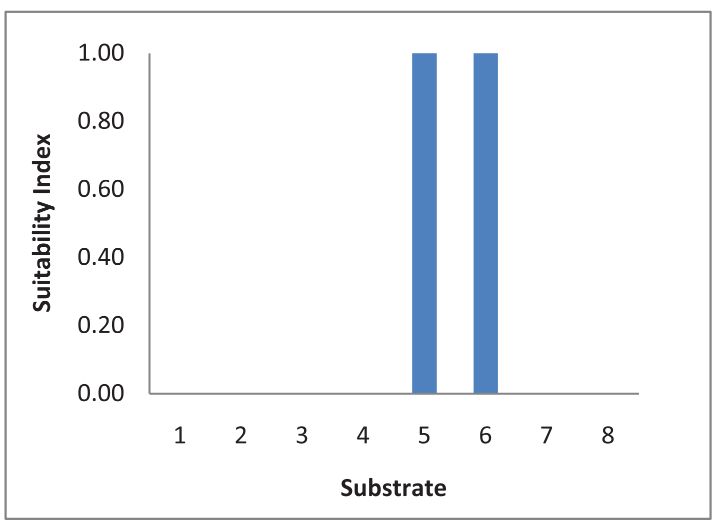
Velocity	SI Value
0.25	0.00
1.00	1.00
2.00	1.00
3.00	1.00
3.50	1.00
4.25	0.00



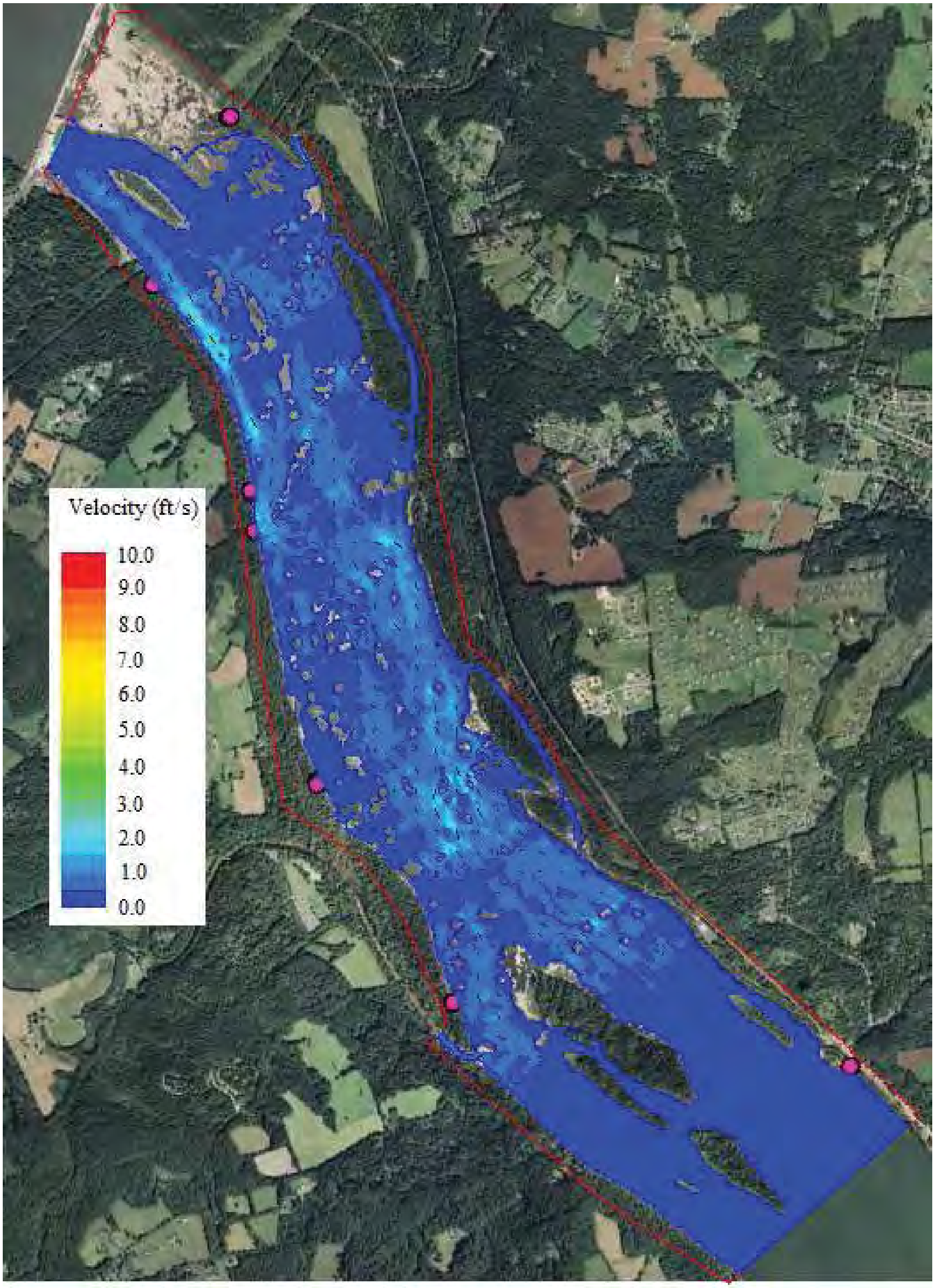
Depth	SI Value
2.00	0.00
2.50	1.00
4.50	1.00
5.00	0.00



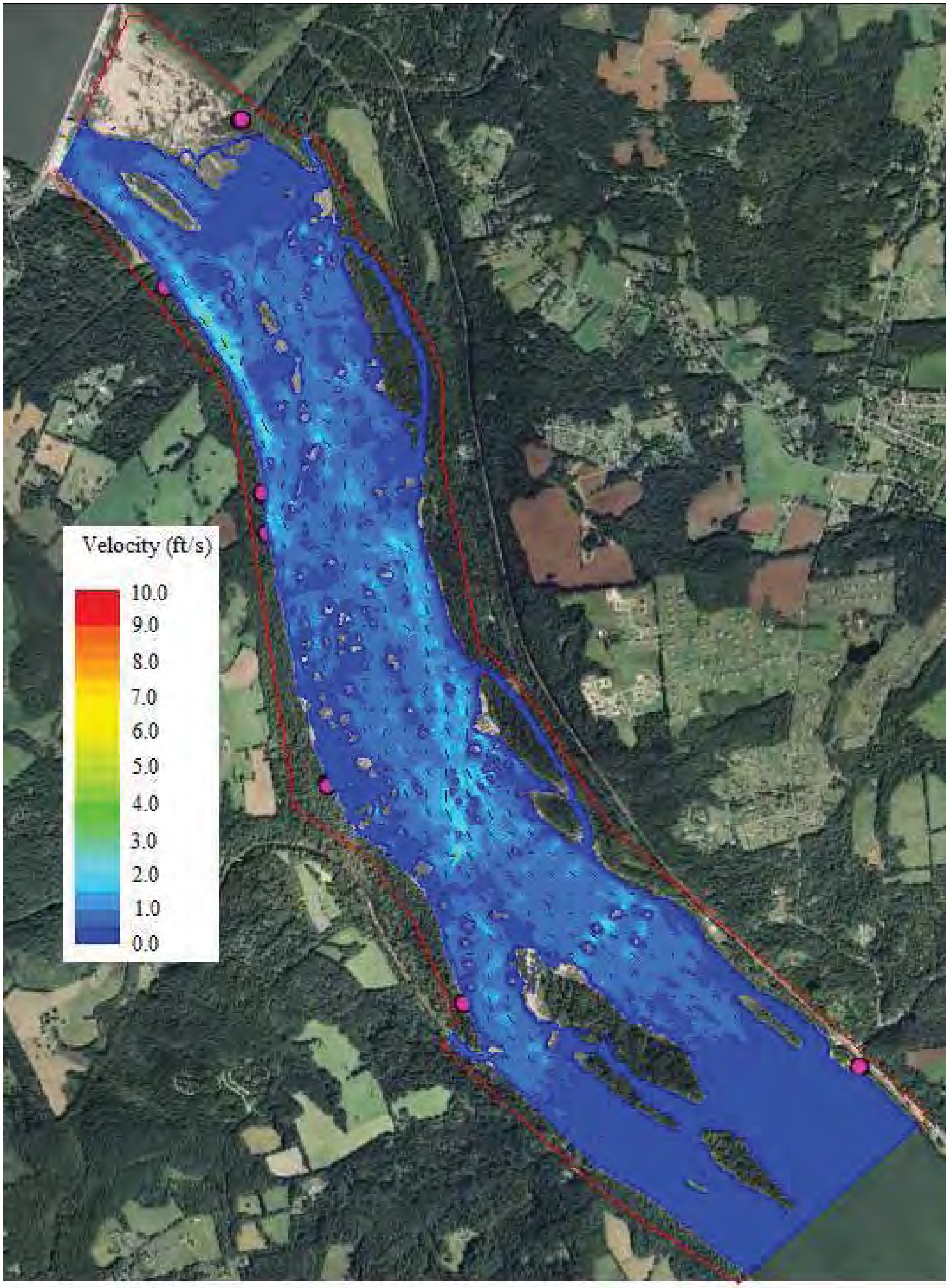
Code	SI Value	Type
1	0.00	Detritus/Organic
2	0.00	Mud/soft clay
3	0.00	Silt
4	0.00	Sand
5	1.00	Gravel
6	1.00	Cobble/rubble
7	0.00	Boulder
8	0.00	Bedrock



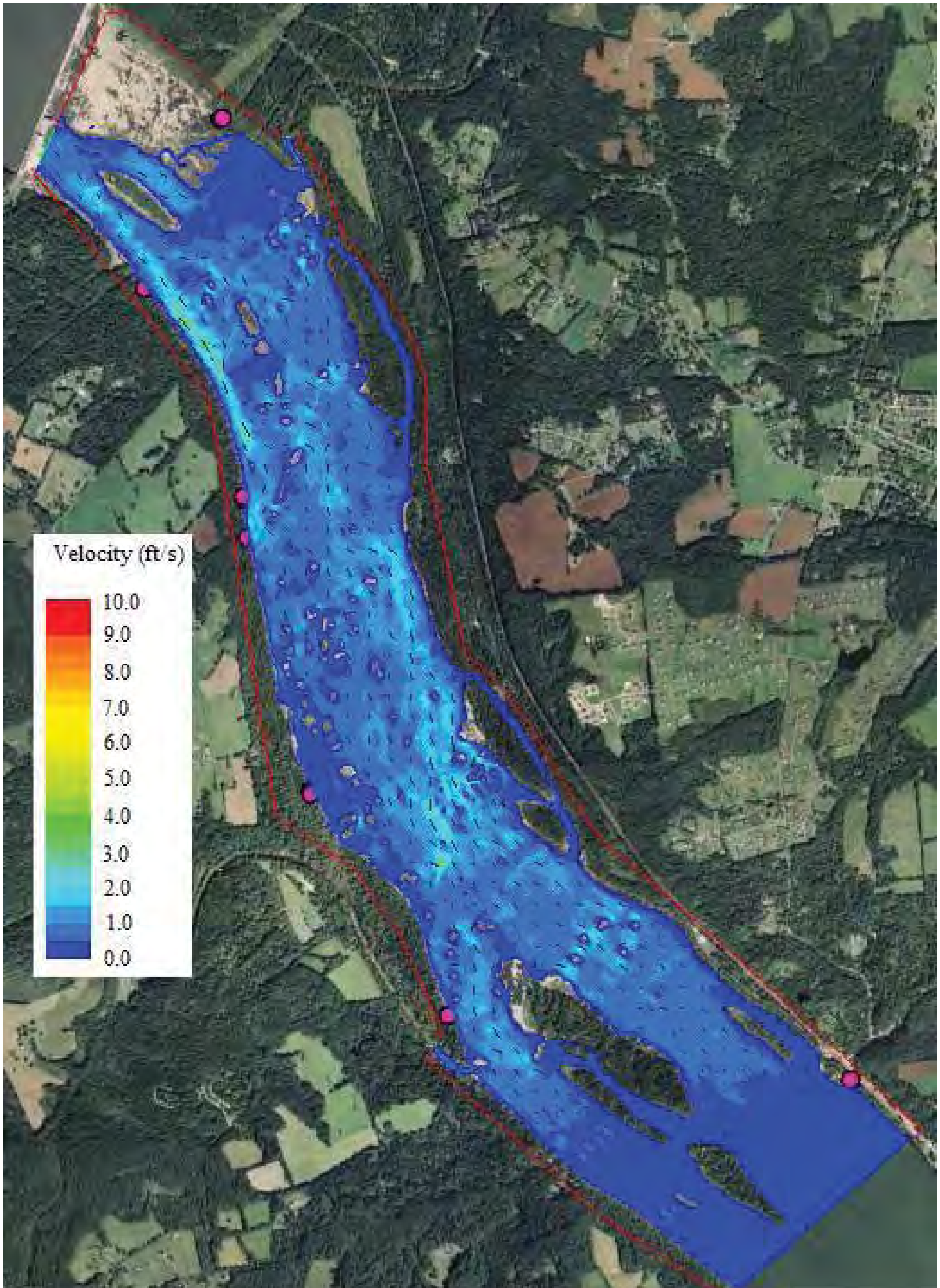
APPENDIX C-WATER VELOCITY PLOTS FOR SIMULATION FLOWS



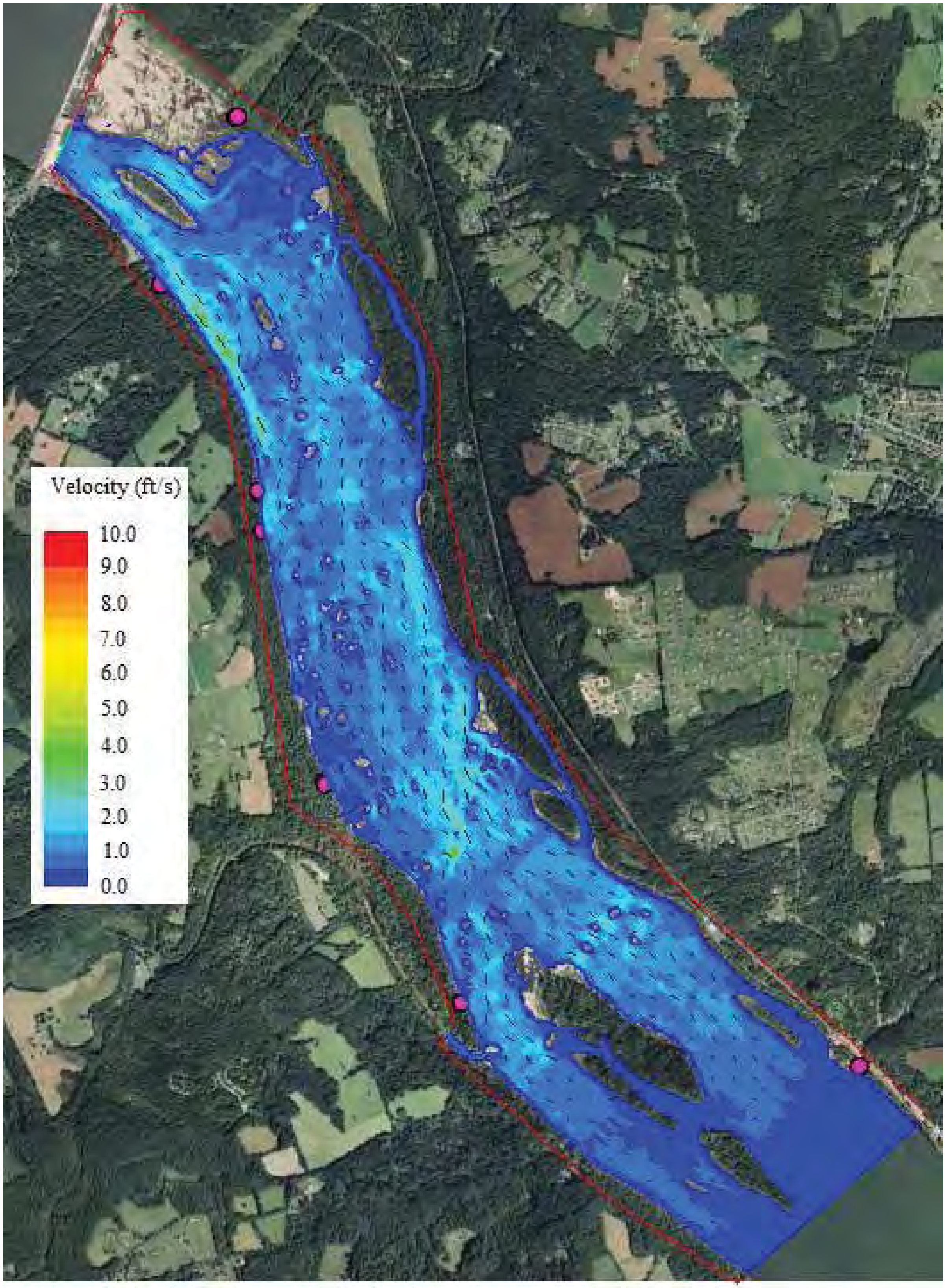
2,000 CFS



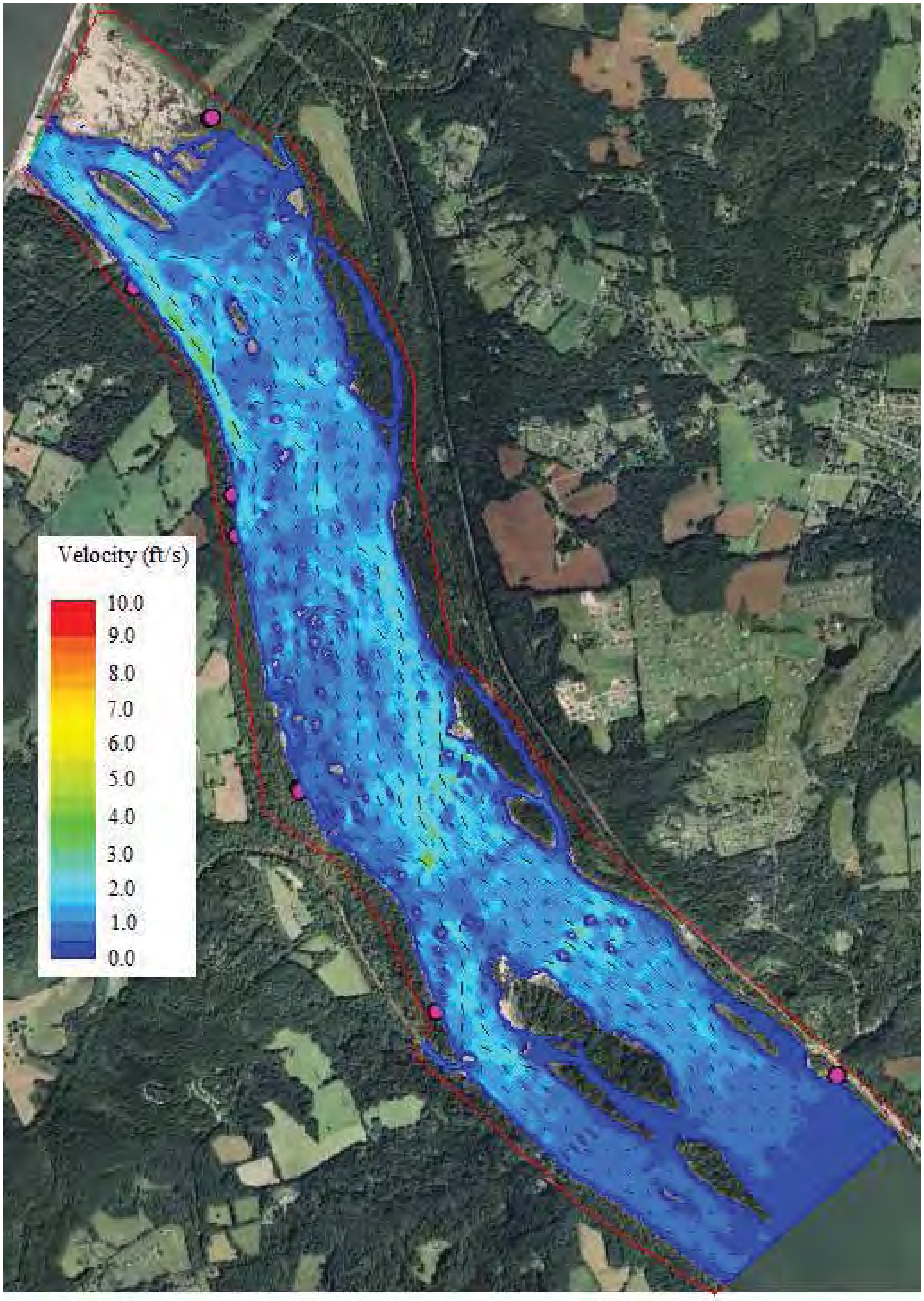
3,500 CFS



5,000 CFS



7,500 CFS



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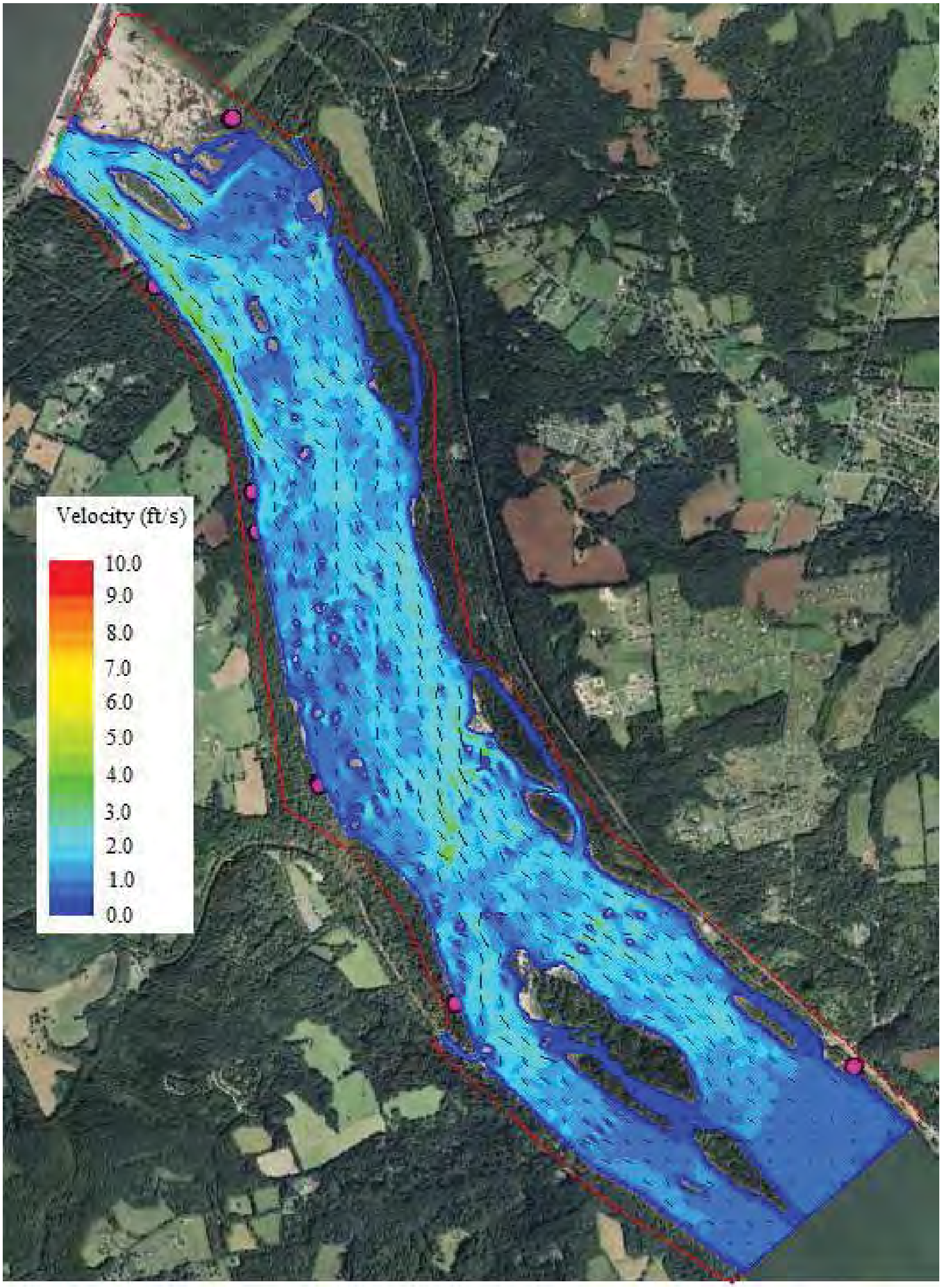

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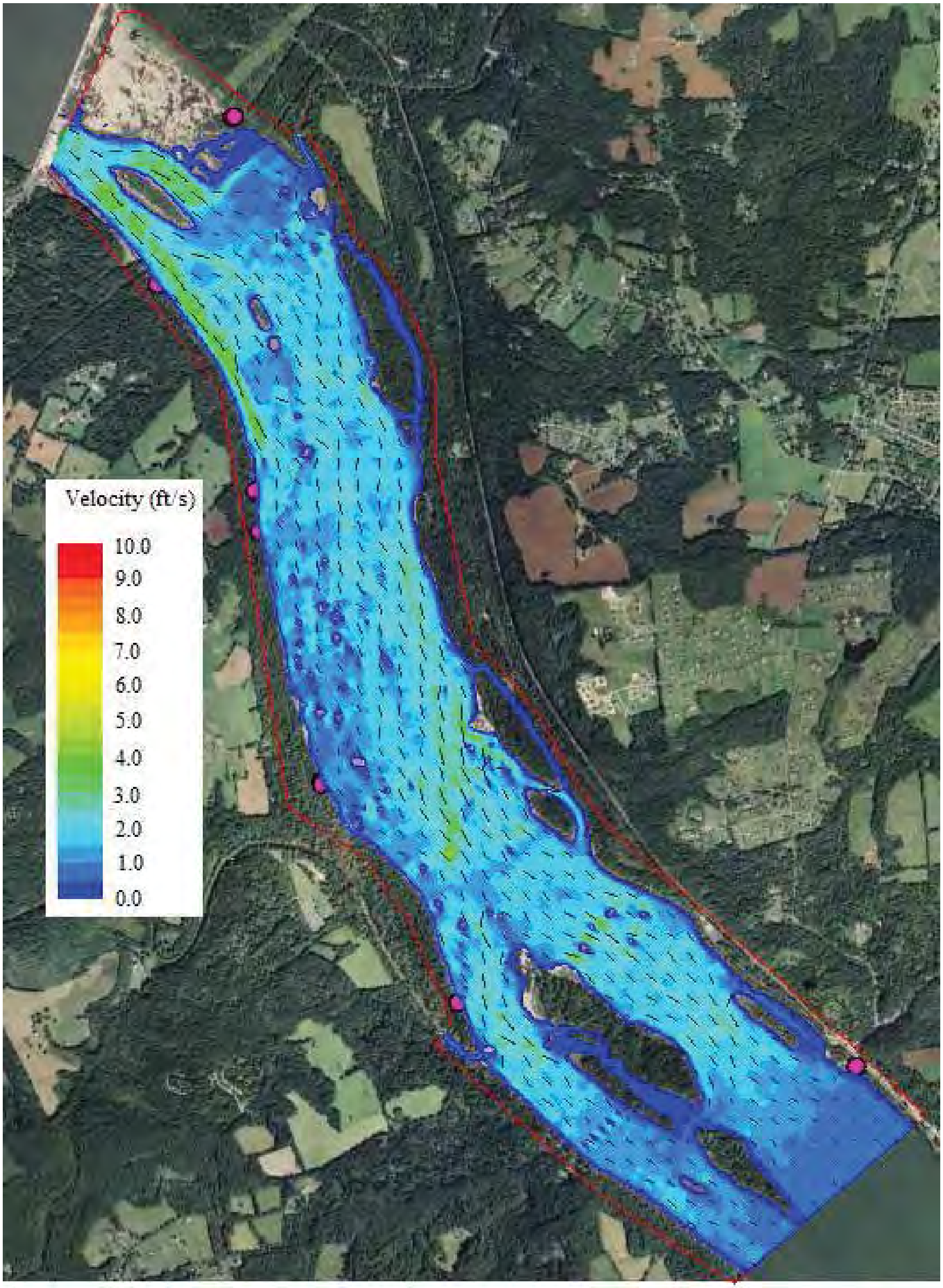

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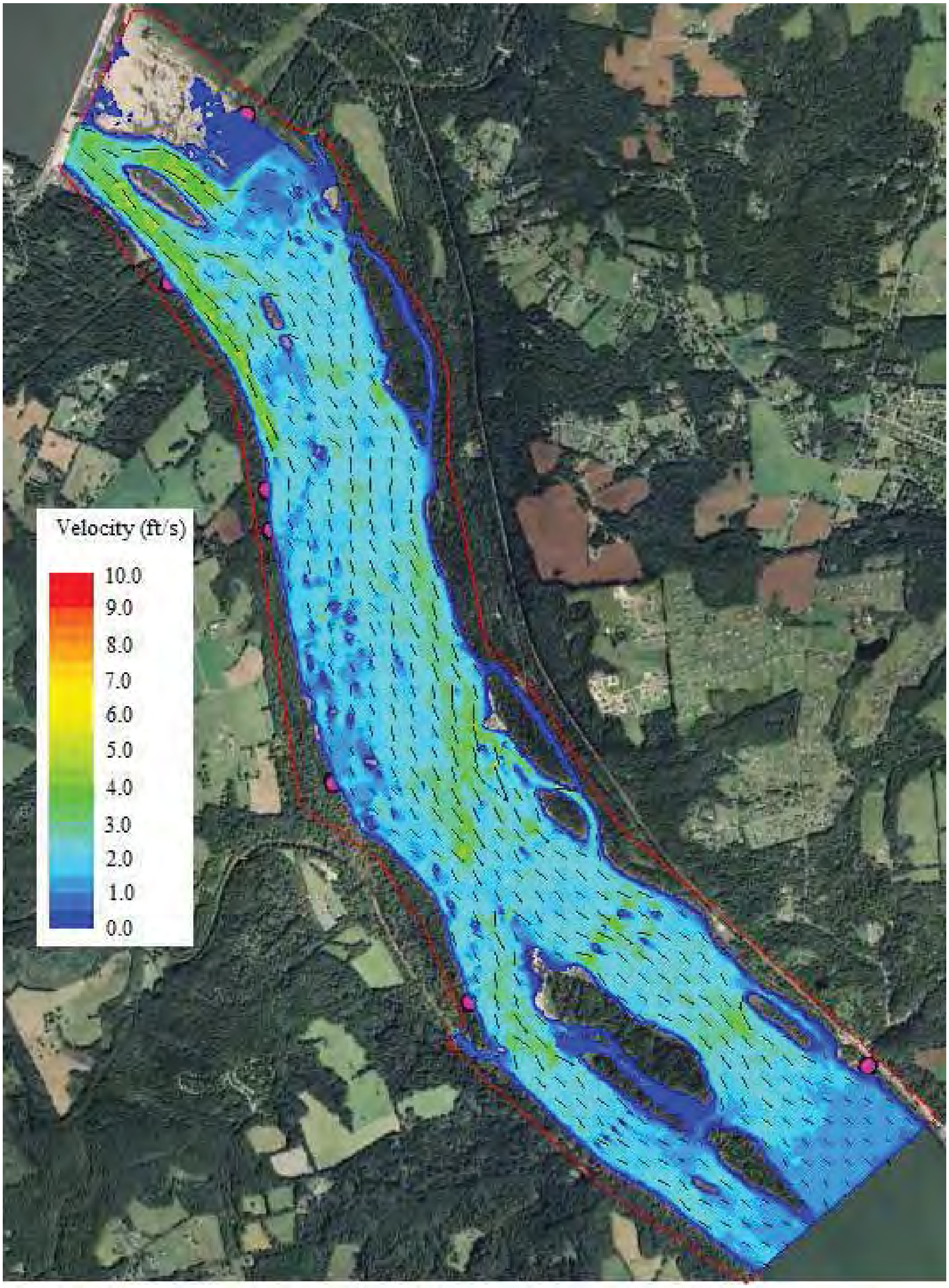
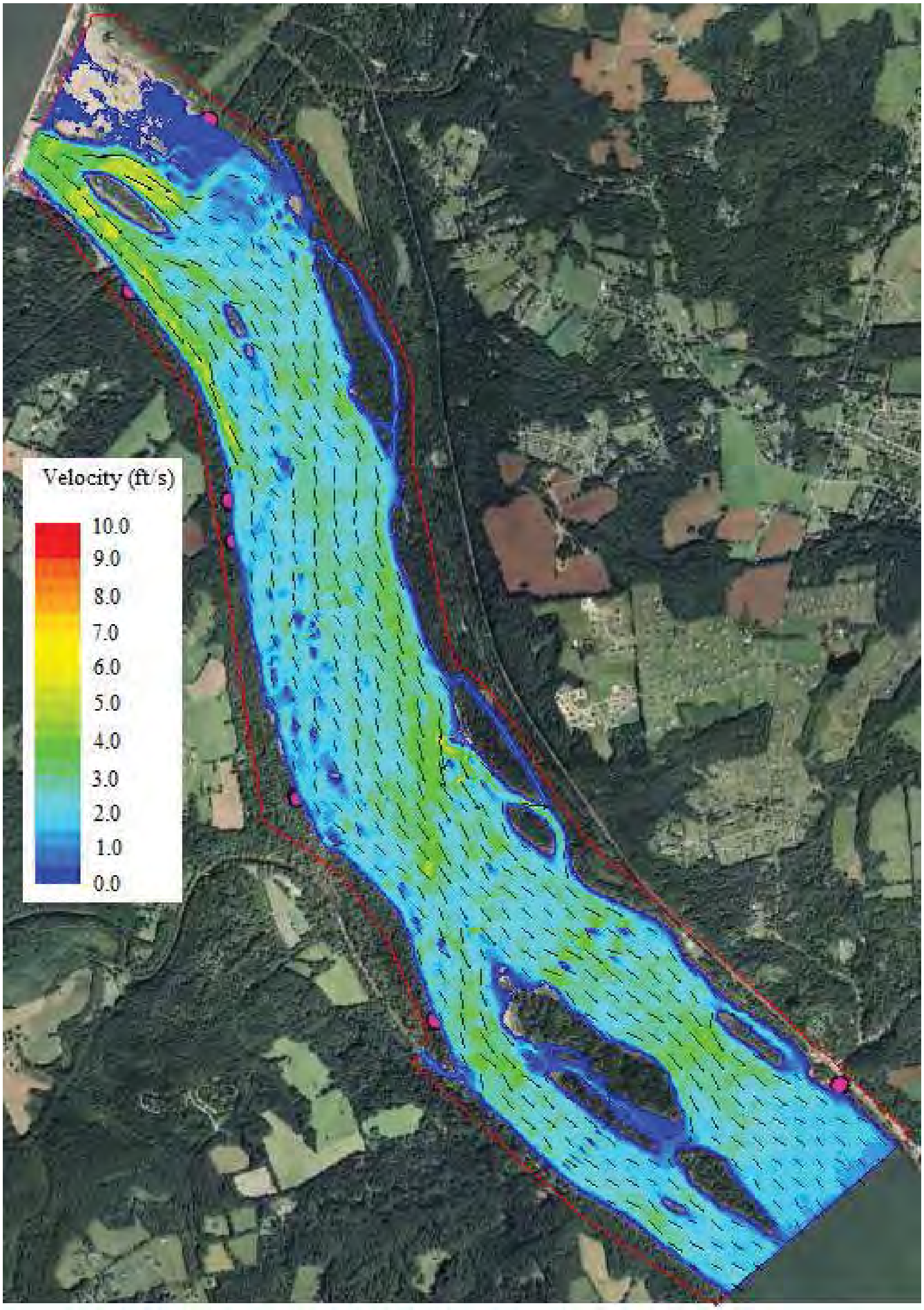


30,000 CFS



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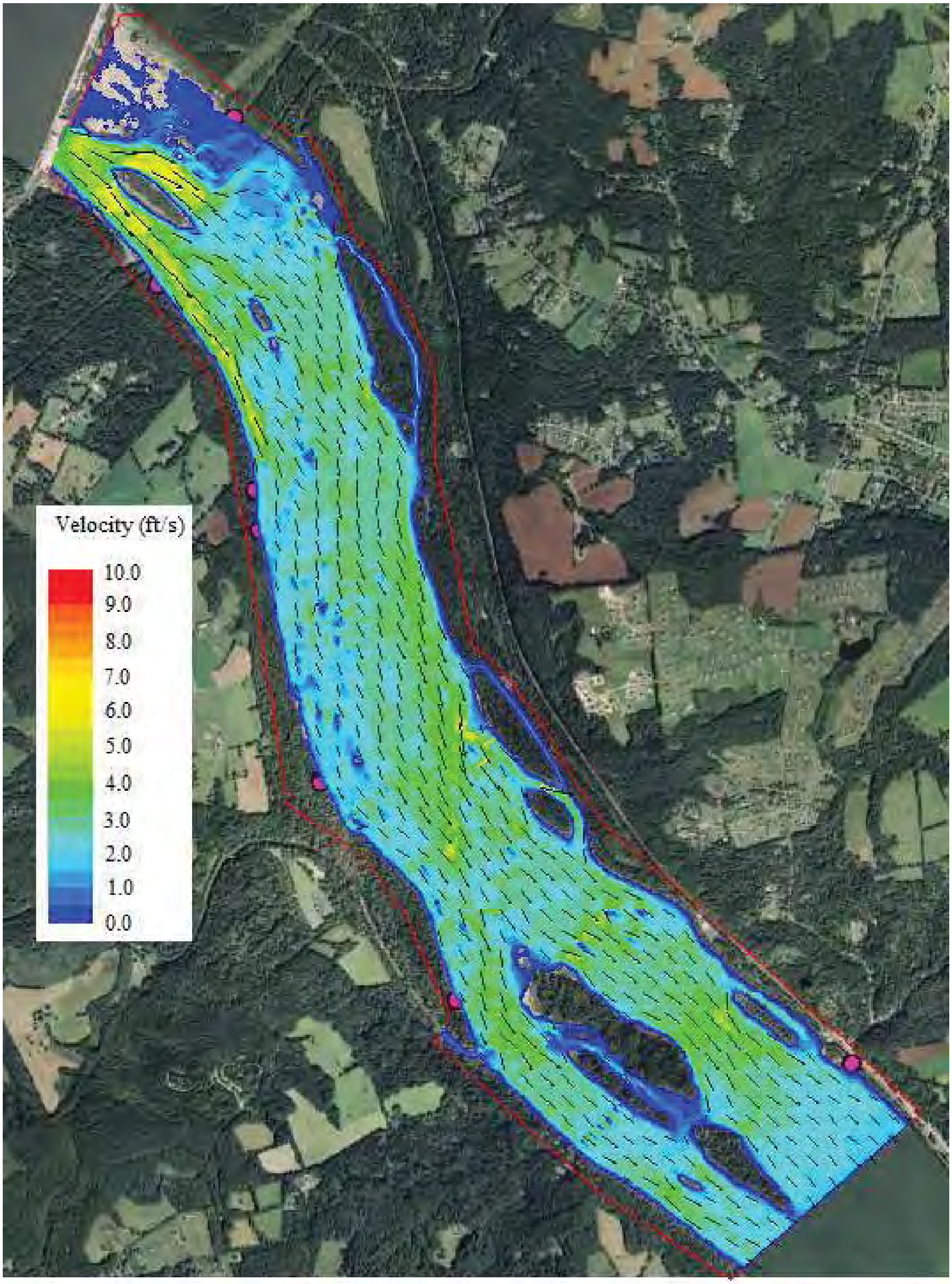
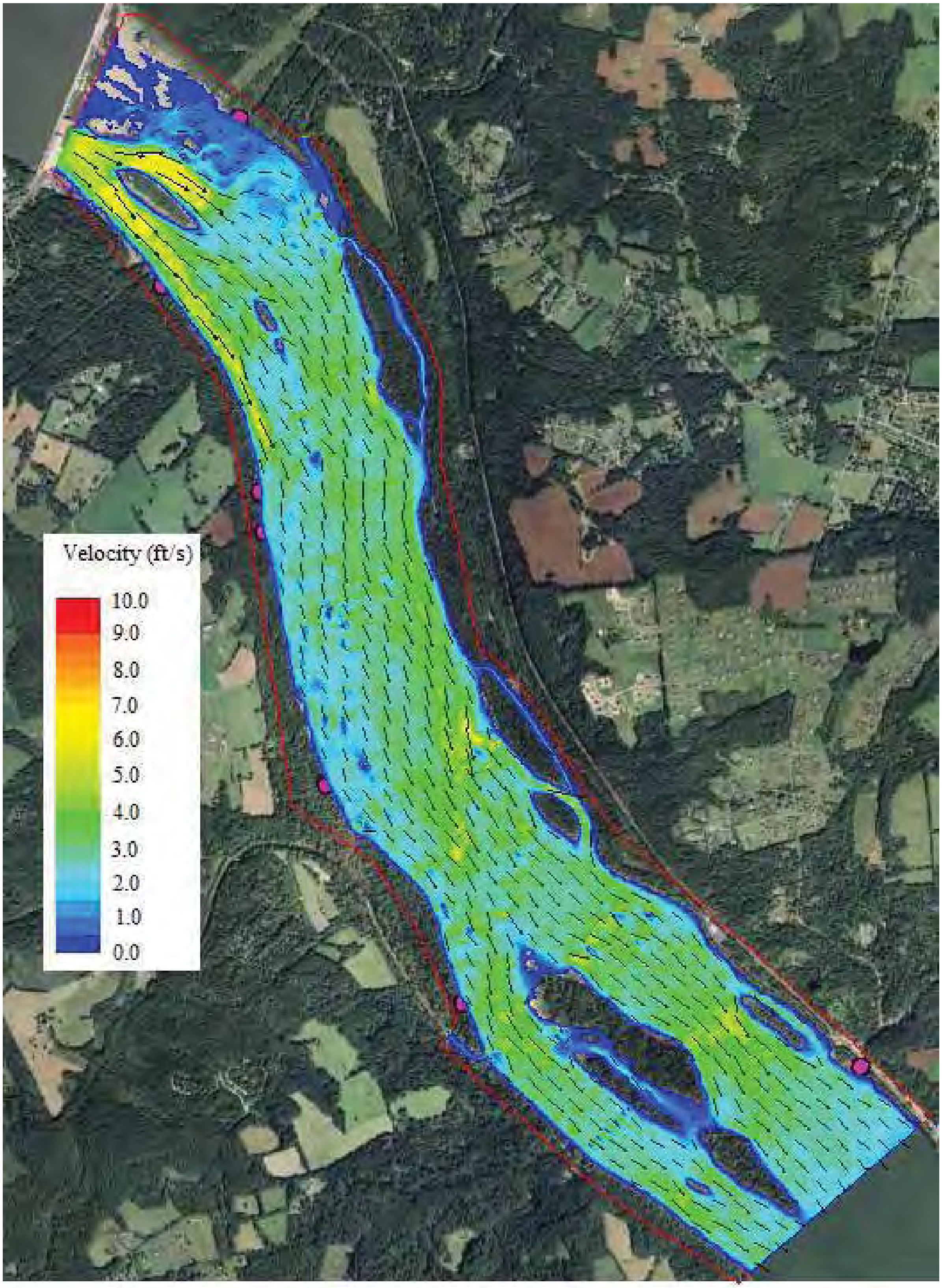
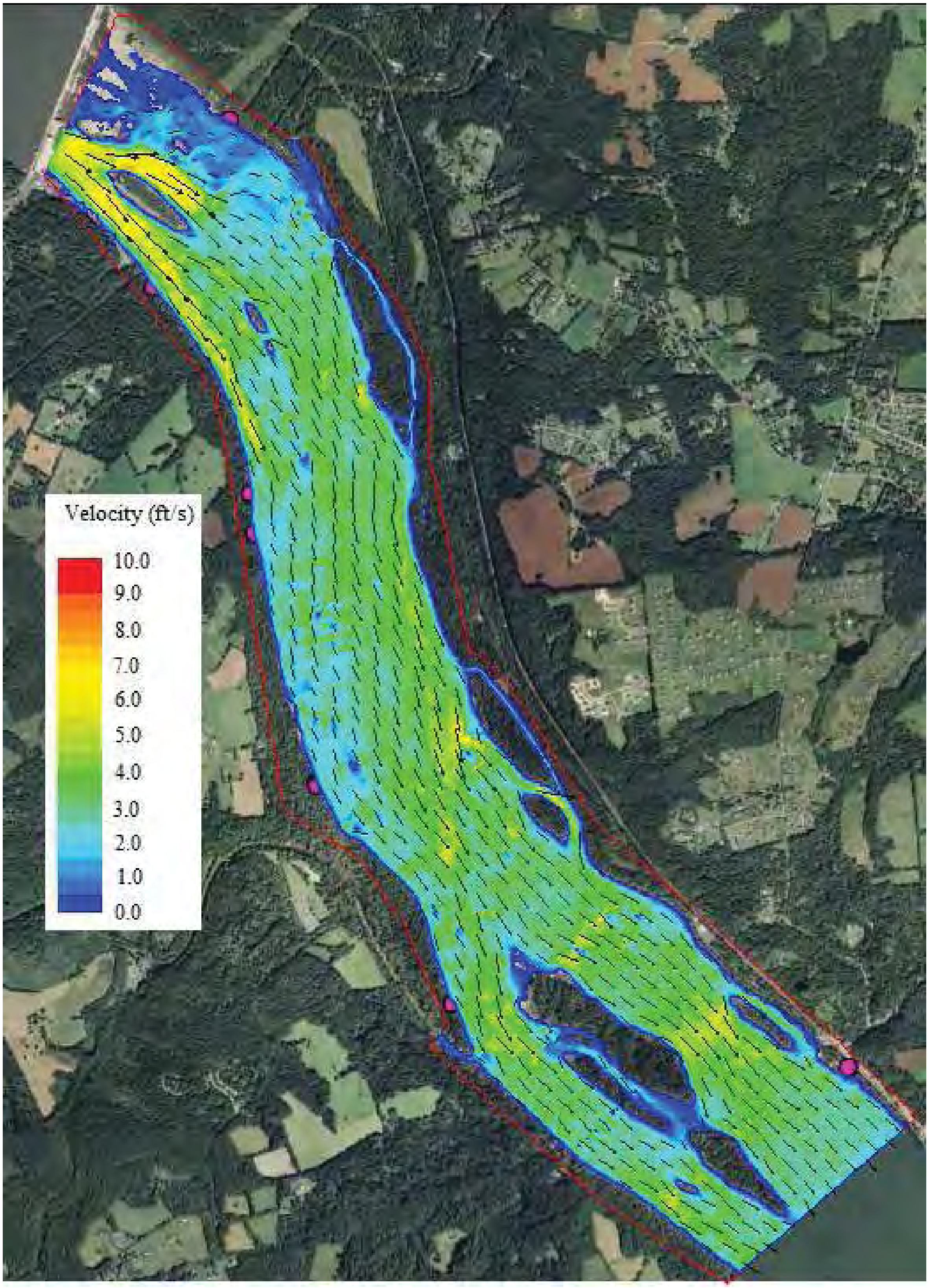


