TRANSCANADA HYDRO NORTHEAST INC.

ILP Study 9 - Instream Flow
Final Study Report

In support of Federal Energy Regulatory Commission Relicensing of:

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

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EXECUTIVE SUMMARY

The goal of this study was to assess current project operational impacts on downstream aquatic resources and habitats in project-affected riverine reaches below Wilder, Bellows Falls and Vernon dams. Study objectives were to compute a habitat index versus flow relationship for key aquatic species and use that relationship to generate habitat duration time series over the range of current normal project operation flows. This final study report updates the interim report filed March 1, 2016, incorporates comments and input from consultation with the aquatics working group, and includes time series and dual flow analysis of the effects of flow fluctuation on selected species and life stages.

This study was based primarily on Physical Habitat Simulation (PHABSIM) which utilizes depth, velocity and substrate as primary measures of aquatic habitat. A total of 85 1-dimensional (1D) transects, inclusive of split and side channels, were established: 43 in Wilder (divided among three reaches), 19 in Bellows Falls, 7 in the Bellows Falls bypassed reach, and 16 in Vernon. Two 2-dimensional (2D) sites were chosen to represent island complexes in the Wilder riverine reach, one site specifically selected for modeling Dwarf Wedgemussel (DWM) habitat. Sumner Falls, a unique bedrock feature downstream of Wilder dam, was evaluated using a combination of a qualitative demonstration flow assessment (DFA) and quantitative depth and wetted width measurements.

Target aquatic species and associated habitat suitability curves (HSC), selected in consultation with stakeholders, represent 24 aquatic species/life stages in addition to four generalized habitat criteria (GHC). In addition, HSC were developed for DWM through a Delphi process (Study 24, Normandeau and Biodrawversity, 2016) and HSC for co-occurring mussel species were developed primarily using existing data collected in the prior Study 24 field studies (Biodrawversity, the Louis Berger Group, and Normandeau, 2014; 2015). Habitat index values were calculated for all species/life stages found within each study reach. The results for flow versus habitat are based on steady state hydrology and do not take into account flow fluctuations related to project operational flows. Habitat versus flow relationships vary greatly between species and life stages and differing flow ranges produce differing optimum habitat. Fry life stages generally show an inclination toward lower flows. Spawning life stages with similar periodicity can show opposing flow requirements. For example, American Shad and Walleye prefer considerably higher flows than Smallmouth Bass and Fallfish, though they all overlap during May.

The effect of operational conditions on aquatic species was evaluated through habitat time series and dual flow analyses. Time series was conducted for all species and life stages and GHC for the three projects. Hydrology was based on five modeled operational years from Study 5 – Operations Modeling Study (Hatch, 2016) and output consisted of habitat duration curves. Dual flow analysis evaluated habitat persistence and quality habitat persistence for all fry and spawning life stages, Tessellated Darter, GHC, and mussel species.

No single flow range, whether daily or seasonally can provide suitable habitat conditions for all species and life stages. Instream flow time series and dual flow analyses are tools that can assist in the decision making process for evaluating current or alternative flows and the effects on important fish habitats and other flow-dependent resources. Results from other ILP studies in conjunction with this study can provide a basis and rationale for deciding future project flow recommendations.

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List of Abbreviations

1D	1-dimensional
2D	2-dimensional
ADCP	Acoustic Doppler Current Profiler
ArcGIS	Geographic Information System
AWS	area weighted suitability
cfs	cubic feet per second
cms	centimeters per second
CR	critical reach
CRWC	Connecticut River Watershed Council
CSI	combined suitability index
DF	dual flow
DFA	Demonstration Flow Analysis
DWM	Dwarf Wedgemussel
FERC	Federal Energy Regulatory Commission
FirstLight	FirstLight Power Resources
fps	feet per second
ft	foot or feet
FWS	US Department of Interior, Fish and Wildlife Service
HEC-RAS	Hydrologic Engineering Centers River Analysis System
GHC	generalized habitat criteria
GPS	Global Positioning System
HSC	Habitat Suitability Criteria
IFIM	Instream Flow Incremental Methodology
ILP	Integrated Licensing Process
in	inch
ISR	Initial Study Report
LiDAR	Light Detection and Ranging
m	meter
NHDES	New Hampshire Department of Environmental Services
NHFGD	New Hampshire Fish and Game Department
PHABSIM	Physical Habitat Simulation System
RHABSIM	Riverine Habitat Simulation
RHYHABSIM	River Hydraulics and Habitat Simulation
RTK	Real Time Kinematic
SEFA	System for Environmental Analysis

SPD	Study Plan Determination
SSR	Site and Transect Selection Report
SZF	stage at zero flow
TNC	The Nature Conservancy
TransCanada	TransCanada Hydro Northeast Inc.
USGS	US Geological Survey
USR	Updated Study Report
VAF	velocity adjustment factor
VANR	Vermont Agency of Natural Resources
VFWD	Vermont Fish and Wildlife Department
WSE	water surface elevation
WUA	weighted useable area

1.0 INTRODUCTION

Operations at TransCanada's Wilder, Bellows Falls and Vernon Hydroelectric Projects (projects) may affect fish and aquatic resources in the riverine sections downstream of each project dam and in the Bellows Falls bypassed reach. In their study requests, the Federal Energy Regulatory Commission (FERC), US Fish & Wildlife Service (FWS), New Hampshire Department of Environmental Services (NHDES), New Hampshire Fish & Game Department (NHFGD), Vermont Agency of Natural Resources (VANR), Connecticut River Watershed Council (CRWC), and The Nature Conservancy (TNC) identified issues regarding the potential effects of current project operations on fish and aquatic resources. Specifically, requesters were interested in answering the following questions:

- are current minimum flows adequate to protect aquatic resources downstream of project dams; and
- what is the effect of current project operations on fish and aquatic resources.

The Revised Study Plan (RSP) for ILP Study 9 – Instream Flow Study, as supported by stakeholders in 2013 and approved by FERC in its February 21, 2014 Study Plan Determination (SPD), provided an overview of the methodology employed during 2014 and 2015 to assess the overall relationship between stream flow and resultant habitat of key aquatic species in the project-affected riverine reaches. This final study report summarizes data collection methods, and presents study results and analyses for the riverine and bypassed sections of the Connecticut River downstream of the three project dams.

A standard approach to instream flow analysis since 1980 has been the Instream Flow Incremental Methodology (IFIM). IFIM is a structured habitat evaluation process initially developed by the Instream Flow Group of FWS in the late 1970s to allow comparison of alternative flow regimes for water development projects (Bovee and Milhous, 1978; Bovee et al., 1998). The IFIM may involve multiple scientific disciplines and stakeholders, in the context of which hydraulic habitat simulation studies are usually designed and implemented. All aspects of this study were based upon discussions and agreements forged during aquatics working group meetings and project area site visits.

This study was based primarily on Physical Habitat Simulation (PHABSIM) which utilizes depth, velocity, and substrate as primary measures of aquatic habitat. It utilizes 1-dimensional (1D) and 2-dimensional (2D) hydraulic habitat modeling as one aspect of the IFIM process for the evaluation of instream flow needs as related to aquatic habitat. Sumner Falls, a unique bedrock feature downstream of Wilder dam, was evaluated using a combination of a qualitative demonstration flow assessment (DFA) and quantitative depth and wetted width measurements.

2.0 STUDY GOALS AND OBJECTIVES

The goal of the Instream Flow Study (Study 9) was to assess current project operational impacts on downstream aquatic resources and habitats. The specific objectives of this study were to:

- Compute a habitat index versus flow relationship for key aquatic species in each study reach; and
- Use the habitat index versus flow relationship to develop a habitat duration time series analysis over the range of current "peaking flows" (normal project operational flows) and dual flow analysis to evaluate the effects of different flow regimes.

3.0 STUDY AREA

The study area includes all project riverine segments of the Connecticut River from Wilder dam to just downstream of Vernon dam (Figure 3.1). Riverine segments consist of a 17.7-mile segment from Wilder dam to Chase Island near Windsor, Vermont; a 5.8 mile segment from Bellows Falls dam to Dunshee Island near Westminster, Vermont; the Bellows Falls bypassed reach; and a 1.5-mile segment downstream of Vernon dam. The Wilder riverine segment was further divided into three sub reaches based on hydrologic accretion: reach 1 from Wilder dam downstream to the White River confluence (1.5 mi); reach 2 from White River downstream to the Ottauquechee River (5.2 mi), and the lowest reach from the Ottauquechee River downstream to the upper end of the Bellows Falls impoundment at Chase Island (11.0 mi).

Study reaches:

- Wilder riverine segment (RM 217.4 – 199.7):
  - Reach 1 – Wilder Dam to White River – 1.5 miles;
  - Reach 2 – White River to Ottauquechee River – 5.2 miles;
  - Reach 3 – Ottauquechee River to Chase Island – 11.0 miles.
- Bellows Falls riverine segment (RM 173.7 – 167.9):
  - Single reach – Bellows Falls powerhouse to Dunshee Island – 5.8 miles;
  - Bellows Falls bypassed reach – Bellows Falls Dam to backwater pool below powerhouse (approximately 3,500 feet long).
- Vernon riverine segment (RM 141.9 – 140.4):
  - Single reach –Tailrace below Vernon Dam to bottom of Stebbins Island – 1.5 miles.

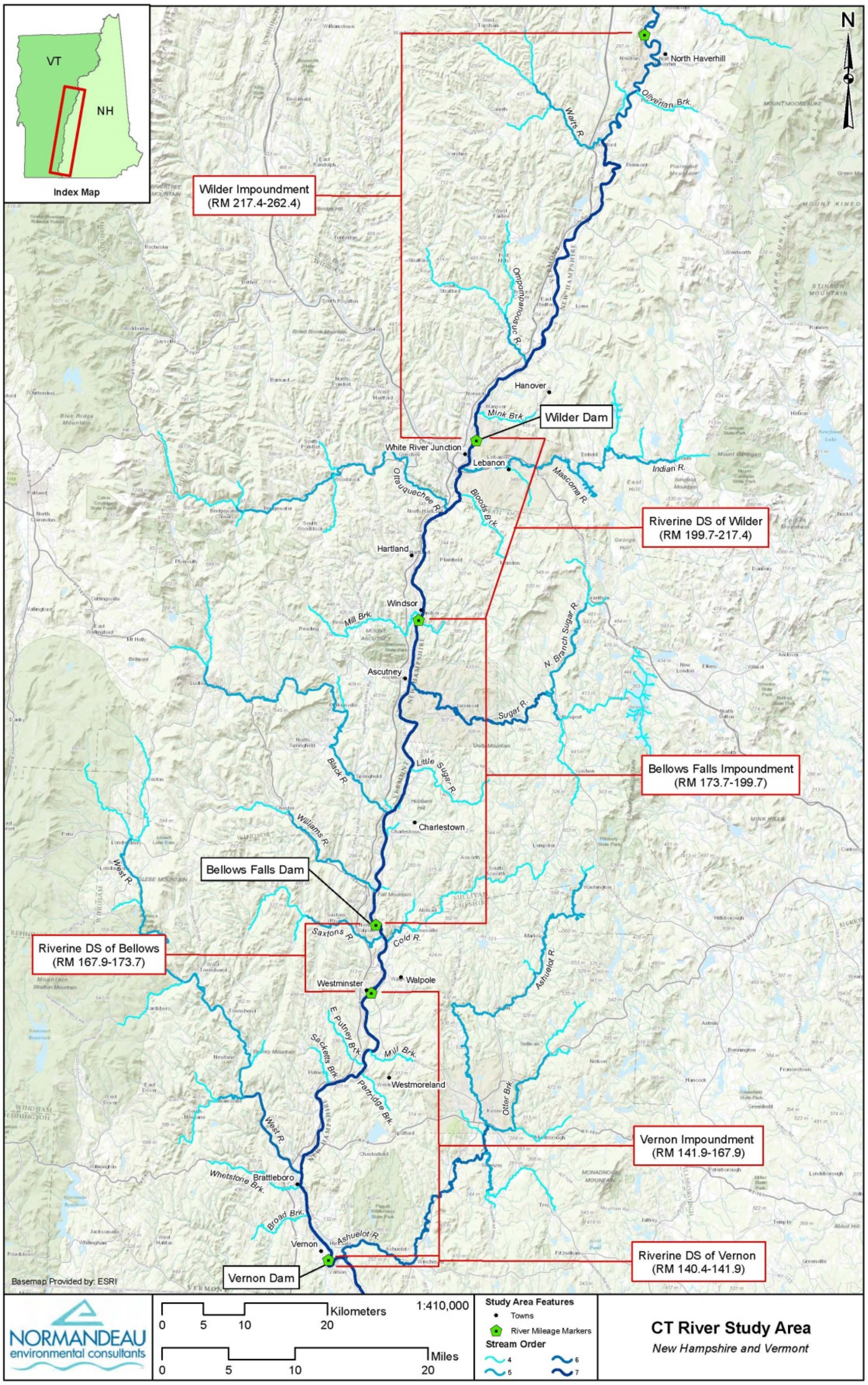


Figure 3.1. Study area.

4.0 METHODS

Specific elements of the Instream Flow Study were:

- Aquatic Habitat Mapping from Study 7 – Aquatic Habitat Mapping (Normandeau, 2015);
- Study Site, Transect Selection, and Sumner Falls Demonstration Flow Assessment (DFA)
- Identification of Key Aquatic Species and Life Stages;
- Selection of Habitat Suitability Criteria (HSC);
- Hydraulic Data Collection;
- Hydraulic and Habitat Modeling;
- Hydrology Development (Study 5 – Operations Modeling Study [Hatch, 2016]);
- Time Series Analysis; and
- Flow Fluctuation and Dual Flow Analysis.

4.1 Habitat Mapping

A PHABSIM study begins with a representative sample of hydraulic and physical habitat conditions within the study area. Generally, the samples are represented by cross sections for 1-dimensional (1D) models or a topographic grid for 2-dimensional (2D) models. For this study, a mesohabitat mapping approach originally described by Morhardt et al. (1983) and summarized by Bovee et al. (1998) was used. This process not only assists in selecting study sites, but also weighting and proportioning the habitat indices based on habitat representation. Habitat mapping methods are described in the Study 7 - Aquatic Habitat Mapping Study Report (Normandeau, 2015).

There were 6 mesohabitat types identified from Study 7. Pools were separated into deep and shallow categories based on evaluation of depth frequency derived from habitat mapping:

- Pool – deep, low velocity with a generally well-defined control and retains water at zero discharge.
    - Deep Pool – maximum depth > 15 ft
    - Shallow Pool – maximum depth < 15 ft
- Glide – shallow flats with moderate velocity distributed across the channel, without a well-defined thalweg, resemble shallow pool if velocities are low.

- Run – deep to moderately deep with fast velocity in a well-defined thalweg, surface may be turbulent, substrate variable.
- Riffle – shallow with gravel, cobble, or boulder substrate, fast water with turbulent flow or white-water, possible exposed substrate.
- Rapid – shallow bedrock, boulder with turbulent white-water flow and possible exposed substrate, may be brief and abrupt across the stream channel or extend for a greater distance.
- Cascade – steep, high gradient, bedrock or boulders with drops and falls.

Based upon the river conditions described in the Study 7 report, pool (deep and shallow combined) was overall the most abundant habitat type in the Wilder and Bellows Falls riverine segments, accounting for over 50 percent of aquatic habitat. Riffle habitat was quite rare, making up 5 percent in the Wilder reach and less than 2 percent in the Bellows Falls reach. No riffles were identified in the Vernon reach, and comparatively equal proportions of pool, run and glide mesohabitats were present. There was a single rapid (Sumner Falls in Wilder reach 3) and a single cascade (below the fish barrier in the Bellows Falls bypassed reach) identified during habitat mapping.

4.2 Study Site and Transect Selection

Study site and transect selection methods for 1D transects in the Wilder, Bellows Falls and Vernon riverine reaches are described in the Revised Instream Flow Site and Transect Selection Report (Revised SSR; Normandeau, 2014a). Selection of study sites and 1D transects was based on mesohabitat distribution within each reach. That report provides proposed 1D transect locations and mesohabitat types, and was used as a guide during the transect selection process by the aquatics working group. Final transect locations were decided upon during the field portion of transect selection with the working group. In most instances transects were placed in the same locations as indicated in that report. The few exceptions and justifications are noted in the results section of this report for those reaches where modifications occurred.

Two 2D model sites were established in the Wilder riverine reach. One at Johnston Island in Wilder reach 2, a complex of braided channels and multiple mesohabitat types that includes the majority of riffle habitat found in the reach. A second 2D study site was established in the lower portion of Wilder reach 3, which includes Chase Island, and spans the transition from the free-flowing reach to the uppermost extent of the Bellows Falls impoundment. This 2D site was selected primarily to assess mussel habitat and encompasses historic Dwarf Wedgemussel (DWM) monitoring sites above and below the Cornish Covered Bridge and also near Horseback Ridge, though no live DWM were found above or below the Cornish Covered Bridge in 2013 surveys (Biodrawversity, the Louis Berger Group, and Normandeau, 2014). However, Study 24 surveys in 2014 (Biodrawversity, the Louis Berger Group, and Normandeau, 2015) did find DWM near the downstream end of Chase Island and also just downstream from the railroad bridge, and both areas fall within the 2D study site. The 2D model site, in conjunction with Study 24 Phase 2 quantitative sampling and development of suitability criteria for co-occurring mussel species, was used to address stakeholder requests for an assessment of potential effects of project flow regimes on DWM and co-occurring mussel populations.

4.2.1 Bellows Falls Bypassed Reach

Overall, pool habitat makes up 73 percent of the Bellows Falls bypassed reach, run accounts for 16 percent, and riffle for 8.5 percent. Initially, based on apparent substrate and hydraulic complexity, it was thought a 2D model might be appropriate to model aquatic habitat in this reach. However, after examination of the reach during habitat mapping it was determined that capturing all hydraulic features such as boulder and bedrock eddies or substrate interstices would be unlikely, especially in the upper portion of the reach. In addition, there are hydraulic drops that are not conducive to 2D modeling.

During site visits to the Bellows Falls bypassed reach on August 11, 2014, working group participants were able to view a series of flows between approximately 300 cfs (somewhat higher than typical leakage flows of 125 cfs) and 3,000 cfs. At that time it was agreed that transects could be used to model aquatic habitat in the upper portion of the reach. Subsequently, 7 transects were established to represent habitat variability in the upper portion of the reach. TransCanada consultants noted that it would only be possible to safely acquire velocity data on all transects at the leakage flow and potentially some transects at around 1,000 cfs. Participants agreed that whatever information could be collected would be beneficial.

4.2.2 Sumner Falls

Sumner Falls consists of irregular bedrock ledge formations that cross the Connecticut River and includes steep riffles, rapids, chutes and pools. The value as aquatic habitat for fish and other species is unknown, though rearing life stages have been observed and fishing is known to take place in the pool just below the falls. Due to the complexities of Sumner Falls, a typical PHABSIM study using either 1D or 2D models was considered unfeasible consequently a demonstration flow assessment (DFA) was proposed by VFWD (letter dated August 27, 2014).

The study goal put forth by VFWD and others was to assess flows at Sumner Falls and determine an appropriate flow that could:

- Maintain water depths that provide suitable aquatic habitat conditions; and
- Minimize dewatering or stranding.

VFWD prepared a revised study plan for Sumner Falls on November 10, 2014 and TransCanada drafted an updated proposal dated December 15, 2014, focusing the study on the upper section of the falls. As proposed, the DFA would involve creating a detailed topographic map of the study area (upper portion of falls) with elevation contours of 0.5 ft. Based on this map, a wetted area and depth delineation map would be produced at different flow levels using depth criteria of 0.5 ft, 0.7 ft (suitable depth for most juvenile fish species) and 1.0 ft (suitable depth for most adult fish). After additional discussion it was decided that establishing a group of three to five transects and gages to supplement a series of flow observations would be more feasible and provide the necessary information (summarized at a February 10, 2015 aquatics consultation conference call). TransCanada prepared an updated study plan on March 6, 2015 which was subsequently accepted by the participants on a July 14, 2014 conference call (documents included in Appendix B of Volume I of the USR filed with FERC on September 14, 2015).

Four-foot-long sections of rebar painted alternately in black and white in 0.1-ft increments were used as staff gages. Three to six gages were positioned at strategic points across each transect, one on each bank and others in locations where channel and water surface elevation changes occurred (Figure 4.2-2). In areas too deep or swift to survey an estimate of the bottom profile was made based on readings as close to the thalweg as possible. The rebar were driven into holes drilled approximately 4 inches deep into the bedrock. A subsequent check of the gages after overnight operations proved that they were not affected by high flows and water velocity.

Figure 4.2-2. Generic representation of cross sectional profile and gage locations of transects for the Sumner Falls DFA.

Target flows were provided by controlled releases from Wilder dam, and the quantity measured with acoustic Doppler current profiler (ADCP) equipment downstream of Sumner Falls at the time of each assessment. Changes in stage were recorded for each flow level at each transect by reading the gages with a high powered scope. In addition, TransCanada acquired aerial imagery at different flow levels using a drone aircraft, though these were not used for quantitative measurements. Transect information were used to asses changes in wetted width and depth within the study area at the different flow levels observed.

4.3 Identify Key Aquatic Species and Life Stages

The RSP identified the primary aquatic species and life stages:

- American Shad (*Alosa sapidissima*)
- Walleye (*Sander vitreus*)
- Fallfish (*Semotilus corporalis*)
- Longnose Dace (*Rhinichthys cataractae*)
- White Sucker (*Catostomus commersonii*)
- Smallmouth Bass (*Micropterus dolomieu*)
- Tessellated Darter (*Etheostoma olmstedi*)
- Sea Lamprey (*Petromyzon marinus*)
- Macroinvertebrates
- Larval fish and eggs of target species
- Dwarf Wedgemussel (*Alasmidonta heterodon*)
- Co-occurring mussel species found in the study area

Through consultation with the working group one additional species, Rainbow Trout (*Oncorhynchus mykiss*), and one additional life stage, Longnose Dace fry were added. In addition, generalized habitat criteria (GHC), which can provide a measure of how habitat changes with flow, were recommended. Final species, life stages, and reaches identified for modeling are shown in Table 4.3-1.

Table 4.3-1. Target species and life stages, periodicity, and reaches to model.

	Species	Life Stage	Periodicity	Reach	Comment
1	American Shad	J	June 7 - Nov 30	V, B	
2	American Shad	A	May 1 - June 30	V, B	
3	American Shad	S	May 1 - July 15	V, B	
4	Walleye	FR	May 1 - July 1	V, B, W	
5	Walleye	J	Year round	V, B, W	
6	Walleye	A	Year round	V, B, W	
7	Walleye	S	April 1 - May 31	V, B, W	
8	Fallfish	FR	June 1 - July 1	V, B, W	
9	Fallfish	J	Year round	V, B, W	
10	Fallfish	A	Year round	V, B, W	
11	Fallfish	S	May 1 - June 30	V, B, W	
12	White Sucker	FR	June 1 - Sep 30	V, B, W	
13	White Sucker	J/A	Year round	V, B, W	
14	White Sucker	S	April 1 - June 30	V, B, W	
15	Longnose Dace	J	Year round	V, B, W	Study 10
16	Longnose Dace	A	Year round	V, B, W	Study 10
17	Longnose Dace	Y	July 1 - Sep 30	V, B, W	Not found in Study 10
18	Tessellated Darter	A	Year round	V, B, W	
19	Sea Lamprey	S	May 1 - July 15	V, B, W	
20	Smallmouth Bass	Y	July 1 - Sep 30	V, B, W	
21	Smallmouth Bass	J	Year round	V, B, W	
22	Smallmouth Bass	A	Year round	V, B, W	
23	Smallmouth Bass	S	May 1 - June 30	V, B, W	
24	Macroinvertebrates	-----	Year round	V, B, W	
25	Rainbow trout	A	Winter/Spring(stocked)	B	Cover TBD
26	GHC shallow-fast	SF	June 7 - Nov 30	V, B, W	
27	GHC shallow-slow	SS	May 1 - June 30	V, B, W	
28	GHC deep-fast	DF	May 1 - July 15	V, B, W	
29	GHC deep-slow	DS	May 1 - July 1	V, B, W	
30	Dwarf Wedgemussel	-----	Year round	B, W	Study 24
31	Co-occurring mussels	-----	Year round	V, B, W	Study 24

Table Key:

Life Stage Abbreviations

A	Adult
J	Juvenile
S	Spawning & Incubation
Y	Young-of-Year
FR	Fry
GHC	Generalized Habitat Criteria

Study Reaches

B	Bellows
V	Vernon
W	Wilder

Study 10 – Fish Assemblage

Longnose Dace adult and juvenile found in Wilder and Bellows Falls riverine reaches

and Bellows Falls bypassed reach.

4.4 Selection of Habitat Suitability Criteria (HSC)

During study planning, it was agreed that TransCanada could use Habitat Suitability Curves (HSCs) developed as part of FirstLight's Turners Falls Project (FERC No. 1889) relicensing for target species and life stages that are the same. TransCanada submitted a draft Study 9 HSC report on December 15, 2014 (Normandeau 2014b) which included the FirstLight HSCs along with some recommended modifications, and proposed HSC for Smallmouth Bass (the only species not on the FirstLight target species list). After additional consultation, working group representatives responded to the report on July 9, 2015 accepting all proposed HSC with the exception of Tessellated Darter (recommendations were made for changes to the curve) and added Longnose Dace fry and Rainbow Trout adult criteria. Relevant consultation documents were included in Appendix B of Volume I of TransCanada's USR filed with FERC on September 14, 2015.

Rainbow Trout adults are found in the Connecticut River as a result of stocking, according to NHFGD Stocking Reports, and potential holdover in the study area (although none were captured during Study 10 – Fish Assemblage Study). The working group recommended the addition of this species-life stage using two different velocity criteria associated with and without velocity refuges. The curves were developed for the Clyde River, a small stream in Vermont where velocity refuges in the form of large substrate are common. Boulders are rare in the Connecticut River within the project area, and the utility of the rainbow trout curves to differentiate refugia is impractical. The occurrence of rainbow trout in the study area is based on sporadic stocking. Recent stocking reports from NHFGD for 2014 and 2015 indicate rainbow trout have only been stocked within the project area in the Bellows Falls reach at Walpole. None were stocked within the project area in 2016 due to low flow conditions and high water temperatures. Because rainbow trout are a supplemental species provided on a seasonal basis for fishing opportunities, and is unlikely to be used for any decision making regarding instream flows, no further analysis has been performed at this time, constituting a minor study plan variance.

TransCanada proposed to develop suitability criteria for some mussel species found within the project-affected areas through the Dwarf Wedgemussel and Co-occurring Mussel Study Phase 2 sampling (Biodrawversity, the Louis Berger Group, and Normandeau, 2015). HSC for Dwarf Wedgemussel (DWM) was developed through a Delphi process described in detail by Normandeau (2016a). The methods used to develop HSC for co-occurring mussels was described in a follow-up report by Normandeau and Biodrawversity (2017) and presented in the Study 24 – Development of Habitat Suitability Criteria for Co-occurring Mussels report (Normandeau, 2017).

Unlike the depth, velocity, and substrate or cover HSC used for other target species, habitat suitability for mussel species relied upon a much larger suite of HSC variables. The benthic and non-mobile nature of mussels and the importance of near-bed shear stresses as discussed among the Delphi panel experts led to the application of seven variables for modeling mussel habitat suitability including:

- Water depth
- Mean column water velocity
- Benthic water velocity
- Substrate composition
- Bed shear stress
- Relative (dimensionless) shear stress
- Shear Velocity

The co-occurring mussel habitat analysis utilized the first six HSC variables but dropped the seventh, due to the feeling of Delphi panelists that shear velocity was redundant to the previous two shear variables and could be dropped from the analysis. Another difference between the DWM and the co-occurring HSC is the source of the HSC curves. Whereas the DWM HSC were developed from professional judgement of the Delphi panel experts, with reference to field data collected in other locations, the co-occurring HSC was developed using site-specific data collected on Eastern Elliptio (*Elliptio complanata*) from the Study 24 field surveys (Biodrawversity, the Louis Berger Group, and Normandeau, 2014; 2015). Elliptio was utilized to represent co-occurring mussels because it is a common species in many locales and represented 87% of all mussels counted in the Chase Island study site (Study 24 – Normandeau and Biodrawversity, 2017). In contrast, the remaining co-occurring species were too rare to develop site-specific HSC. Site specific HSC developed for co-occurring mussels was similar to the HSC developed for DWM for mean column water velocity and benthic water velocity but quite different for bed shear stress, relative shear stress and substrate.

Final HSC and sources for all species are provided in Appendix A (all appendices filed separately).

4.5 Hydraulic Data Collection

Data collection methods for the Bellows Falls bypassed reach are provided in Section 5.4 of this report.

4.5.1 1D Transects

Field data collection and data recording generally followed the guidelines established in the Instream Flow Group (IFG) field techniques manuals (Trihey and Wegner, 1981; Milhous et al., 1984; Bovee, 1997). Additional quality control checks found valuable from previous applications of the simulation models were included. Data collection at each transect consisted of water surface elevation (WSE), cross-section profile elevation (calculated from survey data or water depths), velocity, and substrate composition.

Target calibration flows for developing stage-discharge rating curves for each transect are identified in Table 4.5-1. A minimum of three sets of calibration flow measurements are normally required for adequate model calibration. The basic rule-of-thumb for 1D hydraulic models used in IFIM modeling is they are most reliable between 0.4 times the low calibration flow and 2.5 times the high calibration flow. The range of calibration flows selected allows the 1D hydraulic model simulation to cover normal project operations, between minimum flow and station capacity (Table 4.5-2), and flows up to 25,000 cfs.

Table 4.5-1. Target calibration flows by reach for 1D transect data collection (all Wilder reaches based on release from dam).

Reach	Target Flows		
	Low (cfs)	Middle (cfs)	High (cfs)
Wilder Reach 1	700-2,000	5,000	10,000-12,000
Wilder Reach 2	700-2,000	5,000	10,000-12,000
Wilder Reach 3	700-2,000	5,000	10,000-12,000
Bellows Falls	1,300-2,000	4,500-7,500	9,000-11,000
Vernon	1,600-2,500	5,000-7,500	10,000-12,000

Table 4.5-2. Project operating flows for Wilder, Bellows Falls and Vernon.

Project	Required Minimum (cfs)	Generation Minimum (cfs)	Station Capacity (cfs)
Wilder	675	700	10,700
Bellows Falls	1,083	1,300	11,400
Vernon	1,250	1,600	17,100

One complete set of depths and velocity measurements were collected at each transect at the target high flow or in the case of the Bellows Falls bypassed reach, a flow level that could be effectively and safely measured. Velocity data was collected using a TRD Instruments Rio Grande 1.2 MHz-ADCP mounted on a boat or encased in a rigid 4-ft trimaran hull that can be tethered to the side of a boat or other type of vessel, or pulled across the channel along a tag line. In areas that could not be effectively measured using the ADCP, such as shallow areas inaccessible by boat, velocity measurements were acquired by wading techniques using electromagnetic or mechanical flow meters attached to top-set rods. When wading, mean column velocity was measured at six-tenths of the water depth in depths less than 2.5 feet and at two-tenths and eight-tenths of water depth in depths between 2.5 ft and 4.0 ft. All three points were measured where depths exceeded 4.0 ft, if possible.

Substrate composition information was collected across each transect at low flow or when visibility allowed (Table 4.5-3). In deep areas where the bottom was not visible, an underwater camera was deployed to discern substrate. Because there are often different coding systems used for hydraulic modeling and HSC, some based on dominant substrate or other combinations, a complete assessment of substrate is necessary to encompass any potential coding system. For this study percent composition of all substrate types was collected at each point or blocks of points if substrate did not change over a range of stations (offsets along transect line).

Table 4.5-3. Substrate codes and sizes used for the instream flow study.

Code	Description	Particle Size (mm)	Particle Size (in)
1	Detritus/Organic		
2	Mud/ Clay		
3	Silt	<0.06	<0.002
4	Sand	0.06 – 2.0	0.002 – 0.10
5	Gravel	2.0 – 64.0	0.10 – 2.5
6	Cobble	64.0 – 250.0	2.5 – 10.0
7	Boulder	250+	10+
8	Bedrock		

Source: Bovee, 1982.

Additional quality control checks that have been found valuable during previous studies were employed. Basic field measurement protocols were as follows:

- Staff gages were established and continually monitored throughout the course of collecting data at each study site.
- An independent benchmark, such as an immovable object or additional rebar, was established for each transect or set of transects.
- All elevation surveying was done using an auto-level and telescoping stadia rod. Upon establishment of pin elevations, or during calibration flow surveys, a level loop was shot to check the auto-level measurement accuracy or account for any potential field errors. Allowable error tolerances on level loops were set at 0.02 ft, unless extenuating circumstances such as known movement of pins or benchmarks were noted.
- Water surface elevations were measured on both banks of each transect. If possible, on more complex transects such as riffles with uneven water surface elevations, additional measurements were taken across transects.
- Pin elevations and water surface elevations were calculated during field measurement and compared to previous readings to confirm accuracy.
- Flow meters were calibrated and monitored on a daily basis. Marsh-McBirney Flo-Mate Model 2000 electromagnetic meters or mechanical AA and pygmy meters were used for wading velocity measurements. Marsh-McBirney meters are calibrated to zero velocity and are accurate to $\pm$ 0.05 ft/s and AA and pygmy meters are calibrated using

a spin test and are accurate to ± 3.4% of the true velocity at 0.5 ft/s and ±1.5% of the true velocity at 3.0 ft/s.

- Photographs were taken of all transects at the three calibration flows. An attempt was made to shoot each photograph from the same location at each flow level.

A Leica Viva GS14 Real Time Kinematic (RTK) unit was used to survey pin and benchmark elevations. In some cases, due to geographic aspect or vegetative canopy, reliable measurements could not be made. The elevations measured are not critical to 1D hydraulic modeling but do allow for an additional calibration check of changes in water surface elevations between transects. They were also used to apply representative cross sections to the US Army Corps of Engineers Hydrologic Engineering Centers River Analysis System (HEC-RAS) model (Study 4 - Hydraulic Modeling Study).

4.5.2 2D Study Sites

The 2D hydrodynamic model uses a detailed topographic map of the study site to solve basic equations for conservation of mass and conservation of momentum in two horizontal directions to simulate water depths and velocities. Model inputs are bed topography, channel roughness, and upstream and downstream boundary conditions for water surface elevation and discharge. The x/y/z bathymetric coordinates for the model were collected by boat in deeper areas and by wading in shallow or out-of-water sections.

The equipment used to collect bathymetry at 2D sites consisted of a Leica Viva GS14 RTK unit, a TRDI 1200 kHz ADCP, and USGS Bathmapper software loaded on a Panasonic Toughbook computer. The RTK was mounted directly over the ADCP enabling a horizontal positioning accuracy of less than 0.03-in (0.01-m) and provided vertical water surface positional information at an accuracy of less than 0.1-ft (0.02-0.03 m) to compensate for fluctuations in water levels. The ADCP similarly collected four depth measurements (one for each of the four transducers) every second. All data was streamed to the on-board laptop and processed with the USGS Bathmapper software. The Bathmapper software filtered the data and displayed maps of the vessel track where data was collected. In areas that could not be accessed by boat the RTK unit was used to collect point data to map the river banks, gravel bars and water surface perimeter.

In areas where visibility allowed, substrate was recorded by drawing polygons of areas with similar composition on aerial imagery. In deep areas where the bottom was not visible a boat with an underwater camera was deployed, marking boundaries of different substrate composition with GPS. These boundaries were overlaid in ArcGIS for post-processing to map out additional substrate polygons.

4.6 Hydraulic Modeling

Hydraulic modeling for the Bellows Falls bypassed reach is provided in Section 5.4 of this report.

4.6.1 1D Transects

For 1D application in this study, the hydraulic models and habitat index simulations were performed using SEFA (System for Environmental Flow Assessment, http://sefa.co.nz/). This program was developed jointly by originators of the primary models used in instream flow studies, Tom Payne (RHABSIM), Bob Milhous (PHABSIM), and Ian Jowett (RHYHABSIM), and merges and expands on the capabilities of these older software packages.

The ADCP uses its own proprietary software (WinRiver, RD Instruments) for data acquisition and playback (Figure 4.6-1). Because the ADCP collects water velocities throughout the water column at relatively short intervals, it is necessary to synthesize and condense velocities to mean column for use by PHABSIM software. For this task an ADCP conversion program was developed that allows a user to interactively view bottom profiles and velocity patterns and establish stationing (Figure 4.6-2). The profiles are reversed because WinRiver assumes the user is looking downstream while the standard for PHABSIM transects is looking upstream. Offsets on transects were established at 3-6 ft intervals' depending on their complexity and width. Intervals of 1-2 ft were created for some narrow side channel cross sections. In most cases between 100 to 200 points were established for main channel transects.

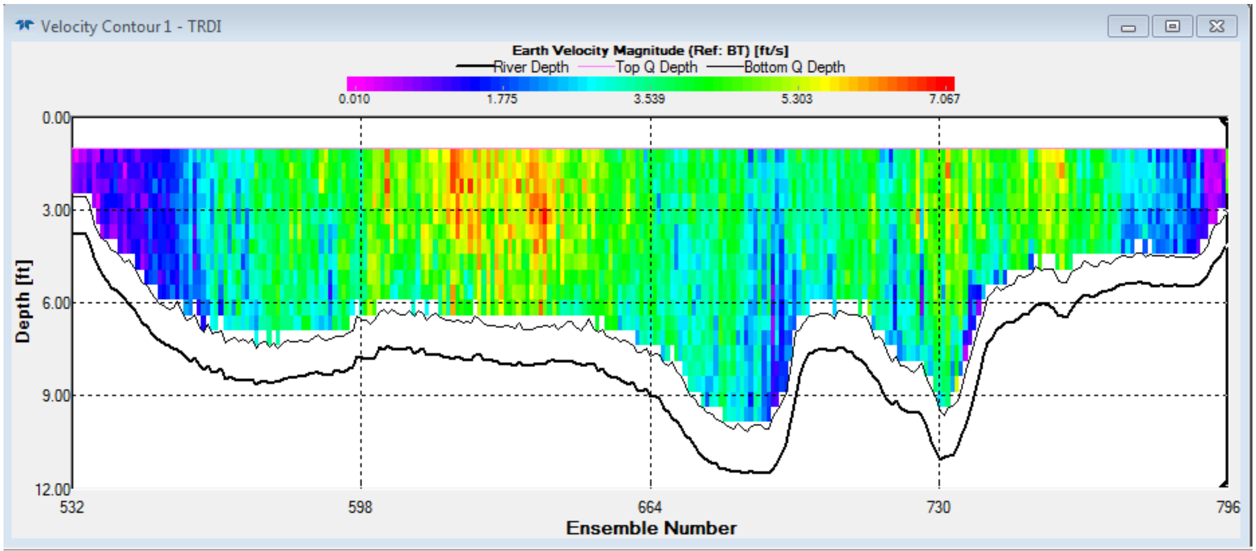


Figure 4.6-1. ADCP output graph from WinRiver.

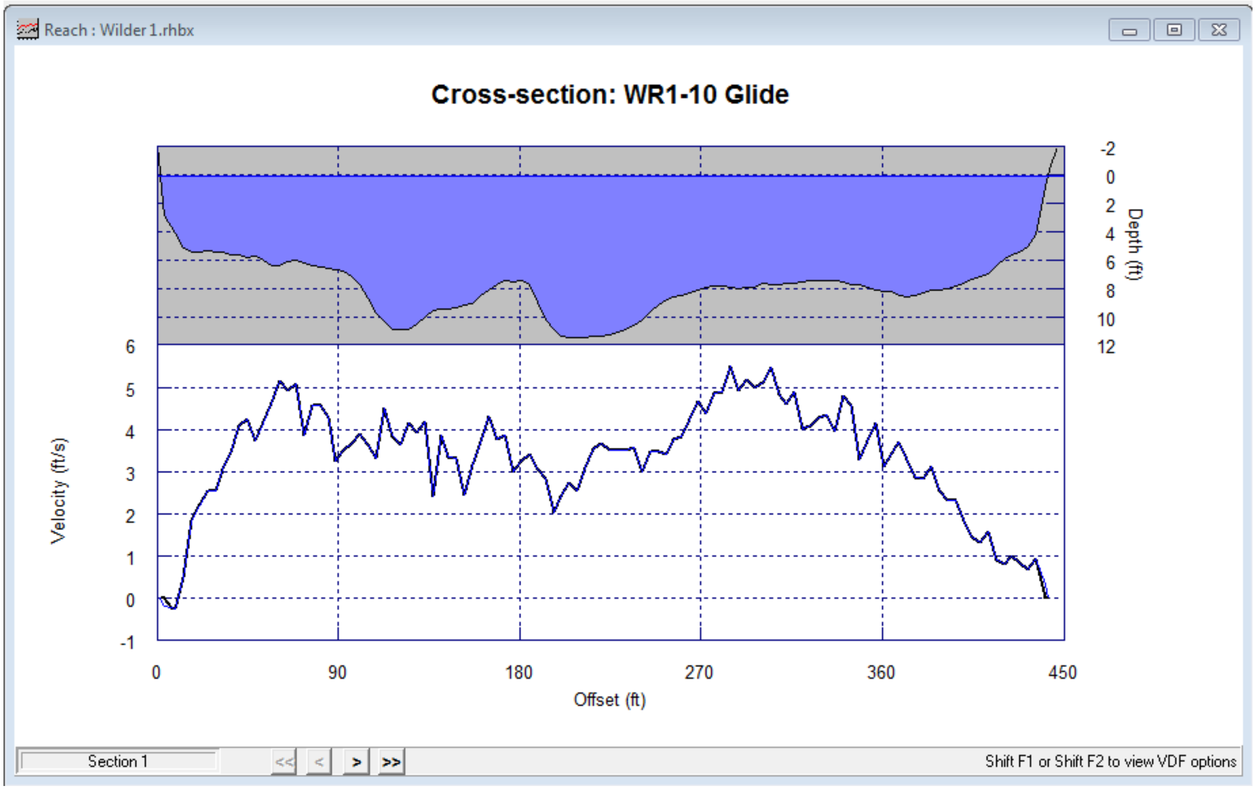


Figure 4.6-2. Transect converted for use in PHABSIM hydraulic model (note: reversed bottom profile).

Stage-Discharge Calibration

Stage-discharge relationships for each transect were developed from measured discharge and water surface elevations using either an empirical log/log formula or a hydraulic channel conveyance method. Under these methods each transect is treated independently. The log/log rating method requires a minimum of three sets of stage-discharge measurements and an estimate of stage-at-zero-flow for each transect. The quality of the stage-discharge relationships is evaluated by examination of mean error (10% or less is good, less than 5% is excellent) and slope output from the model.

Channel conveyance only requires a single stage-discharge pair and utilizes Manning's equation to determine a stage-discharge relationship (Bovee and Milhous, 1978). However, it is generally validated by additional stage-discharge measurements. In situations where irregular channel features occur on a cross section, for instance at bars or terraces, channel conveyance is often better at predicting higher stages than log/log. Conveyance is most often used on riffle or run transects and is not suitable for transects which have backwater effects from downstream controls, such as pools. It can also be used as a test and verification of log/log relationships.

Stage-discharge calibration of split channels was made by calibrating each channel as a separate component. Under this method flow splits must be measured or estimated over the range of simulated flows. SEFA contains a braided channel element that allows split channels to be modeled and flow splits calculated, even if WSE and bed elevations differ between channels.

Velocity Calibration

A single set of measured velocities was used to predict individual cell velocities over a range of flows. Simulated velocities are based on measured data and a relationship between a fixed roughness coefficient (Manning's n) and depth. In some cases roughness or velocity was modified for individual points if substantial velocity errors were noted at simulation flows. Velocity adjustment factors (VAFs) or velocity distribution factors (VDF's) were examined to detect any significant deviations and determine if velocities remain consistent with stage and total discharge. VAFs in the range of 0.9 to 1.1 at the calibration (velocity acquisition) flow are considered good. For those transects or portions of transects where velocities could not be acquired by ADCP or wading due to safety concerns or other extenuating circumstances, a combination of depth-calibration (fixed Manning's n) and roughness coefficient adjustment was used to fill in missing data.

4.6.2 2D Study Sites Model Calibration

For 2D applications in this study, the River2D model was used (Steffler and Blackburn, 2002). River2D is a two-dimensional, depth-averaged hydrodynamic and fish habitat model developed for use in natural streams and rivers. The fish habitat module is based on the PHABSIM habitat index approach, adapted for a triangular irregular spatial grid network. Habitat analysis uses HSC inputs like those used by PHABSIM.

The ground survey data, bathymetry and Light Detection and Ranging (LiDAR) data were combined and processed using ArcMap and entered into the bed topography editor of the River2D program. The resulting digital elevation model, or bed file, was used as the topographic input for the hydrodynamic model. Boundary conditions are also necessary inputs for the hydrodynamic model; they included the external computational boundary, the inflow discharge at the upstream boundary, and water surface elevations at the outflow boundary. All of these data are incorporated into the computational mesh before their use in the River2D program. The River2D model uses a finite-element method to perform numerical calculation of flow conditions. This method allows for a variable-density mesh where areas of hydrologic and/or biological significance can be represented in greater detail. Artificial channel extensions of approximately one/two channel width were added upstream and downstream of the areas of interest in order to minimize boundary condition effects on the modeled areas.

Model calibration consisted of adjusting the roughness values in the model until a reasonable match, generally within 0.1 ft, was obtained between the simulated water surface elevations and the water surface elevations measured at the upstream end of the study area of each modeled flow. Flows between 1,200 cfs and 13,000 cfs were modeled with each flow change run to a steady state solution. That is, for a constant inflow, the model is run until there is a constant outflow and the two flows are essentially equal. Typical convergence tolerance is 1% of the inflow. Another measure of convergence is the solution change. Ideally the solution change will become sufficiently small (0.00001) once converged. In some cases, the solution change will reach a relatively small value and refuse to decrease any further indicating a small, persistent oscillation at one or more points. This oscillation is often associated with a shallow node that alternates between wet and dry. This oscillation may be considered acceptable if the size of the variation is within the desired accuracy of the model (Steffler and Blackburn, 2002).

4.7 Habitat Modeling

The habitat index within SEFA is expressed as area weighted suitability (AWS) in units of m^2 /m or ft^2 /ft. This differs from the standard PHABSIM weighted usable area (WUA) of ft^2/1000 ft only in that the result is not based on distance normalized to 1,000 ft. The change was made in SEFA because the index does not represent an actual area upstream and downstream, but is a based only on points across the stream channel. The only “area” involved in the calculation of AWS is width between points.

Once the hydraulic data was calibrated, AWS by discharge was generated for all species and life stages approved for this study. For each transect data point, a combined suitability index (CSI) was calculated by multiplying the individual variable suitability’s for depth, velocity, and substrate from the HSC. This was multiplied by the width each point represents, summed, and multiplied by the transect weighting. The substrate habitat suitability curve describes the suitability of each substrate category, and the substrate suitability at the measurement point is the sum of the suitability for each category multiplied by the percentage of that substrate category at the point.

The fish habitat component of River2D is based on the same concept used in PHABSIM. The CSI was calculated as the product of suitability values for depth, velocity, and channel index (substrate and/or cover codes). WUA (m^2 or ft^2) for the entire site was calculated by expanding the composite suitability index for every point in the model domain with the area associated with that point, and then summing those values for all points. Substrate coding was based on dominant/subdominant suitability values, with dominant substrate given twice the weight of subdominant. River 2D does not have the capability to use substrate percentages as can be done in SEFA.

DWM and co-occurring mussels required additional steps outside of the 1D SEFA and River2D models. With the exception of shear velocity, shear related variables needed for calculating DWM and co-occurring mussel AWS and WUA are not outputs of 1D and 2D models. Bed shear stress, relative shear stress, and benthic velocity must be calculated independently and computing relative shear stress requires an additional variable, critical shear stress. The formulas below used for computation were taken from Allen and Vaughn (2010) with the exception of benthic velocity.

Bed Shear Stress (BSS):

$$p\ (U)^2$$

Where: p = water density (62.3 lb/ft^3, 0.988 gm/cm^3)

U = shear velocity (fps, cms)

Critical Shear Stress (CSS):

$$\theta_c\ g\ D_{50}\ (p_s - p)$$

Where: θ_c = shields parameter (dimensionless)

g = acceleration of gravity (32.1 fps, 980 cms)

D_{50} = median particle size (ft, cm)

Ps = substrate density (165.4 lb/ft^3, 2.65 gm/cm3)

p = water density (62.3 lb/ft^3, 0.988 gm/cm^3)

The shields parameter is constant for given substrate sizes meaning only D_{50} needs to be determined. D_{50} is output from SEFA for 1D transects based on percent substrate composition and was calculated for 2D points based on the median dominant/subdominant substrate size, with dominant substrate being assigned twice the weight.

Relative Shear Stress (RSS):

$$BSS/CSS$$

Benthic Velocity (BV) based on 1/mth power law (Milhous et al., 1989):

$$V_n = V_{mc}(1+1/m)(D_n/D)^{1/m}$$

Where: V_n = nose velocity

V_{mc} = mean column velocity (fps, cms)

D_n = nose depth, distance from substrate (0.1 ft, 3.05 cm)

D = depth (ft, cm)

and $m = (c/n)\,D^{0.1667}$

c = constant (0.105 English units, 0.128 metric units)

n = Manning's n roughness coefficient

D = depth

Manning's n for 1D transects is an output of SEFA and was calculated for the 2D model based on standard Manning's n values for substrate size classes in natural channels. Though all or some of these variables may have an effect on mussel habitat, it is not clear what the driving factor may be. Standard multiplication of suitability values was used to calculate mussel AWS and WUA. With 6-7 variables the influence of a single small suitability value could override others even if they were all close to 1.0. All calculations were performed using Excel and Visual Basic macro programs written exclusively for this analysis.

4.8 Consultation on Habitat Modeling

Prior to modeling a number of meetings and memoranda exchanges took place between TransCanada and the aquatics working group to decide: 1) species and life stages to be modeled under the time series and dual flow analyses; 2) selection of paired flow combinations (minimum flow and generation flows) for the dual flow analysis; and 3) determine a sub-set of transects to be included in a "critical reach" (CR) evaluation in conjunction with standard assessment using all transects.

A study consultation meeting was held on July 15, 2016 followed by a teleconference on August 2. TransCanada proposed critical reaches for analysis in a memorandum dated July 26. The working group proposed a set of dual flow pairs in a letter from VANR dated July 22, 2016. TransCanada then proposed time series, critical reach, dual flow, and habitat persistence analysis via an email memorandum to the working group on September 13. Comments on the proposed analyses were provided in a joint agency letter on November 9. TransCanada responded to those comments and provided a smaller set of flow pairs for dual flow analysis (Section 4.10) via email on December 20, 2016.

4.9 Time Series Analysis

For the time series all species and life stages and Generalized Habitat Criteria (GHC) were included. AWS or WUA habitat index is a static relationship between discharge and habitat and does not represent the actual occurrence of habitat availability. For this reason a habitat index is generally not considered the final result of an instream flow study. The major basis for habitat time series analysis is that habitat is a function of stream flow and that stream flow varies over time. Habitat time series integrates AWS or WUA with hydrology to represent the magnitude and duration of available habitat seasonally or over periods identified as critical to a species/life stage, often under different operational regimes and/or water year (WY) types.

A habitat duration curve is constructed in exactly the same way as a flow duration curve, but uses habitat values instead of discharges as the ordered data (Figure 4.9-1); however, there is no direct correspondence between the two with regard to percent exceedance. For example, the habitat value that is exceeded 90 percent of the time usually does not correspond to a discharge level that has the same exceedance probability. This conflict happens because the relationship between AWS total habitat and discharge is often not linear. As a result, interpretation of habitat duration can be confusing because AWS with a given exceedance probability might be related to more than one discharge, low or high, each having different probabilities of exceedance. For example, the higher habitat values between 5% and 30% exceedance for a dry WY (Figure 4.9-2) correspond to flow exceedance values between 25% and 50% (Figure 4.9-3). However, the habitat duration curve is best used to quantify the differences in habitat between baseline and/or alternative conditions (Bovee et al., 1998).

Hydrology used in the time series is from the operations model in Study 5 (Hatch, 2016) for five modeled annual hydrologies in a one-hour time step based on ranking of a combination of annual inflow, spring inflow and annual energy production values. The years selected (1992, 1994, 1989, 2007 and 1990) correspond roughly to a progression from dry to wet years.

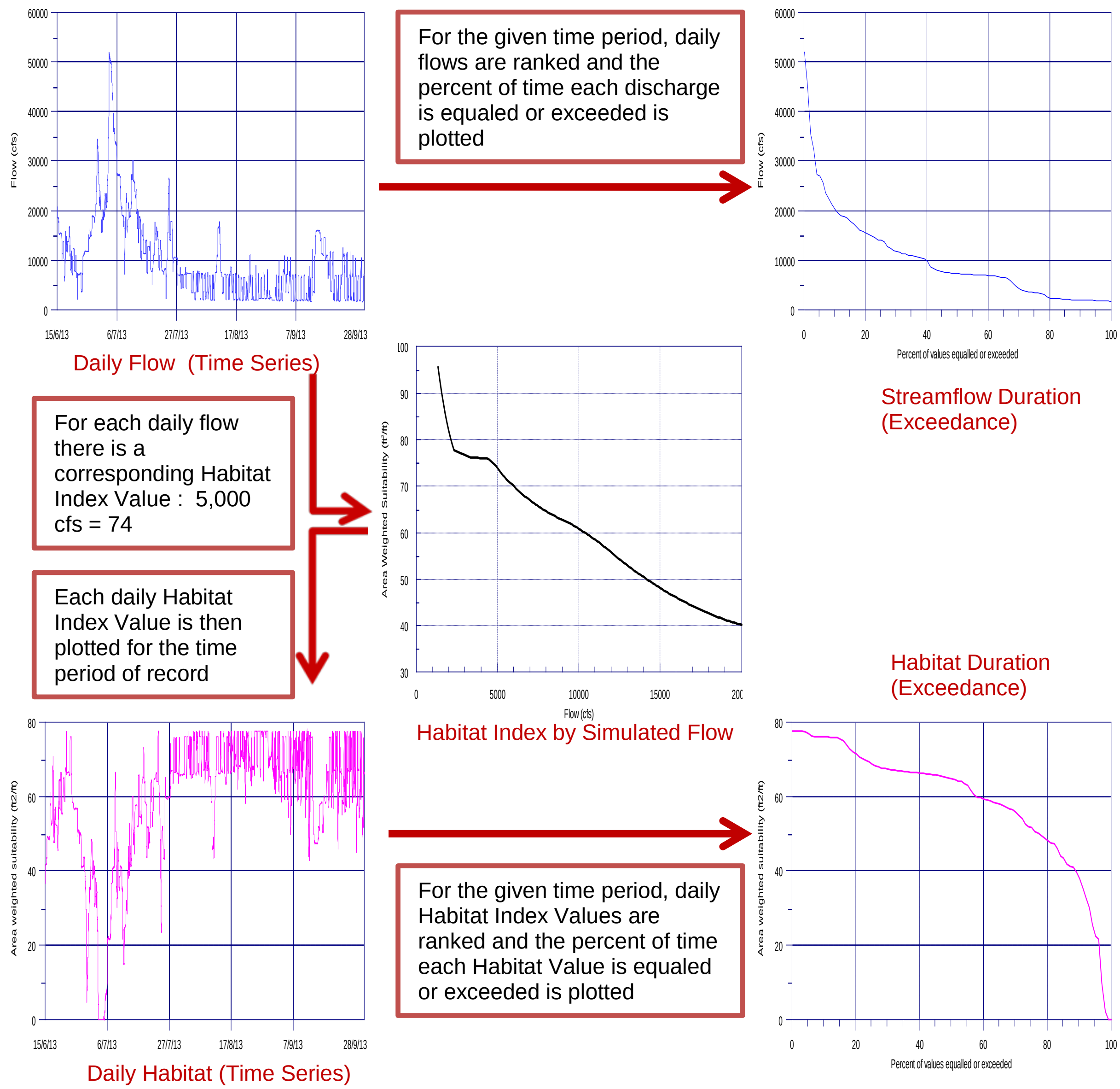


Figure 4.9-1. Time series flow chart.

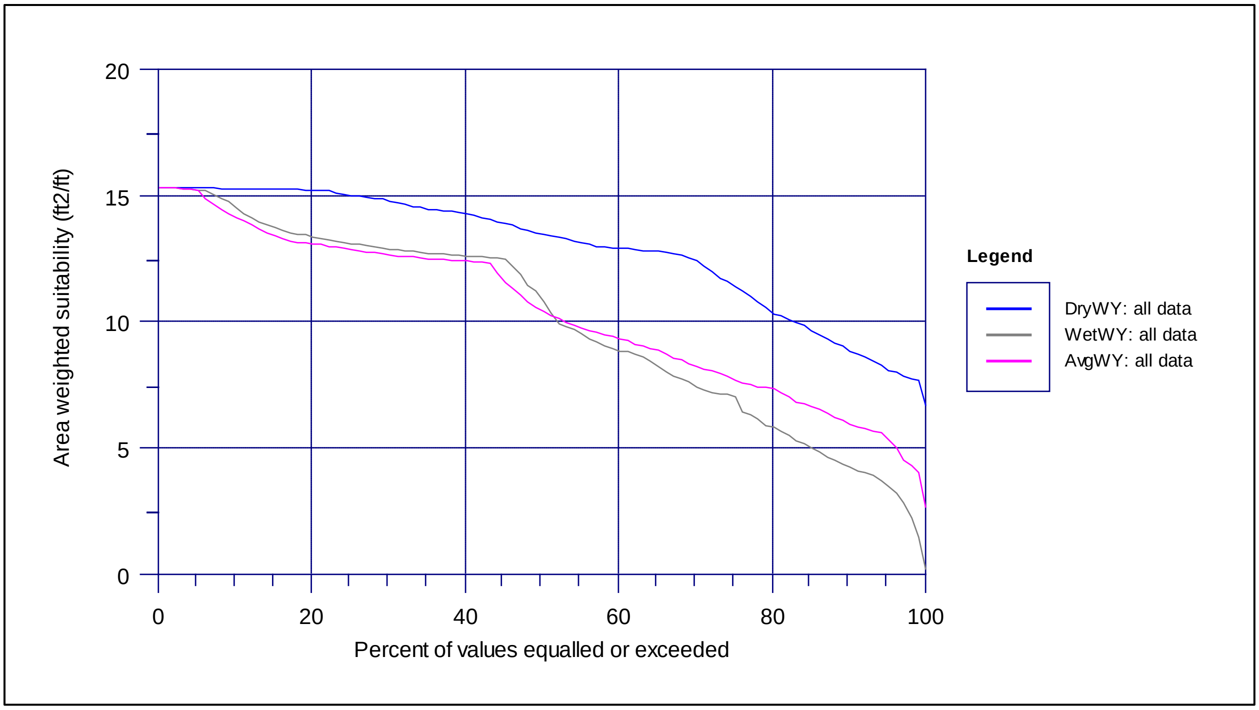


Figure 4.9-2. Example habitat duration curve for three water year (WY) types.

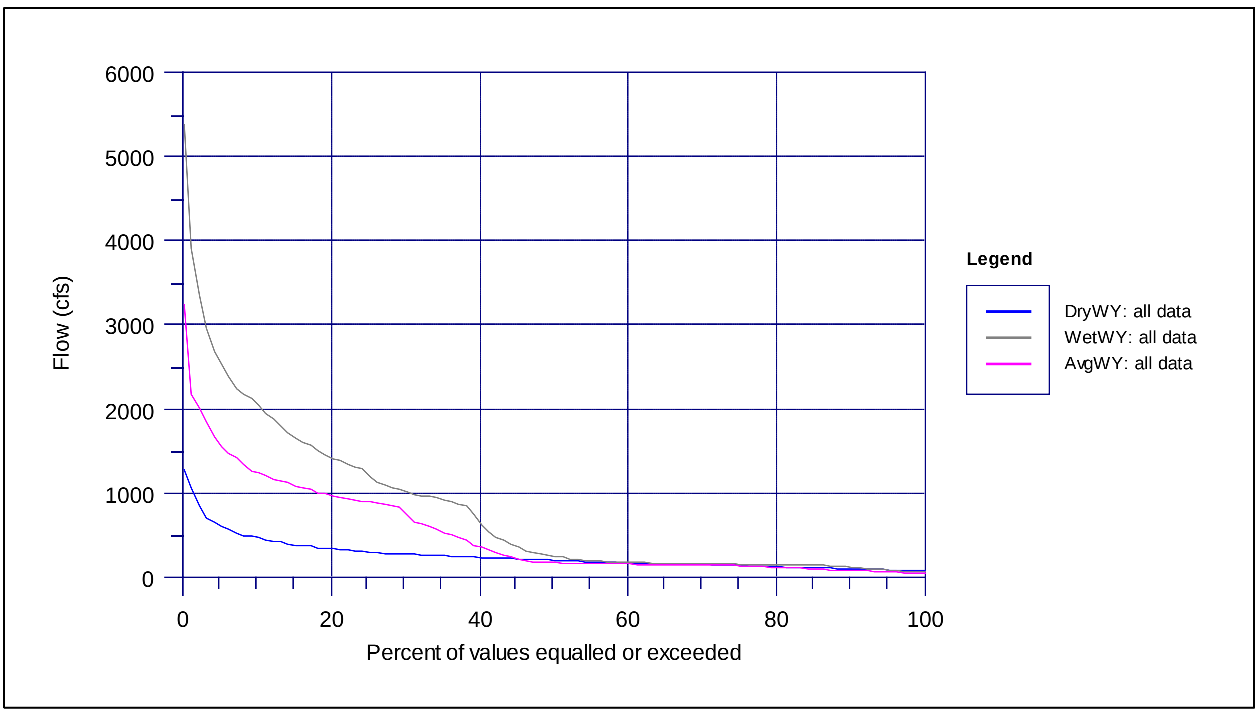


Figure 4.9-3. Example flow duration curve for three water year (WY) types.

4.10 Critical Reach Evaluation

The concept of a critical reach (CR) is that certain habitat types or features are important to some or all target species and life stages being evaluated through the instream flow study. A critical reach does not necessarily need to comprise groups of closely spaced transects or specific study sites, and may involve single transects widely spread out within a given reach.

A number of criteria were suggested by the aquatics working group for selecting CR transects:

- include all riffles;
- include diverse habitats associated with islands, mid-channel bars, and point bars;
- include transects that encompass identified Sea Lamprey spawning areas or potential lamprey spawning areas.

A memorandum dated July 26, 2016 described the selection process and location of CR transects in Wilder, Bellows Falls and Vernon reaches (see Section 5.2). In order not to diminish or increase the effect of any one transect or habitat type, particularly riffles which are rare, all transects were weighted equally for the CR analysis. The only exceptions are small side channels associated with Hart Island in Wilder reach 3, and at the top of the Vernon reach. Transects in these two channels were weighted based on proportions of length and area they represented relative to the reach.

4.11 Dual Flow and Persistent Habitat Analysis

The evaluation of flow fluctuations involves comparing habitat at a range of flows with habitat at a base or given flow. The amount of usable habitat is the minimum amount of habitat at a particular location over the range of flows. Thus, at each simulated flow, the amount of suitable habitat is the amount of habitat that overlaps in space with suitable locations that were available at the base flow. This is often identified as "persistent" habitat, and the analysis assumes that the target life stage is unable to move as flows change (eggs, mussels, and some fry life stages). Persistent habitat results are presented as tables or graphs indicating percent loss or gain in AWS over a specified flow cycle, for example from minimum flow to full generation flow. A dual flow analysis assumes the target organism is fully mobile (juvenile and adult life stages) so that any suitable habitat in the modeled reach is available. Thus the results are presented as bracketed values with persistent habitat as the lowest bound and the minimum suitable reach habitat of the two flows being evaluated as the upper bound.

Flow pairs were selected in consultation with the aquatics working group through a series of meetings and memorandums in 2016 as described in Section 4.8. Initial dual flow pairs were proposed by the aquatics working group based primarily on permutations of various generation flows and maximum turbine efficiency at each project. TransCanada proposed to condense the initial number of potential minimum-generation flow combinations by reducing the number of minimum flows and generation flows, though with the exception of Vernon, the number of generation flows remained similar. It should be noted that effects for intermediary flows can be interpolated from the results, so there is potentially no need to conduct additional paired flow analysis.

In addition to total habitat (AWS or WUA) comparisons, habitat was also evaluated based on quality using a CSI value threshold of ≥ 0.5. Under this framework only AWS and WUA derived from quality habitat is used for calculating persistent habitat.

Though persistent habitat for 1D transects can be calculated in SEFA there is no means to calculate persistent quality habitat for dual flow in SEFA. As a result it was necessary to perform all dual flow and persistent habitat calculations in Excel using Visual Basic macro programs developed for this purpose. For 1D transects, output of CSI values for each individual data point ("cell"), transect, and flow were imported into Excel. Data points for each transect were then matched up for each flow based on offset values. AWS and persistent AWS were calculated for individual transects, weighted and combined to produce the final results by reach. The advantage of this method is that results for the CR analysis merely involved changing individual transect weights. For 2D analysis CSI and WUA were output for each node and flow. Because output from the 2D model always consists of every node, whether it contains relevant data or not, data points remain paired for all flows.

5.0 RESULTS AND DISCUSSION

5.1 Study Sites and Transects

5.1.1 Wilder Reaches

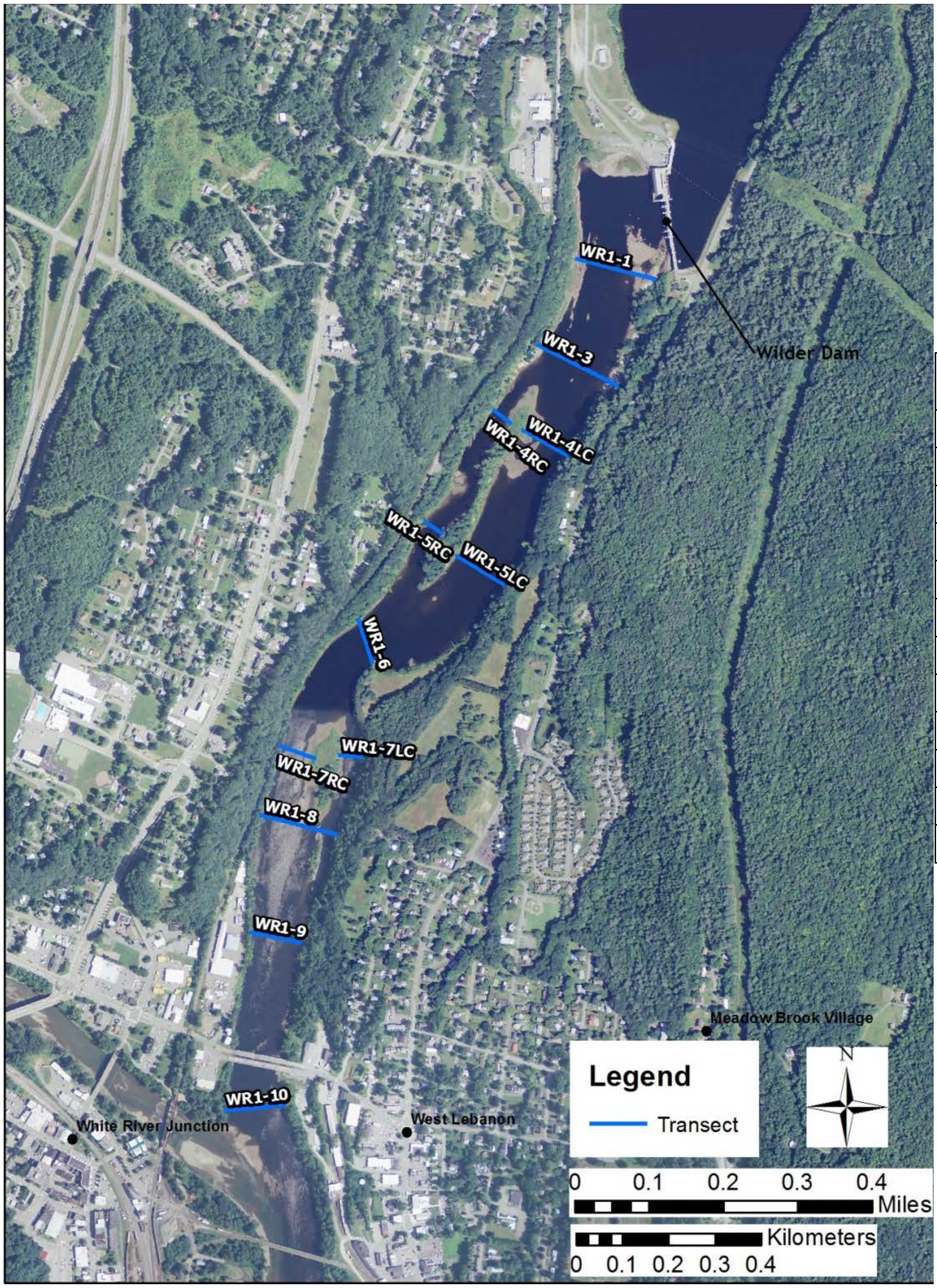
A total of 12 transects were placed in Wilder reach 1, six of which comprise split channels (Figure 5.1-1). Sixteen transects were selected in Wilder reach 2, though the two split channel transects WR2-13 LC and WR2-13 RC were ultimately merged into a single transect (Figures 5.1-2 and 5.1-3). Changes from the Revised SSR (Normandeau, 2014a) for Wilder reach 1 and 2 are: transect WR1-2 was dropped because the riffle mesohabitat it was intended to model was considered transitory; and transect WR2-7b was added to replace WR1-2 and represent a shallow mid-channel bar and run habitat. These changes were made in the field during transect selection with concurrence of the working group. Wilder reach 3 contained 16 transects, three in a small side channel around Hart Island (Figures 5.1-4 and 5.1-5). The two 2D sites are shown in Figure 5.1-2 (Johnston Island) and Figure 5.1-6 (Chase Island).

5.1.2 Bellows Falls Reach

A total of 19 transects were established to model the Bellows Falls reach (Figures 5.1-7 and 5.1-8). During transect selection, transects BF6 and BF7, which represent riffle habitat, were moved downstream slightly from their locations identified in the Revised SSR. These changes were made in the field during transect selection with concurrence of the working group.

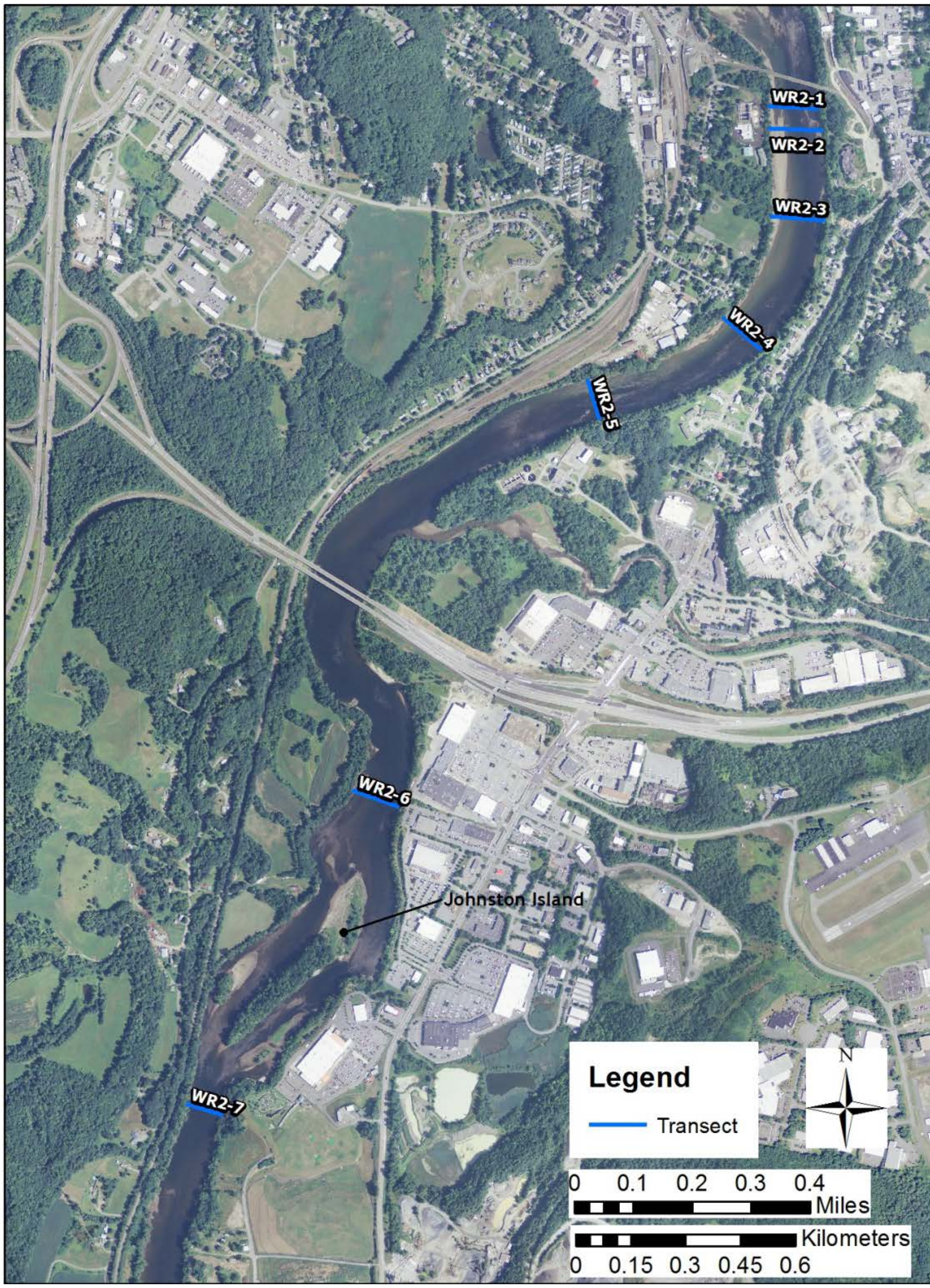
5.1.3 Vernon Reach

A total of 16 transects, 11 in split or side channels, were established to represent habitat in the Vernon reach (Figure 5.1-9). During transect selection, transect VR1 was moved upstream slightly from its original location to incorporate a small side channel. Transect VR10, originally split and located on each side of Stebbins Island, was moved downstream to better represent pool habitat and provide a single main channel transect for hydraulic model calibration if needed. These changes were made in the field during transect selection with concurrence of the working group.



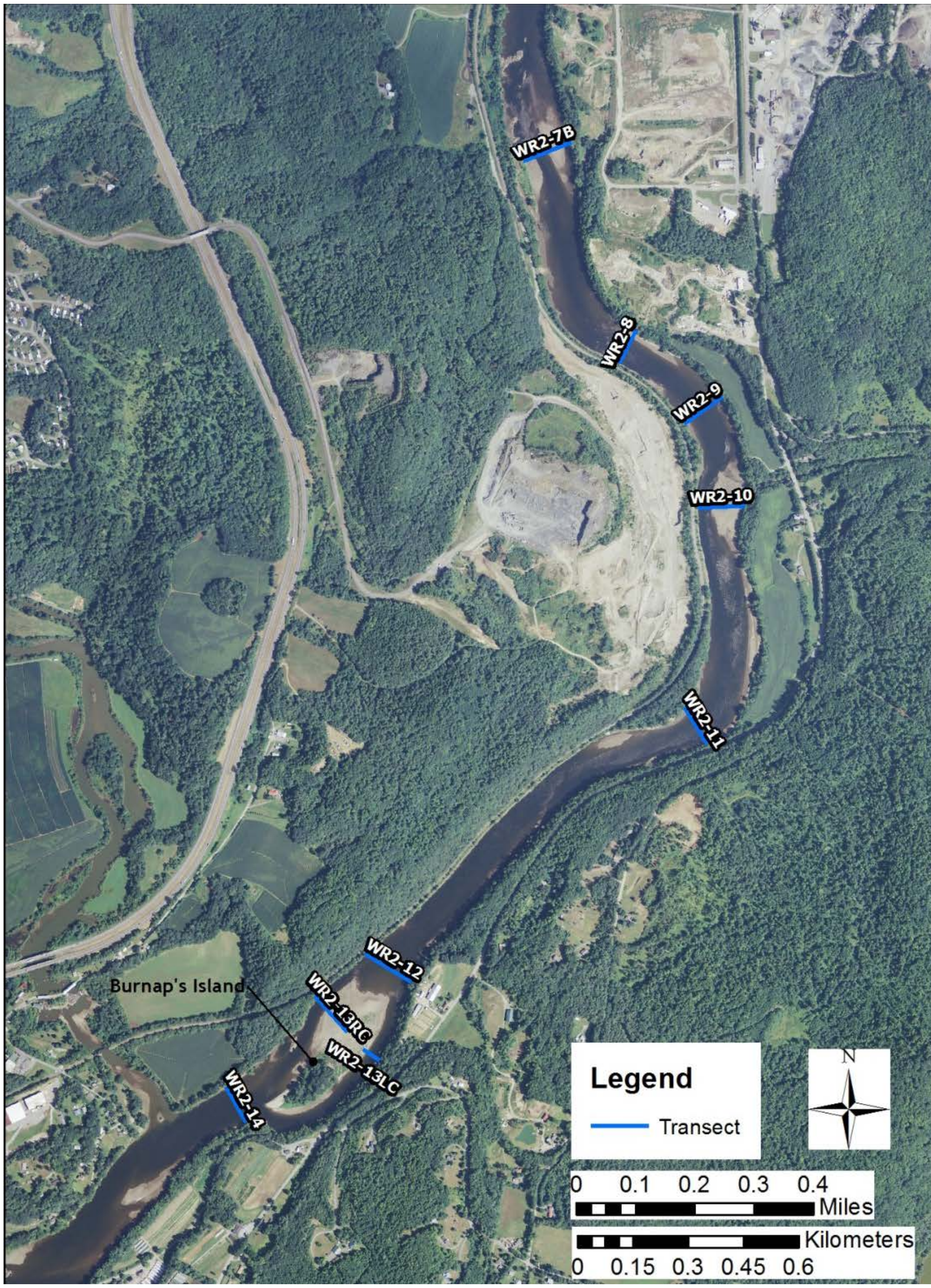
Transect ID	Habitat Type
WR1-1	Deep Pool
WR1-3	Deep Pool
WR1-4 LC	Run
WR1-4 RC	Run
WR1-5 LC	Glide
WR1-5 RC	Run
WR1-6	Deep Pool
WR1-7 LC	Run
WR1-7 RC	Run
WR1-8	Run
WR1-9	Deep Pool
WR1-10	Glide

Figure 5.1-1. Transect locations in Wilder reach 1 – Wilder dam to White River.



