Appendix H

Sediment Budget Analysis Technical Memorandum

TISDALE WEIR REHABILITATION AND FISH PASSAGE PROJECT

Sediment Budget Analysis Technical Memorandum

Prepared for
California Department of Water Resources

October 2019

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TISDALE WEIR REHABILITATION AND FISH PASSAGE PROJECT

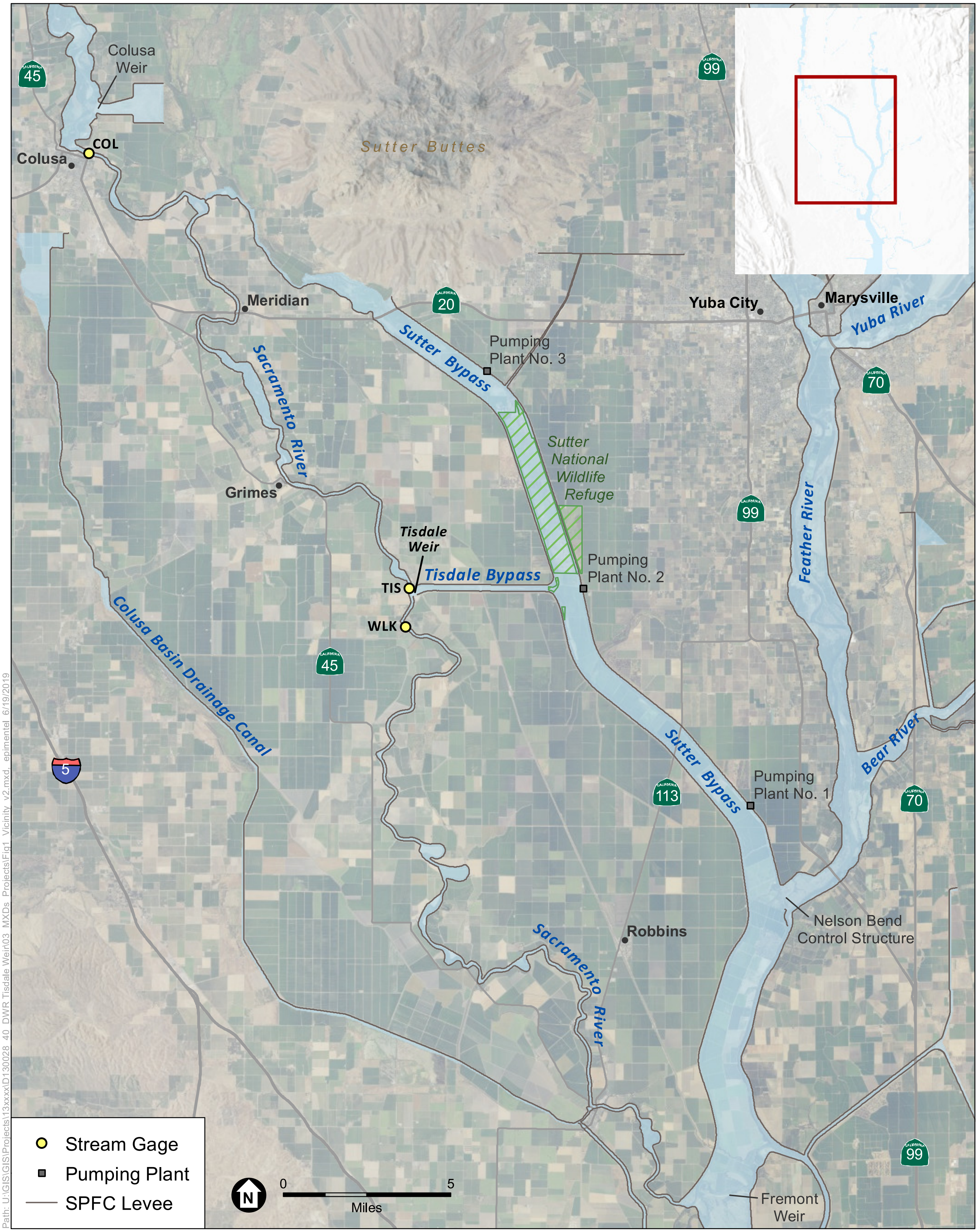
Sediment Budget Analysis Technical Memorandum

1 Introduction

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 spill and the last to stop. The weir is a fixed-elevation, ungated overflow structure. It was designed to spill and convey up to 38,000 cubic feet per second (cfs) from the Sacramento River 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 collection basin (basin) on the downstream side of the weir, installation of a notch and operable gate within the weir, and construction of a channel connecting the notch in the weir to the Sacramento River. Under existing conditions, a portion of the river's suspended sediment that flows over Tisdale Weir is deposited within the four-mile extent of the bypass. As part of routine maintenance for flood control facilities, DWR periodically removes some sediment from the bypass. The proposed notch opening would be approximately 11 feet tall by 32 feet wide, and a bottom-hinged gate would allow the notch to be opened and closed. Under proposed normal operations, the notch gate would likely be opened within a few hours following a weir overtopping event and remain open until the Sacramento River water surface recedes below the invert elevation of the notch (which is currently assumed to be 33 feet NAVD88). Under proposed Project conditions more water, and thus more sediment, would enter the bypass due to the notch and operation of the gate.

To better understand contemporary sedimentation processes within the bypass, and how those may change as a result of the proposed Project, Environmental Science Associates (ESA) calculated a suspended sediment budget for the Tisdale Bypass using two methodologies: topographic change detection and suspended sediment discharge estimates. The objective of the sediment budget is to 1) estimate the annual amount of suspended sediment that deposits within the bypass under existing conditions, and 2) to assess how the amount of suspended sediment deposition in the bypass may potentially change with implementation of the proposed Project.



Path: U:\GIS\GIS\Projects\13xxxx\D130028 40 DWR Tisdale Weir\03 MXDs Projects\Fig1 Vicinity v2.mxd, epimentel 6/19/2019

SOURCE: Esri, 2015

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 1
Project Vicinity

2 Methods

2.1 Topographic Change Detection

Areas and volumes of net deposition and erosion within the bypass were calculated by differencing two digital elevation models (DEM) spanning a ten-year period (11/15/2007 to 10/5/2017) beginning immediately after the last bypass sediment removal project in the fall of 2007. Due to errors inherent in surveying and surface creation, adjustments were made to the raw differencing values to account for error and to provide a range of estimates for the magnitude of detectable topographic change within the Tisdale Bypass.

2.1.1 Data Sources

Topographic differencing was performed using a DEM representing conditions immediately after excavation of sediment from the bypass in 2007, and a DEM representing conditions in the bypass roughly a decade later in 2017. The 2007 DEM was constructed by creating a triangulated irregular network (TIN) surface from elevation contours provided by DWR. The elevation contours were based on a cross section survey performed from 11/4/2007 to 11/15/2007.[1] The 2017 DEM was constructed using a TIN surface created by DWR from a high point-density ground survey performed from 10/2/2017 to 10/5/2017.[2]

2.1.2 Change Detection Algorithm

To determine a range for the magnitude of potential topographic change within the Tisdale Bypass, a raw DEM of difference (DoD) was developed from the 2007 and 2017 DEM surfaces and two different levels of topographic change detection adjustments were made to reflect uncertainty in surveying and surface development. A method developed by Carley et al. (2012) is based on the assumption that where variation in point data is greatest the uncertainty is also greatest (Heritage et al., 2009). In other words, as local variability in topographic data increases, the greater the magnitude of change must be to be considered actual topographic change and not an error due to surveying or surface creation (e.g., interpolation between surveyed points).

The method presented by Carley et al. (2012) was used in our assessment and involved the following steps in ArcGIS 10, as described by Brown and Pasternack (2012):

a. Convert the TIN surfaces to 3-foot raster surfaces.

b. Convert the elevation values from feet to meters to be consistent with the equation for survey and instrument error (SIE) adjustment from Heritage et al. (2009).

c. Use focal statistics to develop a raster of standard deviation (SD) calculated from the 9-foot by 9-foot grid centered around each elevation raster cell (nine points per cell).

1 California Department of Water Resources (DWR), 2007. Tisdale Bypass Sediment Removal Survey [contour data]. Personal Communication.

2 California Department of Water Resources (DWR), 2017. Tisdale Bypass Field Survey [topo/surface data]. Personal Communication.

d. Apply the equation for SIE from Heritage et al. (2009) for a cross-section survey using triangulation with linear interpolation to the SD rasters for 2007 and 2017:

$$SIE = 0.4274 * SD + 0.0808$$

e. Create two separate adjustment rasters – The first adjustment is the combined SIE raster, to remove survey and instrument error from the DoD, calculated using the statistical equation for error propagation:

$$SIE_{combined} = \sqrt{(SIE_{time1})^2 + (SIE_{time2})^2}$$

The second adjustment is the level of detection (LoD) raster, to remove all non-statistically significant differences from the DoD, which is calculated by multiplying the combined SIE by the t-value for the 95 percent confidence interval (1.96):

$$LoD = t * SIE_{combined}$$

f. Create a raw DoD raster by subtracting the 2007 DEM from the 2017 DEM.

g. Create separate erosion and deposition rasters from the raw DoD.

h. Create SIE- and LoD-adjusted erosion and deposition rasters by subtracting SIE and LoD adjustments from deposition values and adding SIE and LoD adjustments to erosion values. If adjusted deposition values are less than zero or adjusted erosion values are greater than zero, then set to zero.

i. Convert SIE/LoD-adjusted DoD rasters from vertical units of meters back to feet.

j. Use zonal statistics to generate areas and magnitudes of deposition and erosion for raw and SIE/LoD-adjusted DoDs.

