Appendix F

Fish Passage Analysis Technical Memorandum

TISDALE WEIR REHABILITATION AND FISH PASSAGE PROJECT

Fish Passage Analysis Technical Memorandum

Prepared for
California Department of Water Resources

September 2019

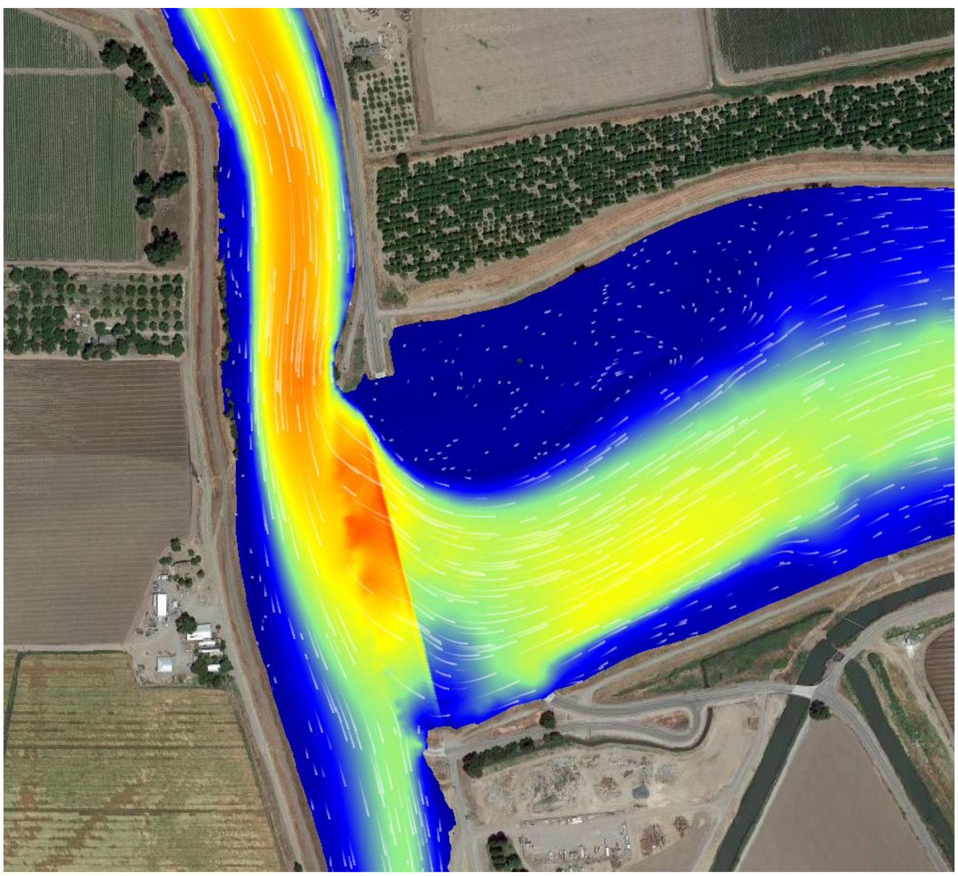

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TABLE OF CONTENTS

Tisdale Weir Rehabilitation and Fish Passage Project Fish Passage Analysis Technical Memorandum

Page

Attachment

List of Figures

List of Tables

TISDALE WEIR REHABILITATION AND FISH PASSAGE PROJECT

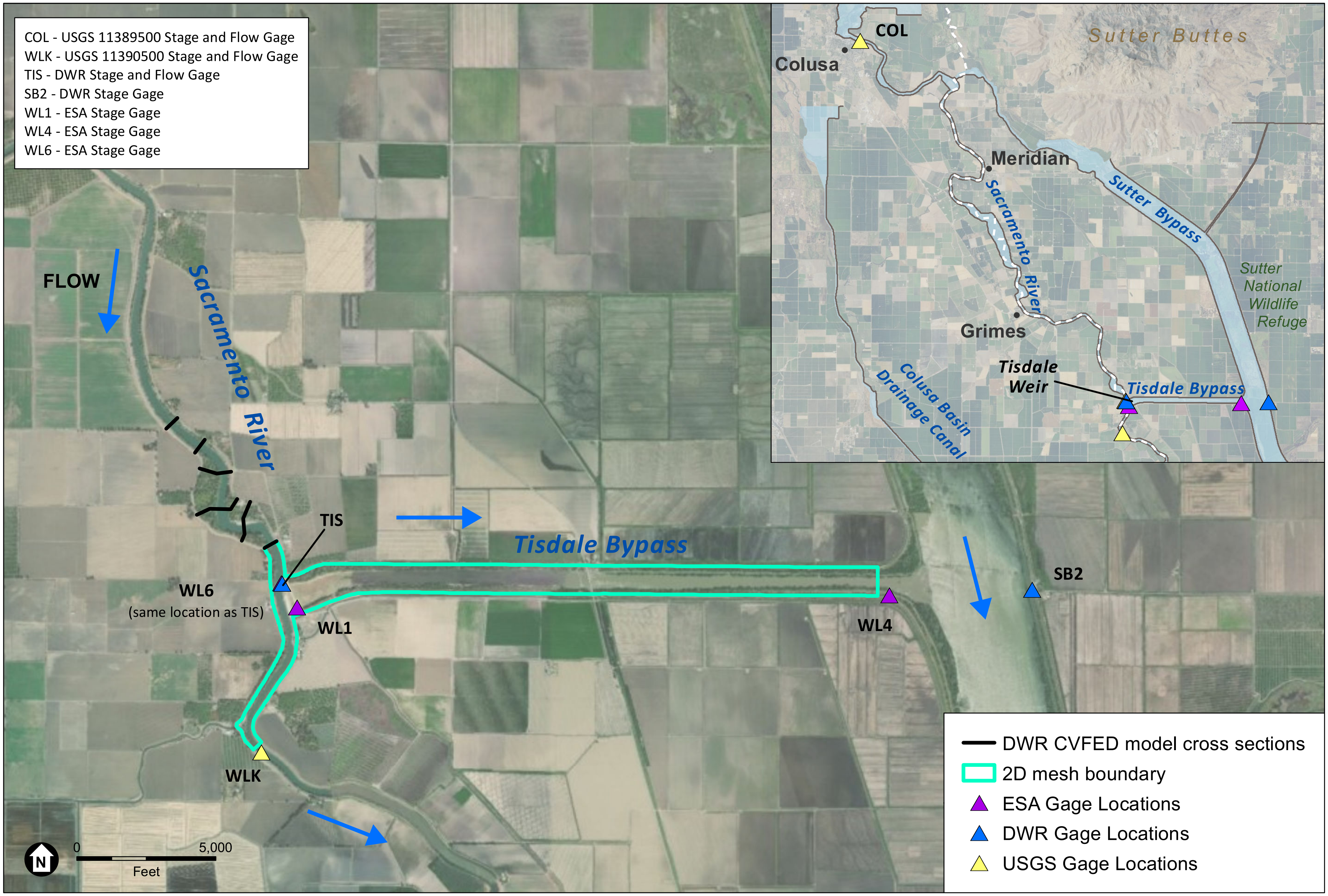
Fish Passage Analysis

1 Background

The Tisdale Weir, completed in 1932, is located along the left bank of the Sacramento River about ten miles southeast of the town of Meridian and about 56 miles north of Sacramento (River Mile 119, as measured upstream from the Sacramento–San Joaquin Delta). The weir is one of five major overflow weirs in the Sacramento River Flood Control Project (SRFCP) and is generally the first to overflow and the last to stop. The weir is a fixed-elevation, ungated overflow structure which was originally designed to spill and convey up to 38,000 cubic feet per second (cfs) of Sacramento River floodwaters into the Tisdale Bypass, a 4-mile long channel flowing eastward to the Sutter Bypass (**Figure 1**) to reduce downstream flood risk.

The California Department of Water Resources (DWR) Tisdale Weir Rehabilitation and Fish Passage Project (project) would include installation of fish passage facilities at the weir to reduce stranding of salmon and sturgeon and improve passage from the bypass to the Sacramento River. The proposed fish passage facilities would consist of a reconstructed energy dissipation and fish passage basin (basin) on the downstream side of the weir; installation of a notch and operable gate at the north end of the weir; and construction of a channel connecting the notch in the weir to the Sacramento River (**Figure 2**).

As part of ESA's conceptual design development, hydrology and hydraulics were assessed in relation to existing and proposed conditions for fish passage, at a level adequate for conceptual design, with the objective of determining the feasibility and effectiveness of the proposed project. A hydrologic analysis to understand the duration and frequency of Sacramento River flows and stages, including when water is spilling from the Sacramento River into the Tisdale Bypass, was performed. A hydraulic model was built to simulate existing and project conditions, and an automated, GIS-based approach to process the results of the model and assess the potential for fish passage from the bypass to the river was developed. This technical memorandum describes the hydrologic analysis, hydraulic modeling, and assessment of fish passage potential for existing conditions and various project condition (with-notch/basin) alternatives.