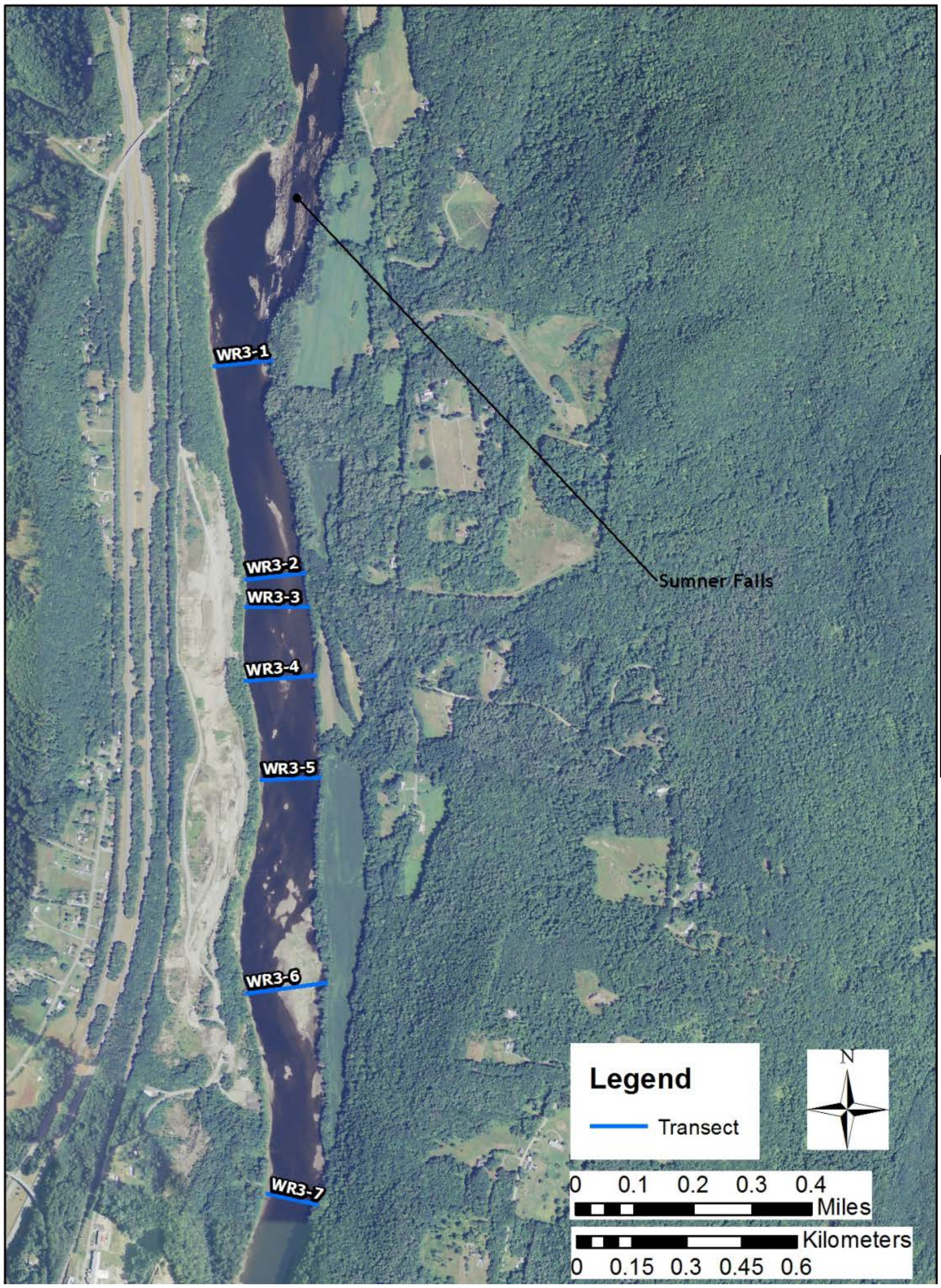
Transect ID	Habitat Type
WR2-1	Run
WR2-2	Riffle
WR2-3	Run
WR2-4	Glide
WR2-5	Pool
WR2-6	Glide
WR2-7	Deep Pool

Figure 5.1-2. Transect locations and 2D study site in the upper portion of Wilder reach 2 – White River to Ottauquechee River. Note: Johnson Island 2D site bounded by WR2-6 and WR2-7 transects.



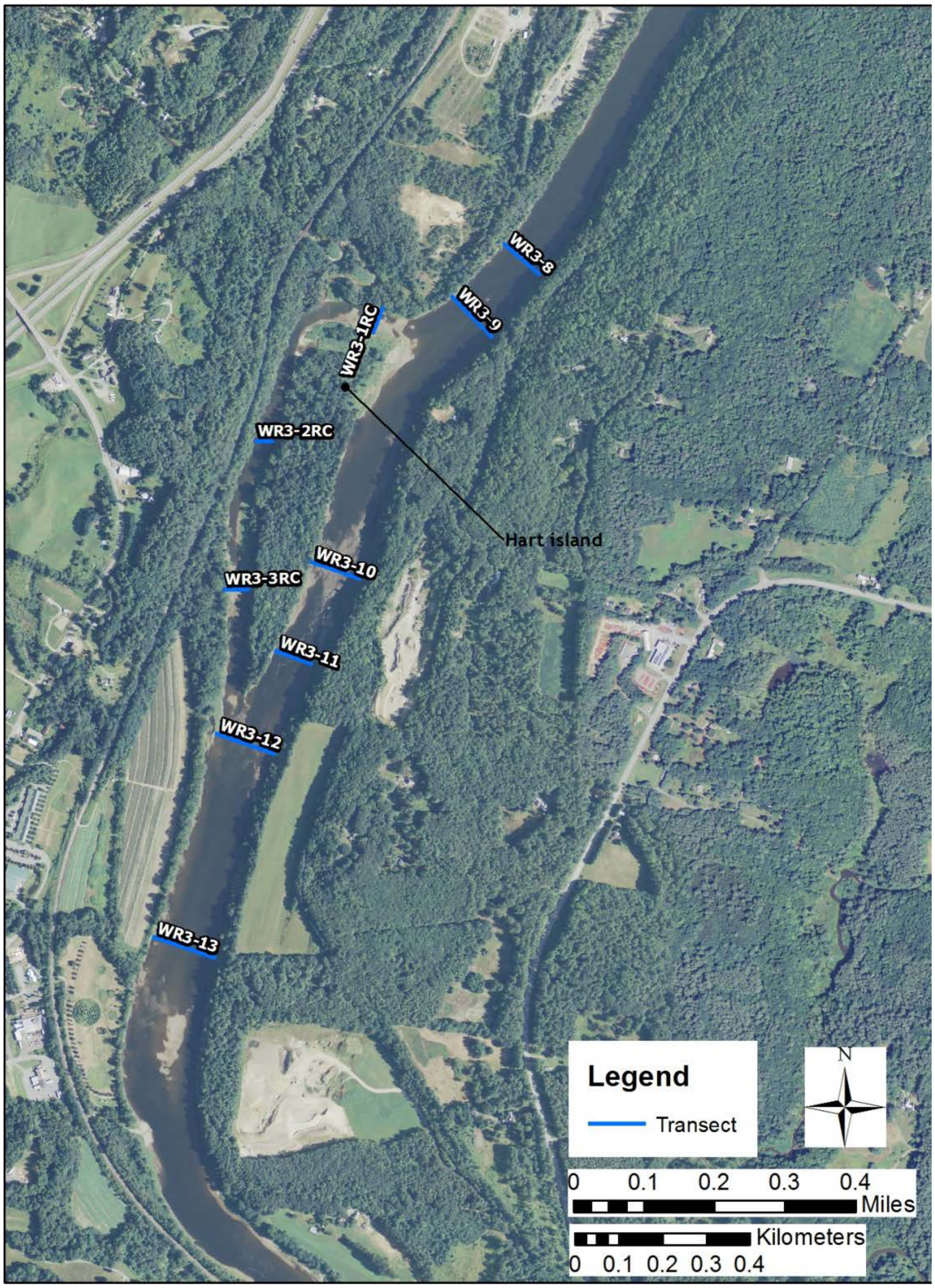
Transect ID	Habitat Type
WR2-7b	Run
WR2-8	Run
WR2-9	Pool
WR2-10	Run
WR2-11	Deep Pool
WR2-12	Glide
WR2-13 LC/RC	Run
WR2-14	Deep Pool

Figure 5.1-3. Transect locations in lower portion of Wilder reach 2 – White River to Ottauquechee River.



Transect ID	Habitat Type
WR3-1	Glide
WR3-2	Pool
WR3-3	Glide
WR3-4	Riffle
WR3-5	Run
WR3-6	Run
WR3-7	Glide

Figure 5.1-4. Transect locations in upper portion of Wilder reach 3 – Ottauquechee River to Chase Island.



Transect ID	Habitat Type
WR3-8	Pool
WR3-9	Glide
WR3-10	Riffle
WR3-11	Pool
WR3-12	Riffle
WR3-13	Glide
WR3-1 RC	Riffle
WR3-2 RC	Pool
WR3-3 RC	Riffle

Figure 5.1-5. Transect locations near Hart Island in the middle portion of Wilder reach 3 – Ottauquechee River to Chase Island

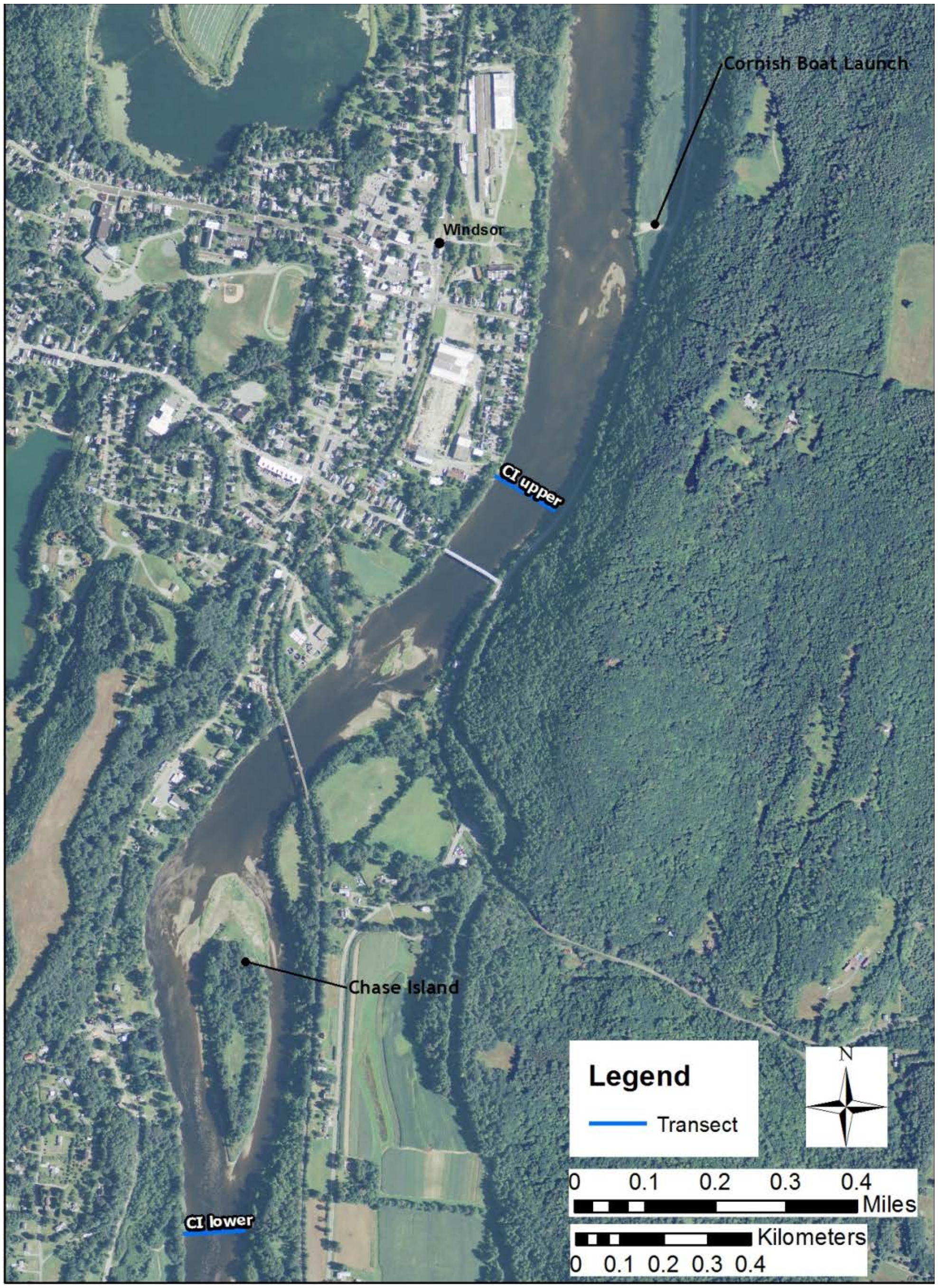
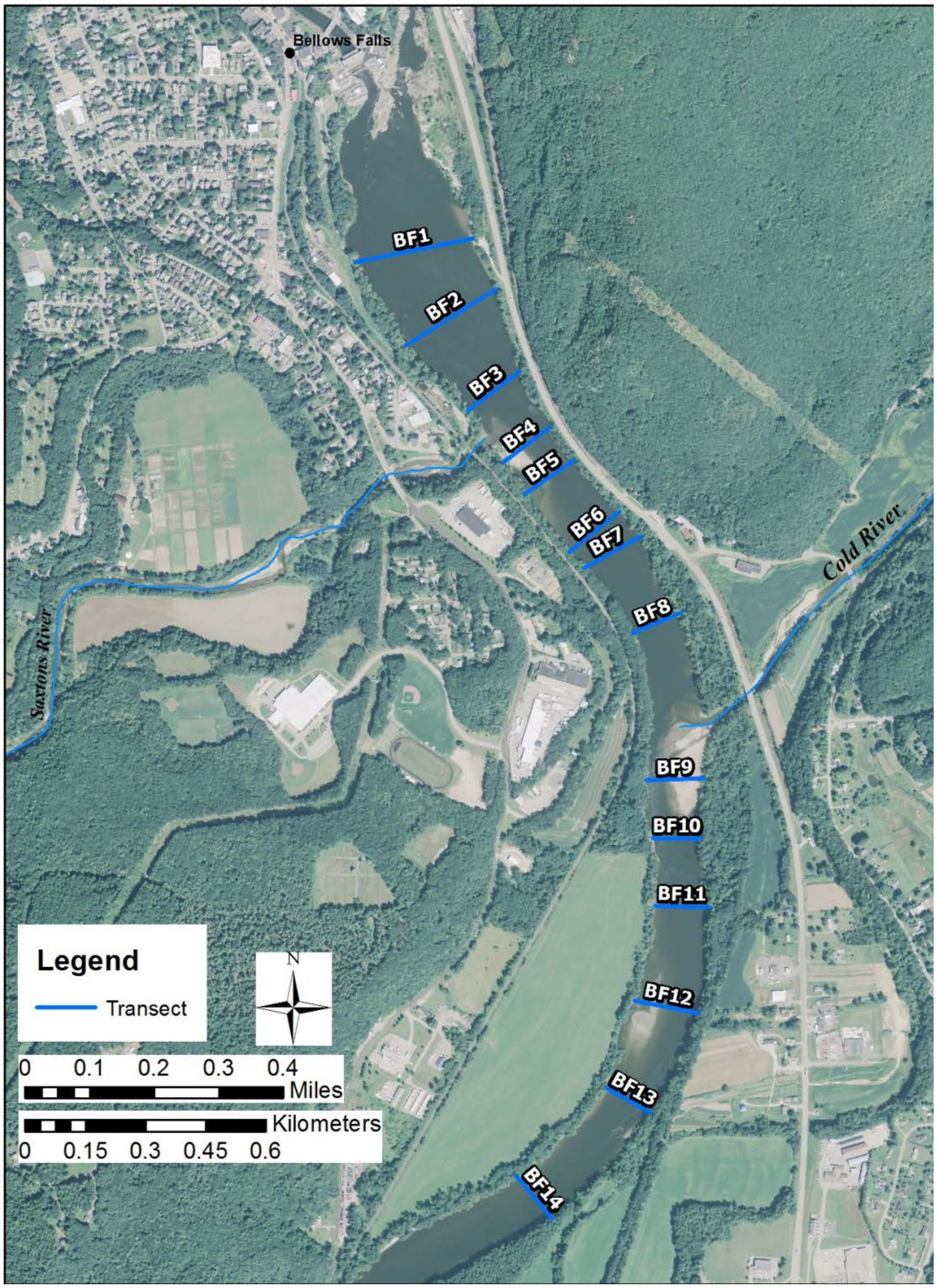
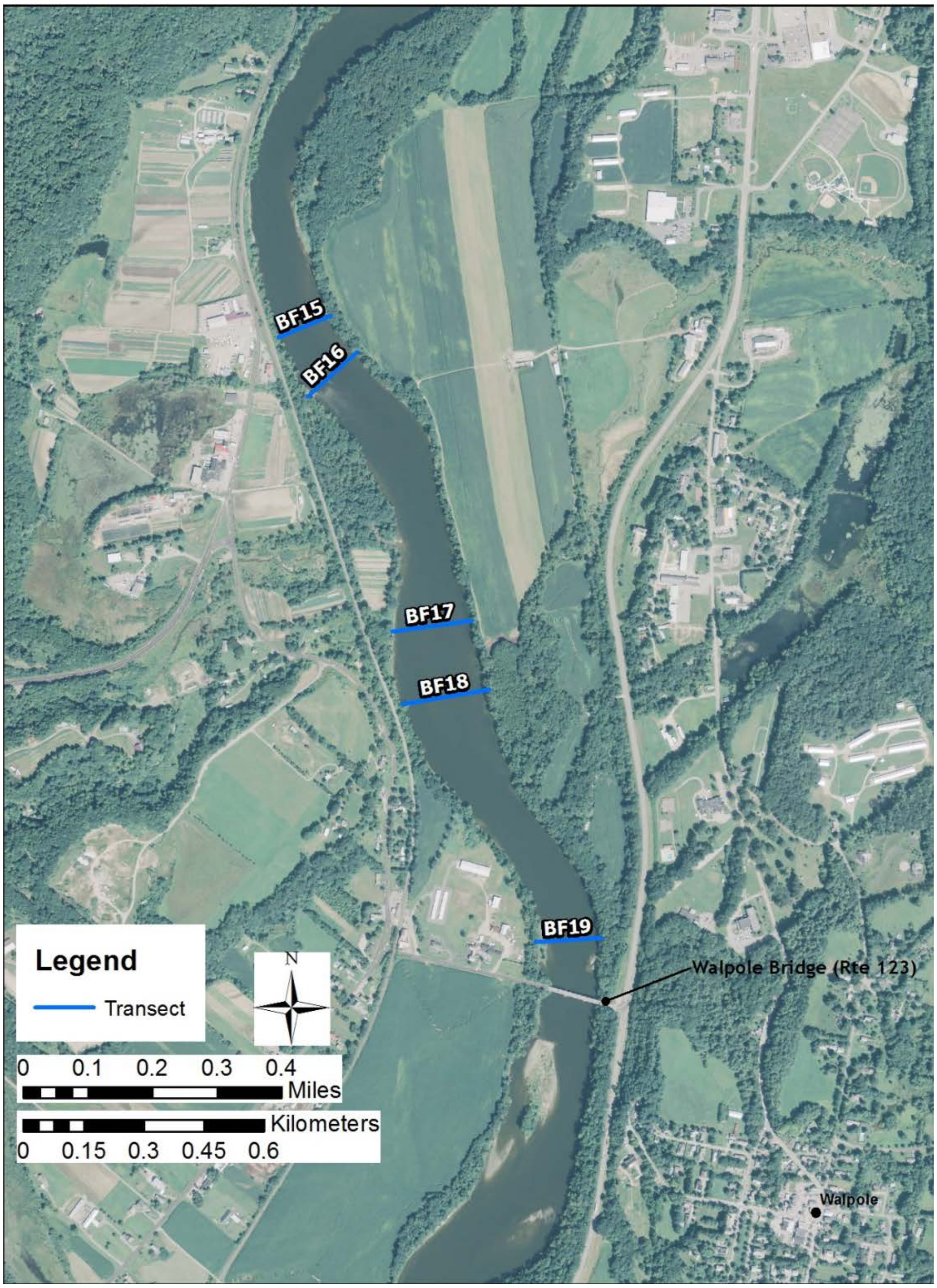


Figure 5.1-6. Chase Island 2D model study site in the lower portion of Wilder reach 3. Site boundaries indicated by upper and lower transects.



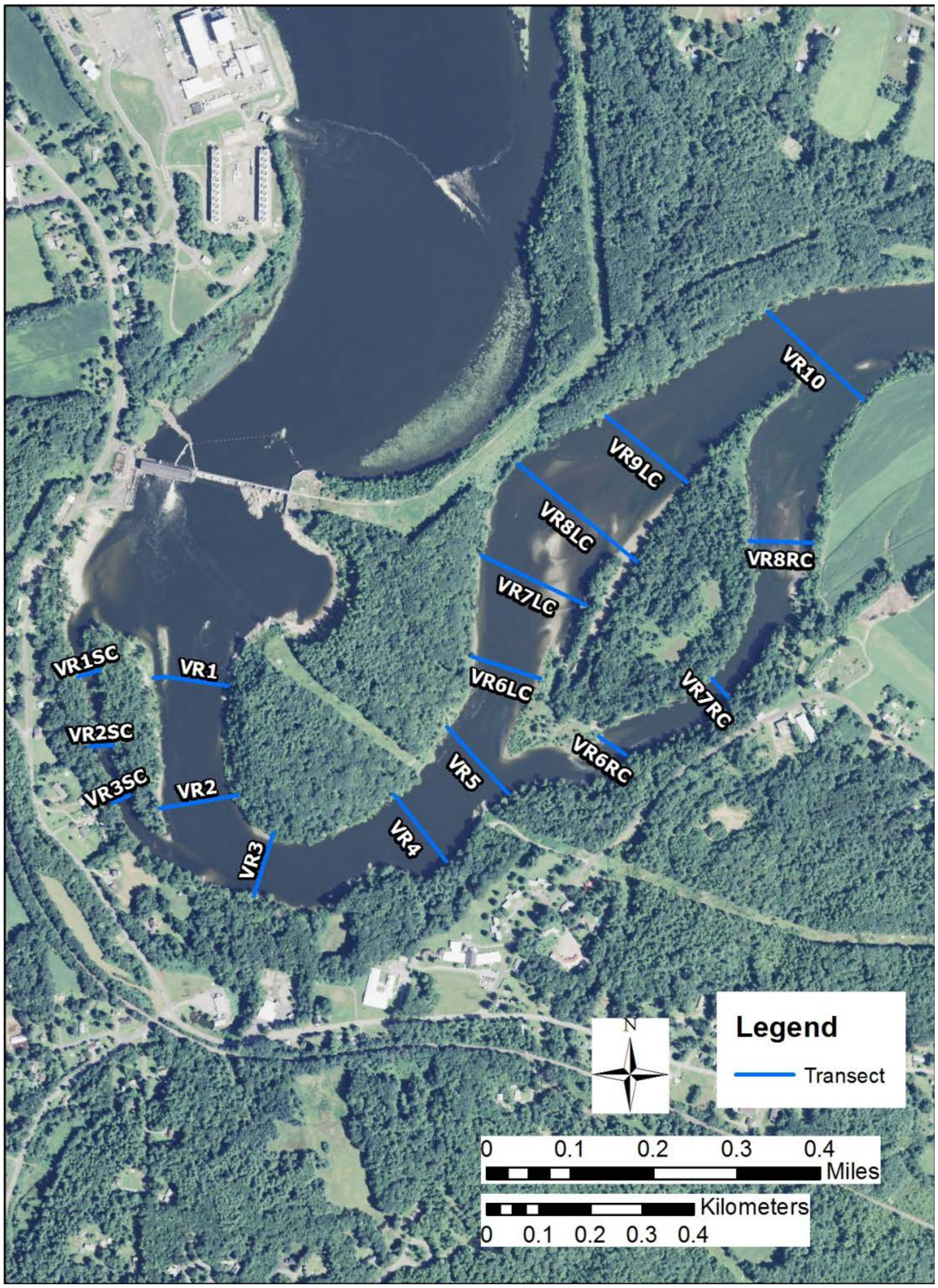
Transect ID	Habitat Type
BF1	Deep Pool
BF2	Glide
BF3	Glide
BF4	Run
BF5	Glide
BF6	Riffle
BF7	Riffle
BF8	Run
BF9	Run
BF10	Pool
BF11	Glide
BF12	Run
BF13	Pool
BF14	Glide

Figure 5.1-7. Transect locations in the upper portion of the Bellows Falls reach.



Transect ID	Habitat Type
BF15	Pool
BF16	Glide
BF17	Pool
BF18	Glide
BF19	Deep Pool

Figure 5.1-8. Transect locations in the lower portion of the Bellows Falls reach.



Transect ID	Habitat Type
VR1	Run
VR2	Run
VR3	Deep Pool
VR4	Deep Pool
VR5	Glide
VR6 LC	Run
VR7 LC	Glide
VR8 LC	Run
VR9 LC	Glide
VR6 RC	Run
VR7 RC	Pool
VR8 RC	Run
VR10	Pool
VR1 SC	Run
VR2 SC	Riffle
VR3 SC	Pool

Figure 5.1-9. Transect locations in the Vernon reach.

5.2 Critical Reach Transects

5.2.1 Wilder

A total of 23 CR transects were selected in the Wilder reaches (Table 5.2-1). In Wilder reach 1, four transects associated with the top of islands and gravel bars were chosen. These locations were used as Sea Lamprey spawning study sites for Study 16, and lamprey nests were identified on or near the transects.

Eight transects were selected in Wilder reach 2. A group of four transects immediately downstream of the White River confluence contained a run/riffle/glide combination and all transects are associated with a large gravel bar along the right bank (RB) that was exposed at lower flows. Two transects containing mid-channel or point bars were also included. Two additional transects at the top and across Burnap's Island, a potential Sea Lamprey spawning location, were incorporated into the critical reach.

Wilder reach 3 contained two groups of transects. Four located just downstream of Sumner Falls are a combination of shallow glide, riffle and runs with primarily gravel substrate and include a large mid-channel bar. The remaining transects are located around Hart Island and include two main channel riffles and two side channel riffles.

Table 5.2-1. List of transects within the three Wilder reaches, critical reach (CR) transects are in bold italics.

Transect ID	Habitat Type	Description
WR1-1	Deep Pool	
WR1-3	Deep Pool	
WR1-4 LC	***Run***	Top of island bar, Lamprey spawning location
WR1-4 RC	***Run***	Top of island bar, Lamprey spawning location
WR1-5 LC	Glide	
WR1-5 RC	Run	
WR1-6	Deep Pool	
WR1-7 LC	***Run***	Top of island bar, Lamprey spawning location upstream
WR1-7 RC	***Run***	Near top of island bar, Lamprey spawning location upstream
WR1-8	Run	
WR1-9	Deep Pool	
WR1-10	Glide	
WR2-1	***Run***	Large gravel bar along RB, exposed at low flow
WR2-2	***Riffle***	Large gravel bar along RB, exposed at low flow
WR2-3	***Run***	Large gravel bar along RB, exposed at low flow
WR2-4	***Glide***	Large gravel bar along RB, exposed at low flow
WR2-5	Pool	
WR2-6	Glide	
WR2-7	Deep Pool	
WR2-7b	***Run***	Mid-channel gravel bar
WR2-8	Run	
WR2-9	Pool	
WR2-10	***Run***	Cobble/gravel point bar associated with Blood's Brook
WR2-11	Deep Pool	
WR2-12	***Glide***	Top of Burnap's Island, potential Lamprey spawning area
WR2-13 LC/RC	***Run***	Crosses Burnap's Island, potential Lamprey spawning area
WR2-14	Deep Pool	
WR3-1	Glide	
WR3-2	Pool	
WR3-3	***Glide***	Shallow with gravel bar along LB
WR3-4	***Riffle***	Shallow with extensive exposed substrate at low flow
WR3-5	***Run***	Shallow with some exposed substrate at low flow on RB
WR3-6	***Run***	Large mid-channel bar with small side channel along LB
WR3-7	Glide	
WR3-8	Pool	
WR3-9	Glide	
WR3-10	***Riffle***	Hart Island complex
WR3-11	***Pool***	Hart Island complex
WR3-12	***Riffle***	Bottom of Hart Island, exposed substrate at low flow
WR3-13	***Glide***	Shallow, some exposed substrate at low flow
WR3-1 RC	***Riffle***	Hart Island complex, side channel, Lamprey spawning area
WR3-2 RC	***Pool***	Hart Island complex, side channel
WR3-3 RC	***Riffle***	Hart Island complex, side channel

Note: RC = Right channel; LC = Left channel. The 3 transects in the RC around Hart Island were weighted equally based on their percent representation within reach 3 of 6.4% by length, and their percent representation of 4% by length for the three reaches combined.

5.2.2 Bellows Falls

A total of 8 transects were selected in the Bellows Falls reach (Table 5.2-2). Six are located between the Saxtons River and Cold River, the only area of complex habitat found in the reach. One of the remaining two transects is associated with a large mid-channel bar and the other was identified as a Sea Lamprey spawning location.

Table 5.2-2. List of transects within the Bellows Falls reach, critical reach (CR) transects are in bold italics.

Transect ID	Habitat Type	Description
BF1	Deep Pool	
BF2	Glide	
BF3	Glide	
BF4	***Run***	Cobble/gravel bar associated with Saxtons River
BF5	***Glide***	Backwater and exposed gravel bar along RB at low flow
BF6	***Riffle***	Shallow and fast, cobble and gravel substrate
BF7	***Riffle***	Shallow and fast, cobble and gravel substrate
BF8	***Run***	Gravel bars along both banks at low flow
BF9	***Run***	Cobble/gravel bar associated with Cold River
BF10	Pool	
BF11	Glide	
BF12	***Run***	Mid-channel bar with small side channel along RB
BF13	Pool	
BF14	Glide	
BF15	Pool	
BF16	***Glide***	Gravel bar along RB, Lamprey spawning location LB
BF17	Pool	
BF18	Glide	
BF19	Deep Pool	

5.2.3 Vernon

Numerous gravel bars are exposed at low flow in the Vernon reach and Lamprey spawning is prevalent, particularly around Stebbins Island. The 12 critical reaches selected include all transects around the island in addition to three other transects associated with Sea Lamprey spawning, or the potential for spawning (Table 5.2-3).

Though transects around Stebbins Island are weighted equally, the fact that those in the left channel are three times as wide and account for more area will effectively balance AWS by channel. The same can be inferred for the three main channel transects. If we were to try and weight transects by percentage of flow, the three main channel transects would be given considerably more weight than those around Stebbins Island.

Table 5.2-3. List of Vernon transects within the Vernon reach, critical reach (CR) transects are in bold italics.

Transect ID	Habitat Type	Description
VR1	***Run***	Gravel bar on RB identified as Lamprey spawning location
VR2	Run	
VR3	Deep Pool	
VR4	Deep Pool	
VR5	***Glide***	Shallow cobble/gravel substrate, Lamprey spawning area
VR6 LC	***Run***	Gravel bar RB and Lamprey spawning area
VR7 LC	***Glide***	Gravel bar RB and Lamprey spawning area
VR8 LC	***Run***	Gravel bar RB and Lamprey spawning area
VR9 LC	***Glide***	Stebbins Island complex
VR6 RC	***Run***	Stebbins Island complex
VR7 RC	***Pool***	Stebbins Island complex
VR8 RC	***Run***	Mid-channel gravel bar, Lamprey spawning location
VR10	***Pool***	Shallow pool with gravel bar RB, Lamprey spawning area
VR1 SC	***Run***	Gravel substrate, potential Lamprey spawning area
VR2 SC	***Riffle***	Lamprey spawning location
VR3 SC	Pool	

Note: RC = Right channel; LC = Left channel; SC = Side channel. The SC near the top of the reach was estimated to represent 3% of the reach by area, the 2 transects within the SC and included in the critical reach were weighted equally at 1.5% each.

5.3 Hydraulic Modeling

This report does not go into great detail presenting or describing hydraulic model calibration results for individual 1D transects due to the number of transects involved; however, calibration details for all reaches and transects (except for the Bellow Falls bypassed reach) are provided in Appendix B. Cross-sectional plots showing calibration WSE with measured and predicted velocities are included in Appendix C. The Bellows Falls bypassed reach was unique from a calibration standpoint and details and results are provided in Section 5.5 of this report.

5.3.1 1D Stage-Discharge Calibration

Measured calibration flows are shown in Table 5.3-1. Higher than expected flows in Wilder reach 1 and 2 are due to accretion from the White River, Ottauquechee River and other tributaries. Measured high flows in Wilder reach 3 were greater than anticipated due to elevated accretion from rain events.

Table 5.3-1. Measured calibration flows by reach for 1D transect data collection. Ranges indicate measurements over multiple days or conducted under varying flow levels.

	Measured Flows		
	Low (cfs)	Middle (cfs)	High (cfs)
Wilder Reach 1	793	5,650	12,057
Wilder Reach 2	1,392	6,598 - 7,340	12,899 - 13,788
Wilder Reach 3	1,661 - 1,737	6,550 - 6,969	15,419 - 16,926
Bellows Falls	1,824 – 1,880	5,400 – 5,575	11,439 – 12,298
Vernon	2,035	4,100 and 8,407	12,458

All transects in the Wilder and Bellows Falls reaches were calibrated using geo-referenced vertical elevations to establish individual transect stage-discharge relationships. Examination of longitudinal WSE relationships between transects allowed general modeling errors such as 'water flowing uphill' to be detected. Longitudinal bed elevations could also be viewed, assisting in determination of stage-at-zero-flow by comparing thalweg elevations of riffles and shallow transects in each reach to plotting stages between transects. Most transect rating curves were based on a log/log regression though a few, primarily riffles, were based on the channel conveyance method if it improved the mean error or velocity simulation. The quality of rating curves was based on examination of mean error. A mean error of less than 5 percent is considered excellent and less than 10 percent is acceptable. In all cases mean errors were less than or equal to 6 percent.

In the Vernon reach WSE and flow split discharges were collected at the high calibration flow and 3 other lower flows on all transects, however no stage-discharge rating curves were developed. WSE for each transect at any given flow is dependent on operations of both the Vernon and Turners Falls projects. Modeling for this reach used stage-discharge rating curves developed from the HEC-RAS model (Study 4) which are based on various Turners Falls impoundment elevations and Vernon discharges.

5.3.2 1D Velocity Calibration

Velocity calibration adjustments were kept to a minimum. The majority of adjustments were to edge cells, primarily those where a single negative velocity occurred. There were instances where velocities were missing across a section of a transect (transects WR2-10, VR4 and VR7-LC). In all cases, ADCP or wading measurements could not be made due to flow conditions. Adjusting Manning's n allowed the model to predict velocities for these points at the high calibration flow. VAF's were examined to assess the quality of measured versus simulated velocities at the high calibration flow. In all Wilder reaches and the Bellows Falls reach, VAF's for all transects ranged from 0.96 to 1.05 at the calibration flow, indicating a 5 percent or less prediction error. VAF's for transects in the Vernon reach fell between 0.94 and 1.04 with the exception of transect VR4, which due to velocity acquisition issues across a portion of the transect, was 0.84.

5.3.3 2D Model Calibration

The final River2D computational mesh for the Johnston Island site consists of 40,969 nodes with a quality index of 0.28 (acceptable values range between 0.1 and 0.5). The bed topography file for the Johnston Island site is based on 521,228 bathymetric survey points. The stage-discharge relationship at the downstream end of each site was used to set the outflow water surface elevations for the model simulations, and the stage-discharge at the upper end of the site was used for model calibration. For the Johnston Island site, the upstream and downstream boundaries and rating curves were 1D transects (WR2-6 and WR2-7). For model calibration, roughness values were adjusted in an attempt to best match the water edges throughout the site and the WSE at the top and bottom of the site (Table 5.3.3-1). Predicted change in WSE versus a given WSE at the upper and lower boundaries of the site was less than 0.08 ft for all modeled flows. Predicted outflow for the model was essentially equal to given inflow with a tolerance of 0.5% or less (Table 5.3.3-2). Figure 5.3.3-1 shows depth contours for the Johnston Island site at a flow of 10,200 cfs.

Table 5.3.3-1. Johnston Island 2D model roughness values and WSE calibration results.

Inflow (cfs)	ks value (roughness)	WR2-6 SEFA modeled WSE (ft)	WR2-6 River2D modeled WSE (ft)	Δ (ft)	WR2-7 SEFA modeled WSE (ft)	WR2-7 River2D modeled WSE (ft)	Δ (ft)
1,200	0.025	324.067	324.140	0.07	319.461	319.399	-0.06
2,200	0.100	324.690	324.720	0.03	320.522	320.547	0.03
3,200	0.100	325.138	325.084	-0.05	321.315	321.291	-0.02
4,200	0.100	325.496	325.424	-0.07	321.968	321.936	-0.03
5,200	0.100	325.799	325.739	-0.06	322.532	322.502	-0.03
6,200	0.100	326.064	326.038	-0.03	323.033	323.015	-0.02
7,200	0.100	326.300	326.307	0.01	323.487	323.480	-0.01
8,200	0.075	326.515	326.494	-0.02	323.904	323.898	-0.01
9,200	0.075	326.712	326.750	0.04	324.291	324.286	-0.01
10,200	0.050	326.895	326.876	-0.02	324.654	324.640	-0.01
11,200	0.050	327.066	327.117	0.05	324.995	324.959	-0.04
13,000	0.025	327.348	327.370	0.02	325.565	325.553	-0.01
15,000	0.025	327.757	327.879	0.12	326.322	326.305	-0.02
20,000	0.025	328.397	329.053	0.66	327.640	327.619	-0.02
25,000	0.025	328.934	330.109	1.17	328.772	328.731	-0.04

Table 5.3.3-2. Given discharge and predicted discharge for 2D model at Johnston Island.

Inflow (cfs)	Outflow (cfs)	Net Change (%)	Solution Change
1,200	1,200	0.020%	0.0865
2,200	2,210	0.448%	0.0499
3,200	3,192	-0.247%	0.0433
4,200	4,181	-0.460%	0.0218
5,200	5,181	-0.373%	0.0369
6,200	6,199	-0.024%	0.0547
7,200	7,176	-0.327%	0.0557
8,200	8,206	0.077%	0.0601
9,200	9,205	0.055%	0.0429
10,200	10,195	-0.048%	0.0577
11,200	11,207	0.062%	0.0413
13,000	13,006	0.049%	0.0962
15,000	14991	-0.062%	0.0971
20,000	20006	0.029%	0.0103
25,000	24995	-0.020%	0.0183

Chase Island model calibration consisted of adjusting the roughness values in the model until a reasonable match was obtained between the River2D simulated water surface elevations and the water surface elevations from HEC-RAS transects at the upstream and downstream boundaries of the study area. Flows between 700 cfs and 25,000 cfs were modeled. The stage-discharge relationship at the downstream end of each site was used to set the outflow water surface elevations for the model simulations and the stage-discharge at the upper end of the site was used for model calibration. The resulting roughness values and water surface calibration results and model statistics are given in Table 5.3.3-3 and Table 5.3.3-4. Depth contours for the Chase Island site at 10,000 cfs are shown in Figure 5.3.3-2

The bed topography file for the Chase Island site is based on 978,363 survey points. The final River2D computational mesh for the Johnston Island site consists of 82,749 nodes with a quality index of 0.20.

Table 5.3.3-3. Chase Island 2D model roughness values and WSE calibration results.

Inflow (cfs)	ks Value (Roughness)	HEC-RAS node 702 modeled WSE	River2D modeled WSE	Percent Error	Δ (ft)
700	0.05	293.3	293.96	0.23	0.66
1,000	0.05	293.6	294.25	0.22	0.65
2,000	0.05	294.4	294.90	0.17	0.50
3,000	0.05	295.0	295.40	0.13	0.40
4,000	0.05	295.4	295.81	0.14	0.41
5,000	0.05	295.9	296.20	0.10	0.30
6,000	0.05	296.3	296.57	0.09	0.27
7,000	0.05	296.7	296.95	0.09	0.25
8,000	0.05	297.1	297.29	0.07	0.19
9,000	0.05	297.5	297.65	0.05	0.15
10,000	0.05	297.9	298.01	0.04	0.11
11,000	0.05	298.3	298.35	0.02	0.05
13,000	0.05	298.9	298.97	0.02	0.07
15,000	0.05	299.6	299.72	0.04	0.12
20,000	0.05	301.2	301.14	0.02	-0.06
25,000	0.05	302.6	302.59	0	-0.01

Table 5.3.3-4. Given discharge and predicted discharge for 2D model at Chase Island.

Inflow (cfs)	Outflow (cfs)	Net Change (%)	Solution Change
700	680	-0.029	0.00385
1,000	1055	0.055	0.0938
2,000	1983	-0.009	0.0435
3,000	2996	-0.001	0.0584
4,000	3988	-0.003	0.0688
5,000	4991	-0.002	0.0506
6,000	5985	-0.002	0.359
7,000	7013	0.002	0.0632
8,000	8056	0.007	0.0962
9,000	8999	0.000	0.0769
10,000	9978	-0.002	0.0989
11,000	10987	-0.001	0.0806
13,000	13004	0.000	0.108
15,000	14981	-0.001	0.0770
20,000	20014	0.001	0.101
25,000	24997	0	0.0996

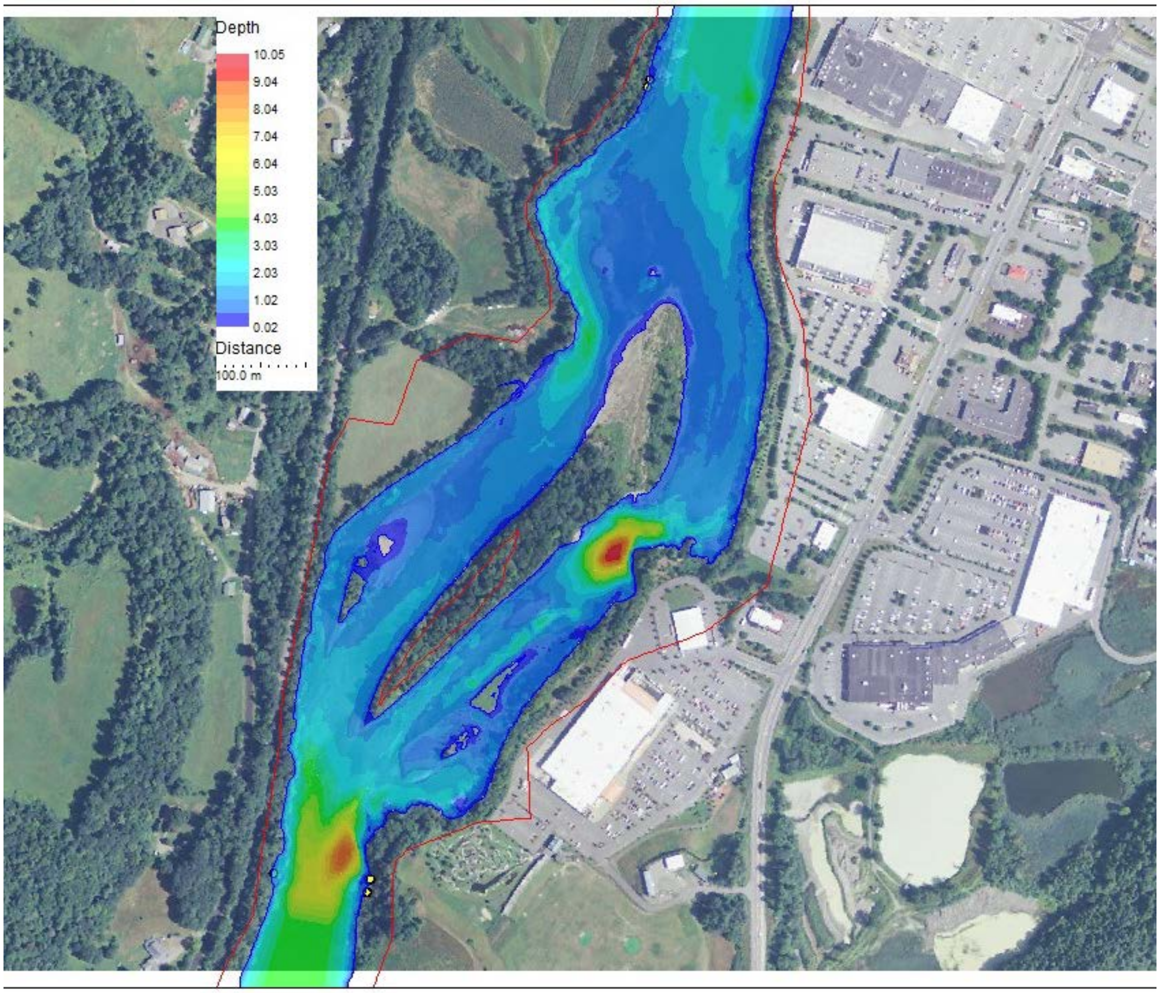


Figure 5.3.3-1. Topography (depth in m) of the Johnston Island 2D site at 10,200 cfs. Deeper areas are red and shallow areas are blue.

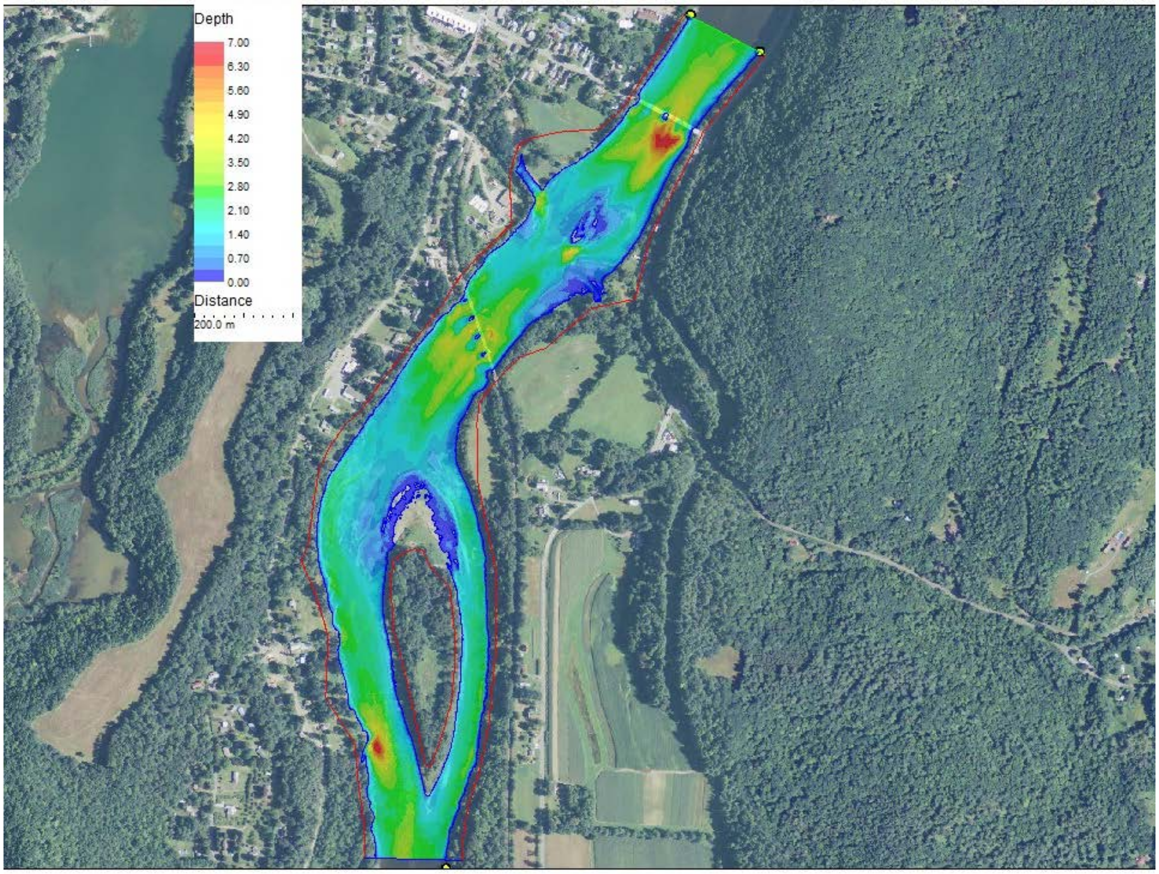


Figure 5.3.3-2. Topography (depth in m) of the Chase Island 2D site at 10,000 cfs. Deeper areas are red and shallow areas are blue.

5.4 Habitat Modeling

At the request of the working group, AWS plots for 1D modeling were constructed by habitat type or groups of habitat types in a reach, in addition to standard weighting of all habitat types together within a reach. The premise was that the results for rare or lower weighted habitat types would be masked by those with higher weighting, primarily pool habitat in most reaches. Conversely, for species or life stages that prefer slow velocities and/or deep water the effect could be the opposite. AWS values for all reaches are presented in Appendix D.

5.4.1 Wilder Reaches

Wilder Reach 1

Transect weighting in Wilder reach 1 is shown in Table 5.4-1. Pool was the predominant habitat type and was given the most weight for modeling. Two habitat groups were also modeled, -run habitat grouped with glide WR1-5 LC, and pool habitat grouped with glide WR1-10. The two glide transects were incorporated based on depth and velocity profiles showing similarities to the run and pool habitats they were grouped with.

AWS curves for Wilder reach 1 are presented in Figures 5.4-1 to 5.4-7. Walleye adult and spawning showed the greatest difference in the shape of AWS curves between run and pool habitat. This is not unexpected since adult suitability is for slow velocities and deep water and spawning suitability is for fast velocities and shallow depths. Most other species and life stages and the GHC have similar shapes to the AWS curves for run and pool habitat and all transects combined, though the amplitude (index values) may differ.

Table 5.4-1. Transect ID, mesohabitat type, and percent transect representation in Wilder reach 1.

Transect ID	Habitat Type	% Transect Weighting
WR1-1	Pool (deep)	15.0
WR1-3	Pool (deep)	15.0
WR1-4 LC	Run	8.1
WR1-4 RC	Run	8.1
WR1-5 LC	Glide	7.8
WR1-5 RC	Run	8.1
WR1-6	Pool (deep)	15.0
WR1-7 LC	Run	8.1
WR1-7 RC	Run	8.1
WR1-8	Run	8.1
WR1-9	Pool (deep)	15.0
WR1-10	Glide	7.8

Note: RC = Right channel; LC = Left channel, looking downstream.

Wilder Reach 2

Transect weighting in Wilder reach 2 is shown in Table 5.4-2. Pool was the dominant habitat type by percentage and given the most weight for modeling the reach. Preliminary habitat runs showed little difference between riffle and run, therefore the single riffle transect was grouped with run transects. Pool and glide also showed littles difference in habitat and were modeled together, in addition to the total weighted reach.

AWS curves for Wilder reach 2 are presented in Figures 5.4-8 to 5.4-14. As is the case in Wilder reach 1 Walleye adult and spawning showed the greatest difference in the shape of AWS curves between run/riffle and pool/glide habitat. Fallfish adult and White Sucker fry and juvenile are more responsive to pool/glide habitat. In contrast all Longnose Dace life stages, Tessellated Darter, Sea Lamprey spawning and macroinvertebrates respond more to run/riffle habitat.

Table 5.4-2 Transect ID, mesohabitat type, and percent transect representation in Wilder reach 2.

Transect ID	Habitat Type	% Transect Weighting
WR2-1	Run	3.7
WR2-2	Riffle	4.2
WR2-3	Run	3.7
WR2-4	Glide	3.6
WR2-5	Pool	13.2
WR2-6	Glide	3.6
WR2-7	Pool (deep)	12.1
WR2-7b	Run	3.7
WR2-8	Run	3.7
WR2-9	Pool	13.2
WR2-10	Run	3.7
WR2-11	Pool (deep)	12.1
WR2-12	Glide	3.6
WR2-13 LC/RC	Run	3.7
WR2-14	Pool (deep)	12.1

Note: RC = Right channel; LC = Left channel, looking downstream.

Wilder Reach 3

Transect weighting in Wilder reach 3 is shown in Table 5.4-3. Weights do not equal 100 percent because the right channel around Hart Island was considered a separate reach for calibration purposes. When reaches are combined in SEFA the transect weights are normalized to equal 100 percent. Again, pool is the dominant habitat type by percentage and given the most weight for modeling the reach. Run and riffle habitat were grouped as were pool and glide habitat in addition to modeling the total weighted reach.

AWS curves for Wilder reach 3 are presented in Figures 5.4-15 to 5.4-21. Results for run/riffle habitat combined, pool/glide habitat combined and total weighted reach differ little for all species and life stages and GHC. Because preliminary habitat results for pool and glide were similar this is interpreted as a function of overall shallower depths for pools and glide in this reach versus reaches upstream.

Table 5.4-3. Transect ID, mesohabitat type, and percent transect representation in Wilder reach 3.

Transect ID	Habitat Type	% Transect Weighting
WR3-1	Glide	6.2
WR3-2	Pool	17.6
WR3-3	Glide	6.2
WR3-4	Riffle	2.0
WR3-5	Run	5.0
WR3-6	Run	5.0
WR3-7	Glide	6.2
WR3-8	Pool	17.6
WR3-9	Glide	6.2
WR3-10	Riffle	2.0
WR3-11	Pool	17.6
WR3-12	Riffle	2.0
WR3-13	Glide	6.2
WR3-1 RC	Riffle	2.13
WR2-3 RC	Pool	2.13
WR2-3 RC	Riffle	2.13

Note: RC= right channel looking downstream. RC around Hart Island accounts for 6.4% of the reach by length. The 3 transects in the RC were weighted equally at 2.13%.

Wilder Reaches Combined

Figures 5.4-22 to 5.4-24 show the result for combined Wilder reaches under a steady-state condition. When reaches are combined in SEFA the transect weights are normalized to equal 100 percent so there is no need to reweight each reach.

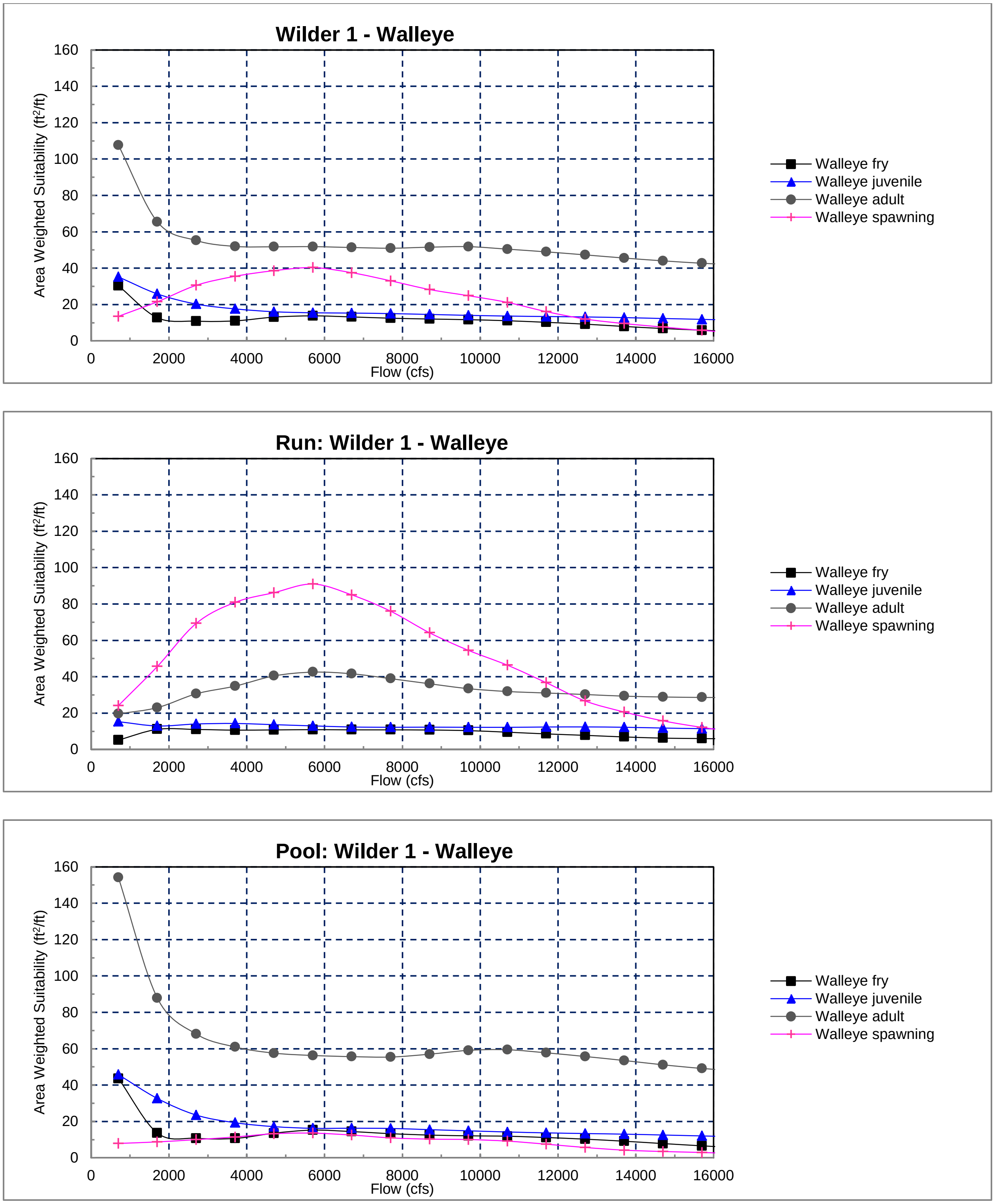
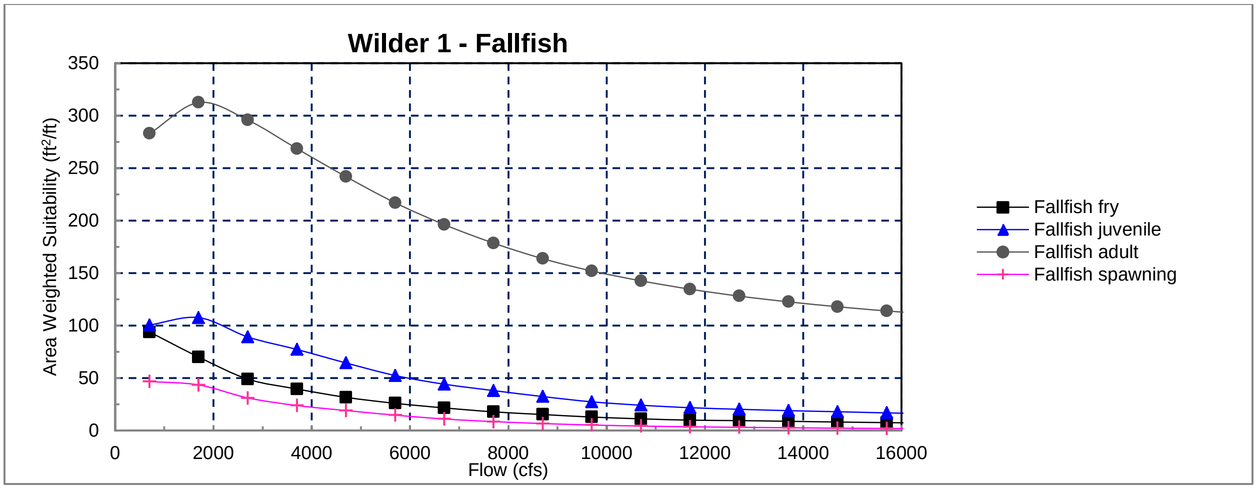
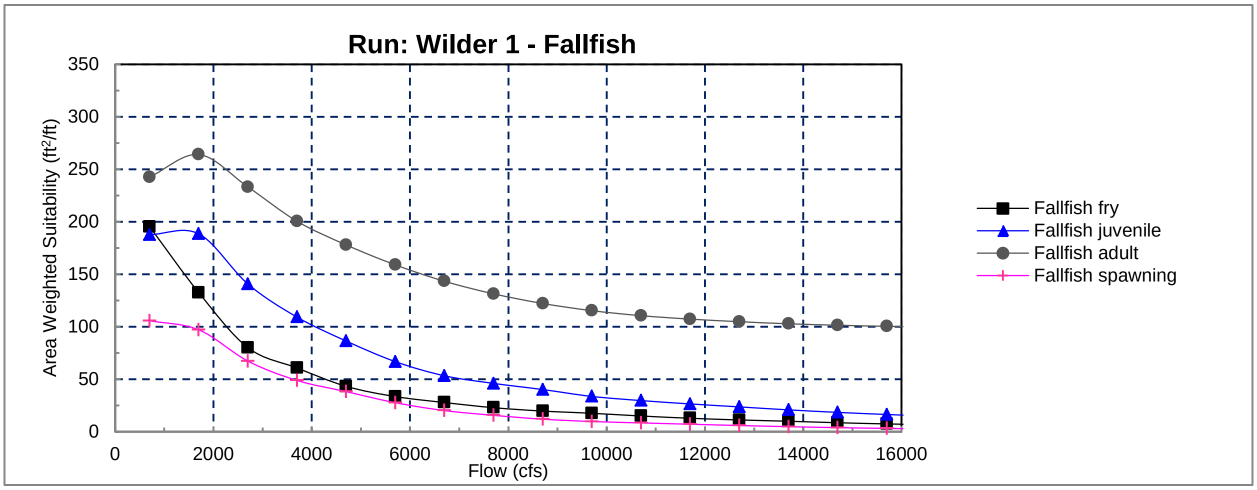


Figure 5.4-1. Walleye AWS for Wilder reach 1, and by habitat groups run and pool.





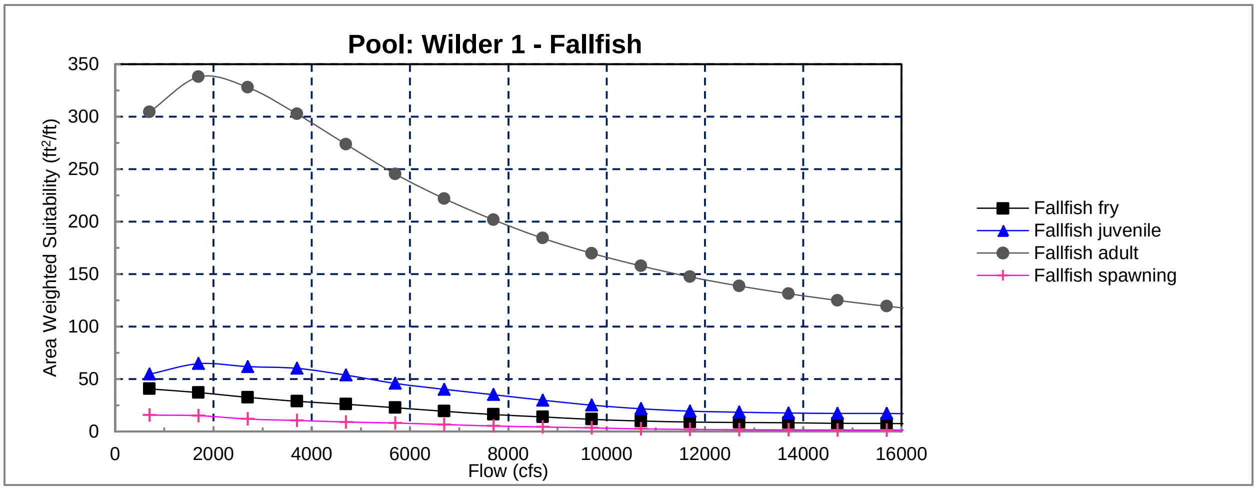


Figure 5.4-2. Fallfish AWS for Wilder reach 1, and by habitat groups run and pool.

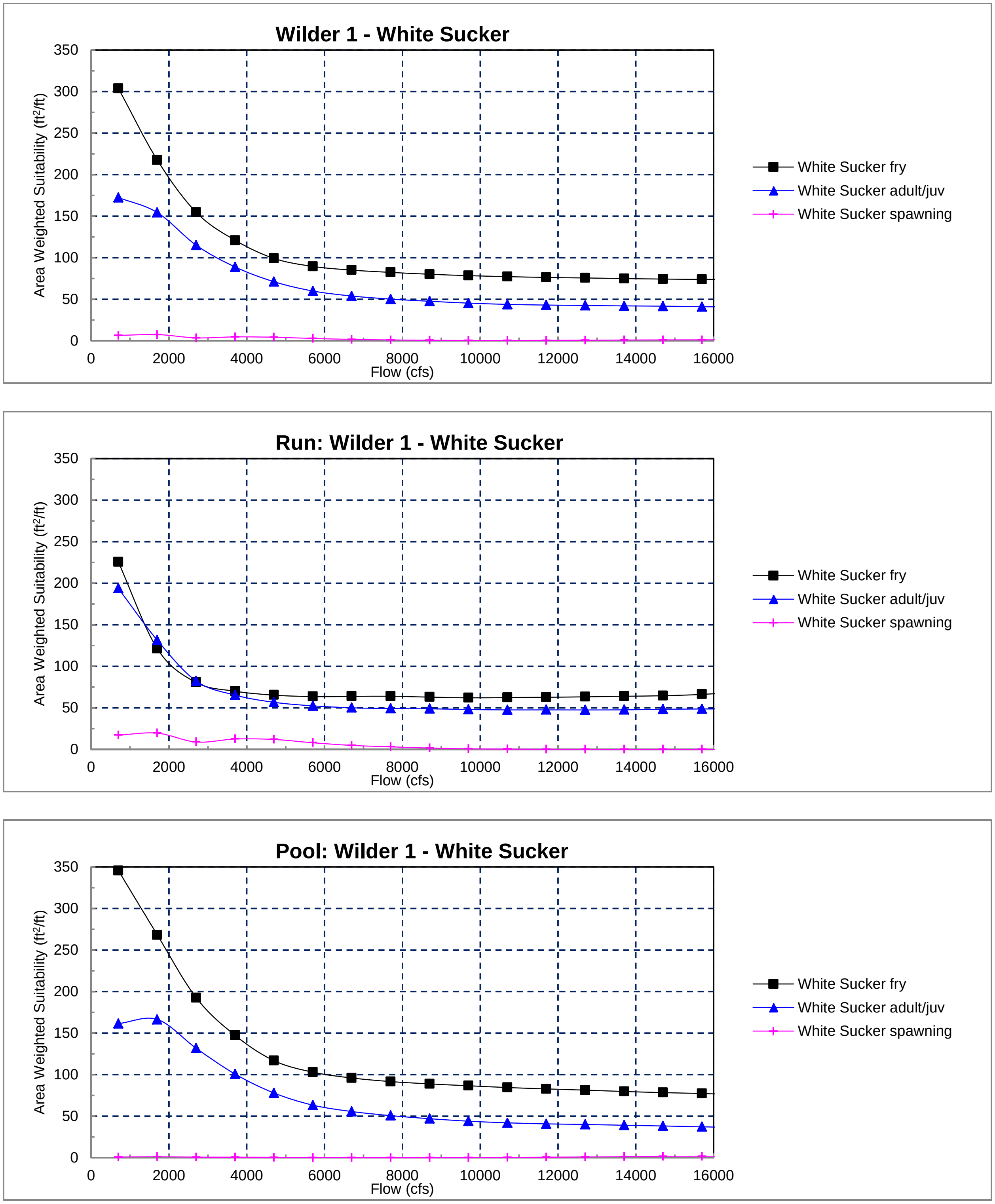
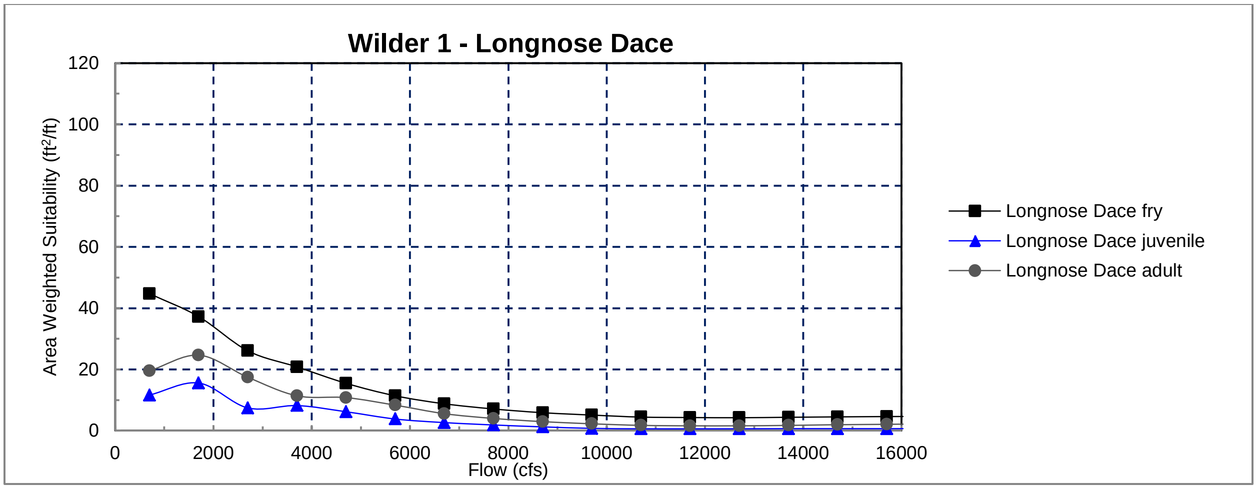
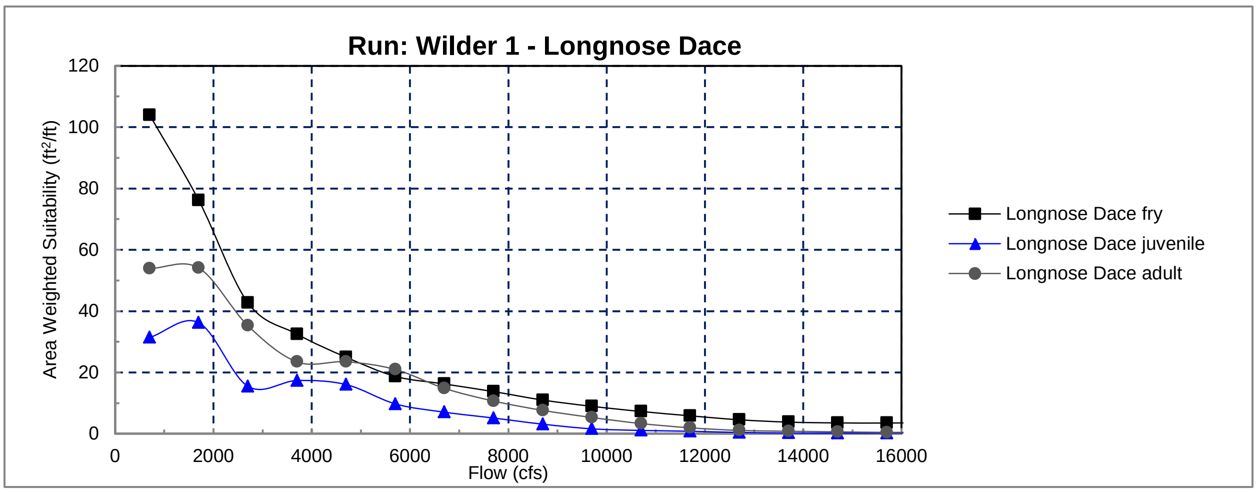


Figure 5.4-3. White Sucker AWS for Wilder reach 1, and by habitat groups run and pool.





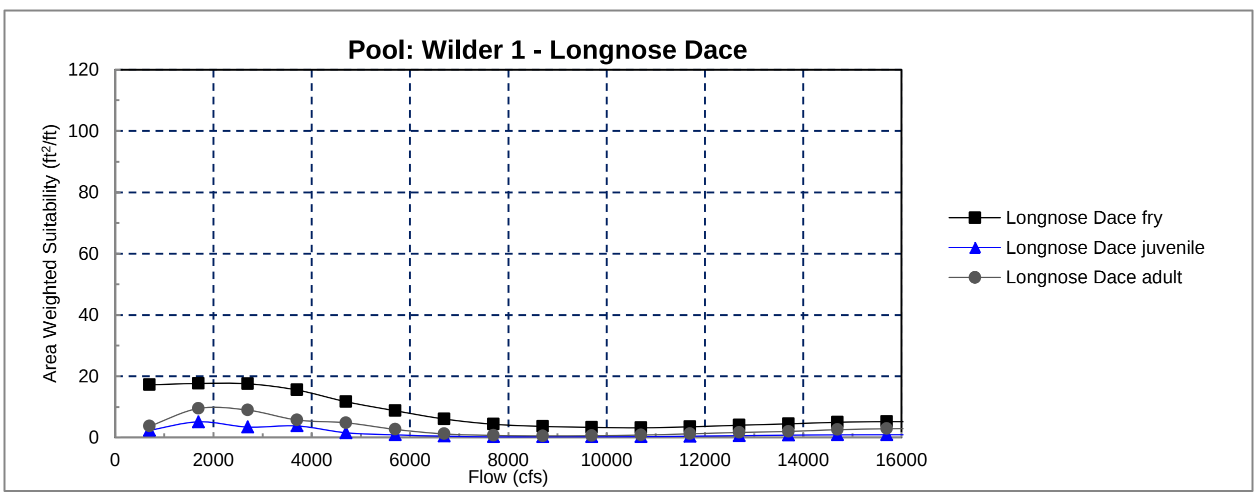


Figure 5.4-4. Longnose Dace AWS for Wilder reach 1, and by habitat groups run and pool.