While a uniform threshold of ± 0.3 meters and ± 0.16 feet was excluded for DoD analysis by Carley et al. (2012) and Brown and Pasternack (2012), respectively, a uniform threshold was not used for this analysis, as the minimum SIE and LoD calculated adjustments (where SD = 0) were 0.4 feet and 0.7 feet, respectively, and we felt this was adequate to account for error and a uniform minimum threshold greater than these values was not necessary.

Two areas were excluded from the topographic change analysis. The first area is a pond (or relic borrow pit) within the bypass that is located approximately 2,000 feet downstream of Tisdale Weir. The pond topography was recorded in the 2017 DEM but not in the 2007 DEM. However, historical maps and aerial imagery show the pond as present for both years and, in fact, as being present well before 2007. The second area is a small, isolated mound located in the bypass approximately 500 feet downstream of the Reclamation Road bridge. Similarly, the mound was present in the 2007 DEM and not in the 2017 DEM, though it appears in aerial imagery for both years.

2.2 Sediment Flux to Tisdale Bypass

For the same ten-year period as the topographic change detection analysis (11/15/2007 to 10/5/2017), the volume of suspended sediment delivered to the bypass was estimated using available sediment transport and flow data; the fraction of that volume deposited (or retained) within the bypass was also estimated.

2.2.1 Data Sources

Observed suspended sediment and flow data were used to develop a sediment rating curve for the Sacramento River at the Project site. Data sources included U.S. Geological Survey (USGS) gages and field data, the DWR gage at Tisdale Weir, and limited field data collected by ESA during water year (WY) 2019. Both the USGS 11389500 Sacramento River at Colusa CA gage (Colusa gage; COL on Figure 1) (USGS, 2019a) and the USGS 11390480 Tisdale Weir near Grimes CA gage (USGS Tisdale gage; TIS on Figure 1) (USGS, 2019b) have discharge and suspended sediment data available. The USGS Tisdale gage was at the Project location and includes suspended sediment measurements representative of water spilling over the weir. However, the period of record for these data is very limited (January 7, 1978 to February 15, 1979) and comprises only nine measurements. Further, this short period of record immediately follows the significant 1976 to 1977 drought, during which there was no spill over the Tisdale Weir, and further complicates how representative these data may be with respect to a broader range of conditions. In addition, because the USGS Tisdale gage data only reflects flow going over the weir, it represents only the higher end of Sacramento River discharges and would not represent suspended sediment rates at lower discharge (e.g., during conditions when flow may only be spilling through the proposed notch in the weir and not over the crest). The USGS Tisdale gage does, however, provide measurements of the grain size distribution of suspended sediment going over the Tisdale Weir into the Tisdale Bypass.

The Colusa gage (USGS, 2019a) is located approximately 24 miles upstream on the Sacramento River and has a much longer period of record for suspended sediment data, from water year 1973 to 1980 and water year 1996 to 2000, with 130 suspended sediment measurements. It covers a broader timeframe that includes both dry years and wet years. This longer-term record reflecting a mixture of dry and wet years is more appropriate for deriving suspended sediment flux estimates on a decadal time scale. In addition, because it measures all flow in the Sacramento River, it includes discharges that are both below and above those that allow flow into the Tisdale Bypass, which is important considering that, for Project conditions, flow may be entering the bypass via the notch only and not spilling over the weir.

ESA also collected suspended sediment samples on 2/5/19 and 3/20/19 for the Sacramento River adjacent to the Tisdale Weir as part of an ongoing data collection campaign. Following techniques described by Edwards and Glysson (1989), depth-integrated samples were collected from the water surface down to the approximate elevation of the weir crest, so as to characterize suspended sediment concentrations and characteristics specific to flow going over Tisdale Weir into the bypass.[3] Samples were collected from a boat using DH-76 (2/5/19) and US D-96 (3/20/19) depth-integrating suspended sediment samplers.

[3] Beginning with the 3/20/19 sampling event, multiple samples were collected at each river location: extending to the depth of the weir crest, extending to the depth of the proposed notch, and extending down to the river bottom. The field campaign and data analysis are ongoing.

The DWR A02960 Tisdale Weir Spill to Sutter Bypass near Grimes gage (DWR Tisdale Gage, TIS on Figure 1) is located on the east bank of the Sacramento River approximately 50 feet upstream of the weir and provides a discharge record for the 2007-2017 study period (DWR, 2018). The USGS 11390500 Sacramento River Below Wilkins Slough near Grimes, CA gage (Wilkins gage; WLK on Figure 1), is located approximately 1.3 miles downstream of the Tisdale Weir and provides a discharge record for the Sacramento River downstream of the Tisdale Weir diversion (USGS, 2019c).

2.2.2 Existing Conditions Methods

A suspended sediment rating curve (flow vs. sediment mass) was developed for the Colusa gage and, coupled with measured (existing conditions) and projected (Project conditions) flow into the bypass, used to estimate the mass of sediment delivered to the bypass over a ten-year period. Our analysis comprised three general steps: we conducted a statistical analysis to see if the Colusa data were different over the periods for which data are available; unable to prove a difference, we then constructed a total suspended sediment rating curve based on the Colusa data; and then we estimated what fraction of the total suspended sediment load to the bypass would be expected to settle-out and deposit. These steps are described in more detail below.

Trend Test

Suspended sediment data for the Colusa gage are available for two distinct time periods: from 1972 to 1980, and from 1996 to 2000. Therefore, we first performed a statistical analysis to test whether or not the relationship between flow and suspended sediment concentration might be different for these two time periods.

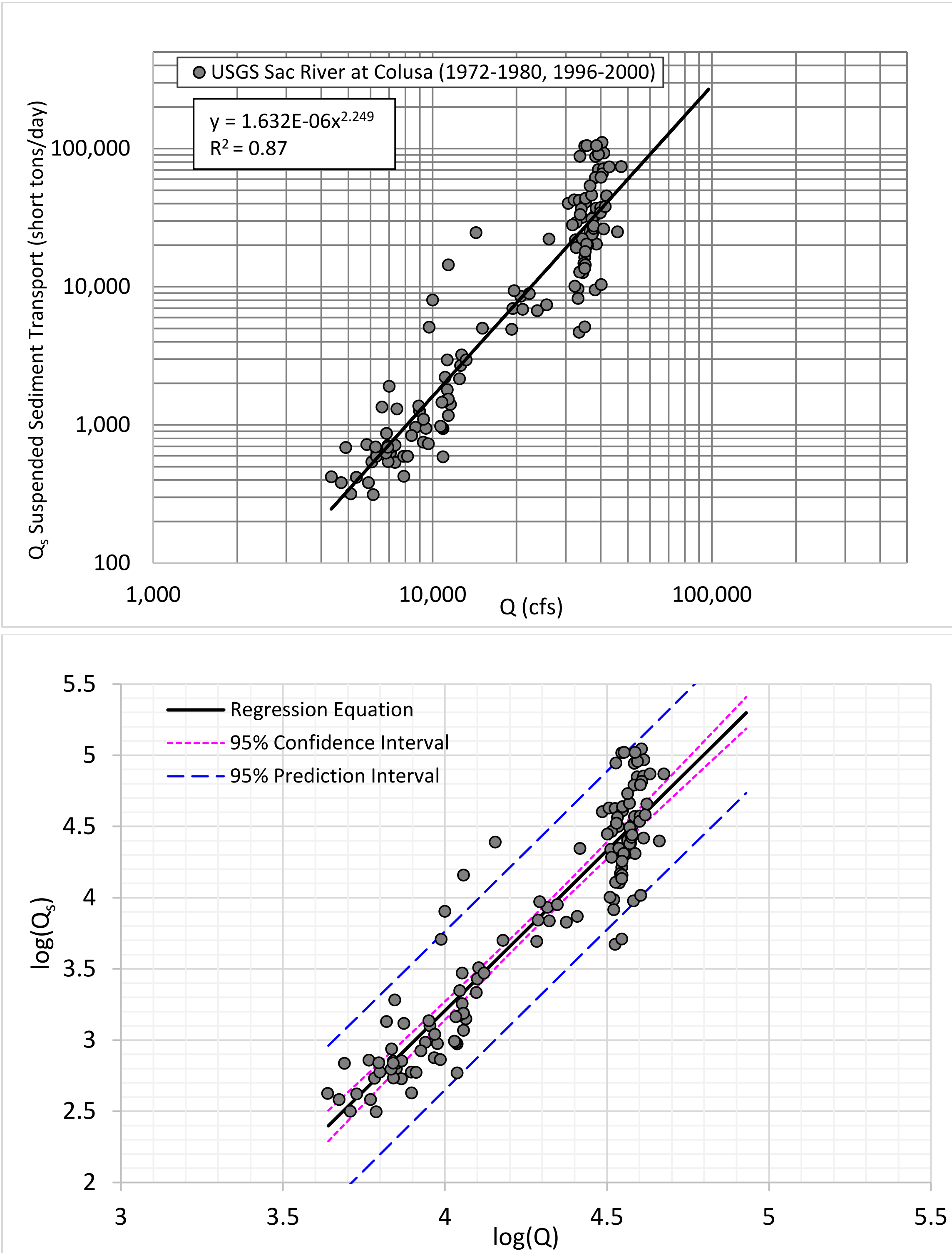
We performed a suspended sediment (mg/l) versus discharge (cfs) regression slope test to determine whether there is a trend in suspended sediment through time in the Colusa gage data as follows. Discharge and suspended sediment concentration data were obtained from the Colusa gage. The data were classified into two periods: 1) 12/19/72 to 1/16/80 and 2) 2/28/96 to 9/14/00. The flow and suspended sediment data were both log-transformed and a linear regression was constructed for each of the two periods. We erected a null hypothesis:

H_0: there is no difference in the regression slope coefficients of these two periods.

