Stockton East Water District and
Calaveras River Habitat Conservation Plan

Appendix E

Stockton East Water District

PHABSIM Habitat Index Analysis of the Calaveras River between Bellota and New Hogan Dam for Steelhead Fry and Juvenile Rearing and Adult Spawning

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Prepared for:

Stockton East Water District

Prepared by:

FISHBIO Environmental, LLC
and
Thomas R. Payne & Associates
Fisheries Consultants

December 16, 2009

Executive Summary

The Calaveras River, a tributary to the San Joaquin River, serves as an important source of water for agricultural and municipal uses in Calaveras and San Joaquin counties. In addition, the Stockton East Water District’s (SEWD) management of the river on behalf of their constituents and Calaveras County Water District (CCWD) over the past thirty years has created conditions that maintain a healthy and abundant resident rainbow trout (*Oncorhynchus mykiss*) fishery. Steelhead, the anadromous form of rainbow trout, opportunistically use the watershed when sufficient rainfall produces passage flows in the system during winter and early spring.

Although some data regarding salmonid populations has been collected in recent years, several data gaps still exist, such as potential streamflow effects on various lifestages of *O. mykiss*. In an effort to address this data gap, an instream flow study was conducted in the lower Calaveras River (New Hogan to Bellota) using a Physical Habitat Simulation (PHABSIM) model to calculate an index relationship between streamflow and potential habitat for steelhead. Four reaches were evaluated including:

Reach 1- New Hogan Dam to Canyon (RM 42.0 to RM 41.3);
Reach 2- Canyon to Jenny Lind (RM 41.3 to RM 34.6);
Reach 3- Jenny Lind to Shelton Road (RM 34.6 to RM 29.3); and
Reach 4- Shelton Road to Bellota (RM 29.3 to RM 24)

Results of the study indicate that low flows ranging from 12 cfs for fry and 30-40 cfs for spawning adults maximize available habitat in the upper two reaches where the majority of spawning and early rearing occur (Stillwater Sciences 2004). Based on WUA/PHI curves, a minimum flow commitment of 20 cfs at Shelton Road (equivalent to about 25 cfs released from New Hogan) ensures that suitable habitat is available in the important spawning and rearing area during the non-irrigation season from late fall through early spring, which encompasses the steelhead spawning season (December through March) as well as year-round rearing. During the non-irrigation season, natural freshet events and/or flood control releases provide migration opportunities during normal to above normal precipitation years, particularly for steelhead. These flow events create conditions that allow adult fish to migrate into the spawning reach where habitat is suitable for spawning and that allow juvenile fish to migrate out of the river on their way to the ocean.

During the irrigation season (late spring through early fall), flows are higher than those that would maximize suitable habitat for fry and juvenile rearing in Reaches 1 and 2 but provide water temperatures that are typically within EPA recommended water temperatures for “core” steelhead rearing (<16°C; 61°F). Irrigation flows provide a relatively high amount of suitable physical habitat in Reach 3 and oversummering water temperatures that are generally within those recommended for “non-core” rearing areas (<18°C; 64°F). Reach 4 is considered to be mostly a migration corridor due to limited habitat structure, presence of predators (e.g., smallmouth bass), and unsuitable oversummering temperatures.

Introduction

The Calaveras River, a tributary to the San Joaquin River, serves as an important source of water for agricultural and municipal uses in Calaveras and San Joaquin counties. In addition, the Stockton East Water District's (SEWD) management of the river on behalf of their constituents and Calaveras County Water District (CCWD) over the past thirty years has created conditions that maintain a healthy and abundant resident rainbow trout (*Oncorhynchus mykiss*) fishery as evidenced by relatively high abundance and fish condition factors (i.e., Fulton's K Factor) recorded during the past several years during rotary screw trap (RST) monitoring and by anecdotal accounts from local fishermen. Steelhead, the anadromous form of rainbow trout, opportunistically use the watershed when sufficient rainfall produces passage flows in the system during winter and early spring.

Although some data regarding *O. mykiss* populations has been collected in recent years, several data gaps still exist, such as potential streamflow effects on various lifestages of steelhead. In an effort to address this data gap, an instream flow study was conducted in the lower Calaveras River (Bellota to New Hogan) using a Physical Habitat Simulation (PHABSIM) model to calculate an index relationship between streamflow and potential habitat for steelhead. PHABSIM is a component of the Instream Flow Incremental Methodology (Bovee et al. 1998), which is a widely accepted framework for guiding the analysis of flow alteration impacts on aquatic habitat. PHABSIM consists of three principal components:

1) ***Hydraulic Model*** which simulates the depths and velocities of river cross sections over a range of specified flows;
2) ***Habitat Suitability Criteria*** (***HSC***) which describe the physical suitability of different values of depth, velocity, and substrate for individual fish species and lifestages; and
3) ***Habitat Simulation Model*** which links the ***hydraulic model*** with the ***HSC*** to produce an "output expressed as usable or optimal microhabitat area, or an index of microhabitat area" (IF200 Lecture Notes 1994). This index is commonly termed Weighted Usable Area (WUA), although it is more accurately termed a Physical Habitat Index (PHI or Φ) (Payne 2003, 2007).

PHABSIM was chosen to evaluate the relationship of Calaveras River flows with steelhead rearing and spawning habitat primarily because it provides a quantitative index suitable for interpretation and understanding. Habitat indices (i.e., WUA/PHI) were computed for steelhead fry and juvenile rearing and for adult steelhead spawning.

Study Location and Methods

Between New Hogan Dam and Bellota, the Calaveras River consists of four distinct reaches which were evaluated in this study:

- Reach 1- New Hogan Dam to Canyon (RM 42.0 to RM 41.3);
- Reach 2- Canyon to Jenny Lind (RM 41.3 to RM 34.6);
- Reach 3- Jenny Lind to Shelton Road (RM 34.6 to RM 29.3); and
- Reach 4- Shelton Road to Bellota (RM 29.3 to RM 24)

These reaches were selected because they are within the area of the river that maintains flows year-round. Reaches 1 and 2 are where the majority of spawning and rearing have been observed (Stillwater Sciences 2004). Summer habitat conditions, especially water temperature, are more optimal in the upper two reaches and less optimal at Reaches 3 and 4; however, Age 1+ fish may utilize Reach 3 and 4 during the winter months (Stillwater Sciences 2004).

