FLOW ANALYSIS FOR DETERMINATION OF THE OPERATING WINDOW AND CONSIDERATION OF THE OPERATIONAL RELIABILITY OF THE FREEMAN DIVERSION FISH PASSAGE SYSTEM

United Water Conservation District
Open-File Report 2018-September

PREPARED BY

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September 2018

THIS REPORT IS PRELIMINARY AND IS SUBJECT TO MODIFICATION BASED UPON FUTURE ANALYSIS AND EVALUATION

Cover Photo: Santa Clara River in 2017 at the Freeman Diversion

Preferred Citation:

United Water Conservation District. 2018. Flow Analysis for Determination of the Operating Window of the Freeman Diversion Fish Passage System. United Water Conservation District. Open-File Report 2018-September.

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1 SUMMARY

This report presents the evaluation process and rationale for decisions leading to identification of an appropriate operational window for design of a fish passage system for the Freeman Diversion. United Water Conservation District (United) carefully considered agency guidance criteria, flow analyses, and operational reliability in identifying the design operational range for a future fish passage facility. Adopting an operational flow range that exceeds what may naturally occur in a system would increase project complexity and cost, while providing little to no additional benefit to biological resources (Lang and Love 2014). The evaluation of the operational high flow presented in this analysis was conducted with consideration of; 1) prior guidance by National Marine Fisheries Service (NMFS) staff (Southwest Region), 2) guidance criteria provided in the Anadromous Salmonid Passage Facility Design Manual (NMFS Design Manual 2011), and 3) guidance criteria presented by the United States Department of Fish and Wildlife (USFWS) in the Fish Passage Engineering Design Criteria (USFWS 2017). The guidance criteria presented by the agencies were evaluated with consideration of potential biological limitations of suspended sediment in conjunction with estimated travel time to verify that the identified operational range (developed using the agencies' standards) is protective enough to provide passage when fish are expected to arrive at, and pass through, the facility. Also, the reliability of the system to operate following peak flows and provide fish passage during the most critical time for passage was assessed. The results indicate that selecting a fish passage facility that is reliable after storms should be prioritized over operating a passage system during higher magnitude flows. Best available science related to behavioral and physiological limitations of steelhead suggests that steelhead migration is unlikely to occur in the Santa Clara River during higher magnitude-peak flows (i.e., >1,800 cfs).

By this process, United identified a target design operational high flow of 1,800 cubic feet per second (cfs) for the fish passage system at the Freeman Diversion. The design operational high flow was identified in accordance with passage criteria in the NMFS Design Manual (2011). The NMFS Design Manual (2011) includes the statement - "It is the responsibility of the applicant to provide compelling evidence in support of any proposed waiver of criteria or modification of a guideline for NMFS approval early in the design process, well in advance of a proposed Federal action." The proposed design operational high flow is based on the most conservative of the interpretations of the criteria presented in the NMFS Design Manual (2011) (i.e., the interpretation that results in the highest maximum flow range) and does require any waiver or modification of NMFS' guidelines.

As discussed in Sections 5.1 through 5.3, there are different ways to interpret how to calculate the design high flow exceedance using the NMFS Design Manual (2011). These different interpretations produce an upper limit for the 5% exceedances ranging from 920 to 1,790 cfs. To be conservative, United chose the highest flow from the various interpretations and rounded up to 1,800 cfs. While the maximum operational design flow of 1,800 cfs is proposed, the new fish passage system is expected to be functionally operational at flows higher than 1,800 cfs.

This analysis also considers how suspended sediment concentration (SSC) is likely to influence steelhead migration in the river by considering behavioral and physiological effects of SSC on steelhead. While SSC was not used to determine the operational range of the fish passage system, it is evaluated to assess the upper operational flow for the fish passage system. Based on potential effects of elevated SCC, it appears that the upper operational flow established in NMFS' standards (NMFS 2010b) likely over-estimates the upper limit of flows when adult steelhead would be expected to be traversing the fish passage facility. Examples from three storms are presented in Section 6 that illustrate that upstream migrants would not be expected to actively migrate during the identified upper operational range. The examples presented in Section 6 indicate that following peak flows, concentrations of suspended sediment in the Santa Clara River below the Freeman Diversion exceed levels that disrupt homing behavior, trigger avoidance behavior, and cause severe physiological stress in migrating adult salmonids.

The suspended sediment analysis in this report provides rationale for the expectation that steelhead are not likely to arrive at the Freeman Diversion and attempt ascending a fish passage system under the conditions present at the upper limits (1,800 cfs) of the identified design operational flow. Additionally, steelhead are unlikely to initiate migration into the Santa Clara River during period of high SCC, due to behavioral and physiological limitations of high suspended sediment. Considering these factors coupled with the travel time necessary to reach the proposed fish passage facility, it is realistic to anticipate that the actual high flow in which steelhead would be expected to arrive at the fish passage facility would be substantially less than the identified design high flow of 1,800 cfs.

Reliability of a fish passage facility is a critical component in determining the operational window of the system. Historical data indicate that approximately 20% of all steelhead passage days occur in years where a peak flow following a storm event exceeded 100,000 cfs (United unpublished data). United is requesting a 50-year permit. In 2017, piles of debris and large boulders were deposited downstream of the diversion by a storm that peaked at less than 30,000 cfs. Exposing a fish passage system to such peaks could potentially risk the functional operations of the facility once suspended sediment and turbulence have subsided and steelhead are expected to be at the ladder. Designing the facility to target the critical flows when upstream migrating steelhead are anticipated to be present at the facility will provide greater reliability of the system. United does not recommend attempting to operate or expose an in-channel fish passage structure to these higher magnitude flows when debris and sediment could damage the system for subsequent operation when conditions are more conducive to fish migration. Operation of a fish passage system during high risk conditions could catastrophically damage the system and remove it from service for a period of years. Priority should be placed on operating the system during conditions when steelhead would be expected to be present, within a range of 45 cfs to 1,800 cfs.

2 HISTORY OF THE FACILITY

2.1 HISTORICAL OPERATIONS AND FACILITIES PRIOR TO THE FREEMAN DIVERSION

United, and its predecessor agency, the Santa Clara River Conservation District, have diverted water from the Santa Clara River since the late 1920s. In 1950, radial gates were installed at the diversion headworks on the south bank of the river. This structure was capable of bypassing several thousand cfs when the river had too much suspended sediment to divert. If flows exceeded the capacity of the radial gates, then a soft plug would wash out creating potential passage for steelhead through the diversion. United was very aggressive in getting the soft plug rebuilt after large flows had subsided. Typically, once flow in the river receded to approximately 1,500 cfs, bulldozers were used to push the soft plug into place, thereby eliminating passage opportunities for upstream migrating steelhead. Gravel mining activities and development of levees downstream of the diversion caused downward cutting of the river bed. As the profile of the river bed dropped, the point of diversion was moved further upstream to allow for the diverted water to flow by gravity past the radial gates to the recharge basins. Due to the radial gate installation in 1950, it is likely that upstream passage at the diversion would have only occurred when the soft plug was washed out. Because the facilities at the time had no fish screen, any smolts or kelts migrating downstream were likely diverted with the water when the soft plug was in place. When the plug was washed out, downstream passage of smolts and kelts would have been possible.

2.2 EXISTING FISH PASSAGE FACILITY AND OPERATIONS REQUIREMENTS

In 1990, United built the Vern Freeman Diversion Project to control the erosional down cutting of the Santa Clara River. In doing so, a 25-foot differential was established between the downstream and upstream side of the diversion. Under United's water rights permit (#18908) conditions, California Department of Fish and Wildlife (CDFW) and the State Water Resources Control Board required a fish ladder be included to support steelhead migration as part of the Freeman Diversion Project, although steelhead were not listed at the time. A Denil fish ladder was designed for the Project, which was reviewed and approved by CDFW before its construction.

3 NATIONAL MARINE FISHERIES SERVICE ANALYSIS AND GUIDANCE

3.1 NATIONAL MARINE FISHERIES SERVICE ASSESSMENT OF THE DENIL FISH PASSAGE SYSTEM

On July 24, 2008, NMFS issued a jeopardy BO to the Bureau of Reclamation for the operations of the Vern Freeman Diversion (NMFS 2008a). The existing Denil fish passage was deemed insufficient in the BO, mostly due to inferred attraction flow issues. The analysis in NMFS BO relied on photographs taken by United staff of the diversion face at different discharges or spills over the crest of the diversion. From visual observation of the photos, NMFS BO (2008a) determined that the fish ladder would likely only provide enough attraction flows during conditions when the total river flow at the Freeman Diversion was below 500 cfs. NMFS BO (2008a) included two Reasonable and Prudent Alternatives (RPAs) to the proposed project identified in the Biological Assessment. RPA 1 included the design and implementation of a new passage system. RPA 1 (c) provided the following guidance for the low and high flow parameters for the fish passage system; “The low, high, and flood-flow design (i.e., the streamflow range for safe and quick passage of steelhead) shall be defined during the preliminary-design phase[22] (Table 9-1).”

Footnote 22 stated:

> [22] The design low flow is the mean daily average streamflow that is exceeded 95% of the time during periods when migrating fish are normally present at the site. The design high flow is the mean daily average streamflow that is exceeded 5% of the time during periods when migrating fish are normally present at the site.

Footnote 22 was guidance taken from NMFS’ February 2008 Anadromous Salmonid Passage Facility Design (NMFS 2008b). Table 9-1 in NMFS BO (2008a) (Figure 1 in this document) shows the exceedance values at various points in the river for different months during the potential steelhead migration period. The flows were derived by a summation of upstream gages in the tributaries to estimate the potential flows at the Freeman Diversion. Diversions were then subtracted from the estimated river flow to estimate the flows present in the Santa Clara River near the Highway 101 bridge. NMFS BO (2008a) did not present a specific value for the 5% exceedance, however an average of the monthly 5% exceedances near the Highway 101 bridge would be 1,051 cfs (Figure 1).

Figure 1. Table 9.1 from the 2008 Biological Opinion with the Average 5% Exceedance from January to May Added

Table 9-1.— Flow-related information for the Santa Clara River.

A: Sums of exceedance values for Santa Clara River U/S of Piru Creek plus Piru Creek, Sespe Creek and Santa Paula Creek (this includes all north slope watersheds upstream of Freeman).

	January	February	March	April	May
1%	5994.7	16196.9	8530.6	3486.8	2685.5
5%	1155.85	4128.4	3183.8	1469	872.8
10%	551.5	1649.9	1663.2	836	405.3
20%	248	544.4	695.6	400	186.8
50%	93	148	167	127	76

B: Diversion rate exceedance values at Vern Freeman diversion dam.

	January	February	March	April	May
1%	343.1	364.2	354	397.9	400.4
5%	260.4	261.6	315.2	343.5	318.6
10%	221	215	288	314	276.1
20%	147.4	186.4	222.8	245	205
50%	88	106	94	94	92

C: Values Table B subtracted from those in Table A (river flow to the dam, less diversion rate)

	January	February	March	April	May
1%	5651.6	15832.7	8176.6	3088.9	2285.1
5%	895.45	3866.8	2868.6	1125.5	554.2
10%	330.5	1434.9	1375.2	522	129.2
20%	100.6	358	472.8	155	-18.2
50%	5	42	73	33	-16

D: Exeedance values at gage 10-11 miles D/S of Vern Freeman (at Hwy 101)
Compare with values in Table C

	January	February	March	April	May	
1%	6270	19960	6980	2464	1220	
5%	937.4	3830	2073	1200	218.6	1,051 (avg.)
10%	279.6	1190	1222	520	31.2	
20%	42	300	434.4	105	5.3	
50%	0.1	0.8	2.9	0.2	0	

3.2 SUBSEQUENT RECOMMENDED GUIDELINES FOR THE OPERATIONAL PASSAGE WINDOW

The first element of RPA 1 in NMFS BO (2008a) was to convene a fish passage panel to make recommendations for modifying or replacing the existing fish passage facilities. On November 16, 2009, NMFS wrote a letter identifying an upper and lower passage-design flow for consideration by the panel. In the letter, NMFS (2009) recommended that the design high flow be determined based on the 50–67% exceedance probability for peak flows in Santa Clara River, calculated using data from United States Geological Survey (USGS)(Gage #11114000). These flows were determined to be 12,930 cfs (50%) and 6,541 cfs (67%). The upper flow range of 12,930 cfs equates to a 2-year peak frequency occurrence. A velocity limit of 8.0 ft/s was then assumed to be the maximum velocity that limits upstream steelhead migration. In the letter, NMFS (2009) determined that the average velocities at modeled transects below the Freeman Diversion were below the maximum velocity of 8.0 ft/s at a flow of 12,930 cfs. United and the panel did not agree with the assessment, because there was no biological basis for an upper flow range with a 2-year storm frequency, which only occurs for a brief period of time once every 2 years on average.