We then constructed a linear model with an interaction term of $\log_{10}$(suspended sediment) * $\log_{10}$(discharge). The analysis of variance (ANOVA) statistics for this comparison showed we could not reject the null hypothesis ($F = 0.6742$, $df = 1$, $P = 0.4132$). So, we concluded the slope for the first period was not statistically different from the slope of the second period (at the 95 percent confidence level) and this suggested that there was not more suspended sediment produced per unit of discharge in either of these two periods. Therefore, all available suspended sediment data from the Colusa gage were used for constructing the sediment rating curve.

Sediment Rating Curve

A suspended sediment rating curve was developed using suspended sediment flux (short tons/day) versus discharge for the Colusa gage (**Figure 2**). There is considerable scatter in the data at the top end of the rating curve due to the influence of the Colusa Weir (which is upstream



Tisdale Weir Rehabilitation and Fish Passage Project

Figure 2
(Top) Suspended sediment rating curve. (Bottom) Log-transformed suspended sediment rating curve and statistical intervals.

of the Colusa gage), which truncates the flow at the Colusa gage during flood conditions, but the overall relationship between flow and sediment discharge appears reasonable. Following methods outlined in Glysson (1987), the rating curve was derived by performing a simple linear regression on the log-transformed values of flow and sediment discharge. Figure 2 also presents the 95-percent confidence and prediction intervals for the log-transformed data following the methods presented by Helsel and Hirsch (2002).[4]

Mean daily flow data from the Wilkins gage (USGS, 2019c) and DWR Tisdale gage (DWR, 2018) were compiled for the same timeframe as the topographic change detection period. The sediment rating curve was then applied to the sum of the mean daily discharge time series for the two gages, which represent the discharge of the Sacramento River just upstream of the Tisdale Weir, to determine the suspended sediment flux in the Sacramento River upstream of the weir. For days when the weir was spilling, the Sacramento River sediment flux was then multiplied by the percentage of the Sacramento River discharge that flowed over the Tisdale Weir and into the bypass.[5] Subsequently, we calculated the annual sediment flux into the bypass, in short tons per water year.

Deposition Fraction

We used suspended sediment grain size distribution data to then estimate what fraction of the sediment delivered may be deposited within the bypass. For fluvial or river environments, generally all sediment grains smaller than approximately 0.125 millimeters (mm) (very fine sand) tend to always travel in suspension (Wilcock et al., 2009). At times the Tisdale Bypass is subject to a backwater effect from the Sutter Bypass, and so this general threshold may shift toward a smaller grain size under such conditions. For this assessment we make a simple assumption that the grains always carried in suspension (i.e., wash load) generally range from less than 0.125 mm (very fine sand) to less than 0.063 mm (silt) in size; thus, we assume grains larger than these sizes would eventually fall out of suspension and be deposited and stored within the bypass.

Suspended sediment size distribution data were obtained from the USGS Tisdale gage and, more recently, samples collected by ESA in the Sacramento River adjacent to Tisdale Weir. Both sources reflect the size distribution of suspended sediment traveling in the upper part of the water column and that would be flowing over the weir. ESA collected depth-integrated suspended sediment samples during weir spill events on 2/5/2019 and 3/20/2019. ESA collected multiple samples integrated over varying depths (e.g., only the top part of the water column flowing over the weir, the entire water column, to a depth equivalent to an assumed notch invert, etc.). On average, 10 percent of the suspended sediment flowing into the bypass is larger than 0.125 mm (fine sand and larger), and 19 percent of the suspended sediment is larger than 0.063 mm (very fine sand and larger). Therefore, under existing conditions we estimated that a range of 10 to

4 A *confidence interval* describes the average expected value of suspended sediment discharge for a given flow. A *prediction interval* describes the expected range in suspended sediment discharge for a given flow, or in other words, the likelihood that a single data point for suspended sediment discharge comes from the underlying population of flow versus suspended sediment discharge. These definitions are derived from Helsel and Hirsch (2002).

5 We assumed the water column was evenly mixed and there was no vertical stratification of sediment concentration, and so this simplified approach likely overestimates the amount of sediment going over the weir. This assumption will be evaluated through our ongoing field data collection and the calculations may be updated, as necessary.

19 percent of the suspended sediment that is delivered to the bypass may be expected to deposit in the bypass, while the rest of the sediment (primarily clay and silt) would be expected to stay in suspension and continue downstream into the Sutter Bypass.

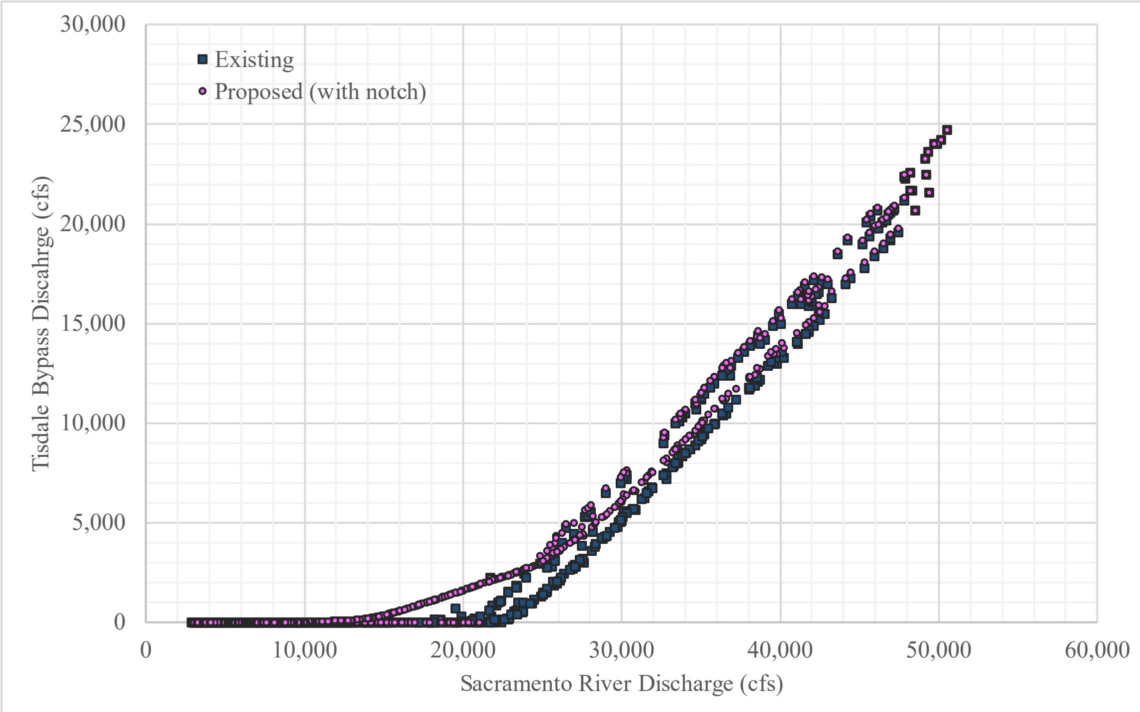
2.2.3 Project Conditions Methods

For the Project condition we estimated the additional flow volume that would be discharged to the bypass with the proposed notch, and then we estimated the amount of additional sediment that would be delivered and potentially deposited using our suspended sediment rating curve and assumptions described above. The Project-condition total flow volume for the bypass is comprised of 1) the estimated flow through the notch and 2) the estimated spill over the weir.

Flow through the notch for a given Sacramento River discharge was derived from the HECRAS 1D/2D model (HECRAS model) developed by ESA (see *Tisdale Weir Fish Passage Analysis Technical Memorandum)*. Daily Sacramento River discharges over the analysis period were calculated by summing the measured daily flow values at Tisdale Weir (DWR, 2018) and the measured daily flow values in the Sacramento River at Wilkins Slough (USGS, 2019c). Using the HECRAS model-predicted notch flows, a synthetic daily flow hydrograph of notch flows over the analysis period was generated. The synthetic notch flow hydrograph was then adjusted assuming a simplified gate operations scheme, as the exact gate operations have yet to be determined:

1. The gate will open once the Sacramento River water surface crests the top of the weir and will remain open until river levels drop below the notch invert.
2. The gate will be closed during times when Sacramento River flows meet or exceed the 10-percent-annual-chance flood (48,000 cfs) (due to assumed USACE 408 permit limitations).

Weir spill for the Project condition was taken from the existing condition (i.e., DWR-reported weir spill) and scaled down to account for the influence of the notch itself. The scaling factor was derived from the HECRAS model, which showed that flow through the notch lowered the stage on the Sacramento River and, subsequently, reduced the spill over the weir crest for a given Sacramento River discharge. As such, the total Project-condition flow into the bypass was calculated as the sum of the predicted notch flows and the scaled-down, measured Tisdale Weir flows. **Figure 3** shows the relationship between the Sacramento River discharge and associated Tisdale Bypass discharge for both existing- and Project conditions. Using the Project-condition hydrology, the estimated Project-condition suspended sediment discharge into the bypass was then calculated.