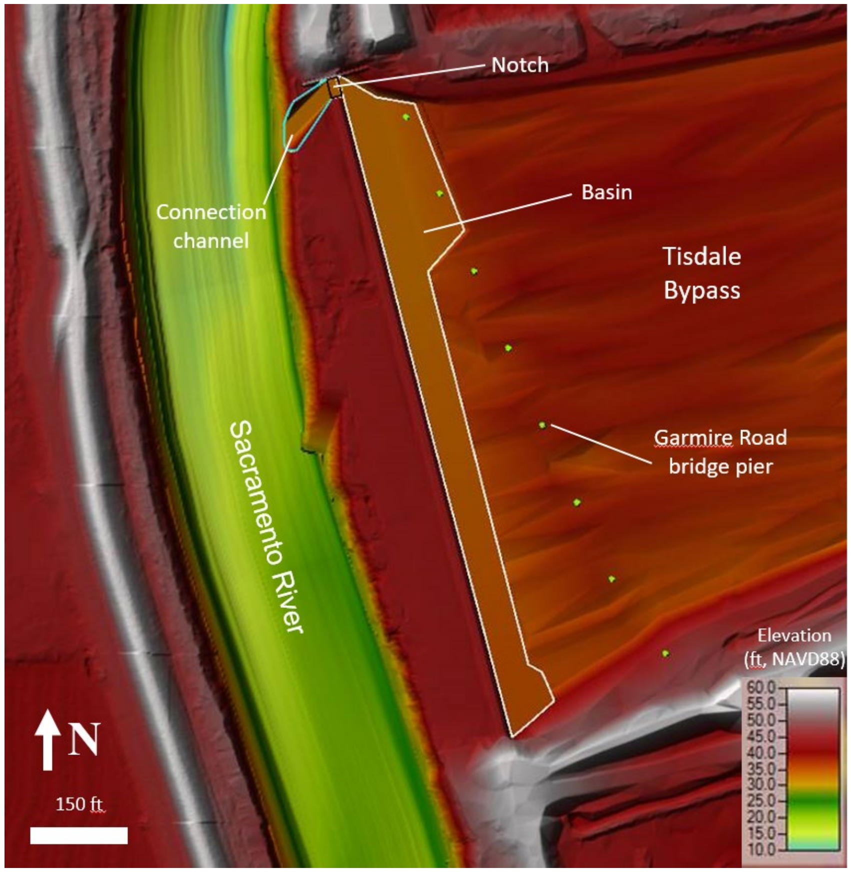


SOURCE: USGS (https://waterdata.usgs.gov/ca/nwis/sw), DWR (http://cdec.water.ca.gov/), ESA

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 1
Project Area (incl. Modeling Domain and Gage Locations)

ESA



Tisdale Weir Rehabilitation and Fish Passage Project

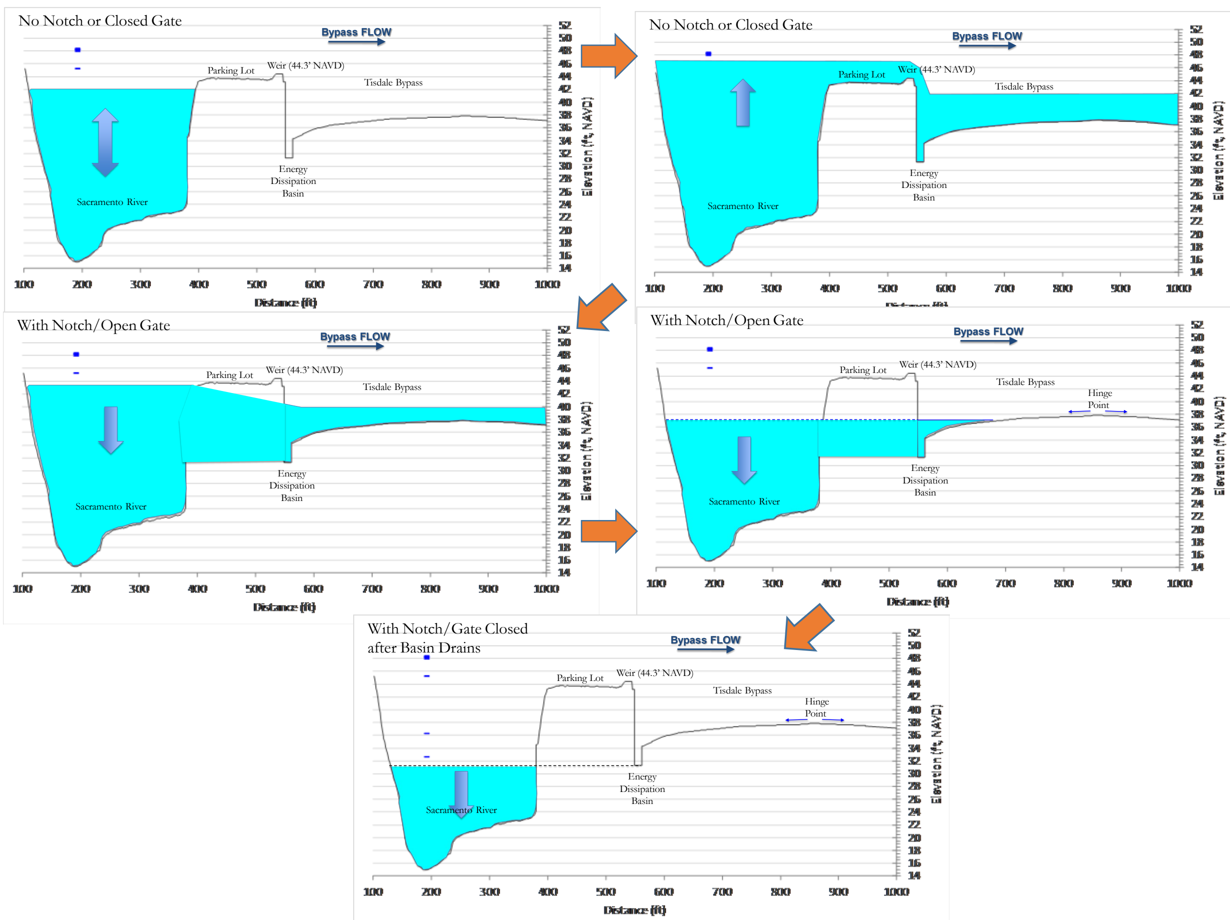
Figure 2
Proposed notch, connection channel, and basin.

1.1 Overview of Weir Hydrology and Project Concept

A conceptual summary of existing and potential project condition hydrology, connectivity, and water level relationships is illustrated in **Figure 3**. Most of the time, the Sacramento River rises and falls without overtopping the weir. When the Sacramento River at Tisdale Weir reaches a discharge of approximately 20,000-22,000 cfs, flow begins to spill over the weir and into the Tisdale Bypass (the crest elevation of the weir is approximately 44.1 feet NAVD).[1] On average, flow spills over the weir on about 12 percent of the days in a year, based on recent historic mean daily flow rates. The Tisdale Bypass conveys floodwaters eastward into the larger Sutter Bypass (Figure 1). When Sacramento River flow recedes back below the crest of the weir, most of the upstream half of the Tisdale Bypass (i.e., upstream of Reclamation Road) is either already drained or drains rather quickly (e.g., within a few hours). Once the water surface just downstream of the weir in the bypass drops to an elevation of approximately 37 feet, the eastward (or downstream) flow of water within the bypass generally ceases; we refer to this 37-foot elevation as the “hinge point.” Installing a notch and operable gate in the weir, with an invert elevation well below the weir crest (e.g., 10 feet below), would allow for Sacramento River water

1 All elevations presented herein are referenced to NAVD88, unless otherwise indicated.

to continue to flow into the bypass when the river water surface elevation drops below the weir crest elevation; this would greatly enhance the opportunities for fish passage at the weir and substantially reduce fish stranding. With such a notch, when the Sacramento River stage falls below approximately 37 feet but above the notch invert, the river and bypass would remain connected, but water would cease flowing east into the basin and bypass, and a ponded, stillwater condition would initially exist within the basin. The basin would then draw down and drain out to the river at a rate dependent on the rate at which the Sacramento River recedes. The basin would be designed to drain positively toward the river, and all elevations within the basin would be at or above the notch invert elevation. Thus, when the river water surface elevation recedes below the notch invert, the basin would have already drained west, into the river.



Tisdale Weir Rehabilitation and Fish Passage Project

Figure 3
Conceptual illustration of existing and potential project conditions.

Conceptually, during normal operations the notch gate would be opened within a few hours following a weir overtopping event and would remain open until the river recedes below the invert elevation of the notch. Therefore, the duration of the ponded condition within the basin would largely be a function of the invert elevation of the notch, and this is therefore a key design feature of the proposed project. Previous analyses suggest that 33 to 34 feet is the optimal invert elevation with respect to performance of the fish passage facility.[2] For example, if the invert elevation is too low, then the duration of the connection between the river and the basin would persist for too long prior to closing the gate, and poor water quality or other undesirable conditions may develop in the basin. On the other hand, if the invert elevation is too high, then water depths within the basin may not be adequate for fish movement at lower river flows and/or the risk of fish stranding may not be sufficiently reduced.

2 Passage Hydrology

Hydrologic conditions relevant to fish passage were assessed using the water year (WY) 1978-2017 time period.[3] Daily average flow data were gathered for three primary locations: the USGS Sacramento River gage at Colusa (USGS 11389500), the USGS Sacramento River gage below Wilkins Slough (USGS 11390500), which is approximately one mile downstream of the weir, and the DWR Tisdale Weir gage for spill over the weir (A02960) (Figure 1). The combined flow reported for the Sacramento River at Wilkins Slough and Tisdale Weir gages provides a good estimate of the flow in the Sacramento River just upstream of the weir, and this combined flow estimate is typically close to that reported for the Sacramento River at Colusa gage (there are no major flow contributions to the river between Colusa and the Tisdale Weir). Frequency and duration statistics that are relevant to fish passage, and which were used to iterate and refine the project design, were derived from the Wilkins Slough and Tisdale Weir gages, and the Colusa gage data were used primarily as a check.

2.1 Existing Conditions

With respect to fish passage, the only relevant flows are those associated with spill events and the period of time that a connection between the river and bypass does or would, with the project, exist: the flow characteristics during and sometime after a weir overtopping event, when fish may be present in the bypass and attempting to move upstream into the Sacramento River. **Figure 4** summarizes the annual number of days the weir was spilling in a given year from 1978 to 2017, and **Figure 5** shows the seasonality and duration of spill events over approximately the last decade. The variability amongst years can be considerable. For example, in very wet years the weir may spill for 120 days or more (though not necessarily consecutively), and in very dry years the weir may not spill at all. On average, the weir spills for approximately 43 days per year (or, about 12 percent of the time, as noted above). Further, as shown on Figure 5, on a monthly basis most of the weir spill events occur in the December through March period, which corresponds to the months of highest average and largest range of flows on the Sacramento River.