On June 23, 2010, NMFS provided a subsequent recommendation for the flow range (referred to as the "operative standard"). In this recommendation, NMFS (2010b) developed the cumulative frequency of flows at the USGS Gage # 1114000 (at Montalvo below the Freeman Diversion) including all data from 1928 to 2004, using only flows ranging from 45 cfs to 13,000 cfs, from January 1 to May 31. The frequencies were grouped into 1,000 cfs interval classifications. The results from the analysis found that the 5% exceedance of the flows fell between 4,000 to 5,000 cfs. NMFS (2010b) concluded that the 4,000 to 5,000 cfs range should be a priority for the fish passage operational design. Because the analysis was done in intervals of 1,000 cfs the exact discharge at a 5% cumulative exceedance was not known in their write-up. However, in the June 23, 2010 letter, NMFS (2010b) recommended 5,000 cfs for the upper operational range of the fish ladder, presumably selecting the higher end of the 4,000-5,000 cfs classification.

The calculation of the operational range by NMFS appeared to have been done with the intent to follow similar methods later published in the NMFS Design Manual (2011). However, there are inconsistencies between the methods used to select the operational range that was recommended in the June 23, 2010 letter (NMFS 2010a) and the guidance published afterward in the NMFS Design Manual (2011). These inconsistencies include:

1) High flows above 6,000 and low flows below 45 were not used in the analysis. The NMFS Design Manual (2011) does not recommend limiting the flow range.
2) A period from 1928 to 2004 was used for the hydrological data, not the previous 25 years as suggested in the NMFS Design Manual (2011).
3) Flows for the analysis were taken downstream of the losing reach and not representative of the exceedances at the proposed fish passage facility.
4) Flows for the analysis were based on actual historic hydrology instead of the hydrology that will occur under the proposed action in United's Habitat Conservation Plan (HCP).
5) Flows were grouped in 1,000 cfs increments and the highest value of the increment was then used.

The analysis from the table shown in Figure 2 was recreated using the same period and range of data detailed in NMFS' analysis presented in the June 2010 letter (NMFS 2010a). Instead of grouping the data every 1,000 cfs, a more standard cumulative frequency curve was used to determine the exact discharge defined by the 5% exceedance criteria. A more detailed calculation of the exceedance is important, because a difference of hundreds of cfs can greatly impact the cost and reliability of a fish passage system, as well as the likelihood that steelhead will be present at the facility to pass. The graph in Figure 3 shows that using the daily cumulative frequency curve method the 5% exceedance is 4,190 cfs, and not 5,000 cfs as recommended in the June 2010 letter (NMFS 2010a). Again, this analysis was performed using a subset of the total flows that were not representative of the future flow regime proposed in the HCP.

Figure 2. Frequency Analysis by NMFS in the June 2010 Letter (NMFS 2010a)

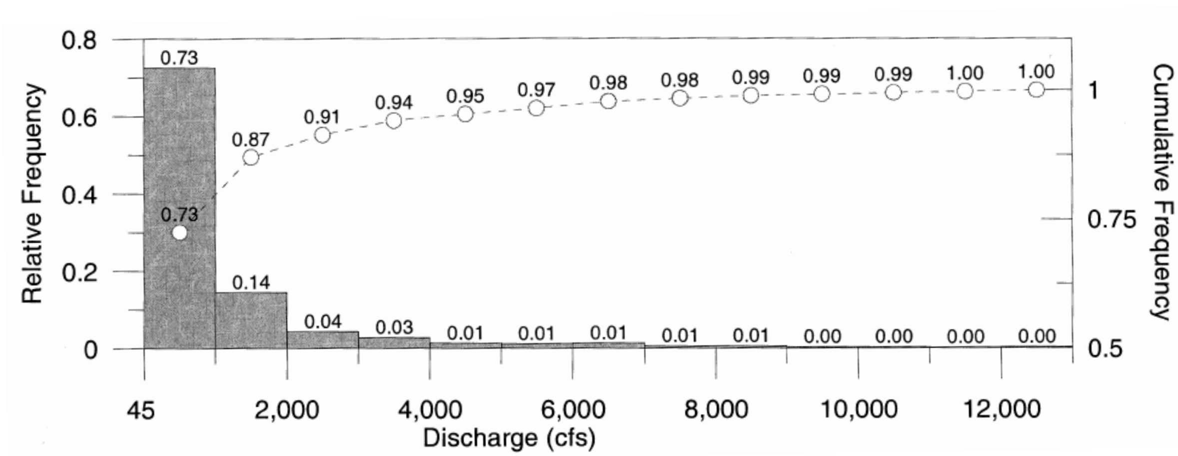
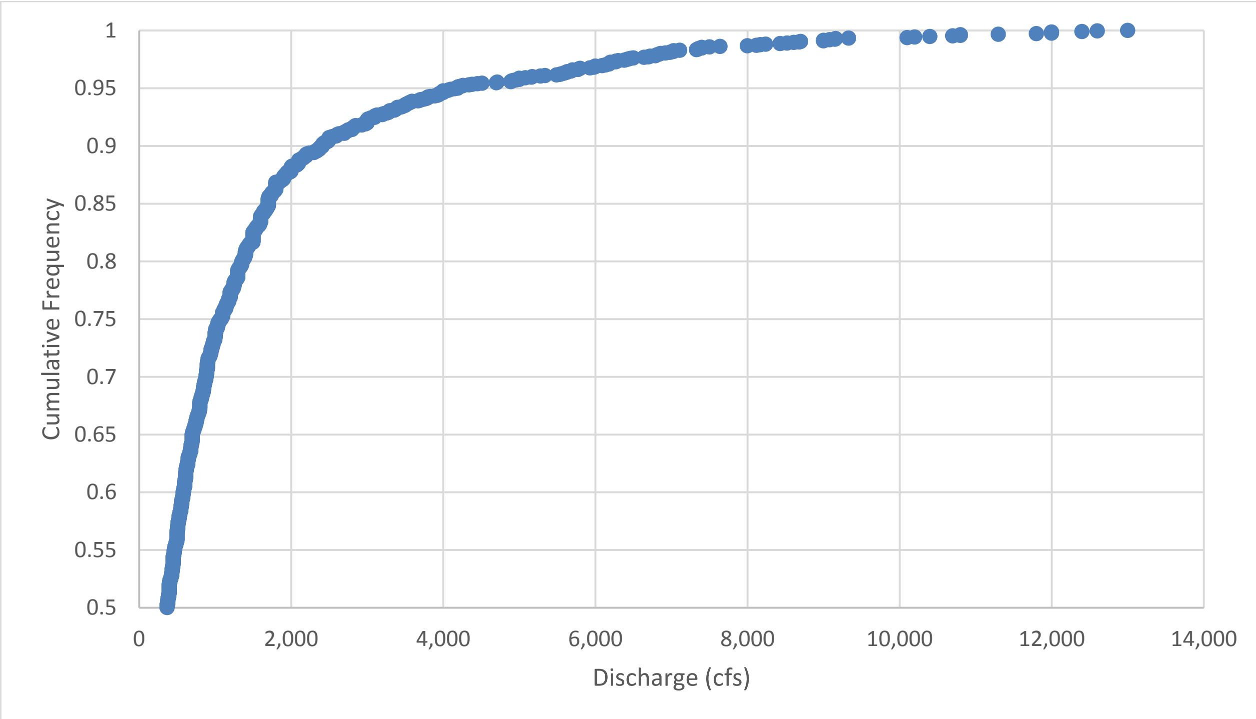


Figure 3. Cumulative frequency using specific range of flows from 45 cfs to 13,000 cfs Following the Approach of the June 2010 Letter (NMFS 2010a)



4 FISH PASSAGE PANEL’S ANALYSIS (ASCENDOGRAPH)

In 2010, the expert fish passage panel assessed the consequences of potential migration delay on steelhead through the Freeman Diversion (Fish Passage Panel 2010). A model called the “ascendograph” was created by the panel. The basic premise of the model was to determine if migration delay at the diversion would eliminate spawning success in the tributaries upstream of the diversion. The model simulated upstream migrants through the watershed on a daily basis throughout historic hydrographs. If elevated discharges precluded steelhead through the diversion, then fish would be delayed until a suitable flow was present at the diversion to provide passage. If the delay through the diversion was significant, then the fish may not reach the tributaries in time for spawning success. The panel did not include turbidity as a possible limitation when considering the potential passage delays. They panel concluded that “Extremely high turbidity at higher stream flows could make migration in general, and finding ladder entrances specifically, much more challenging.” NMFS recognized the challenges the panel had in the assessment and determined that “The assessment simplifies complex factors that are known to influence migratory behavior and ecology. Accordingly, NMFS continues to question the application of this specific process to the current situation” (NMFS 2009). As a result of

NMFS' conclusion, the panel's product was not used to determine the operational range for a fish passage system.

5 REGULATORY GUIDANCE FOR FISH PASSAGE FACILITY OPERATIONAL RANGES

5.1 NMFS 2011 PASSAGE CRITERIA

As previously discussed, NMFS published guidelines to determine the operational range for fish passage in their 2008 and 2011 design manuals (NMFS 2008b, 2011). The NMFS Design Manual (2011) states:

> Design high flow for fishways is the mean daily average streamflow that is exceeded 5% of the time during periods when migrating fish are normally present at the site. This is determined by summarizing the previous 25 years of mean daily streamflows occurring during the fish passage season…

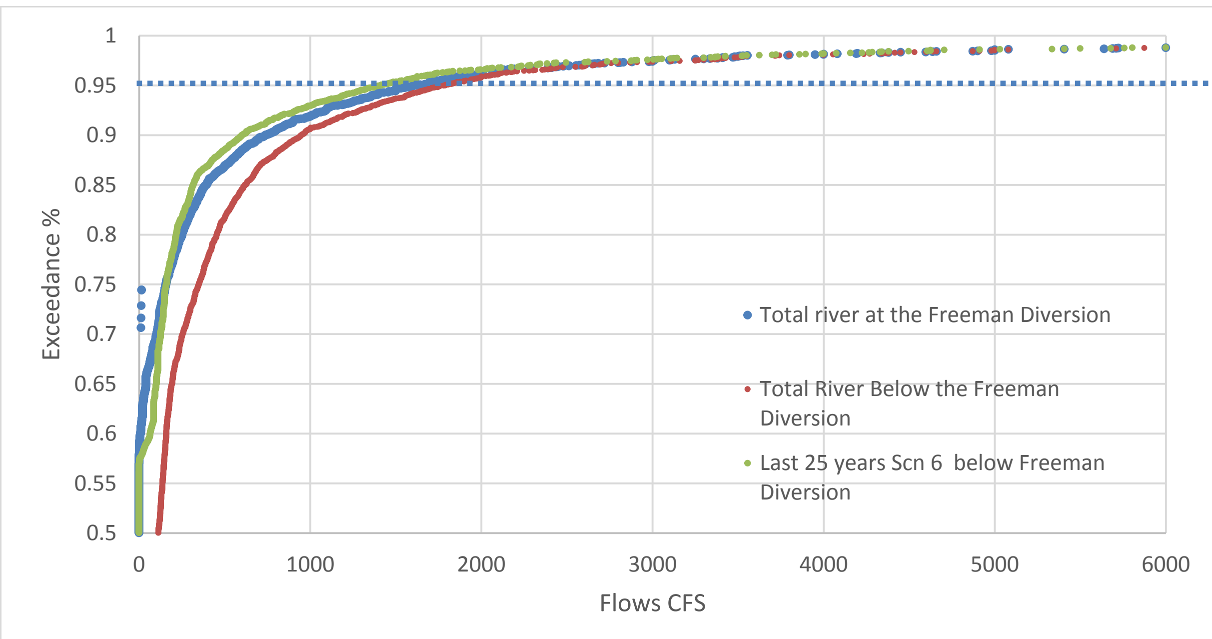
The high flow is defined as the "highest streamflow for which migrants are expected to be present, migrating, and dependent on the proposed facility for safe passage." NMFS (2011) states that these criteria are "specific standards for fishway design, maintenance, or operation that cannot be changed without a written waiver from NMFS….in general a specific criterion cannot be changed unless there is site-specific biological rationale for doing so."