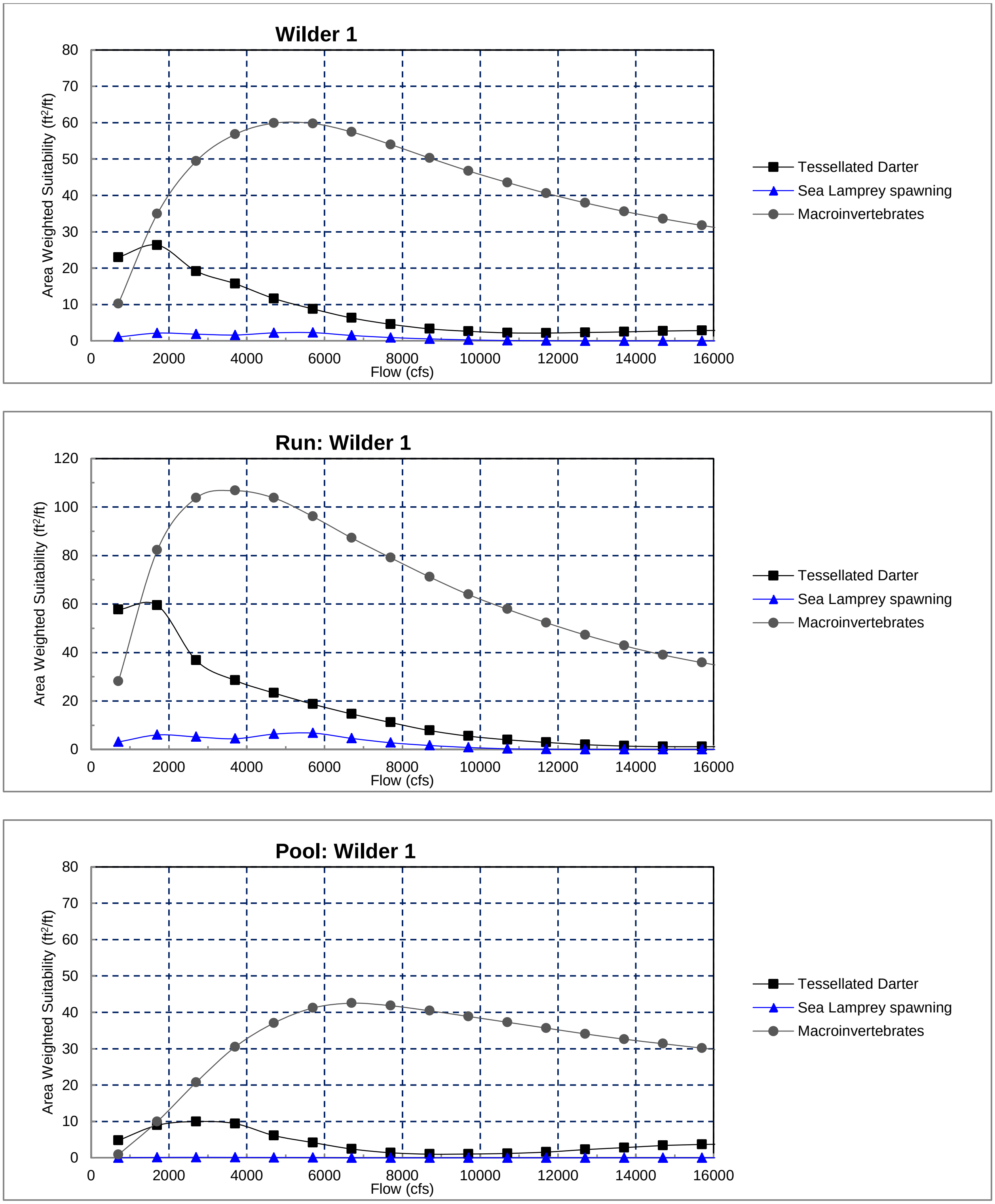
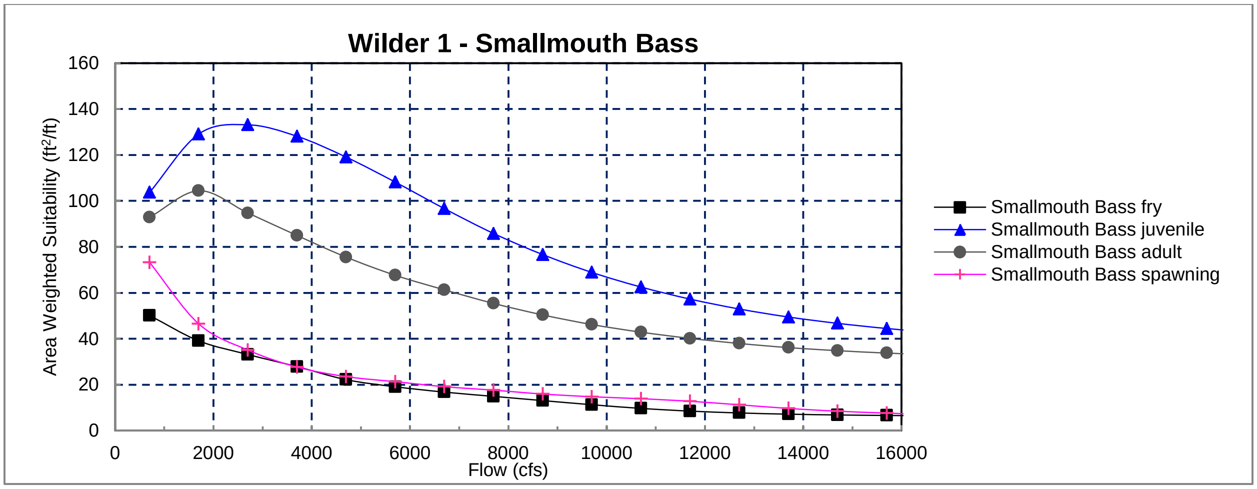
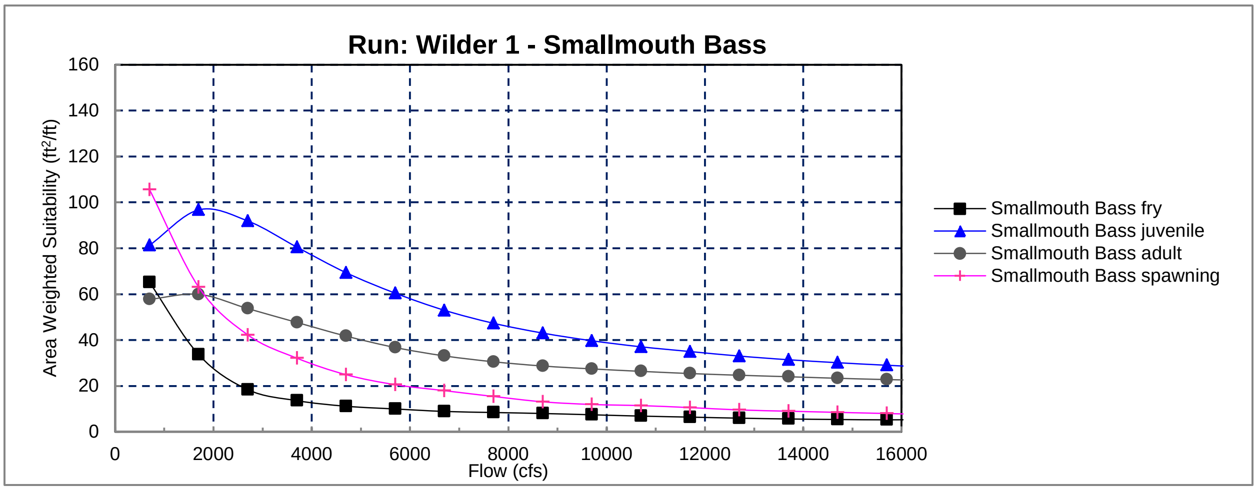


Figure 5.4-5. Tessellated Darter, Sea Lamprey spawning, and macroinvertebrate AWS for Wilder reach 1, and by habitat groups run and pool.





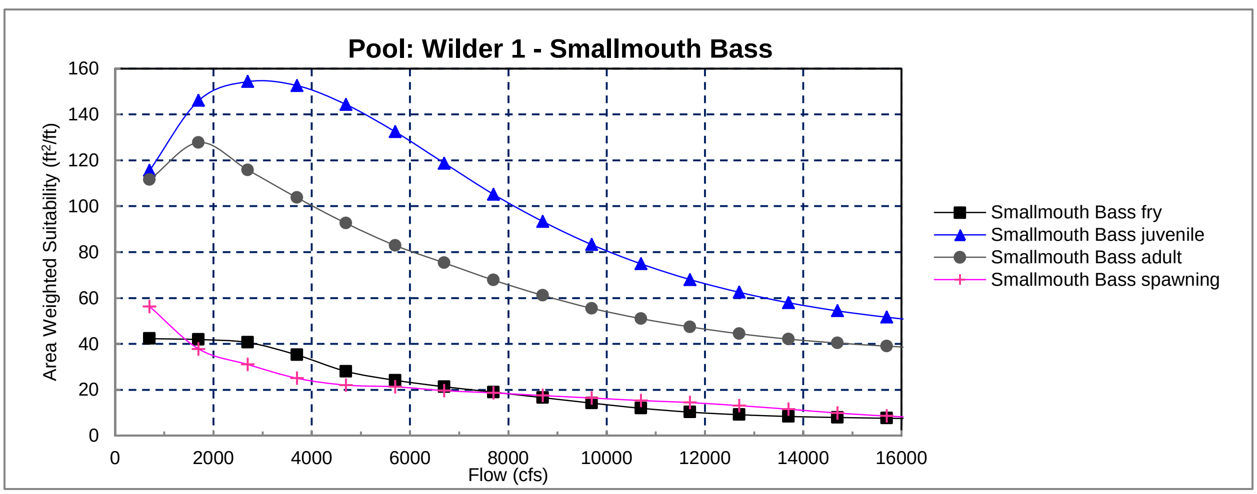


Figure 5.4-6. Smallmouth Bass AWS for Wilder reach 1, and by habitat groups run and pool.

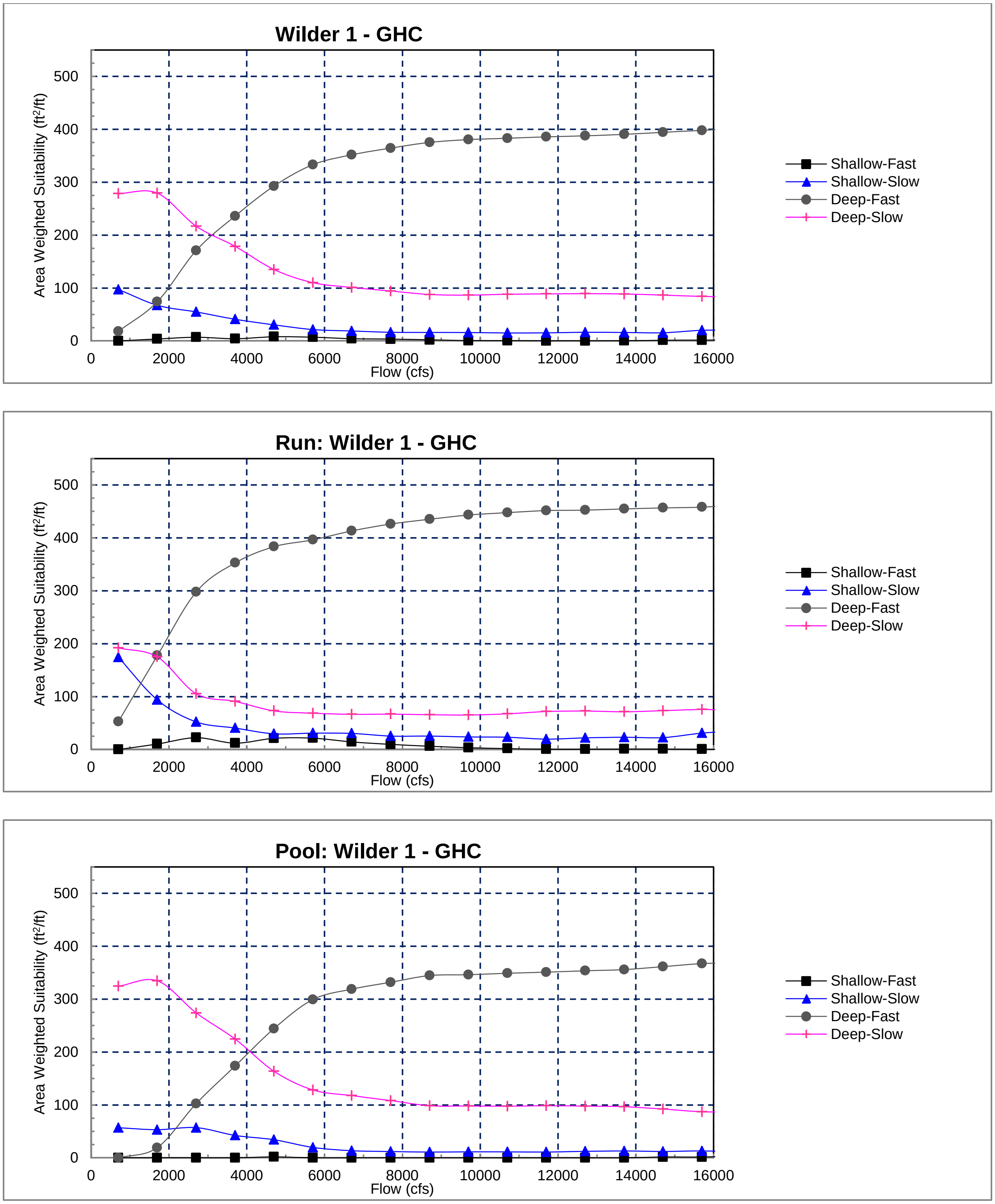
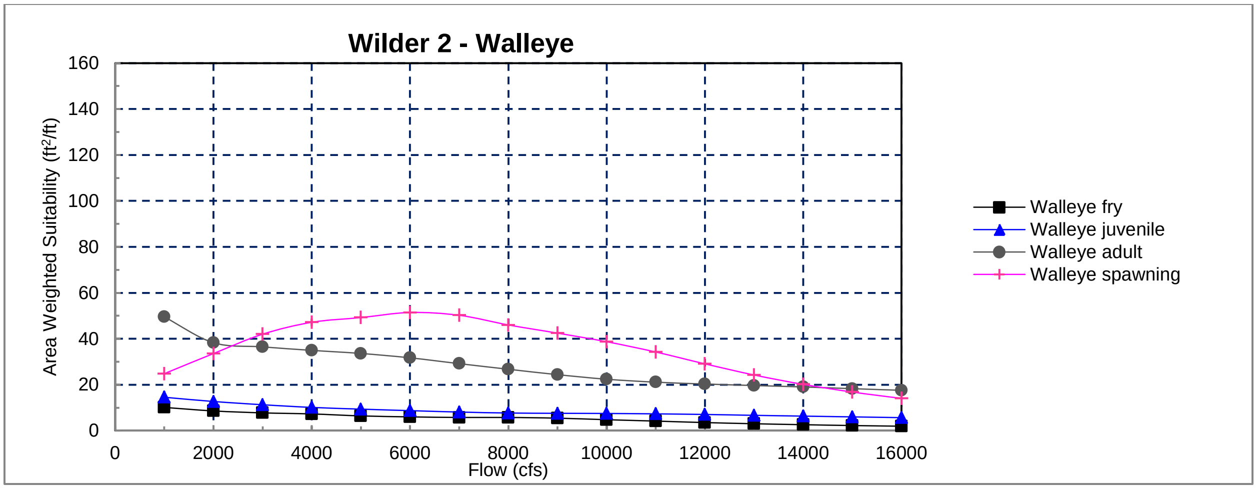
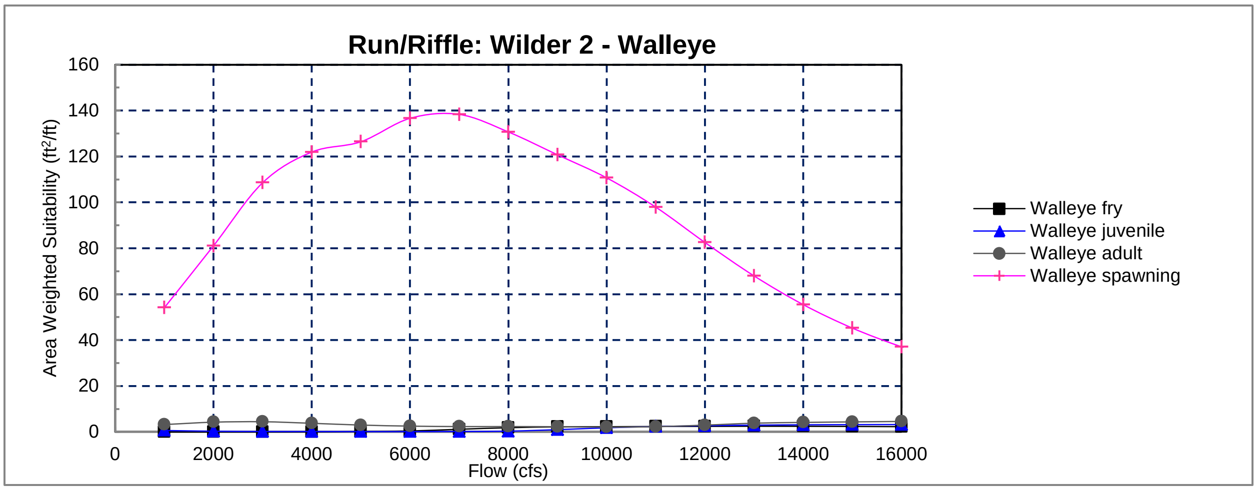


Figure 5.4-7. Generalized Habitat Criteria AWS for Wilder reach, and by habitat groups run and pool.





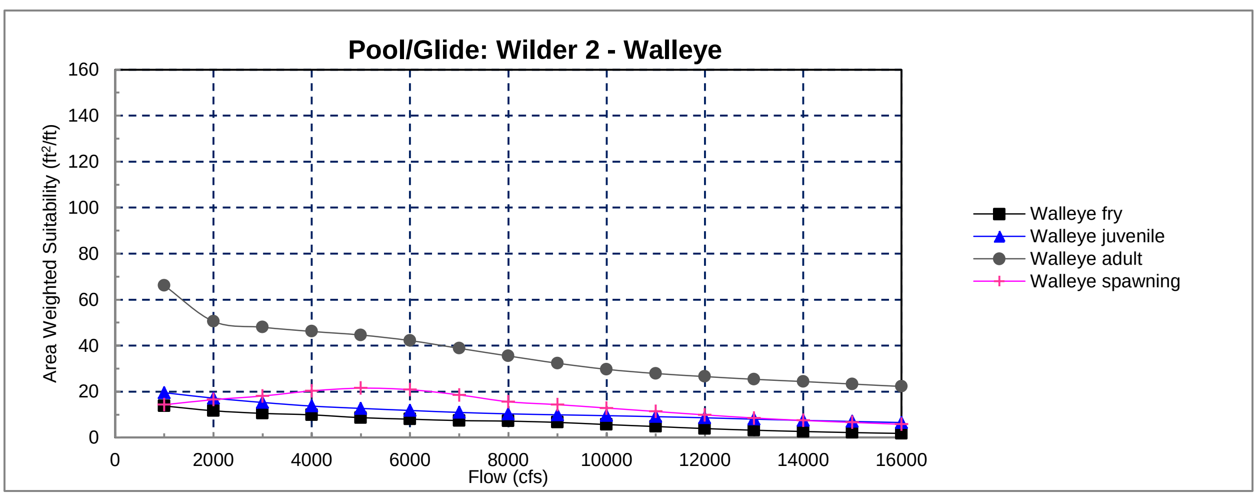


Figure 5.4-8. Walleye AWS for Wilder reach 2, and by habitat groups run/riffle and pool/glide.

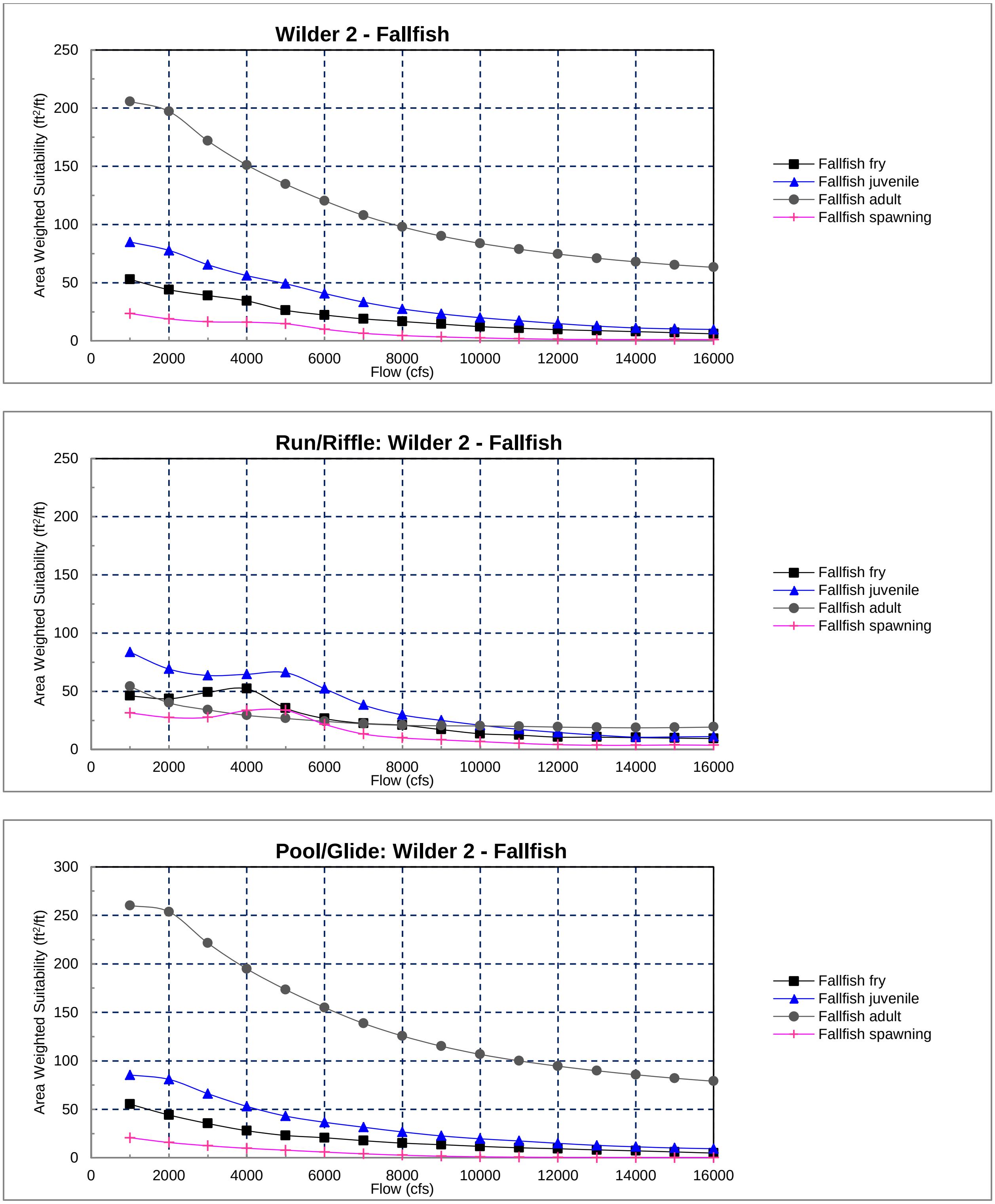


Figure 5.4-9. Fallfish AWS for Wilder reach 2, and by habitat groups run/riffle and pool/glide.

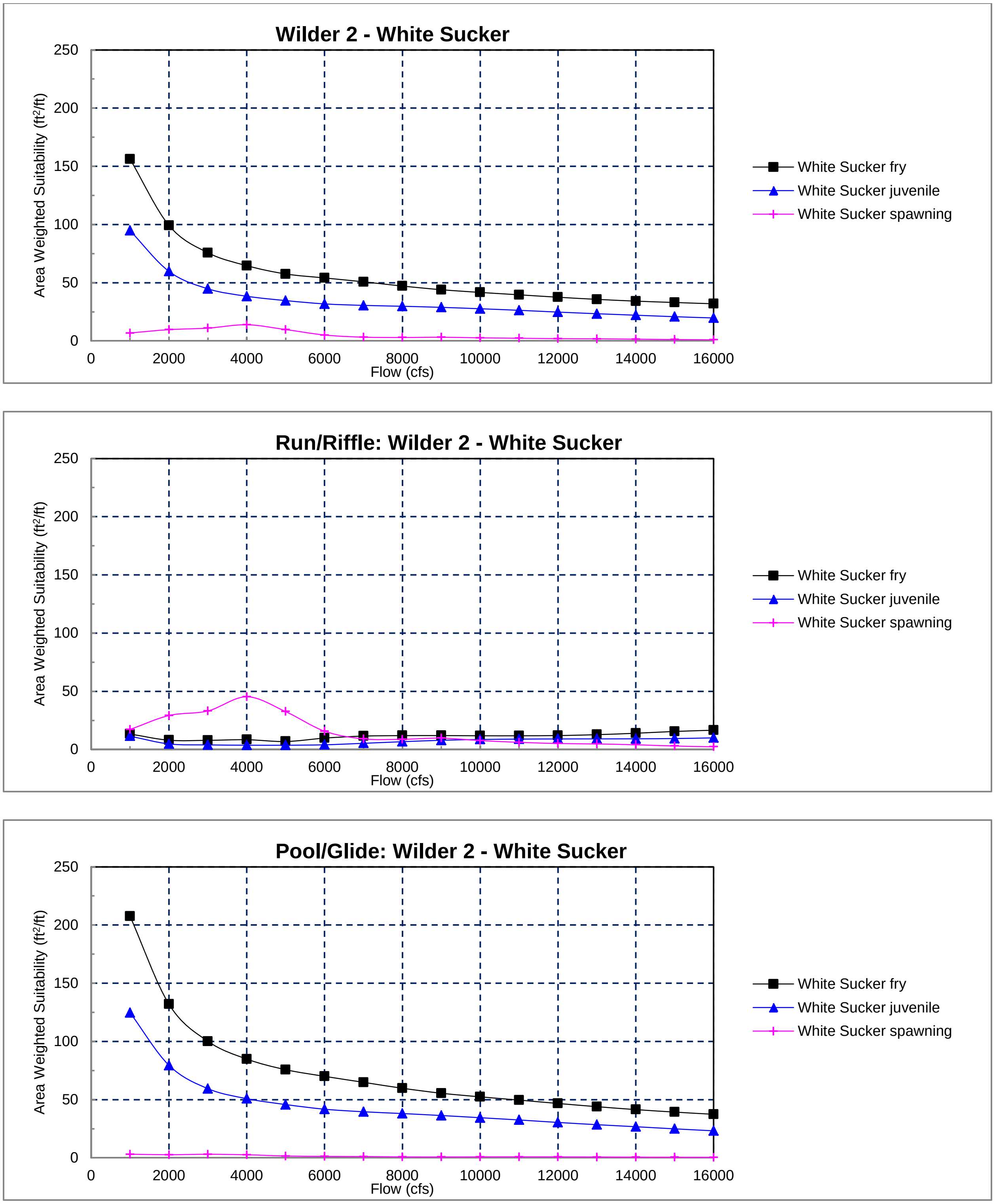


Figure 5.4-10. White Sucker AWS for Wilder reach 2, and by habitat groups run/riffle and pool/glide.

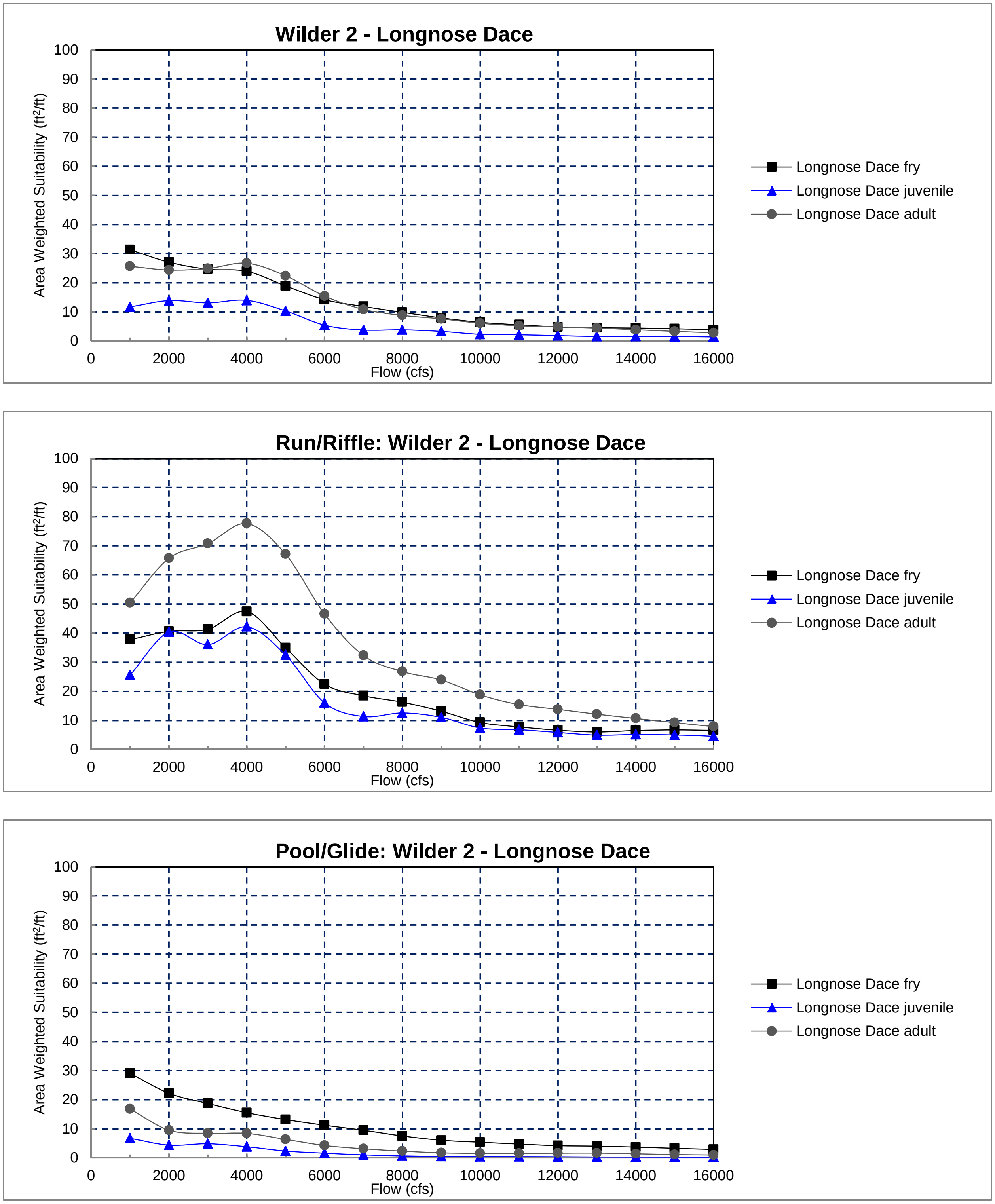


Figure 5.4-11. Longnose Dace AWS for Wilder reach 2, and by habitat groups run/riffle and pool/glide.

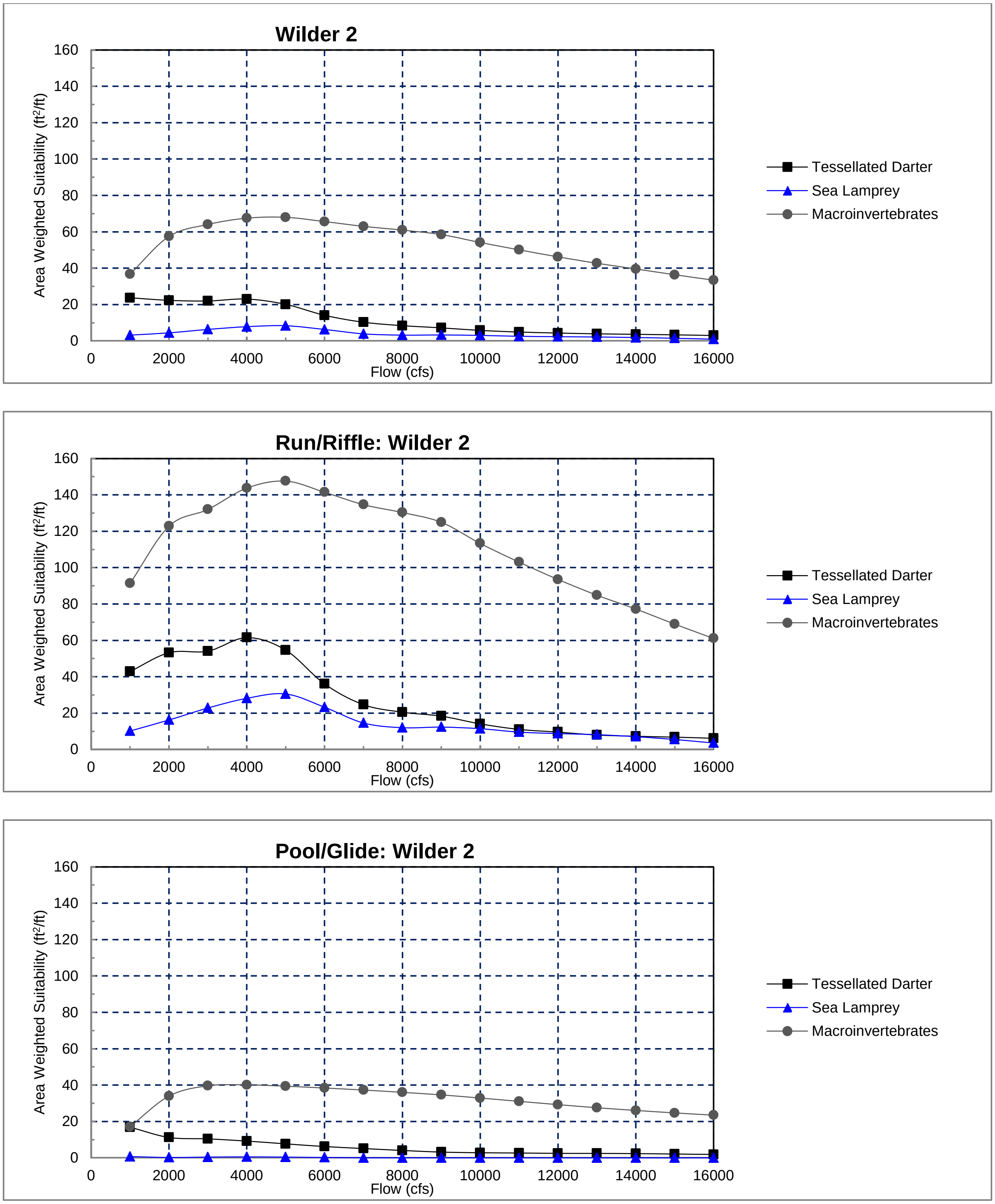


Figure 5.4-12. Tessellated Darter, Sea Lamprey spawning, and macroinvertebrate AWS for Wilder reach 2, and by habitat groups run/riffle and pool/glide.

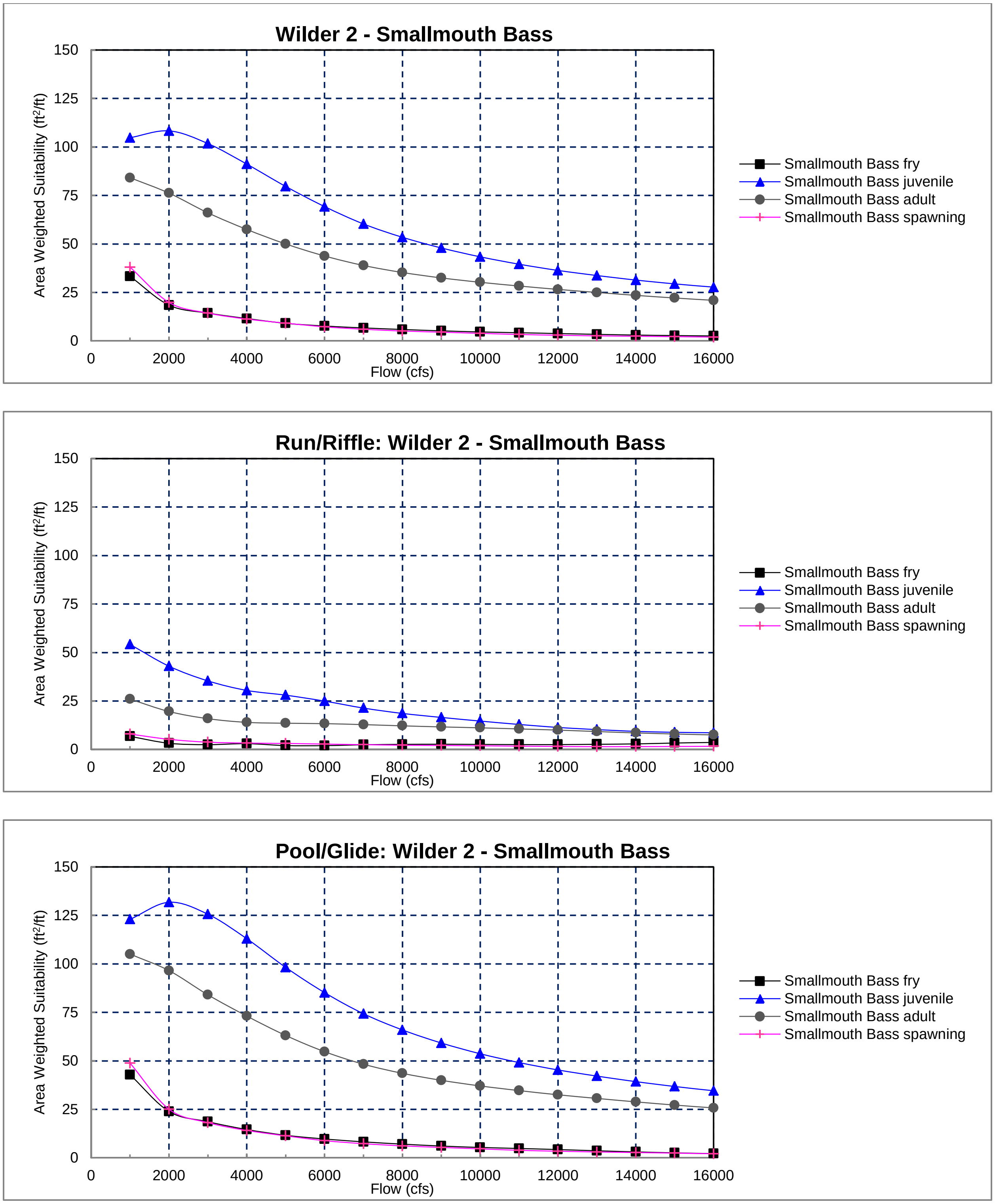
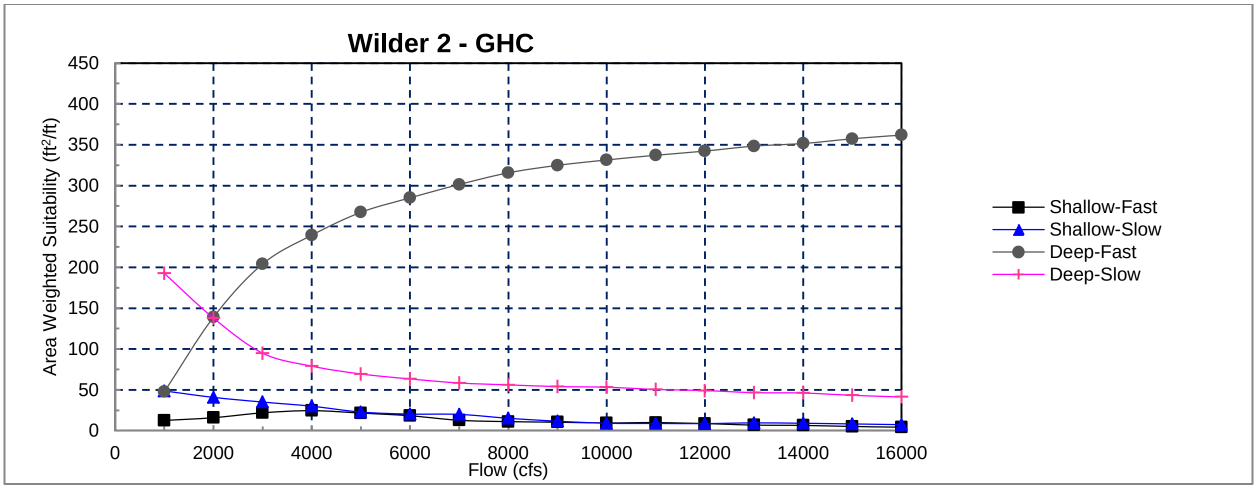
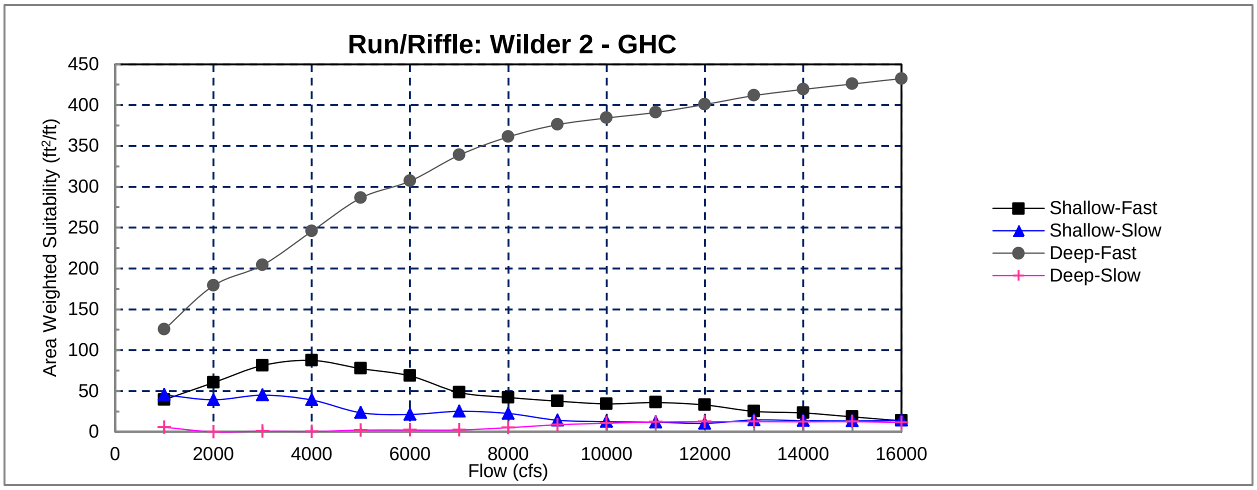


Figure 5.4-13. Smallmouth Bass AWS for Wilder reach 2, and by habitat groups run/riffle and pool/glide.





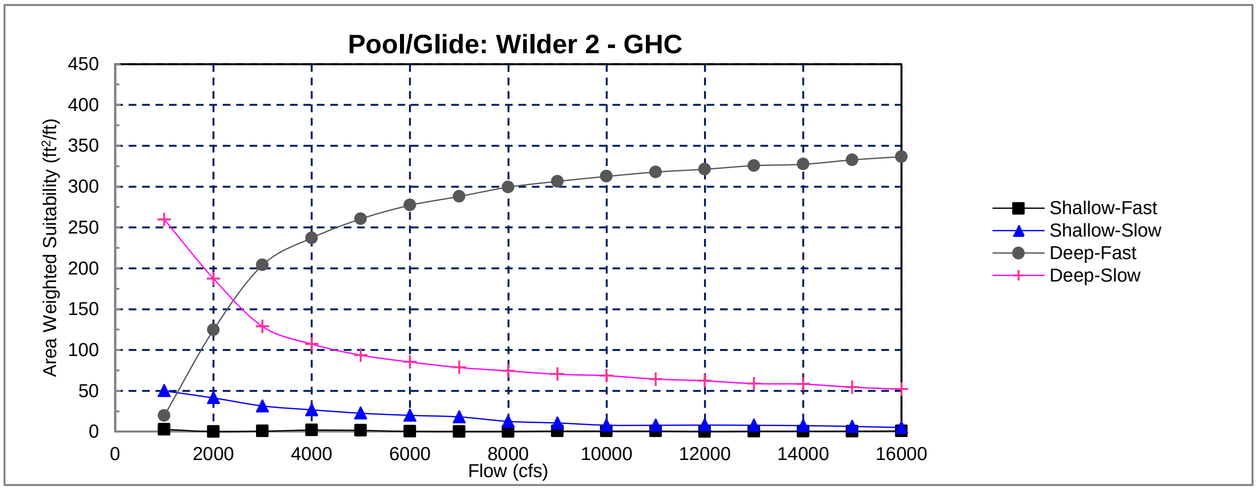


Figure 5.4-14. Generalized Habitat Criteria AWS for Wilder reach 2, and by habitat groups run/riffle and pool/glide.

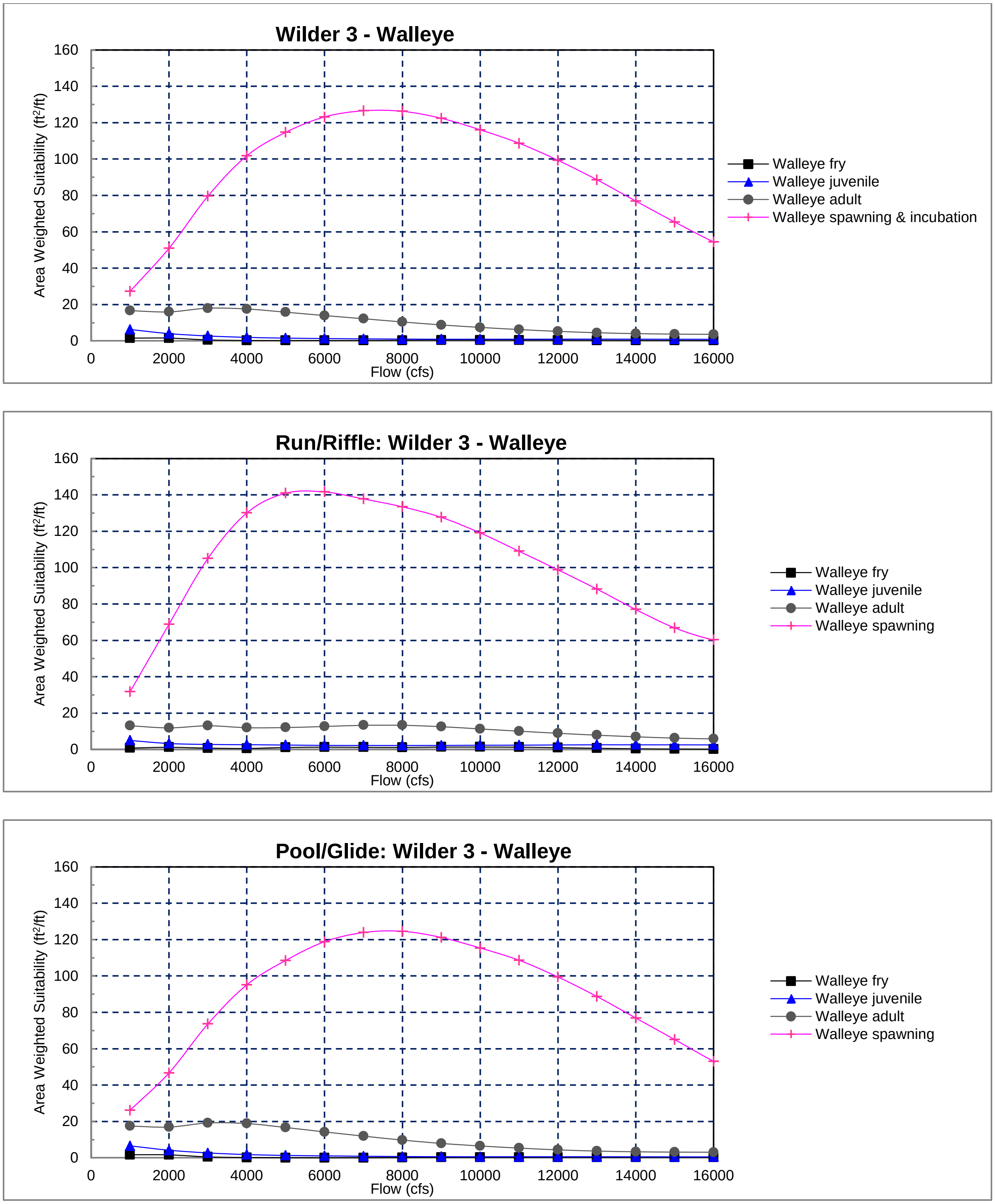


Figure 5.4-15. Walleye AWS for Wilder reach 3, and by habitat groups run/riffle and pool/glide.

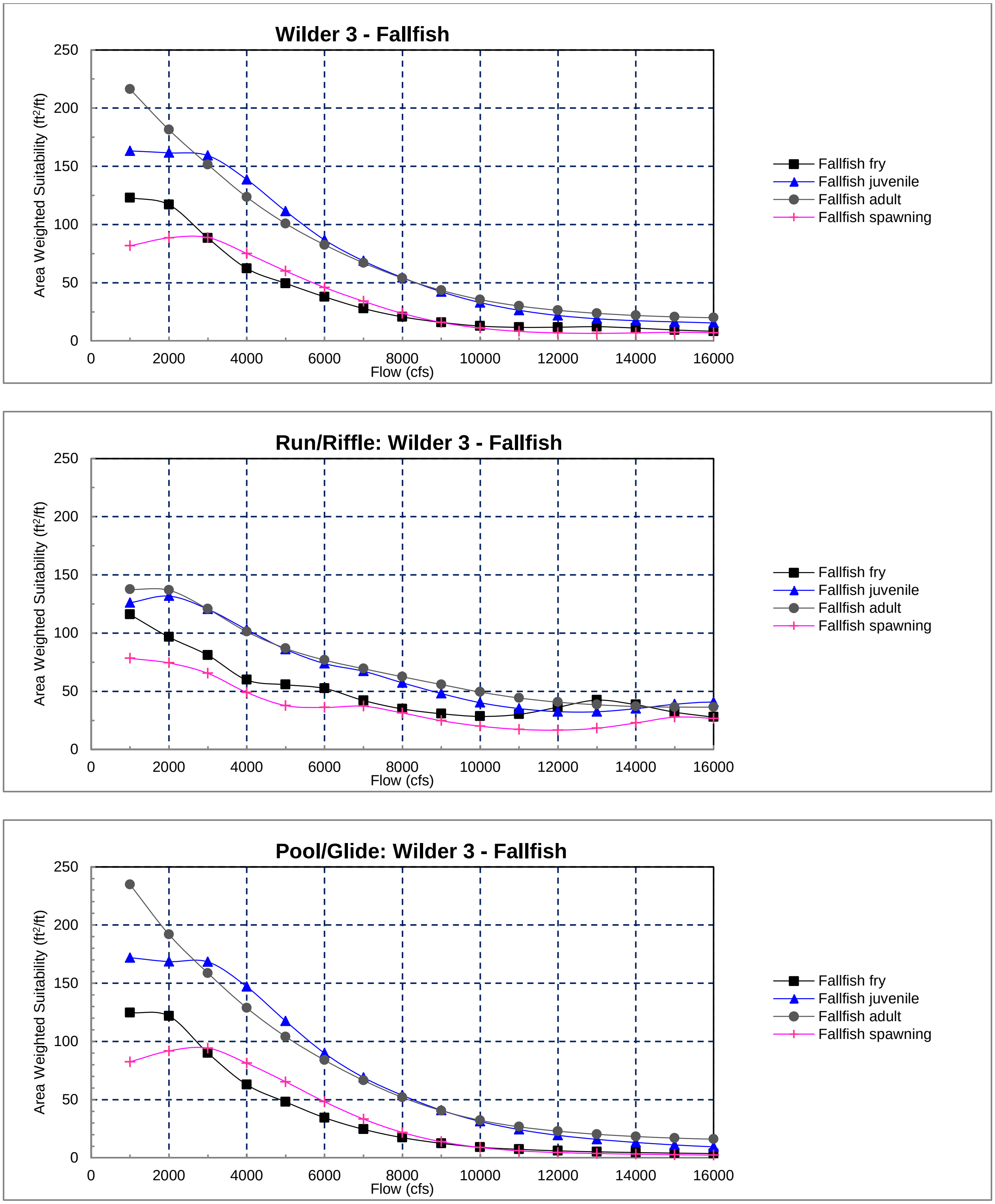


Figure 5.4-16. Fallfish AWS for Wilder reach 3, and by habitat groups run/riffle and pool/glide.

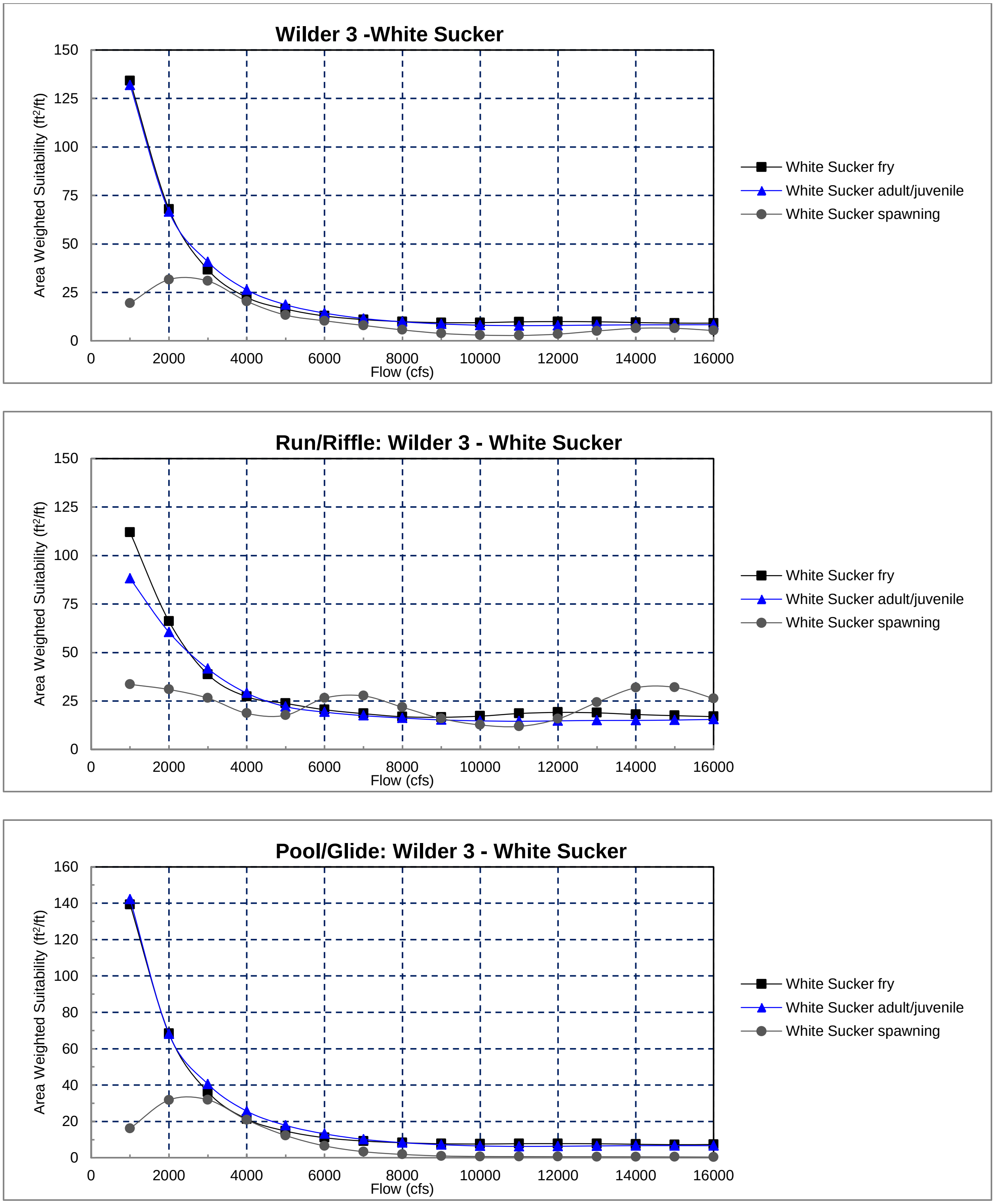


Figure 5.4-17. White Sucker AWS for Wilder reach 3, and by habitat groups run/riffle and pool/glide.

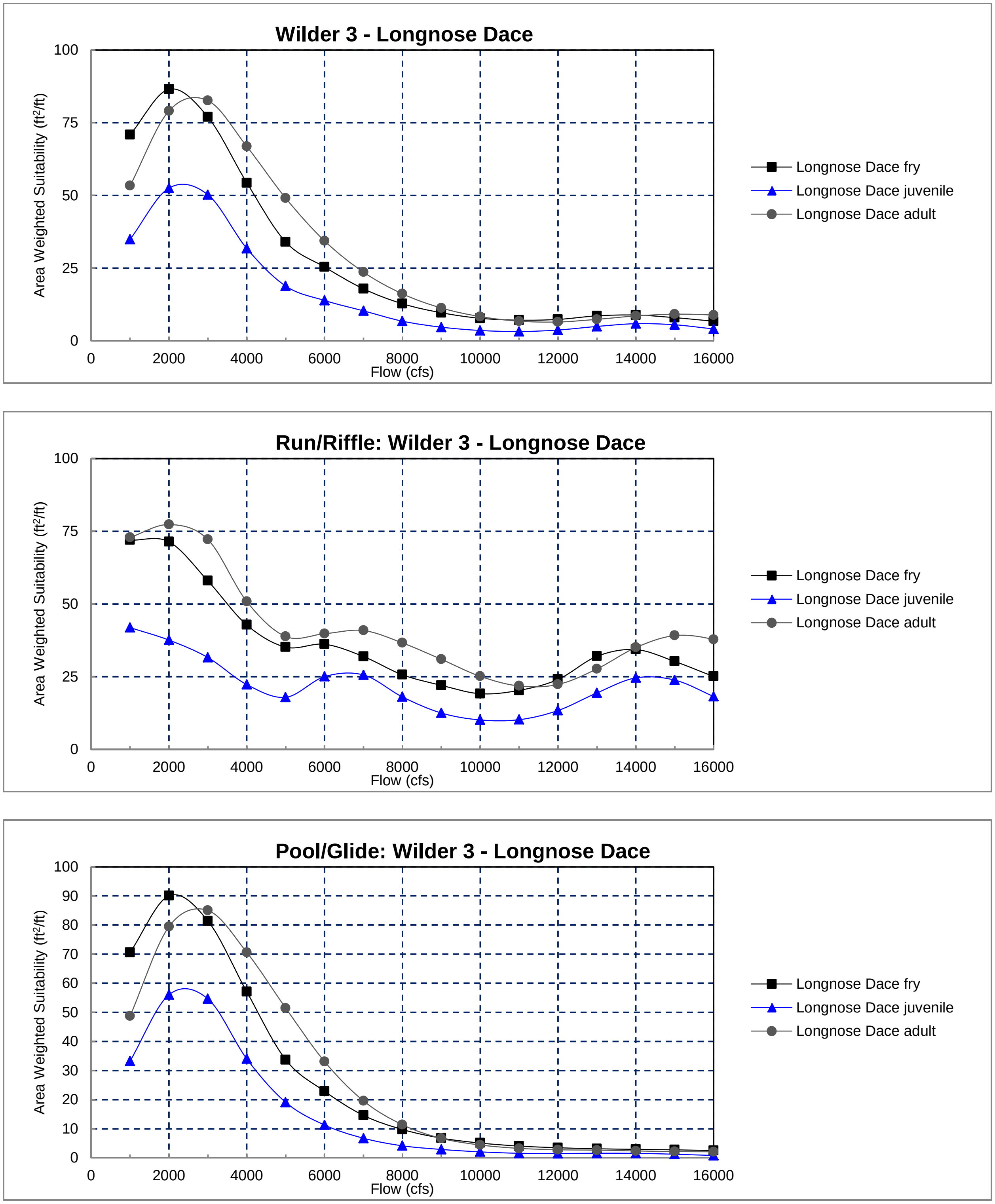
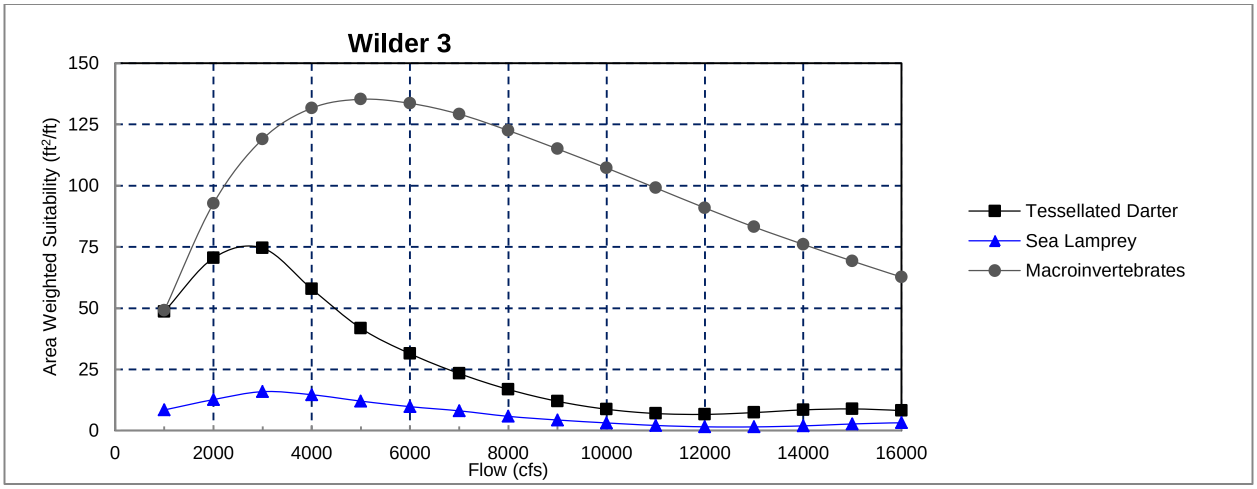
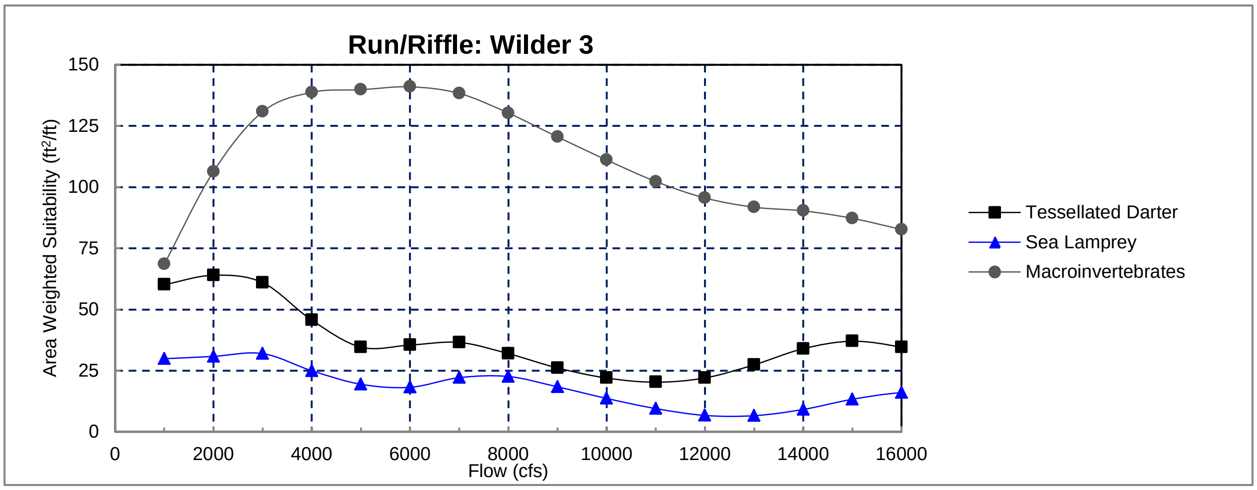


Figure 5.4-18. Longnose Dace AWS for Wilder reach 3, and by habitat groups run/riffle and pool/glide.





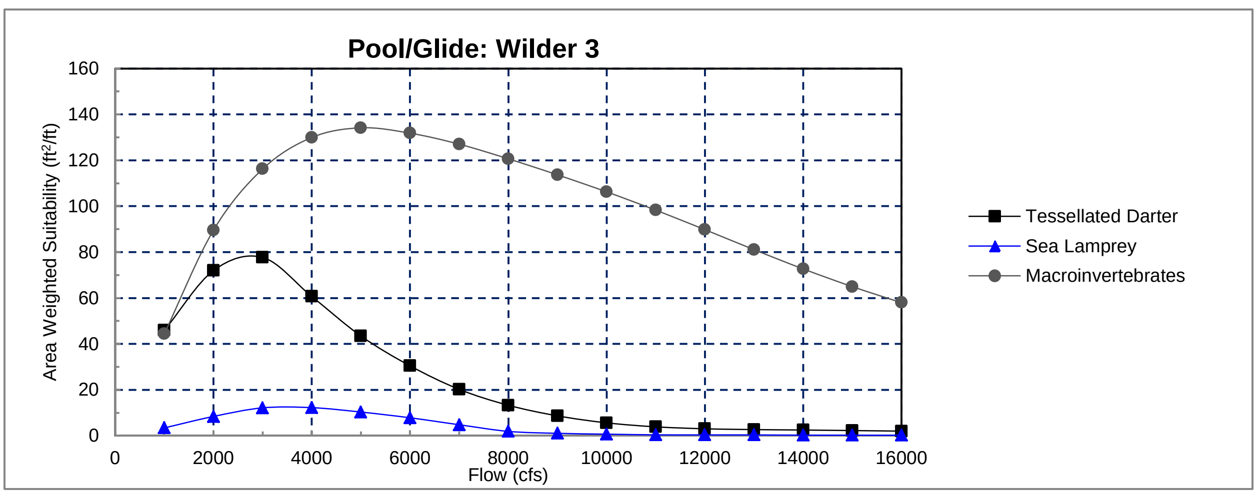
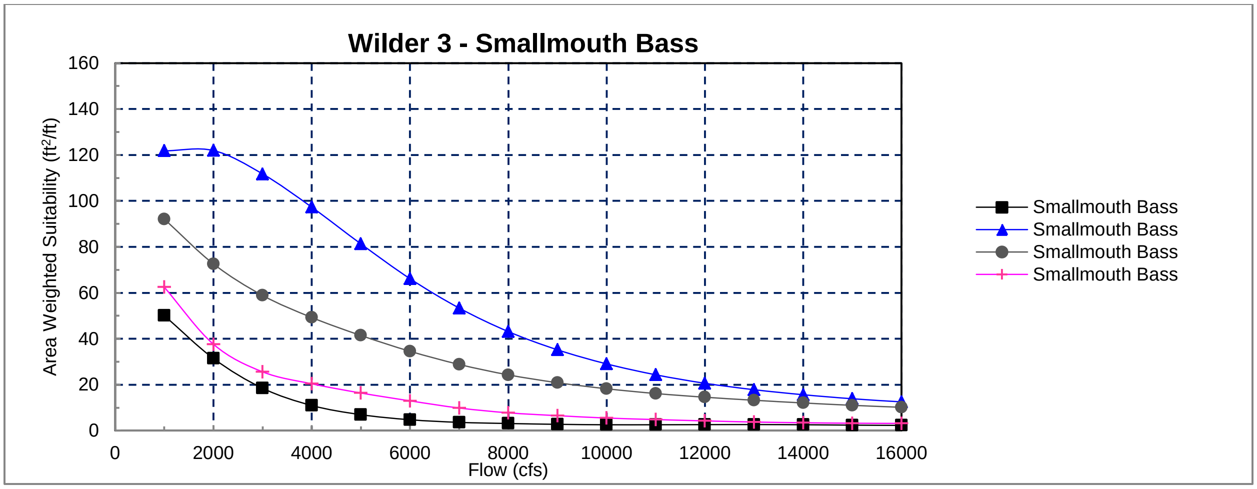
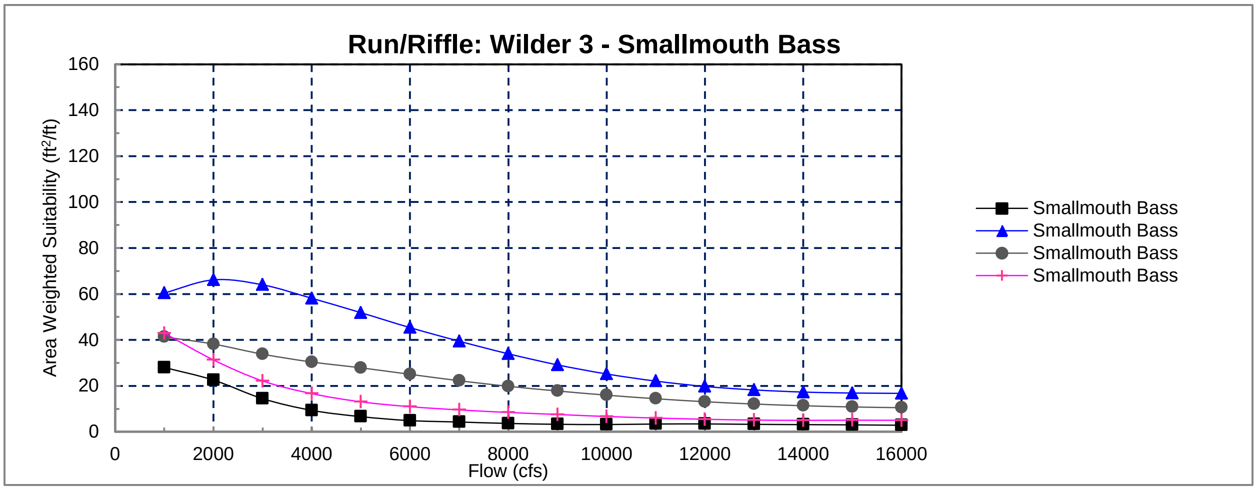


Figure 5.4-19. Tessellated Darter, Sea Lamprey spawning, and macroinvertebrate AWS for Wilder reach 3, and by habitat groups run/riffle and pool/glide.





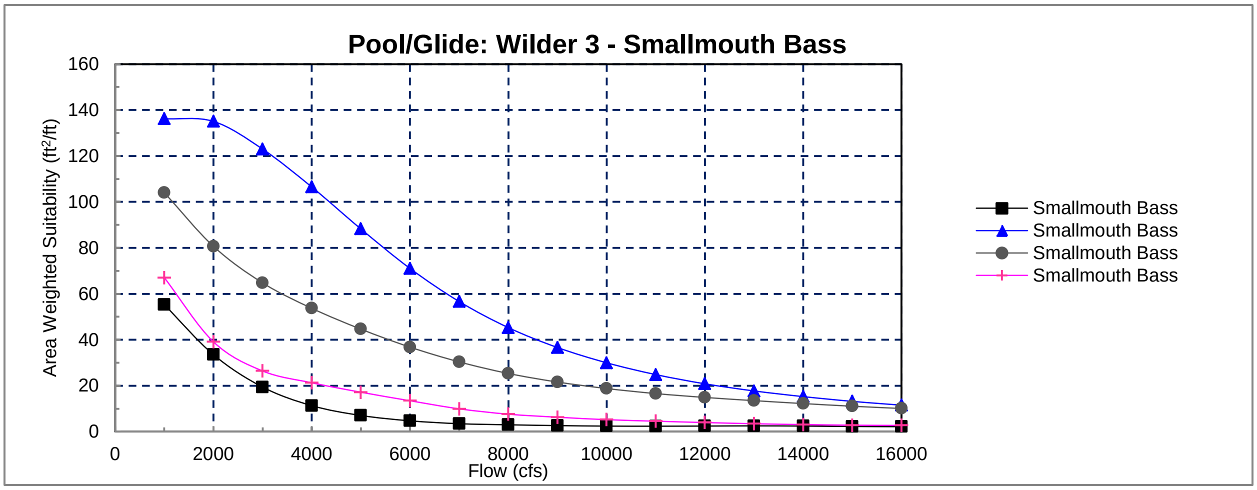


Figure 5.4-20. Smallmouth Bass AWS for Wilder reach 3, and by habitat groups run/riffle and pool/glide.

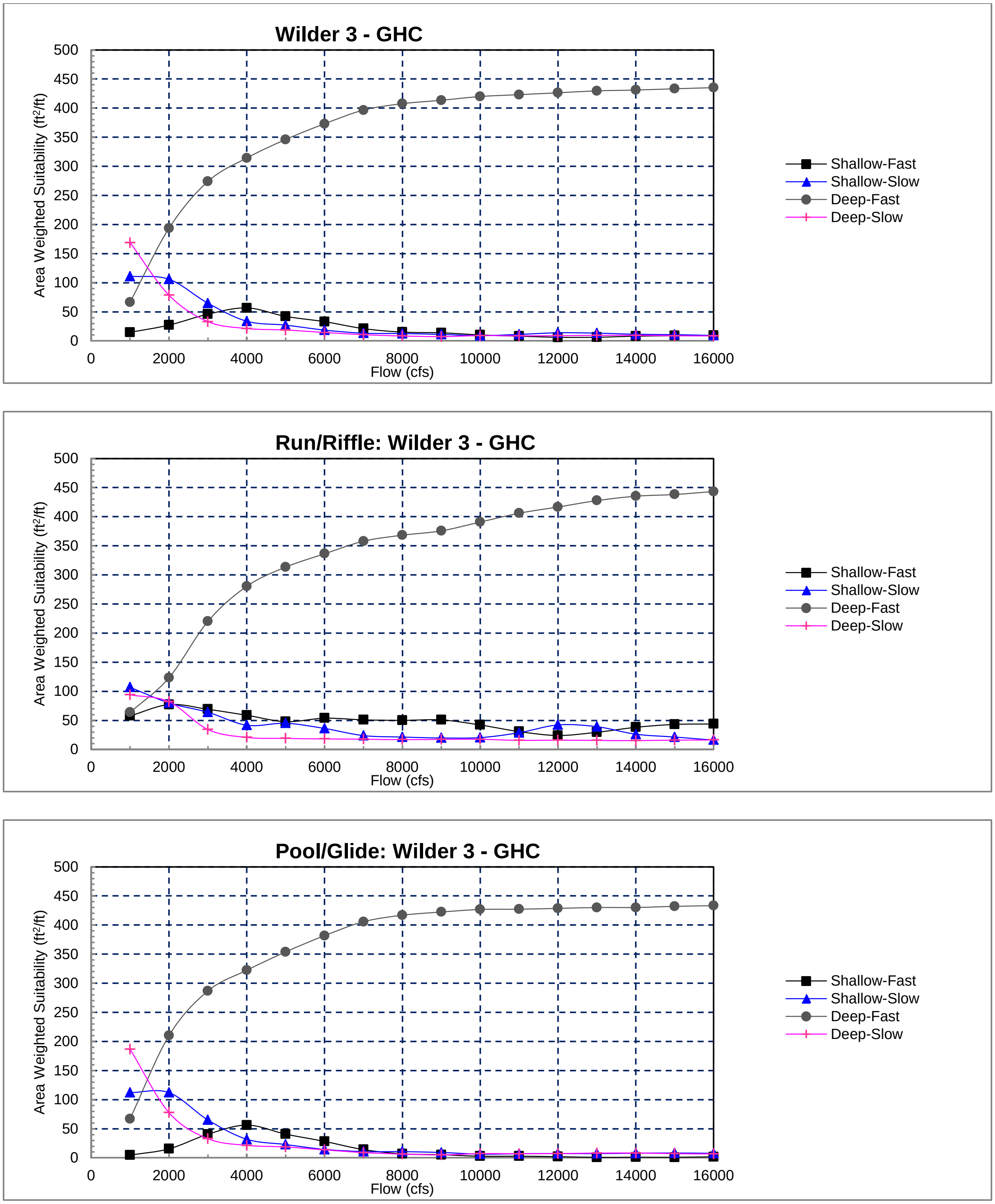


Figure 5.4-21. Generalized Habitat Criteria (GHC) AWS for Wilder reach 3, and by habitat groups run/riffle and pool/glide.

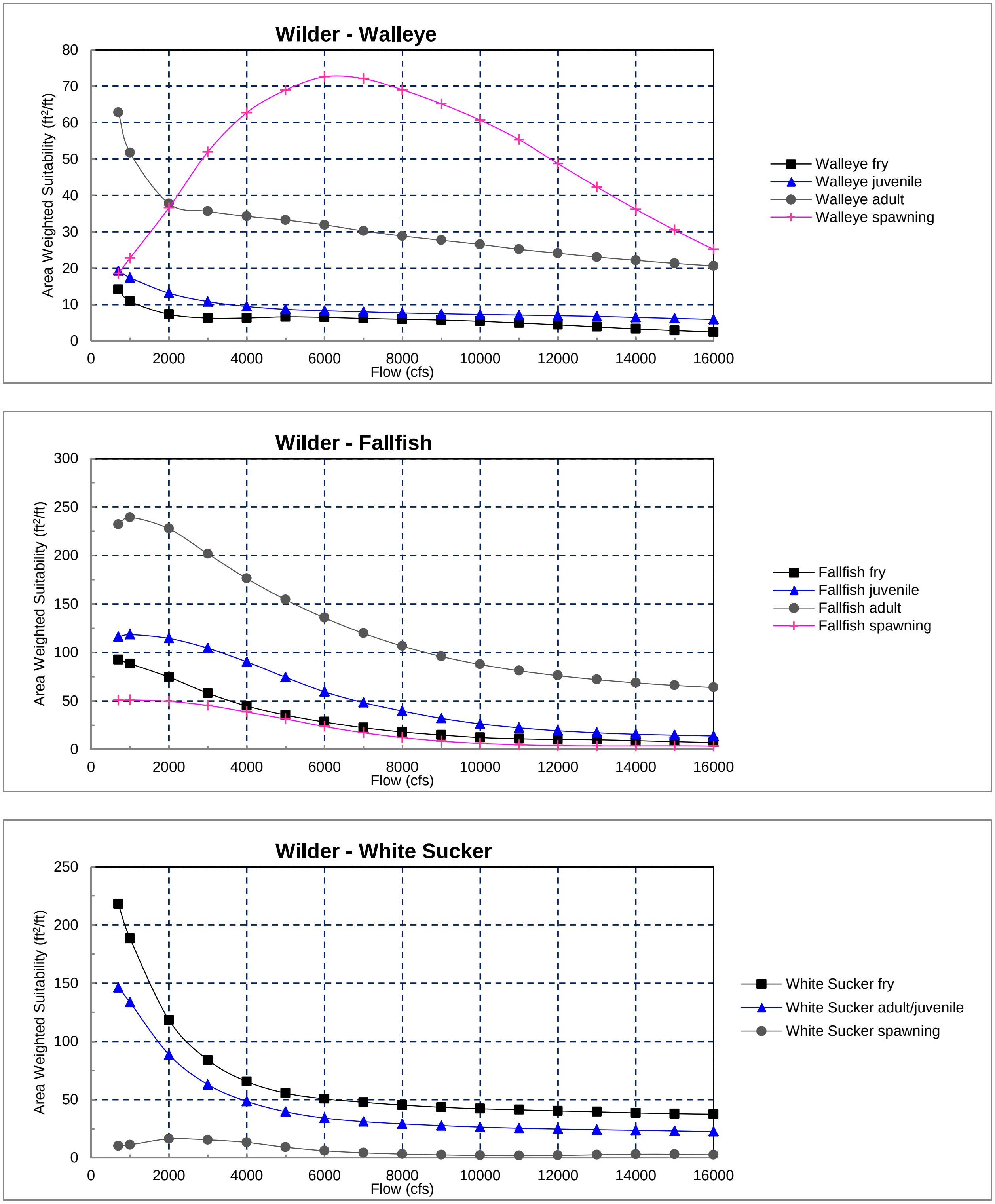
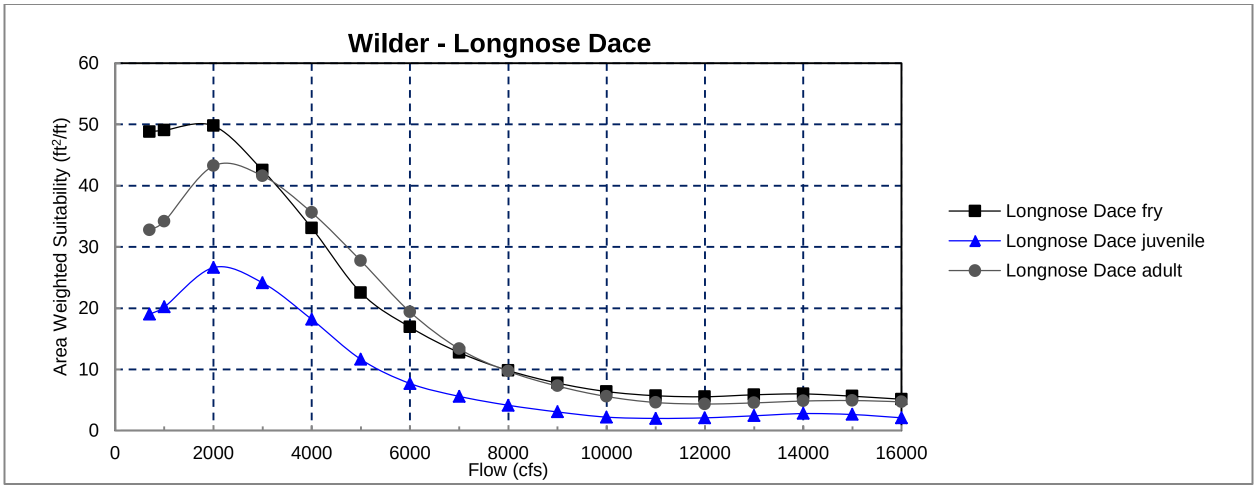


Figure 5.4-22. AWS for Walleye, Fallfish, and White Sucker for Wilder reaches combined.