Source: Existing (DWR 2018; USGS 2019c)

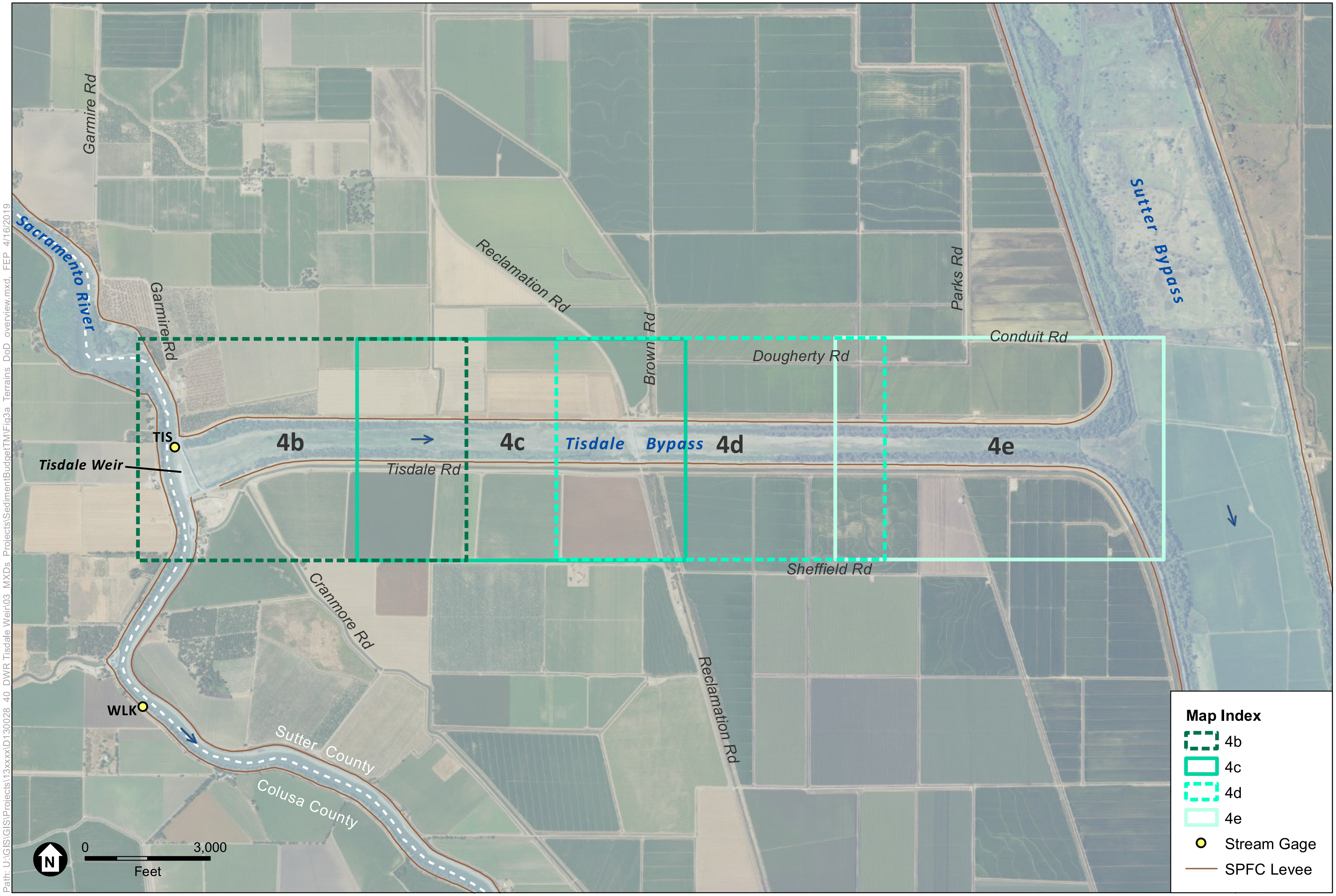
Tisdale Weir Rehabilitation and Fish Passage Project

Figure 3
Tisdale Bypass flow versus upstream Sacramento River discharge (11/15/2007 to 10/5/2017).

3 Results

3.1 Topographic Change Detection Results

Figures 4a to 4e show the LoD-adjusted topographic change in the bypass over the 2007 to 2017 time period. While magnitudes differed for the raw and SIE-adjusted analyses, the general patterns of erosion and deposition are the same. A process previously described in the context of Sacramento Valley flood control weirs (Singer and Alto, 2009) is also apparent in these results: a short hydraulic shadow zone in the Tisdale Bypass immediately downstream of the Tisdale Weir and a broader depositional zone downstream of the hydraulic shadow. The hydraulic shadow zone extends approximately 60 feet just downstream of the weir and is an area that incurs no net sedimentation and is effectively maintained by the weir hydraulics during spill events. A large depositional zone then extends downstream another approximately 1,500 feet. This elongated, low-amplitude depositional zone essentially represents a natural levee-building process typical within river floodplains, though in this case the process is interrupted and offset to some degree by the presence of the weir (Singer and Alto, 2009).

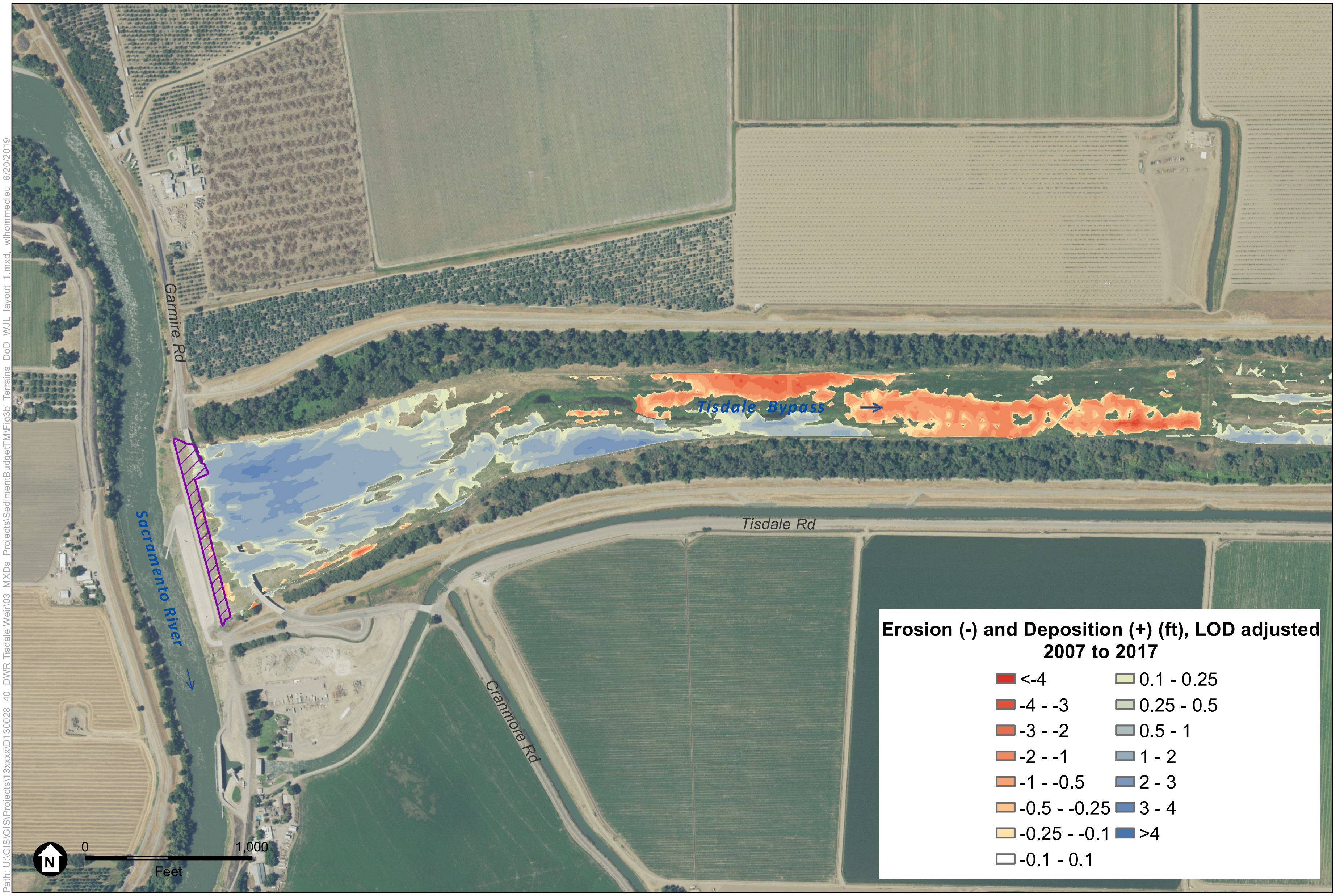


SOURCE: USDA, 2016; DWR, 2019; ESA, 2019

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 4a
DEM of Difference (2007 to 2017)
Map Index

ESA



SOURCE: 2007 Tisdale sediment removal surface (CADWR), 2017 Tisdale survey surface (CADWR)
NOTES: Hatched area represents boundary of proposed fish basin

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 4b
DEM of Difference (2007 to 2017)