The NMFS Design Manual (2011) calls for using the past 25 years of data for the analysis. The manual was written for all types of passage structures in a river system. The guidance provided in the manual does not clarify if the total river flow upstream of the facility or the total river flow downstream of the facility is to be used for calculations. The manual also does not address changed circumstances (if a project requires future modifications to the flow regime, passage criteria calculations should be based on the proposed flows). While using 25 years of data may provide a good representation of the hydrologic variability in the watershed, United has also compiled a 71-year period of hydrologic data that can also be used for the exceedance values. Below is a brief discussion of multiple analyses implemented to determine the design high flow operational limit in accordance with passage criteria established in the NMFS Design Manual (2011). Rigid application of the NMFS Design Manual (2011) (25-year dataset) with a narrower migration window (January – May) produces the most conservative (i.e. highest) 5% exceedance values. However, several analyses are presented for illustrative purposes.

5.1.1 SIMULATION USING PAST 25 YEARS OF RECORDED HYDROLOGIC DATA

Three exceedance curves were developed using the past 25 years of recorded hydrologic data (Figure 4). The curves developed included: 1) the total river flow above the diversion, 2) the actual total river flow below the diversion, and 3) proposed operations total river flow below the diversion (initial operations; 375 maximum instantaneous diversion). The total river flow at the Freeman Diversion was quantified using the Hydrologic Operations Simulation System/Freeman Operations Model (HOSS/FOM) developed for the HCP effects analysis (R2 2016). These data are the best representation of the actual and simulated flows upstream and downstream of the Freeman Diversion. To obtain the 25-year period for the analysis, flow data recorded between March 1, 1993, and March 1, 2018, were analyzed. The migration period (i.e., when adult steelhead are expected to be migrating upstream in the system) was defined as January 1 to May 31 for each year (a longer migration period is discussed in Section 5.1.2).

Figure 4. Exceedance Graph using the Past 25 Years of Hydrology Data Upstream and Downstream of the Freeman Diversion from January 1 to May 31



The 5% exceedance for the total river flow (flows upstream of the diversion not considering diversions) is calculated to be 1,790 cfs. The 5% exceedance for the actual instream flows downstream of the diversion was calculated to be 1,600 cfs. When considering the instream flows in the proposed operations, the 5% exceedance decreases to 1,415 cfs if diversions are considered. The guidance in the NMFS Design Manual (2011) most reflects the actual instream flows, because these flows are what steelhead historically experienced as they migrated upstream to the diversion.

5.1.2 CALCULATION OF EXCEEDANCES USING MODELED FLOWS

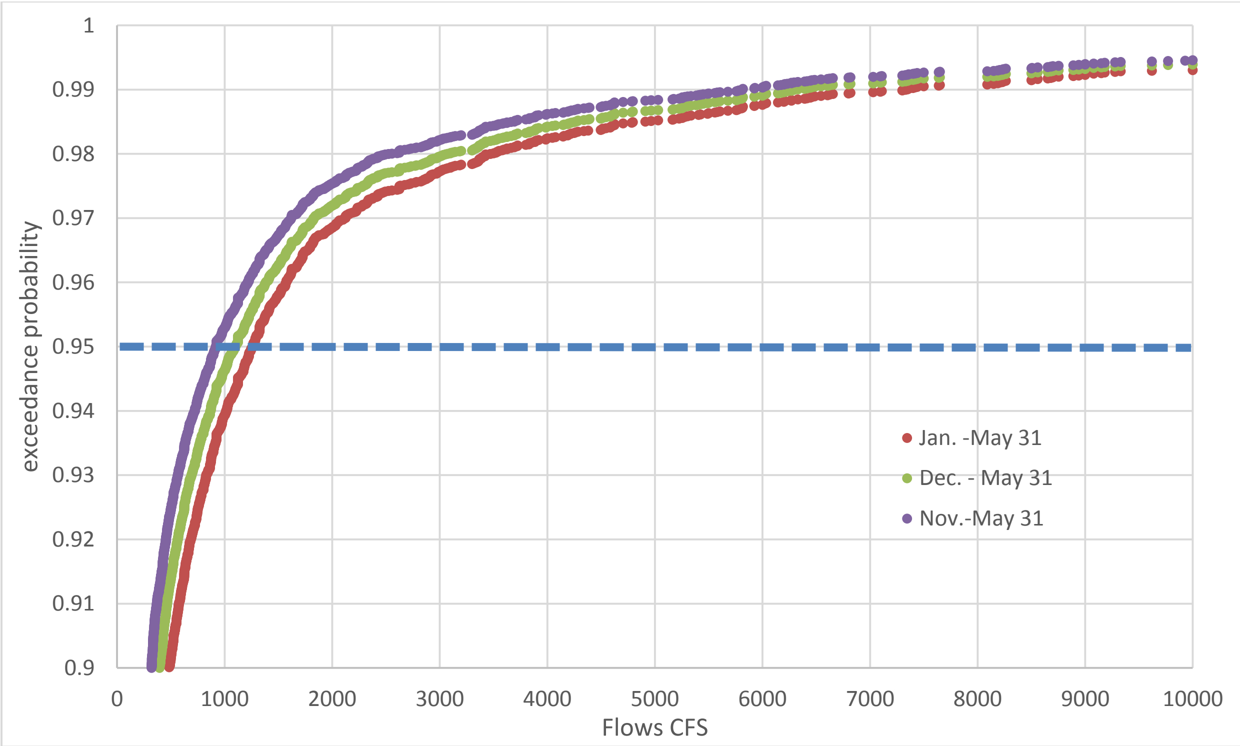
United developed a more robust data set that includes 71 years of data (1944 to 2014) that is more representative of the past hydrology. The past 25 years represents a slightly wetter period than the long-term average. Additionally, flows downstream of the diversion in the proposed operations of the HCP will be different than the historical record due to the additional flows United will be providing to promote migration opportunities. Using the same migration window of January 1 to May 31 with the expanded data set to include 71 years of flows, including the flows anticipated to be bypassed downstream following the HCP proposed operations, the 5% exceedance is 1,265 cfs. The 5% exceedance value is lower using the 71 years of data compared to the past 25 years of data, mostly due to the wetter period that occurred within the last 25 years.

In order to evaluate the effects of different migration windows on the operational range for a fish passage system, the following migration windows were evaluated:

1) November 1 through May 31
2) December 1 through May 31
3) January 1 through May 31

This analysis relied on the operational flows proposed in the HCP (initial operations). The downstream flows (flows immediately downstream of the diversion) generated by the HOSS/FOM model from 1944 to 2014 were used for the exceedance simulation. Figure 5 shows the flow exceedance curves for the three alternative migration windows.

Figure 5. Flow Exceedance Curve of the Santa Clara River Downstream of the Freeman Diversion using the Proposed Operations



1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
exceedance probability
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Flows CFS
Jan. -May 31
Dec. - May 31
Nov.-May 31

When considering the passage window from January 1 through May 31 (operational period proposed in the HCP) flows greater than 1,265 cfs are exceeded 5% of the time. Using a longer migration period (December and November through May) produces slightly less flow (<1,000 cfs) at the 5% exceedance due to the commonly lower peak flows early in the wet season (Table 5-1). A similar reduction in the 5% exceedance value is observed when evaluating the 25-year dataset under lengthened migration windows.

Table 5-1 5% Exceedance for Three Migration Periods under Proposed Operations

Migration Period Considered	Flows at 5% Exceedance
January 1 through May 1	1,265 cfs
December 1 through May 1	1,098 cfs
November 1 through May 1	920 cfs

5.2 REGION 5 UNITED STATES FISH AND WILDLIFE SERVICE FISH PASSAGE ENGINEERING DESIGN CRITERIA

Region 5 of the USFWS developed and published specific criteria for fish passage (USFWS 2017). The criteria outlined in the USFWS Manual (USFWS 2017) are similar to criteria outlined in the NMFS Design Manual (2011). Both manuals identify the high design flow as the mean daily average river flow that is equaled or exceeded 5% of the time during the migration period of record for the target species, which is the specific season that the targeted species is migrating. The USFWS Manual (2017) differs from the NMFS Design Manual (2011) in that the recommended period of the hydrologic analysis includes the past 30 years of data. Although the exceedance criteria was not calculated for the past 30-year period, it is expected to be similar to the NMFS Design Manual (2011) guidance for the 25-year period of data.

5.3 OTHER STUDIES FOR FISH PASSAGE OPPORTUNITIES

In August 2014, a document prepared for NMFS called "Comparing Fish Passage Opportunity Using Different Fish Passage Design Flow Criteria in Three West Coast Climate Zones" (Lang and Love 2014) was completed. This study analyzed the difference in passage opportunities between various climate zones along the west coast. In general, its findings show that the natural window of migration opportunity in southern California steelhead streams is shorter than equivalent sized streams in northern California and Oregon. Therefore, if criteria are established for a passage window that reduces a percentage of the entire migration season, then a larger portion of the actual opportunities will be reduced in creeks further south.

The document focused on 16 small watersheds in the western coastal region. The specific conclusions of the study are difficult to apply to the Santa Clara River due to the fact it focused on much smaller watersheds (the largest of which was Sespe Creek, a tributary of the Santa Clara River which occupies 20% of the Santa Clara watershed) and passage criteria developed for culverts and road crossings. However, the study did reach some more generalized conclusions that are applicable to the Santa Clara watershed.

One conclusion was that passage opportunities decrease from moving from north to south and as the size of the watershed decreases. Another conclusion was that both biological factors and natural occurring features may further limit the natural opportunities for fish migration. The study (Lang and Love 2014) cites such factors as velocity, turbulence, turbidity, and inadequate depths as some possibilities that would naturally impede migration. The following statement is from page 57 of the study:

> "Many watersheds pose additional water quality or hydraulic conditions that limit migration timing. Identifying natural upper flow limits for migration due to factors (e.g., turbidity, velocities, turbulence, etc.) at a particular location or channel condition might better match Q_{hfp} criteria to fish migration needs of the watershed."

Section 6 of the study (Lang and Love 2014) discusses turbidity/suspended sediment as a factor that may limit steelhead migration opportunities in the Santa Clara River.

5.4 SUMMARY OF STANDARDS

Table 5-2 provides results from the various interpretations of the criteria established in the NMFS Design Manual (2011) as well as exceedance calculations based on the 71-year dataset and proposed operations under the HCP.