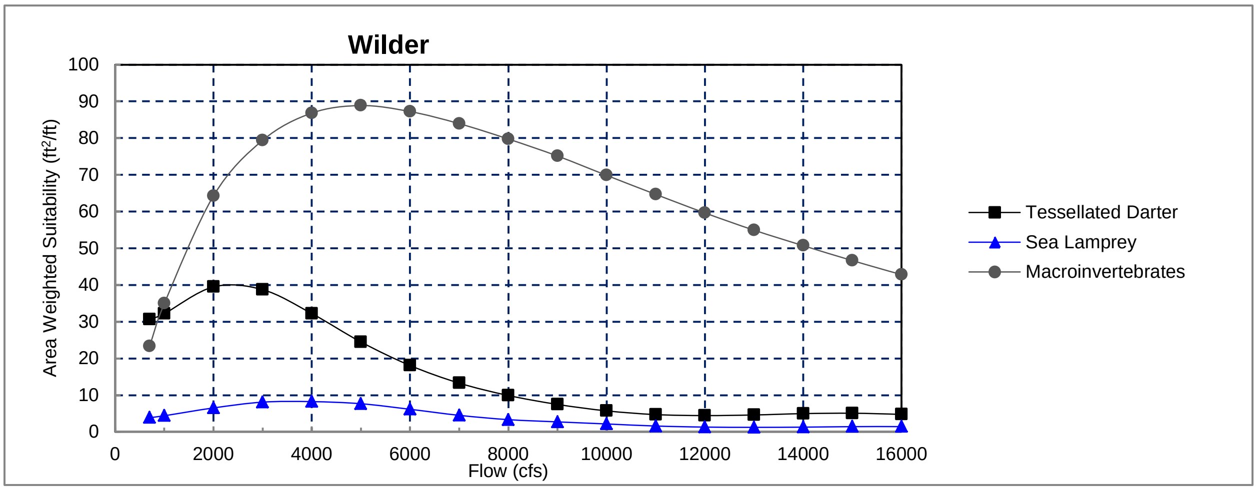
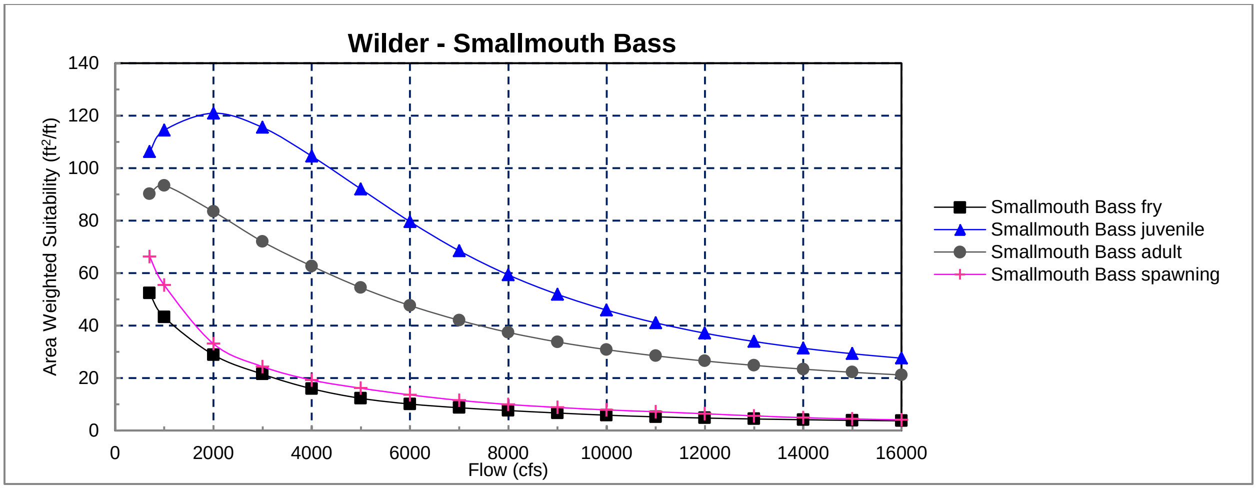


Figure 5.4-23. AWS for Longnose Dace, Tessellated Darter, Sea Lamprey spawning, and macroinvertebrates for Wilder reaches combined.



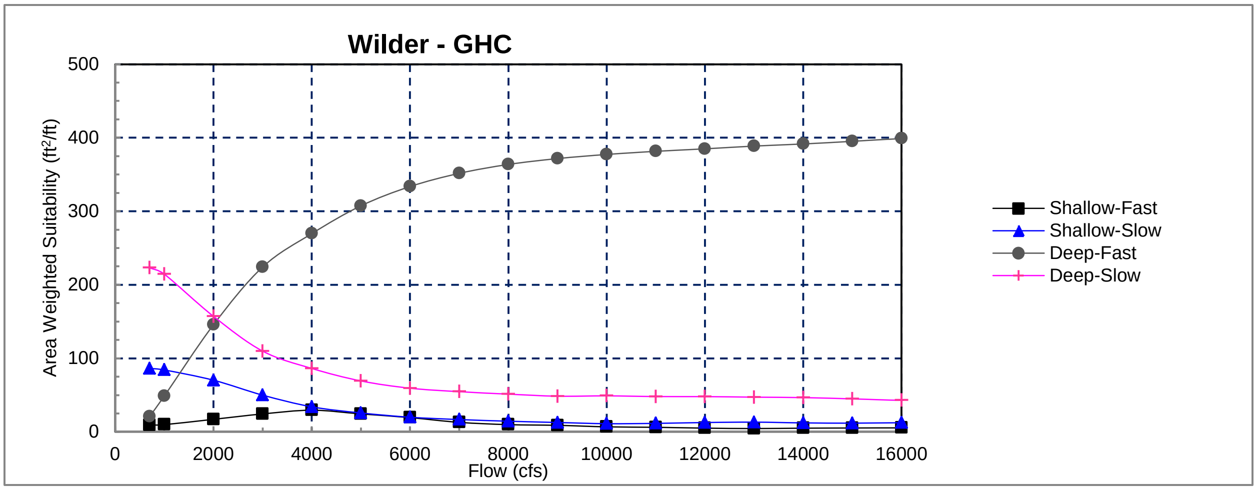


Figure 5.4-24. AWS for Smallmouth Bass and Generalized Habitat Criteria for Wilder reaches combined.

Johnson Island and Chase Island 2D Sites

The Johnson Island study site contained the majority of riffle habitat by length (76 percent) in Wilder reach 2, though the total amount of riffle habitat in the reach was only 4.2 percent (Table 5.4-4). A similar percentage of riffle habitat was found for all three Wilder reaches combined. Compared to Wilder reach 2 and Wilder combined reaches which were dominated by pool habitat, the Johnston Island 2D site was dominated by riffle and run habitat (61 percent).

Table 5.4-4. Percent representation of mesohabitat types in Wilder reach 2, Wilder reaches combined and Johnston Island 2D site (2D site percentage based on area).

Habitat Type	Wilder Reach 2 Percent by Length	Wilder Reaches Combined Percent by Length	Johnston Island 2D Site Percent by Area
Pool	62.6	55.5	30.4
Glide	10.7	23.4	9.0
Run	22.4	14.7	33.8
Riffle	4.2	5.0	26.8
Rapid	0.0	1.4	0.0
Cascade	0.0	0.0	0.0
Totals	100.0	100.00	100.0

In contrast, mesohabitat percentages for the Chase Island 2D site are very similar to those of the entire Wilder reach, with pool, riffle and run/glide percent nearly identical (Table 5.4-5).

Table 5.4-5. Percent representation of mesohabitat types in Wilder reaches combined, Chase Island 2D site and Johnston Island 2D site (2D site percentages based on area).

Habitat Type	Wilder Reaches Combined Percent by Length	Chase Island 2D Site Percent by Area	Johnston Island 2D Site Percent by Area
Pool	55.5	56.1	30.4
Glide	23.4	15.9	9.0
Run	14.7	21.9	33.8
Riffle	5.0	6.2	26.8
Rapid	1.4	0.0	0.0
Cascade	0.0	0.0	0.0
Totals	100.00	100.0	100.0

Combining habitat index results between the 2D and 1D models can be problematic due to the difference in spatial scale. Results from River2D are expressed in WUA (m^2 or ft^2) over the entire 2D site, with weighting based on the area of each node multiplied by the CSI for that node (see Appendix E). Model results for 1D transects are expressed in AWS (ft^2/ft) which is the CSI for each point multiplied by the width represented by that point and summed. Each transect is then weighted by percent representation and all transects are summed to produce the final AWS for a reach.

Comparison of habitat index results from the 2D sites and Wilder reaches combined are presented in Figures 5.4-25 to 5.4-31. The most important element to examine is not the habitat index values themselves but the shape of the curves. In general, curves from the Johnston Island 2D site are similar to those for Wilder reaches combined in shape and location of maximum habitat index versus flow. Dissimilarities between the 2D site and Wilder reach 2 are attributable to a difference in proportion of riffle habitat represented by the two models (only a single riffle was characterized by a 1D transect in Wilder reach 2).

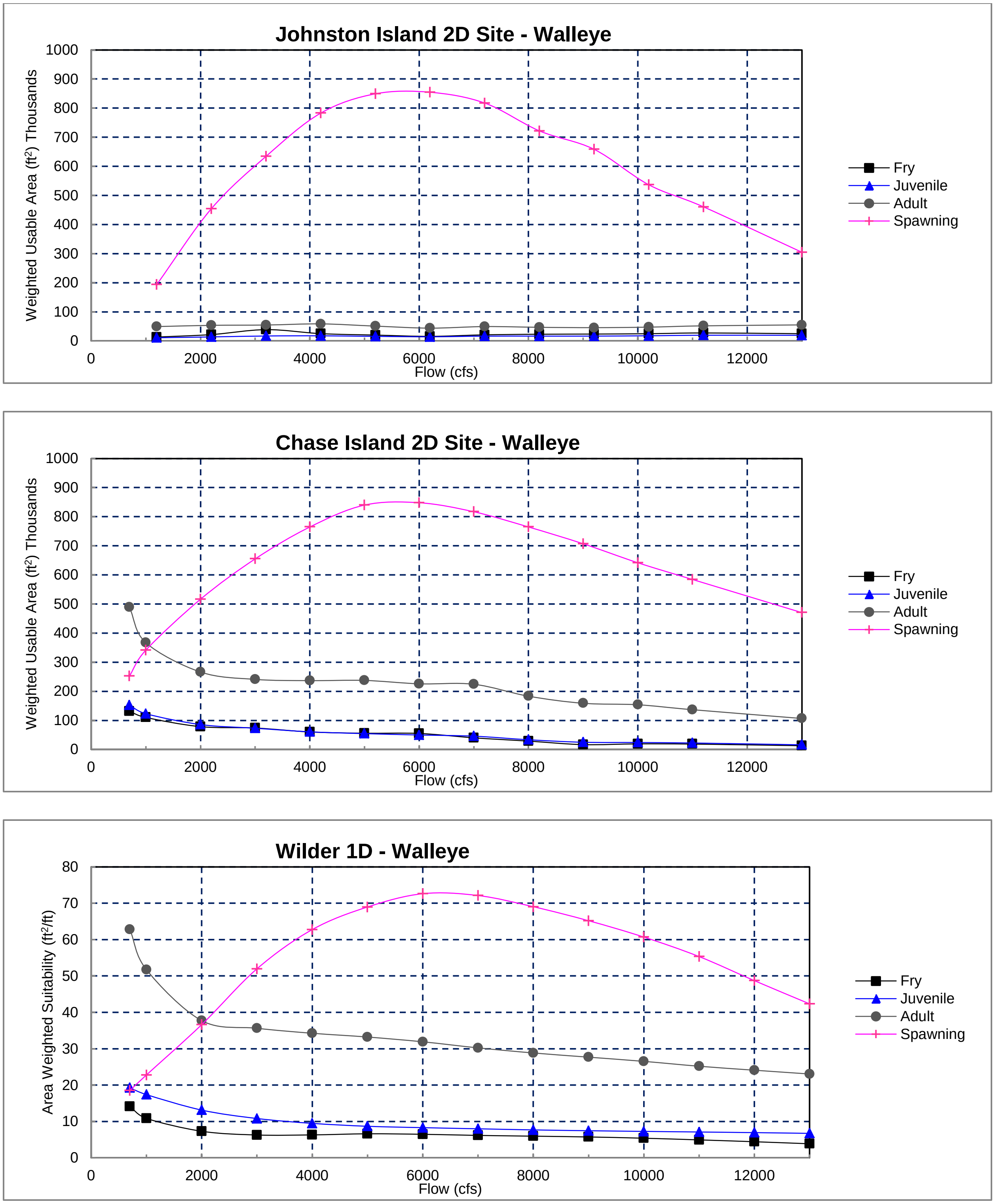
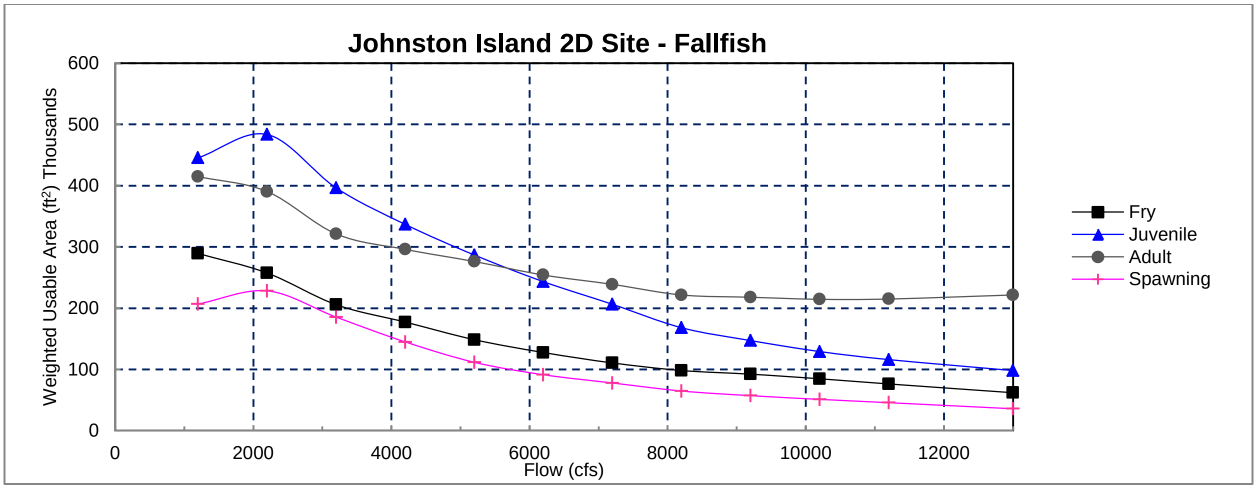
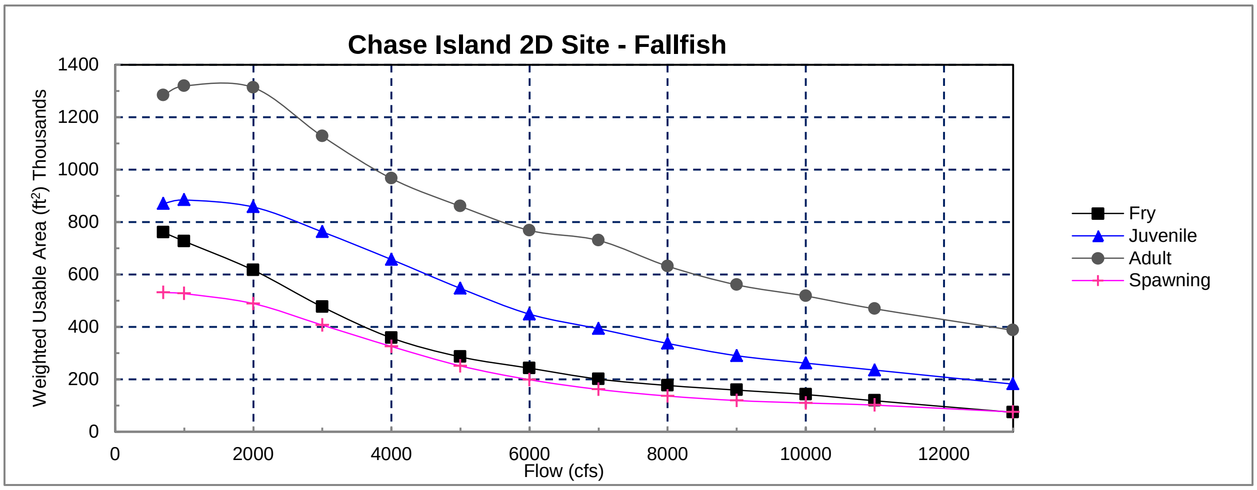


Figure 5.4-25. Walleye WUA for Johnston Island and Chase Island 2D sites and AWS for Wilder 1D reach combined.





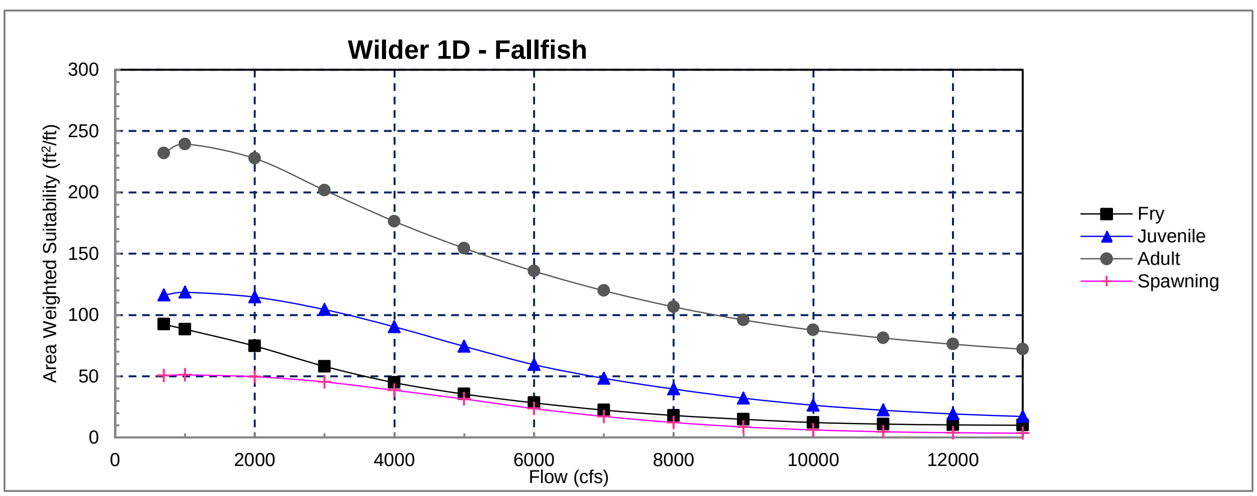
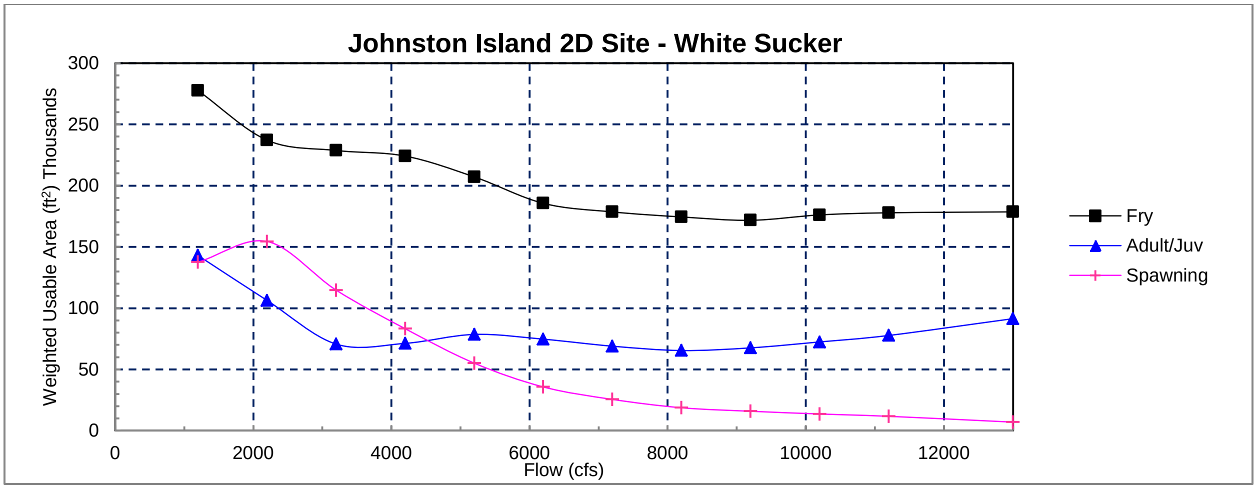
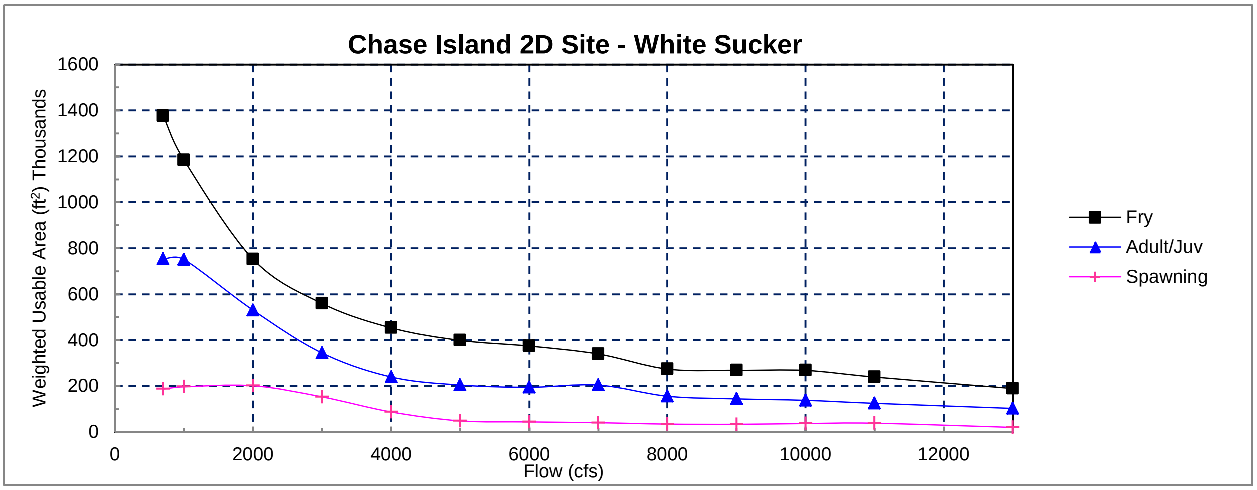


Figure 5.4-26. Fallfish WUA for Johnston Island and Chase Island 2D sites and AWS for Wilder 1D reach combined.





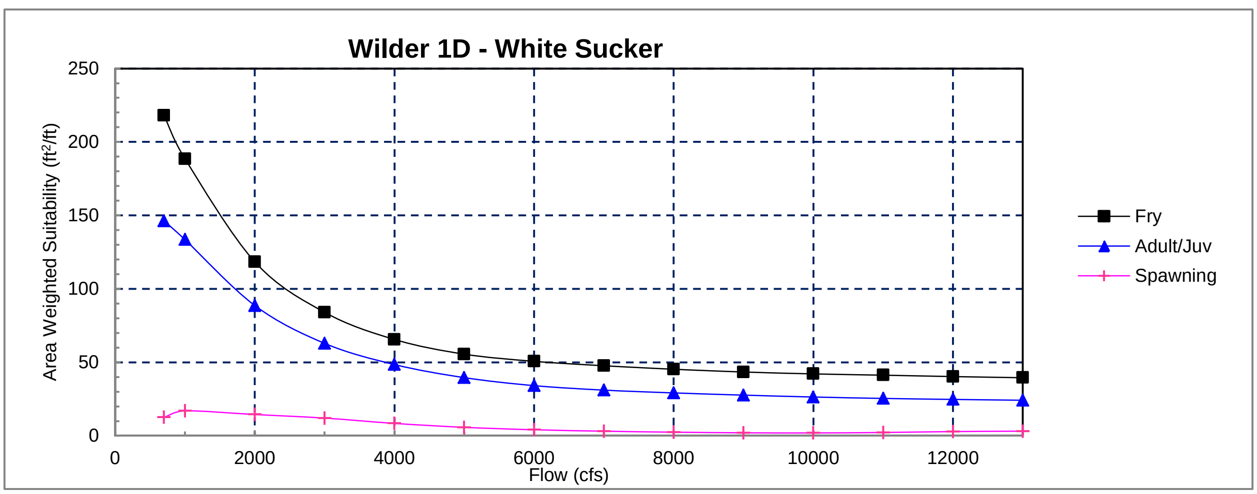


Figure 5.4-27. White Sucker WUA for Johnston Island and Chase Island 2D sites and AWS for Wilder 1D reach combined.

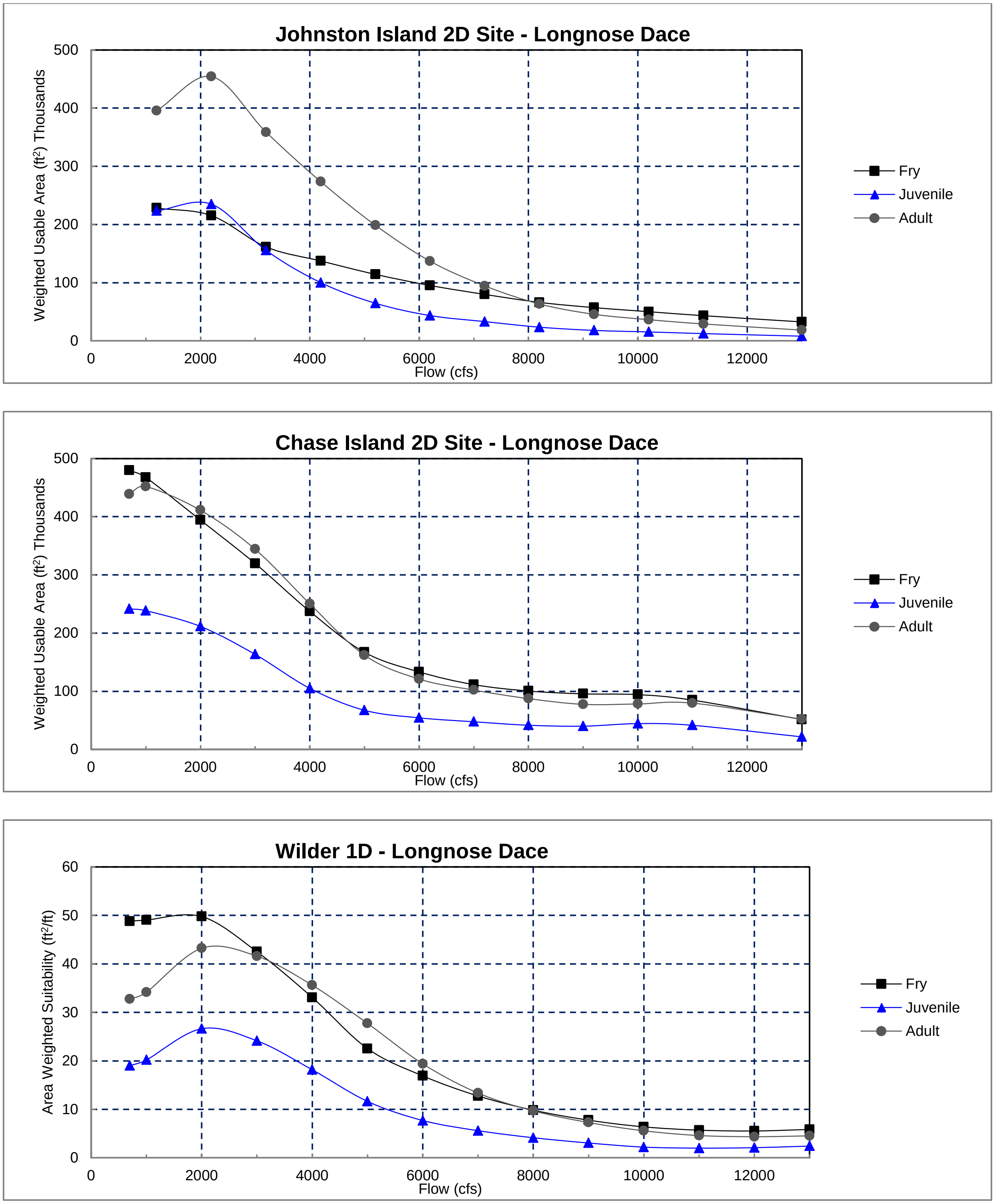


Figure 5.4-28. Longnose Dace WUA for Johnston Island and Chase Island 2D sites and AWS for Wilder 1D reach combined.

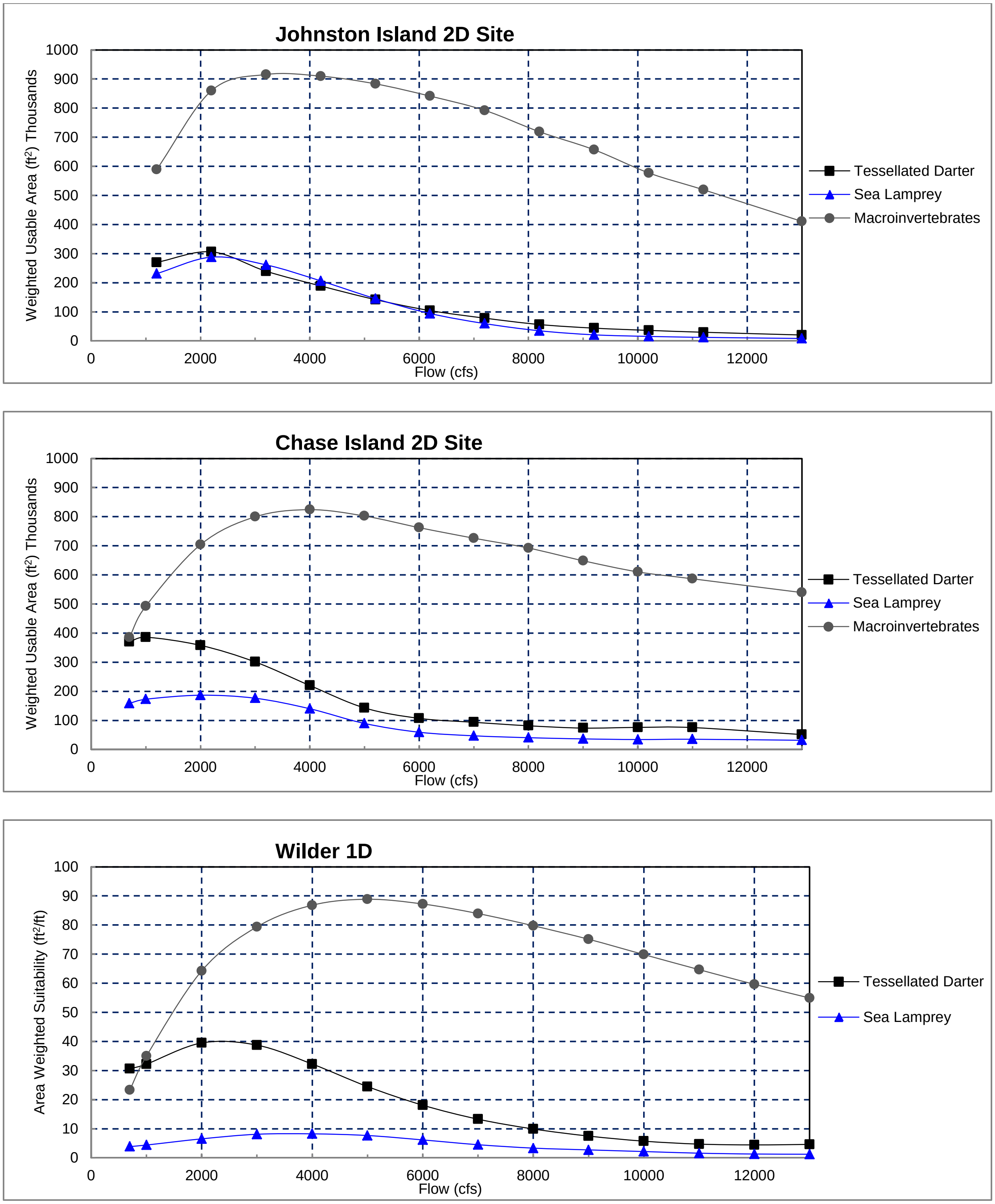
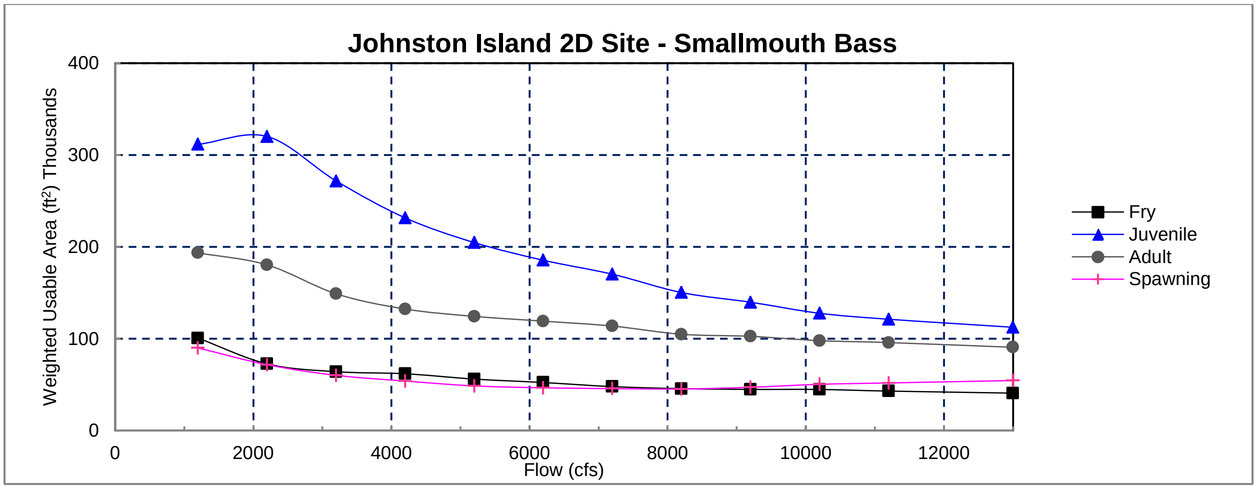
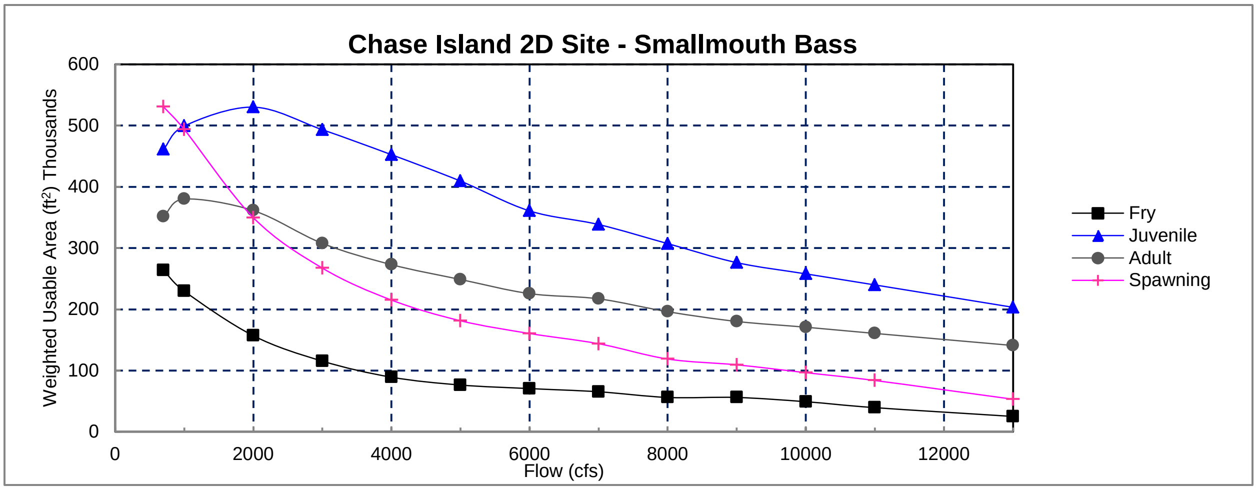


Figure 5.4-29. Tessellated Darter adult, Sea Lamprey spawning, and macroinvertebrates WUA for Johnston Island and Chase Island 2D sites and AWS for Wilder 1D reach combined.





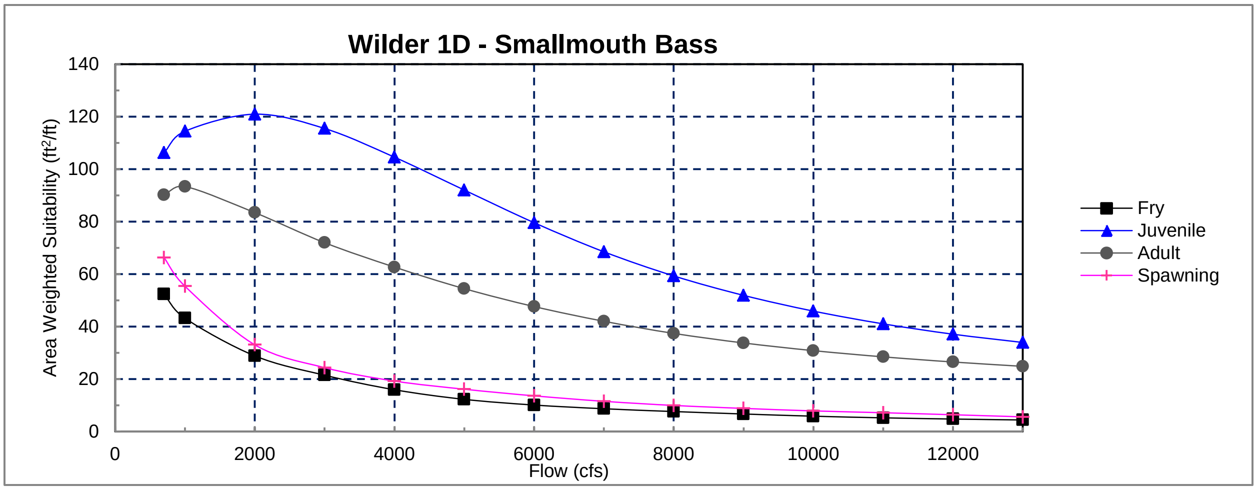


Figure 5.4-30. Smallmouth Bass WUA for Johnston Island and Chase Island 2D sites and AWS for Wilder 1D reach combined.

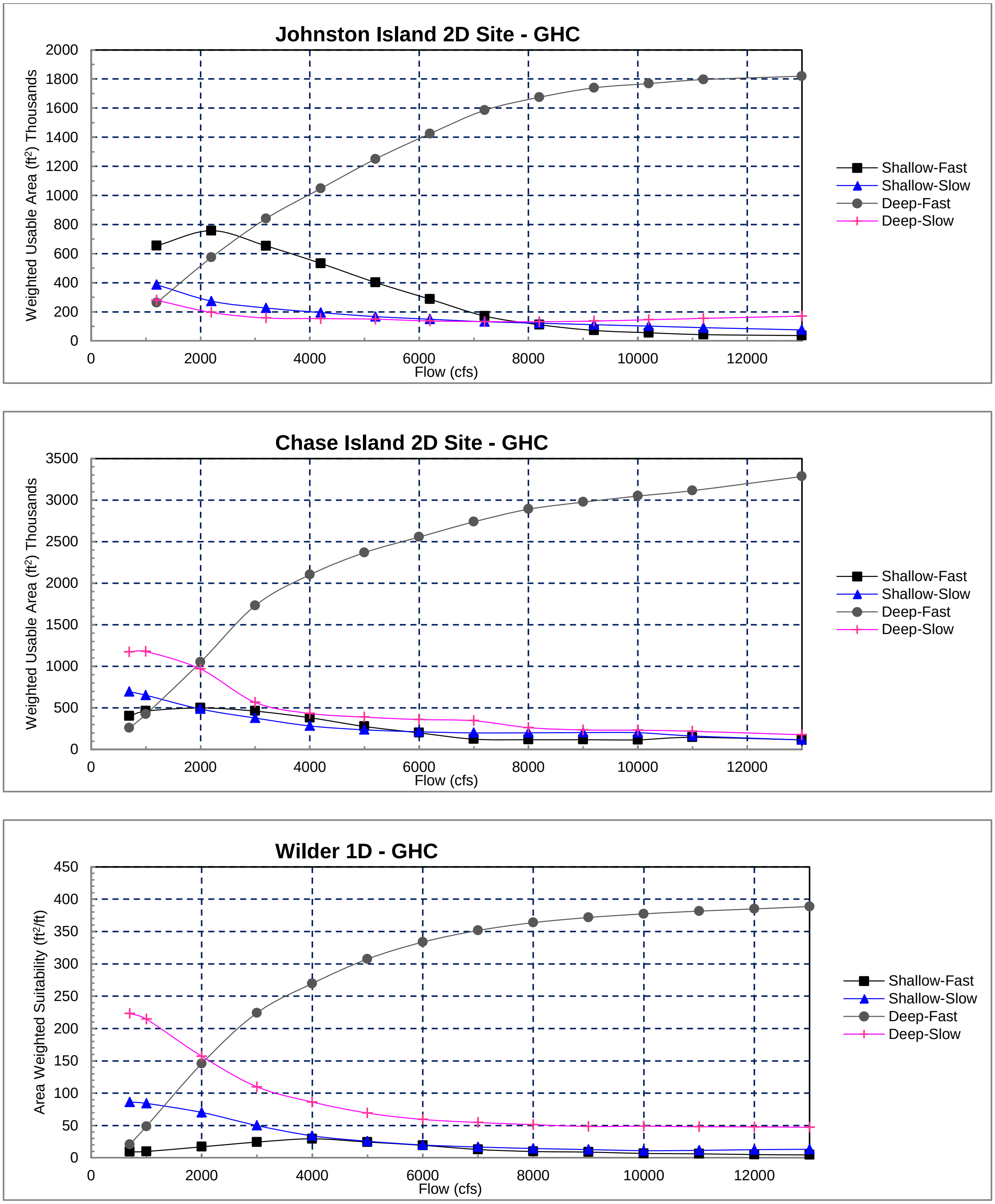


Figure 5.4-31. Generalized Habitat Criteria WUA for Johnston Island and Chase Island 2D sites and AWS for Wilder 1D reach combined.

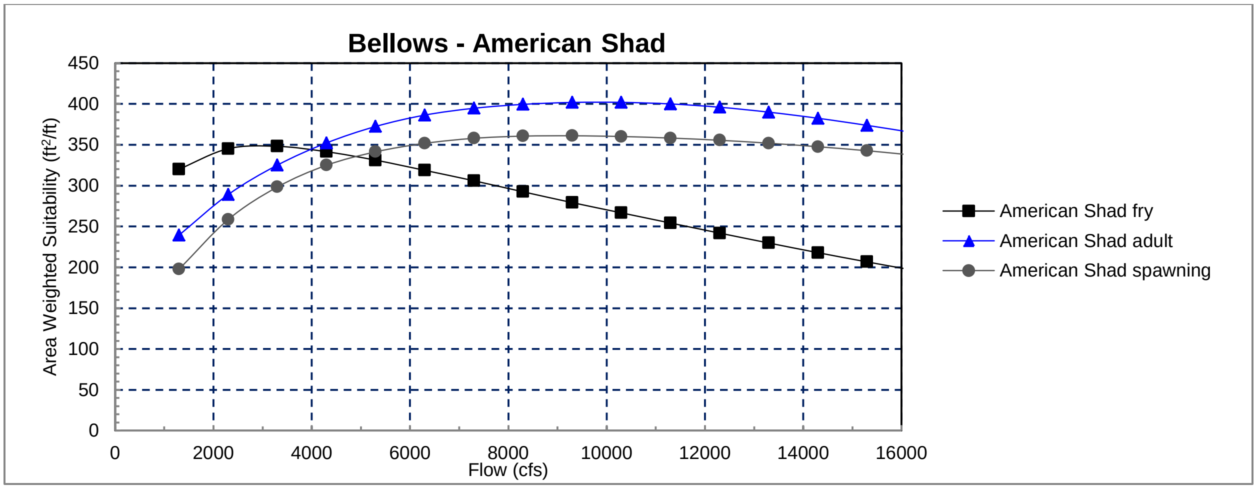
5.4.2 Bellows Falls Reach

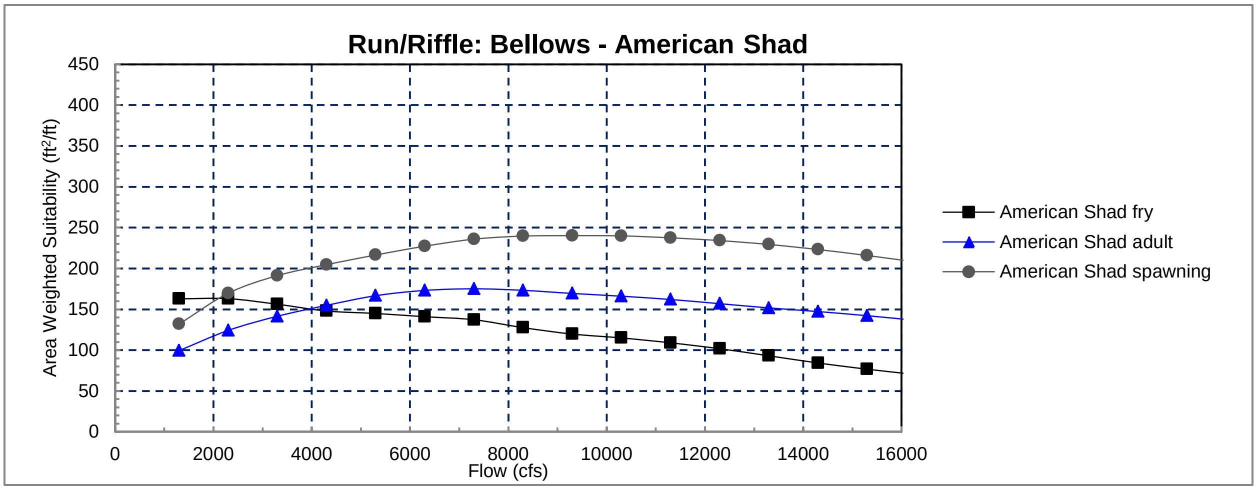
Transect weighting in the Bellows Falls reach is shown in Table 5.4-5. A single, deep pool just downstream of the powerhouse accounts for 11.2 percent of transect weight. Three other pools account for 27.3 percent. Run and glide have almost equal weighting and riffle accounts for a little less than 2 percent. Run and riffle habitat were combined and pool and glide combined in addition to modeling the total weighted reach.

AWS curves for Bellows Falls are presented in Figures 5.4-32 to 5.4-39. Results for Walleye adult, Fallfish adult and White Sucker fry and juvenile/adult show the greatest response to pool/glide habitat. All other species and life stages show little difference in the shape of AWS curves between habitat type groupings.

Table 5.4-5. Transect ID, mesohabitat type, and percent transect representation in the Bellows Falls reach.

Transect ID	Habitat Type	% Transect Weighting
BF1	Pool (deep)	11.2
BF2	Glide	3.5
BF3	Glide	3.5
BF4	Run	3.8
BF5	Glide	3.5
BF6	Riffle	0.9
BF7	Riffle	0.9
BF8	Run	3.8
BF9	Run	3.8
BF10	Pool	9.1
BF11	Glide	3.5
BF12	Run	3.8
BF13	Pool	9.1
BF14	Glide	3.5
BF15	Pool	9.1
BF16	Glide	3.5
BF17	Pool	9.1
BF18	Glide	3.5
BF19	Pool (deep)	11.2





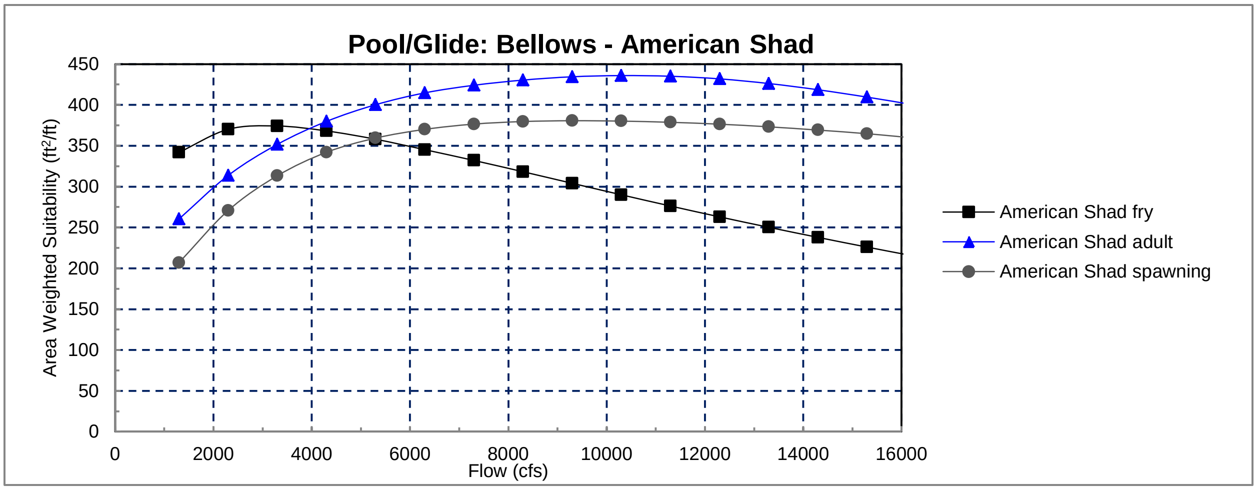
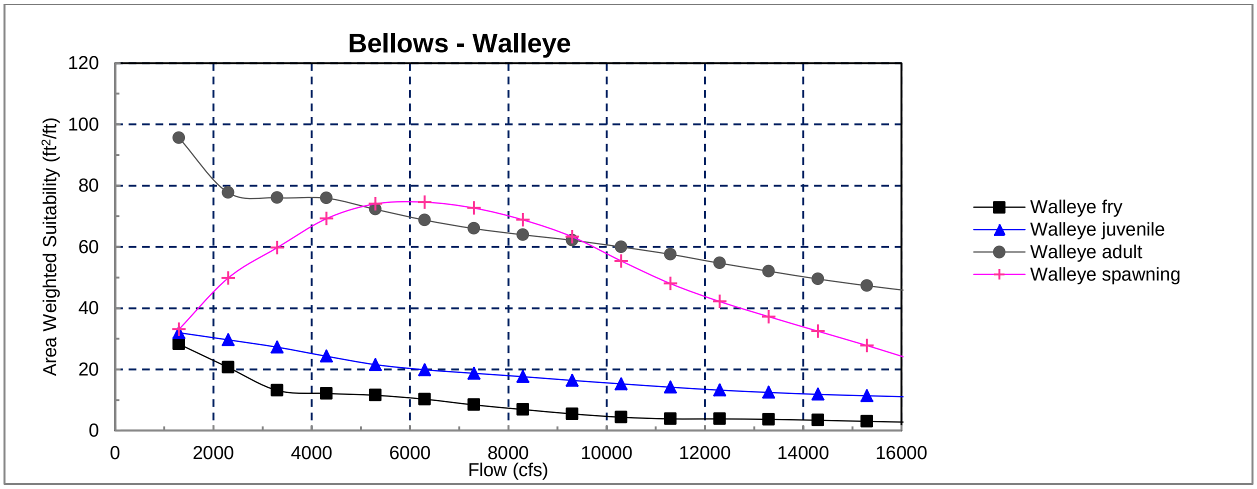
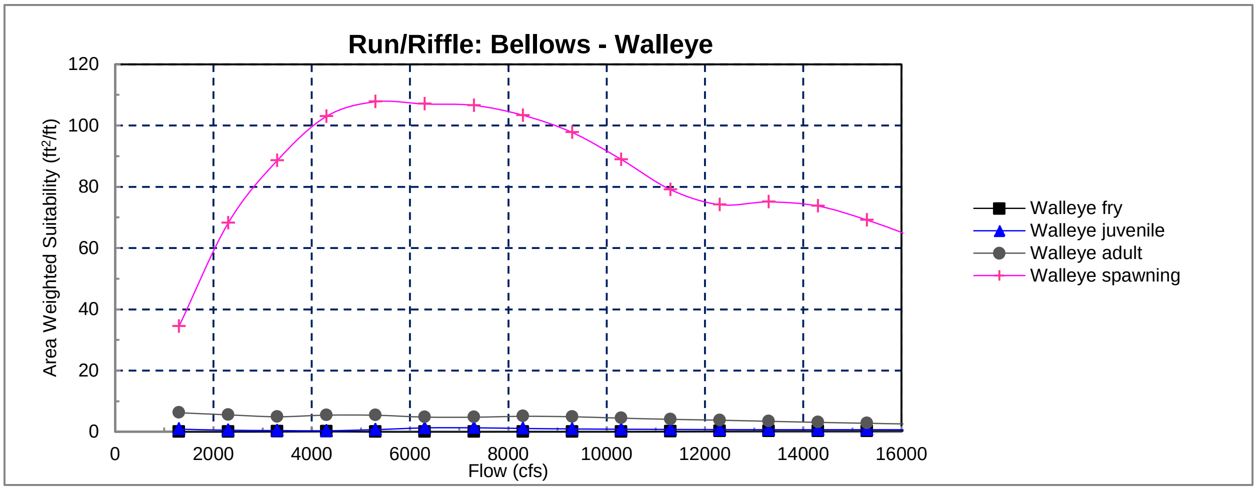


Figure 5.4-32. American Shad AWS for Bellows Falls reach, and by habitat groups run/riffle and pool/glide.





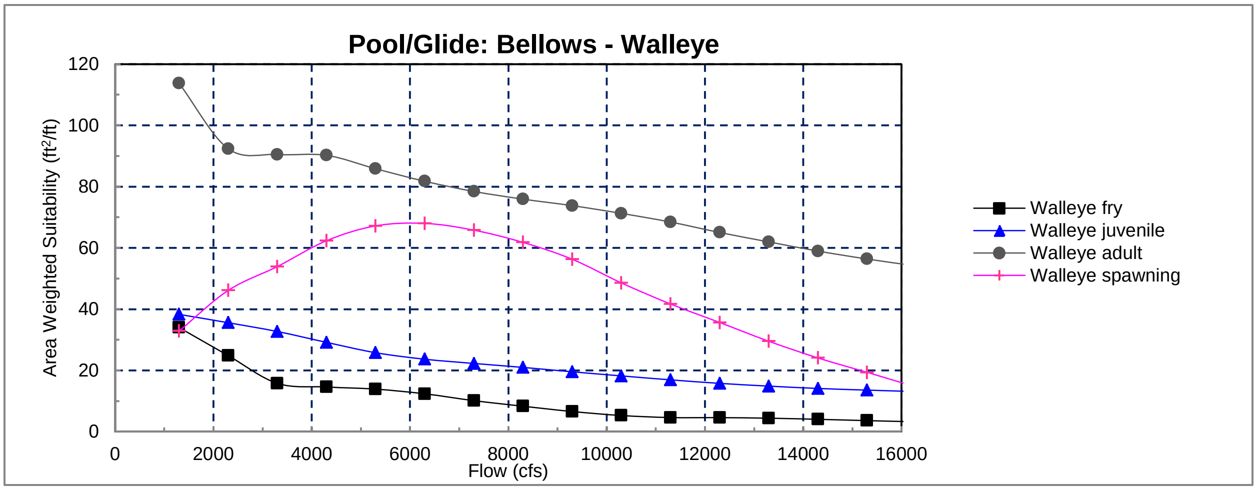
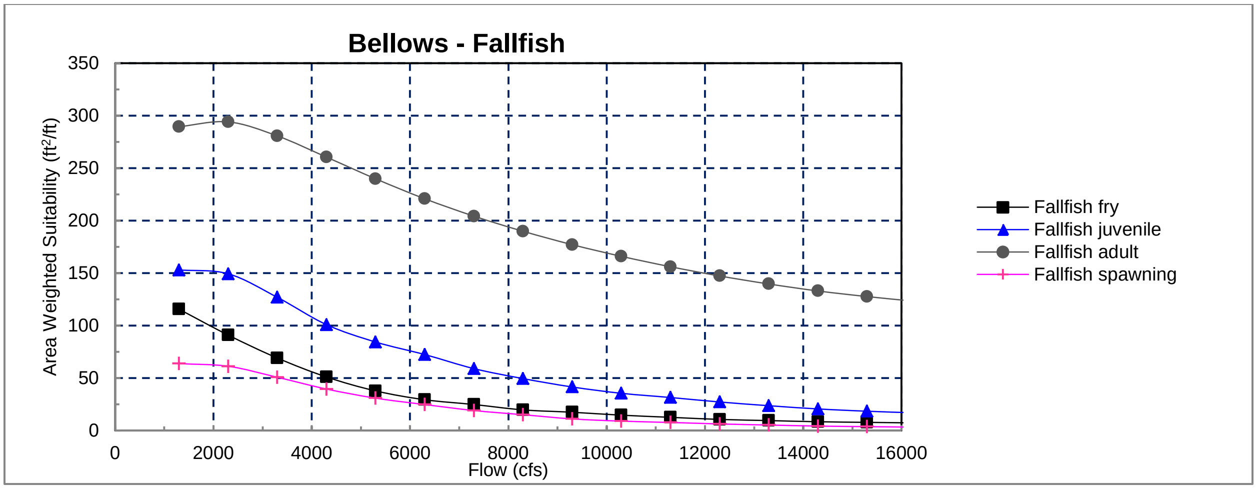
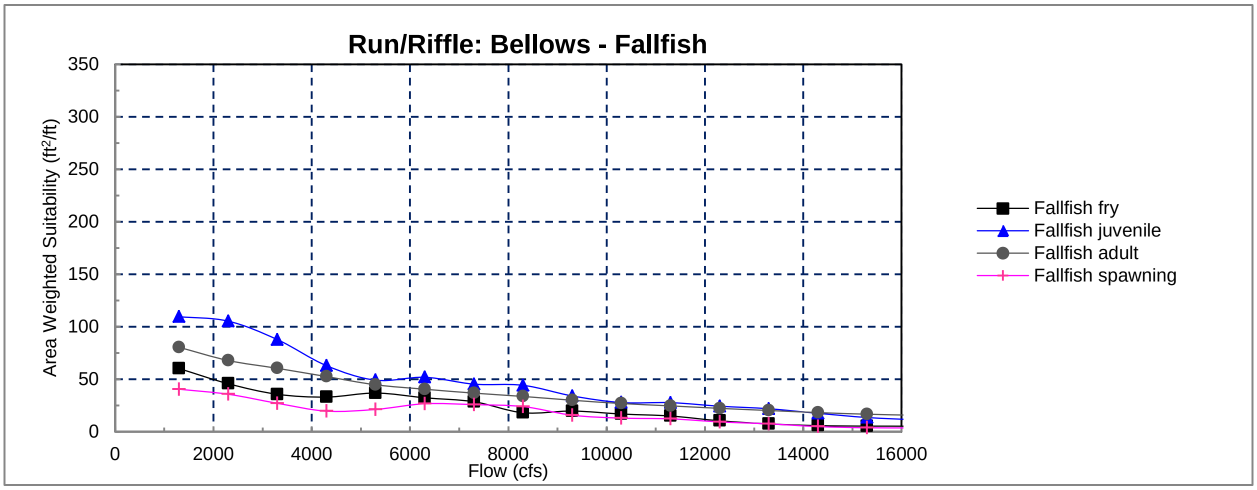


Figure 5.4-33. Walleye AWS for Bellows Falls, and by habitat groups run/riffle and pool/glide.





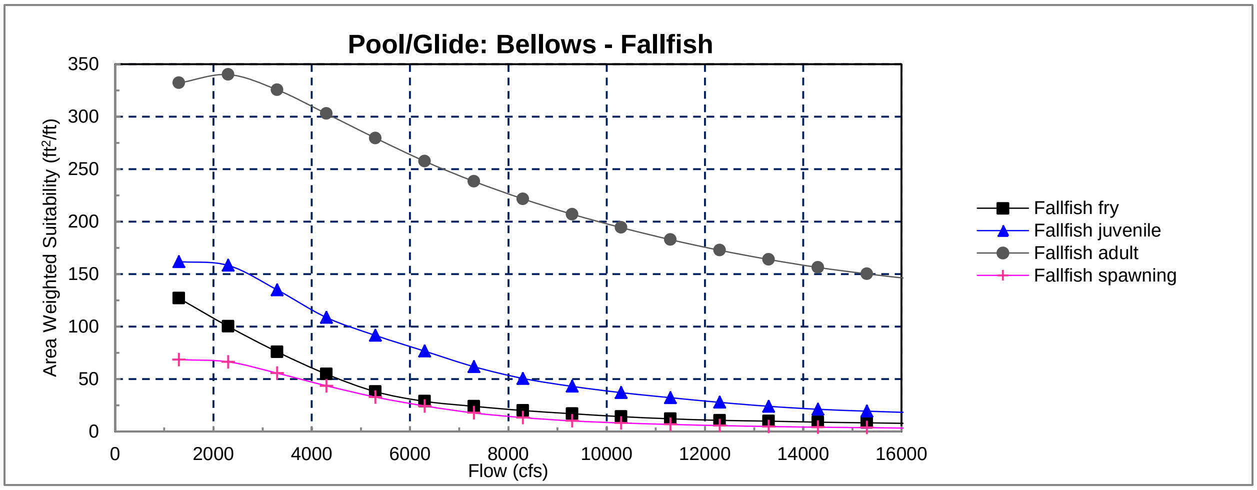
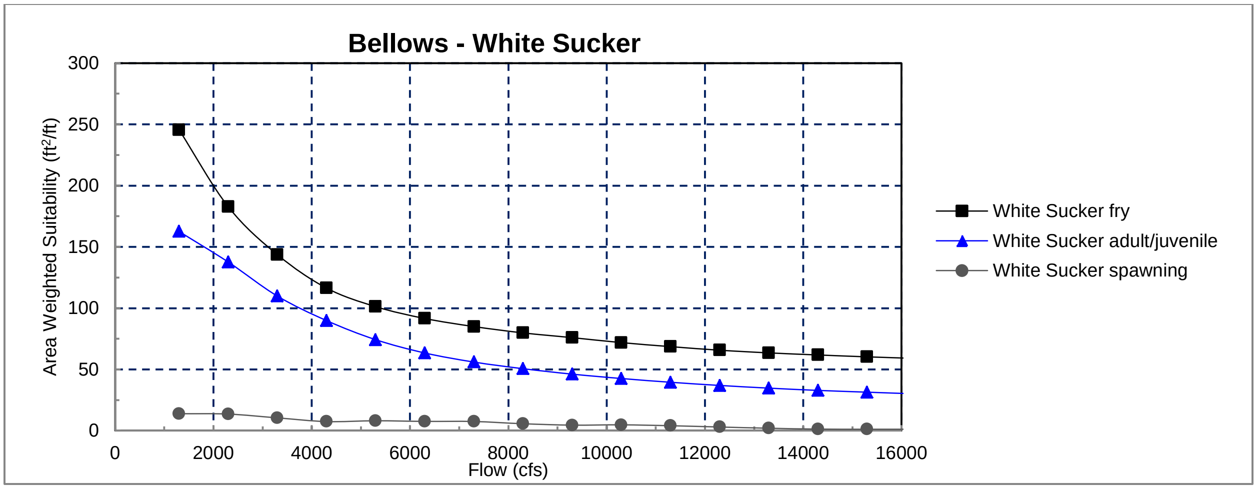
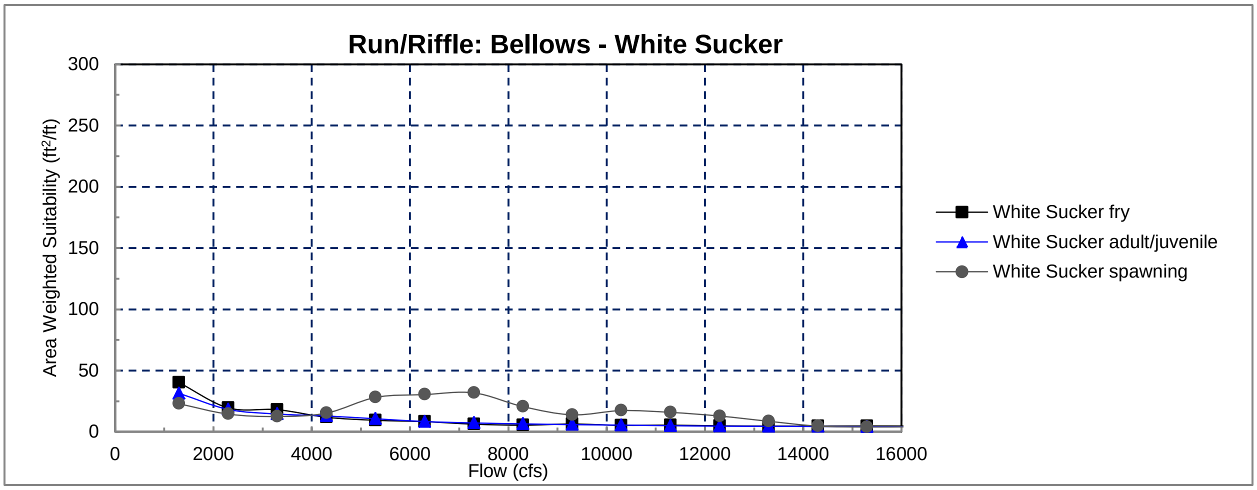


Figure 5.4-34. Fallfish AWS for Bellows Falls reach, and by habitat groups run/riffle and pool/glide.





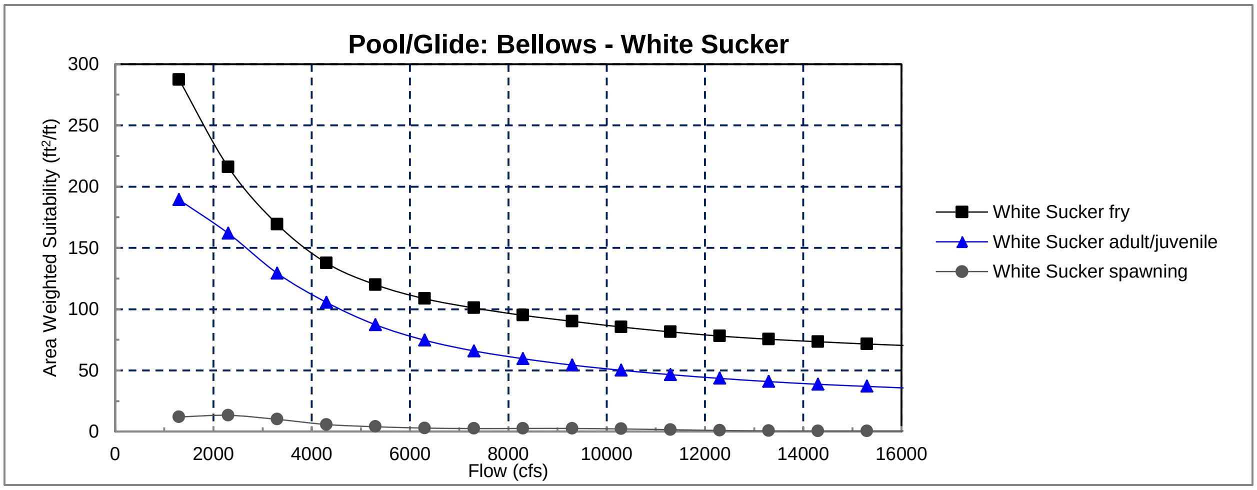
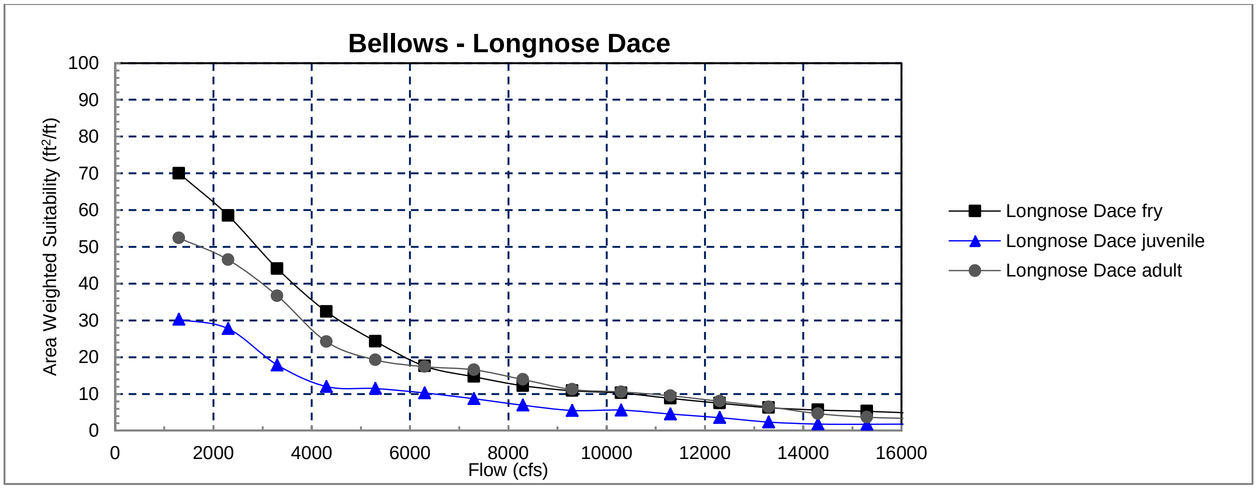
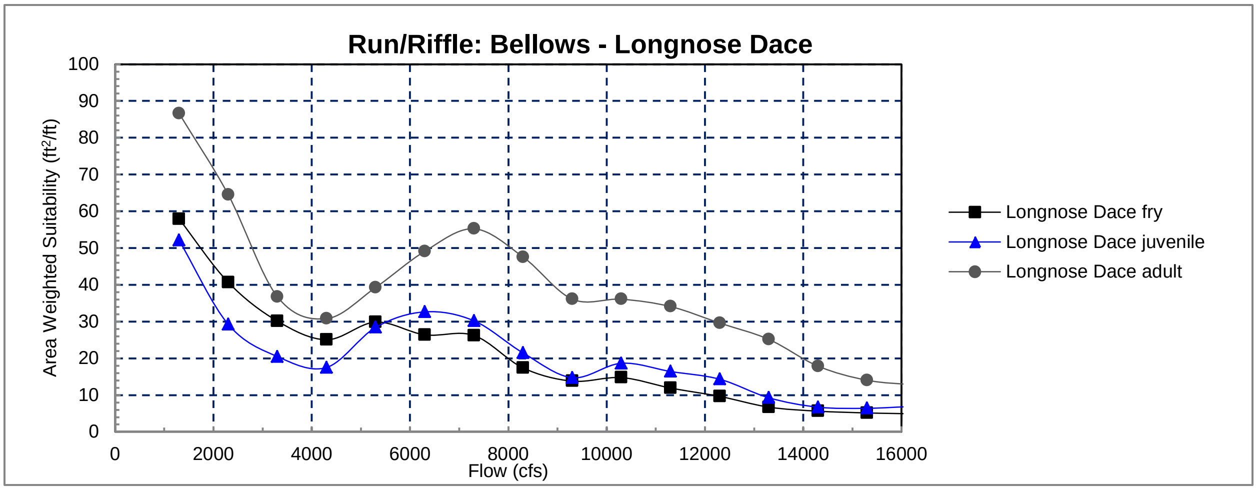


Figure 5.4-35. White Sucker AWS for Bellows Falls reach, and by habitat groups run/riffle and pool/glide.





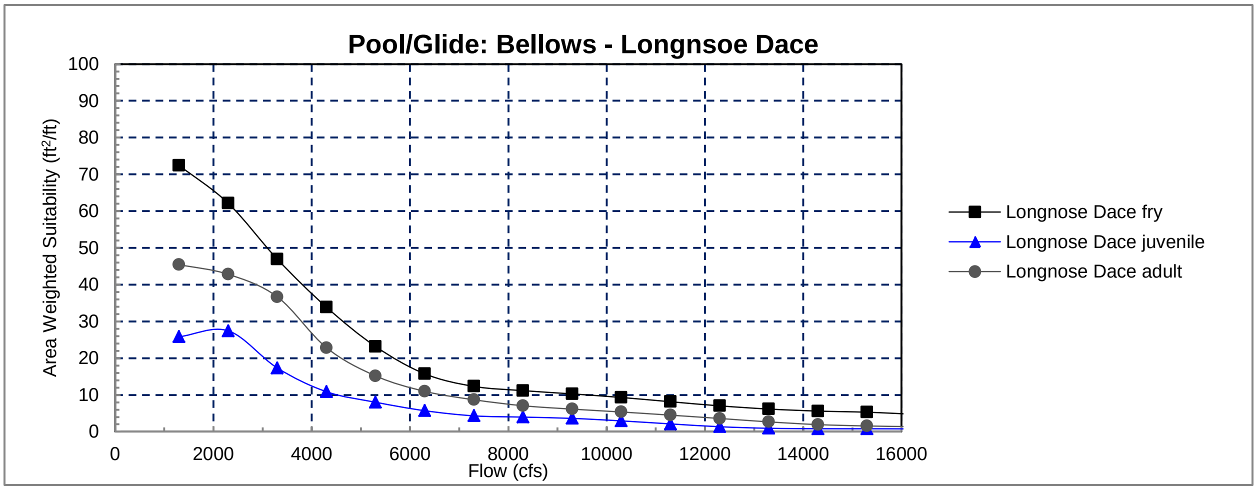


Figure 5.4-36. Longnose Dace AWS for Bellows Falls reach, and by habitat groups run/riffle and pool/glide.