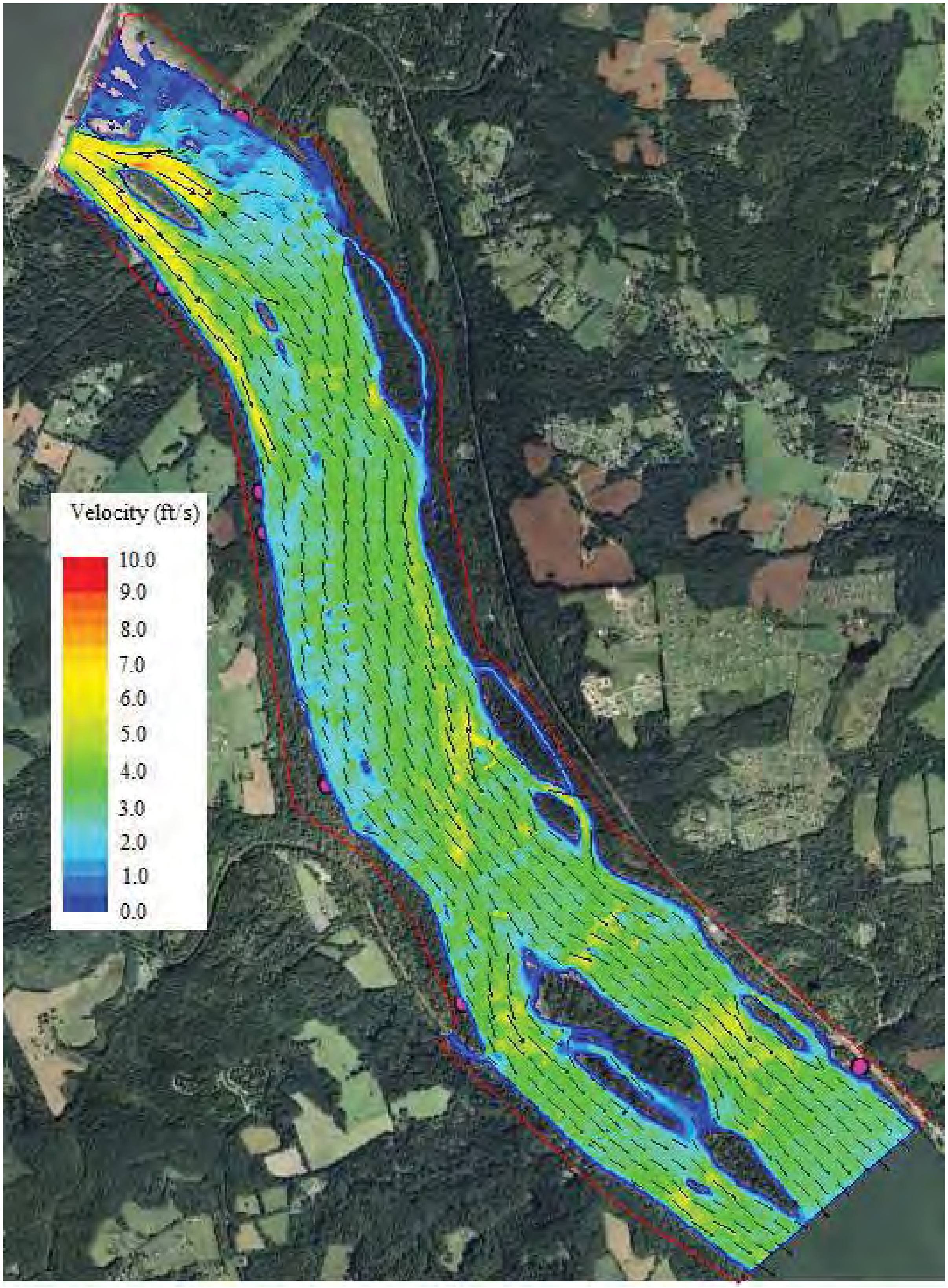
50,000 CFS



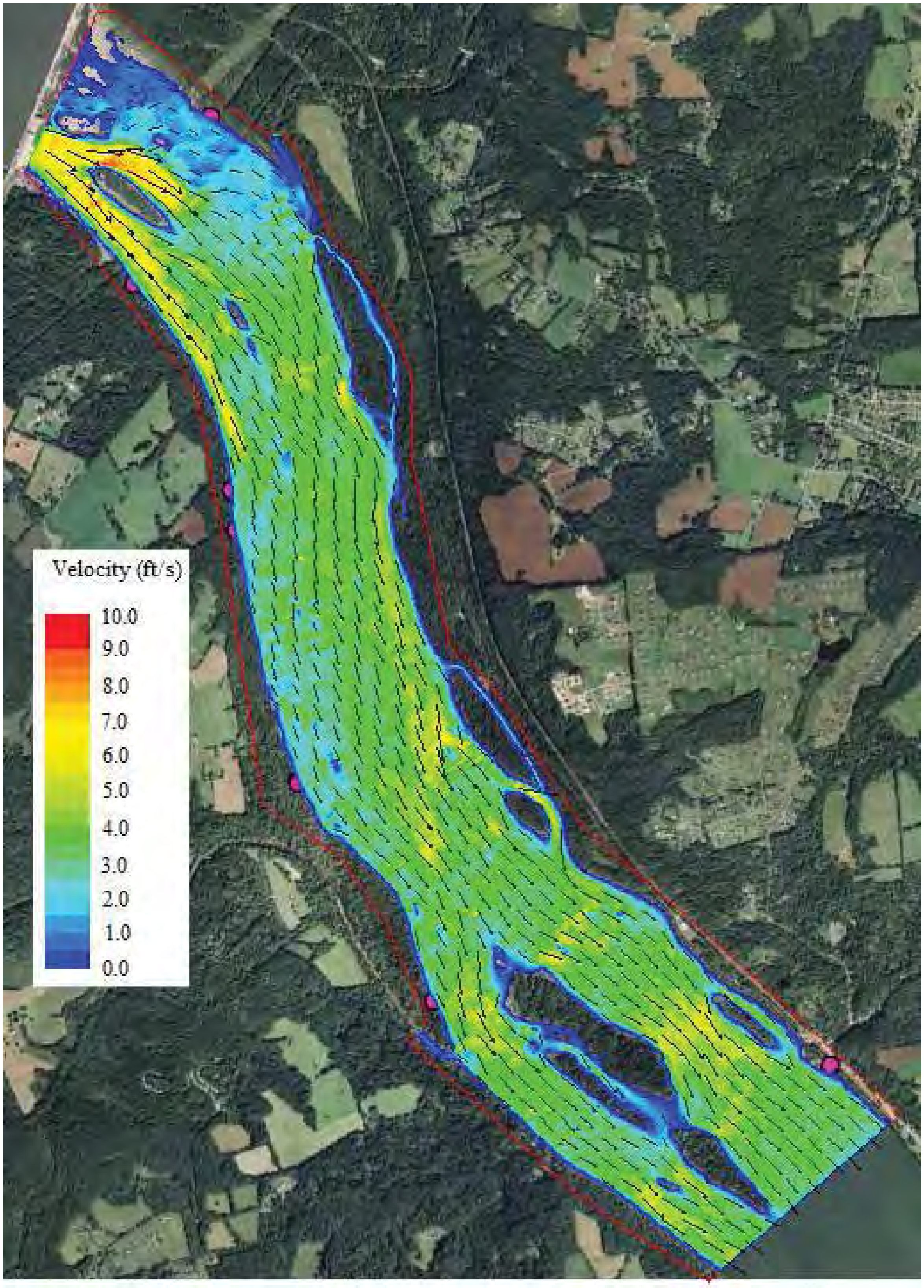
60,000 CFS



70,000 CFS

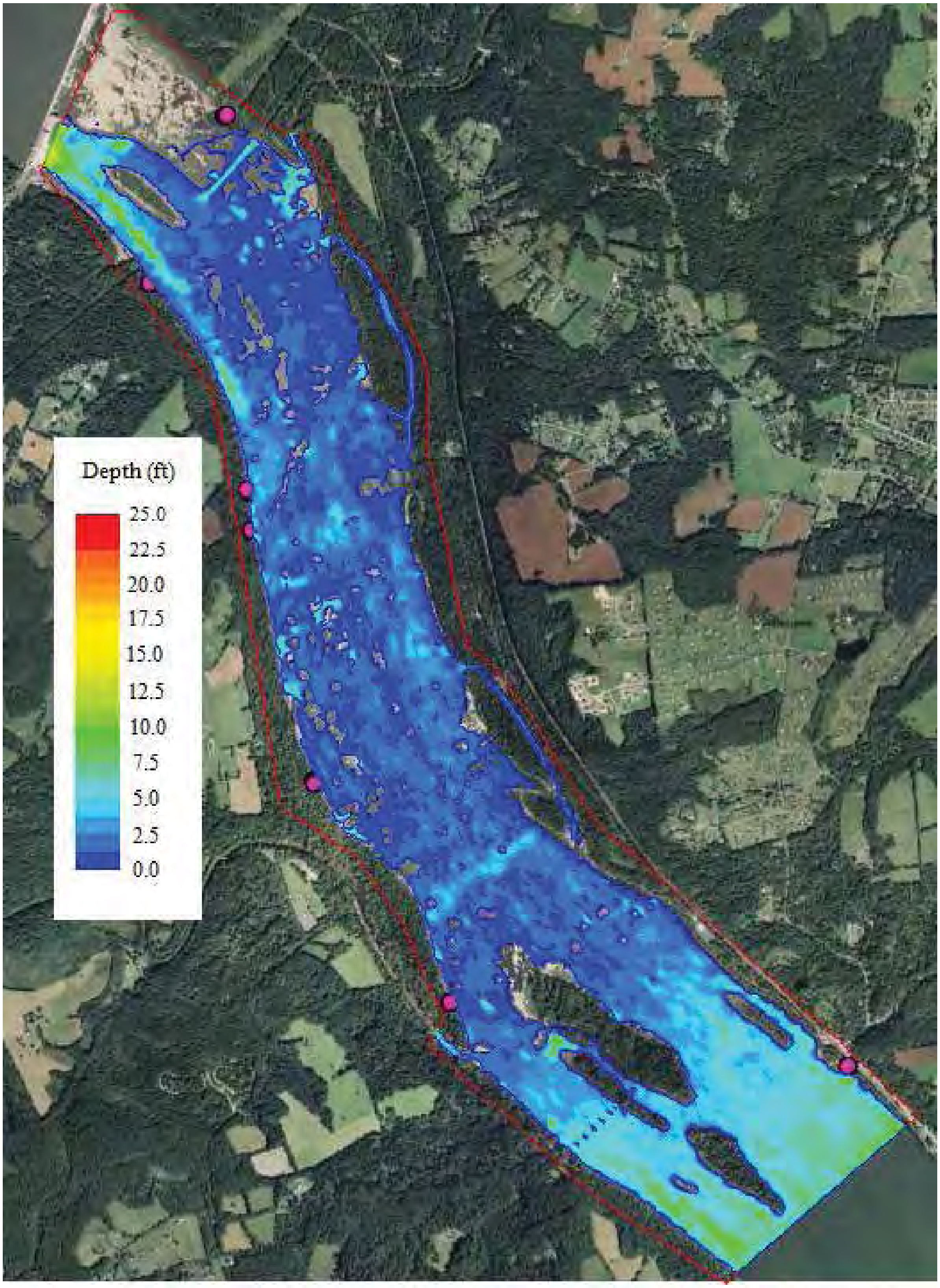


80,000 CFS

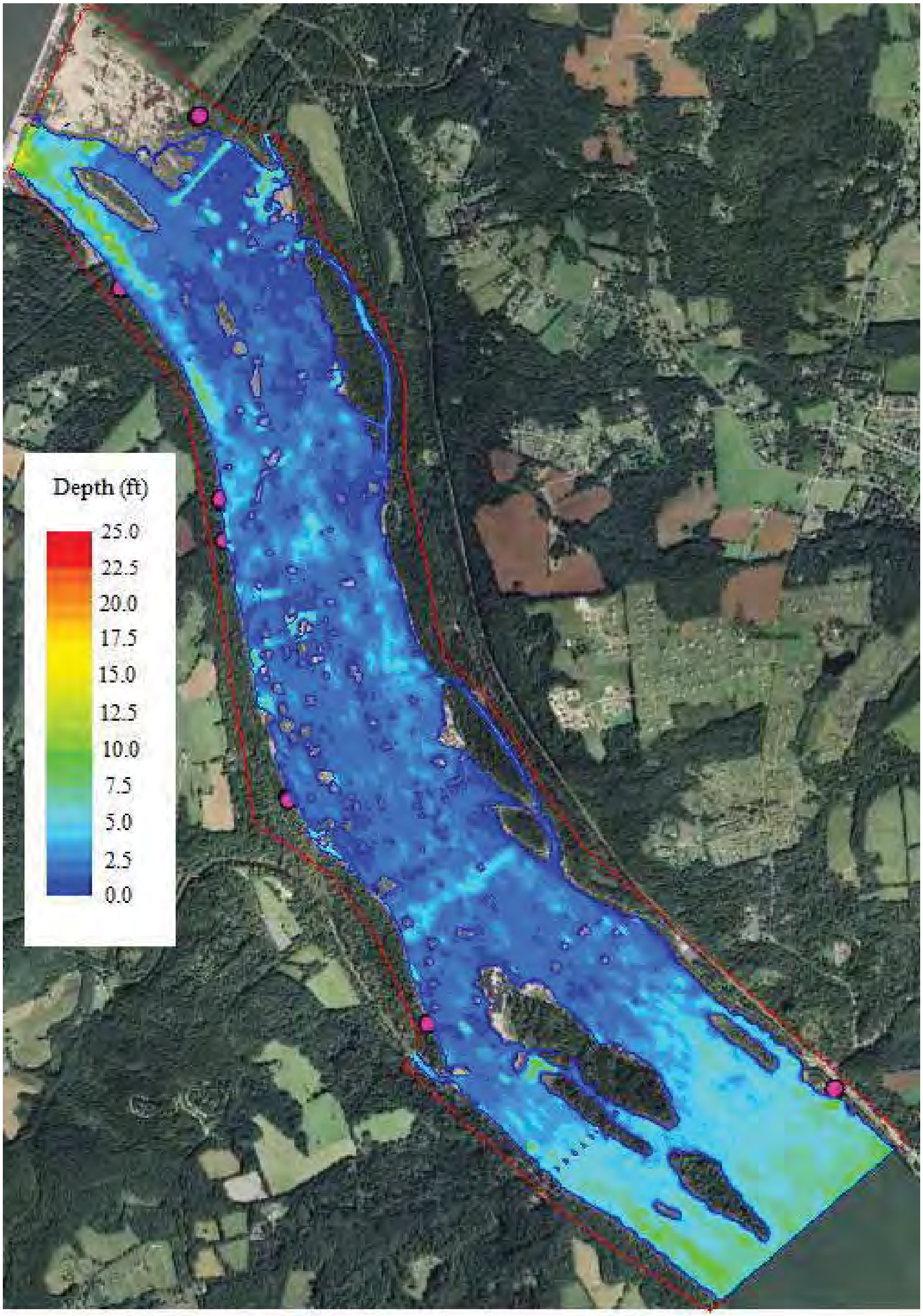


86,000 CFS

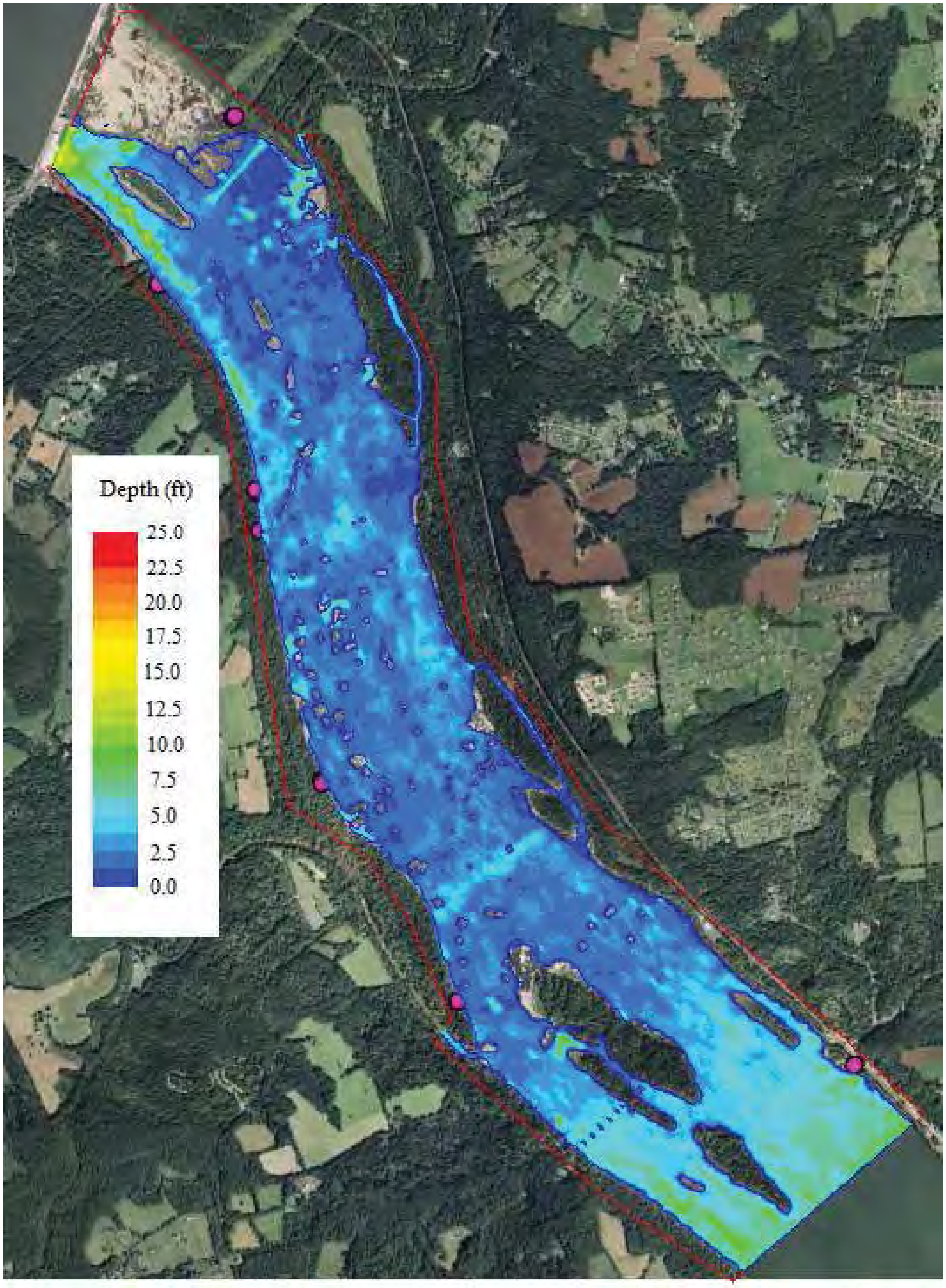
APPENDIX D-DEPTH PLOTS FOR SIMULATION FLOWS