ESA

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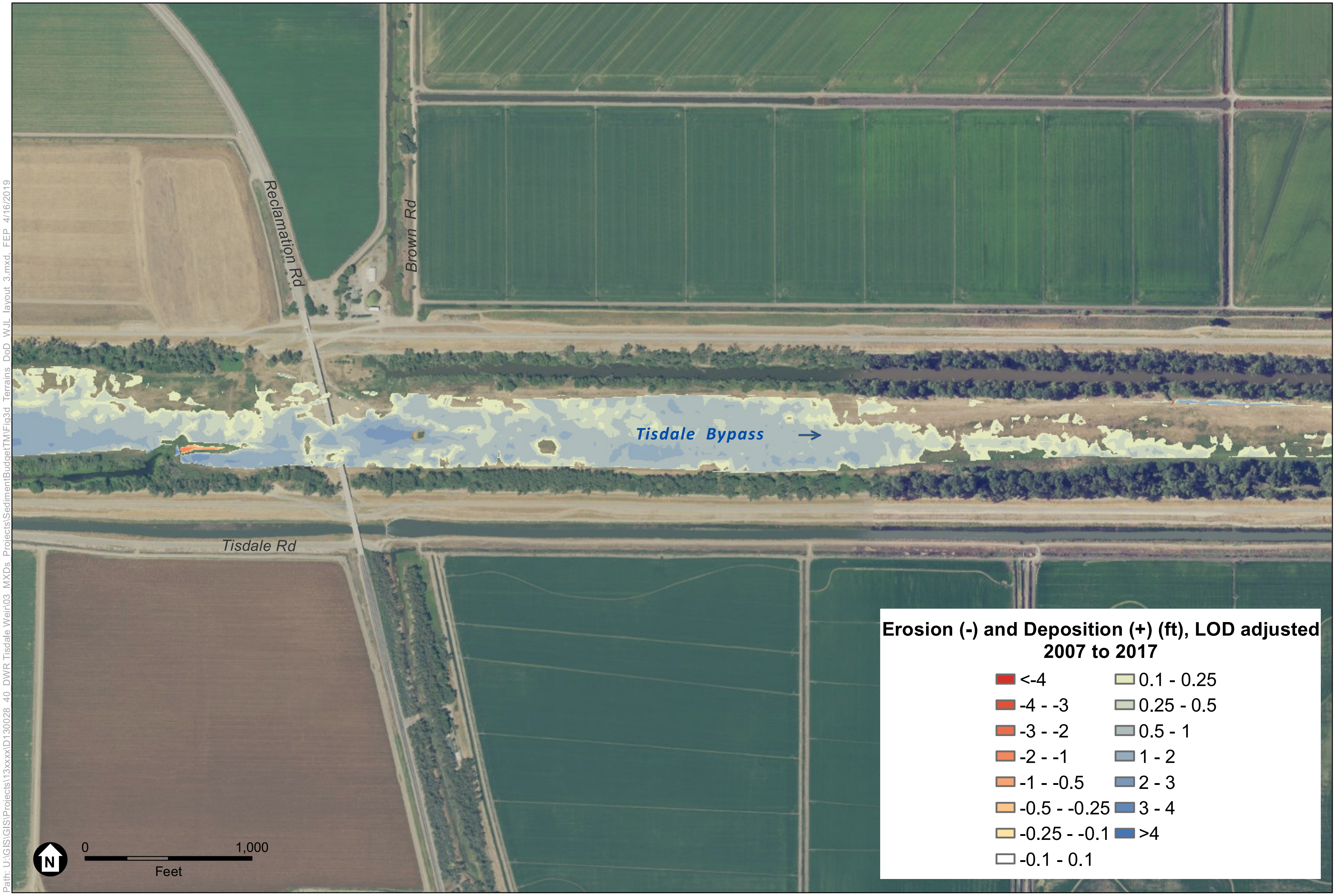
SOURCE: 2007 Tisdale sediment removal surface (CADWR), 2017 Tisdale survey surface (CADWR)

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 4c
DEM of Difference (2007 to 2017)

ESA

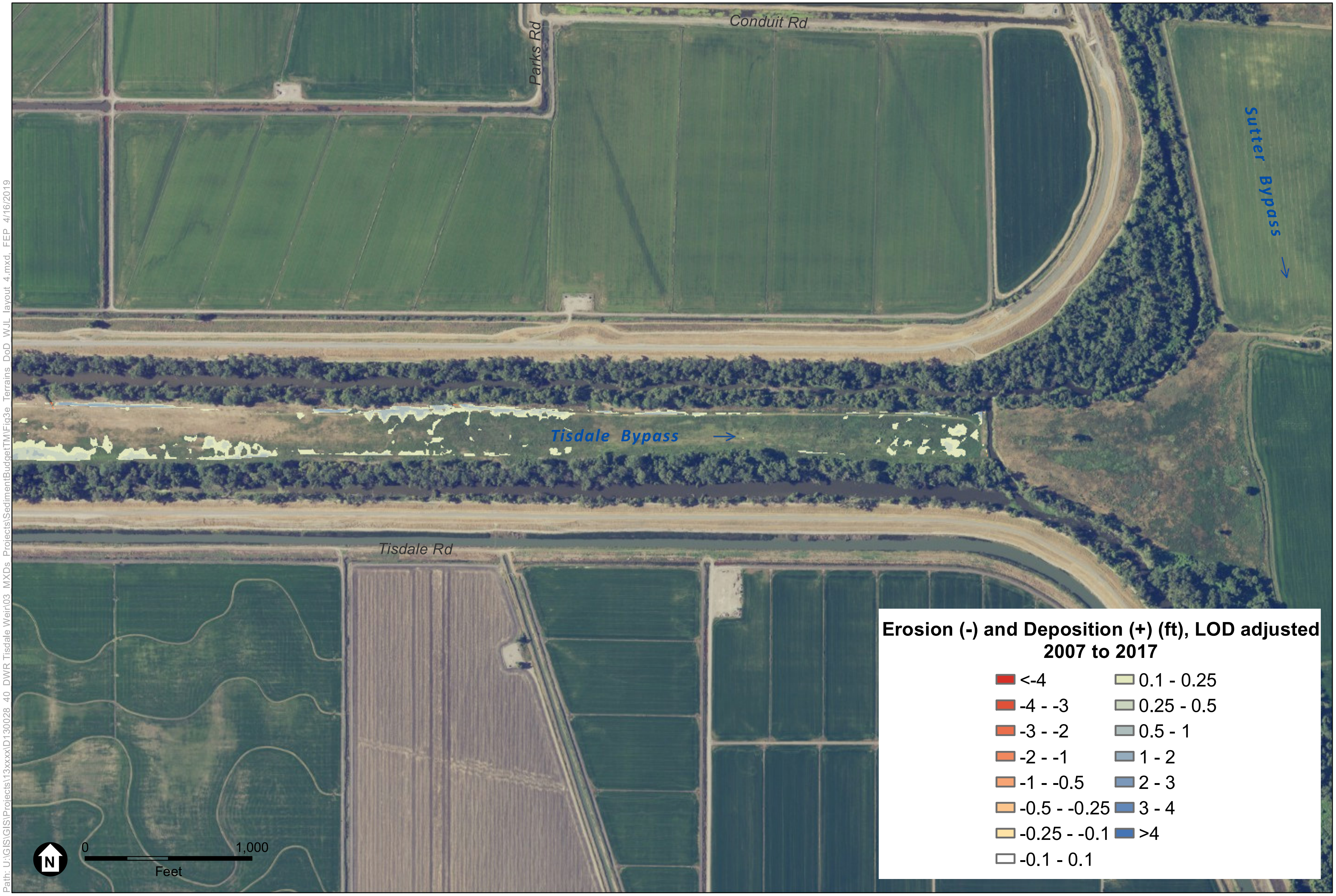


SOURCE: 2007 Tisdale sediment removal surface (CADWR), 2017 Tisdale survey surface (CADWR)

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 4d
DEM of Difference (2007 to 2017)

ESA



SOURCE: 2007 Tisdale sediment removal surface (CADWR), 2017 Tisdale survey surface (CADWR)

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 4e
DEM of Difference (2007 to 2017)

ESA

With respect to overall net change, the bypass was depositional over the ten-year analysis period. The greatest magnitude of deposition, 4.7 feet, occurred just downstream of Tisdale Weir. The greatest magnitude of erosion, 4.7 feet, occurred along the southern side of the bypass approximately 5,600 feet downstream of Tisdale Weir (Figure 4b). The bypass appears to be generally depositional from Tisdale Weir to approximately 3,000 feet downstream of the weir (Figure 4b). From approximately 3,000 feet to 6,000 feet downstream of the weir, the bypass switches to predominantly erosional (Figure 4b). From approximately 6,000 feet to 15,700 feet downstream of the weir, the bypass transitions back to depositional (Figures 4c and 4d). From 15,700 feet downstream of the weir to where Tisdale Bypass flows enter the Sutter Bypass, the Tisdale Bypass is characterized by a mixture of depositional and no detectable change areas (Figures 4d and 4e).

Table 1 shows the results of the topographic change analysis for the bypass using the raw and adjusted DoDs. SIE- and LoD adjusted volumes were approximately 65 percent and 40 percent of raw erosion and deposition volumes, respectively. Overall, the topographic change analysis results suggest that the bypass experiences approximately six times mores deposition than erosion. The results indicate that the net volume of deposition within the bypass over the topographic change detection period is between 107,000 and 273,000 cubic yards of sediment, resulting in an average change in elevation of +0.3 to +0.8 feet. However, very little net change occurred within the footprint of the proposed Project basin, as the basin footprint is primarily located within the hydraulic shadow zone.

TABLE 1
SUMMARY OF TOPOGRAPHIC CHANGE ANALYSIS FOR RAW AND SIE/LOD ADJUSTED DOD

Change	DoD	Average Change (feet)	Volume (CY) (rounded to the nearest thousand)	% Raw
	Raw	+0.8	+273,000	--
Net	***SIE***	***+0.5***	***+177,000***	***65%***
	LoD	+0.3	+107,000	39%
	Raw	+1.1	+327,000	--
Deposition	SIE	+0.7	+211,000	65%
	LoD	+0.4	+129,000	39%
	Raw	-0.9	-54,000	--
Erosion	SIE	-0.6	-35,000	65%
	LoD	-0.4	-22,000	41%

3.2 Sediment Flux Results

3.2.1 Existing Conditions Sediment Flux into Tisdale Bypass

The existing conditions sediment flux into Tisdale Bypass was calculated for each water year within the topographic change detection period (**Table 2**). The bookend dates for the sediment flux analysis were truncated to match the dates of the two topographic data collection efforts used for the change detection analysis. The total flux was calculated as well as the flux for sediment larger than 0.125 mm and 0.063 mm; these two size classes and associated volumes represent our assumed range for the fraction of sediment eventually deposited within the bypass during the ten-year analysis period. Based on this assumption, approximately 10 to 19 percent of the suspended sediment delivered to the bypass would be deposited (at least temporarily). As evidenced in Table 2, the range in the estimated volume of suspended sediment delivered to the bypass varies considerably from year to year. For example, WY 2014 had no flow and WY 2012 had very little flow into the bypass, and hence very little estimated sediment deposition in these years. In contrast, WY 2017 was a very wet year and resulted in an estimated 108,100 to 205,400 CY of sediment deposited within the bypass, which is approximately 60 percent of the total volume of sediment deposited in the bypass during the ten-year period. Sediment deposition within the Tisdale Bypass is highly variable from year to year depending on flows into the bypass.

