

# SUPPORTING ANALYSES FOR THE SALINAS RIVER OPERATIONS HABITAT CONSERVATION PLAN STEELHEAD EFFECTS ANALYSIS

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## Introduction

The Monterey County Water Resources Agency (MCWRA) manages water operations along the Salinas River while minimizing flood risk to the areas surrounding the Salinas River Lagoon. One of MCWRA's objectives is water conservation, implemented primarily by maximizing the amount of groundwater recharge into the Salinas Valley aquifers. This recharge is largely achieved through the regulated release of water from Nacimiento and San Antonio Dams to do the following.

- Maintain Salinas River streamflow to increase groundwater recharge through the streambed.
- Operate the Salinas River Diversion Facility (SRDF) to allow a reduction in groundwater pumping from, primarily, the 180/400 Foot Aquifer subbasin, which in turn minimizes seawater intrusion.

MCWRA also makes specific water releases to promote migration to and from the lagoon to the Arroyo Seco River of federally listed South-Central California Coast steelhead (*Oncorhynchus mykiss*) and manages minimum releases to maintain rearing and spawning habitat conditions. Since the 2007 issuance of a biological opinion for Phase I of the Salinas Valley Water Project, MCWRA has managed reservoir releases to provide flows for South-Central California Coast steelhead; minimum flows below Nacimiento Dam are maintained at 60 cubic feet per second (cfs) per the 2007 biological opinion. In a letter dated February 19, 2019, the National Marine Fisheries Service (NMFS) determined that all non-discretionary terms and conditions of the 2007 biological opinion had been met. Soon thereafter, the U.S. Army Corps of Engineers (USACE) provided a letter to MCWRA concluding that the Clean Water Act Section 404 permit issued for construction of Phase I of the Salinas Valley Water Project was complete. USACE has also declined to take jurisdiction over sandbar management activities undertaken by MCWRA as part of its flood management responsibilities. As a result of these regulatory conclusions, MCWRA has no federal nexus under which to conduct an Endangered Species Act Section 7 consultation. Therefore, MCWRA is now undertaking development of the Salinas River Operations Habitat Conservation Plan (HCP), a multi-species regional conservation plan. HCPs and their incidental take permits are a durable mechanism to provide take coverage to non-federal entities for the incidental take of federally listed species. An HCP can be developed in a comprehensive and flexible manner to address long-term regulatory needs. HCPs may also streamline permitting for projects with a federal nexus that require a Section 7 consultation. Therefore, MCWRA is preparing a comprehensive, programmatic HCP to cover impacts on species associated with reservoir and SRDF operations.

A key milestone in developing an HCP is establishing the methods by which the effects analysis will be conducted to evaluate impacts on covered species. Larger-scale and regional HCPs often use habitat models to quantify impacts. This is generally straight-forward for terrestrial species whose habitat changes little year to year and can be mapped using a geographic information system (GIS).

Models are also used to quantify impacts on aquatic species but there is more variability in the application of such models given the difficulty in monitoring aquatic species and their habitats.

A detailed technical memo was provided to NMFS and the U.S. Fish and Wildlife Service (collectively, the Services) in fall 2023 and provided background regarding how effects analyses should be conducted per federal Endangered Species Act regulations, a summary of the core covered activities to be covered by the HCP, an overview of the stressors facing steelhead trout related to the core covered activities, and a detailed description of an analytical approach suitable for the HCP and steelhead trout (ICF 2023). This memo focuses on part of the analyses described in the 2023 memo, spawning and rearing habitat availability in the lower Nacimiento and San Antonio Rivers and the minimum flows at each dam to maintain adequate spawning and rearing habitat quality to promote steelhead productivity.

## Study Setting

This study evaluates rearing and spawning habitat conditions in two key tributaries to the Salinas River, the Nacimiento and San Antonio Rivers below the dams (Figure 1). The mainstem Salinas River is considered a migration corridor for adults and smolts and does not support rearing or spawning life stages (National Marine Fisheries Service 2007). Therefore, habitat modeling for rearing and spawning life stages was not completed in these areas.

Habitat conditions were mapped in the lower Nacimiento and San Antonio Rivers during the spring and summer of 2023 to categorize current conditions within each system as they relate to rearing and spawning steelhead life stages (Table 1). Density of large wood, mesohabitat unit composition (e.g., pool, riffle, glide), substrate composition, and canopy coverage were used to characterize the rearing habitat conditions within each river and the total area of suitable gravel patches were categorized availability of spawning habitat in the lower Nacimiento River.

By far the highest quantity of large wood was recorded in Nacimiento River reach 1 with more than 70 pieces per kilometer (Figure 2). The other Nacimiento River reaches had considerably less large wood—fewer than 20 pieces per kilometer. Density of large wood in the San Antonio River reaches was lower than Nacimiento River reach 1 with less than 45 pieces per kilometer. San Antonio reach 2 had nearly 30 pieces of large wood per kilometer compared to reach 1 near the dam which had about 10 pieces per kilometer.

Habitat composition within the lower Nacimiento River surveyed reaches was dominated by runs and pools (Figure 3). Pools were the dominant unit type in reaches 1 and 4 and runs were the dominant unit type in reaches 2 and 3 (Table 2). A similar trend was observed in the San Antonio River. Across all surveyed reaches of both rivers, less than 5% of habitat types were categorized as riffles.

All reaches on the Nacimiento River were dominated by sand, gravel, and cobble substrates (Figure 4). Substrate conditions were generally better closer to the Nacimiento Dam compared to further downstream where more fines and sand substrate was documented. The proportion of cobble substrates also declined as distance downstream increased. Both San Antonio River reaches were dominated by sand and fines, and very little gravel or cobble was observed in either reach.

Canopy cover along all surveyed reaches was variable, although most units were lacking long continuous swaths of riparian canopies (Figure 5). The highest amounts of canopy cover were

observed in Nacimiento River reach 1. This trend is consistent with the higher amount of instream large wood recorded in reach 1; instream large wood originates most often from riparian areas.

Most spawning gravel patches were observed in the Nacimiento River (Figure 6). One small patch was measured in a riffle in San Antonio River reach 2. Reaches 1 and 3 in the Nacimiento River contained the most spawning patches and were dispersed amongst all habitat types. Spawning gravel patches had relatively low proportions of fines and sand, in most cases less than 25% (Figure 7). One riffle in Nacimiento River reach 2 had more than 50% fines, sand, or other substrates.

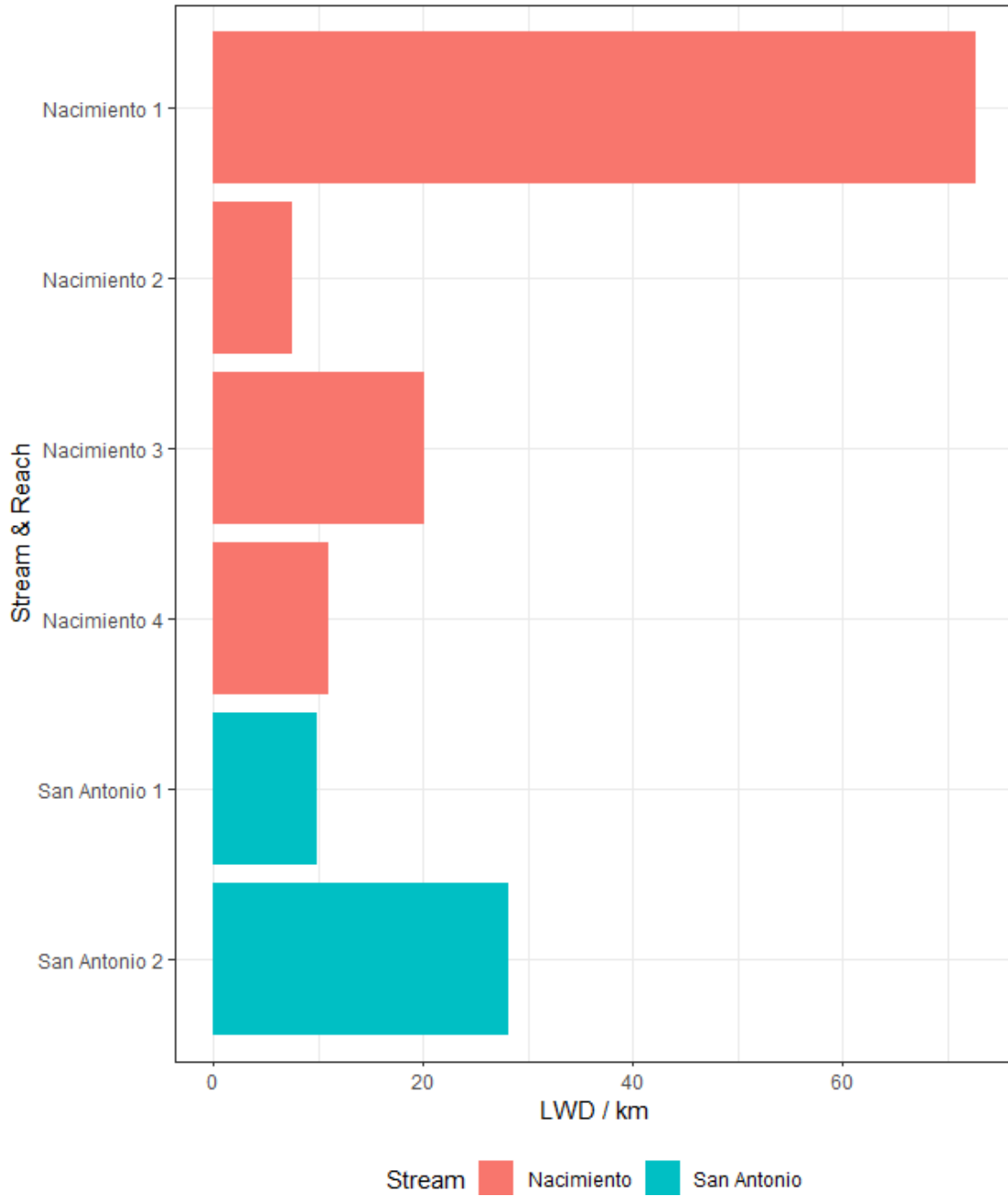


Figure 1. Location of Study Area.

Table 1. Habitat Features Measured in the Lower Nacimiento and San Antonio Rivers

Habitat Feature	Description
Channel Unit Types	Identification of level III channel unit types as defined by CDFW (1998) (pools, riffles, glides, etc.)
Channel Unit Wetted Width (ft)	Distance across the individual unit perpendicular to the flow of water. Measured at one to three locations depending on unit type and width variability.
Channel Unit Depth (ft)	Average water depth across the channel unit. Measured at three locations to capture variability in water depth.
Bankfull Width (ft)	Width of the channel measured perpendicular to the stream from the bankfull flow line on each side of the channel. Bankfull is typically defined as the 1.5-year high water line.
Flood-Prone Width (ft)	The stream width at a discharge level roughly twice the maximum bankfull depth.
Instream Shelter Complexity	Rating of -0, 1, 2, or 3; based on the presence of wood, boulders, riparian vegetation, undercut banks, submerged aquatic vegetation, etc. See CDFW 1998 for addition details.
Instream Shelter Percent Cover	Measurement of the total area of habitat occupied by instream shelter.

<b>Habitat Feature</b>	<b>Description</b>
Substrate Composition	Proportion of each substrate type occupying the channel bottom. Substrate types include gravel, cobble, boulders, sand, silt, and bedrock.
Large Wood	Counts of large wood 1 foot in diameter or larger and between 6 and 20 feet or more than 20 feet.
Canopy Cover	Percent of the channel unit area influence by tree canopy.
Percent of Vegetated Banks	Proportion of each bank that is covered by vegetation from bankfull discharge level to 20 feet upslope.
Channel Unit Spatial Location	GPS coordinates or up and downstream locations of the channel.
Spawning Gravel	Composition of spawning gravels expressed as a proportion.
Dimension of Spawning Units	Length and width of spawning gravel patches expressed as units of area.



**Figure 2. Counts of Large Woody Debris per Kilometer in each Surveyed Reach in the Nacimiento and San Antonio Rivers.**

### Mesohabitats along each reach

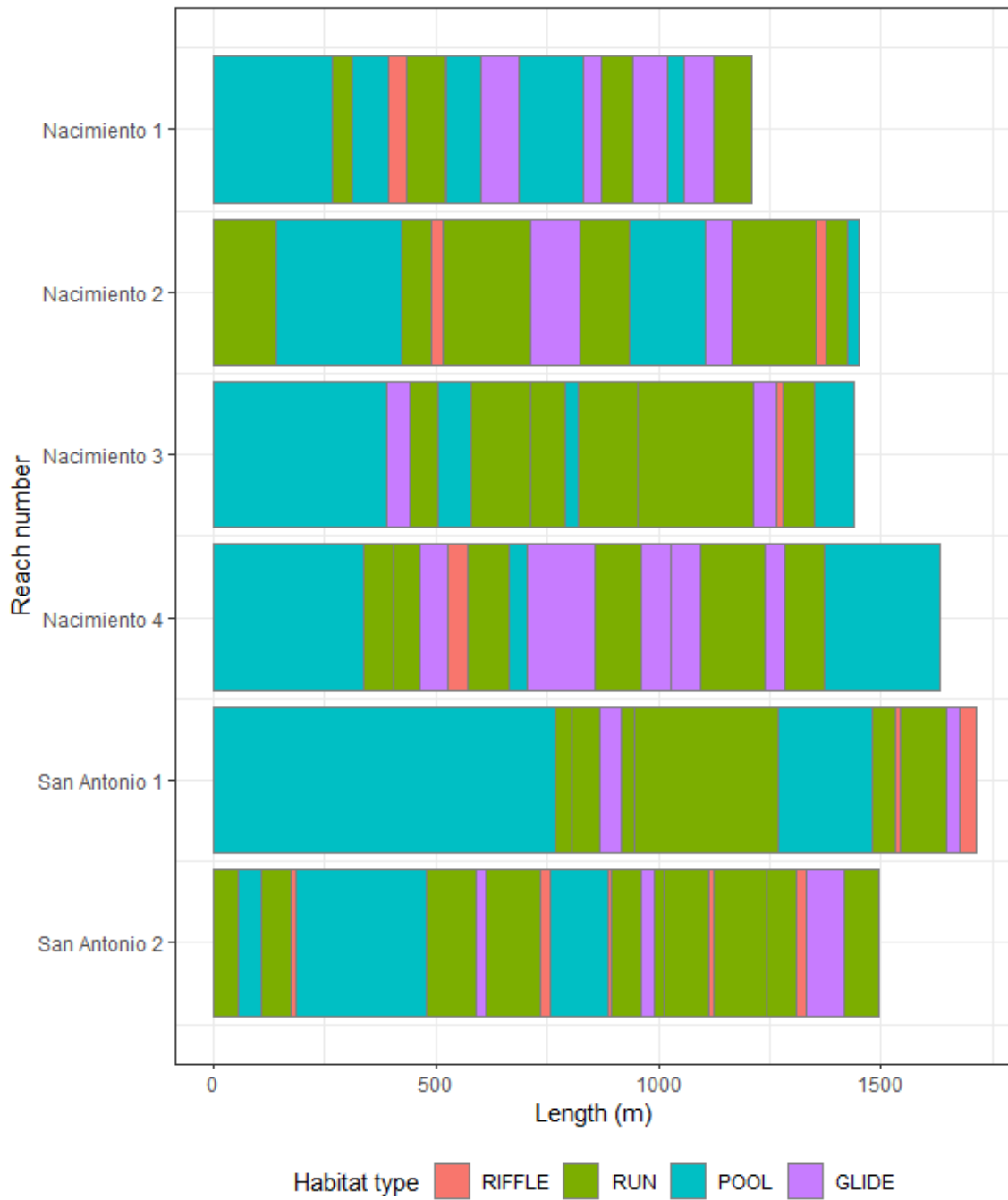
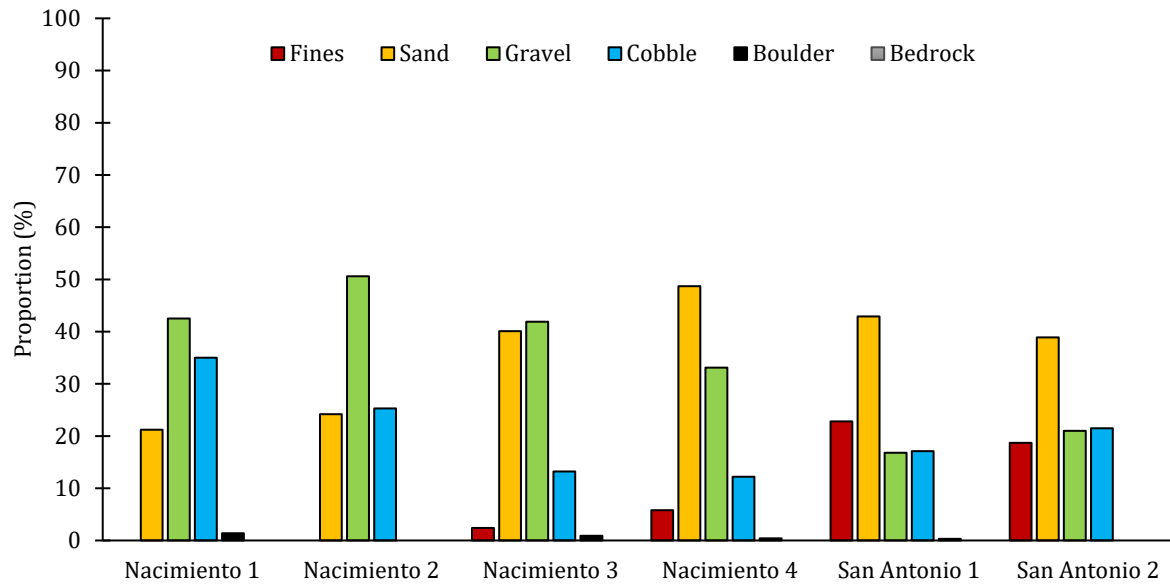


Figure 3. Length and Relative Position of Habitat Unit Types Along each Surveyed Reach in the Nacimiento and San Antonio Rivers.

Table 2. Proportion of Habitat Unit Types Observed in Nacimiento and San Antonio River Reaches.

Stream	Reach	Riffle (%)	Run (%)	Pool (%)	Glide (%)
	1	3.7	23.4	50.1	22.7

Stream	Reach	Riffle (%)	Run (%)	Pool (%)	Glide (%)
Nacimiento	2	3.4	51.6	33.1	12.0
	3	1.1	50.8	40.8	7.3
	4	2.8	34.2	39.1	23.9
San Antonio	1	2.9	35.5	57.3	4.3
	2	5.0	54.1	31.8	9.1



**Figure 4. Proportion Substrate Types Visually Measured in Surveyed Reaches of the Nacimiento and San Antonio Rivers. No Bedrock was Observed in Either River.**

### Canopy coverage along stream reaches

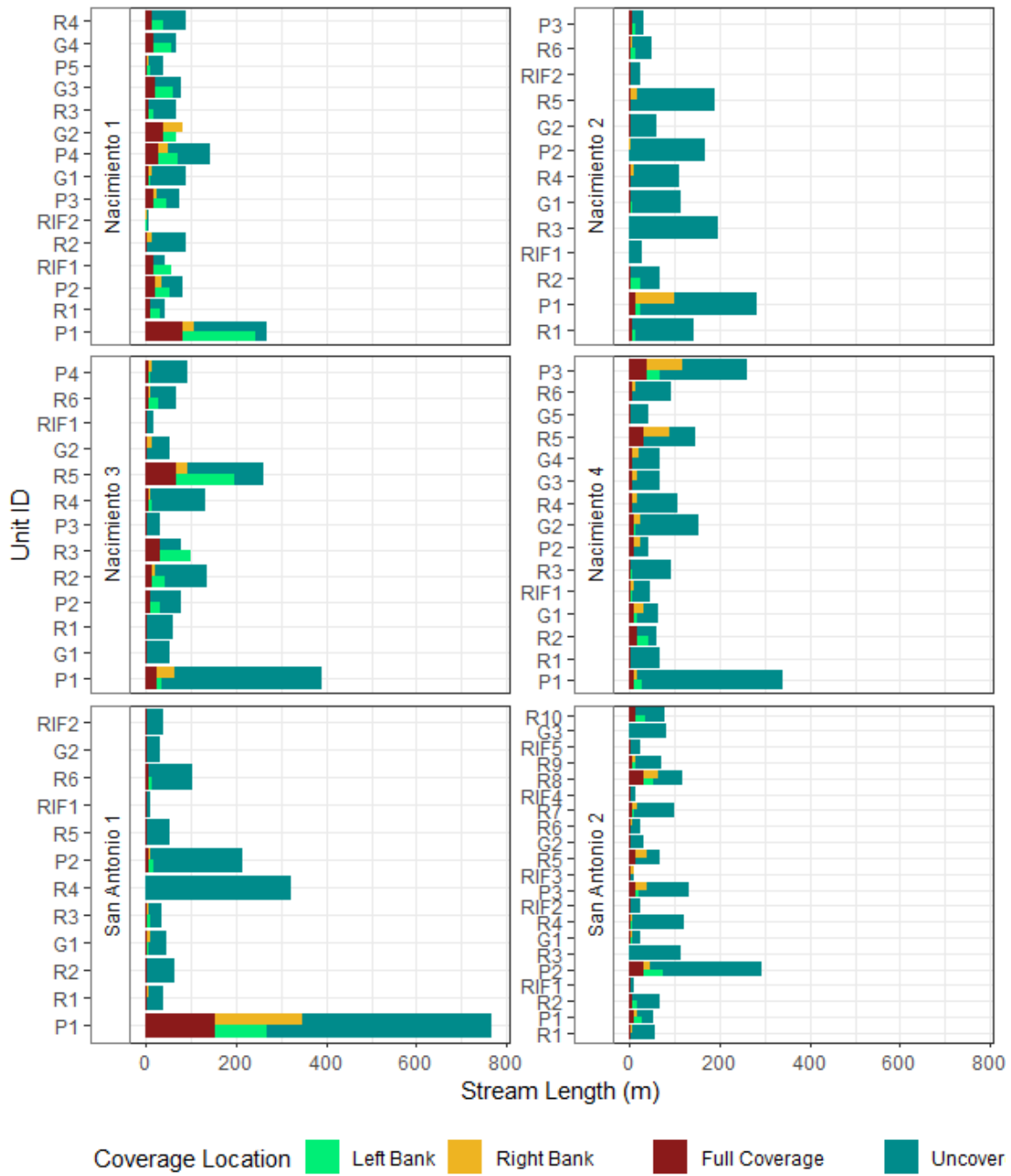


Figure 5. Canopy Coverage along each Channel Unit in the Surveyed Reaches of the Nacimiento and San Antonio Rivers.

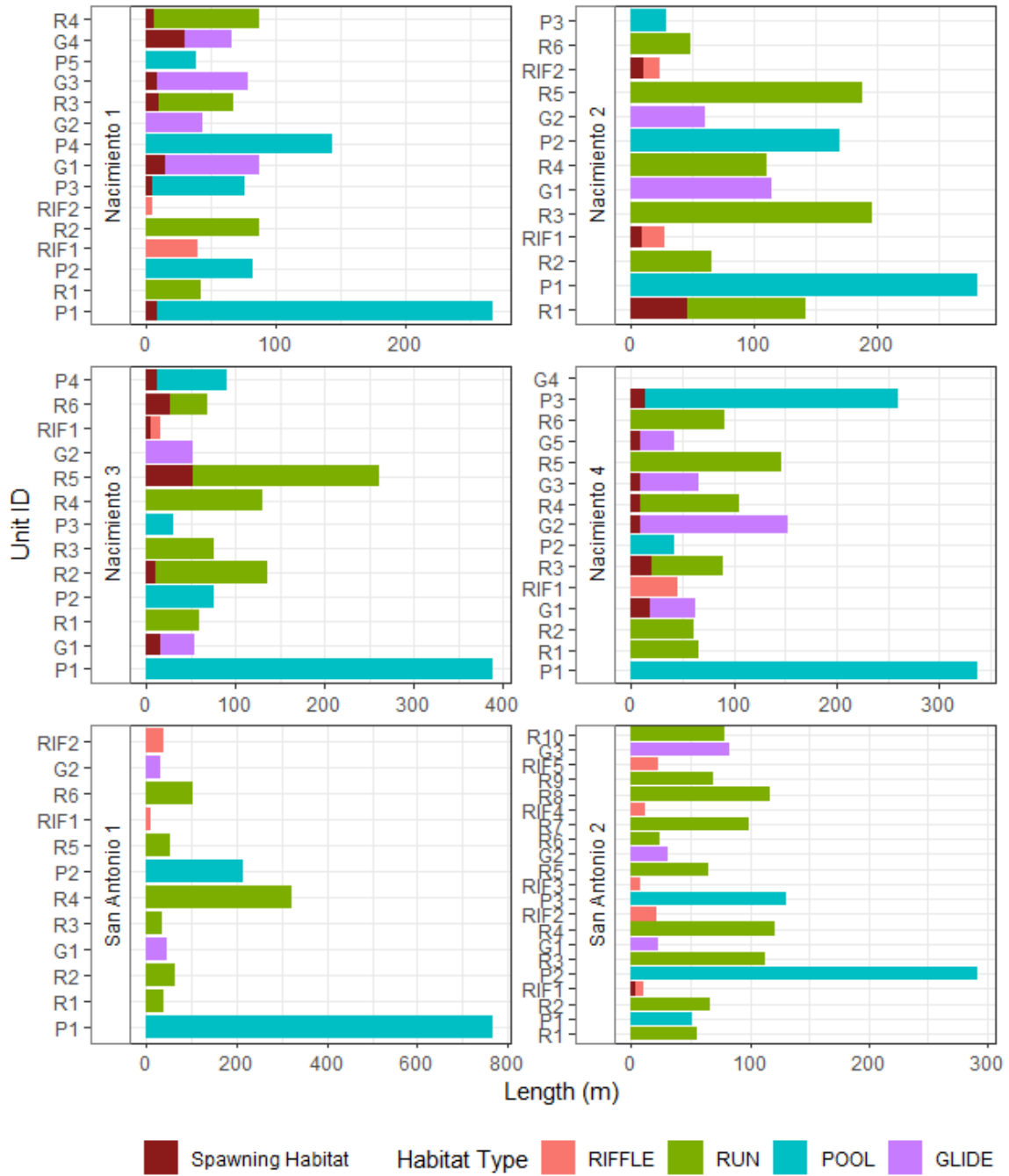


Figure 6. Length of Spawning Habitat Measured in Habitat Types within Reaches in the Nacimiento and San Antonio Rivers.

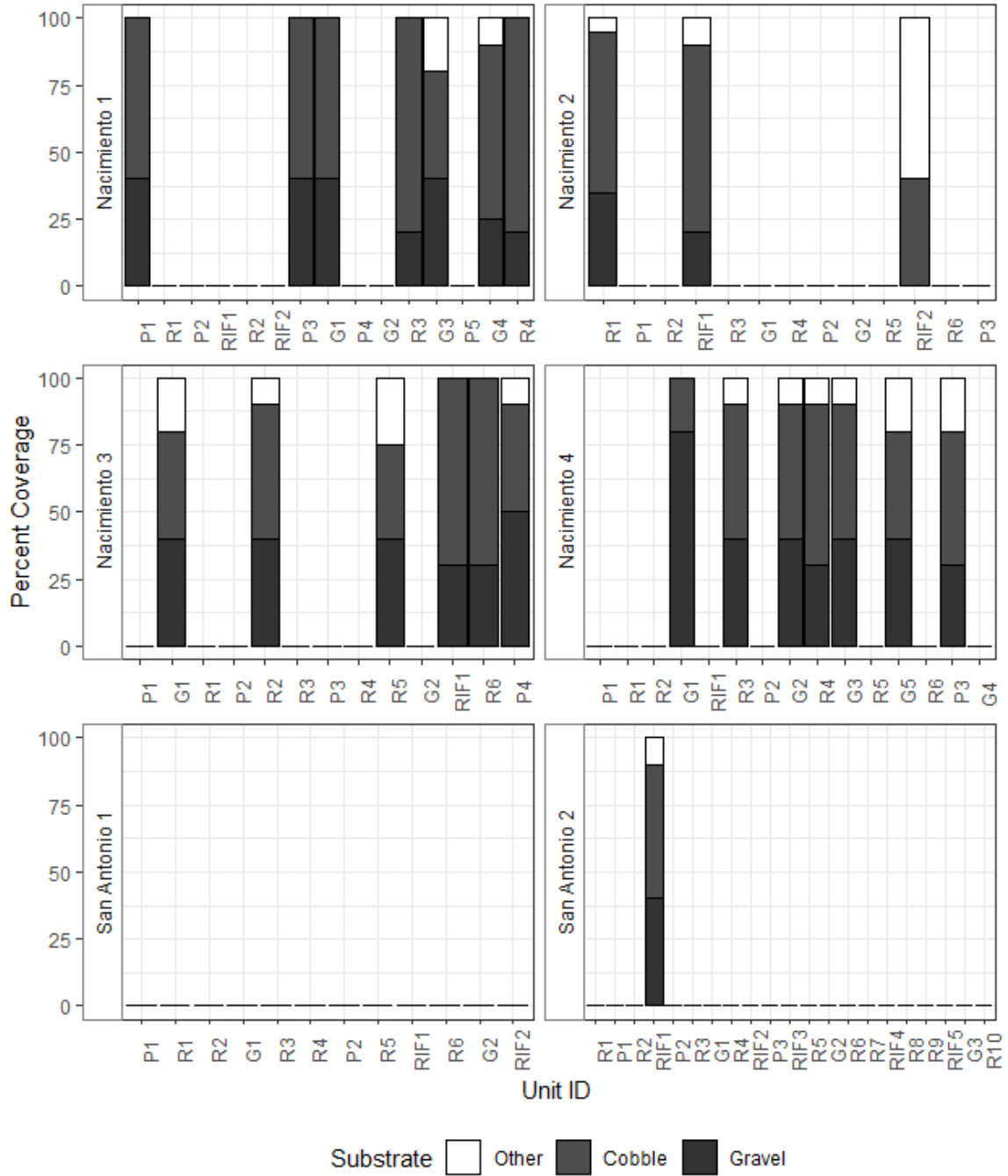


Figure 7. Composition of Spawning Habitat Substrate Identified in each the San Antonio and Nacimiento Rivers.

# Methods

Changes in flow influence the area and characteristics of steelhead habitat and have a direct impact on steelhead life history expression. Quantifying the change in available steelhead spawning and rearing habitat as a function of dam releases was completed using a combination of hydrologic, hydraulic, and habitat suitability modeling tools. The following sections describe the quantitative tools used to model changes in steelhead habitat as a function of dam releases.

## Salinas Valley Operational Model

The Salinas Valley Operational Model (SVOM) was used to simulate reservoir releases from Nacimiento and San Antonio Dams as well as instream flows in the Nacimiento and San Antonio Rivers. The SVOM is based on a historical model, the Salinas Valley Integrated Hydrologic Model (SVIHM), also developed by the U.S. Geological Survey (USGS). Both models are informed by a watershed rainfall-runoff model, USGS’ Salinas Valley Watershed Model (SVWM). Although the SVIHM and SVWM will not be analyzed in detail for this project, the results of these models are central to the SVOM. The SVOM uses historical data from the SVIHM to model changes in water operational strategies. Within the SVOM, reservoir operations, flow prescriptions, and water rights were modified, and model results were compared across scenarios. Modeled instream flows were produced for specific locations within the permit area identified through conversations with the technical team and based on modeling constraints. Mean daily modeled instream flows were then used to estimate spawning and rearing habitat availability in the Nacimiento and San Antonio Rivers for each HCP water management scenario (Table 3) based on instream flows by the model (Table 4). A detailed description of the SVOM methods and preliminary results from the comparison point hydrologic scenarios are described in detail by West-Yost and Associates (2024).

**Table 3. Comparison Point Scenarios Evaluated.**

Scenario	Description
1. <b>Non-Operation:</b> Bypassing All Flows Under Current Physical and Flood Management Constraints	This scenario would demonstrate the condition of flows in the Salinas River if all Nacimiento and San Antonio Reservoir inflows were bypassed (i.e., reservoir inflow is allowed to pass downstream) to the extent feasible given the physical limitations of the dams (e.g., reservoir outlet capacity is limited, no bypass mechanism exists below dead pool) and while upholding flood management responsibilities. This scenario would be compared against Scenario 3 to reveal the impacts (based on a yet-to-be-determined unit of take) associated with operating the reservoirs without consideration of covered species impact minimization. This scenario would also be compared to the final re-operation protocol covered in the HCP to demonstrate that impacts are minimized (as required by 16 United States Code 1539(a)(2)(B)(ii)) and if any impacts remain that require additional mitigation.
2. <b>Current Operations:</b> Procedures Including the 2007 NMFS Biological Opinion Flow Requirements	Operations currently included in MCWRA’s water right. This scenario would provide the environmental baseline for the Section 7 analysis. This scenario would also be used to inform the re-operation protocol based on current best available data.
3. <b>Current Operations:</b> Procedures Excluding the 2007 NMFS Biological Opinion Flow Requirements	This scenario would represent the “core” covered activity for the HCP, representing the water users’ preference in dam operation, including April–October Salinas River Diversion Facility operation, but not considering covered species habitat needs.

**Table 4. Summary Statistics of the Comparison Point Hydrologic Scenarios for Each Surveyed Reach in the Nacimiento and San Antonio Rivers.**

River	Reach	Flow Scenario	Flow (cfs)		
			Minimum	Mean	Maximum
Nacimiento River	Reach 1	Current Operations	0	160	10,799
		No Flow Prescription	0	159	12,057
		No Operations	0	273	17,466
	Reach 2	Current Operations	0	160	10,799
		No Flow Prescription	0	159	12,057
		No Operations	0	273	17,466
	Reach 3	Current Operations	0	160	10,799
		No Flow Prescription	0	159	12,057
		No Operations	0	273	17,466
	Reach 4	Current Operations	0.2	165	10,774
		No Flow Prescription	0.2	164	12,102
		No Operations	0	277	17,524
San Antonio River	Reach 1	Current Operations	0	167	3,158
		No Flow Prescription	0	160	4,453
		No Operations	0	97	1,558
	Reach 2	Current Operations	1	183	3,276
		No Flow Prescription	1	175	4,659
		No Operations	0.5	110	1,771

## U.S. Army Corps of Engineers Hydraulic Engineering Center’s River Analysis System Hydraulic Model

A one-dimensional (1-D) hydraulic model from the USACE Hydraulic Engineering Center’s River Analysis System (USACE, HEC n.d.) was used to simulate changes in channel conditions including depth, velocity, and wetted area as a function of river discharge. HEC-RAS has the capability of simulating 1-D or 2-D unsteady flows in river systems. For the purposes of the HCP analysis, a 1-D model was used due of the coarseness of the surrounding elevation data sources. The model was calibrated using site-specific channel geometry derived from instream channel profile measurements, estimates of channel roughness, water releases from the dams, tributary inputs, and meteorological conditions. Lidar of the area surrounding the surveyed transects was used to further refine the HEC-RAS model and calibrate results (Figure 8).

Stream channel profile measurements were collected using the California Department of Fish and Wildlife (CDFW) *Standard Operating Procedures for Streambed and Water Surface Elevation Data Collection in California* (California Department of Fish and Wildlife 2013) (Figure 9). The data collected as part of this process included water surface elevations, wetted streambed elevations, bankfull discharge elevations, mean water column velocities, and substrate and cover classifications (Holmes and Cowan 2014) during low- and high-flow conditions. Measurements were taken in the Nacimiento River on April 26 and 27 and June 5 and 6, 2023. Measurements were collected on the San Antonio River on June 13 and 14, 2023.

Daily estimates of streamflow for each transect location measured in the field were extracted from the corresponding location in the SVOM (Table 5) for all scenarios listed in Table 3 for water years

1968 to 2018 and compiled. These compiled data were then applied to the HEC-RAS model to estimate changes in water surface elevation, surface area, depth, and velocity in spawning and rearing habitats in the lower Nacimiento and San Antonio Rivers (Table 6).

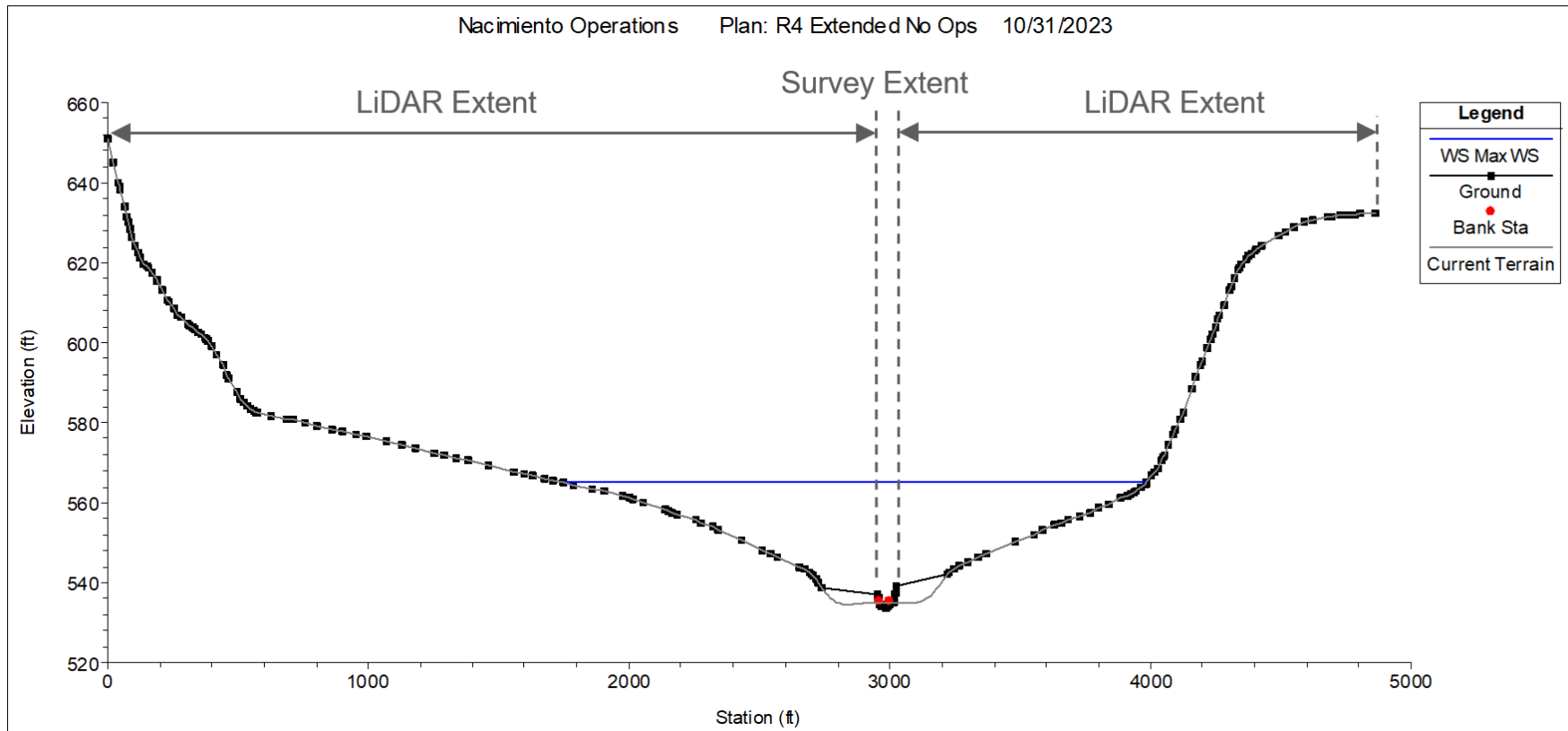


Figure 8. Example of Channel Cross Section Combining Channel Elevation from Lidar and Field Surveys.

