LOWER KINGS RIVER FISHERY HABITAT CHARACTERIZATION AND IDENTIFICATION OF HABITAT ENHANCEMENT OPPORTUNITIES

A STUDY BY CRAMER FISH SCIENCES FOR THE KINGS RIVER FISHERY MANAGEMENT PROGRAM

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27 September 2019

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DISCLAIMER

The findings and recommendations presented in this report are those of Cramer Fish Science to help inform the Lower Kings River Fishery Management Program (KRFMP) regarding potential habitat enhancement actions in the lower river between Pine Flat Dam and Fresno Weir.

EXECUTIVE SUMMARY

The Kings River Water Association (KRWA), Kings River Conservation District (KRCD), and California Department of Fish and Wildlife (CDFW) collaboratively developed and implemented the Kings River Fishery Management Program (KRFMP) for the Kings River downstream of Pine Flat Dam. Although attention is given to the entire lower Kings River (LKR) aquatic community, for this study the primary species of interest is the Rainbow Trout (*Oncorhynchus mykiss*), which supports a popular sport fishery.

To assist in continued development of a Framework for Agreement actions, the Program commissioned an aerial LiDAR survey (green LiDAR) to map topography of the lower river channel.

The purpose of this project was to:

a. Apply the LiDAR and associated physical data (e.g., flow, water temperature) to model Rainbow Trout physical habitat conditions within the 9-mile river reach between Pine Flat Dam and Fresno weir; and
b. Provide modeled Rainbow Trout life stage-specific habitat output to inform potential future fisheries management actions focusing on habitat enhancement.

With guidance from the KRCD, CDFW, and KRWA, we undertook a 5-step approach to identify how much and what type of habitat is needed to support hypothetical KRFMP fisheries goals and identify candidate habitat enhancement actions and potential locations to support those needs (Figure I).

Key Outcomes

Spawning Habitat Modeling – At flows of 100 cfs, the model predicts ~40-70 acres of river channel meet spawning depth and velocity preferences of Rainbow Trout. At 250 cfs, this increases to ~70-100 acres. However, the substrate analysis implies that less than 25% of bed surface particles within areas that meet spawning depth and velocities could be mobilized by spawning Rainbow Trout (substrate is too large). Although some variability in grainsize was observed along the stream corridor, oversized material appears to be a chronic issue throughout the study reach. Shear stress predictions, coupled with reduced sediment recruitment from upstream (reservoir storage), suggest that at 8,800 cfs the current channel configuration does not facilitate persistence of Rainbow Trout spawning gravels within the study reach. For a minimum viable population of 833 spawners (Population 1), our model predicts ~ 0.5 acres (SD 0.3) of spawning habitat is needed. For a harvestable population (Population 2) that supports past angling pressure (1,600-2,300 spawners; 35,000 harvestable fish annually), the model predicts ~2.6 acres (SD 1.9) of suitable spawning habitat is required.

TASK 1. RAINBOW TROUT DATA REVIEW SUMMARY FOR CONCEPTUAL LIFE CYCLE AND STAGE TRANSITIONS

We characterized the Rainbow Trout general life cycle, including life stages and timing. These characterizations provide a framework for identifying fishery habitat needs within the managed flow regime of the lower Kings River. To focus subsequent tasks, we hypothesized spawning and over-summer rearing habitat may limit Rainbow Trout production in the lower Kings River.

TASK 2. HYDRAULIC MODELING

Two-dimensional hydrodynamic models are used to evaluate fish habitat and plan/assess habitat enhancement programs. However, meaningful 2D modeling requires the river's hydrology be put into the context of the target organism's life cycle (ecohydrology). Under this task, we describe 2D hydraulic model development. This includes LiDAR data preparation, identification of flow scenarios we would expect key trout life stages (Task 1) to be exposed to, and evaluation of model performance.

TASK 3. HABITAT SUITABILITY MODELING

Habitat suitability models use relationships between habitat preferences (e.g., depth, velocity, substrate, cover) and flow (Task 2) to predict habitat availability. We used model results to predict potential Rainbow Trout spawning and rearing habitat below Pine Flat Reservoir. We also assessed spawning substrate suitability using videography and boat-based surveys to further inform our modeled habitat estimates. Finally, we characterized historic water temperature data to determine potential thermal limitations to habitat for key trout life stages that may guide future potential habitat enhancement prioritization.

TASK 4. QUANTITATIVE LIFE CYCLE MODEL AND ASSOCIATED HABITAT NEEDS – LOWER KINGS RIVER RAINBOW TROUT POPULATION

Understanding relationships between fish populations, resource availability (i.e., funds and habitat), management actions, and angler harvest expectations is critical for effective fisheries management. To support evaluation of habitat rehabilitation actions against potential fisheries goals, we identified bookend Rainbow Trout populations that included a: (1) minimum viable population; and (2) population that supports historic harvest expectations. We then used life cycle modeling, in concert with Task 3 results, to test our habitat-specific hypotheses. Results inform Task 5.

TASK 5. ALTERNATIVE HABITAT IMPROVEMENT

Before exploring habitat enhancement alternatives, it is important to examine the river's physical structure in context to its current hydrogeomorphology. Using Task 1-4 results, we characterized the present fluvial and geomorphic conditions of the lower river. Of note is that over 60% of the study area is characterized as slackwater habitat, which is not preferred by Rainbow Trout. From these results we developed candidate enhancement actions to improve river habitat, identify potential locations for different actions, and prioritize these actions.

Figure I. General process undertaken to complete the Lower Kings River Fishery Habitat Characterization and Identification of Habitat Enhancement Opportunities Project.

Rearing Habitat Modeling – Habitat suitability modeling predicted ~96 –155 acres of hydraulically suitable (suitable depth and velocity) juvenile rearing habitat for the range of flows modeled. However, when considering modeled edge cover needs, potential habitat ranges from 1.4 – 46 acres with an average between ~7 and 21 acres depending on modeled flow and trout size.

Population 1 model results indicate a range of 3 – 10 acres of fry/parr rearing habitat is needed in the early summer period. In contrast, model results indicate 5 – 22 acres of fry/parr rearing habitat is needed to support the modeled harvestable population (Population 2) during the early summer period. During the July-September period, model results suggest rearing juveniles require 10 – 15 acres (Population 1) and 26 – 43 acres (Population 2). Using conservative assumptions, modeling outcomes indicate a deficit of 1.5 – 13.5 acres of early summer and 6 – 22 acres of July-September rearing habitat enhancement are needed, depending on Rainbow Trout population goals.

Comparison of potential needs provided by the life cycle model and potential available habitat identified by combining 2-D hydraulic modeling and substrate analysis, offers a measure of possible habitat deficits that could be addressed to reach potential future KRFMP goals.

Temperature – In general water temperatures are both warmer and more variable at the Fresno Weir location compared to the USACE Bridge. Temperatures were mostly within optimal ranges for spawning and incubation at the USACE Bridge with only a small instance of stressful conditions at the beginning of the hypothesized spawning season. Temperatures for rearing juvenile fish did not exceed stressful limits but on average were outside the optimal range for roughly half the year. Fresno Weir temperatures were elevated to a range considered to be unsuitable for all life stages under certain conditions, especially for dry years and maximum values for normal and dry years. Location of a single data logger at the downstream end of a large pool at Fresno Weir may have exaggerated water temperature during the summer period. A more fully developed temperature monitoring program is suggested. Ultimately, the results of the temperature exercise suggest that future enhancement actions should focus from upstream down to maximize potential enhancement actions.

Integrating Existing Physical & Biological Data - Shear stress predictions at the highest modeled flow (8,800 cfs) indicate the current channel configuration does not support a large amount of area where Rainbow Trout-sized spawning gravels would persist. Of the mapped hydraulically suitable spawning habitat only 40% would support spawning gravel in the river's current configuration. Limited gravel recruitment supports field observations that bed sediments are generally too coarse for Rainbow Trout spawning due to gravel mobilization during peak flows.