Habitat Mapping

In the spring of 2008, the four stream reaches were habitat-mapped (Morhardt et al. 1983) on foot or kayak by FISHBIO and TRPA fisheries biologists to quantify by length the proportions and locations of designated mesohabitat categories (e.g., riffles, pools, runs, etc.). Then, during a site visit with NOAA Fisheries, transect selection protocols were established. In three of the reaches (Reach 1, 3 and 4), transects were subsequently selected to represent the various observed mesohabitats using a stratified random selection approach (Allen 1992). A total of twenty-one transects were placed in the three study reaches (seven each) in conformity with the protocols established.

No transects were selected in Reach 2 because the ability to conduct transect measurements would be extremely difficult at the required range of flows and it was determined that Reach 1 could be used to represent Reach 2 based on similarities in gradient, confinement, and bedrock control. Transect measurements would be problematic because access to Reach 2 is highly restricted. There are only a few privately owned roads where point access is possible and the locations that could be measured from these access points would not provide optimal representation and would not provide any better results than using Reach 1 to represent Reach 2. The only other access point is entering at the upstream of the canyon and traversing the entire length via kayak; however, kayak access is frequently not feasible at either lower flows due to extensive chutes and shallow rapids or at higher flows due to safety issues and limited haul-outs, which prevents measurements being taken at the range of flows necessary for modeling purposes.

Reach 1 is similar in gradient, confinement, and bedrock control to Reach 2; therefore, the shape of resulting habitat index curves will be the same for each reach even though the magnitude could be slightly shifted due to some of the differences observed in mesohabitat percentages. The shape of the curve is largely determined by how a species' preferred mesohabitat type behaves in response to flow. For example, if a particular species/lifestage prefers depth, velocity, and substrate conditions that are primarily associated with riffles, the shape of the curve will be largely determined by how depths and velocities in riffles change with flow and a riffle in Reach 2 is expected to behave the same as a riffle in Reach 1 due to its similarities in gradient, confinement, and bedrock control, so the shape of the curve will be the same. On the other hand, the magnitude of the habitat index would be affected by the amount of riffle habitat in each reach such that if there were a higher percentage of riffle area in Reach 2, then the magnitude of the curve would be higher than in Reach 1 (i.e., if the peak of the fry rearing curve is at 12 cfs in Reach 1, it will remain 12 cfs for Reach 2, but the WUA/PHI index may change from 6,000 for Reach 1 to something higher for Reach 2).

Field Data Collection

A PHABSIM study requires collection of hydraulic data (depth and velocity cross-sections) over a range of flows that ideally (1) encompasses the potentially-suitable flow range for rearing and spawning and (2) also allows simulation of flows that are both lower and higher than the potentially-suitable flow range. At each site, transects were placed across the stream channel perpendicular to the predominant flow direction (Figure 1) and marked at each end using 3 foot long pins of 0.5 inch rebar. The left bank headpin (looking upstream) was used as the zero point for all stationing and vertical control was referenced to a fixed benchmark (typically a large boulder). Depths and velocities along all transects were measured at the highest flow available at intervals of 3 feet or less, depending on the width of the channel and the distribution of flow across the transect (minimum of 15-20 point measurements, preferred 20-30). Water surface elevations (i.e., stage) were measured at all flow levels, with three stage measurements at each transect at each flow.

Stage measurements were correlated with measured discharge to develop stage/discharge rating curves for each transect. The stage-discharge relation is used to relate water level to an associated streamflow and the rating curve allows the use of stream stage data to estimate the corresponding streamflow at nearly any stream stage. The data sets acquired for calibration of the PHABSIM hydraulic model are listed in Table 1.