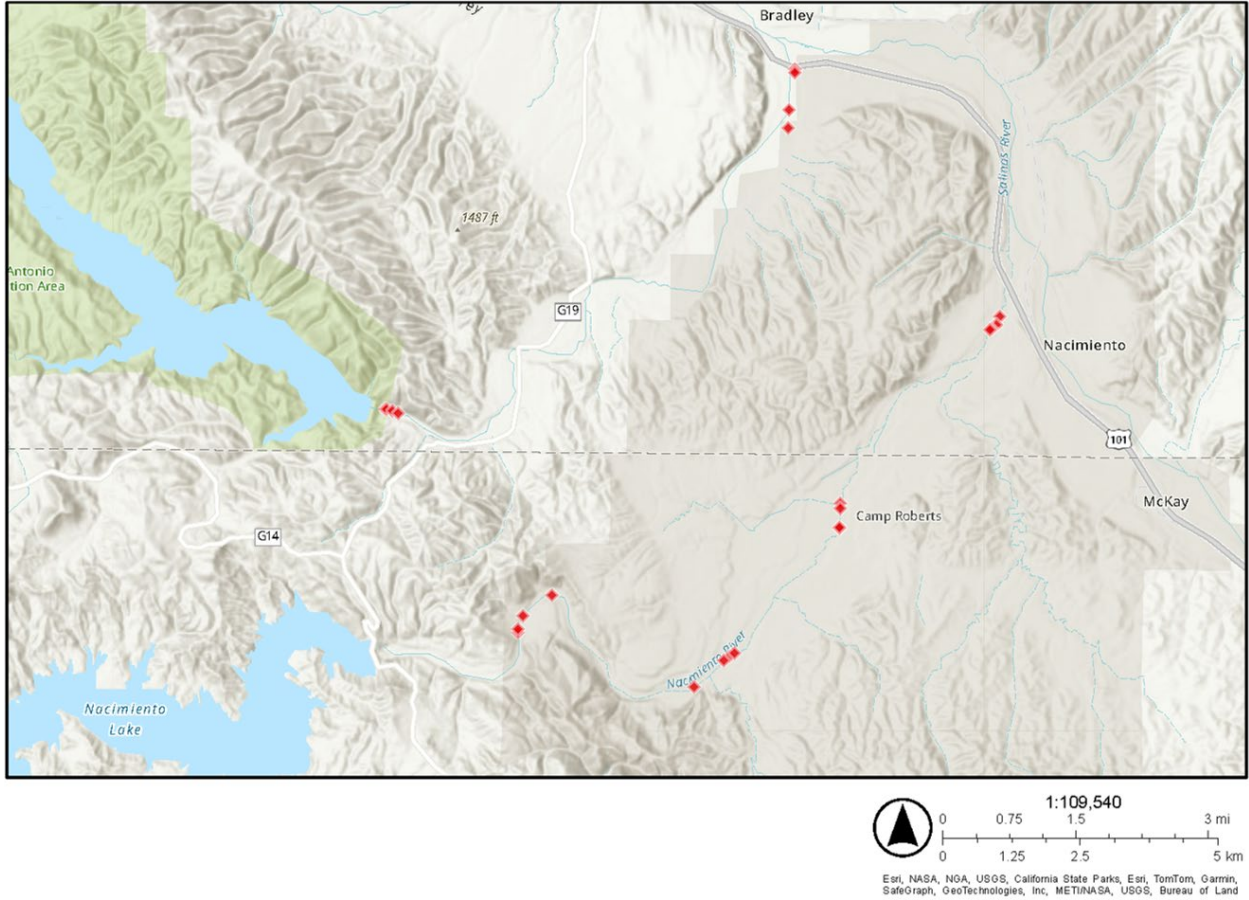


Figure 9. Locations of Instream Channel Transects within the Study Area.

Table 5. Locations of Channel Transects Measured in the Nacimiento and San Antonio Rivers.

River	Reach	Transect	Latitude	Longitude	SVOM Point	Meso-Habitat Type	Interpolated Flow at Time of Survey (cfs)
Nacimiento	1	R1-R4	35.762527	-120.855752	S025R01	Run	60.9
	1	R1-G4	35.763078	-120.855797	S025R01	Glide	73.7
	1	R1-P5	35.765201	-120.854717	S025R01	Pool	73.7
	1	R1-F2	35.768667	-120.848992	S025R01	Riffle	75.9
	2	R2-R3	35.758634	-120.813161	S025R01	Run	73.7
	2	R2-G1	35.757926	-120.814272	S025R01	Glide	73.7
	2	R2-F1	35.7592	-120.81206	S025R01	Riffle	60.9
	2	R2-P3	35.75361	-120.82034	S025R01	Pool	58.8
	3	R3-F1	35.779532	-120.791033	S025R01	Riffle	58.8
	3	R3-G2	35.779686	-120.790969	S025R01	Glide	58.8
	3	R3-P3	35.78358	-120.79084	S025R01	Pool	58.8
	3	R3-P4	35.78276	-120.79084	S025R01	Pool	58.8
	4	R4-P1	35.814117	-120.758703	S028R07	Pool	58.8
	4	R4-R1	35.812853	-120.759251	S028R05	Run	58.8
	4	R4-G1	35.812195	-120.760342	S028R05	Glide	60.9
4	R4-F1	35.811964	-120.760682	S028R04	Riffle	60.9	

San Antonio	1	R1-F2	35.799017	-120.882597	S052R03	Riffle	14.7
	1	R1-G2	35.799079	-120.882206	S052R03	Glide	12.7
	1	R1-R6	35.798708	-120.881169	S052R04	Run	11
	1	R1-P2	35.79834	-120.879957	S052R04	Pool	11.2
	2	R2-R1	35.854605	-120.799979	S058R52	Run	8.9
	2	R2-P1	35.853949	-120.799995	S058R51	Pool	8.9
	2	R2-G1	35.844967	-120.801214	S058R44	Glide	6.2
	2	R2-F3	35.847974	-120.801084	S058R46	Riffle	9

**Table 6. One Dimensional HEC-RAS Calibration Statistics for Each Field Measured Channel Transect in the Nacimientto and San Antonio River.**

River	Reach	Habitat	Name	Slope for Normal Depth Boundary Condition	Invert Elevation (feet)	Manning's Roughness Coefficient		
						Left Bank	Channel	Right Bank
Nacimientto River	Reach 1	Run	R1 R4	0.006	592.79	0.1	0.06	0.07
		Glide	R1 G4		593.24	0.1	0.06	0.08
		Pool	R1 P5		591.87	-	0.045	-
		Riffle	R1 F2		590.05	0.085	0.045	0.085
	Reach 2	Pool	R2 P3	0.01	572.13	0.1	0.06	0.1
		Glide	R2 G1		571.56	0.085	0.04	0.08
		Run	R2 R3		570.63	0.06	0.04	0.09
		Riffle	R2 F1		570.78	0.05	0.04	0.1
	Reach 3	Riffle	R3 F1	0.0001	560.45	0.1	0.04	0.1
		Glide	R3 G2		559.69	0.1	0.06	0.1
		Run	R3 R4		558.86	0.095	0.04	0.095
		Pool	R3 P3		556.82	0.1	0.08	0.1
	Reach 4	Riffle	R4 F1	0.00006	535.26	0.057	0.06	0.085
		Glide	R4 G1		533.73	0.065	0.06	0.1
		Run	R4 R1		533.71	0.09	0.04	0.09
		Pool	R4 P1		532.06	0.1	0.1	0.095
San Antonio River	Reach 1	Riffle	R1 F2	0.000035	589.36	0.057	0.04	0.055
		Glide	R1 G2		589.18	0.075	0.05	0.055
		Pun	R1 R6		588.64	0.08	0.05	0.06
		Pool	R1 P1		587.97	0.097	0.07	0.097
	Reach 2	Riffle	R2 F3	0.00003	501.25	0.07	0.045	0.095
		Glide	R2 G1		499.85	0.045	0.04	0.045
		Pool	R2 P1		498.40	0.095	0.06	0.06
		Run	R2 R1		498.50	0.09	0.035	0.06

## Steelhead Habitat Model

Output from the HEC-RAS model was then characterized using rearing and spawning habitat suitability indices (HSI) from the applicable literature (Table 7). Data from the HSI curves cited in Table 7 were digitized using a plot digitization software<sup>1</sup> (Figure 10 and Figure 11). Hydraulic model outputs of depth and velocity were then translated into HSI values using general additive models

<sup>1</sup> <https://plotdigitizer.com/>

(GAM) fit to the digitized curve data from the referenced studies in Table 7. In most cases, the GAM were fit to explain nearly 100% of the variance observed in the digitized HSI data (see Appendix A, *HSC Generalized Additive Model Fits*), meaning the models were appropriate tools to quantitatively relate depth and velocity estimates from the hydraulic model to the literature-derived HSI curves. Additional GAM results are included in Appendix A. For rearing fry and juvenile steelhead, a composite HSI for each depth and velocity estimate was then calculated by averaging the suitability ratings derived from each study curve. For spawners, HSI data from the Big Sur River were used to classify habitat suitability. By relating depth and velocity outputs from the hydraulic model to HSI values habitat can be weighted on a scale of 0 to 1, with 1 being the most suitable.

It was necessary to develop a relationship between weighted usable area (WUA) and discharge to determine how habitat suitability varied among the HCP operational scenarios. First, WUA was calculated by multiplying the product of the life stage HSI values calculated for depth and velocity by area (square feet), which was expressed as the quotient of cross-sectional discharge (cfs) and velocity (feet per second) (Equation 1). WUA was calculated for the range of flows observed in the three comparison point scenarios (Table 4) using flow increments of 50 cfs (Figure 12 and Figure 13). These data were then used to fit life stage-specific GAMs for each transect (Appendix B, *WUA Generalized Additive Model Fits*, provides model fit results). These quantitative models were then used to estimate WUA based on cross-sectional discharge estimates from the hydraulic model for each data point in the comparison point scenarios summarized by month and water year type (Figure 14). WUA was then extrapolated to the reach scale by multiplying transect-specific WUA estimates by the sum of channel unit length in each reach (Table 5). The relationship between WUA and flow was also used to evaluate minimum dam releases and provide recommendations about the minimum flows to provide as part of the HCP protocols.

**Equation 1. Equation for Calculating Weighted Usable Area per Transect using Habitat Suitability Indices**

$$(HSI_v \times HSI_d) \times \left( \frac{Q_{xs}}{V_{fps}} \right) = WUA$$

Where:  $HSI_v$  = Habitat Suitability Index, velocity  
 $HSI_d$  = Habitat Suitability Index, depth  
 $Q_{xs}$  = Cross sectional discharge (cfs)  
 $V_{fps}$  = Cross sectional velocity (fps)  
 $WUA$  = weighted usable area (ft<sup>2</sup>)

**Table 7. California Studies Used to Evaluate Rearing Habitat Conditions in the Lower Nacimiento and San Antonio Rivers.**

Study River	Life Stages Evaluated	Citation
Trinity River	Juvenile, Fry	Hampton (1997)
Klamath River	Juvenile, Fry	Hardy and Addley (2001)
Big Sur	Juvenile, Fry	Holmes and Cowan (2014)
Multiple	Juvenile, Fry	Bovee (1978)
Hollow Tree	Juvenile, Fry	Gephart et al. (2020)
Big Sur	Spawners	Holmes et al. (2014) <sup>2</sup>

<sup>2</sup> Data was provided by R.W. Holmes via email on September 13, 2023.

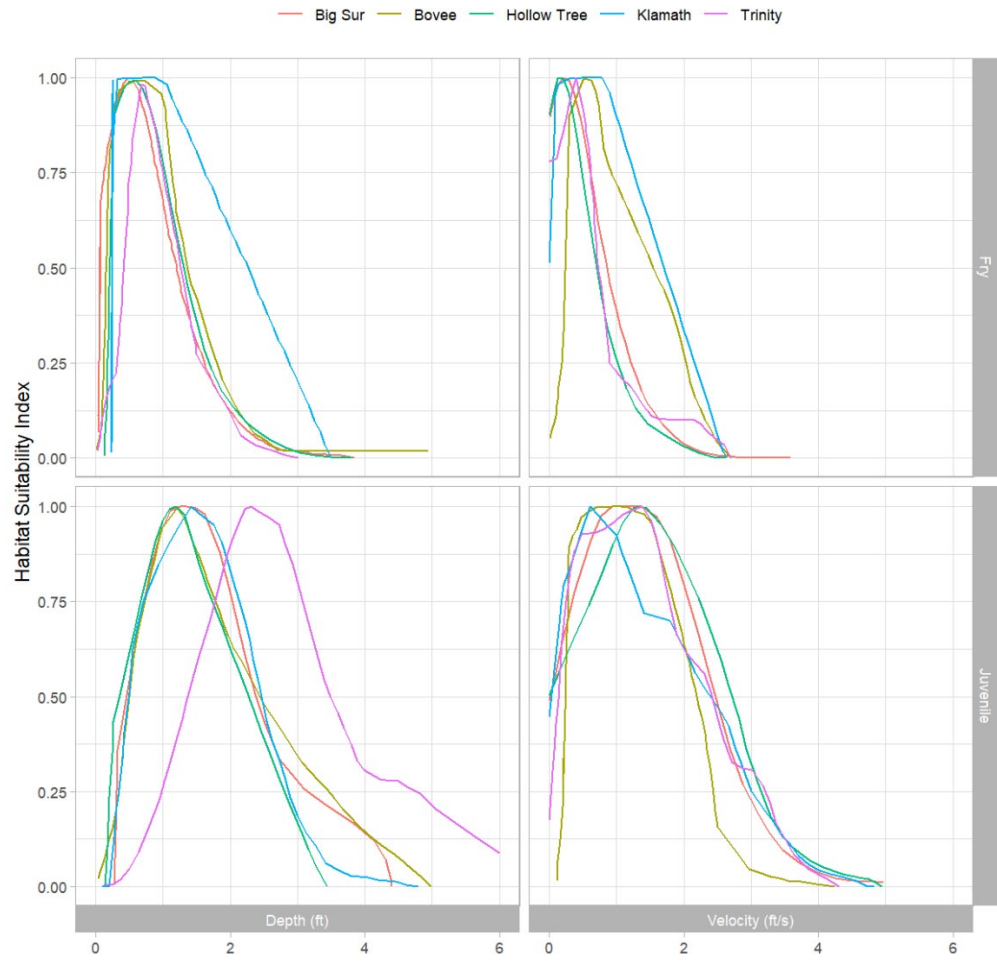
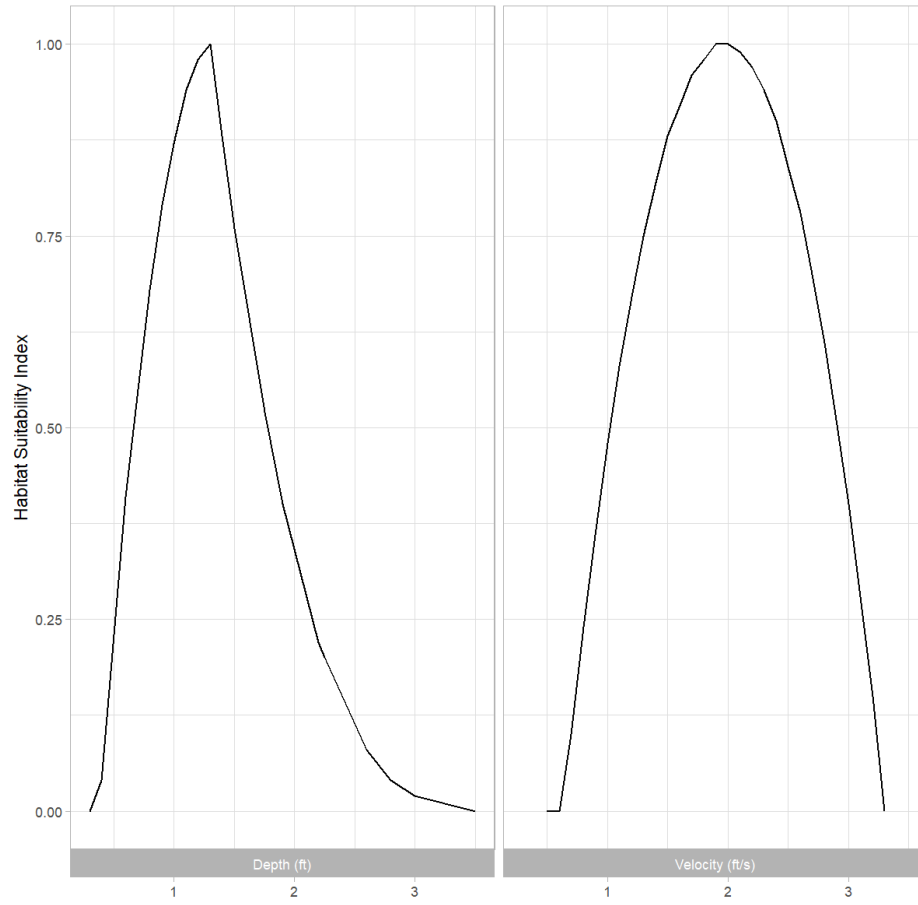
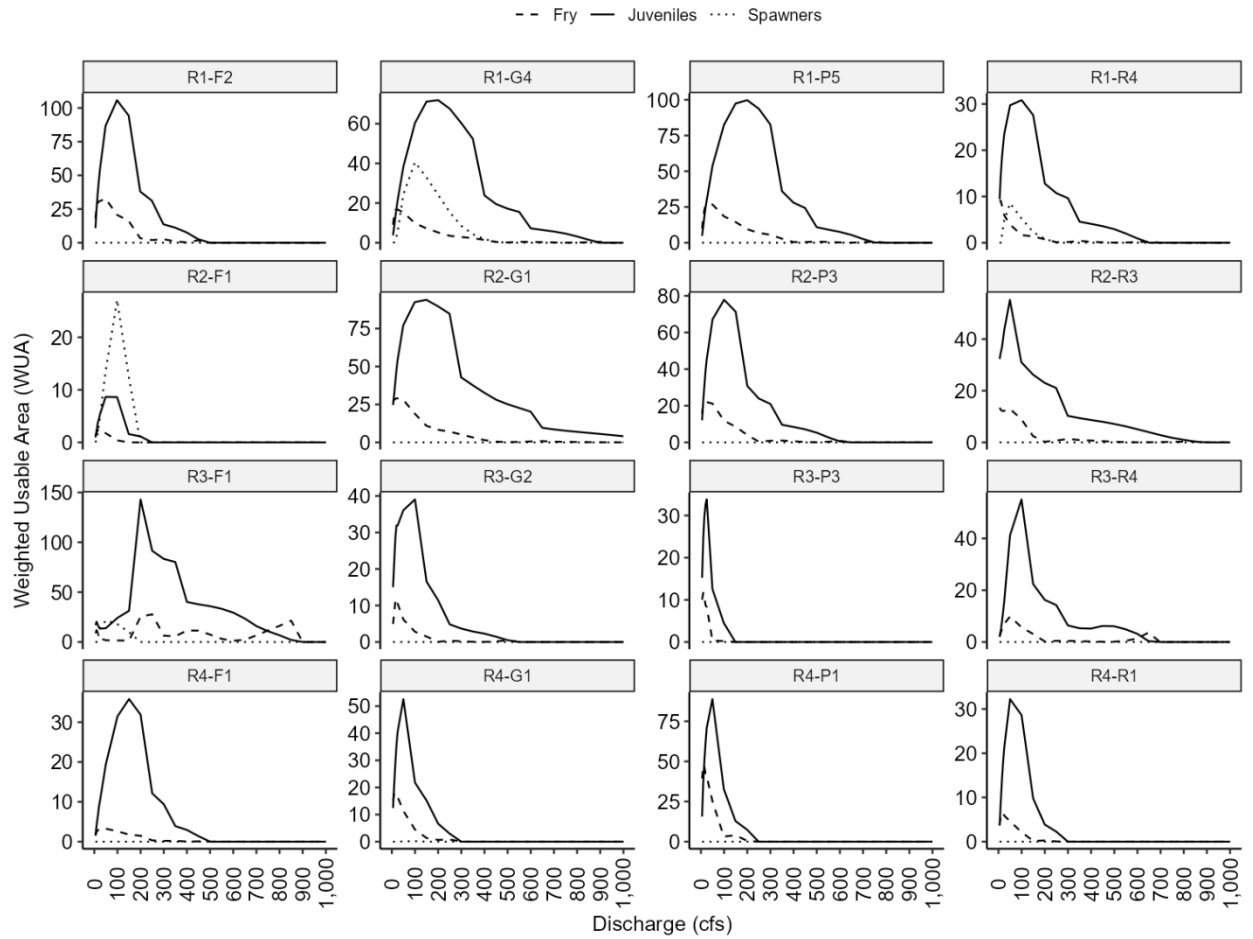


Figure 10. Habitat Suitability Criteria for Juvenile and Fry Life Stages Derived from the Studies Listed in Table 7.



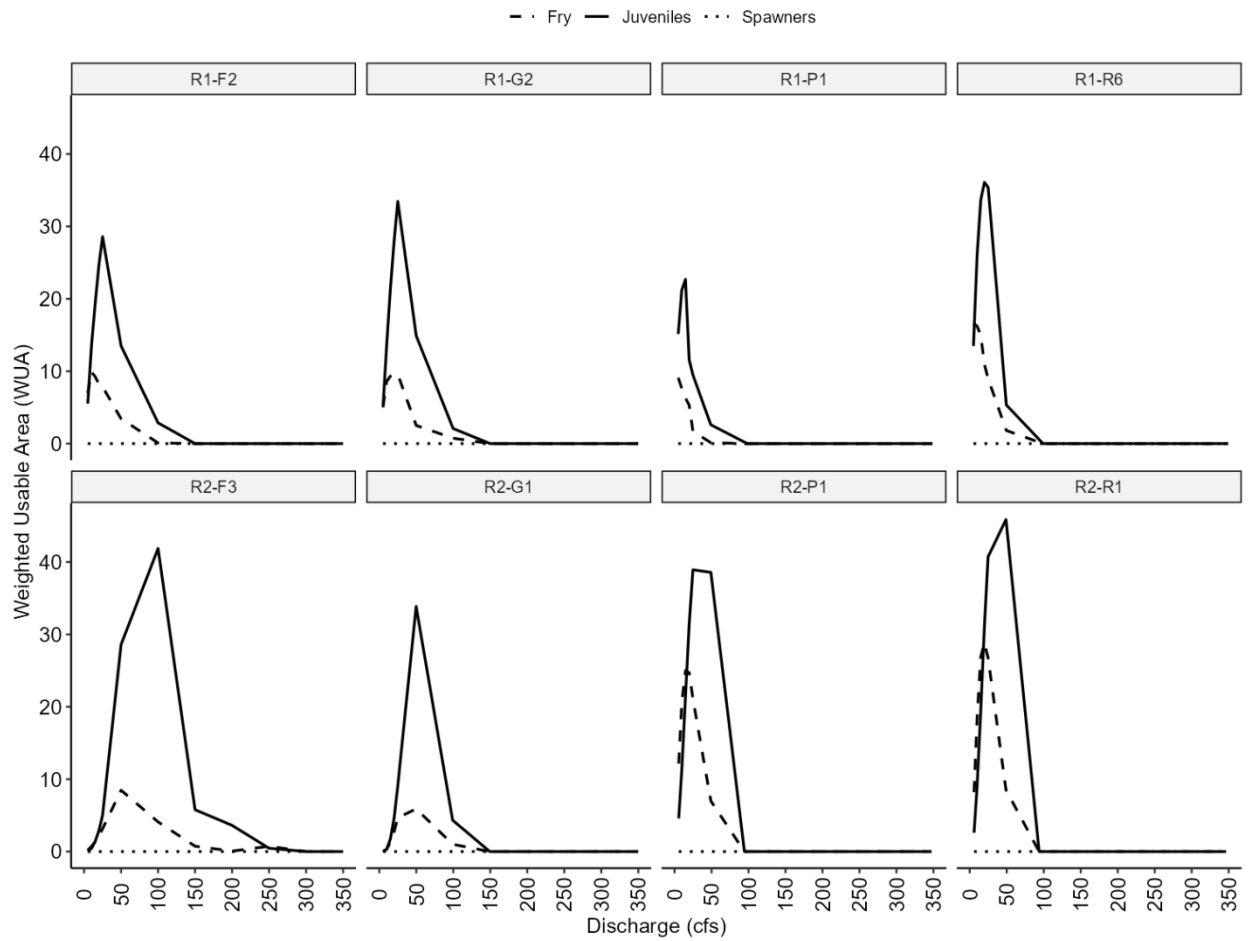
**Figure 11. Habitat Suitability Criteria for Spawning Adult Life Stage Derived from the Studies in Table 7.**

Nacimientto River

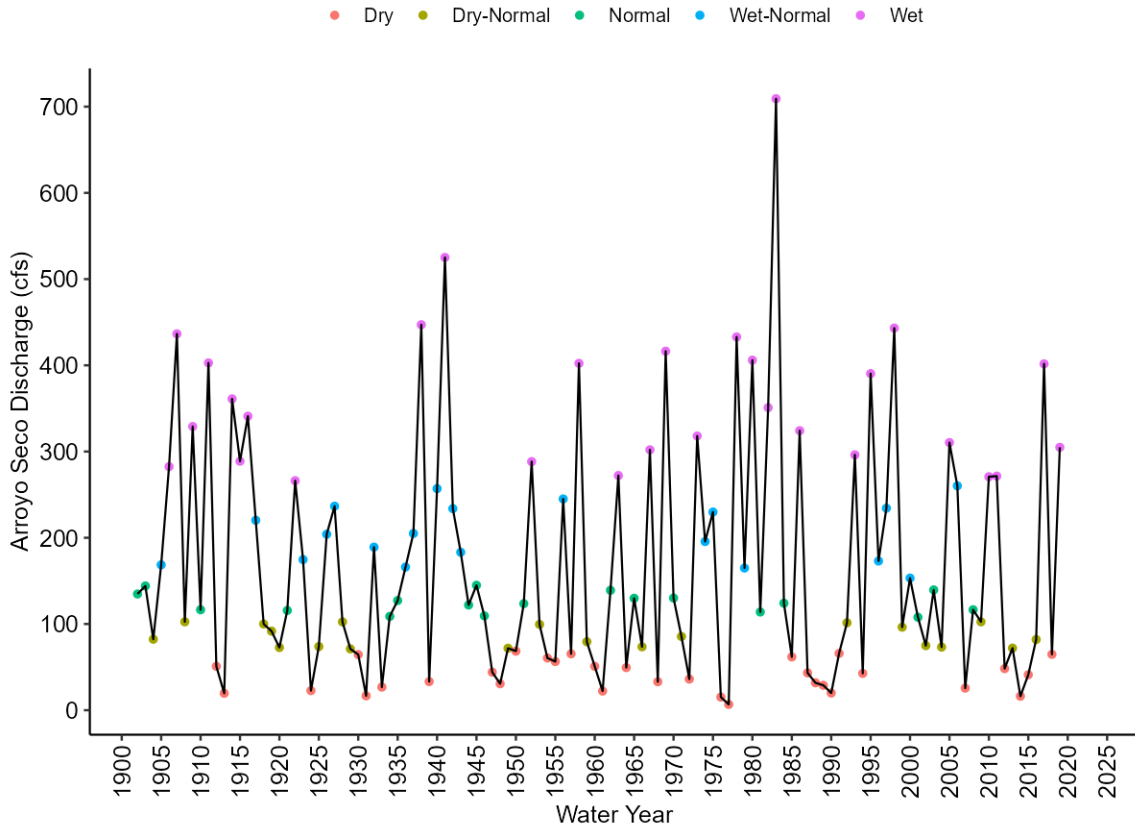


**Figure 12. Life Stage–Specific Weighted Usable Area as a Function of Cross-Sectional Discharge at Each Field-Measured Transect Location in the Lower Nacimientto River. The X-Axis is Truncated to 1,000 cfs to Highlight Relationship; WUA Declines to Zero when Flows Exceed 1,000 cfs.**

San Antonio River



**Figure 13. Weighted Usable Area as a Function of Cross-Sectional Discharge at each Field-Measured Transect Location in the Lower San Antonio River. X-axis was truncated to 250 cfs to highlight relationship.**



**Figure 14. Water Year Types from 1902 to 2023 Categorized based on Arroyo Seco Discharges (cfs).**

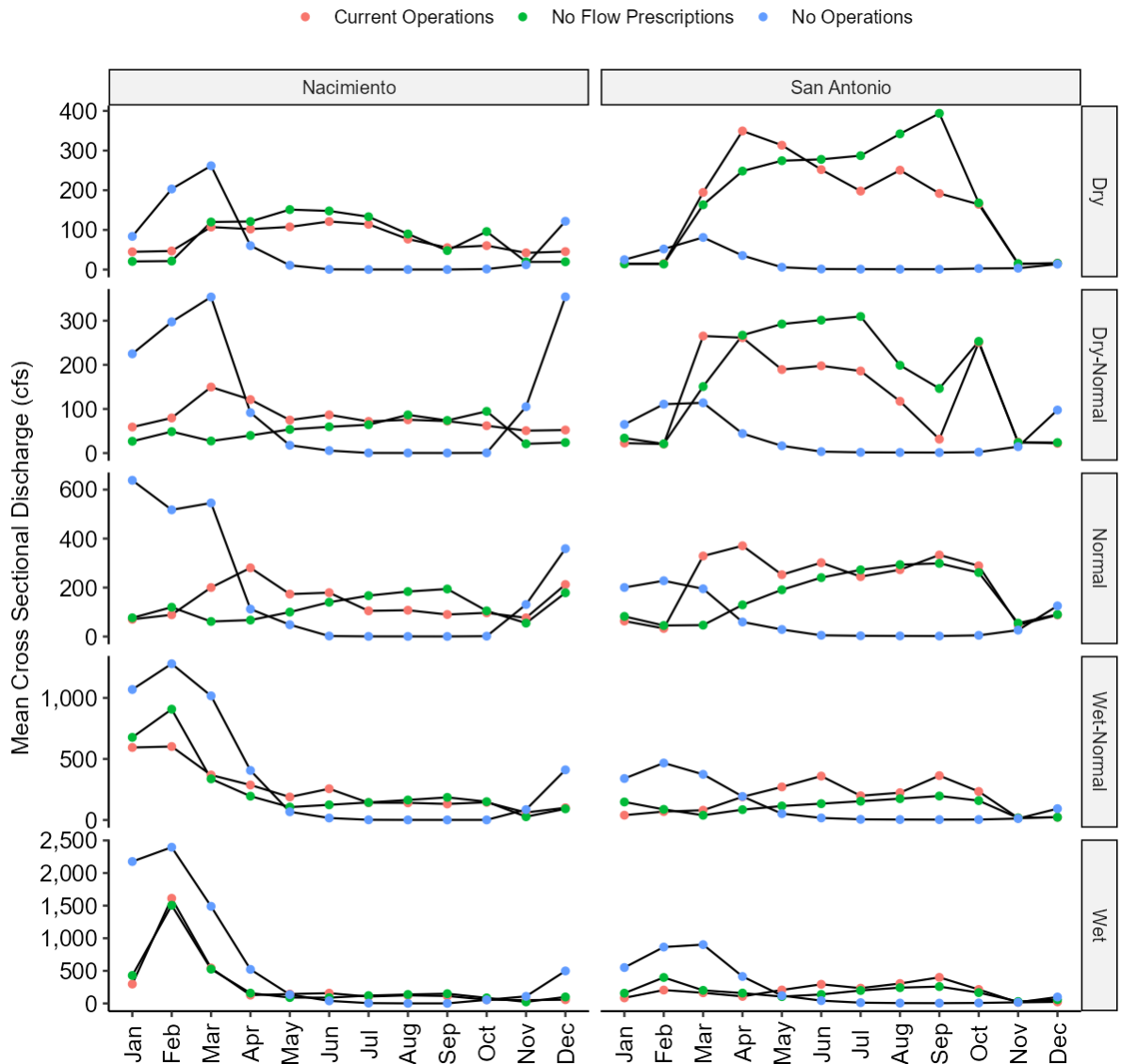
**Table 8. Length of Mesohabitat Unit Types Measured in Lower Nacimiento and San Antonio River Reaches in 2023.**

Stream Reach	Riffle Length (ft)	Run Length (ft)	Pool Length (ft)	Glide Length (ft)
Nacimiento 1	148	931	1,990	903
Nacimiento 2	162	2,456	1,575	571
Nacimiento 3	51	2,402	1,927	345
Nacimiento 4	149	1,833	2,098	1,282
San Antonio 1	161	1,998	3,224	243
San Antonio 2	246	2,653	1,558	447

# Results

## Evaluation of Comparison Point Scenarios

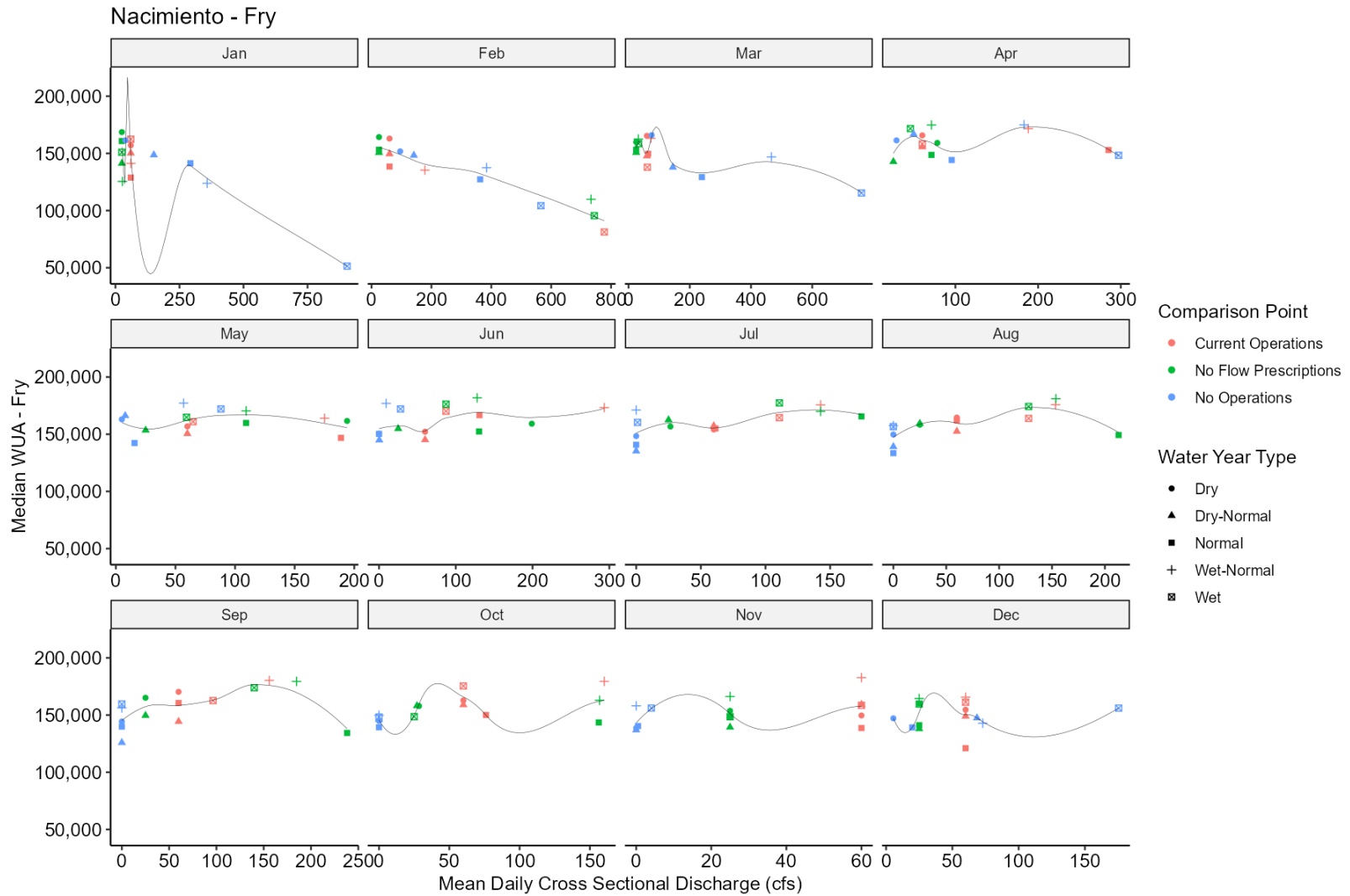
Model results were compiled for fry, juvenile, and spawning steelhead life stages in each river for all scenarios (Table 3) and water year types (Figure 14). Mean monthly discharges modeled at transects in the Nacimiento River tended to experience greater variability under the No Operations scenario compared to Current Conditions and No Flow Prescription scenarios (Figure 15). In both the Nacimiento and San Antonio Rivers mean daily flows were higher in the summer months under the Current Conditions and No Flow Prescription scenarios compared to the No Operations scenario. This trend is consistent with MCWRA strategy to store water from winter storms and release water during the spring and summer for groundwater recharge and operation of the SRDF.



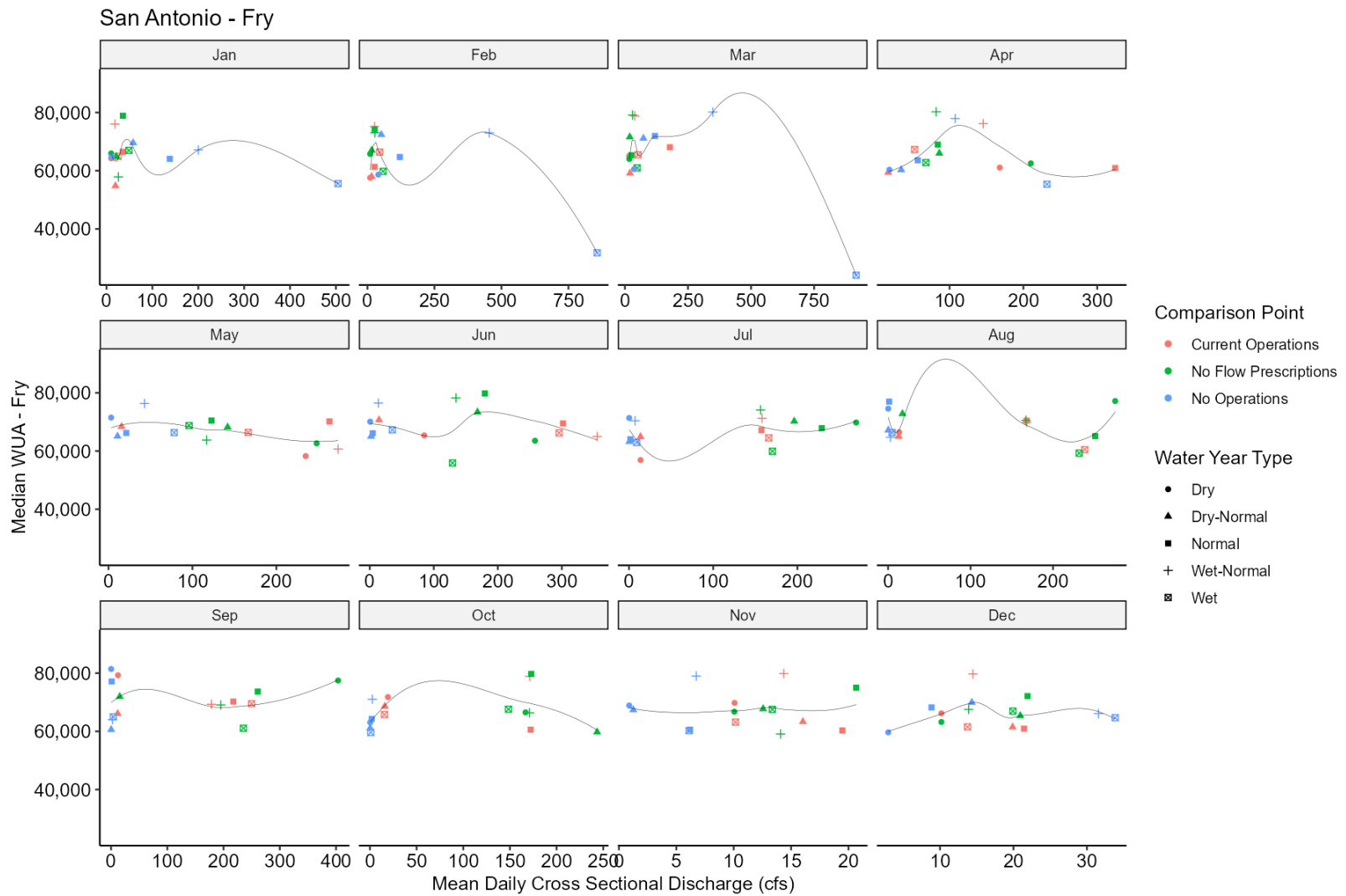
**Figure 15. Mean Cross Sectional Discharge (cfs) at Nacimiento and San Antonio Transects by Water Year Types and Comparison Point Scenarios.**

## **Fry**

Steelhead fry habitat modeling results expressed as WUA for the Nacimiento and San Antonio Rivers are presented in Figure 16, Figure 17, Table 9, and Table 10. Water year type median monthly WUA varies slightly among scenarios but are generally similar. This is true for both rivers. Interestingly, in both rivers, median WUA is lowest in January and February of wet years under the No Operations scenario (Figure 16 and Figure 17). Steelhead fry are more sensitive to higher velocities and deeper water, which could explain the lower WUA values during wet years in the winter when flows are presumably higher.