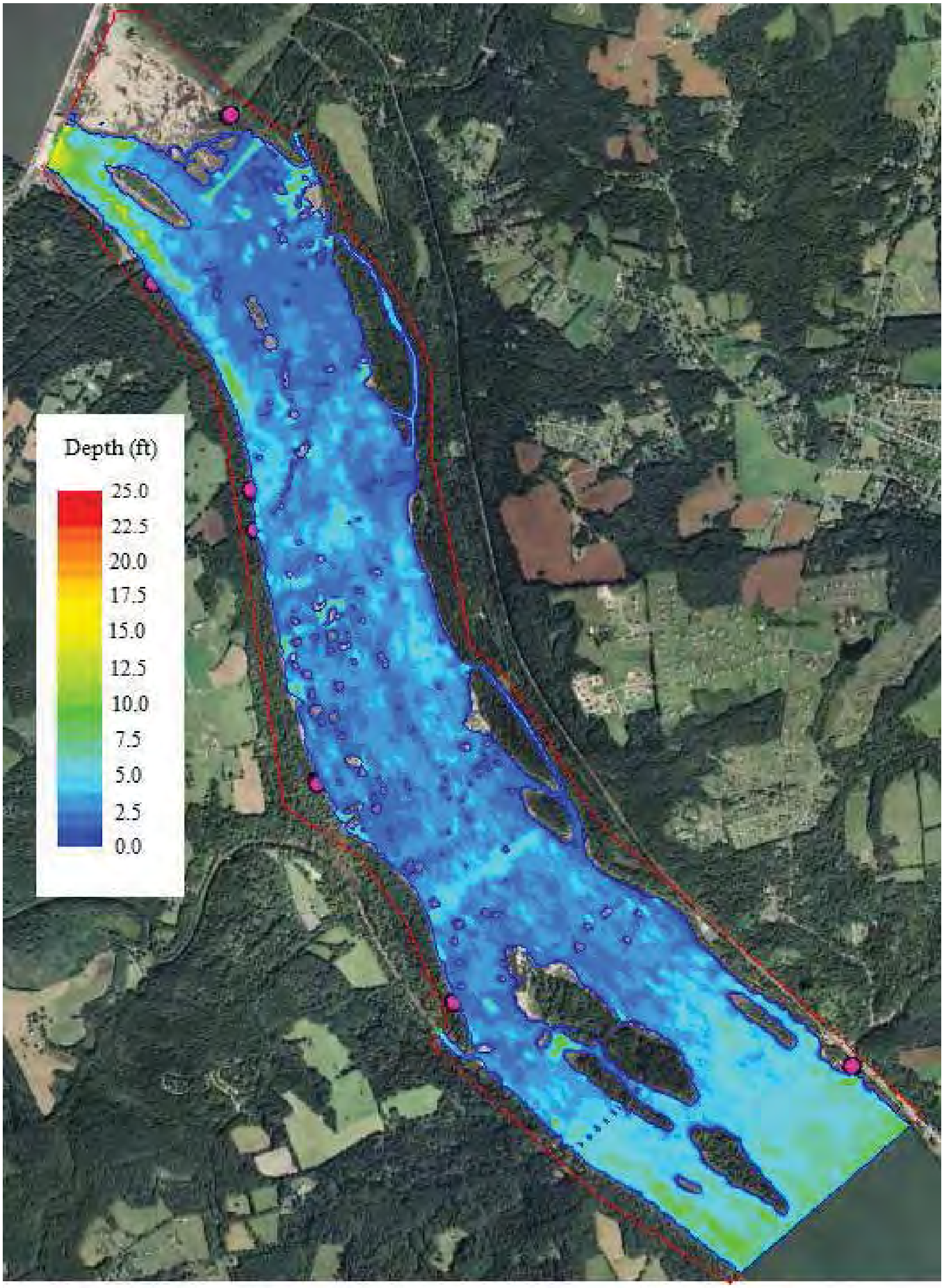
2,000 CFS



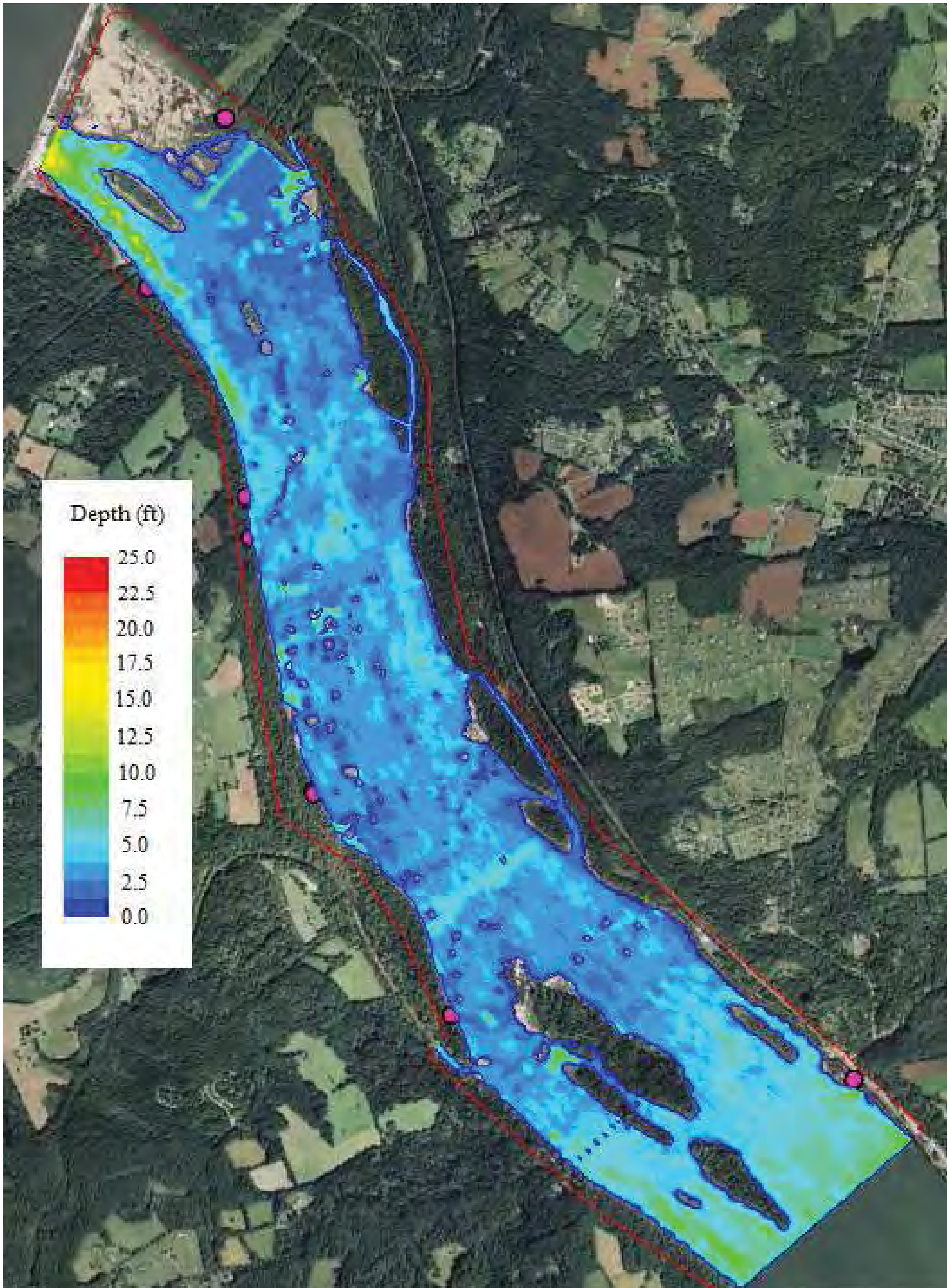
3,500 CFS



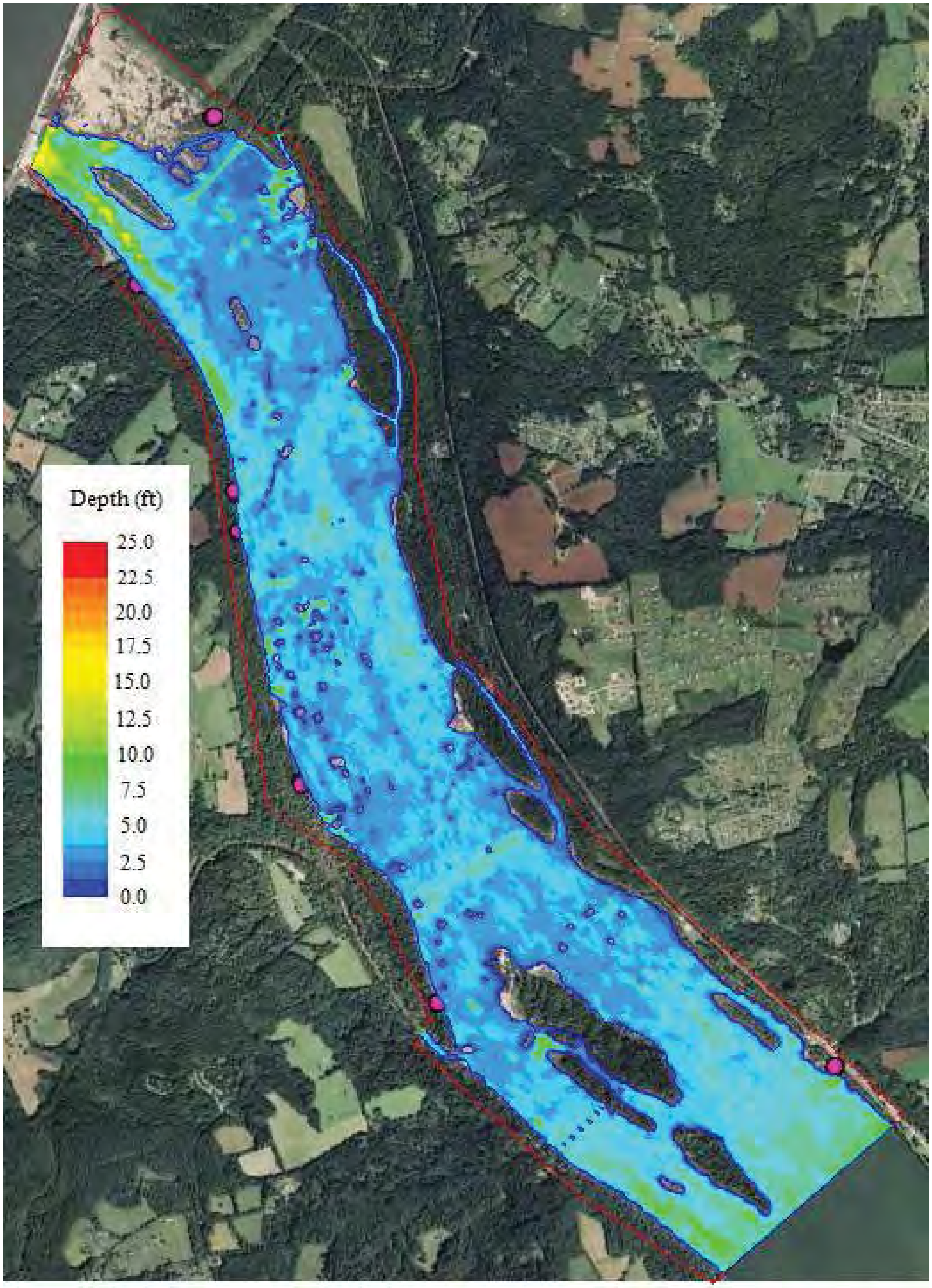
5,000 CFS



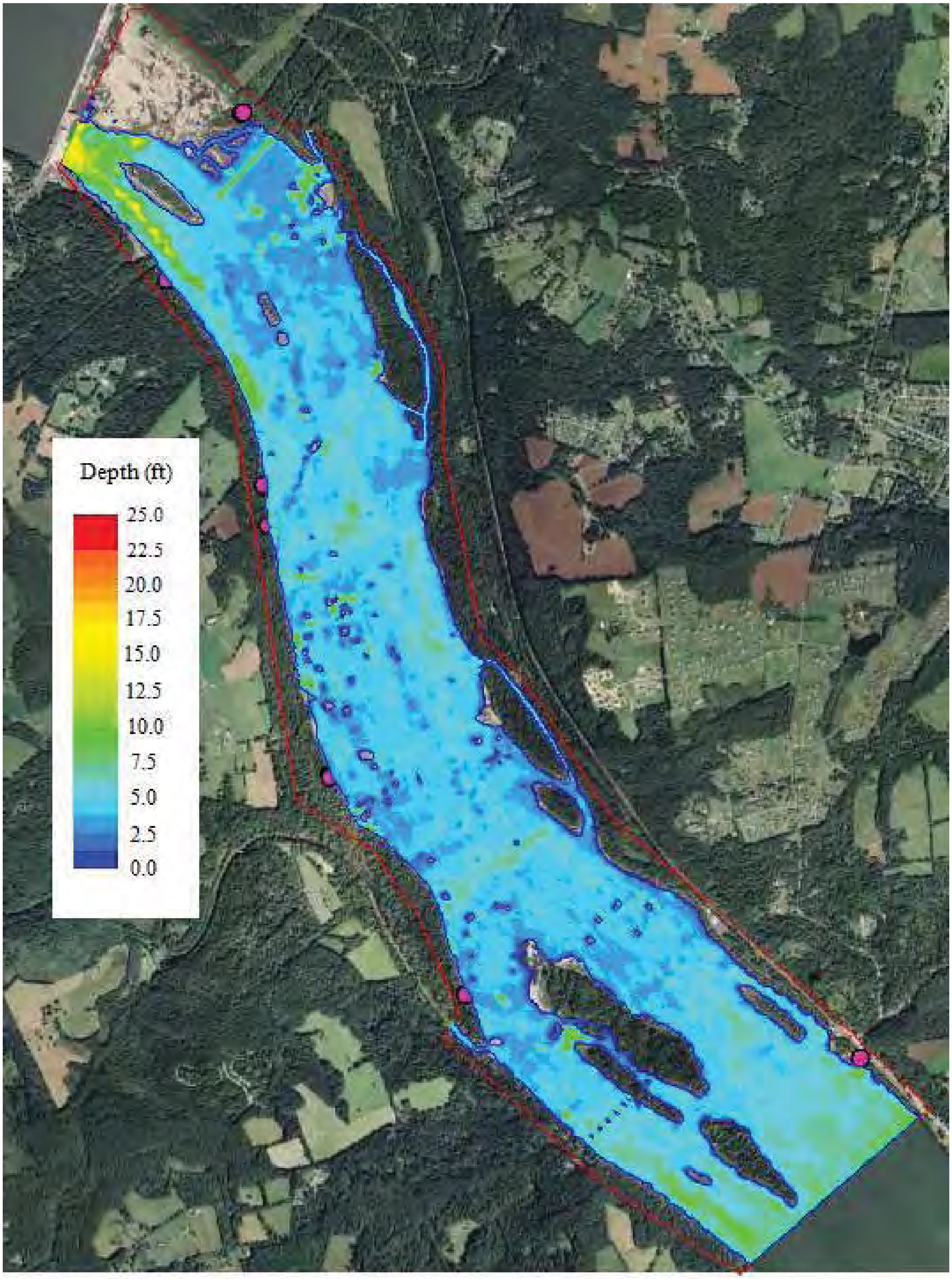
7,500 CFS



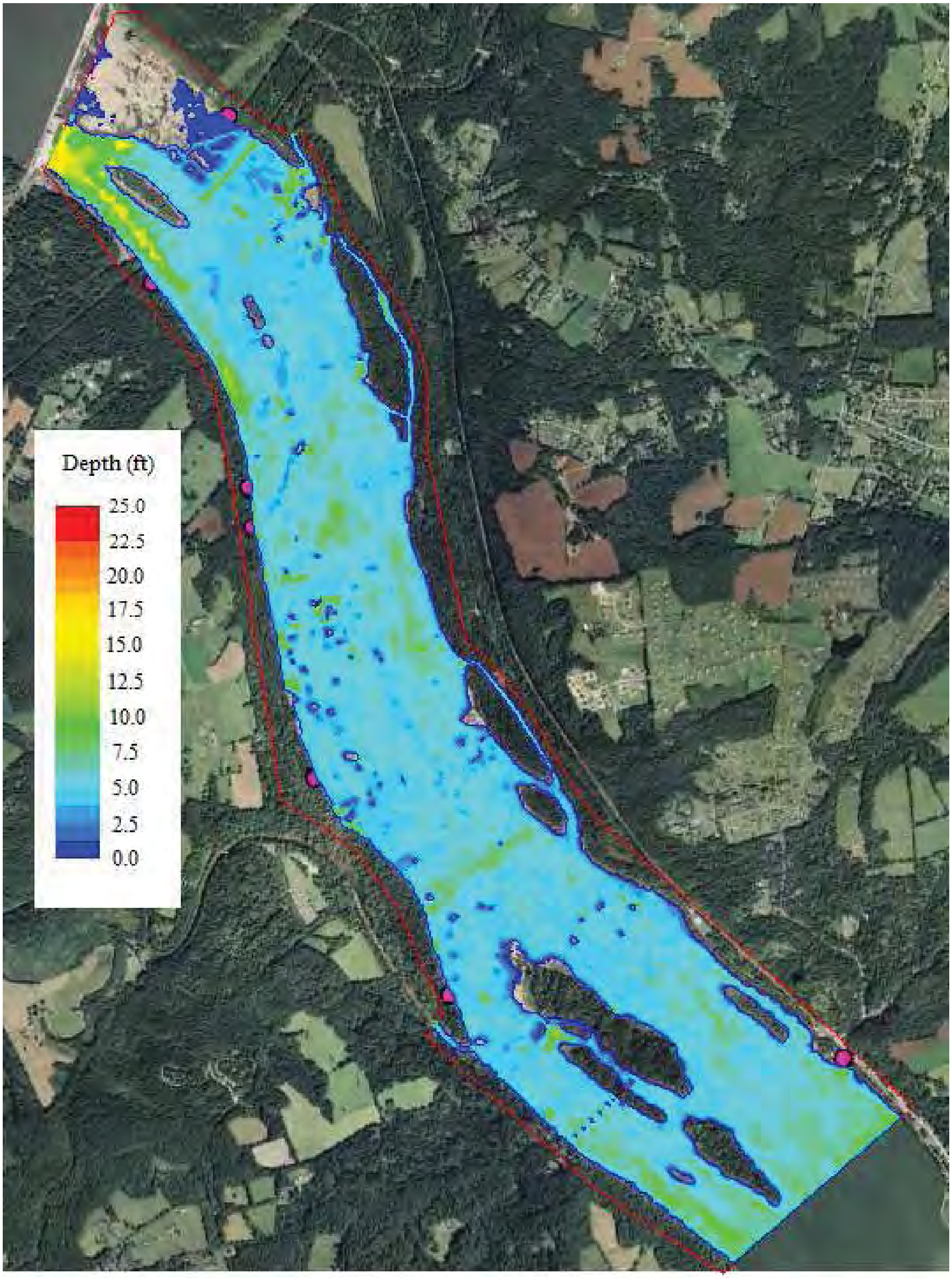
10,000 CFS



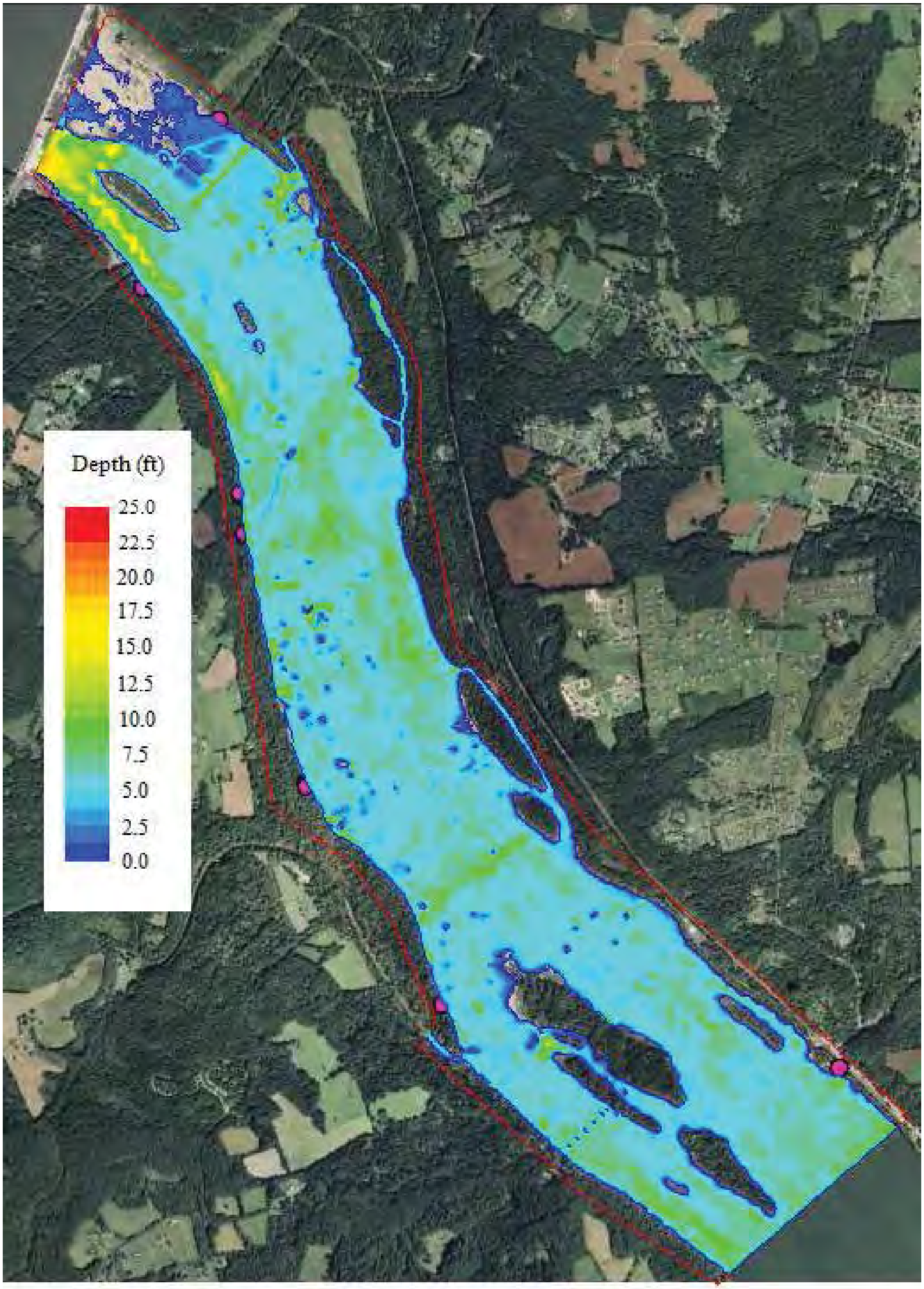
15,000 CFS



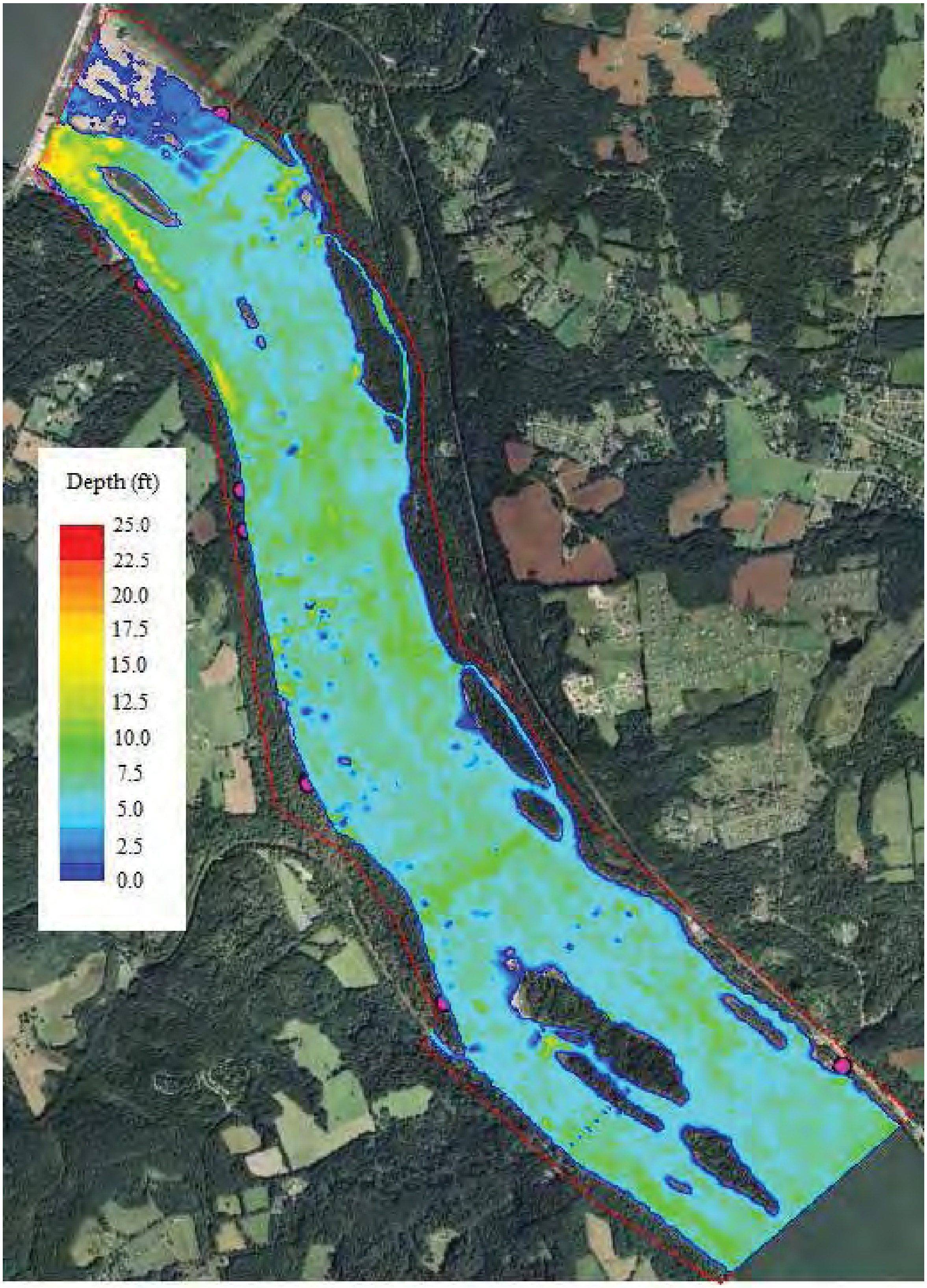
20,000 CFS



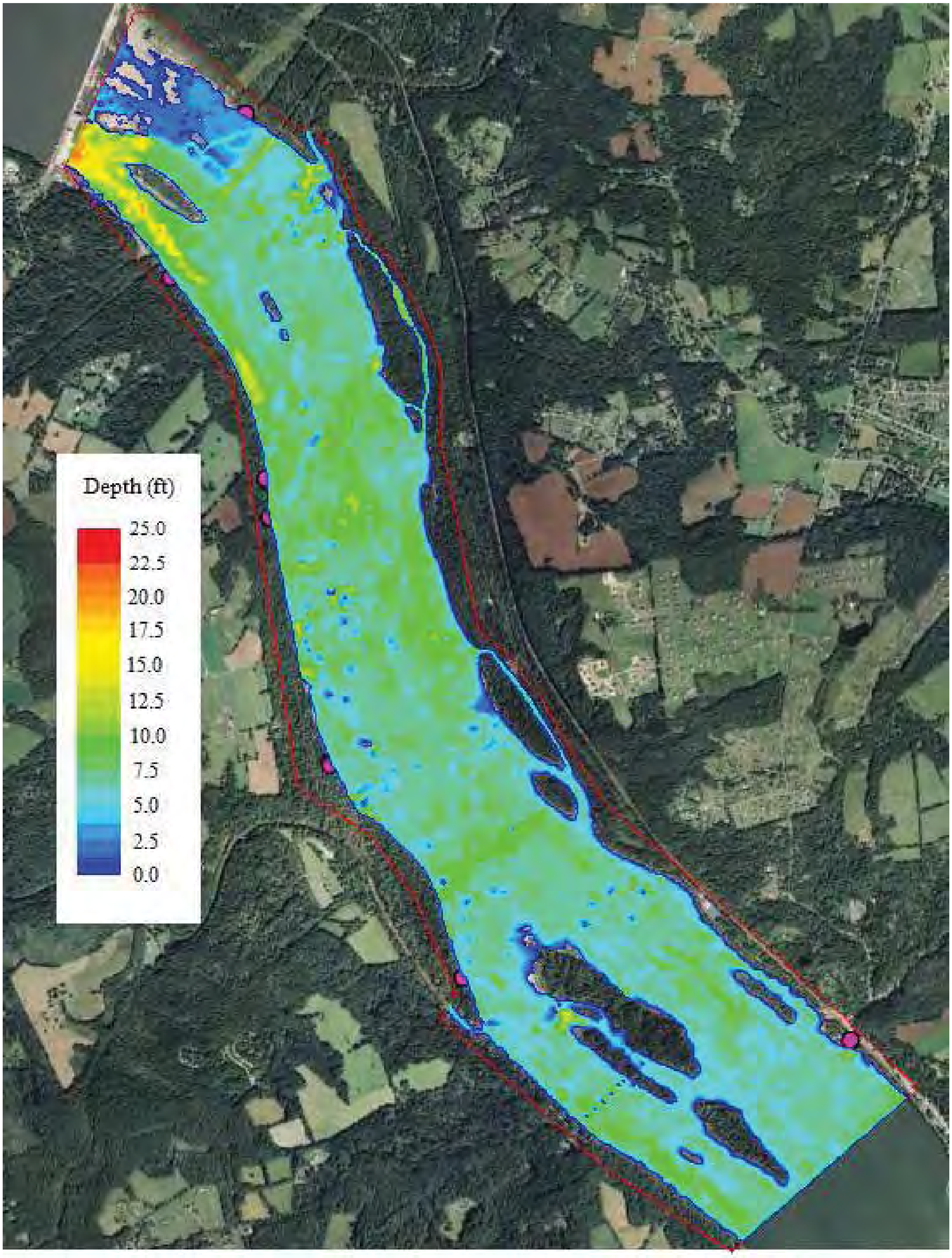
30,000 CFS



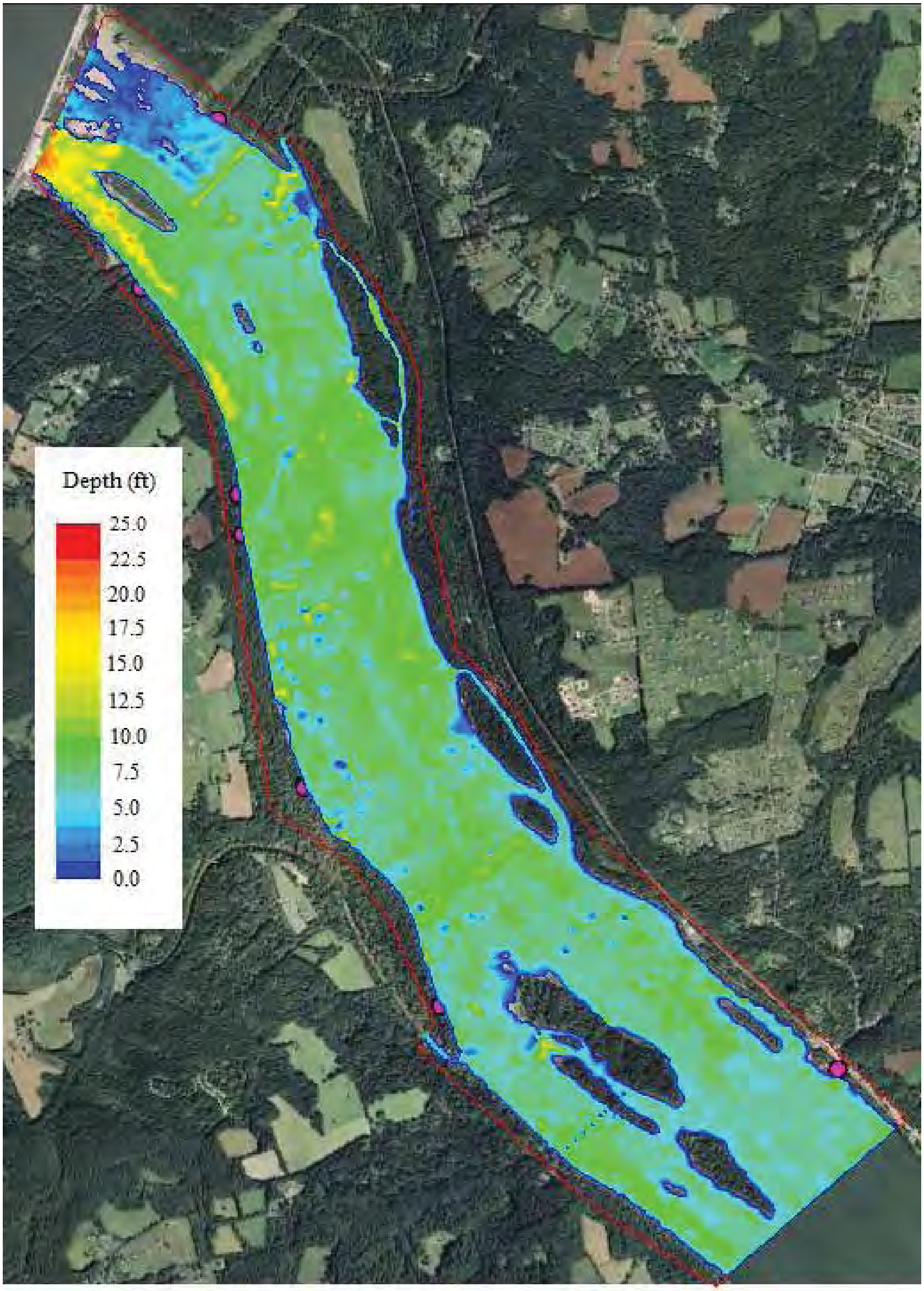
40,000 CFS



50,000 CFS



60,000 CFS



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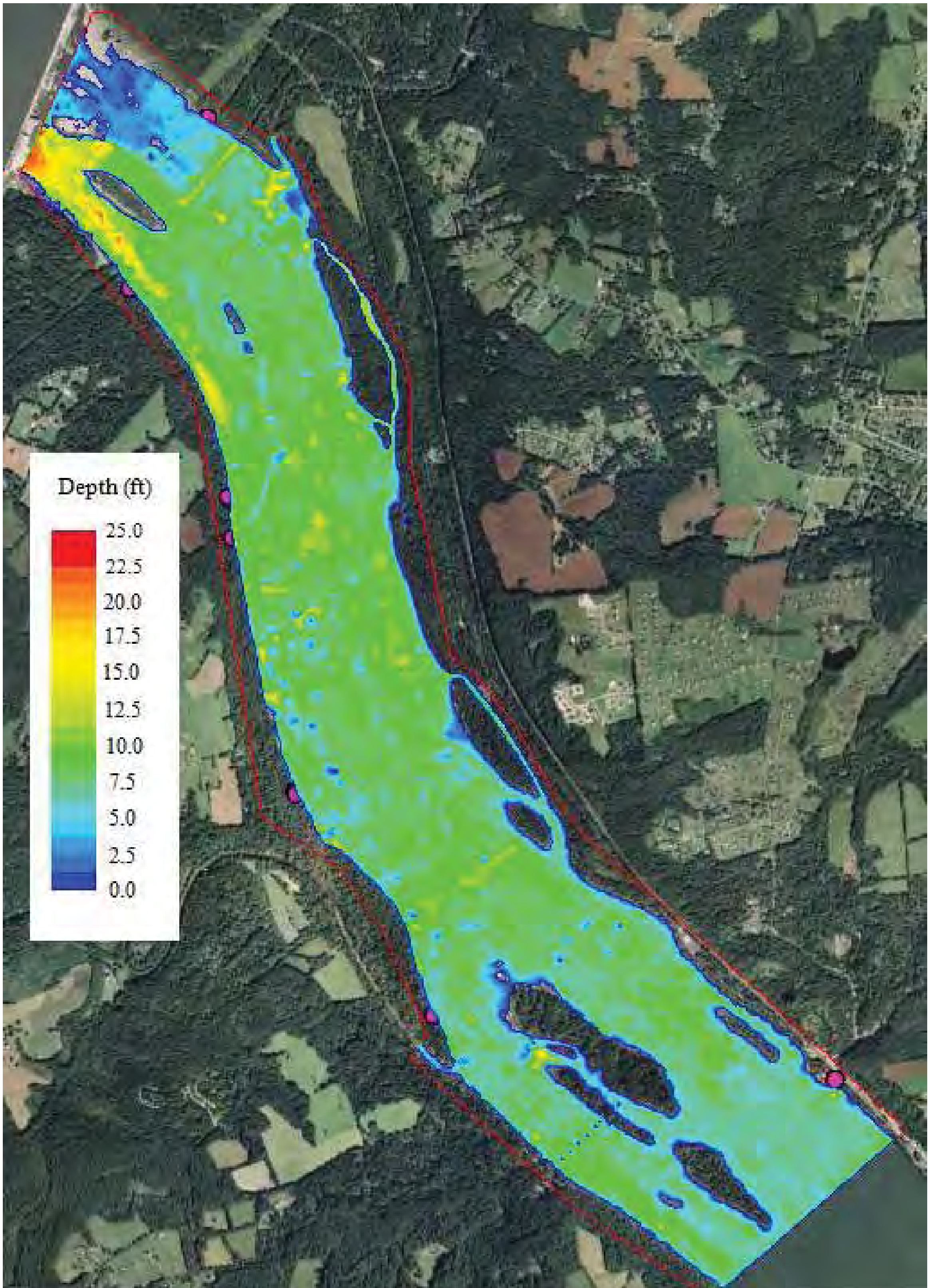
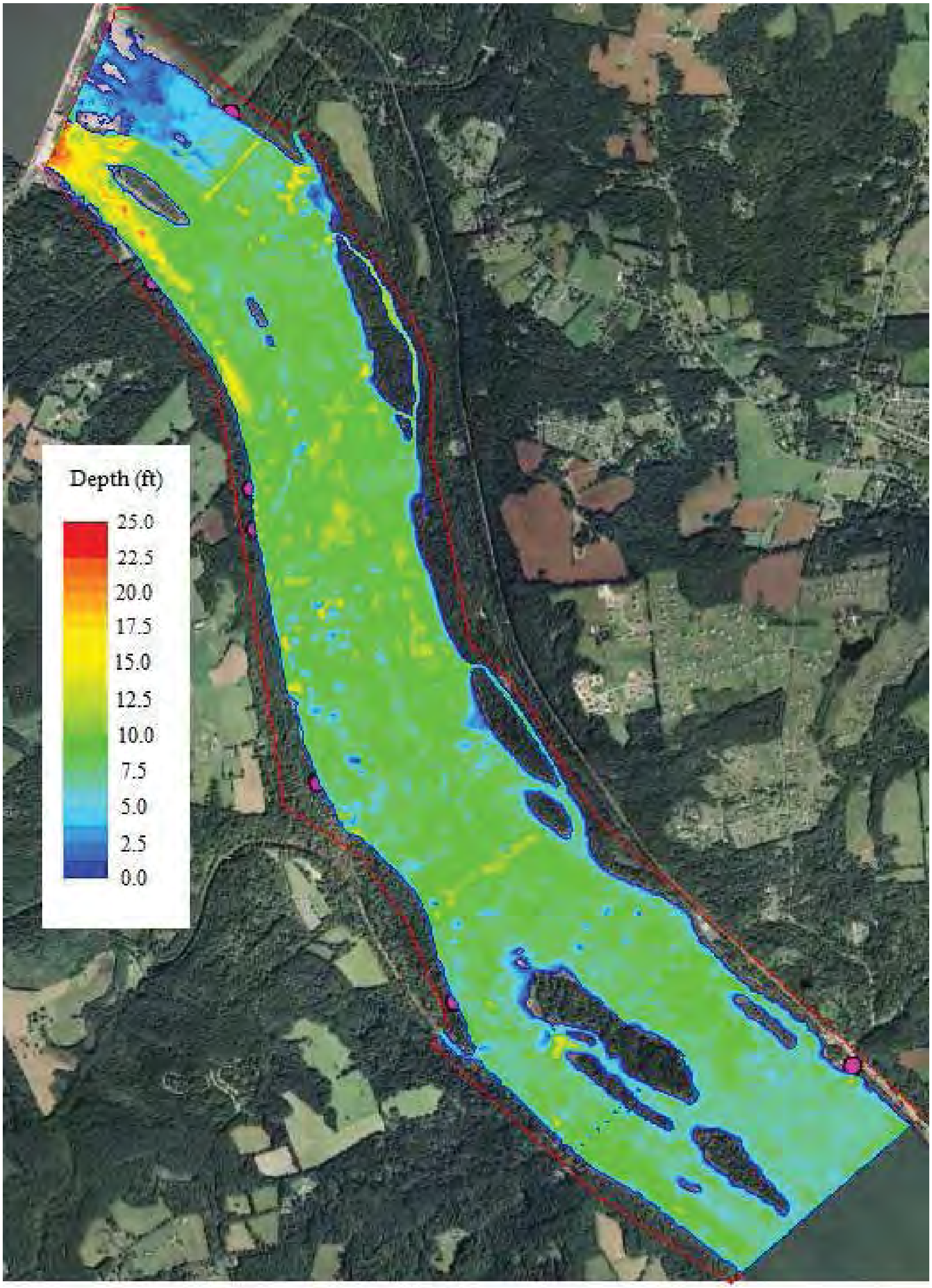
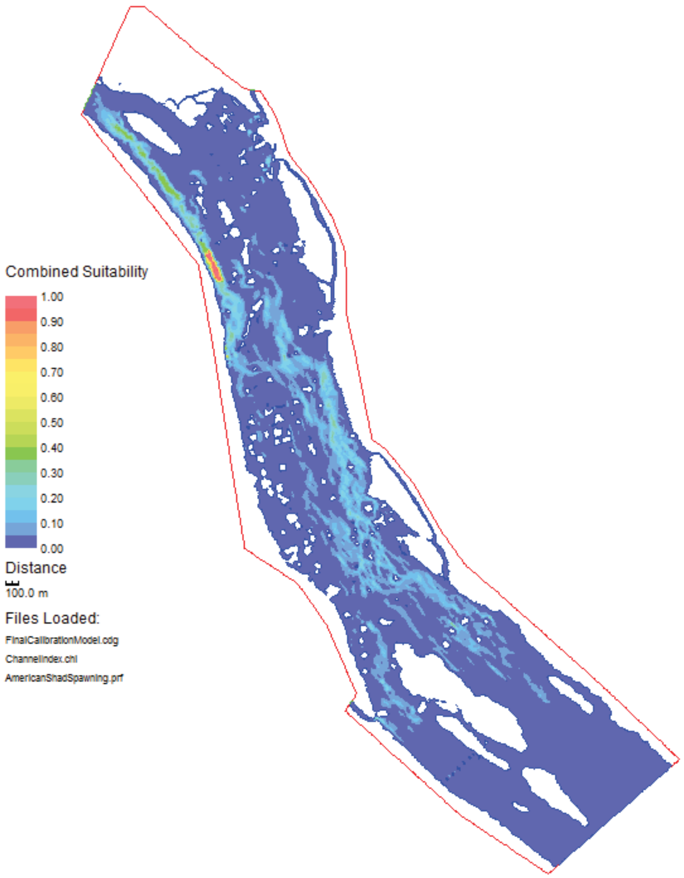


80,000 CFS

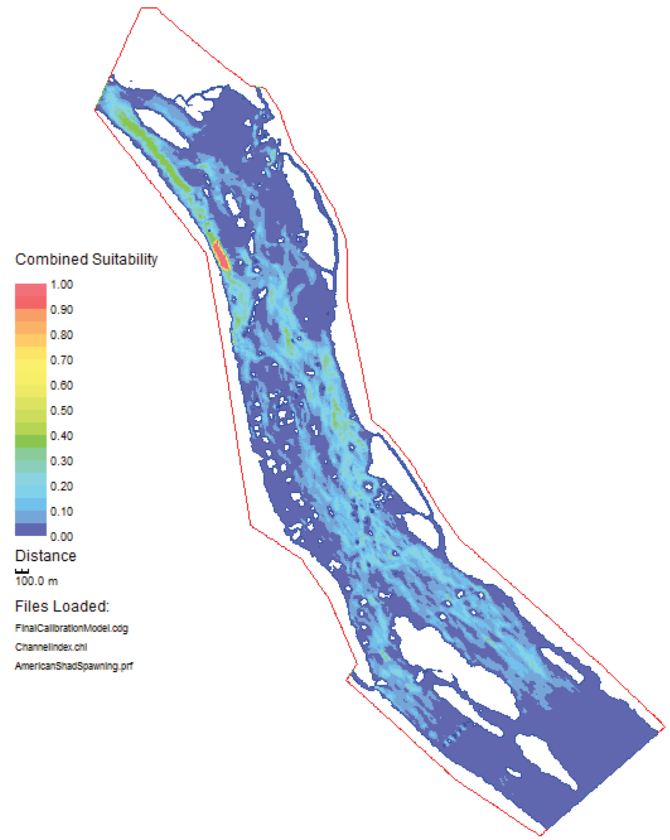


86,000 CFS

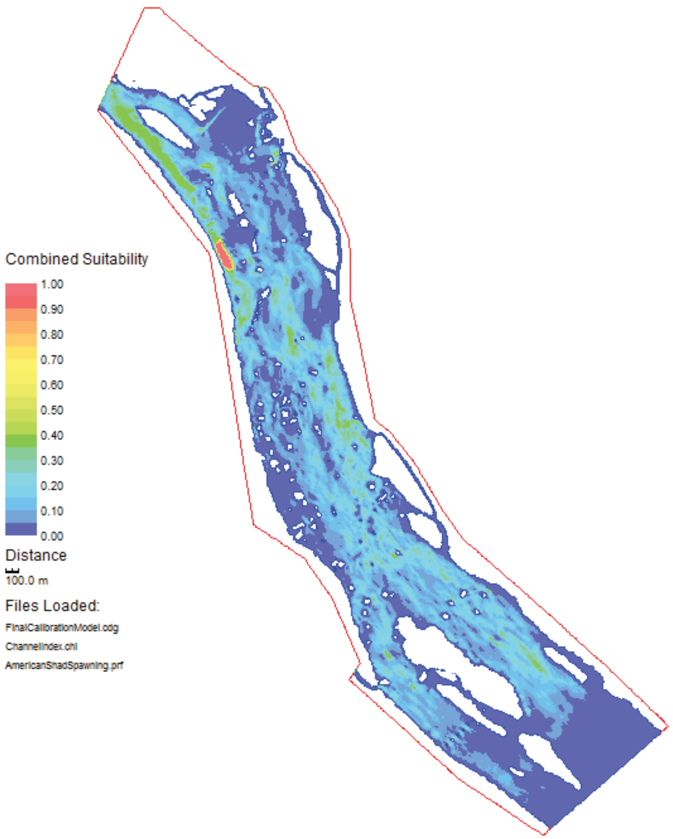
APPENDIX E-COMBINED SUITABILITY HABITAT MAPS FOR SIMULATION FLOWS



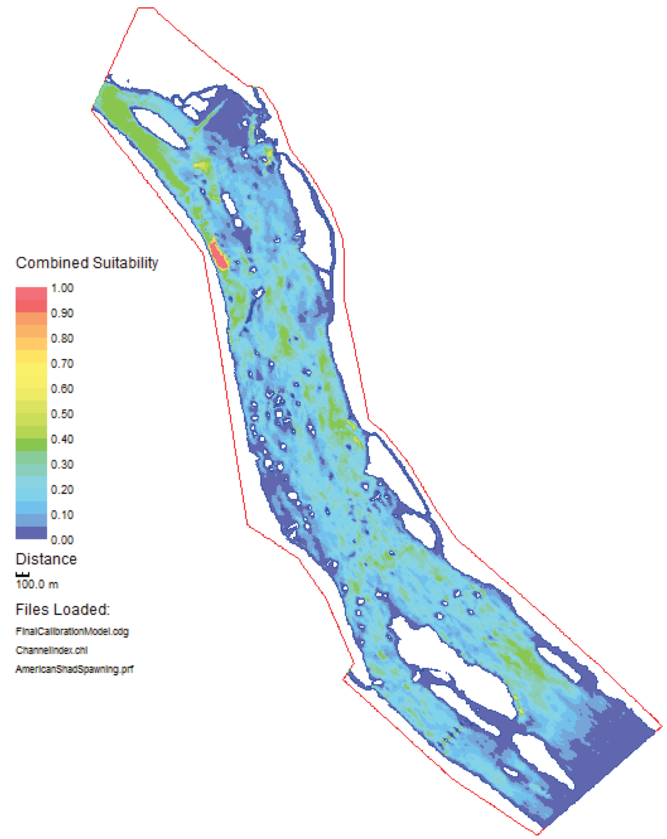
American Shad Spawning – 2,000 cfs



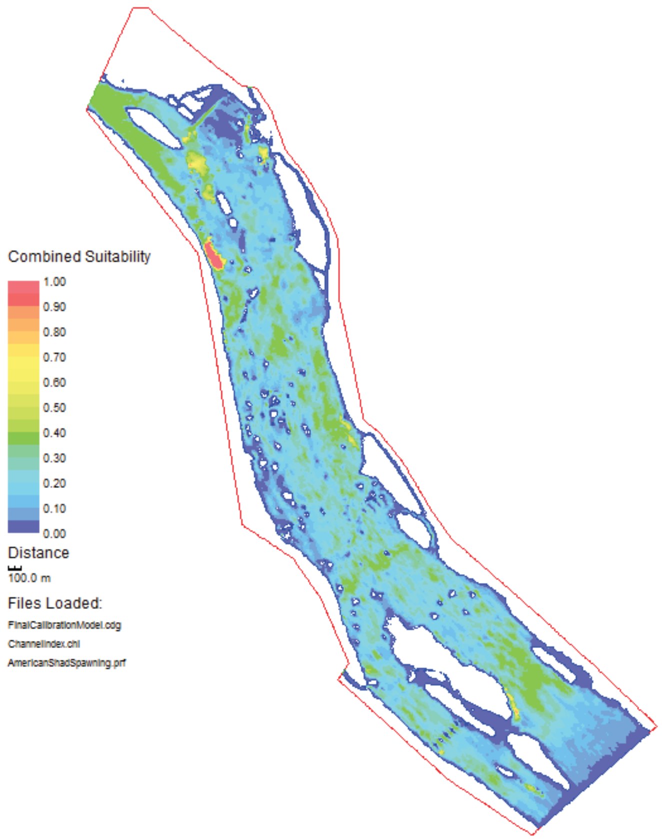
American Shad Spawning – 3,500 cfs



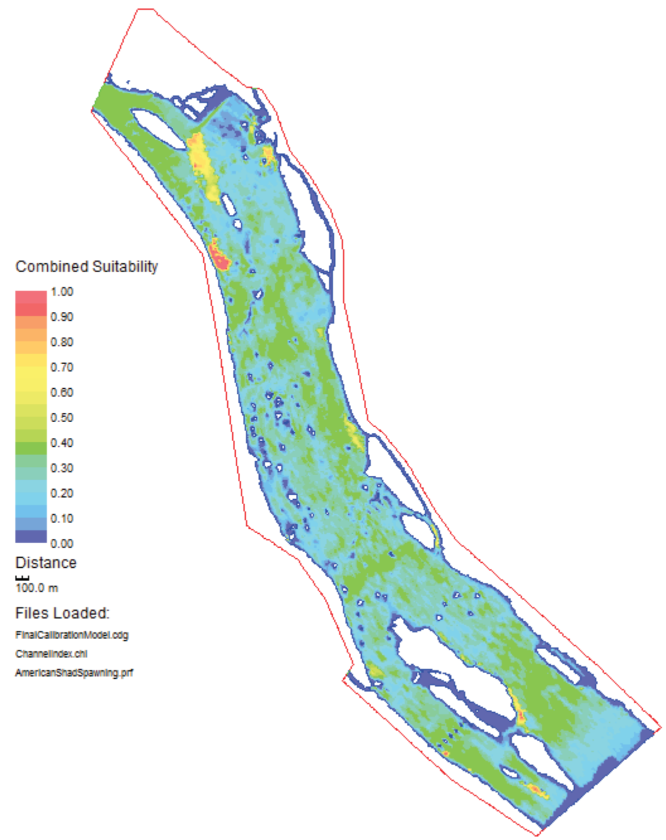
American Shad Spawning – 5,000 cfs



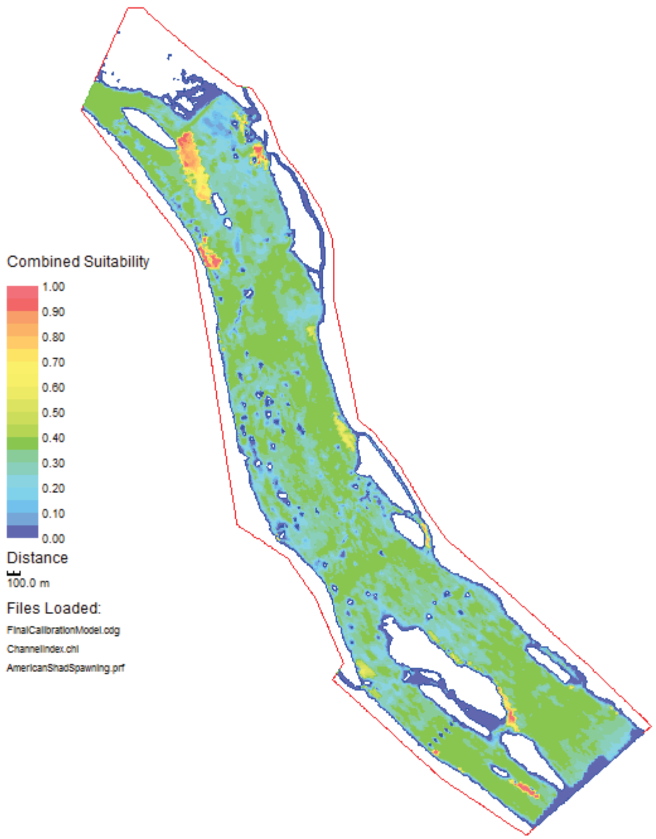
American Shad Spawning – 7,500 cfs



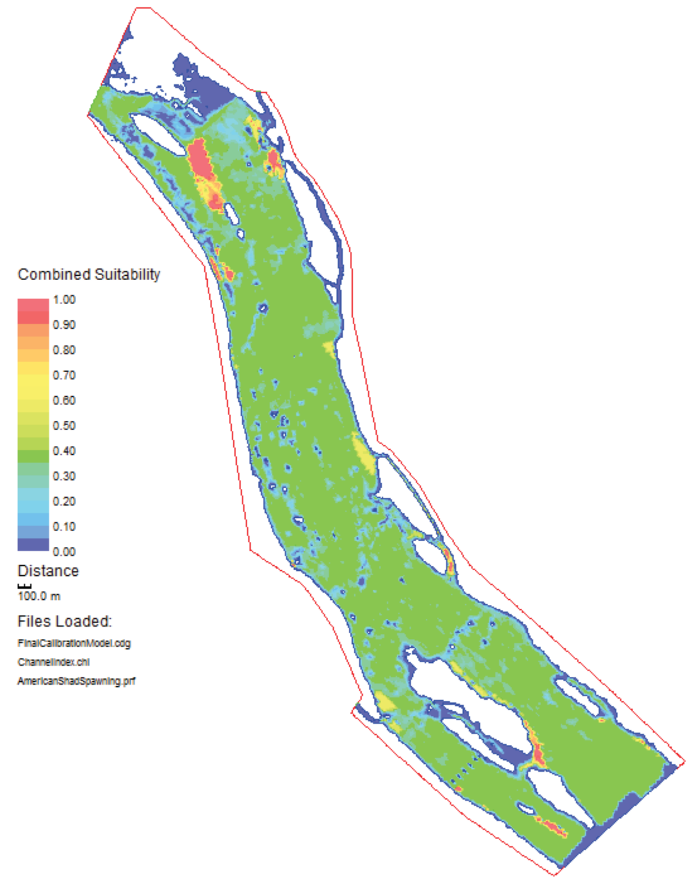
American Shad Spawning – 10,000 cfs



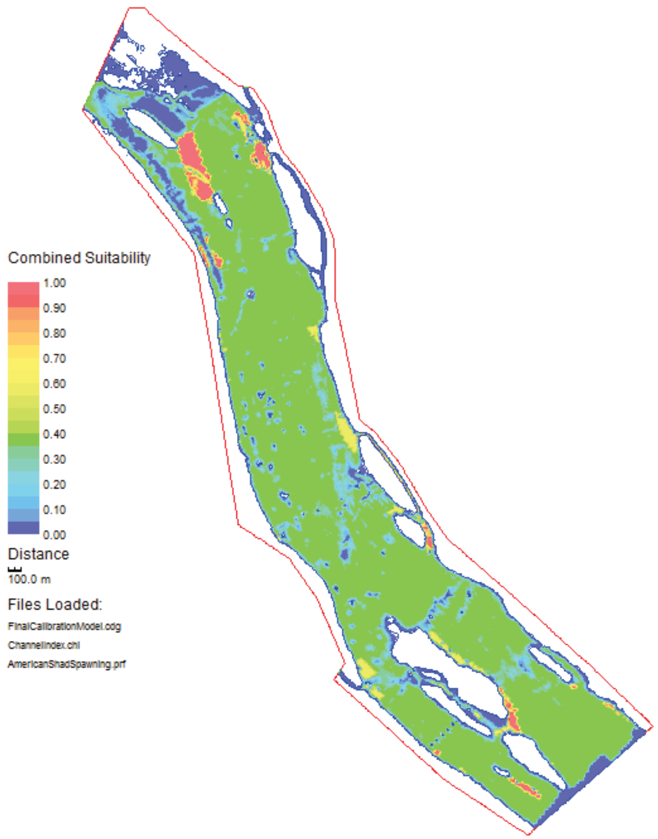
American Shad Spawning – 15,000 cfs



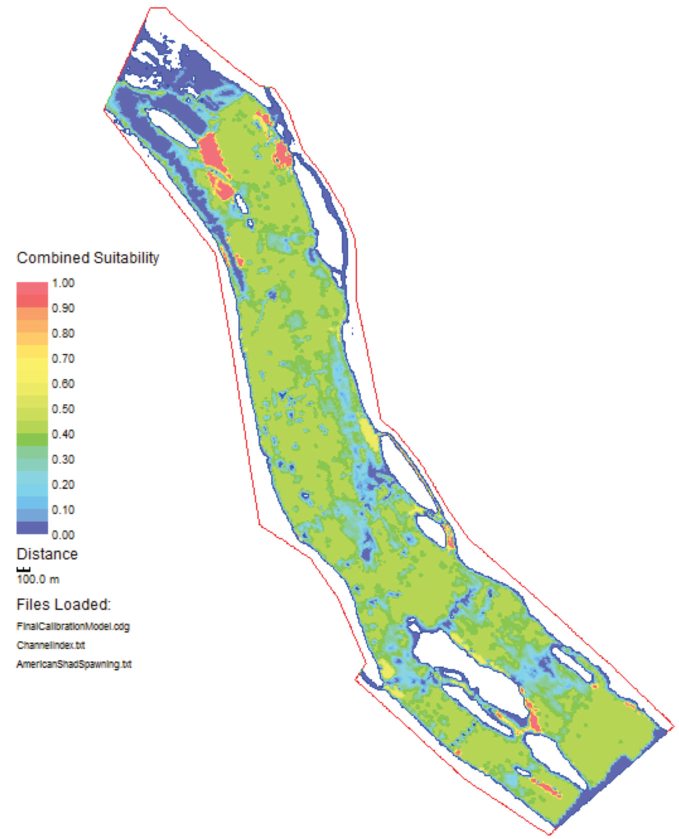
American Shad Spawning – 20,000 cfs



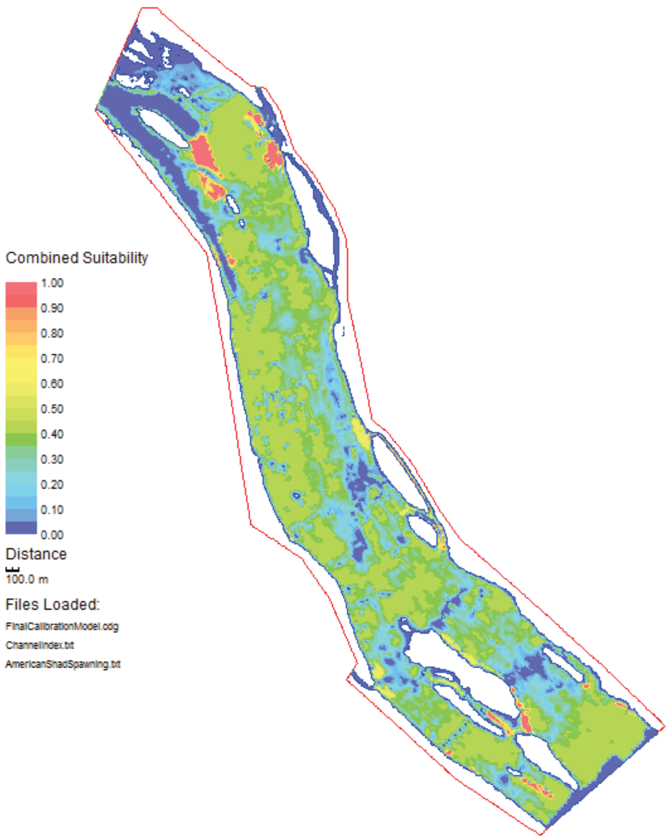
American Shad Spawning – 30,000 cfs



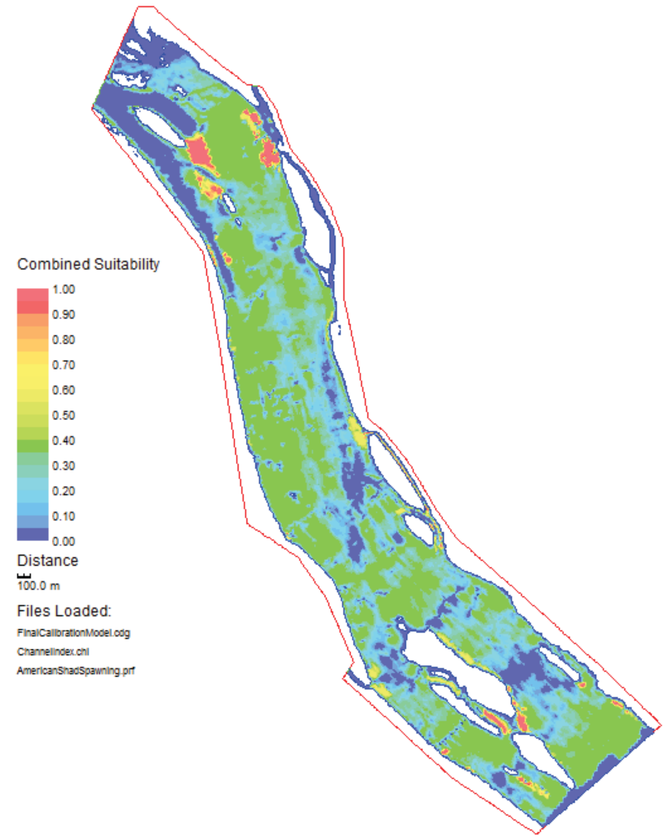
American Shad Spawning – 40,000 cfs



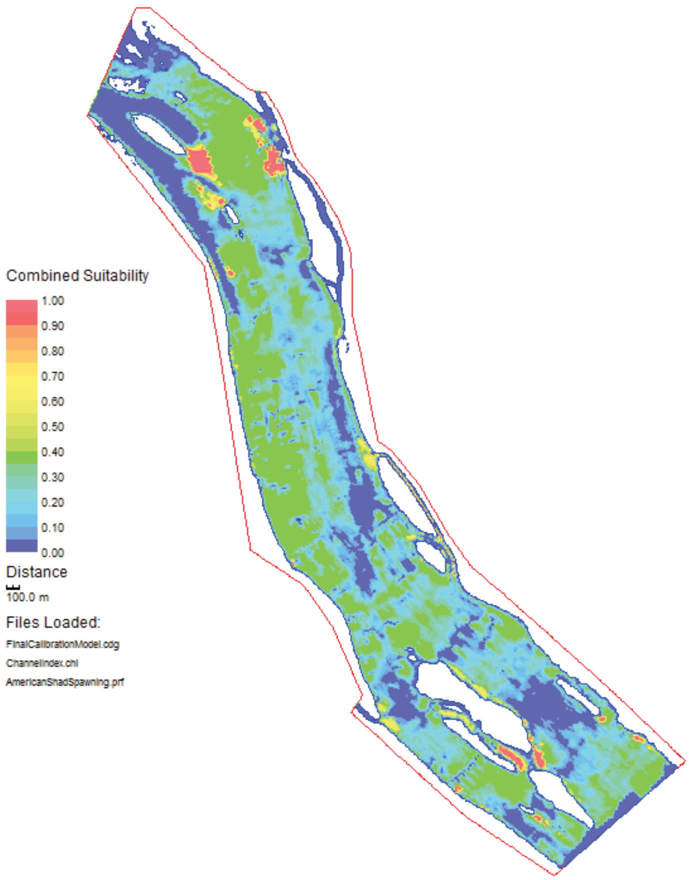
American Shad Spawning – 50,000 cfs



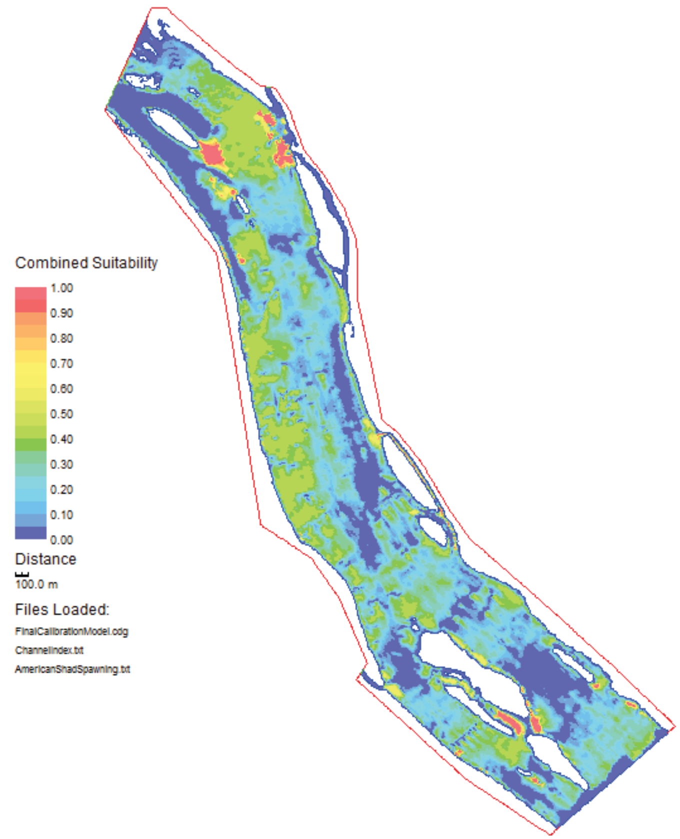
American Shad Spawning – 60,000 cfs



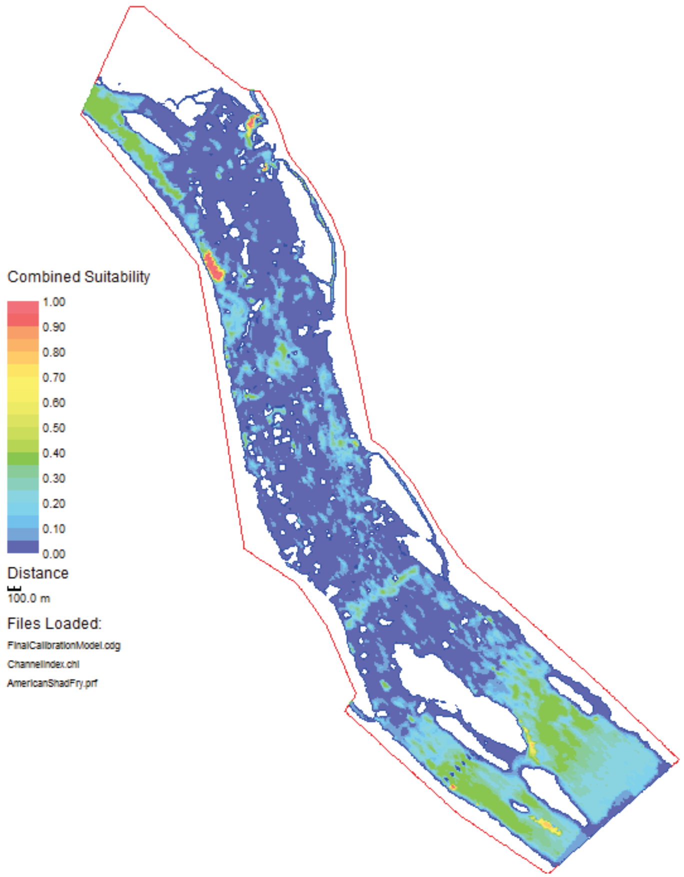
American Shad Spawning – 70,000 cfs



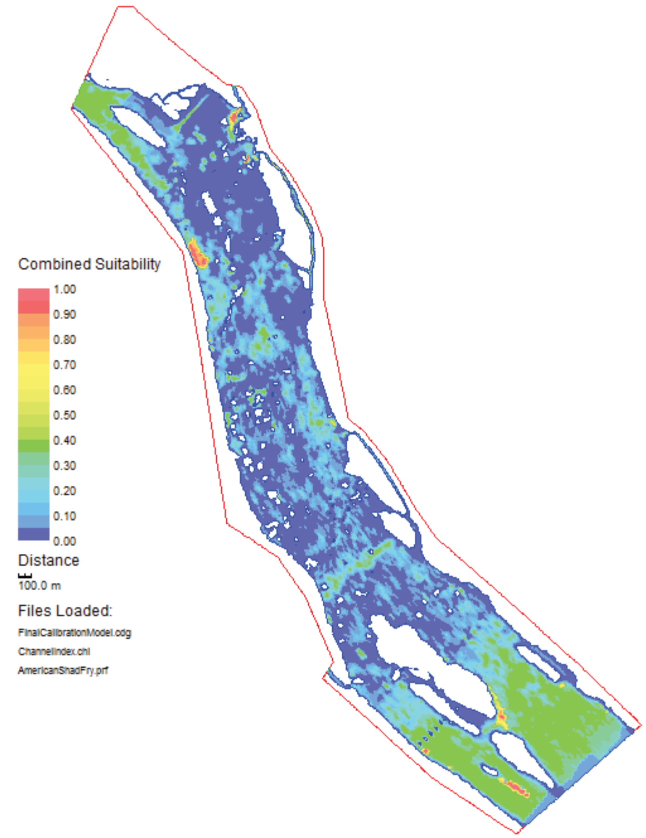
American Shad Spawning – 80,000 cfs



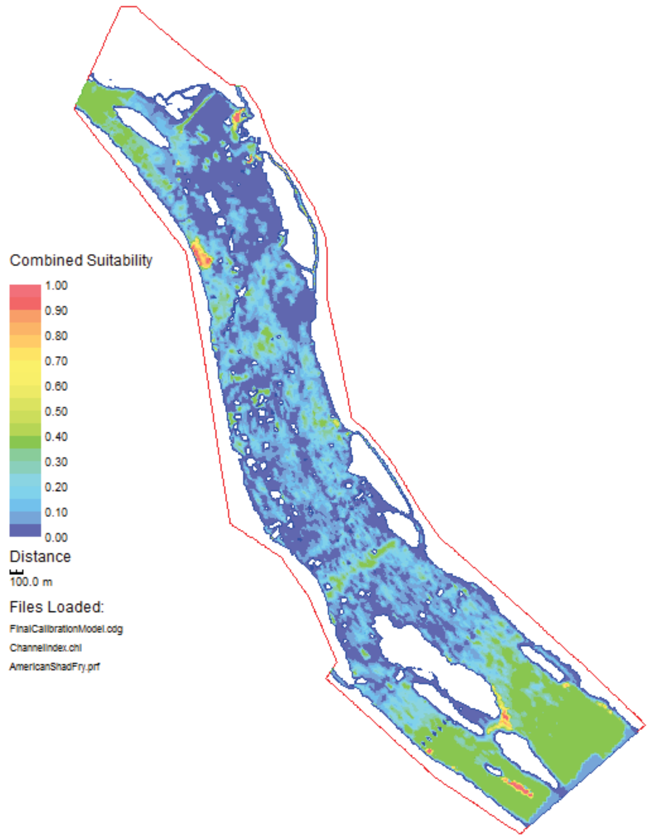
American Shad Spawning – 86,000 cfs



American Shad Fry – 2,000 cfs



American Shad Fry – 3,500 cfs



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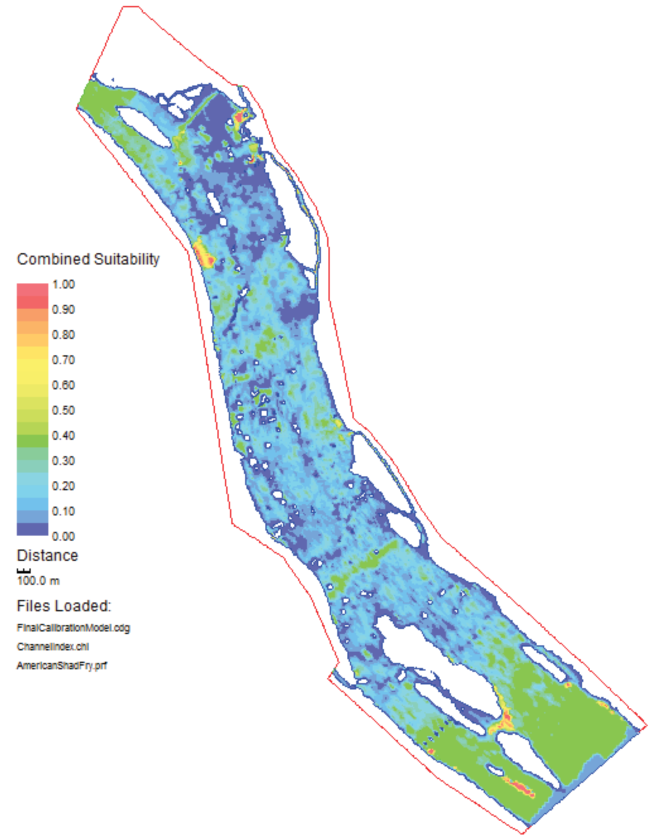
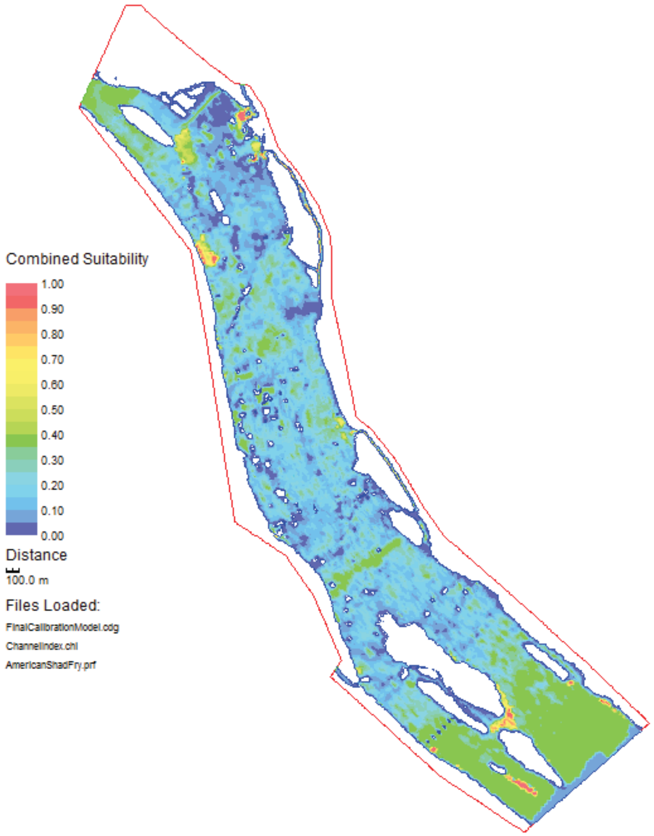
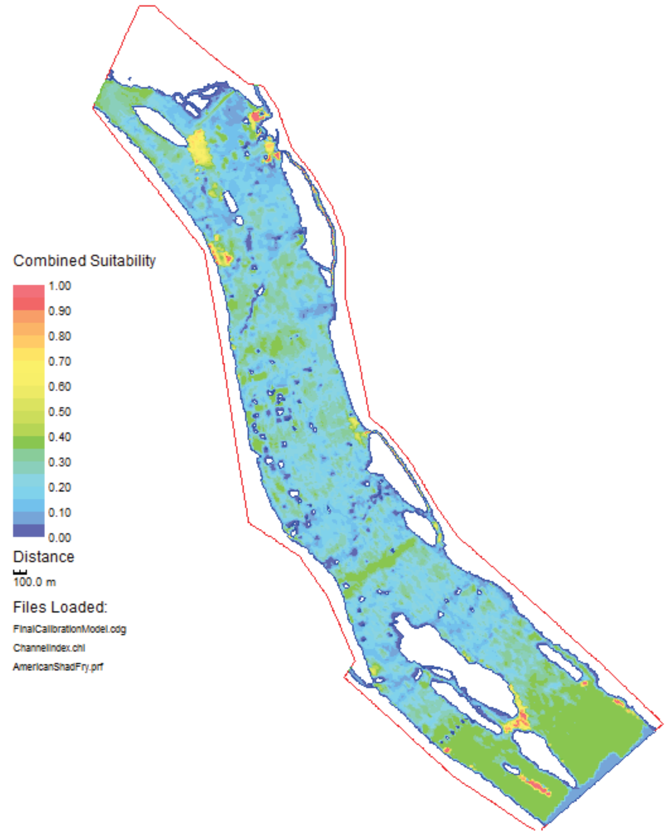