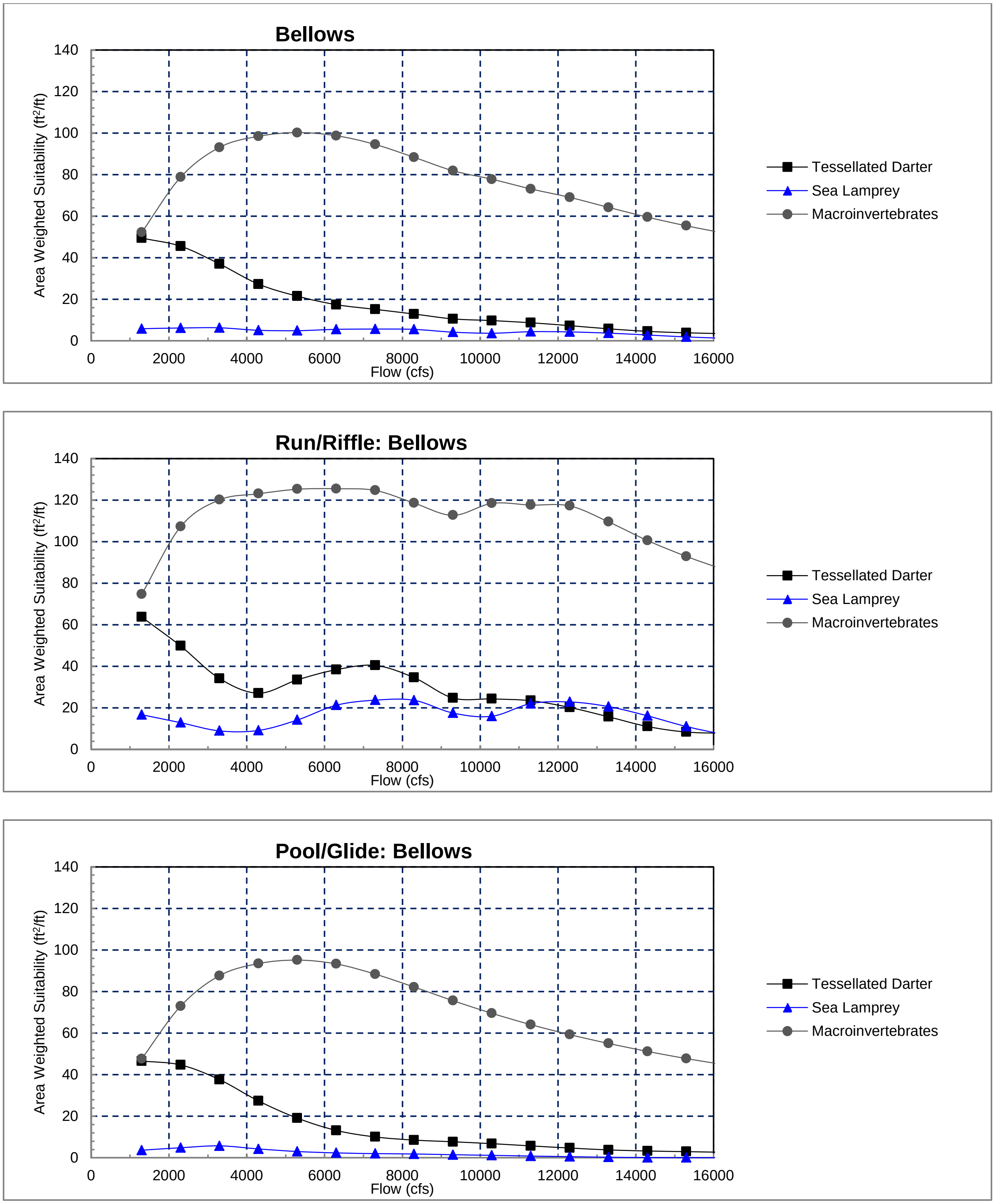
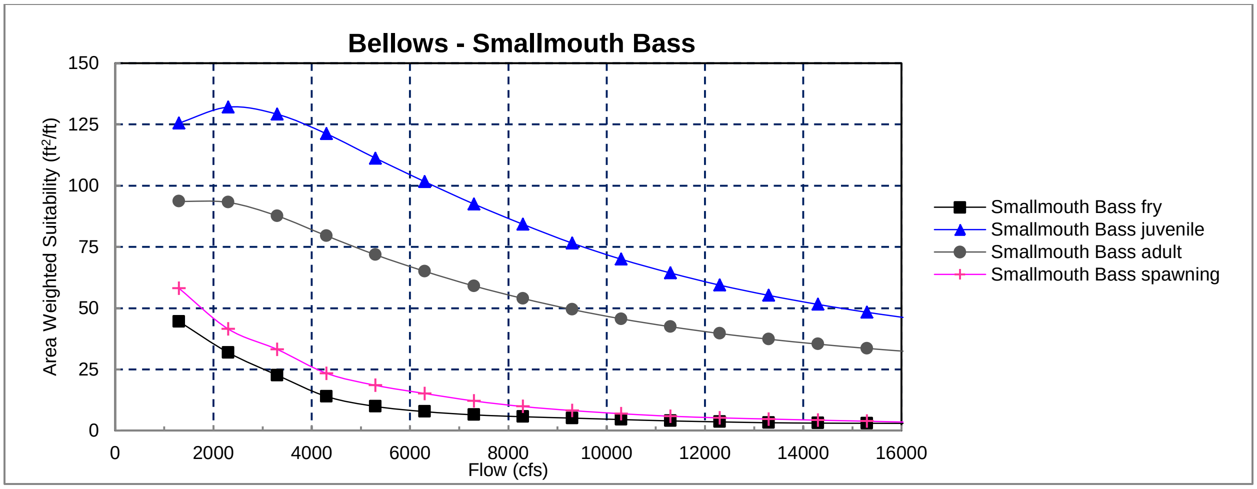
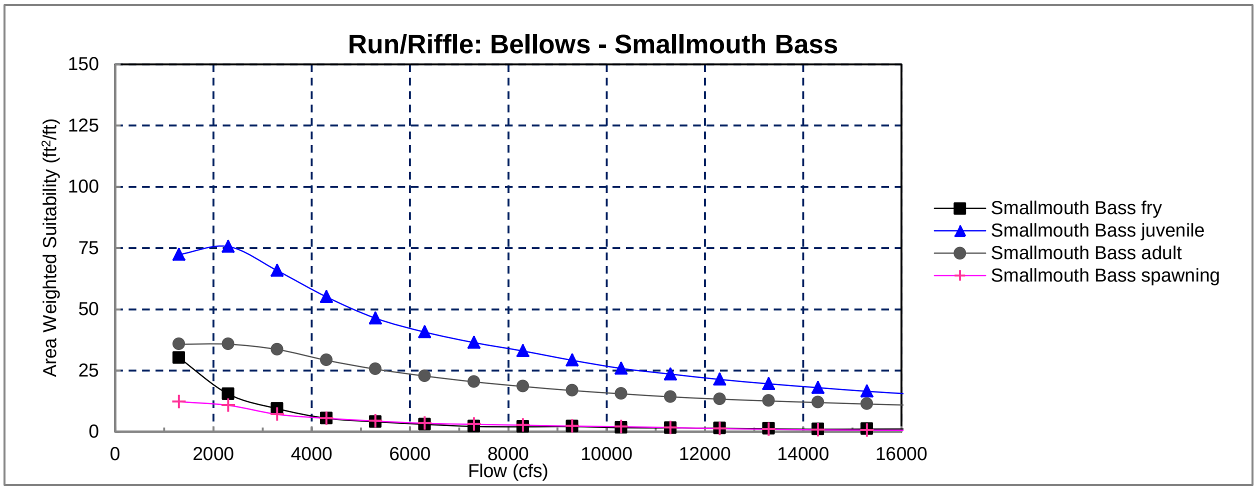


Figure 5.4-37. Tessellated Darter, Sea Lamprey spawning, and macroinvertebrate AWS for Bellows Falls reach, and by habitat groups run/riffle and pool/glide.





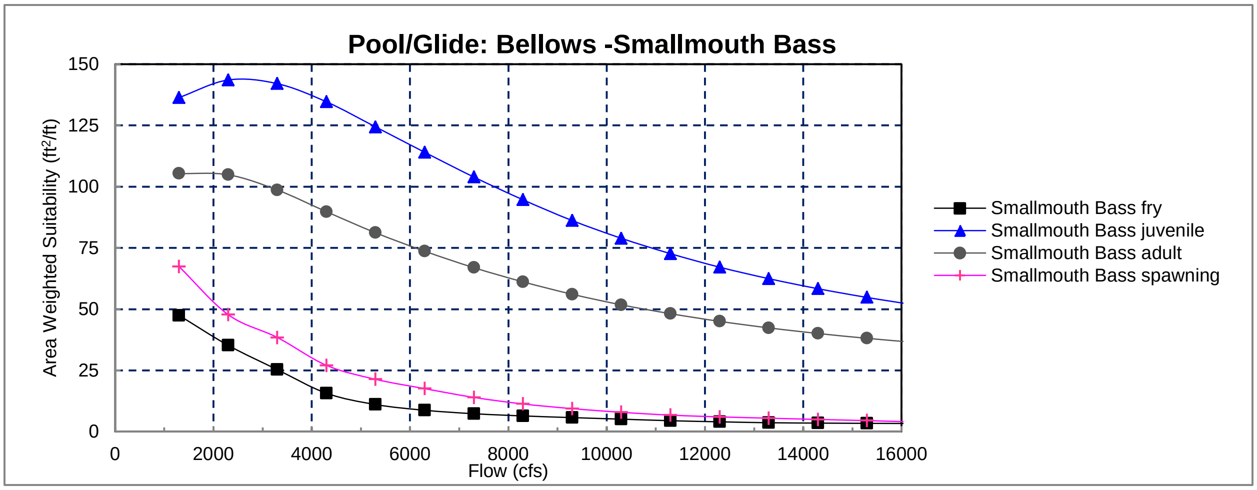


Figure 5.4-38. Smallmouth Bass AWS for Bellows Falls reach, and by habitat groups run/riffle and pool/glide.

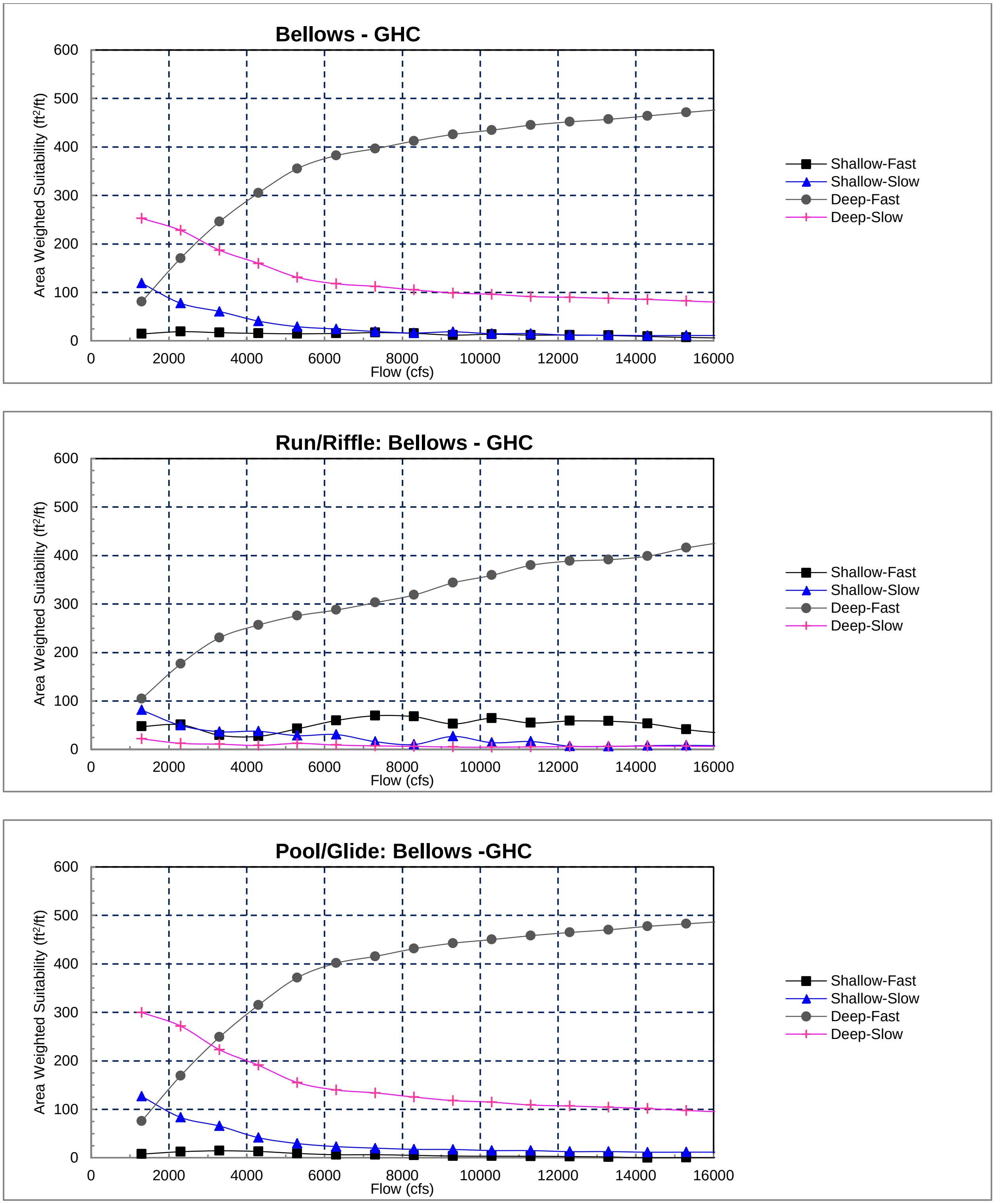


Figure 5.4-39. Generalized Habitat Criteria (GHC) AWS for Bellows Falls reach, and by habitat groups run/riffle and pool/glide.

5.4.3 Vernon Reach

Transect weighting in the Vernon reach is shown in Table 5.4-6. Like Wilder reach 3, weights do not equal 100 percent because a small side channel at the top of the reach was considered a separate reach for calibration purposes. When reaches are combined in SEFA the transect weights are normalized to equal 100 percent. The majority of the upper half of the reach was mapped as deep pool and the bottom of the reach around and below the downstream end of Stebbins Island was considered pool. The split around Stebbins Island identified as left channel (LC) and right channel (RC) were weighted by the proportion of flow in each channel. Based on discharge measurements over a range of flows, the amount of total discharge stayed the same, 67 percent in the LC and 33 percent in the RC. For habitat modeling run and glide (and the small riffle in the side channel or SC) were combined and pool was modeled separately, in addition to modeling the total weighted reach.

Initial high flow WSE for transects is based on HEC-RAS model calibration data (Study 4) for the day of data collection. As noted in Section 5.2, stage-discharge rating curves for analyses are based on HEC-RAS output. The AWS results shown in Figures 5.4-40 to 5.4-46 are for a steady-state condition from the HEC-RAS model using a Turners Falls impoundment elevation of 180.6 feet (NAVD88), the approximate middle of the licensed dam elevation range for Turners Falls dam. AWS output for all 10 Turners Falls dam WSE steady state cases in one-foot intervals from 175.6 feet to 184.6 feet (NAVD88) can be found in Appendix D.

Many AWS curves show little difference in shape between run/glide and pool habitat modeling. Some exceptions are Walleye adult and Fallfish adult which show a large response to pool habitat and Tessellated Darter which responds to run/glide. Sea Lamprey spawning, Fallfish spawning and White Sucker spawning HSC show the highest suitability for shallow depths and gravel/cobble substrate and, as expected, display a propensity for run/glide habitat. AWS for Walleye spawning also respond primarily to run/glide habitat due to the suitability of high velocities, shallow depths and gravel/cobble substrate.

Table 5.4-6. Transect ID, mesohabitat type, and percent transect representation in the Vernon reach (weighting for LC and RC transects based on proportion of flow within each channel).

Transect ID	Habitat Type	% Transect Weighting
VR1	Run	7.2
VR2	Run	7.2
VR3	Pool (deep)	12.4
VR4	Pool (deep)	12.4
VR5	Glide	5.3
VR6 LC	Run	6.9
VR7 LC	Glide	6.8
VR8 LC	Run	6.9
VR9 LC	Glide	6.8
VR6 RC	Run	2.4
VR7 RC	Pool	8.7
VR8 RC	Run	2.4
VR10	Pool	14.7
VR1 SC	Run	1.0
VR2 SC	Riffle	1.0
VR3 SC	Pool	1.0

Note: RC = right channel, LC = left channel looking downstream; SC =side channel. The SC near the top of the reach was estimated to represent 3% of the reach by area and the 3 transects in the side channel were weighted equally at 1.0%.

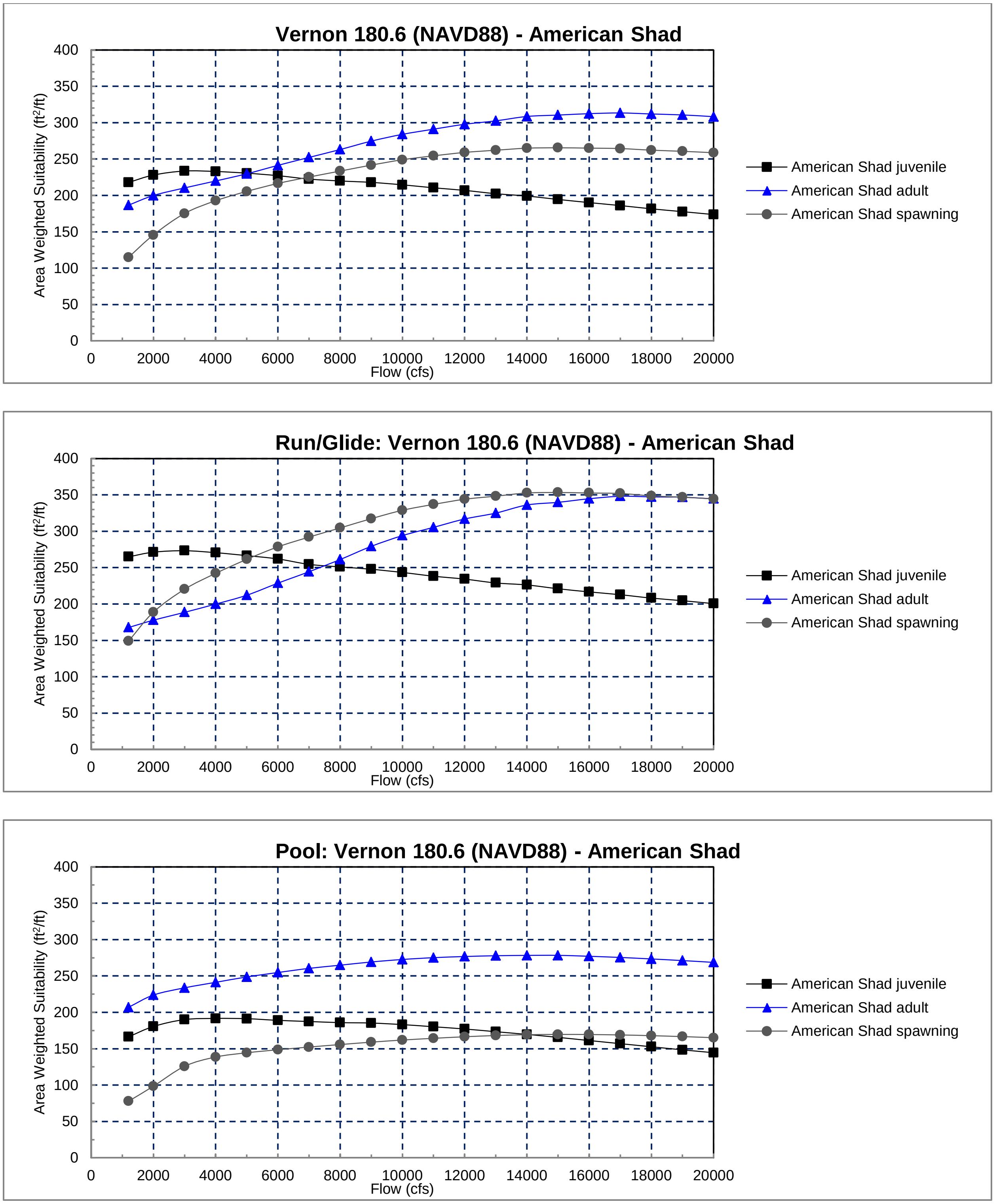


Figure 5.4-40. American Shad AWS for Vernon reach, and by habitat groups run/glide and pool at Turners Falls dam WSE of 180.6 ft (NAVD88).

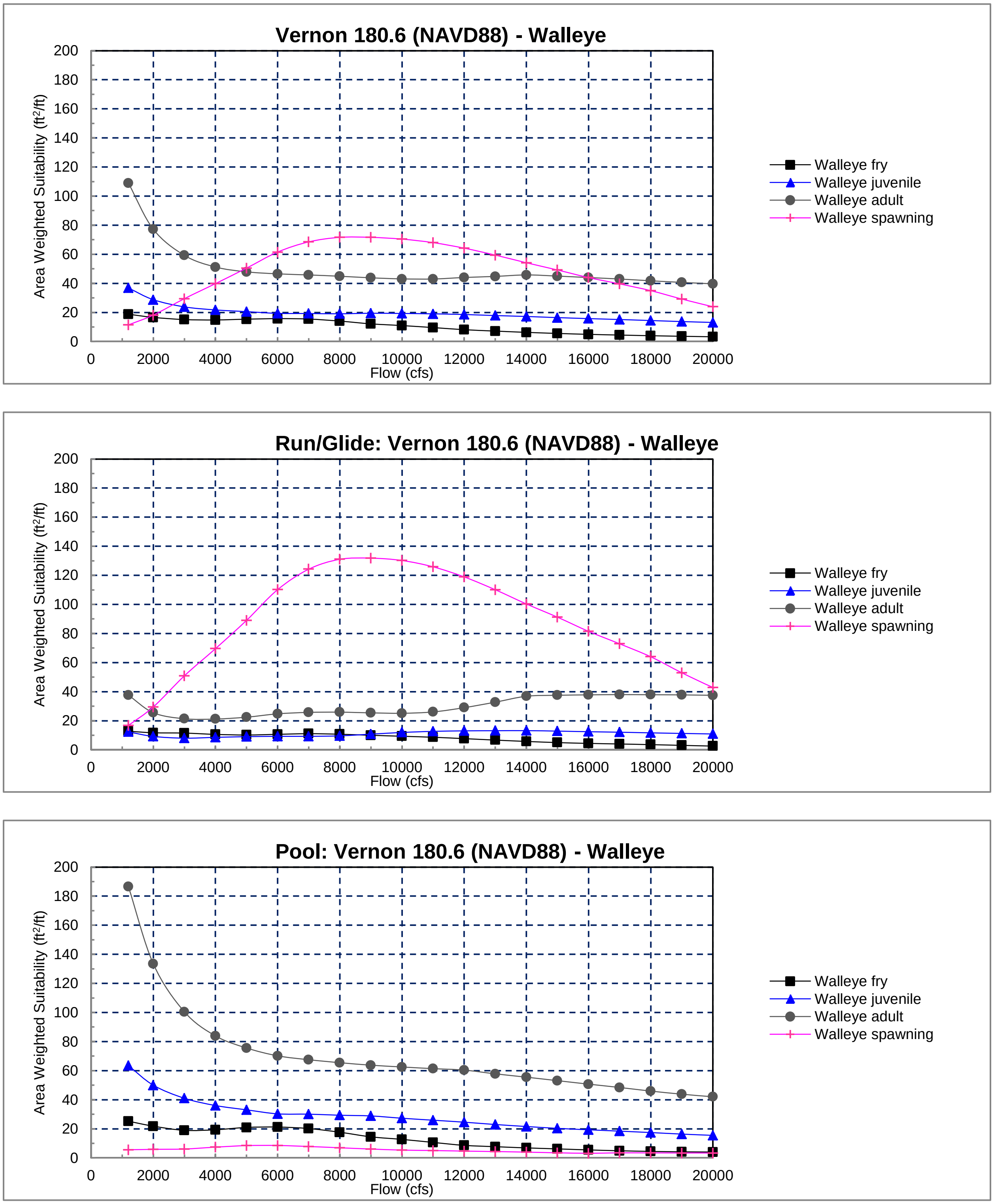


Figure 5.4-41. Walleye AWS for Vernon reach, and by habitat groups run/glide and pool at Turners Falls dam WSE of 180.6 ft (NAVD88).

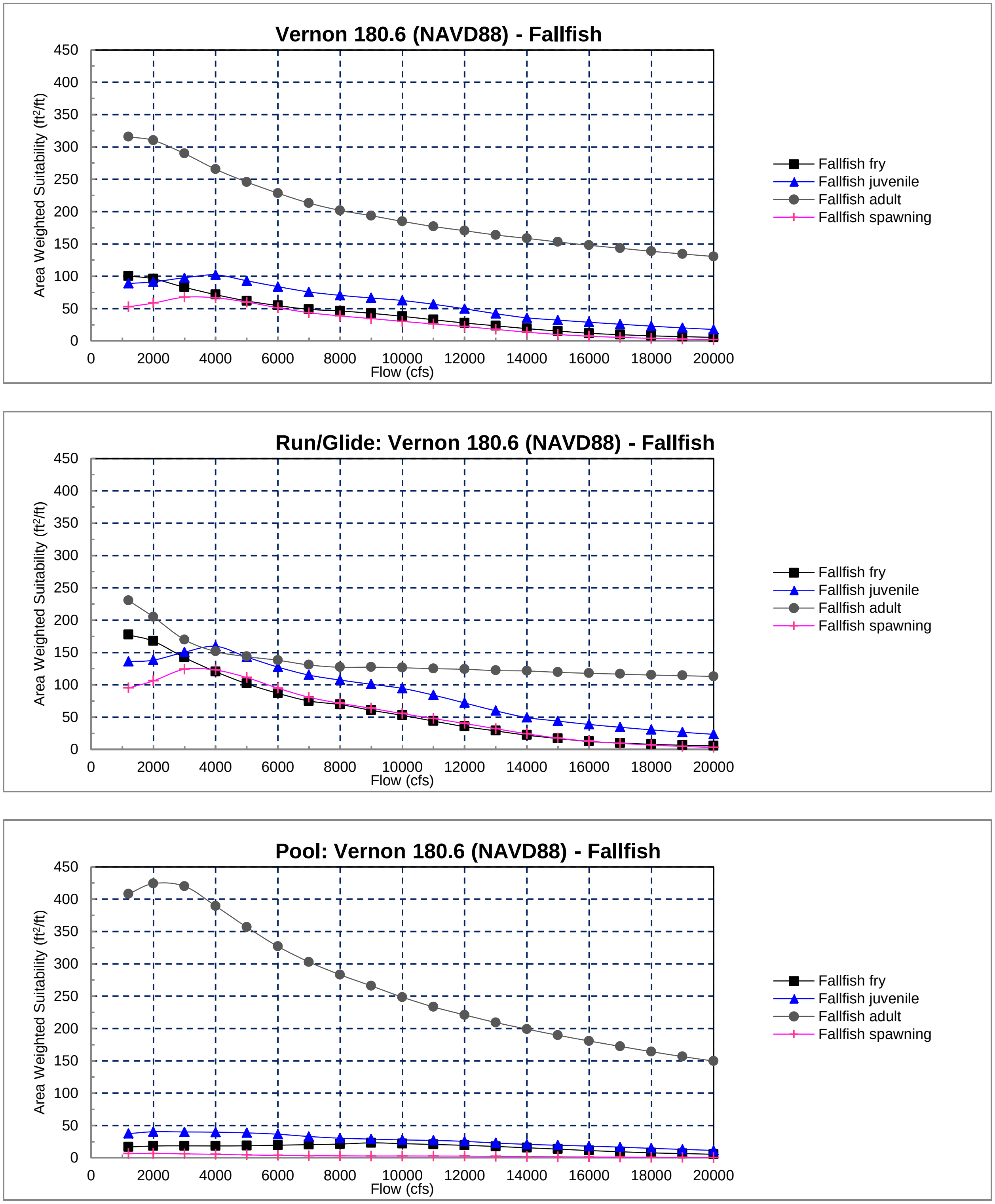


Figure 5.4-42. Fallfish AWS for Vernon reach, and by habitat groups run/glide and pool at Turners Falls dam WSE of 180.6 ft (NAVD88).

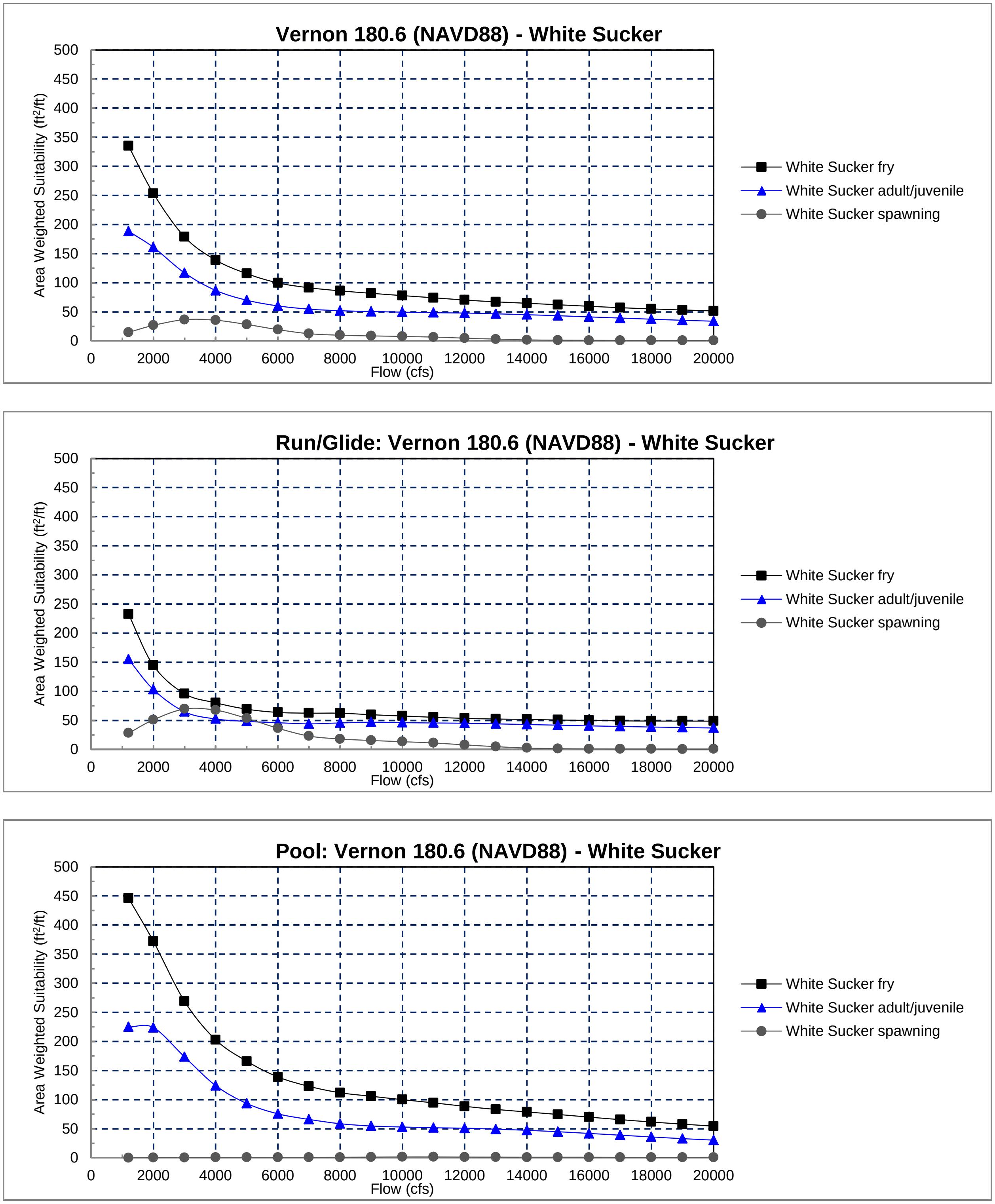


Figure 5.4-43. White Sucker AWS for Vernon reach, and by habitat groups run/glide and pool at Turners Falls dam WSE of 180.6 ft (NAVD88).

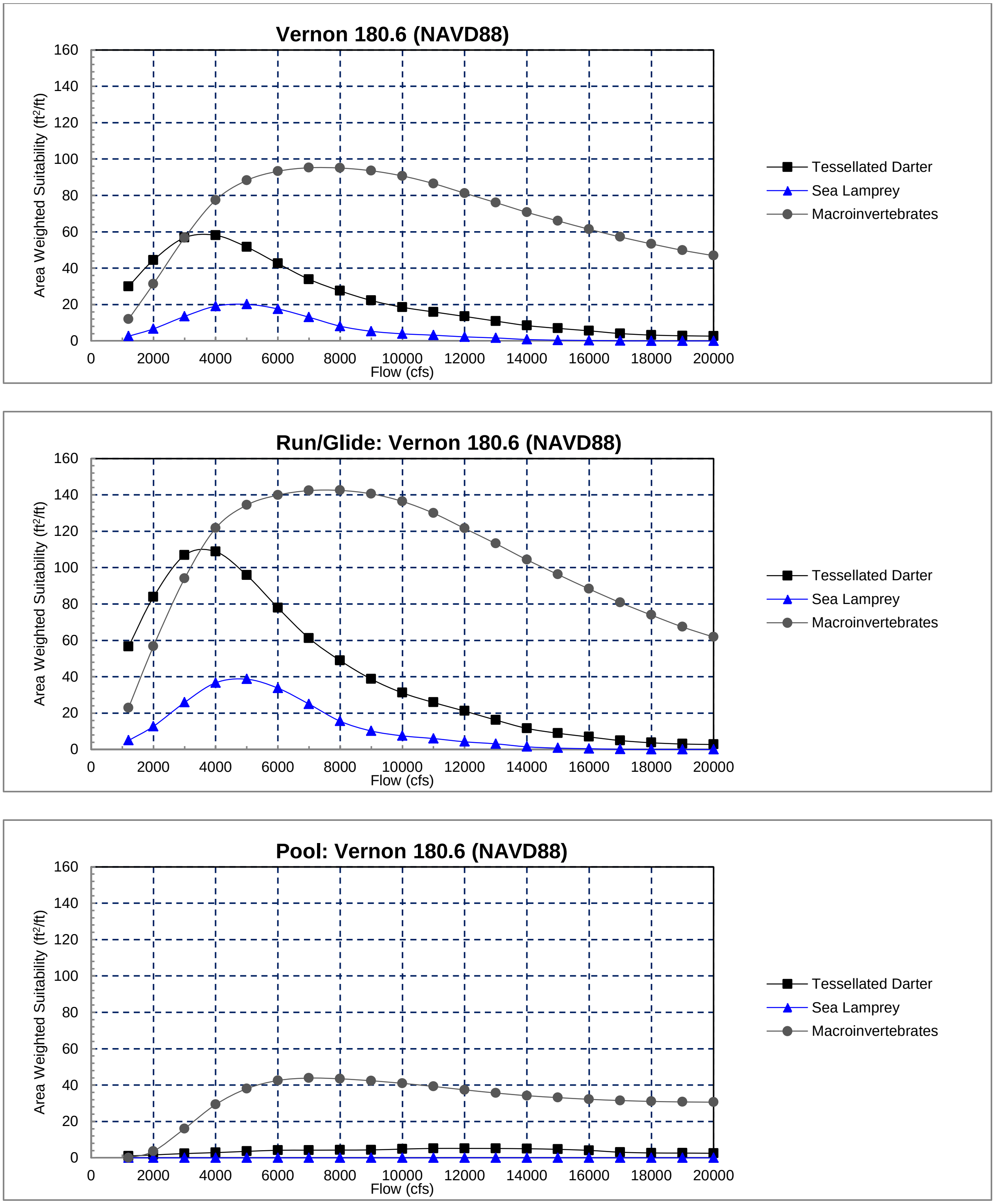
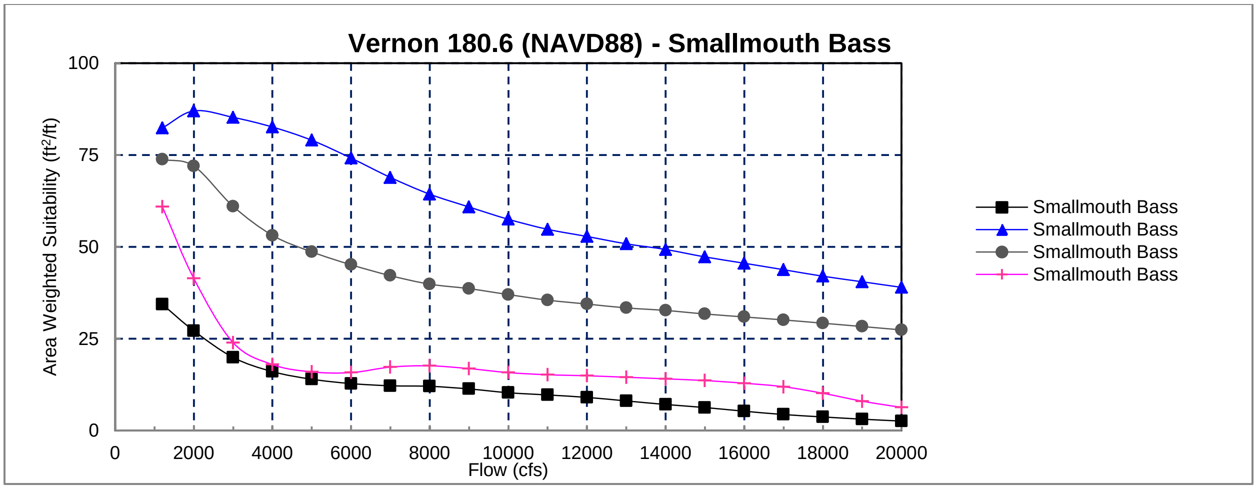
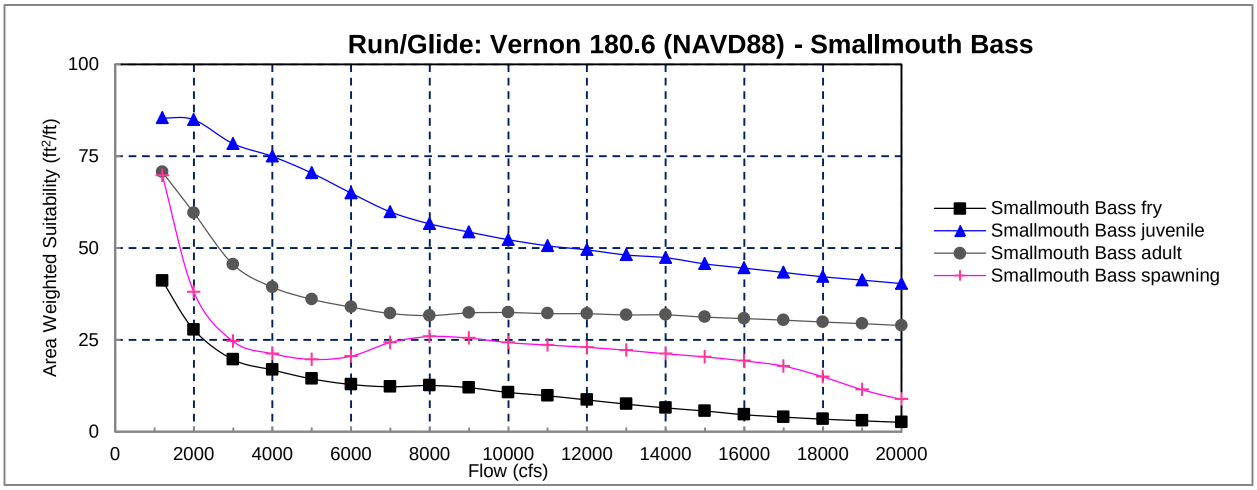


Figure 5.4-44. Tessellated Darter, Sea Lamprey spawning, and macroinvertebrate AWS for Vernon reach, and by habitat groups run/glide and pool at Turners Falls dam WSE of 180.6 ft (NAVD88).





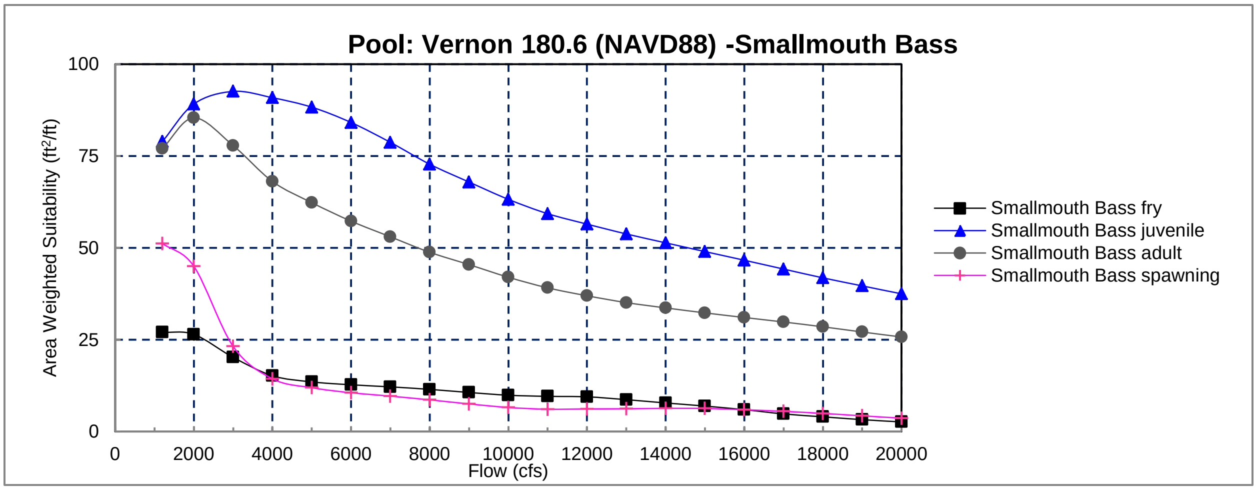
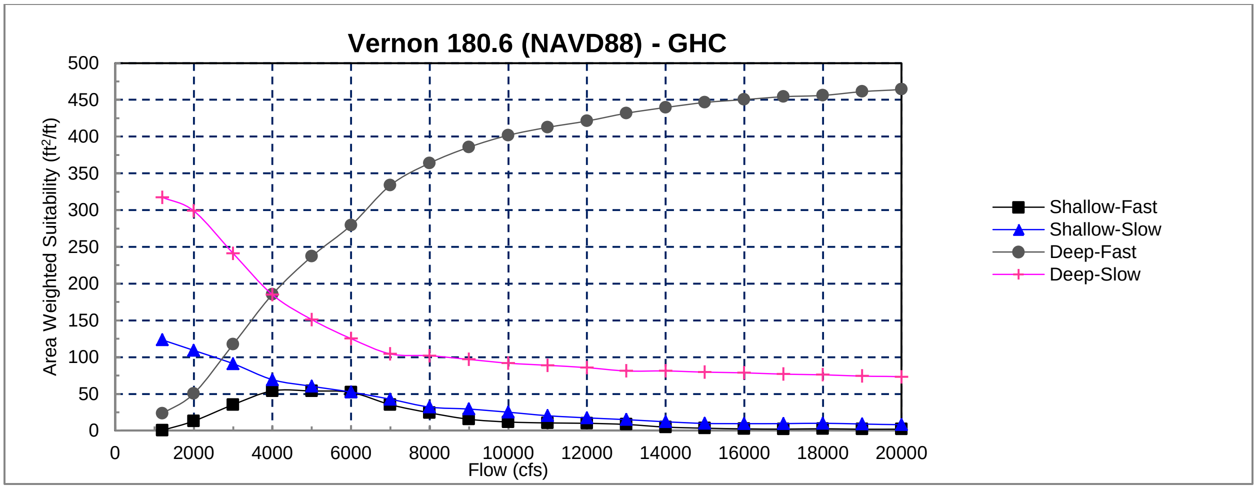
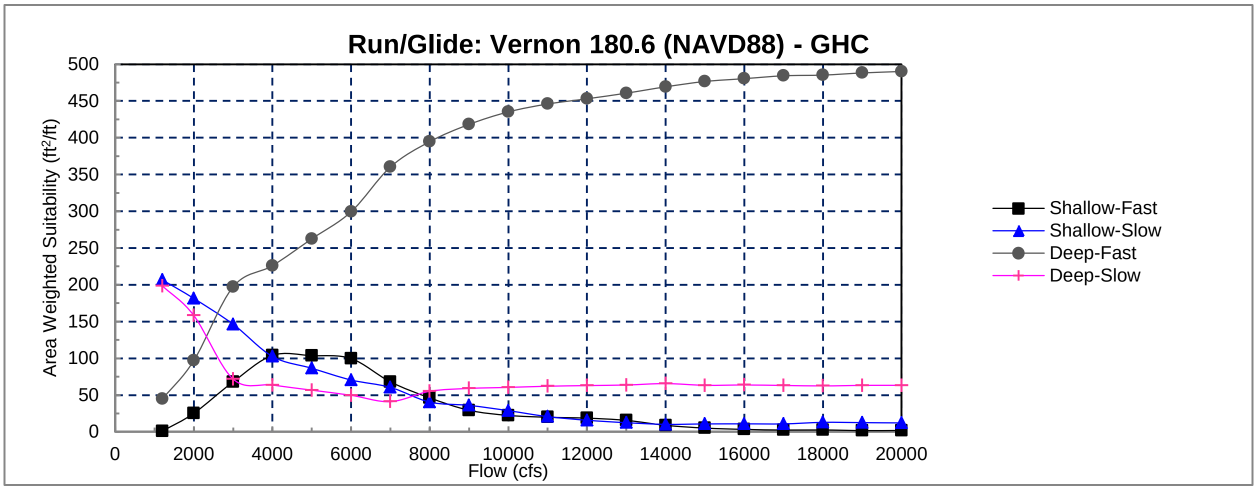


Figure 5.4-45. Smallmouth Bass AWS for Vernon reach, and by habitat groups run/glide and pool at Turners Falls dam WSE of 180.6 ft (NAVD88).





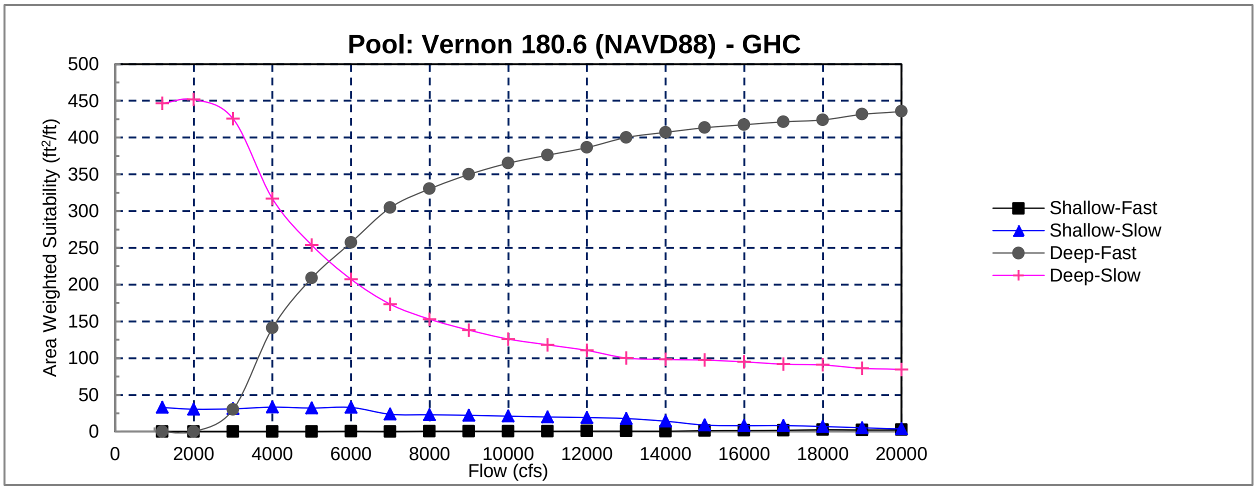


Figure 5.4-46. Generalized Habitat Criteria (GHC) AWS for Vernon reach, and by habitat groups run/glide and pool at Turners Falls dam WSE of 180.6 ft (NAVD88).

5.5 Bellows Falls Bypassed Reach

Seven transects were selected to represent the upper portion of the Bellows Falls bypassed reach (Figure 5.5-1). Most were placed in riffle and run habitat, though the lowest transect, BFB7, is a pool with a large eddy on the right bank. Transect BFB4 crosses a main channel riffle and a large cobble bar on the right bank, an unusual feature in this bedrock and boulder dominated reach (Figure 5.5-2).

Data collection in the Bellows Falls bypassed reach took place in October 2014 at leakage flow of 286 cfs based on an average of 27 ADCP measurements and in May 2015 at an estimated flow of 921 cfs released through the dam. It was anticipated that WSE could be marked at each transect at a third calibration flow of around 2,500 cfs during releases for the white water boating flow assessment (Study 31, Louis Berger Group and Normandeau, 2016). However, -flows were never stable enough to mark WSE locations and obtain a reliable estimate of actual flow at the time. Substrate coding was done at low flow when visibility was best. In deep areas that were not visible, substrate composition was estimated based on the last point where coding occurred on each bank.

5.5.1 Stage-Discharge

Normally three or more stage-discharge measurements are used to create transect rating curves. In this case, with only two points, stage-discharge relationships were calculated employing a channel conveyance method which uses Manning's equation, and assumes that hydraulic roughness varies either with discharge or hydraulic radius. The default method is to allow roughness to vary with discharge. Using the basic presumption that up to 2.5 times the highest measured calibration flow will produce reliable rating curves, simulation was extended to 2,500 cfs. Because there are only two points there is no mean error to test the quality of the rating curves. However, Manning's equation beta values can be examined. Beta's between -0.1 and -0.6 are considered good and all values fell within this range.

5.5.2 Velocity

Velocity profiles were collected on all transects at the low calibration flow of 286 cfs using a combination of ADCP (pulled across the channel attached to a tag line) and wading methods. At the middle calibration flow of 921 cfs complete velocity profiles were obtained on only two transects due to a combination of safety concerns and the inability of the ADCP to track and acquire velocities in turbulent conditions.

Few adjustments were made to low flow velocities during model calibration. Four transects had no adjustments and only edge cells with negative or very low velocities were adjusted on others. These adjustments were made to allow velocities to reasonably increase as areas became inundated at higher flows. Points on transects that had no measured velocities at middle flow were calibrated by adjusting roughness values so the resulting velocity pattern was reasonable and allowing VAF's to predict velocities so they summed to the given flow.

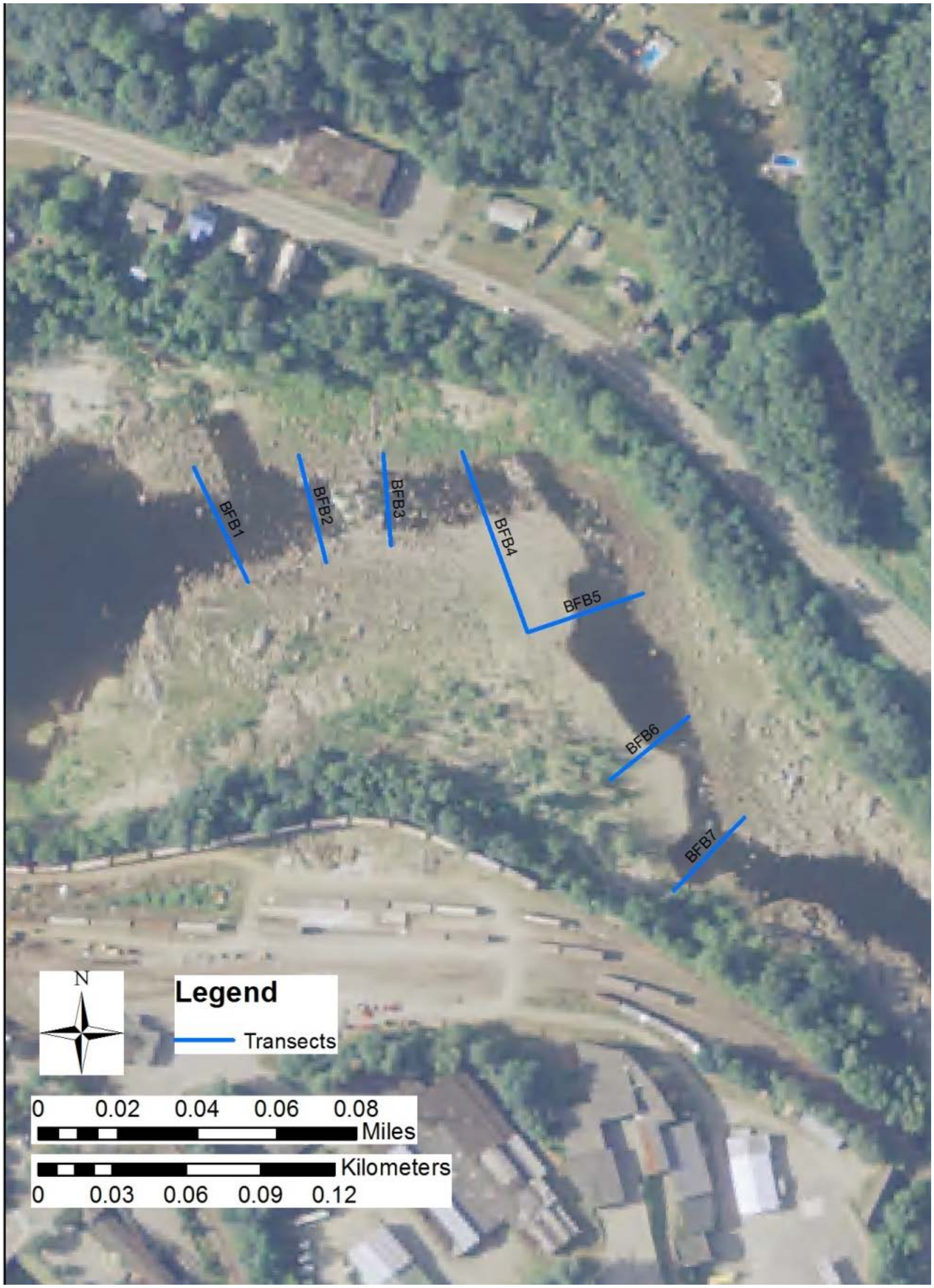


Figure 5.5-1. Transect locations in the upper portion of the Bellows Falls bypassed reach.

Figure 5.5-2. Upstream view of transect BFB4 cobble bar at low (286 cfs) and middle (921 cfs) flow.

Measured and simulated velocities are shown in Figures 5.5-3 to 5.5-16. Using low flow velocities to simulate above 1,000 cfs produces unrealistically high velocities, with simulation at 2,500 cfs showing peak velocities ranging from 10 feet/second (fps) to over 15 fps. Extrapolation of middle flow velocities for transects BFB1 and BFB2, where complete velocity sets were obtained, produces a more reasonable velocity pattern up to 2,500 cfs. The spikey patterns for both low and middle flow velocities is a product of large substrate creating velocity shelters, eddies, and chutes.

5.5.3 Habitat Modeling

At the request of the aquatics working group all species and life stages identified in the Bellows Falls bypassed reach were modeled. Results from the fish assemblage study (Study 10) found juvenile and adult Longnose Dace (n=127) and juvenile and young-of-year (yoy) Smallmouth Bass (n=43) in the reach. Other species of interest included Tessellated Darter adult and juvenile (n=15), White Sucker yoy (n=8), and Fallfish yoy (n=2). Due to lack of suitable spawning habitat for White Sucker, Smallmouth Bass, and Fallfish it is presumed that presence of yoy is due to high flow spills or leakage flows into the reach during the 2015 Study 10 sampling season.

The AWS results are similar using the low flow hydraulic model and middle flow hydraulic model, unexpected considering the differences in the velocity simulation patterns (Figures 5.5-17 to 5.5-23). Much has to do with high velocities being predicted in mid-channel using both models and the suitability of depths and velocities for the target life stages. Longnose Dace juvenile and adult prefer shallow depths (<3 feet) and velocities less than 3 fps. Smallmouth Bass juvenile and adult criteria show unlimited depth suitability and preferred velocities less than 2.5 fps. Shallow habitat and low velocities occur only along the edges.

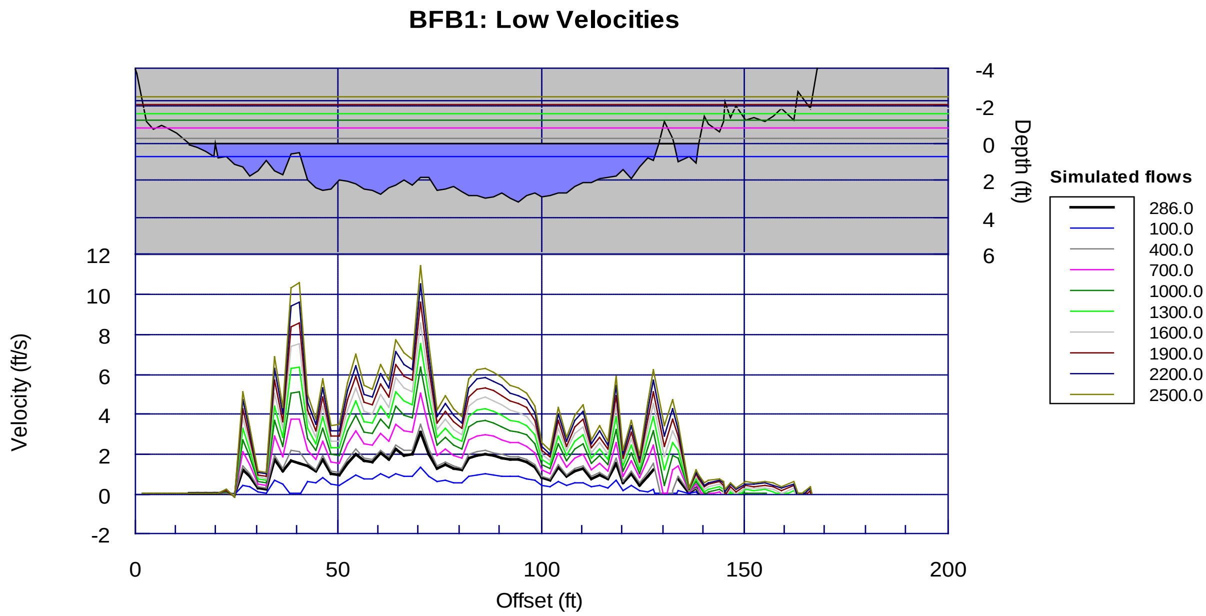


Figure 5.5-3. Measured low flow velocities (black line) and simulated velocities for transect BFB1 in the Bellows Falls bypassed reach.

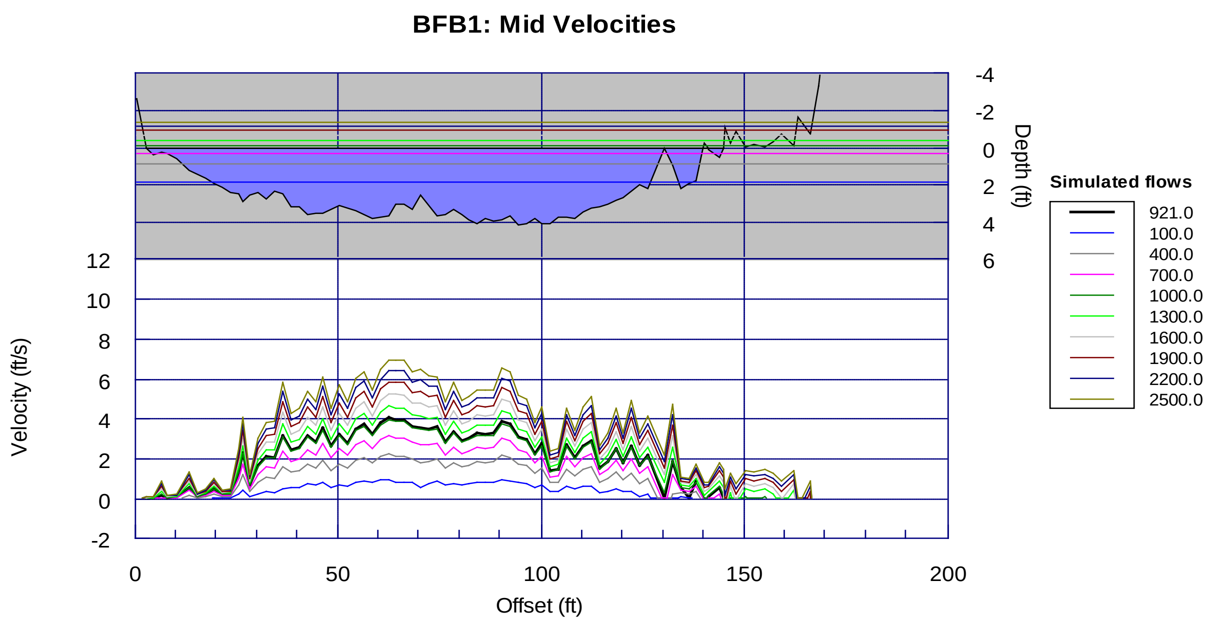


Figure 5.5-4. Measured middle flow velocities (black line) and simulated velocities for transect BFB1 in the Bellows Falls bypassed reach.

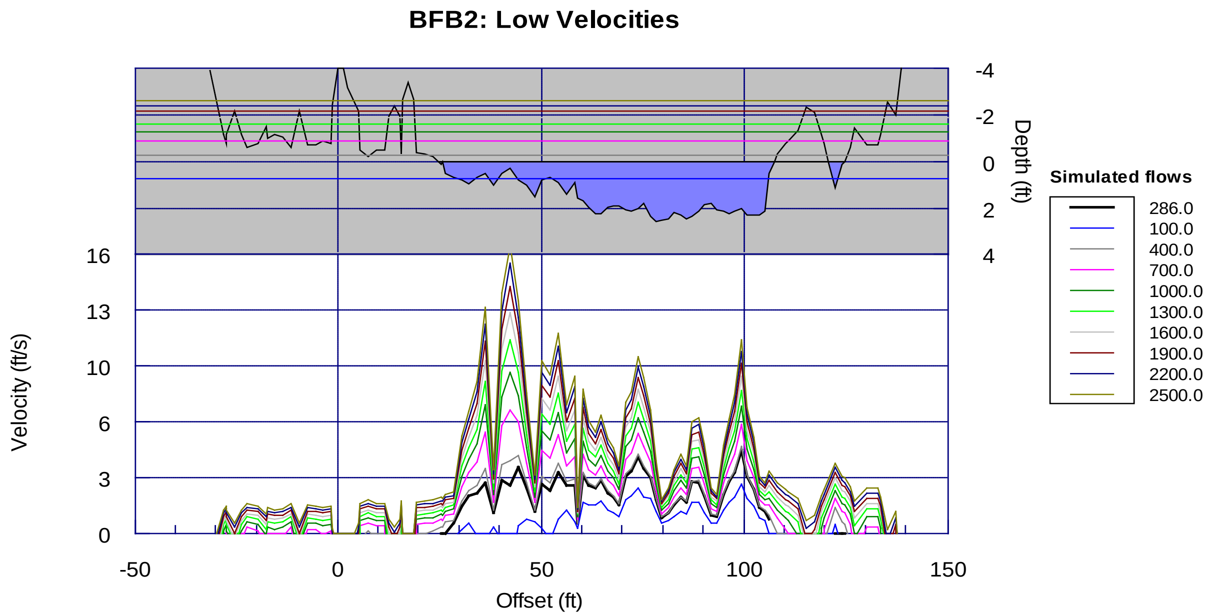


Figure 5.5-5. Measured low flow velocities (black line) and simulated velocities for transect BFB2 in the Bellows Falls bypassed reach.

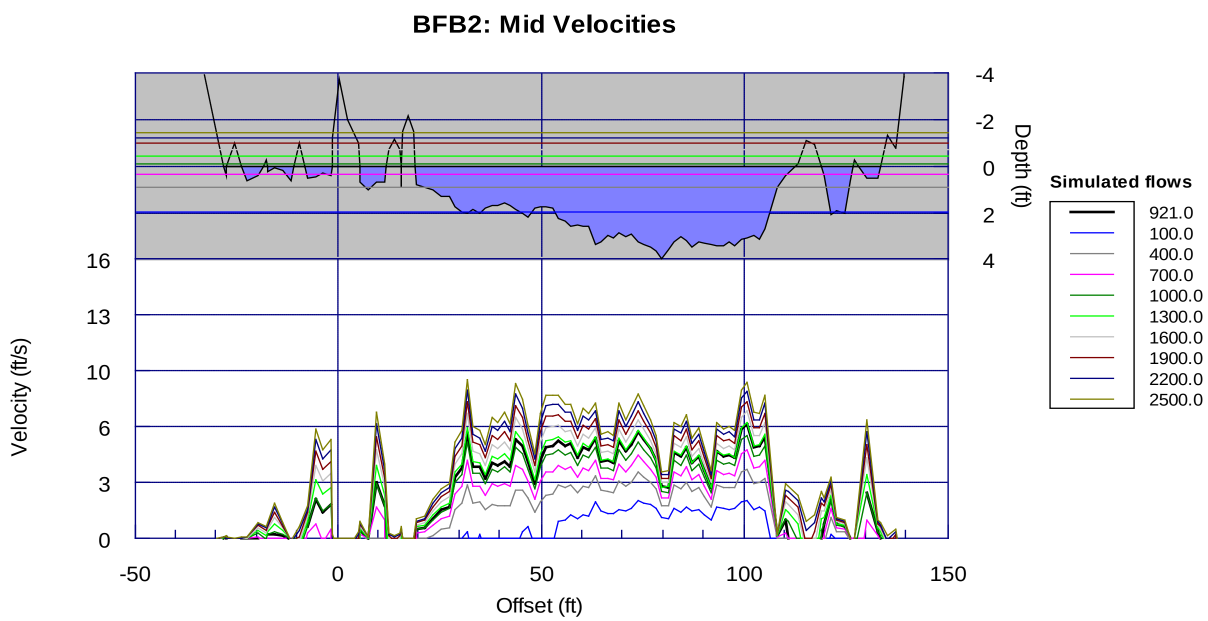


Figure 5.5-6. Measured middle flow velocities (black line) and simulated velocities for transect BFB2 in the Bellows Falls bypassed reach.

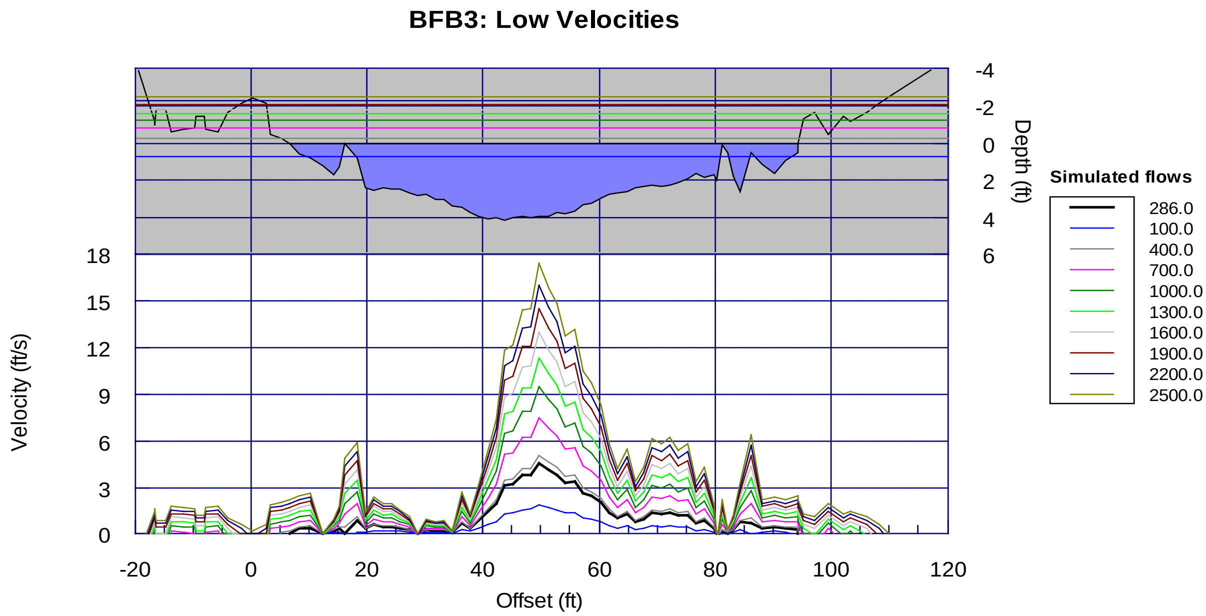


Figure 5.5-7. Measured low flow velocities (black line) and simulated velocities for transect BFB3 in the Bellows Falls bypassed reach.

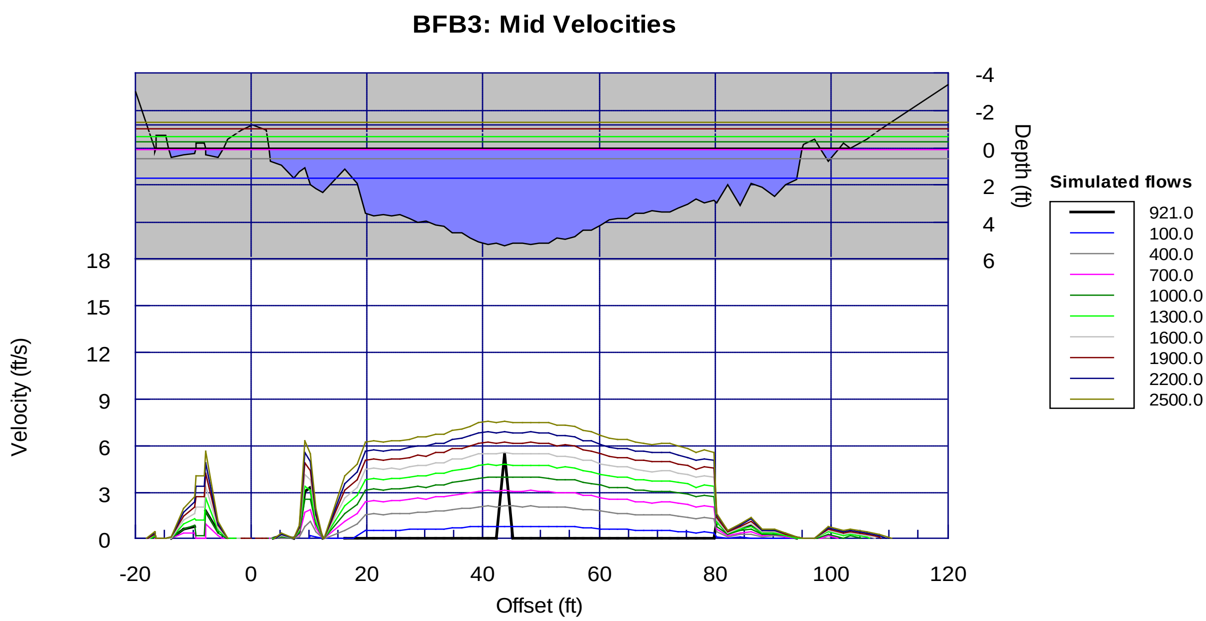


Figure 5.5-8. Measured middle flow velocities (black line, point mid-channel used for calibration) and simulated velocities for transect BFB3 in the Bellows Falls bypassed reach.

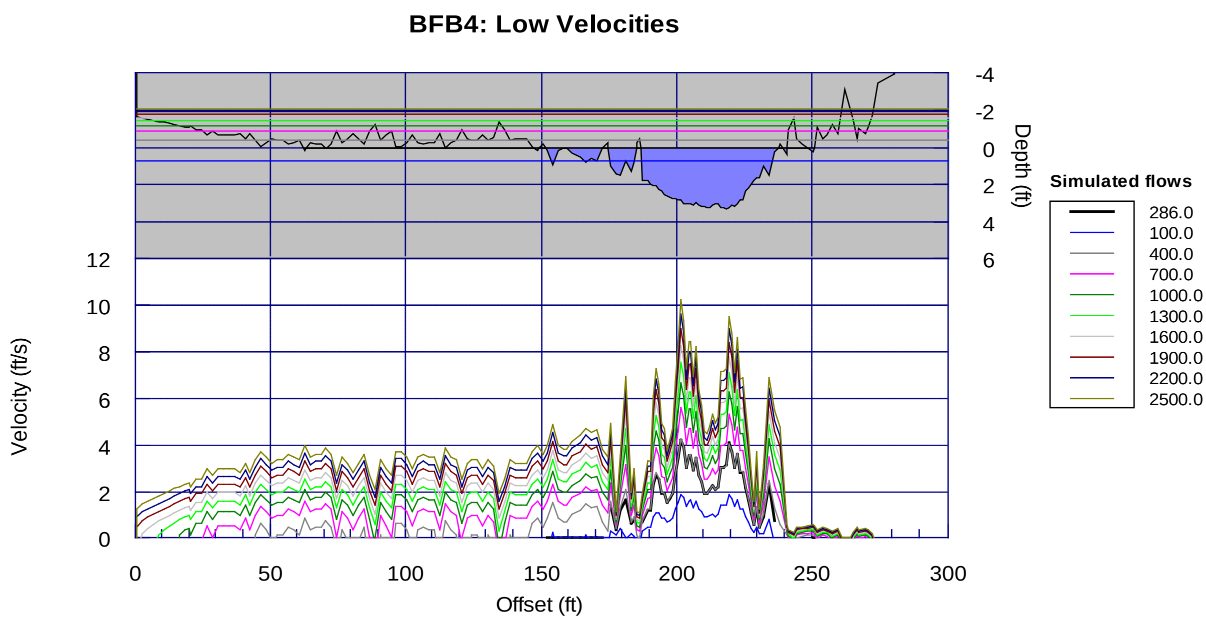


Figure 5.5-9. Measured low flow velocities (black line) and simulated velocities for transect BFB4 in the Bellows Falls bypassed reach.

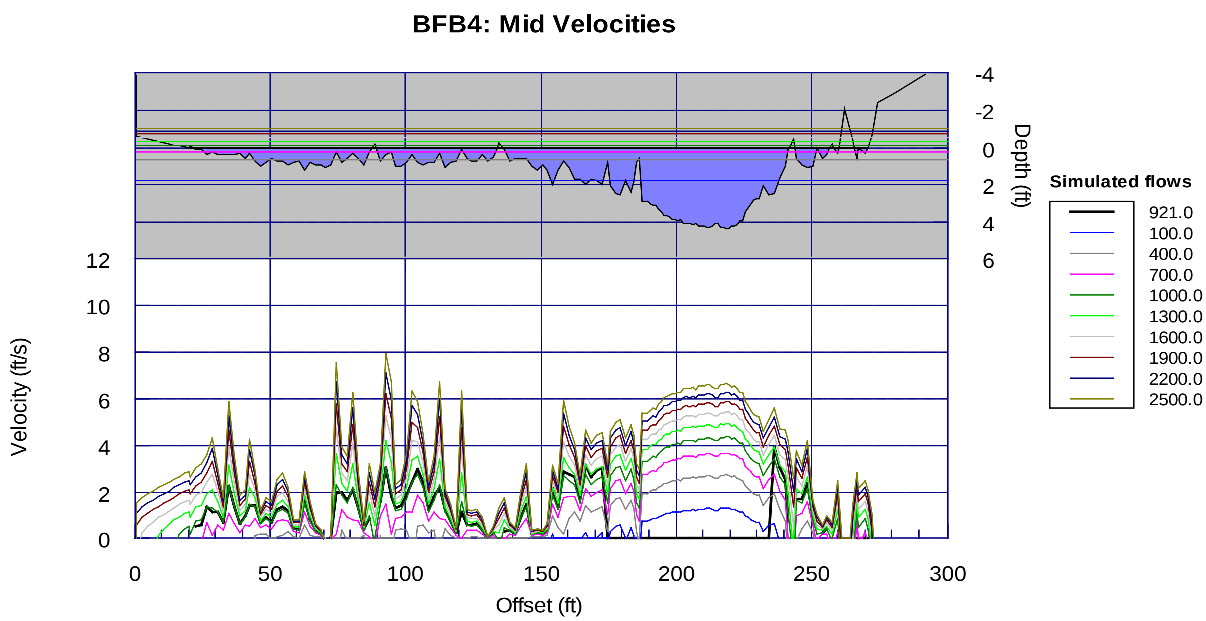


Figure 5.5-10. Measured middle flow velocities (black line) and simulated velocities for transect BFB4 in the Bellows Falls bypassed reach.

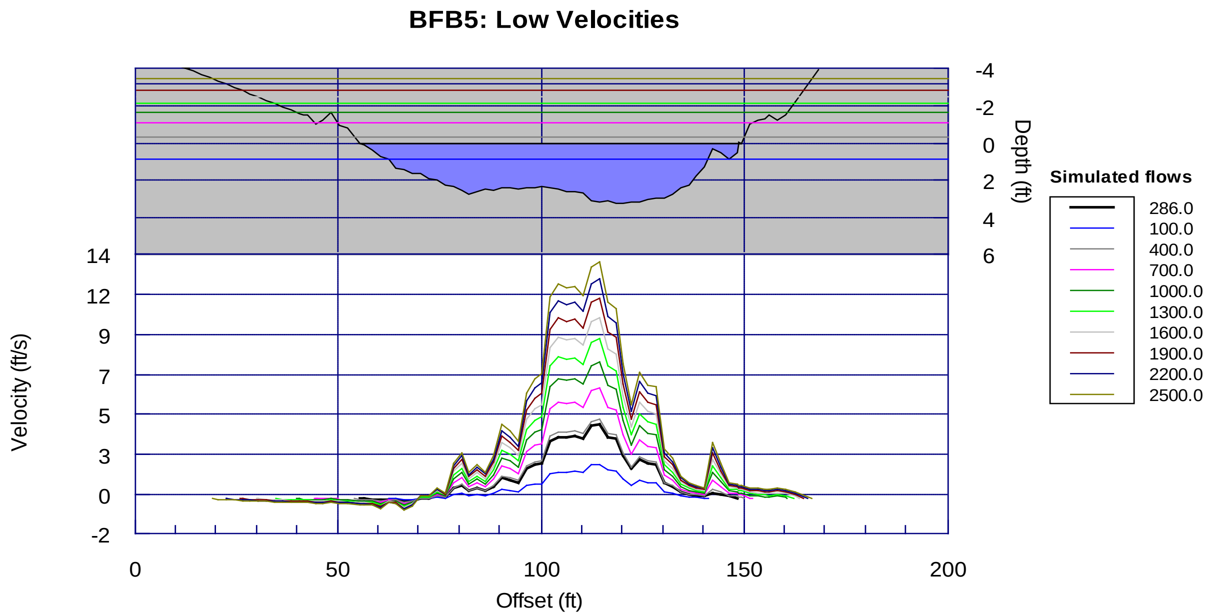


Figure 5.5-11. Measured low flow velocities (black line) and simulated velocities for transect BFB5 in the Bellows Falls bypassed reach.