**Figure 16. Mean Total Daily Weighted Usable Area for Steelhead Fry in the Nacimiento River Summarized by Month, Water Type, and Comparison Point Scenarios. Smoothed Best Fit Trend Lines are Included in Each Panel.**



**Figure 17. Mean Total Daily Weighted Usable Area for Steelhead Fry in the San Antonio River Summarized by Month, Water Type, and Comparison Point Scenarios. Smoothed Best Fit Trend Lines are Included in Each Panel.**

**Table 9. Summary of Mean Daily Weighted Usable Area for Fry Steelhead in the Lower Nacimiento River. Cell Color Indicates which Scenario had the Highest Mean Value.**

Month	Dry	Dry-Normal	Normal	Wet-Normal	Wet
Jan	168,597	150,196	160,784	141,224	162,400
Feb	164,252	150,674	153,177	137,487	104,235
Mar	165,945	150,717	153,154	163,233	158,574
Apr	165,750	166,856	152,923	174,989	171,684
May	163,019	166,200	159,832	177,149	172,117
Jun	159,181	154,840	166,619	181,789	176,301
Jul	156,738	162,535	165,586	175,597	177,403
Aug	164,553	159,316	162,021	181,018	174,224
Sep	170,292	149,616	160,554	180,277	173,901
Oct	162,776	158,975	150,044	179,418	175,413
Nov	153,701	159,237	148,227	182,715	158,473
Dec	160,016	148,997	141,112	165,592	161,248
Current Operations		No Flow Prescriptions		No Operations	

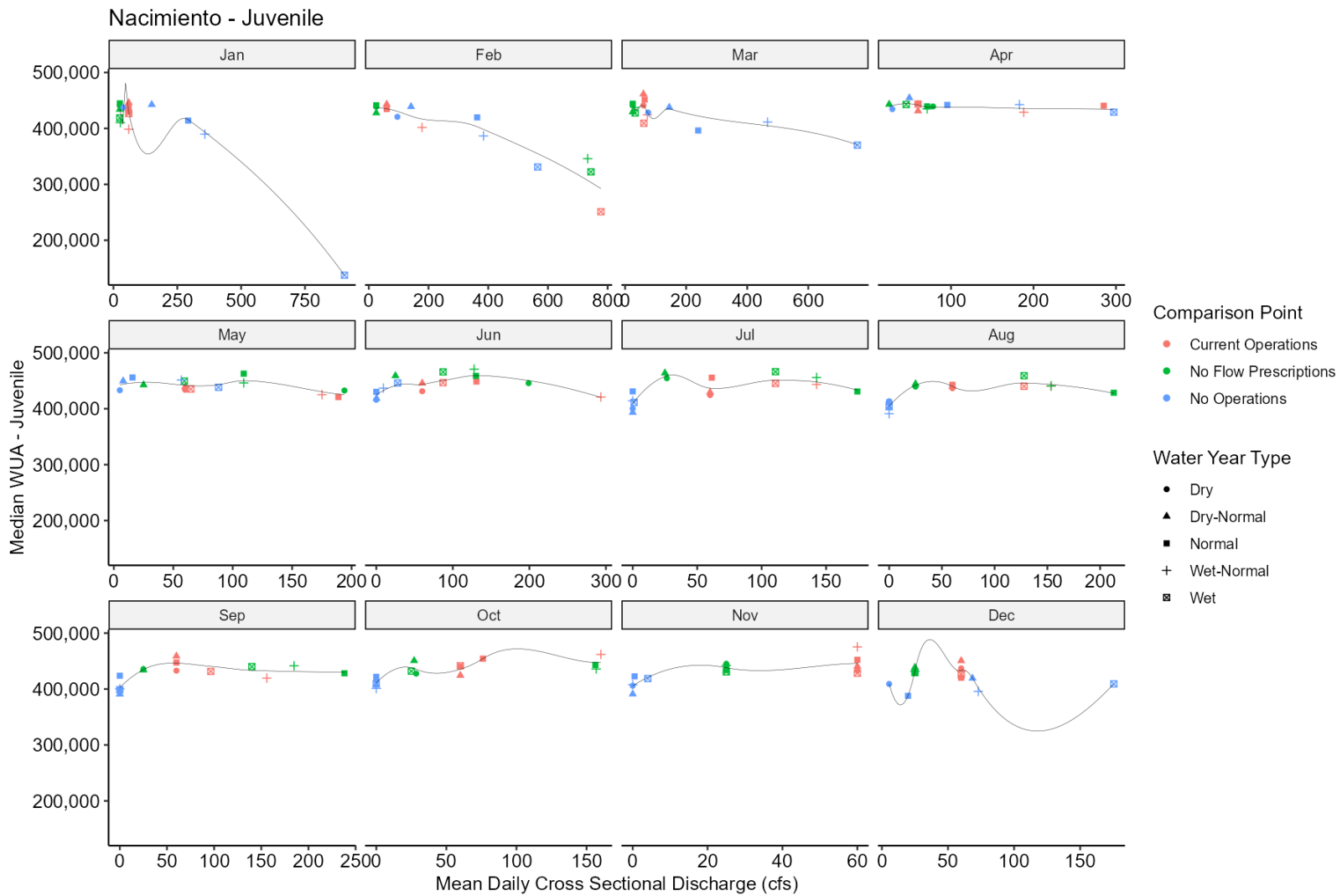
**Table 10. Summary of Mean Daily Weighted Usable Area for Fry Steelhead in the Lower San Antonio River. Cell Color Indicates which Scenario had the Highest Mean Value.**

Month	Dry	Dry-Normal	Normal	Wet-Normal	Wet
Jan	65,955	69,579	78,881	76,044	66,982
Feb	65,765	72,391	74,260	75,175	66,410
Mar	65,035	71,597	71,932	80,168	65,492
Apr	62,527	65,998	68,961	80,258	67,299
May	71,497	68,376	70,453	76,338	68,755
Jun	70,092	73,371	79,806	78,242	67,265
Jul	71,362	70,236	67,854	74,109	64,532
Aug	77,171	72,806	76,988	70,580	66,354
Sep	81,420	71,926	77,145	69,284	69,497
Oct	71,778	68,603	79,728	78,871	67,601
Nov	69,782	67,720	74,998	79,853	67,542

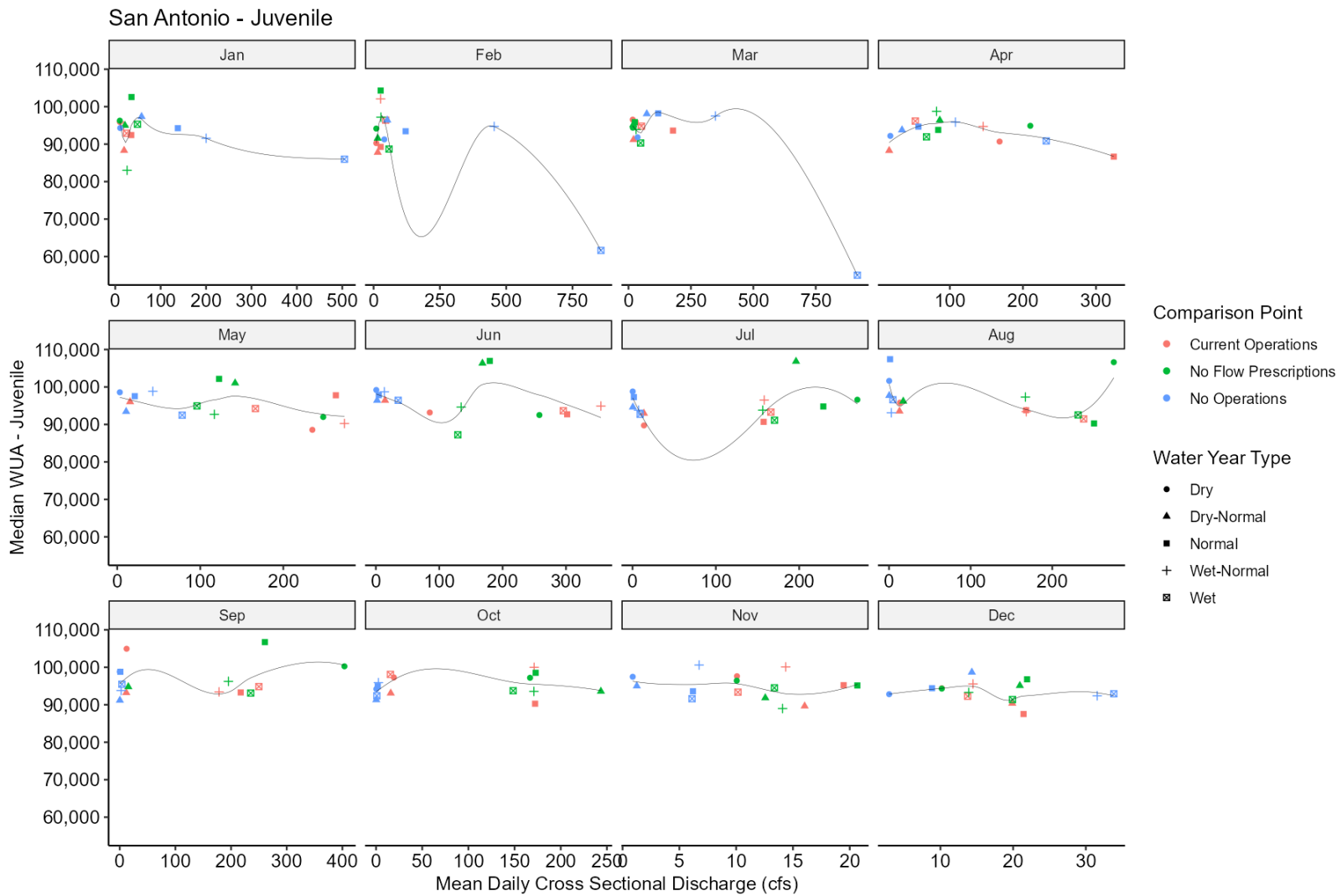
Dec	66,208	69,940	72,101	79,753	66,941
Current Operations		No Flow Prescriptions		No Operations	

## Juveniles

Steelhead juveniles habitat modeling results expressed as WUA for the Nacimiento and San Antonio Rivers are presented in Figure 18, Figure 19, Table 11, and Table 12. Water year type median monthly WUA varies slightly among scenarios but are generally similar. This is true for both rivers.



**Figure 18. Mean Total Daily Weighted Usable Area for Steelhead Juveniles in the Nacimiento River Summarized by Month, Water Type, and Comparison Point Scenarios. Smoothed Best Fit Trend Lines are Included in Each Panel.**



**Figure 19. Mean Total Daily Weighted Usable Area for Steelhead Juveniles in the San Antonio River Summarized by Month, Water Type, and Comparison Point Scenarios.**

**Table 11. Summary of Mean Daily Weighted Usable Area for Juvenile Steelhead in the Lower Nacimiento River. Cell Color Indicates the Scenario with the Highest Mean Value.**

Month	Dry	Dry-Normal	Normal	Wet-Normal	Wet
Jan	440,440	445,993	444,828	410,314	426,737
Feb	438,965	443,201	441,412	401,750	331,090
Mar	443,134	461,588	451,603	437,513	427,576
Apr	444,933	454,572	442,104	442,601	443,486
May	433,917	449,710	462,762	451,350	449,484
Jun	445,762	458,896	458,705	470,833	465,885
Jul	454,548	463,810	455,591	455,955	466,275
Aug	439,564	444,442	442,809	440,941	459,031
Sep	435,524	458,855	447,312	441,535	440,131
Oct	440,156	450,814	454,347	461,918	441,716
Nov	445,080	440,477	452,379	475,347	430,617
Dec	436,935	450,632	428,438	432,714	429,451
Current Operations		No Flow Prescriptions		No Operations	

**Table 12. Summary of Mean Daily Weighted Usable Area for Juvenile Steelhead in the Lower San Antonio River. Cell Color Indicates the Scenario with the Highest Mean Value.**

Month	Dry	Dry-Normal	Normal	Wet-Normal	Wet
Jan	96,260	97,348	102,569	94,901	95,297
Feb	94,152	96,398	104,301	102,074	96,409
Mar	96,544	98,081	98,216	97,507	94,796
Apr	94,887	96,390	94,668	98,753	96,162
May	98,582	101,036	102,159	98,843	94,951
Jun	99,193	106,323	106,954	98,718	96,434
Jul	98,792	106,832	97,300	96,521	93,299
Aug	106,614	97,707	107,412	97,313	96,598
Sep	104,937	94,790	106,720	96,240	95,478
Oct	97,293	93,582	98,523	99,985	98,103
Nov	97,620	95,003	95,228	100,601	94,512
Dec	94,394	98,674	96,793	95,552	92,925
Current Operations		No Flow Prescriptions		No Operations	

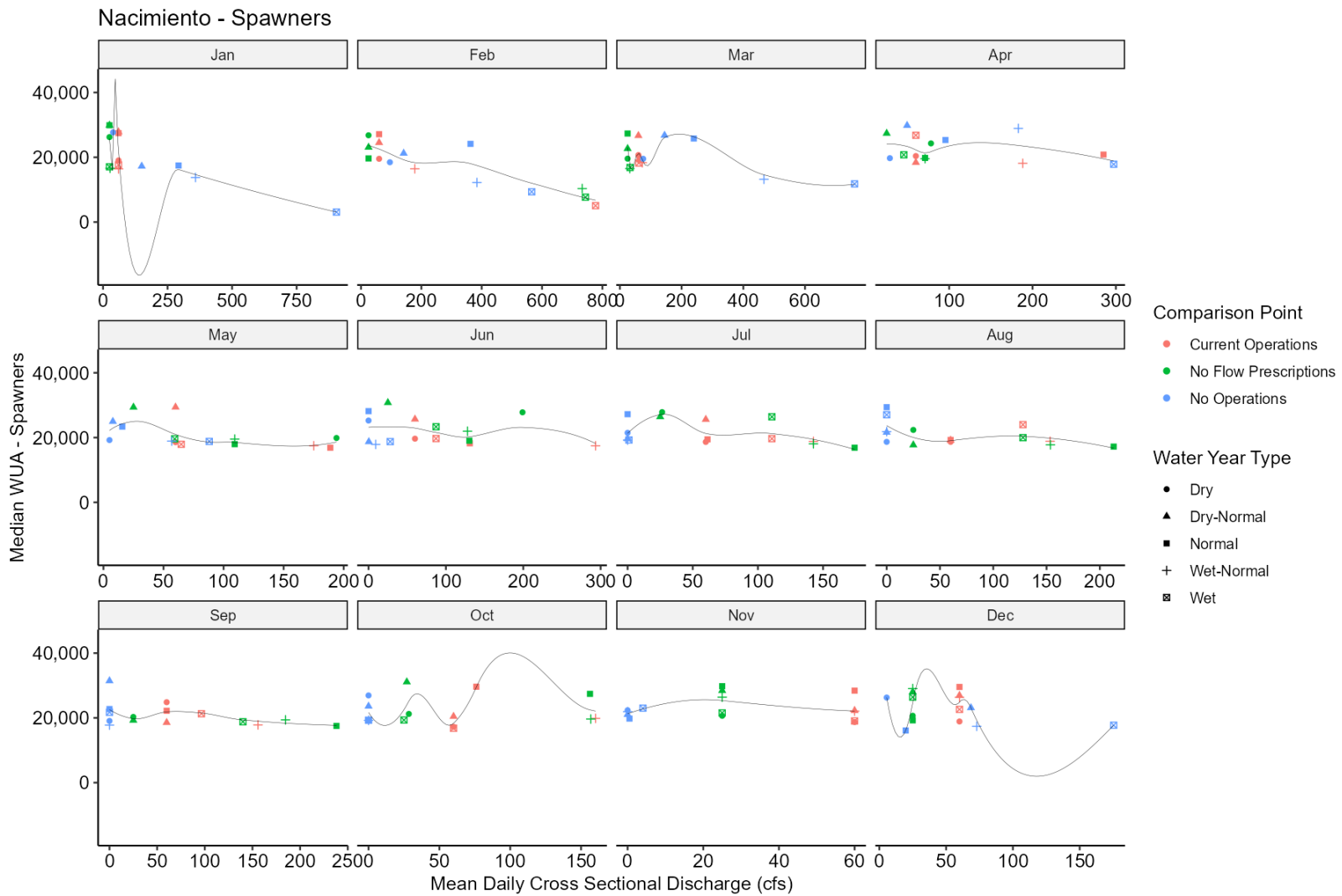
## Spawners

Documented spawning habitat was limited to the Nacimiento River.<sup>3</sup> During the steelhead spawning period (December to March) under all year types, median daily WUA is highest under the Current Conditions scenario, particularly during wet-normal and wet water year types (Figure 20) when high flows are captured in the reservoir. Current Conditions include the Flow Prescriptions and appear to maximize habitat conditions for spawning steelhead in the lower Nacimiento River (Table 13). The No Operations scenario, without the storage of winter storm flows, appears to cause depth and velocity conditions to exceed spawning steelhead preferences (Figure 11). The storage of winter flows in the reservoir appears to keep depth and velocity conditions more suitable for spawning steelhead compared to the No Operations scenario.

**Table 13. Summary of Mean Daily Weighted Usable Area for Spawning Steelhead in the Lower Nacimiento River. Cell Color Indicates the Scenario with the Highest Mean Value.**

Month	Dry	Dry-Normal	Normal	Wet-Normal	Wet
Nov	22,355	28,417	29,786	26,397	23,003
Dec	26,284	28,017	29,552	29,045	26,426
Jan	27,688	29,878	29,887	16,612	17,644
Feb	26,789	24,519	27,130	16,441	9,340
Mar	20,691	26,769	27,335	18,319	18,224
Apr	24,289	29,807	25,326	28,913	26,799
Current Operations		No Flow Prescriptions		No Operations	

<sup>3</sup> One small gravel patch was observed in the San Antonio River but was not included in the habitat models for this round of modeling.



**Figure 20. Mean Total Daily Weighted Usable Area for Steelhead Spawners in the Nacimiento River Summarized by Month, Water Type, and Comparison Point Scenarios. Smoothed Best Fit Trend Lines are Included in Each Panel.**

## Evaluation of Minimum Dam Releases

Nacimiento and San Antonio Reservoirs are operated to meet irrigation, agricultural, groundwater, and fish passage needs throughout the Salinas River basin. Following installation of the Nacimiento Hydroelectric plant in 1987, MCWRA was required by CDFW Code 5937 to maintain at least 25 cfs from the reservoir when elevation is greater than 687.8 feet to keep conditions below the dam suitable for fish (Monterey County Water Resources Agency 2018). MCWRA later decided to increase those minimum flows to 60 cfs in 2007 when the Salinas Valley Water Project biological opinion was issued, and releases have been managed to maintain minimum flows at 60 cfs since that time. At San Antonio Dam MCWRA manages minimum releases at 10 cfs to support steelhead life stages using the reaches downstream of the dam (Monterey County Water Resources Agency 2005). The reservoirs are also jointly operated during steelhead migration periods to provide passage opportunities for adults and juveniles from the Salinas River mouth to the Arroyo Seco and Nacimiento Rivers.

As part of the 2007 biological opinion, it was acknowledged that additional studies were needed to adequately evaluate minimum dam releases necessary to maintain rearing and spawning habitat quality sufficient for steelhead in both rivers. The following sections summarize the previous evaluations undertaken as part of the 2007 consultation, further analyze the minimum flows necessary for steelhead, and recommend minimum flows to be implemented as part of the proposed HCP release schedule.

### Spawning

In 2000, roughly 25 years ago, Hagar Environmental Services (HES) assessed rearing and spawning habitats in 4.7 miles of the lower Nacimiento River below the dam at high and low flow conditions. At 33 cfs HES identified 54 square feet of suitable spawning habitat per 100 feet of stream surveyed and 181 square feet per 100 feet at 330 cfs (Monterey County Water Resources Agency 2005). HES estimated based on these findings that within the 10 miles of river below the dam to the Salinas River confluence that there are roughly 40,000 linear feet (7.5 miles) of stream habitat with 21,000 square feet of spawning habitat at 33 cfs. They further estimated the 7.5-mile section of the lower Nacimiento River could support up to 420 spawning pairs of steelhead assuming an average redd size of 5 square feet and spawning territory of 50 square feet.

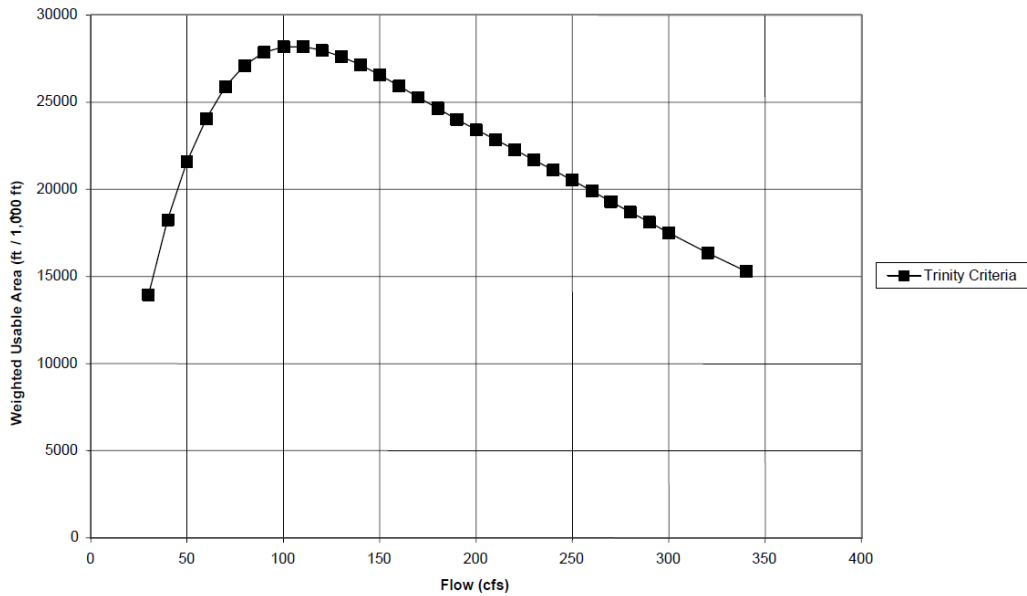
Later, in 2003, ENTRIX evaluated spawning suitability in the lower river using PHABSIM and spawning suitability criteria derived from the Trinity River in Northern California (Monterey County Water Resources Agency 2005). This analysis concluded that suitable spawning habitat, expressed as WUA, increased up to about 100 cfs and then gradually declined with increasing flow (Figure 21). They suggest, based on this relationship, that spawning habitat is greatly increased between 60 and 190 cfs, peaking around 100 cfs.

In 2023, the lower Nacimiento River was surveyed for spawning and rearing habitat and hydraulic conditions on April 25, 26, and 27, as part of the HCP development process. Average daily flows ranged from 62 to 70 cfs during the surveys (Figure 22). During the 2023 spring surveys roughly 36,000 square feet of spawning habitat was identified with roughly 80% located in Reaches 1, 2, and 3 (Table 14). Spawning gravels were widely distributed in pools, glides, riffles, and runs (Figure 23), but nearly 55% was recorded in units classified as runs (Table 14). The 2023 survey results suggest that on average there is about 190 square feet of habitat per 100 feet of stream (Table 14). This area

varied by reach, with reaches 1 and 3 having the highest density of spawning habitat, followed by reach 1. Findings from the 2023 surveys suggest that at approximately 65 cfs, there is roughly 120,384 square feet of spawning habitat in the 12 miles of river from the dam to the Salinas River confluence. This finding is higher than the HES estimate because HES constrained their estimates to 7.5 miles, deeming the lower quarter of the river to be too sandy to support steelhead spawners. Using the HES constrained estimate of river length, 2023 survey data suggest that there is roughly 76,000 square feet of spawning gravels in the lower river. While still slightly higher, these results are similar to the findings from HES (2001).

In our assessment using hydraulic and habitat suitability modeling, spawning suitability is maximized between 50 and 100 cfs depending on reach and channel unit type (Table 15) and then declines to zero around 200 cfs for most transects (Figure 24). On average, suitability was maximized at roughly 75 cfs.

Use of the lower San Antonio River by steelhead spawners is limited. While steelhead likely used the San Antonio River historically, conditions are no longer suitable for spawning steelhead. Spawning habitat was extremely limited during 2023 spring surveys; roughly 100 square feet of spawning habitat was documented.



Source: ENTRIX (2003) PHABSIM spawning analysis, v2, July 17, 2003, in MCWRA 2005.

**Figure 21. Composite Weighted Usable Area as a Function of Flow for Steelhead Trout in the Nacimiento River.**

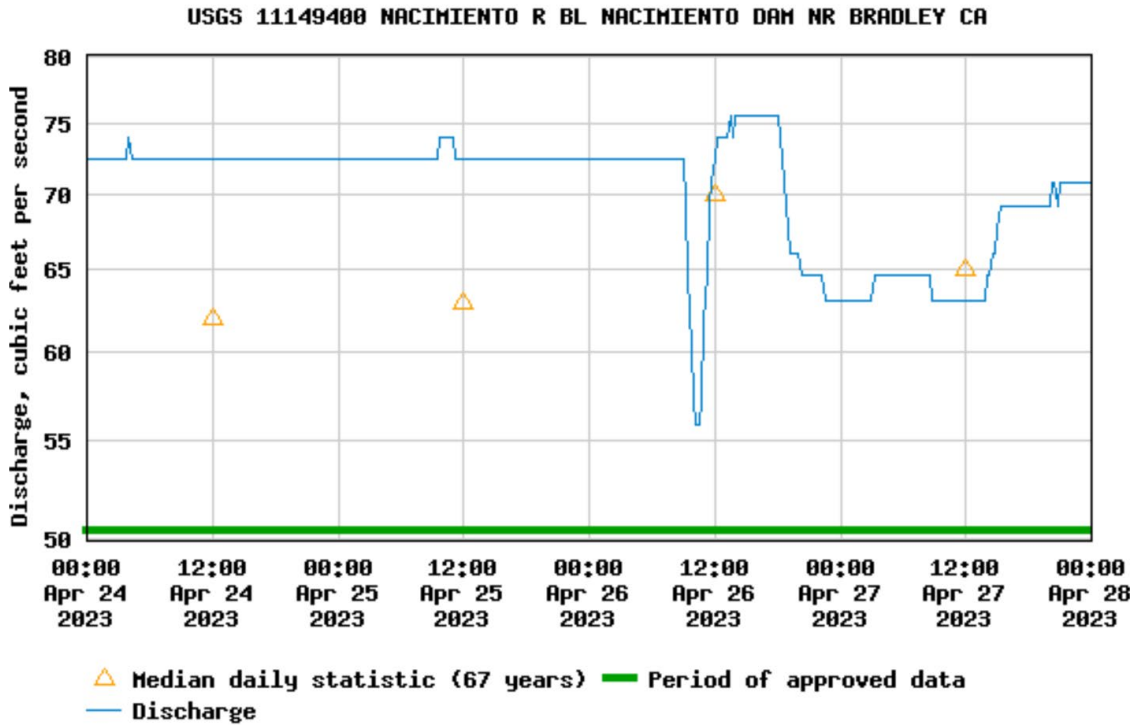
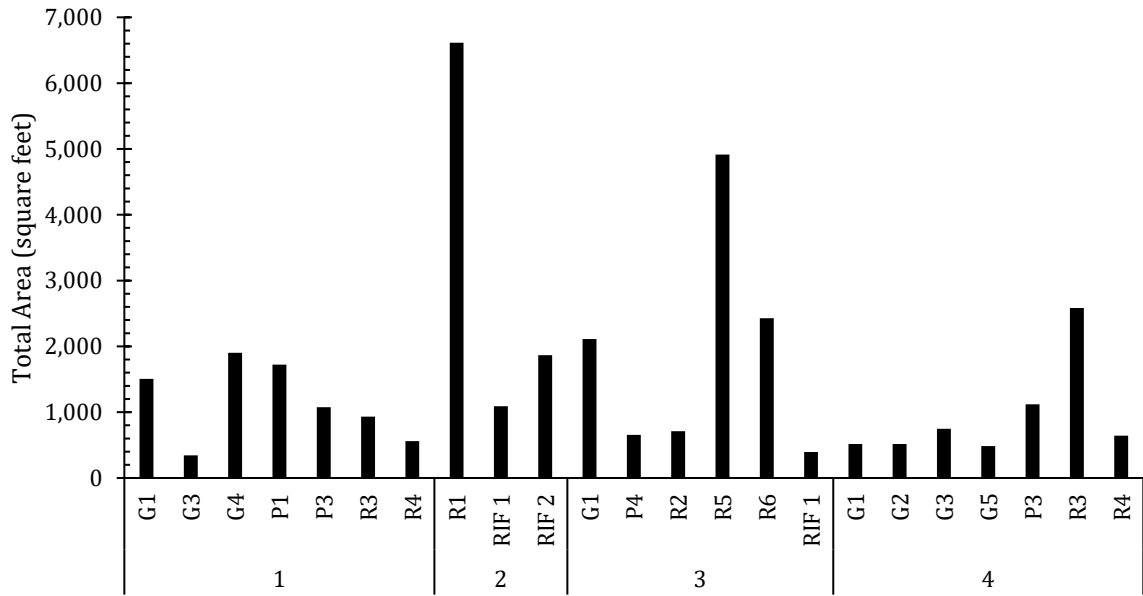


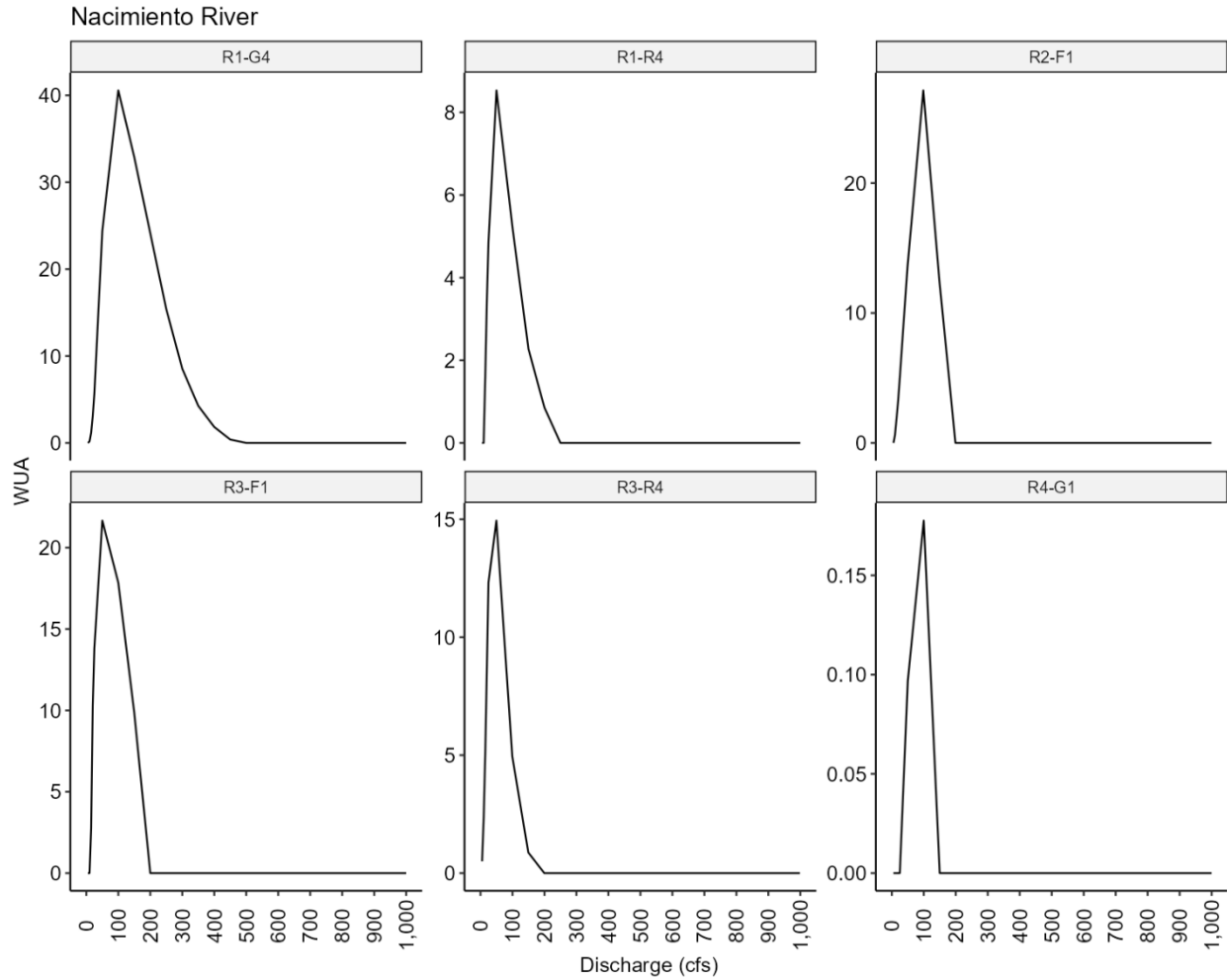
Figure 22. Daily Discharge Measured at USGS Gage 11149400 on the Nacimiento River Below the Dam Near Bradley.

Table 14. Total Spawning Areas Measured During Spring 2023 Habitat Surveys in each Nacimiento River Reach.

Reach	Total Spawning Area (ft <sup>2</sup> )	Proportion of Total	Reach Length (ft)	Total Area (ft <sup>2</sup> ) per 100 Linear Feet
1	8,044	23%	3,754	214
2	9,570	27%	4,764	201
3	11,218	32%	4,725	237
4	6,610	19%	5,362	123
<b>Total</b>	<b>35,441</b>		<b>18,606</b>	<b>190</b>



**Figure 23. Total Area of Spawning Habitat Measured during Spring Habitat Surveys in the Lower Nacimiento River.**



**Figure 24. Spawning Specific Weighted Usable Area as a Function of Cross-Sectional Discharge at Each Field-Measured Transect Location in the Lower Nacimientto River where Spawning Habitat was Observed during 2023 Spring Habitat Surveys.**

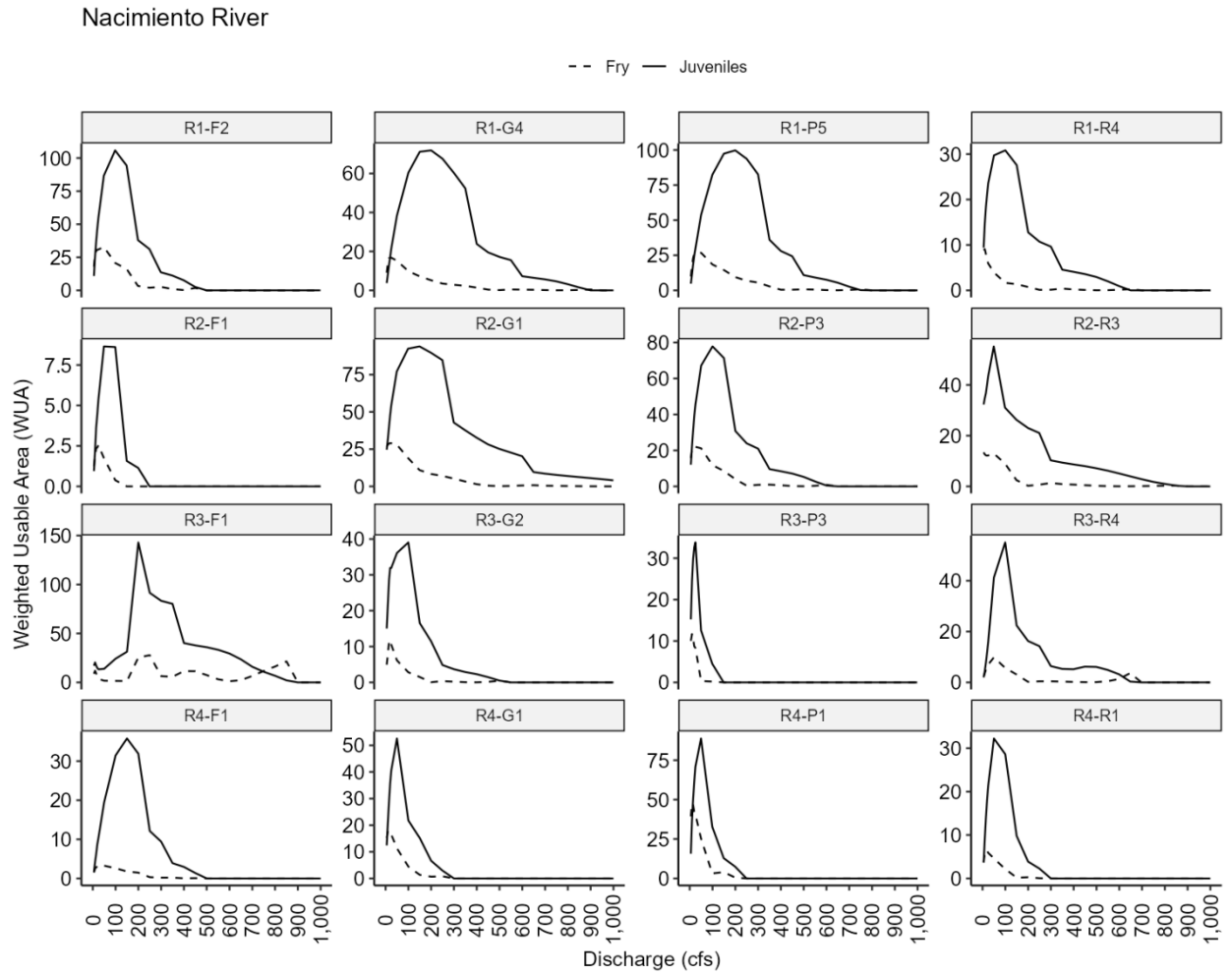
**Table 15. Channel Unit Type, Length, Spawning Area, and associated WUA and Flow in the Lower Nacimientto River.**

Transect	Unit Type	Length (ft)	Spawning Area (ft <sup>2</sup> )	Flow (cfs)	WUA
R1-G4	Glide	287.73	1,901.62	99.94	40.57
R1-R4	Run	286.42	559.72	50.00	8.53
R2-F1	Riffle	88.58	1,865.74	98.56	27.14
R3-F1	Riffle	50.85	394.68	50.00	21.67
R3-R4	Run	430.45	3,358.34	49.70	14.94
R4-G1	Glide	206.36	516.67	99.93	0.18

## Rearing

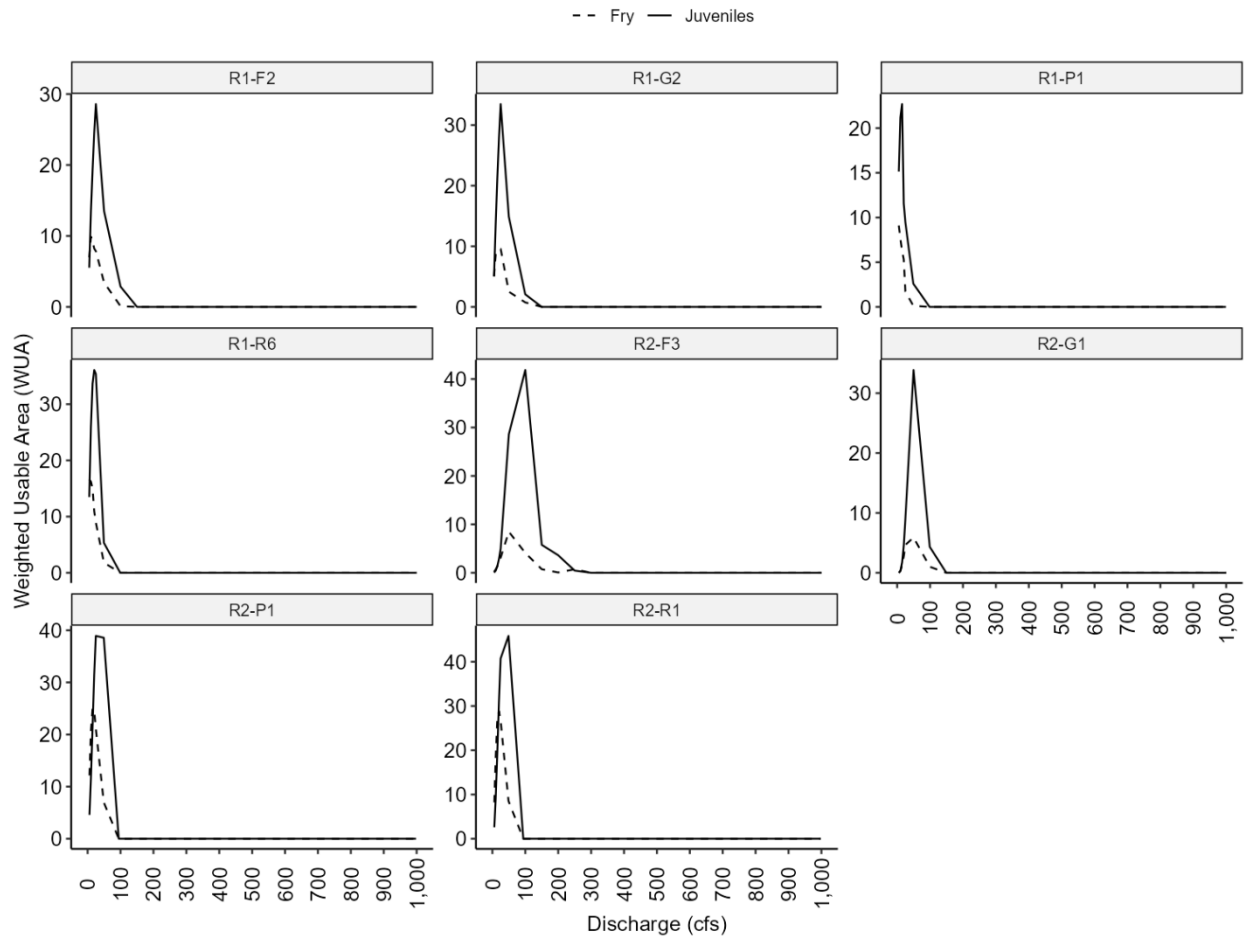
Juvenile steelhead reside in fresh water between 1 and 2 years. After emergence, fry have poor swimming ability and select shallow low-velocity areas in side channels and along channel margins to avoid high velocities and predators (Everest and Chapman 1972). As steelhead grow and mature,

they move to faster and deeper water, using riffles and other faster water habitats to feed and grow. Because of these differences in habitat preferences depth and velocity suitability indices differ between life stages (Figure 10). Therefore, the relationships between cross-sectional WUA and discharge vary between the two life stages (Figure 25 and Figure 26).