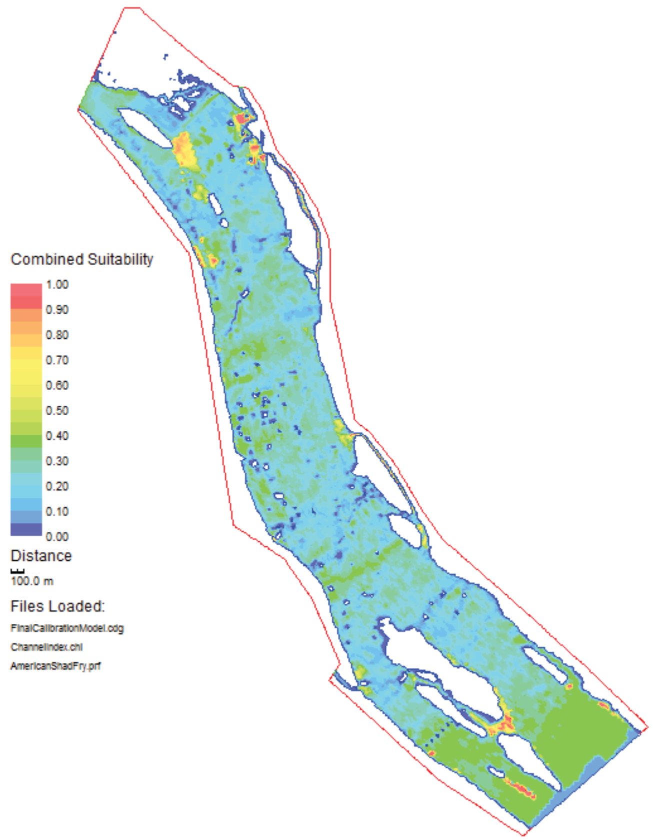
American Shad Fry – 7,500 cfs



American Shad Fry – 10,000 cfs



American Shad Fry - 15,000 cfs



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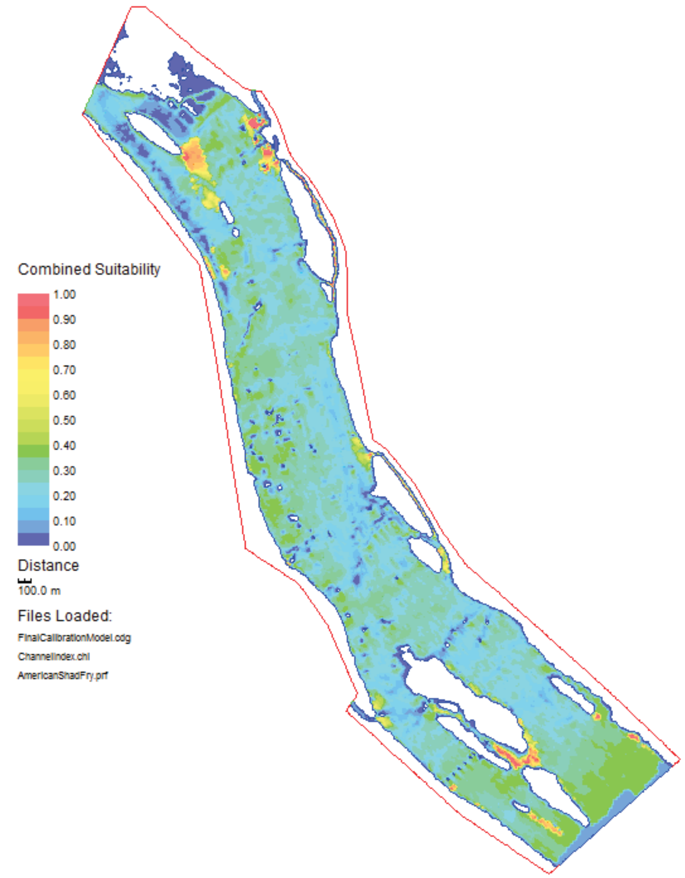
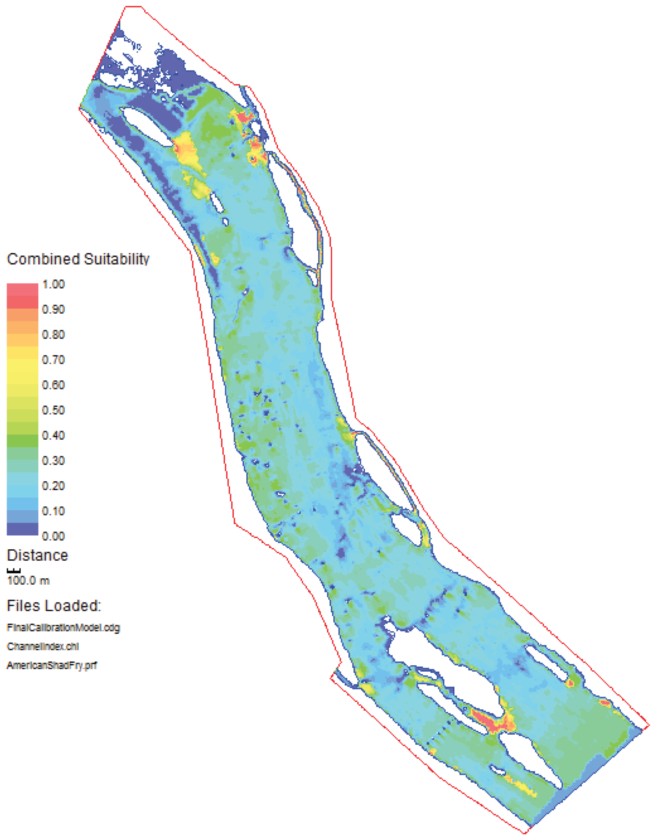
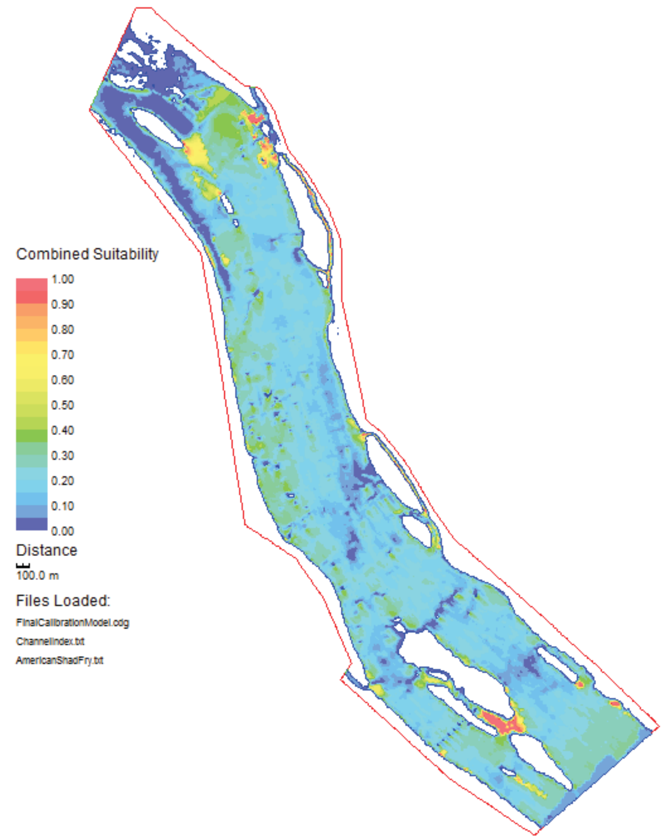


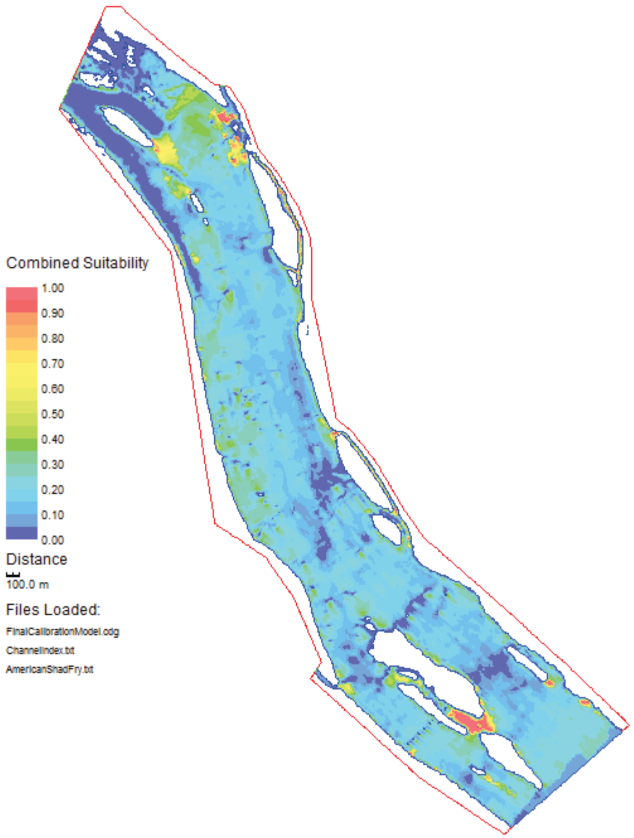
American Shad Fry – 30,000 cfs



American Shad Fry – 40,000 cfs



American Shad Fry – 50,000 cfs



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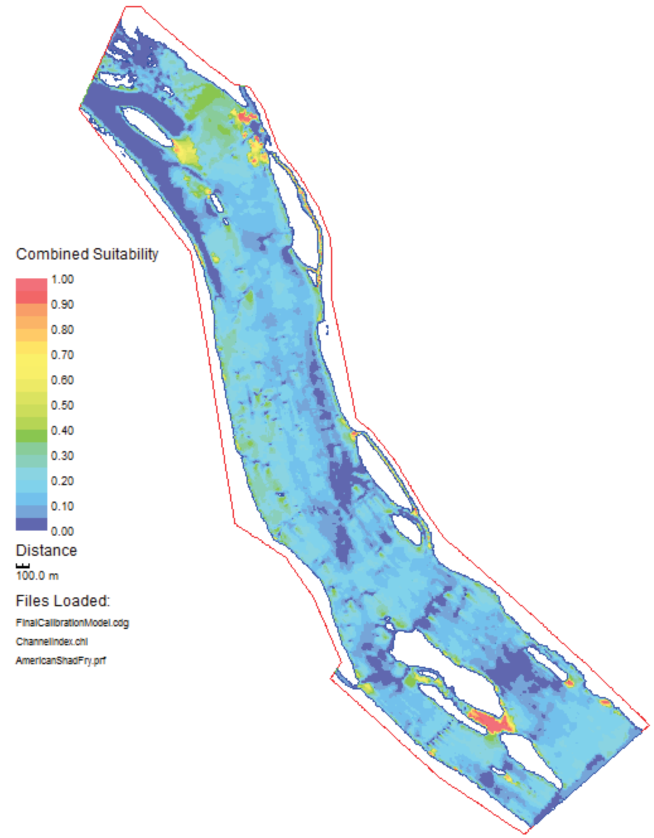
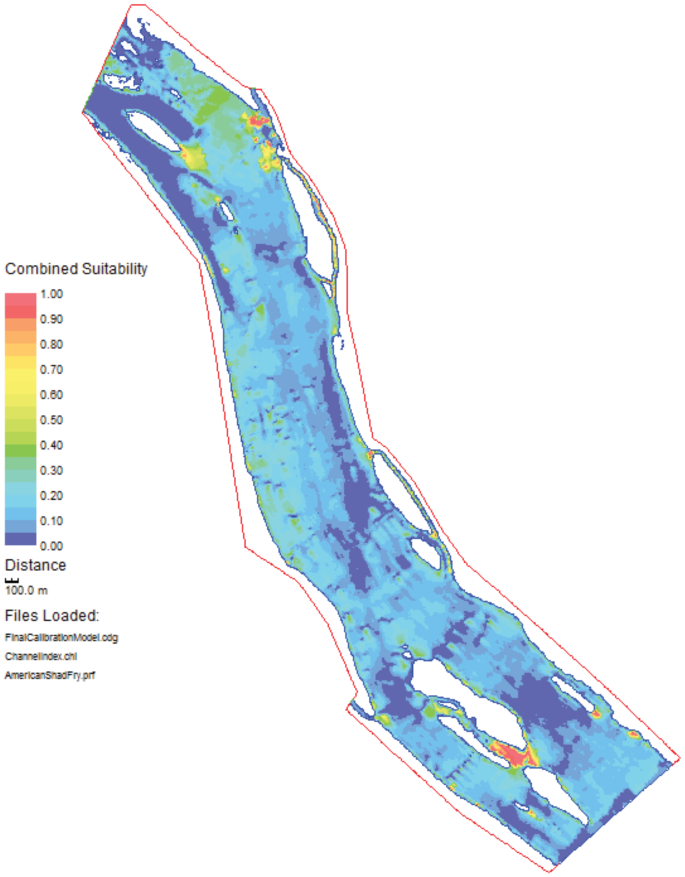
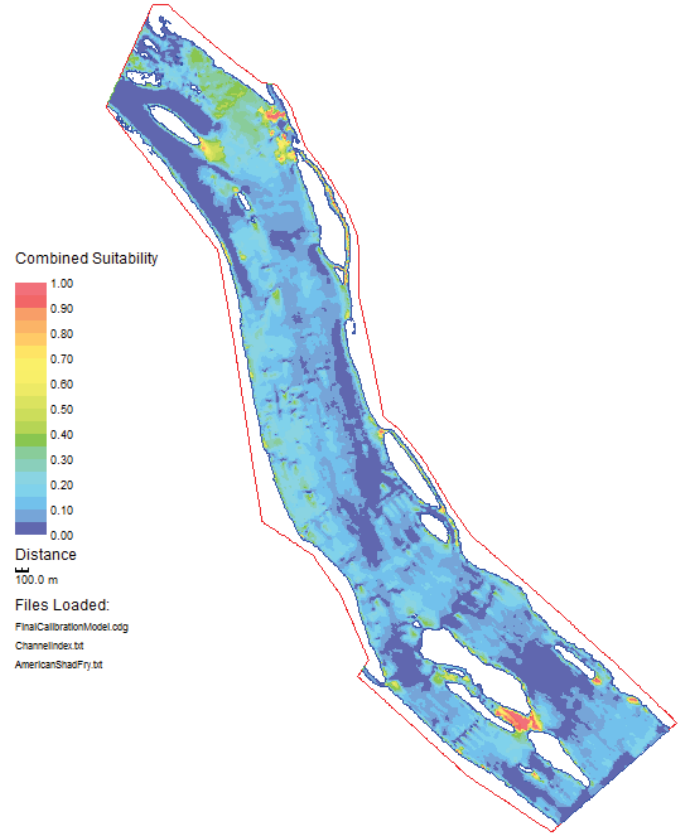