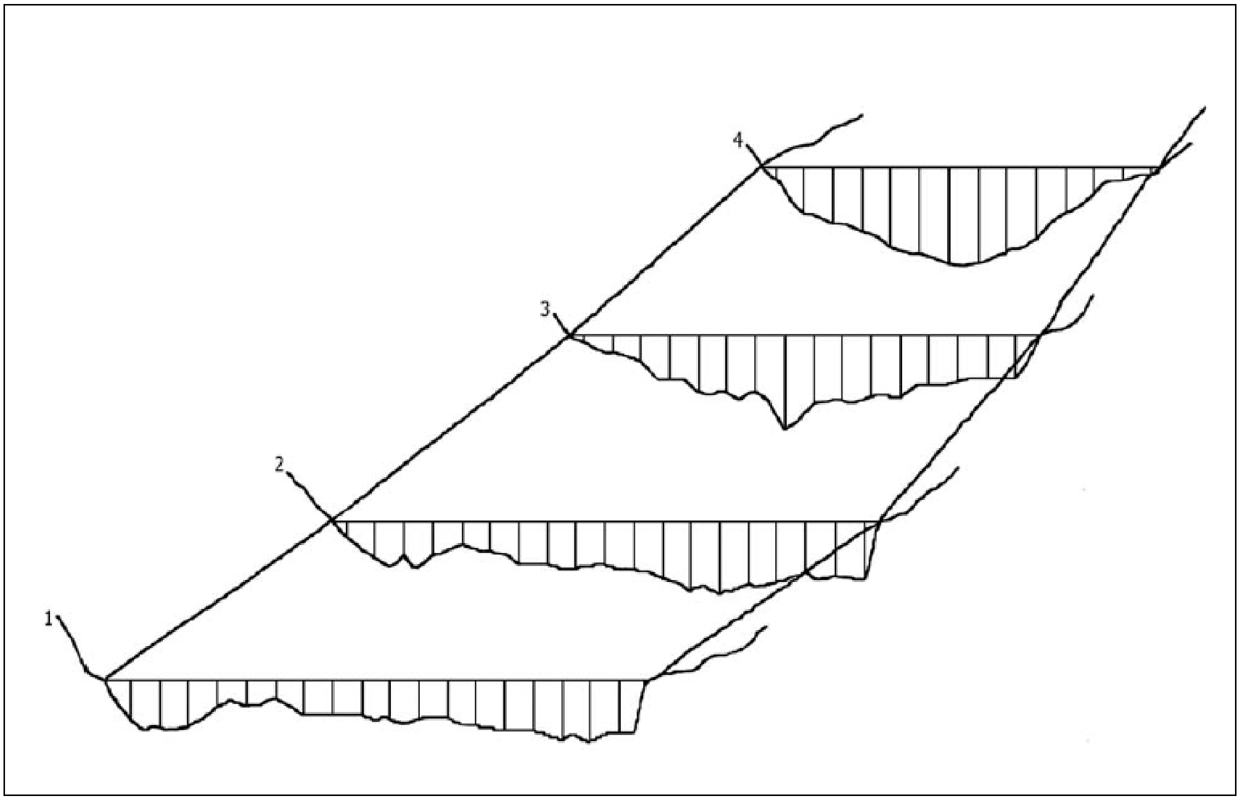

Figure 1.Typical transects showing sampling locations at verticals. Source: Payne 2003.

Table 1. Calibration flows (cfs) measured in 2008 on Calaveras River at the twenty one transects. Bold and italics flow levels indicate discharge for each transect at which water velocities were measured.

Reach 1- New Hogan Dam to Canyon

Flow Level	Date	Flow (cfs)
High	4/29	***162.5***
Middle	3/26	71.9
Low	3/24	29.3

Reach 3- Jenny Lind to Shelton Road

Flow Level	Date	Flow (cfs)
High	4/29	***162.4***
Middle	3/26	69.8
Low	3/24	26.0

Reach 4- Shelton Road to Bellota

Flow Level	Date	Flow (cfs)
High	4/30	***163.8***
Middle	3/27	71.3
Low	3/24	30.7

Substrate observations were made at each depth and velocity measurement point across all transects at the lowest calibration flow (when visibility and access were best). Substrate particle size classes and relative abundance were characterized using the Bovee substrate coding system (see Table 2). This method of substrate coding (Bovee 1978) uses a single digit corresponding to a substrate size category and a decimal corresponding to abundance. The two-digit code describes the mixture of two adjacent-sized particle classes which dominate a particular measurement point by assigning a number for the smaller-diameter size class to the digit place (number 1 through 8 as in Table 2) and a volumetric percentage of the larger-diameter size class to the decimal place (0 through 9 for 0% to 90%). Examples:

- 5.0 is pure gravel
- 4.6 is sand and 60% gravel
- 5.5 is gravel and 50% cobble
- 5.3 is gravel and 30% cobble

Table 2. Substrate size class coding using the Bovee system.

Substrate Size Code	Substrate Size Range
1	Organic debris or vegetation
2	Mud or soft clay (<0.002")
3	Silt (<0.002")
4	Sand (0.002"-0.25")
5	Gravel (0.25"-3.0")
6	Cobble/Rubble (3.0"-12.0")
7	(>12.0")
8	Bedrock

PHABSIM Components

The three components of PHABSIM (i.e., Hydraulic Model, Habitat Suitability Criteria and Habitat Simulation Model) are described below.

1. Hydraulic Model and Calibration

The purpose of hydraulic simulation using PHABSIM is to allow simulation of depths and velocities in streams under a range of stream flow conditions. Simulated depth and velocity data are then used to calculate the WUA/PHI, either with or without substrate and/or cover information. Components of the hydraulic model include water surface elevation prediction and water velocity prediction and calibration. Calibration flows typically enable the hydraulic and habitat models to simulate habitat conditions from 40% of the measured low flow to 250% of the measured high flow.

Water Surface Elevation Prediction

For moderate to low gradient streams such as the Calaveras River, stage-discharge relationships often utilize a log/log linear regression formula between water surface elevation and flow based on measured data (Bovee and Milhous 1978). This method is best used with a minimum of three pairs of stage and discharge observations. The stage relative to the benchmark elevation control is adjusted to absolute stage by subtracting the measured stage-at-zero-flow prior to conversion to logarithmic scales and linearity computed. In this method, each cross section is treated independently of others in the study site, so transect placement must consider backwater effects that might violate the assumption of log-log linearity.

Water Velocity Prediction and Calibration. Water velocity predictions can be made in several ways. These include predicting velocities from a template of measured velocities from a single flow (one-flow method), deriving velocities from flow based on depth (no-velocity method), or regressing measured velocities against discharge for two or more flows (three-flow regression method). The latter velocity regression is rarely used in instream flow studies and is no longer recommended (Milhous & Schneider 1985).

For predicting water velocities along the Calaveras River study cross-sections, the “one-flow” technique was primarily utilized. From a single set of measured velocities and the measured depths, and using Manning’s formula, the Manning’s *n* is solved on an individual data point basis along a transect. At the simulated discharges, the model uses Manning’s formula and these previously derived Manning’s *n* values together with the projected depth to predict velocities. In this sense, the one set of velocities is used as a template to predict the simulated velocities at other discharges. For pool transects that were very deep (five feet or deeper during the high flow event), no velocities were measured and velocities were derived within the model by apportioning flow by depth (no-velocity method). Simulated velocities were inspected during hydraulic calibration.

The purpose of velocity calibration is to determine, through examination of the simulated velocity adjustment factors (VAF's) and velocity patterns, the adequacy of velocity simulations up to a given flow level. It is also important to preserve as closely as possible the measured velocities. Generally, few data points require adjustment during velocity calibration. In those cases when adjustments are needed, individual calibration modifications are limited to minor velocity changes in shallow edge simulations or to points that either significantly deviated from surrounding patterns or contributed to substantial errors in discharge calculations. Calibration is generally accomplished by specifying an adjacent point's Manning's *n* roughness value and applying it to the target point. A second technique is to average Manning's *n* values or velocities from adjacent points, then substitute a new Manning's *n* in the target pointl.