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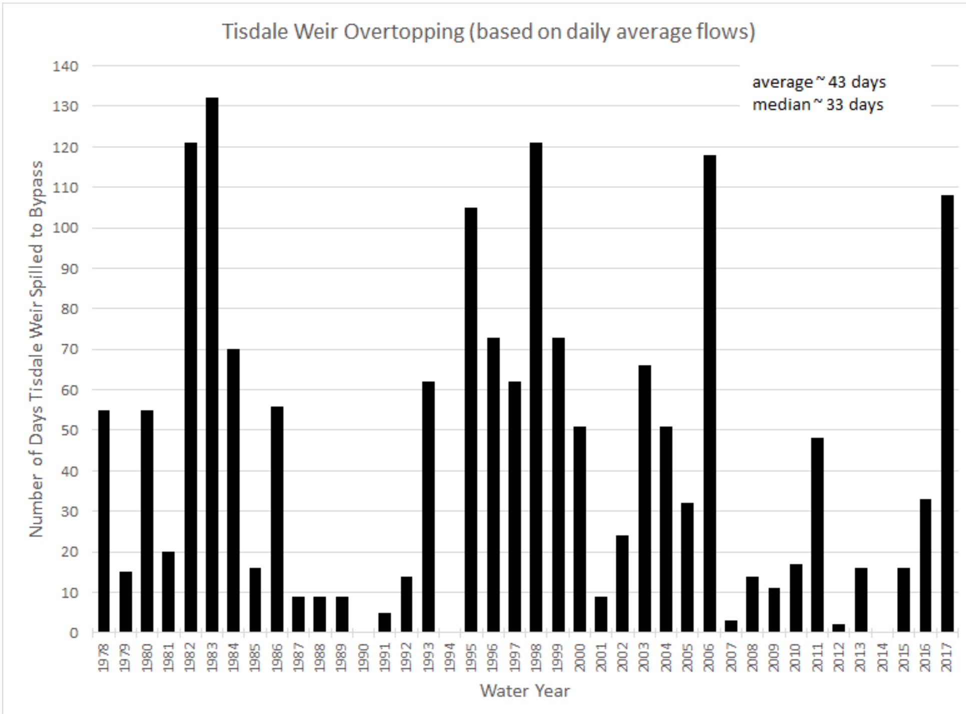
2 See *Basis of Design Report* for more details.

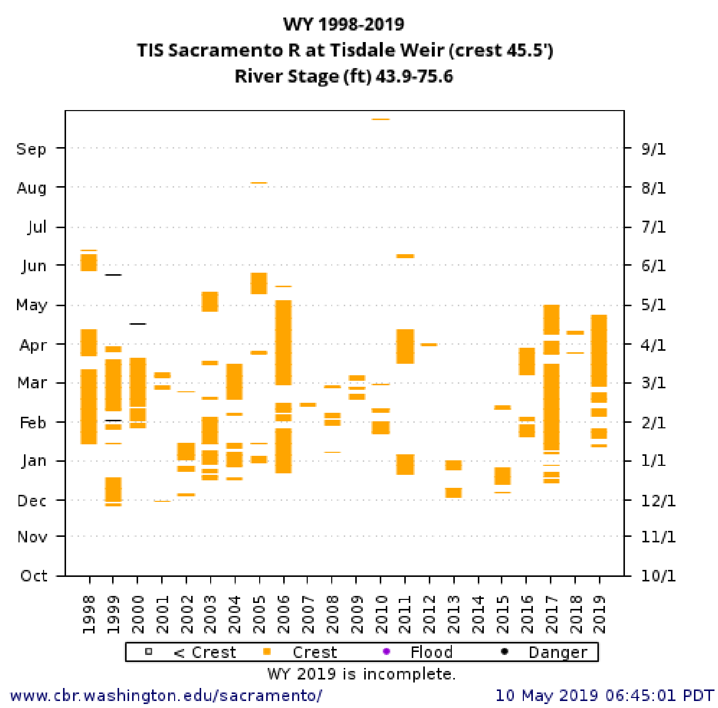
3 This period reflects post-dam (after 1963) hydrology (i.e., after Whiskeytown, Black Butte, and Shasta dam construction) as well as contemporary conditions with respect to water deliveries and project (State and Federal) operations.



SOURCE: (flow data) DWR, 2019a

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 4
Tisdale Weir overtopping days, WY 1978-2017.



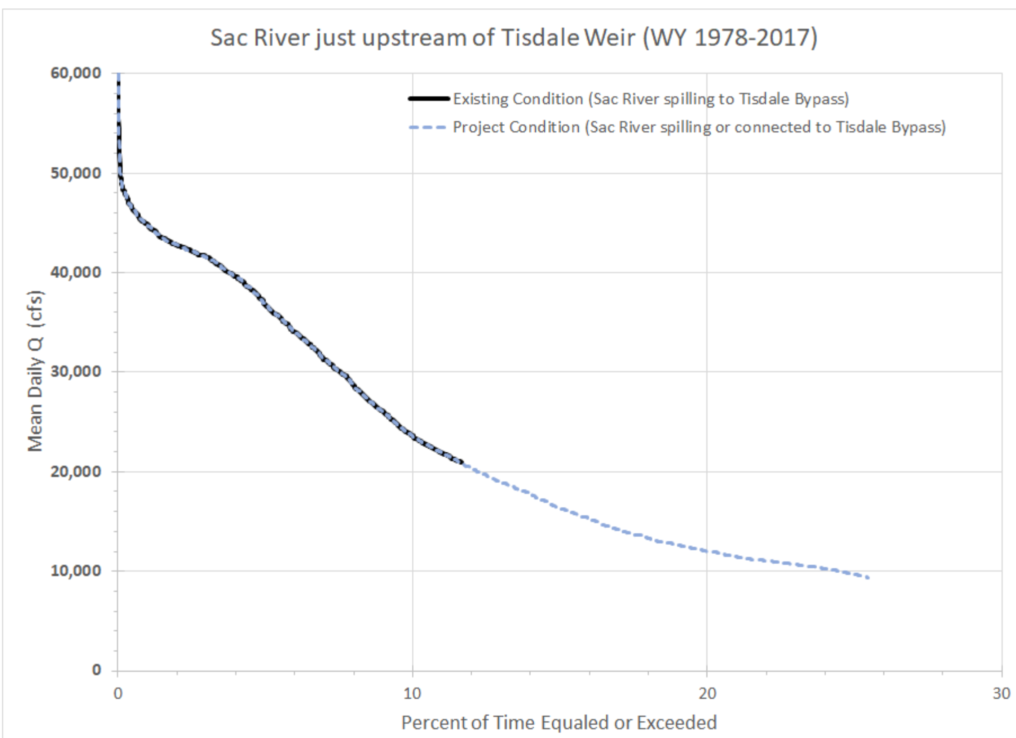
SOURCE: Univ. of Washington, 2019

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 5
Tisdale Weir overtopping days and months, WY 1998-2019.

2.2 Project Conditions

For purposes of assessing hydrology specific to fish passage under project conditions, simple assumptions were made about how the gate in the proposed notch would be operated: the gate would be opened once the weir is overtopped and then closed when the Sacramento River recedes below the notch invert elevation, assumed at 34 feet. Thus, the time between gate opening and closing defines the duration of a spill event in the context of the project condition. Because of the notch, there would be more spill events, or a longer duration of connection between the river and the bypass, under project conditions. This approach essentially considers the full range of additional time that fish passage may be possible, or that a connection between the river and bypass could be made, under project conditions. While the operating rules for the gate would likely be further developed and refined through the design and/or adaptive management processes, this simple conceptual model assumes that the gate would shift to a fully open or fully closed condition instantaneously for purposes of this preliminary analysis. **Figure 6** shows existing Sacramento River flow durations and periods of connection under both existing and proposed project conditions. The weir is overtopped (and the river and bypass are connected) approximately 12 percent of the days in a year, on average, and fish passage is currently possible only during a small fraction of this time (further discussed below in Section 4, *Fish Passage Assessment*). Implementation of the project would likely increase the average connection duration between the river and bypass to approximately 25 percent of the days in a year, which extends the period of time fish could pass from the bypass to the river.



SOURCE: (flow data) DWR, 2019a; USGS, 2019

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 6
Sacramento River at Tisdale Weir flow duration curves.

In the context of the proposed design, some additional key points about the general flow and stage durations are as follows: the river is above a stage of 37 feet (or about 11,000 to 12,000 cfs) approximately 20 percent of the days in a year (i.e., above the hinge point, such that with a notch the river would be flowing into the basin), and the river is above a stage of 34 feet (or about 8,000 to 9,000 cfs) approximately 25 percent of the days in a year (i.e., above the proposed notch invert elevation). Thus, the ponded condition within the proposed basin (i.e., a water surface elevation between 37 and 34 feet) would persist, on average, for a duration that is the difference in these two values, or about 5 percent of the days in a year.

3 Hydraulic Modeling

3.1 Model Domain

ESA developed a combined one-dimensional (1D)/two-dimensional (2D) hydraulic model in HEC-RAS version 5.0.6. The model extends from approximately 1.5 miles upstream of the weir on the Sacramento River down to the USGS Wilkins Slough gage, and it spans the full length of the Tisdale Bypass down to the confluence with the Sutter Bypass (Figure 1). Laterally, the model spans the area between levee crests for both the Sacramento River and the Tisdale Bypass. The upstream end of the model was modeled in 1D using cross sections SAC R12 120.607 through 119.359 from the DWR Integrated 1D-2D Bypass HEC-RAS model (DWR, 2017). A 1D approach was used upstream to efficiently route inflows down to the 2D mesh section and avoid potential computational artifacts associated with directly inputting flows to the mesh so close to the weir, at a point where the hydraulics are of greatest interest. Mesh cell size varies from 5 feet near the weir, where complex 2D distributions of depth and velocity need to be resolved, to 100 and 200 feet for the downstream ends of the Sacramento River and Tisdale Bypass, respectively, where only the water surface profile needs to be simulated.