Morphologic unit mapping at 100 cfs indicate that ~60% of both reaches consist of slackwater, a habitat unit not preferred by Rainbow Trout. The available riffle-pool habitat is much less than the 1:1 ratio reported for productive Rainbow Trout streams. In fact, mapped morphologic units show that these habitat units are relatively deficient in the study area. Mapping indicates only six locations had direct pool to riffle transitions, and half of these had intermediate slackwater units, suggesting habitat enhancement is a potentially viable tool for the LKR.

Priority Ranking of Habitat Enhancement Scenarios – Six potential habitat improvement scenarios were identified including: (1) gravel injection, (2) spawning riffle enhancement, (3) local widening and augmentation, (4) island creation, (5) channel morphology rehabilitation, and (6) off-channel habitat excavation. Given that study results imply spawning substrate is highly deficient and there is sufficient juvenile rearing habitat for a minimum viable population, we recommend that gravel augmentation and spawning habitat enhancement projects be prioritized first. Spawning habitat enhancement projects can also yield direct benefits to fry and juvenile salmonids; therefore, benefitting multiple life stages. We identified 16 locations for ~25 and 40 acres of potential spawning and rearing habitat enhancement, respectively. Of these, five sites were ranked as high priority locations for potential habitat enhancement actions. As a result of temperature modeling outcomes, we recommend initiating enhancement projects from upstream down to avoid potential reduction of project value associated with potential negative temperature effects observed at Fresno Weir.

LOWER KINGS RIVER FISHERY HABITAT CHARACTERIZATION AND IDENTIFICATION OF HABITAT ENHANCEMENT OPPORTUNITIES

BACKGROUND AND PURPOSE

Pine Flat Dam was constructed on the Lower Kings River (LKR) by the United States Army Corps of Engineers (USACE) in 1954 primarily for flood control and water storage (KRFMP 2012). In 1984 the Kings River Conservation District (KRCD) built the Jeff L. Taylor 165-megawatt hydroelectric power plant at the base of the dam. Over the last six decades, water passing Pine Flat Dam has been managed to meet the needs of local agriculture and municipalities, hydroelectric power generation, and support a popular Rainbow Trout (*Oncorhynchus mykiss*) tailwater fishery.

The LKR recreational Rainbow Trout fishery extends from Pine Flat Dam downstream to Highway 180 (Figure 1) and is sustained by frequent trout plants of various life stages from hatcheries and natural reproduction (Hanson and Bajjaliya 2005). Rainbow Trout are managed within a harvest reach (five fish limit) between Pine Flat Dam and Cobbles Weir and a catch-and-release reach (zero trout limit) between the Cobbles and Fresno weirs. In the late 1990’s the KRCD, Kings River Water Association (KRWA), and California Department of Fish and Wildlife (CDFW) collaboratively established the Kings River Fisheries Management Program (KRFMP) to support and pursue a program to improve and manage fisheries and aquatic habitat conditions within Pine Flat Reservoir and the Kings River below Pine Flat Dam. The governing KRFMP (Framework Agreement; KRFMP 1999) document provides several recommendations that aim to improve and maintain the LKR fishery that include minimum instream flows and guidelines for cold water pool management within Pine Flat Reservoir and in-channel fish habitat improvements. As part of the KRFMP management and habitat enhancement actions, the CDFW has maintained an annual stocking program that includes approximately 25,000 fingerling and 36,000 catchable-sized trout (KRFMP 2011). The overarching aim of these efforts in the river reaches from Pine Flat Dam to Fresno Weir is to create and maintain recreational fishing opportunities in a year-round, high-quality trout fishery, while providing habitat and management for native species to ensure their continued survival in the Kings River system (KRFMP 1999).

Successful fisheries habitat improvement projects are designed to activate under contemporary hydrographs and flow schedules and create or enhance habitat types, features, and or processes that limit productivity of a target species and population. Therefore, it is imperative that resource managers understand: 1) what the population target or goal is (e.g., population size, abundance of adults, etc.), 2) how much habitat is currently available for the target species and if that amount of habitat is sufficient for meeting fishery management goals, and 3) identify what type of habitat is limiting the population’s productivity and ability to reach the desired goal. Resource managers will be able to clearly identify how to measure success for a given habitat enhancement action or management strategy by defining these three key elements of their fishery.

The purpose of this project is to support the KFRMP in defining specific habitat management/enhancement goals for the Rainbow Trout fishery, within the framework of the KRFMP, and identify how much and what type of habitat is needed to support reaching those goals. Specifically, with collaboration of the KRCD, CDFW, and KRWA we used a Light Detection and Ranging (LiDAR) dataset commissioned by the KRFMP to simulate hydraulic conditions for target flow levels along a 9-mile reach of the LKR between Pine Flat Dam and Fresno Weir (Study Reach; Figure 1).

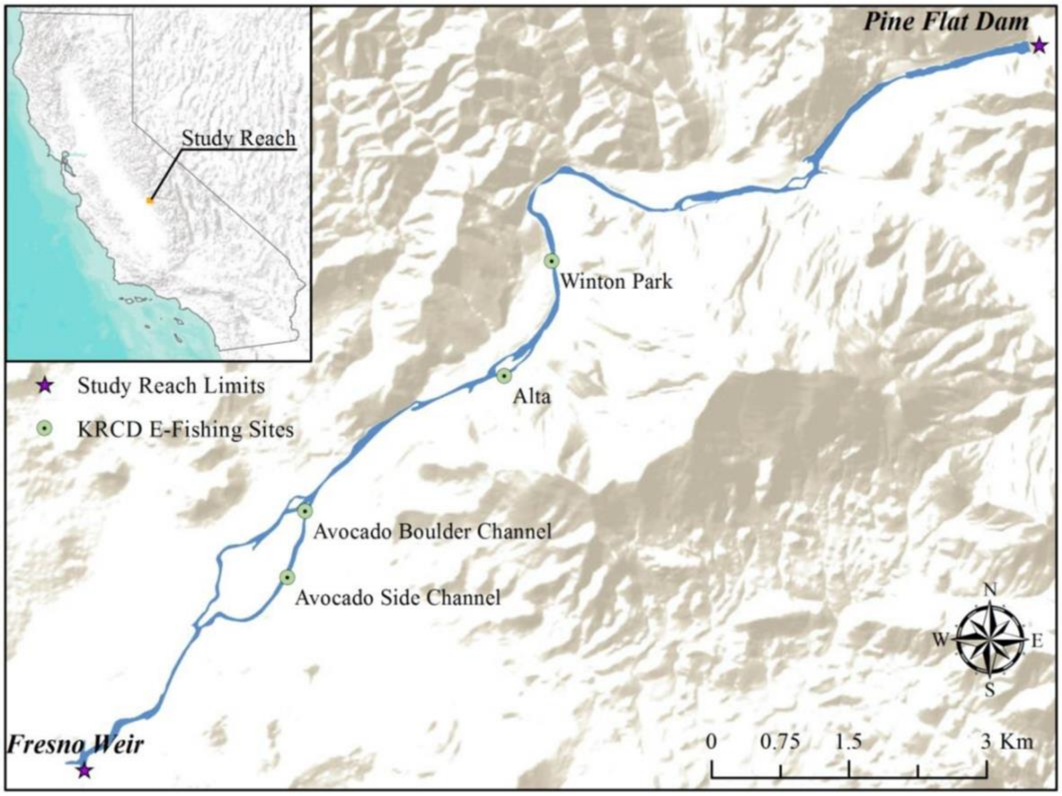


Figure 1. The study reach spans nine river miles downstream of Pine Flat Dam to the Fresno Weir (purple stars) on the Kings River, CA. Note KRCD electrofishing site locations are approximate.