TABLE 2
EXISTING CONDITIONS SEDIMENT FLUX INTO TISDALE BYPASS FOR THE TOPOGRAPHIC CHANGE DETECTION PERIOD

Water Year	Total Volume (CY) of sediment (rounded to nearest hundred)	Volume (CY) of sediment larger than 0.125 mm (rounded to nearest hundred)	Volume (CY) of sediment larger than 0.063 mm (rounded to nearest hundred)
WY 2008 (partial WY starting 11/15/2007)**	19,700	2,000	3,700
WY 2009	25,900	2,600	4,900
WY 2010	71,800	7,200	13,600
WY 2011	317,100	31,700	60,200
WY 2012	1,000	100	200
WY 2013	69,200	6,900	13,100
WY 2014	None	None	None
WY 2015	63,400	6,300	12,000
WY 2016	163,200	16,300	31,000
WY 2017	1,081,200	108,100	205,400
WY 2018 (partial WY ending 10/5/2017)**	None	None	None
Total* (11/15/2007 to 10/5/2017)	**1,812,400***	**181,200***	**344,400***
Est. Average Annual (per year)	**181,200**	**18,100**	**34,400**

NOTE:
* Total based on non-rounded numbers
** The bookend dates for the sediment flux analysis were truncated to match the dates of the two topographic data collection efforts used for the change detection analysis.

3.2.2 Project Conditions Sediment Flux into Tisdale Bypass

The volumes of suspended sediment delivered to and deposited within the bypass were also estimated for the Project condition (**Table 3**). Under existing conditions, only when the river overtops the weir would flow enter the bypass. However, based on the presence of the notch and the simple, conceptual operating rules described earlier, the Project condition would allow more flow, and thus more sediment, to be delivered to the bypass in most years. For example, with implementation of the Project, the Sacramento River could flow into the bypass even when the river water surface elevation was below the crest of the weir. Curves relating flow into the bypass for a given flow in the Sacramento River, for existing (weir spill only) and Project conditions (weir spill plus flow through a notch), are shown in Figure 3. Under Project conditions, the volume of sediment was calculated separately for days with flow only through the proposed notch and for days where there is flow over the weir and through the proposed notch. The volume of coarse (sand-sized) suspended sediment from days with flow only through the proposed notch comprises less than four percent of the total volume of coarse sediment entering the bypass under Project conditions.

TABLE 3
PROJECT CONDITIONS SEDIMENT FLUX INTO TISDALE BYPASS FOR THE TOPOGRAPHIC CHANGE DETECTION PERIOD

	All Days (Flow Over Weir and Through Notch)	Days With Flow Only Through Proposed Notch		All Days (Flow Over Weir and Through Notch)	
Water Year (WY)	Total Volume (CY) of sediment (rounded to nearest hundred)	Volume (CY) of sediment larger than 0.125 mm (rounded to nearest hundred)	Volume (CY) of sediment larger than 0.063 mm (rounded to nearest hundred)	Volume (CY) of sediment larger than 0.125 mm (rounded to nearest hundred)	Volume (CY) of sediment larger than 0.063 mm (rounded to nearest hundred)
WY 2008 (partial WY starting 11/15/2007)**	30,700	600	1,200	3,100	5,800
WY 2009	34,100	400	800	3,400	6,500
WY 2010	86,800	900	1,600	8,700	16,500
WY 2011	345,500	1100	2,000	34,600	65,700
WY 2012	3,300	200	400	300	600
WY 2013	78,500	200	400	7,900	14,900
WY 2014	None	None	None	None	None
WY 2015	74,600	500	1,000	7,500	14,200
WY 2016	183,800	700	1,300	18,400	34,900
WY 2017	1,110,800	2,100	4,000	111,100	211,100
WY 2018 (partial WY ending 10/5/2017)**	None	None	None	None	None
Total* (11/15/2007 to 10/5/2017)	**1,948,200**	**6,700**	**12,800**	**194,800**	**370,200**
Est. Average Annual (per year)	**194,800**	**700**	**1,300**	**19,500**	**37,000**

NOTE:
* Total based on non-rounded numbers
** The bookend dates for the sediment flux analysis were truncated to match the dates of the two topographic data collection efforts used for the change detection analysis

4 Discussion

4.1 Existing Conditions Analysis

A discussion of the results for the two existing conditions analyses is presented below.

4.1.1 Existing Conditions Topographic Change Detection and Sediment Flux Comparison

The topographic change detection results compare well with the sediment budget estimates developed separately using flow and suspended sediment data. The topographic change detection results indicate *total* (or *gross*) sediment deposition within Tisdale Bypass over a ten-year period of between 129,000 and 327,000 cubic yards, while the sediment flux analysis yields *total* deposition estimates of 181,200 to 344,400 cubic yards. Thus, the range of total sediment deposition within the Tisdale Bypass over the 2007-2017 timeframe appears to be on the order of 150,000 to 350,000 cubic yards, or 15,000 to 35,000 cubic yards per year when averaged. Further, based on the topographic change detection results, the *net* volume deposited would be approximately 83 percent of the total (i.e., after accounting for erosion from the bypass) (see Table 1); thus the range of *net* deposition within the Tisdale Bypass over the analysis period is likely on the order of 125,000 to 300,000 cubic yards, or 12,500 to 30,000 cubic yards per year when averaged.

4.1.2 Qualitative Uncertainty Considerations

While the method used here to adjust for uncertainty in topographic change detection is more robust than applying a uniform threshold, it is likely that some actual change is being classified as no detectable change. The bypass has a bottom width of approximately 500 feet, on average, and little local variability in slope, so it is likely that deposited sediment forms thin uniform layers that could result in an overall thickness less than the 0.4 feet and 0.7 feet minimum thresholds for change detection using SIE and LoD adjustments, respectively. Therefore, the SIE and LoD adjustments may underestimate the actual topographic change.

The topographic change detection represents the difference between two snapshots in time (2007 and 2017) and, thus, net change relative only to these two years rather than the cumulative, volumetric change over time. For example, some material that was deposited between 2007 and 2017 may have become re-suspended and transported out of the Tisdale Bypass within the 2007 to 2017 period, and therefore would not have been captured in the topographic change detection numbers. In contrast, the sediment flux numbers represent the cumulative potential deposition over time, without adjustment for erosion, and this may be one reason why the sediment flux volumes are somewhat larger than the topographic change detection volumes for the 2007 to 2017 timeframe.

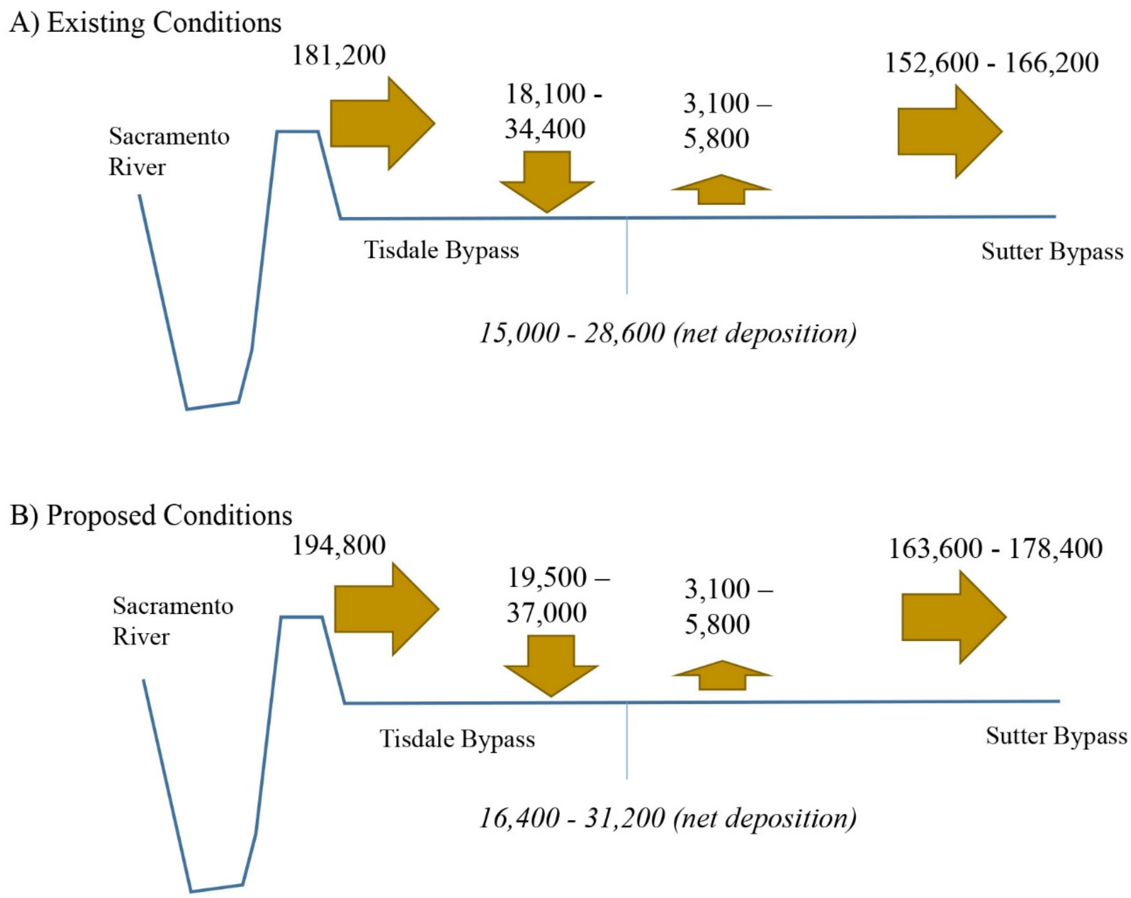
There is notable variability and thus uncertainty in the sediment rating curve relationship (Figure 2). The 95-percent confidence interval constrains the mean sediment discharge for a given flow fairly well, though the width of the 95-percent prediction interval illustrates there is substantial variability in the range of sediment discharge at a given Sacramento River flow. Many factors can influence and control this variability, including, but not limited to, sediment transport hysteresis, seasonal differences and timing, antecedent rainfall and runoff conditions (both inter- and intra-annual), changes in land cover or land use, episodic delivery of sediment (e.g., due to major upstream bank erosion or landslide), and extreme conditions or natural disasters (e.g., drought, fire, etc.).