Table 5-2. Summary of 5% Exceedance Calculations

Period of Record	Migration Season	Discharge Used	5% Exceedance Value
25 years	Jan. 1- May 31	Actual flows upstream of diversion	1,790 cfs
25 years	Jan. 1- May 31	Actual flows downstream of diversion	1,600 cfs
25 years	Jan. 1- May 31	Proposed operations flows downstream of diversion	1,415 cfs
71 years	Jan. 1- May 31	Actual flows downstream of diversion	1,265 cfs
71 years	Dec. 1- May 31	Actual flows downstream of diversion	1,098 cfs
71 years	Nov. 1- May 31	Actual flows downstream of diversion	920 cfs

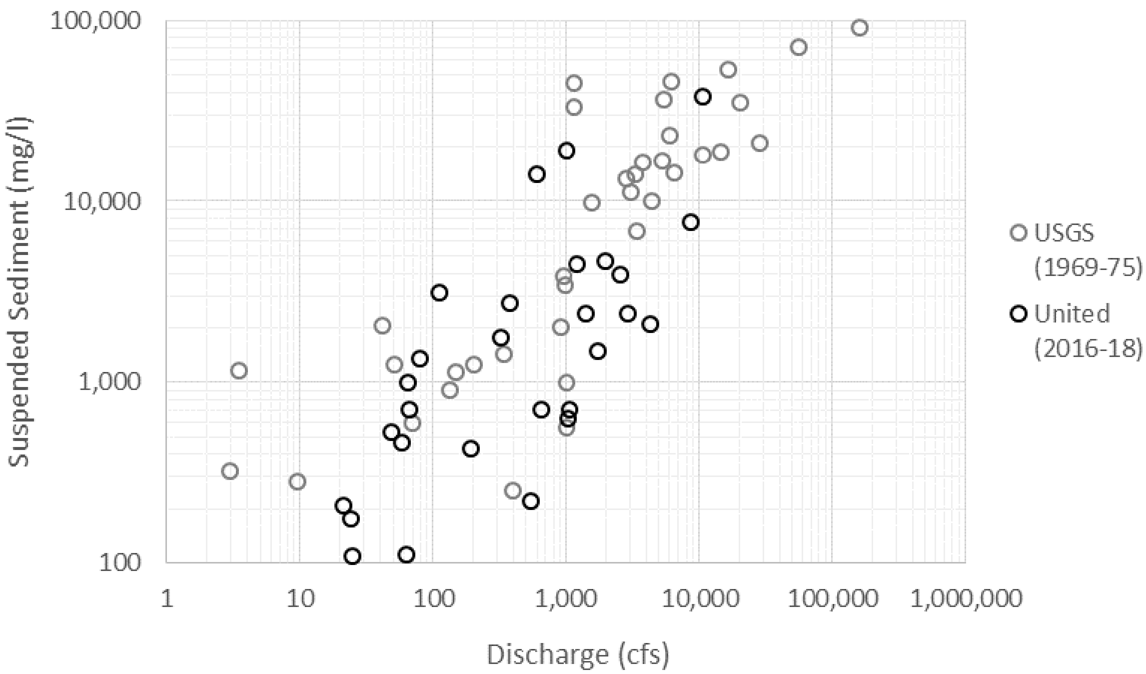
In summary, flows upstream of the diversion will produce a higher exceedance value than flows downstream of the diversion. In addition, calculations based on the past 25 years of record produce a higher exceedance value than the longer period of record. Calculations using the shorter migration window will also produce a higher exceedance value. Therefore the 5% exceedance value of 1,790 cfs is representative of the most conservative set of assumptions using the past 25 years of hydrology on the total river flow upstream of the diversion with a migration window of January 1 to May 31.

6 TURBIDITY/SUSPENDED SEDIMENT CONSIDERATIONS IN THE SANTA CLARA RIVER

The Santa Clara River is largely a sand-bed river that can suspend and transport high sediment loads under high flow conditions, and has some of the highest sediment delivery rates in the world (Stillwater 2011). Based on USGS and United analysis flows over 1,800 cfs are predicted to have suspended sediment concentrations (SSC) greater than 2,000 mg/l (Figure 6). Depending on the duration and concentration of suspended sediment transported, commonly observed effects on adult migrating salmonids include: avoidance of turbid waters in homing adults, physiological stress and respiratory impairment, damage to gills, and reduced survival, and direct mortality (Newcombe and Jensen 1996). When SSC approach and exceed 2,000 mg/l for even periods of time, major physiological stress resulting in delayed migration for adult steelhead is predicted. The available data on SSC in the Santa Clara, and implication for migrating steelhead are discussed in detail below.

In addition to the data provided by the USGS, United has also measured SSC in samples from the Santa Clara River. Figure 7 shows SSC from samples collected at the Freeman Diversion during a large magnitude storm that occurred in 2017. During the ascending limb of the hydrograph, the concentration of suspended sediment was measured at 38,000 mg/L. United started diverting and operating the fish ladder when the concentration of suspended sediment decreased to 7,600 mg/L on the receding limb of the hydrograph. Within one day, the concentration of suspended sediment decreased further to 2,400 mg/L and the total river flow receded below 3,000 cfs.

Figure 6. Relationship between Suspended Sediment Concentration and Santa Clara River Discharge



*USGS samples were collected from the Montalvo station; United samples were collected at the Freeman Diversion

6.1.1 STEELHEAD BEHAVIOR AND PHYSIOLOGY WITH RESPECT TO SUSPENDED SEDIMENT CONCENTRATIONS

Newcombe and Jensen (1996) reviewed and synthesized 80 published reports of fish responses to suspended sediment in laboratories, streams, and estuaries and established a set of equations to calculate "severity of ill effect" (SEV) indices. A suite of six equations were developed that evaluate the effects of suspended sediment (at various concentrations, durations of exposure, and particle sizes) on various taxonomic groups of fishes and life stages of species within those groups. The data presented in Newcombe and Jensen (1996) include studies where fish were held at constant exposure to the SSC, and not in a system where the fish can behaviorally regulate by swimming away from turbid water or holding in a turbidity refuge of some kind (avoidance behavior). Variability in levels of mortality was observed at different SSC exposures. The literature review yielded a wide variety of results with documented tolerance at SSC as high as 2,500 mg/L while other results documented mortality at less than 500 mg/L. Newcombe and Jensen (1996) concluded that duration of exposure and water temperature explain some of this variance.

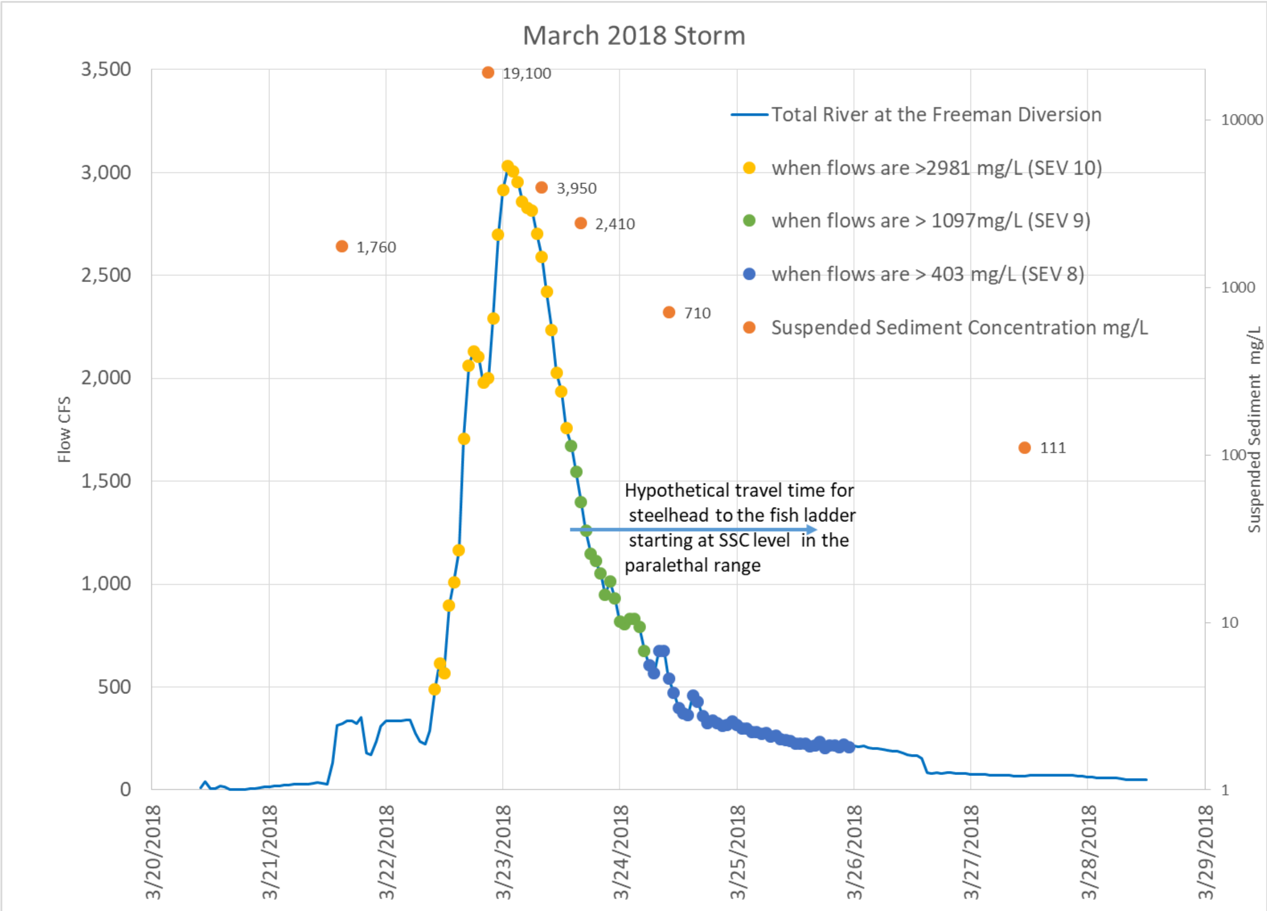
Based on the application of the Newcombe and Jensen (1996) modeling approach for adult steelhead exposed to coarse sediment of even 2,000 mg/l for a one day duration would result in an SEV of at least an 8.6, resulting in major physiological stress. Exposure to up 10,000 mg/l is an SEV of 9.6, which can be lethal for adult steelhead. Impaired homing in adult migrating salmonids (SEV of 7) is predicted at SSC as low as 148 mg/l (Newcombe and Jensen 1996). As summarized in Table A.1 of Newcombe and Jensen (1996), adult steelhead exposed to 500 mg/l for even 3 hours showed signs of sublethal stress, and blood cell count and blood chemistry was altered after 9 hours (Redding and Schreck 1982). Avoidance behavior, or impaired migration is a consequential outcome. With longer exposures (10 days) of adult steelhead to SSCs around 1,600 mg/l, complete avoidance and loss of habitat has been observed (Coats et al. 1985).

It has been postulated that southern California steelhead evolved in a high sediment system, and therefore have physiological adaptations that allow them to persist in a high SSC environment. However, there is no known science that shows special adaptation of the gills or other relevant morphological differences between southern California steelhead and other steelhead. An alternative hypothesis is that steelhead have evolved behavioral avoidance of potentially toxic environments as demonstrated in the peer reviewed literature. It follows, that if a river system demonstrates a correlation between discharge and suspended sediment concentration, there would be ranges of discharge where fish would be expected to not initiate movement upstream; stop movement upstream and seek refuge; or actually turn around and move downstream to avoid and minimize toxic exposure, gill trauma, and/or mortality. This is consistent with observations in the Ventura River, where the Casitas Municipal Water District (2008) reported that in 2008 the six observed adult steelhead all migrated upstream following (not during) high flow events, when the turbidity levels at the time of passage ranged from 2 Nephelometric Turbidity Units (NTU) to 22.5 NTU (despite the Vaki Riverwatcher monitoring equipment operating in conditions up to 200 NTU in 2008). A complete description of NTU is described below, indicating that in general this would correspond with SSC when adult steelhead were observed to migrate of less than 100 mg/l. Similarly, Thomas Payne (2005) analyzed telemetry tracking data by the CDFW on migration of adult steelhead in the Mad River (northern California) in relation to sediment data from the watershed (collected by Sparkman 2003). From this analysis Payne (2005) concluded that “Steelhead movement appeared to be reduced at higher turbidities. There were some movement observations at turbidity values between 400 and 500 NTU while no movement occurred above 500 NTU.” Based on existing information, few if any adult steelhead are anticipated to migrate past the Freeman Diversion when SSC levels are over 1,800 mg/l, which in the Santa Clara River correlates with around 1,800 cfs. Therefore, an upper operational range of the fish ladder exceeding 1,800 cfs is anticipated to remain effective during periods when adult steelhead are most likely to migrate.