These hydraulic simulations provide the foundation from which our team evaluated the availability of existing physical habitat for key Rainbow Trout life stages, and in turn, possible habitat deficits that could hinder reaching KRFMP goals. We then used this information to identify habitat enhancement opportunities throughout the study reach. We then put these data into a framework that can inform the KRFMP's evaluation of how several different enhancement actions might impact the Rainbow Trout fishery based on the spatiotemporal context of their habitat needs. Finally, in collaboration with the KRFMP, our team then developed a set of criteria that can be used to rank the value of competing habitat rehabilitation actions. These criteria are generally based on Rainbow Trout spawning/incubation, and rearing habitat potential, landowner support, and the estimated impact to the Rainbow Trout population. Results from this study are meant to improve our general understanding of habitat related to study reach flows and provide a framework for evaluating how disparate habitat rehabilitation and management strategies can aid the KRFMP in reaching management goals for the tailwater Rainbow Trout fishery below Pine Flat Dam. It is important to note that this project focuses on the relationship between flow, channel morphology and substrate particle size. Many other factors, including, but not limited to, water quality, food production, harvest rates, invasive species etc. also contribute to fishery success but were not direct components of this project.

Strategy

Fishery management is a process intended to accomplish predetermined goals and objectives, including habitat maintenance or enhancement. Unfortunately, fisheries programs rarely explicitly state goals or when they do, goals are often put into generalized terms of "best" or "wise" use with no supporting objective statements (Barber and Taylor 1990). Goals are ideals or major accomplishments to be achieved that direct management planning, strategy development, and direction of organization activities. Objectives operationally support goals and are measurable, verifiable statements of intermediate tasks that must be accomplished for goal attainment (Hallahan 2015). These objectives help define goals, identify conflicting activities, guide elements of the decision-making process, and ensure accountability within an organization. Without clearly defined goals and supporting objectives, goal displacement often occurs (Barber and Taylor 1990). What makes measurable goals and objectives so difficult to identify is that they are influenced by values, which are personal or individual standards as to what is good or bad, fair or unfair, and hence influence management decisions. Therefore, the more incongruent the participants' values are in an organization, the more difficult it is to determine and reach an organization's goals and objectives (Barber and Taylor 1990). Values influence the allocation process: How much is allocated and where allocated resources go. Thus, the fisheries management process often suffers from lack of recognizing the roles and dynamics of goals, objectives, and values in effective fisheries management. Therefore, measurable goals are a difficult, yet crucial aspect of fisheries management that can help guide the planning process, including setting angling standards and developing habitat rehabilitation or enhancement activities.

In practice, fisheries managers must analyze and select options to maintain or alter the structure, dynamics, and interaction of habitat, aquatic biota, and society to achieve management goals and objectives (Lacky 1998). Fisheries management theory generally subscribes to the idea that managers or decision makers attempt to maximize renewable ‘output’ from an aquatic resource by choosing from among a set of decision options and applying a set of actions that generate an array of outputs (Figure 2).

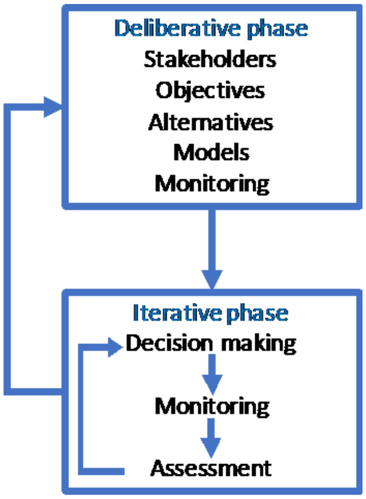
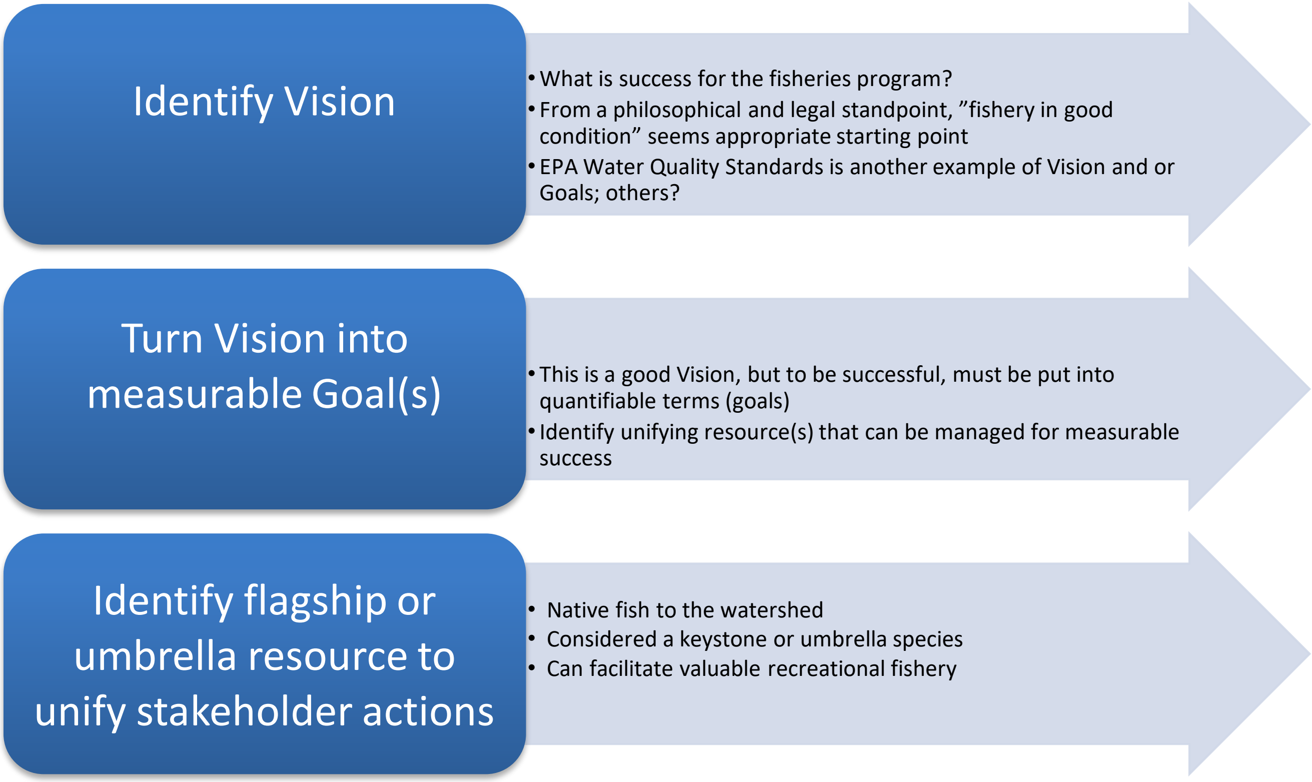


Figure 2. Two-phase learning in adaptive management. Technical learning involves an iterative sequence of decision-making, monitoring, and assessment. Social and institutional learning involves periodic reconsideration of the set-up elements in the deliberative phase (taken from Williams and Brown 2014).

Science, including the development of hypotheses related to management actions, and in turn environmental response, monitoring, and assessment, are meant to inform the adaptive process, which supports wise resource management (Williams and Brown 2014). In short, our strategy was to provide objective science to support stakeholders in making informed decisions about the management of the LKR tailwater trout fishery including the determination of measurable goals. Therefore, this project was not meant to develop management visions or goals but to provide information that could facilitate development of measurable KRFMP targets and weigh the cost and benefits of various management actions, focusing on habitat rehabilitation (Figure 3).



Identify Vision

- What is success for the fisheries program?
- From a philosophical and legal standpoint, ”fishery in good condition” seems appropriate starting point
- EPA Water Quality Standards is another example of Vision and or Goals; others?