3.2 Topography

ESA developed the existing conditions topographic surface using the datasets listed in **Table 1**. Due to the absence of a bathymetric surface for the river, the DWR HEC-RAS model cross sections were used to generate a bathymetric surface through interpolation. The Garmire Road and Reclamation Road bridge piers are relatively minor flow obstructions (assuming no debris) and were therefore not included in the surface for the hydraulic modeling used in the fish passage assessment.

TABLE 1
TOPOGRAPHIC DATASETS

Dataset	Area used
DWR 2018 basemap	Western half of the Tisdale Bypass
CVFED 2010 cross sections	Sacramento River bathymetry
CVFED 2008 LiDAR	Sacramento River levee side slopes
DWR 2015 LiDAR	Tisdale Bypass levee side slopes
DWR 2017 ground survey	Tisdale Bypass bed

A wide variety of weir notch configurations (surfaces) were developed in AutoCAD Civil 3D to investigate the effect of different notch properties on fish passage performance. **Table 2** lists the properties considered and iterated upon in the notch and basin design. The basin was designed primarily for conditions relevant to the recession of the Sacramento River stage, during which the velocity is low and the hydraulics are less complex through this feature.

TABLE 2
RELEVANT PROPERTIES FOR NOTCH AND BASIN DESIGNS

Notch property	Basin property
Width	Eastern conform elevation
Skew angle	Eastern conform location
Side slope	Longitudinal profile slope
Invert elevation	Cross section shape
Number (one or two)	
Location (north or south)	

3.3 Roughness

A map of Manning's n-values (roughness) was developed by ESA using DWR Integrated 1D-2D Bypass HEC-RAS model cross section roughness values as a reference for the Sacramento River, and the DWR Tisdale Bypass HEC-RAS model (DWR, 2014) cross section roughness values as a reference for the bypass. **Table 3** lists the roughness values used for each cover type.

TABLE 3
MANNING'S ROUGHNESS BY COVER TYPE

Cover type	Manning's roughness (n-value)
Sacramento River (low vegetation)	0.035
Tisdale Bypass (low vegetation)	0.03
Moderate vegetation	0.06
High vegetation	0.08
Tisdale weir parking lot	0.015
Tisdale weir crest	0.015

3.4 Boundary Conditions

The boundary conditions for the hydraulic model include inflows defined by a synthetic hydrograph and stage-flow rating curves for the downstream ends of the Sacramento River and Tisdale Bypass. A simple, trapezoidal synthetic hydrograph (i.e., rising and falling) was used for modeling the existing condition and weir notch scenarios to simulate the full range of flow conditions that could occur (**Figure 7**). Fish passage performance could then be related to any given Sacramento River flow value. The USGS Wilkins Slough gage rating curve was used for the downstream boundary condition on the Sacramento River (**Figure 8**). Daily average Tisdale Bypass observed weir spill flow data (CDEC TIS gage) and concurrent Sutter Bypass observed stage data at the confluence with the Tisdale Bypass (CDEC SB2 gage) were used to construct a rating curve of Sutter Bypass stage versus Tisdale Bypass flow to account for the backwater imposed by the Sutter Bypass (**Figure 9**).

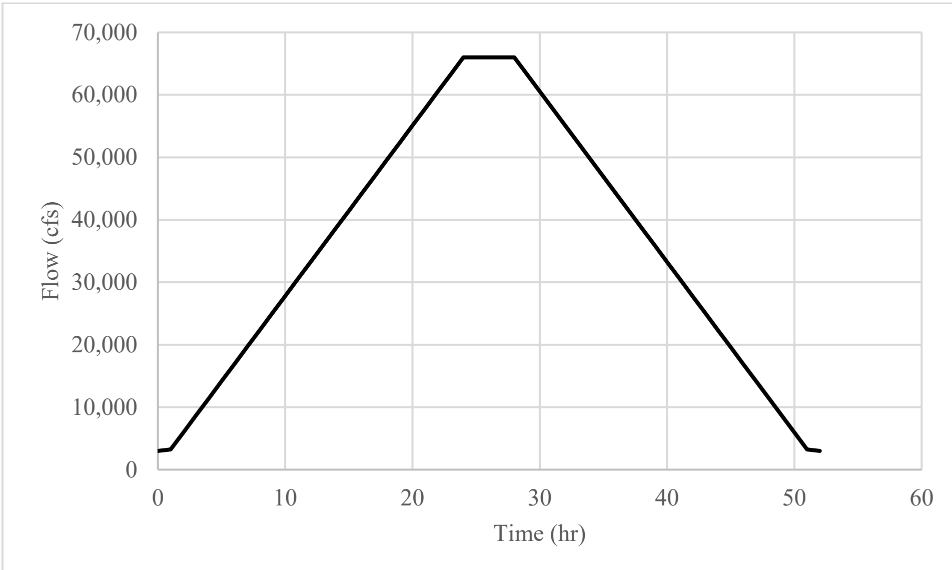


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Figure 7
Synthetic input hydrograph used in the HEC-RAS model.

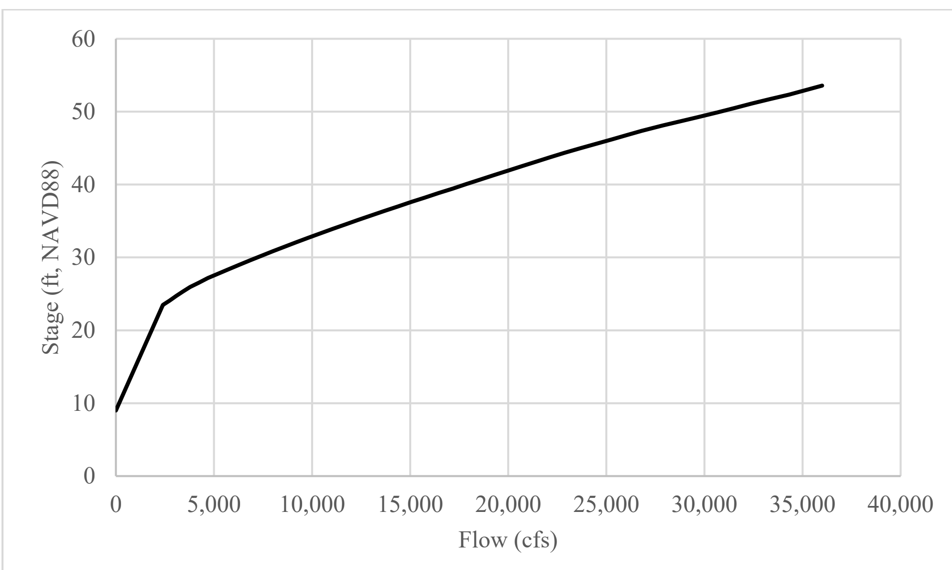

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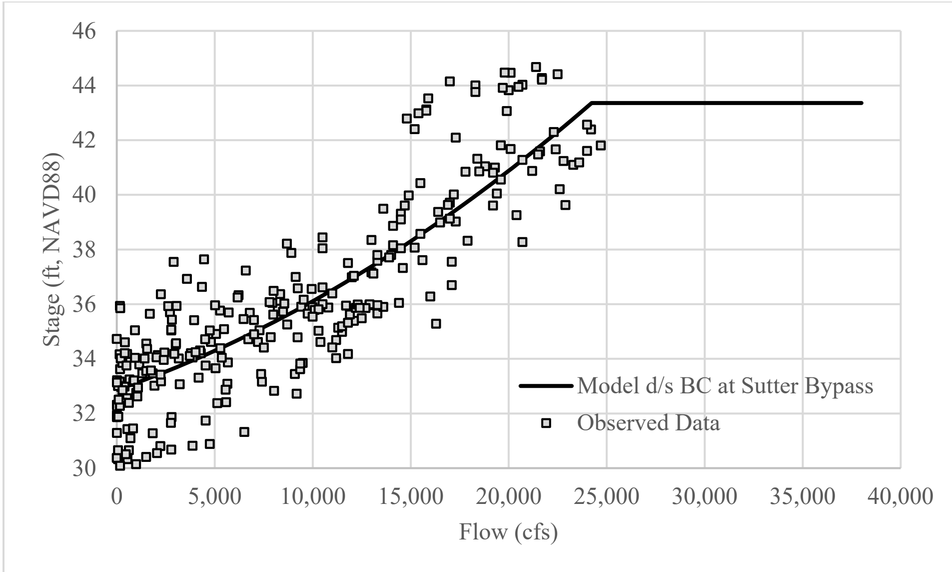
Figure 8
USGS Wilkins Slough gage rating curve used in the HEC-RAS model.



SOURCE: (observed data) DWR, 2019a, 2019b

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 9
Rating curve for Sutter Bypass stage vs. Tisdale Bypass flow (WY 2008-2017).

3.5 Validation

The existing conditions model results were validated in three ways. First, ESA plotted stage and flow observations made during WY 2019 against rating curves obtained from the hydraulic model at two locations, just upstream of the Tisdale weir on the Sacramento River (**Figure 10**) and just downstream of the weir in the bypass at Garmire Road, i.e., the weir tailwater (**Figure 11**). Observed stage values were from ESA-deployed gages (WL1 and WL6) as well as DWR field surveys, and the observed flow values are from DWR Acoustic Doppler Current Profiler (ADCP) measurements. The modeled rating curves show close agreement with the measured values, particularly in the 45 to 46-foot stage range where fish passage through the notch appears sensitive to slight changes in notch configuration (see Section 4, *Fish Passage Analysis*, below). The second source of validation was an observed weir spill event on about January 19, 2019 for which stage at the aforementioned locations was recorded by the ESA gages. Upstream Sacramento River flow was obtained from the USGS Colusa gage, and stage at the downstream end of the bypass was obtained from another ESA gage (WL4), such that the 1D/2D model was run for this event using these observed boundary conditions. The modeled and observed stage hydrographs for the weir headwater and tailwater are displayed in **Figure 12**, showing good agreement on the rising limb and peak of the hydrograph for the Sacramento River stage. The modeled weir tailwater stage is higher than the observed, which is due to greater modeled spill into the bypass than observed. This is consistent with the results of the third source of validation: the observed and modeled flow split between Sacramento River and Tisdale Bypass (**Figure 13**). The modeled curve plots slightly above the observed values, indicating the model somewhat overestimates spill into the bypass, which yields a higher-than-observed tailwater stage.