As an example, river discharge data, SSC measurements, and the Newcombe and Jenson (1996) severity scale can be applied to three different storm events in the Santa Clara River to better understand anticipated behavioral and physiological effects on steelhead. As discussed in Chapter 7, the following analyses assume a 2-day travel time from the ocean to the Freeman Diversion, and therefore an associated 2-day exposure duration to a given SSC. (At the higher discharges, average velocities in the river can exceed 5 feet per second potentially increasing the duration of travel time to the Freeman Diversion.)

Given the two-day exposure assumption, the following SSC thresholds from Newcombe and Jensen (1996) were considered. When SSC levels reach 55 mg/L for two days (SEV 7), salmonids exhibit impaired homing. When SSC levels reach 403 mg/L for two days (SEV 8), salmonids exhibit major physiological stress. This is also well past the SSC levels that result in alarm behavior, abandonment of cover, and avoidance behavior, suggesting that steelhead would not subject themselves to major physiological stress to ascend the river at this point. When SSC levels reach 1,097 mg/L for two days (SEV 9), salmonids exhibit “paralethal” effects. When SSC levels reach 2,981 mg/L for two days (SEV of 10), up to 20% mortality is predicted, as SSC increases until SEV 12, where >40-60% of salmonids are predicted to die when exposed to 162,755 mg/L for two days.

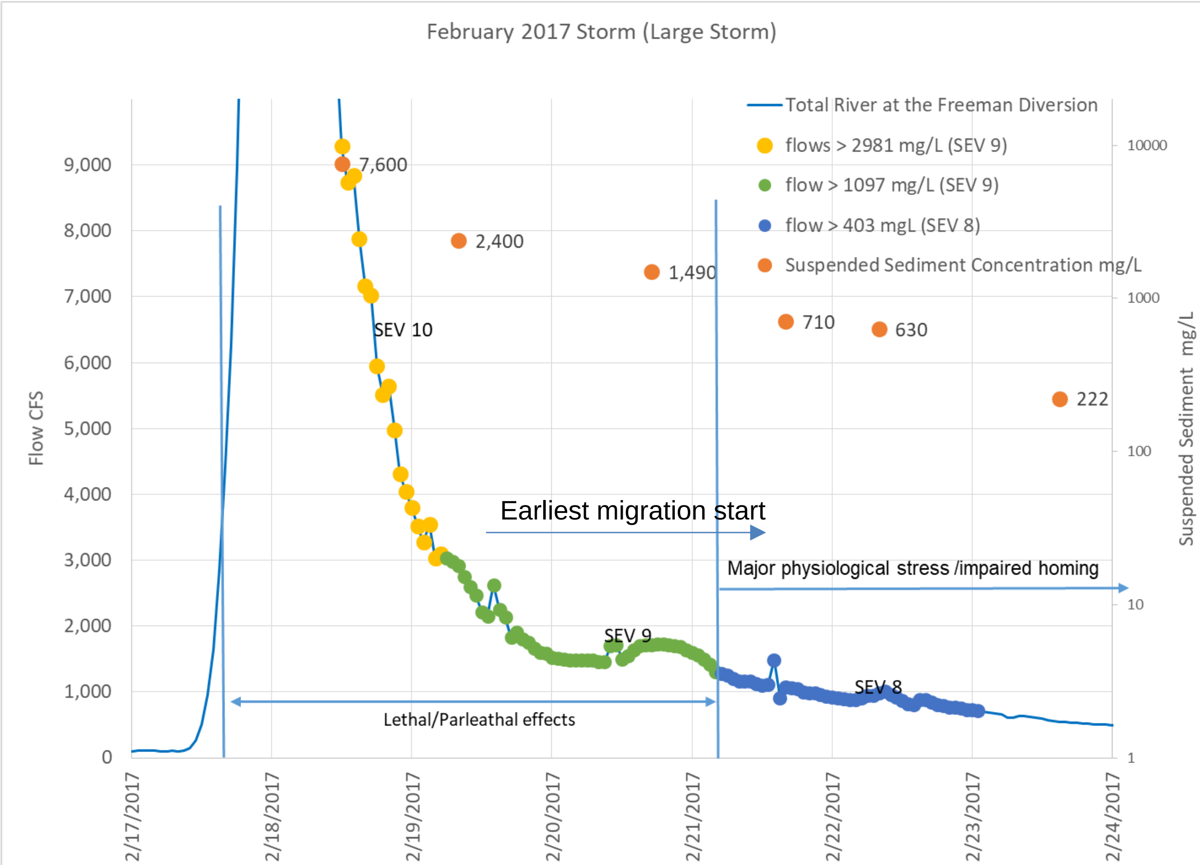
Figure 6. Hydrograph of a Storm Event on March 23, 2018 Compared to Suspended Sediment Concentrations and Associated Severity Scale Values



A moderate size storm occurred on March 23, 2018 (Figure 8). Throughout the storm, water samples were taken for lab analysis to determine SSC in the Santa Clara River at the Freeman Diversion. When suspended sediment was not measured, it was interpolated from the measured SSC points to approximate the SEV for a given point in time on the hydrograph. The hydrograph and SSC samples show that a SEV of 10 occurred throughout the peak of the storm (yellow circles). An SEV of 10 is predicted to result in up to 20% mortality of exposed adult salmonids, although adults would be expected to delay or halt migration at much lower levels of SCC to avoid exposure. Flows on the receding limb of the hydrograph that ranged from 3,000 cfs down to 1,700 cfs were also classified as an SEV of 10. The green circles depict the range of flows with an SEV of 9, the "paralethal" range for salmonids. It was not until flows subsided to 209 cfs (SEV of 8), that SSC levels subsided to below the "lethal and paralethal effects" category; however, an SEV of 8 is still defined by "indications of major physiological stress". Therefore, hypothetically, if a motivated steelhead had entered the estuary and began migrating through paralethal levels of SSC (SEV 9) on March 24th at 5:00 am, it would arrive at the Freeman Diversion when the flow in the river was at 200 cfs and would still experience SSC levels associated with moderate physiological stress and disrupted homing behavior and again well past the SSC levels associated with behavioral avoidance. Based on the March 2018 storm event, an operational range upper limit of 1,800 cfs would be a conservative range of when fish would be expected to endure suspended sediment at the Freeman Diversion.

Suspended sediment samples were also collected during a larger storm event on February 18, 2017 (Figure 9). The storm peaked at 26,000 cfs, equating to an approximately three-year storm occurrence. Due to the size of the storm, high flows were sustained for many days after the peak of the storm. Near the peak of the storm, a suspended sediment sample measured 38,000 mg/L, which is well above the 22,026 mg/L limit when mortality is predicted for adult steelhead, even within a 7-hour exposure. By the next morning both flows, and SSC, decreased substantially, although SSC would still have been in the paralethal range, and above levels for major physiological stress for adult salmonids. It was not until flows receded to 1,300 cfs, when the SSC cleared to SEV 8, which is still expected to cause major physiological stress at a two-day exposure time. In this example hydrograph, it again appears that the operational range upper limit of 1,800 cfs would be a conservative value of when steelhead would be expected to arrive at the Freeman Diversion during upstream migration.

Figure 7. Hydrograph of a Three-Year Storm Event on February 18, 2017 Compared to Suspended Sediment Concentrations and Associated Severity Scale Values.



The two sample storms in 2017 and 2018 were representative of events that occurred during the recent drought. Because sediment production in the Santa Clara Watershed may be different during a wetter period for a similar size storm, the third storm analyzed was from a period of multiple wet years in 2005 and 2006 (Figure 10). The total river flow from this storm was taken from the Ventura County Watershed Protection District Gage (#720) on the 12th street Bridge upstream of the Freeman Diversion, although downstream of all the major tributaries. The sediment samples were taken at the Freeman Diversion and measured by Fruit Growers Lab in Santa Paula, California. The suspended sediment generated from this storm was generally slightly less when compared to the discharge from the other two examples. In this storm, in order for a steelhead to be at the Freeman Diversion when the total river discharge was at 1,800 cfs, migration through the estuary would have started on the ascending limb of the hydrograph or even before the storm had started. The upstream migrant would have had to swim at a rate of 5 miles per day with SSC exceeding 11,800 mg/L.

Figure 8. Large January 2006 Storm Flows Compared to Suspended Sediment Concentration