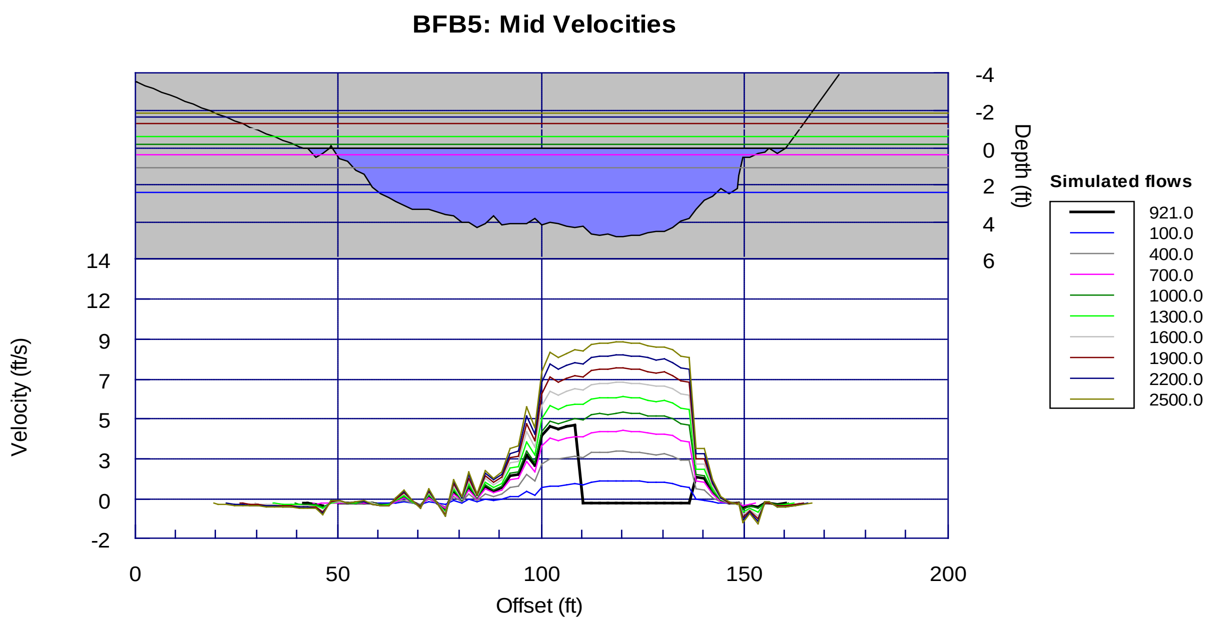


Figure 5.5-12. Measured middle flow velocities (black line) and simulated velocities for transect BFB5 in the Bellows Falls bypassed reach.

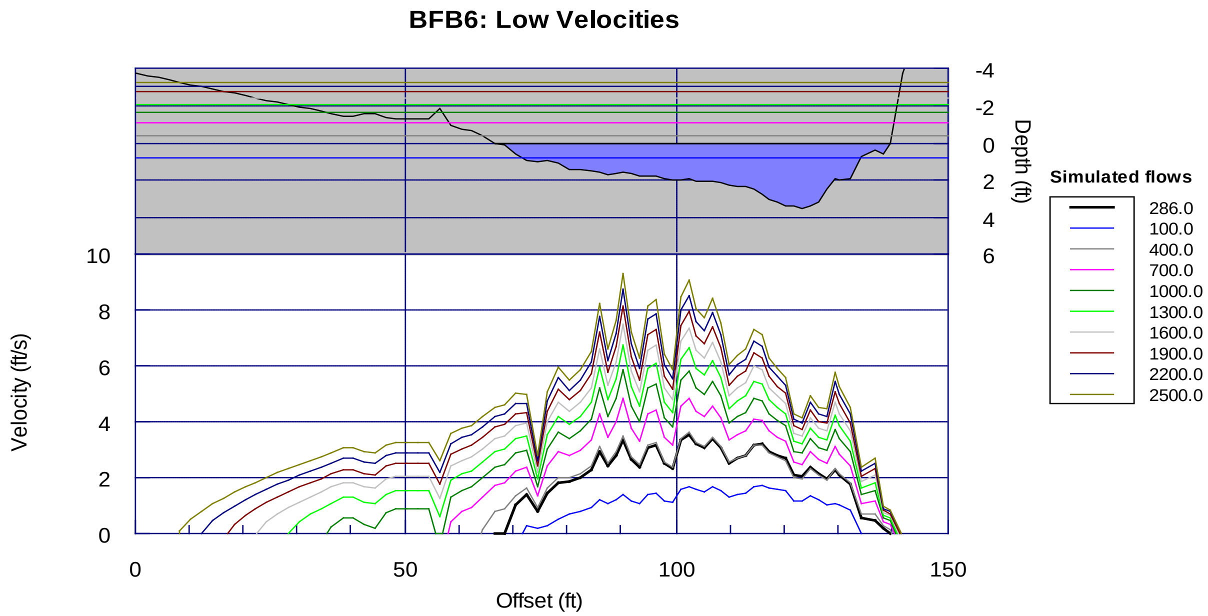


Figure 5.5-13. Measured low flow velocities (black line) and simulated velocities for transect BFB6 in the Bellows Falls bypassed reach.

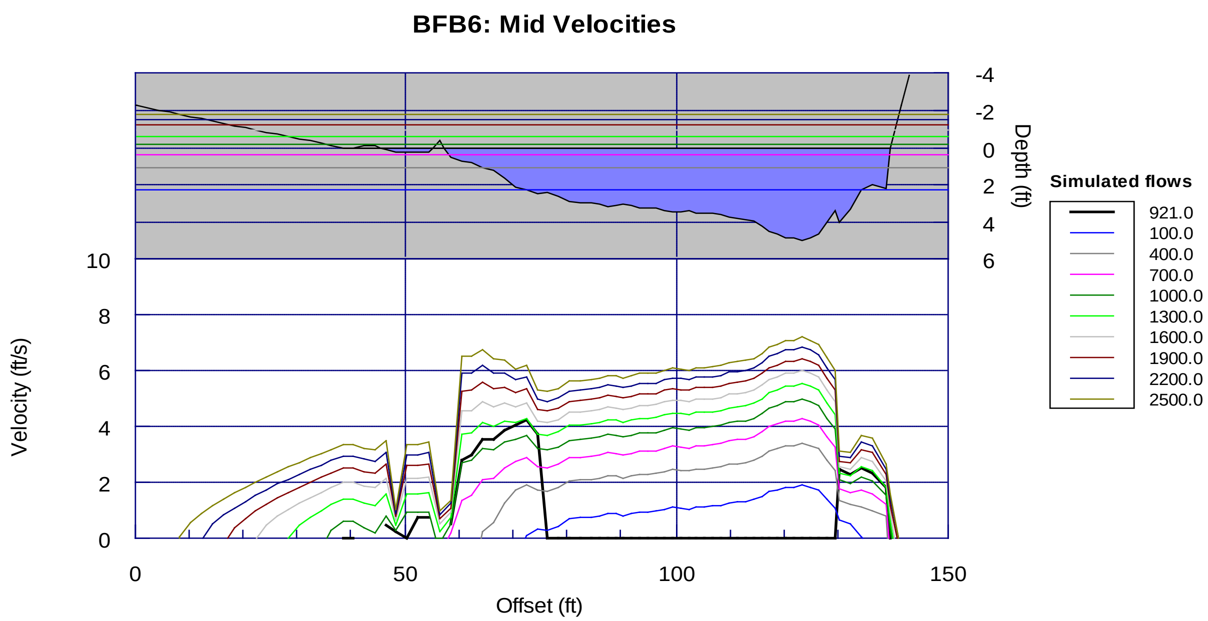


Figure 5.5-14. Measured middle flow velocities (black line) and simulated velocities for transect BFB6 in the Bellows Falls bypassed reach.

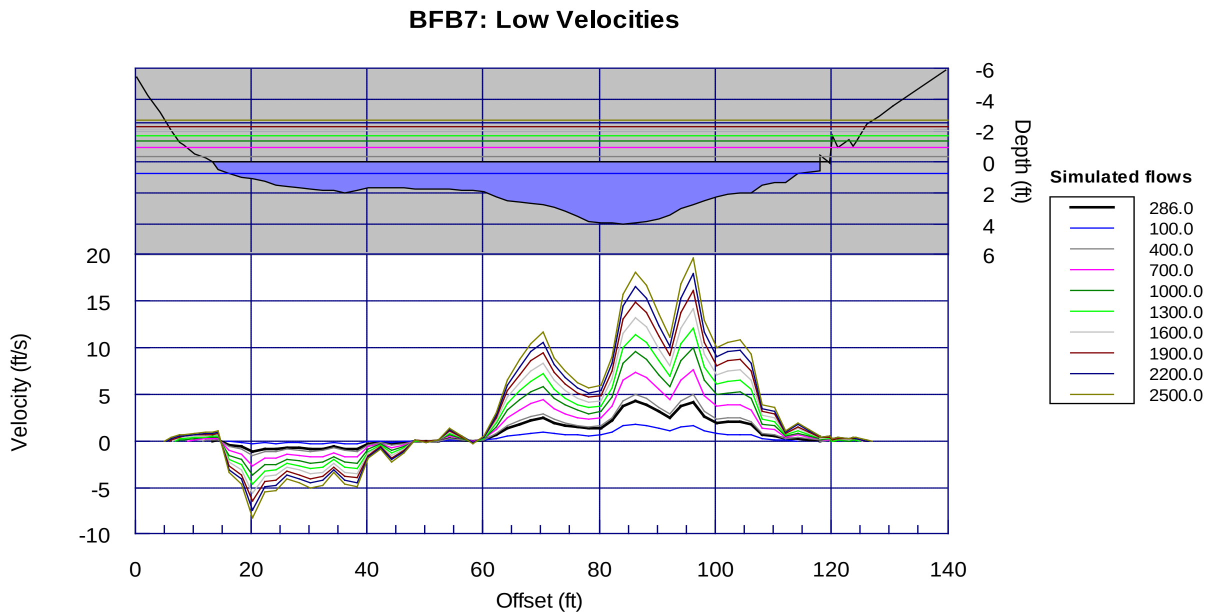


Figure 5.5-15. Measured low flow velocities (black line) and simulated velocities for transect BFB7 in the Bellows Falls bypassed reach.

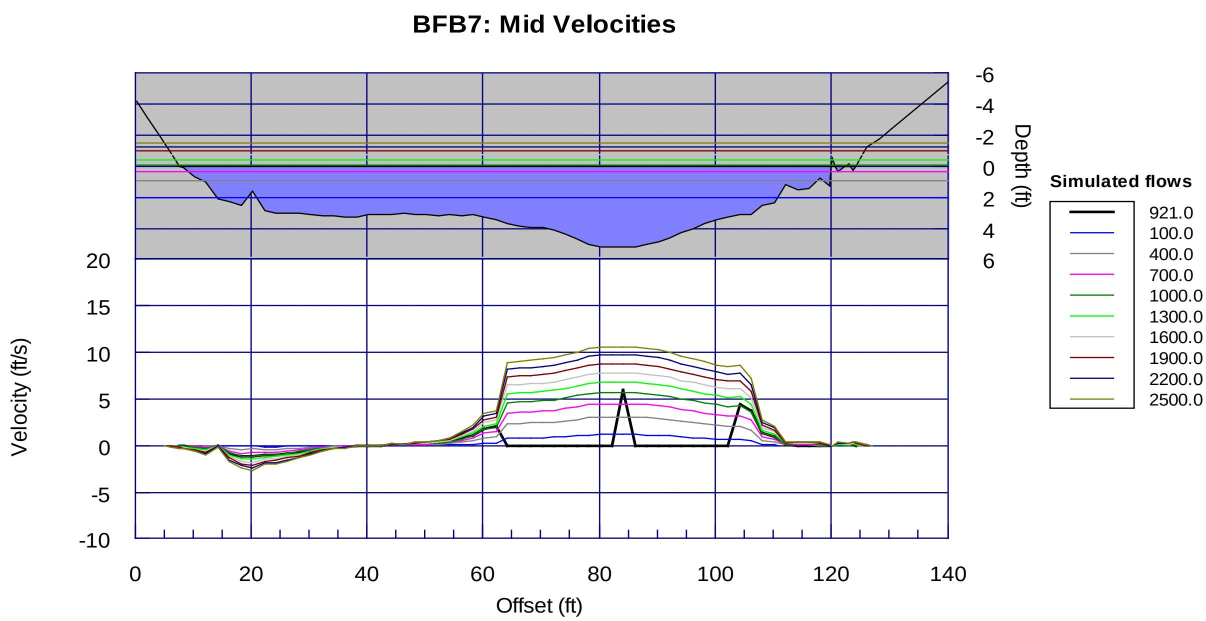
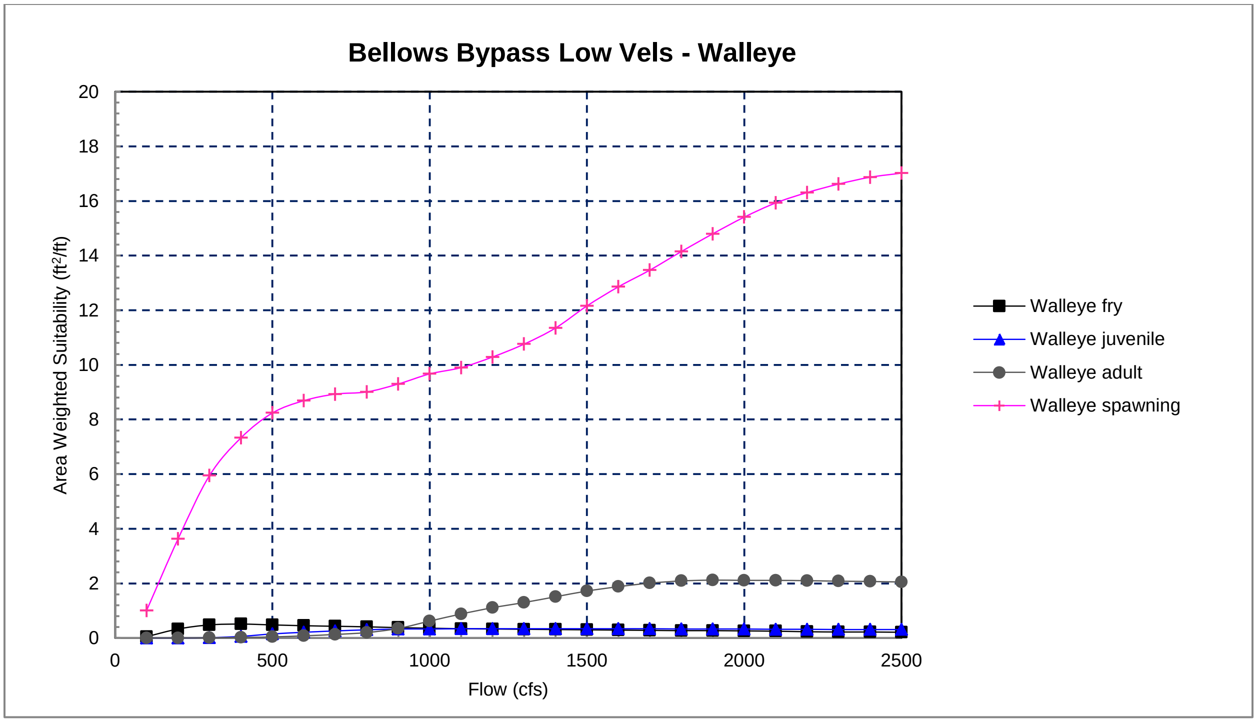


Figure 5.5-16. Measured middle flow velocities (black line, point mid-channel used for calibration) and simulated velocities for transect BFB7 in the Bellows Falls bypassed reach.



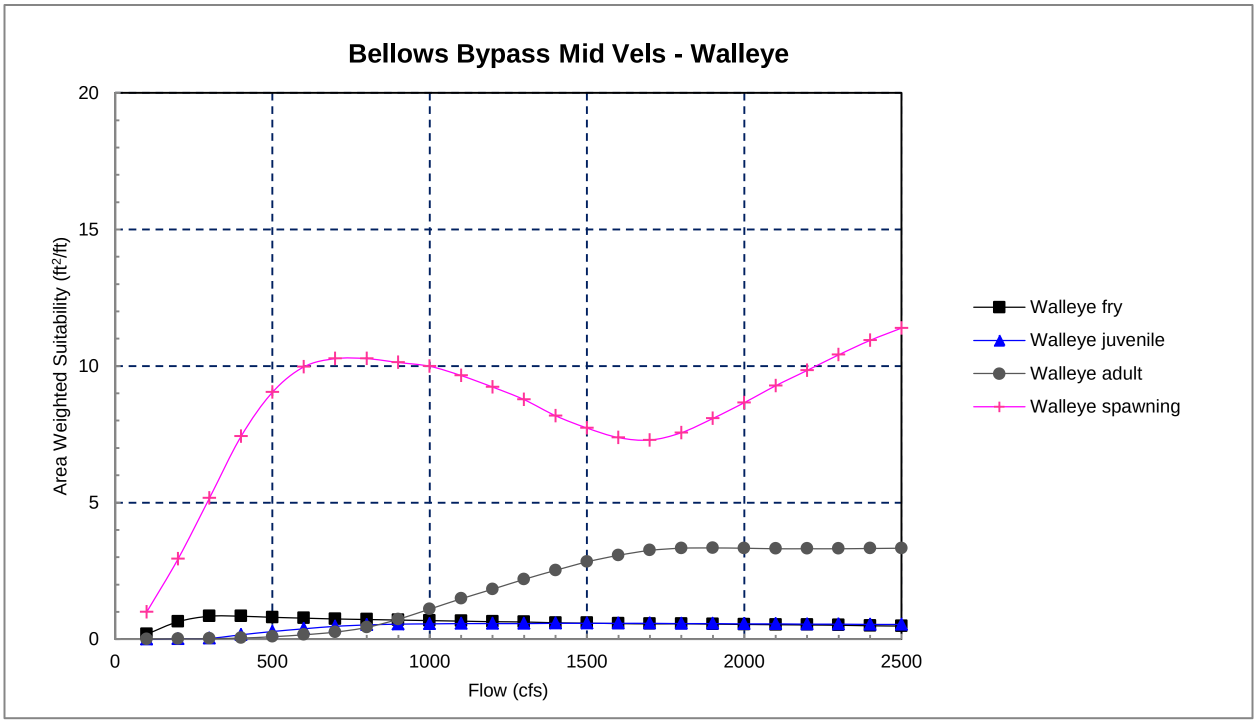


Figure 5.5-17. Walleye AWS in the Bellows Falls bypassed reach based on low and middle flow velocity calibration.

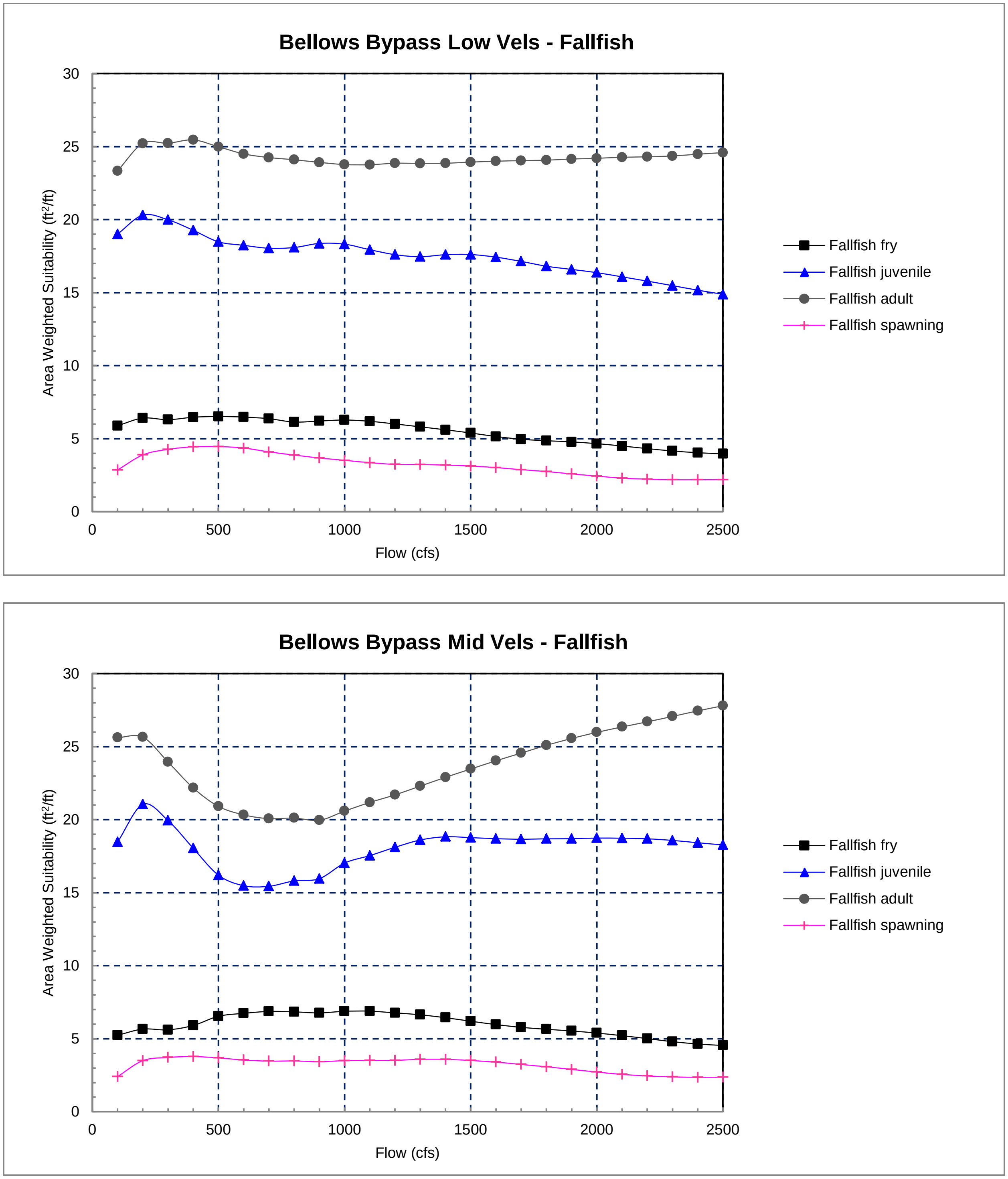
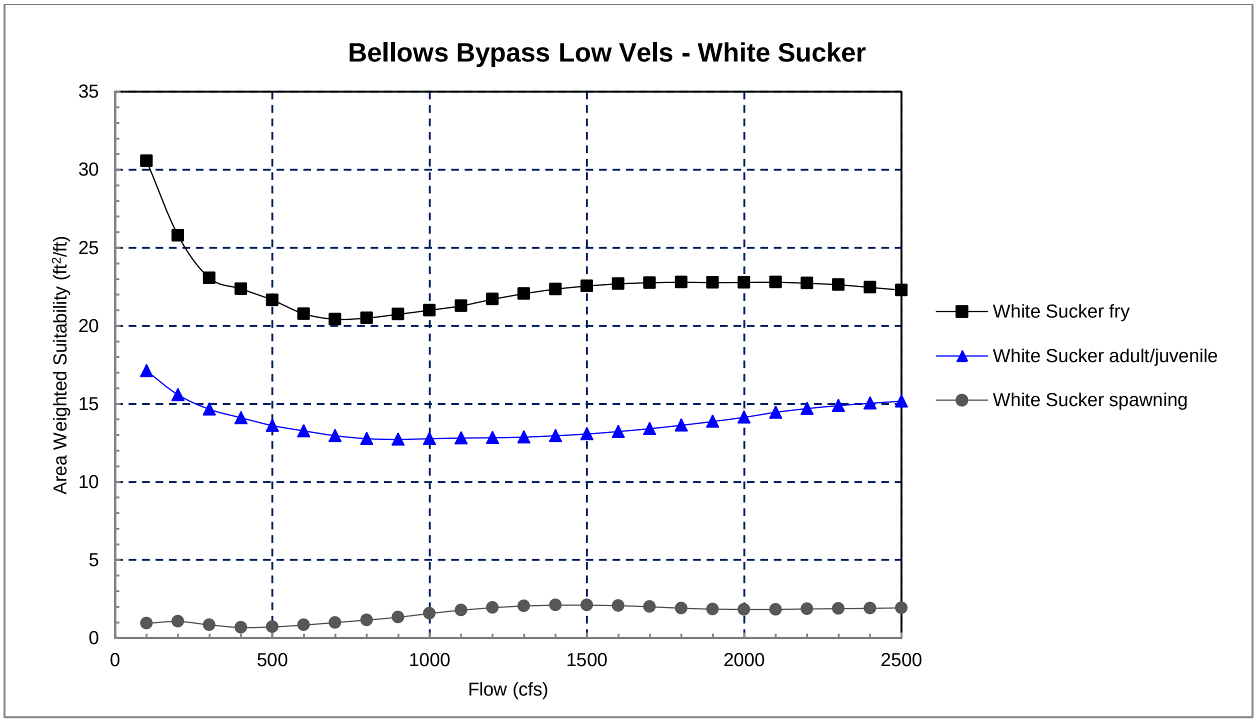


Figure 5.5-18. Fallfish AWS in the Bellows Falls bypassed reach based on low and middle flow velocity calibration.



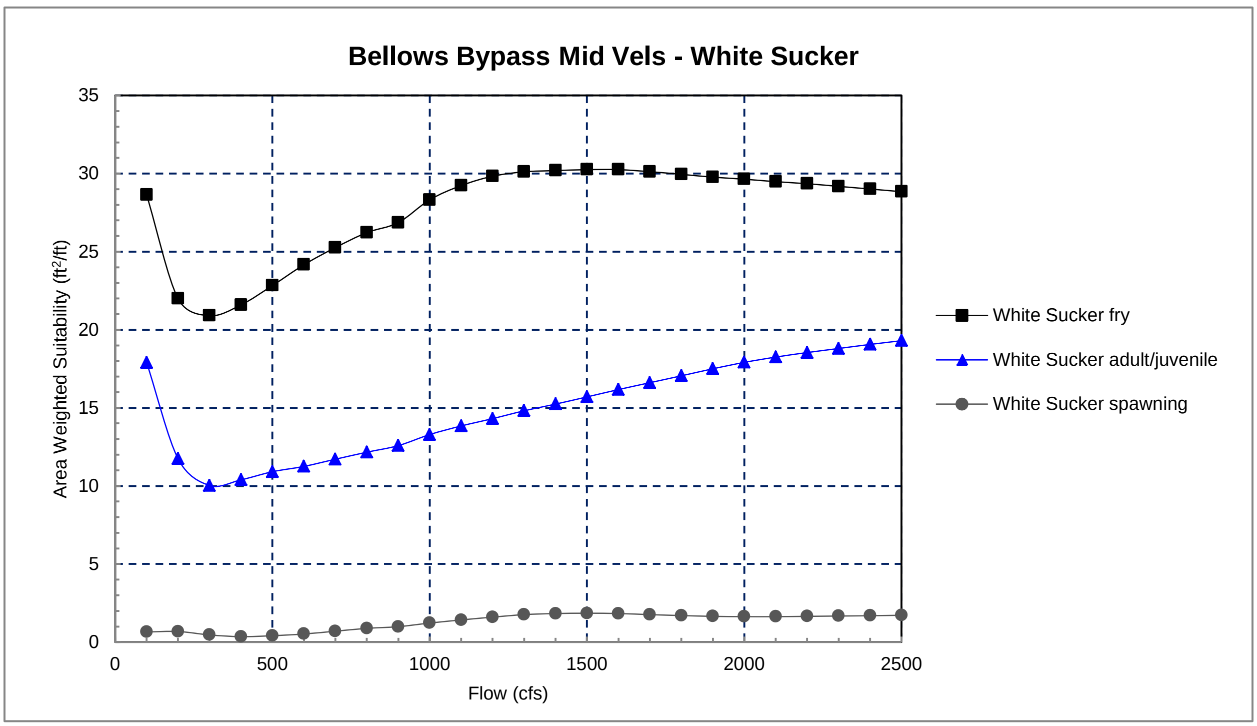
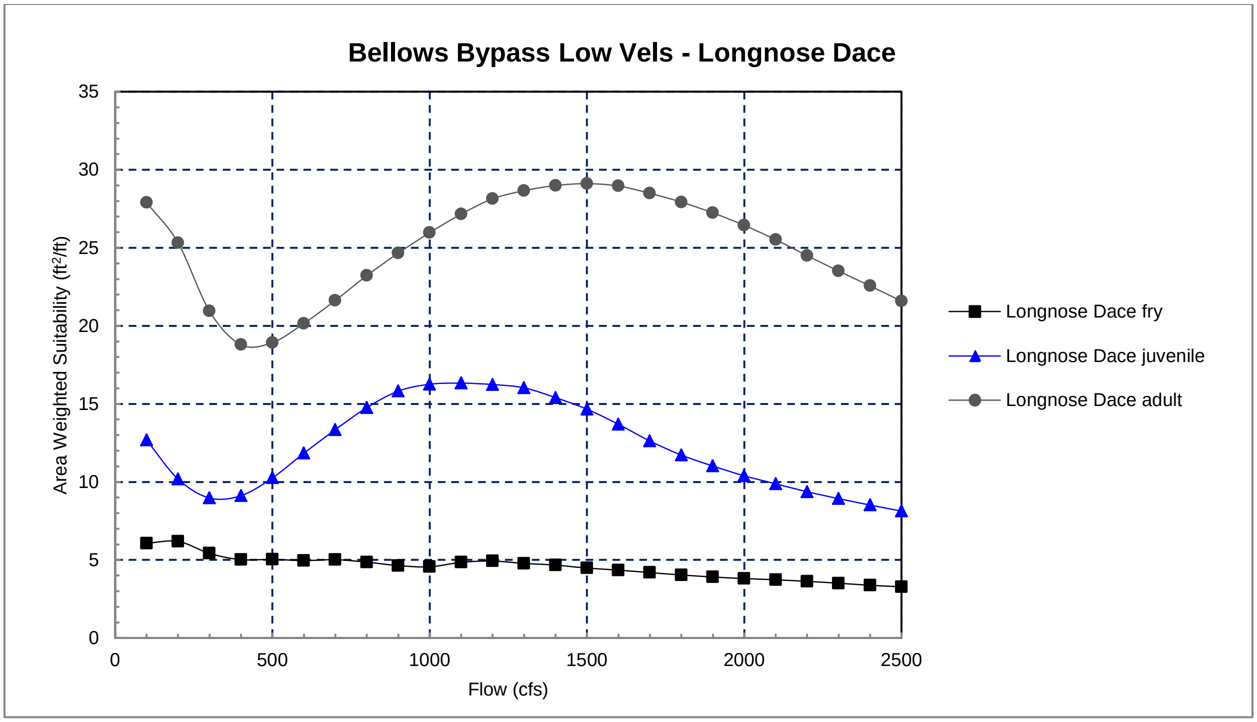


Figure 5.5-19. White Sucker AWS in the Bellows Falls bypassed reach based on low and middle flow velocity calibration.



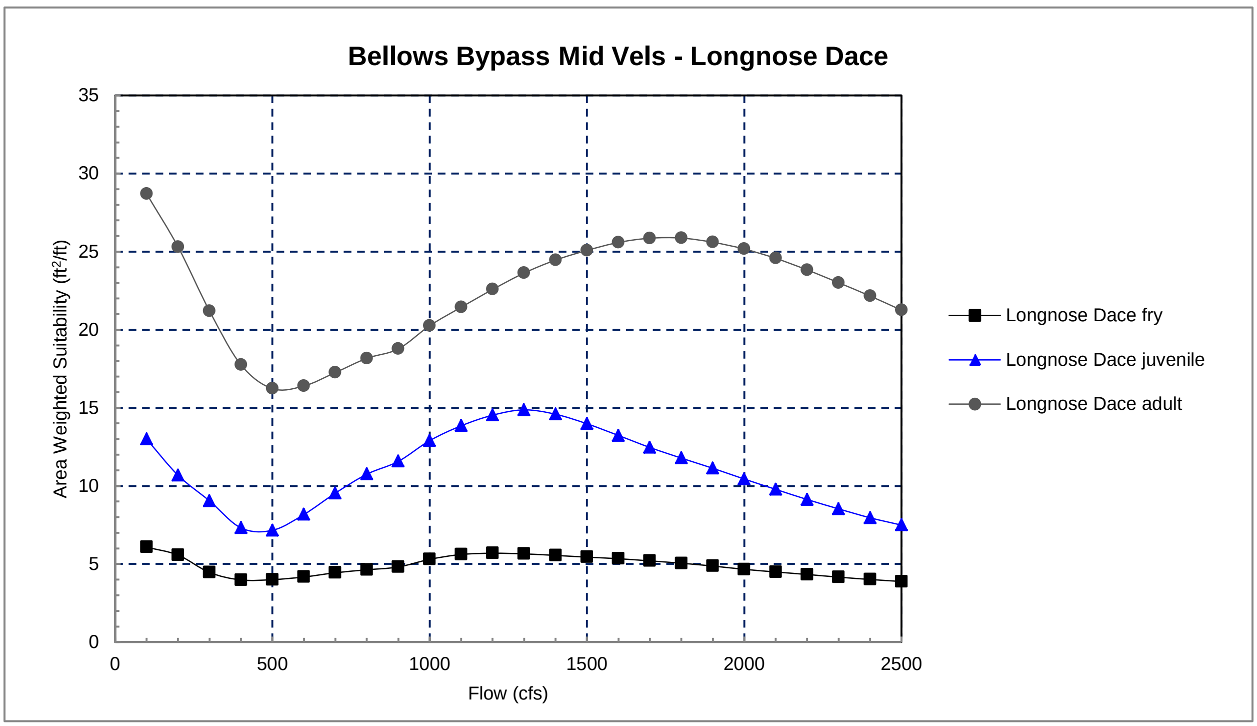
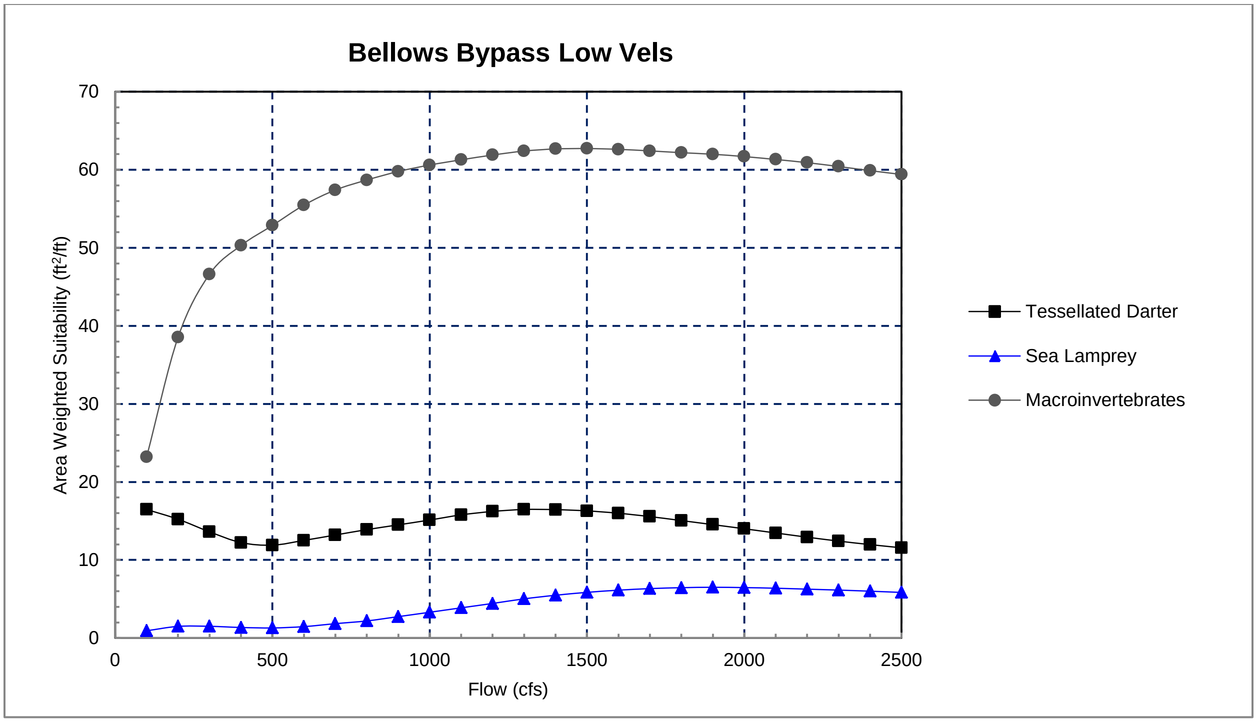


Figure 5.5-20. Longnose Dace AWS in the Bellows Falls bypassed reach based on low and middle flow velocity calibration.



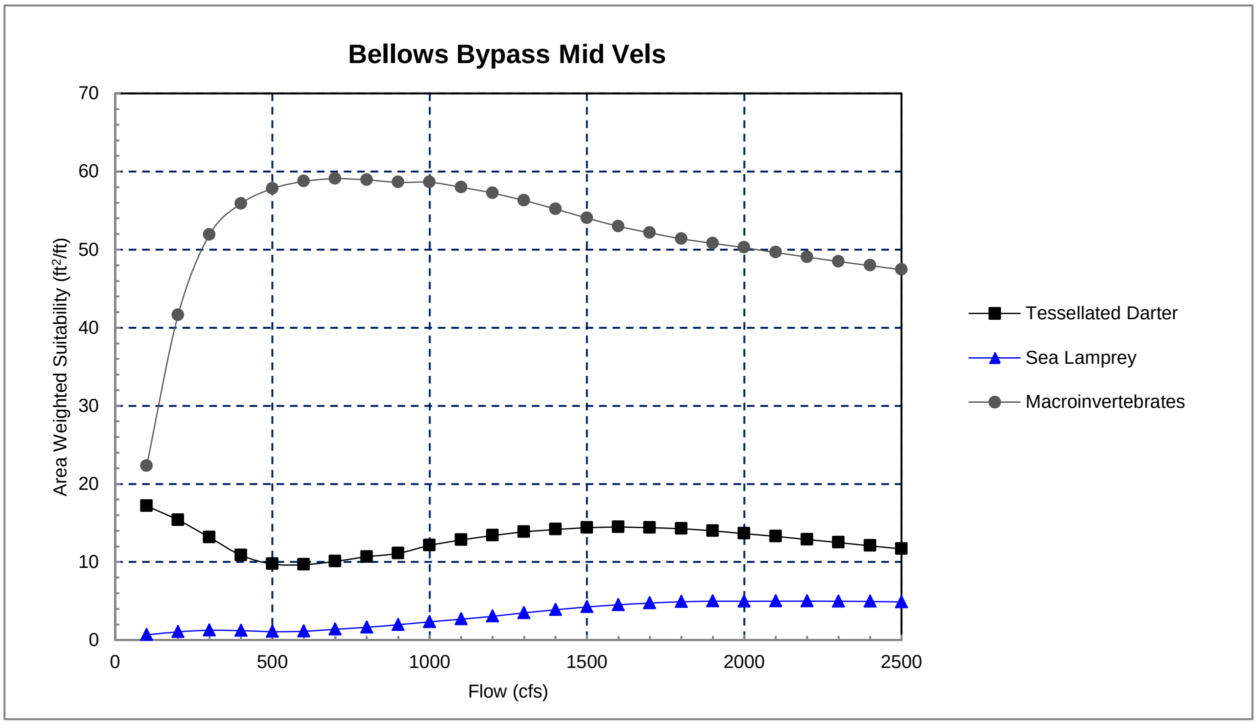
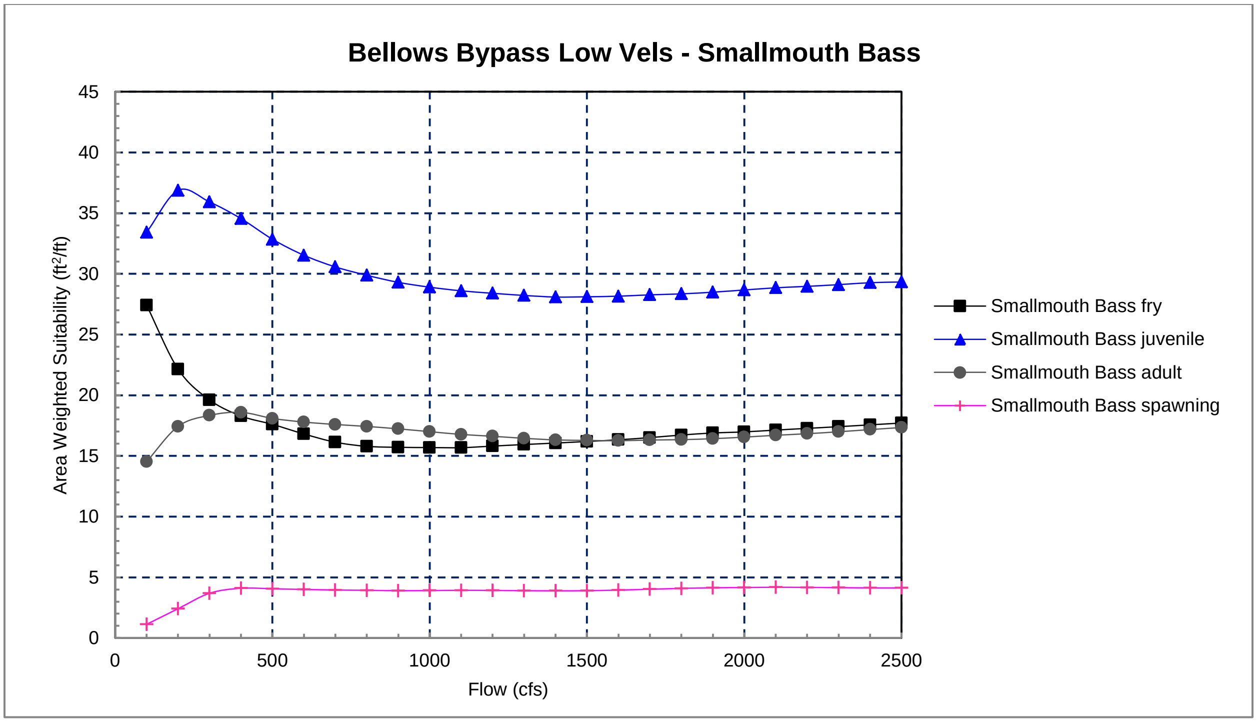


Figure 5.5-21. AWS for Tessellated Darter, Sea Lamprey Spawning and macroinvertebrates in the Bellows Falls bypassed reach based on low and middle flow velocity calibration.



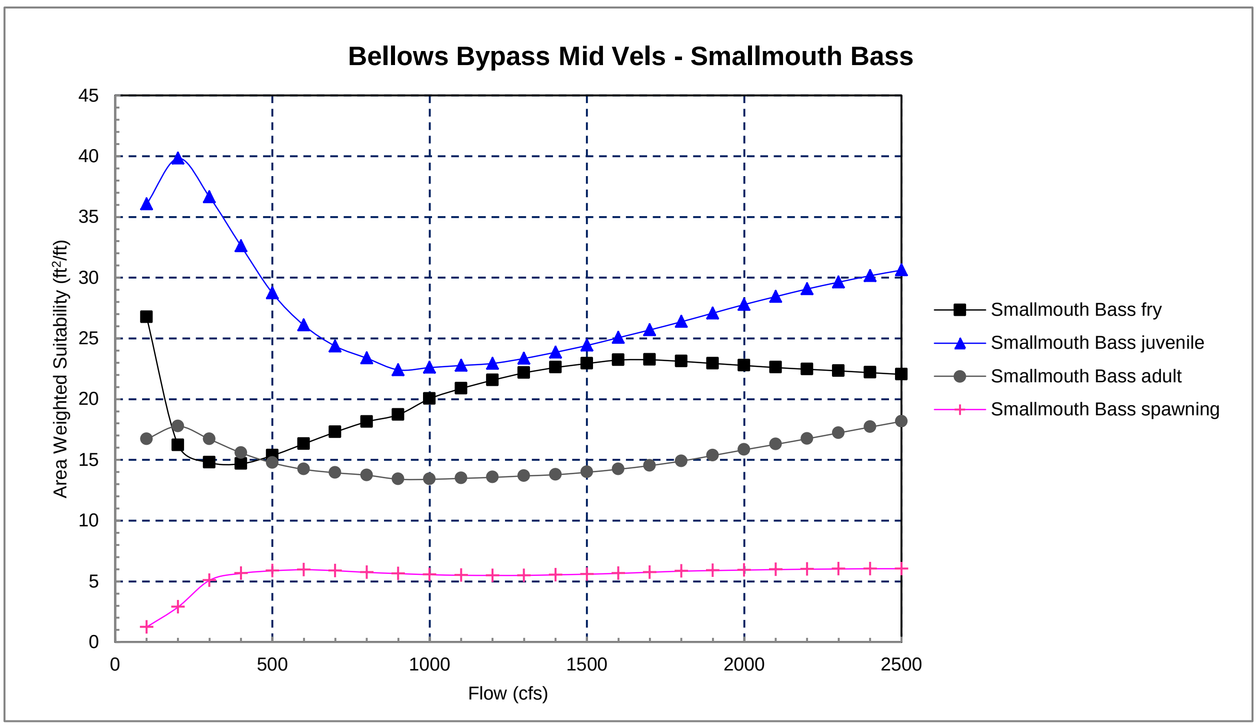
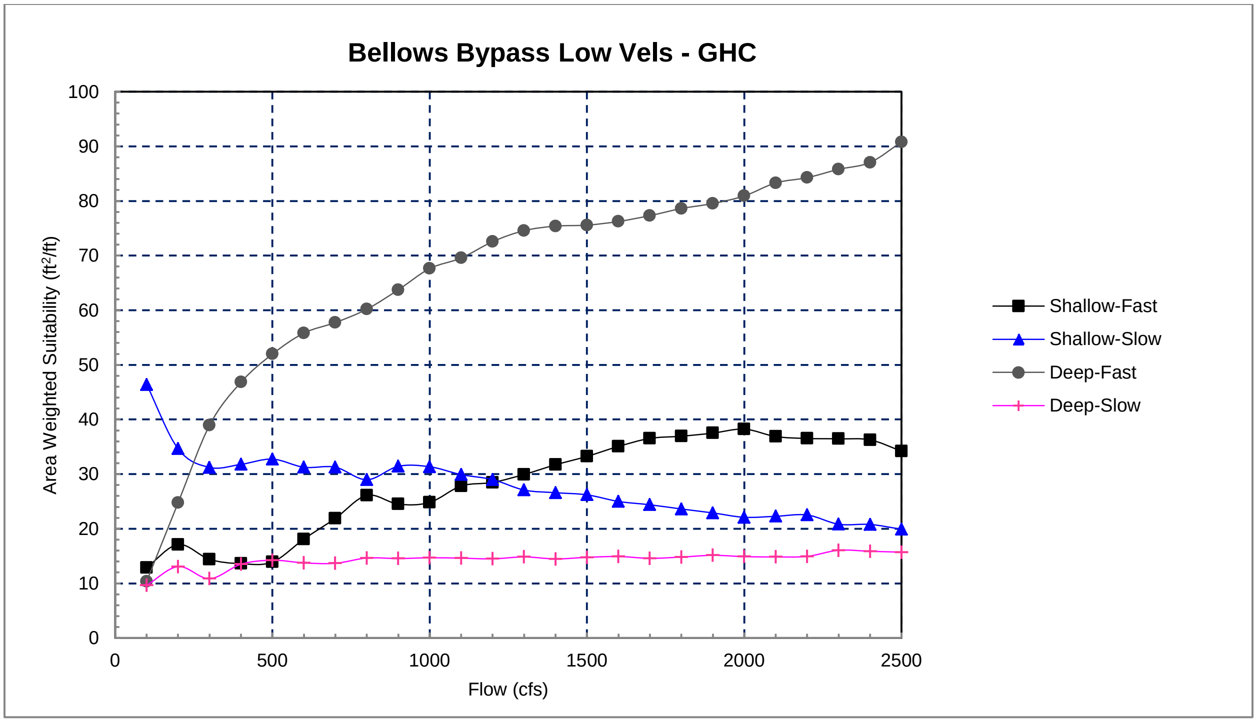


Figure 5.5-22. Smallmouth Bass AWS in the Bellows Falls bypassed reach based on low and middle flow velocity calibration.



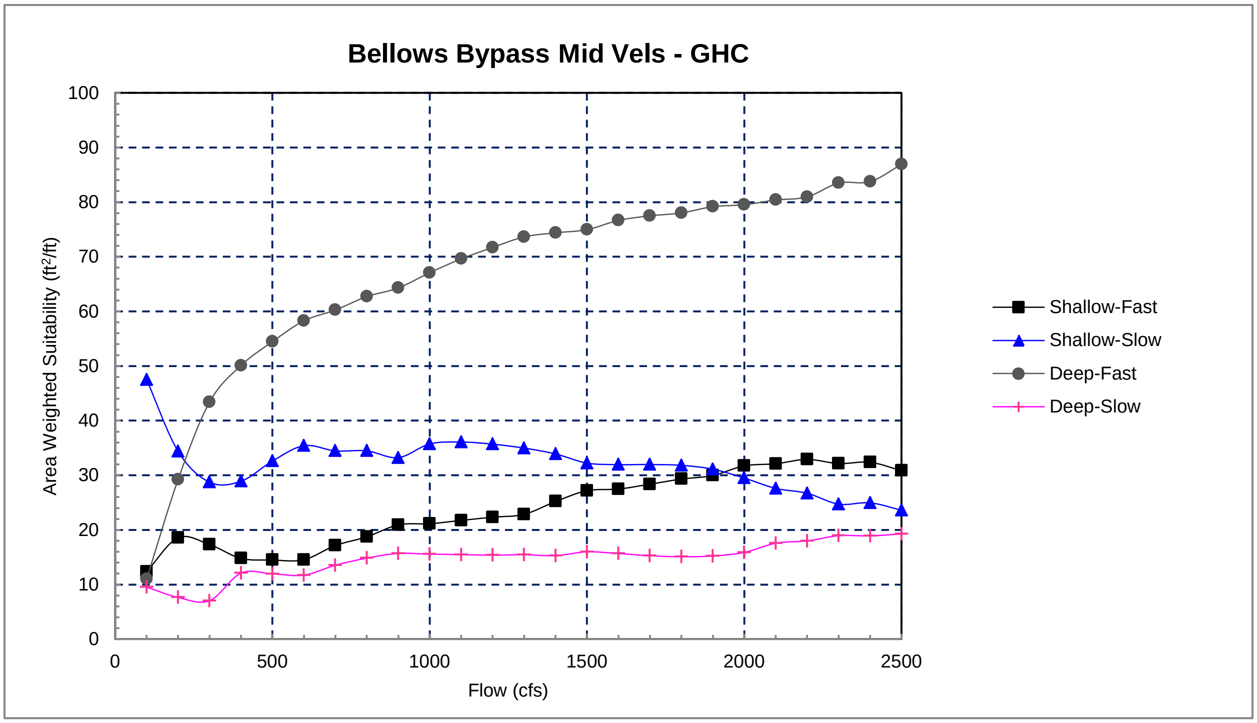


Figure 5.5-23. Generalized Habitat Criteria (GHC) AWS in the Bellows Falls bypassed reach based on low and middle flow velocity calibration.

5.6 Sumner Falls Demonstration Flow Assessment

Under low flow conditions TransCanada and working group participants identified 5 transect locations within the Sumner Falls study site that encompass areas where shallow water depths and dewatering and/or pooling may occur (Figure 5.6-1). TransCanada consultants surveyed bottom profiles at low flow and set up gages prior to the release of demonstration flows. All surveyed points were referenced to an established vertical elevation (NAVD88) benchmark in the vicinity of the local Jesup’s Milk Vetch population (Normandeau, 2013).

The DFA schedule was set up to provide four flows with time for each flow to stabilize at Sumner Falls on August 5, 2015:

- Demonstration flow #1: 700 cfs out of Wilder and stable at the site by 0900.
- Demonstration flow #2: 1,500 cfs out of Wilder and stable at the site by approximately 1100.
- Demonstration flow #3: 2,500 cfs out of Wilder and stable at the site by approximately 1400.
- Demonstration flow #4: 3,500 cfs out of Wilder and stable at the site by approximately 1700.

A temporary staff gage at the site was tracked to determine when flows stabilized and observations of the study area and gage readings could be taken. During this time ADCP flow measurements were taken at regular intervals to determine the flow at the site (Table 5.6-1). Based on input from upstream tributaries it was estimated that an additional 500 cfs of accretion would be added to the releases from Wilder dam.

Table 5.6-1. Observation time and flows for the Sumner Falls DFA.

Observation Time	Flow from Wilder	Observation Flow at Sumner Falls
NA	700	1,300
1300	1,500	2,078
1600	2,500	3,121
1800	3,500	3,942

During each flow observation aerial imagery was taken over Sumner Falls using a drone aircraft. Images of the study area at the four flows with transects overlaid are presented in Appendix F.

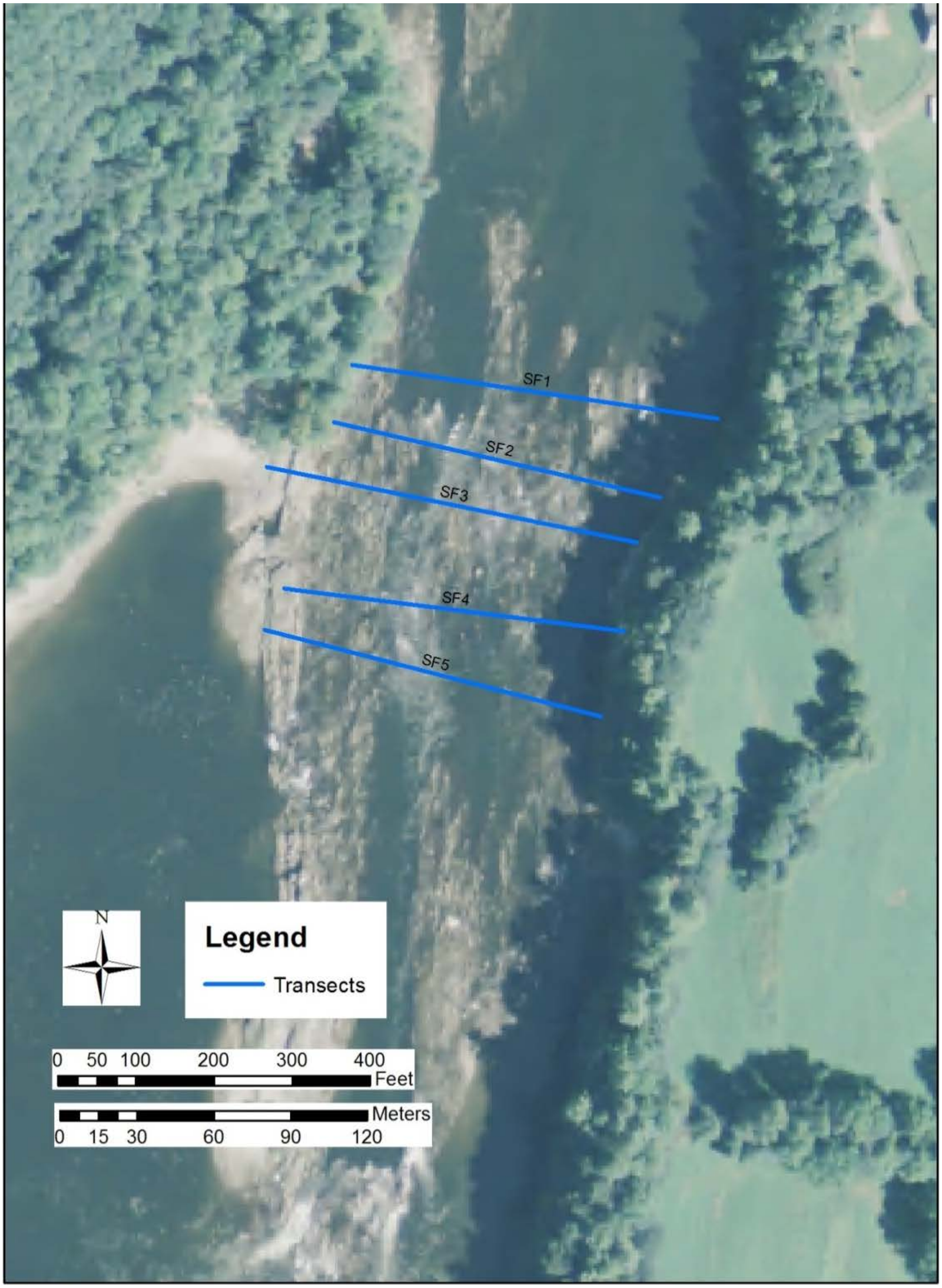
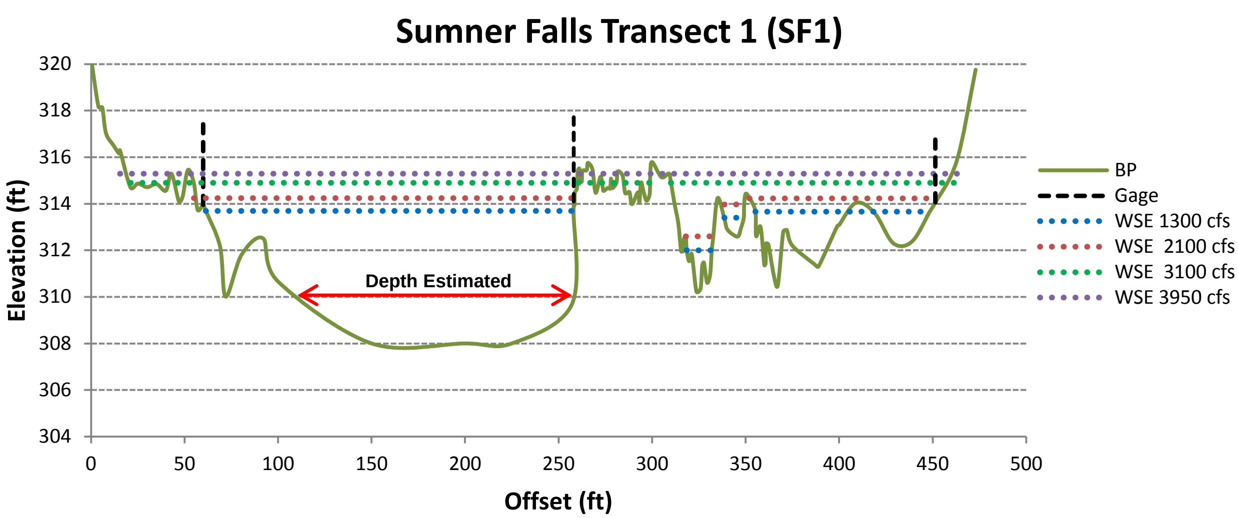


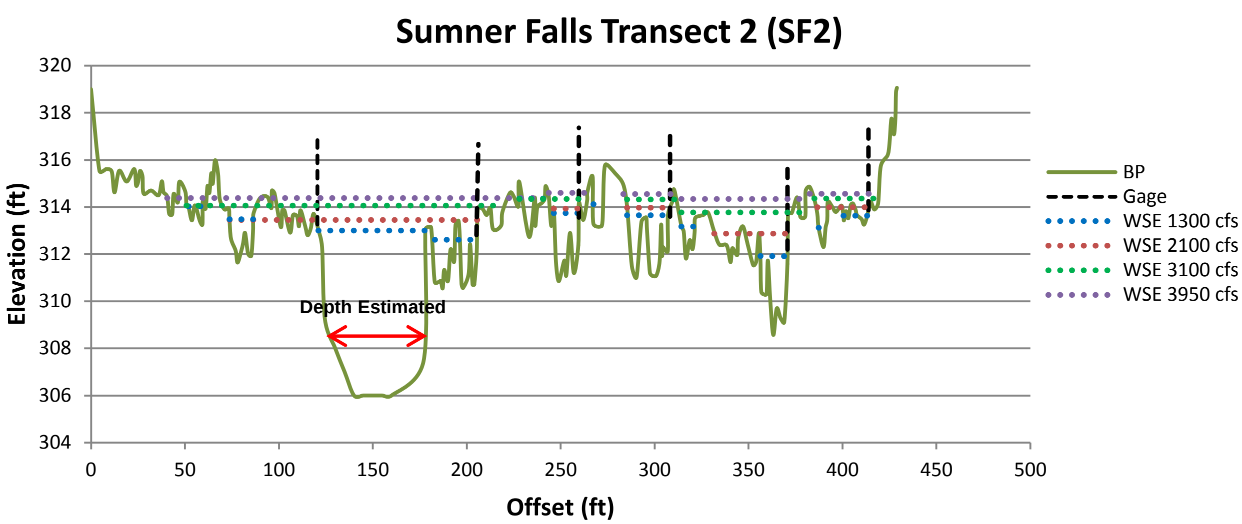
Figure 5.6-1. Sumner Falls study area and demonstration flow assessment transect locations.

Observed WSE based on gage readings and resulting changes in depth were plotted and tables created to display wetted width for ranges of depths and percent wetted width for depths ≥0.5 ft, ≥0.7 ft and >1.0 ft (Figures 5.6-2 to 5.6-6). Depths greater than 1.0 ft were predominant due to some deep channels that run through the study area and accounted for over 50% of wetted width on transects SF1, SF4 and SF5 at the low flow. The greatest change in total wetted width occurred between 1,300 cfs and 3,100 cfs for all transects. Little change in wetted width for all depth categories occurred between 3,100 cfs and 3,950 cfs.



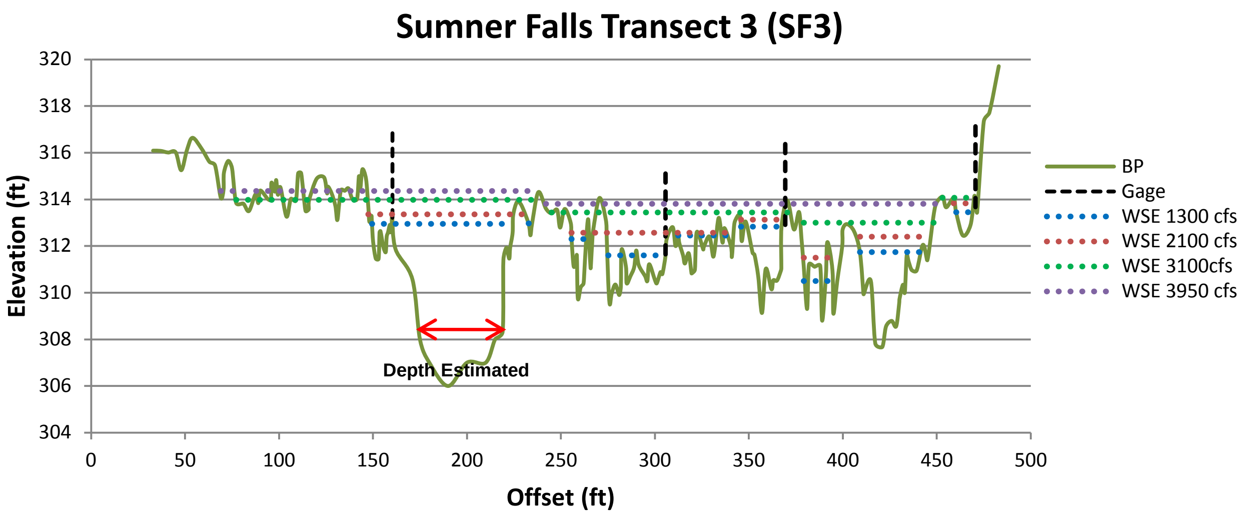
SF1	Wetted Width by Depth Range (ft)					Percent Wetted Width by Depth				
Depth (ft)	<0.5	≥0.5<0.7	≥0.7<1.0	> 1.0	Total	<0.5	≥0.5	≥0.7	> 1.0	Total
1300 cfs	28.1	14.9	10.1	250.4	303.4	6%	58%	55%	53%	64%
2100 cfs	24.1	28.2	1.9	280.4	334.6	5%	66%	60%	59%	71%
3100 cfs	45.2	8.0	27.6	322.0	402.8	10%	76%	74%	68%	85%
3950 cfs	26.6	15.5	20.1	355.2	417.3	6%	83%	79%	75%	88%
Total Width					473					

Figure 5.6-2. Bottom profile, WSE, and calculations of depths and wetted widths for transect SF1 in Sumner Falls.



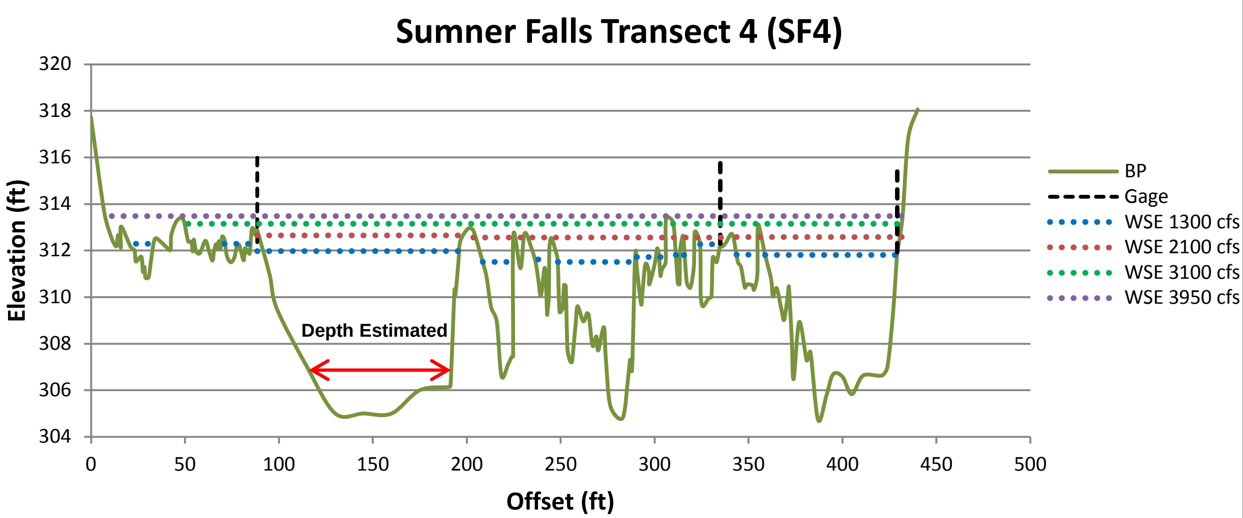
SF2	Wetted Width by Depth Range (ft)					Percent Wetted Width by Depth				
Depth (ft)	<0.5	≥0.5<0.7	≥0.7<1.0	> 1.0	Total	<0.5	≥0.5	≥0.7	> 1.0	Total
1300 cfs	22.5	9.9	15.5	122.2	170.1	5%	34%	32%	28%	40%
2100 cfs	41.0	19.8	11.3	138.4	210.4	10%	39%	35%	32%	49%
3100 cfs	67.9	17.7	33.5	179.9	299.0	16%	54%	50%	42%	70%
3950 cfs	39.2	29.5	29.4	213.5	311.5	9%	63%	57%	50%	73%
Total Width					429					

Figure 5.6-3. Bottom profile, WSE, and calculations of depths and wetted widths for transect SF2 in Sumner Falls.



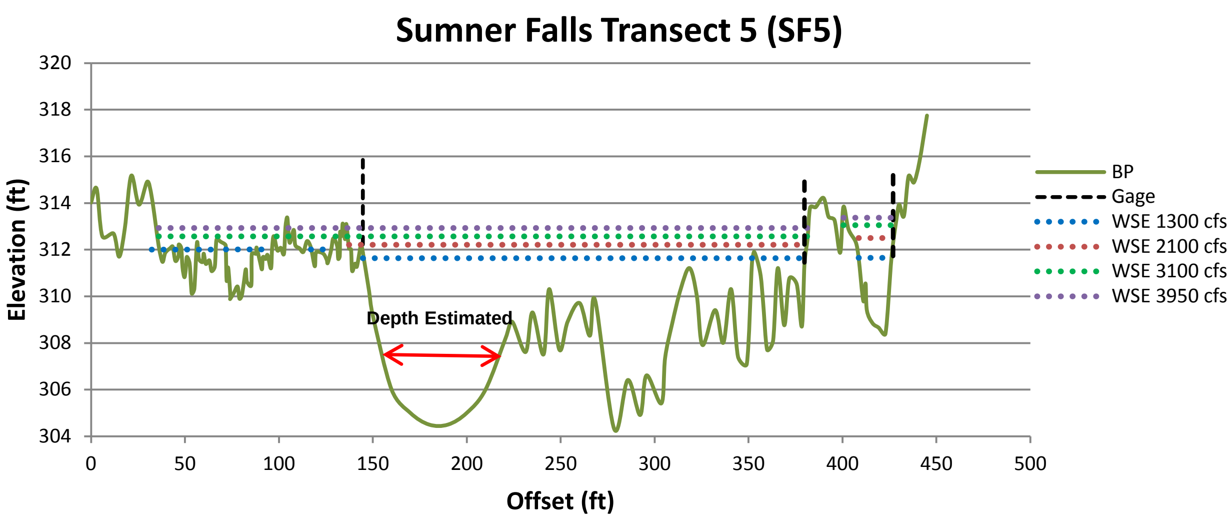
SF3	Wetted Width by Depth Range (ft)					Percent Wetted Width by Depth				
Depth (ft)	<0.5	≥0.5<0.7	≥0.7<1.0	> 1.0	Total	<0.5	≥0.5	≥0.7	> 1.0	Total
1300 cfs	30.7	9.2	15.7	99.7	155.3	6%	26%	24%	21%	32%
2100 cfs	71.9	20.0	29.5	125.1	246.4	15%	36%	32%	26%	51%
3100 cfs	56.3	21.5	36.2	203.6	317.5	12%	54%	50%	42%	66%
3950 cfs	49.2	18.9	25.1	249.1	342.2	10%	61%	57%	52%	71%
Total Width					483					

Figure 5.6-4. Bottom profile, WSE, and calculations of depths and wetted widths for transect SF3 in Sumner Falls.



SF4	Wetted Width by Depth Range (ft)					Percent Wetted Width by Depth				
Depth (ft)	<0.5	≥0.5<0.7	≥0.7<1.0	> 1.0	Total	<0.5	≥0.5	≥0.7	> 1.0	Total
1300 cfs	21.6	13.1	17.3	246.8	298.7	5%	63%	60%	56%	68%
2100 cfs	24.1	8.1	17.3	286.2	335.6	5%	71%	69%	65%	76%
3100 cfs	25.3	8.4	23.9	325.9	383.4	6%	81%	79%	74%	87%
3950 cfs	18.7	14.5	21.6	369.7	424.5	4%	92%	89%	84%	96%
Total Width					440					

Figure 5.6-5. Bottom profile, WSE, and calculations of depths and wetted widths for transect SF4 in Sumner Falls.



SF5	Wetted Width by Depth Range (ft)					Percent Wetted Width by Depth				
Depth (ft)	<0.5	≥0.5<0.7	≥0.7<1.0	> 1.0	Total	<0.5	≥0.5	≥0.7	> 1.0	Total
1300 cfs	32.6	9.0	12.7	245.4	299.7	7%	60%	58%	55%	67%
2100 cfs	29.4	6.7	27.5	252.2	315.7	7%	65%	64%	57%	72%
3100 cfs	32.7	21.2	19.4	292.2	365.5	7%	76%	71%	66%	83%
3950 cfs	13.5	9.7	25.3	323.1	371.7	3%	81%	79%	73%	84%
Total Width					445					

Figure 5.6-6. Bottom profile, WSE, and calculations of depths and wetted widths for transect SF5 in Sumner Falls.

5.7 Dwarf Wedgemussels and Co-Occurring Mussels

Recent studies have determined that complex shear hydraulic variables (shear velocity, shear stress, and relative shear stress) may be limiting factors for freshwater mussel habitat and distribution (Steuer et al., 2008; Allen and Vaughn, 2012; Maloney et al., 2012). Steady state flow 1D AWS results for DWM and co-occurring mussels in the Wilder and Bellows Falls reaches show a steady decline in habitat with increasing flow (Figure 5.7-1). An examination of individual suitability factors indicates that shear stress is the primary driving factor in the decrease of habitat with increasing flow, supporting the idea that shear-related hydraulic variables may limit available habitat. Similar results for DWM and co-occurring mussel WUA were found for the Chase Island 2D site (Figure 5.7-2). Both DWM and co-occurring mussels display relatively flat habitat versus flow relationships for the Johnston Island 2D site, indicating little effect on habitat with changes in flow. Because DWM are not known to occur in the Vernon reach only co-occurring mussels were modeled there (Figure 5.7-3). The results for the 182.6 ft (NAVD88) WSE case are greater than for 180.6 ft (NAVD88), likely a function of overall lower velocities with the increase in depth. AWS tabular results for 1D transects are presented in Appendix D and WUA results for 2D sites in Appendix E.

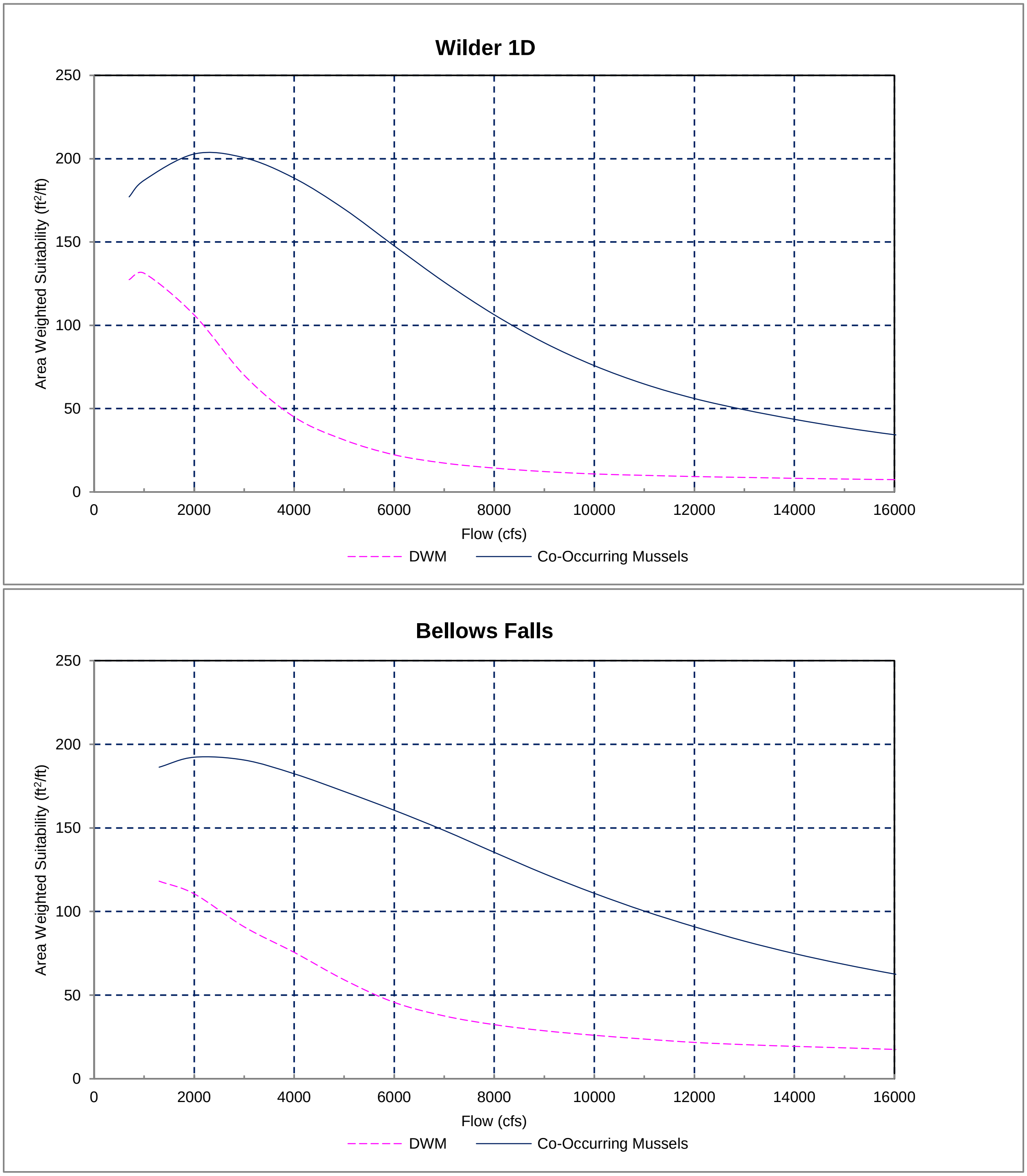
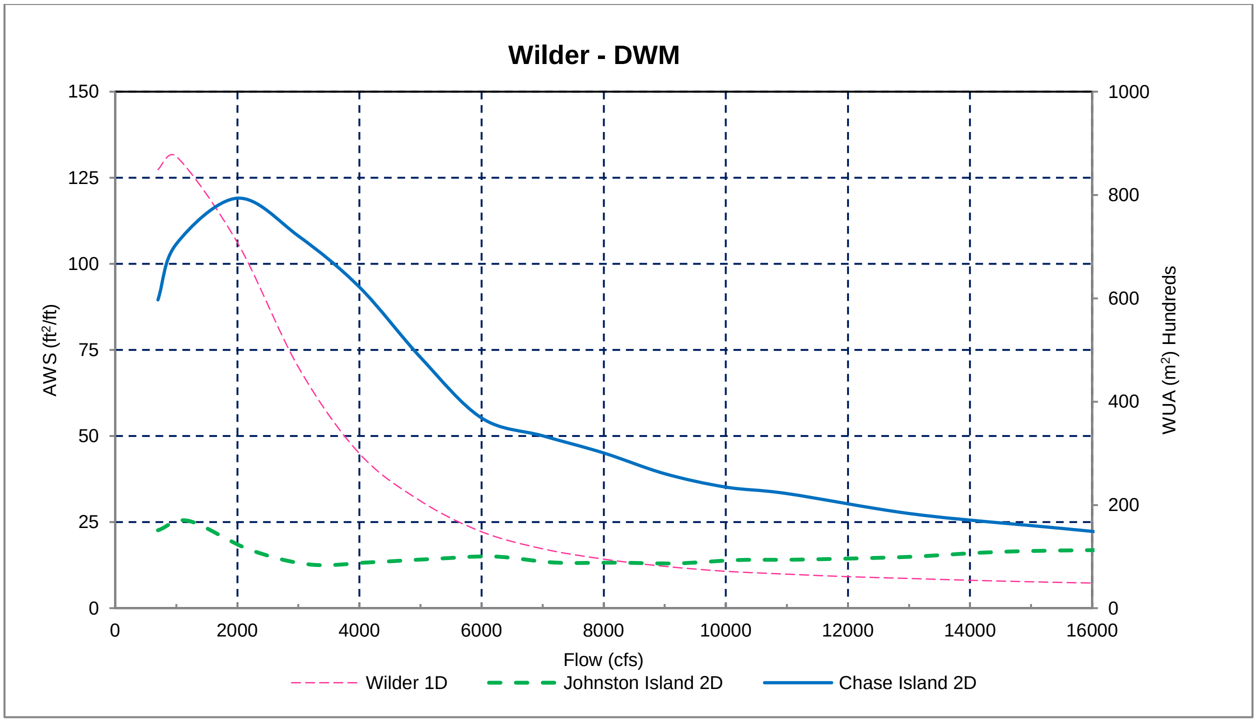


Figure 5.7-1. AWS results for DWM and co-occurring mussels in the Wilder and Bellows Falls reaches.