A substantial amount of large wood accumulated on the southern half of the weir and parking lot area over the course of the WY 2019 wet season. Based on field observations, this wood obstructed and altered flow over the weir and, to some degree, may explain the discrepancy between observed and modeled stage and flow values. Given the overall model performance in these three validation exercises, the model was determined to be sufficient for evaluating the notch and basin designs.

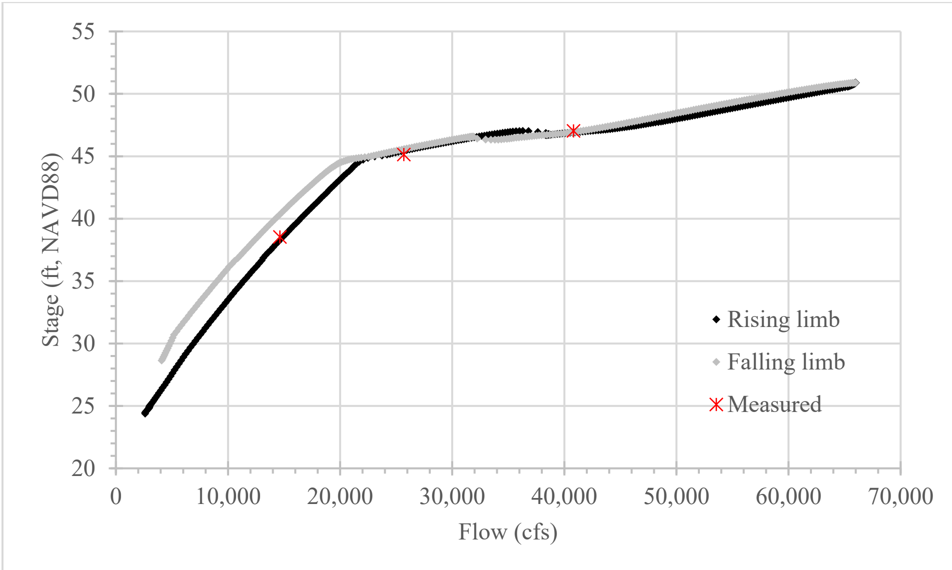


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Figure 10
Modeled stage vs. flow rating curve with values measured on the falling limb on the Sacramento River just upstream of the Tisdale weir.

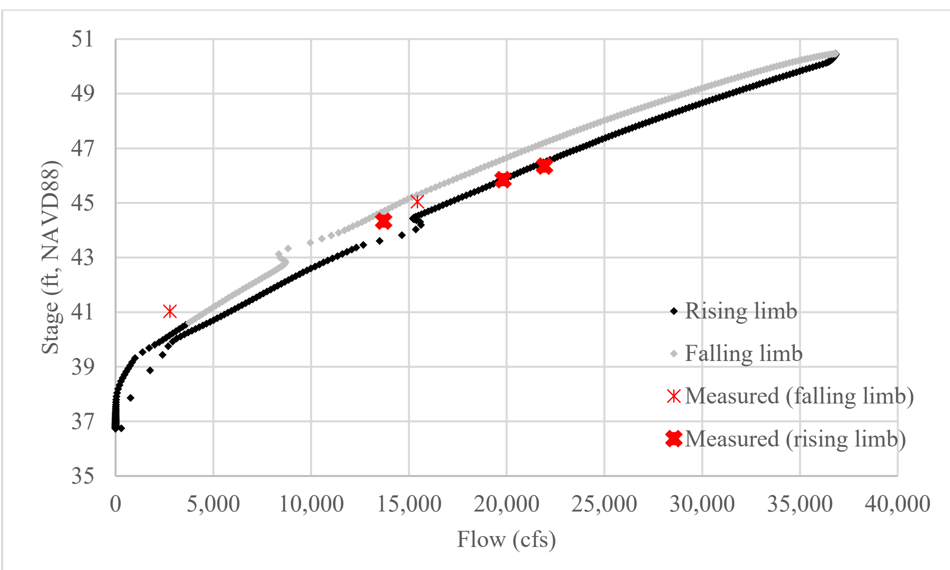

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Figure 11
Modeled stage vs. flow rating curve in the bypass just downstream of the Tisdale weir (weir tailwater).

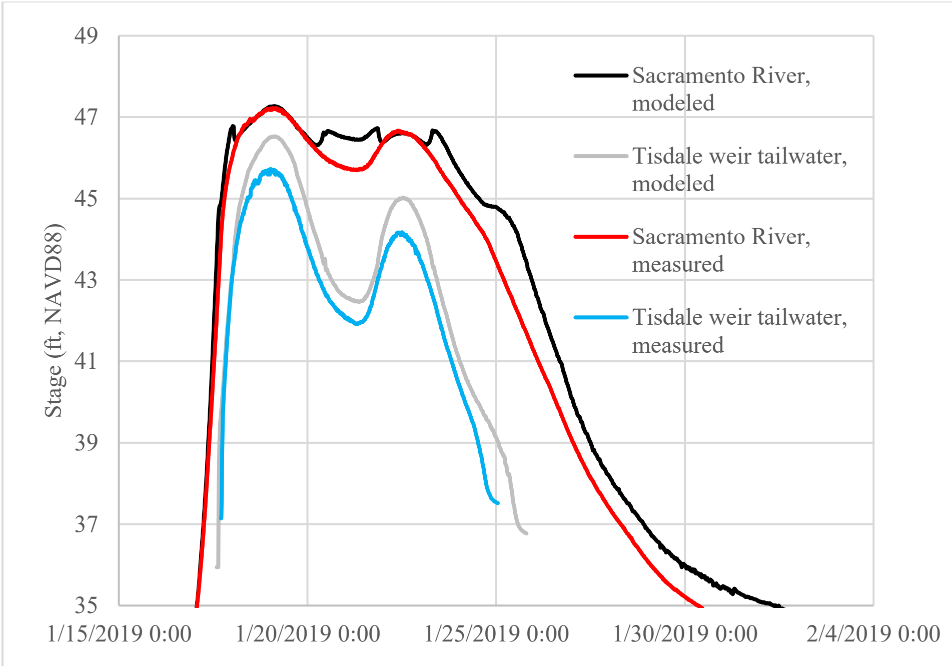

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Figure 12
Modeled and measured stage hydrographs for the Sacramento River just upstream of the weir and in the bypass just downstream of the weir.

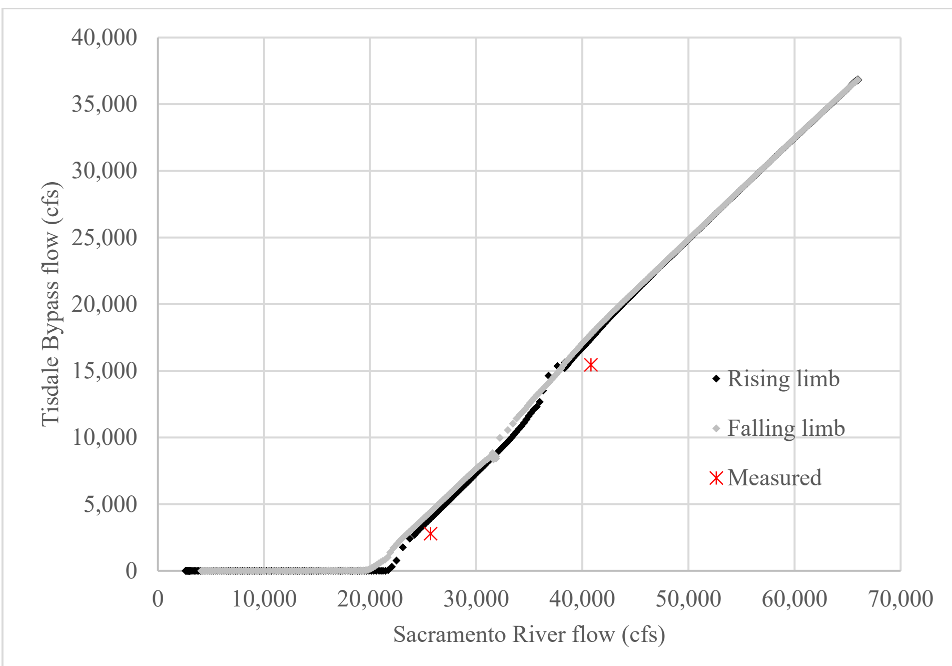

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Figure 13
Modeled and measured (falling limb) Tisdale Bypass flow vs. Sacramento River flow.

4 Fish Passage Assessment

4.1 Fish Passage Criteria

Fish passage performance was assessed using the same general velocity, depth, and width criteria as developed for the Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project (USBR/DWR, 2018) and presented in **Table 4**. These criteria were further confirmed and vetted through a number of collaborative and informational interagency meetings. The same maximum velocities were used for salmon and sturgeon for short (< 60 feet) and long (60-200 feet) distances, but different minimum depths and widths were used for salmon and sturgeon. The majority of modeled notch and connection channel configurations (including the preferred configuration) were less than or equal to 200 feet long, and therefore only criteria for 200 feet or less were evaluated.