Turn Vision into measurable Goal(s)

- This is a good Vision, but to be successful, must be put into quantifiable terms (goals)
- Identify unifying resource(s) that can be managed for measurable success

Identify flagship or umbrella resource to unify stakeholder actions

- Native fish to the watershed
- Considered a keystone or umbrella species
- Can facilitate valuable recreational fishery

Figure 3. The pathway to creating and maintaining a successful Kings River trout fishery.

This Document in Context of Kings River Fisheries Management Goals

Although goals for the LKR fishery have yet to be defined in measurable terms, several administrative actions provide a framework for fisheries management within the study area to guide this work (KRCD and KRWA 2009):

(1) for over 50 years, Rainbow Trout have been the primary angling focus within this 9-mile tailwater fishery;

To maintain the productivity and quality of the fishery-

(2) a flow standard has been developed;
(3) a long-standing trout planting program occurs;
(4) habitat rehabilitation has been implemented; and
(5) angling regulations related to management reaches intended for (a) catch and release and (b) angler harvest are meant to support quality and productivity of the fishery.

These activities have been driven by general angler perceptions of success and satisfaction nested in a range of angler community visions from a “put and take” to a purely “wild trout” fishery, which have culminated in a Put and Take zone (emphasis “All-year high yield trout fishery”) and Catch and Release zone (emphasis “All-year premium-quality trout fishery”) (KRFMP 1999).

Habitat Management in Context of Fisheries Goals

Understanding the relationships between fish populations, fishing success, resource availability (i.e., funds and habitat), management actions, and angler satisfaction is critical for effective fisheries management (Spencer and Spangler 1992). However, linking habitat to management and conservation is not trivial. Conventional wisdom suggests that preservation or rehabilitation of ‘habitat’ underpins effective management and conservation of organisms and ecosystem services (e.g., water quality, trout fishery, etc.). This implies that understanding, identifying, protecting, and maintaining critical ‘habitat’ are the best avenues for success. Clearly, effective management strategies consider the biological components (e.g. species), but also the dynamics of their interactions because these may sustain the habitats of many species (Naiman and Latterell 2005). While this document focuses on a Rainbow Trout fishery, due to their popularity and angling value, it is important to recognize Sierra Nevada foothill streams within elevations less than 2,500 feet historically were part of the pikeminnow-hardhead-sucker assemblage described by Moyle (2002). Therefore, a diverse community of native and non-native fish occur within the study reach supporting a wide range of ecological services and management challenges (KRCD 2016). Future research should consider key aspects of the entire aquatic community that help represent healthy ecosystem function for the lower Kings River.

Angling Regulations and Fishery Success

Rainbow Trout are well-suited as an overall management focus for the LKR tailwater because they are typically high on the food web, can strongly influence food web dynamics (Power 1990), have a relatively high caloric need of diverse prey species, and even though non-anadromous, Rainbow Trout use a variety of habitats to complete their life cycle, showing demonstrable responses to habitat quality change (Suttle et al. 2004). The stretch of river immediately below Pine Flat Dam most-likely fit into Foothill Community (Pikeminnow-hardhead-sucker Zone). It is unclear how significant *O. mykiss* were within the historic fish community of the study reach prior to construction of Pine Flat Dam. Even so, because this species indicates habitat function on many levels of the stream and is highly prized by the local angling community, it is the focus of habitat management for the LKR and in turn the focus of this study (Figure 4).

Population has low chance of going extinct in foreseeable future

- Genetic assessment dictates minimum viable population as starting point

Demonstrates diverse population traits

- Numerous age classes
- Variety of life cycle strategies
- Variability in morphologies

Demonstrates overall ecosystem benefits as population comes on line

- Changes in food web complexity and productivity (e.g., overall fish community health; macroinvertebrate community; osprey population benefits)
- Benefits to physical habitat processes (e.g., increased habitat complexity; sediment segregation; water quality etc.)

Provides Quantifiable Ecosystem Services

- A productive fishery – supports recreational fishery (how many per year? Put and take vs catch and release? Revenue? Tourism?)
- Educational opportunities – trout in classroom; student learning opportunities
- Sight-Seeing - Spawning viewing

Figure 4. Focal species management. Defining values and goals for a successful fishery.

Hatchery Versus Wild

The use of hatchery-reared, catchable-sized trout to supplement existing wild stream-dwelling trout populations is an accepted fisheries management practice/action in North America (Meyer et al. 2012). While hatchery supplementation is not the focus of this document, it can have a significant effect on wild trout production, and the subsequent habitat needed to support the mixed fishery of the LKR (Figure 5). This may further result in tradeoffs between fish quantity and quality, creating conflict in perceived satisfaction associated with specific angler values and may mask overall ecosystem issues (Vincent 1987; Lewen et al. 2006). For instance, stocking catchable-size trout to create sport fisheries is based on a simple conceptual model: stocking more fish creates better fisheries that attract more anglers (Patterson and Sullivan 2013). Under this premise, organizations typically stock variable fish densities (i.e., cost) and expect correlated responses in catch rate and angler effort (i.e., benefit). However, stocking practices can have a range of outcomes depending on visions, goals and personal values of the angling community (Figure 5). McCormick and Porter (2014) examined factors influencing anglers' perceptions to quantify their satisfaction in an Oregon Rainbow Trout fishery. They found the probability of increased angler satisfaction rating was positively related to mean length and number of fish caught per hour. However, younger anglers tended to have higher satisfaction ratings at lower mean fish length and catch rates than did older anglers. This suggests quantitative, measurable, objectives can be identified that will satisfy desired percentages of anglers and lead to more effective fisheries management. Patterson and Sullivan (2013) further tested the assumption of cost (stocking rates) to benefit (catch rates) in a stocked Alberta Rainbow Trout fishery and found no correlation between stocking and catch rates. Rather, stocking low or high trout densities created low-density stocks supporting low-catch-rate fisheries, but attracted many anglers if catch rates exceeded 0.08 trout/angler- hr and fisheries were close to anglers' homes. From these results, they proposed a fiscally responsible stocking model (i.e., stock minimum fish numbers to remain above an optimal catch rate at locations selected to attract anglers) allowing managers to either increase stocking sites or reduce stocking costs while maintaining angler effort.

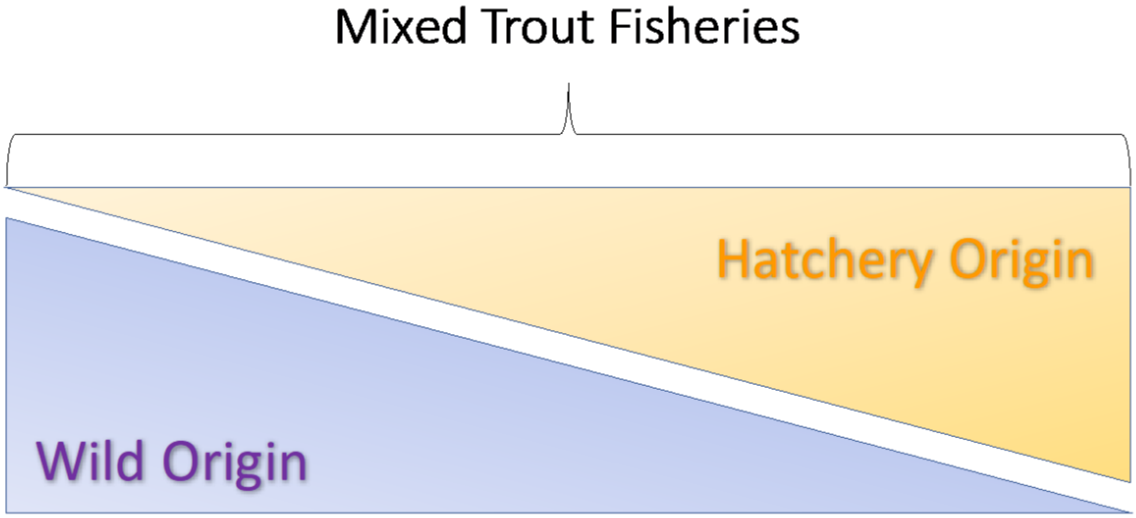


Figure 5. The composition of a successful trout fishery will be a product of the inherent habitat capacity of the system and stake-holder interests and goals.