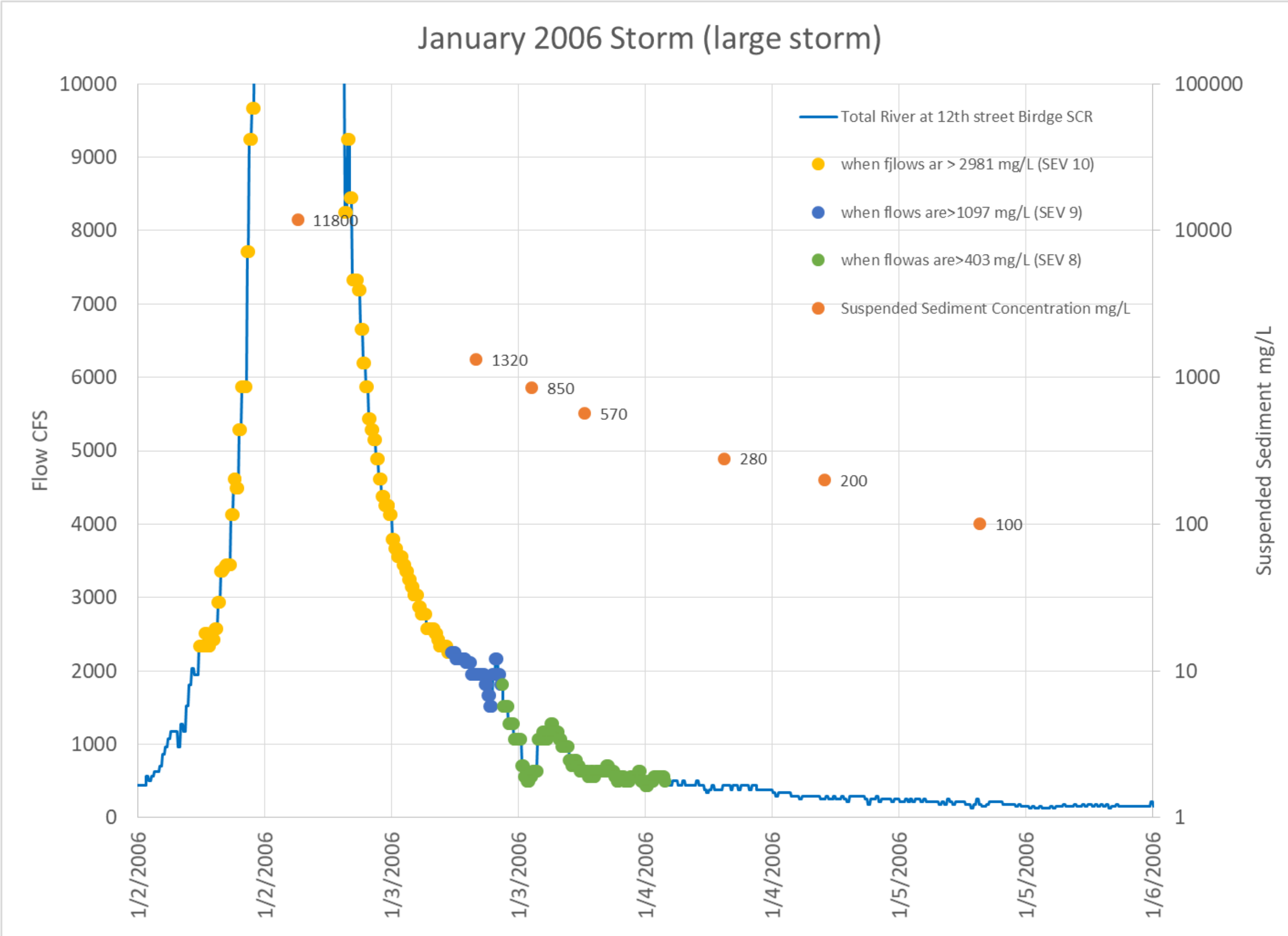


Table 6-1 shows the flow at the Freeman Diversion if a steelhead started migrating into the Santa Clara River from the estuary at the various severity levels depicted by Newcombe and Jensen (1996). This assumes that once the river drops to the SSC levels associated with the SEV levels a steelhead would take 2 days to arrive at the Freeman Diversion. For example, in the 2006 storm, if a steelhead were to start migration into the Santa Clara River when SSC levels drop below 8,103 mg/L (i.e., below the level associated with 0-20% mortality), then they would be entering the river when the total river flow was 8,450 cfs. With a 2-day travel time, the migrant would arrive at the Freeman Diversion when the total river flow was at 292 cfs. Entering the river at this SSC level is unlikely given anticipated behavioral avoidance and physiological stress discussed above. In all three example storm events discussed, the total river flow would be under 1,500 cfs in all cases once the fish arrives at the diversion. Overall, the best available science predicts that elevated SSC levels present a behavioral and/or physiological barrier to steelhead migration, and decreased total river flows at the diversion well below 1,800 cfs would be expected when adult steelhead are predicted to migrate past the diversion.

Table 6-1	Expected Water Quality and Quantity Conditions for Steelhead Migration through the Three Example Storms								
		SEV 10 (0-20% Mortality)				SEV 9 (Paralethal)		SEV 8 (major physiological stress/impaired homing	
	SSC mg/L	8103 mg/L		2981 mg/L		1097 mg/L		403 mg/L	
Storm year	Storm Size	Flow at start	Flow at arrival to FM	Flow at start	Flow at arrival to FM	Flow at start	Flow at arrival to FM	Flow at start	Flow at arrival to FM
		CFS	CFS	CFS	CFS	CFS	CFS	CFS	CFS
2017	Large	10,925	**1,493**	3,033	**1,259**	1,284	**655**	713	**436**
2018	Med.	2,826	**273**	1,673	**223**	606	**202**	209	**65**
2006	Large	8,450	**292**	2,250	**212**	1,810	**180**	501	**151**

6.1.2 MAD RIVER ANALYSIS

Thomas Payne (2005) analyzed telemetry tracking data by CDFW on movement of steelhead in in the Mad River in relation to sediment data from the watershed (Sparkman 2003). From this analysis Payne (2005) concluded that "Steelhead movement appeared to be reduced at higher turbidities. There were some movement observations at turbidity values between 400 and 500 NTU while no movement occurred above 500 NTU." As with the Santa Clara River, the Mad River has a direct correlation between elevated river flows and SSC.

United obtained a portion of the data obtained from the CDFW radio tracking of steelhead movement on the Mad River in 2002 (Figure 11). Only wild (nonhatchery steelhead) tagged that year were used in this example. The solid light blue line represents the total river flow as measured at the USGS gaging station 11481100 at the lower end of the watershed. The other lines represent the distance traveled by the steelhead during the study period. A flat line would indicate no movement of the tagged steelhead. A positive slope line indicates upstream migration in miles. A negative sloped line indicates backtracking from the prior day's position in the river (i.e., traveling downstream). The upstream travel in miles is not the river mile but the net gain in miles for each individual steelhead. The steelhead tracked were mostly in the lower portion of the river near the estuary to upstream of the hatchery near the 299 bridge.

Figure 9. Adult Steelhead Movement in the Mad River Compared to Total River Flow

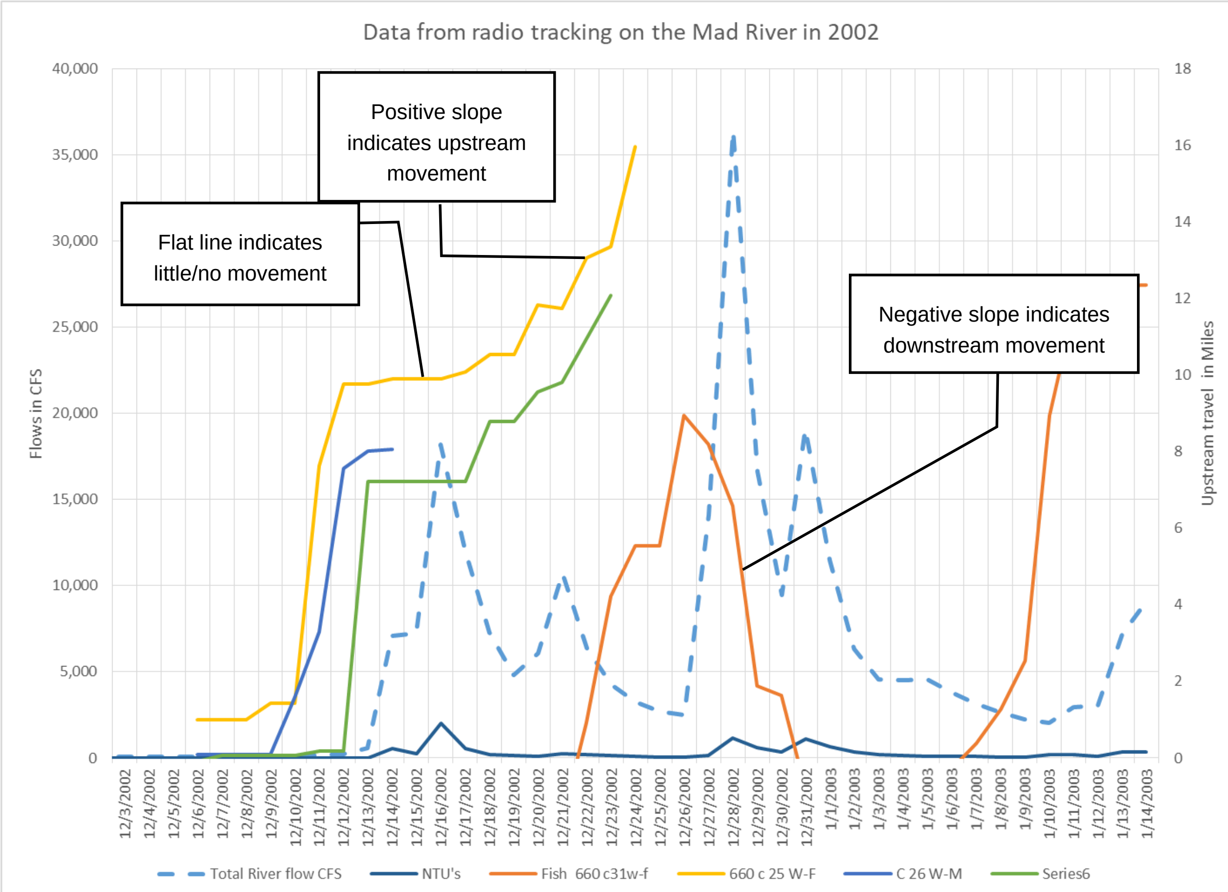
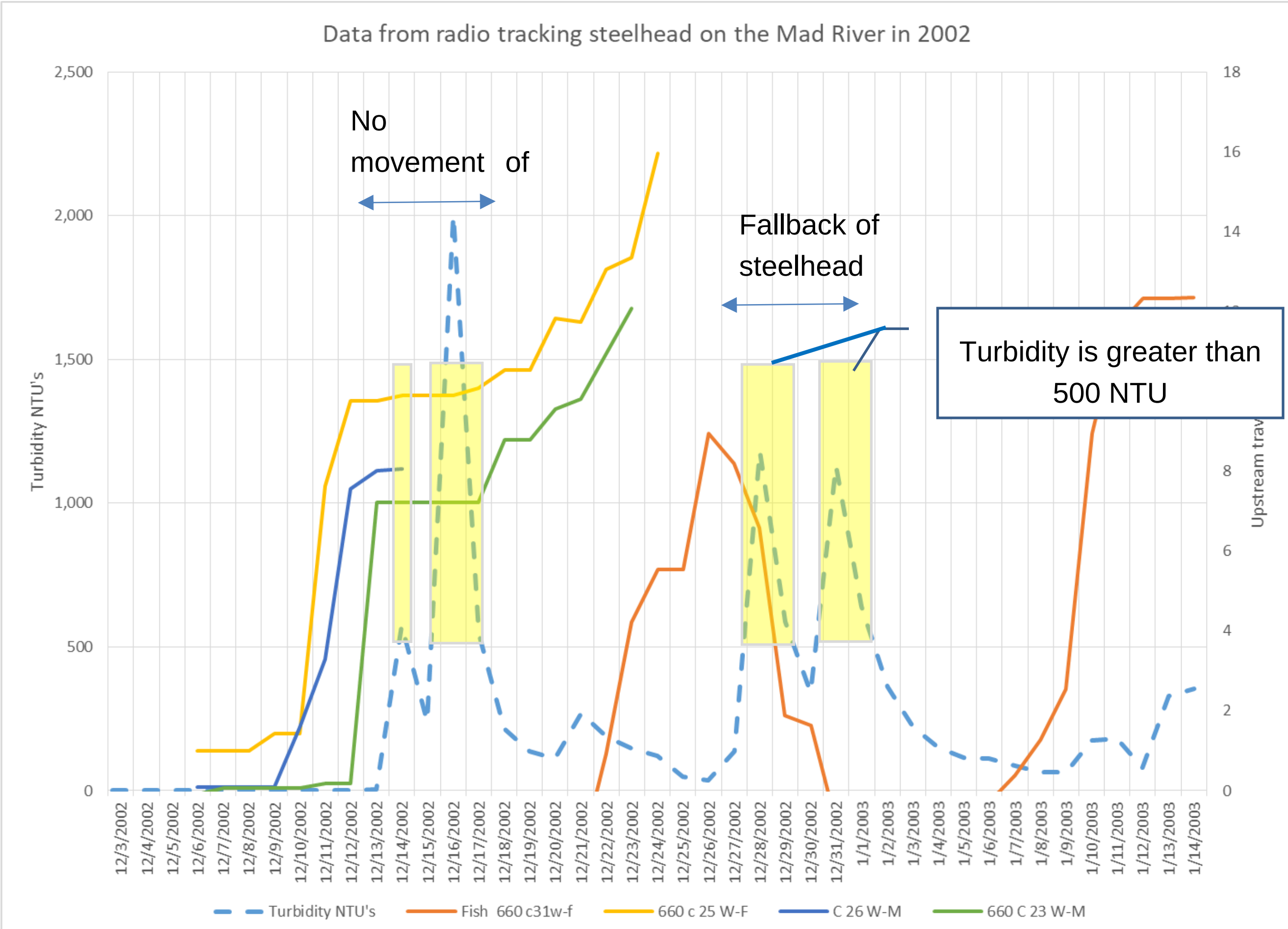