TABLE 4
SUMMARY OF FISH PASSAGE CRITERIA FOR FEDERALLY LISTED SPECIES WITHIN THE SACRAMENTO RIVER DEVELOPED FOR THE YOLO BYPASS SALMONID HABITAT RESTORATION AND FISH PASSAGE PROJECT

Species	Adult migration time	Minimum flow depth (short distance, <60 ft)	Minimum flow depth (long distance, 60-200 ft)	Minimum channel width	Maximum flow velocity (short distance, <60 ft)	Maximum flow velocity (long distance, 60-200 ft)
Adult sturgeon	Jan-May	3	5	10	6	4
Adult salmon	Nov-May	1	3	4		

SOURCE: USBR/DWR, 2018

4.2 Fish Passage Algorithm

The above fish passage criteria were developed for application to 1D culvert hydraulics, though this analysis was not constrained to a one-dimensional problem. There would be spatial (2D) variation in flow velocity and depth within and near the notch and connection channel, including flow separation and expansion/contraction, and modeling this spatial variation is important for both the hydraulic assessment of project performance and for subsequent design iterations. Thus, the passage criteria were adapted to the 2D model results using the GIS algorithm described below and programmed in Python for application in this analysis. Velocity and depth results were exported from the model on the falling limb of the synthetic hydrograph for Sacramento River flows corresponding to 1-foot stage increments (the flow vs. stage increments are relative to existing conditions for the Sacramento River just upstream of the weir). As shown earlier, the modeled Sacramento River stage varies on the rising and falling limb. Falling limb results were used for this analysis assuming this part of the hydrograph would generally be when the notch would be opened (via operable gate) to allow for passage. The general algorithm for spatially processing and assessing the 2D model results for fish passage is as follows:

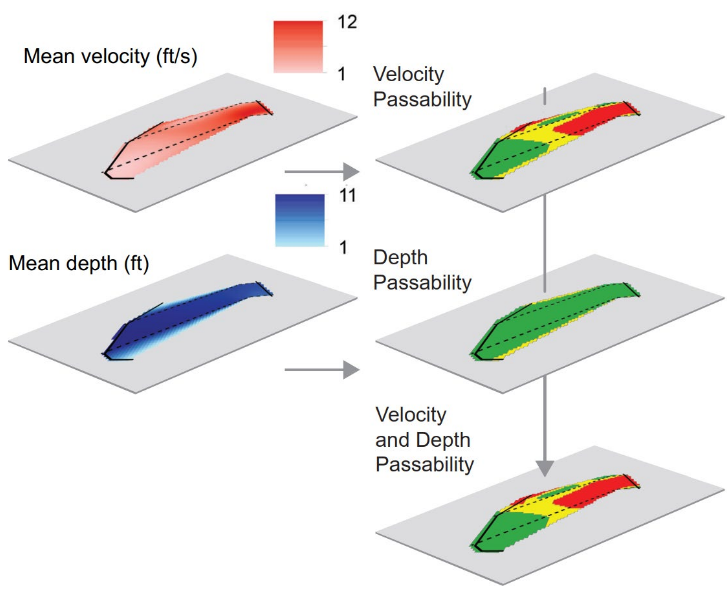
1. *Compute mean depth and velocity within 4-foot (salmon) and 10-foot (sturgeon) moving windows across the raster grids of modeled velocity and depth*. In other words, for each 4x4 foot and 10x10 foot group of cells in the raster grids, a single mean depth and velocity were

calculated. This method converts the raw depth and velocity output to values that also incorporate the minimum passage width criteria, e.g., a raster cell with a computed mean velocity of 2 feet per second (ft/s) indicates that the surrounding flow meets the velocity passage criterion within an area that also meets the width passage criterion.

2. *Delineate "patches" based on the passage categories listed below (**Table 5**).* **Figure 14** illustrates how both mean depth and mean velocity were used in delineating patches of different passage categories. In short, green indicates areas that meet the long-distance passage criteria, yellow indicates areas that meet the short-distance (i.e., < 60 feet) passage criteria, and red indicates areas that do not meet any passage criteria.

TABLE 5
PASSAGE CATEGORIES FOR PATCHES OF CERTAIN COMBINATIONS OF DEPTH AND VELOCITY

Passage category	Depth	Velocity
green	> long distance min	< long distance max
yellow	> short distance min	< short distance max
red	< short distance min or:	> short distance max



Note: For reference, solid lines are the east and west ends of the notch, and dashed lines are the side slope toes.

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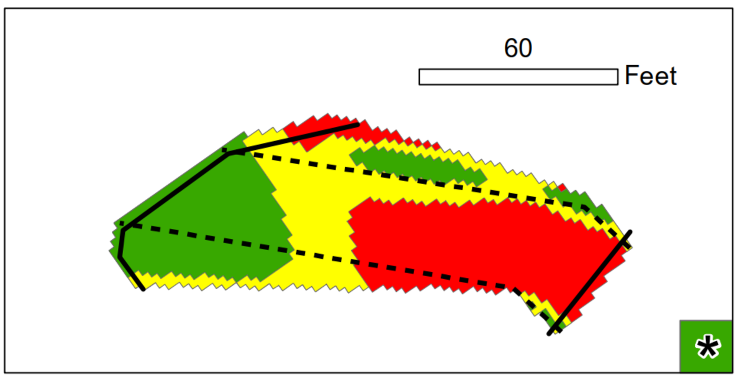
Figure 14
Passability delineation for a notch using mean velocity and depth.

3. *Identify passable "patches" that are continuous from one end of the notch to the other and assign the overall passage performance of the notch using the categories below (**Table 6**).* This step translated the mosaic of different passage conditions that may occur within the notch into a summary rating for the notch that depended on the continuity of the passage conditions. The green-star category was added to better resolve subtler distinctions in passage performance across notch alternatives; it indicates that the yellow category short-distance criteria are met for a continuous distance of less than 60 feet, meaning that passage is possible. **Figure 15**

shows an example of a notch with a green-star rating, as there are no continuous patches through the entire notch exhibiting green passage conditions, but the green patches are separated by short (< 60 feet) distances of yellow passage conditions.

TABLE 6
PASSAGE CATEGORIES FOR OVERALL NOTCH PERFORMANCE

Passage category	Depth	Velocity	Continuous distance (ft) with these conditions
green	> long distance min	< long distance max	<200
green*	> short distance min	< short distance max	<60
yellow	> short distance min	< short distance max	60-200
red	< short distance min or:	> short distance max	<200



Note: For reference, north is toward the scale bar, solid lines are the east and west ends of the notch, and dashed lines are the side slope toes.

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Figure 15
A notch exhibiting a green-star rating for passage conditions.

4.3 Fish Passage Results

4.3.1 Classification of Passability for Salmon and Sturgeon

Table 7 and **Table 8** show salmon and sturgeon passage results, respectively, for early iterations of the notch and connection channel configurations, and Table 9 summarizes the passage results for the current preferred alternative at a higher-level of design detail. The early iterations of conceptual alternatives included different notch and connection channel locations and configurations, as well as different options for how the eastern edge of the basin could be tied into the bypass (e.g., see Table 2). Through many model iterations the various elements listed in Table 2 were assessed with respect to their influence on passage hydraulics, and a combined set of best-performing elements was identified for the preferred alternative. Additionally, and after this initial vetting of conceptual alternatives, further refinements to the design were made to improve constructability, such as the inclusion of a wall along the north bank of the basin to support an equipment pad. Thus, the results for the latest version of the preferred alternative are in Table 9 and differ from the earlier iterations presented in Tables 7 and 8, which compare a broader set of alternatives at a more conceptual level. Full passage results for design iterations exploring the effects of the properties listed in Table 2 are shown in **Attachment 1**, as well as a plan view of the preferred notch alternative and associated passage zones across multiple stages.

TABLE 7
SALMON PASSABILITY FOR EXISTING CONDITIONS AND SELECT NOTCH ALTERNATIVES

Sacramento River just upstream of the weir			Salmon passability					
			Existing conditions	Early notch alternative: 50 ft gate width, 0° skew angle, 31.5 ft invert elevation, 2:1 side slopes‡			Preferred notch alternative: north, 32.6 ft gate width, 45° south skew angle, vertical to 2:1 side slope transition, 34 ft invert elevation	
Stage (ft, NAVD88)†	Flow (cfs)	% exceedance[1]		North	South	North and south	Basin conform to 2017 bypass surface	Basin conform to uniform 37 ft elevation
48	47419	0.31		*				
47	41215	3.18	*	*				
46	27970	8.23				*	*	*
45	22525	10.60			*		*	*
44	19077	12.94		*			*	*
43	17684	14.07					*	*
42	16493	14.93					*	*
41	15226	16.01						*
40	14149	16.99						
39	13066	18.30						
38	11971	20.12						
37	10881	22.55	Basin drainage condition					
36	9875	24.68						
35	8974	25.47						
34	8072	--						
33	7172	--						

NOTES:

† Stage for existing conditions, falling limb stage, which is higher than stage under with-notch conditions given the decrease in downstream river flow and associated backwater, due to notch spill into the bypass.

‡ The associated hydraulic model runs used a normal depth downstream boundary condition for the bypass, which didn't differ significantly from the Sutter Bypass rating curve used in later runs with the preferred notch alternative.

1 For WY 1978-2017 and only for flow events during which the river and bypass would be connected per the proposed project.

Key:

Passage category	Depth	Velocity	Continuous distance (ft) with these conditions
	> long distance min	< long distance max	<200
*	> short distance min	< short distance max	<60
	> short distance min	< short distance max	60-200
	< short distance min or:	> short distance max	<200

TABLE 8
STURGEON PASSABILITY FOR EXISTING CONDITIONS AND SELECT NOTCH ALTERNATIVES

Sacramento River just upstream of the weir			Sturgeon passability					
			Existing conditions	Early notch alternative: 50 ft gate width, 0° skew angle, 31.5 ft invert elevation, 2:1 side slopes‡			Preferred notch alternative: north, 32.6 ft gate width, 45° south skew angle, vertical to 2:1 side slope transition, 34 ft invert elevation	
Stage (ft, NAVD88)†	Flow (cfs)	% exceedance[1]		North	South	North and south	Basin conform to 2017 bypass surface	Basin conform to uniform 37 ft elevation
48	47419	0.31		*				
47	41215	3.18		*				
46	27970	8.23				*	*	*
45	22525	10.60					*	*
44	19077	12.94		*	*		*	*
43	17684	14.07					*	*
42	16493	14.93					*	
41	15226	16.01						
40	14149	16.99						
39	13066	18.30						
38	11971	20.12						
37	10881	22.55	Basin drainage condition					
36	9875	24.68						
35	8974	25.47						
34	8072	--						
33	7172	--						

NOTES:

† Stage for existing conditions, falling limb stage, which is higher than stage under with-notch conditions given the decrease in downstream river flow and associated backwater, due to notch spill into the bypass.