**Figure 25. Relationship Between Weighted Usable Area and Cross-Sectional Channel Discharge Juvenile and Fry Life Stages at Transect Locations in the Lower Nacimiento River.**

## San Antonio River



**Figure 26. Relationship Between Weighted Usable Area and Cross-Sectional Channel Discharge Juvenile and Fry Life Stages at Transect Locations in the Lower San Antonio River.**

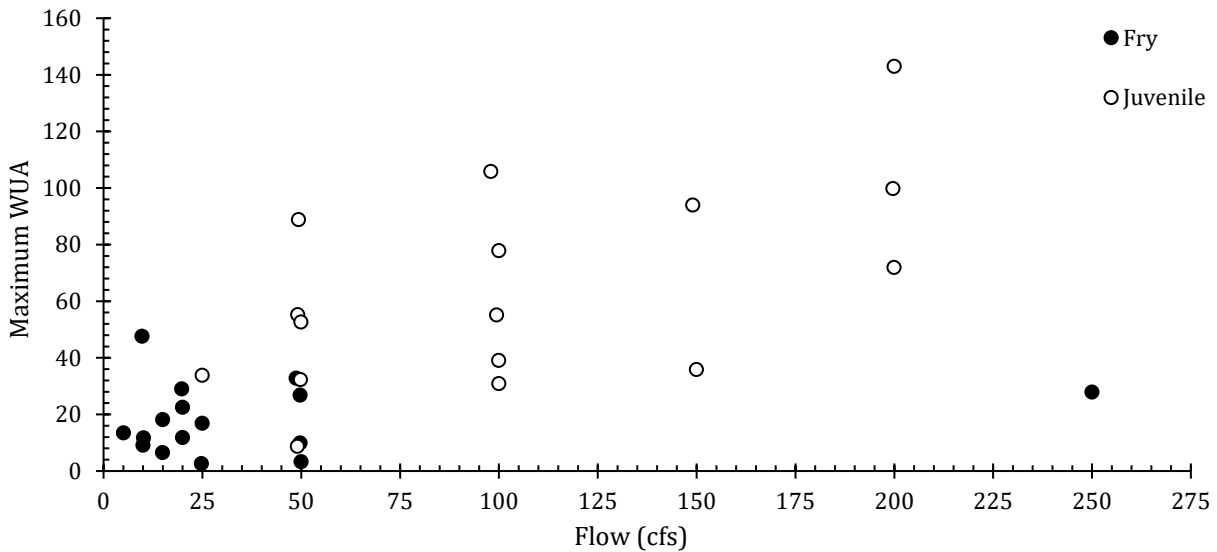
## Lower Nacimiento River

The entire 12-mile stretch of river between Nacimiento Dam and the Salinas River confluence provides rearing habitat opportunities for fry and juvenile steelhead. Rearing conditions are initially described in the preceding section titled *Study Setting*. Instream cover is a critical component of rearing habitat and smaller fry life stages rely heavily on large wood, boulders, cobbles, and gravels to avoid and escape predators. Reach 1 had by far the most instream cover of all reaches surveyed in 2023 (Figure 2). Additionally, more boulders were observed in reach 1 than the other three reaches; however, boulders accounted for less than 1% of substrate in reach 1 (Figure 4). Riparian canopy cover was also highest in reach 1 with numerous channel units having fully covered riparian areas (Figure 5). Pools and runs were the dominate mesohabitat type in all four reaches (Table 2). Deep pools and runs are less suitable for fry steelhead because they typically select shallow low-velocity off-channel habitats until they are large enough to navigate deeper and faster water. However, pools and runs may be selected by larger juveniles, particularly during the summer when high air temperature can degrade water temperatures.

Fry and juvenile WUA at channel transects was maximized at varying flow conditions, ranging from 5 to 250 cfs and 25 to 200 cfs, respectively (Table 16). On average, WUA was maximized at 40 cfs and 105 cfs, for fry and juveniles respectively. Some points were outliers in that WUA was maximized at much higher or lower flows than the other transect locations (Figure 27). For example, WUA was maximized in reach 3 riffle 1(R3-F1) for fry at 250 cfs compared to 5 to 50 cfs for the other transects. This may have been due to the riffle being exceptionally shallow at lower flows, which would reduce habitat suitability and degrade modeled WUA. Similarly, reach 3 pool 3 (R3-P3) juvenile WUA was maximized at 25 cfs compared to the other channel which ranged from 50 to 200 cfs. This is likely because at flow greater than 25 cfs, R3-P3 exceeded depth criteria for juveniles.

**Table 16. Maximum Weighted Usable Area and Corresponding Cross-Sectional Channel Discharge for Fry and Juvenile Life Stages at Channel Transects in the Lower Nacimiento River.**

Reach	Transect	Fry		Juvenile	
		Maximum WUA	Flow (cfs)	Maximum WUA	Flow (cfs)
1	R1-F2	32.75	48.73	105.78	97.99
	R1-G4	16.79	24.99	71.86	199.94
	R1-P5	26.75	49.75	99.74	199.68
	R1-R4	9.09	10.00	30.82	100.00
2	R2-F1	2.55	24.78	8.65	49.06
	R2-G1	29.00	19.78	93.96	149.05
	R2-P3	22.47	20.00	77.83	100.00
	R2-R3	13.42	5.07	55.21	49.12
3	R3-F1	27.83	250.00	142.97	200.00
	R3-G2	11.80	20.00	39.05	99.98
	R3-P3	11.66	10.11	33.80	24.96
	R3-R4	9.85	49.73	55.08	99.42
4	R4-F1	3.26	50.00	35.80	150.00
	R4-G1	18.12	14.99	52.60	49.96
	R4-P1	47.55	9.78	88.81	49.36
	R4-R1	6.47	14.96	32.25	49.82



**Figure 27. Relationship Between Maximum Modeled Fry (blacked points) and Juvenile (white points) Steelhead Life Stage WUA and Cross-Sectional Flow at Lower Nacimiento River Transects.**

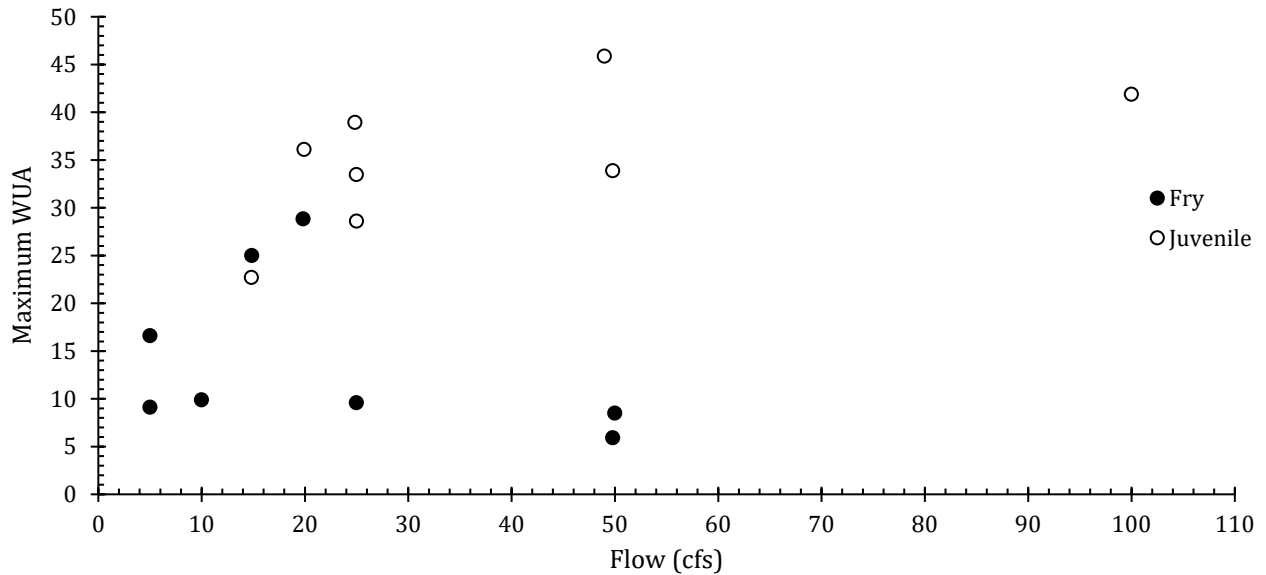
**Lower San Antonio River**

The lower San Antonio River spans about 8 miles from the dam to its confluence with the Salinas River. Habitat conditions are described in the preceding section titled *Study Setting*. The two reaches surveyed in 2023 were primarily composed of runs and pools (Table 2) and had substantially less instream cover such as large wood (Figure 2) and riparian canopies compared to the Nacimiento River (Figure 5). Fines and sand substrates were also more prevalent in the San Antonio River, making up more than 20% of overall substrate composition (Figure 4).

Fry and juvenile WUA values were maximized between 5 and 50 cfs, and 15 and 100 cfs, respectively (Table 17). On average, fry WUA was maximized at 23 cfs and juvenile WUA at 40 cfs. This reflects each life stage’s habitat suitability preferences, with fry selecting slower and shallower habitats and juveniles using higher velocities and deeper water habitats.

**Table 17. Maximum Weighted Usable Area and Corresponding Cross-Sectional Channel Discharge for Fry and Juvenile Life Stages at Channel Transects in the Lower San Antonio River.**

Reach	Transect	Fry		Juvenile	
		Maximum WUA	Flow (cfs)	Maximum WUA	Flow (cfs)
1	R1-F2	9.88	10.00	28.59	25.00
	R1-G2	9.57	24.98	33.47	24.98
	R1-P1	9.10	5.00	22.69	14.82
	R1-R6	16.59	5.00	36.09	19.92
2	R2-F3	8.48	50.00	41.87	100.00
	R2-G1	5.90	49.79	33.87	49.79
	R2-P1	24.99	14.86	38.92	24.84
	R2-R1	28.83	19.82	45.86	48.99



**Figure 28. Relationship Between Maximum Modeled Fry (blacked points) and Juvenile (white points) Steelhead Life Stage WUA and Cross-Sectional Flow at Lower San Antonio River Transects.**

# Discussion

## Comparison Point Scenarios

The purpose of the steelhead habitat model is to provide a quantitative tool to evaluate the effects of the covered activities on steelhead using habitat quantity and quality as a surrogate. Results of steelhead habitat modeling using the comparison point hydrologic scenarios generally suggest that the management of water operations out of the Nacimiento and San Antonio Dams are not as impactful on spawning and rearing steelhead as previously assumed. In general, modeling revealed that a significant amount of habitat exists under both Current Conditions and No Flow Prescriptions scenarios relative to the No Operations scenario. Modeling did not suggest that habitat conditions would change significantly from No Operations to either of the managed scenarios. In fact, given the propensity for the system to dry out completely during dry water year types, it is likely that the minimum flow requirements at both dams under the managed scenarios increases habitat availability for juvenile and fry steelhead relative to No Operations.

The approach described above does not account for other important drivers of steelhead production such as water temperature and turbidity, which can influence juvenile and fry growth rates and egg survival rates. In general, salmonids require cool water temperatures to thrive, although thermal tolerances and thresholds vary by species. Water temperature influences salmonid physiology, including the development of embryos and alevins, metabolic rates, timing and behavior of life history events such as upstream migration, spawning, freshwater rearing, and seaward migration, and the availability of food (Carter 2005). While the analysis detailed above does not account for the effects of water temperatures on steelhead rearing and spawning habitat quality, this is an important factor in the consideration of effects from the HCP.

Similarly, turbidity can cause significant behavioral and physical effects on steelhead habitat quality and production potential. These effects include avoidance of turbid waters by adults and juveniles, displacement of juveniles when suspended sediments are high, reduced feeding and growth of juvenile salmonids, physiological and respiratory impairment, physical damage to gills, reduced tolerance to disease and toxins, and reduced survival and direct mortality. The most sensitive life stages for salmonids to habitat modifications from management-related increases in fine sediment are incubating eggs and fry before emergence from the spawning redd. Deposited fine sediment in redds coats the surface of incubating eggs, reducing or preventing the exchange of oxygen, which can ultimately lead to suffocation (Bennett et al. 2003). In addition, reduced oxygen delivery to incubating eggs can result in delayed embryo development, early emergence, or smaller emergent fry. If the amount of fine sediment deposited is significant, it can physically preclude fry emergence (Beschta and Jackson 1979), essentially burying incubating eggs and preventing alevins from migrating through gravels and emerging as fry (Everest et al. 1987). Fine sediment can also reduce the exchange of hyporheic water that is imperative for incubating egg survival and flushing out toxic metabolic wastes (Baxter and Hauer 2000; Sedell et al. 1990).

Next steps will include an assessment of how water operations are expected to influence water temperatures and suspended sediments and the associated effects on steelhead rearing and spawning habitat availability in the lower Nacimiento and San Antonio Rivers.

## Minimum Dam Releases

As described in various regulatory and science documents specific to the Salinas River basin, Nacimiento and San Antonio Dams have had major impacts on the basin's hydrology including changing the magnitude and frequency of low and high flows. The purpose of the HCP is to minimize the likelihood of take of covered species resulting from the modified water regime to the extent practicable and mitigate for any remaining take through conservation actions. One of the actions to minimize effects and thus take of steelhead in Salinas River basin, specifically those life stages occupying the Nacimiento River below Nacimiento Dam and the San Antonio River below San Antonio Dam, is to manage water operations to maintain or increase rearing and spawning habitat opportunities in these areas. The above analyses provide the basis for establishing minimum flow releases from the dams to provide habitat sufficient for fry, juvenile, and spawning steelhead. The minimum flow concept establishes the floor below which managed flows would not fall, and conditions would exceed those minimums during most of the year to meet other operational and conservation objectives such as providing flows to facilitate upstream and downstream steelhead migration in and out of the two rivers.

The results of the analysis in the preceding sections conducted for the HCP to establish minimum flows for rearing and spawning steelhead are similar to the minimum flows maintained by MCWRA since 2007. On average, WUA is maximized at roughly 40 and 100 cfs for fry and juvenile steelhead, respectively, and 75 cfs for spawners in the Nacimiento River and 23 and 40 cfs for fry and juveniles, respectively, in the San Antonio River (Table 18). The findings from this analysis suggest that the minimum flows managed as part of the Flow Prescriptions have provided sufficient minimum habitat quality and quantity to support all life stages of steelhead occupying the areas below the dams.

Within the lower Nacimiento River the analysis suggests that minimum flows should be between roughly 40 and 105 cfs, depending on life stage. Current operations maintain minimum releases of 60 cfs from Nacimiento Dam, which likely translates into higher flows under most year types further downstream, considering tributary inflows and watershed run off during and following storm events. When flows exceed minimums additional channel areas such as side channels and flood plains are inundated and become accessible for juveniles. Side channel and floodplain habitats play a crucial role in the development and survival of juvenile steelhead. These off-channel areas provide a refuge from the high-velocity flows and predators found in the main river channel. The calmer waters of side channels and floodplains allow juvenile steelhead to conserve energy, which is vital for their growth and development. Additionally, these habitats often have higher water temperatures compared to the main channel, especially during the winter and spring. This warmer environment enhances metabolic rates and increases food availability, creating an ideal rearing environment for young steelhead. The preceding minimum dam release analysis does not fully account for the change in inundated off channel areas that are likely accessible to fry and juveniles at higher flows.

There are additional limitations to the model results due to limitations of the modeling tools. The first limitation is that the 1-D HEC-RAS used for this analysis provides average depth and velocity for each flow value at the field-measured transects. Ideally habitat suitability models estimate depth and velocity across the points measured along each cross-sectional transect (Figure 9) to provide a characterization of the microhabitats that would be used by juvenile steelhead. Therefore, the modeling results presented here provide a more generalized assessment of habitat condition. Due to this limitation, proportions of certain habitat units are likely to remain suitable at higher flows than

estimated by the habitat models, particularly those with high amounts of instream structure such as large wood, cobbles, and boulders where fish could avoid high-velocity conditions. Therefore, analysis is likely better suited to identifying minimum flows rather than maximum flows at which habitat conditions would be too degraded to be suitable for fry, juveniles, or spawners. For example, the analysis does not take into account the relationship between flow and sediment mobilization, which would be important for identifying conditions that might cause steelhead redds to be scoured out by high-flow conditions.

Finally, the model is further limited because it relies on habitat suitability data from outside basins rather than data from the Salinas River basin. While this type of approach is commonly used when basin-specific data is lacking, it would be worth considering including field evaluations to quantify HSI for depth and velocity for individuals within Salinas River basin streams. However, field evaluations may be difficult considering the low abundance of observed steelhead. Furthermore, based on the limitations of this analysis the HCP’s monitoring and adaptive management plan should include additional field surveys and analyses to further quantify the relationships between flow and habitat suitability. By collecting additional data and observations more quantitatively rigorous tools may be developed to more accurately model habitat conditions and provide precise estimates of minimum dam releases to optimize habitat conditions for fry, juveniles, and spawners. Additionally, studies could be designed to evaluate the flows at which spawning-sized gravels are mobilized and channel scouring occurs. This type of evaluation would further inform how water is managed at both dams to minimize impacts on steelhead habitat.

**Table 18. Mean Cross Sectional Flow at which WUA is Maximized for each Life Stage in the Nacimiento and San Antonio Rivers.**

Life Stage	Mean Flow (cfs) when WUA is Maximized ( $\pm 1SE$ )	
	Nacimiento River	San Antonio River
Fry	38.9 (14.1)	22 (6.0)
Juvenile	104.3 (14.3)	38.5 (9.3)
Spawner	74.7 (10.1)	N/A

## **Purpose**

To support development of the Salinas River Operations HCP it was necessary to develop a model of lagoon connectivity to demonstrate how water supply and flood management operations may influence the duration of lagoon and ocean connectivity. The Salinas River Lagoon is dynamic, and connectivity depends on numerous factors. This memo describes the process of developing a quantitative tool to model lagoon connectivity under two HCP operational scenarios.

## **Background**

The Salinas River Lagoon is a dynamic feature of the Salinas River basin, closing periodically due to the formation of a sandbar sealing the lagoon from the ocean (Figure 29); it is common for Central California coastal river systems to terminate into seasonal lagoons. The lagoon forms when the estuary is separated from the ocean by the formation of a sandbar, which forms because of seasonal sand deposition onto the beach combined with reduced river outflows. For a typical or average water year, sandbars form across Central California coast estuaries in late spring or summer and remain intact until high river flows due to winter rain and wave events cause the sandbar to breach. In wet water years, the sandbar may form later in the summer or in the fall, while in dry years the bar may form in the late winter or early spring.

A closed lagoon can also lead to flooding in the surrounding areas if inflows from upstream cause water elevations to exceed critical levels. When the lagoon is closed MCWRA manages water levels within the lagoon to prevent flooding of the adjacent areas using the Old Salinas River (OSR) channel slidegate, which diverts water from the lagoon down the OSR into Moss Landing Harbor. The OSR is limited in the volume of water it can convey from the lagoon to the harbor, so once inflow into the lagoon from the Salinas River exceeds OSR capacity flooding can occur, which would require MCWRA to facilitate a sandbar breach to allow water to escape to the ocean and prevent inland flooding. Facilitated breaching typically occurs in conjunction with fall and winter storms when flows are high. The sandbar can also be naturally breached when flows from the Salinas River are high enough to overtop the beach.

A key limiting factor for Salinas River steelhead (*Oncorhynchus mykiss*) recovery is lagoon connectivity (National Marine Fisheries Service 2013). When the lagoon is disconnected from the ocean, adult steelhead are unable to move from the ocean to the Salinas River via the lagoon. As part of the HCP NMFS has advocated for making releases from the reservoir to support fish passage regardless of lagoon connectivity, which presents several operational and permitting challenges for MCWRA.

During dry years when the lagoon is disconnected due to low inflow from upstream, facilitated breaching would not be feasible for establishing a connection with the ocean because there would not be enough water available to release from the reservoirs to maintain the connection channel. During dry years there is often not enough stored water in the reservoirs to maintain flow along the

entirety of the Salinas River all the way to the lagoon because much of that water is lost to groundwater recharge. Without sufficient inflow to the lagoon from the river, wave action from the ocean would quickly fill the breach channel, sealing the lagoon off from the ocean. During wetter water years the lagoon is more likely to breach naturally due to inflows from the Arroyo Seco and other tributary inflows. If a facilitated breach is necessary, there are typically sufficient natural flows to maintain the connection channel without supplementation from the reservoirs.

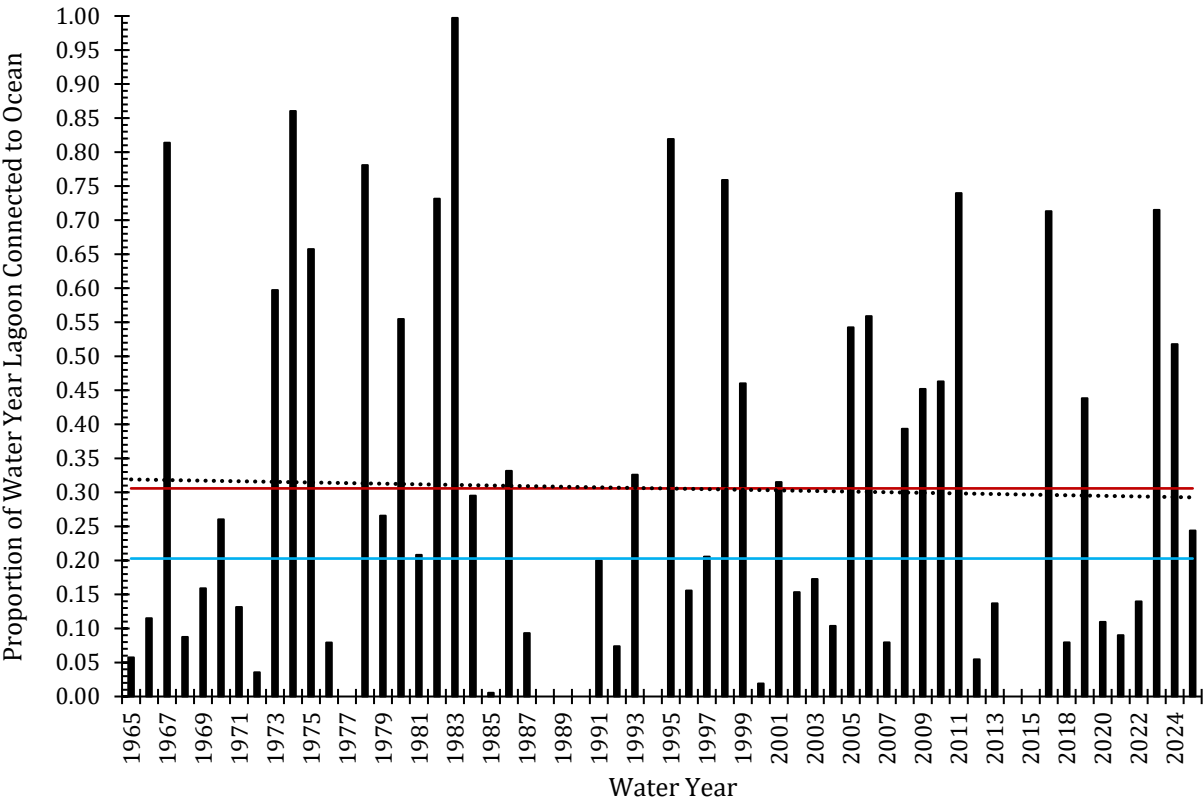
Status of the lagoon being open or closed depends on numerous factors including Salinas River flow, inflow volume, wave action at the sandbar, lagoon elevation, and meteorological conditions, making it a challenging and complex natural system to model and predict. To fully evaluate the effects of the covered activities proposed for inclusion in the HCP it was necessary to investigate developing an empirically based model to estimate the timing and duration of lagoon connectivity based on the proposed water supply and flood management activities included in the HCP. The following analysis examines the historical record of lagoon connectivity and proposes candidate empirical models to estimate the duration of lagoon connectivity because of HCP management scenarios.



Figure 29. Aerial Image of the Salinas River Lagoon with the Sandbar Intact.

# Methods

This analysis aimed to estimate the duration of lagoon-ocean connectivity at both annual and monthly temporal scales to support ecological assessments for steelhead. The lagoon in question is seasonally influenced by a dynamic sandbar that opens and closes in response to hydrologic, oceanographic, and meteorological conditions. Annual models were developed to capture long-term trends, while monthly models were used to assess seasonal variability critical to steelhead migration and estuarine habitat use. While the available data may be more suitable for developing an annual quantitative model—capturing long-term trends in lagoon-ocean connectivity—the monthly model is essential for understanding seasonal variability that directly affects steelhead. The timing and duration of lagoon openings influence critical life stages such as migration and estuarine rearing, making monthly estimates vital for assessing ecological impacts and guiding species-specific management strategies. Therefore, two response variables were evaluated: (1) number of days the lagoon is connected annually (Figure 30) and (2) the number of days the lagoon is connected on a monthly basis (Figure 31).



**Figure 30. Proportion of days the Salinas River Lagoon was open to the ocean by water year from 1965 to 2025. The horizontal red and blue lines represent the mean and median proportions of days the lagoon was connected to the ocean during the time period, respectively.**



Figure 31. Timing of Salinas River Lagoon Opening for Water Years 1965 to 2025.

## Covariates

Eight covariates were evaluated for inclusion in the annual and monthly models including meteorological and hydrological variables (Table 19).

**Table 19. Covariates Considered for Annual and Monthly Models**

<b>Variable</b>	<b>Model Parameter</b>	<b>Temporal Scale</b>	<b>Description</b>	<b>Resolution</b>
Mean annual Salinas River discharge at Spreckels	Covariate; continuous	Annual	Mean daily flows (cfs) averaged monthly at USGS gage near Spreckels	Flows reported as mean daily by the USGS from 1942 to 2025 at gage 11152500
Total days Salinas River flows exceed 80 cfs at Spreckels	Covariate; count	Annual, Monthly	Total number of days that mean daily flows at Spreckels exceed 80 cfs.	
Preceding month mean daily Salinas River discharge at Spreckels	Covariate; continuous	Monthly	Mean daily flows (cfs) averaged on a monthly basis at Spreckels for the month preceding	
Preceding month total days Salinas River flows exceed 80 cfs at Spreckels	Covariate; count	Monthly	Total number of days that mean daily flows at Spreckels exceed 80 cfs	
Mean maximum daily flows at Spreckels	Covariate; continuous	Monthly	Mean maximum daily flows by month at Spreckels	
Total monthly rainfall	Covariate; continuous	Monthly	Total monthly rainfall measured at King City in inches	National Weather Service NOWData ( <a href="#">Climate</a> )
Lagoon volume	Covariate; continuous	Annual, monthly	Total inflow to the lagoon measured at Spreckels	Flows reported as mean daily by the USGS from 1942 to 2025 at gage 11152500
Water year	Covariate; categorical	Annual	Water year ranging from 1965 to 2024	
Month	Covariate; categorical	Annual	Month expressed numerically (1 through 12)	



Figure 32. Correlation Plot of Covariates Considered

## Annual Model Development

A generalized linear model (GLM) was used to estimate the total number of days per year that the lagoon was connected to the ocean. Eight candidate covariates were evaluated, representing climatic, hydrologic, and geomorphic drivers. Model selection was based on the following criteria:

- Akaike Information Criterion (AIC)
- Bayesian Information Criterion (BIC)
- Log-likelihood
- McFadden's pseudo  $R^2$

The final model was selected based on a balance between goodness-of-fit and model parsimony.

## Monthly Model Development

To model seasonal variability, we estimated the proportion of each month during which the lagoon was connected to the ocean. Two modeling approaches were explored:

- GLM, using a binomial distribution based on the response variable characteristics (proportion from 0 to 1)
- GAM, to account for potential non-linear relationships between covariates and response

#### **GLM Model Selection Criteria**

- AIC
- BIC
- Log-likelihood
- McFadden's pseudo  $R^2$

#### **GAM Model Selection Criteria**

- AIC
- BIC
- Generalized Cross-Validation (GCV) score
- Deviance Explained (%)
- Effective Degrees of Freedom (EDF)
- Root Mean Square Error (RMSE)
- Mean Absolute Error (MAE)

#### **GLM and GAM Model Comparison**

The final GLM and GAM models for monthly estimates were compared using the following performance metrics:

- RMSE
- MAE
- $R^2$

This comparison was used to evaluate whether the increased flexibility of the GAM provided meaningful improvements in model accuracy over the GLM.

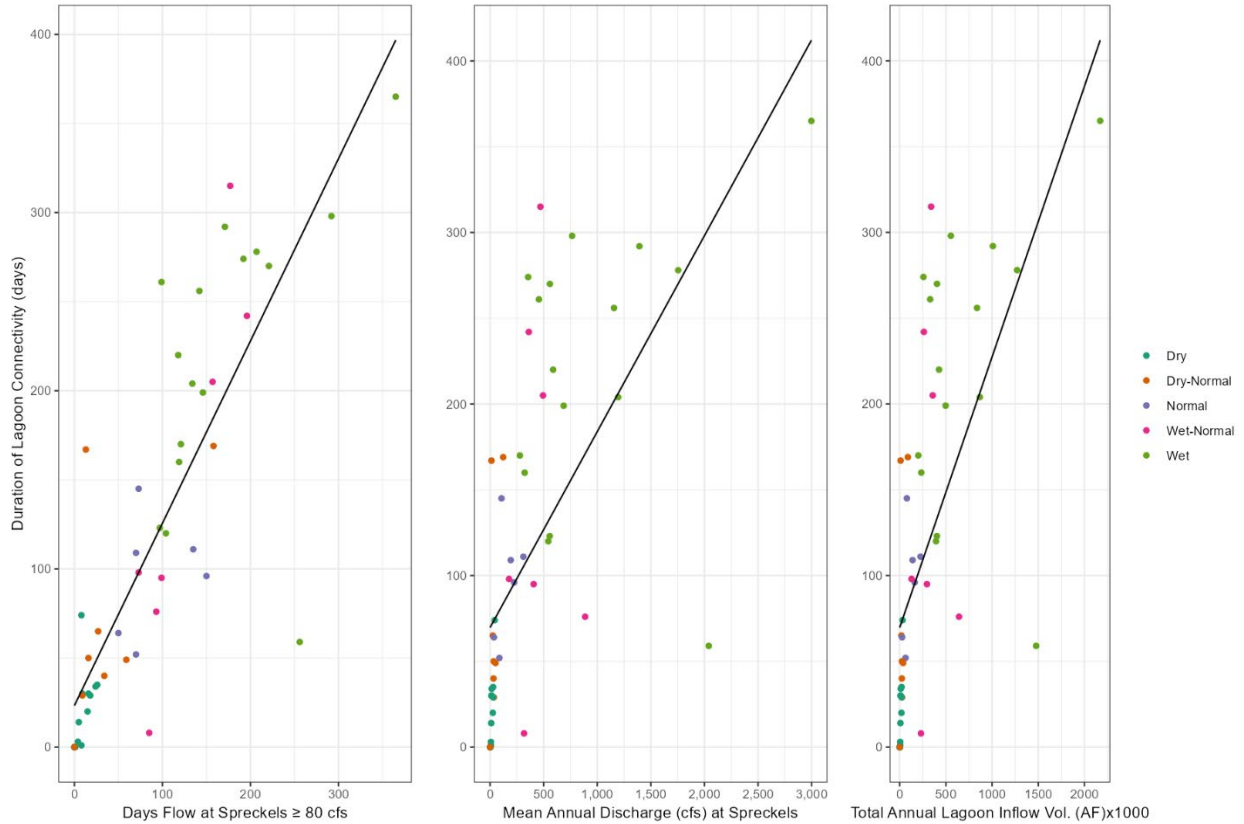
## **Applying Final Model to SVOM Hydrologic Results**

Once a final model was selected using the criteria listed in the preceding sections it was applied to SVOM hydrologic results to estimate lagoon connectivity on an annual and monthly basis for Scenario 2: Current Conditions and Scenario 4: HCP Operations.

# **Results**

## **Annual Model**

Three annual models were developed and compared and included the number of days Salinas River flows equaled or exceeded 80 cfs at Spreckels and mean annual flow at Spreckels (Figure 33). These covariates were evaluated additively (Model 1) and singularly (Models 2 and 3) (Table 20). Based on model fit selection criteria (Table 20) and residual plots (Figure 34), Model 2 was selected as the most appropriate and best fit for the dataset and explained roughly 70% of the observed variance.