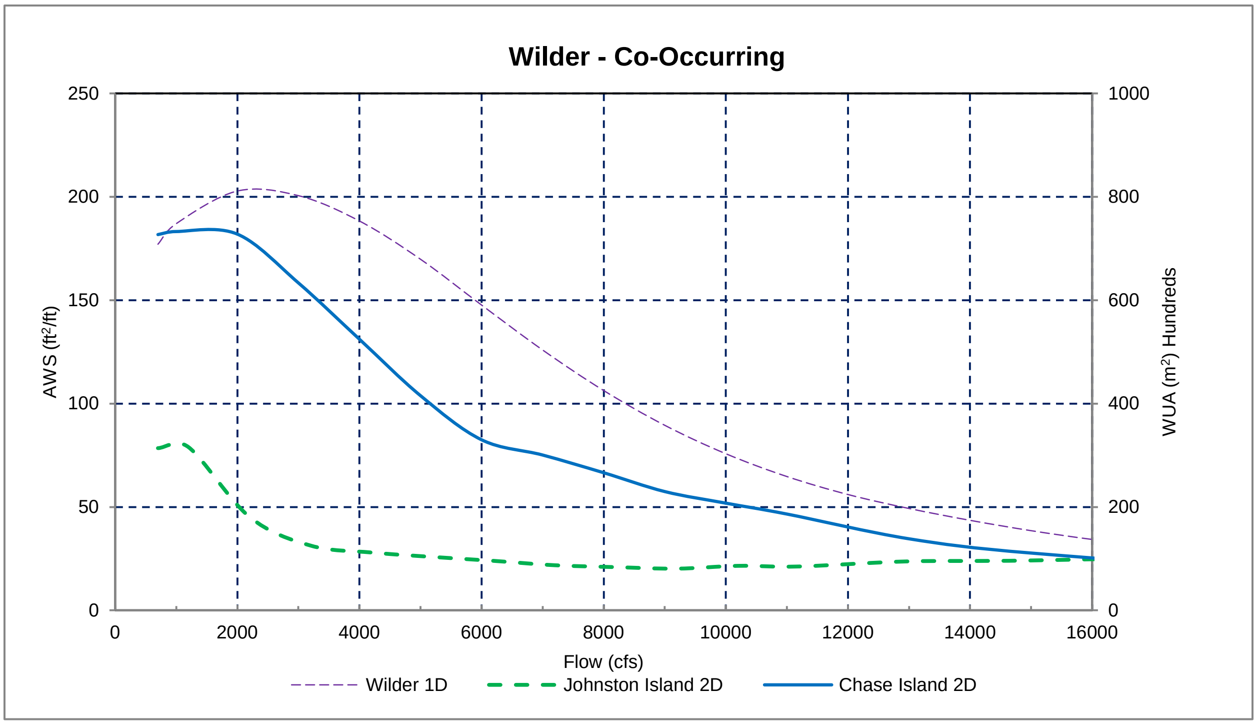


Figure 5.7-2. DWM and co-occurring mussels AWS results for the Wilder reach and WUA results for Johnston Island and Chase Island 2D sites.

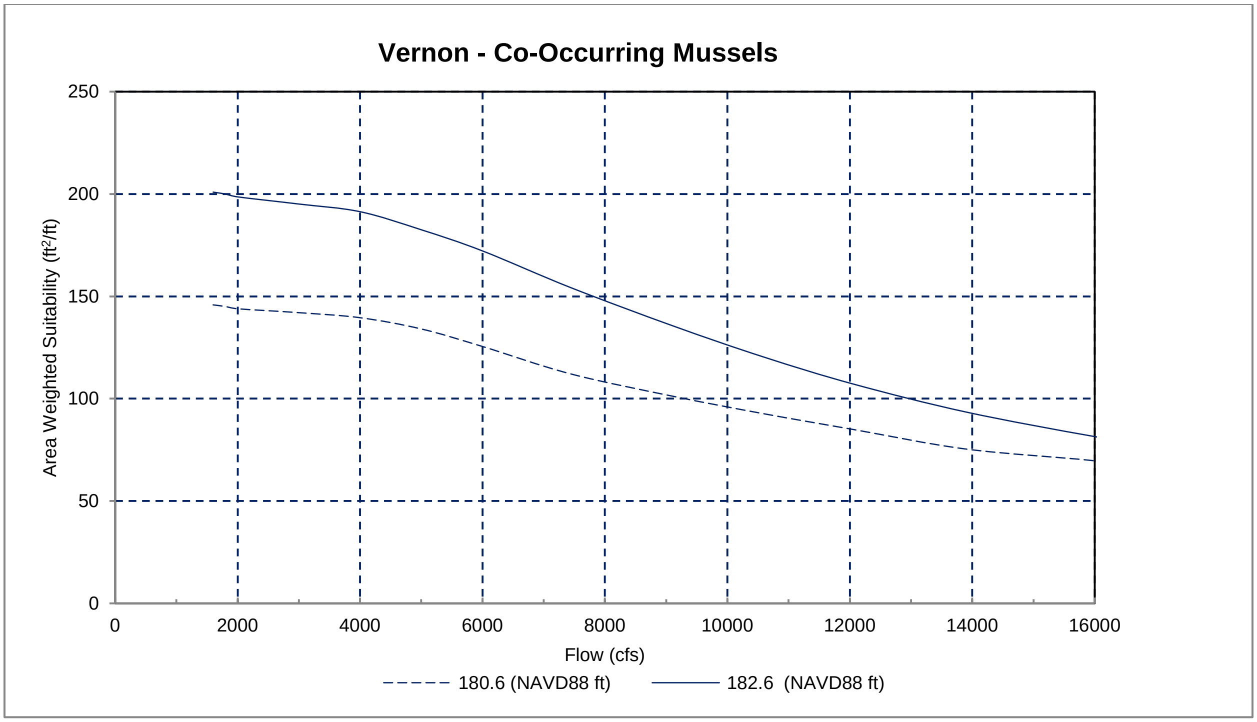


Figure 5.7-3. Co-occurring mussels AWS results for the Vernon reach at two Turners Falls dam WSE scenarios.

5.8 Sea Lamprey Spawning

During review of the FirstLight instream flow study (Gomez and Sullivan, and Kleinschmidt, 2016), FWS noted potential limitations of the current Sea Lamprey spawning HSC to large rivers (FWS comment letter filed with FERC on January 27, 2017). The FWS review suggested that the source information used to develop the proposed HSC was based on smaller channels that would not be expected to possess the same availability of larger substrate materials or deep water habitats as is present in the Connecticut River study area. FERC subsequently requested that FirstLight consider modifying their HSC using site-specific data collected in the Connecticut River. Consequently, TransCanada chose to compare the FirstLight HSC with Sea Lamprey spawning data collected in the three project riverine reaches.

Note that because flow fluctuations in the riverine reaches result in diurnal changes in lamprey nest depths, this comparative analysis of depth criteria should be viewed as approximate. In contrast, substrate composition is assumed to remain constant over the flow range controlled by TransCanada facilities during Sea Lamprey spawning. Also, water velocities over lamprey nests were not identified as a concern by FWS so this analysis is limited to HSC for spawning substrate and spawning depth only.

The dominant substrate observed both within and adjacent to 49 Sea Lamprey nests in the three reaches was visually assessed in the three project reaches in Study 16 – Sea lamprey Spawning Assessment (Normandeau, 2016b). The percentage of nests dominated by fines, gravel, and cobble was averaged between the within-nest and adjacent-nest data, normalized to a maximum value of 1.0 then compared to the proposed substrate HSC for spawning. As seen in Figure 5.8-1, the resulting values are highly similar, with the TransCanada data showing only slightly less suitability for larger substrate types. Consequently, we do not propose to modify the current substrate HSC.

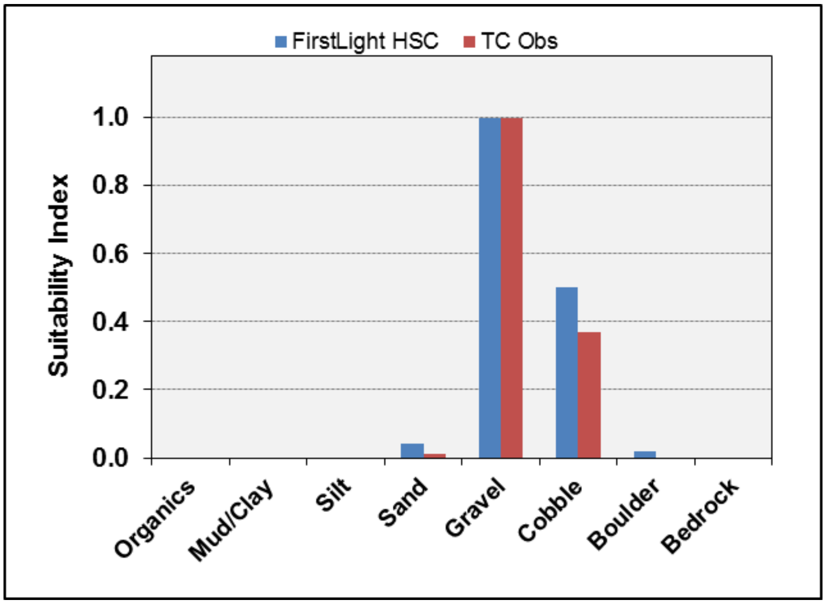


Figure 5.8-1. Dominant substrate composition at Sea Lamprey nests observed during TransCanada studies compared to HSC proposed by FirstLight.

The range of depths over Sea Lamprey nests observed in the three riverine reaches was assessed by evaluating depths at 56 observed nests based on modeled 2015 WSE data. The measured nest elevations were compared to predicted depths based on the nearest HEC-RAS cross-section node from Study 4 (GEI, 2016) or the average of two nodes for nests located between two nodes. Estimated WSEs were calculated over the May 15 to July 15, 2015 period to fully encompass the time when lamprey nest construction, egg incubation, and ammocoete emergence was expected to occur. Using estimated depths from the one-hour WSE data at each nest resulted in a total of about 83,000 estimated depths at the 56 lamprey nests. Use of the modeled WSE data allowed assessment of the range in depths experienced over time at each nest, rather than a snap-shot measurement of nest depth taken at a single point in time. Using the HEC-RAS WSEs produced a very similar distribution of depths to water level logger data (Figure 5.8-2).

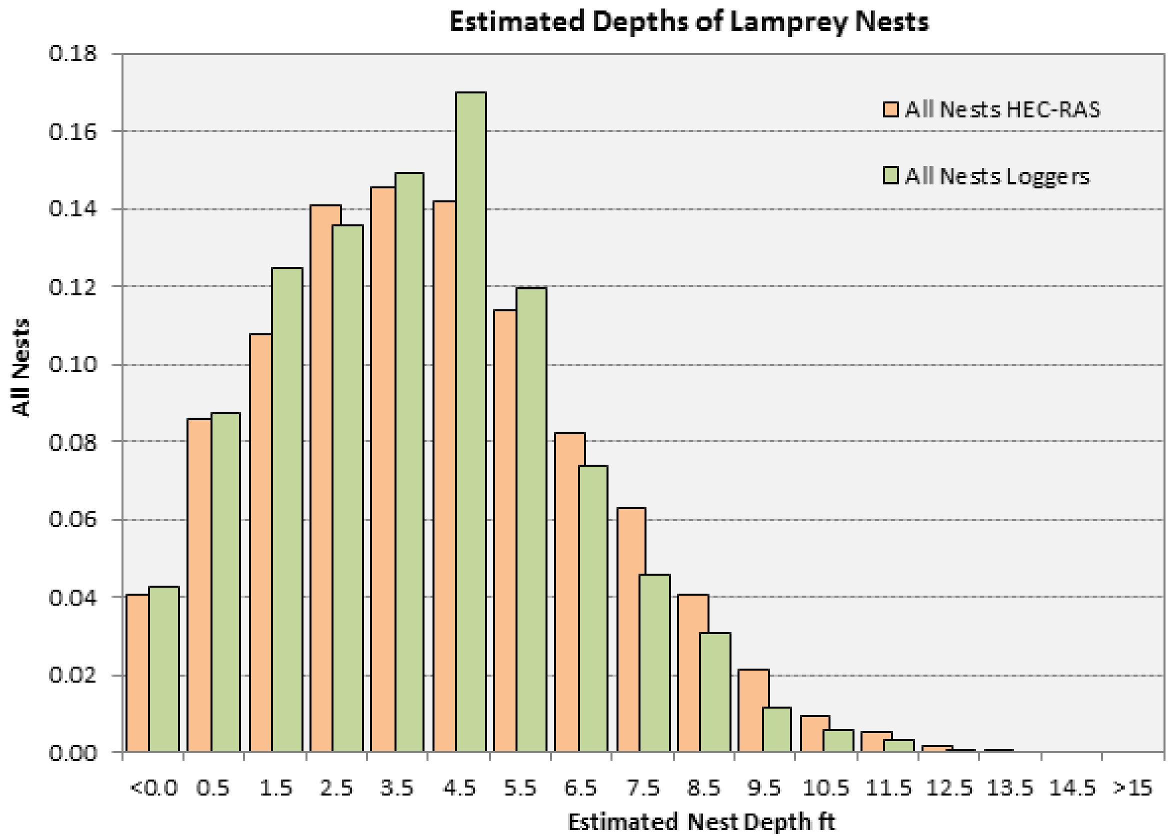


Figure 5.8-2. Frequency distribution of estimated depths at Sea Lamprey nests based on modeled WSE from May 15 - July 15, 2015 compared to depths measured by water level loggers.

A relative frequency distribution based on the estimated depths suggested that active lamprey nests experienced depths ranging from <0 ft (e.g., nests that were ultimately exposed) to just over 13 ft, with nests experiencing the greatest frequency of depths between 2 ft and 5 ft (Figure 5.8-3). Note that active spawning behavior (e.g., an adult lamprey on a nest) was observed at 11 nests, and those actual measured depths are also shown. Although most actual depths were in the 2-3 ft range, lamprey nests could not be easily seen in deeper water so the true distribution of nest depths during active nest construction is likely deeper than the 11 actual depth measurements shown, and could be similar to the estimated depths which peak slightly deeper than the measured depths.

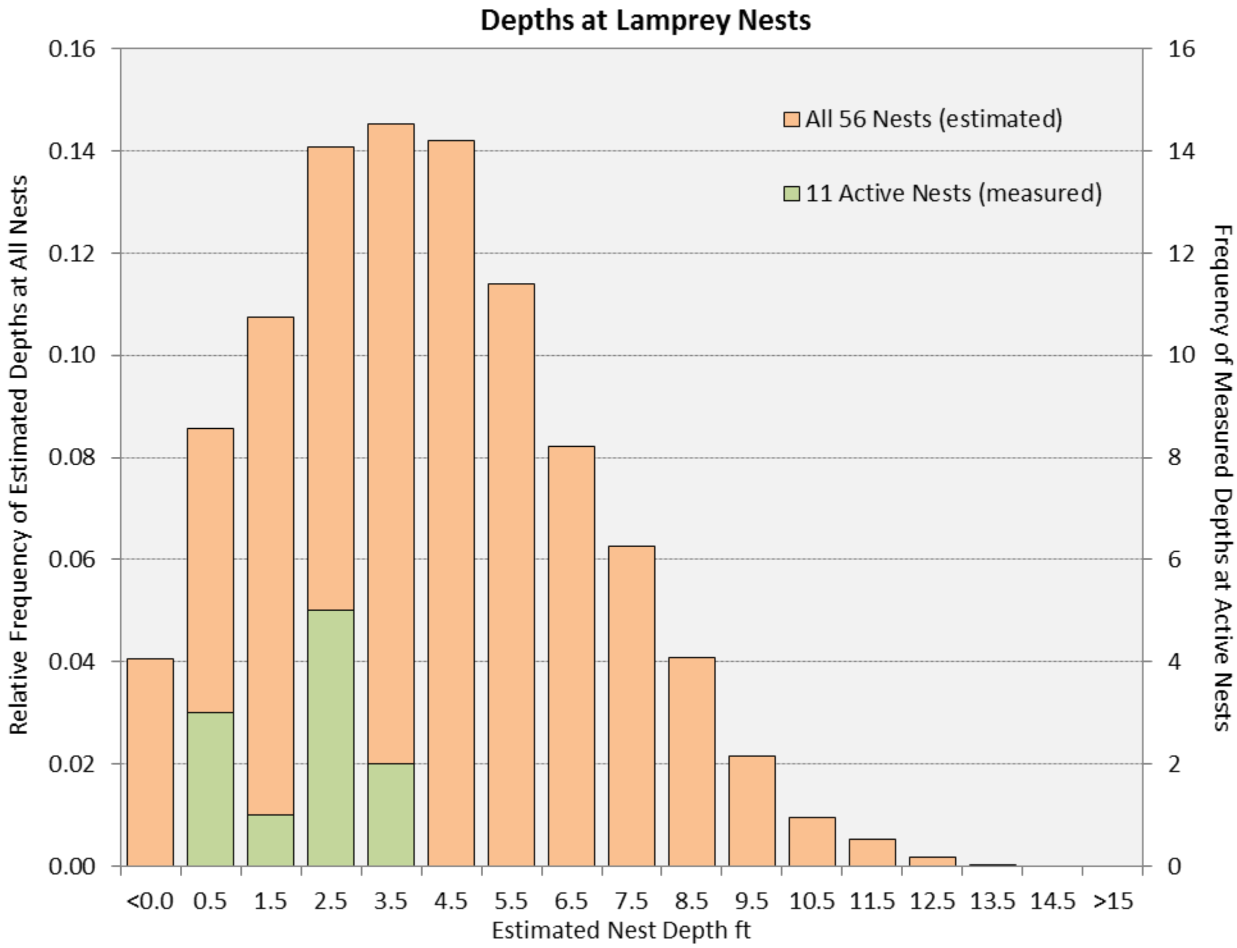


Figure 5.8-3. Frequency distribution of estimated depths at Sea Lamprey nests based on modeled WSE from May 15 - July 15, 2015 compared to depths measured at active nests when adults were present.

Comparison of this distribution to the FirstLight depth HSC suggests that Sea Lamprey in the three riverine reaches may spawn over a greater range of depths than indicated by the HSC (Figure 5.8-4). Consequently, an alternative depth HSC curve was developed by bracketing the FirstLight HSC curve with the predicted depths from the TransCanada observations and modeled WSE data. This produced a plateau of maximum suitability for spawning depths from 0.79-3.5 ft, declining to zero suitability at 13.5 ft. This proposed HSC curve incorporates the original HSC curve because that curve is assumed to be representative of actual depth measurements at active nests, and because the limited data on active nests in the Connecticut River also showed that nest construction occurred at depths <2 ft.

The original velocity and substrate HSC for Sea Lamprey spawning and the proposed modification for depth HSC are shown in Appendix A. An example of results based on the current and combined depth HSC for the Bellows Falls reach shows the dramatic difference caused by the change in depth suitability (Figure

5.8-5); however the combined depth HSC has not yet been evaluated and results have not been provided. Results will be updated pending agreement by stakeholders on curve modification.

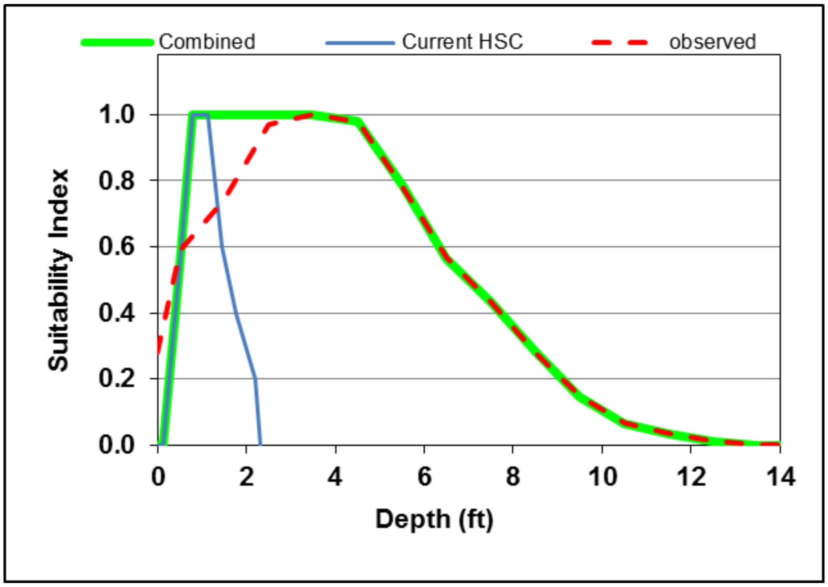


Figure 5.8-4. Comparison of estimated depths at Sea Lamprey nests observed during TransCanada studies compared to HSC proposed by FirstLight, with an alternative (combined) HSC curve.

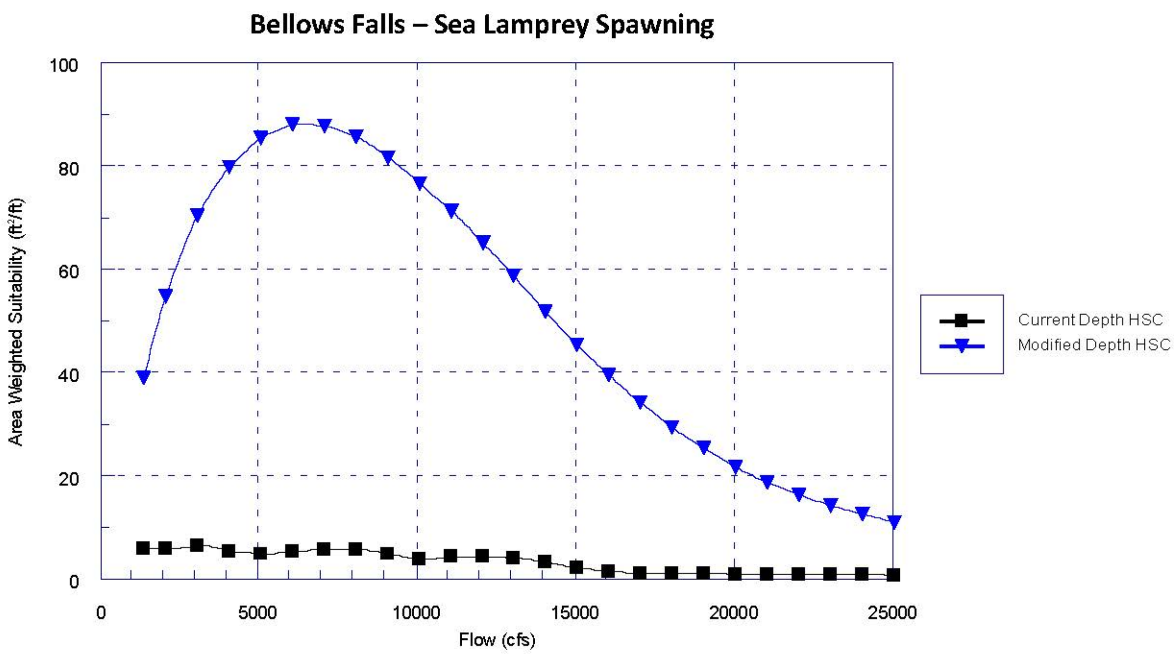


Figure 5.8-5. Comparison of AWS for Sea Lamprey spawning based on current depth and combined depth HSC.

6.0 ASSESSMENT OF PROJECT EFFECTS

Time series and dual flow analysis are tools used to assess project effects on aquatic resources. Hydrology developed from Study 5 - Operations Modeling Study (Hatch, 2016) was used in the time series analysis to address the effects of project operations on an annual and seasonal basis. As discussed above, the operations model used five annual inflow hydrologies generally corresponding to a progression from dry to wet years: 1992, 1994, 1989, 2007, and 1990, to produce five annual project operation simulations of station, dam and impoundment operations designated by the corresponding inflow years (1992 for example). The dual flow analysis provides information on potential project effects due to daily flow fluctuations between base or minimum flow and generation flows.

6.1 Habitat Time Series

The operations model divided the Wilder riverine segment into seven reaches between Wilder dam (Vista 1) and Chase Island (Vista 7) based on travel time of flow from the Wilder project, and to a lesser degree local inflow and tributary junctions (Figure 6.1-1). The Bellows Falls riverine reach was divided into two Vista reaches to account for flow travel time (Figure 6.1-2). The short riverine section below Vernon dam did not require any adjustments for flow travel time or accretion.

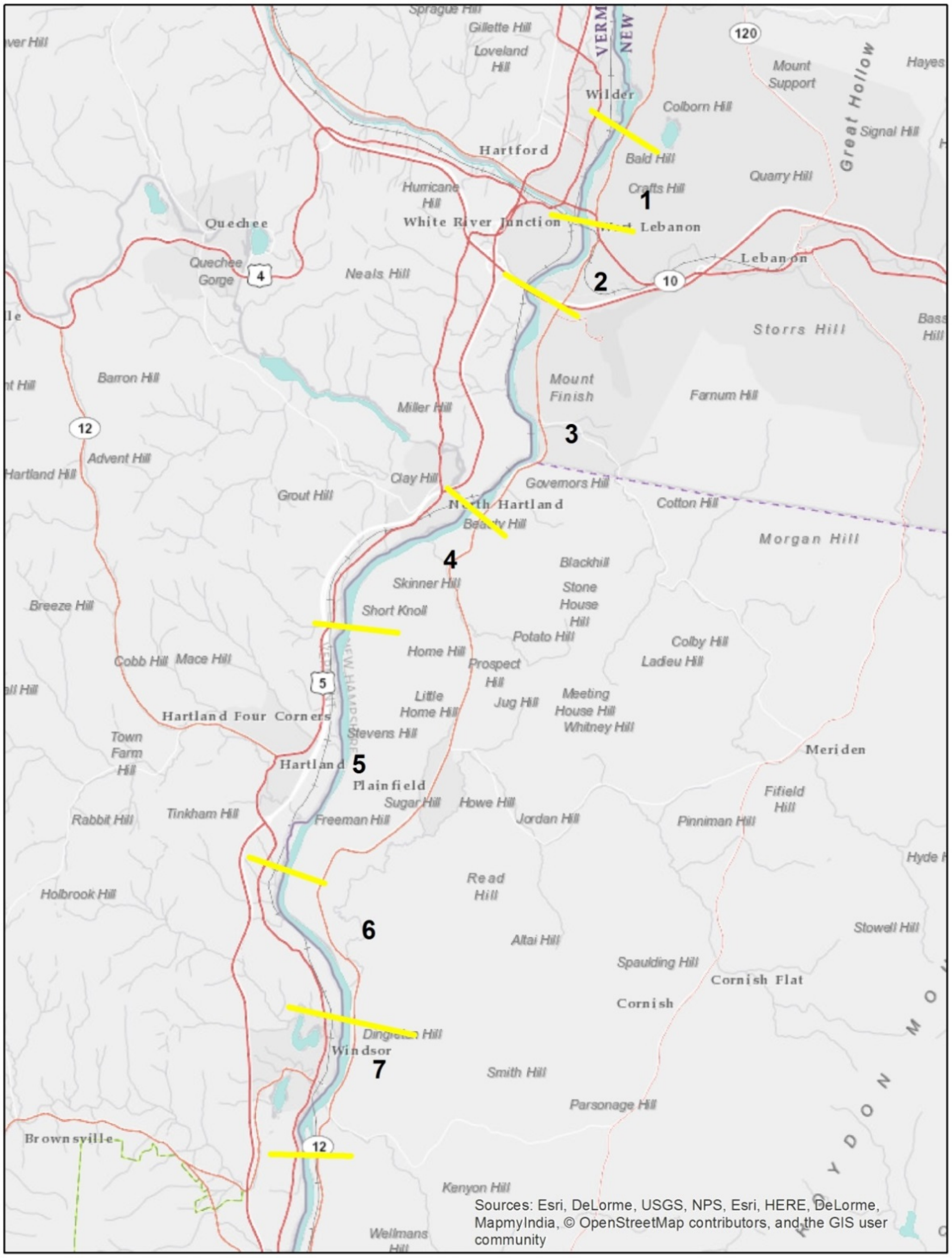


Figure 6.1-1. Operations model Vista reaches in Wilder riverine reach.

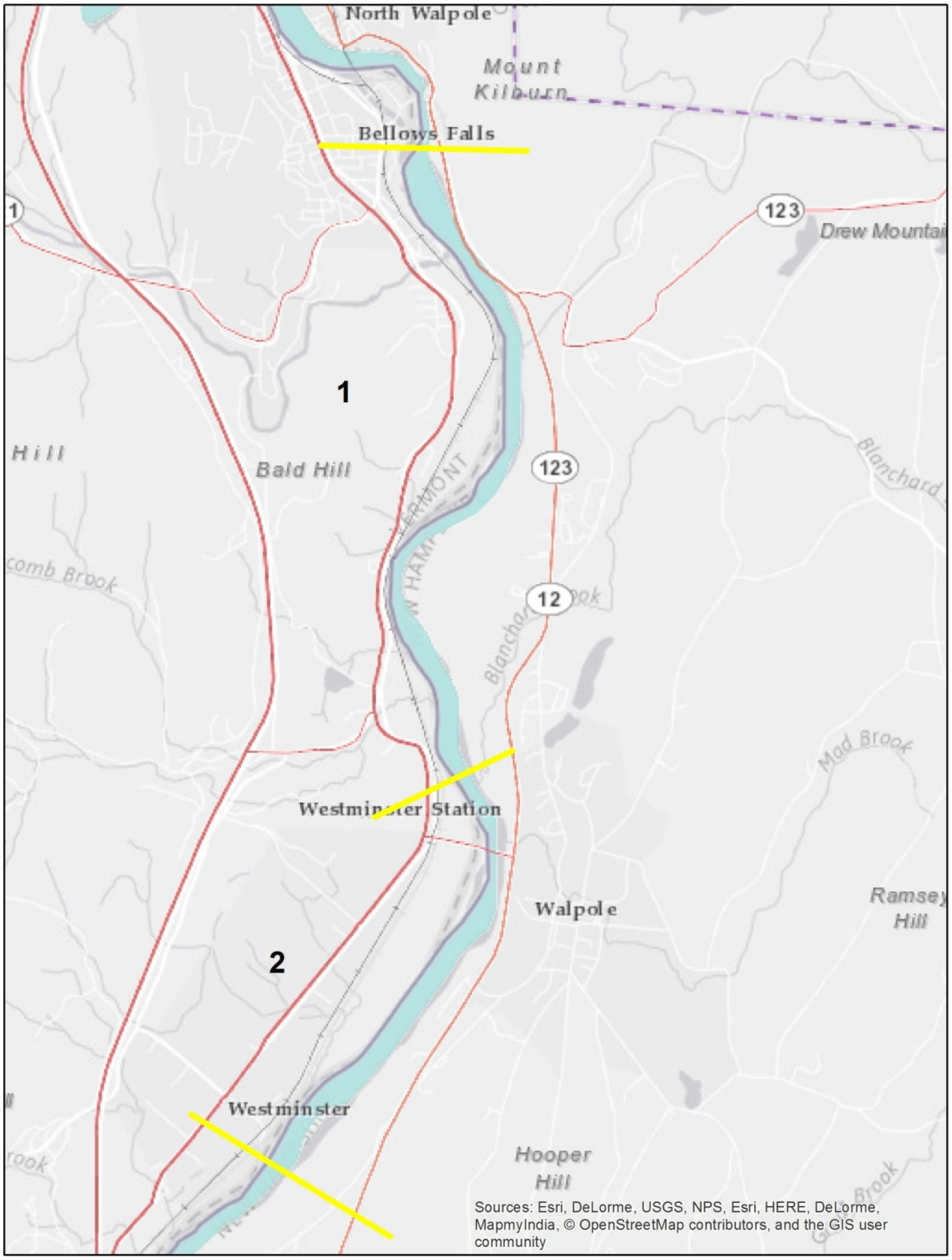


Figure 6.1-2. Operations model Vista reaches in Bellow Falls riverine reach.

6.1.1 Wilder

Flow Duration

Flow duration curves (1992 for example) for Vista reaches 1-5, which encompass the reaches where 1D transects were located, show the additive effect of local inflow (primarily at low flow) between Wilder dam (Vista 1) and Hart Island (Vista 5); (Figure 6.1.1-1). Flow duration curves by reach between the 5 modeled hydrologies are comparable for 1992 and 1994, and 1989 and 2007, with 1990 showing the least similarity (Figures 6.1.1-2 and 6.1.1-3). Vista reach 7 at Chase Island (Figure 6.1.1-4) shows identical flow duration to Vista reach 5 because no accretion due to tributaries was added to the model between the reaches. In fact, Vista reaches 2 and 3 have comparable flow duration curves as do Vista reaches 4 through 7 because accretion was only added to the model at White River and the Ottauquechee River.

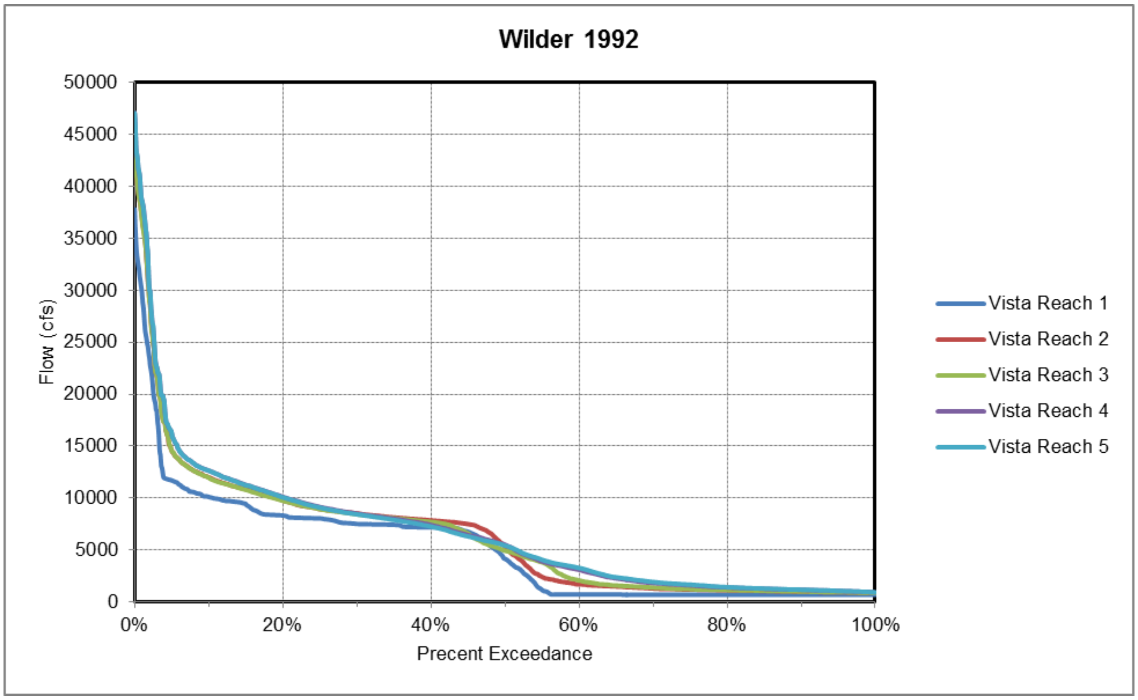


Figure 6.1.1-1. Flow duration for Wilder Vista reaches 1-5 for 1992 hydrology.

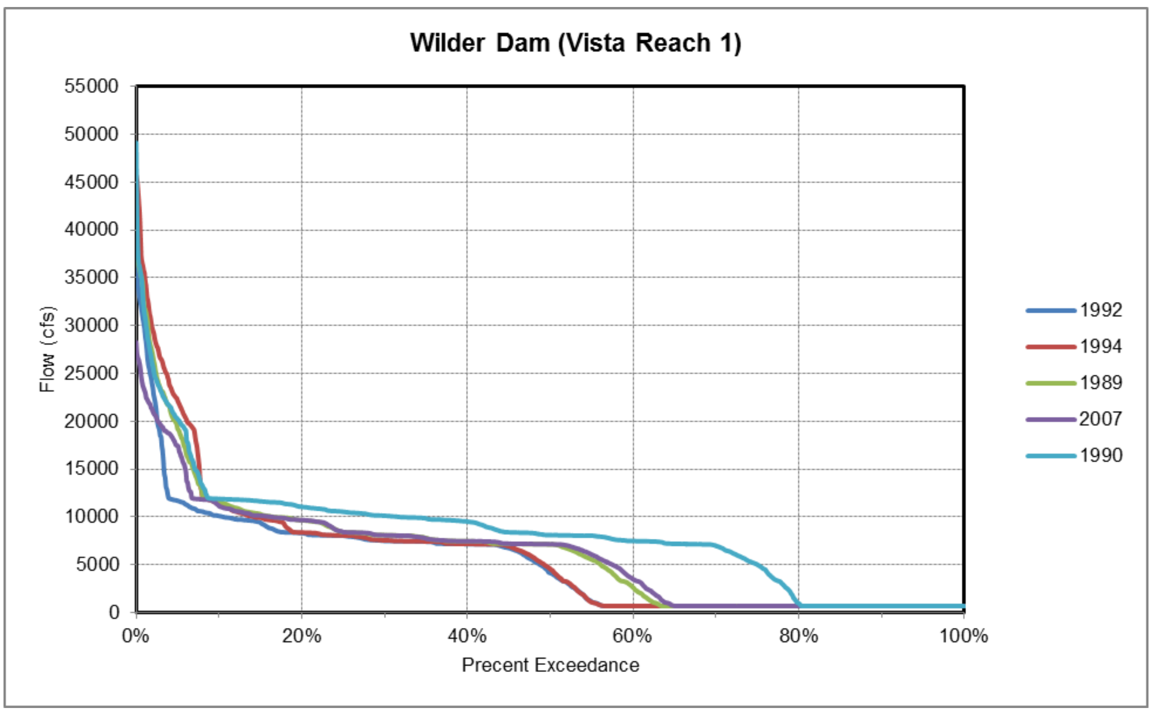


Figure 6.1.1-2. Flow duration for Wilder Dam (Vista reach 1) for 5 modeled hydrologies.

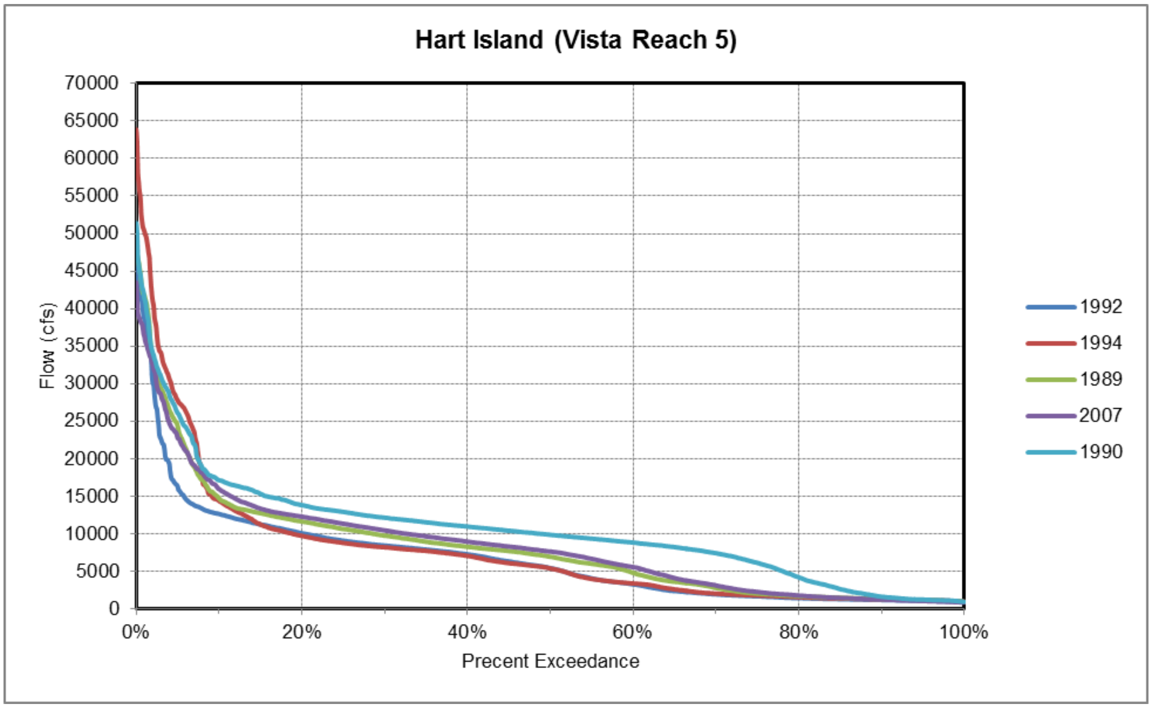


Figure 6.1.1-3. Flow duration for Vista reach 5 at Hart Island for 5 modeled hydrologies.

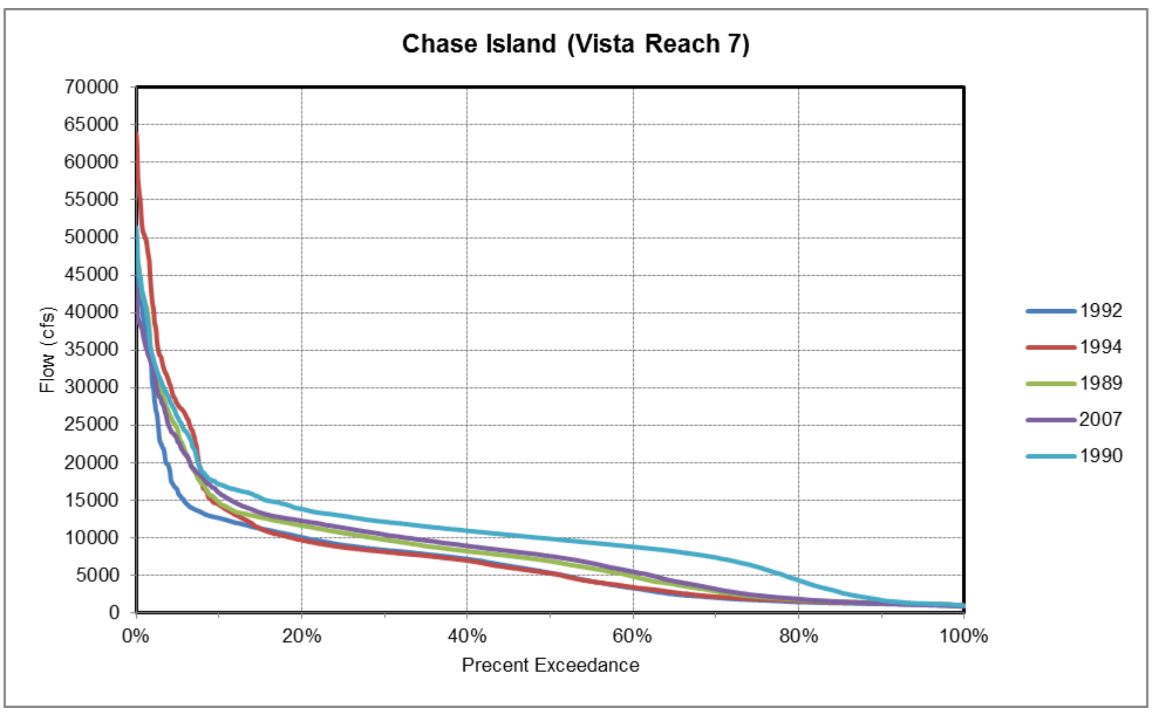


Figure 6.1.1-4. Flow duration for Vista reach 7 at Chase Island for 5 modeled hydrologies.

Habitat Duration

To account for variation in discharge due to accretion, AWS was calculated for only those 1D transects located within each of the five Vista reaches. Hourly time series run for the individual Vista reaches were then combined to represent the entire Wilder reach. Habitat duration for the Johnston Island 2D site and the Chase Island 2D site were based on flows in Vista reach 3 and Vista reach 7, respectively.

Interpretation of habitat duration curves requires examination of AWS or WUA flow versus habitat values from graphic or tabular output. For example, Walleye spawning has corresponding AWS values for flows between approximately 1,500 cfs and 6,000 cfs, and flows between 6,000 cfs and 15,000 cfs. Walleye juvenile on the other hand have no overlap of AWS with flow and show a steady downward progression with increasing flow (Figure 6.1.1-5).

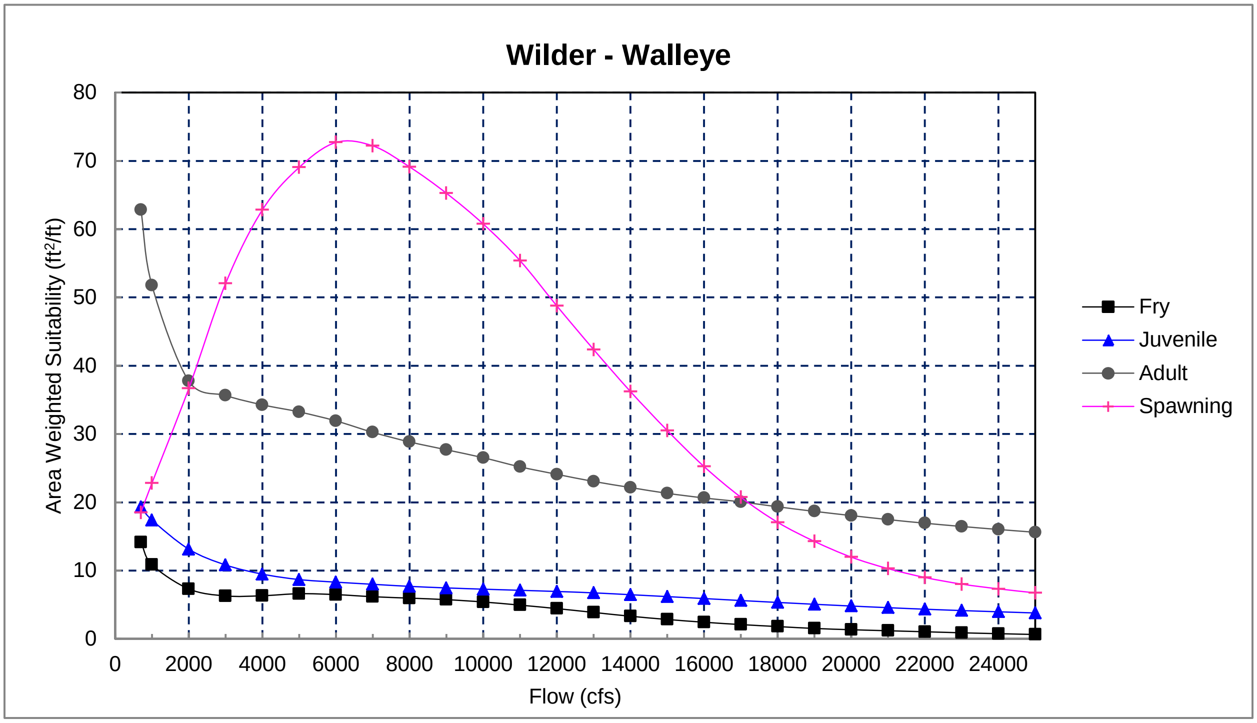


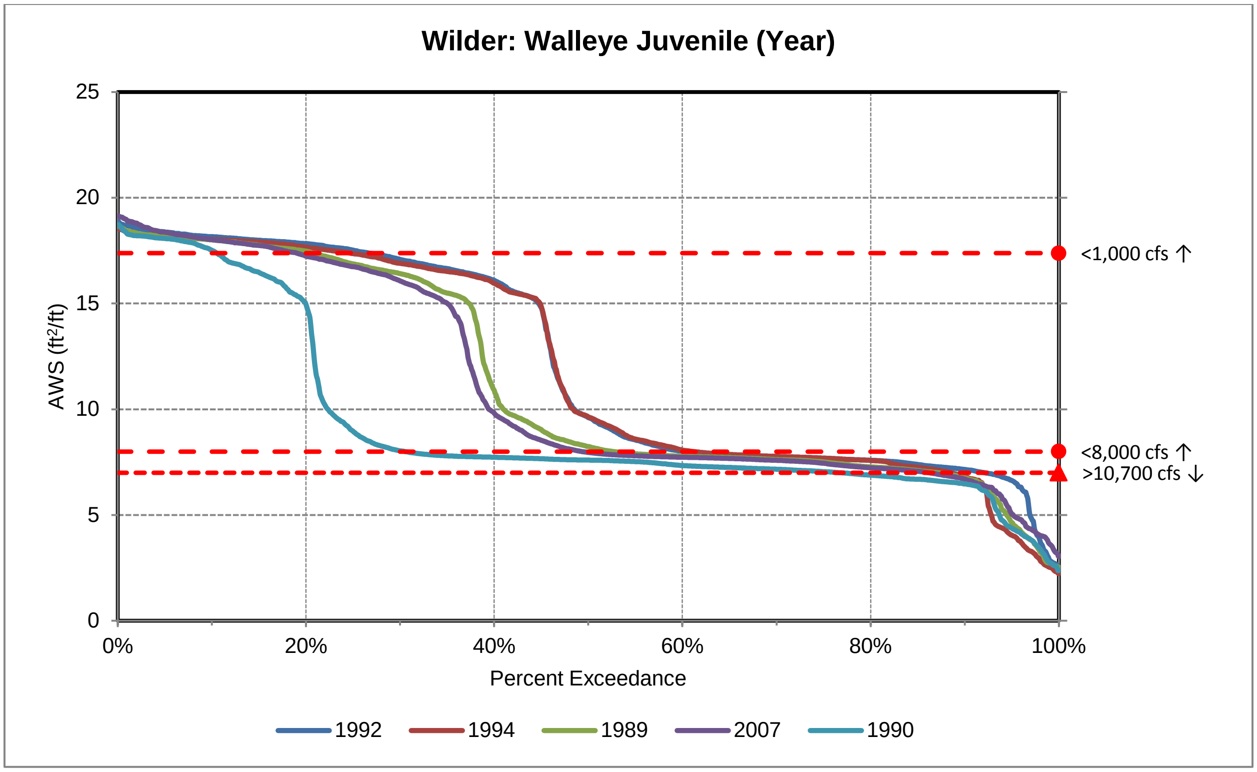
Figure 6.1.1-5. AWS for Walleye in the Wilder riverine reach.

When habitat duration curves are created the connection between AWS and flow is no longer obvious. In order to assist with interpretation, flow or flow ranges are denoted on habitat duration graphs or provided in tabular form next to the graph.

For example it can be ascertained from Figure 6.1.1-6 below that any AWS value greater than 30 ft^2/ft for Walleye spawning is attributed to flows between 1,500 and 15,000 cfs. If one were to view habitat duration for Walleye spawning without the connection between flow and AWS, there would be no way of equating habitat exceedance between 0% and 60% for 1990 (AWS values above the 1,500-15,000 cfs red dashed line) to this range of flows nor would we associate 0% to 40% exceedance to a narrower flow range between 4,000 and 11,000 cfs which falls within operational constraints (Figure 6.1.1-6). Walleye juvenile habitat duration is more succinct with the highest AWS values derived from flows less than 1,000 cfs, values exceeded less than 20% of the time, and the lowest AWS values due to flows greater than project capacity (e.g., 10,700 cfs, identified by a red triangle for clarity) which occur about 10% of the time (Figure 6.1.1-6).

Habitat duration results based on CR transects are similar to those based on all transects (Figure 6.1.1-7) though the AWS values are doubled for Walleye spawning and less than half for Walleye juvenile, a function of predominantly shallow water habitat represented by the CR transects. A similar result is shown for Longnose Dace adult, a shallow-fast water species, where the CR AWS is double that using all transects, though the resulting percent exceedance curves are nearly identical (Figure 6.1.1-8).

Habitat Duration for most species and life stages for the Johnston Island and Chase Island 2D sites generally mirrors the Wilder 1D reach as a whole. There are a few exceptions, notably for Walleye juvenile at the Johnston Island site (Figure 6.1.1-9). The WUA vs flow relationship, shown in tabular form on the graph, is relatively flat and the highest values are attributed to flows above project capacity. On the other hand, the habitat duration for Walleye juvenile at the Chase Island 2D site is similar to the Wilder 1D reach where the highest habitat values are due to low flows (Figure 6.1.1-10). Duration curves and percent exceedance are nearly identical for Walleye spawning for Wilder 1D reaches and 2D sites (Figures 6.1.1-6, 6.1.1-7, and 6.1.1-9, 6.1.1-10) because high spring flows extend throughout the Wilder riverine section during the spawning season and there is little project flow control.



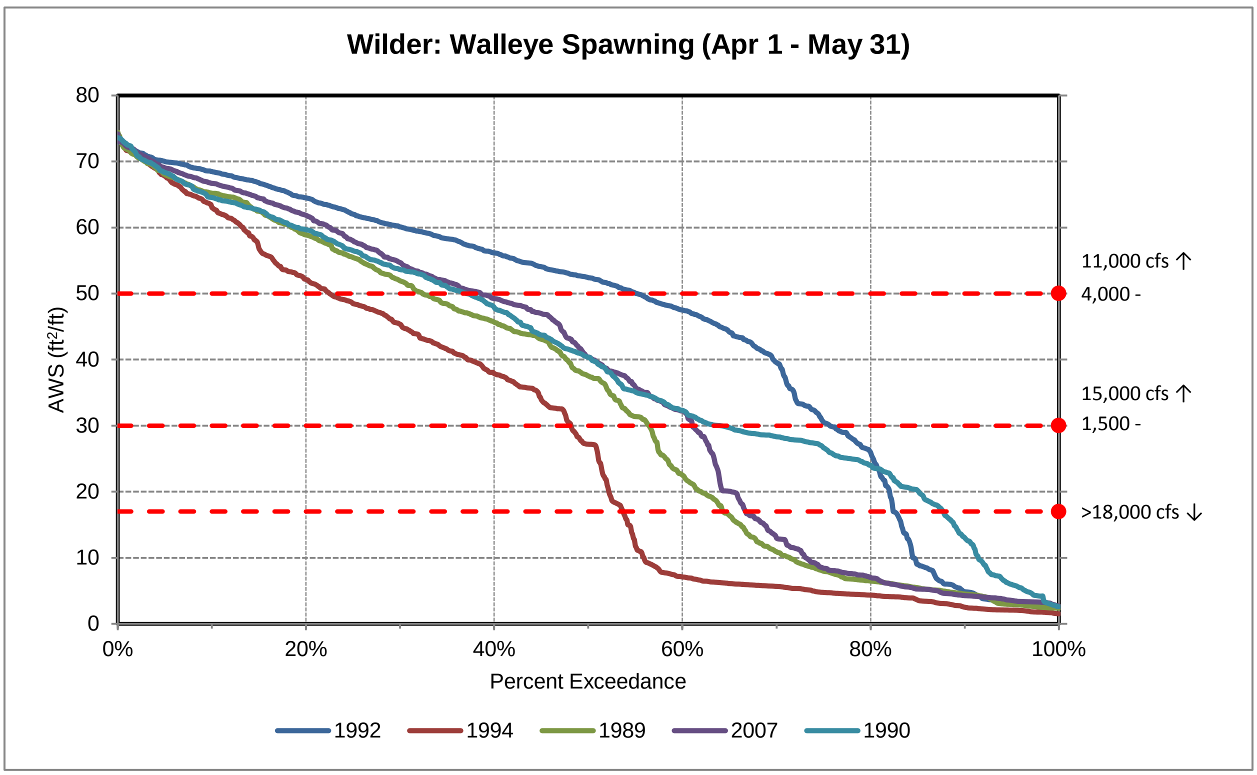
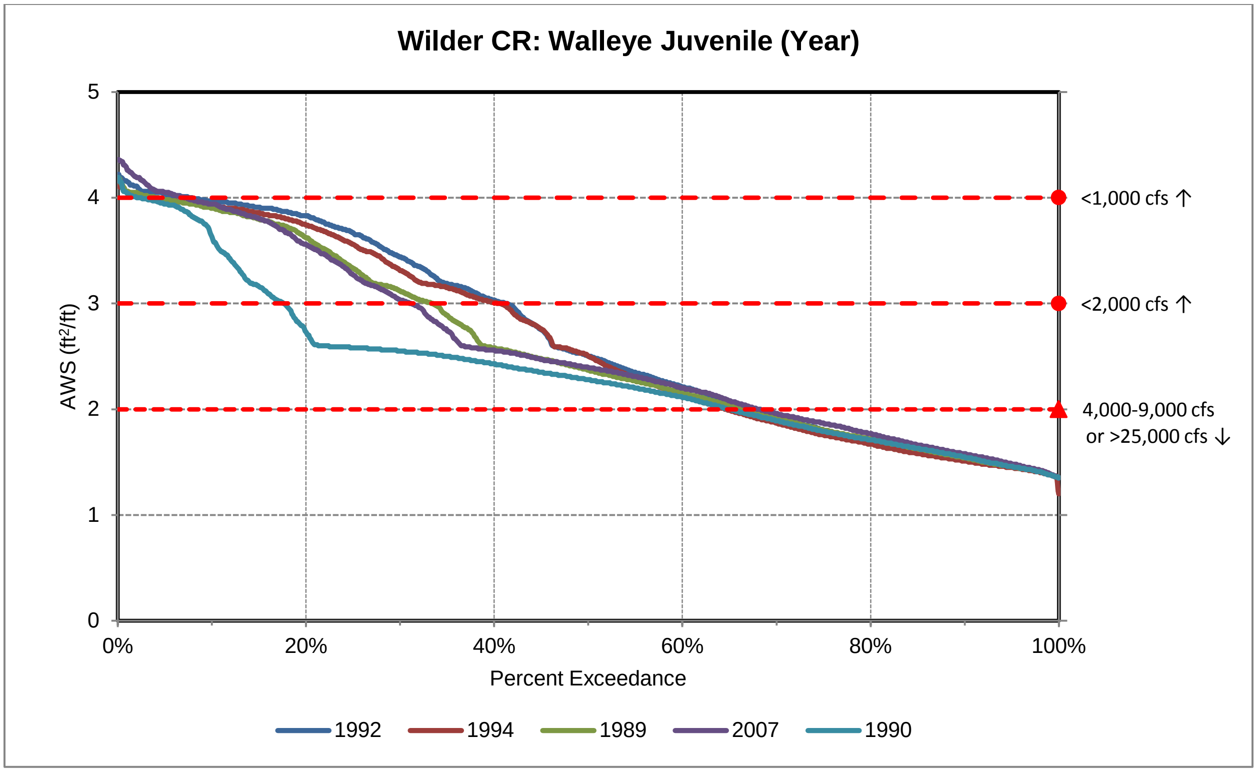


Figure 6.1.1-6. Wilder Walleye spawning and juvenile AWS habitat duration and associated flow levels.



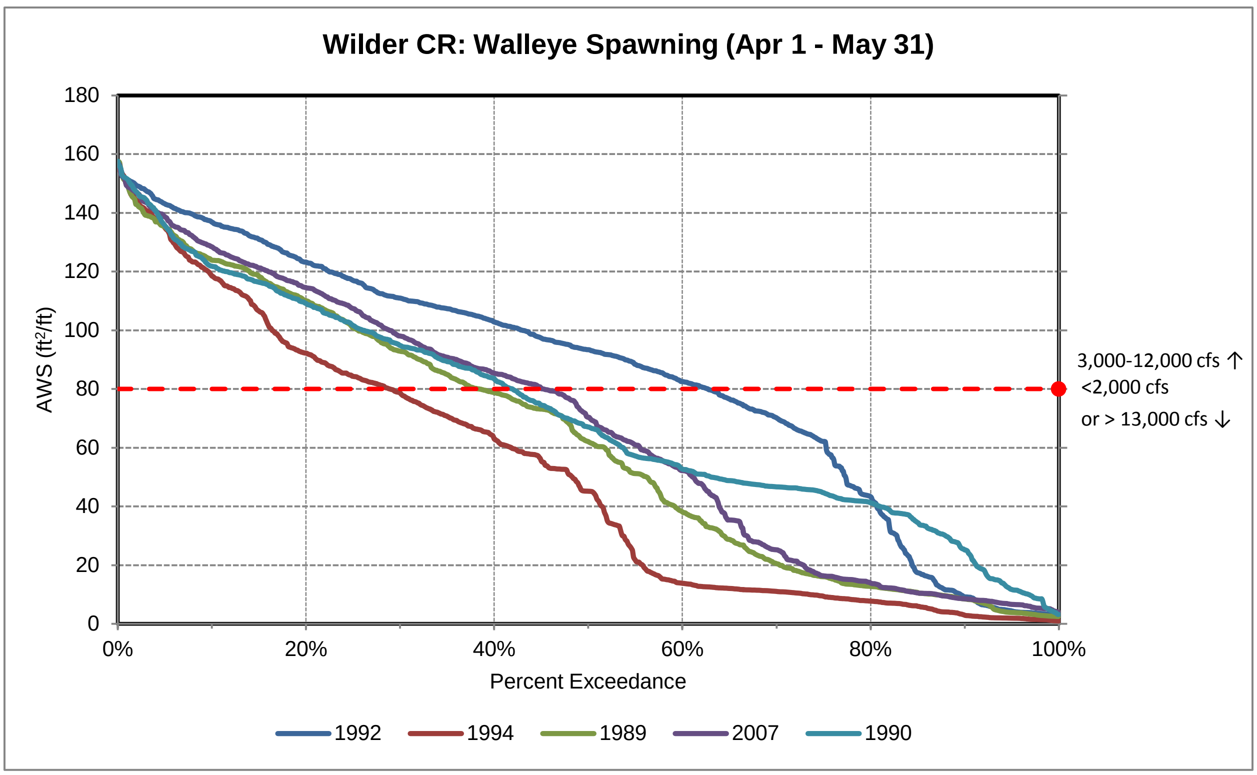
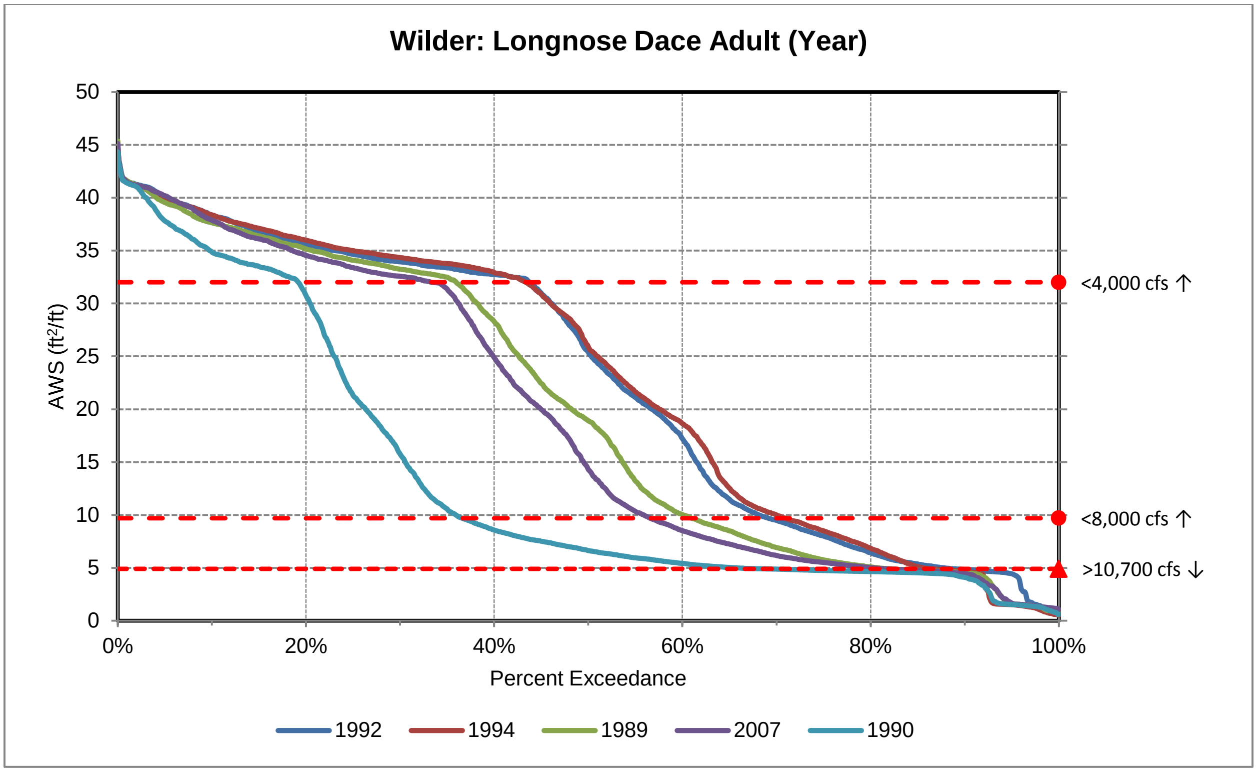


Figure 6.1.1-7. Wilder CR Walleye juvenile and spawning AWS habitat duration and associated flow levels.



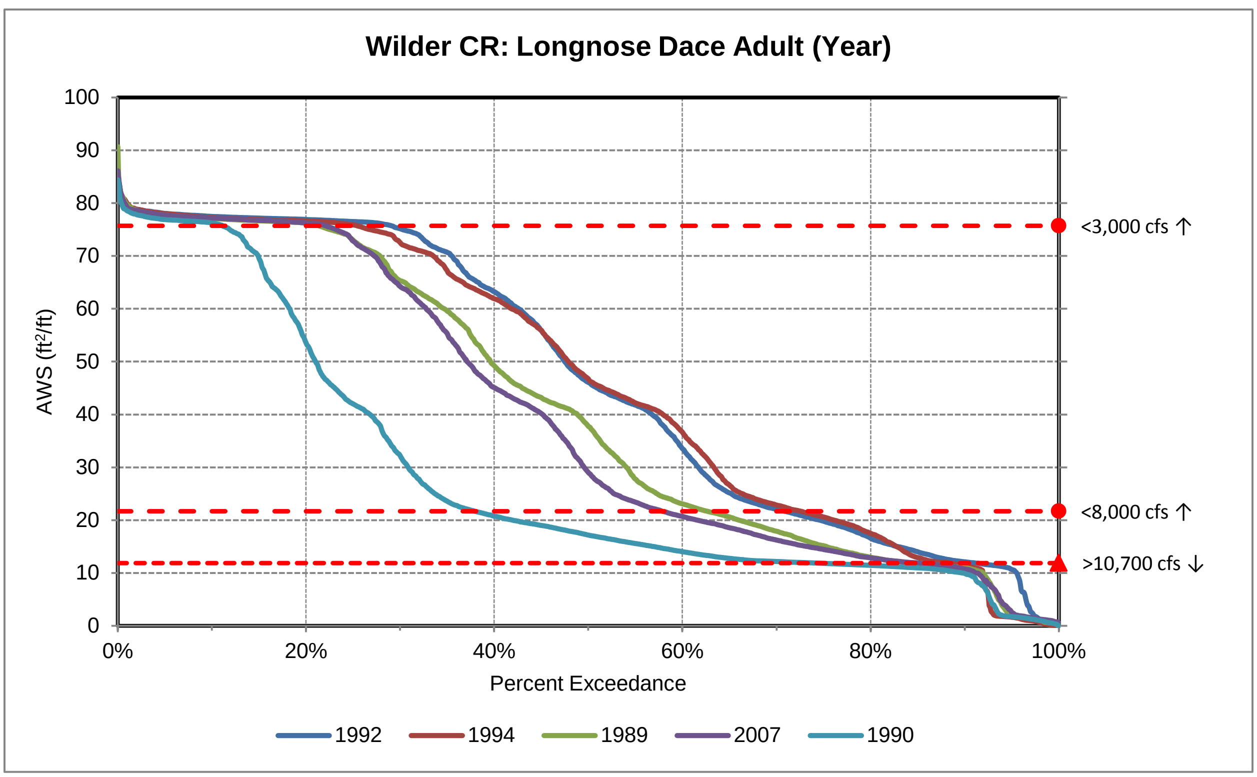
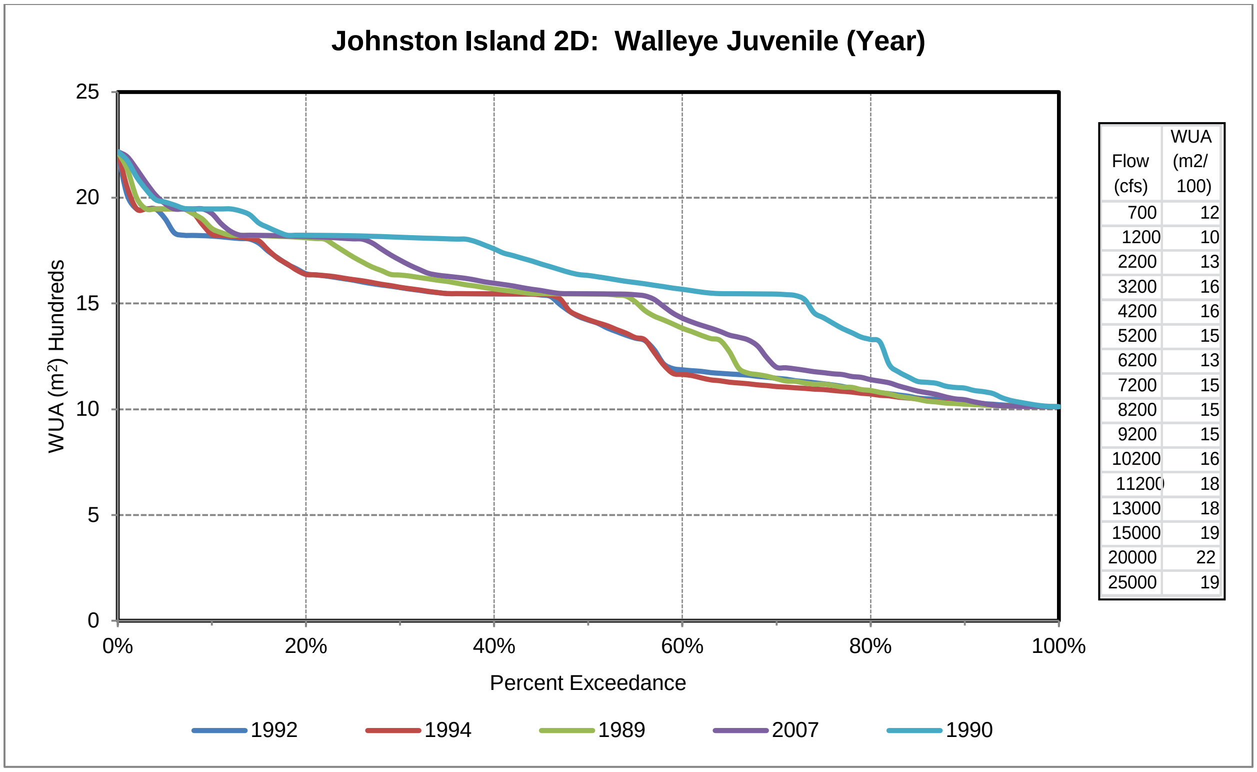
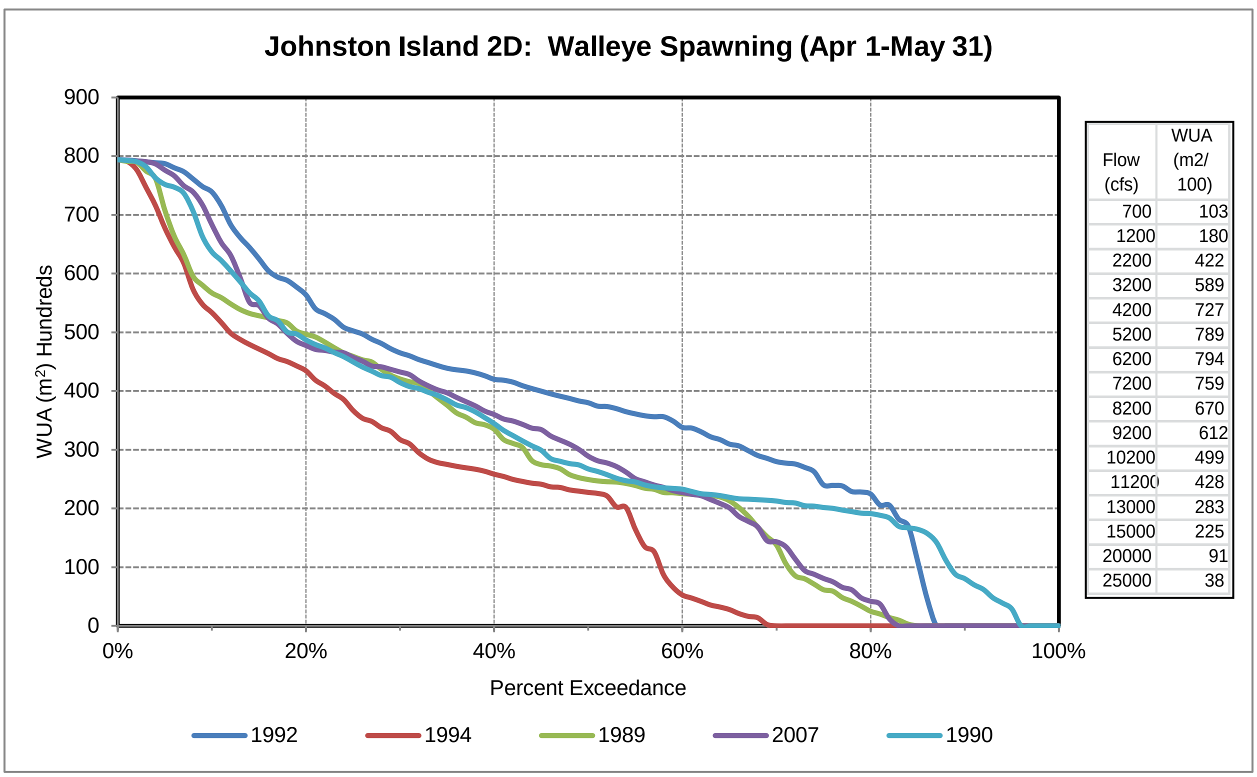


Figure 6.1.1-8. Wilder all transects and Wilder CR transects for Longnose Dace adult AWS habitat duration and associated flow levels.