Other calibration adjustments involve changing negative velocities to positive, or not applying observed angles to velocities, especially for cases when a transect under-calculates discharge. These situations usually occur in edge areas, or at points where an upstream obstruction creates a negative or angular velocity that is likely to change or turn positive at higher levels of flow. This method has little effect on habitat index simulations because the program uses absolute values of the velocities for habitat suitability, provided the total computed discharge remains close to the same.

Habitat Suitability Criteria

The second primary component of an instream flow study using PHABSIM is the habitat suitability criteria (HSC) that describe the relative physical suitability of depth, velocity, stream substrate, and cover types to the fish species being evaluated. For this study of the Calaveras River, the target species is the anadromous *O. mykiss* in the fry, juvenile and rearing life stages. The most reliable methods for acquiring HSC are to 1) make numerous observations of the target species within the study area, 2) select existing HSC from similar streams, and 3) use the best professional judgment of experienced fish biologists. Due to limited data in the Calaveras River, the second method was selected and available HSC were reviewed for applicability.

The best HSC candidates for the Calaveras River appeared to be from a previous study of the Feather River, a moderate to low gradient, west-slope northern Sierra river (CDWR 2004, 2005). Although the Feather River is larger than the Calaveras River, the two rivers are more similar (and in closer geographic proximity) than other large streams in Oregon and Washington where HSC have been developed, and potential spawning steelhead trout are more likely to be similar in size. Figure 1 illustrates the steelhead trout fry criteria used for velocity (feet per second) and depth (feet). Figure 2 shows the steelhead trout juvenile criteria used for velocity and depth, while Figure 3 illustrates the steelhead spawning criteria used for velocity, depth, and substrate (Bovee code and noted in the graph as "Attribute 1"). Suitability criteria for spawning substrates were taken from Bovee (1978) because the Feather River study used a substrate coding system that was different from (and incompatible with) the data collected on the Calaveras River. The third variable (substrate or cover) was set to full suitability (1.0) for the fry and juvenile lifestages, since suitable substrate and cover dominated all reaches and results would be unaffected.

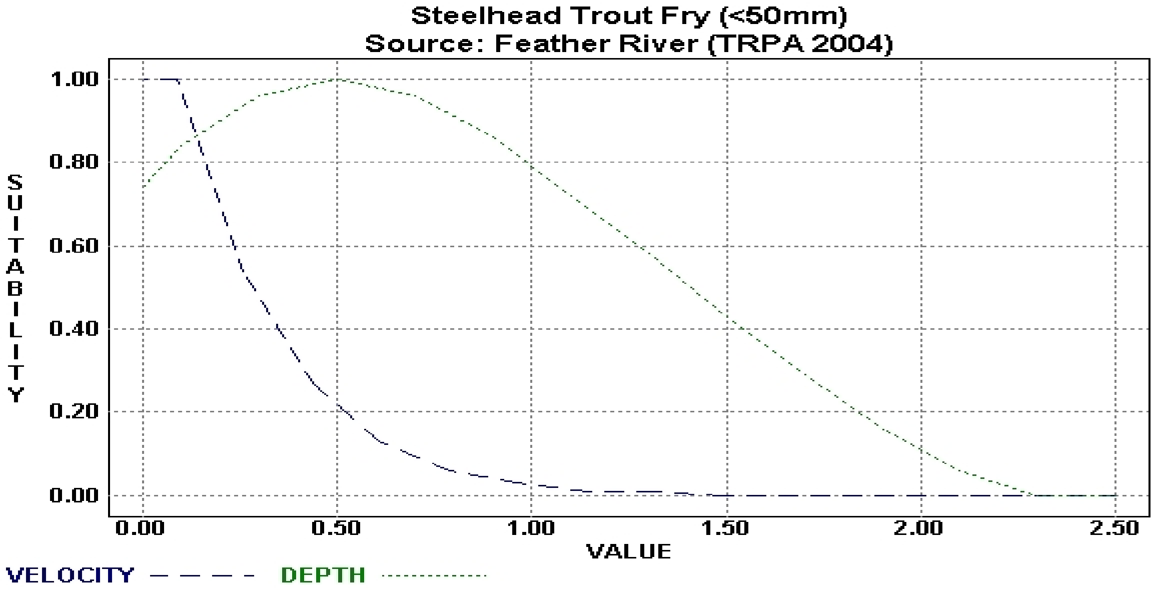

Figure 2. Habitat Suitability Criteria used for PHABSIM analysis of relationship between steelhead fry rearing and flow in the Calaveras River. Developed from field data collected on the Feather River (CDWR 2004, 2005).