**Figure 33. Relationship between Annual Model Covariates, Total Days per Year Flows Equaled or Exceeded 80 cfs at Spreckels and Mean Annual Discharge Recorded at Spreckels, and the Annual Duration of Lagoon Connectivity (days). Linear trend lines are included for each covariate.**

**Table 20. Generalized Linear Model Formulations for Annual Lagoon Connectivity**

Model	Formula	Family (link)	AIC	BIC	Log-Likelihood	Pseudo R <sup>2</sup> (McFadden)
1	$y = 1.18x_1 - 0.79x_2 + 0.001x_3 + 21.6$	Gaussian	587.58	597.43	-288.8	0.10 (0.6865)
2	$y = 1.08x_1 - 0.01x_2 + 22.4$	Gaussian	584.01	593.45	-315.4	0.10 (0.6865)
3	$y = 1.04x_1 + 23.2$	Gaussian	620.02	589.98	-315.5	0.10 (0.696)
4	$y = 0.11x_2 + 67.3$	Gaussian	620.02	625.93	-334.1	0.04 (0.40)
5	$y = 1.12x_1 - x_3 + 21.7$	Gaussian	585.58	593.46	-288.79	0.10 (0.693)
6	$y = x_3 + 69.66$	Gaussian	620.02	625.94	-307.01	0.04 (0.4)

y = Annual lagoon connectivity in days per year;  $x_1$  = Total days per year Salinas River flows at Spreckels equal or exceed 80 cfs;  $x_2$  = Average annual Salinas River flows (cfs) at Spreckels;  $x_3$  = annual volume of lagoon inflow (AF)

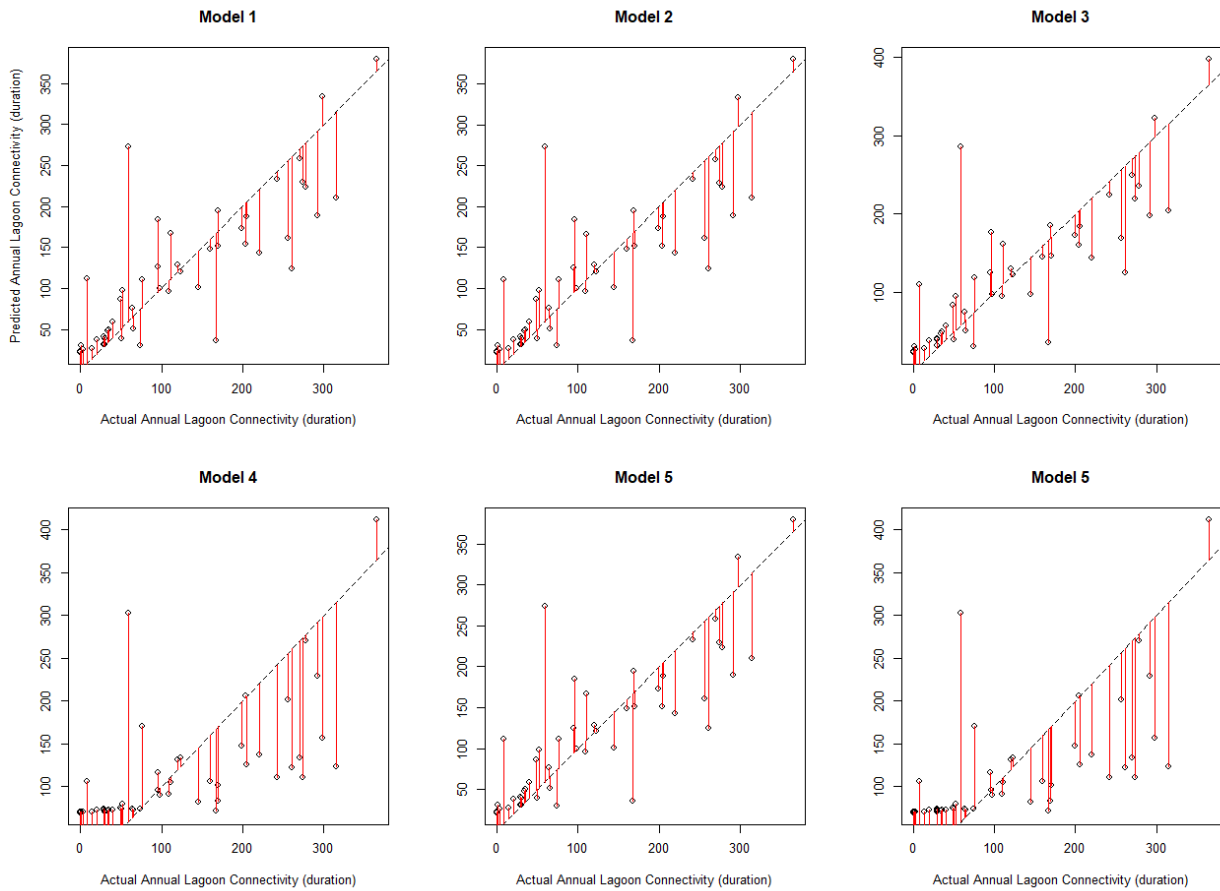
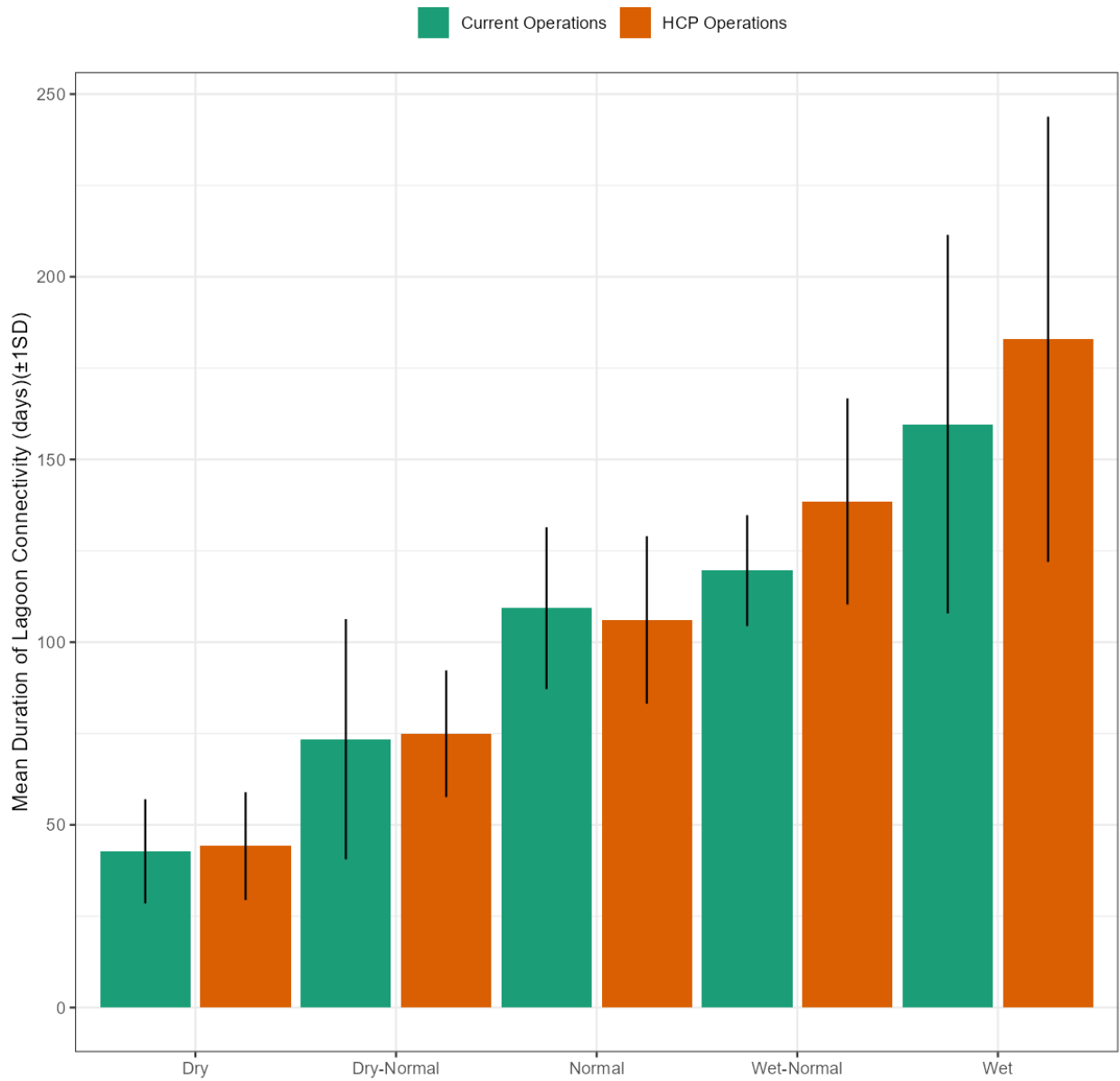


Figure 34. Diagnostic Plots for Generalized Linear Model Formulations described in Table 20.

## Estimating Lagoon Connectivity on an Annual Basis for Management Scenarios

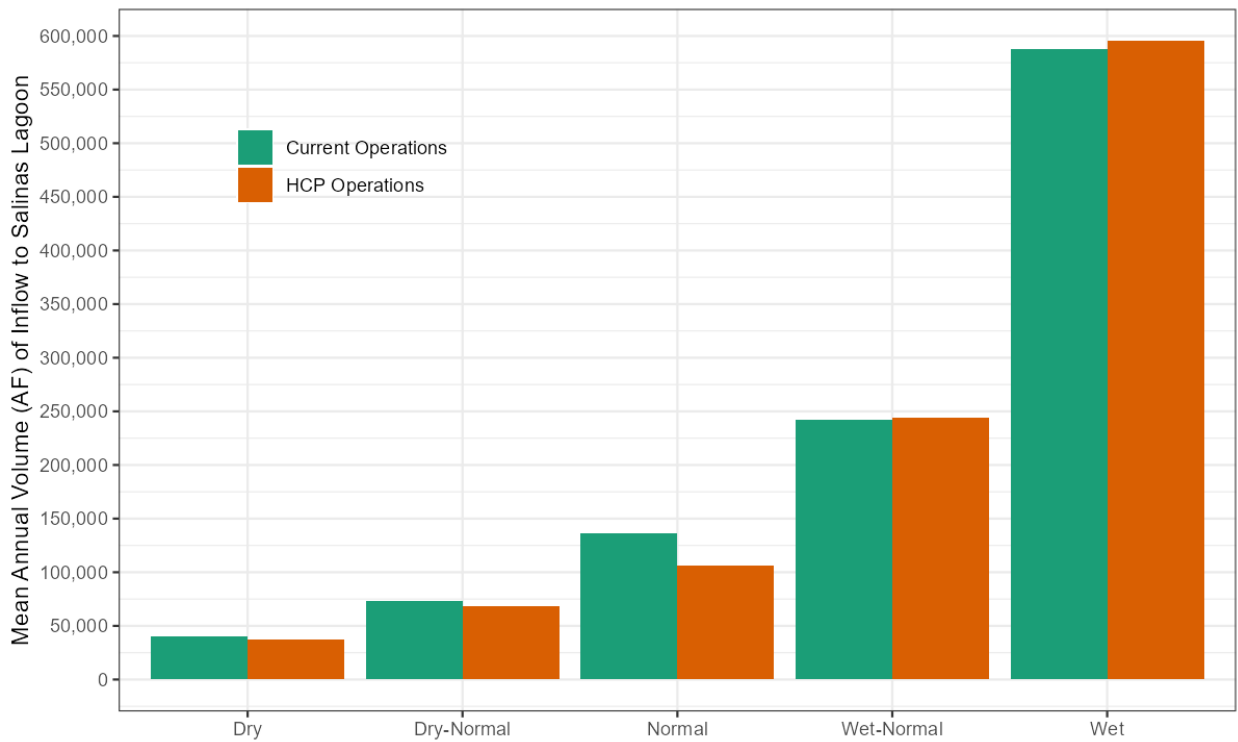
Using hydrologic results from the SVOM, the annual duration of lagoon connectivity was estimated by applying Model 5 parameters to Scenario 2 and Scenario 4 results. Based on Model 5, the mean annual duration of lagoon connectivity is expected to decline as a result of the HCP under all water year types (Figure 35). This is largely due to the lower volume of water expected to enter the lagoon (Figure 36).



**Figure 35. Mean Annual Duration of Lagoon Connectivity Estimated Using Model 5 Described in Table 20. Vertical lines represent  $\pm 1$  standard deviation from the mean.**

**Table 21. Mean Annual Duration of Lagoon Connectivity Estimated Using Model 5 Described in Table 20.**

Scenario	Water Year Type	Mean Annual Duration (days)	1 Standard Deviation Annual Duration (days)
Current Operations	Dry	42.8	14.3
	Dry-Normal	73.4	32.9
	Normal	109.0	22.2
	Wet-Normal	120.0	15.2
	Wet	160.0	51.8
HCP Operations	Dry	44.2	14.8
	Dry-Normal	74.9	17.3
	Normal	106.0	22.9
	Wet-Normal	139.0	28.2
	Wet	183.5	60.9



**Figure 36. Mean Annual Volume of Water Modeled to Flows into the Salinas River Lagoon.**

## Monthly Model

Nine models were developed and evaluated using monthly proportion of lagoon connectivity as a response. Two GLM and seven GAM models were parameterized using the covariates from Table 19. Model 2 from the full GLM model was selected using the “step” model selection function in R which resulted in retaining four covariates: 1) monthly proportion of days flows equaled or exceeded 80 cfs at Spreckels, 2) the previous months proportion of days flows were greater than or equal to 80 cfs at Spreckels, 3) water year, and 4) month (Table 22). GLM model 2 explained roughly 53% of the observed variance. All covariates were significant (p-value < 0.01).

Of the seven GAM models evaluated, permutation 1.6 was selected due to its low AIC and BIC scores and it had the fewest terms while maintaining low RMSE values and explaining roughly 60% of the deviance observed in the data. Model 1.6 also included monthly proportion of days flows equaled or exceeded 80 cfs at Spreckels, the previous months proportion of days flows were greater than or equal to 80 cfs at Spreckels, water year, and month. However, these covariates were applied using a smoothing term which increased the variance explained by the model compared to GLM model 2.

Between GLM 2 and GAM 1.6, GAM 1.6 was selected to apply to the modeled hydrologic data from SVOM to estimate the proportion of each month in the SVOM dataset the lagoon was likely to be connected to the ocean. In addition to explaining more of the variance/deviance in the observed data, GAM 1.6 also had a lower RMSE and MAE values indicative of better model fit.

**Table 22. Generalized Linear Model Fits for Monthly Proportional Lagoon Connectivity**

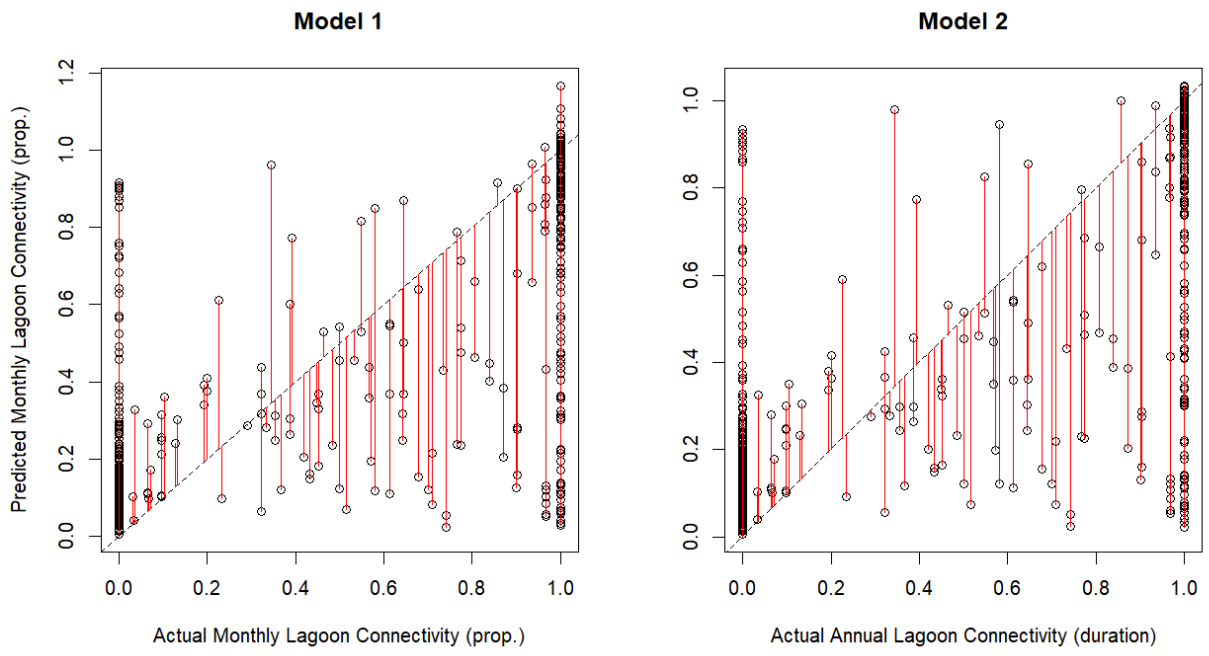
<b>Model #</b>	<b>Formula</b>	<b>Family (link)</b>	<b>AIC</b>	<b>BIC</b>	<b>Log-Likelihood</b>	<b>Pseudo R<sup>2</sup> (McFadden)</b>
1	$y = mx_1 + mx_2 + mx_3 + mx_4 + mx_5 + mx_6 + mx_7 + mx_8 + x_9 + b$	Gaussian	298.84	349.12	-138.42	0.66
2	$y = mx_1 + mx_2 + mx_7 + mx_8 + b$	Gaussian	292.37	319.80	-140.18	0.66

y = monthly proportion lagoon connected to ocean; x<sub>1</sub> = monthly proportion of days flows ≥ 80 cfs at Spreckels; x<sub>2</sub> = previous month x<sub>1</sub>; x<sub>3</sub> = monthly maximum daily discharge (cfs) at Spreckels; x<sub>4</sub> = monthly mean daily discharge (cfs) at Spreckels; x<sub>5</sub> = previous month's x<sub>4</sub>; x<sub>6</sub> = total monthly rainfall measured at King City; x<sub>7</sub> = water year; x<sub>8</sub> = numerical month; x<sub>9</sub> = monthly inflow volume to Salinas River Lagoon

**Table 23. General Additive Model Fits for Monthly Proportional Lagoon Connectivity**

Model #	Formula	AIC	BIC	GCV	Deviance Ex. (%)	EDF	RMSE	MAE
1	$y=s(mx_1)+s(mx_2)+s(mx_3)+s(mx_4)+s(mx_5)+s(mx_6)+s(mx_7)+s(mx_8)+s(x_9)+b$	246.95	353.37	0.08	58.5	21.3	0.28	0.18
1.1	$y=s(mx_1)+s(mx_2)+mx_3+mx_4+mx_5+mx_6+s(mx_7)+s(mx_8)+s(x_9)+b$	2543.11	373.77	0.08	58.5	20.4	0.28	0.18
1.2	$y=s(mx_1)+s(mx_2)+mx_3+mx_4+mx_6+s(mx_7)+s(mx_8)+x_9+b$	253.09	374.07	0.08	58.3	20.5	0.28	0.18
1.3	$y=s(mx_1)+s(mx_2)+mx_4+mx_6+s(mx_7)+s(mx_8)+x_9+b$	251.01	367.55	0.08	58.6	20.5	0.28	0.18
1.4	$y=s(mx_1)+s(mx_2)+mx_4+s(mx_7)+s(mx_8)+x_9+b$	249.13	361.10	0.08	58.6	20.5	0.27	0.18
1.5	$y=s(mx_1)+s(mx_2)+s(mx_7)+s(mx_8)+x_9+b$	247.1644	354.77	0.08	58.4	20.5	0.28	0.18
1.6	$y=s(mx_1)+s(mx_2)+s(mx_7)+s(mx_8)+b$	248.19	351.03	0.08	58.3	20.5	0.28	0.18

y = monthly proportion lagoon connected to ocean;  $x_1$  = monthly proportion of days flows  $\geq 80$  cfs at Spreckels;  $x_2$  = previous month  $x_1$ ;  $x_3$  = monthly maximum daily discharge (cfs) at Spreckels;  $x_4$  = monthly mean daily discharge (cfs) at Spreckels;  $x_5$  = previous month's  $x_4$ ;  $x_6$  = total monthly rainfall measured at King City;  $x_7$  = water year;  $x_8$  = numerical month;  $x_9$  = monthly inflow volume to Salinas River Lagoon; s = covariate is smoothed indicating non-linear relationship; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion; GCV = generalized cross-validation; EDF = effective degrees of freedom; RMSE = root mean squared error; MAE = mean absolute error



**Figure 37. Diagnostic Plots for Generalized Linear Model Formulations Described in Table 22.**

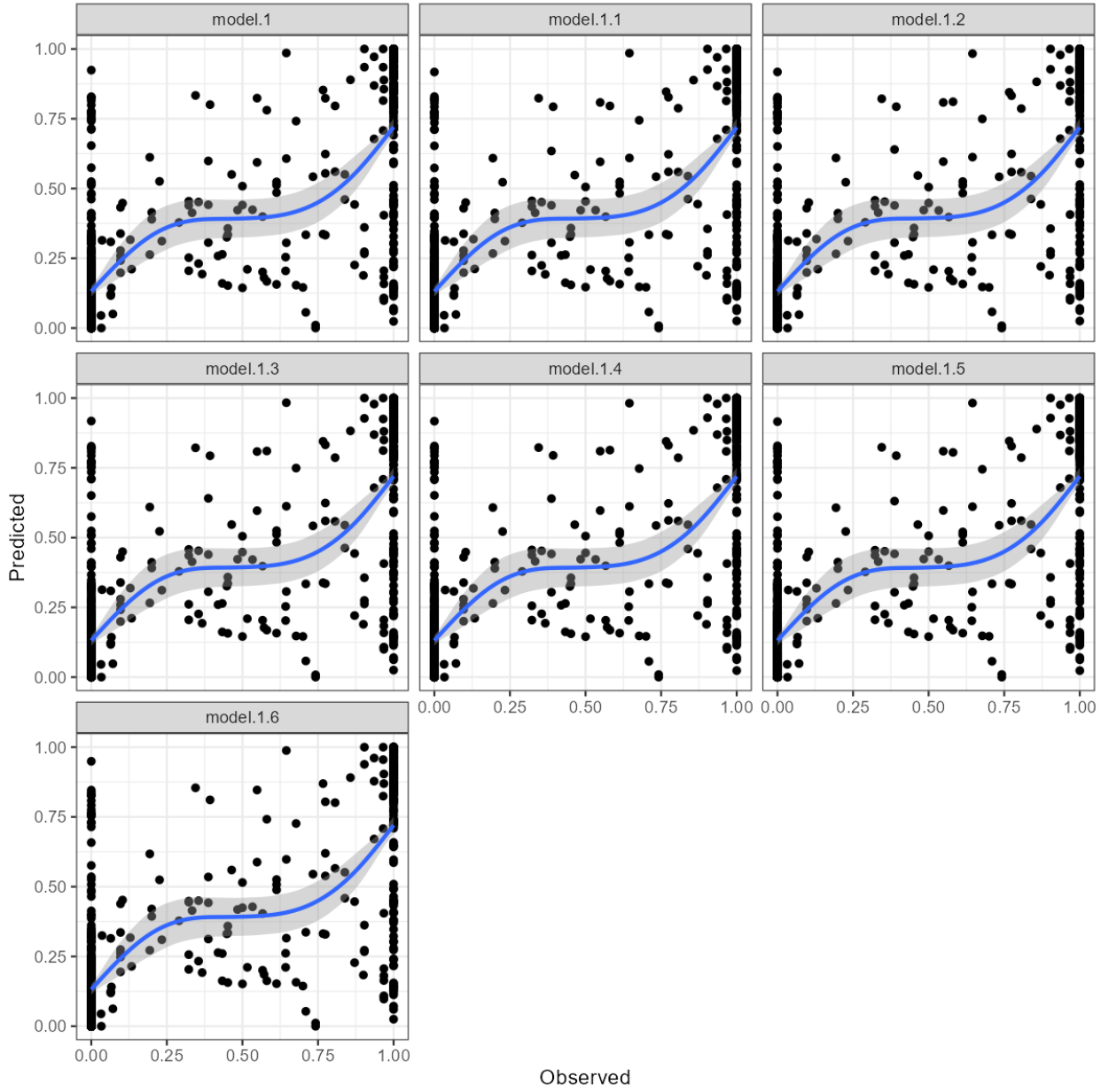
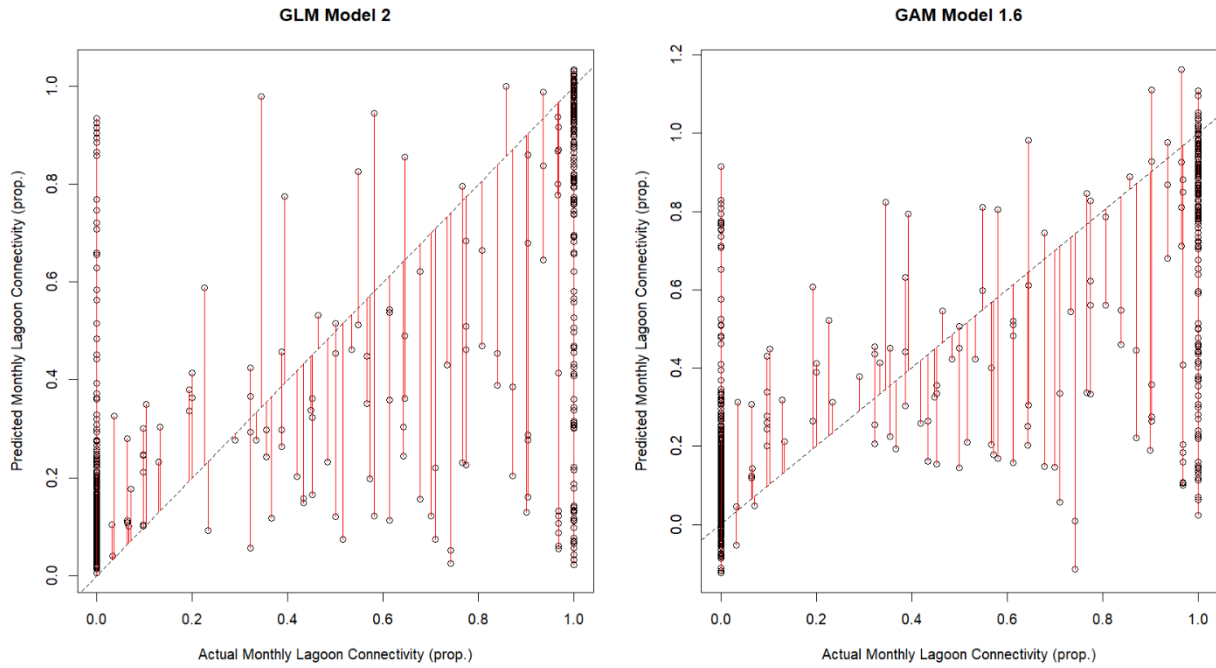


Figure 38. Observed vs. Modeled Values from the GAM Models Described in Table 23



**Table 24. Comparison of Residuals for GLM Model 2 and GAM Model 6.**

### **Estimating Lagoon Connectivity on a Monthly Basis by Management Scenarios**

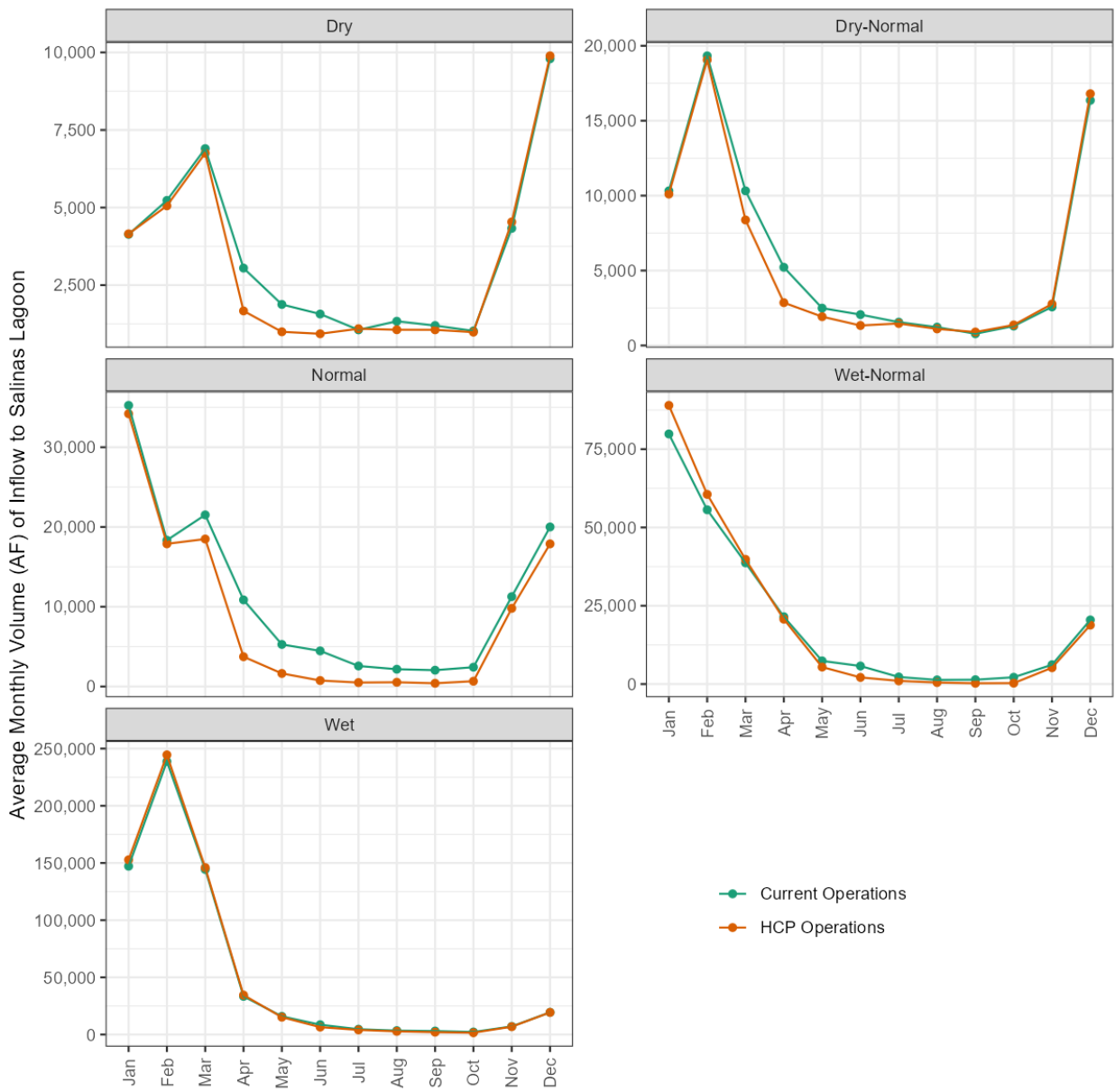
Using hydrologic results from the SVOM, the monthly proportion of time the lagoon is connected to the ocean was estimated by applying GAM model 1.6 to parameters to Scenario 2 and Scenario 4 results. Overall, similar to the annual model, the duration of time per month that the lagoon is connected to the ocean is expected to decline based on the results from the monthly model at varying magnitudes by month and water year types (Figure 39 and Table 25).



Figure 39. Average Proportion Lagoon is Connected to the Ocean per Month and Water Year Type

**Table 25. Average Proportion Lagoon is Connected to the Ocean per Month and Water Year Type Based on Equation 5.**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
<b>Current Operations</b>	0.41 (0.23)	0.43 (0.23)	0.42 (0.22)	0.27 (0.18)	0.17 (0.12)	0.15 (0.1)	0.13 (0.07)	0.09 (0.06)	0.06 (0.05)	0.03 (0.04)	0.05 (0.07)	0.19 (0.23)
Dry	0.17 (0.09)	0.08 (0.08)	0.09 (0.14)	0.08 (0.09)	0.1 (0.06)	0.12 (0.06)	0.11 (0.06)	0.08 (0.06)	0.05 (0.05)	0.03 (0.04)	0.03 (0.04)	0.05 (0.05)
Dry-Normal	0.2 (0.13)	0.23 (0.2)	0.18 (0.2)	0.1 (0.11)	0.09 (0.05)	0.12 (0.05)	0.11 (0.05)	0.08 (0.04)	0.05 (0.03)	0.02 (0.03)	0.03 (0.03)	0.22 (0.27)
Normal	0.47 (0.26)	0.36 (0.27)	0.25 (0.23)	0.13 (0.11)	0.09 (0.06)	0.11 (0.07)	0.1 (0.07)	0.07 (0.06)	0.04 (0.05)	0.03 (0.04)	0.1 (0.18)	0.29 (0.37)
Wet-Normal	0.55 (0.36)	0.72 (0.28)	0.79 (0.19)	0.46 (0.27)	0.21 (0.14)	0.16 (0.05)	0.15 (0.05)	0.11 (0.05)	0.08 (0.05)	0.05 (0.05)	0.04 (0.04)	0.16 (0.23)
Wet	0.64 (0.31)	0.76 (0.34)	0.78 (0.33)	0.58 (0.31)	0.36 (0.27)	0.25 (0.25)	0.16 (0.11)	0.1 (0.07)	0.06 (0.05)	0.04 (0.04)	0.05 (0.06)	0.2 (0.22)
<b>HCP Operations</b>	0.49 (0.23)	0.51 (0.24)	0.5 (0.23)	0.33 (0.21)	0.21 (0.15)	0.17 (0.11)	0.13 (0.09)	0.09 (0.07)	0.06 (0.05)	0.04 (0.04)	0.07 (0.1)	0.24 (0.28)
Dry	0.19 (0.13)	0.08 (0.09)	0.1 (0.18)	0.1 (0.13)	0.12 (0.09)	0.12 (0.06)	0.11 (0.06)	0.08 (0.06)	0.05 (0.05)	0.03 (0.04)	0.03 (0.04)	0.09 (0.13)
Dry-Normal	0.28 (0.15)	0.37 (0.27)	0.25 (0.23)	0.12 (0.12)	0.09 (0.05)	0.12 (0.05)	0.11 (0.05)	0.08 (0.04)	0.05 (0.03)	0.02 (0.03)	0.03 (0.03)	0.28 (0.3)
Normal	0.65 (0.23)	0.51 (0.27)	0.44 (0.28)	0.21 (0.17)	0.12 (0.12)	0.11 (0.07)	0.1 (0.07)	0.07 (0.06)	0.04 (0.05)	0.03 (0.04)	0.15 (0.23)	0.32 (0.42)
Wet-Normal	0.65 (0.32)	0.77 (0.25)	0.88 (0.14)	0.55 (0.29)	0.26 (0.17)	0.18 (0.09)	0.15 (0.05)	0.11 (0.05)	0.08 (0.05)	0.05 (0.05)	0.04 (0.04)	0.22 (0.23)
Wet	0.69 (0.32)	0.82 (0.32)	0.84 (0.32)	0.68 (0.32)	0.44 (0.29)	0.29 (0.29)	0.19 (0.22)	0.12 (0.13)	0.08 (0.06)	0.05 (0.06)	0.11 (0.14)	0.28 (0.3)



**Figure 40. Average Monthly Volume of Inflow to Salinas River Lagoon Summarized from SVOM Hydrologic Results.**

## Proposal for Analyzing Lagoon Connectivity in the HCP

While the quantitative models described above fit the data reasonably well, focusing the analysis solely on the scenario-specific lagoon connectivity estimates fails to account for the dynamic nature of the lagoon, which is influenced by wave action and meteorological conditions in addition to Salinas River flows. For the effects analysis we recommend using the annual model to estimate how lagoon connectivity might change as a result of the HCP but rely on lagoon monthly water year type inflow modeling for species analyses requiring a monthly evaluation (e.g., steelhead migration). Because the analyses in the effects analysis chapter break down metrics into water year types and months the lagoon connectivity dataset is likely too small to fully capture the range of variability likely to occur during future water year types and months. We would then pair this modeling with a strong adaptive management and monitoring plan that would monitor the duration of lagoon connectivity monthly. Should, after a specified period (i.e., 10 years), the duration of connectivity deviate substantially from the average durations in Table 26, the dam operations could be reevaluated.

**Table 26. Average Monthly Duration of Lagoon Connectivity Recorded between 1965 and 2024 by MCWRA**

<b>Month</b>	<b>Average Duration of Lagoon Connectivity (days)</b>	<b>Average Proportion of Month Lagoon is Connected</b>
January	15.3	0.495
February	15	0.532
March	15.5	0.500
April	14.4	0.479
May	12	0.386
June	8.93	0.298
July	6.02	0.194
August	4.43	0.143
September	3.97	0.132
October	3.30	0.106
November	2.75	0.092
December	6.75	0.218

## Chapter 3 References

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## Appendix A

# HSC Generalized Additive Model Fits

**Table A-1. Parameters of the Fitted General Additive Models to Juvenile and Fry Depth and Velocity Habitat Suitability Criteria (HSC) Derived from the Studies in Table 7. Models Were then Used to Convert Estimates of Depth and Velocity to HSC Values Defined in Figure 10 and Figure 11.**

Study	Model	Intercept (SE)	F-Statistic Smoothed Cross Section Flow (cfs) Variable	R <sup>2</sup> Adjusted (Deviance Explained)	GCV
Big Sur (Holmes et al. 2014)	Fry - Depth	0.45* (0.008)	158*	0.919	0.009
	Fry - Velocity	0.44* (0.001)	13,720*	1	<0.01
	Juvenile - Depth	0.50* (0.01)	146.4*	0.98	0.004
	Juvenile - Velocity	0.50* (0.001)	11,511*	1	<0.01
Multiple (Bovee 1978)	Fry - Depth	0.39* (0.009)	122.3*	0.933	0.008
	Fry - Velocity	0.48* (0.008)	123.7*	0.949	0.005
	Juvenile - Depth	0.45* (0.002)	1,590*	0.99	<0.01
	Juvenile - Velocity	0.53* (0.01)	121*	0.947	<0.01
Hollow Tree (Gephart et al. 2020)	Fry - Depth	0.44* (0.01)	56.43*	0.928	0.01
	Fry - Velocity	0.48* (0.001)	4,886*	0.99	<0.01
	Juvenile - Depth	0.52* (0.006)	305.2*	0.988	<0.01
	Juvenile - Velocity	0.52* (0.001)	14,583*	1	<0.01
Klamath (Hardy and Addley 2001)	Fry - Depth	0.54* (0.02)	12.98*	0.564	0.05
	Fry - Velocity	0.62* (0.008)	144.7*	0.973	<0.01
	Juvenile - Depth	0.45* (0.004)	699.8*	0.99	<0.01
	Juvenile - Velocity	0.51* (0.003)	1,257*	0.99	<0.01
Trinity (Hampton 1997)	Fry - Depth	0.42* (0.003)	1,447*	0.99	<0.01
	Fry - Velocity	0.45* (0.002)	2,752*	0.99	<0.01
	Juvenile - Depth	0.47* (0.001)	6,538*	0.99	<0.01
	Juvenile - Velocity	0.55* (0.003)	932.8*	0.99	<0.01

\* p-value <0.01

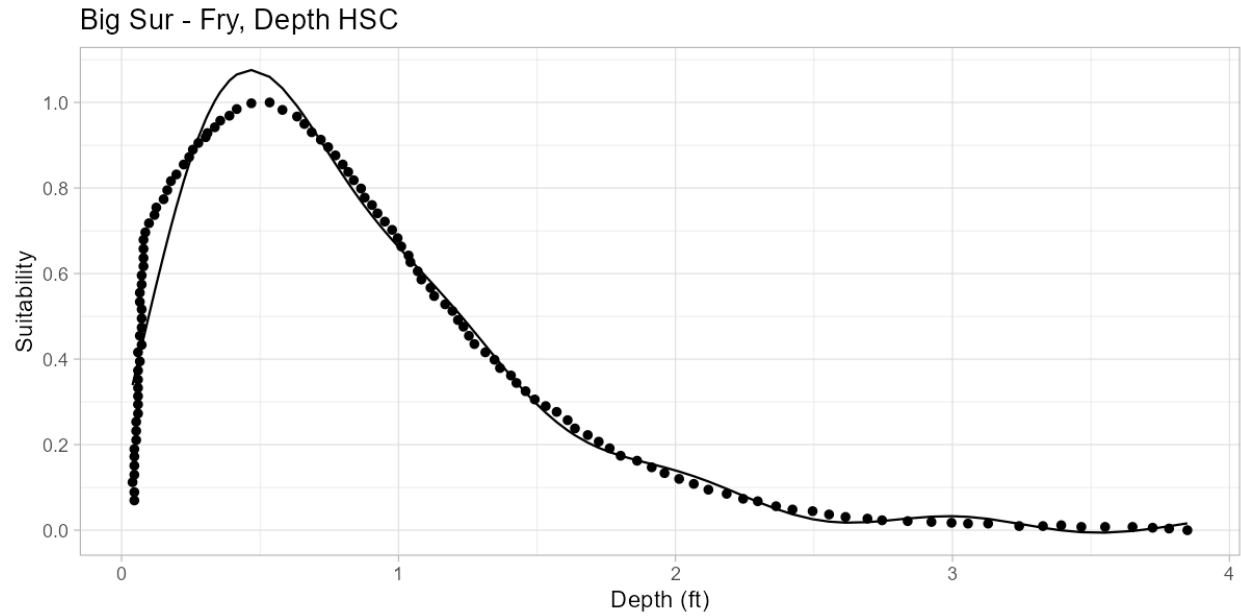


Figure A-1. Big Sur River, Fry Steelhead, Depth Habitat Suitability Curve (Holmes and Cowan 2014). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.

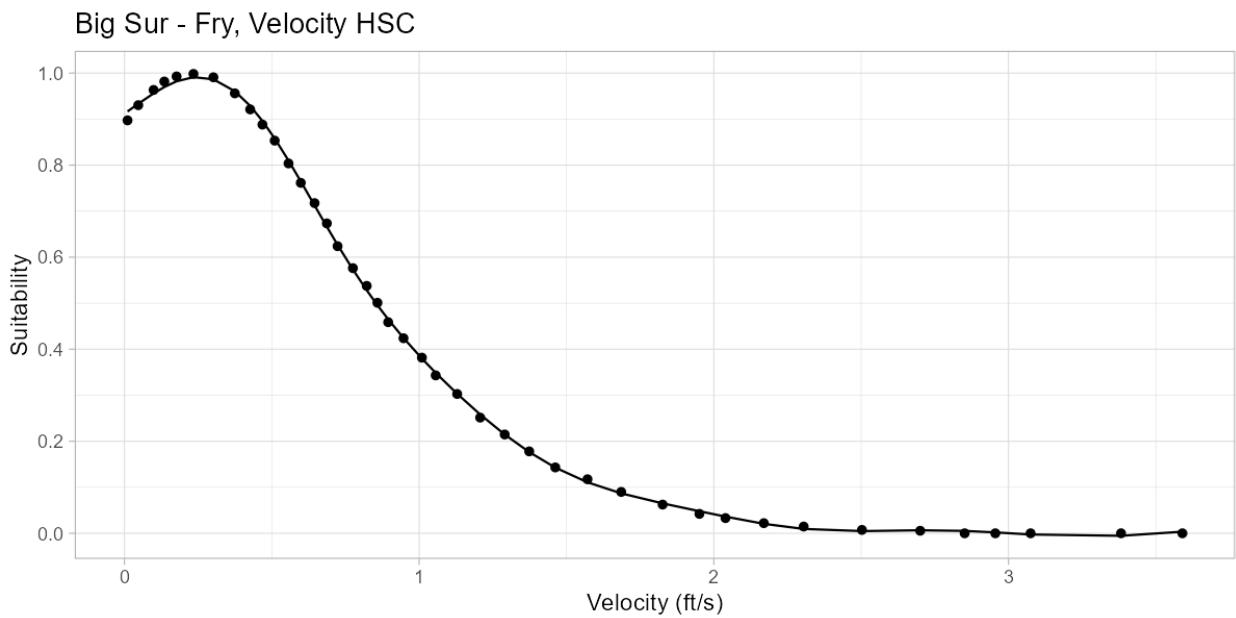


Figure A-2. Big Sur River, Fry Steelhead, Velocity Habitat Suitability Curve (Holmes and Cowan 2014). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.