Miko et al. (1995) evaluated three stocking densities of harvestable-size Rainbow Trout—low (700 trout/ha), medium (1,400 trout/ha), and high (2,100 trout/ha)—to determine a stocking strategy that provides maximum fishery benefits from a limited number of fish. Catch rates were significantly higher for waters with medium and high stocking densities. However, angler effort, proportion of stocked fish caught, angler fishing success rating, and angler trip satisfaction rating did not differ among stocking treatments. Despite catch rates of 0.5 trout/hr, anglers rated fishing-success less than "fair" and trip satisfaction less than "good." Schramm et al. (1998) found that informing anglers about actual Rainbow Trout catch rates in the previous year significantly improved anglers' fishing success ratings and suggested that angler fishing-success rating is an important element of fishery evaluation and providing catch rate standards is necessary for realistic angler evaluation. These results suggest that before a stocking strategy can be designed, a management goal must be set because no single stocking strategy proves superior for all management goals considered. Understanding stakeholder goals, the carrying capacity of the system, and the resources available to manage the fishery are important pieces of information that will ultimately inform management decisions on the appropriate goals for the fishery (Figure 6).

It has been demonstrated that hatchery fish behave differently than their naturally-produced counterparts (Fenderson et al. 1968; Berejikian et al. 1996); may have greater or lesser survival than naturally- produced fish (Reisenbichler and Rubin 1999); and, may ultimately alter the gene pool of naturally- produced fish populations posing a risk to race preservation (Banks et al. 2000; Leary et al. 1985).

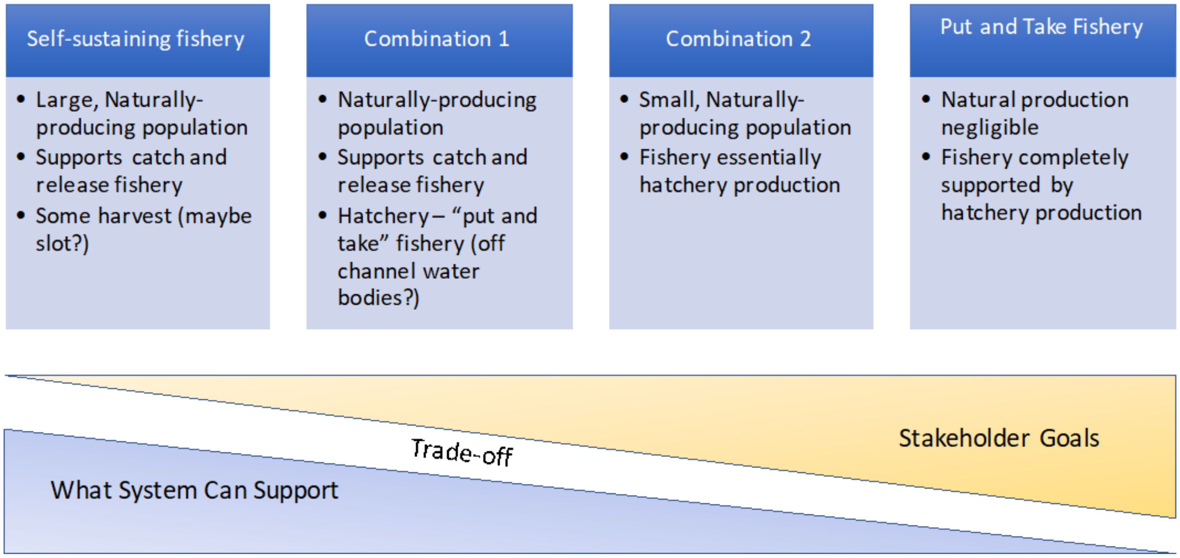


Figure 6. Conceptual ideas for comparing trade-off between what the system can support and stakeholder goals. Both system carrying-capacity and stakeholder goals will most likely shift over time.

Loss of genetic variation in the hatchery environment can even affect population susceptibility to pathogens (Arkush et al. 2002). Domestication selection is typically inferred from improved survival of progeny under culture and changes in behavioral characteristics and reproductive performance (Doyle et al.1995). Bettinger and Bettoli (2002) found that in a popular Tennessee Rainbow Trout fishery maintained by an extensive stocking program, low survival and return rates of catchable trout were attributed to their rapid, long-range movements and high activity levels, causing low energy efficiency and high predation vulnerability in relationship to resident trout. When wild (naturally-produced) trout are a fishery objective, hatchery release strategies can have a range of effects on wild trout, and in turn the fishery's success. For instance, Petrosky and Bjornn (1988) found that wild trout in two Idaho streams were unaffected by low stocking rates of catchable-size Rainbow Trout but were significantly impacted at the highest stocking rates. No matter the ultimate management goal, hatchery and naturally-produced fish will compete for habitat and food requiring a habitat management plan (McMichael et al. 1999).

Angling Regulations and Fishery Success

Angling regulations and community preferences can significantly influence fishery performance and in turn habitat needs, depending on overall goals, community buy-in and regulation enforcement. For example, Anderson and Nehring (1984) found that in a South Platte River catch-and-release area dominated by Rainbow Trout, fish biomass was as high as 667 kg/hectare, and 50% of trout were greater than 30 cm long. In contrast, the trout population of a standard regulation (eight trout per day) area was dominated by Brown Trout (*Salmo trutta*), had a maximum biomass of 219 kg/hectare, and only 17% of the population were longer than 30 cm. Trout population characteristics difference was attributed to respective harvest rates. Rainbow Trout were more vulnerable to angling than Brown Trout, and Age 3+ and older trout were more exploited than young/smaller fish. Catch rates averaged 48% greater in the catch-and-release area than in the standard-regulation section that had the benefit of catchable-trout stocking. The catch rate of trophy-sized trout (longer than 38 cm) was 28 times greater in the catch-and- release area than in the harvest area.

Habitat Enhancement and Fishery Goals

There is a clear consensus that fish and fish habitat are affected by river regulation, but the severity and direction of the response varies widely (Murchie et al. 2008). Although dams clearly alter the downstream hydrograph, reduction in quantity and quality of downstream fish habitat is typically associated with change in geomorphologic processes such as sediment cycling (Nilsson and Berggren 2000). Reservoirs typically trap sediment previously transported downstream (Ligon et al. 1995). The water released from a reservoir tends to restore its original sediment and nutrient load, resulting in increased erosion downstream of the dam (Kondolf 1997). This erosion leads to channel simplification and reduced geomorphologic activity in the riverbed including reduced point-bar deposition and river meandering (Johnson 1992). Reduction in pool riffle frequency, incision of the main channel from secondary channels and floodplains and over-coarsening of channel bed surface sediments (armoring) can reduce the overall health and productivity of fish communities, including salmonids (Schneider et al. 2000). It can also take years or decades to see these impacts manifest in overall fishery change, and in turn the ability to determine the appropriate rehabilitation actions (Rasid 1979).