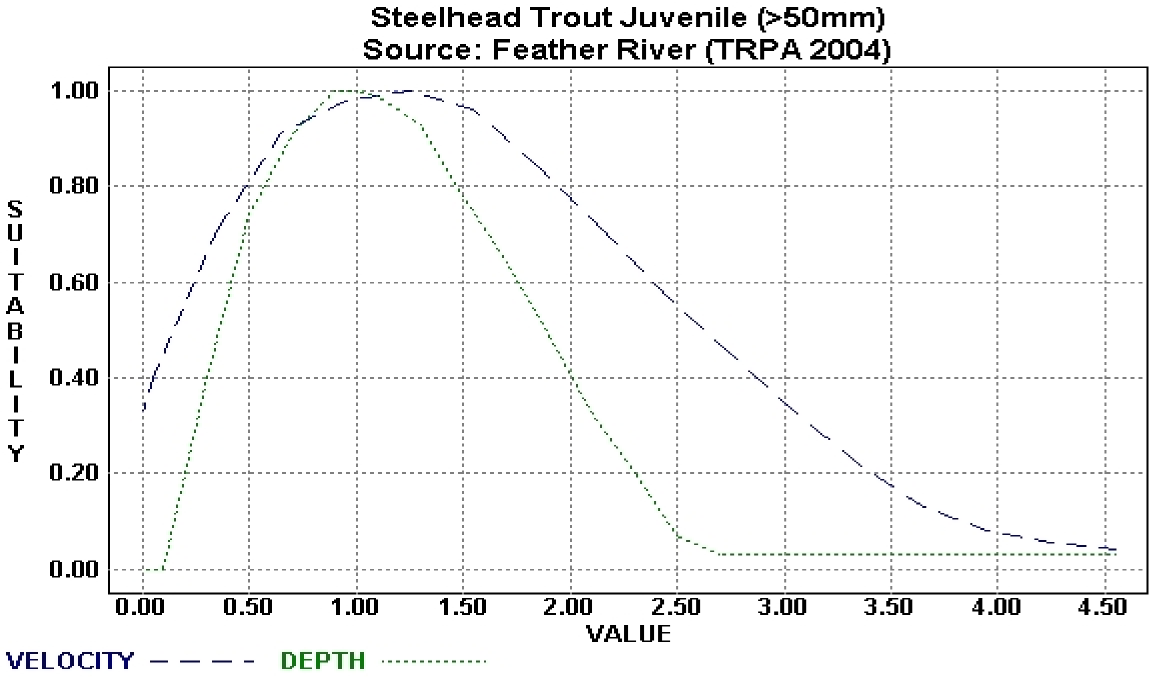

Figure 3. Habitat Suitability Criteria used for PHABSIM analysis of relationship between steelhead juvenile rearing and flow in the Calaveras River. Developed from field data collected on the Feather River (CDWR 2004, 2005).

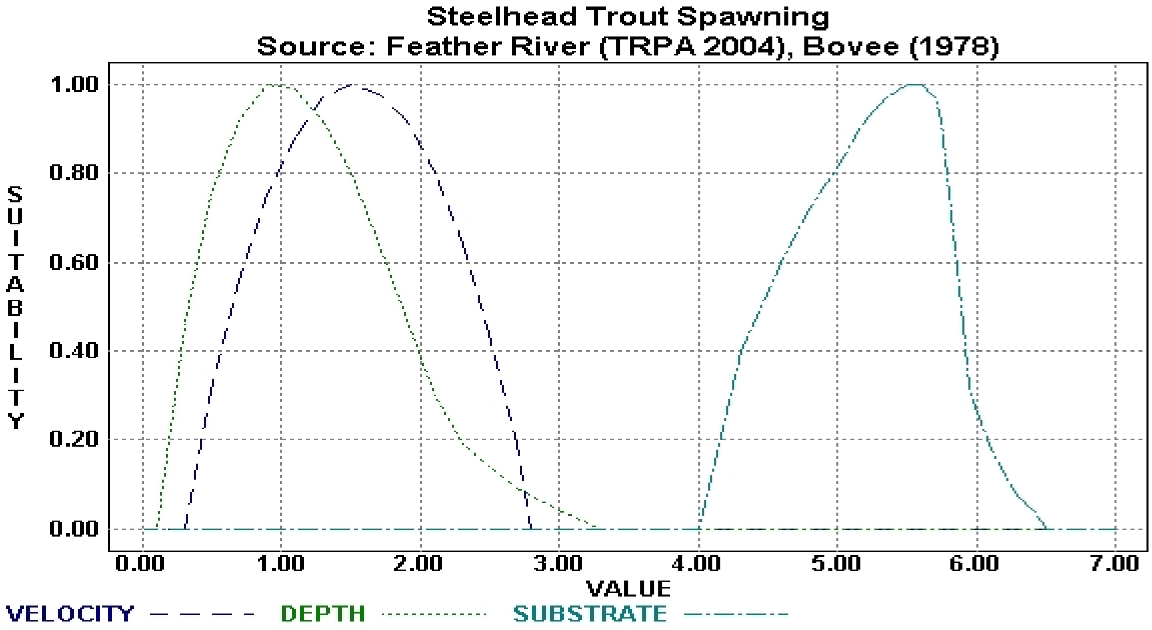

Figure 4. Habitat Suitability Criteria used for PHABSIM analysis of relationship between steelhead spawning and flow in the Calaveras River. Developed from field data collected on the Feather River (CDWR 2004, 2005), and substrate noted as "Attribute 1" (from Bovee 1978).

Habitat Index Simulation

Habitat index simulation is the process that combines hydraulic estimates of velocity and depth (i.e., the results of the hydraulic simulation) with the suitability values for those attributes (i.e., the habitat suitability criteria) to weight the area of each data point at the simulated flow. The weighted values for all points are summed to give a single habitat index, WUA/PHI. The WUA/PHI (index of aquatic habitat suitability) describes the incremental relationship between physical habitat and stream discharge. Hydraulic and habitat index modeling were conducted using RHABSIM Version 3.0 (Riverine Habitat Simulation, Payne 1994).

Results

Habitat Mapping

Habitat mapping was conducted on foot on March 12, 2008 (Reach 1) and by kayak on March 23, 2008 (Reach 2), March 12-13, 2008 (Reach 3), and March 12, 2008 (Reach 4). Reach 1 consists of about 54% pool habitat (deep and shallow combined) and nearly 30% run habitat with some lower gradient riffle (Table 3). Reach 2 has 47% pool habitat (deep and shallow combined, 35% riffle and 18% run habitat. In Reach 3, pool habitat (deep and shallow) dominates at 46% with run habitat the next most prevalent at 36%. Pool habitat truly dominates in Reach 4 comprising 73% of the reach, followed by run at 20% and riffle habitat is minimal at 7%. Seven transects were placed in each of Reaches 1, 3, and 4 (n= 21) to represent the various habitat types.

Table 3. Calaveras River habitat mapping summary for Reaches 1-4.