‡ The associated hydraulic model runs used a normal depth downstream boundary condition for the bypass, which didn't differ significantly from the Sutter Bypass rating curve used in later runs with the preferred notch alternative.

1 For WY 1978-2017 and only for flow events during which the river and bypass would be connected per the proposed project.

Key:

Passage category	Depth	Velocity	Continuous distance (ft) with these conditions
	> long distance min	< long distance max	<200
*	> short distance min	< short distance max	<60
	> short distance min	< short distance max	60-200
	< short distance min or:	> short distance max	<200

TABLE 9
SALMON AND STURGEON PASSABILITY FOR EXISTING CONDITIONS AND THE PREFERRED NOTCH ALTERNATIVE

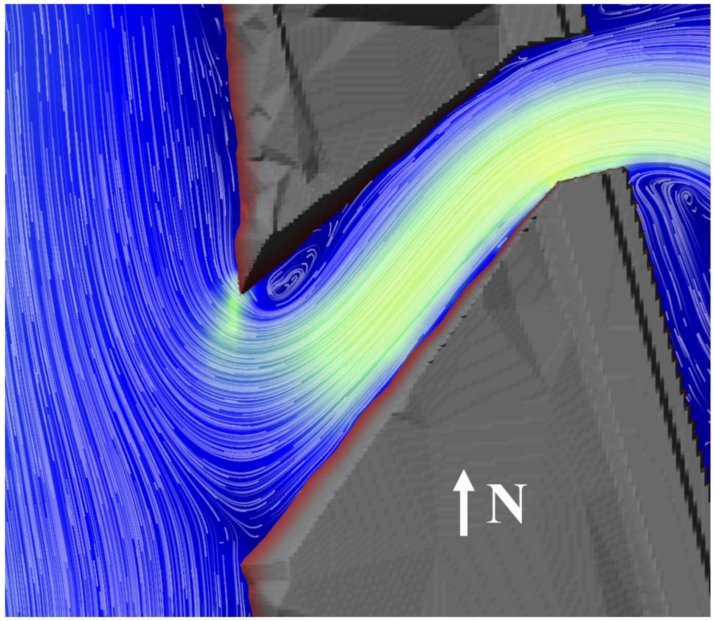
Sacramento River just upstream of the weir			Existing conditions		**Preferred notch alternative: north, 32.6 ft gate width, 45° south skew angle, vertical to 2:1 side slope transition, **33 ft invert elevation, constructability refinements*	
Stage (ft, NAVD88)†	Flow (cfs)	% exceedance[1]	Salmon	Sturgeon	Salmon	Sturgeon
48	47419	0.31				
47	41215	3.18	*			
46	27970	8.23			*	*
45	22525	10.60			*	
44	19077	12.94			*	*
43	17684	14.07			*	*
42	16493	14.93				
41	15226	16.01				
40	14149	16.99				
39	13066	18.30				
38	11971	20.12				
37	10881	22.55				
36	9875	24.68				
35	8974	25.47	Basin drainage condition			
34	8072	--				
33	7172	--				

NOTES:
† Stage for existing conditions, falling limb stage, which is higher than stage under with-notch conditions given the decrease in downstream river flow and associated backwater, due to notch spill into the bypass.
** These parameters reflect the latest version of the design, including constructability considerations and a higher-level of design detail compared to Tables 7 and 8.
1 For WY 1978-2017 and only for flow events during which the river and bypass would be connected per the proposed project.

Key:

Passage category	Depth	Velocity	Continuous distance (ft) with these conditions
	> long distance min	< long distance max	<200
*	> short distance min	< short distance max	<60
	> short distance min	< short distance max	60-200
	< short distance min or:	> short distance max	<200

As expected, velocity is the limiting factor for passage across most of the investigated range in Sacramento River flows, while depth becomes limiting at flows well below the weir crest. The 2D model revealed the presence of two, relatively persistent lower velocity zones in the notch (**Figure 16**). These zones were key to understanding the passage performance of the notch alternatives and would not have been resolved with a 1D model. In the southwest corner of the notch, flow diverged into the notch and down the Sacramento River resulting in a stagnation zone of lower velocity. On the north side of the notch, in the lee of the side slope, there was a lower velocity flow separation zone in the form of an eddy. The sizes and positions of these two slow zones with respect to each other often determined whether the notch was passable for a given Sacramento River flow, and therefore the effect of notch and connection channel configurations on the extent of these zones helped explain much of the variation in modeled notch performance.



Tisdale Weir Rehabilitation and Fish Passage Project

Figure 16
Velocity and tracers for a notch showing the eddy on the north side and stagnation zone on the south side.

Headwater stage is the primary control on flow and velocity over the existing weir and through the notch alternatives, so it was logical to summarize model results and passage in one-foot increments of headwater stage (Table 7 and Table 8); exceedance values are also shown for the respective flow and stage increments. As shown above, for flows below the weir crest (or, below approximately 22,500 cfs) the modeled stage exhibited a hysteresis effect (i.e., for a given flow, the modeled stage was lower on the rising limb and higher on the falling limb). Based on headwater stage, the falling limb would result in a more conservative approach to the fish passage analysis (i.e., higher modeled velocities through the notch could be expected when using a higher headwater stage for a given Sacramento River flow).

The preferred alternative (conformed to the 2017 bypass topography) provides passage for salmon over the entire range of flows analyzed, and for sturgeon over most flows. For sturgeon, depth becomes limiting as the basin is drawing down with the recession of the Sacramento River. However, when velocity is the primary constraint (i.e., for flows above approximately 14,000 cfs), according to the model results the weir structure would be passable over most flows for both salmon and sturgeon (e.g., except for between roughly 22,500 and 28,000 cfs for sturgeon). For existing conditions, based on modeling results, the weir is not passable for sturgeon, and for salmon it is passable only when the Sacramento River is flowing above approximately 41,000 cfs, which occurs approximately 3 percent of days in a year. Implementation of the preferred alternative would increase the window of passable conditions to approximately 25 percent of the days in a year, when the Sacramento River and Tisdale Bypass would be connected under project conditions.

Below approximately 37 feet the hydraulic modeling results are not necessarily relevant, as this is when the basin would be draining out to the Sacramento River. A stage of 37 feet roughly corresponds to the cessation of eastward flow through the bypass due to the elevation of a topographic hinge point (or sill). In other words, with an open notch, the Sacramento River would not flow into the Tisdale Bypass if the river water surface were below this elevation. Stages at and below this elevation are associated with placid drainage of the basin in which the basin would be drawn down concurrent with the drop of the river, such that depth eventually becomes limiting with respect to passage as depth would eventually go to zero. The assumed invert elevation of the notch would control how rapidly the basin drains (goes dry); the higher the invert, the sooner the basin gets cut off from the river and goes dry. The invert elevation was selected with the intention of encouraging fish to exit the basin and enter the river as soon as possible.

Stages above approximately 48 feet (or, approximately 48,000 cfs) correspond to the 1957 design flows (USACE, 1957), and the assumption was made that the proposed project could not alter the hydraulics within this range and, in effect, would not be allowed to operate, i.e., the gate would be closed. The upper flow limit, if any, on potential project operations is yet to be determined; this will ultimately be established through consultation with the USACE as part of the Section 408 permitting process. However, within this range of large flood flows, the existing weir is already predicted to be passable for both salmon and sturgeon: due to the influence of the Sutter Bypass backwater, the tailwater elevation is high enough, and submerges the weir enough, to allow for passage.

4.3.2 Sensitivity of Alternative Configurations

Notch width and connection channel skew angle had the most prominent influence on passage performance; other project configurations and parameters were also assessed, though their relative influence on passage performance was not as significant. Notch width had the effect of changing how close these two slow zones were to one another. For example, even if a wider notch exhibited lower average velocity than a narrower notch, a narrower notch could perform better because the slow zones were closer together, which could be the difference between a yellow and a green-star passage rating. However, there was a limit to how narrow the notch could be, as the narrowest notches exhibited a large head gradient from headwater to tailwater that resulted in high velocity and suppressed the slow zones. Connection channel skew angle changed the size of the slow zones. A zero skew angle reduced the ability of the north side slope to act as a shadow to the high velocity flow accelerating into the notch, and the eddy here on the north side of the notch was consequently smaller. A large skew angle, i.e., that associated with a 200-foot long connection channel, created a long slow zone along much of the connection channel's northern side, but the angle also steered the higher velocity flow into the north side of the notch at the east end, thereby cutting off a passage route. An intermediate skew angle balanced these competing effects.

A number of other project configurations and parameters were also assessed. Notch side slopes that transitioned from vertical at the gate to too shallow at the west end had the effect of funneling in more flow to the notch and increasing velocities, with 2:1 side slopes performing the best. Notch invert elevation and basin downstream edge elevation were dictated more by how long the basin was intended to be inundated during a season as the Sacramento River stage recedes (see forthcoming *Basis of Design* for further discussion). The selection of a north versus south location for the notch was influenced more by other factors with respect to feasibility (for example, potential for large wood debris to clog the notch, damage the gate, or otherwise significantly increase the maintenance burden; see the *Engineering Feasibility Report* for further discussion), as passage performance wasn't significantly different. The two basin conform options showed nearly identical passage performance. Alcoves were tested on the north and south sides of the connection channel, and the north alcove only created local resting conditions without changing passage, while the addition of a south alcove deflected the high velocity flow into the north side of the notch and limited passage. Lastly, closing a hypothetical two gate notch on the south side (i.e., constricting the opening to approximately 16-foot width) in an attempt to baffle the jet that passes along the south side, instead accelerated flow on the north side and limited passage. Full passage results for design iterations exploring the effects of the properties listed in Table 2 are shown in Attachment 1.