Salmonid habitat rehabilitation below dams is typically grouped into three methodologies: (1) sediment augmentation, (2) hydraulic structure placement and (3) bed enhancement (Wheaton et al. 2004). Despite widespread use of stream enhancement to improve fish habitat, few quantitative studies have evaluated their effectiveness. Furthermore, Roni et al. (2008) found that failure of many enhancement projects to achieve objectives is attributable to inadequate assessment of historic conditions and factors limiting biotic production; poor understanding of watershed-scale processes that influence localized projects; and monitoring at inappropriate spatial and temporal scales. In contrast, Whiteway et al. (2010) used a meta-analysis approach to test the effectiveness of five types of in-stream enhancement structures (weirs, deflectors, cover structures, boulder placement, and large woody debris) on both salmonid abundance and physical habitat characteristics. Data compilation from 211 stream habitat enhancement projects showed a significant increase in habitat complexity and salmonid density (mean effect size of 0.51, or 167%) and biomass (mean effect size of 0.48, or 162%) following structure installation. Large differences were observed between species, with Rainbow Trout showing the largest density and biomass increases. Sediment augmentation and channel bed enhancement have also demonstrated positive results when put into the context of lifestage-specific needs of target salmonids (Zeug et al. 2014; Sellheim et al. 2016; Merz et al. 2019). Therefore, for successful long-term management of the Kings River tailwater Rainbow Trout fishery, an appropriate understanding of population goals, life stage-specific habitat needs, and appropriate rehabilitation methods are warranted.

Relating Fish Population Goal to Habitat Needs- General Assumptions

To support a healthy Rainbow Trout population, the management area must provide enough habitat of the appropriate quality to support each life stage. The connectivity of the different habitat elements in a broad spatio-temporal context and their nestedness, define the fishery’s fitness both on the individual (e.g., growth performances) and population (i.e., population structure, mortality, etc.) level (Schiemer et al. 2000). Relevant spatial scales can be the entire river-scape in the case of migration or the availability of complementary microhabitat elements (e.g., during incubation). The significance of connectivity at various scales from whole river to local reach must be evaluated based on the requirements, reaction norms, and ecological flexibility of the focal species. Habitat needs must be evaluated with regard to (Schiemer et al. 2000):

(1) population genetics over extensive biogeographic areas and in long time scales;

(2) supplementary habitats during the life cycle of individual species with ontogenetic habitat shifts

and specific requirements during the reproductive phase;

(3) longitudinal and lateral transport and exchange processes determining local habitat conditions and the food supply for fish.

Therefore, enough habitat must activate at the right time and duration to allow each life stage to successfully transition to the next life stage to support overall management goals (Merz et al. 2013). Activation includes facilitation of fish access to and from the habitat at the appropriate time (e.g., incubation, hatch and emergence from redd before scour or desiccation).

How Much Habitat?

Numerous studies have found that drift-feeding salmonids defend exclusive feeding territories (Chapman 1966; Grant and Kramer 1990; Keeley and Slaney 1996), thereby limiting the density and production of salmonids to the number of territories that could fit within a given patch habitat (Cramer and Ackerman 2009; Neuswanger et al. 2014). While previous studies assume territory size is fixed and inflexible for a given habitat and size of fish (Elliot 1990; Keeley and Slaney 1996; Grant and Kramer 1990), recent studies show that salmonid territory size varies with population density (Lindeman et al. 2015; Wood et al. 2012), indicating a more complex role of territoriality in the regulation of population size. Territory sizes of juvenile Rainbow Trout (Wood et al. 2012) and Atlantic Salmon (*Salmo salar*) (Lindeman et al. 2015) have been observed to decrease as density increased until a minimum territory size was reached. This asymptotic minimum territory size would set the maximum number of settlers in any particular habitat patch (Lindeman et al. 2015). Therefore, if assumptions can be made about the minimum feeding area requirements of juvenile salmonids, and if there is knowledge of salmonid abundance, body size, and location, then estimates of population-level habitat needs can be calculated (Figure 7). Thus, providing adequate territory quantity (Figure 8) during each life stage can reduce negative population effects (e.g., stress, reduced growth, and increased mortality) associated with competition for space (Keeley 2001).

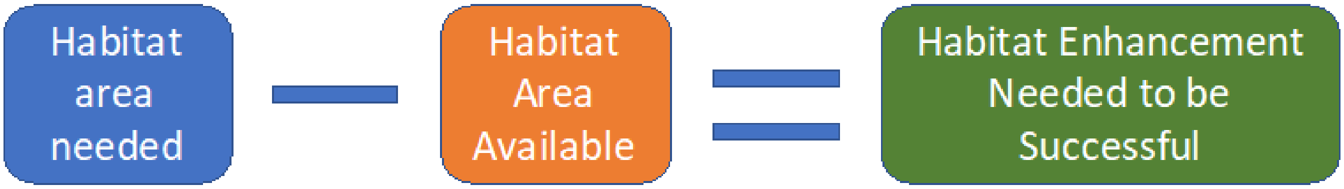


Figure 7. The general relationship between habitat availability and habitat need provides an estimate of habitat enhancement goals.

As previously mentioned, the largest driver of rearing and spawning salmonid territory size is fish size. Because stream salmonids defend territories from the fry stage until they become sexually mature, they must increase the area they defend to meet increasing energy requirements (Keeley and Slaney 1996).

Therefore, fish size in a population may be a good predictor of space requirements and hence maximum population densities. Habitat quality may also control the amount of habitat an individual fish requires, providing options for stream managers where cost, access and other factors limiting the ability to influence the quantity or quality of habitat available (Figure 8; Figure 9).

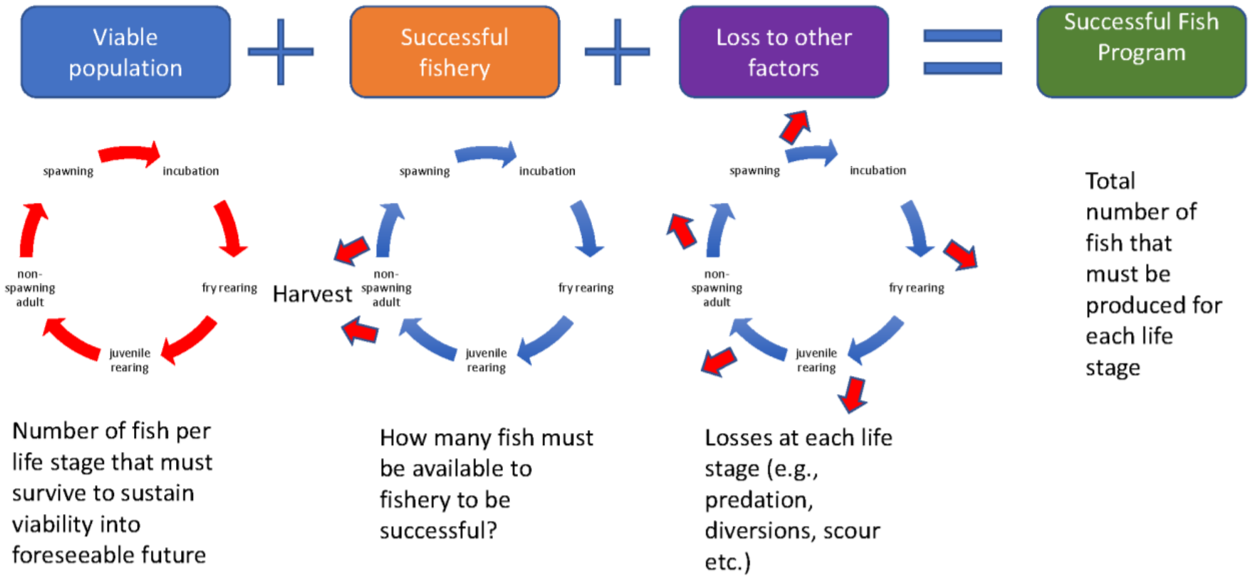


Figure 8. As greater production is needed for the managed population (e.g., harvest rates), the amount of available suitable habitat needed for each life stage that supports the population must be represented at a level that supports the number and size of the population.