Habitat Type	Length (feet)	Percentage of Total Reach	Number of Transects
Reach 1-New Hogan Dam to Canyon			
Run	2,125	29	3
Deep Pool	2,966	40	2
Shallow Pool	1,045	14	1
Riffle	1,222	17	1
Cascade	53	-	0
Total	***7,411***	***100***	***7***
Normalized	***7,358***	-	-
Reach 2- Canyon to Jenny Lind			
Run	1,956	18	-
Deep Pool	4,489	41	-
Shallow Pool	631	6	-
Riffle	3,795	35	-
Total	***10,871***	***100***	-
Normalized	***10,871***	-	-
Reach 3- Jenny Lind to Shelton Road Bridge			
Run	9,025	36	3
Deep Pool	6,700	26	2
Shallow Pool	5,105	20	1
Riffle	4,549	18	1
Cascade	30	-	0
Road Crossing	29	-	0
Total	***25,438***	***100***	***7***
Normalized	***25,379***	-	-
Reach 4-Shelton Road Bridge to Bellota			
Run	5,076	20	2
Deep Pool	12,069	47	2
Shallow Pool	6,582	26	2
Riffle	1,710	7	1
Lake	2,430	-	0
Total	***27,867***	***100***	***7***
Normalized	***25,437***	-	-

Hydraulic Model and Calibration

All transect water surface elevations were simulated using log-log stage-discharge regression (IFG4). The regression statistics for all transects from the three reaches are displayed in Table 6 for the Calaveras River.

For all transects located in the three study reaches of the Calaveras River, the mean errors for the log-stage/log-discharge regressions for these transects are at or below five percent, with the error for most transects two percent or less. Except for transect 5 in Reach 4, the slopes for these regressions are within the range of 2 to 4.5 as recommended by the Instream Flow Group (1995). Transect 5 is unusually broad and shallow and its slope value of 1.69 is appropriate for this kind of stream channel configuration.

In general, the Y-intercept values for the transects are all consistent. These characteristics meet the established quality control standards for PHABSIM hydraulic simulation.

Standard procedures were followed in making velocity calibration adjustments to account for “edge effect”, excessive velocity prediction, and over- or under-calculation of discharge. After calibration, the velocity adjustment factors (VAF) were within the recommended 0.1 to 10 over the range of simulated flows (Instream Flow Group 1995). The VAFs for the three study reaches of the Calaveras River simulation (12 to 410 cfs) are illustrated in Figures 4, 5, 6. The VAFs for all transects generally transition through 1.0 at their velocity calibration flow.

Table 4. Log-stage/log-discharge regression statistics for the twenty one RHABSIM study transects on Calaveras River. N is the number of calibration flows.

Transect Name	N	Y-Intercept	Slope	Mean Error (%)	Variance	Standard Deviation
Reach 1-New Hogan Dam to Canyon						
1	3	13.51	2.61	1.42	0.36	0.61
2	3	8.74	2.78	1.19	0.26	0.51
3	3	8.88	2.73	0.22	0.01	0.09
3b	3	8.28	2.79	1.7	0.51	0.72
4	3	8.57	2.78	0.86	0.13	0.37
5	3	8.42	2.79	3.43	1.97	1.4
6	3	4.3	3.22	0.94	0.16	0.4
Reach 3- Jenny Lind to Shelton Road Bridge						
1	3	26.57	3.42	2.89	1.42	1.19
2	3	25.99	3.38	0.05	0	0.02
3	3	25.96	3.31	0.22	0.01	0.1
4	3	24.7	3.43	2.28	0.9	0.95
5	3	14.81	3.09	0.12	0	0.05
6	3	10.29	4.49	0.35	0.02	0.15
7	3	20.98	4.04	2.71	1.58	1.26
Reach 4-Shelton Road Bridge to Bellota						
1	3	36.38	2.05	0.2	0.01	0.09
2	3	36.08	2.07	0.05	0	0.02
3	3	36.01	2.09	0.88	0.15	0.39
4	3	29.83	2.3	2.14	0.8	0.9
5	3	90.35	1.69	2.03	0.72	0.85
6	3	80.13	2.05	5.08	4.31	2.08
7	3	66.55	1.98	4.56	3.49	1.87

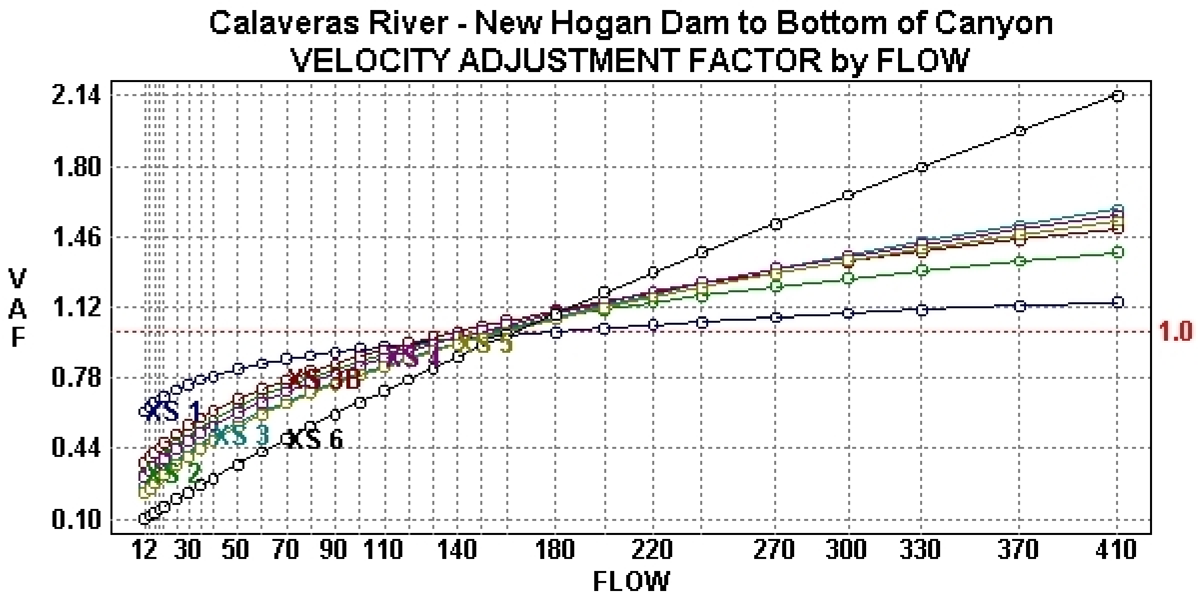

Figure 5. Velocity adjustment factors used for RHABSIM velocity simulations on the New Hogan Dam to Bottom of Canyon (i.e., Jenny Lind)(Reaches 1 and 2) transects included in the Calaveras River study.