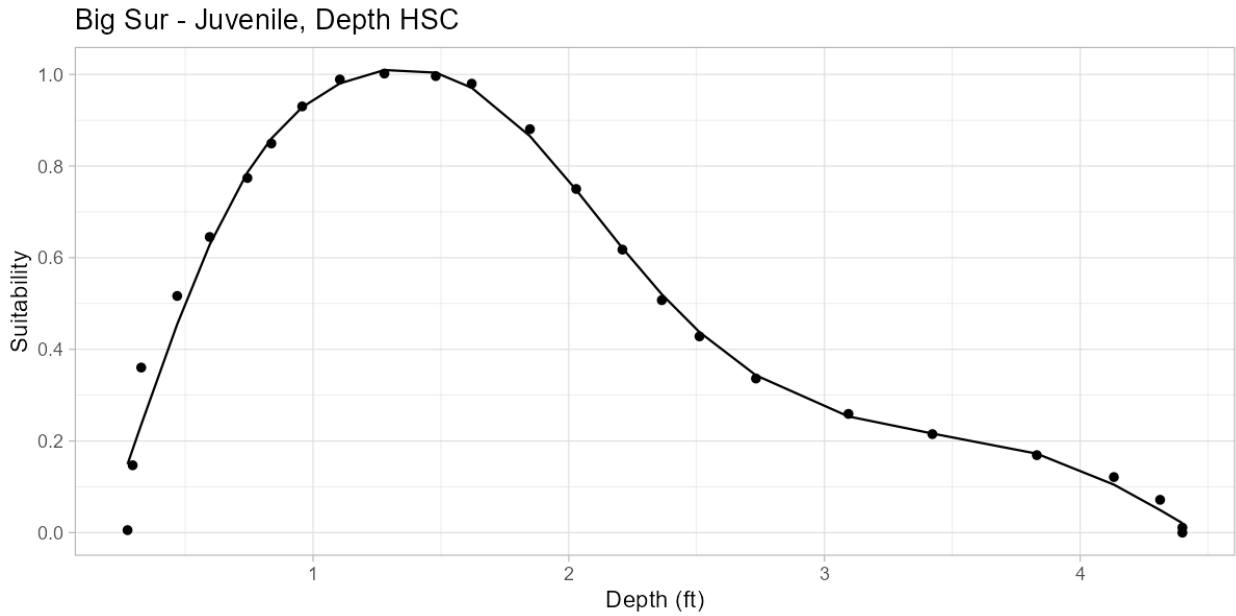


Figure A-3. Big Sur River, Juvenile Steelhead, Depth Habitat Suitability Curve (Holmes and Cowan 2014). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.

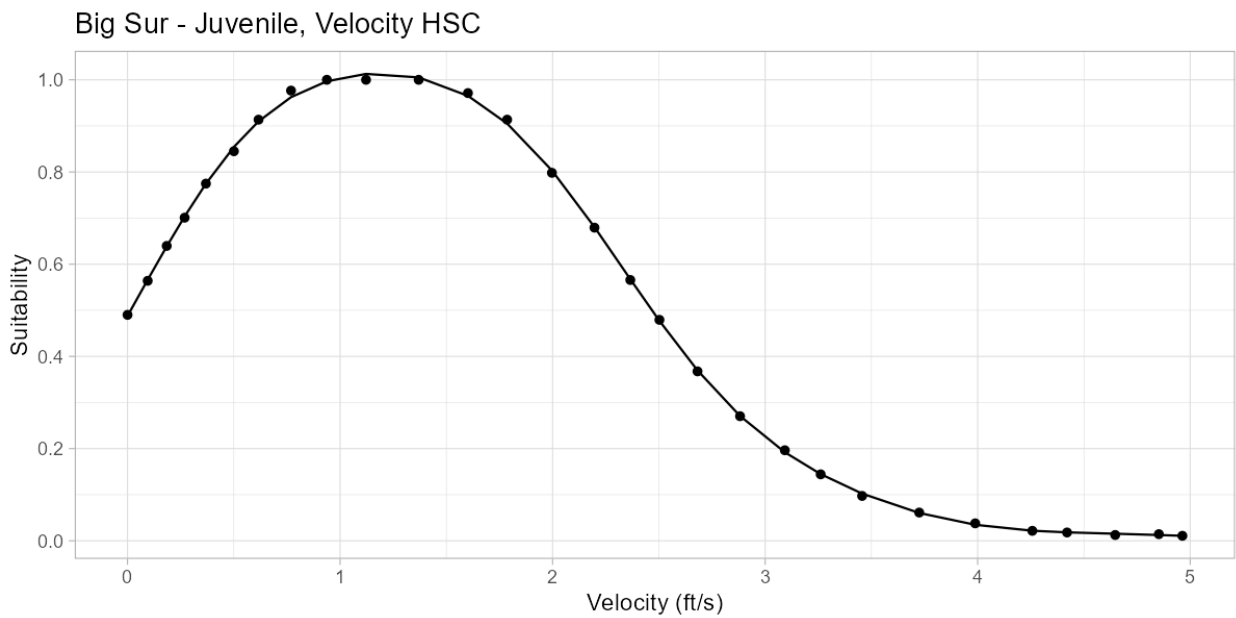


Figure A-4. Big Sur River, Fry Steelhead, Velocity Habitat Suitability Curve (Holmes and Cowan 2014). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.

Bovee - Fry, Depth HSC

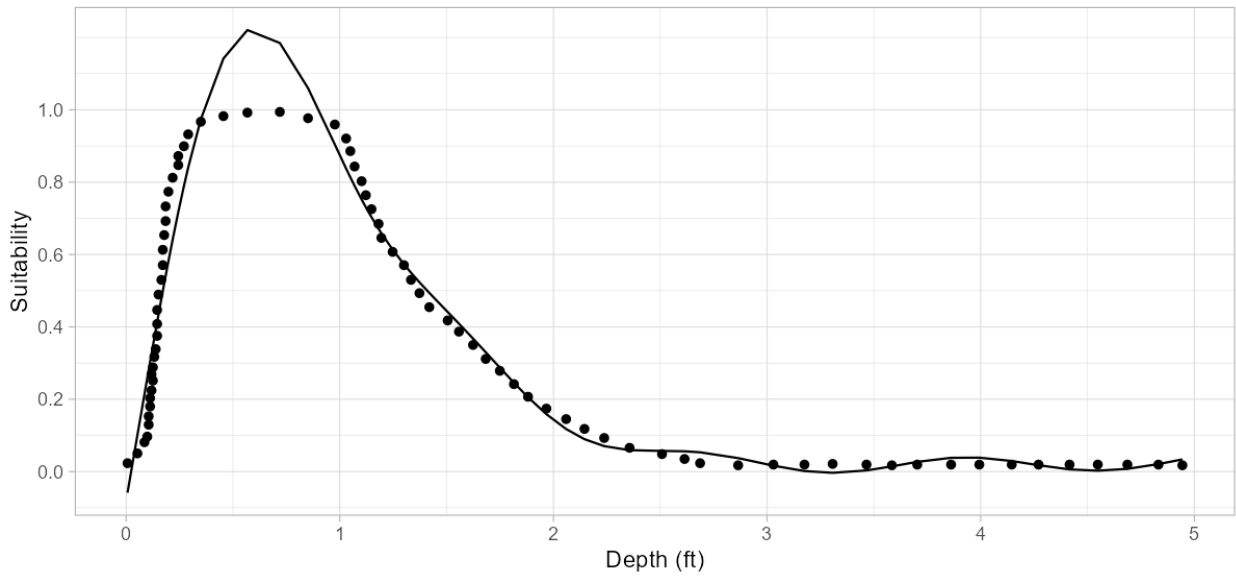


Figure A-5. Various River Systems, Fry Steelhead, Depth Habitat Suitability Curve (Bovee 1978). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.

Bovee - Fry, Velocity HSC

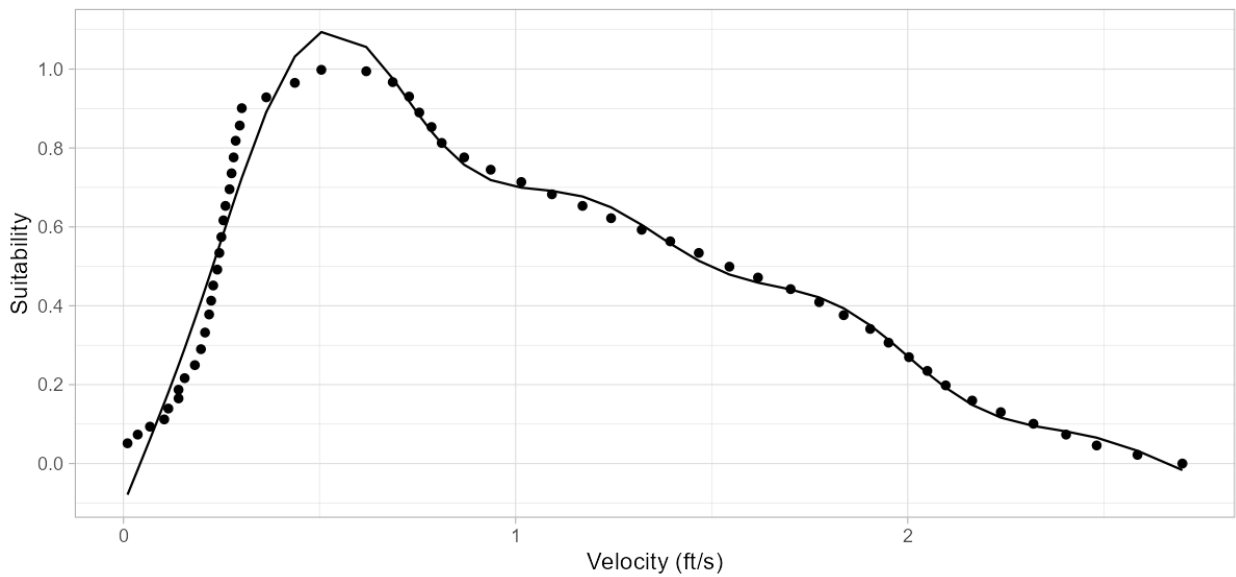
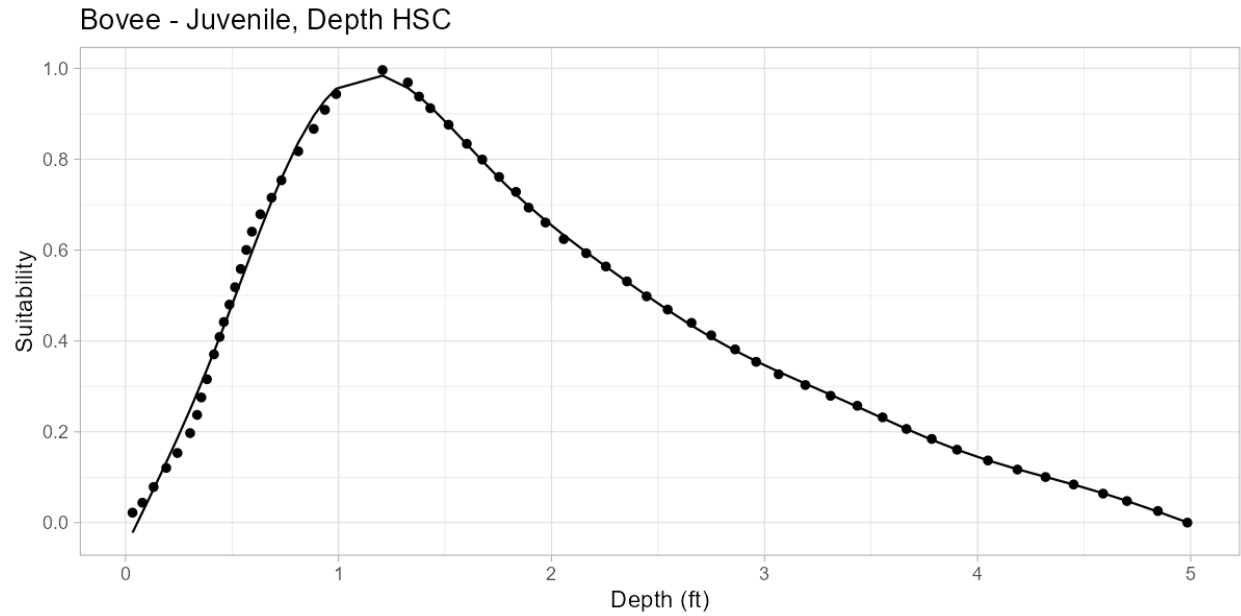
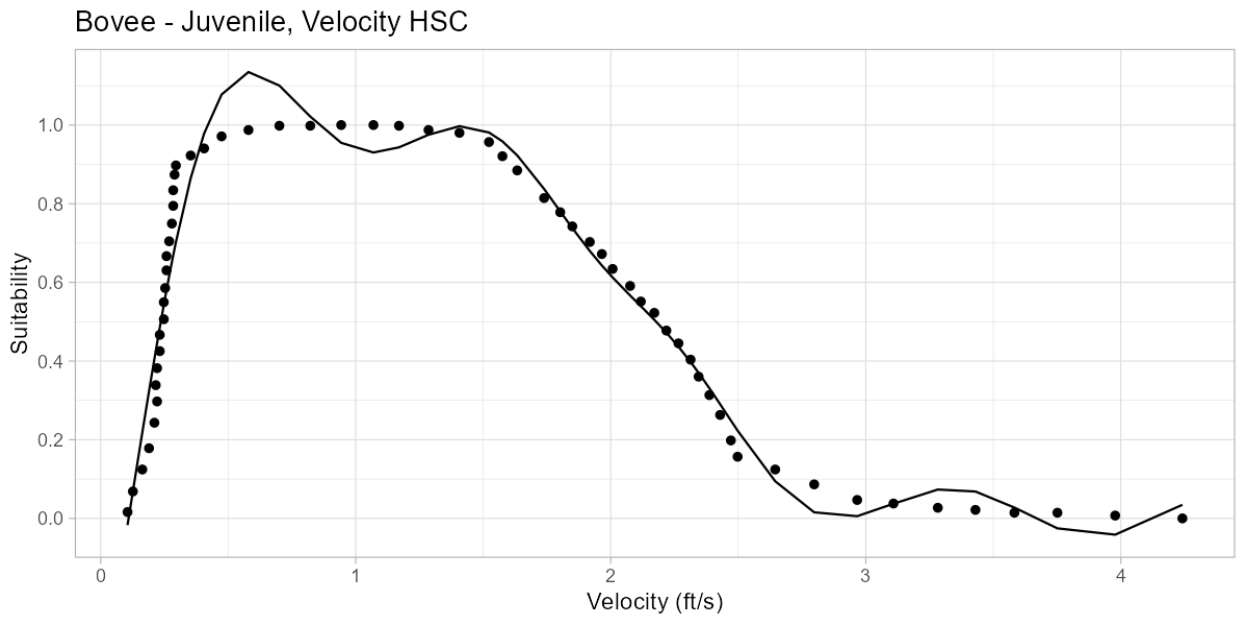


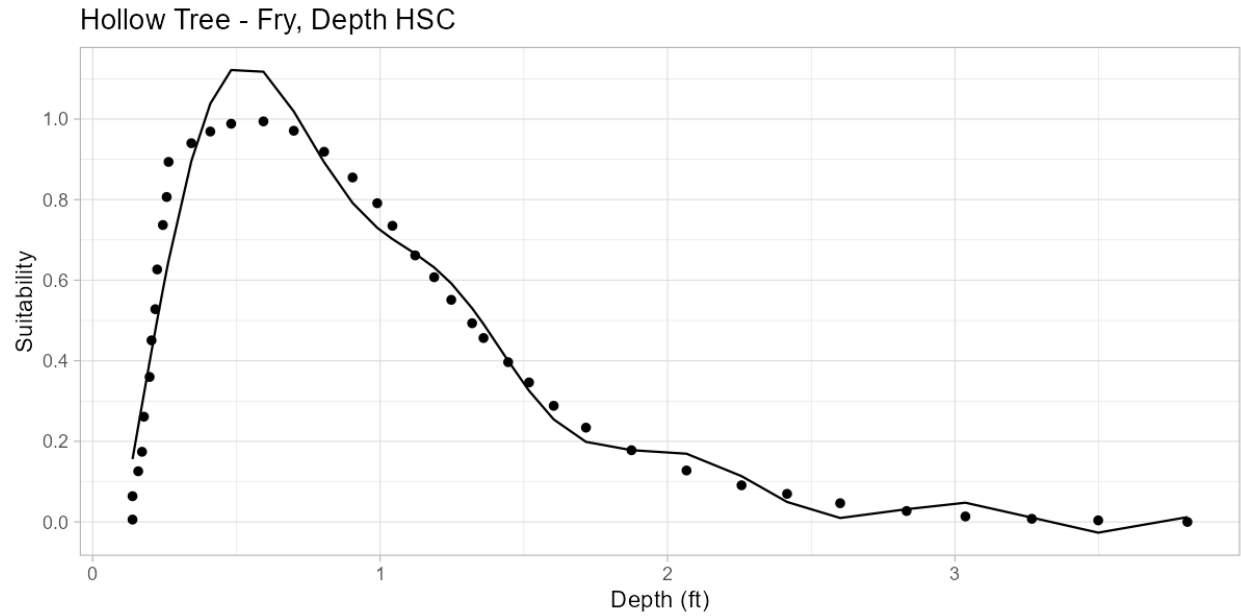
Figure A-6. Various River Systems, Fry Steelhead, Velocity Habitat Suitability Curve (Bovee 1978). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.



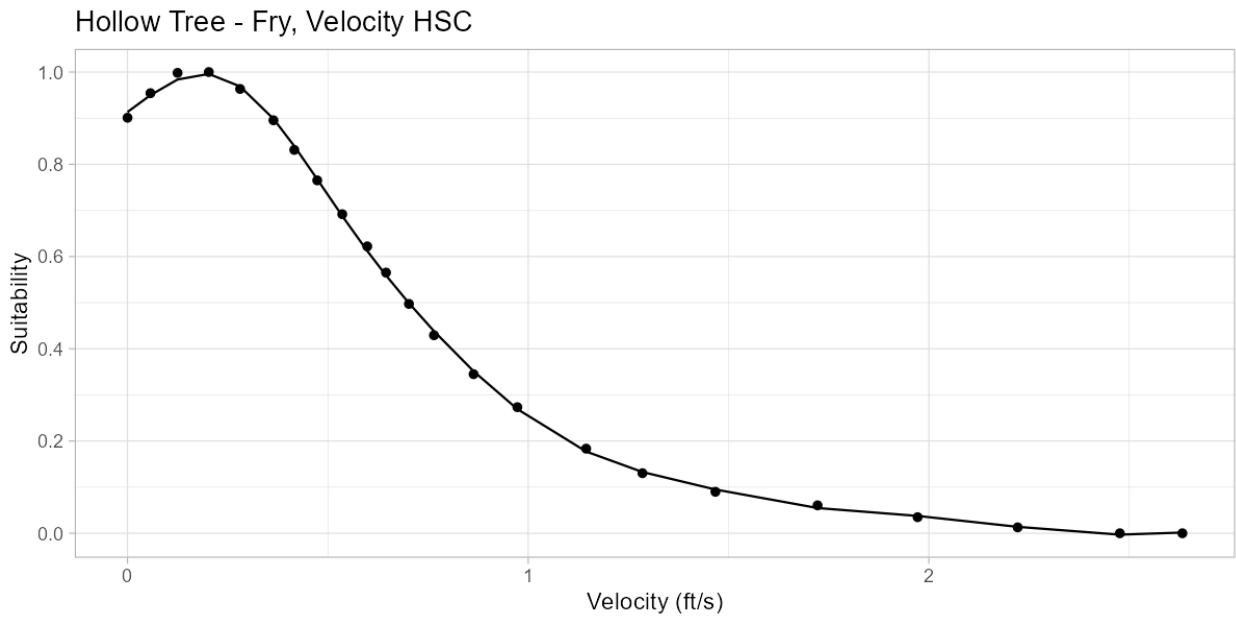
**Figure A-7. Various River Systems, Juvenile Steelhead, Depth Habitat Suitability Curve (Bovee 1978). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



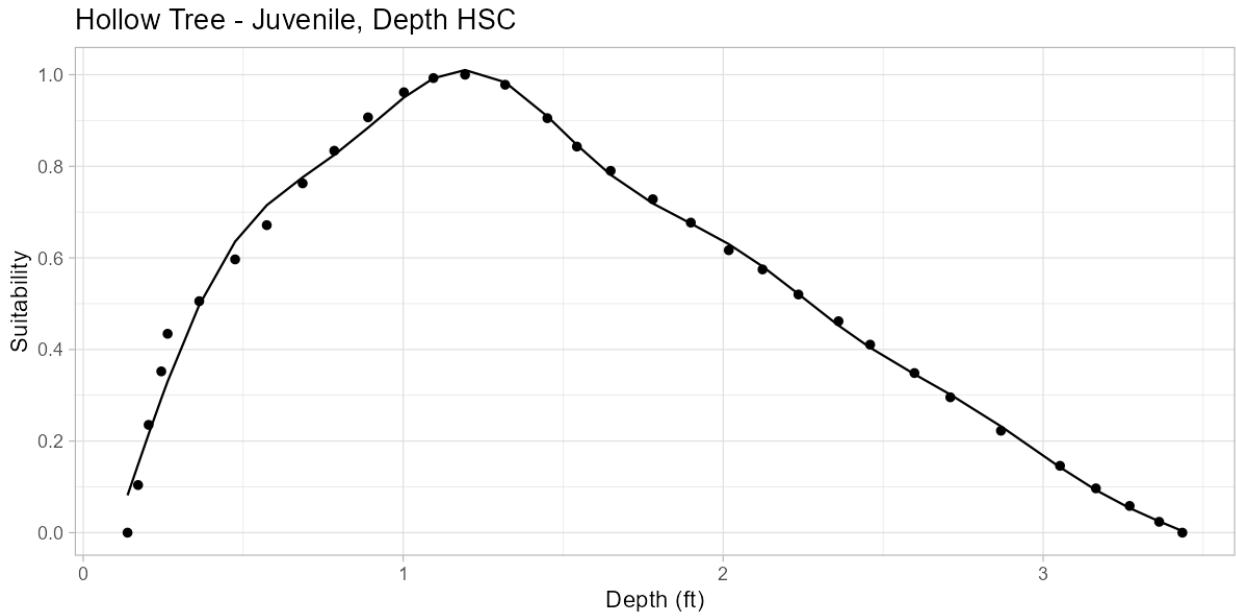
**Figure A-8. Various River Systems, Juvenile Steelhead, Velocity Habitat Suitability Curve (Bovee 1978). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



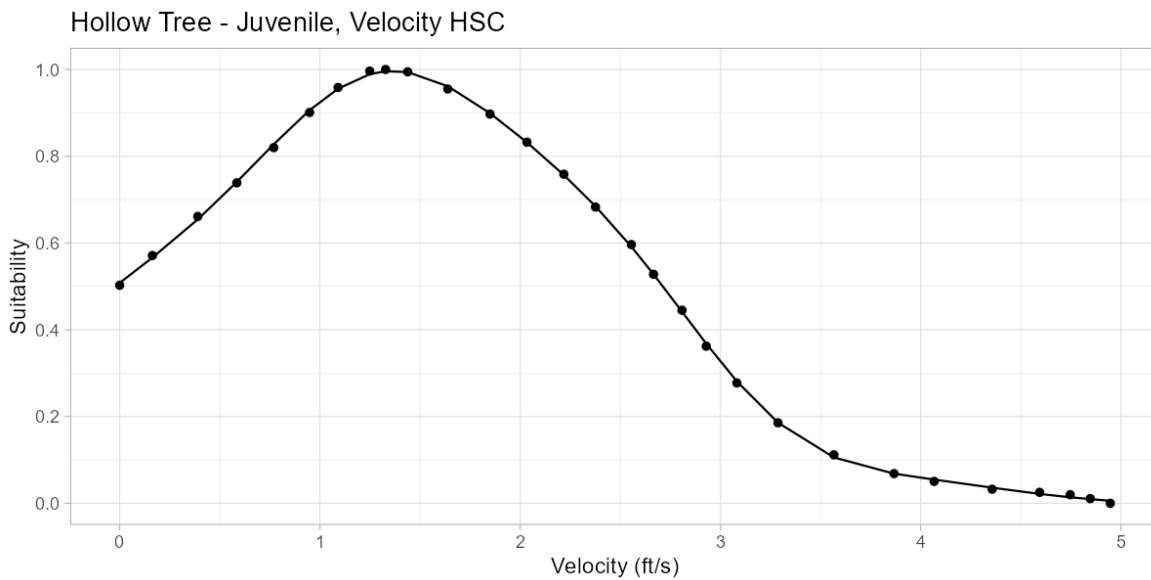
**Figure A-9. Hollow Tree Creek, Fry Steelhead, Depth Habitat Suitability Curve (Gephart et al. 2020). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



**Figure A-10. Hollow Tree Creek, Fry Steelhead, Velocity Habitat Suitability Curve (Gephart et al. 2020). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



**Figure A-11. Hollow Tree Creek, Juvenile Steelhead, Depth Habitat Suitability Curve (Gephart et al. 2020). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



**Figure A-12. Hollow Tree Creek, Juvenile Steelhead, Velocity Habitat Suitability Curve (Gephart et al. 2020). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**

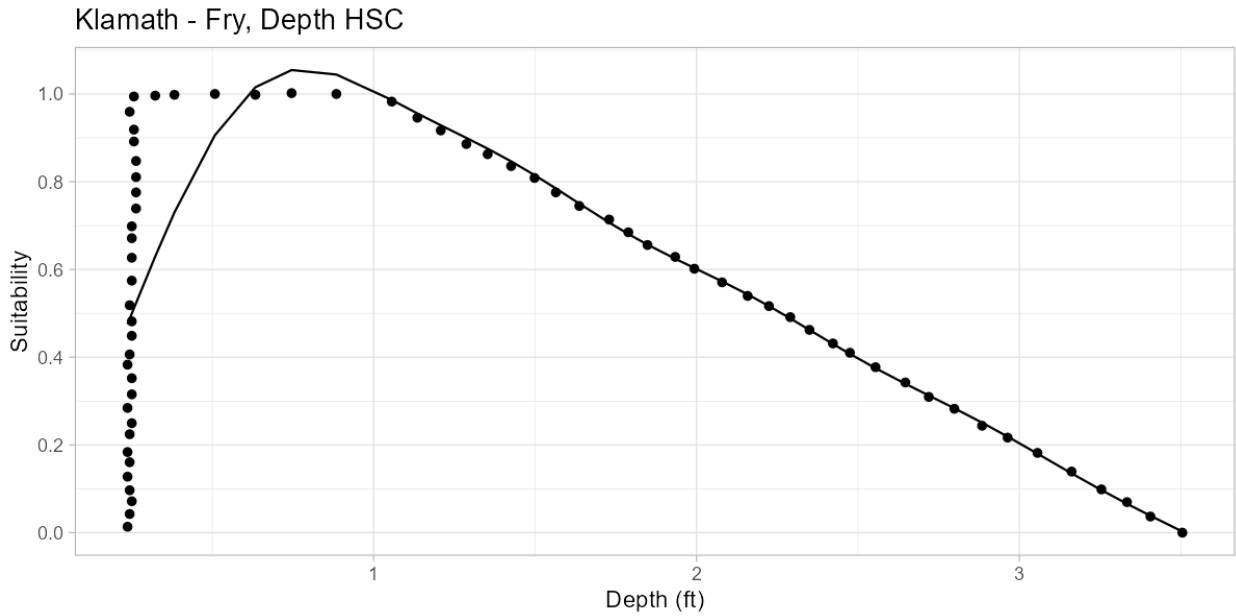


Figure A-13. Klamath River, Fry Steelhead, Depth Habitat Suitability Curve (Hardy and Addley 2001). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.

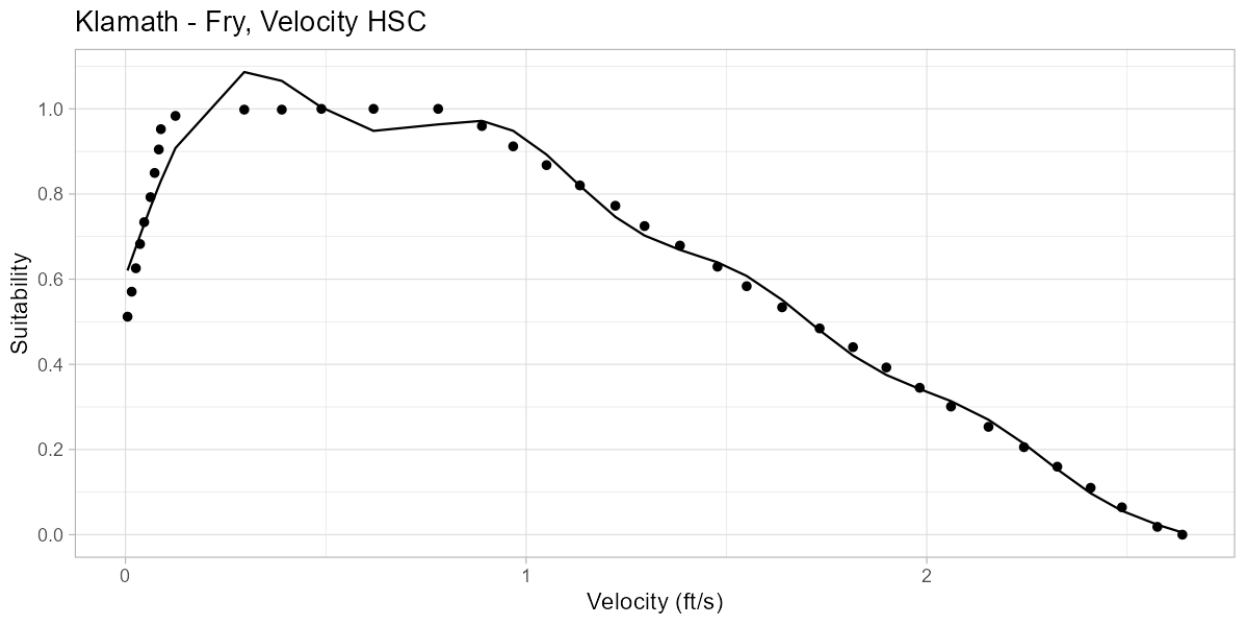
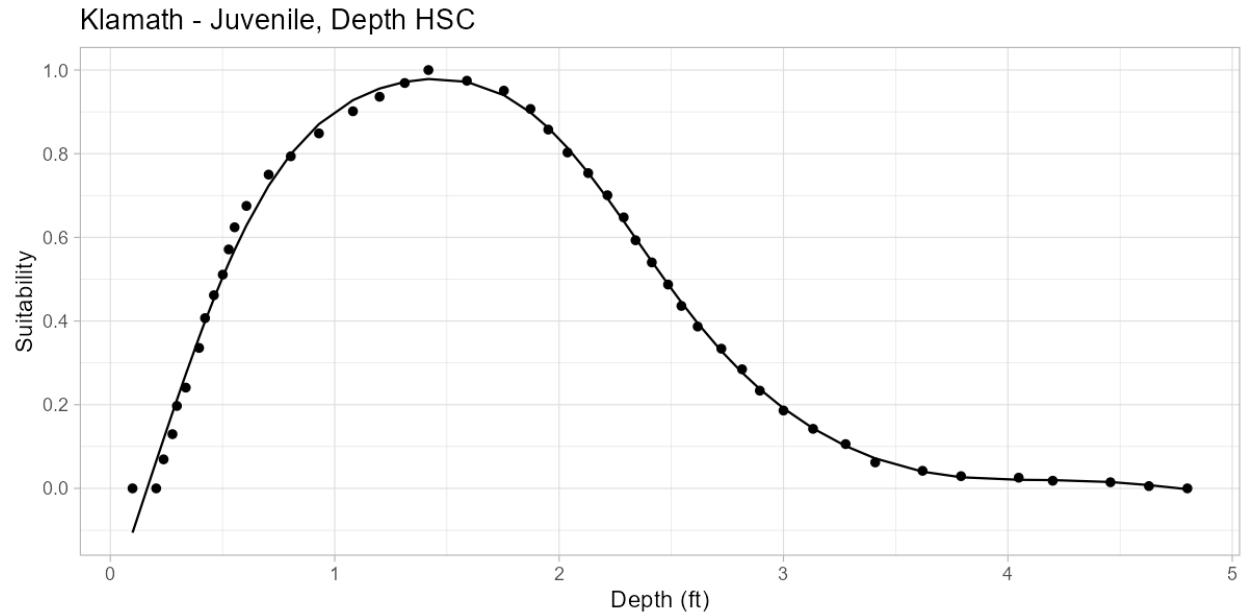
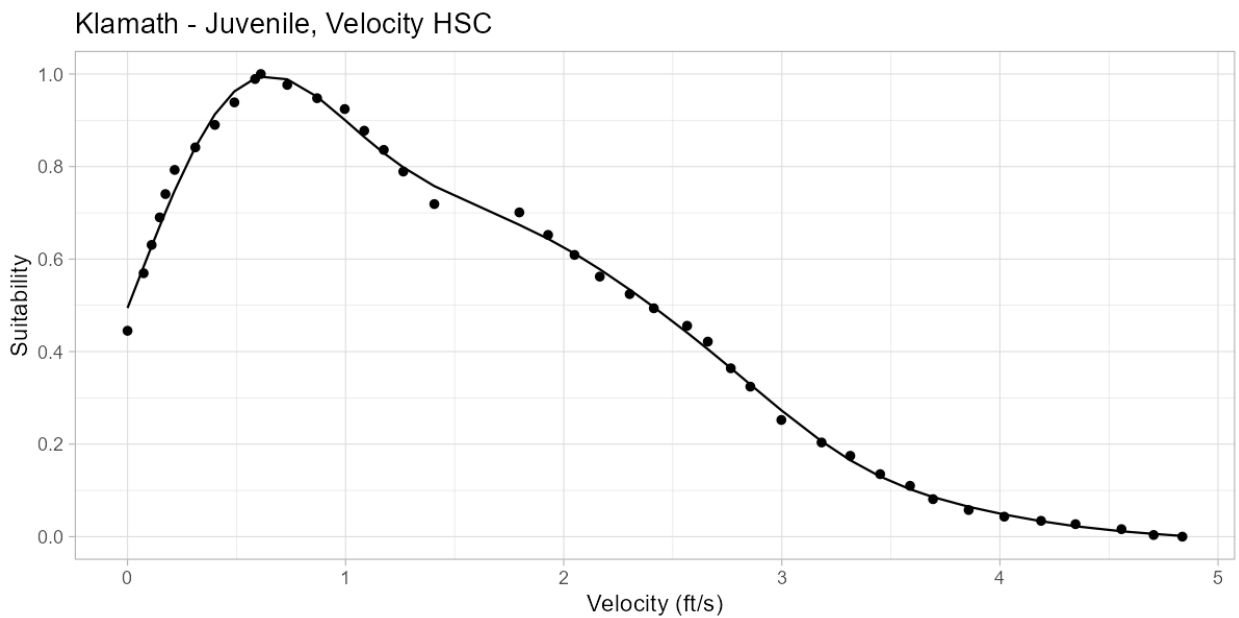


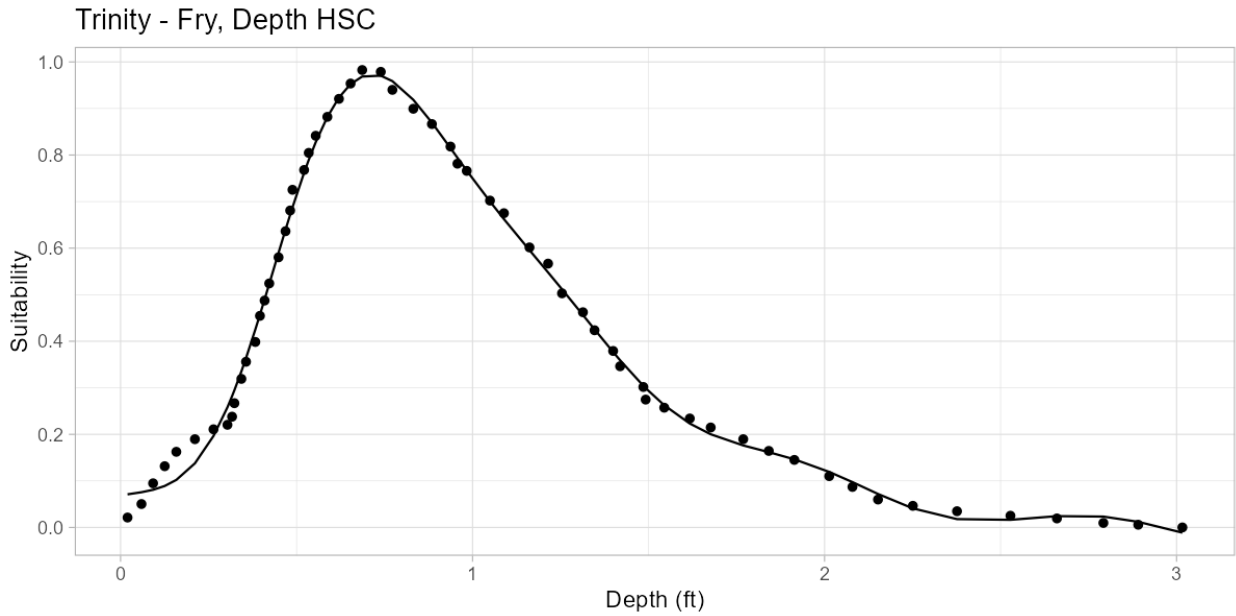
Figure A-14. Klamath River, Fry Steelhead, Velocity Habitat Suitability Curve (Hardy and Addley 2001). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.