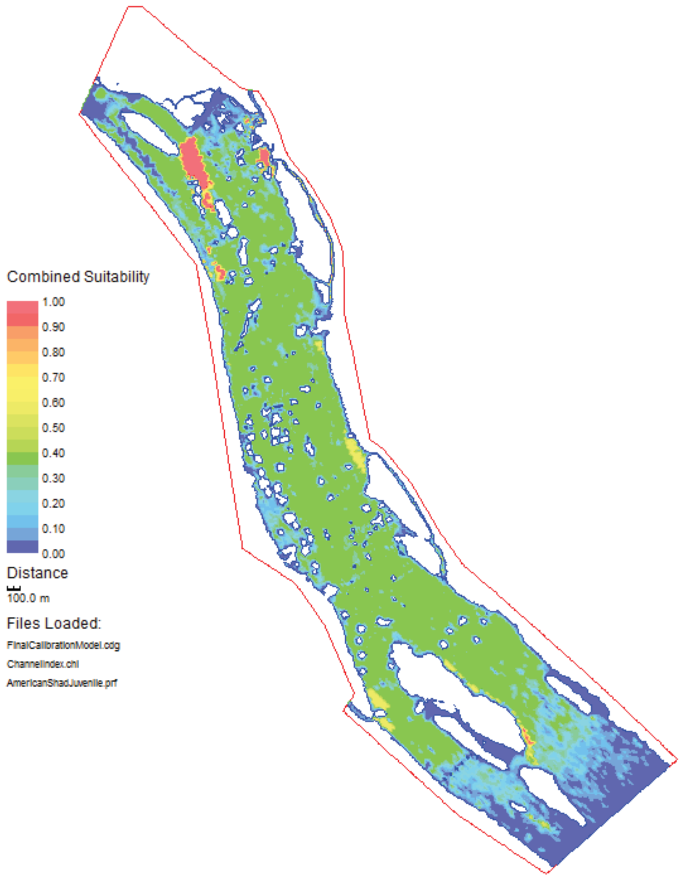
American Shad Fry – 70,000 cfs



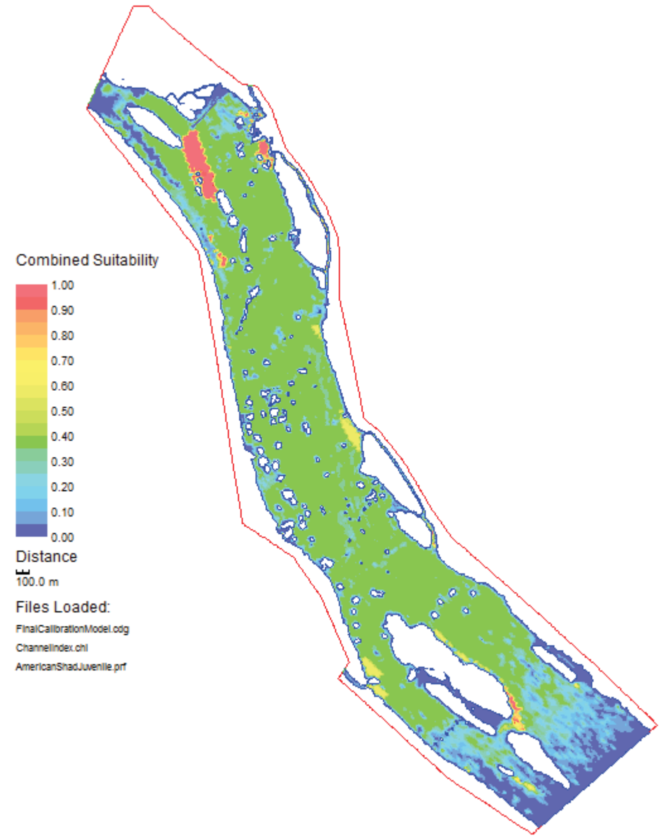
American Shad Fry – 80,000 cfs



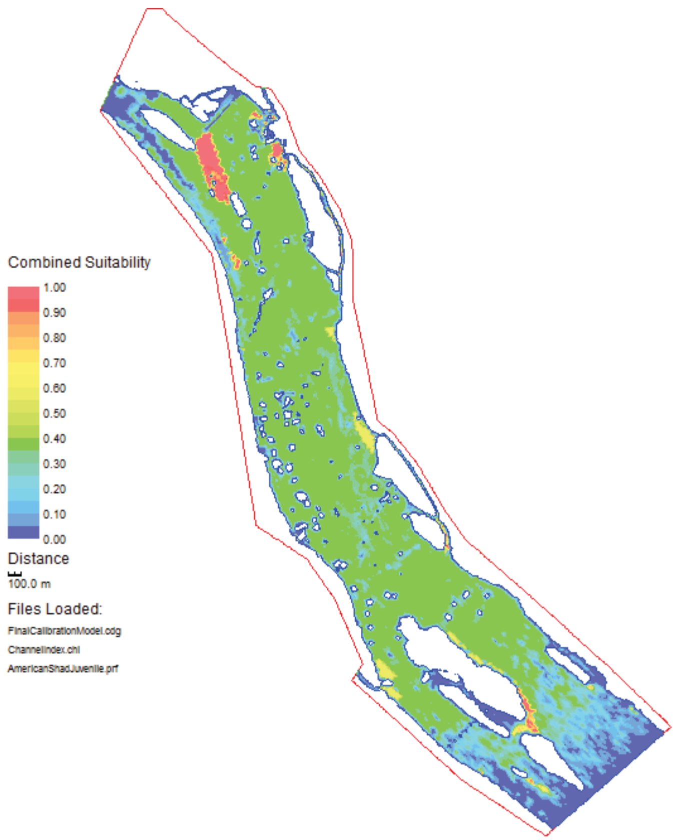
American Shad Fry – 86,000 cfs



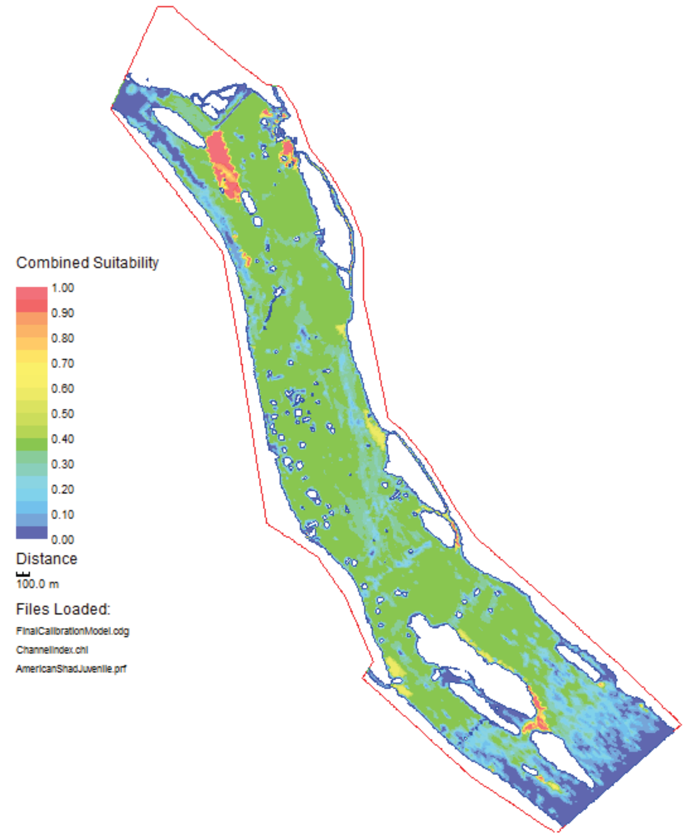
American Shad Juvenile – 2,000 cfs



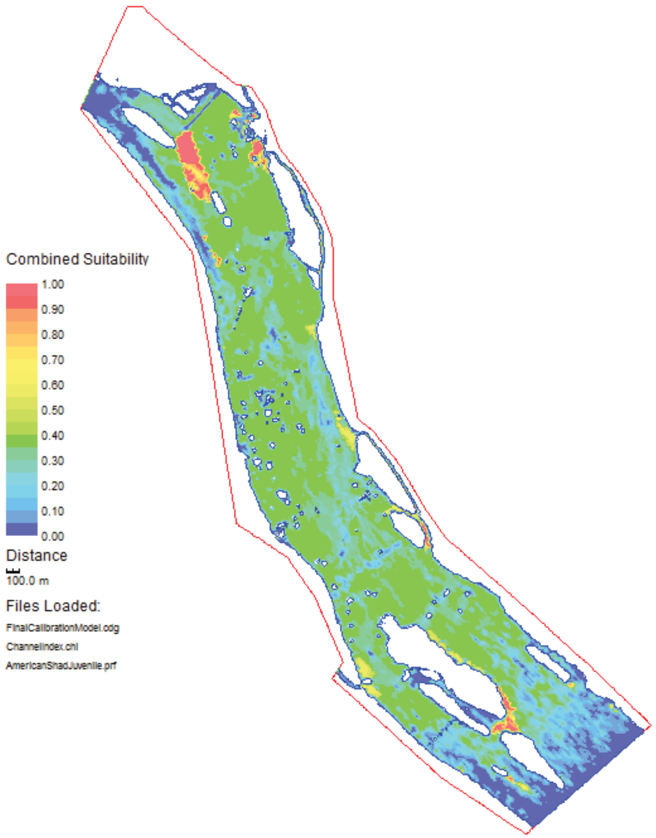
American Shad Juvenile – 3,500 cfs



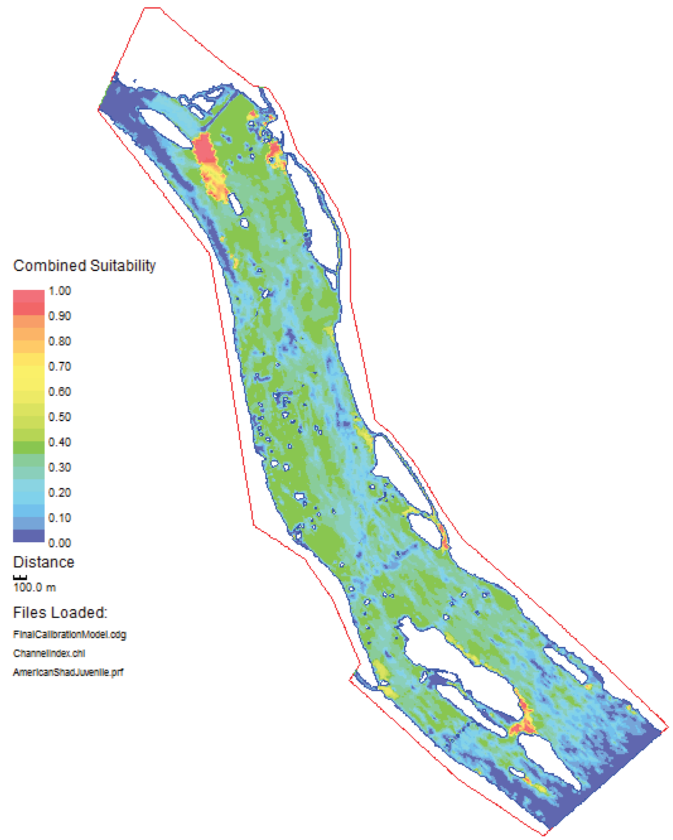
American Shad Juvenile – 5,000 cfs



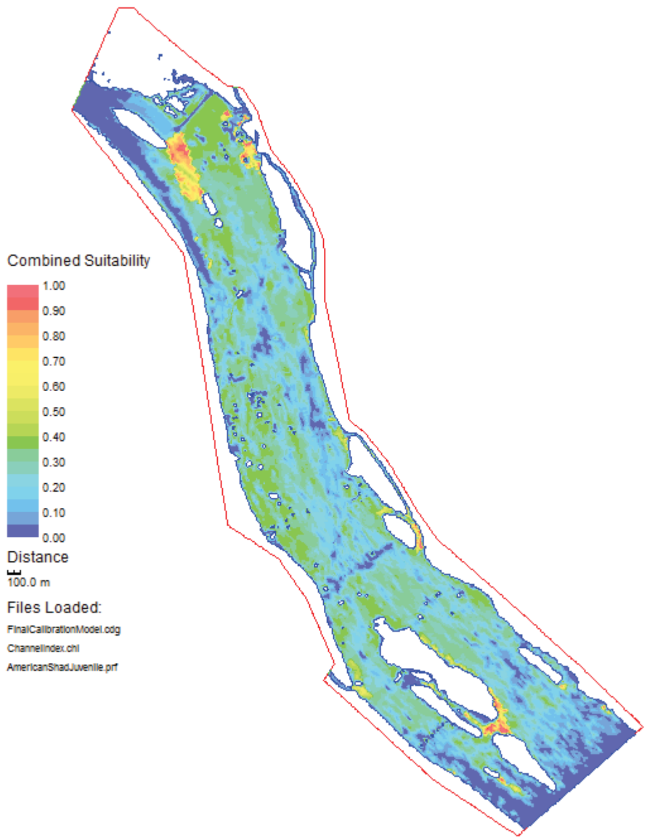
American Shad Juvenile – 7,500 cfs



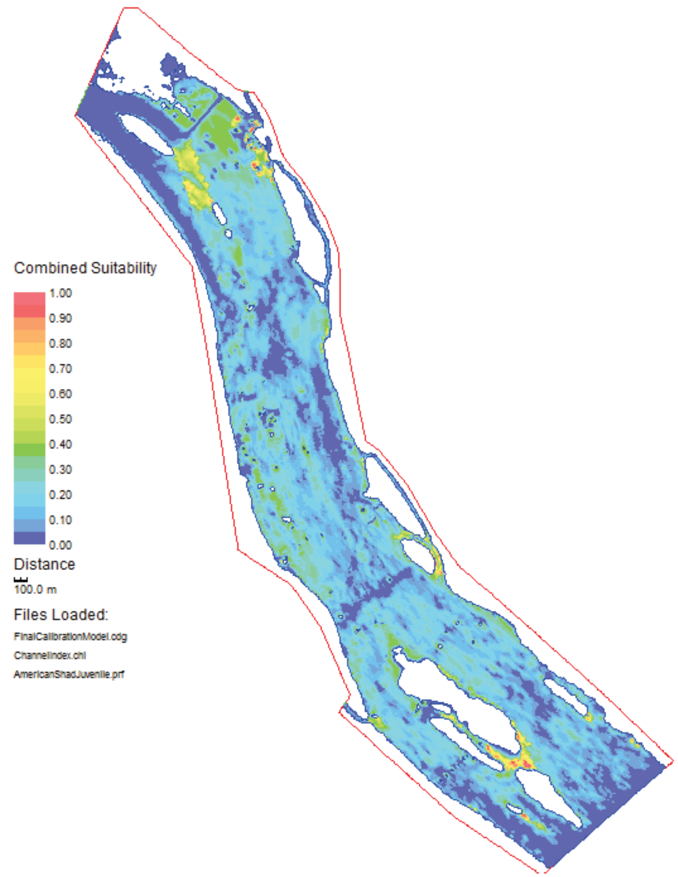
American Shad Juvenile – 10,000 cfs



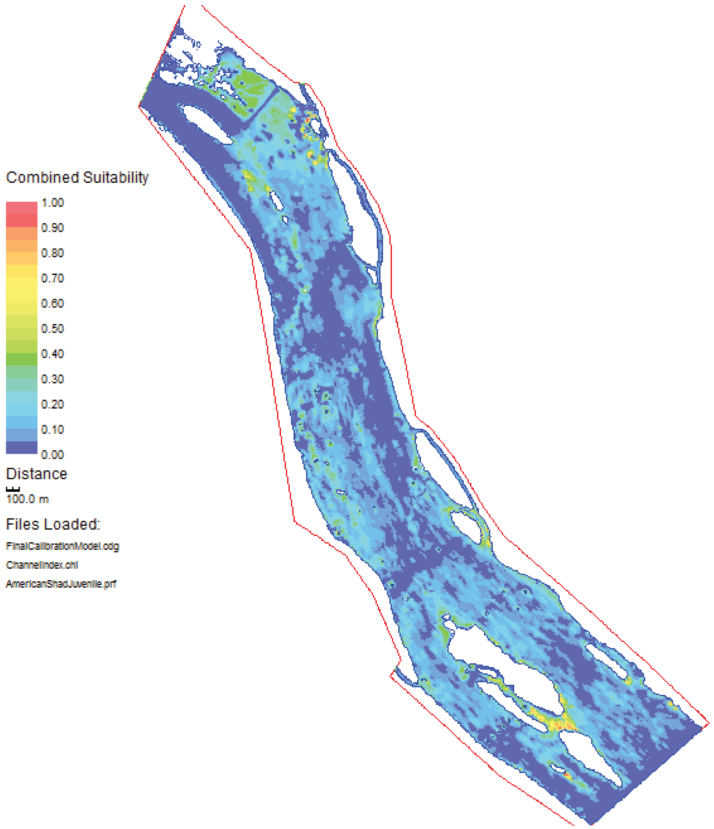
American Shad Juvenile – 15,000 cfs



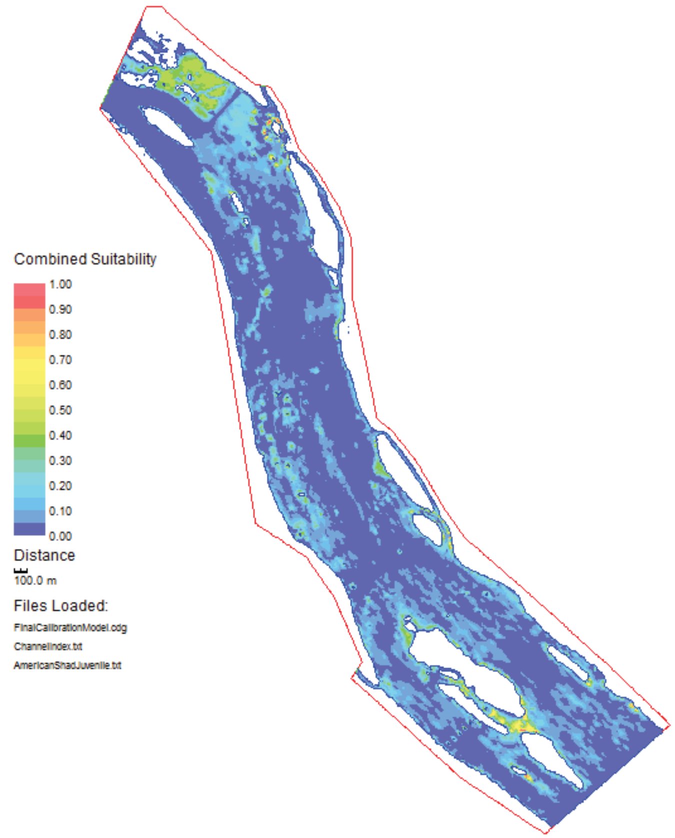
American Shad Juvenile – 20,000 cfs



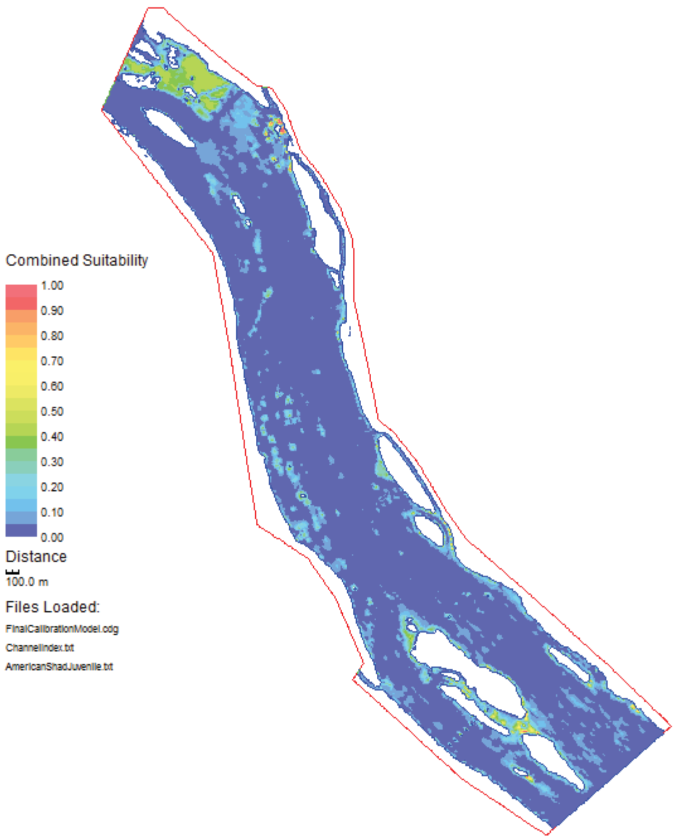
American Shad Juvenile – 30,000 cfs



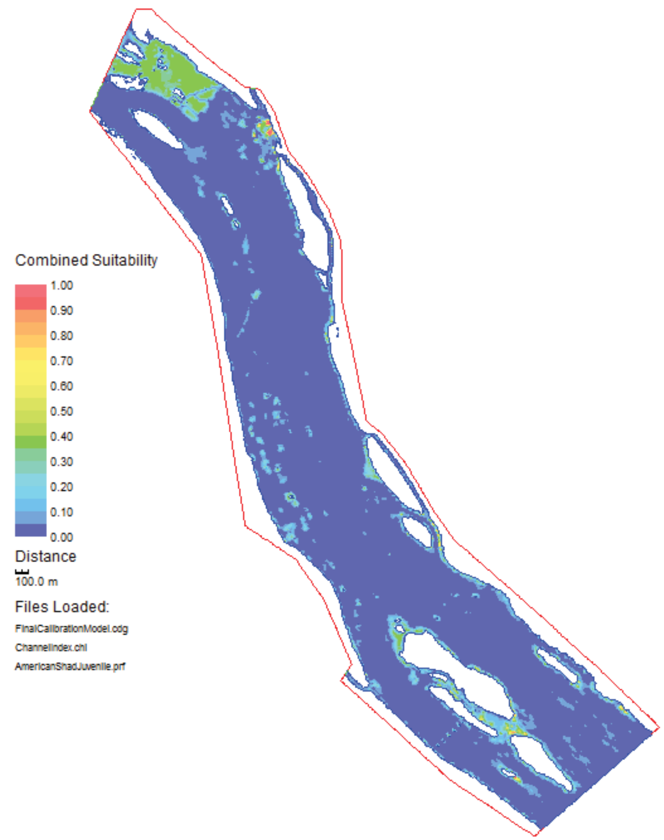
American Shad Juvenile – 40,000 cfs



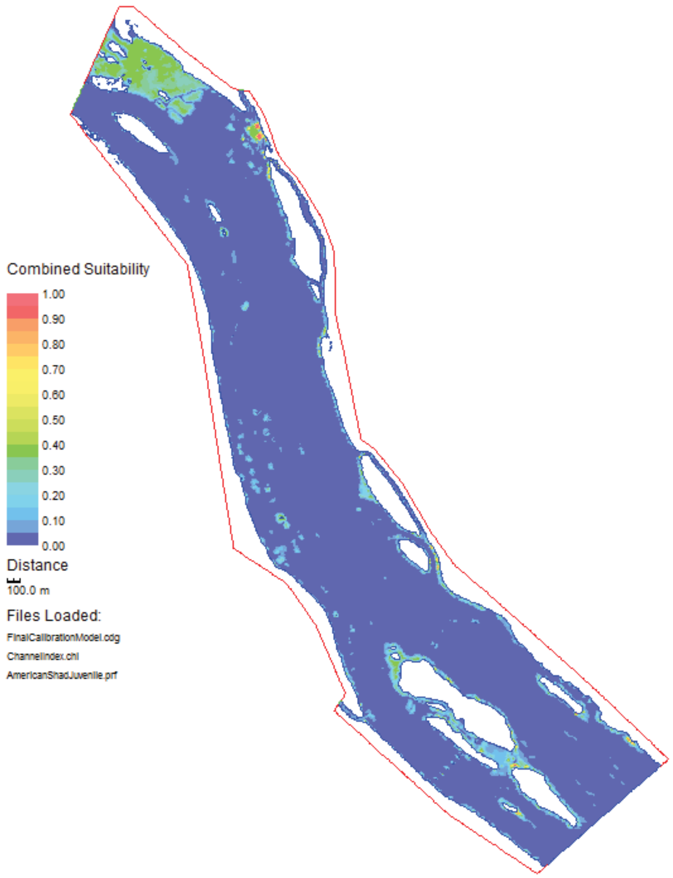
American Shad Juvenile – 50,000 cfs



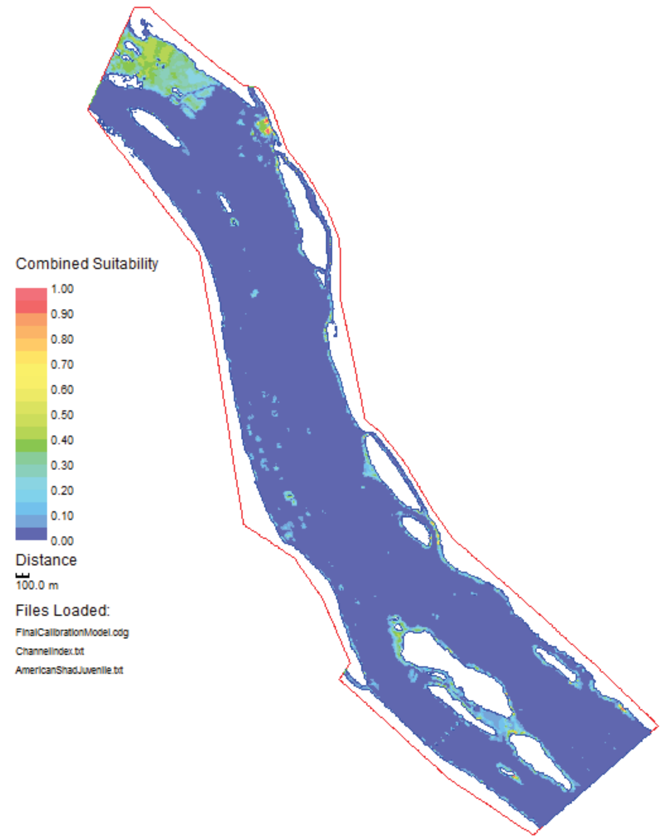
American Shad Juvenile – 60,000 cfs



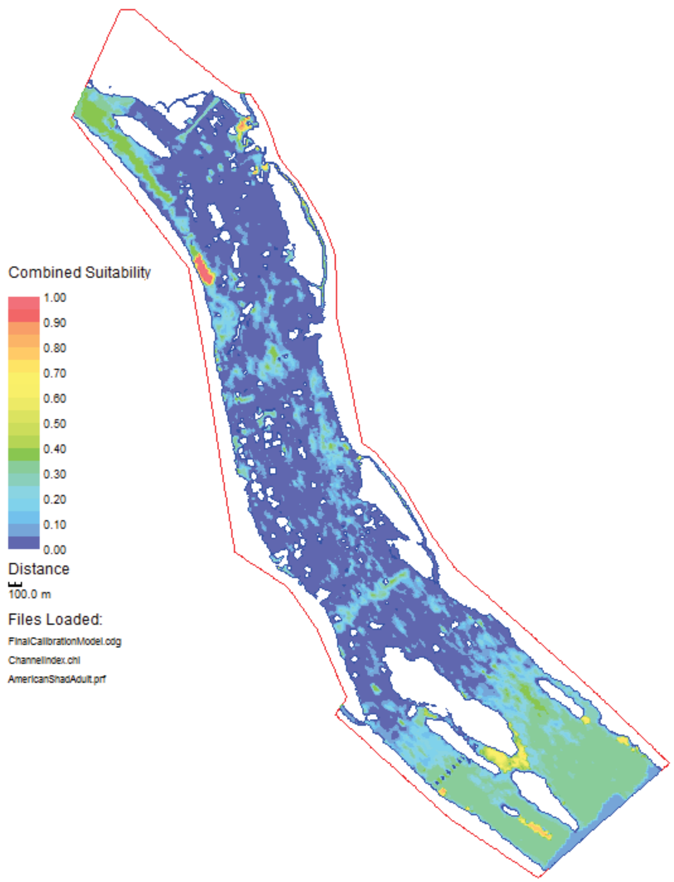
American Shad Juvenile – 70,000 cfs



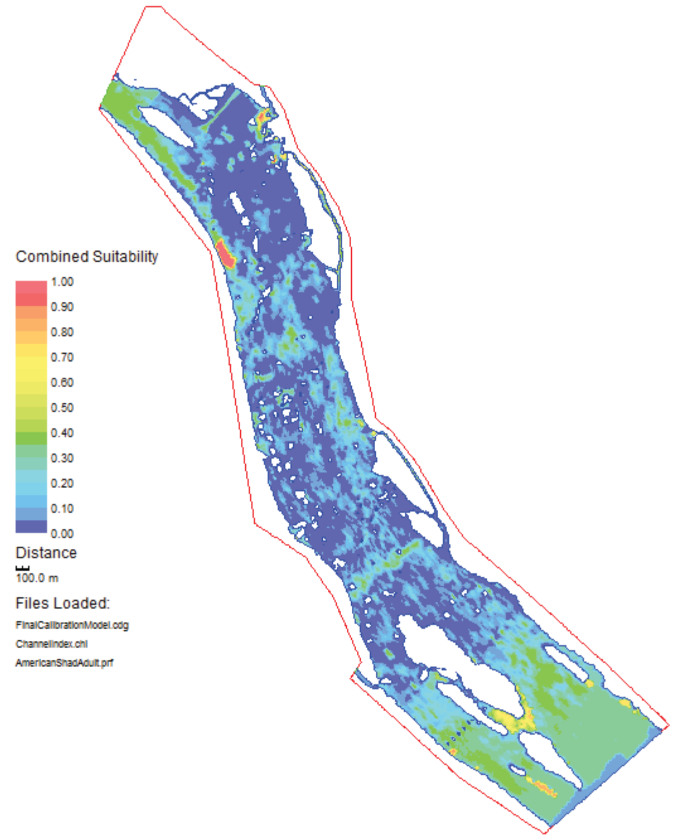
American Shad Juvenile – 80,000 cfs



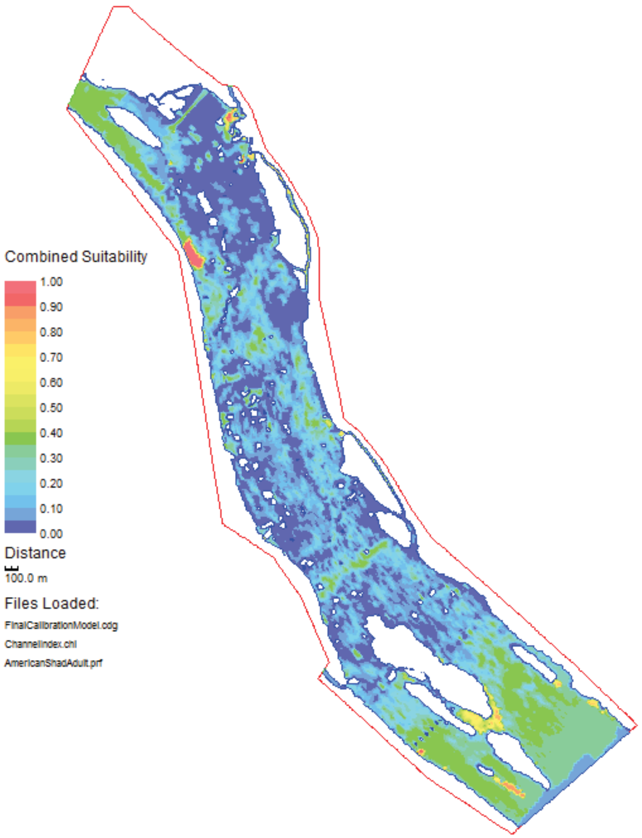
American Shad Juvenile – 86,000 cfs



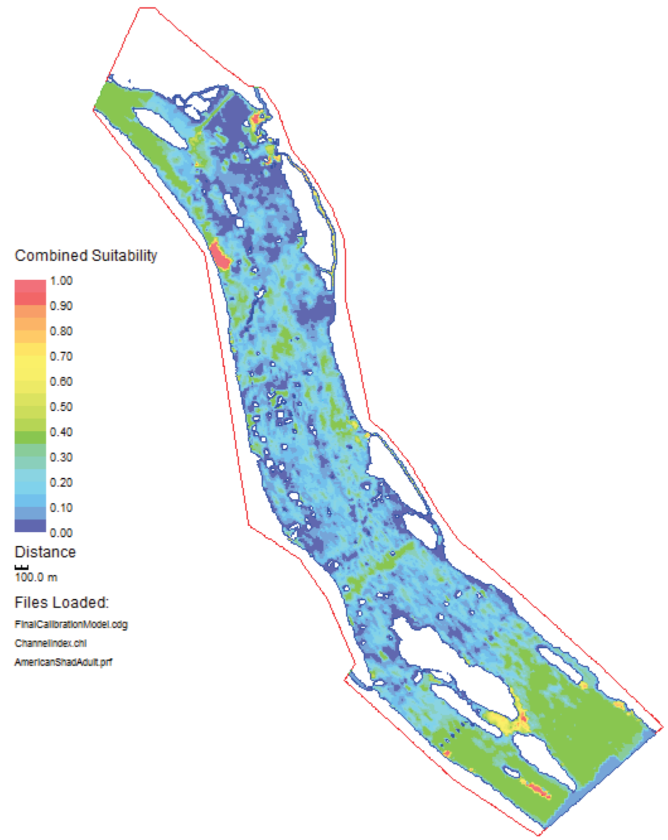
American Shad Adult – 2,000 cfs



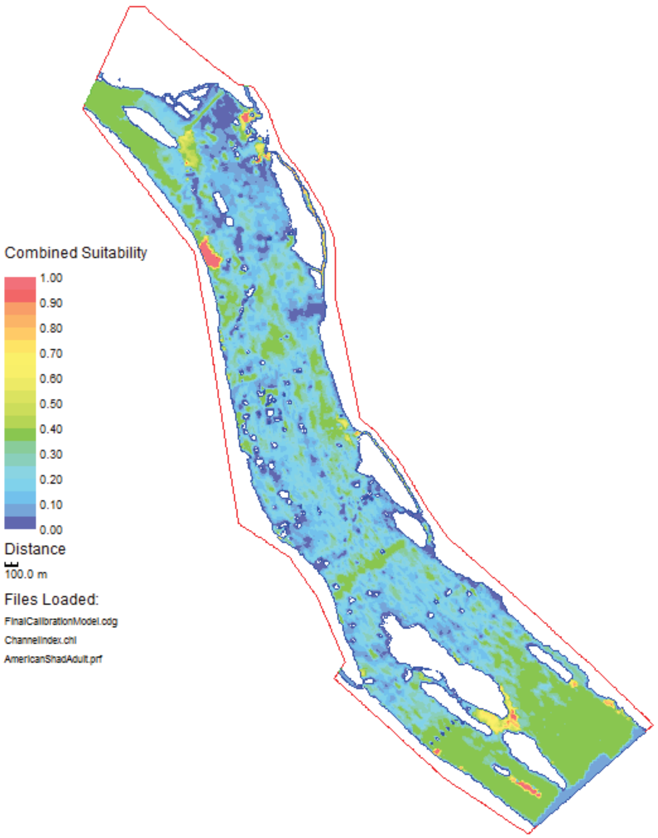
American Shad Adult – 3,500 cfs



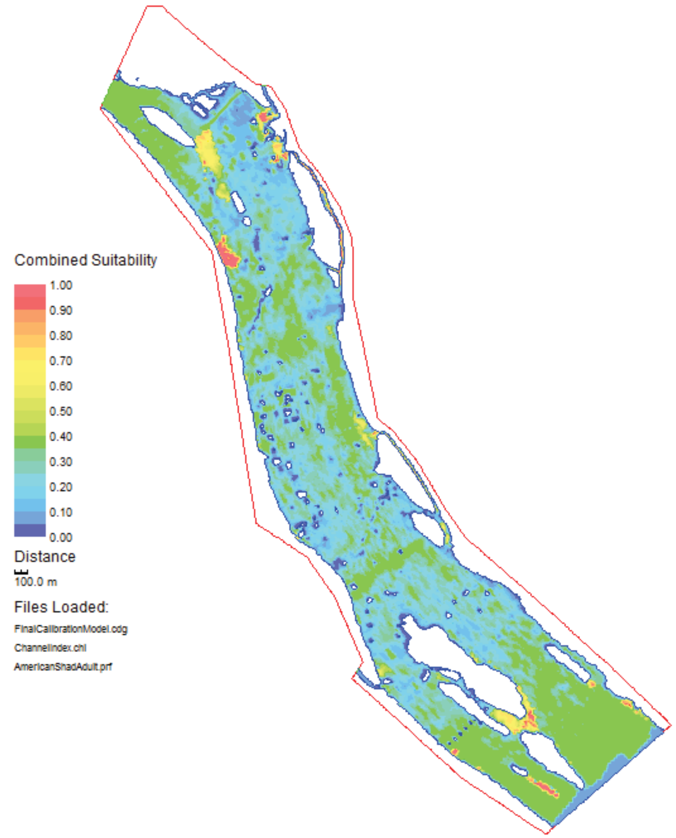
American Shad Adult – 5,000 cfs



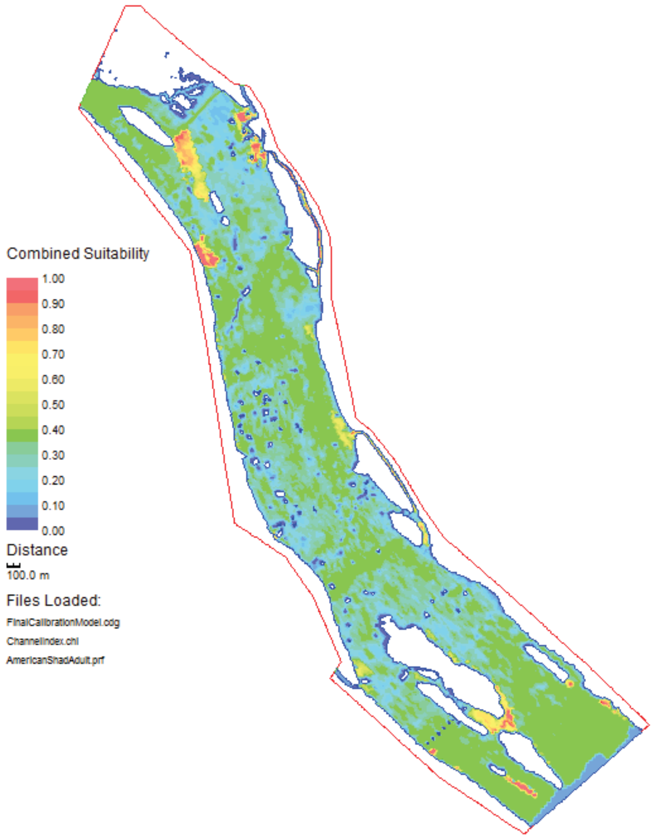
American Shad Adult – 7,500 cfs



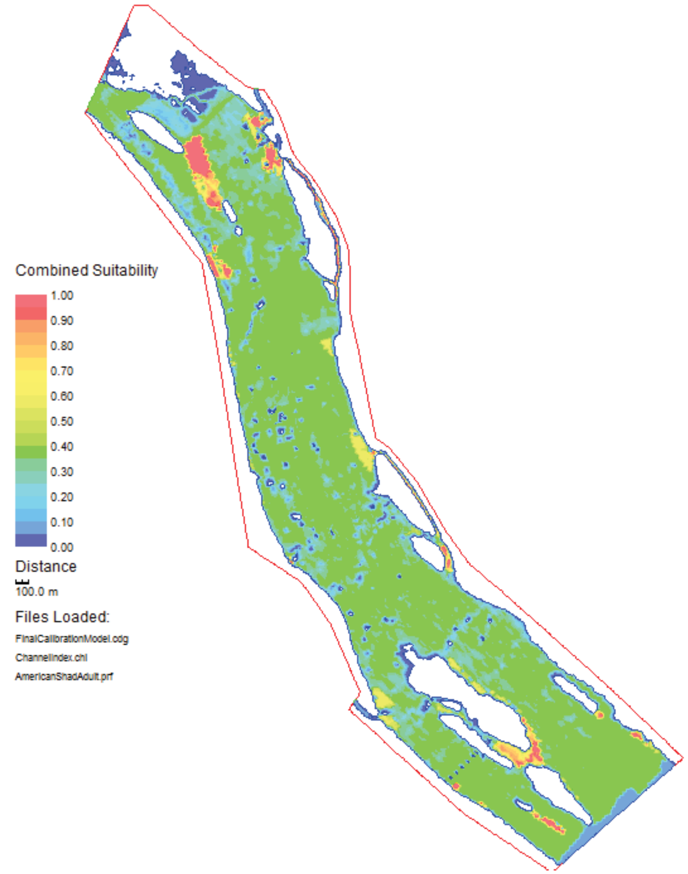
American Shad Adult – 10,000 cfs



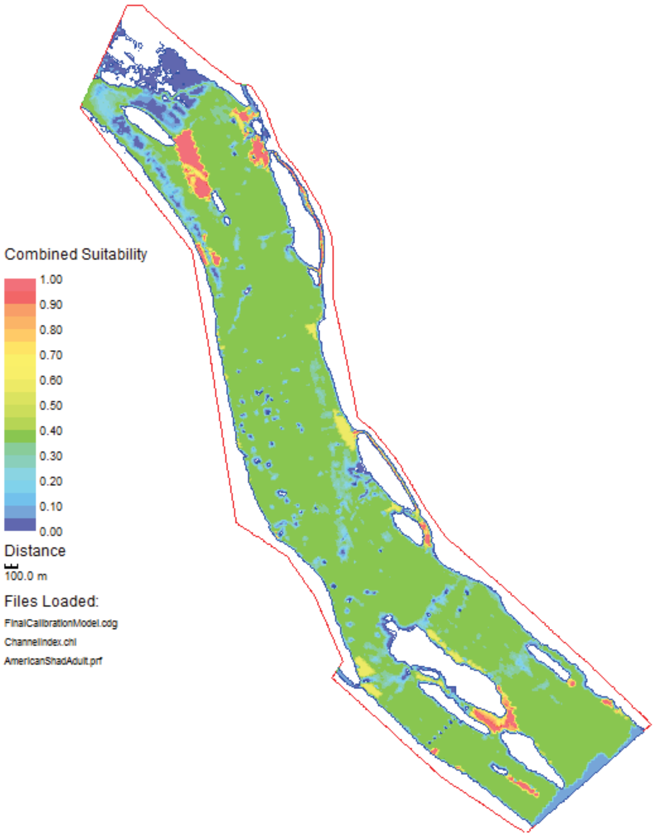
American Shad Adult – 15,000 cfs



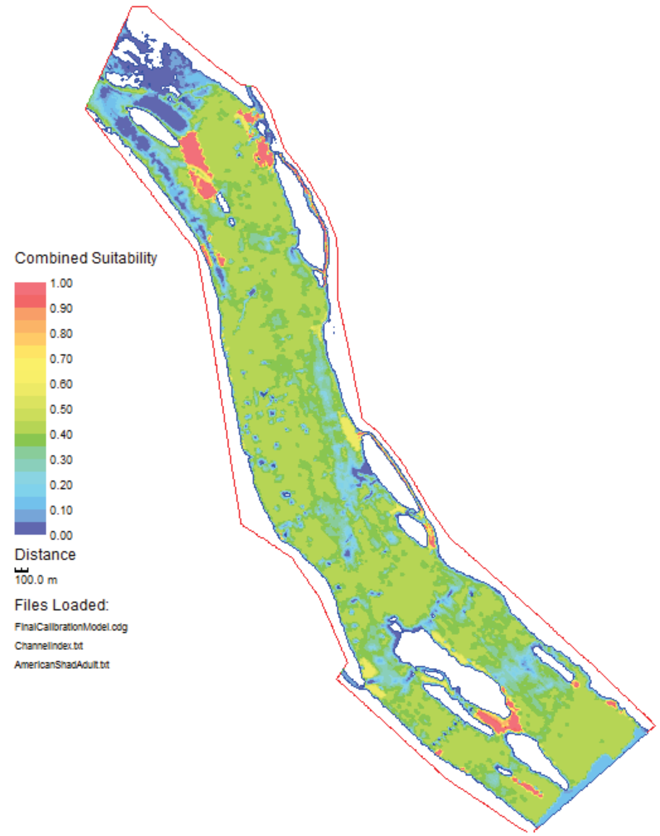
American Shad Adult – 20,000 cfs



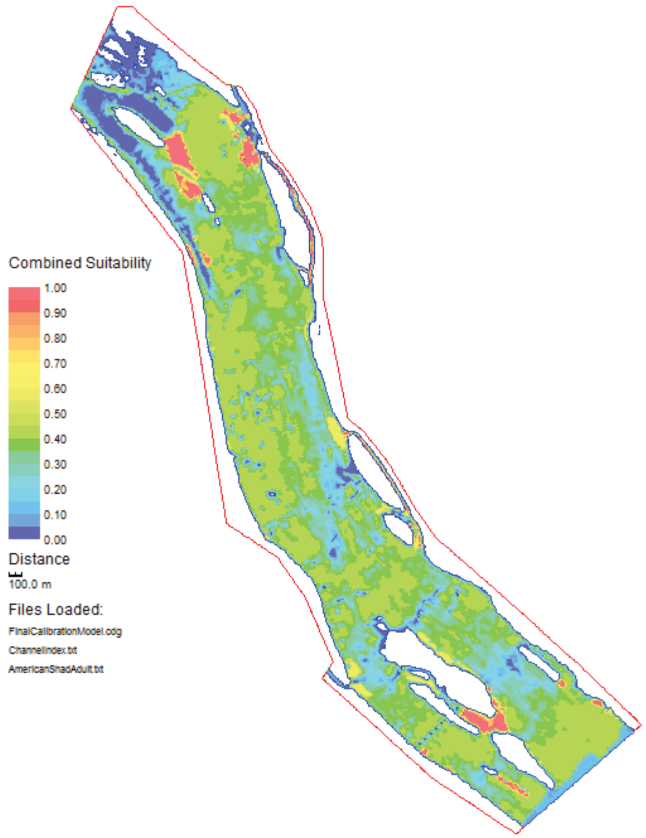
American Shad Adult – 30,000 cfs



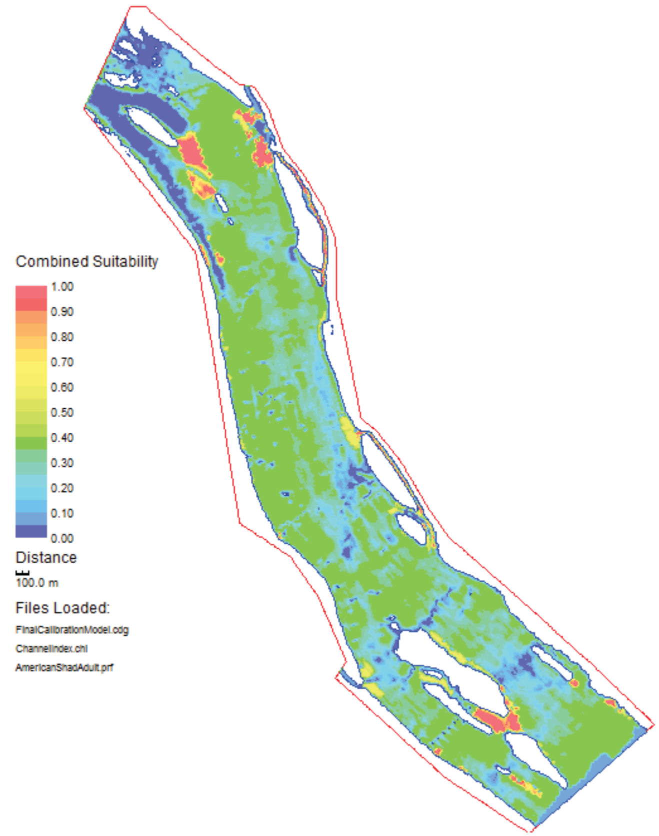
American Shad Adult – 40,000 cfs



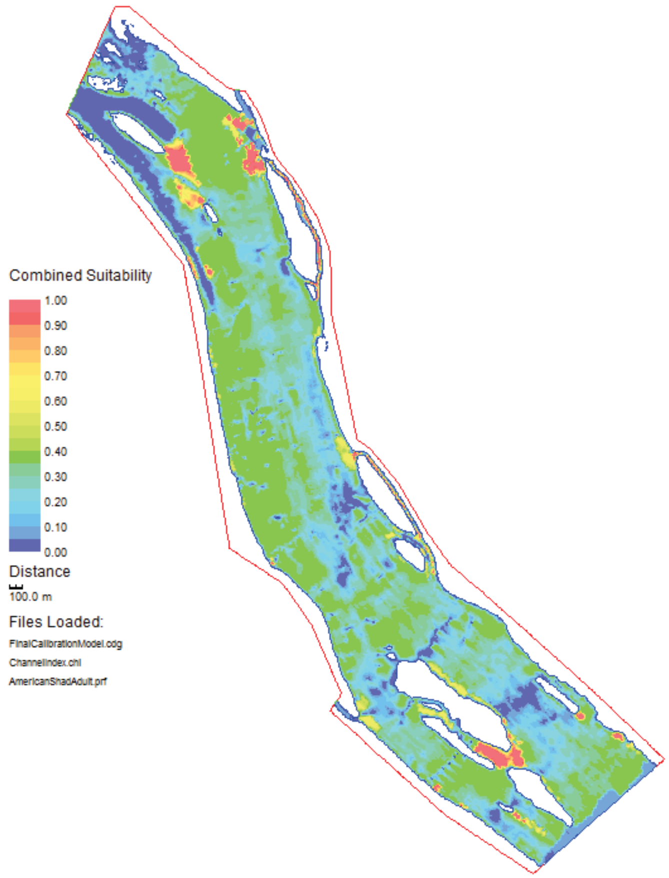
American Shad Adult – 50,000 cfs



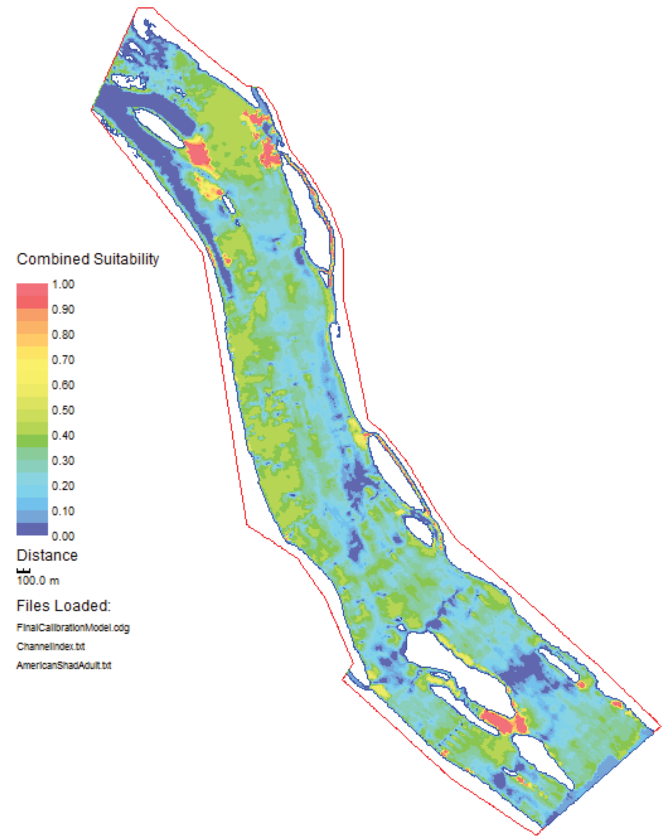
American Shad Adult – 60,000 cfs



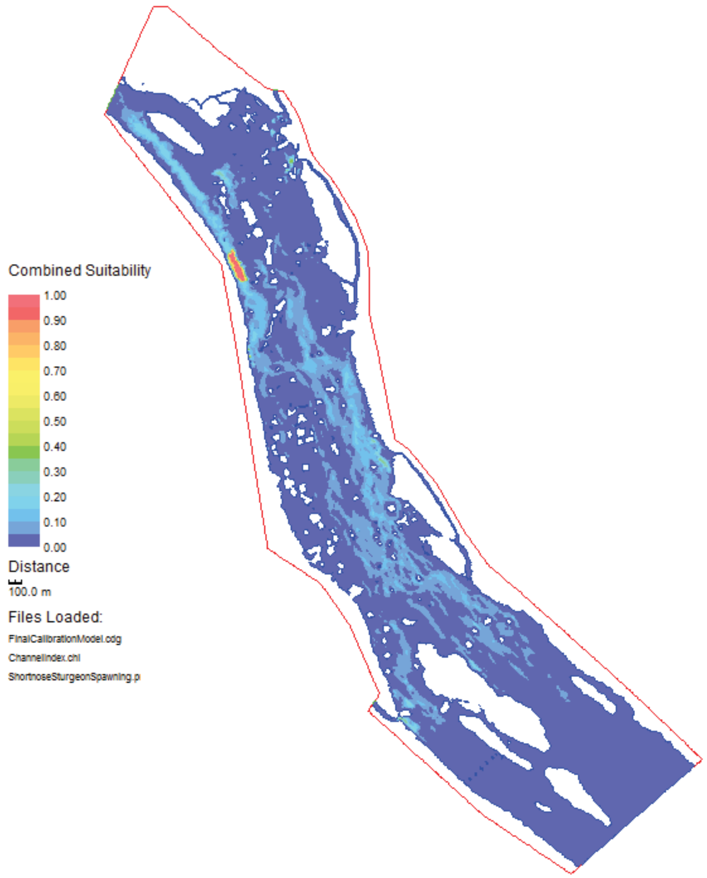
American Shad Adult – 70,000 cfs



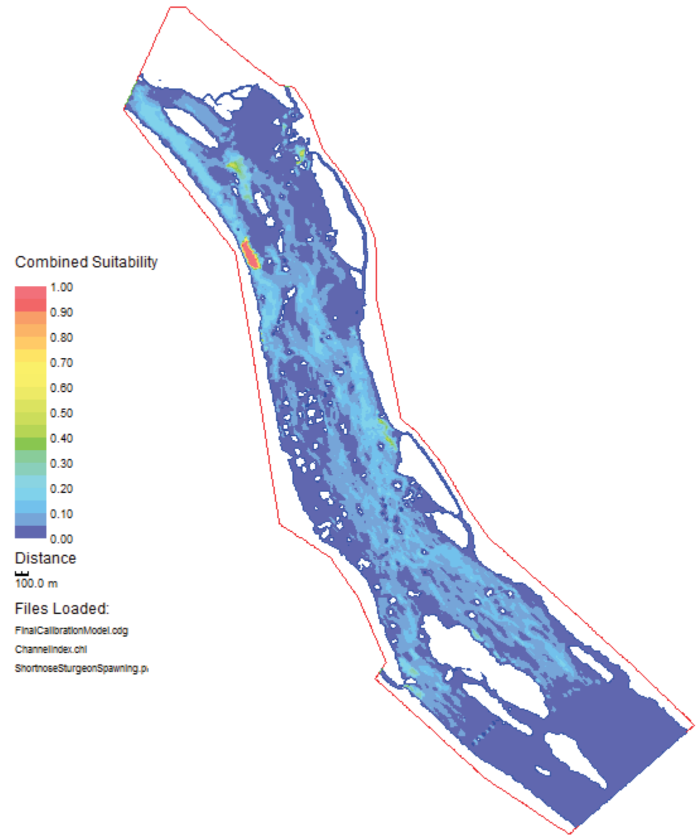
American Shad Adult – 80,000 cfs



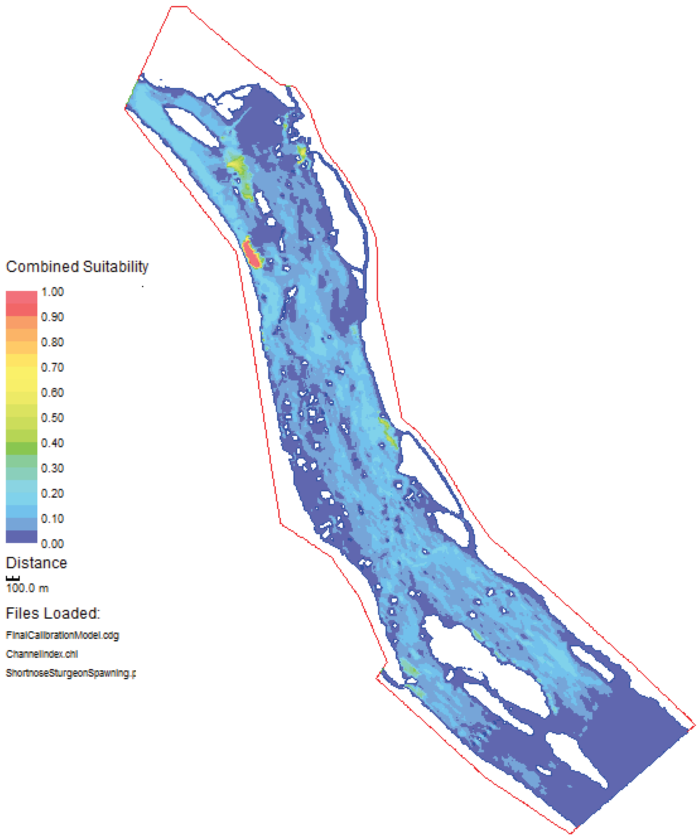
American Shad Adult – 86,000 cfs



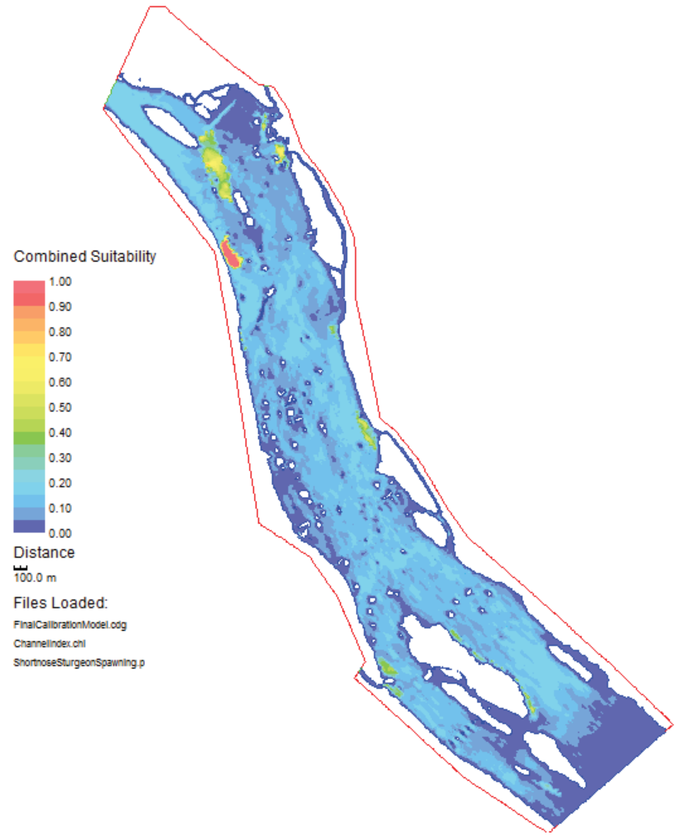
Shortnose Sturgeon Spawning – 2,000 cfs



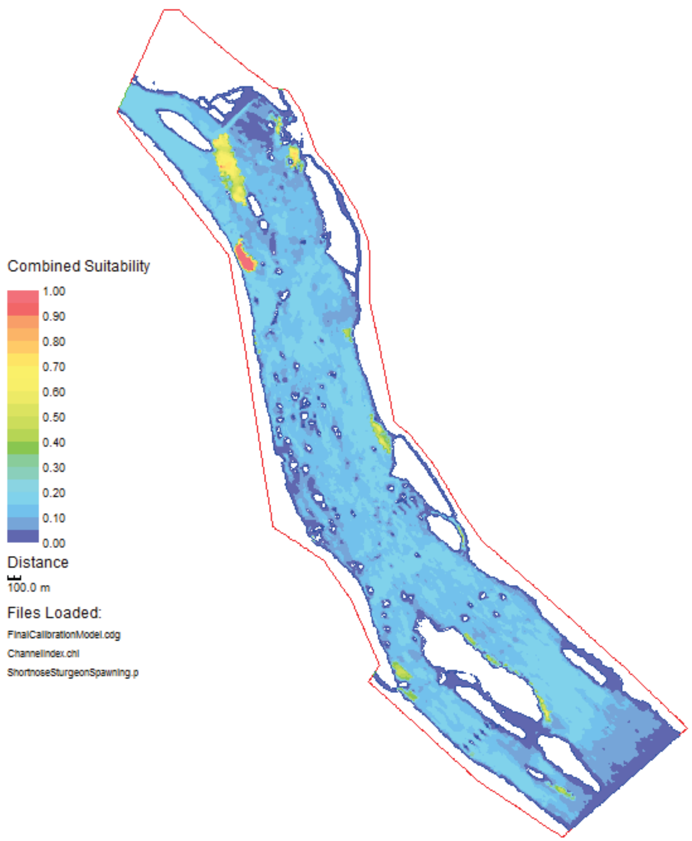
Shortnose Sturgeon Spawning – 3,500 cfs



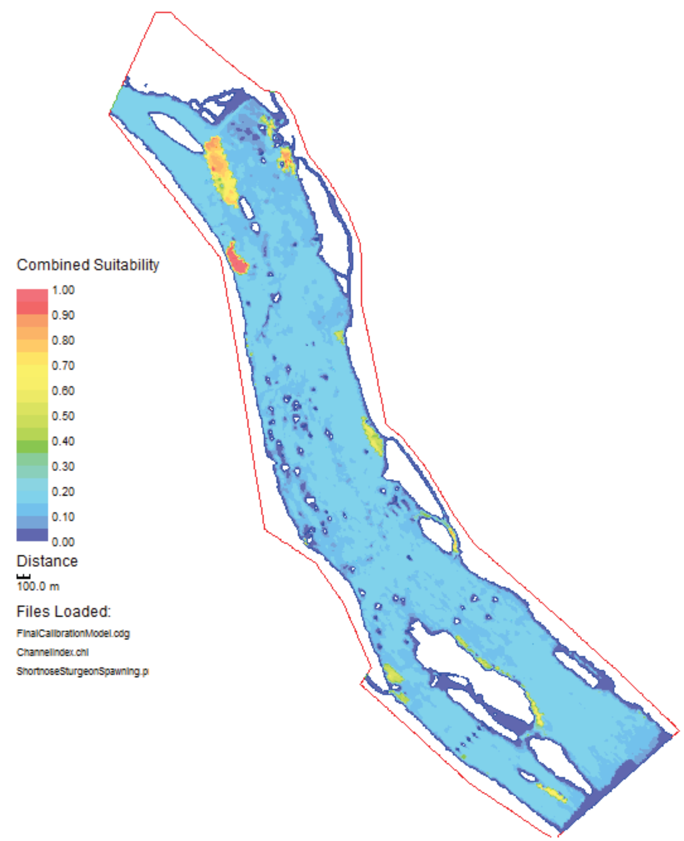
Shortnose Sturgeon Spawning – 5,000 cfs



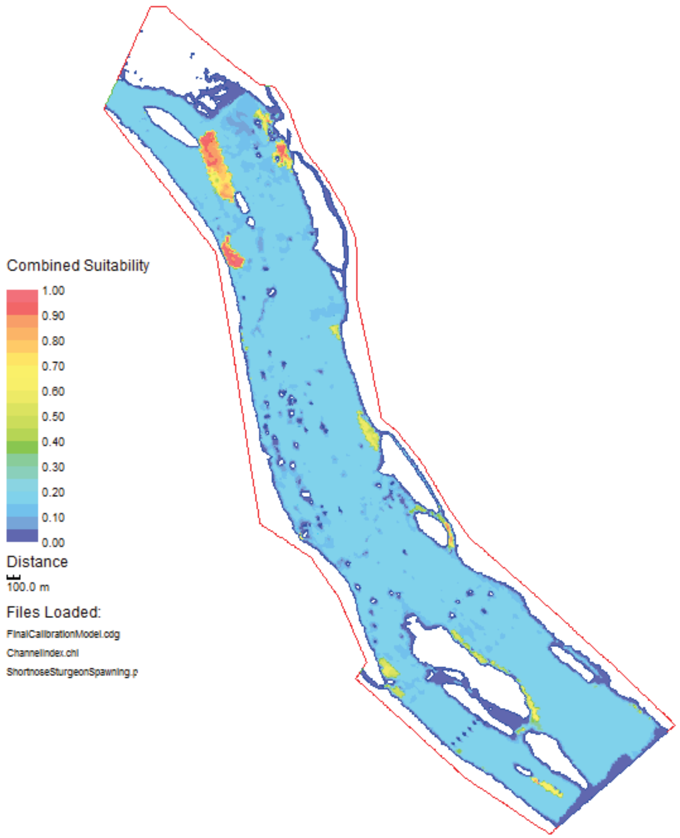
Shortnose Sturgeon Spawning – 7,500 cfs



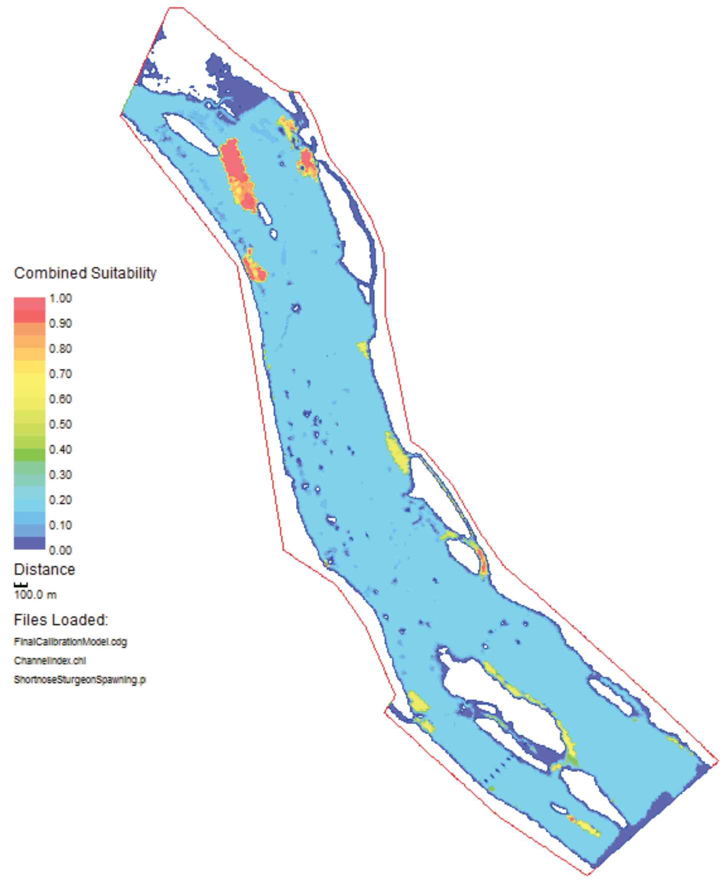
Shortnose Sturgeon Spawning – 10,000 cfs



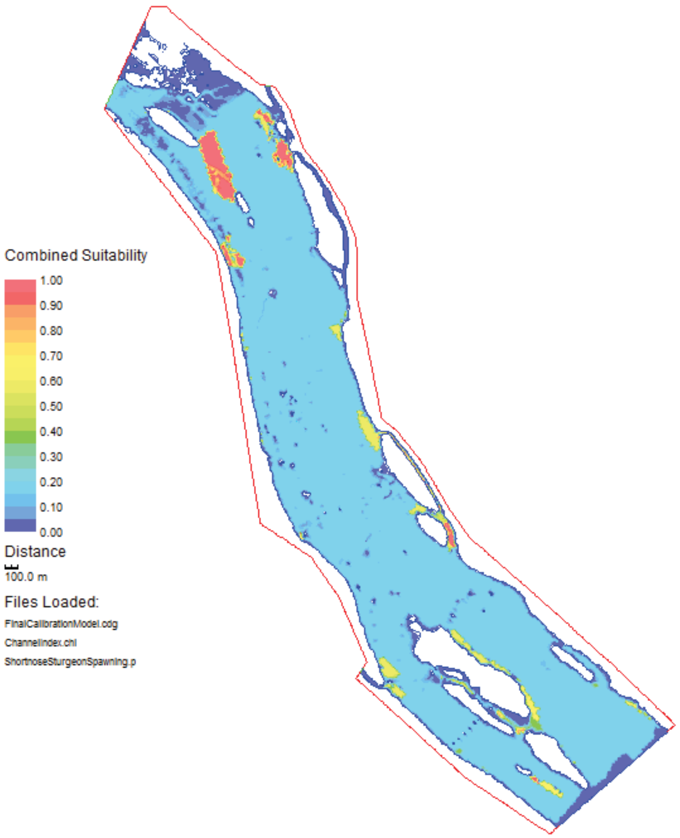
Shortnose Sturgeon Spawning – 15,000 cfs



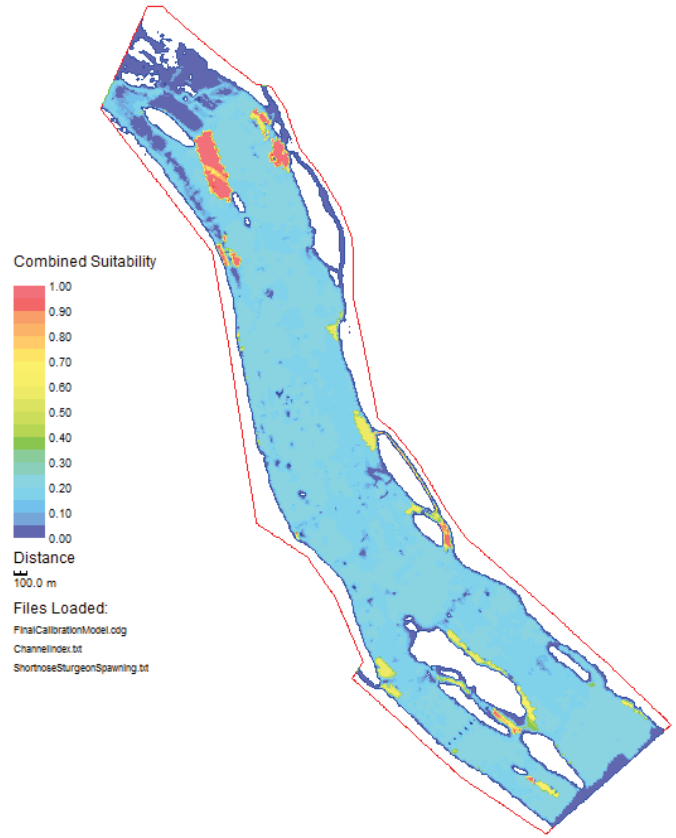
Shortnose Sturgeon Spawning – 20,000 cfs



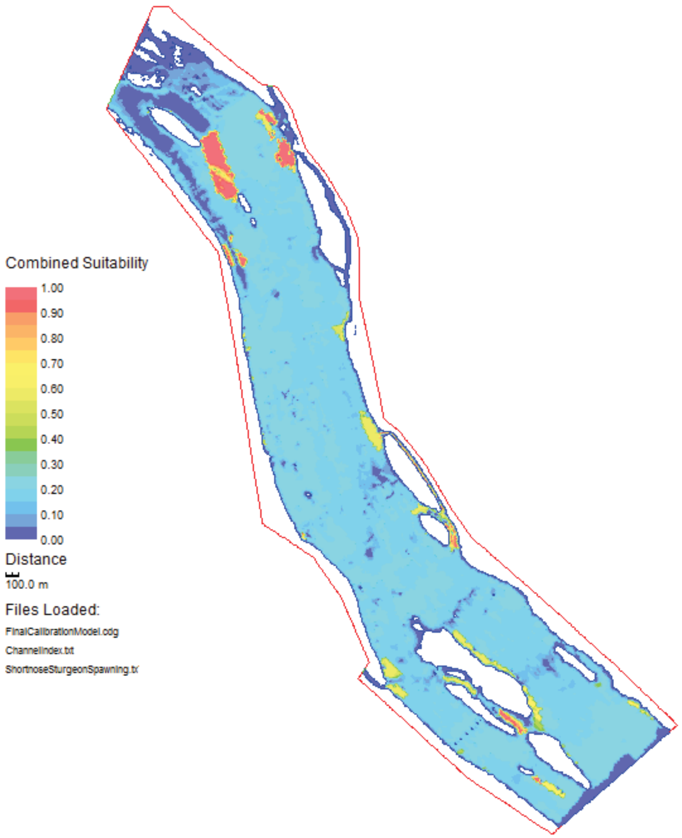
Shortnose Sturgeon Spawning – 30,000 cfs



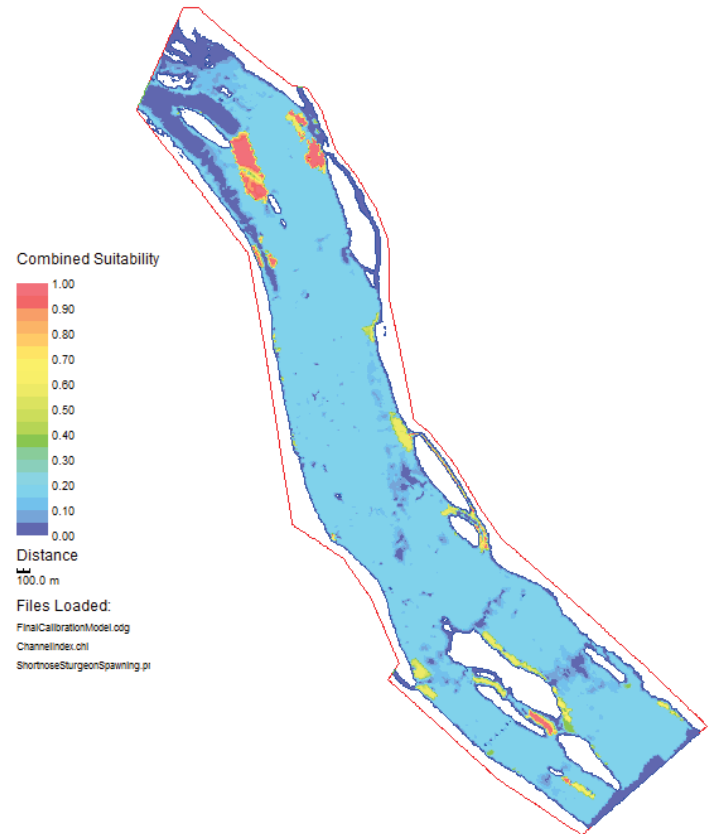
Shortnose Sturgeon Spawning – 40,000 cfs



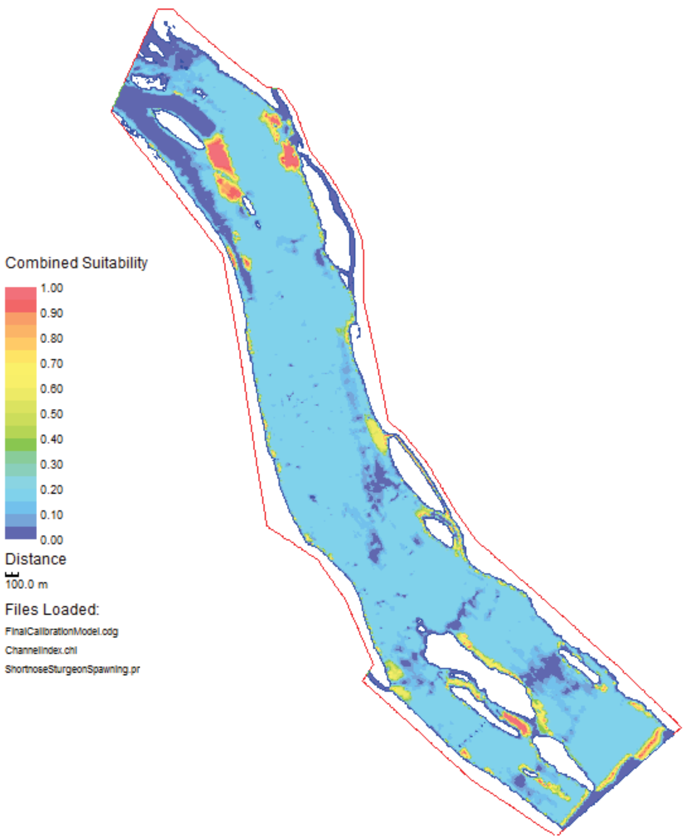
Shortnose Sturgeon Spawning – 50,000 cfs



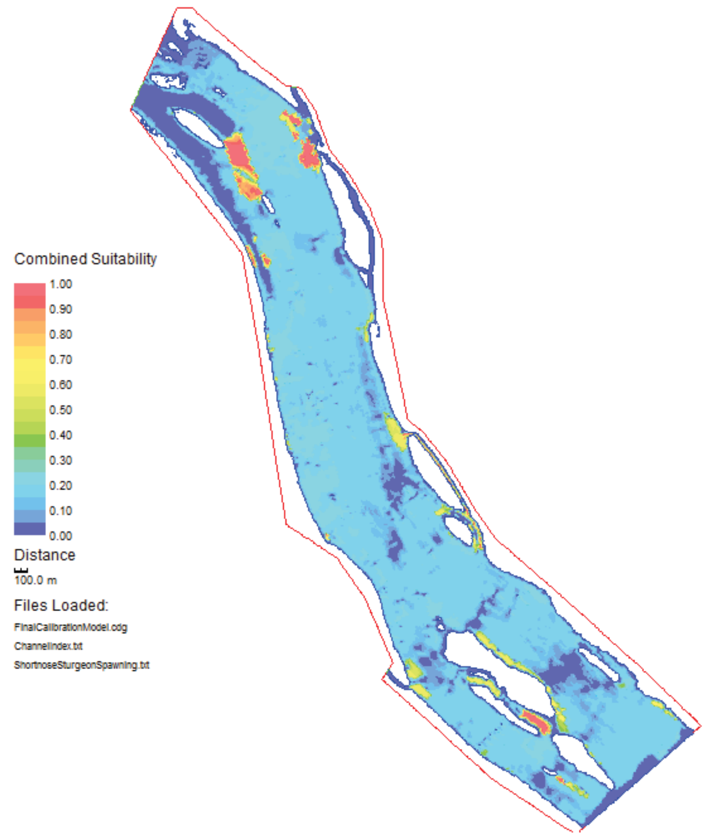
Shortnose Sturgeon Spawning – 60,000 cfs