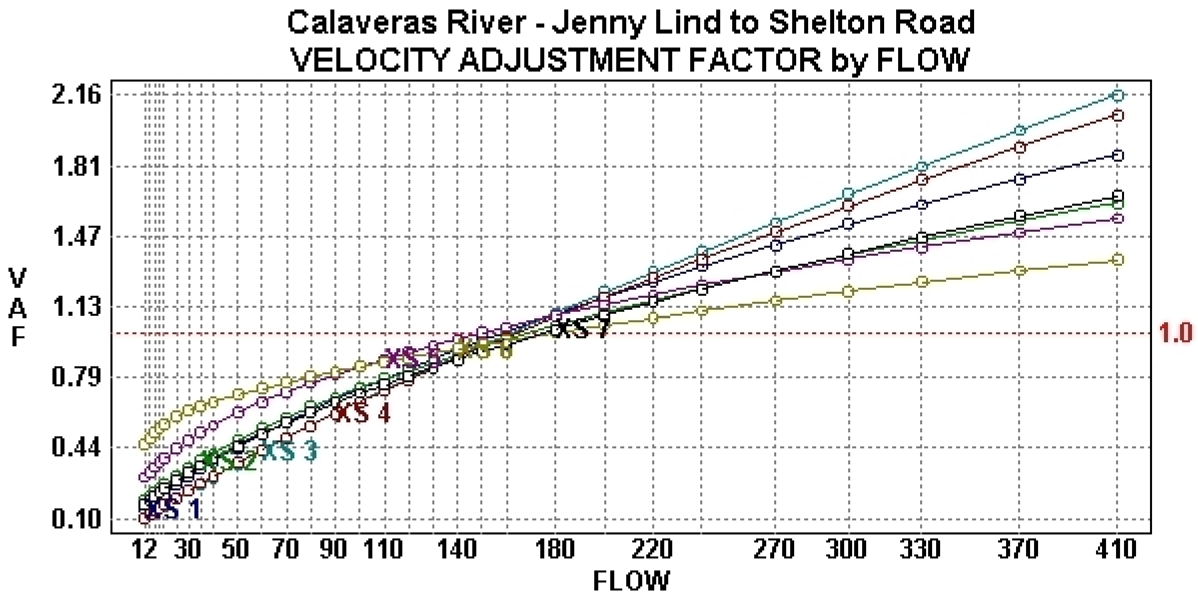

Figure 6. Velocity adjustment factors used for RHABSIM velocity simulations on the Jenny Lind to Shelton Road (Reach 3) transects included in the Calaveras River study.

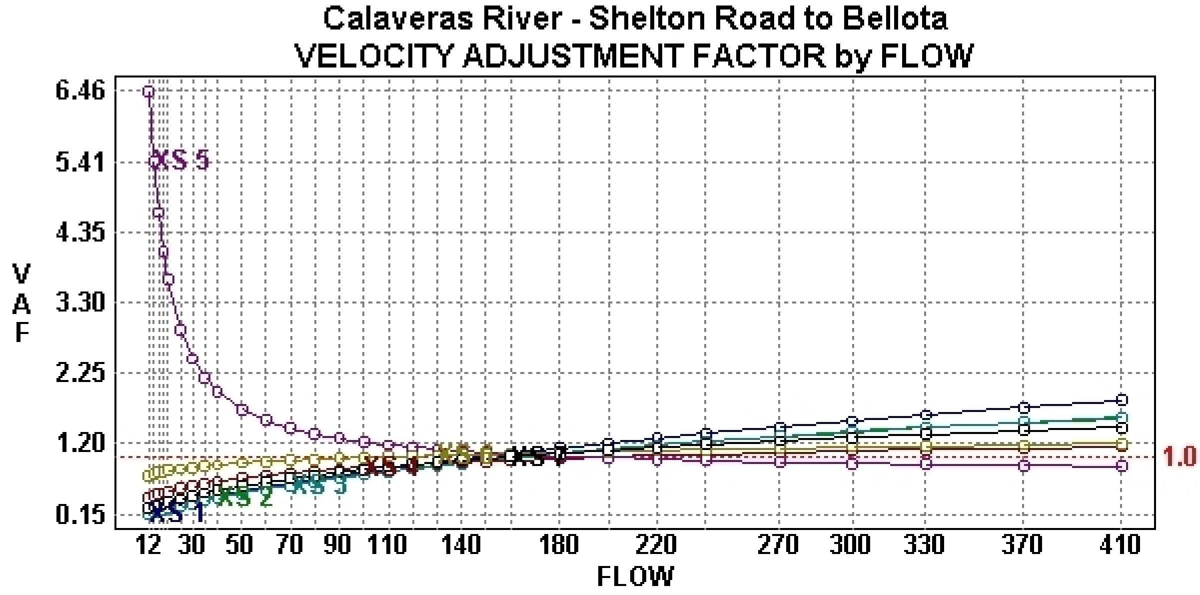

Figure 7. Velocity adjustment factors used for RHABSIM velocity simulations on the Shelton Road to Bellota (Reach 4) transects included in the Calaveras River study.

Habitat Index Simulation

The results of the steelhead trout habitat analysis for the Calaveras River represent the relationship between stream flow and the extent of match to the habitat suitability criteria of depth, velocity, and substrate. The y-axis of the graph is the index to WUA/PHI for any particular flow, expressed in dimensionless units per 1,000 feet of stream. Combining the hydraulic modeling results with the habitat suitability criteria curves for the various steelhead life stages in the three study reaches generated different WUA/PHI relationships. Because of the differences in the suitability criteria among the life stages, each exhibits a different response of WUA/PHI to discharge, both in the quantity of WUA/PHI and the flows where a peak may occur. The results of the habitat index simulations are discussed by study reach.