5 References

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Attachment 1

Passability Tables for Various Alternatives and Passability Figure for the Preferred Alternative

Sacramento River just upstream of the weir			Notches at north end of weir with invert at 34 ft, 45° south skew angle of inlet, vertical gate sides									
			Passability (salmon)					Passability (sturgeon)				
Stage (ft, NAVD88)†	Flow (cfs)	% exceedance	Existing	24.5 ft gate width‡	32.6 ft gate width‡	40.8 ft gate width‡	50 ft gate width‡	Existing	24.5 ft gate width‡	32.6 ft gate width‡	40.8 ft gate width‡	50 ft gate width‡
48	47419	0.31										
47	41215	3.18	*		*	*	*			*	*	*
46	27970	8.23			*	*	*			*	*	*
45	22525	10.60			*					*		
44	19077	12.94		*	*	*	*		*			*
43	17684	14.07		*	*	*	*		*	*	*	*
42	16493	14.93		*	*	*	*		*	*	*	*
41	15226	16.01							*			
40	14149	16.99										
39	13066	18.30										
38	11971	20.12										
37	10881	22.55	Basin drainage condition									
36	9875	24.68										
35	8974	25.47										
34	8072	25.47										
33	7172	25.47										
32	6286	25.47										

†Stage for existing conditions, falling limb stage, which is higher than stage under with-notch conditions given the decrease in downstream river flow and associated backwater, due to notch spill into the bypass.

‡The associated hydraulic model runs used a normal depth downstream boundary condition for the bypass, which didn't differ significantly from the Sutter Bypass rating curve used in later runs with the preferred notch alternative.

See Table 6 in the main report for the key.

			Notches at north end of weir with invert at 34 ft, 32.6 ft gate width, 45° south skew angle of inlet, vertical gate sides									
Sacramento River just upstream of the weir			Passability (salmon)					Passability (sturgeon)				
Stage (ft, NAVD88)†	Flow (cfs)	% exceedance	2:1 side slope transition, 27 ft wide connection channel width‡	2:1 side slope transition, 32.6 ft wide connection channel width‡	2:1 side slope transition, closed south gates‡	4:1 side slope transition‡	2:1 side slopes, 200 ft long connection channel‡	2:1 side slope transition, 27 ft connection channel width‡	2:1 side slope transition, 32.6 ft connection channel width‡	2:1 side slope transition, closed south gates‡	4:1 side slope transition‡	2:1 side slopes, 200 ft long connection channel‡
48	47419	0.31				*	*				*	*
47	41215	3.18			*					*		
46	27970	8.23	*					*				
45	22525	10.60	*			*		*			*	
44	19077	12.94	*	*		*		*	*		*	
43	17684	14.07	*	*		*	*	*	*		*	*
42	16493	14.93	*		*			*	*	*	*	
41	15226	16.01			*					*		
40	14149	16.99								*		
39	13066	18.30										
38	11971	20.12										
37	10881	22.55	Basin drainage condition									
36	9875	24.68										
35	8974	25.47										
34	8072	25.47										
33	7172	25.47										
32	6286	25.47										

†Stage for existing conditions, falling limb stage, which is higher than stage under with-notch conditions given the decrease in downstream river flow and associated backwater, due to notch spill into the bypass.

‡The associated hydraulic model runs used a normal depth downstream boundary condition for the bypass, which didn't differ significantly from the Sutter Bypass rating curve used in later runs with the preferred notch alternative.

See Table 6 in the main report for the key.

			Notches at north end of weir with invert at 34 ft, 32.6 ft gate width, 2:1 side slope transition, 45° south skew angle of inlet, vertical gate sides							
Sacramento River just upstream of the weir			Passability (salmon)				Passability (sturgeon)			
Stage (ft, NAVD88)†	Flow (cfs)	% exceedance	No additional features	North side alcove	North and south side alcoves	Halved skew angle	No additional features	North side alcove	North and south side alcoves	Halved skew angle
48	47419	0.31								
47	41215	3.18								
46	27970	8.23	*	*			*	*		
45	22525	10.60	*	*		*	*	*		
44	19077	12.94	*	*	*	*	*	*	*	*
43	17684	14.07	*	*	*	*	*	*	*	*
42	16493	14.93	*			*	*	*		*
41	15226	16.01								
40	14149	16.99								
39	13066	18.30								
38	11971	20.12								
37	10881	22.55	Basin drainage condition							
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34	8072	25.47								
33	7172	25.47								
32	6286	25.47								

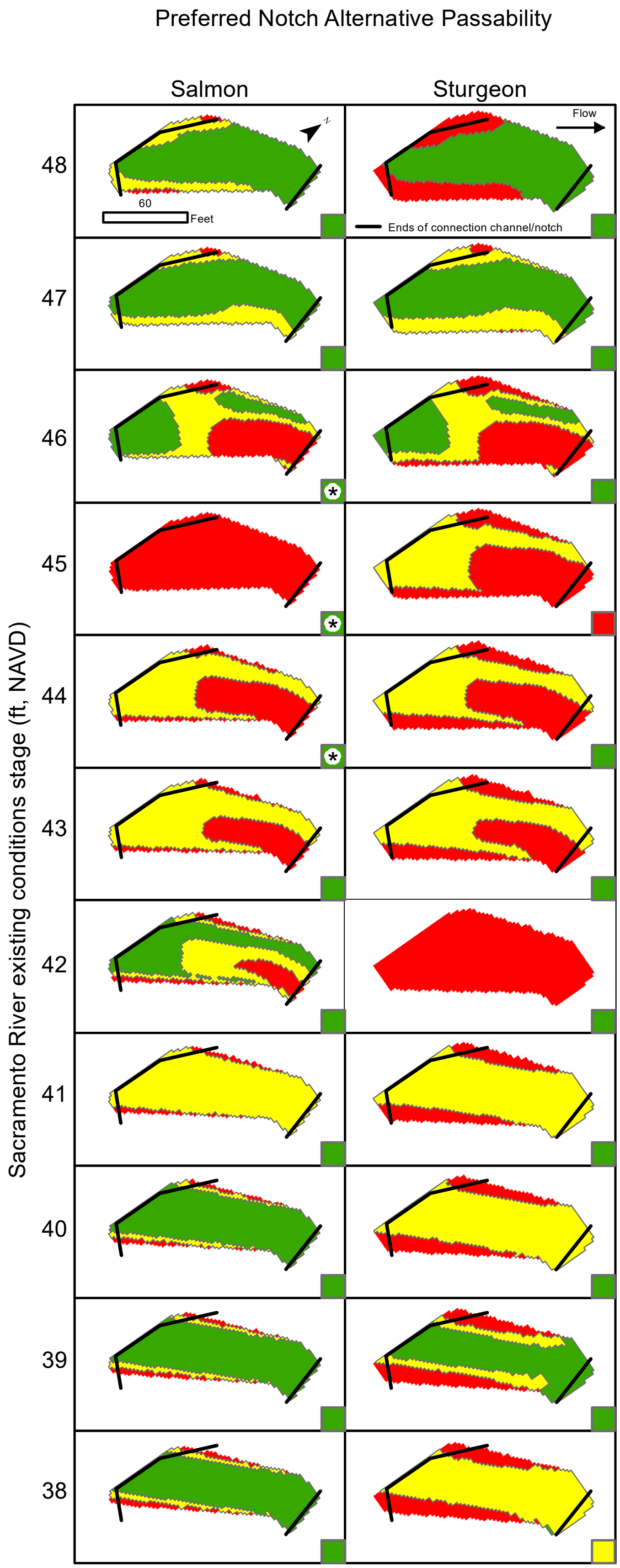
†Stage for existing conditions, falling limb stage, which is higher than stage under with-notch conditions given the decrease in downstream river flow and associated backwater, due to notch spill into the bypass.

See Table 6 in the main report for the key.

			Notches at north end of weir with invert at 34 ft, 32.6 ft gate width, 2:1 side slope transition, 45° south skew angle of inlet, vertical gate sides											
Sacramento River just upstream of the weir			Passability (salmon)						Passability (sturgeon)					
Stage (ft, NAVD88)†	Flow (cfs)	% exceedance	2017 topo conform	36 ft hinge	37 ft hinge	2017 topo conform and north bank setback	36 ft hinge and north bank setback	37 ft hinge and north bank setback	2017 topo conform	36 ft hinge	37 ft hinge	2017 topo conform and north bank setback	36 ft hinge and north bank setback	37 ft hinge and north bank setback
48	47419	0.31				*	*	*				*	*	*
47	41215	3.18												
46	27970	8.23	*	*	*	*	*	*	*	*	*			
45	22525	10.60	*	*	*				*	*	*			
44	19077	12.94	*	*	*	*	*	*	*	*	*	*	*	*
43	17684	14.07	*	*	*	*	*	*	*	*	*	*	*	*
42	16493	14.93	*	*	*	*	*	*	*			*		
41	15226	16.01		*	*		*	*				*		
40	14149	16.99					*	*						
39	13066	18.30												
38	11971	20.12		*			*							
37	10881	22.55	Basin drainage condition											
36	9875	24.68												
35	8974	25.47												
34	8072	25.47												
33	7172	25.47												
32	6286	25.47												

†Stage for existing conditions, falling limb stage, which is higher than stage under with-notch conditions given the decrease in downstream river flow and associated backwater, due to notch spill into the bypass.

See Table 6 in the main report for the key.


Preferred Notch Alternative Passability
Salmon
Sturgeon
Flow
N
60
Feet
Ends of connection channel/notch
Sacramento River existing conditions stage (ft, NAVD)
48
47
46
45
44
43
42
41
40
39
38