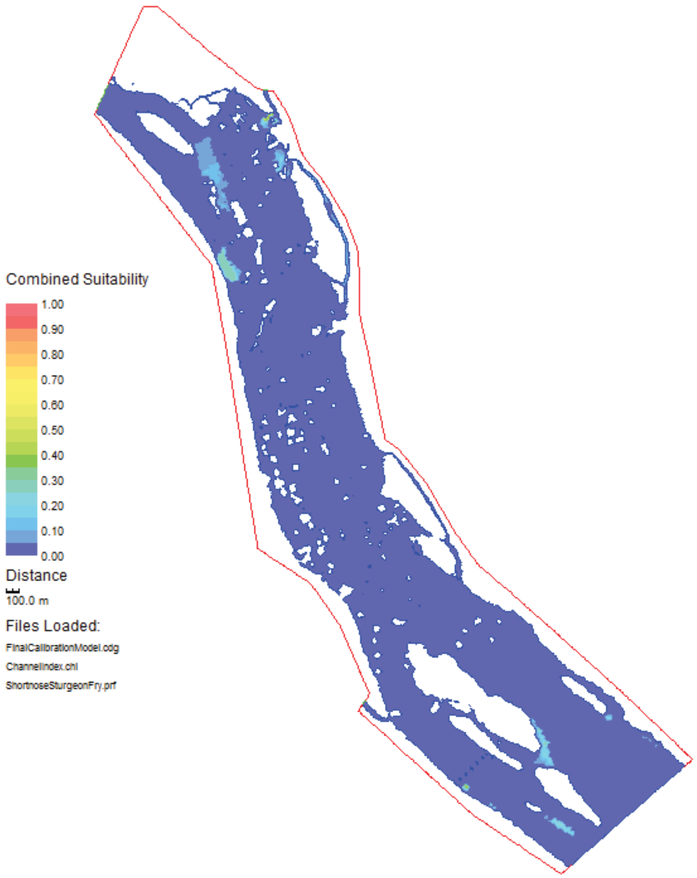
Shortnose Sturgeon Spawning – 70,000 cfs



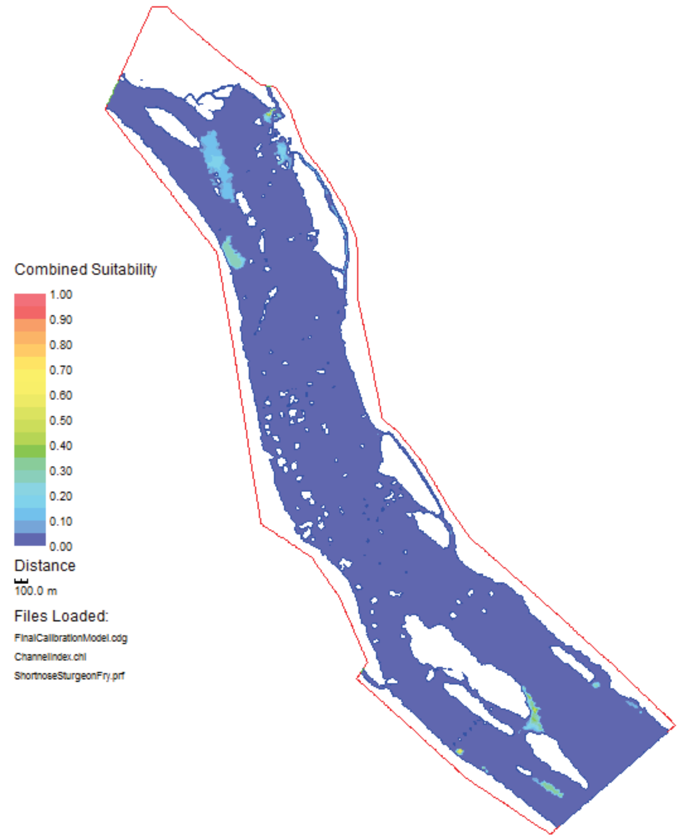
Shortnose Sturgeon Spawning – 80,000 cfs



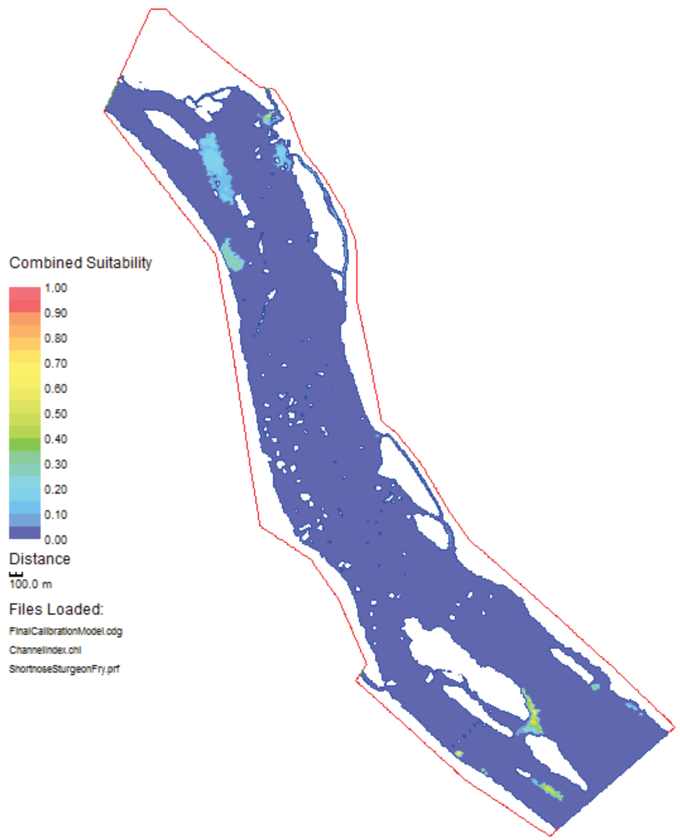
Shortnose Sturgeon Spawning – 86,000 cfs



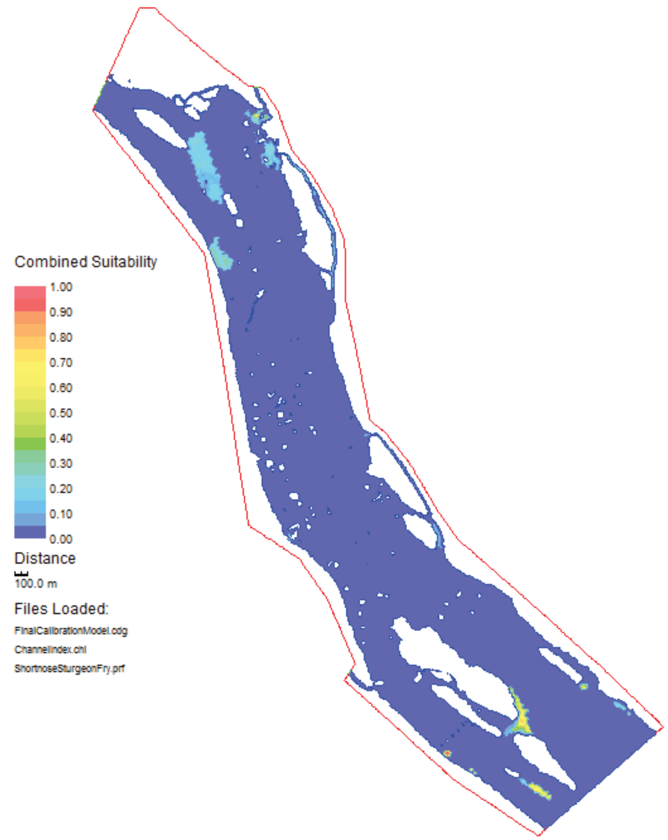
Shortnose Sturgeon Fry – 2,000 cfs



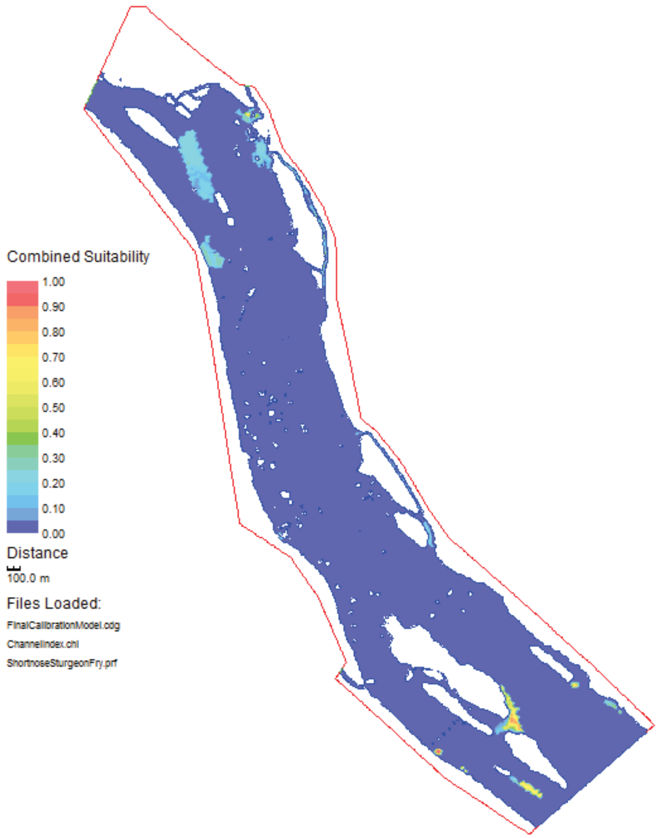
Shortnose Sturgeon Fry – 3,500 cfs



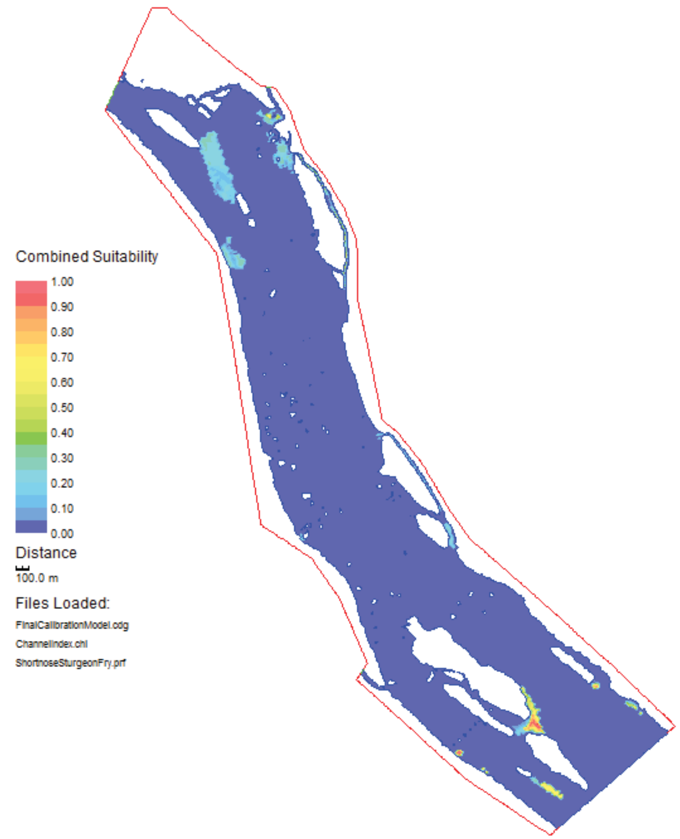
Shortnose Sturgeon Fry – 5,000 cfs



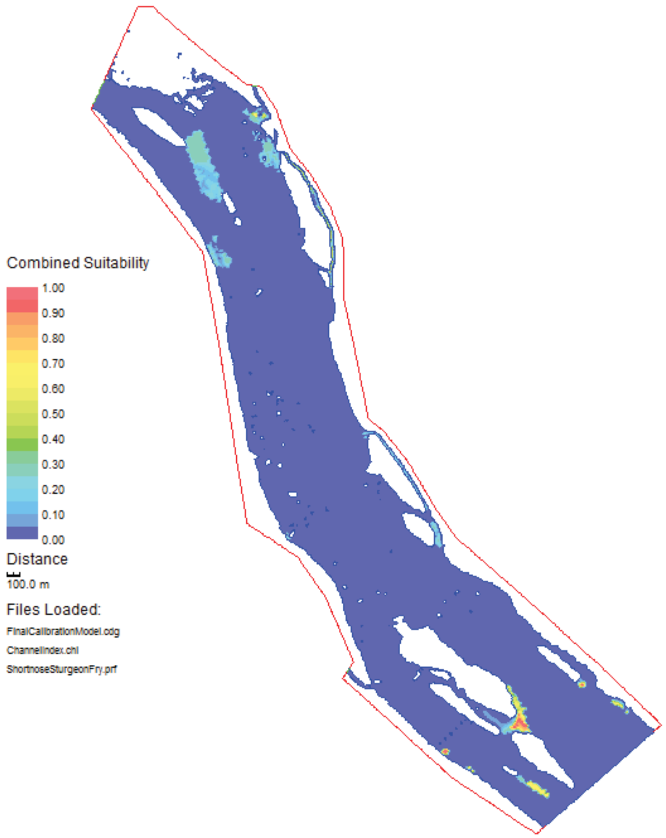
Shortnose Sturgeon Fry – 7,500 cfs



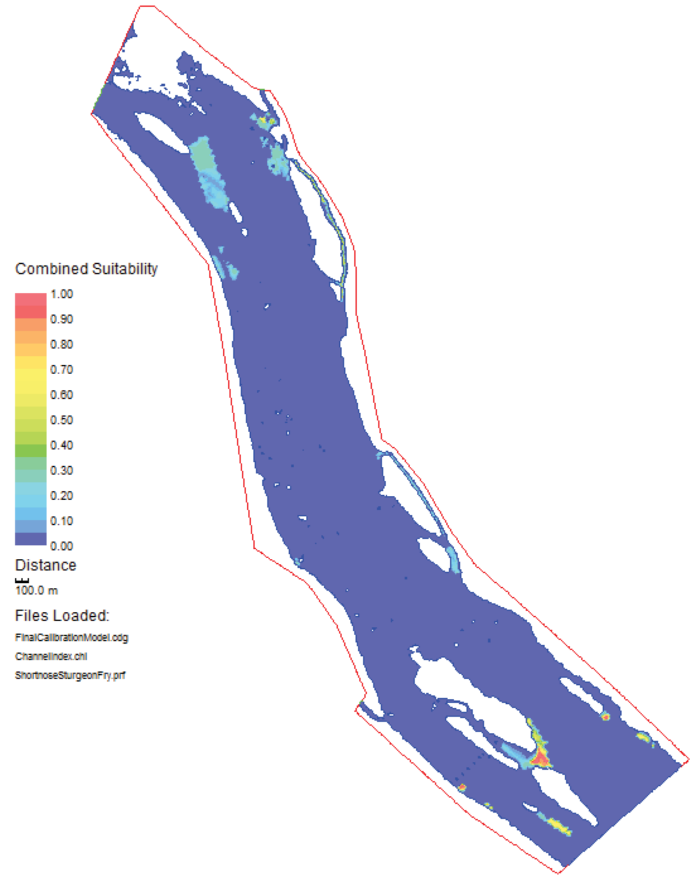
Shortnose Sturgeon Fry – 10,000 cfs



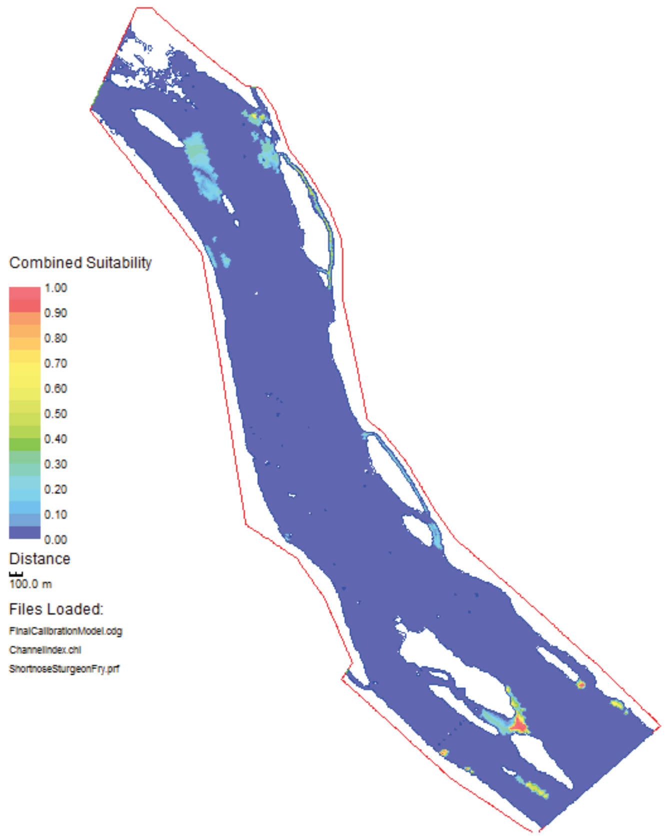
Shortnose Sturgeon Fry – 15,000 cfs



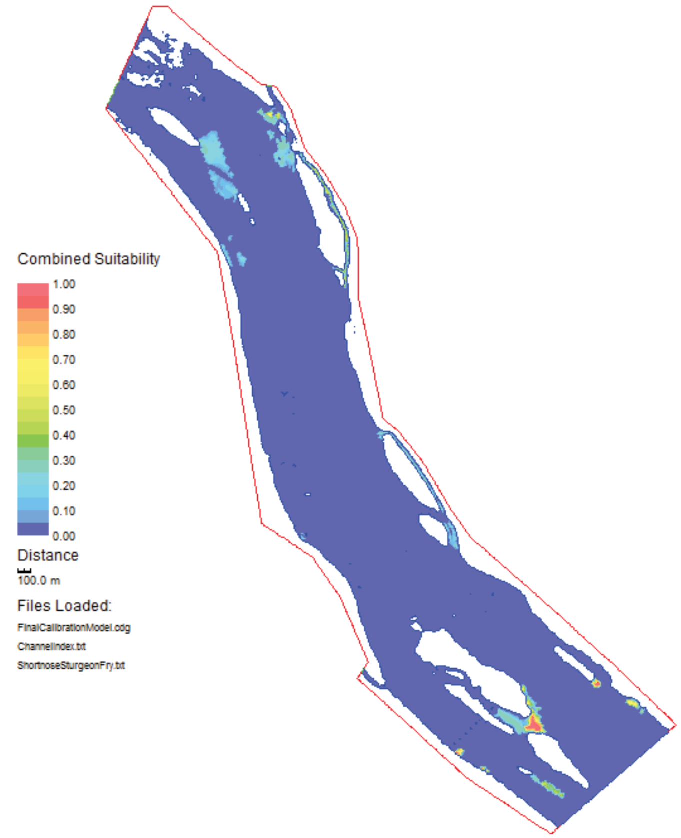
Shortnose Sturgeon Fry – 20,000 cfs



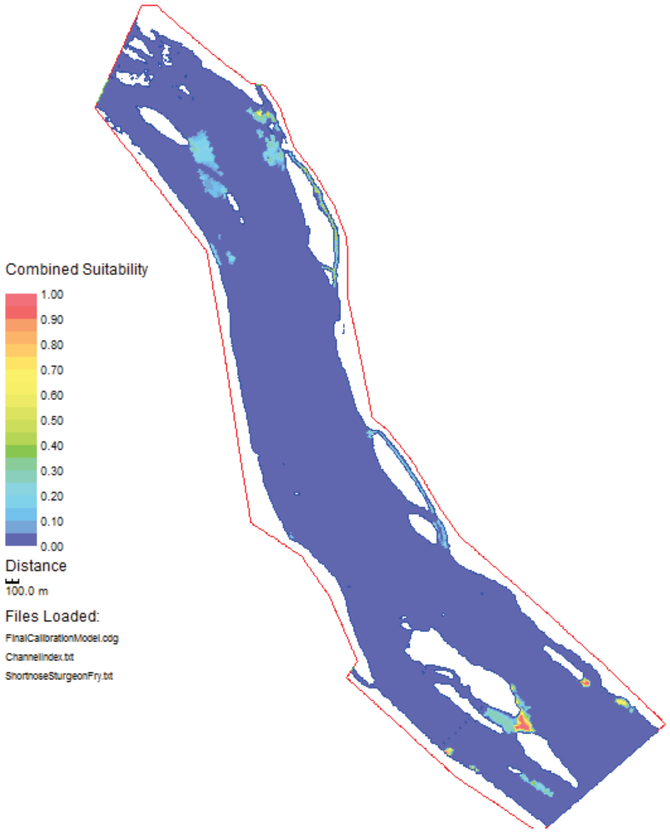
Shortnose Sturgeon Fry – 30,000 cfs



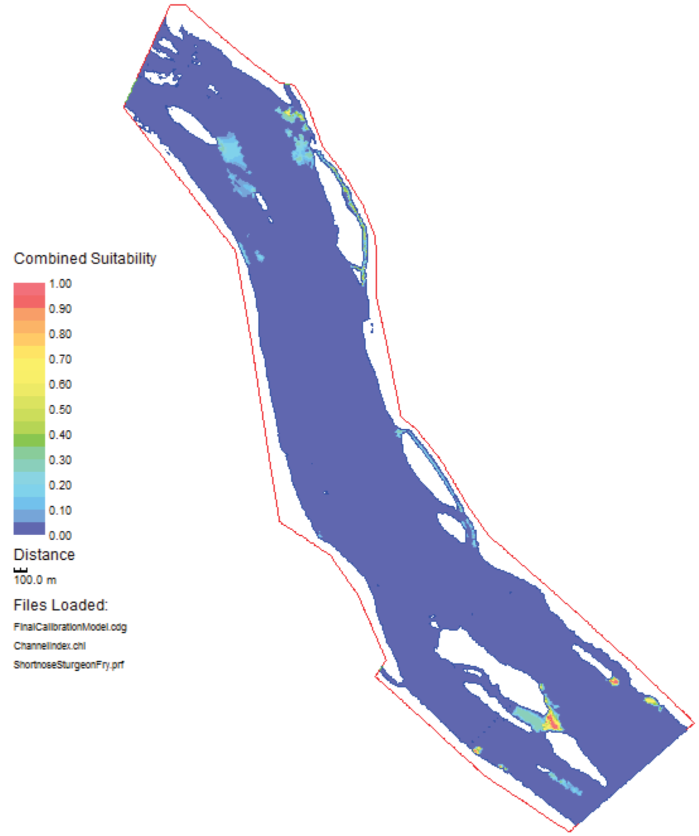
Shortnose Sturgeon Fry – 40,000



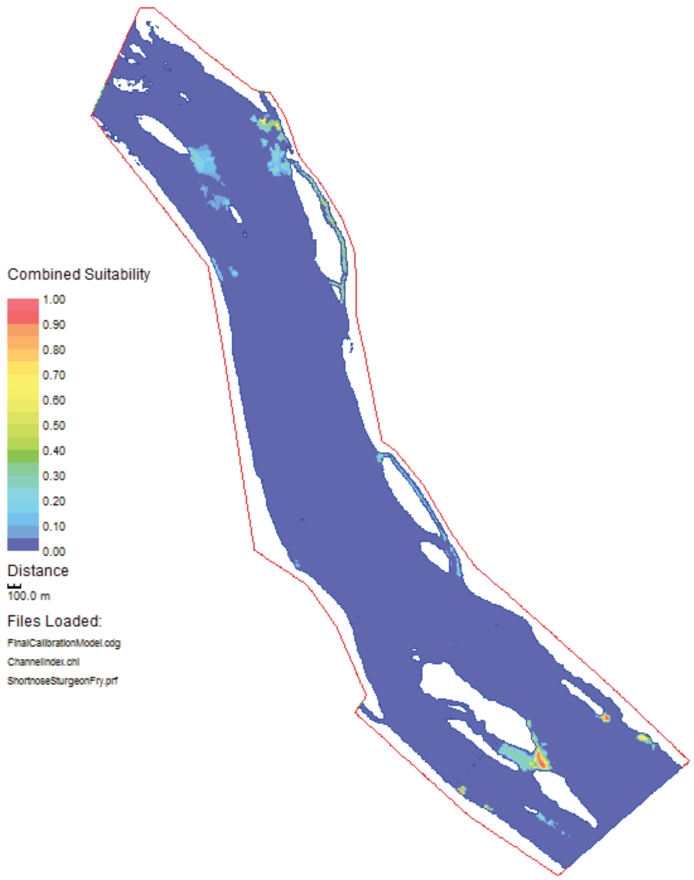
Shortnose Sturgeon Fry – 50,000 cfs



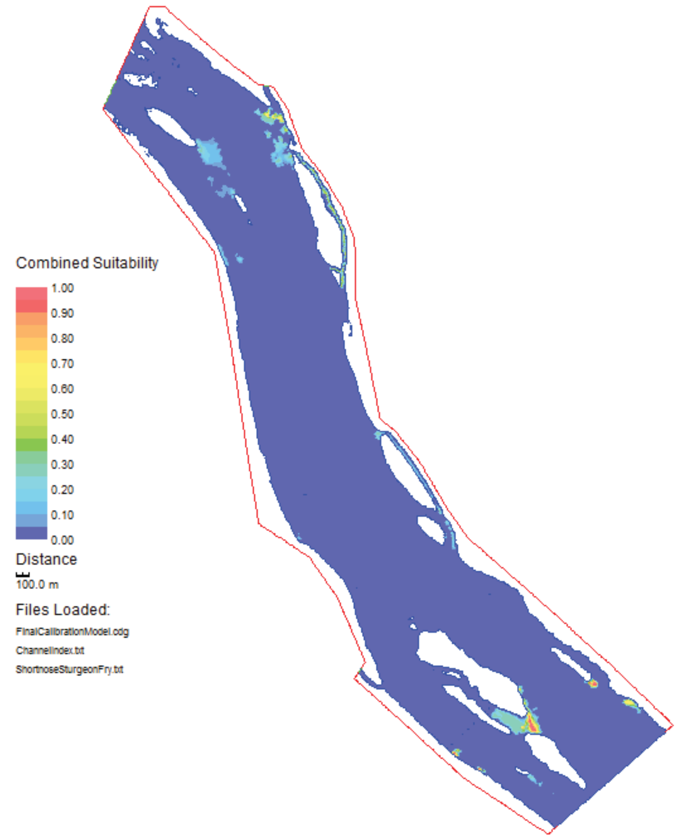
Shortnose Sturgeon Fry – 60,000 cfs



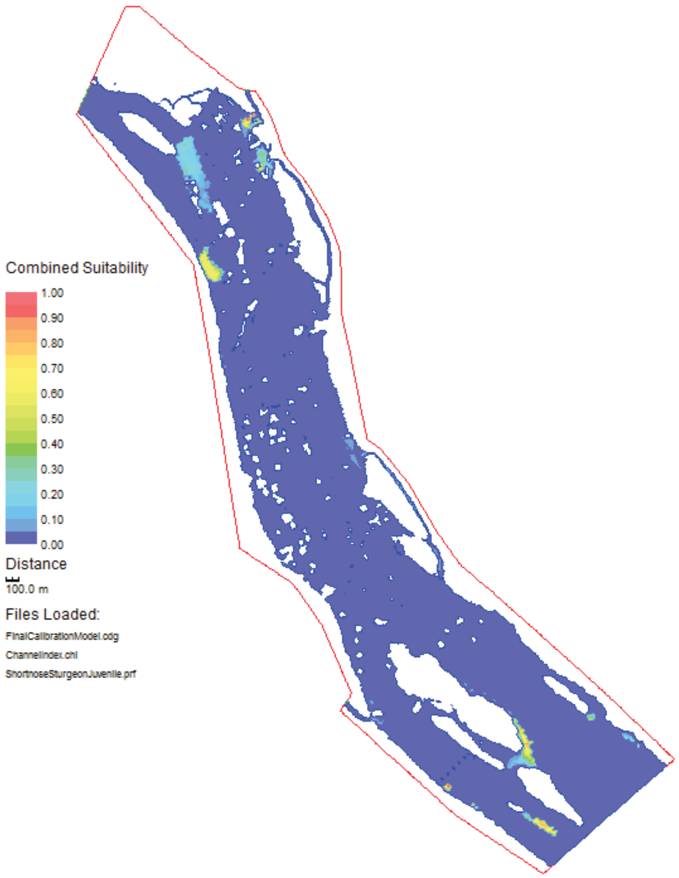
Shortnose Sturgeon Fry – 70,000 cfs



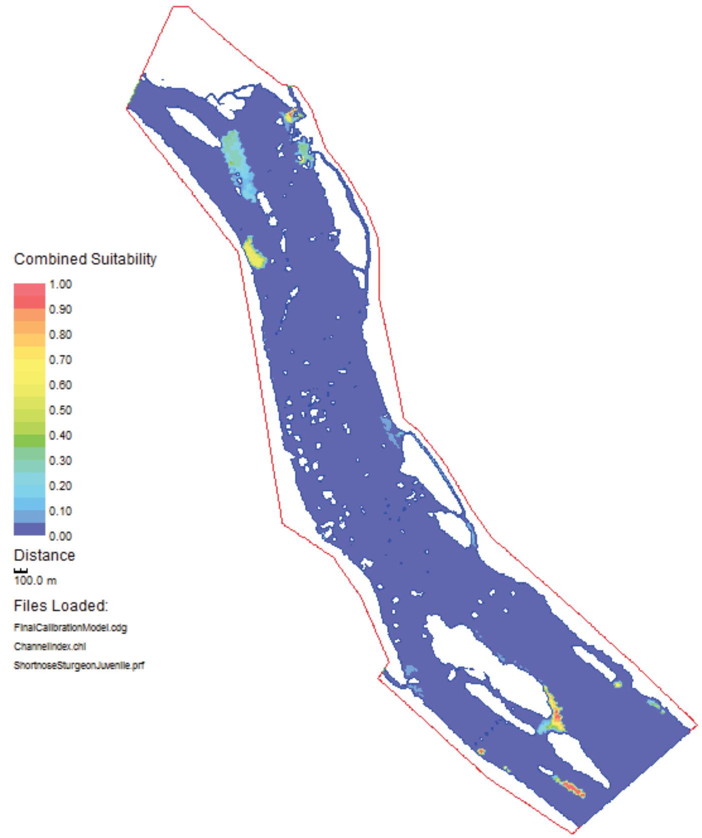
Shortnose Sturgeon Fry – 80,000 cfs



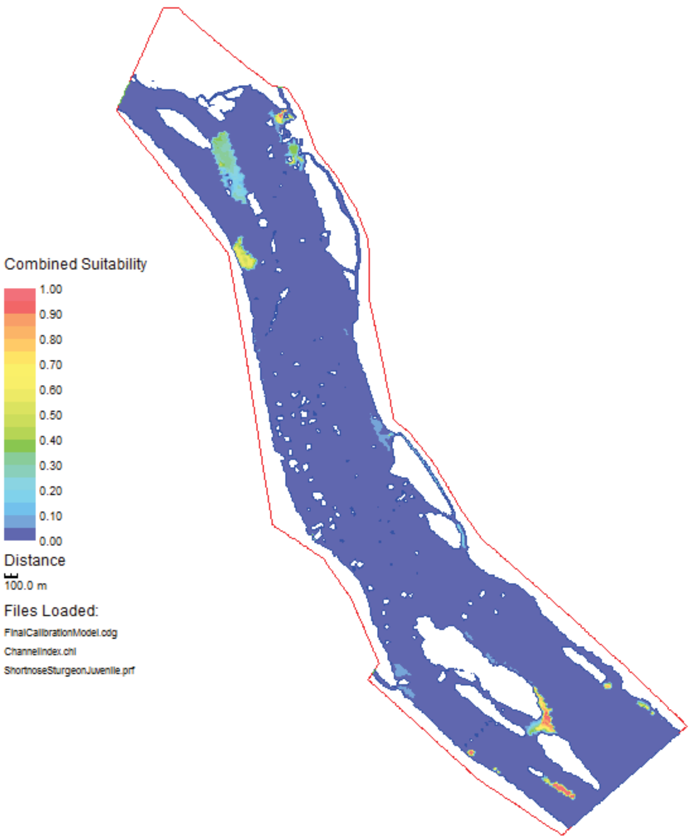
Shortnose Sturgeon Fry – 86,000 cfs



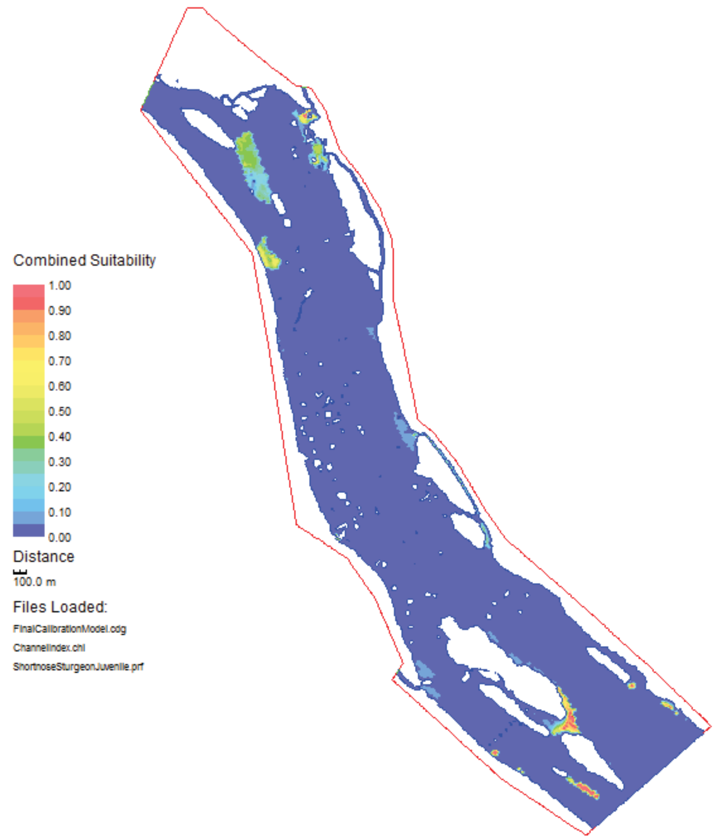
Shortnose Sturgeon Juvenile – 2,000 cfs



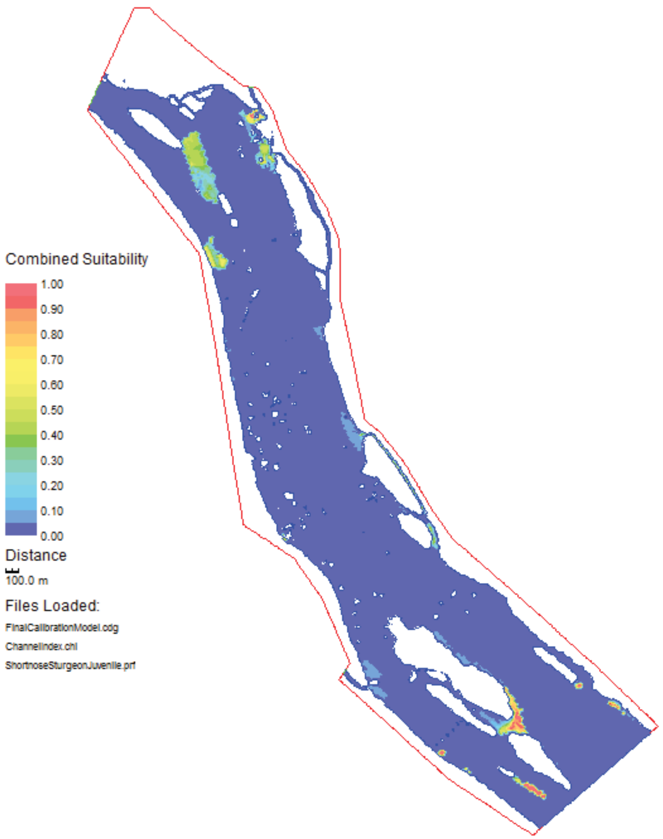
Shortnose Sturgeon Juvenile – 3,500 cfs



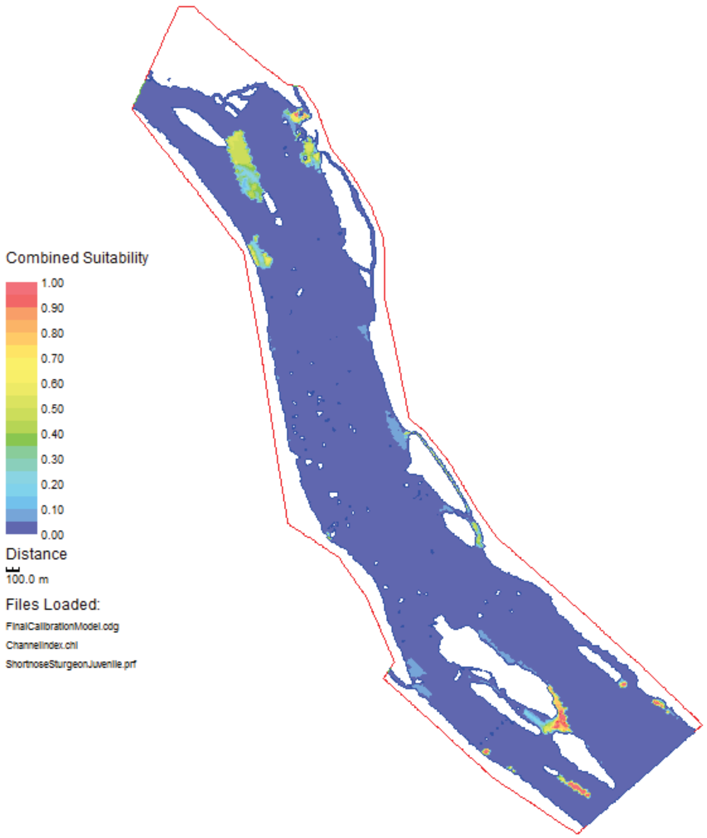
Shortnose Sturgeon Juvenile – 5,000 cfs



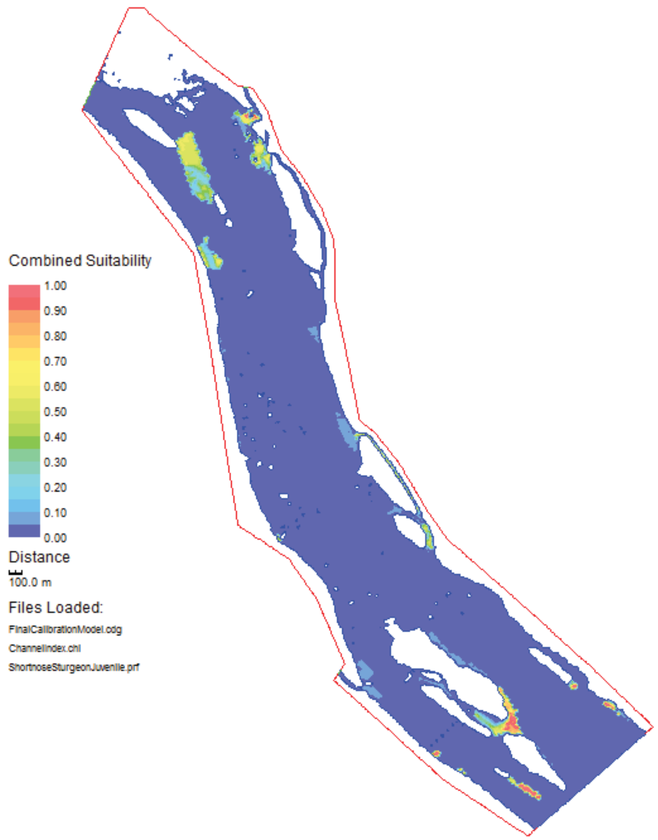
Shortnose Sturgeon Juvenile – 7,500 cfs



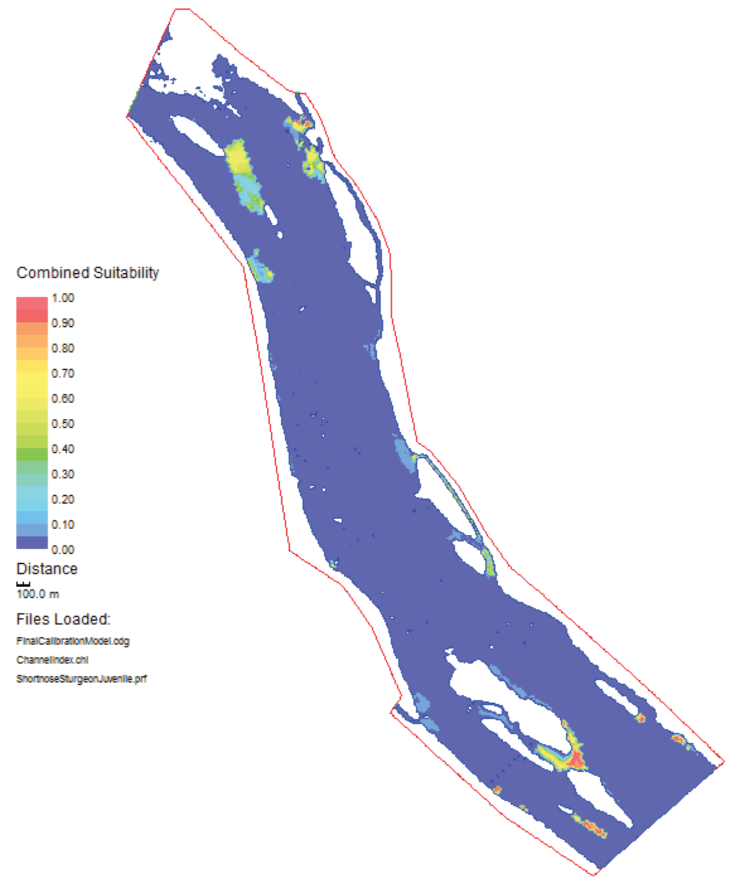
Shortnose Sturgeon Juvenile – 10,000 cfs



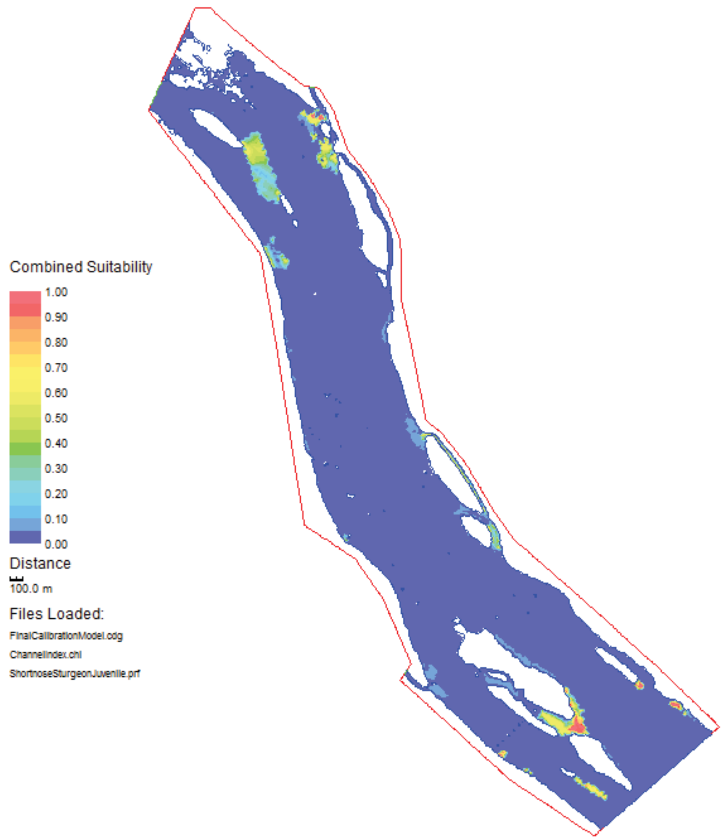
Shortnose Sturgeon Juvenile – 15,000 cfs



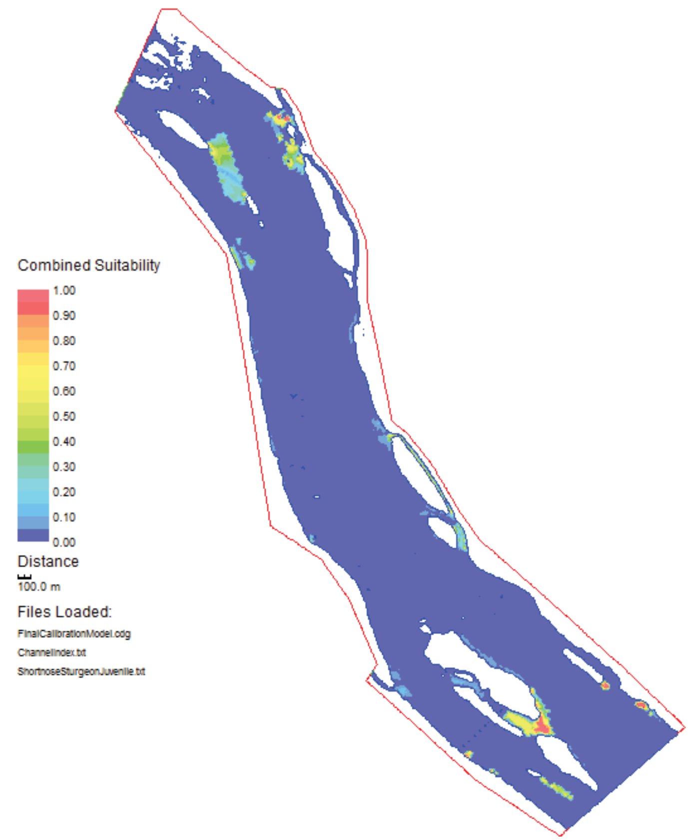
Shortnose Sturgeon Juvenile – 20,000 cfs



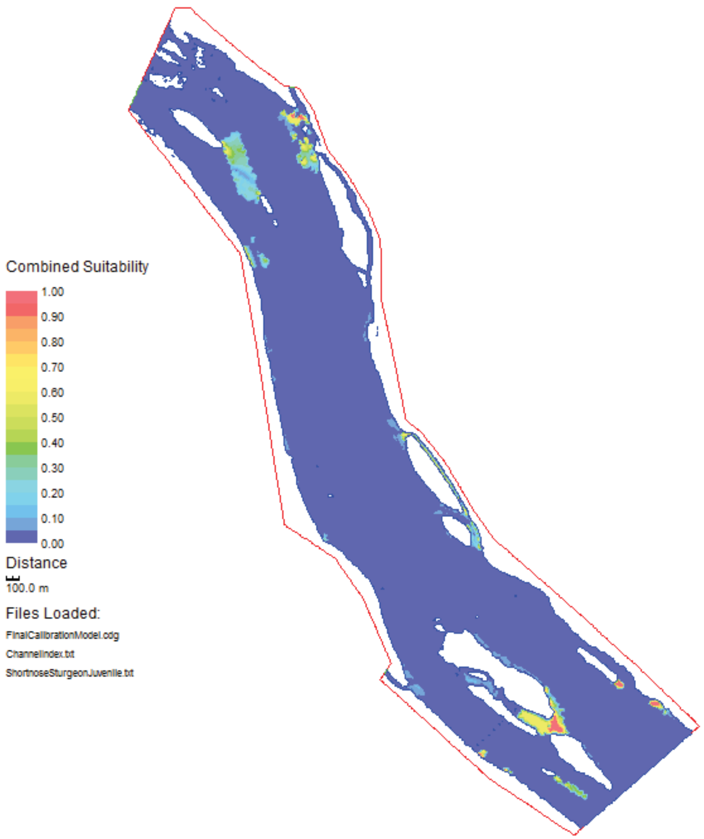
Shortnose Sturgeon Juvenile – 30,000 cfs