4.2 Existing Conditions/Project Conditions Comparison

Under Project conditions more water would enter Tisdale Bypass and, as a result, this would increase the amount of suspended sediment that would be delivered to, as well as deposited within, the bypass. Based on the sediment flux analysis, under Project conditions it is estimated that 194,800 to 370,200 cubic yards of sediment would have deposited in the bypass for the 2007 to 2017 timeframe, compared with 181,200 to 344,400 cubic yards of sediment under existing conditions. This represents an approximate 8 percent potential increase in sediment deposition within the bypass when compared to existing conditions.

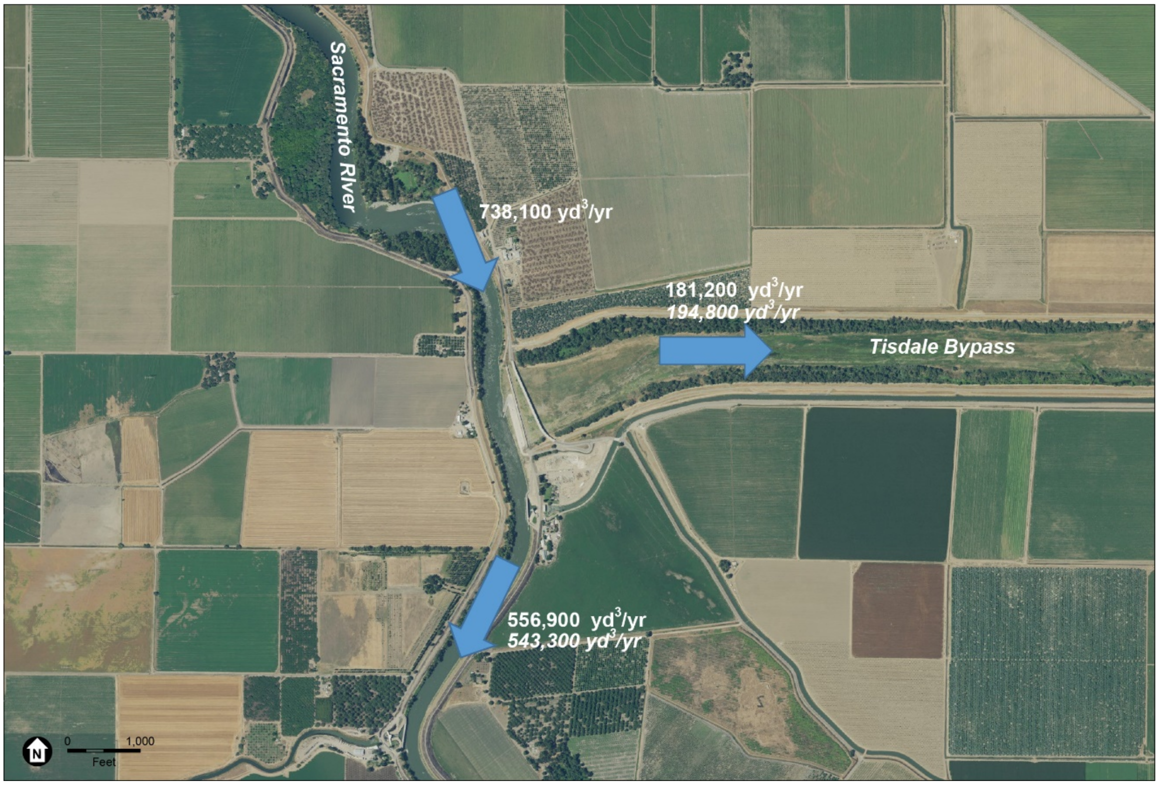
Figure 5 summarizes our estimated annual suspended sediment budget for the Tisdale Bypass for both existing and Project conditions. To complete and refine the estimated flux-based sediment budgets for the bypass, we used the eroded volumes derived from the topographic change analysis to estimate the amount of sediment that may be removed from the bypass through erosion and/or resuspension (i.e., the gross erosion volume was approximately 17 percent of the gross deposition volume for the topographic change detection analysis, see Table 1). We did not assess how erosion or resuspension of sediment within the bypass may be influenced by the proposed Project, and therefore this part of the budget is left unchanged. However, it is reasonable to assume that most of the measured erosion within the bypass occurs during large flood events when the weir is overtopping, and in these cases the influence of the proposed notch on flow or other hydraulic processes throughout the bypass would be minimal. Thus, the proposed Project may increase the suspended sediment volume delivered to the Tisdale Bypass and areas downstream by approximately 8 percent, and it may increase the *net* volume of sediment deposited within the Tisdale Bypass by up to approximately 9 percent (assuming the eroded volume would not change). The sediment that accumulates within the Tisdale Bypass would likely be periodically removed as part of the continued and ongoing maintenance implemented by DWR.

Figure 6 summarizes the broader-scale suspended sediment budget estimates in the context of the Sacramento River (based on 2007-2017 conditions). The upstream Sacramento River estimate was derived using the same suspended sediment rating curve, though applied to the total river flow instead of just the flow discharged into the Tisdale Bypass. The downstream Sacramento River estimate represents the upstream estimate less the flux of the sediment into the Tisdale Bypass.



Tisdale Weir Rehabilitation and Fish Passage Project

Figure 5
Tisdale Bypass annual suspended sediment budget estimates (cubic yards per year).



NOTE: (Project conditions shown in *italics*).

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 6
Sacramento River and Tisdale Bypass suspended sediment budget estimates.

4.3 Project Conditions Comparison with Basin

Under existing conditions very little sediment tends to accumulate within the proposed footprint of the basin, as the footprint essentially encompasses the hydraulic shadow area evidenced in the comparison of the 2007 and 2017 topography (see Figure 4b). For example, the net topographic change between 2007 and 2017 just within the basin footprint was approximately 60 to 70 cubic yards of deposition, which represents less than 0.05 percent of the total net deposition within the bypass as calculated in the topographic change detection analysis.[6] Assuming that the Project may increase the volume of net deposition within the bypass by up to 9 percent, this would only equate to up to an additional 6 cubic yards (76 cubic yards total) deposited within the basin footprint over a ten-year period equivalent to 2007-2017. However, the topographic change analysis only assessed two snapshots in time, and information is lacking on the potential changes throughout the ten-year analysis period. Further, the notch may influence and change the volume and spatial pattern of sediment deposition within the basin footprint.

6 Some annual maintenance and grading by DWR occurs in this area, though it is our understanding that these activities are primarily limited to cleaning out the existing energy dissipation basin on the downstream side of the weir (this feature is not included in the topographic change detection analysis) and leveling-out the bypass surface just downstream (e.g., cut-fill balance).

We used our analyses and results to further elucidate potential shorter-term or seasonal sediment impacts within the proposed basin as a result of the notch, and what implications there may potentially be for fish passage and maintenance of the proposed energy dissipation and fish collection basin. As described above, for the Project conditions sediment flux, we divided our estimate to reflect two flow conditions: days when flow is spilling into the bypass only through the notch, and days when flow is spilling both through the notch and over the weir crest. Days when flow would be spilling through the notch only would most likely occur on the falling limb of the hydrograph when the Sacramento River water surface is below the weir crest elevation. This condition may be followed by another overtopping event, during which we would expect scour and turbulence on the downstream face of the weir to create or maintain the hydraulic shadow area within the basin (as previously discussed). However, if the river continues to recede, or if a subsequent overtopping event is particularly brief or does not occur, then this would represent a condition where the deposition of incoming sediment through the notch would more likely be directly influenced by the basin and occur within the basin to some extent. In this case, the basin may also act as a sediment trap to some degree and the depositional pattern just downstream of the weir would likely look different than under existing conditions, at least until the next overtopping event or implementation of a maintenance action. For example, **Figures 7a through 7c** show the spatial distribution of shear stress under various river stages for both existing and Project conditions (see *Tisdale Weir Fish Passage Analysis* for model description).[7] At low to moderate flows, the depositional pattern, and potentially volume as well, may change compared to existing conditions within the basin footprint and areas immediately downstream. There may be a tendency for a bar to deposit in the eddy along the south side of the flow jet created by the notch (for example, see Figure 7b). At higher flows there is not much difference in shear stresses, and we also know that under high flow conditions the hydraulic shadow is likely to be created and maintained through scour and flow turbulence.