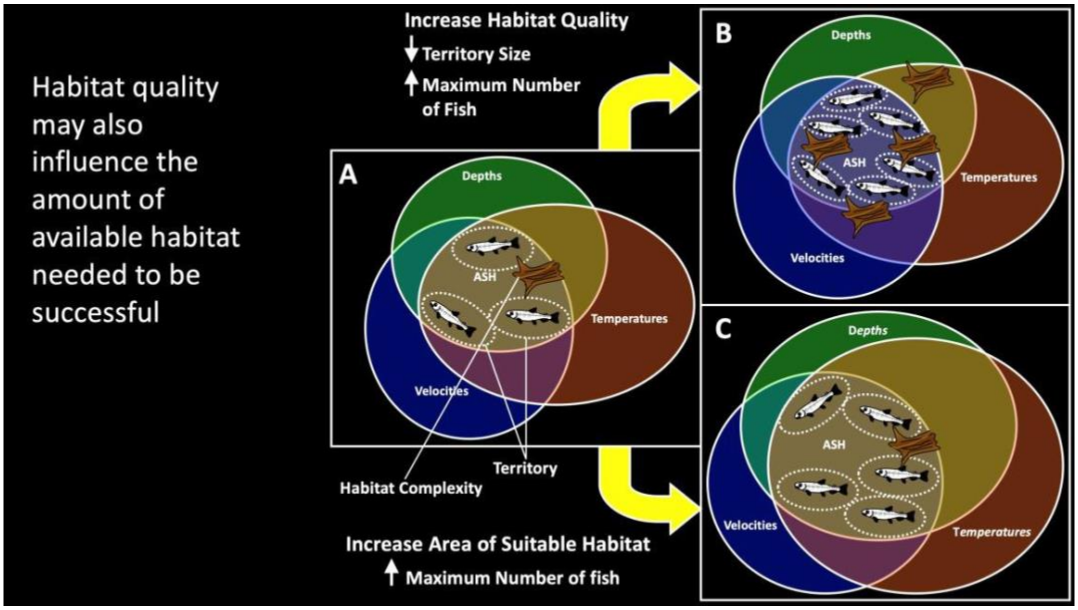


Figure 9. Habitat quality may also influence the amount of habitat needed to support the overall fishery goal.

The relationship between female size to spawning habitat also generally holds true but is more related to the area a female needs to build a successful redd (Crisp and Carling 1989). These relationships are the foundation of our habitat analysis.

TASK 1. RAINBOW TROUT DATA REVIEW SUMMARY FOR CONCEPTUAL LIFE CYCLE AND STAGE TRANSISTIONS

Background and Purpose

Rainbow Trout were identified as the focal fish species associated with the LKR Fishery Habitat Characteristics and Habitat Enhancement Opportunities Project. Because a key aspect of the project is to support the KRFMP in further developing a framework for clearly identifying fisheries goals and habitat needs to support that fishery, Task 1 centers on identifying the life cycle and stage transitions of Rainbow Trout so that we can develop a framework for identifying fisheries goals and habitat needs to support the fishery. Specifically, what lifestage-specific habitat needs limit Rainbow Trout production in the study reach?

Focus Species - Rainbow Trout

Rainbow Trout belong to the same genus as Pacific salmon (Oncorhynchus), and to the family Salmonidae, which includes Atlantic Salmon (*Salmo salar*), various trout (both Oncorhynchus and Salmo) and char (*Salvelinus* spp.), grayling (*Thymallus* spp.) and whitefish (*Coregonus* spp.) (Behnke 2010). Rainbow Trout are native to areas around the Pacific Rim, from southern California and Baja California through Alaska, the Aleutians and the western Pacific areas of the Kamchatka Peninsula and Okhotska Sea drainages. Rainbow Trout primarily inhabit fresh water, but in the eastern and western North Pacific, anadromous stocks are found. These stocks follow a life cycle similar to Pacific salmon, in that they spend a part of their life in the ocean but return to lakes and rivers for spawning and the fry and juvenile stages of their life history. Most Rainbow Trout strains can adapt to life in sea water, once they reach the post-juvenile stage (c. 75–100 g), through a gradual increase in salinity of their rearing water (Hardy 2002). This is one of the qualities of Rainbow Trout that has led to their prominence as a farmed species. Rainbow Trout have been cultured for hundreds of years and are the most widely farmed trout in the world (Hardy 2002). Rainbow Trout can tolerate a wide range of water temperatures and other environmental variables, such as water quality, but they require highly oxygenated water and thrive in water temperatures of 13–18°C. Due to their ability to flourish in hatcheries, Rainbow Trout have been introduced into much of the United States and now inhabit many streams and lakes throughout the country. Rainbow Trout popularity among anglers has placed it among the top five sport fishes in North America, and it is considered by many to be the most important game fish west of the Rocky Mountains. In this section, we provide background information on Rainbow Trout from numerous sources because information specific to populations of the LKR are still limited. Future research should shed light on timing and specific environmental conditions conducive to each lifestage within the LKR.

Rainbow Trout Life History

Coastal Rainbow Trout have highly diverse life history strategies (Figure 10). This, in combination with a prolific hatchery program, make them the most widespread of the Pacific salmonids in California.

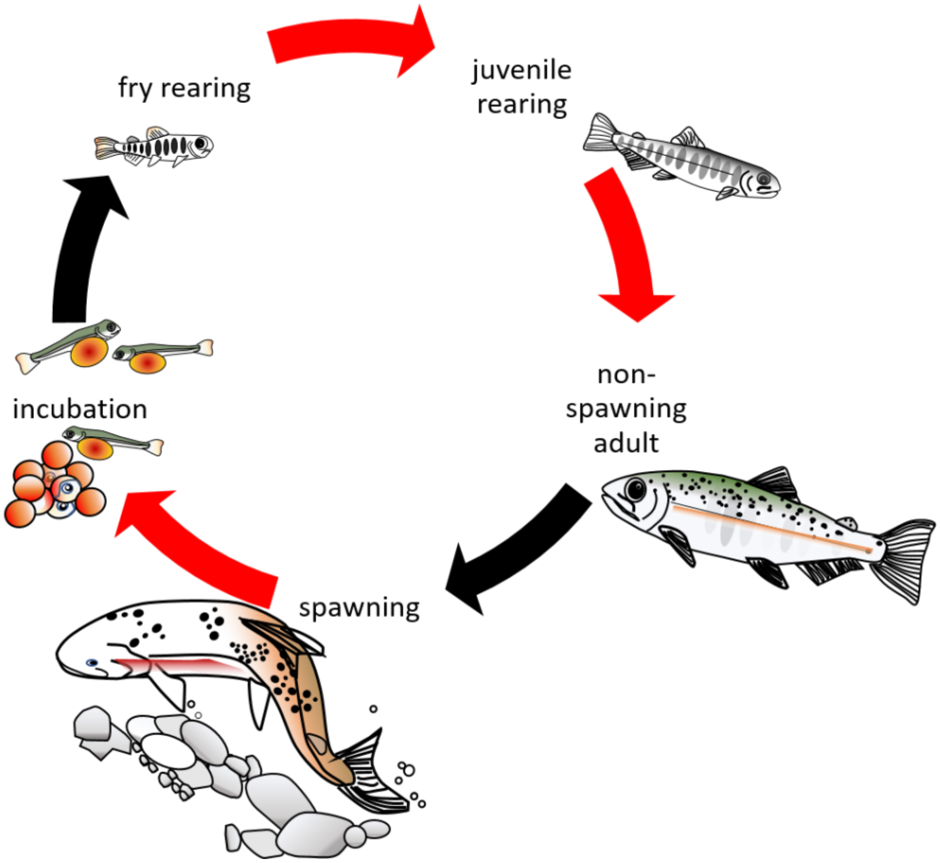


Figure 10. Simplified Rainbow Trout life cycle associated with habitat management in the lower Kings River, California.