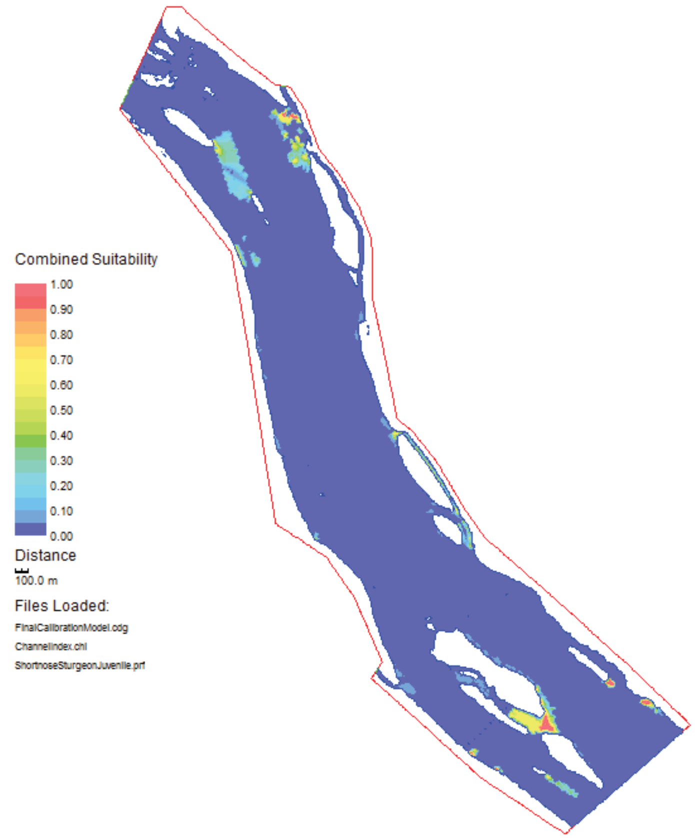
Shortnose Sturgeon Juvenile – 40,000 cfs



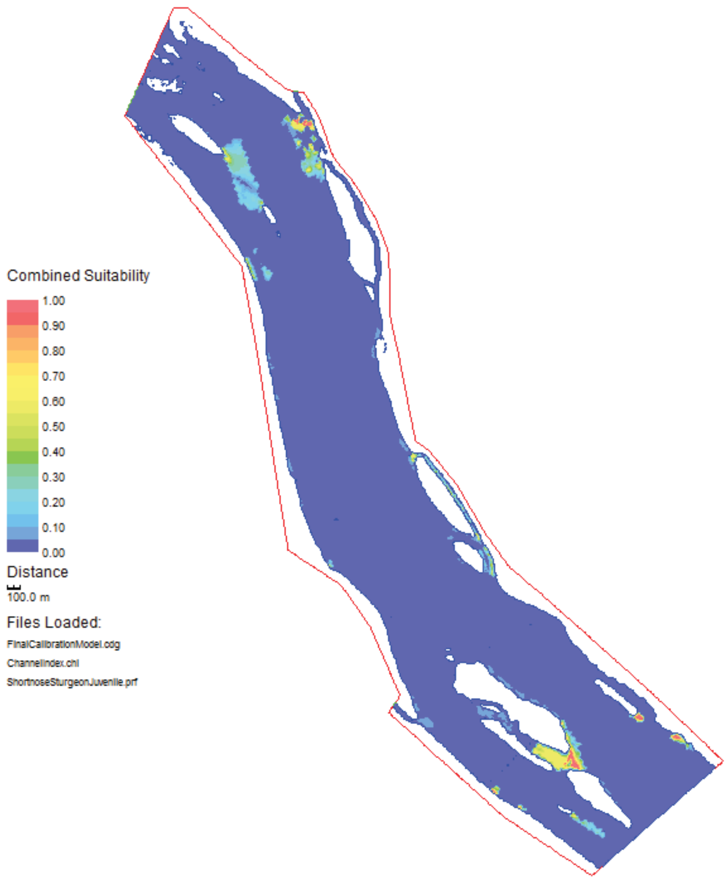
Shortnose Sturgeon Juvenile – 50,000 cfs



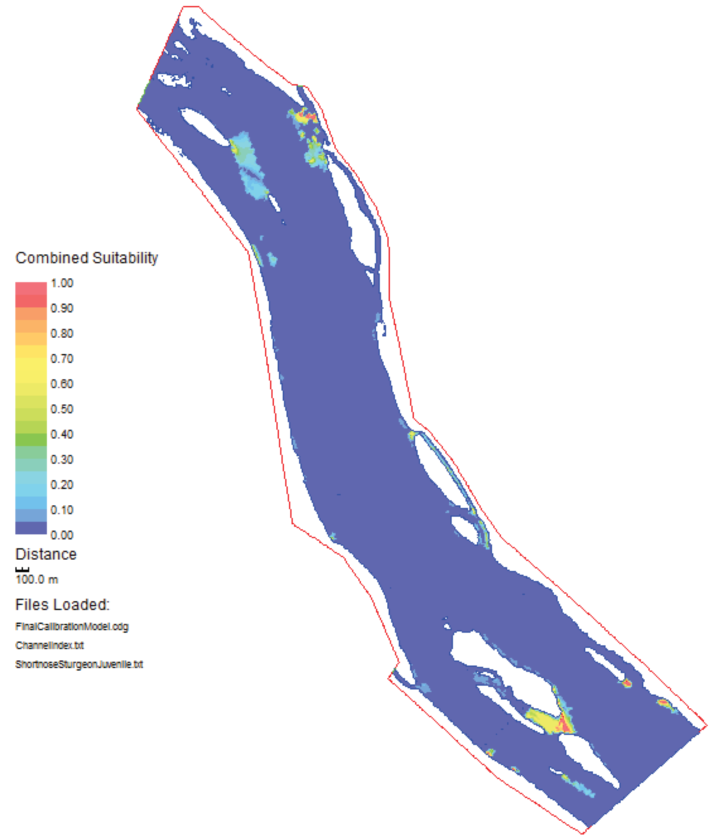
Shortnose Sturgeon Juvenile – 60,000 cfs



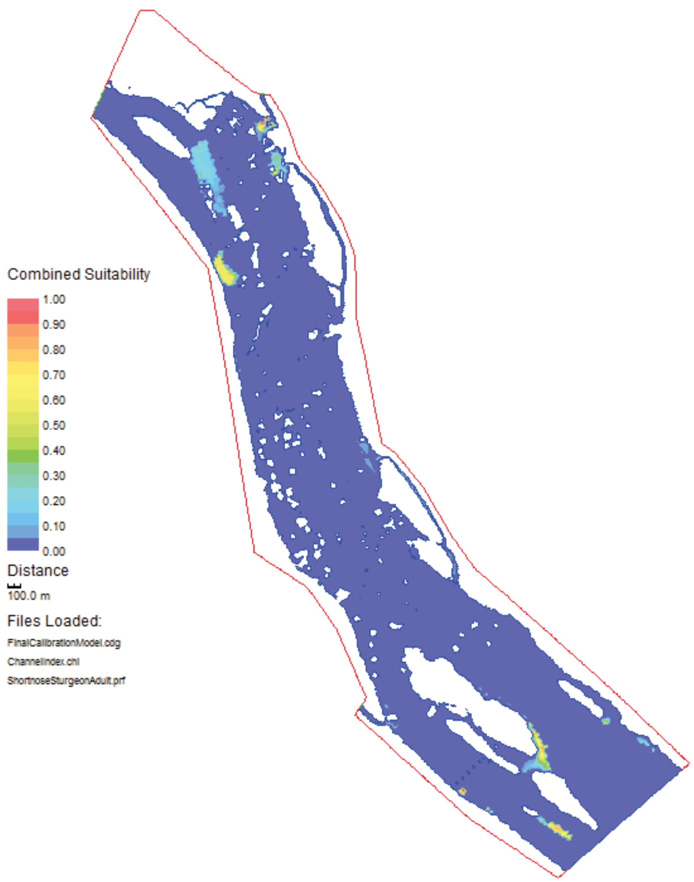
Shortnose Sturgeon Juvenile – 70,000 cfs



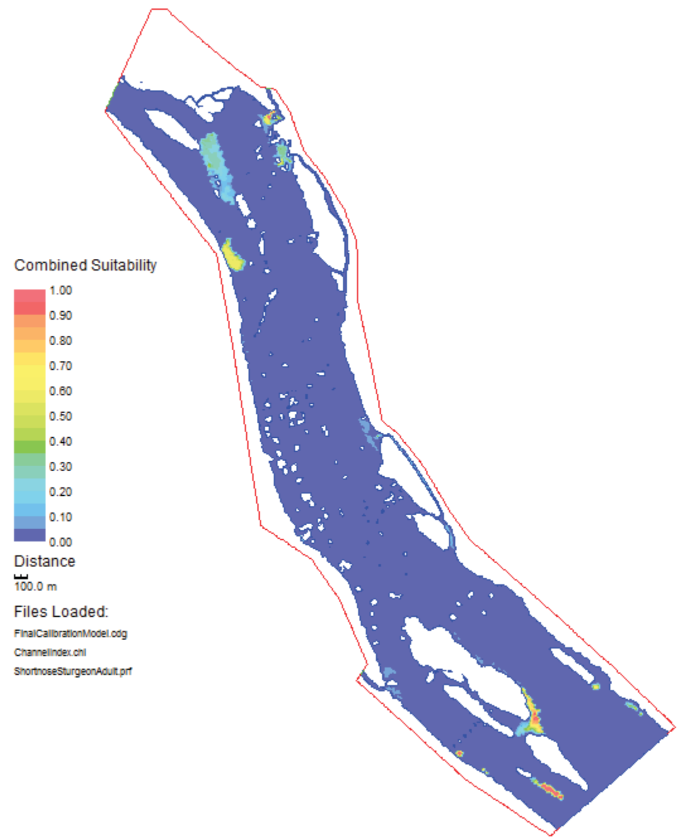
Shortnose Sturgeon Juvenile – 80,000 cfs



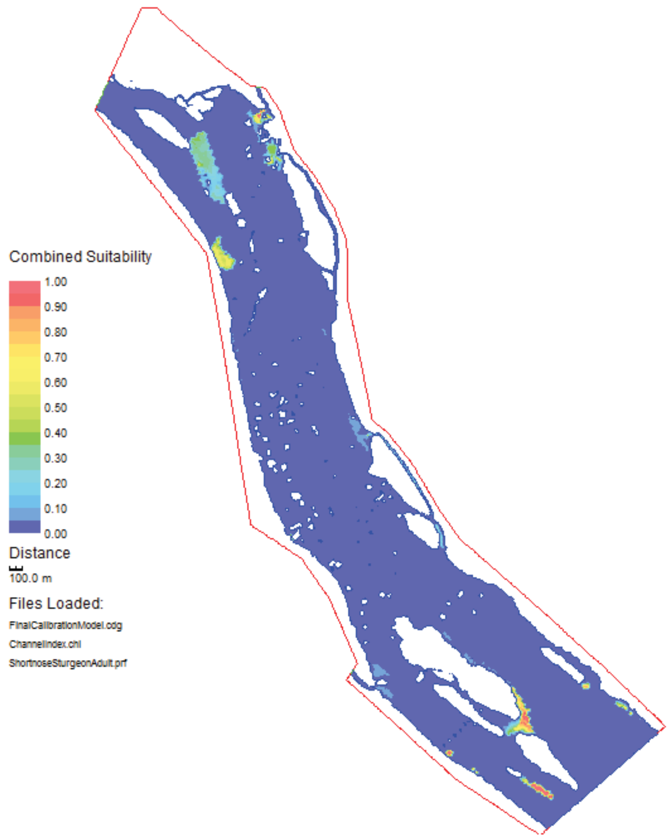
Shortnose Sturgeon Juvenile – 86,000 cfs