Between 2007 and 2017, under Project conditions, we estimate that on average approximately 700 to 1,300 cubic yards of sediment per year would have been deposited into the bypass on days with flow only through the proposed notch (Table 3), conditions similar to those depicted in Figure 7a. The proposed basin area has a corresponding volume of approximately 4,150 cubic yards, and this range of estimated annual deposition during notch-only flow conditions is equivalent to approximately 17 to 31 percent of the basin volume. However, not all of the incoming sediment during notch-only flow conditions would deposit or remain within the basin for an extended period of time (i.e., throughout the wet season), but short-term accumulations could still temporarily affect fish passage through the basin. We also know that the year-to-year supply of sediment to the bypass can be highly variable, and a majority of the sediment on a decadal scale could be delivered in one or two wet years, which adds to the uncertainty in estimating the amount of sediment that may deposit only within the basin during any given year. The development of sediment conditions that may temporarily inhibit fish passage, particularly in years with few and/or relatively brief overtopping events, would be monitored and addressed as outlined in the *Tisdale Weir Operations, Maintenance, and Long-Term Management Plan* being developed for the proposed Project.

7 The changes in boundary shear stress *exactly* coincident with the basin footprint are an artifact of lower assumed roughness and the stress partitioning in the model – they do not reflect potential changes in actual transport capacity.

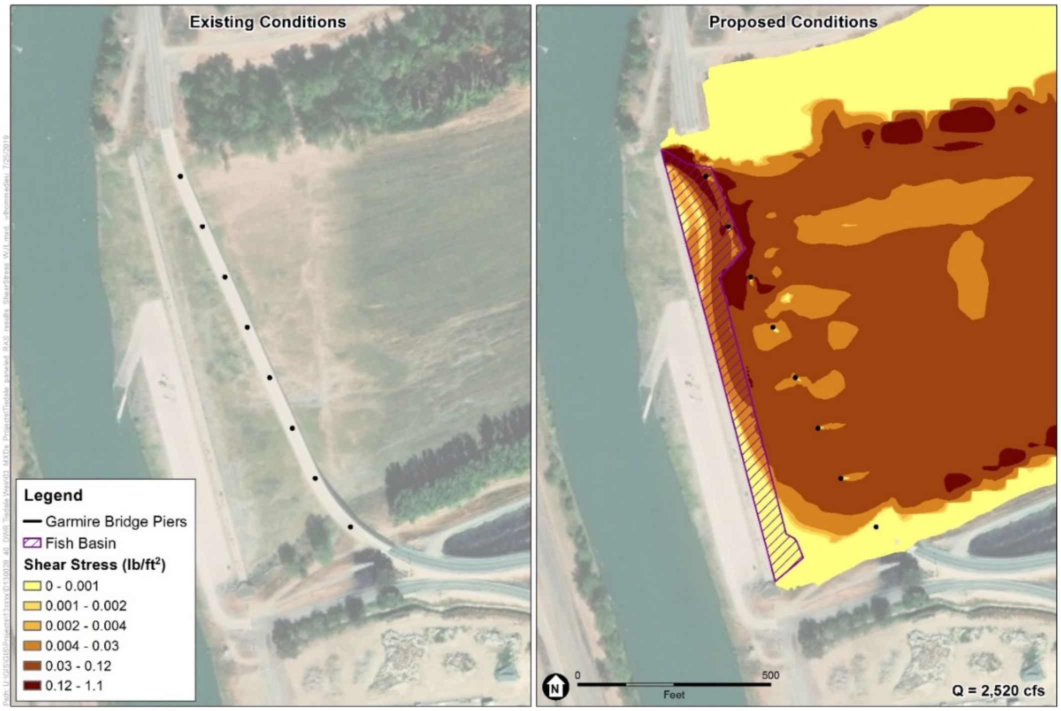


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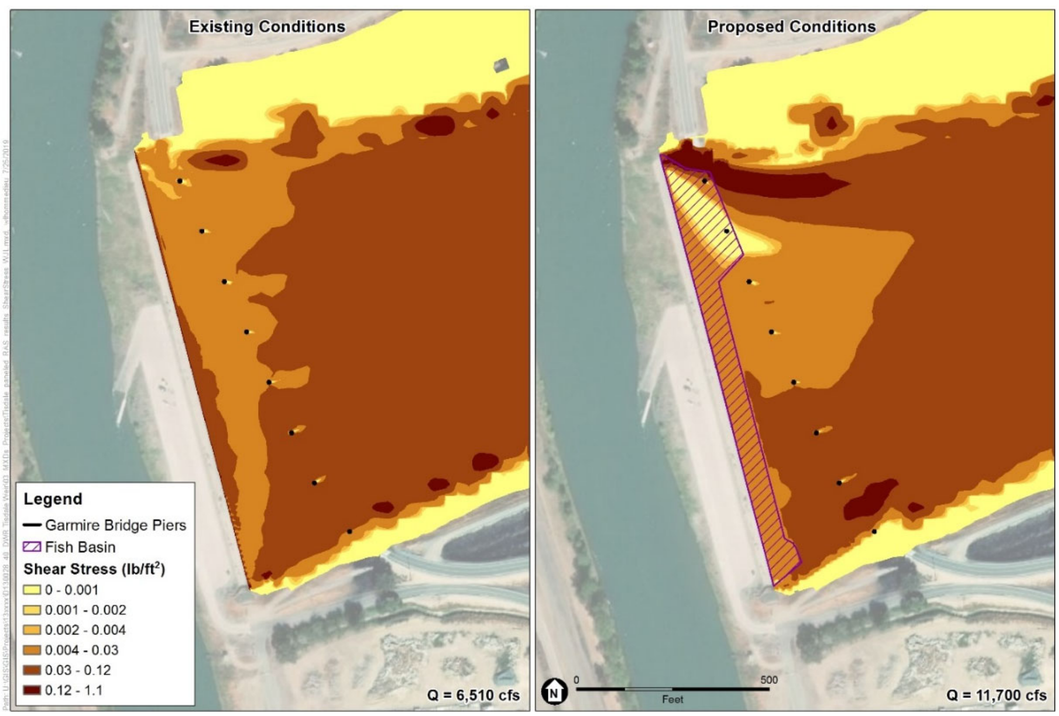
Figure 7a
2D model shear stress output, Sacramento River stage of 44 ft (NAVD88).



NOTE: See Footnote 6.

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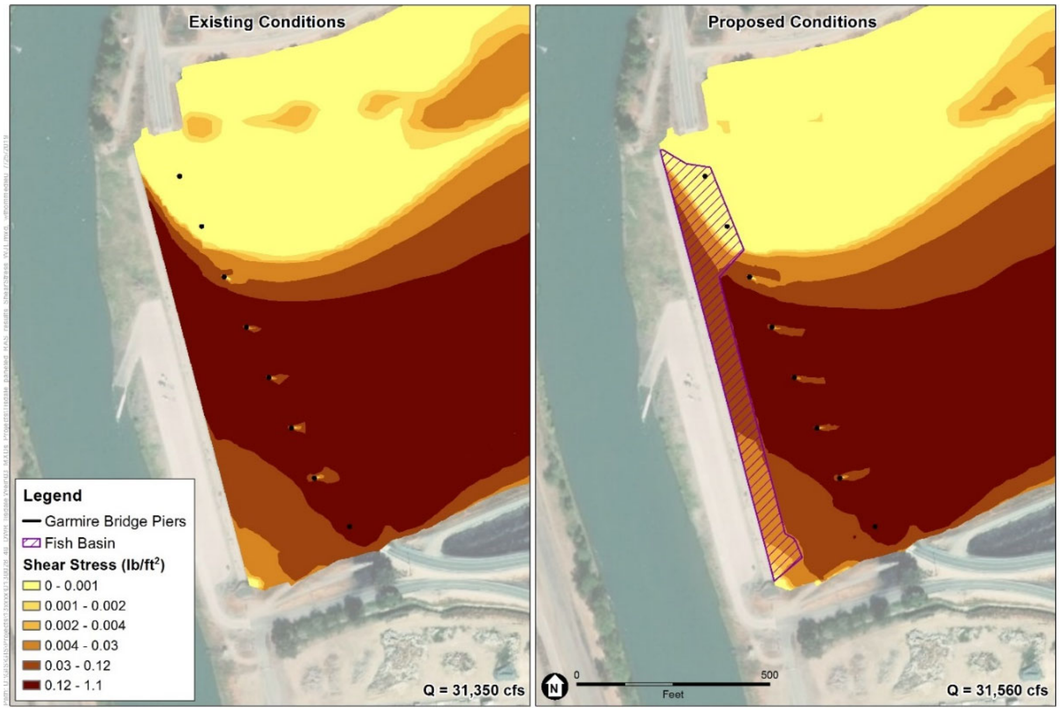
Figure 7b
2D model shear stress output, Sacramento River stage of 46 ft (NAVD88).



NOTE: See Footnote 6.

Tisdale Weir Rehabilitation and Fish Passage Project

Figure 7c
2D model shear stress output, Sacramento River stage of 50 ft (NAVD88).

5 Ongoing and Future Work

ESA began collecting field data during the 2019 water year. Our efforts included suspended sediment sampling in the Sacramento River at Tisdale Weir, in-situ monitoring of sediment deposition within the Tisdale Bypass, and installation of water level gages. These efforts are expected to continue during the 2020 water year and, as appropriate, the relationships and findings presented in this memorandum would be updated based upon the data collected.

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