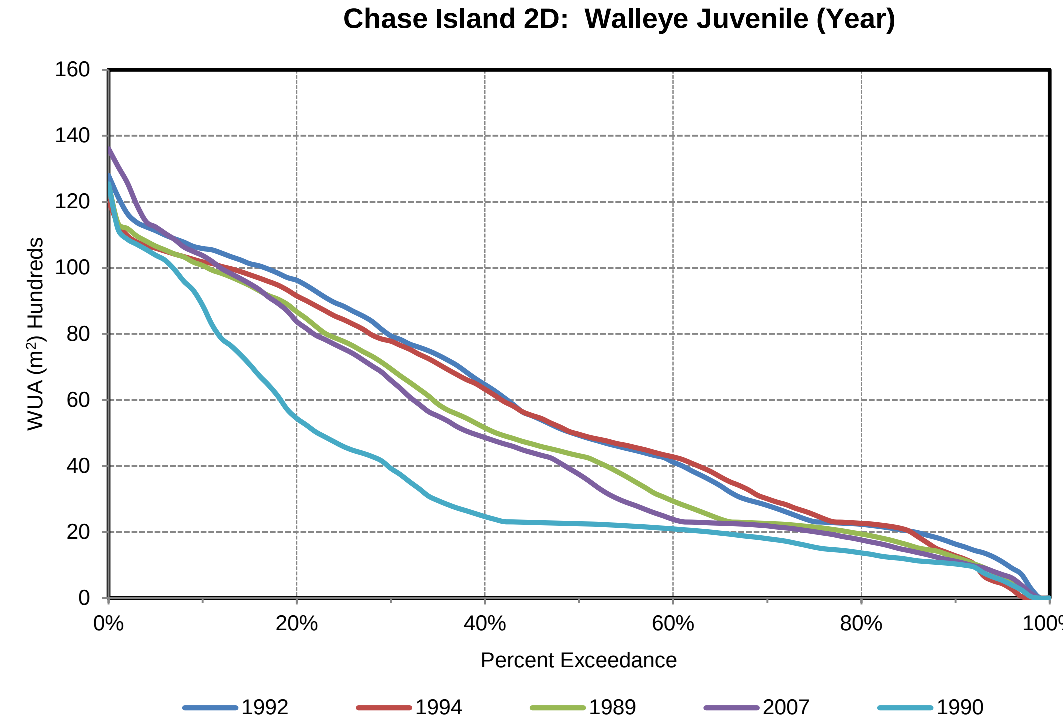


Flow (cfs)	WUA (m2/ 100)
700	12
1200	10
2200	13
3200	16
4200	16
5200	15
6200	13
7200	15
8200	15
9200	15
10200	16
11200	18
13000	18
15000	19
20000	22
25000	19

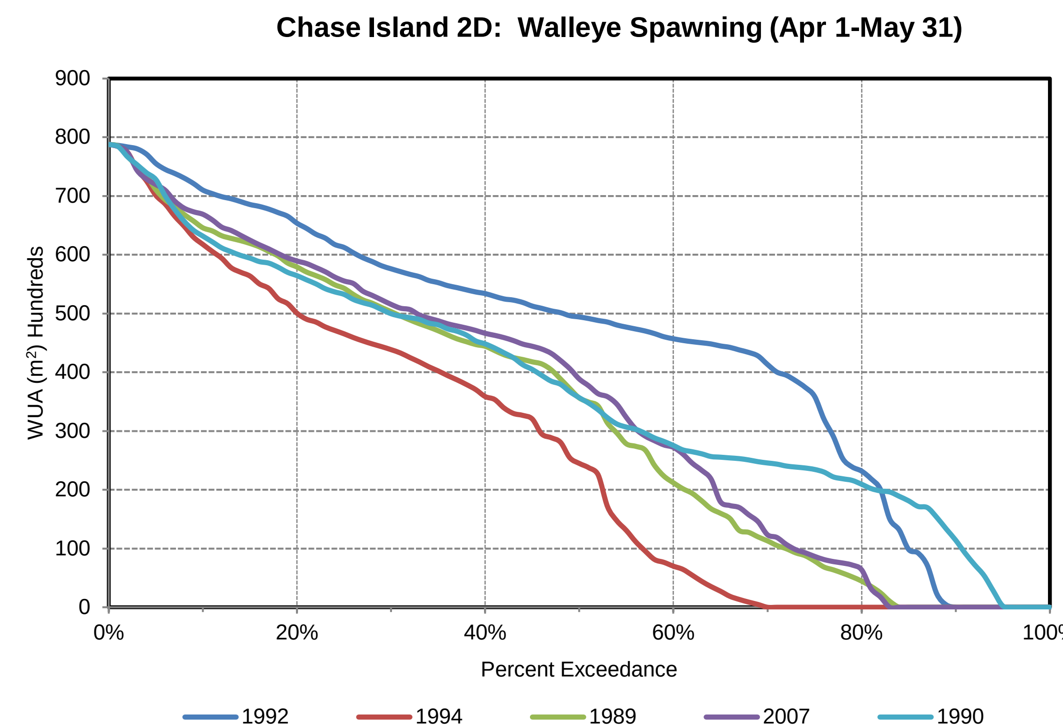


Flow (cfs)	WUA (m2/ 100)
700	103
1200	180
2200	422
3200	589
4200	727
5200	789
6200	794
7200	759
8200	670
9200	612
10200	499
11200	428
13000	283
15000	225
20000	91
25000	38

Figure 6.1.1-9. Johnston Island 2D Walleye juvenile and spawning WUA habitat duration and flow/WUA table.



Flow (cfs)	WUA (m2/ 100)
700	142
1000	114
2000	80
3000	68
4000	56
5000	51
6000	46
7000	43
8000	31
9000	23
10000	22
11000	21
13000	15
15000	12
20000	9
25000	6



Flow (cfs)	WUA (m2/ 100)
700	234
1000	317
2000	480
3000	609
4000	710
5000	780
6000	788
7000	759
8000	710
9000	657
10000	596
11000	543
13000	437
15000	301
20000	134
25000	63

Figure 6.1.1-10. Chase Island 2D Walleye juvenile and spawning WUA habitat duration and flow/WUA table.

Habitat duration curves for Wilder based on all transects, CR transects and 2D sites, including seasonal habitat duration for year-round life stages and GHC, can be found in Appendices G and H. In general for year-round aquatic life stages the hydrologies for 1992/1994 provides the highest AWS for the longest period of time and 1990 provides the least. For spring fry and spawning life stages, the 1992 hydrology provides the greatest amount of habitat and 1989/1990 the least. These differences are due to the seasonal and annual hydrologic variation between the five modeled hydrologies.

6.1.2 Bellows Falls

Flow Duration

In the operations model, the Bellows Falls riverine segment is separated into 2 Vista reaches between Bellows Falls dam and Dunshee Island, with the break occurring between transects BF16 and BF17. Even though major accretion occurs near the upper end of the reach between transects BF4 and BF9 (from the Saxtons River and Cold River) it is accounted for in the first hour of travel time within the operations model, which extends farther downstream. Flow duration curves for Bellows Falls dam (Figure 6.1.2-1) and Dunshee Island (Figure 6.1.2-2) show the effect of local inflow, which, similar to Wilder, is primarily attenuation of low flows.

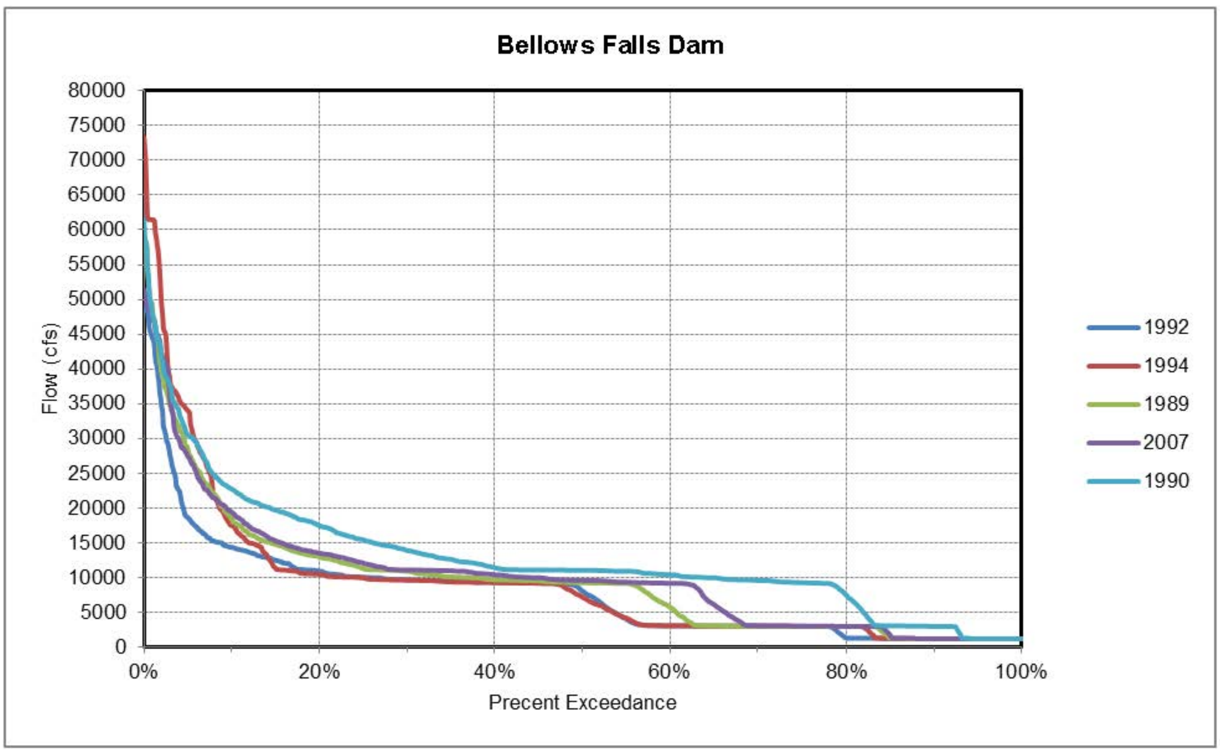


Figure 6.1.2-1. Flow duration at Bellows Falls dam for 5 modeled hydrologies.

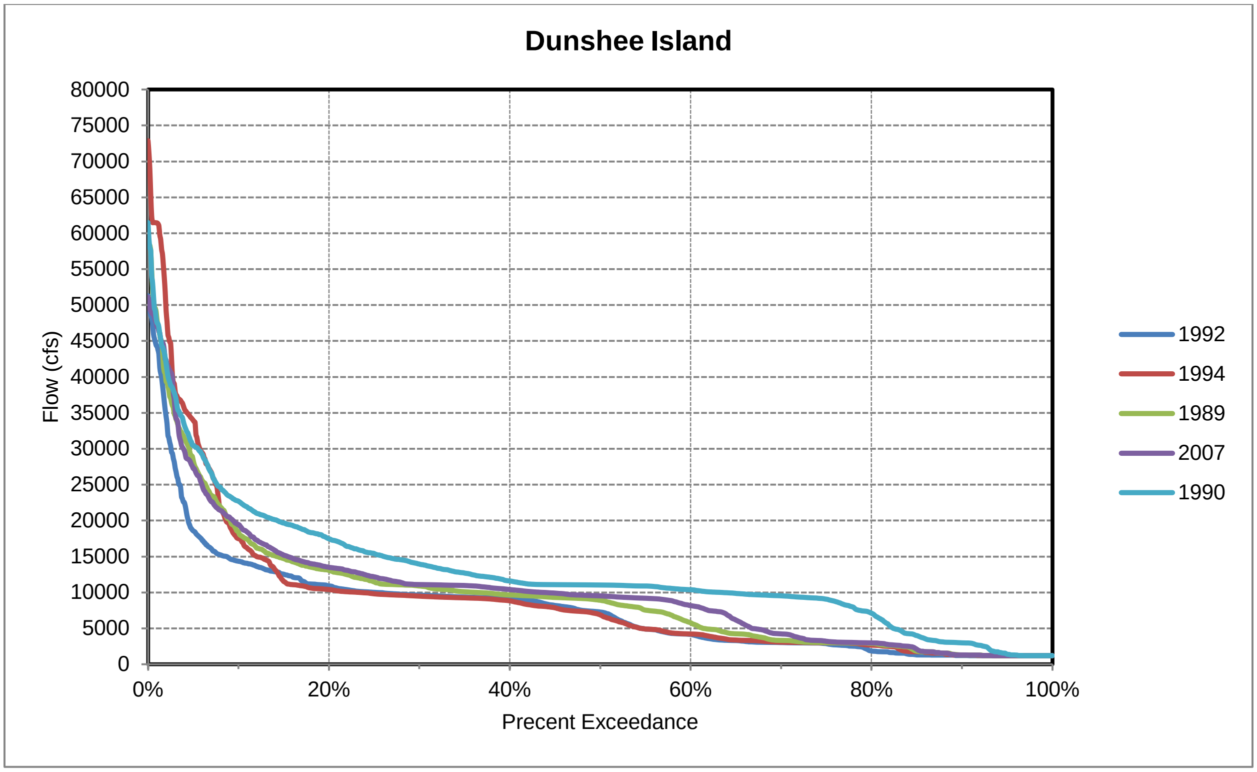
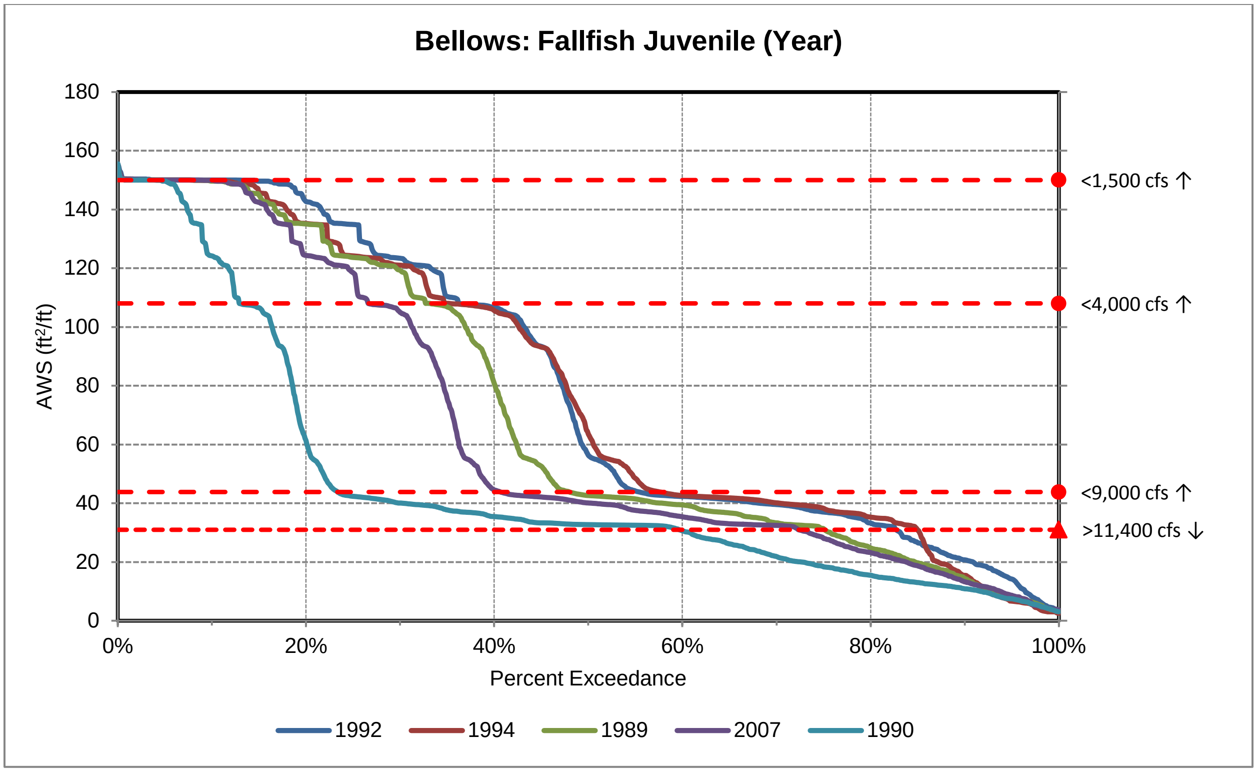


Figure 6.1.2-2. Flow duration at Dunshee Island, bottom of the Bellows Falls reach, for 5 modeled hydrologies.

Habitat Duration

The most noticeable feature of the Bellows Falls habitat duration curves are the identifiable steps, particularly for the CR transect analysis (Figure 6.1.2-3). This is primarily due to distinct flow levels that occur in the reach as part of the Bellows Falls operations. The well-defined steps in the CR analysis are a result of: 1) all CR transects being located in the section of the reach where the operations model produced distinct flow levels (Figure 6.1.2-1); and 2) the three transects included in the total reach analysis and not part of the CR assessment (BF17-BF19), account for 24% of the reach by weight and the flows in this reach (Figure 6.1.2-2) show less distinguishable steps (flow levels).

Similar to the Wilder reach, comparison of the habitat duration based on all transects versus CR transects are similar, though the AWS values can be quite different depending on the preferred habitat of a given species or life stage (Figures 6.1.2-4 and 6.1.2-5). For example, Sea Lamprey prefer shallow-fast habitat for spawning, which is representative of the CR transects.



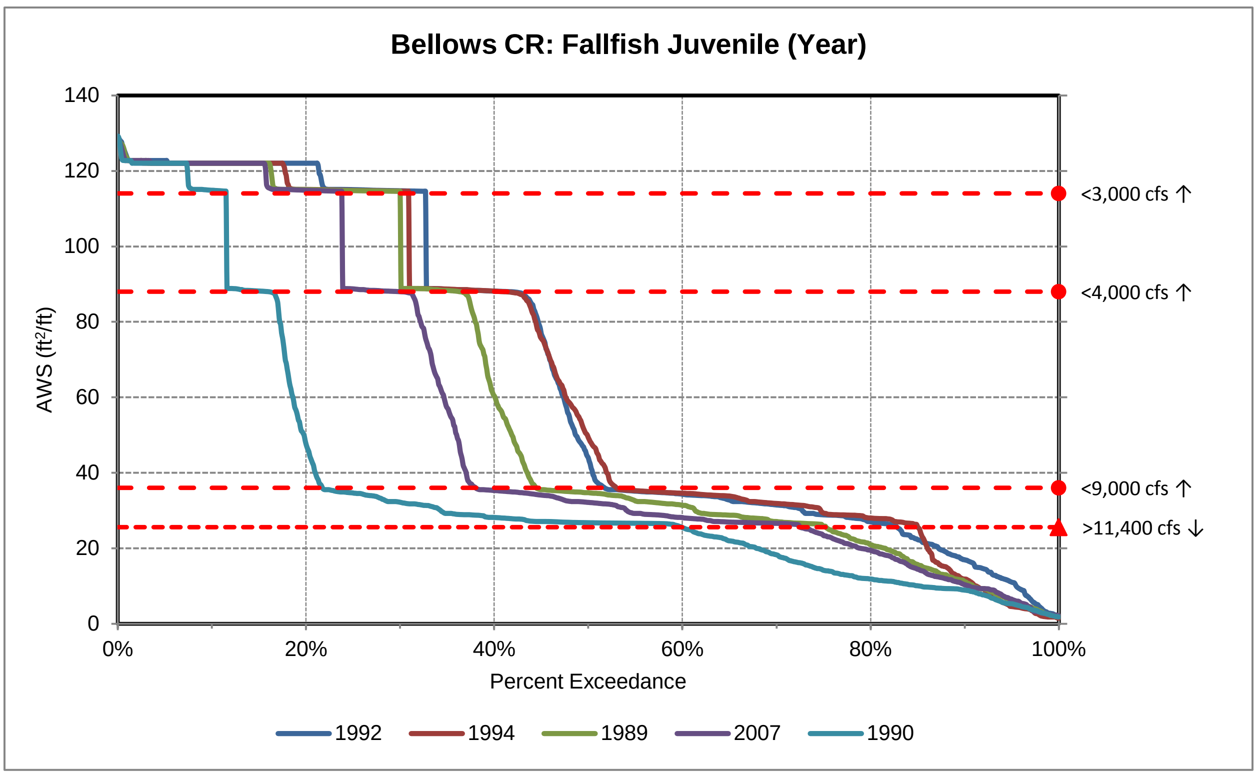
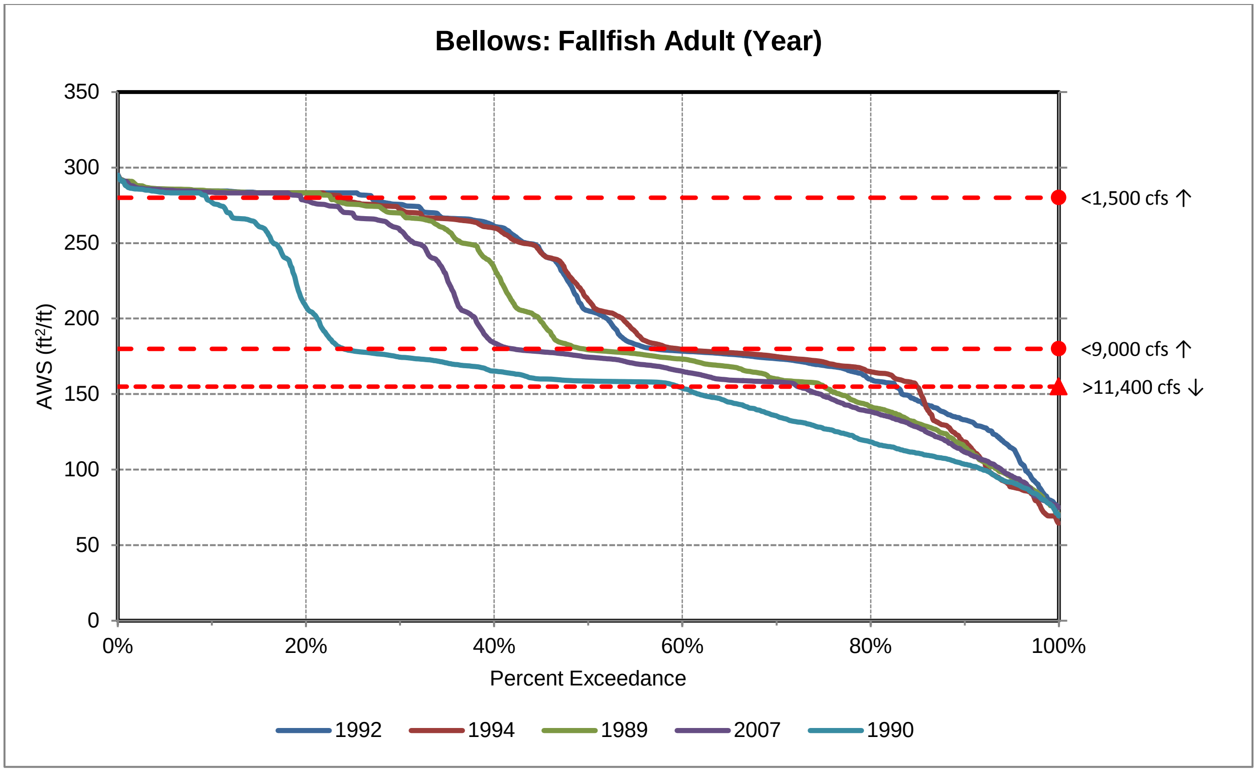


Figure 6.1.2-3. Habitat duration and associated flow levels for Fallfish juvenile in the Bellows Falls reach and CR.



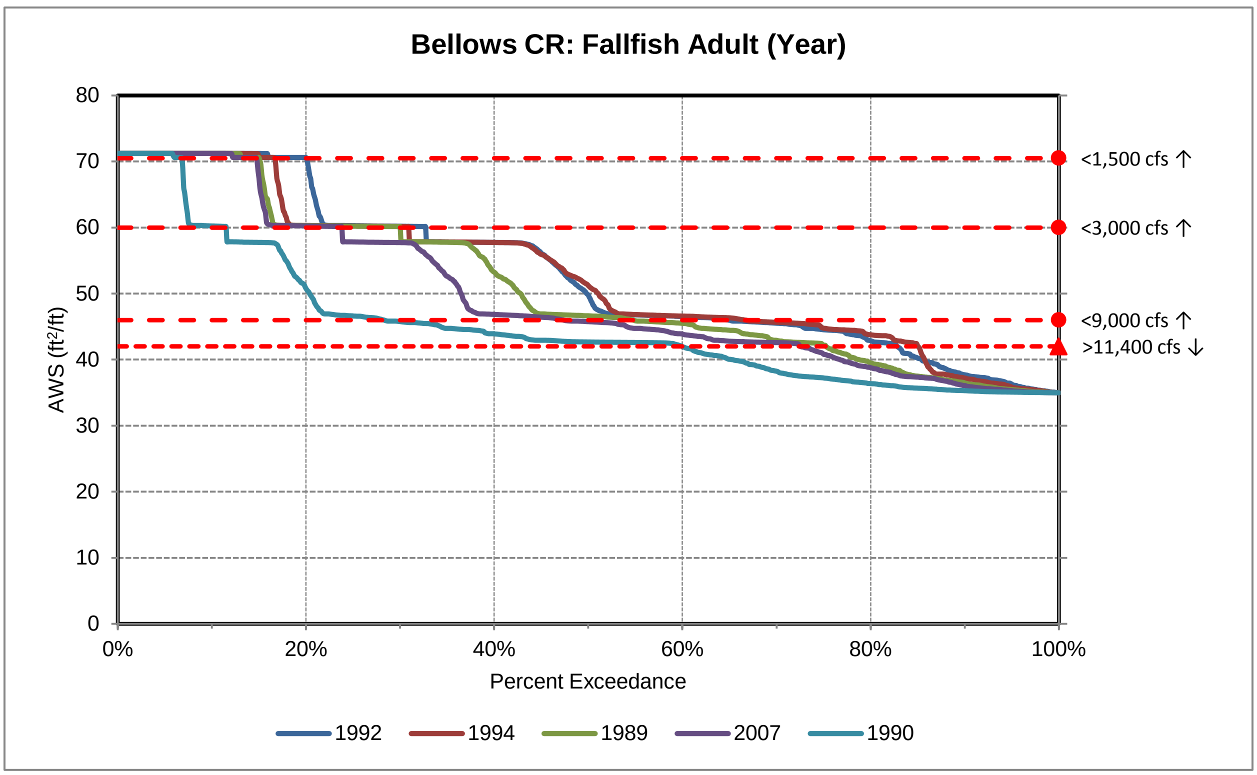
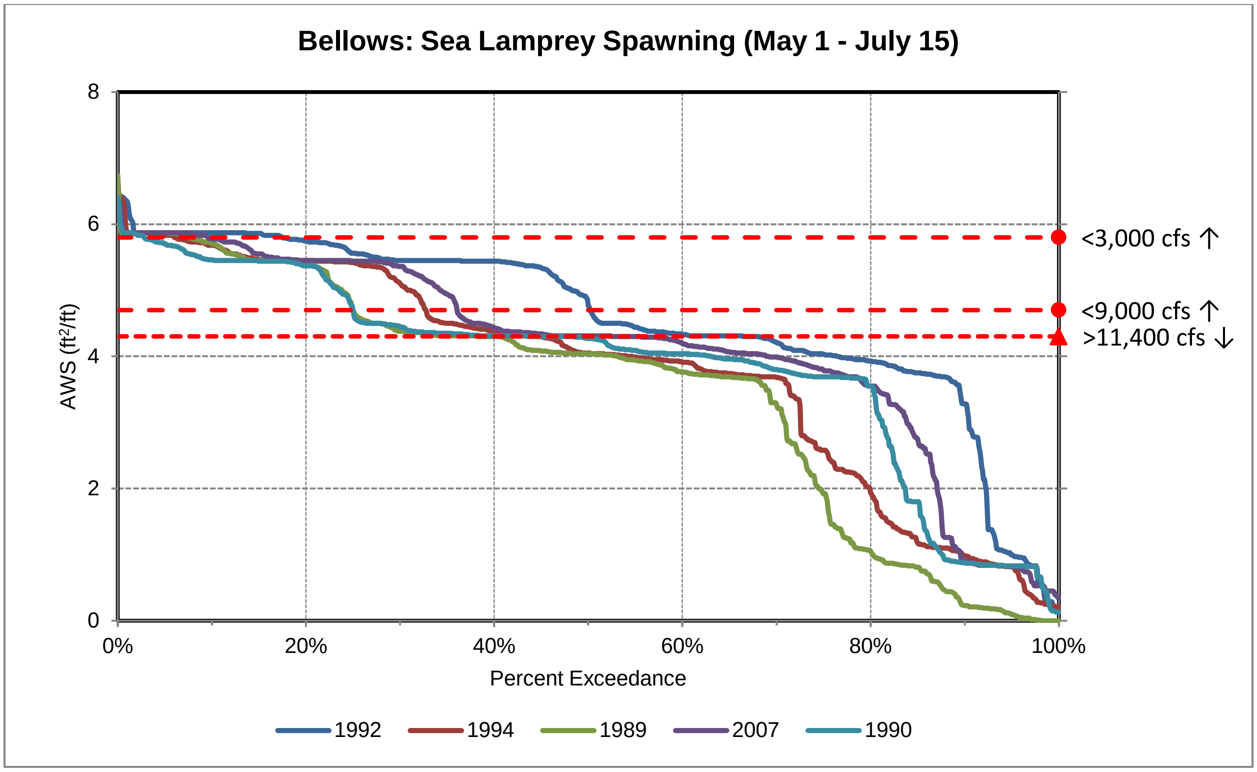


Figure 6.1.2-4. Habitat duration and associated flow levels for Fallfish adult in the Bellows Falls reach and CR.



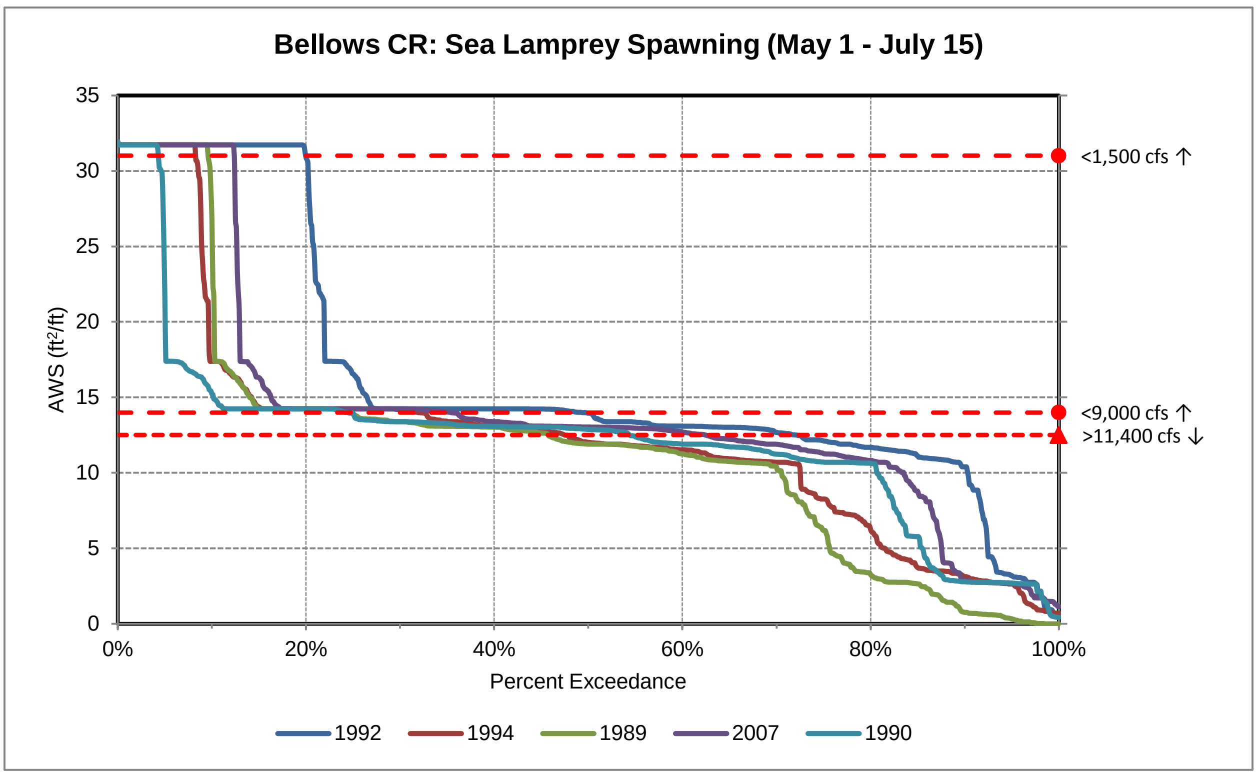


Figure 6.1.2-5. Habitat duration and associated flow levels for Sea Lamprey spawning in the Bellows Falls reach and CR.

Habitat duration curves for Bellows Falls based on all transects and CR transects, including seasonal habitat duration for year-round life stages and GHC, can be found in Appendix I. Similar to results from the Wilder analysis 1992/1994 provides the highest AWS for the longest period of time for year-round aquatic life stages and 1990 provides the least. For spring fry and spawning life stages, 1992 provides the greatest amount of habitat and 1989/1990 the least. These differences are due to the seasonal and annual hydrologic variation between the five modeled hydrologies.

6.1.3 Vernon

Flow Duration

Vernon flow duration shows that 20-45% of the time, depending on the year, the project is at or near minimum flow (Figure 6.1.3-1). Flows above the theoretical maximum combined unit discharge capacity of 17,100 cfs occur 10-20% of the time. Flows above nominal maximum station discharge capacity of about 15,600 cfs occur 25-35% of the time. The time series and resulting habitat duration for the Vernon reach is unique in that both flow and WSE must be accounted for due to the operation of the Turners Falls impoundment downstream which can back water up into the reach. WSE normally ranges between 180 ft and 183 ft (NAVD88) 90% of the time at the bottom of the Vernon reach (Figure 6.1.3-2) based upon the operations model output.

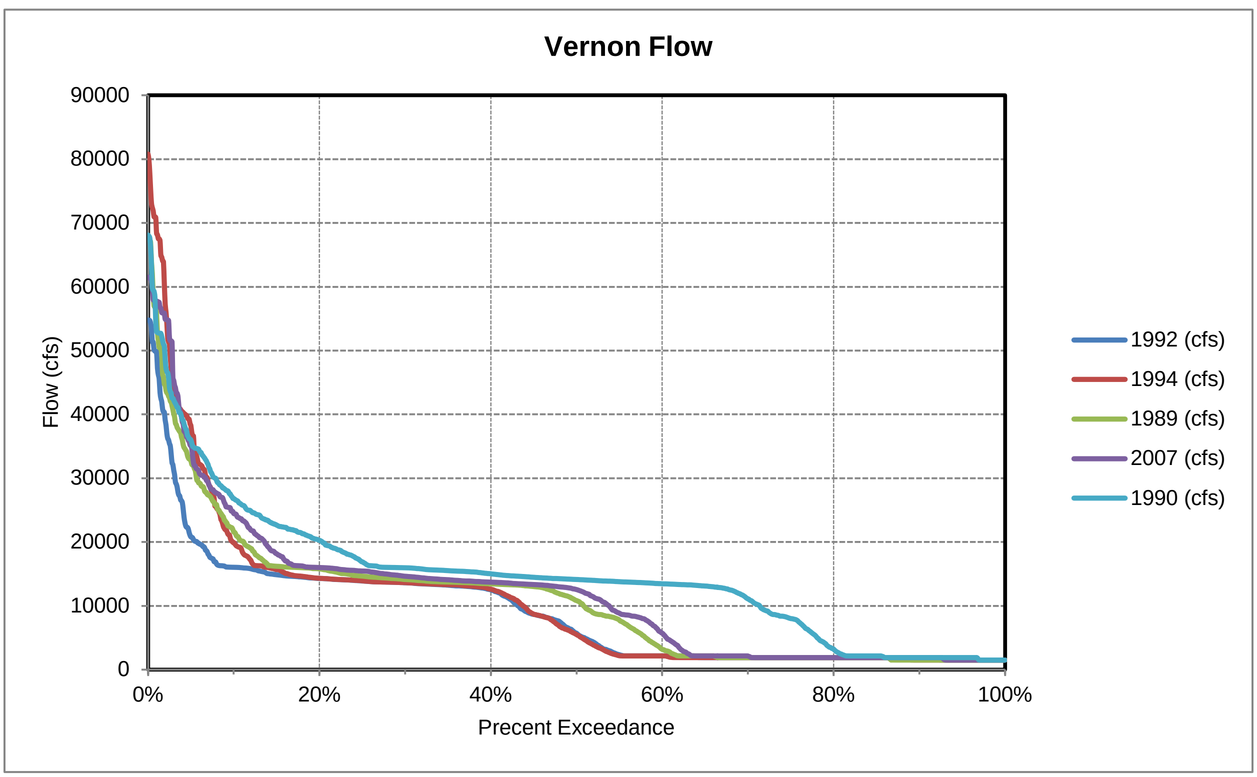


Figure 6.1.3-1. Flow duration at Vernon for 5 modeled hydrologies.

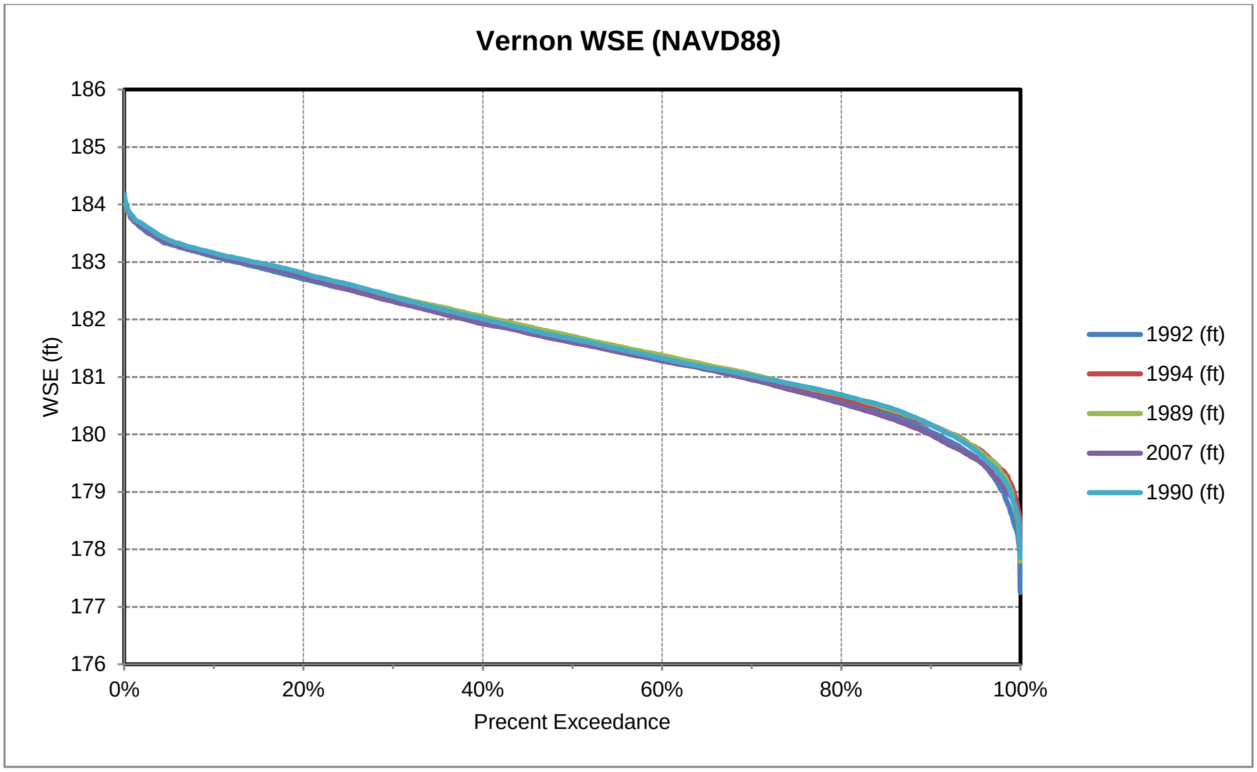


Figure 6.1.3-2. WSE duration at Vernon based on Turners Falls dam elevations (feet NAVD88) for 5 modeled hydrologies.

Habitat Duration

To account for changes in WSE with flow AWS habitat index curves were produced for ten Turners Falls reservoir WSE cases ranging from 175.6 feet to 184.6 feet (NAVD88) for flows between 1,200 cfs to 25,000 cfs (Figure 6.1.3.-3).

Unlike Wilder and Bellows Falls habitat duration curves where AWS values can be attributed to specific flows or ranges of flows, there tends to be a great deal of overlap in the Vernon AWS due to the effect of variations in WSE for each flow modeled. AWS for specific flow and WSE pairs were obtained by interpolating between results from the ten WSE/flow cases. Table 6.1.3-1 provides an example for Walleye juvenile and Fallfish adult during a typical operations cycle. A flow of 2,150 cfs can produce AWS between 24.2 ft^2/ft and 49.1 ft^2/ft for Walleye juvenile and 260.9 ft^2/ft and 443.9 ft^2/ft for Fallfish adult depending on WSE. In addition, a flow of 6,293 cfs provides the same AWS as a flow of 14,191 cfs for Fallfish adult.

As a result there is a large amount of overlap in AWS values attributable to any particular flow range. For example, AWS values between 20 ft^2/ft and 56 ft^2/ft (0-50% exceedance) for Fallfish adult can be due to flows ranging anywhere from minimum flow to 10,000 cfs (Figure 6.1.3-4). Due to the overlap of AWS and flows it was not possible to denote distinct breaks on Vernon habitat duration graphs.

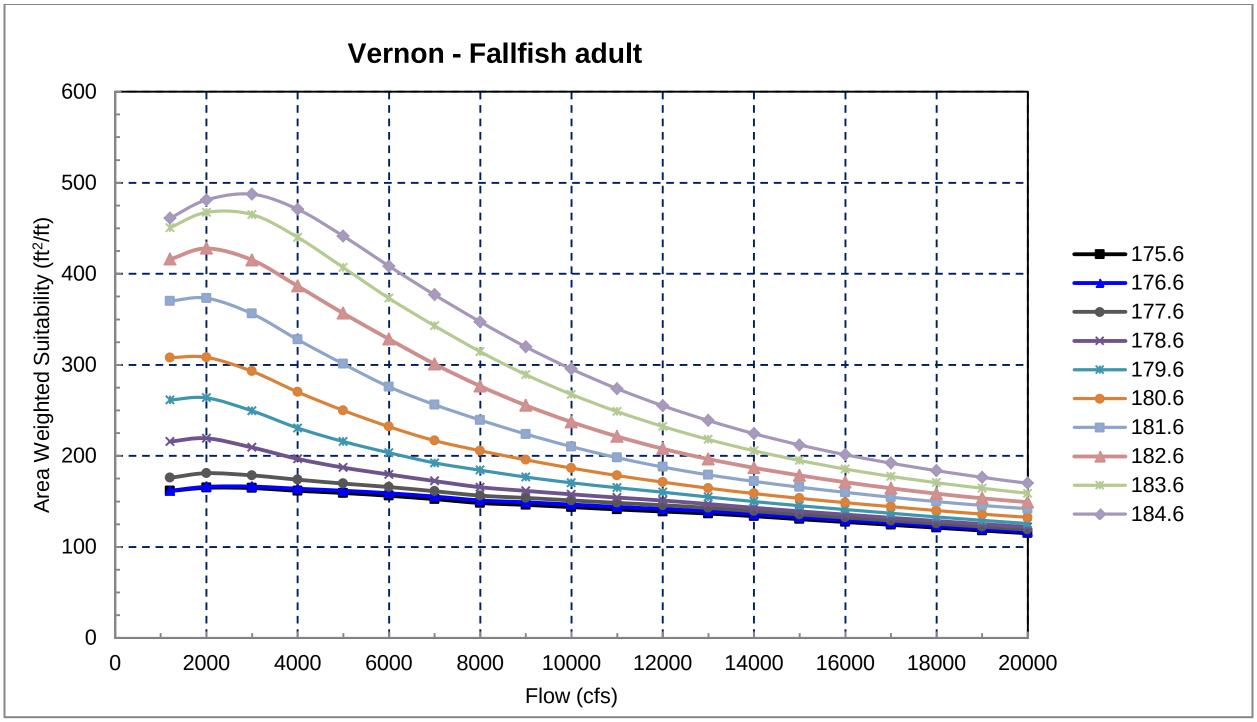


Figure 6.1.3-3. AWS curves for Fallfish adult based on 10 Turners Falls dam elevations (NAVD88).

Table 6.1.3-1. Example of different AWS values calculated for a range of flows and WSE pairs for a normal generation cycle in the Vernon reach.

Date:Hour Ending	Flow (cfs)	WSE (ft NAVD88)	Walleye Juvenile AWS (ft^2/ft)	Fallfish Adult AWS (ft^2/ft)
07-04-1990:01	2,171	183.3	46.69	437.09
07-04-1990:02	2,150	182.8	41.64	417.16
07-04-1990:03	2,150	182.3	37.30	388.95
07-04-1990:04	2,150	181.8	32.93	355.81
07-04-1990:05	2,150	181.2	28.91	317.57
07-04-1990:06	2,150	180.6	26.23	286.97
07-04-1990:07	2,150	180.0	24.24	260.97
07-04-1990:08	6,293	179.6	17.16	190.54
07-04-1990:09	8,956	179.7	17.38	171.85
07-04-1990:10	8,854	179.2	16.93	166.07
07-04-1990:11	9,563	179.1	16.96	160.83
07-04-1990:12	14,127	179.4	15.85	145.35
07-04-1990:13	14,405	179.8	15.89	146.99
07-04-1990:14	15,416	180.4	15.50	146.42
07-04-1990:15	15,673	180.9	15.66	149.64

Date:Hour Ending	Flow (cfs)	WSE (ft NAVD88)	Walleye Juvenile AWS (ft^2/ft)	Fallfish Adult AWS (ft^2/ft)
07-04-1990:16	15,627	181.5	16.14	156.24
07-04-1990:17	15,577	182.1	16.67	163.42
07-04-1990:18	15,524	182.6	17.21	170.35
07-04-1990:19	14,295	183.0	18.75	184.18
07-04-1990:20	14,139	183.1	19.06	187.79
07-04-1990:21	14,191	183.2	19.14	189.48
07-04-1990:22	14,429	183.3	18.93	188.06
07-04-1990:23	2,150	183.4	48.37	441.70
07-04-1990:24	2,150	183.4	48.53	442.16
07-05-1990:01	2,160	183.1	44.70	431.08
07-05-1990:02	2,150	182.6	39.75	404.85
07-05-1990:03	2,150	182.1	34.98	373.80
07-05-1990:04	2,150	181.5	30.84	335.91
07-05-1990:05	2,150	180.8	27.17	299.29
07-05-1990:06	2,150	180.2	25.13	272.64

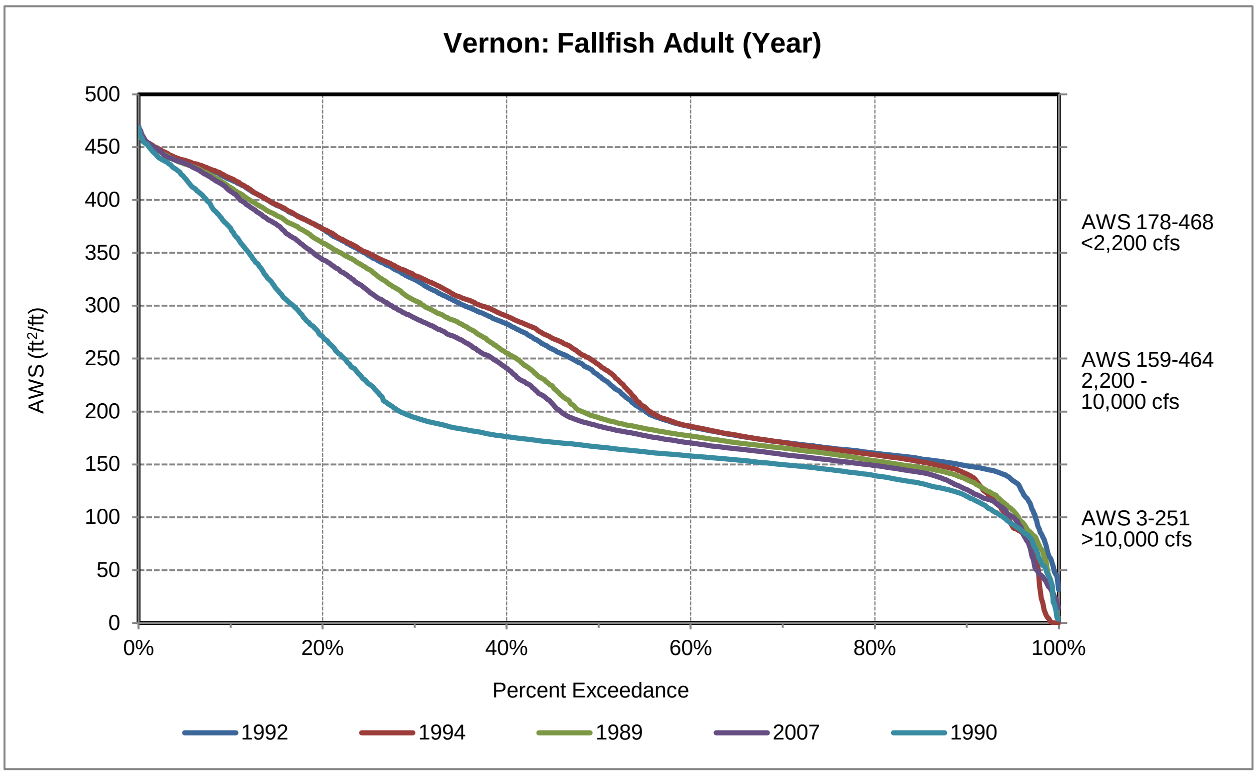


Figure 6.1.3-4. Habitat duration and associated flow levels for Fallfish adult in the Vernon reach.

Habitat duration curves for Vernon based on all transects and CR transects, including seasonal habitat duration for year round life stages and GHC, can be found in Appendix J. Similar to results from Wilder and Bellows Falls, the 1992/1994 hydrologies provide the highest AWS for the longest period of time for most year-round aquatic life stages and 1990 provides the least. For spring fry and spawning life stages, 1992 provides the greatest amount of habitat and 1989/1990 the least. These differences are due to the seasonal and annual hydrologic variation between the five modeled hydrologies.

6.2 Dual Flow Analysis

Dual flow analyses for fully mobile organisms (e.g., juvenile and adult life stages) specify that any habitat between persistent habitat and available habitat (AWS or WUA) for the two flows being evaluated are suitable. For target life stages unable to move as flows change (eggs) or that may have limited mobility (fry life stages and mussels) only persistent habitat is considered, though available habitat (AWS or WUA) is often included for comparison.

All fry and spawning life stages of the target species were selected for evaluation in addition to year-round species, Tessellated Darter adult, macroinvertebrates, DWM, co-occurring mussels and GHC criteria. GHC results do not include quality habitat because the HSC binary data points only produce completely suitable or entirely unsuitable output. Examples of dual flow results are presented in graphic (Figure 6.2-1) and tabular form (Table 6.2-1) and fully provided in Appendices K - N.

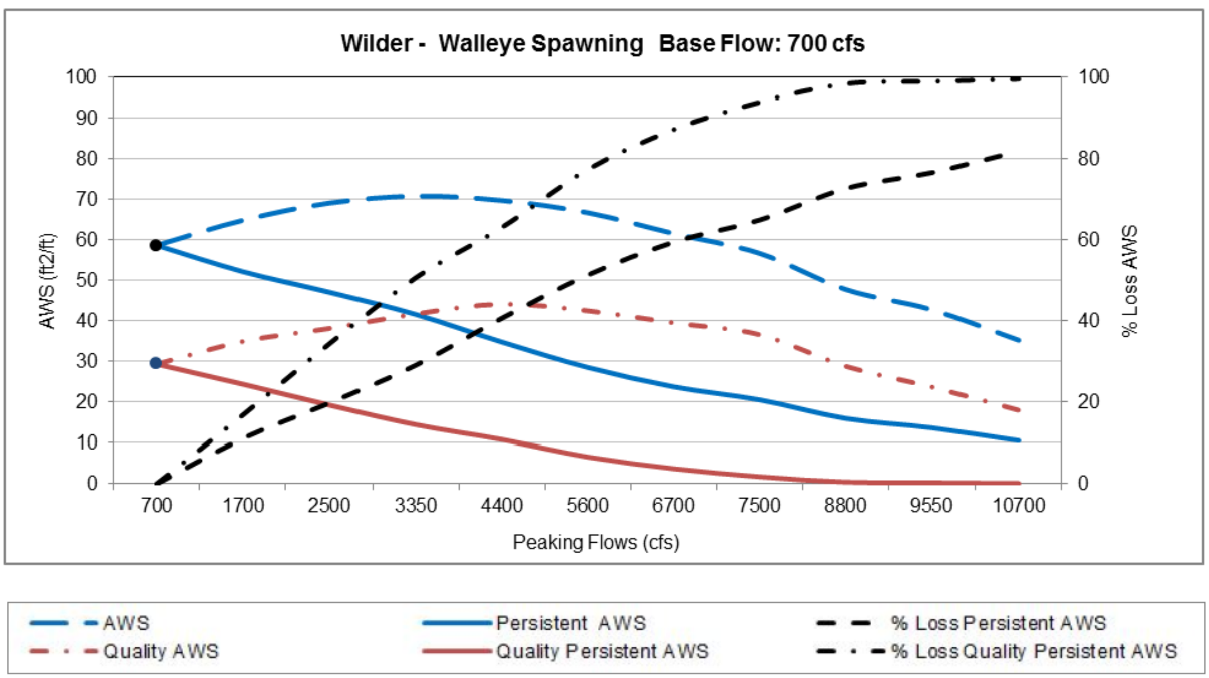


Figure 6.2-1. Walleye spawning persistent habitat and persistent quality habitat in Wilder starting from a base flow of 700 cfs with normal generation ("peaking") flows up to 10,700 cfs.

The tabular form includes persistent habitat and percent loss of persistent habitat from a series of base flows (or minimum flows) over a range of normal project operation flows (what agencies have referred to as “peaking flows”). Separate tables provide results by reach and critical reach (CR) with associated persistent quality habitat (habitat with CSI values ≥ 0.5). Figures provide a visual comparison between persistent habitats in addition to total AWS over the range of normal project operation flows.

Table 6.2-1. Walleye spawning persistent habitat, persistent quality habitat and percent loss persistent habitat in the Wilder reach over a range of normal project operation flows.

Base Flows	Base Flow AWS	Persistent AWS (ft^2/ft)									
		Peaking Flows									
		1700	2500	3350	4400	5600	6700	7500	8800	9550	10700
700	58.74	52.22	47.13	41.65	34.82	28.56	23.77	20.56	15.99	13.69	10.57
1000	60.80	56.08	50.86	45.16	37.99	31.50	26.39	22.87	17.76	15.12	11.64
1250	62.37	59.27	53.94	48.07	40.71	34.02	28.65	24.83	19.27	16.42	12.60
1500	63.75	62.35	56.91	50.90	43.39	36.57	30.84	26.77	20.75	17.66	13.58
1750	65.21		59.94	53.79	46.10	39.10	33.07	28.76	22.24	18.95	14.63
2000	66.72		63.05	56.70	48.81	41.62	35.32	30.75	23.77	20.33	15.71
2250	68.09		66.07	59.51	51.42	44.05	37.51	32.70	25.32	21.69	16.78
2500	69.14		69.14	62.37	54.11	46.54	39.71	34.67	26.85	23.04	17.85
3000	70.44			67.50	58.95	50.92	43.60	38.24	29.81	25.66	19.90
3500	70.94				63.40	54.94	47.21	41.56	32.70	28.16	21.70
4000	70.49				67.07	58.25	50.24	44.37	35.02	30.20	23.36
5000	68.58					63.80	55.21	48.83	38.87	33.75	26.23

Base Flows	Base Flow AWS	Persistent Quality AWS (ft^2/ft)									
		Peaking Flows									
		1700	2500	3350	4400	5600	6700	7500	8800	9550	10700
700	29.37	24.42	19.30	14.48	10.82	6.61	3.73	1.76	0.45	0.28	0.12
1000	31.50	27.95	22.70	17.71	13.96	9.51	6.33	3.97	0.99	0.37	0.14
1250	32.83	30.57	25.23	20.13	16.26	11.64	8.26	5.59	1.64	0.48	0.22
1500	34.45	33.33	27.86	22.69	18.78	14.04	10.26	7.40	2.93	1.22	0.24
1750	34.91		29.82	24.61	20.59	15.65	11.66	8.59	3.51	1.56	0.30
2000	35.31		32.11	26.70	22.60	17.45	13.13	9.85	4.33	2.29	0.67
2250	37.01		35.06	29.53	25.26	19.89	15.44	11.79	5.84	3.64	1.34
2500	38.17		38.17	32.47	28.01	22.32	17.56	13.75	7.50	5.04	2.39
3000	40.23			38.12	33.24	27.08	21.89	17.33	10.59	7.89	4.57
3500	42.32				37.93	31.11	25.49	20.67	13.42	10.19	6.28
4000	43.63				41.76	34.30	28.53	23.51	15.54	11.80	7.58
5000	43.57					39.59	33.01	27.63	19.09	14.84	9.62

Base Flows	% at Base Flow	% Loss Persistent AWS									
		Peaking Flows									
		1700	2500	3350	4400	5600	6700	7500	8800	9550	10700
700	0	11	20	29	41	51	60	65	73	77	82
1000	0	8	16	26	38	48	57	62	71	75	81
1250	0	5	14	23	35	45	54	60	69	74	80
1500	0	2	11	20	32	43	52	58	67	72	79
1750	0		8	18	29	40	49	56	66	71	78
2000	0		6	15	27	38	47	54	64	70	76
2250	0		3	13	24	35	45	52	63	68	75
2500	0		0	10	22	33	43	50	61	67	74
3000	0			4	16	28	38	46	58	64	72
3500	0				11	23	33	41	54	60	69
4000	0				5	17	29	37	50	57	67
5000	0					7	20	29	43	51	62

Base Flows	% at Base Flow	% Loss Persistent Quality AWS									
		Peaking Flows									
		1700	2500	3350	4400	5600	6700	7500	8800	9550	10700
700	0	17	34	51	63	77	87	94	98	99	100
1000	0	11	28	44	56	70	80	87	97	99	100
1250	0	7	23	39	50	65	75	83	95	99	99
1500	0	3	19	34	45	59	70	79	92	96	99
1750	0		15	29	41	55	67	75	90	96	99
2000	0		9	24	36	51	63	72	88	94	98
2250	0		5	20	32	46	58	68	84	90	96
2500	0		0	15	27	42	54	64	80	87	94
3000	0			5	17	33	46	57	74	80	89
3500	0				10	26	40	51	68	76	85
4000	0				4	21	35	46	64	73	83
5000	0					9	24	37	56	66	78

6.2.1 Wilder

Accretion within the Wilder reach was accounted for using the average difference in flow of the five hydrologies from the operations model (Study 5, Hatch, 2016) for seasonal and life stage periodicity (Table 6.2.1-1). Seasonal accretion values were applied to year-round species/life stages and GHC criteria (Table 6.2.1-2). Accretion values for Wilder reach 3 were also applied to the Chase Island 2D site. The dual flow analysis for the Johnston Island 2D site in Wilder reach 2 was not performed. However given the similarity in AWS and WUA results between Johnston Island 2D, Chase Island 2D and Wilder 1D for the majority of species and life stages, dual flow results would be very comparable. Flows in tables and figures for Wilder are based on releases from the dam with accretion applied to 1D transects in reach 2 and reach 3 and the Chase Island 2D site. Results for 1D transects are presented in Appendix K and the Chase Island 2D site in Appendix L.

Table 6.2.1-1. Accretion estimates (cfs) for Wilder reach 2 and 3 based on operations model (Study 5) for fry and spawning life stage seasonality.

	Species / Life Stage						
	Walleye fry Fallfish spawning Smallmouth spawning	Fallfish Fry	White Sucker Fry	Longnose Dace fry Smallmouth Fry	Walleye Spawning	White Sucker Spawning	Sea Lamprey Spawning
Reach	**May 1 - Jun 30**	**Jun 1 - July 1**	**Jun 1 - Sep 30**	**Jul 1 - Sep 30**	**Apr 1 - May 31**	**Apr 1 - Jun 30**	**May 1 - July 15**
Wilder 2	1,670	1,018	722	621	3,289	2,544	1,476
Wilder 3	2,192	1,308	912	779	4,302	3,319	1,929

Table 6.2.1-2. Seasonal accretion estimates (cfs) for Wilder reach 2 and 3 based on operations model (Study 5).

	Season			
Reach	**Winter (Jan-Mar)**	**Spring (Apr-Jun)**	**Summer (Jul-Sep)**	**Fall (Oct-Dec)**
Wilder 2	1,396	2,544	621	1,353
Wilder 3	1,806	3,319	779	1,737

Dual flow persistent habitat results based on Wilder 1D transects and the Chase Island 2D site are similar for all species and life stages, an outcome which was not unexpected considering the similarity in AWS and WUA output from the two models. Examples for Fallfish fry, Smallmouth Bass spawning, Walleye spawning and Tessellated Darter are shown in Tables 6.2.1-3 to 6.2.1-6.

Fewer minimum flows were evaluated for the Chase Island site because: 1) the extensive effort involved in running the 2D model with new flows, and 2) results for intermediate flows can be easily interpolated. In addition, because accretion values for winter and fall are nearly identical, winter flows were not evaluated separately in the Chase island analysis.

Table 6.2.1-3. Comparison of percent loss of persistent AWS for Wilder 1D transects (top) and WUA for Chase Island 2D site (bottom) for Fallfish fry.

Base Flows (cfs)	% at Base Flow	% Loss Persistent AWS							
		Flow (cfs)							
		3350	4400	5600	6700	7500	8800	9550	10700
700	0	75	85	92	96	97	99	99	100
1000	0	70	82	90	95	97	99	99	99
1500	0	59	75	86	92	95	98	99	99
2000	0	47	67	81	89	93	97	98	99
2500	0	31	56	74	84	89	94	96	98
3000	0	14	44	66	78	85	92	94	97

Base Flows (cfs)	% at Base Flow	% Loss Persistent WUA							
		Flow (cfs)							
		3350	4400	5600	6700	7500	8800	9550	10700
700	0	76	86	93	96	98	99	99	100
1000	0	70	82	90	95	97	99	99	100
1500	0	60	75	86	92	95	98	99	99
2000	0	47	67	81	89	93	96	98	99
2500	0	33	57	75	86	90	95	97	99
3000	0	16	45	68	81	87	93	96	98

Table 6.2.1-4. Comparison of percent loss of persistent AWS for Wilder 1D transects (top) and WUA for Chase Island 2D site (bottom) for Smallmouth Bass spawning.

Base Flows (cfs)	% at Base Flow	% Loss Persistent AWS							
		Flow (cfs)							
		3350	4400	5600	6700	7500	8800	9550	10700
700	0	76	85	91	94	96	97	98	99
1000	0	70	80	88	92	94	96	97	98
1500	0	57	71	81	87	90	93	95	96
2000	0	43	61	74	82	85	90	92	95
2500	0	28	51	67	76	81	87	89	92
3000	0	12	39	59	70	75	82	86	90

Base Flows (cfs)	% at Base Flow	% Loss Persistent WUA							
		Flow (cfs)							
		3350	4400	5600	6700	7500	8800	9550	10700
700	0	60	71	83	88	90	94	96	97
1000	0	56	67	80	86	89	93	95	97
1500	0	47	60	75	82	86	91	93	96
2000	0	35	51	70	78	83	89	92	94
2500	0	24	43	64	74	80	86	90	93
3000	0	11	33	57	69	76	83	87	92

Table 6.2.1-5. Comparison of percent loss of persistent AWS for Wilder 1D transects (top) and WUA for Chase Island 2D site (bottom) for Walleye spawning.

Base Flows (cfs)	% at Base Flow	% Loss Persistent AWS Flow (cfs)							
		3350	4400	5600	6700	7500	8800	9550	10700
700	0	29	41	51	60	65	73	77	82
1000	0	26	38	48	57	62	71	75	81
1500	0	20	32	43	52	58	67	72	79
2000	0	15	27	38	47	54	64	70	76
2500	0	10	22	33	43	50	61	67	74
3000	0	4	16	28	38	46	58	64	72

Base Flows (cfs)	% at Base Flow	% Loss Persistent WUA Flow (cfs)							
		3350	4400	5600	6700	7500	8800	9550	10700
700	0	30	40	52	61	67	75	81	90
1000	0	26	36	48	57	64	72	79	88
1500	0	23	34	47	56	63	72	78	88
2000	0	18	30	43	53	60	70	76	86
2500	0	12	25	39	50	57	67	74	85
3000	0	6	19	34	46	53	64	72	83

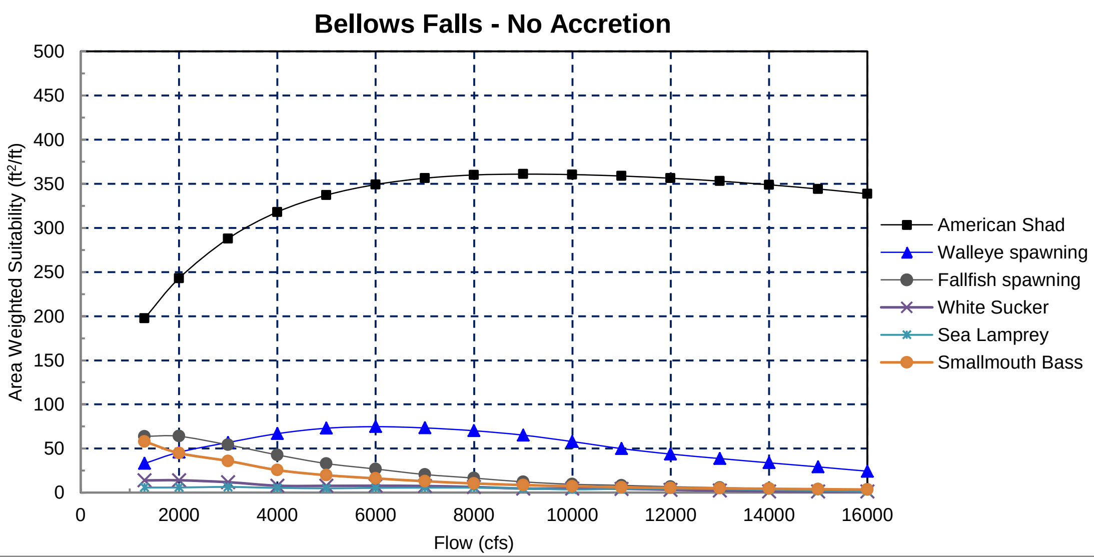
Table 6.2.1-6. Comparison of percent loss of persistent AWS for Wilder 1D transects (top) and WUA for Chase island 2D site (bottom) for Tessellated Darter for summer season.

Base Flows (cfs)	% at Base Flow	% Loss Persistent AWS Flow (cfs)							
		3350	4400	5600	6700	7500	8800	9550	10700
700	0	80	89	95	97	98	99	100	100
1000	0	72	85	92	95	97	99	99	100
1500	0	60	78	88	94	96	99	99	100
2000	0	48	71	86	93	96	98	99	100
2500	0	33	62	81	91	94	98	99	100
3000	0	15	51	75	87	93	97	98	99

Base Flows (cfs)	% at Base Flow	% Loss Persistent WUA Flow (cfs)							
		3350	4400	5600	6700	7500	8800	9550	10700
700	0	90	96	98	99	100	100	100	100
1000	0	87	94	98	99	100	100	100	100
1500	0	80	89	96	99	99	100	100	100
2000	0	71	82	94	98	99	100	100	100
2500	0	60	74	90	96	98	100	100	100
3000	0	46	64	86	95	98	99	100	100

6.2.2 Bellows Falls

There is minimal accretion in the Bellows Falls reach. Based on USGS gage data average spring (April-June) accretion is 193 cfs from the Saxtons River and 165 cfs from the Cold River. These flows were applied to transects located downstream of each tributary to produce AWS output that were indiscernible during the spring (April-June) spawning season for a number of species (Figure 6.2.2-1). Based on these results it was concluded that no adjustments were necessary to account for accretion in the Bellows Falls reach for this analysis.



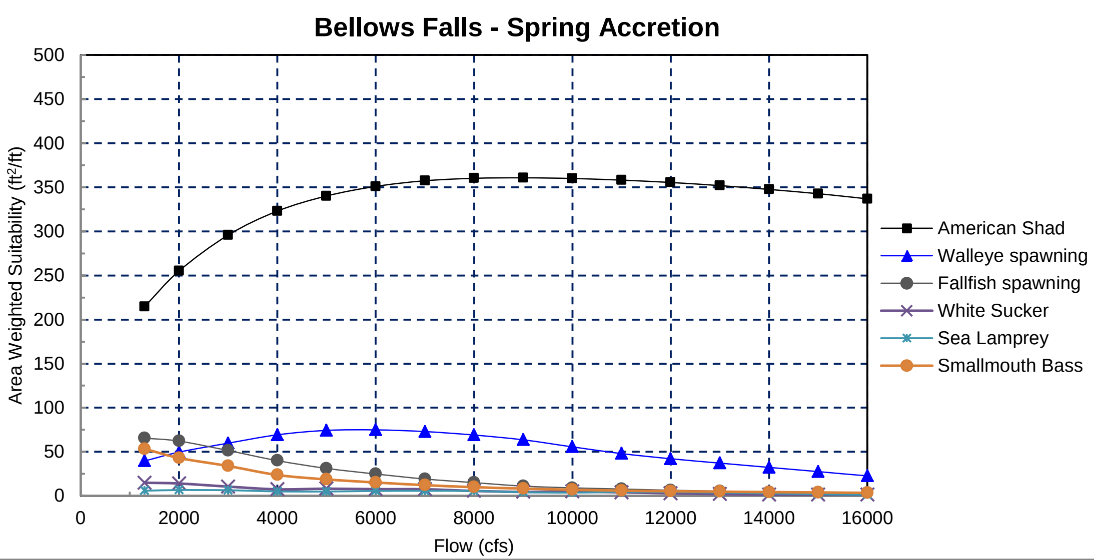


Figure 6.2.2-1. Comparison of AWS for spawning life stages in the Bellows Falls reach with and without accretion during spring (April-June).

Results for the Bellows Falls reach that are presented in Appendix M are similar to results for Wilder.

6.2.3 Vernon

It was agreed with the working group that up to three Vernon reach scenarios based on Turners Falls dam WSEs would be provided. Preliminary flow duration curves were examined and the following Turners Falls dam WSEs and exceedance values were estimated:

- 179.2 ft (NAVD88) at 90% exceedance
- 180.6 ft (NAVD88) at 50% exceedance
- 182.6 ft (NAVD88) at 10% exceedance

Final duration curves (Figure 6.2.3-1) produced the following elevations and exceedance values:

- 180.1 ft (NAVD88) at 90% exceedance
- 180.6 ft (NAVD88) at 80% exceedance
- 181.6 ft (NAVD88) at 50% exceedance
- 182.6 ft (NAVD88) at 20% exceedance
- 183.1 ft (NAVD88) at 10% exceedance

Based on this information dual flow analysis for 180.6 ft (NAVD88) and 182.6 ft (NAVD88) is included in this report. Pending results, additional elevations may be evaluated; however it is improbable that any elevation scenarios that are 1.0 feet or less apart would produce any perceivable differences.

Results based on the two elevation scenarios shows the greatest difference for fry and spawning life stages that have a narrow depth criteria range. Any differences tend to be less when comparing CR transects which are comprised primarily of shallow water habitat units. Results are shown in Appendix N.

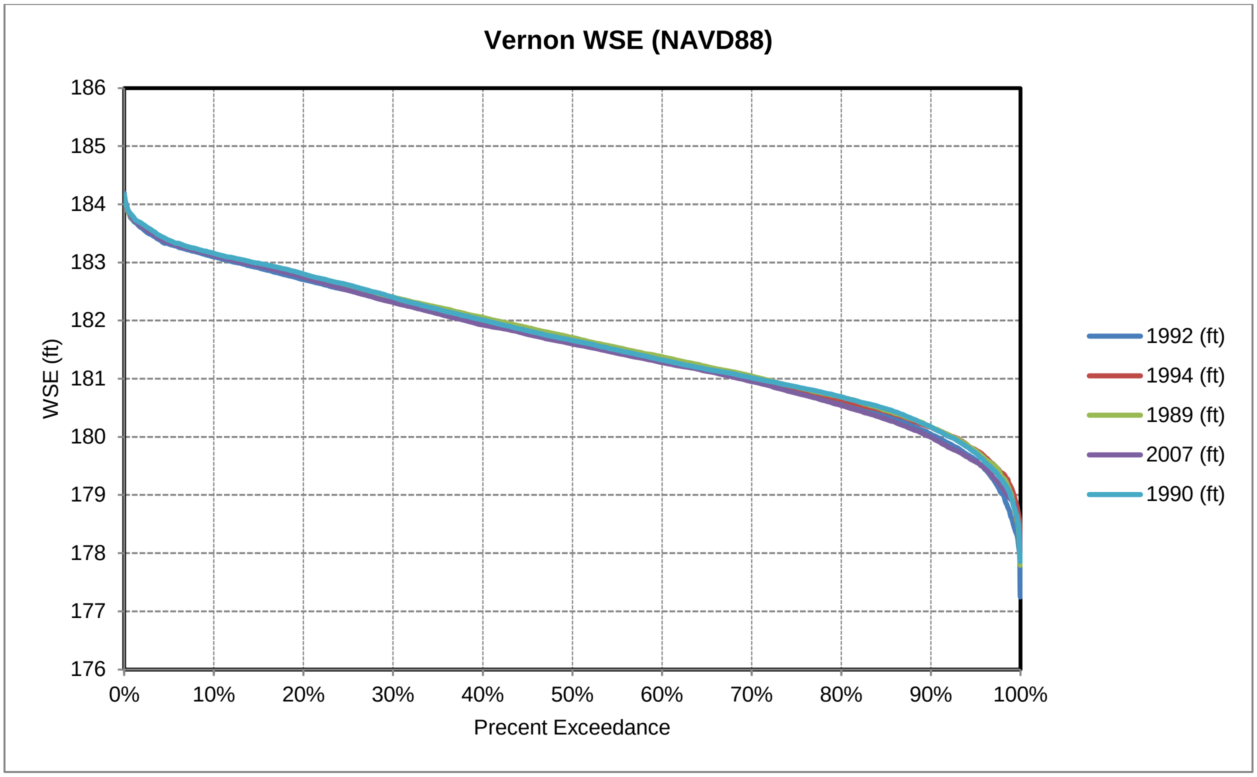


Figure 6.2.3-1. Vernon WSE (ft, NAVD88) exceedance based on five annual hydrologies from the operations model (Study 5, Hatch, 2016).

6.3 Study Conclusions

No definitive conclusion can be drawn from an instream flow study time series and habitat duration analysis alone, except to infer that one flow scenario may produce more or less habitat than another. For this study lower flows tend to provide the highest AWS values for a majority of species and life stages (see Appendix D for all reaches and life stages, and Appendices G - J for critical reaches). Only by evaluating alternative operational flow regimes to those modeled for the baseline (current) operations can conditions that maintain or produce the most habitat over extended periods of time be determined.

The degree of habitat persistence varies greatly depending on the species and life stage being evaluated. In most cases the greatest change, typically loss of habitat, occurs when flows increase from minimum flow to maximum normal project operational flows. As would be expected the narrower the range of project operational flows the more attenuated the change in habitat becomes. In general, species and life stages with broad suitability ranges, particularly for depth, show the least decline in quality habitat and persistent habitat versus total habitat (e.g., shad spawning, macroinvertebrates, Walleye spawning, White Sucker fry, DWM, co-occurring mussels) and those with narrow ranges of suitability for depth and/or velocity show the greatest decline in quality habitat versus total habitat (e.g., most fry life stages, Fallfish spawning, Smallmouth Bass spawning, White Sucker spawning, Sea Lamprey spawning).

If the intent is to determine flow and operational conditions that may be suitable for all target species, the task becomes daunting if not impossible. Spawning behavior for different species ranges from nest building to broadcast spawning, rarely resulting in similar flow requirements. Life stages with narrow depth and low velocity criteria will always respond negatively to changes from low to high flows based on AWS or WUA. Trade-offs between what are perceived to be ideal flows need to be balanced with the effect of alternative stream flows on project operations and on other resources (e.g., odonates, beetles). Without a focused approach and prioritization of select species or aquatic habitat it is unlikely any consensus could be reached by all parties involved.

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LIST OF APPENDICES FILED SEPARATELY

Interim Report Appendices, updated for Final Report filed separatley in pdf (zipfile) format:

APPENDIX A: Habitat Suitability Criteria

APPENDIX B: 1D Model Calibration details

APPENDIX C: 1D Transect Cross Section Profiles

APPENDIX D: 1D AWS Tables

APPENDIX E: Johnston Island and Chase Island 2D Model WUA Tables and Figures

APPENDIX F: Sumner Falls Aerial Photographs

Time Series Appendices filed separately in pdf (zipfile) format:

APPENDIX G: Wilder 1D Habitat Duration Analysis

APPENDIX H: Wilder 2D Habitat Duration Analysis

APPENDIX I: Bellows Falls 1D Habitat Duration Analysis

APPENDIX J: Vernon 1D Habitat Duration Analysis

Dual Flow Appendices filed separately in pdf (Zipfile) format:

APPENDIX K: Wilder 1D Dual Flow Analysis

APPENDIX L: Wilder 2D Chase Island Dual Flow Analysis

APPENDIX M: Bellows Falls 1D Dual Flow Analysis

APPENDIX N: Vernon 1D Dual Flow Analysis