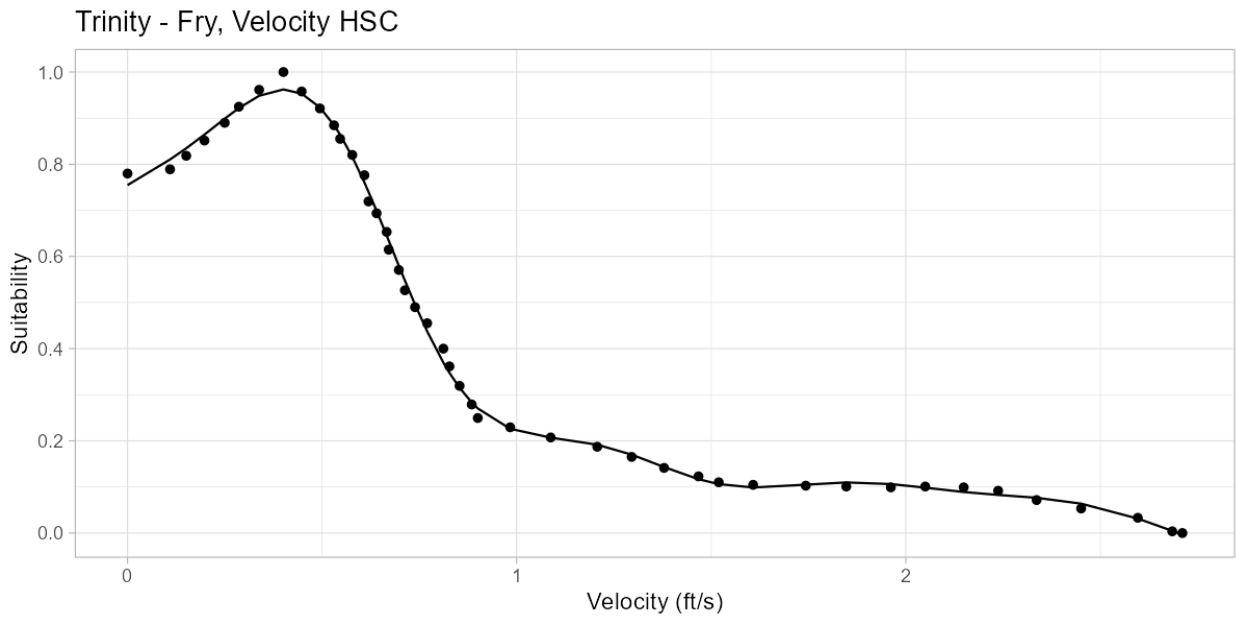
**Figure A-15. Klamath River, Juvenile Steelhead, Depth Habitat Suitability Curve (Hardy and Addley 2001). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



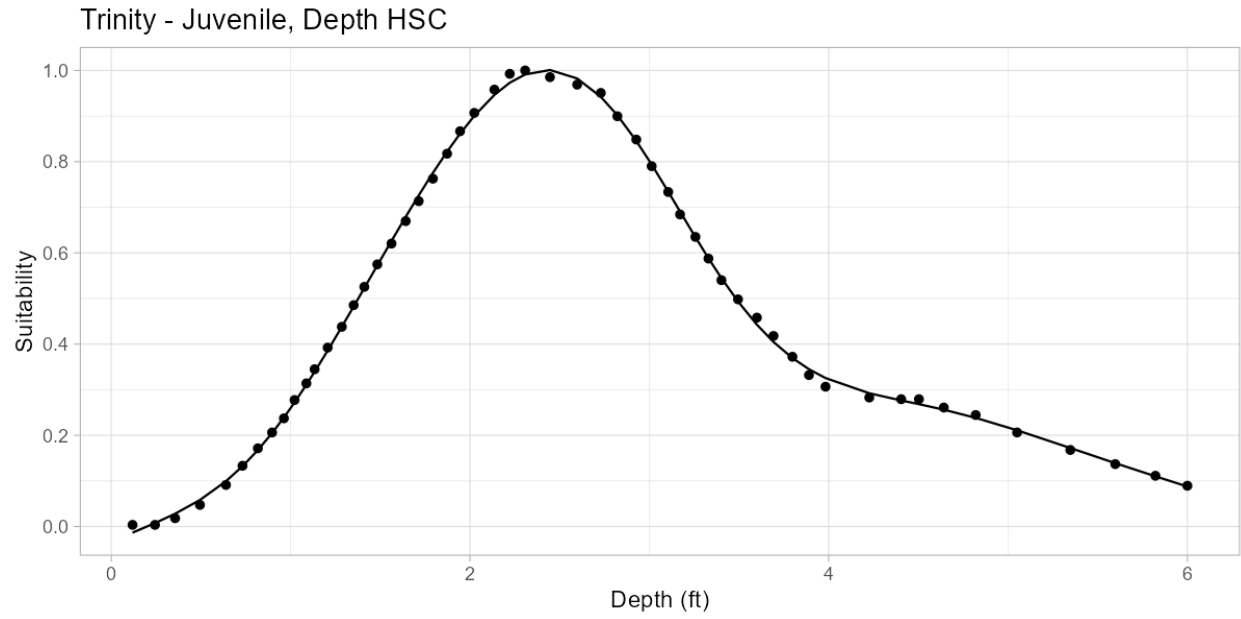
**Figure A-16. Klamath River, Juvenile Steelhead, Velocity Habitat Suitability Curve (Hardy and Addley 2001). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



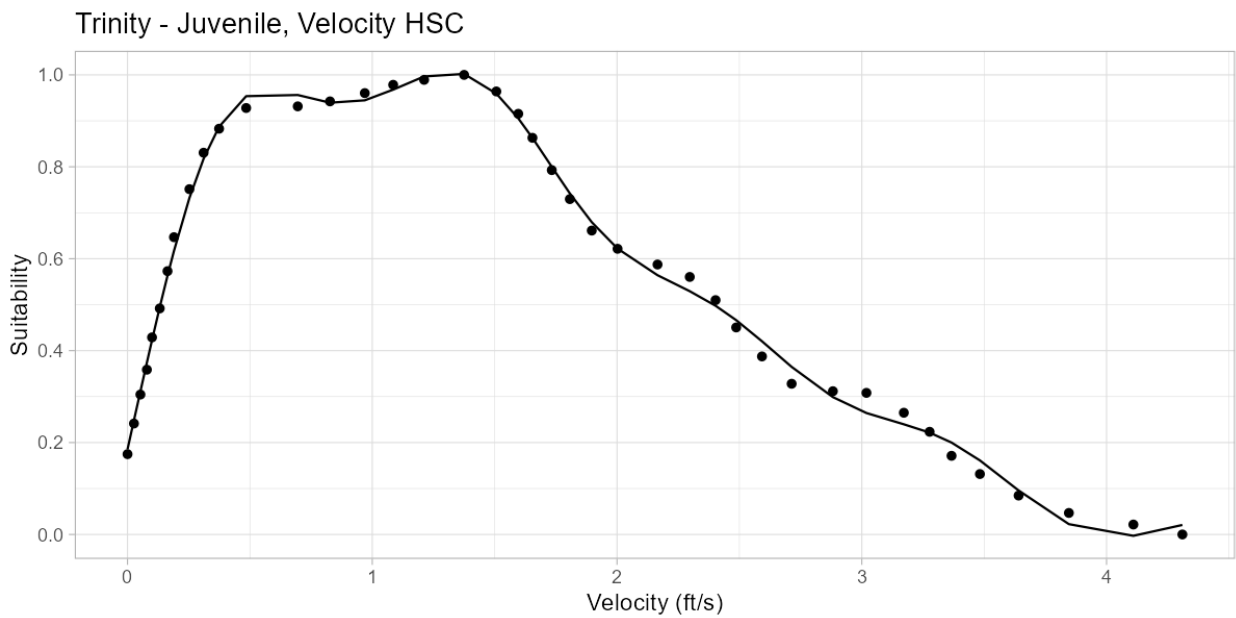
**Figure A-17. Trinity River, Fry Steelhead, Depth Habitat Suitability Curve (Hampton 1997). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



**Figure A-18. Trinity River, Fry Steelhead, Velocity Habitat Suitability Curve (Hampton 1997). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



**Figure A-19. Trinity River, Juvenile Steelhead, Depth Habitat Suitability Curve (Hampton 1997). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**



**Figure A-20. Trinity River, Juvenile Steelhead, Velocity Habitat Suitability Curve (Hampton 1997). Points Represent Digitized Data from the Studies Listed in Table 7 and the Solid Line is the Generalized Linear Model Fit Described in Table A-1.**

## Appendix B

# WUA Generalized Additive Model Fits

**Table B-1. Model Fit Statistics for Generalized Additive Models of Weighted Usable Area (WUA) for Fry Steelhead as a Function of Cross-Sectional Discharge for Field-Measured Transects.**

River	Transect Model	Intercept (SE)	F-Statistic Smoothed Cross Section Flow (cfs) Variable	R <sup>2</sup> Adjusted (Deviance Explained)	GCV
Nacimientto	R1-F2	8.63* (0.66)	37.77*	0.93	16.49
	R2-G4	4.92* (0.35)	69.13*	0.92	3.77
	R1-P5	7.66* (0.75)	41.74*	0.86	16.44
	R1-R4	1.90* (0.10)	103.50*	0.97	0.40
	R2-F1	0.50* (0.07)	24.92*	0.86	0.15
	R2-G1	9.13* (0.30)	256.10*	0.98	2.75
	R2-P3	6.09* (0.38)	87.67*	0.95	4.65
	R2-R3	3.71* (0.15)	147.00*	0.98	0.85
	R3-F1	8.1* (1.0)	4.14*	0.58	40.66
	R3-G2	2.33* (0.32)	24.46*	0.84	3.18
	R3-P3	1.99* (0.25)	26.99*	0.91	2.39
	R3-R4	2.00* (0.26)	9.63*	0.77	2.78
	R4-F1	0.92 (0.07)	34.47*	0.92	0.19
	R4-G1	4.15* (0.21)	130.50*	0.98	1.61
	R4-P1	9.98* (0.61)	91.38*	0.97	14.46
R4-R1	1.42* (0.14)	43.84*	0.92	0.64	
San Antonio	R1-F2	1.83* (0.17)	45.66*	0.94	1.07
	R1-G2	1.81* (0.29)	18.66*	0.83	2.74
	R1-P1	1.2* (0.24)	11.25*	0.80	2.29
	R1-R6	2.78* (0.31)	34.89*	0.93	3.73
	R2-F3	0.87* (0.33)	4.98*	0.28	2.96
	R2-G1	0.64* (0.26)	4.93*	0.30	1.87
	R2-P1	4.42* (0.73)	5.68*	0.82	18.19
	R2-R1	4.30* (1.10)	10.99	0.70	34.64

\* p-value <0.01

**Table B-2. Model Fit Statistics for Generalized Additive Models of Weighted Usable Area (WUA) for Juvenile Steelhead as a Function of Cross-Sectional Discharge for Field-Measured Transects.**

River	Transect Model	Intercept (SE)	F-Statistic Smoothed Cross Section Flow (cfs) Variable	R <sup>2</sup> Adjusted (Deviance Explained)	GCV
Nacimiento	R1-F2	22.54* (1.21)	73.49*	0.97	60.1
	R2-G4	23.60* (0.59)	192.8*	0.98	13.91
	R1-P5	28.92* (1.08)	115.1*	0.98	43.63
	R1-R4	9.10* (0.47)	51.2*	0.95	8.90
	R2-F1	1.46* (0.38)	9.1*	0.50	4.05
	R2-G1	35.91* (1.23)	64.26*	0.96	57.76
	R2-P3	19.03* (1.00)	58.95*	0.96	41.78
	R2-R3	16.32* (1.00)	71.07*	0.90	29.66
	R3-F1	31.43* (3.10)	11.41*	0.80	360.89
	R3-G2	9.92* (0.75)	32.55*	0.92	22.64
	R3-P3	6.13* (0.97)	19.23*	0.82	30.70
	R3-R4	9.15* (1.12)	12.87*	0.82	51.02
	R4-F1	7.19* (0.35)	104.8	0.98	4.85
	R4-G1	9.50* (1.6)	18.25	0.72	77.41
	R4-P1	15.04* (2.99)	14.39*	0.67	263.77
R4-R1	5.71 (1.28)	11.08	0.55	47.40	
San Antonio	R1-F2	4.32* (0.97)	11.61*	0.67	29.11
	R1-G2	4.74* (1.20)	9.77*	0.62	43.16
	R1-P1	3.31* (0.58)	14.28*	0.83	12.35
	R1-R6	5.99* (1.32)	10.99*	0.72	55.96
	R2-F3	3.60 (1.86)	4.02	0.11	93.70
	R2-G1	2.16 (1.31)	2.14	47.31	47.31
	R2-P1	5.85* (1.77)	7.35	0.50	91.95
	R2-R1	5.93* (2.06)	6.40*	0.41	121.83

\* p-value <0.01

**Table B-3. Model Fit Statistics for Generalized Additive Models of Weighted Usable Area (WUA) for Spawning Steelhead as a Function of Cross-Sectional Discharge for Field-Measured Transects.**

River	Transect Model	Intercept (SE)	F-Statistic Smoothed Cross Section Flow (cfs) Variable	R <sup>2</sup> Adjusted (Deviance Explained)	GCV
Nacimiento	R1-F2	--	--	--	--
	R2-G4	6.5* (0.41)	84.55*	0.97	6.76
	R1-P5	--	--	--	--
	R1-R4	1.07* (0.36)	5.77*	0.33	3.63
	R2-F1	2.55* (0.43)	20.21	0.88	7.72
	R2-G1	--	--	--	--
	R2-P3	--	--	--	--
	R2-R3	--	--	--	--
	R3-F1	3.05* (1.05)	5.50	0.31	30.87
	R3-G2	--	--	--	--
	R3-P3	--	--	--	--
	R3-R4	--	--	--	--
	R4-F1	--	--	--	--
	R4-G1	0.01 (0.01)	2.15	0.045	0.0016
	R4-P1	--	--	--	--
R4-R1	--	--	--	--	

\* p-value <0.01

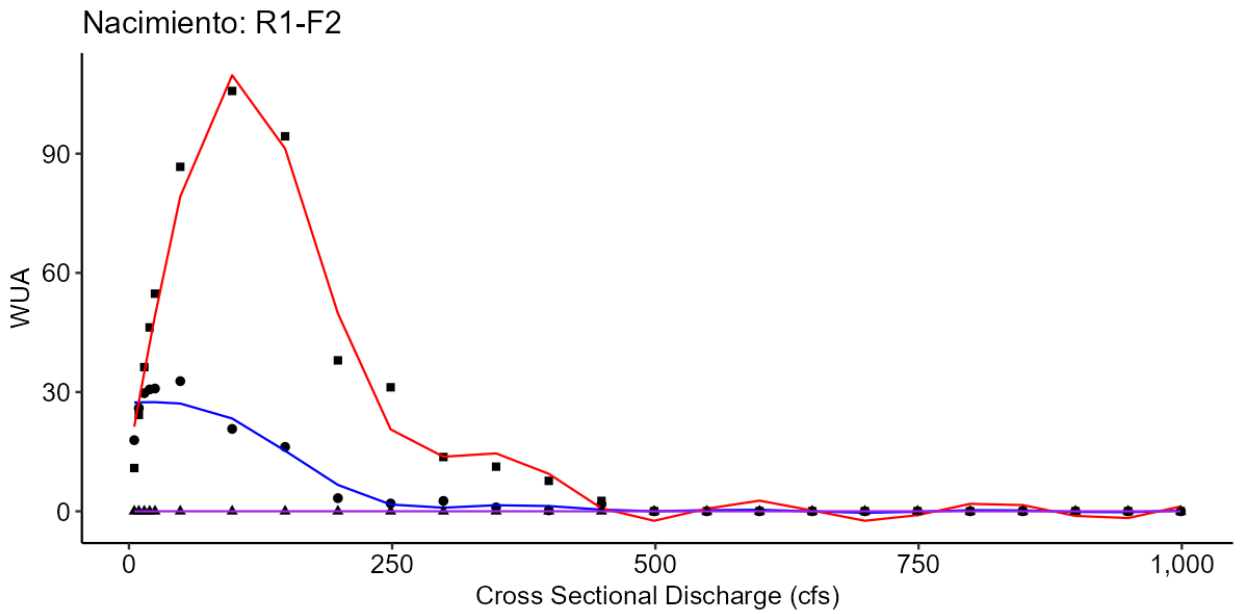


Figure B-1. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R1-F2 (Riffle).

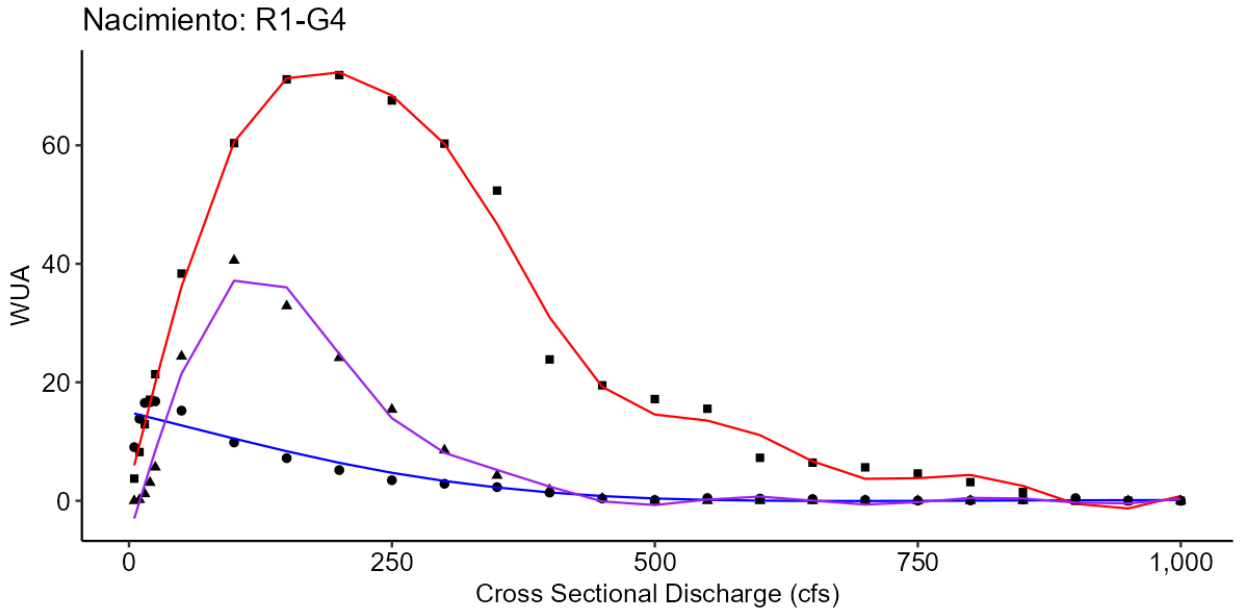


Figure B-2. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R1-G4 (Glide).

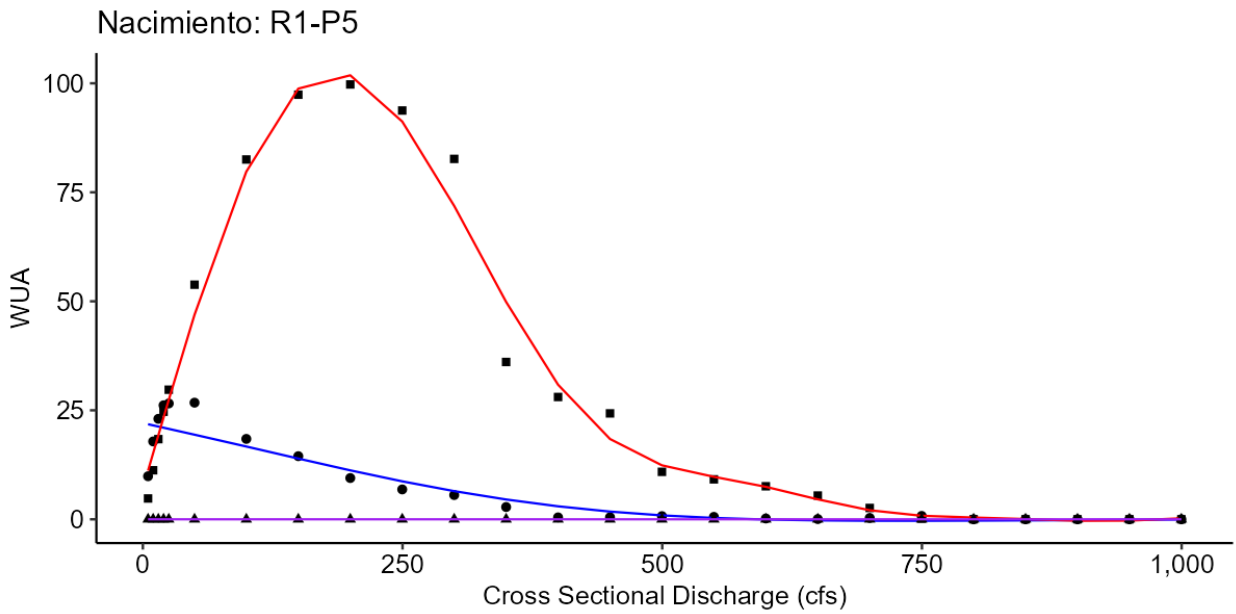


Figure B-3. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R1-P5 (Pool).

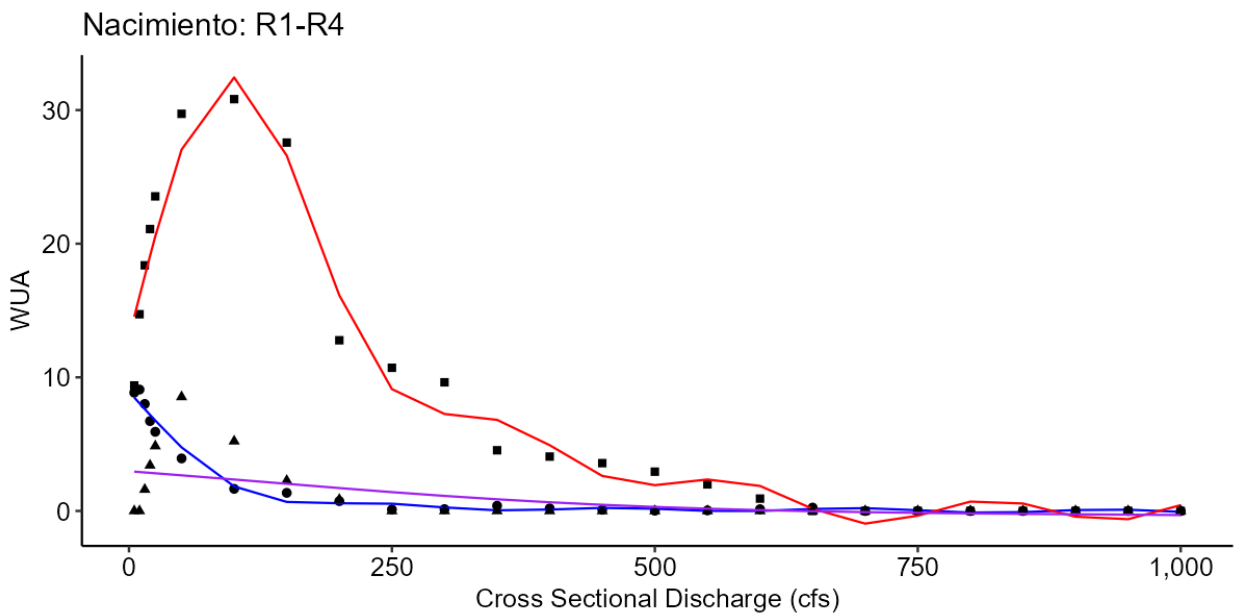


Figure B-4. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R1-R4 (Run).

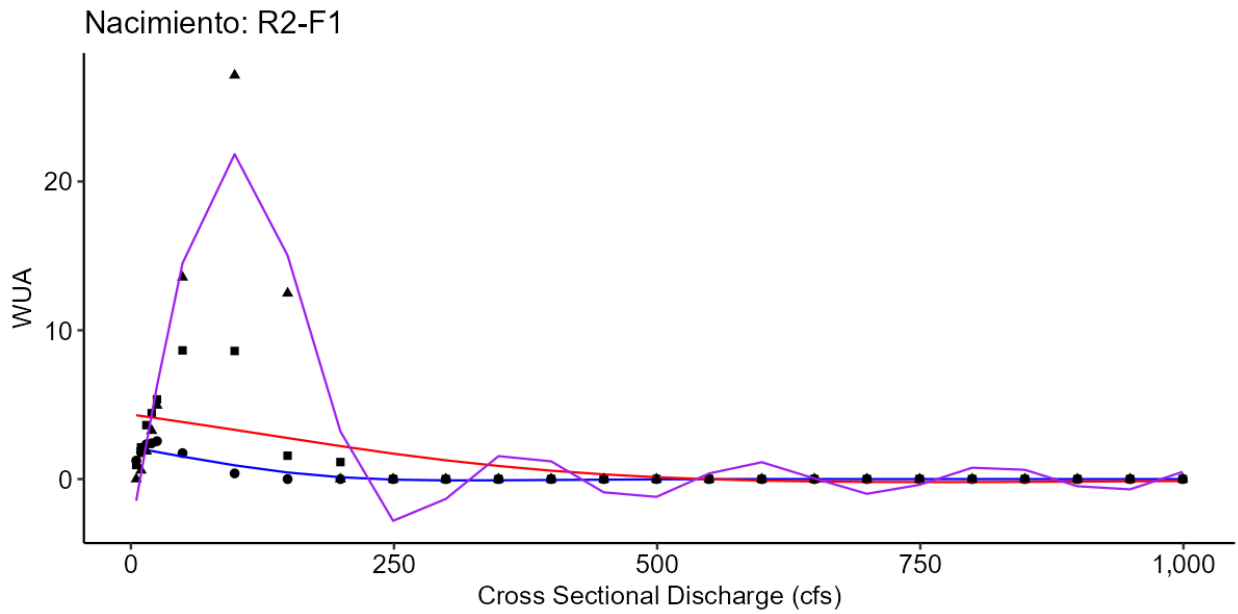


Figure B-5. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R2-F1 (Riffle).

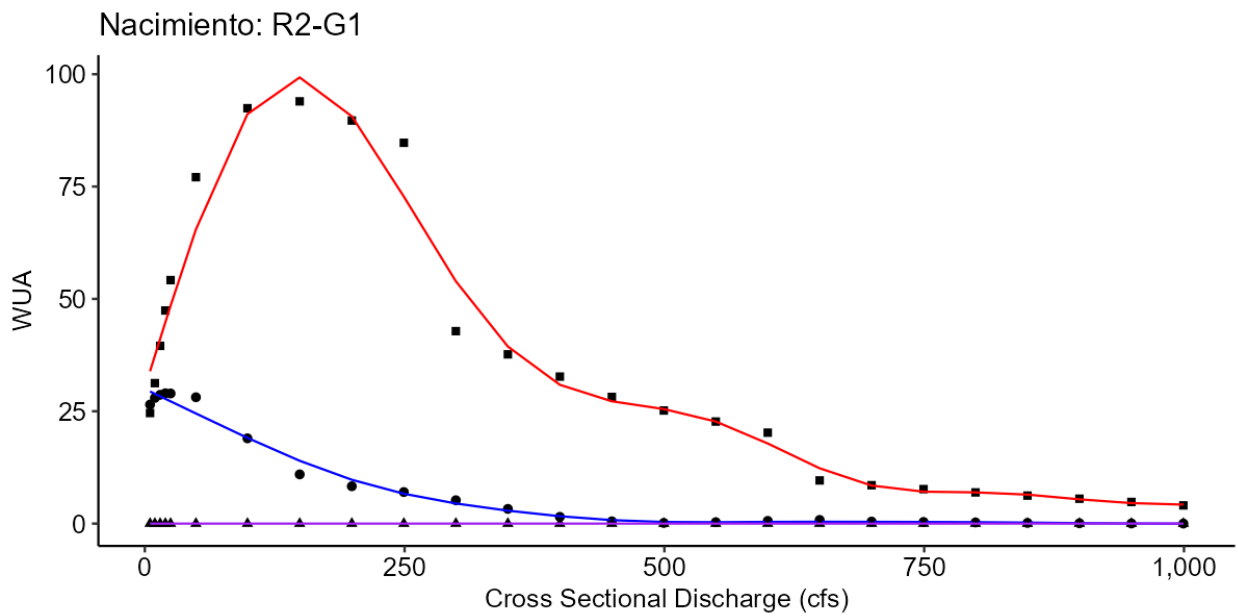


Figure B-6. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R2-G1 (Glide).

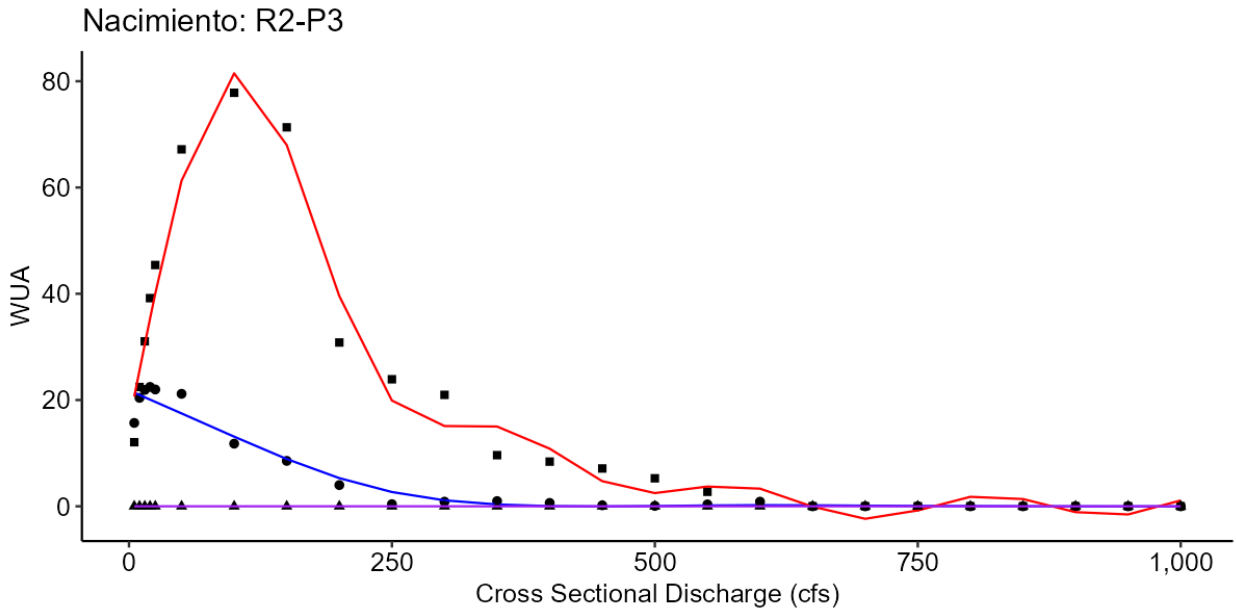


Figure B-7. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R2-P3 (Pool).

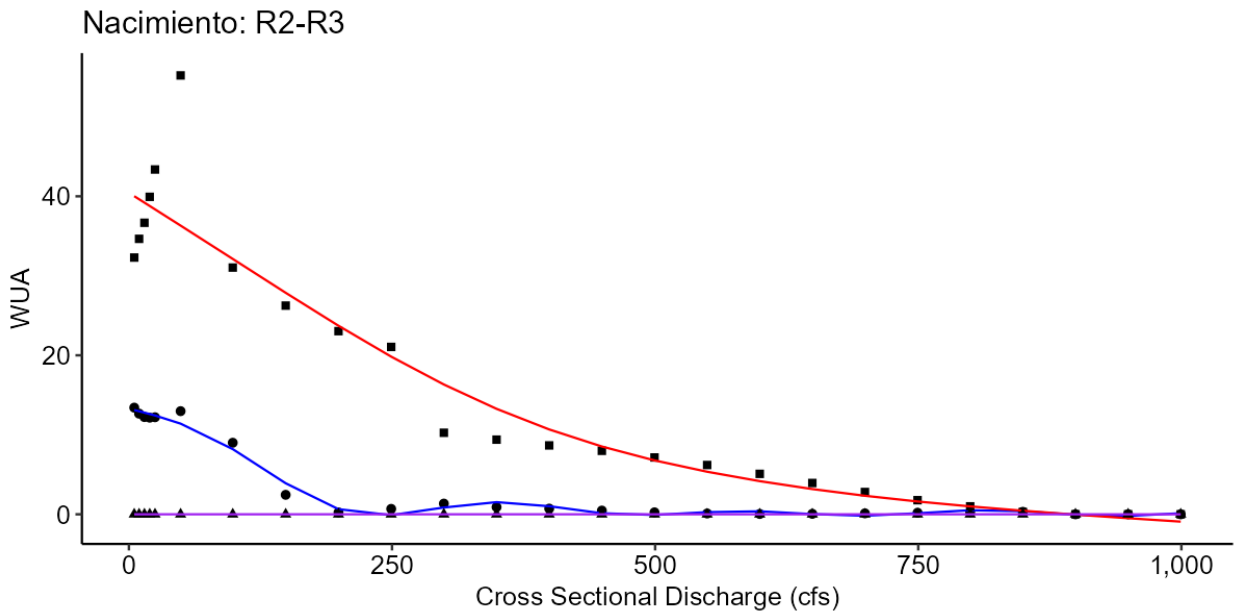


Figure B-8. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R2-R3 (Run).

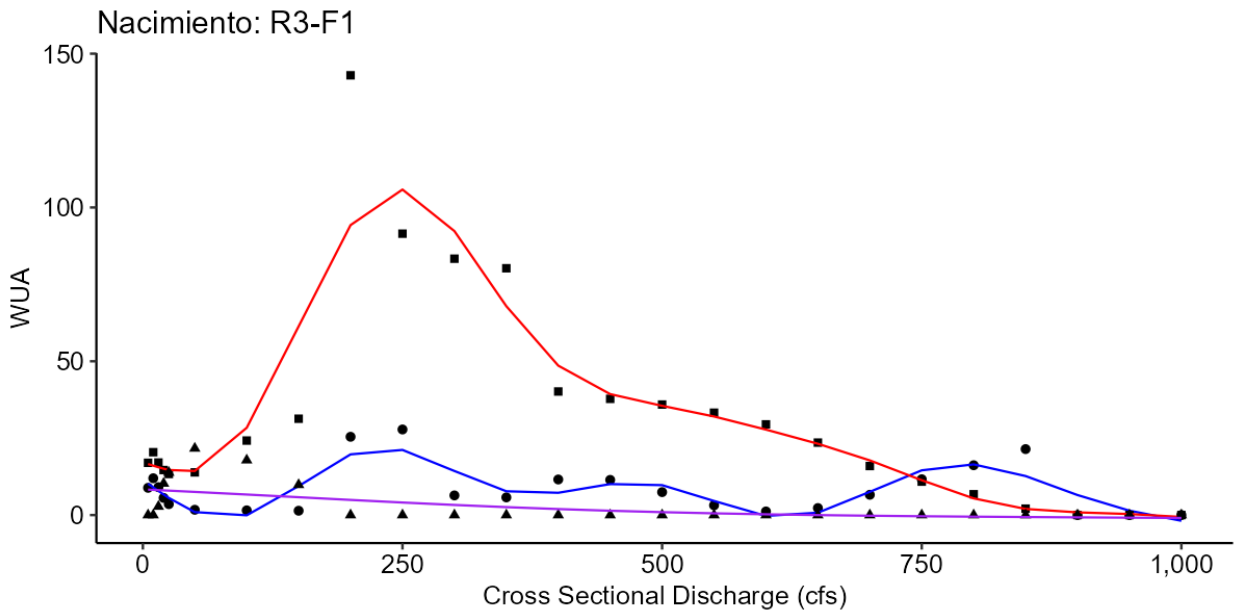


Figure B-9. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R3-F1 (Riffle).

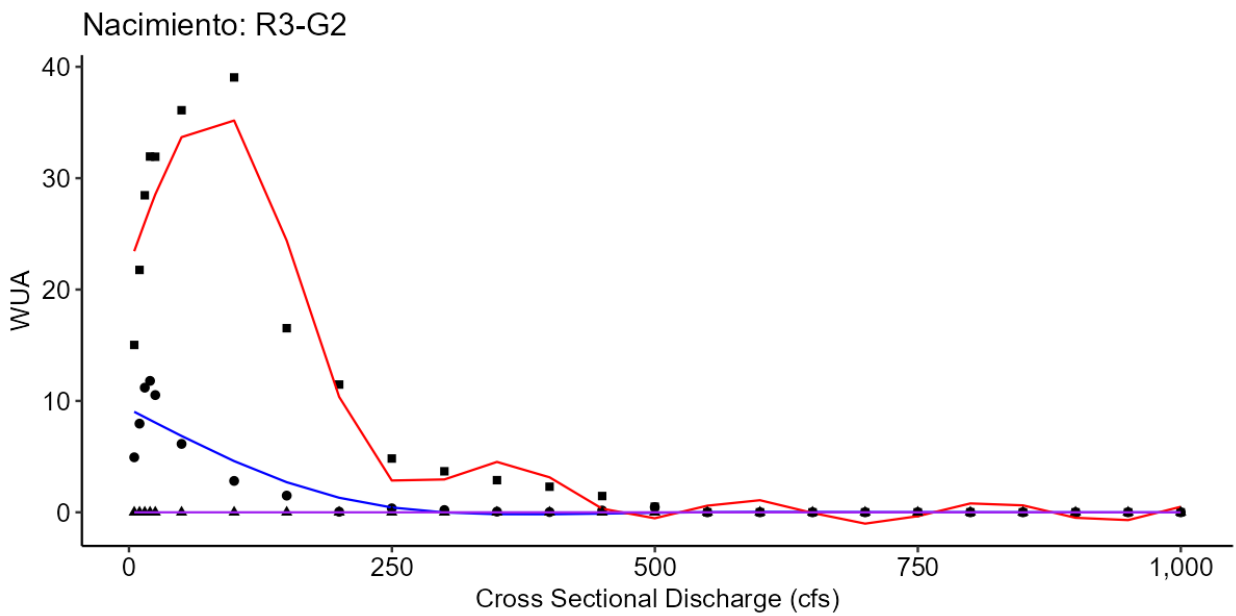


Figure B-10. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R3-G2 (Glide).

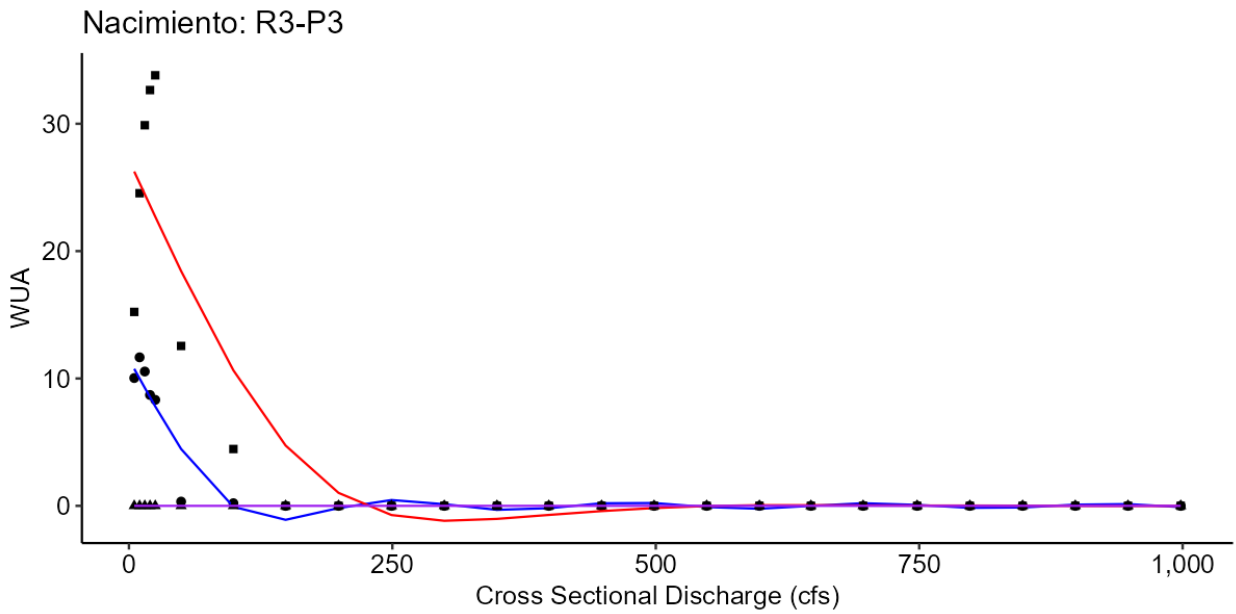


Figure B-11. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R3-P3 (Pool).