Reaches 1 and 2- New Hogan Dam to Jenny Lind. In Reaches 1 and 2, the highest index for steelhead trout fry occurs at the lowest flow modeled (12 cfs), and then declines steadily as flows increase (Figure 7). The index for juvenile steelhead trout peaks in the 20 to 30 cfs range and slowly decreases with an increase in flow to about 280 cfs and then slightly increases thereafter. The index for spawning steelhead trout increases steadily to between 30 to 40 cfs, steadily decreases thereafter to 280 cfs, then slowly increases up to the maximum modeled (410 cfs).

Figure 8. The relationship of rearing and spawning to flow for rainbow trout steelhead on the Calaveras River, New Hogan Dam to the bottom of the canyon (i.e., Jenny Lind)(Reaches 1 and 2). Habitat conditions simulated from 40% of the measured low flow to 250% of the measured high flow.

Reach 3- Jenny Lind to Shelton Bridge. In Reach 3, the highest index for steelhead trout fry occurs at the lowest flow modeled (12 cfs), and then generally declines steadily as flows increase (Figure 8). The index for juvenile steelhead trout increases to a peak of approximately 100 to 110 cfs, thereafter slowly decreasing with an increase in flow. The index for spawning steelhead trout increases rapidly to between 90 to 100 cfs and steadily decreases thereafter to the maximum flow modeled.

Reach 4- Shelton Bridge to Bellota. In Reach 4, the highest index for steelhead trout fry occurs at the lowest flow modeled (12 cfs) but it does not change significantly with a change in flow (Figure 9). The index for juvenile steelhead trout increases to a peak of approximately 130 cfs, thereafter slowly decreasing with an increase in flow. The index for spawning steelhead trout increases rapidly to between 120 to 130 cfs and steadily decreases thereafter to the maximum flow modeled.

Figure 9. The relationship of rearing and spawning to flow for rainbow trout steelhead on the Calaveras River, Jenny Lind to Shelton Road (Reach 3). Habitat conditions simulated from 40% of the measured low flow to 250% of the measured high flow.

Figure 10. The relationship of rearing and spawning to flow for rainbow trout steelhead on the Calaveras River, Shelton Bridge to Bellota (Reach 4). Habitat conditions simulated from 40% of the measured low flow to 250% of the measured high flow.

Summary

In general, physical habitat conditions for steelhead trout fry are maximized by flows in the lower range (12 cfs) in all modeled reaches. For steelhead trout juveniles, physical habitat conditions are maximized at flows between 20 and 30 cfs in the upper two reaches, and at 100 to 130 cfs in the lower two reaches. A similar pattern is seen for steelhead trout spawning where physical habitat conditions are maximized at flows between 30 and 40 cfs in the upper two reaches and at 90 to 130 cfs in the lower two reaches. Flows higher or lower than these levels create physical conditions that are faster, slower, shallower, or deeper than those which best match the suitability criteria specified for steelhead trout habitat.

Flows which provide higher WUA/PHI numbers are more likely over time to support greater numbers of spawning and rearing fish; however, the exact numbers and the abundance ratios among lifestages are influenced by too many other factors (e.g., upstream migration barriers, numbers of steelhead spawners and reproductive seeding density, availability of food sources, water temperature, and the number and type of competitors and/or predators) to allow numbers of fish to be quantified.

In the upper two reaches (New Hogan Dam- RM 42.0 to Jenny Lind- RM 34.6), there is better quality habitat (e.g., large woody debris, pocket water, water temperature) than the other reaches and the majority of *O. mykiss* spawning and rearing has been observed here (Stillwater Sciences 2004; SEWD unpublished data). Based on WUA/PHI curves, a minimum flow commitment of 20 cfs at Shelton Road- RM 29.3 (equivalent to about 25 cfs released from New Hogan) ensures that a balance between suitable spawning and rearing habitat is available in this important spawning and rearing reach during the non-irrigation season (begins on or about October 16 and ends on or about April 14), which encompasses the steelhead spawning season (December through March) as well as year-round rearing.

During the irrigation season (begins on or about April 15 and ends on or about October 15), flows average about 150 cfs which are higher than those that would maximize suitable habitat for fry and juvenile rearing in Reaches 1 and 2 but provide water temperatures that are typically within EPA recommended water temperatures for “core” rearing (<16°C; 61°F)[1]. Irrigation flows provide a relatively high amount of suitable physical habitat in Reach 3 and oversummering water temperatures that are generally within those recommended for “non-core” rearing areas (<18°C;

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[1] Little is known about the specific responses of Central Valley salmonid species to water temperatures (Williams and others 2007). In absence of Central Valley specific data, criteria developed for more northern stocks are typically used as a conservative objective. For example, a Peer Review Panel on the nearby Stanislaus River recommended that EPA Region 10 criteria (developed based on laboratory studies of Pacific Northwest and Alaskan stocks; EPA 2003) be used as objectives to evaluate potential benefits of various operating scenarios against one another (Deas and others 2004).These temperature criteria are believed to be conservative for Central Valley salmonids since water temperatures in more southern areas have always been naturally higher, particularly in the San Joaquin basin, and regional salmonids have likely evolved to withstand higher temperatures. Therefore, it was assumed that as long as temperatures were within the EPA criteria which are based on a 7-day average of the daily maximum (DADM) values (i.e., <13°C [55°F] for salmonid spawning, egg incubation, and fry emergence; <16°C [61°F] for “core” rearing areas; and <18°C; 64°F for migration plus “non-core” rearing areas), the likelihood of temperature effects to salmonids would be minimized. These objectives can be applied in a similar approach to the Calaveras River.

64°F). Although Reach 4 also has suitable physical habitat at higher irrigation season flows, it is considered to be mostly a migration corridor due to limited habitat structure, (e.g., smallmouth bass), and unsuitable oversummering temperatures.

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