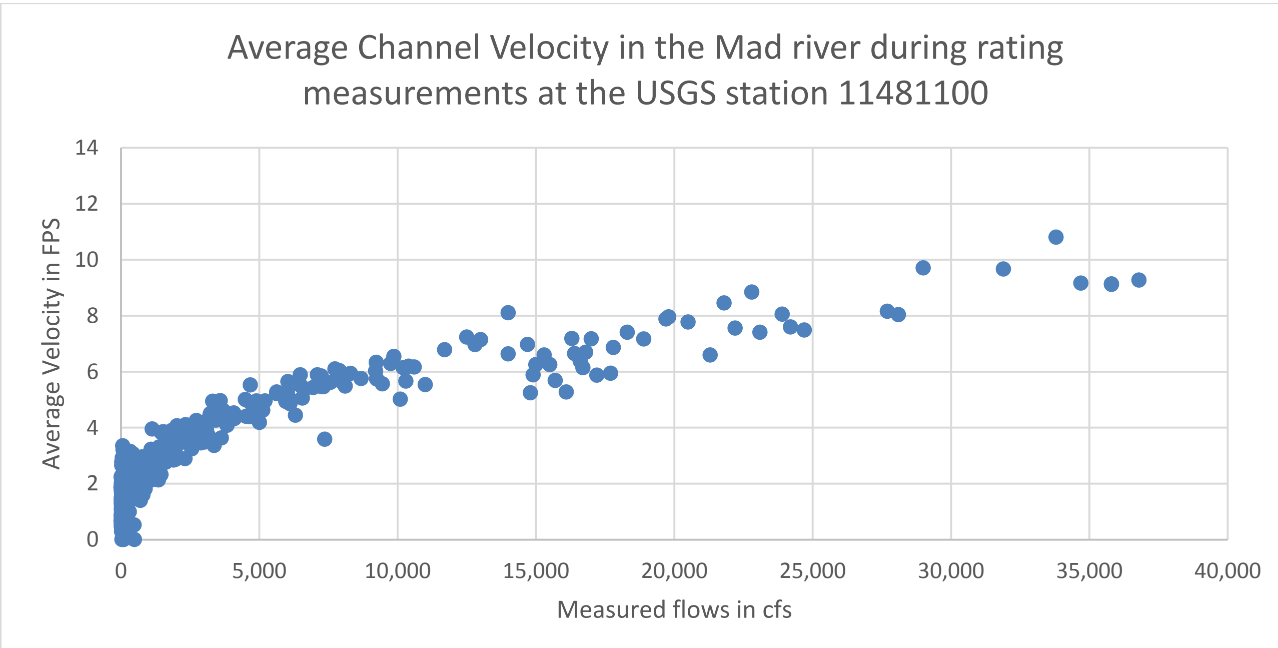
Figure 10. Adult Steelhead Movement in the Mad River (turbidity on the left y-axis and fish movement on the right y-axis)



The Humbolt Bay Municipal Water District monitors turbidity on a daily basis in the Mad River approximately 4 miles upstream of the USGS station and within the area of steelhead migration in the telemetry study (M. Sparkman pers. comm., 2018). When comparing the fish migration data to turbidity data, the tagged steelhead either stopped (flat line) or fell back (negative slope) at times when turbidity was greater than 500 NTU's (Figure 12). The fish identified as Fish "31 W-F" showed substantial fall back when turbidity levels exceeded 500 NTU and increased up to a little over 1,000 NTU. During this period, 31 W-F moved downstream over 8 miles and did not move upstream until turbidity and flows receded. While this study (M. Sparkman pers. comm., 2018) was not designed to assess steelhead movement related to turbidity, the resultant data are consistent with the hypothesis that steelhead hold up or move downstream when flows and turbidity increase (conditions that occur near the peaks of storms). It was the opinion of the author of the study that elevated discharge or velocity was not a limiting factor for steelhead movement during the peaks of the storm and turbidity was likely the reason upstream movement stopped (M. Sparkman pers. comm., 2018). Figure 13 shows the average velocity in the Mad River at various discharge measurements recorded at the USGS Site 11481100.

These measurements were conducted either on the 299 bridge or wading in the river nearby. The steelhead monitored in the study held-up or fell-back when the flows were between 5,000 to 30,000 cfs where the average velocities would have been near 4 to 8 feet per second. A velocity of 8 fps is considered passable for upstream migration (NMFS 2012). Similar data was obtained during the 2001/2002 migration season with an additional 4 fish that also showed no upstream movement when turbidity levels exceeded 500 NTU.

Figure 11. Comparison of Discharge to Average Velocity in the Mad River



6.1.3 CONSISTENCY OF TURBIDITY IN THE CHANNEL

In some river systems, adult steelhead have been observed moving along the margins of a river while migrating upstream. One interpretation of these observations is that steelhead avoid elevated SSC in the main channel and swim through lower SSC on river margins. In 2018, United tested whether there were observable differences in SSC in the main channel versus the river margin and whether SSC and turbidity decreased closer to the margin. United conducted four sampling events at three sampling locations where turbidity and SSC samples were collected and analyzed at the river margin and within the main channel. The three sampling locations were:

A. South bank of the river in the Oxnard Forebay upstream side of the 118 Bridge,
B. The critical reach at the location of the critical riffle in 2017 and 2018 (~3 miles downstream of the Freeman Diversion), and
C. The compliance point in the downstream portion of the Oxnard Forebay about 4,000 ft upstream of the 101 Bridge.

On March 23, 2018, United staff collected turbidity data and SSC samples during the receeding limb of the hydrograph following a storm event (Figure 14). During sampling, total riverflow was measured to be between 1,900 and 1,700 cfs downstream of the Freeman Diversion. Turbidity was measured using a Hach hand held meter, and SSC samples were collected by United staff then sent for analysis by Fruit Growers Lab in Santa Paula, California. The measured average turbidity at the study sites was 4,880 NTU and the SSC was 3,950 mg/L sampled at the Freeman Diversion one hour prior to the start of the study. For the first three sampling events, high velocities prevented staff from safely wading in the river, therefore samples were taken using a rod up to 10 feet from the river's edge. Three locations were sampled from each site: 1) The sample closest to the river's edge was taken when the depth of flow was measured at 0.5 feet, 2) an intermediate sample was taken about 4-5 ft away from the bank, and 3) 8-10 feet from the river bank depending on channel location. Each sample location was meaured for turbidity in triplicate to obtain an average turbidity for each sampling point.

Figure 12. United Water Conservation District Hydrologist Gathering a Suspended Sediment Sample near the Edges of the River when Total River Flow was Approximately 2,000 cfs in the Critical Reach

Two of the three sites showed a slight decrease and one site showed a slight increase in turbidity closer to the margin (Figure 15-17).

Figure 13. Turbidity Sample Taken at Highway 118 to Assess Potential for Lower Turbidity at the Edges

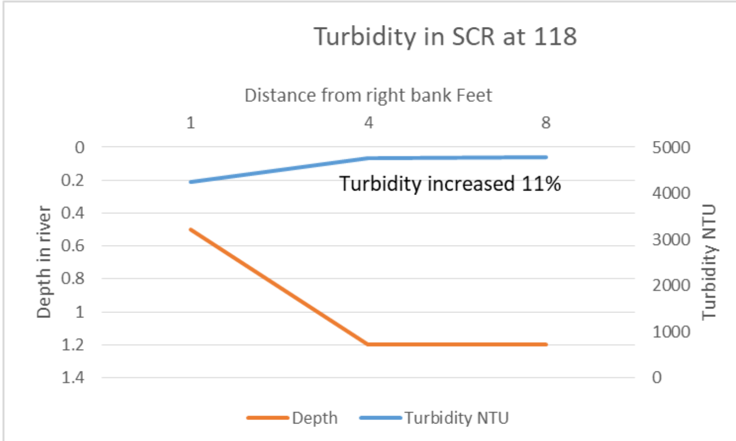


Figure 14. Turbidity Sample Taken 0.8 miles Downstream of the 118 Bridge (Boat Site)

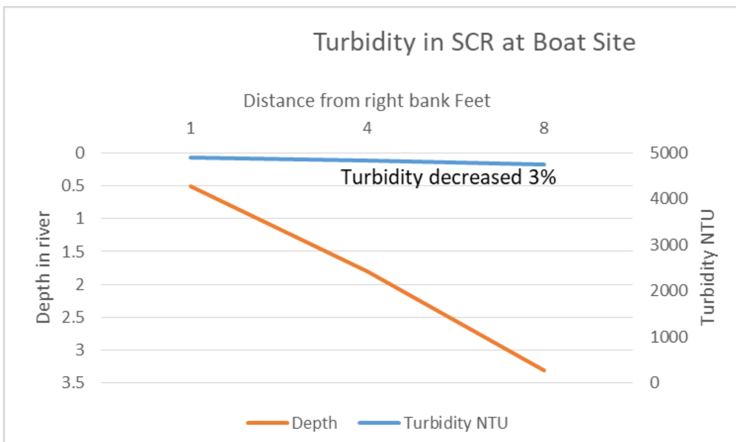
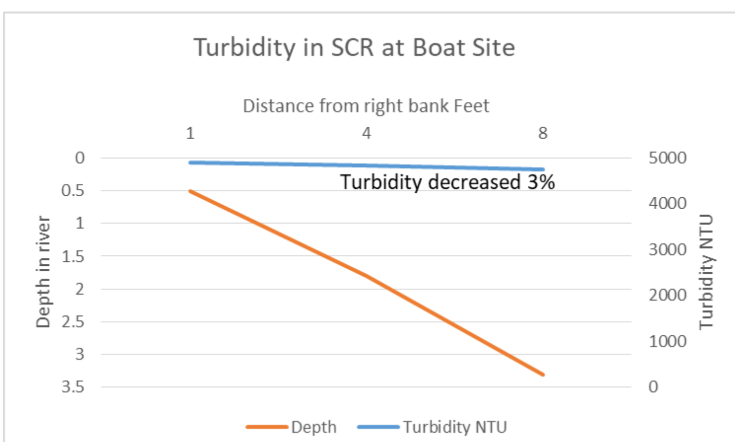


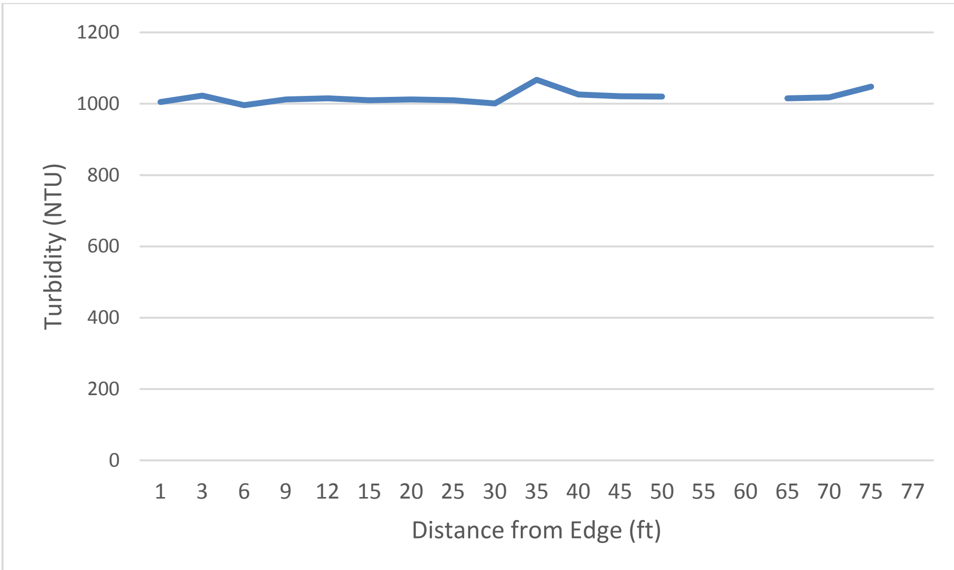
Figure 15. Turbidity Sample Take at the Compliance Point 0.76 Miles Upstream of the 101 Bridge



United staff collected a fourth set of samples from the critical reach sampling location when the river flow subsided to approximately 400 cfs and samples could be safely obtained across the entire river channel. Turbidity was measured every 3 feet. Figure 18 shows the turbidity measured going across the channel from the south to north bank. Turbidity was relatively uniform across the entire channel.