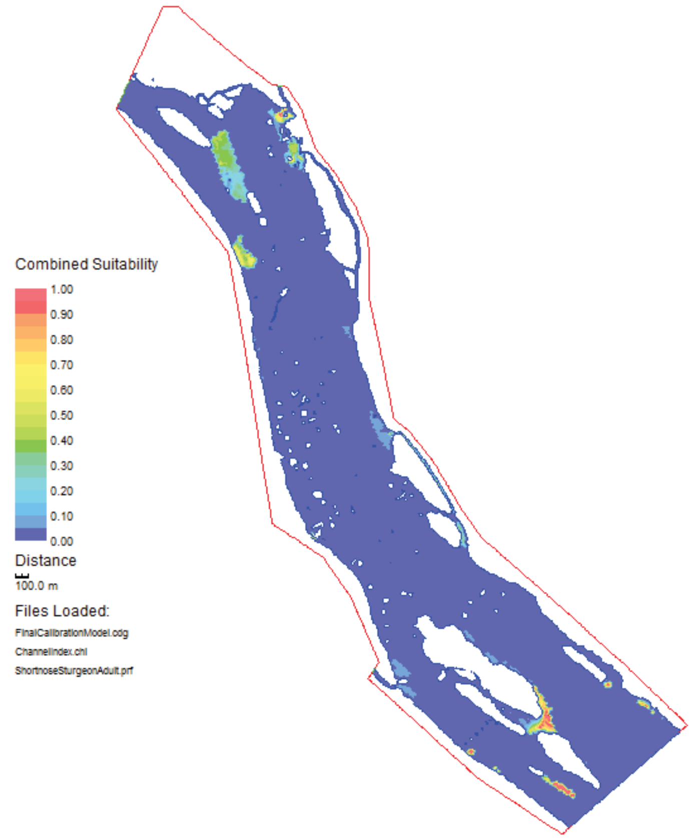
Shortnose Sturgeon Adult – 2,000 cfs



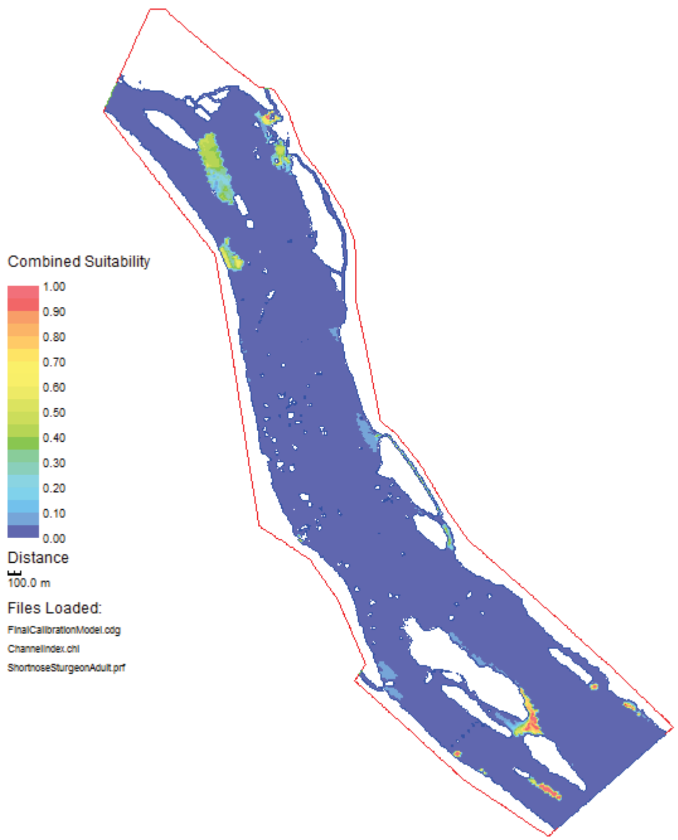
Shortnose Sturgeon Adult – 3,500 cfs



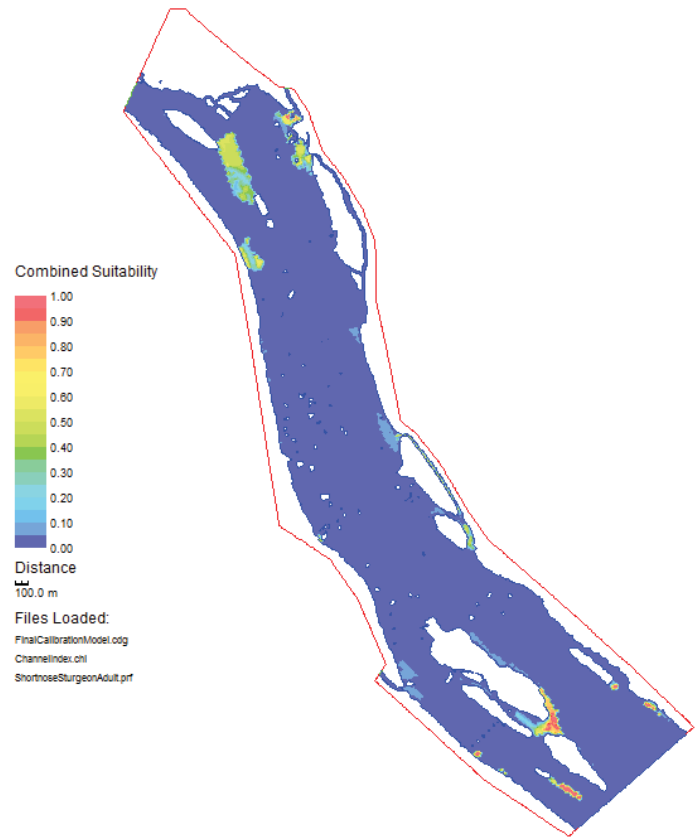
Shortnose Sturgeon Adult – 5,000 cfs



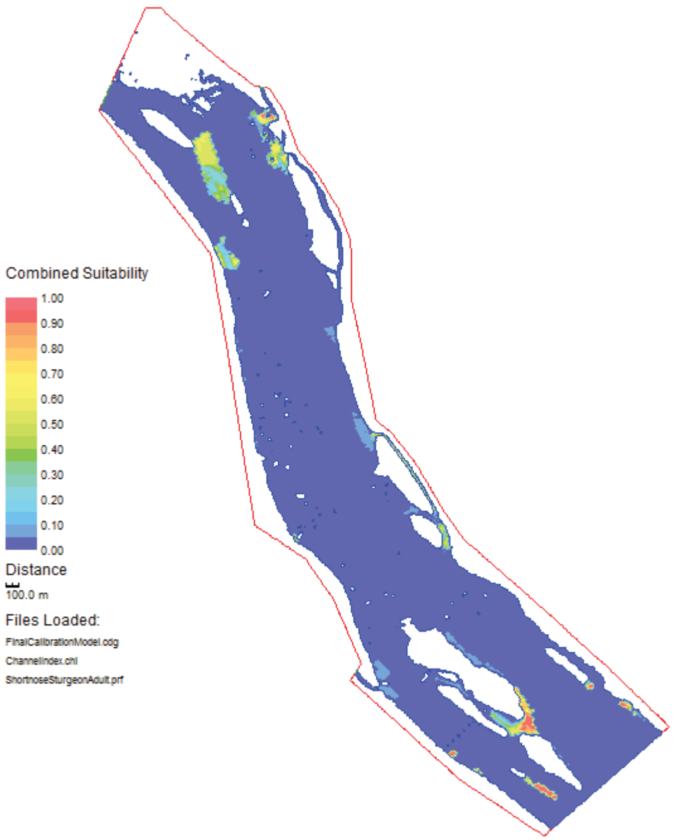
Shortnose Sturgeon Adult – 7,500 cfs



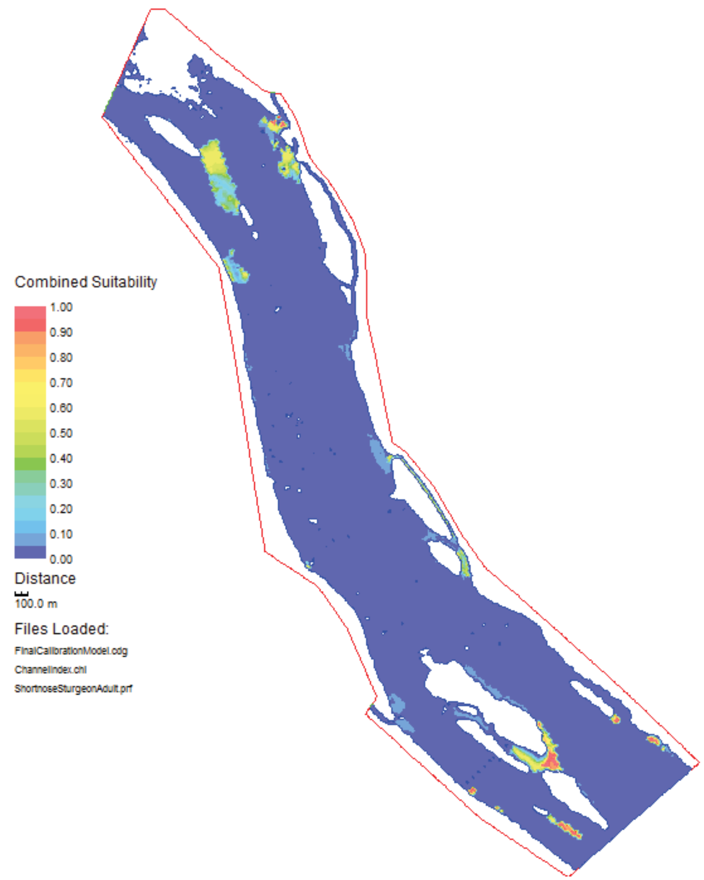
Shortnose Sturgeon Adult – 10,000 cfs



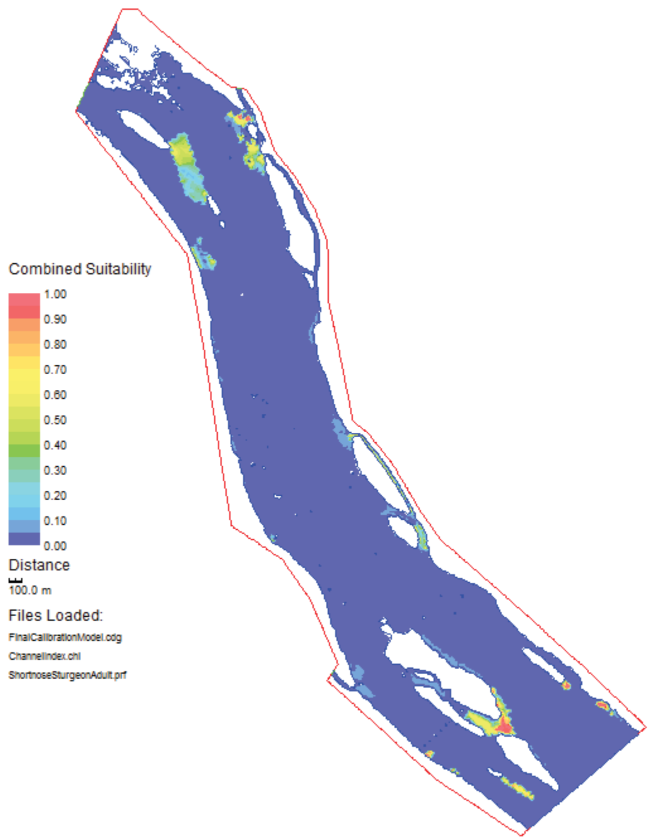
Shortnose Sturgeon Adult – 15,000 cfs



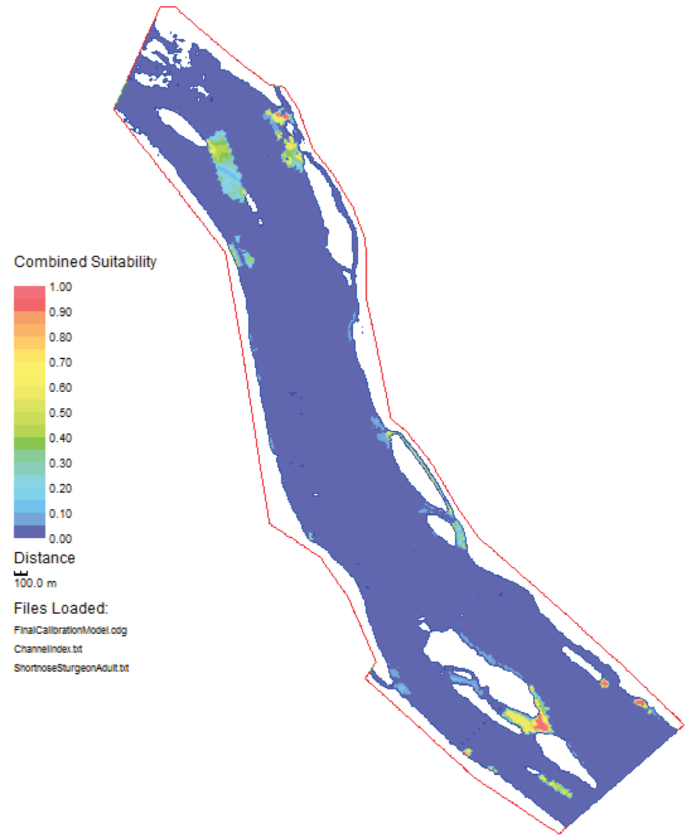
Shortnose Sturgeon Adult – 20,000 cfs



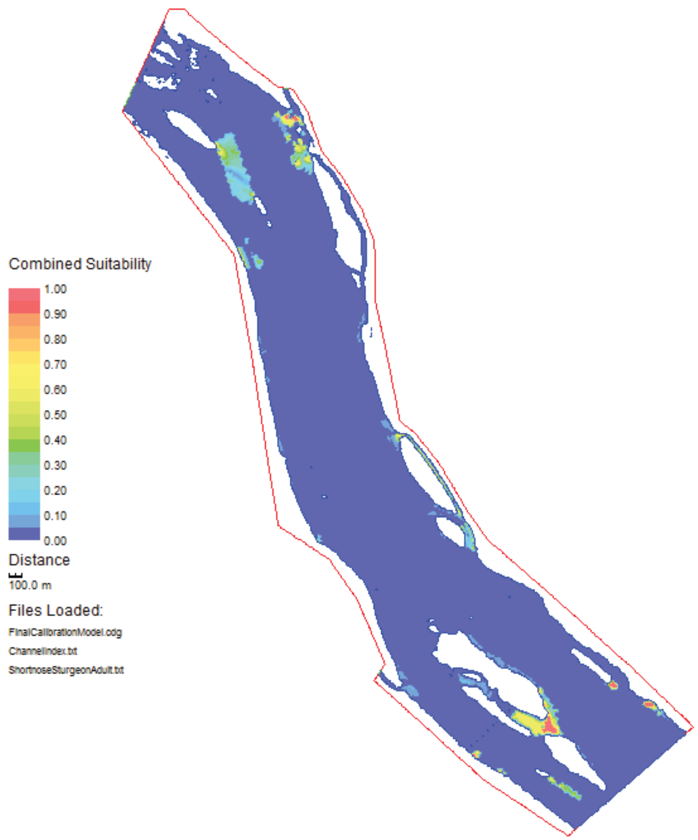
Shortnose Sturgeon Adult – 30,000 cfs



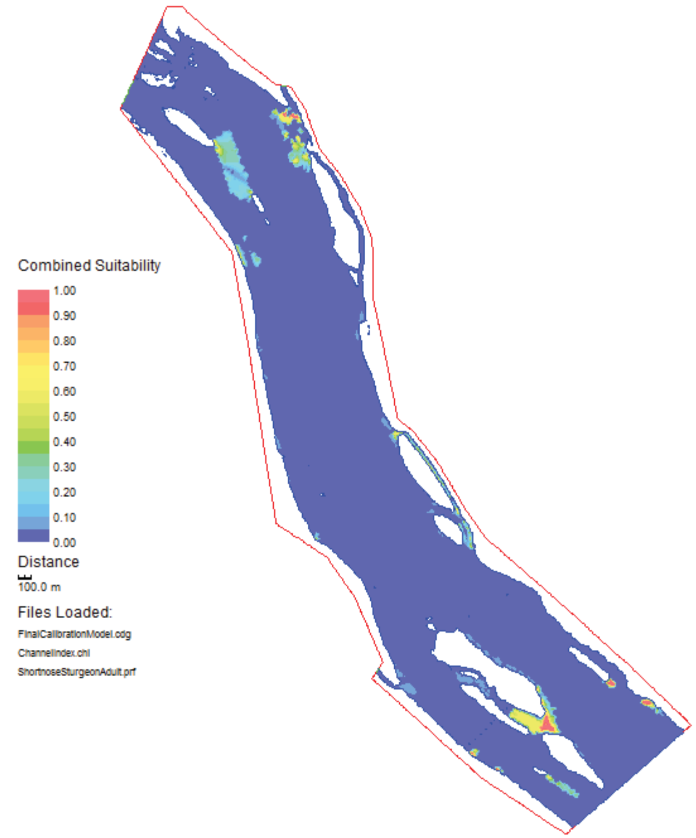
Shortnose Sturgeon Adult – 40,000 cfs



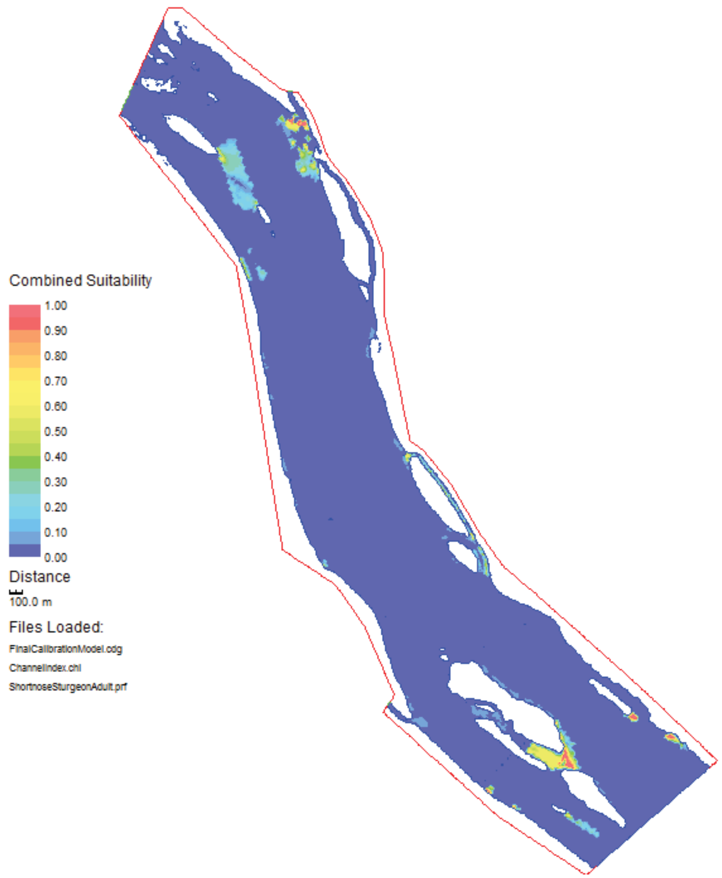
Shortnose Sturgeon Adult – 50,000 cfs



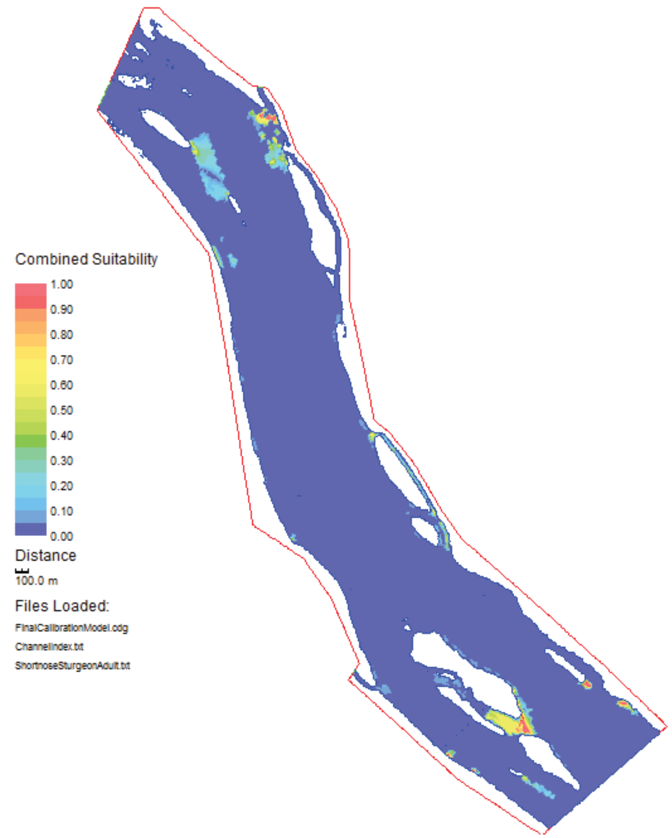
Shortnose Sturgeon Adult – 60,000 cfs



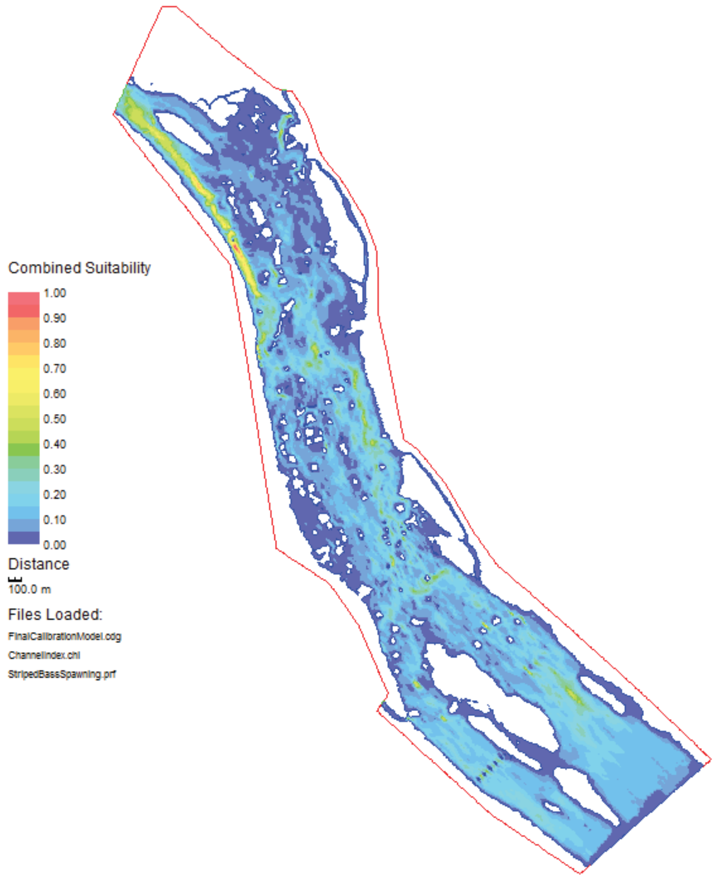
Shortnose Sturgeon Adult – 70,000 cfs



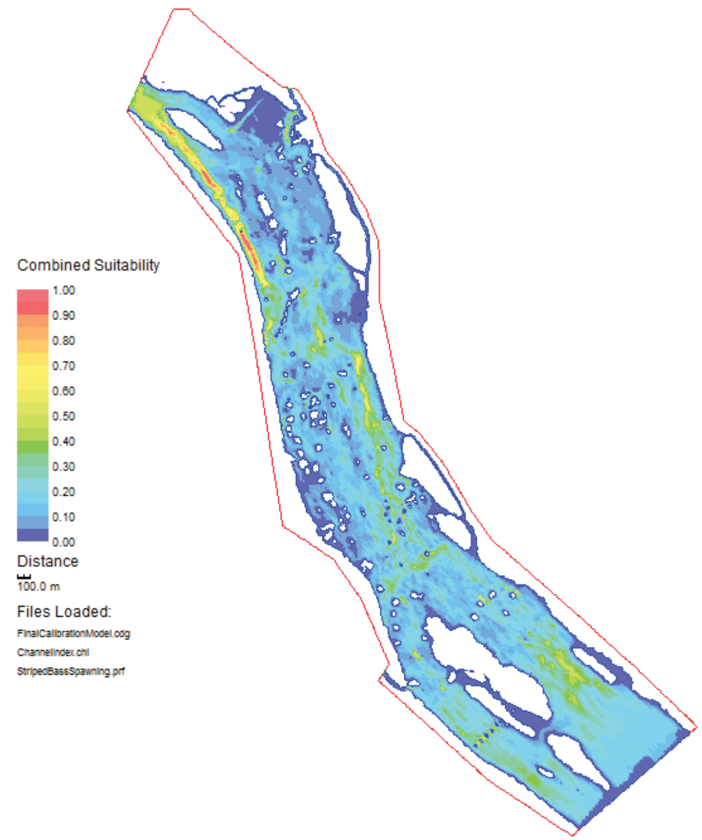
Shortnose Sturgeon Adult – 80,000 cfs



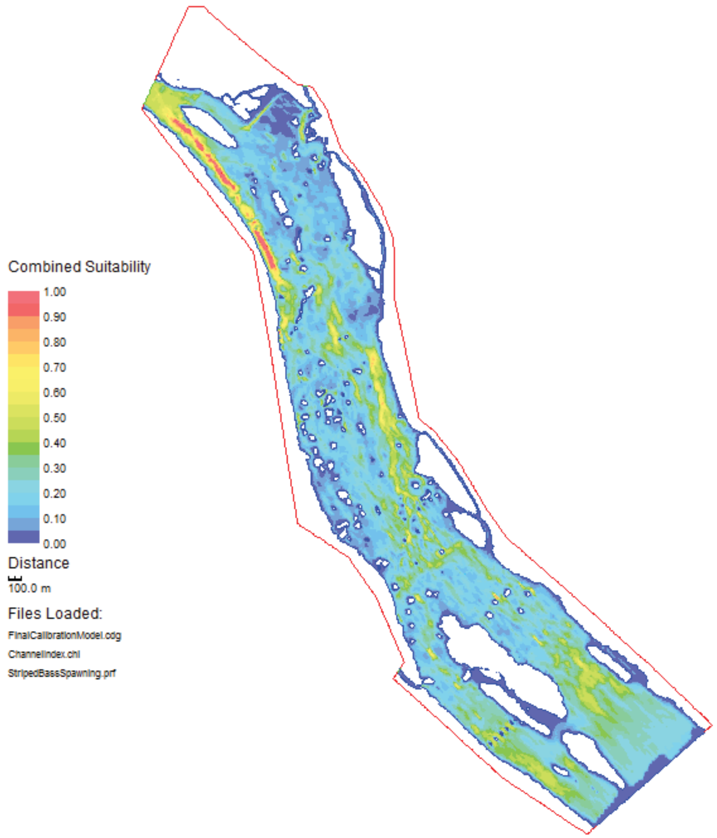
Shortnose Sturgeon Adult – 86,000 cfs



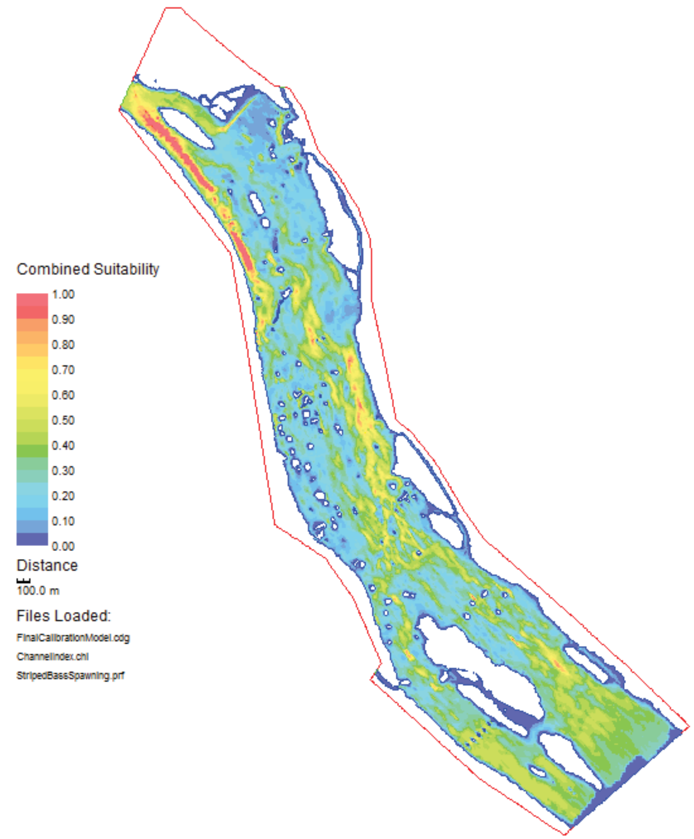
Striped Bass Spawning – 2,000 cfs



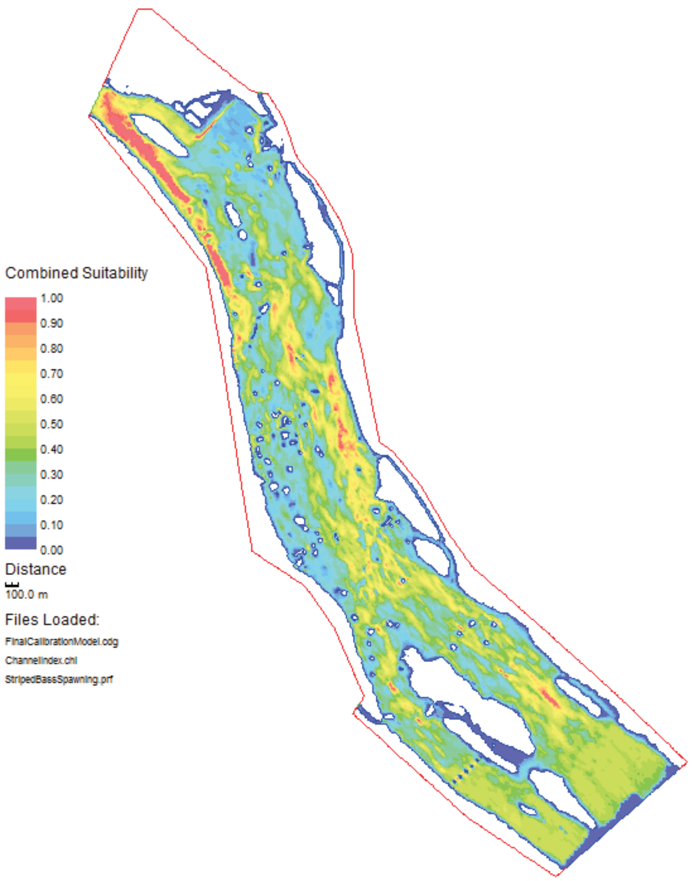
Striped Bass Spawning – 3,500 cfs



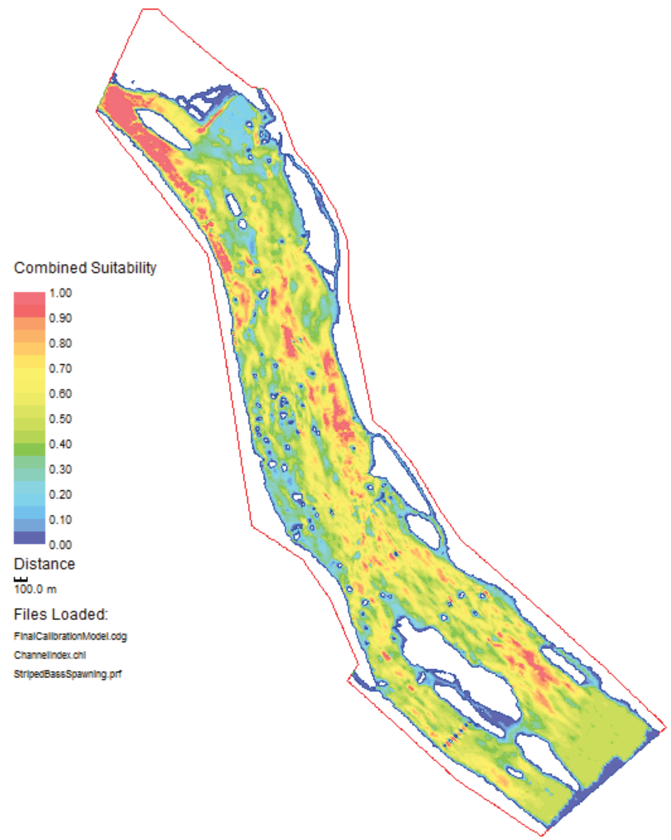
Striped Bass Spawning – 5,000 cfs



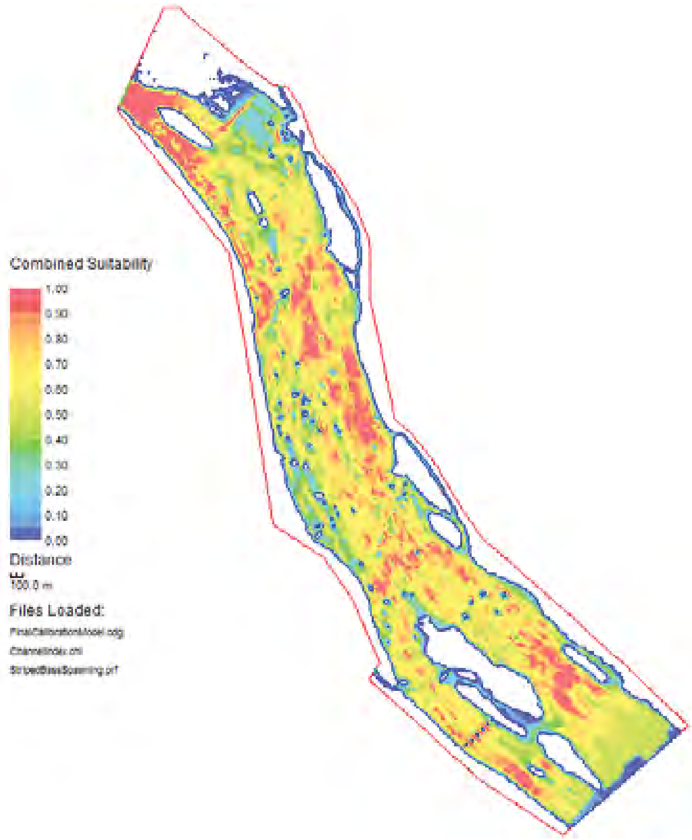
Striped Bass Spawning – 7,500 cfs



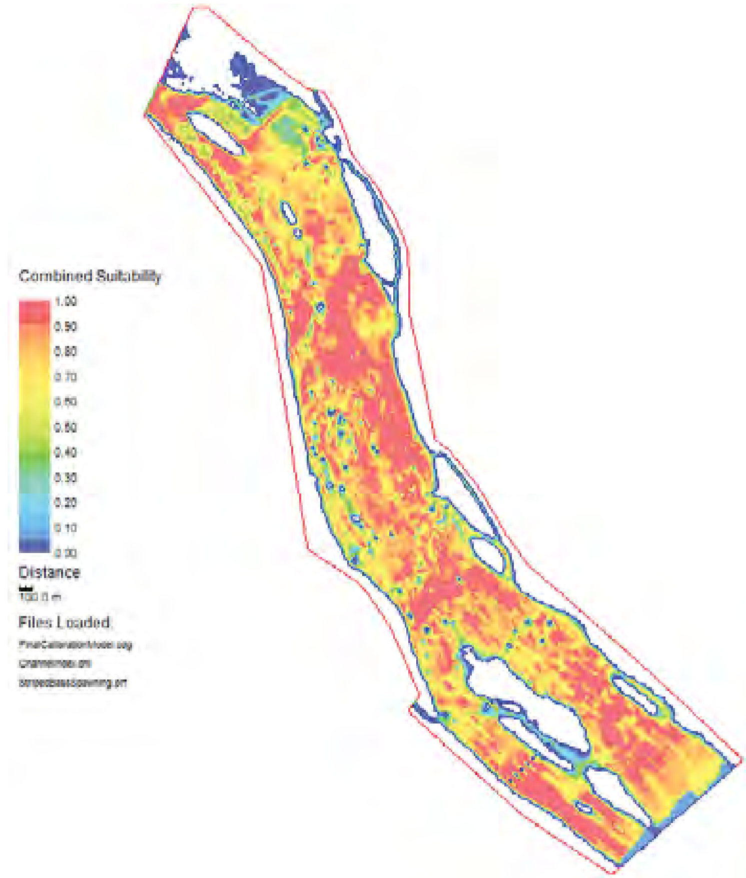
Striped Bass Spawning – 10,000 cfs



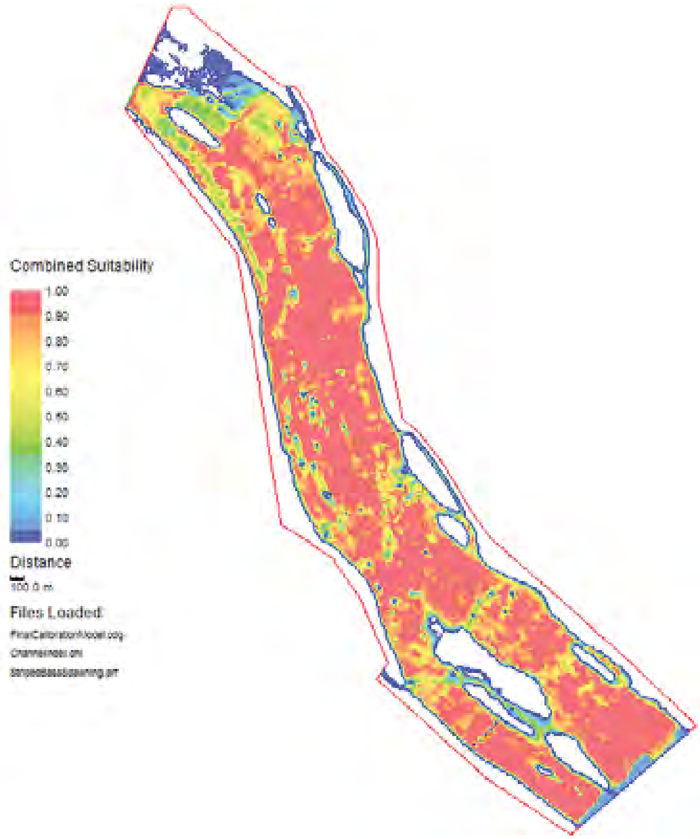
Striped Bass Spawning – 15,000 cfs



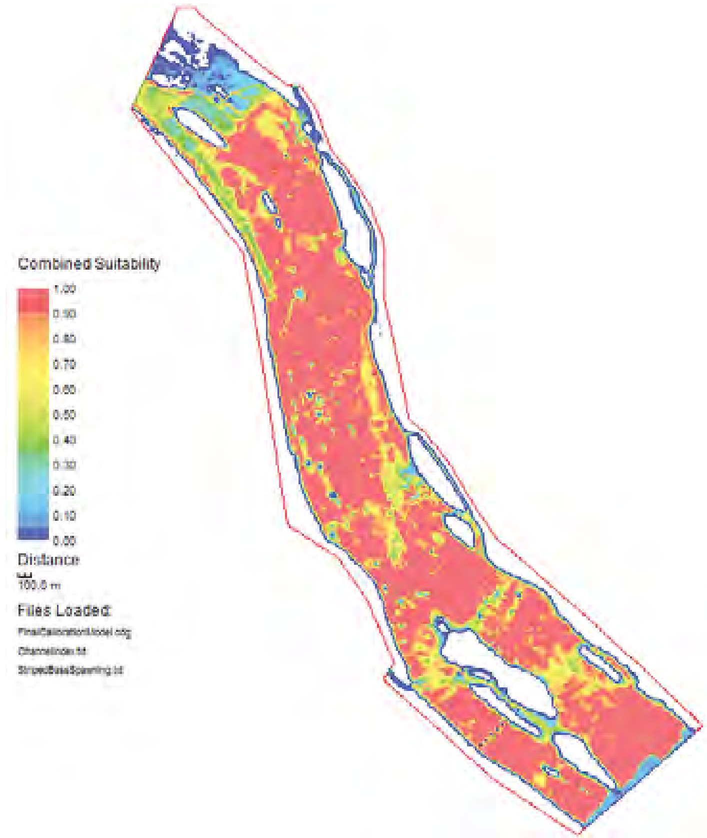
Striped Bass Spawning – 20,000 cfs



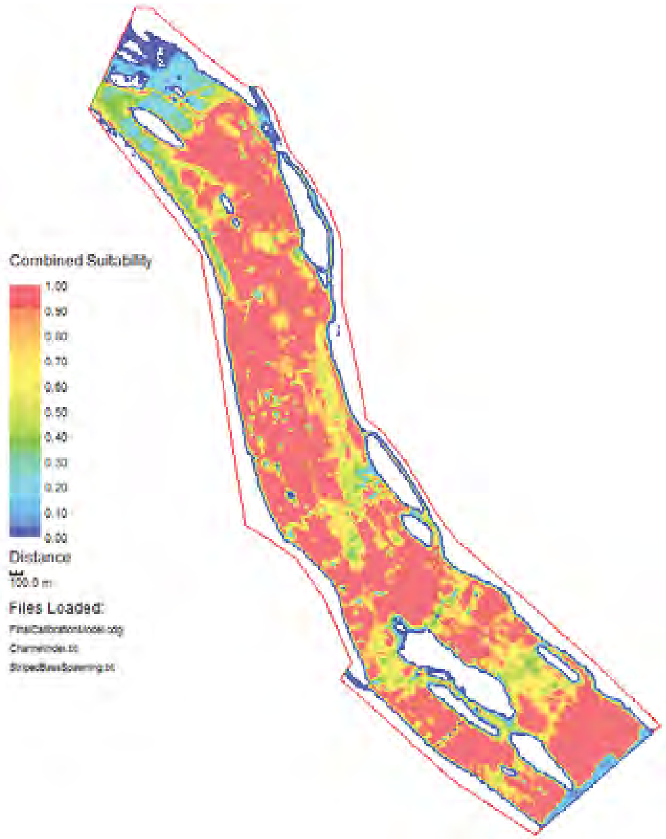
Striped Bass Spawning – 30,000 cfs



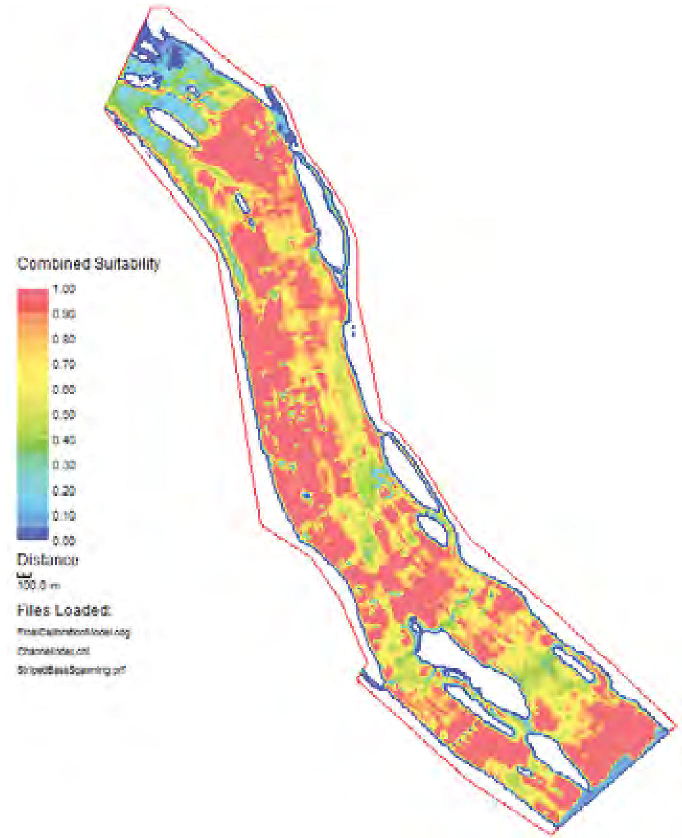
Striped Bass Spawning – 40,000 cfs



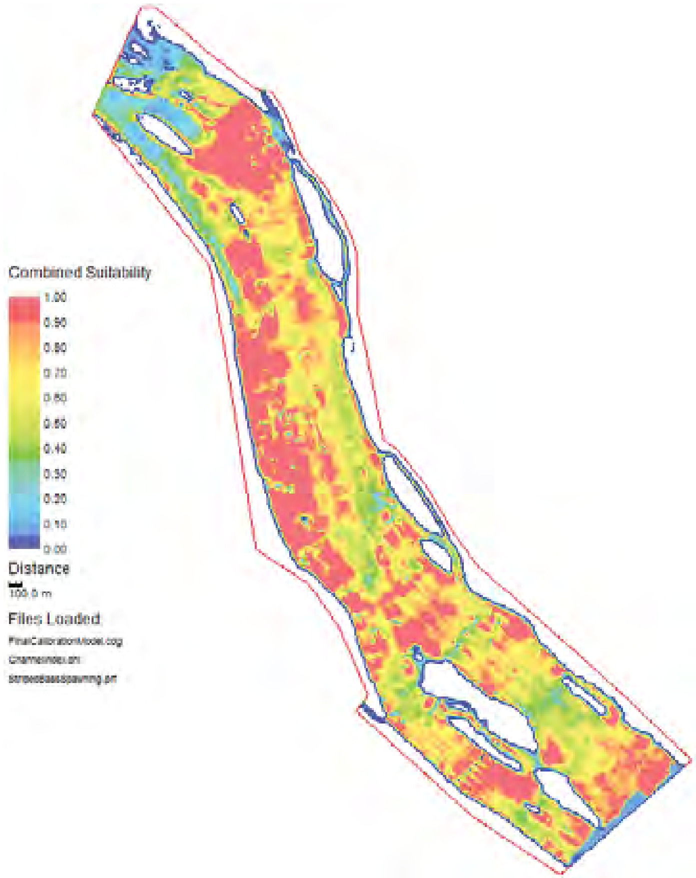
Striped Bass Spawning – 50,000 cfs



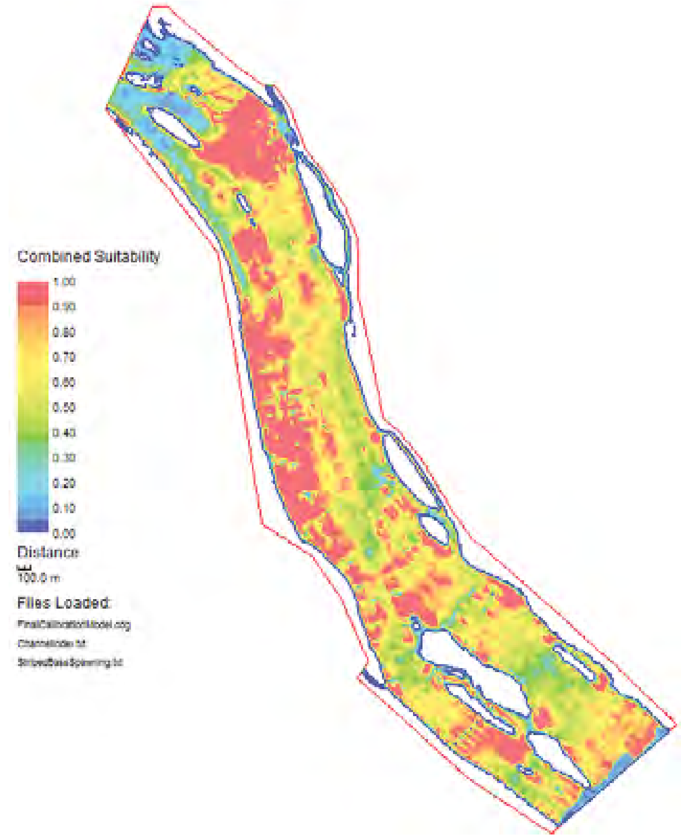
Striped Bass Spawning – 60,000 cfs



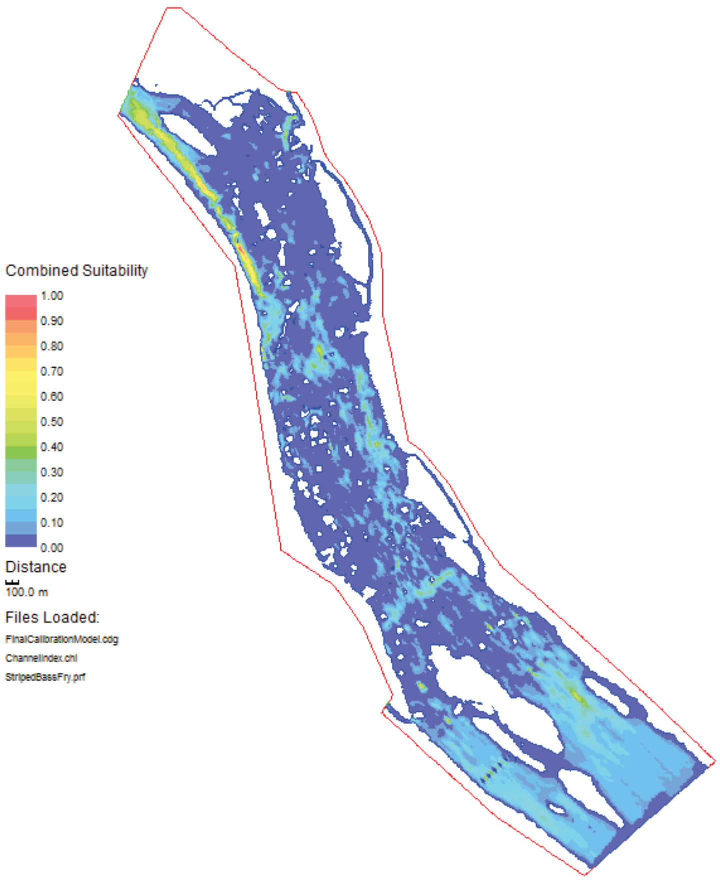
Striped Bass Spawning – 70,000 cfs



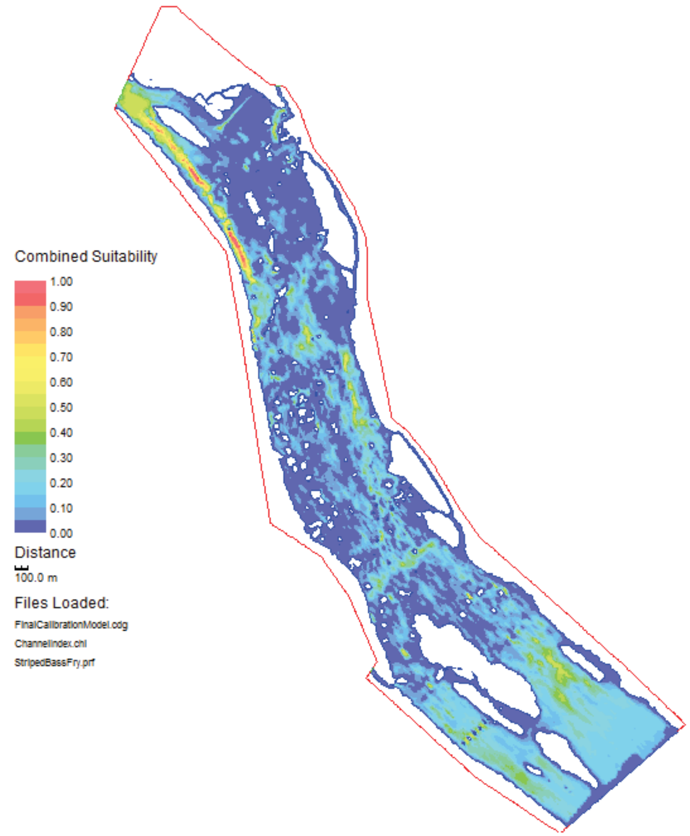
Striped Bass Spawning – 80,000 cfs



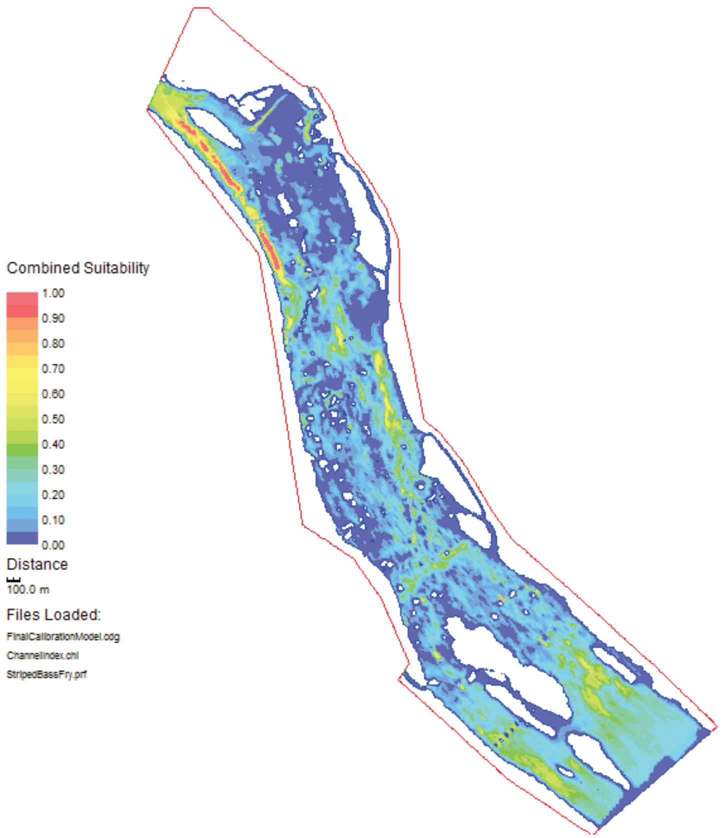
Striped Bass Spawning – 86,000 cfs



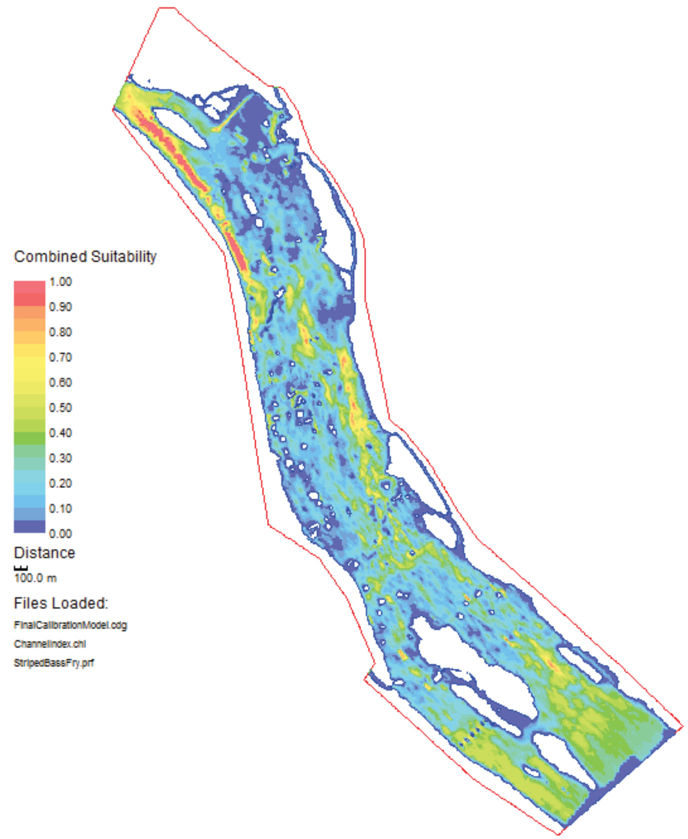
Striped Bass Fry – 2,000 cfs



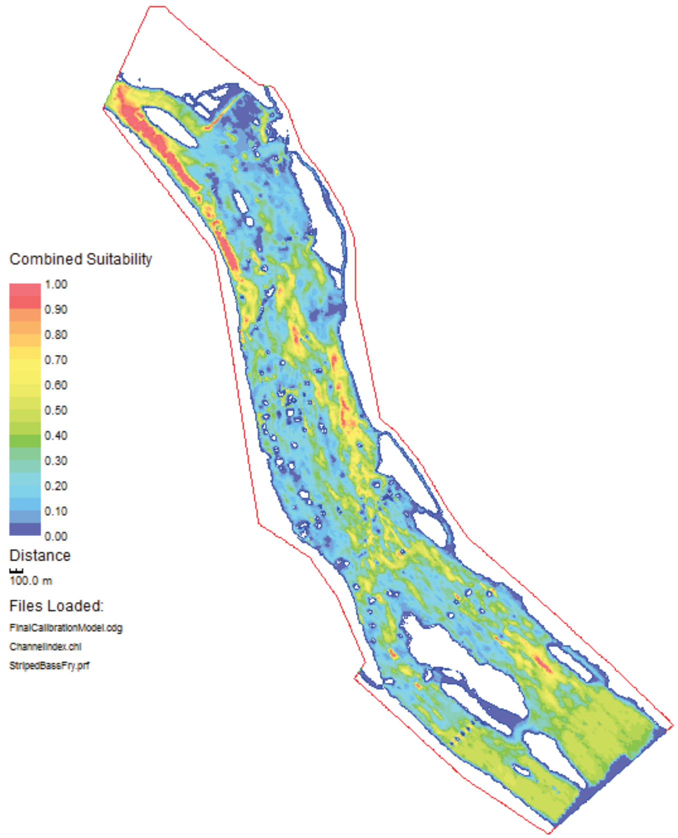
Striped Bass Fry – 3,500 cfs



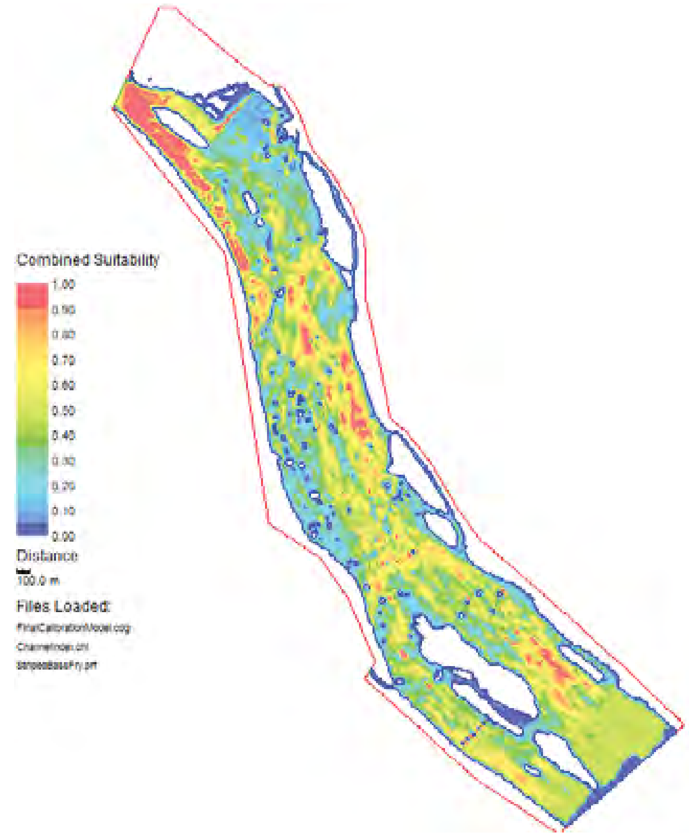
Striped Bass Fry – 5,000 cfs



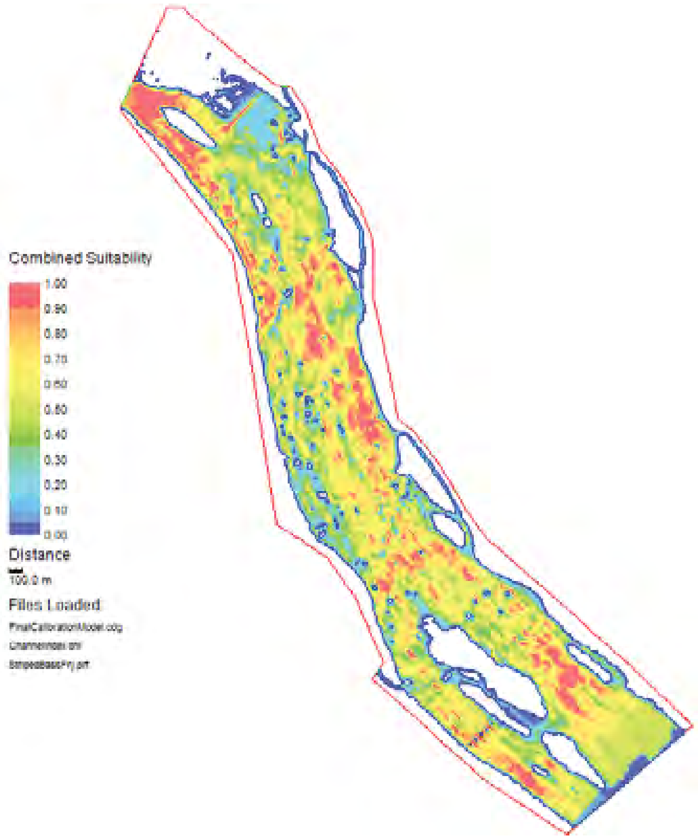
Striped Bass Fry – 7,500 cfs



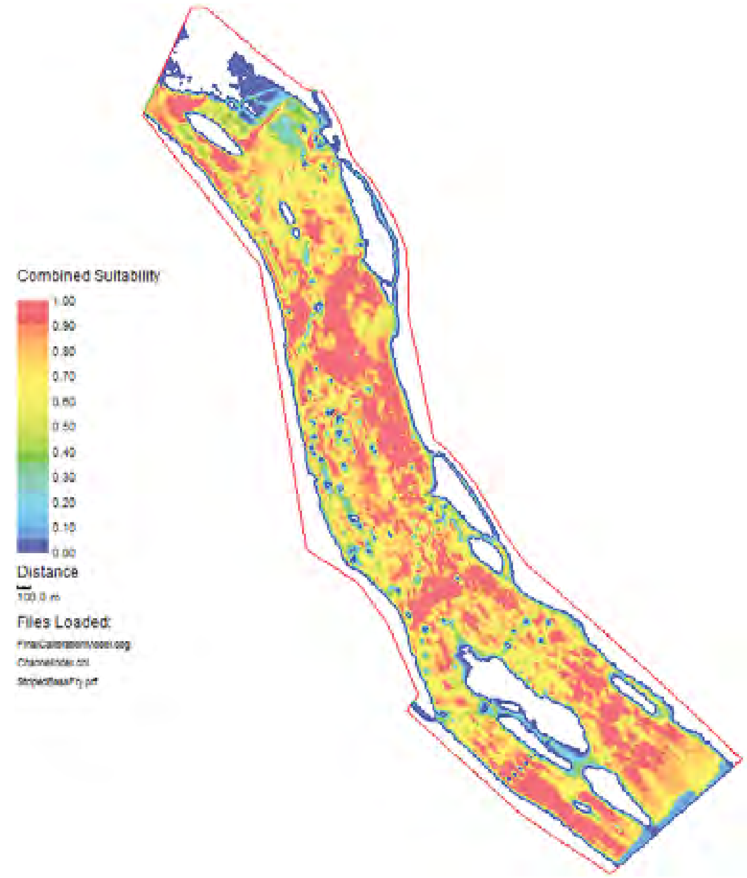
Striped Bass Fry – 10,000 cfs



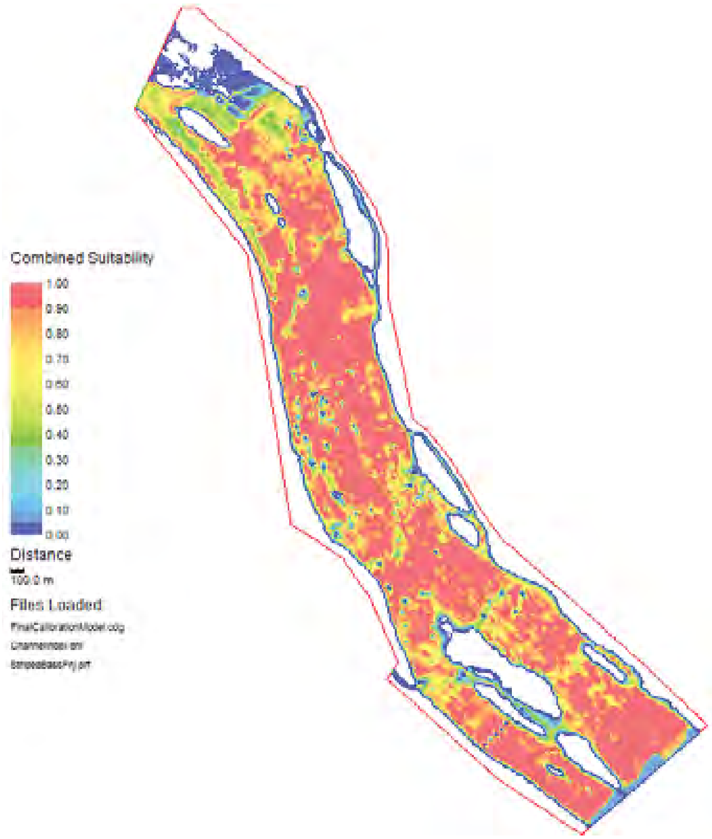
Striped Bass Fry – 15,000 cfs



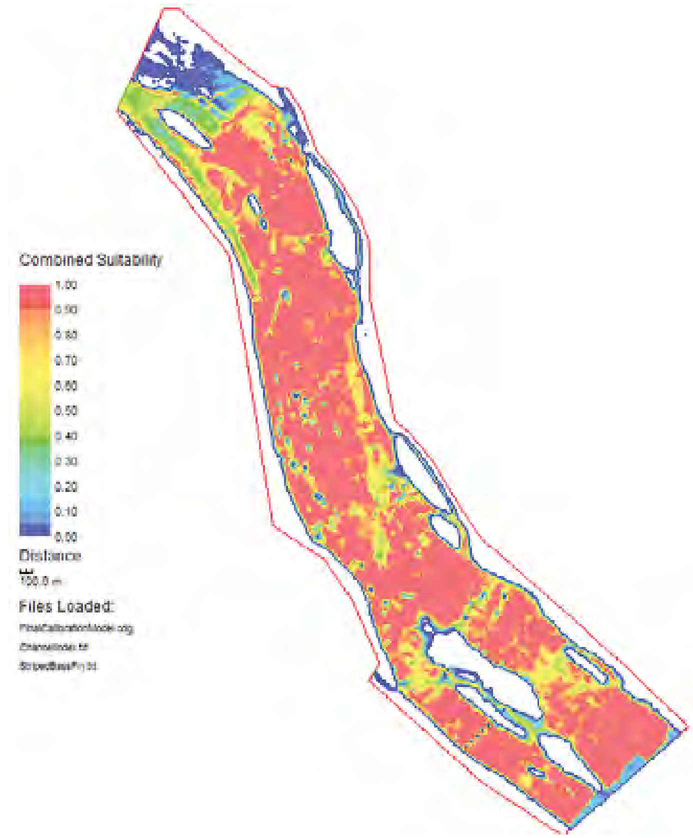
Striped Bass Fry – 20,000 cfs



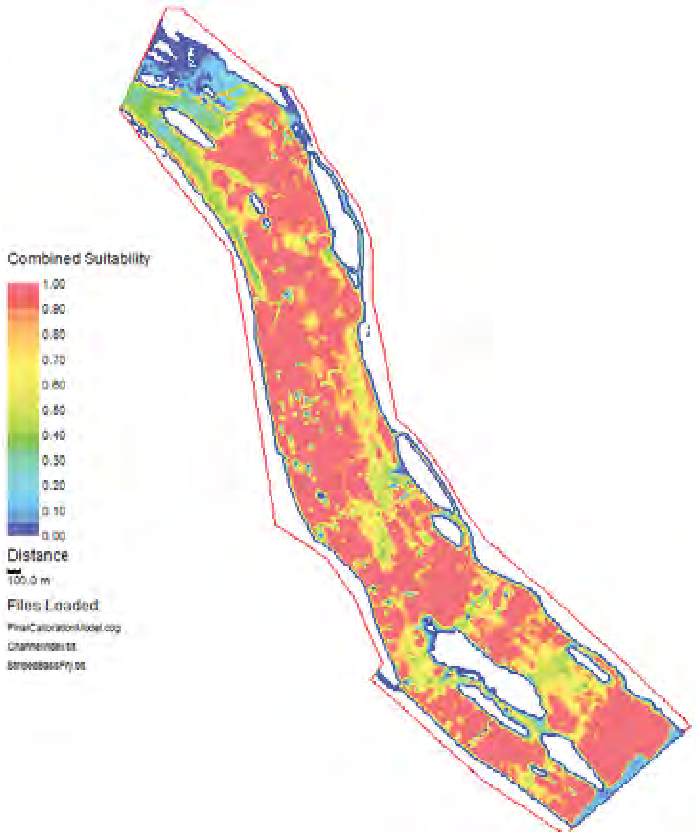
Striped Bass Fry – 30,000 cfs



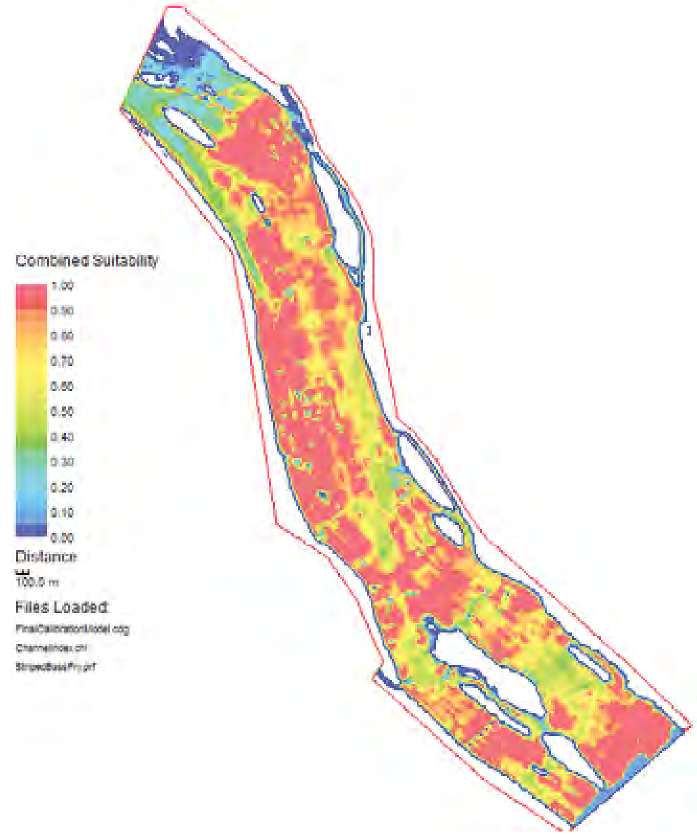
Striped Bass Fry – 40,000 cfs



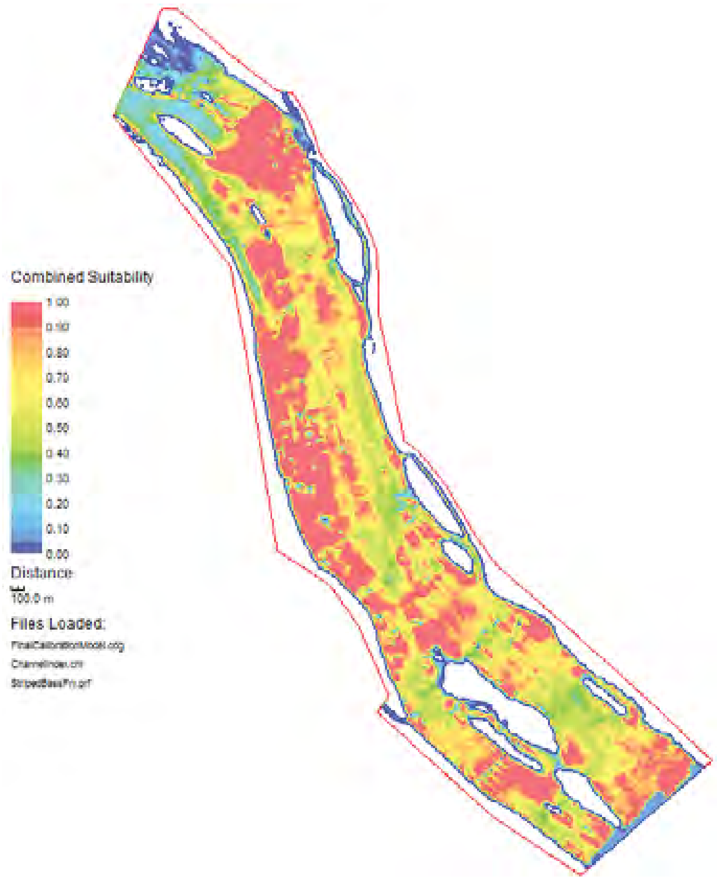
Striped Bass Fry – 50,000 cfs



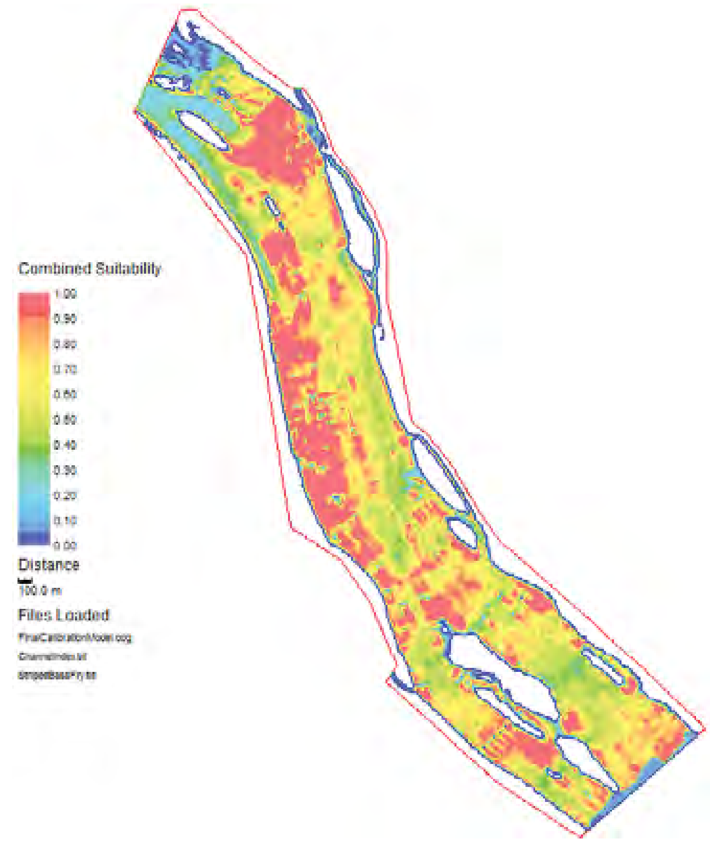
Striped Bass Fry – 60,000 cfs



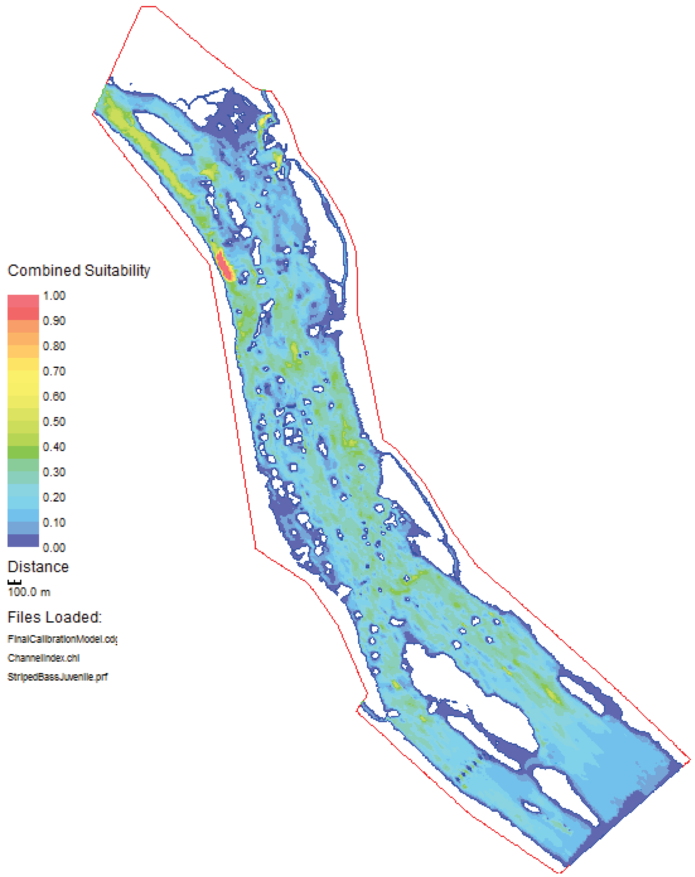
Striped Bass Fry – 70,000 cfs



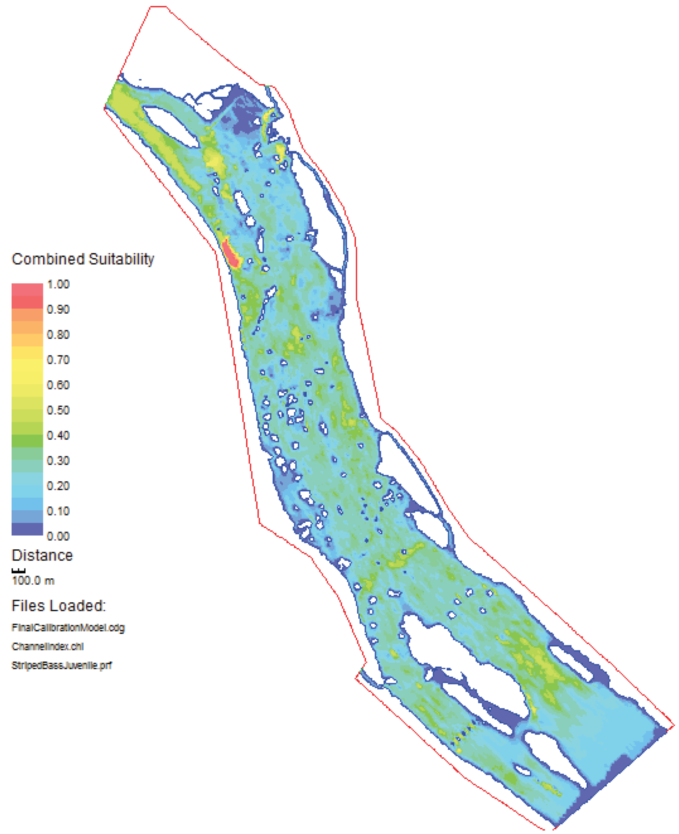
Striped Bass Fry – 80,000 cfs



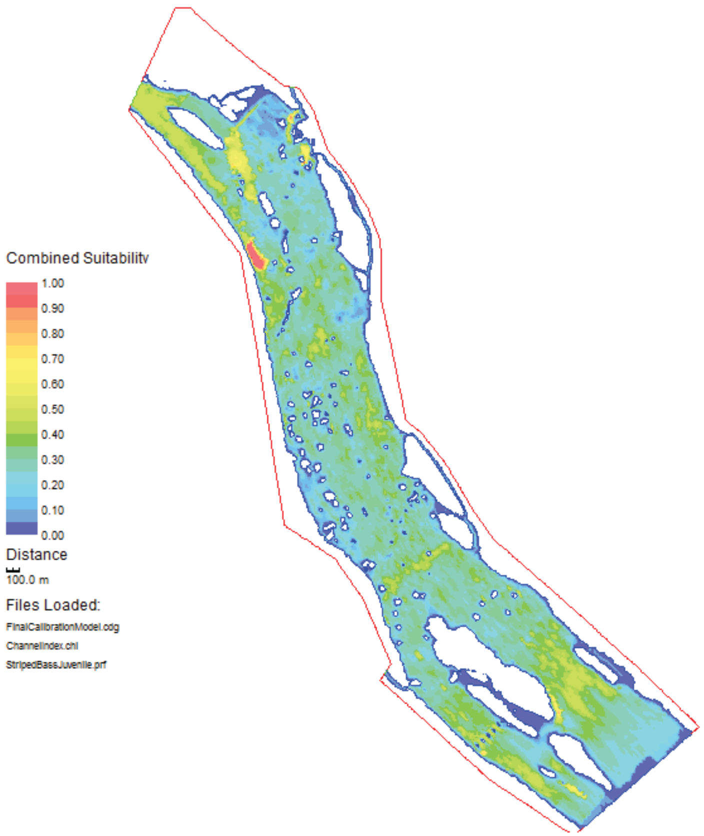
Striped Bass Fry – 86,000 cfs



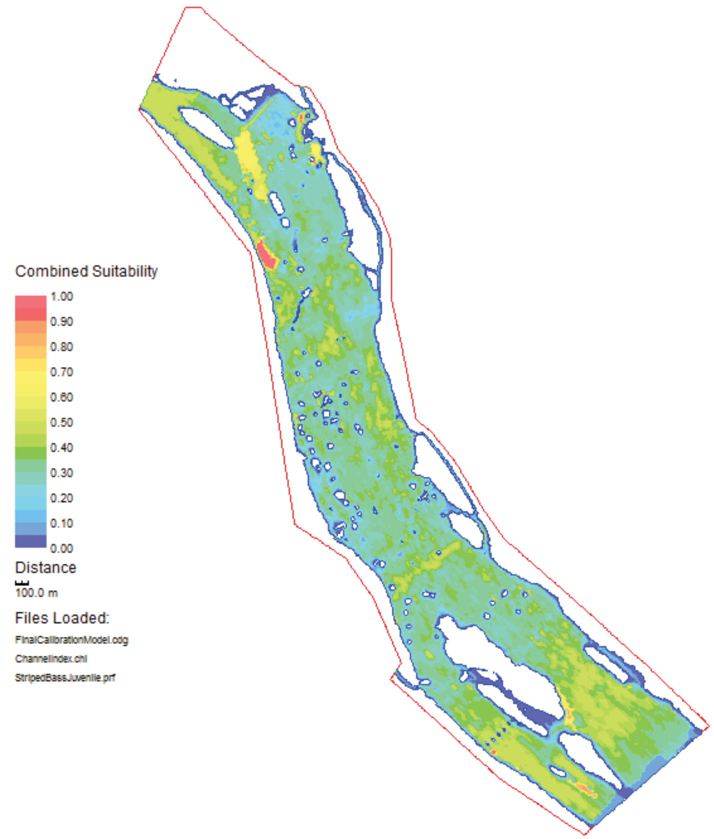
Striped Bass Juvenile – 2,000 cfs



Striped Bass Juvenile – 3,500 cfs



Striped Bass Juvenile – 5,000 cfs



Striped Bass Juvenile – 7,500 cfs