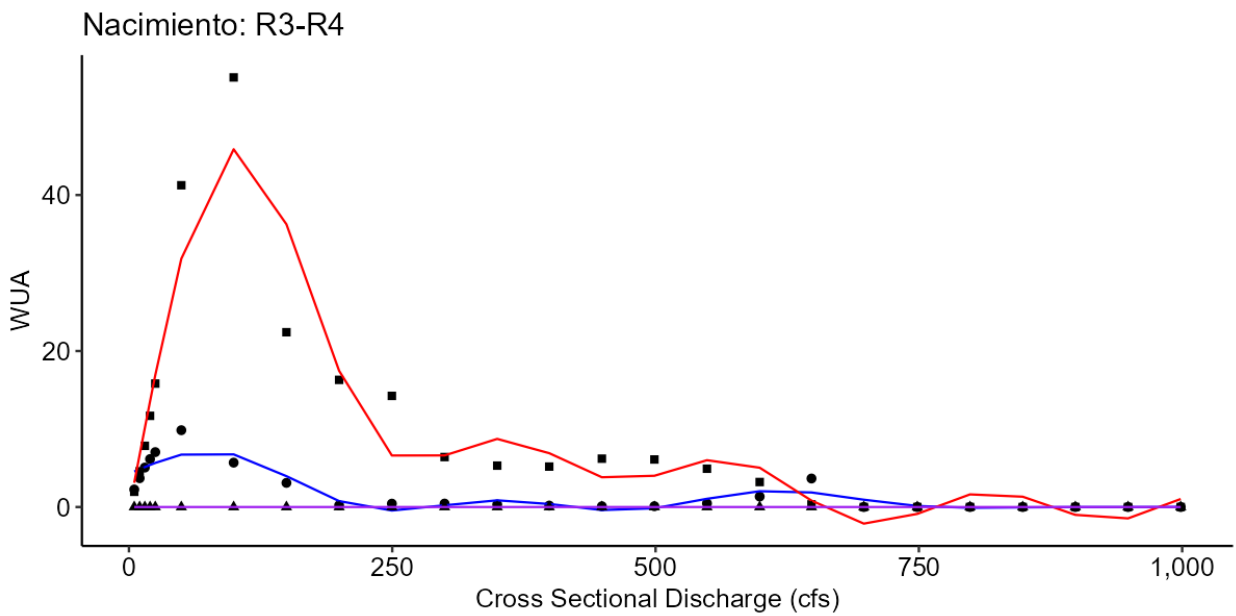


Figure B-12. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R3-R4 (Run).

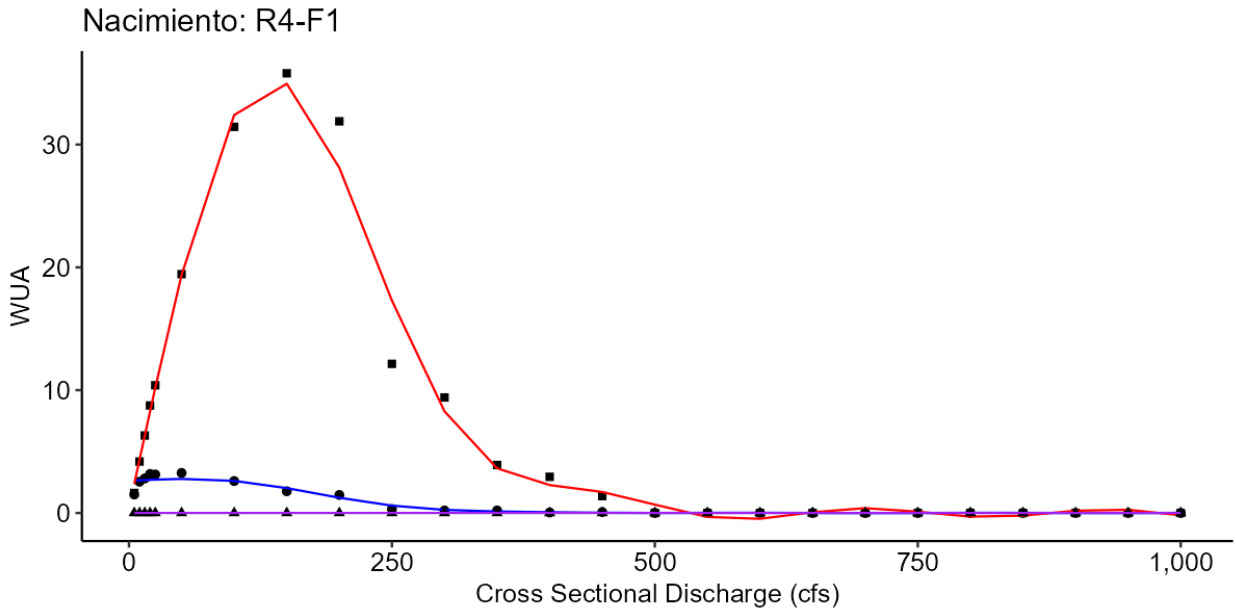


Figure B-13. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R4-F1 (Riffle).

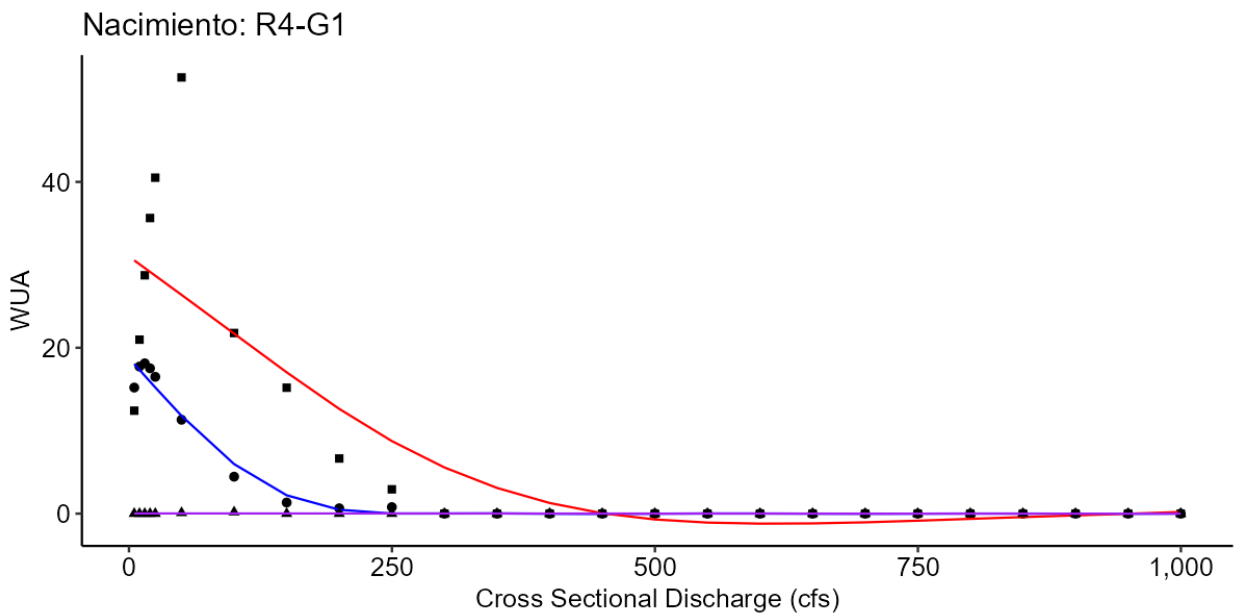


Figure B-14. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R4-G1 (Glide).

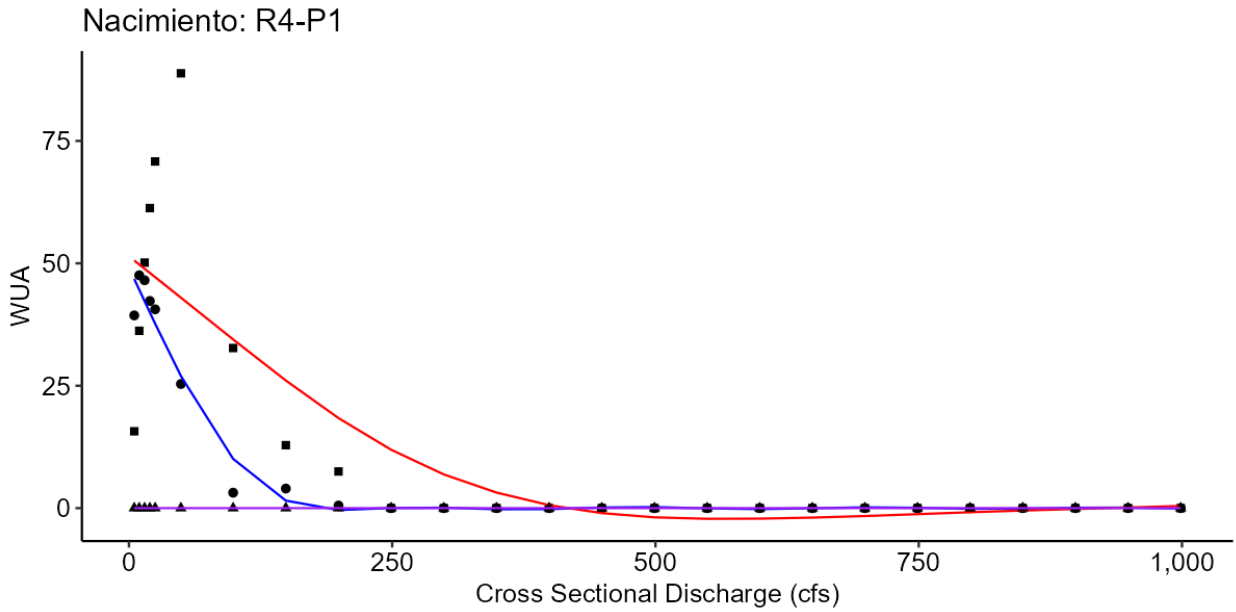


Figure B-15. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R4-P1 (Pool).

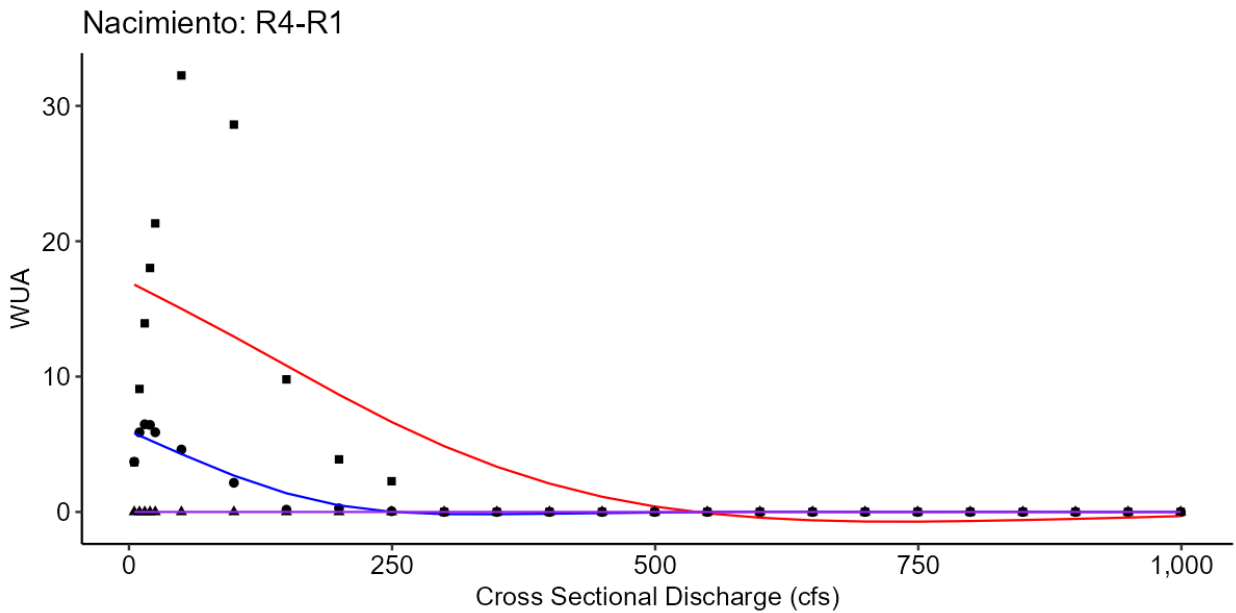


Figure B-16. Generalized Additive Model Fits for Juvenile (square points, red line), Fry (circle points, blue line), and Spawners (triangle points, purple line) Steelhead at Nacimiento River Transect R4-R1 (Run).

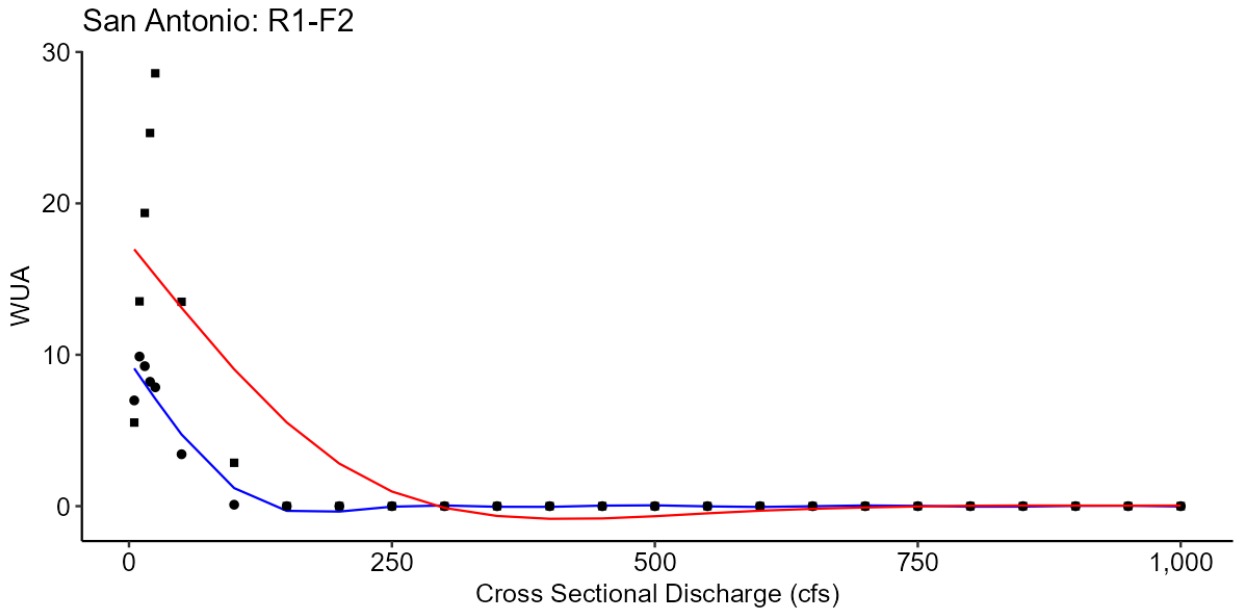


Figure B-17. Generalized Additive Model Fits for Juvenile (square points, red line), and Fry (circle points, blue line) Steelhead at San Antonio River Transect R1-F2 (Run).

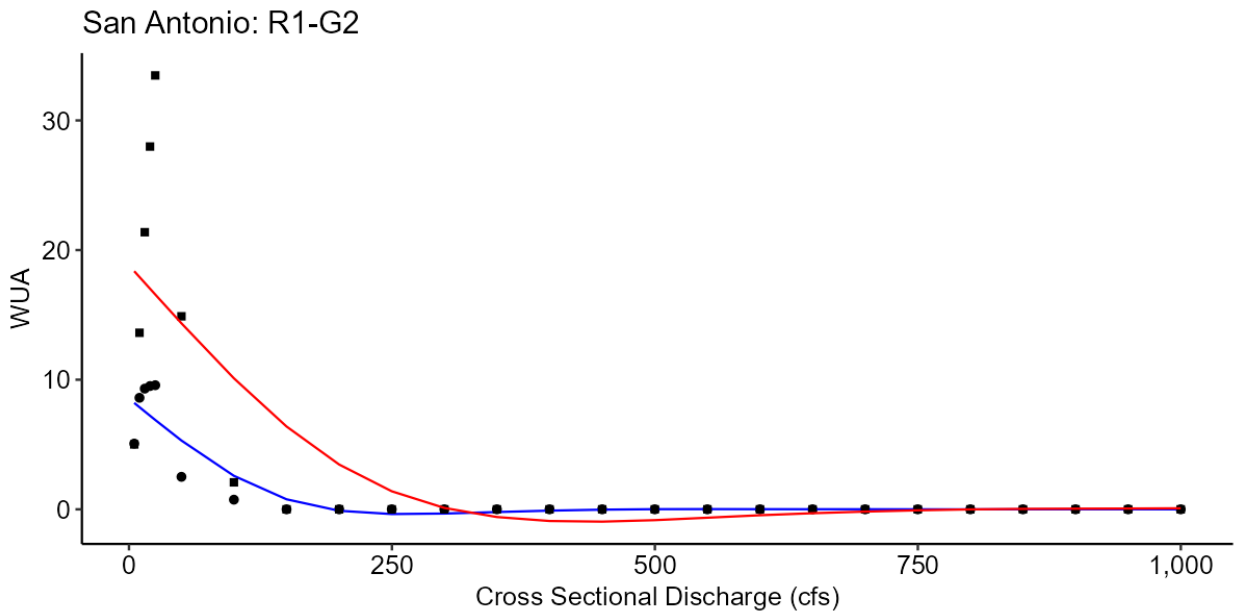


Figure B-18. Generalized Additive Model Fits for Juvenile (square points, red line), and Fry (circle points, blue line) Steelhead at San Antonio River Transect R1-G2 (Glide).

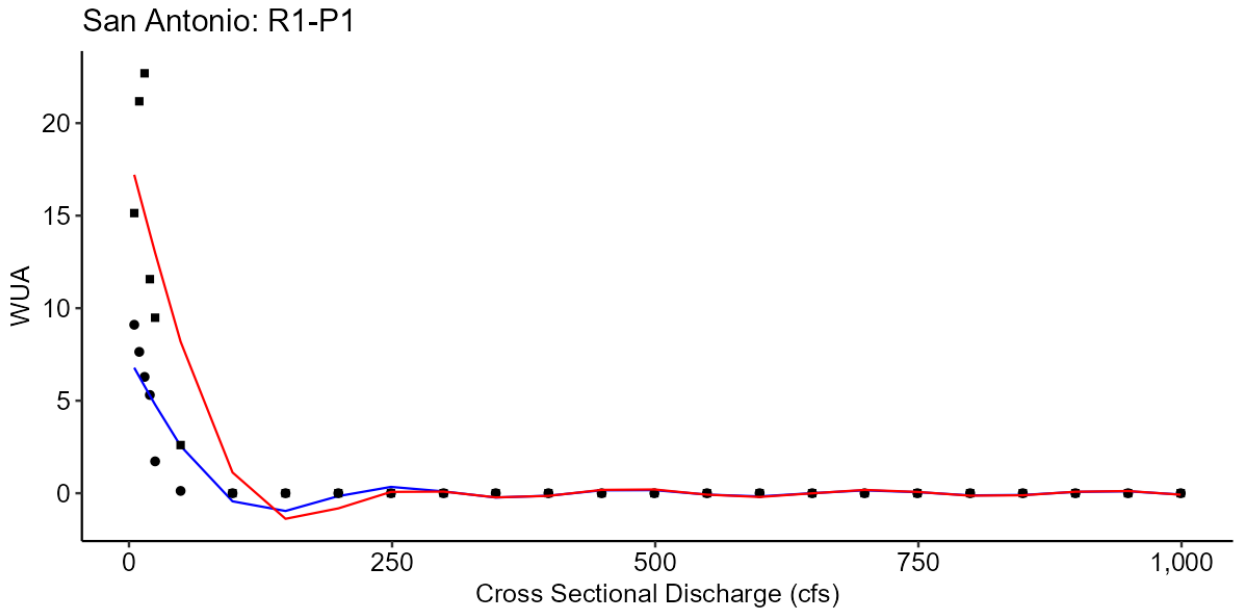


Figure B-19. Generalized Additive Model Fits for Juvenile (square points, red line), and Fry (circle points, blue line) Steelhead at San Antonio River Transect R1-P1 (Pool).

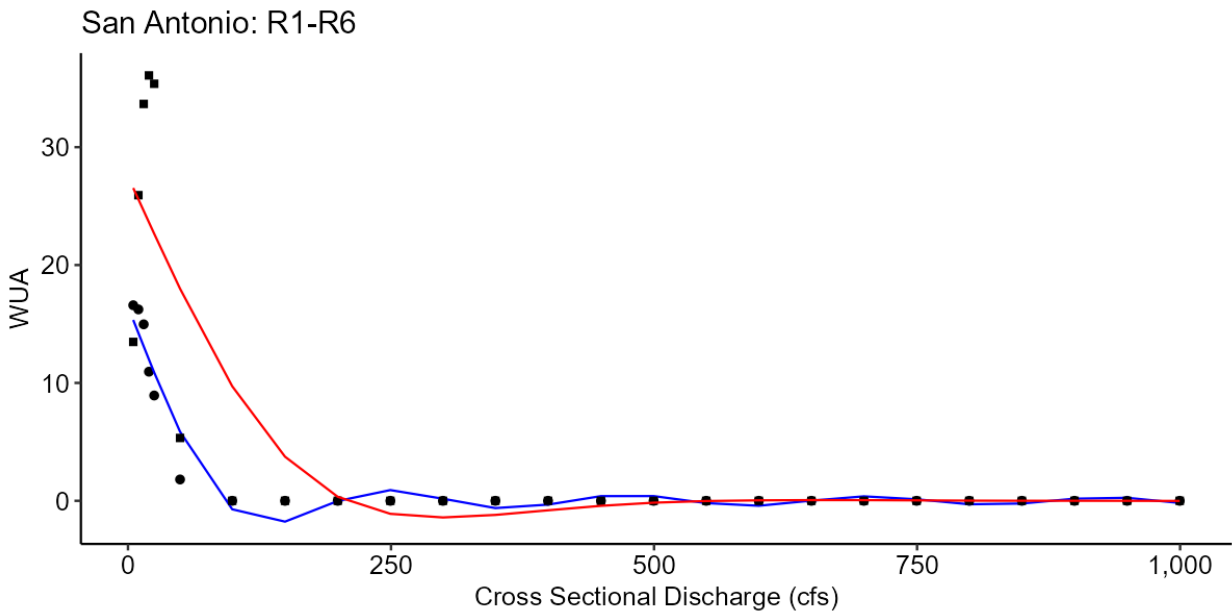


Figure B-20. Generalized Additive Model Fits for Juvenile (square points, red line), and Fry (circle points, blue line) Steelhead at San Antonio River Transect R1-R6 (Run).

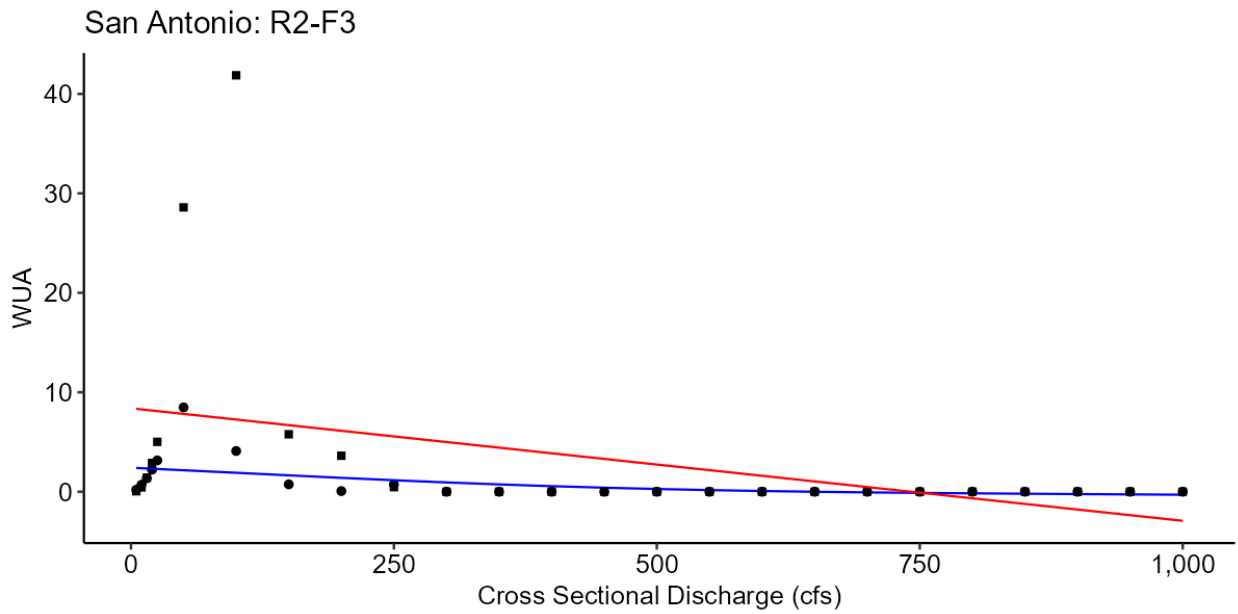


Figure B-21. Generalized Additive Model Fits for Juvenile (square points, red line), and Fry (circle points, blue line) Steelhead at San Antonio River Transect R2-F3 (Riffle).

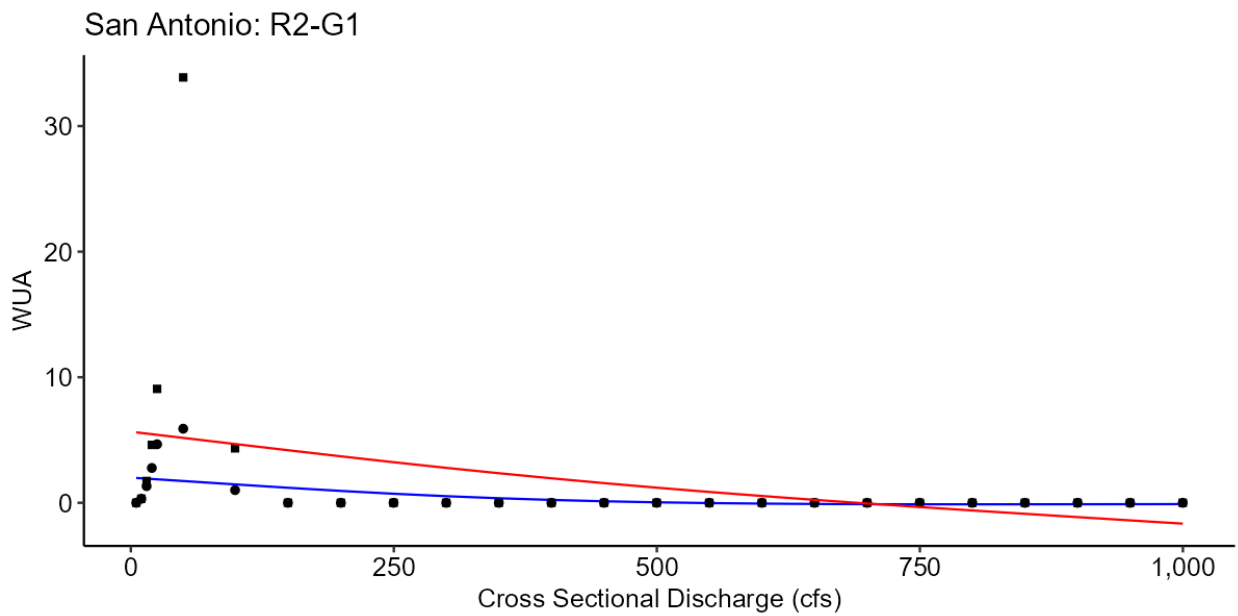


Figure B-22. Generalized Additive Model Fits for Juvenile (square points, red line), and Fry (circle points, blue line) Steelhead at San Antonio River Transect R2-G1 (Glide).

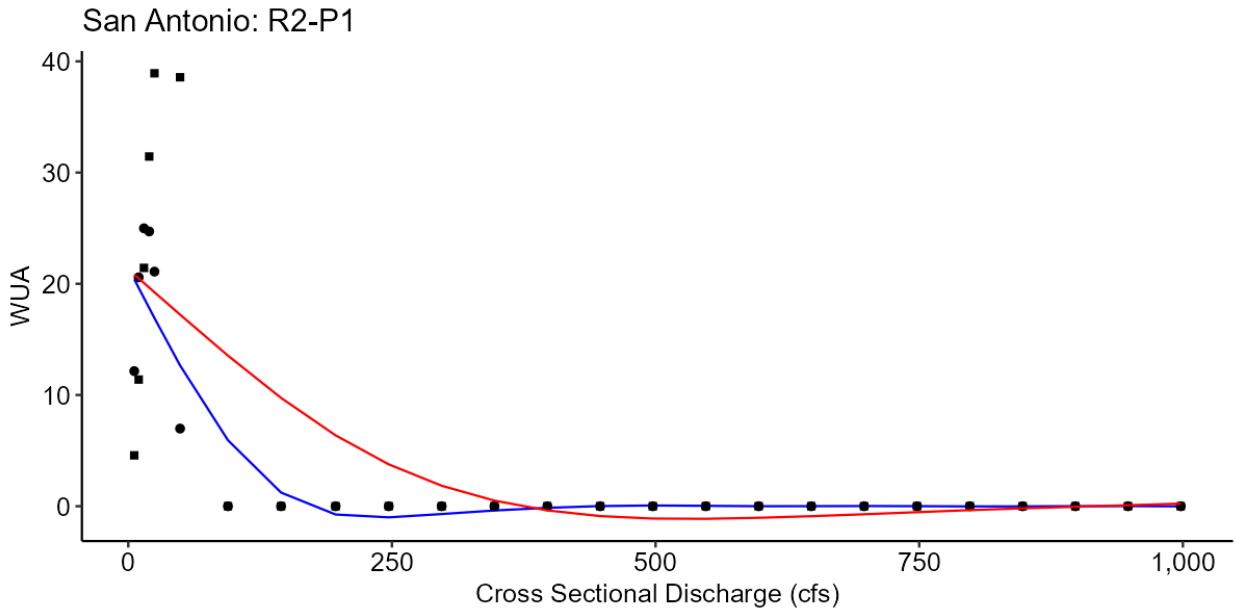


Figure B-23. Generalized Additive Model Fits for Juvenile (square points, red line), and Fry (circle points, blue line) Steelhead at San Antonio River Transect R2-P1 (Pool).

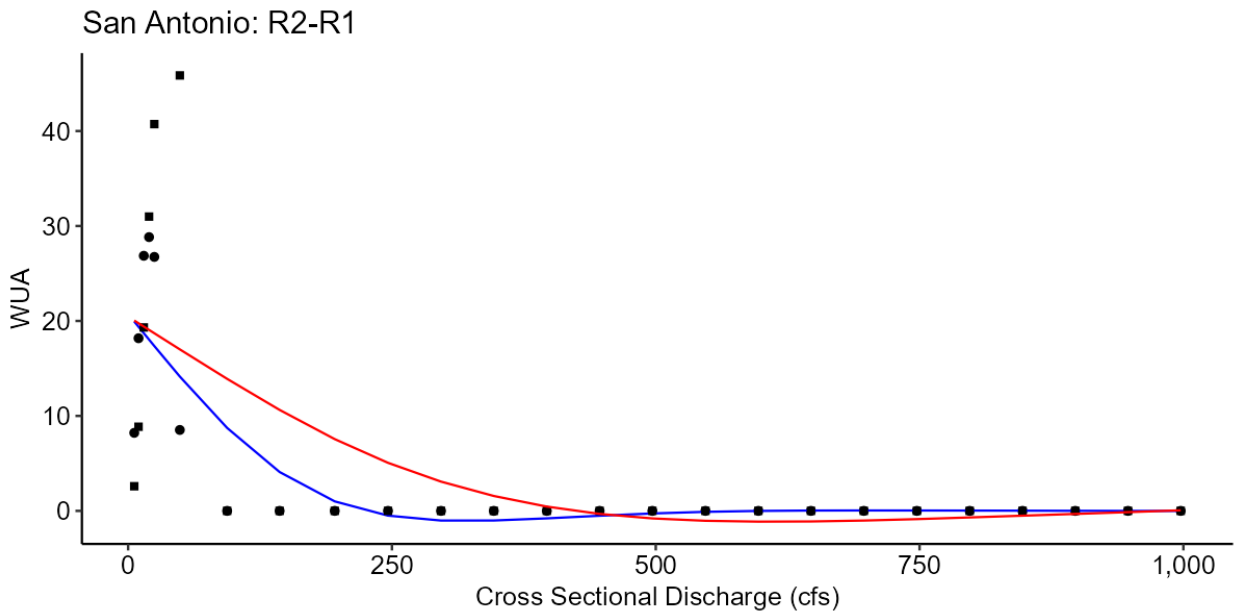
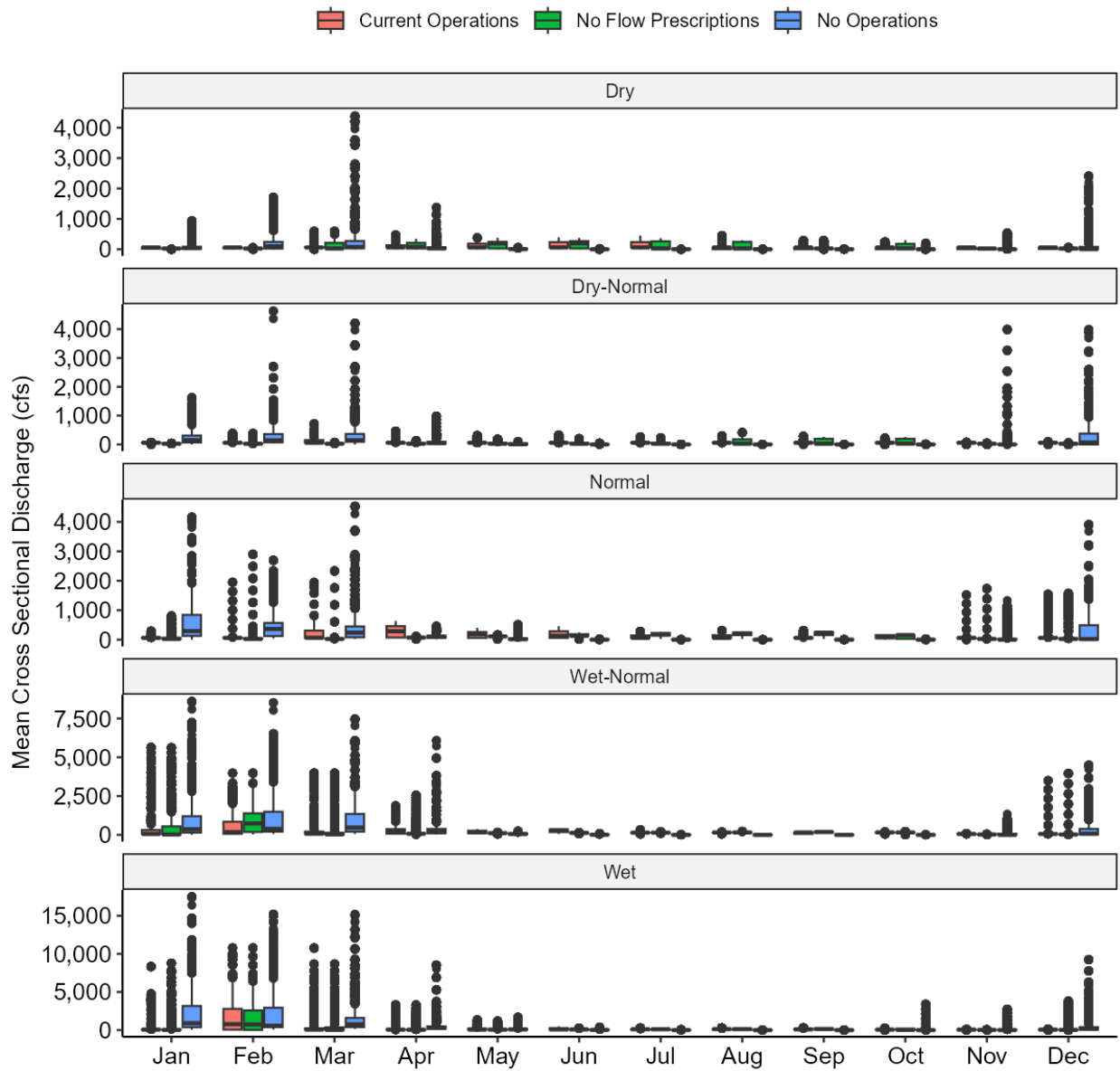


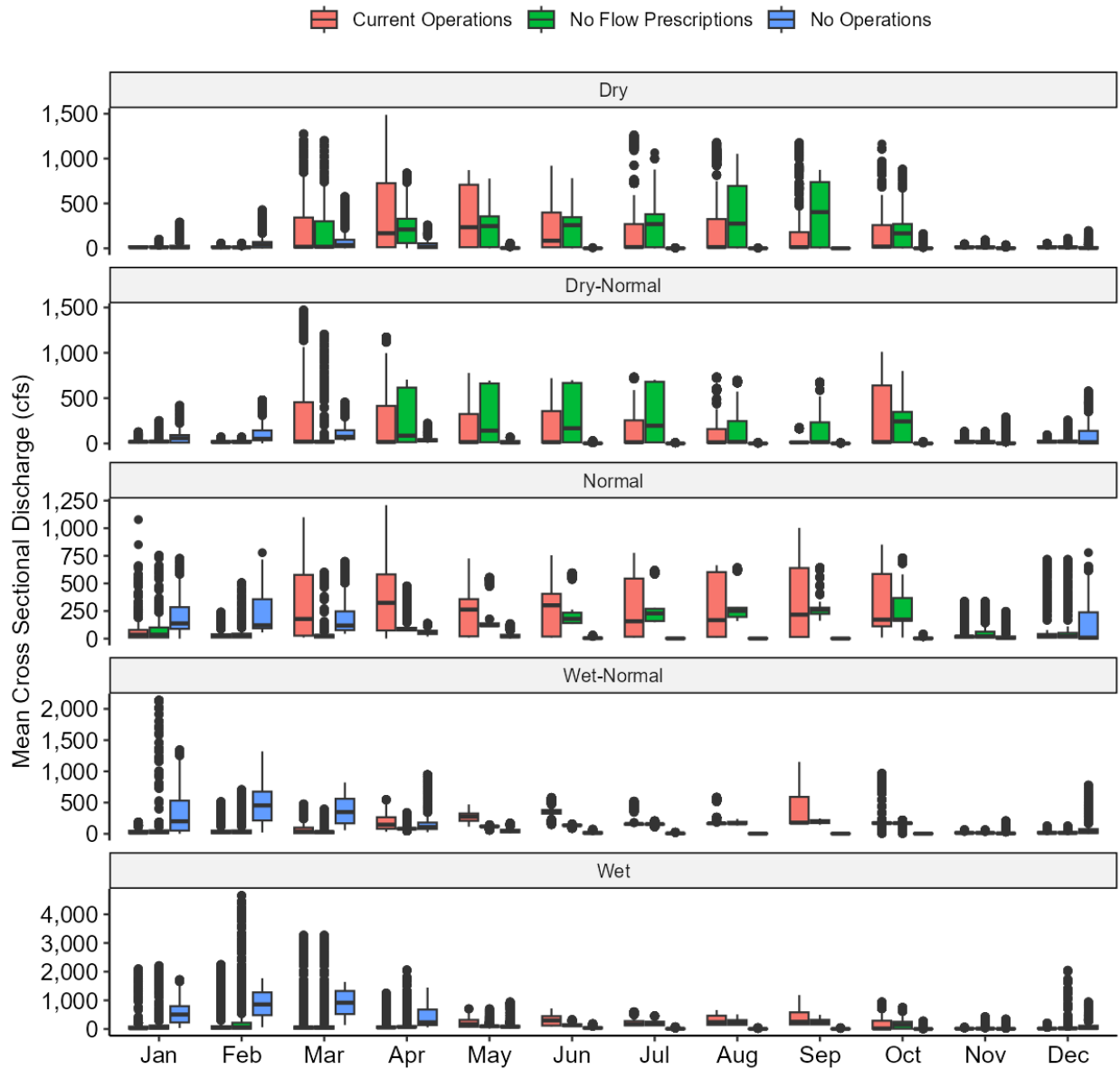
Figure B-24. Generalized Additive Model Fits for Juvenile (square points, red line), and Fry (circle points, blue line) Steelhead at San Antonio River Transect R2-R1 (Run).

# Appendix C

## Supplemental Habitat Model Results



**Figure C-1. Monthly Cross-Sectional Discharges (cfs) for Transects in the Nacimientto River Summarized by Scenario and Water Year Type.**



**Figure C-2. Monthly Cross-Sectional Discharges (cfs) for Transects in the San Antonio River Summarized by Scenario and Water Year Type.**