Based on data collected to date, there does not appear to be a substantial reduction in SSC along the edges of the river that could reliably support upstream migration of adult steelhead when the measured SSC levels are too high at the Freeman Diversion.

Figure 16. Turbidity Taken across the Channel at 1,000 cfs at the Critical Reach Sampling Location



7 RECOMMENDED FLOW CRITERIA

7.1 OPERATIONAL RELIABILITY OF THE FISH PASSAGE SYSTEM

A high percentage of the potential passage days for upstream migration occur after large storms. Reliability of a fish passage system after these large storms is therefore an important consideration when designing and deciding when to operate the new passage system. United's existing Denil fish ladder has been reliable after such large storms, because it is fully protected during the peaks of the storm and is not in operation until flows have become less destructive. Examples of the failure of fish passage systems that are exposed to the river during high flow events can be seen in Santa Paula Creek, a tributary to the Santa Clara River. Two fish passage systems were built less than 5 years before they were subjected to high flows in 2005.

Figure 17. Harvey Diversion Fish Ladder on Santa Paula Creek before and after 2005 Storms

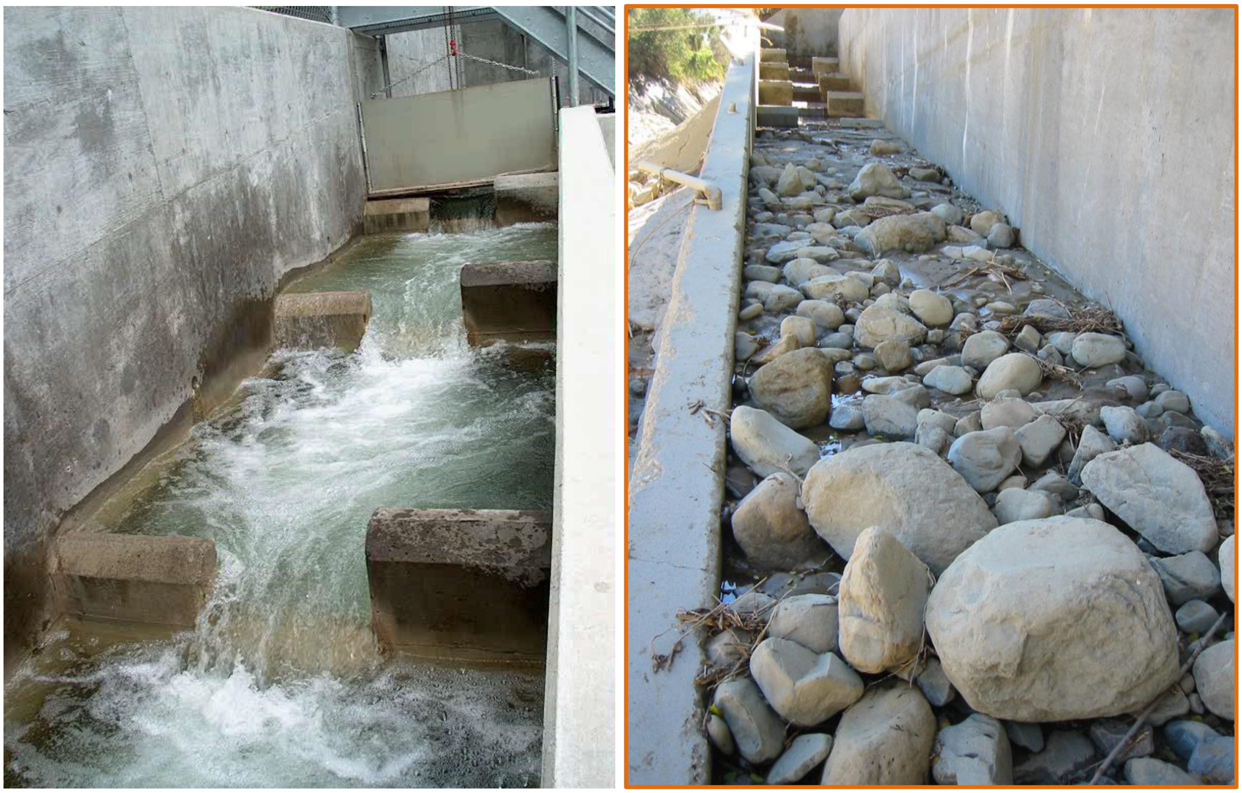
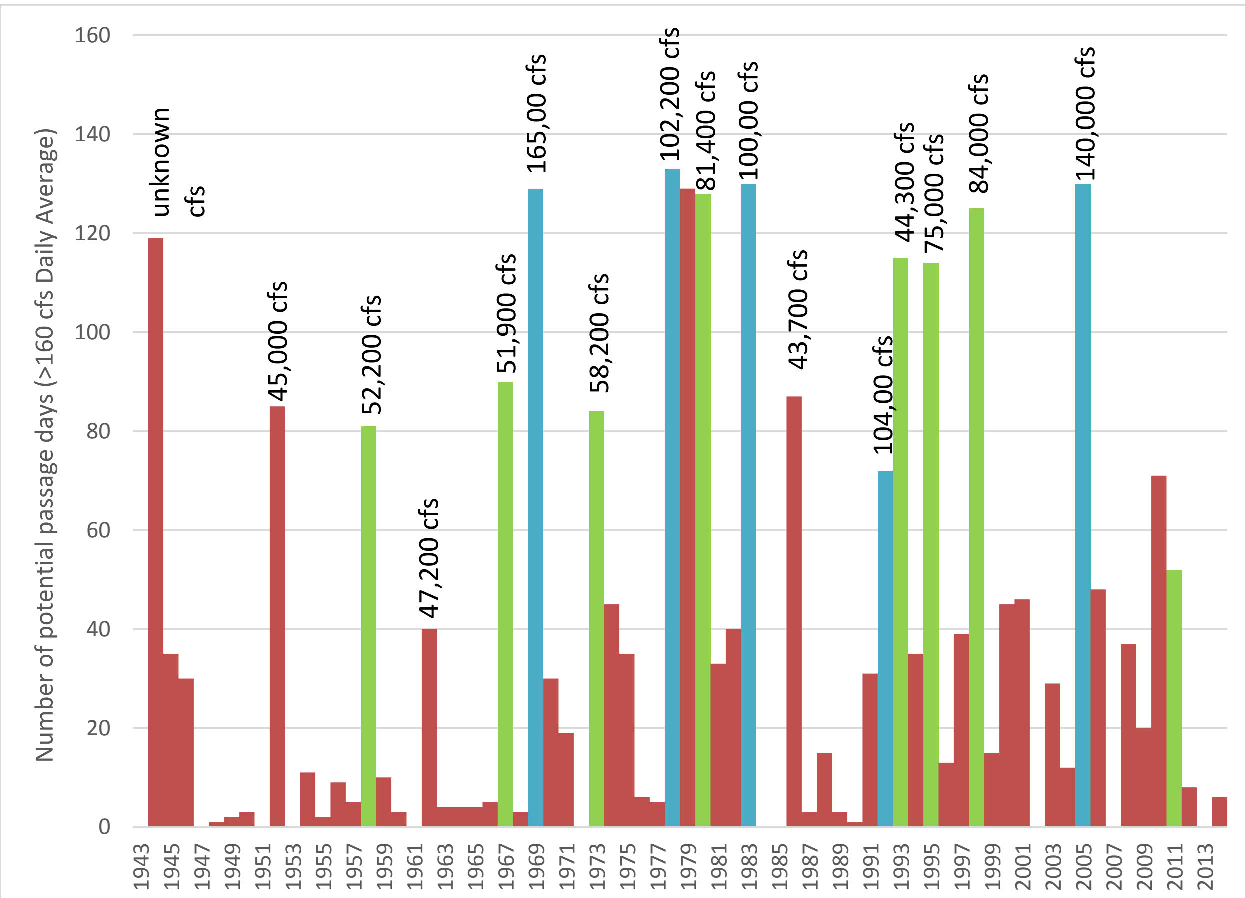


Figure 18. Army Corps of Engineers Fish Ladder on Santa Paula Creek before and after 2005 Storms

In 2005, the Santa Clara River experienced a peak flow estimated at 140,000 CFS. From the same storm, the Ventura County Watershed Protection District (Gage #709B) estimated a peak of 27,500 cfs in Santa Paula Creek. Figure 19 and Figure 20 show the conditions before and after the storm highlighting the damage that resulted from these storms. Figure 19 shows a portion of the Harvey Diversion fish ladder that filled with boulders and sediment during the storm. The riverbed below the diversion cut down about 8 feet leaving the fish ladder entrance impassible for upstream migrants. Figure 20 shows the Army Corps of Engineers fish passage system downstream of the Harvey diversion within the town of Santa Paula. The flows in 2005 caused the failure of the step pools made of concrete armored in steel. The river then moved around the ladder as can be seen in the upper portion of the “after” photograph. While flows at the Freeman Diversion were nearly 5 times as high as the flows in Santa Paula Creek, the Denil fish passage system was fully operational just a couple of days after flows had subsided, because it was protected from the most destructive portion of the storm. As a result, the fish ladder at the Freeman Diversion ran for 124 days that year and continues to run, while both of the Santa Paula Creek fish ladders remain out of commission now 13 years later.

The reliability of the fish passage system after high magnitude storms is a critical consideration. The number of day's flows are greater than or equal to 160 cfs below the critical riffle was calculated for the proposed operations of the HCP using the HOSS/FOM (Figure 19). Each bar of Figure 19 represents the number of days per year where flows exceeded 160 cfs. For illustration purposes, these days may be considered a portion of the "good migration days". The blue colored bars represent years when a peak flow in the Santa Clara River exceeded 100,000 cfs. The green colored bars represent years when a peak flow in the Santa Clara River exceeded 50,000 cfs. The red colored bars represent years when flows were always less than 50,000 cfs.

Figure 19. Number of passage days with associated peak flow of the largest storm event that year



Modeling results for the proposed operations calculated that flows exceeded 160 cfs for a total of 2,531 days downstream of the critical riffle for the 71-year period of analysis. Years where peak flow exceeds 100,000 are rare (only 7% of the 71 years); however, these years contain nearly a quarter (543 days out of the total 2,531 days or 21%) of the "passage days" over 160 cfs. If a fish passage facility was built that may be unreliable or is likely to fail at flows exceeding 100,000 cfs, then passage over the diversion would be at risk for 21% of the days over 160 cfs and depending on the extent of the damage, the structure could be out of operation for years at a time. Similarly, if flows from 50,000 cfs to 100,000 cfs make the passage system unreliable, then an additional 20% of the days over 160 cfs would be at risk. Together, that would be 41% or almost half of the passage days.

In 2017, a storm event was associated with a peak flow of 26,000 cfs at the Freeman Diversion. After the flows subsided, piles of debris were noted downstream of the diversion (Figure 20 and 21). This debris came from the watershed above the diversion. If a fish ladder was exposed to such debris, it is likely that it could destroy the fish passage structure or at least make it inoperable until flows subsided and equipment could safely access the debris for removal.

Figure 20. Pile of Woody Debris Fluvially Deposited about 100 Yards Downstream of the Freeman Diversion during 2017 Storm Flows

Figure 21. Rocks Deposited Downstream of the Freeman Diversion during 2017 Storm Flows

8 CONCLUSION

In conclusion, United staff recommend a fish passage facility upper limit of at least 1,800 cfs based on agency standards, considerations of fish behavior and physiology given SSC in the Santa Clara River system, and challenges of reliability in a flashy system prone to extreme flooding events and associated debris. The analyses described here support the conclusion that designing to 1,800 cfs is supported by agency standards while also being protective of adult steelhead upstream migration in the mainstem Santa Clara River.

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