While the classic pattern for resident trout is to spend most of their lives in a short section of stream, making only short migrations (a few meters to a few kilometers) for spawning (Moyle 2002); riverine Rainbow Trout have been documented also making extensive and complex migrations (Meka et al. 2003). However, one can consider transition between each lifestage requiring some type of migration, whether movement from feeding to spawning grounds, incubation substrate to water column (to begin exogenous feeding) or movement from main channel to floodplains and off channels during high flow events (Fausch et al. 2002). Each must be generally facilitated (e.g., appropriate depths, velocities, cover, substrate etc.) at the appropriate time and duration for a population to be successful (Figure 11).

Spawning

Female Rainbow Trout typically mature in their third year and males in year two, spawn 1-3 times, but rarely live more than five or six years. Throughout their range, spawning normally occurs from January to July, depending on location (Behnke 1979). Per Moyle (2002), California spawning takes place from February to June, depending on flows and temperatures. In the Lower American River, *O. mykiss*, spawning, including steelhead, occurs from late December through mid-April (CFS 2015). On the lower Mokelumne River, *O. mykiss* may begin spawning as early as late November (Bilski and Rible 2013). However, it is important to note that both the lower American and Mokelumne rivers support anadromy and Moyle focuses on populations above Sierran rim dams. Hatchery selection has resulted in fall spawning strains and hatchery fish spawning may occur in almost any month, depending on the strain (Scott and Sumpter 1983; Behnke 1979). Rainbow Trout spawn almost exclusively in streams (Raleigh et al. 1984). Stream spawners typically select gravel and small cobble areas of cool, flowing waters. In general, salmonids spawn in coarse sediments with a median diameter up to about 10% of their body length (Kondolf and Wolman 1993). Spawning in certain river systems may occur in intermittent tributaries (Everest 1973; Price and Geary 1979). In one case, up to 47% of a stream Rainbow Trout population spawned in intermittent tributaries that dried up in midsummer and fall (Erman and Leidy 1975; Erman and Hawthorne 1976).

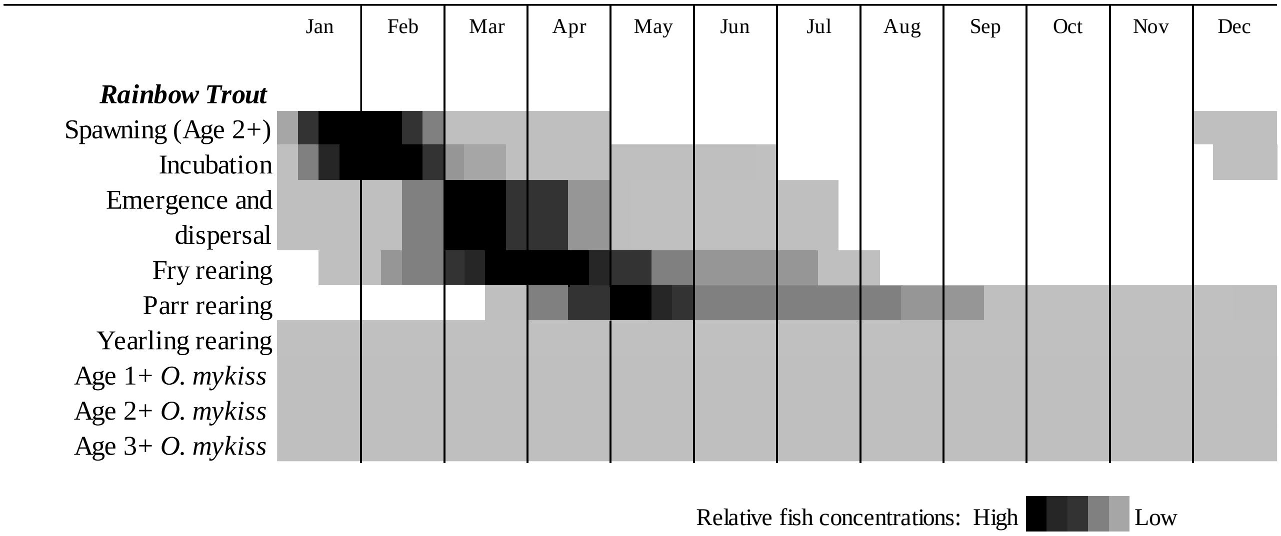


Figure 11. The estimated timing for each life stage of Rainbow Trout in the LKR. Timing comes from a variety of sources including direct observations, published studies from adjacent watersheds and local professional judgement. Coastal Rainbow Trout (Moyle 2002); CDFW observations; Lower American River Steelhead spawning complete by mid-April (CFS 2013-2017); Feb - Jun; CDFW observations suggest some early spawning happens in early December. Embryos hatch in 3-4 weeks (at 10-15° C) and the fry emerge 2-3 weeks later (Moyle 2002); Mokelumne length frequency analysis suggest fry emergence begins in February and complete by August (Merz et al. 2015); rearing timing assumed from Mokelumne River seining surveys (Merz 2015). See following life stage descriptions and associated references. This information is somewhat speculative and future LKR-specific research may shed more light on this subject.

Although stream salmonids have been observed spawning in a variety of habitats, female trout generally select spawning sites at the head of a riffle or downstream edge of a pool (Greeley 1932; Orcutt et al. 1968). The redd pit, is typically longer than the female and deeper than her greatest body depth (Greeley 1932). There is a direct relationship between egg burial depth and female body length with 60 cm female salmonids burying eggs between 10 and 20 cm (Quinn 2011). Hooper (1973) determined that depth of trout egg deposition is 15 cm. Because of these relatively shallow depths, successful resident trout must choose spawning locations that avoid scour during the incubation process (Montgomery et al. 1999). Proximity to cover (e.g., pools, large woody debris, boulder clusters, and overhanging vegetation) and flow shear zones provide important refuge from predation, redd scour and resting zones for energy conservation (Wheaton et al. 2004; Merz 2001). During spawning, the female makes a redd (area containing several individual nests) by turning on her side and repeatedly flexing her body to force gravel and fine sediment into the water column; this action coarsens the spawning bed and finer sediments are deposited a short distance downstream. Salmonids typically deposit their eggs into several egg pockets (Crisp and Carling 1989). The completed nest forms an oval depression with a mound of bed material located immediately downstream. Often several males will court the female and her eggs may be fertilized by more than one male. Rainbow

Trout often abandon the redd after its completion.

The space required for spawning depends on the size and behavior of the spawners and the quality of habitat at a specific location. Tolerance of nearby spawners varies by species (Bjornn and Reiser 1991). Poor quality habitat may cause females to construct more than one redd. Redd density depends on the amount of stream area suitable for spawning, the number and size of spawners, and the area required for each redd. Burner (1951) suggests that a conservative estimate of the number of salmon a stream can accommodate can be obtained by dividing the area suitable for spawning by four times the average redd area.

Fecundity increases with fish size although there is significant variation, with some stocks producing almost twice as many eggs as others and the number and size of eggs per female varies greatly among populations (Bromage et al. 1992). Rainbow Trout fecundity is positively related to length, but is highly variable, ranging from 500 to 3,161 eggs per stream resident female (Carlander 1969). Density dependent (e.g., disease, redd superimposition) and independent variables (e.g. temperature, flow) can affect spawning success and health of gametes released to the stream (Patterson 2004; Tierney et al. 2009). Since available spawning areas are often limited, later spawners may superimpose redds on previously constructed sites, displacing eggs deposited by earlier spawners and causing fry production to be inversely related to adult spawner numbers, thereby reflecting a density dependent relationship (McNeil 1964; Heard 1978; Buklis and Barton 1984; Parenskiy 1990; Chebanov 1991). Redd superimposition can be a major mortality factor for incubating embryos at high spawning densities (McNeil 1964; Fukushima et al. 1998). Redd superimposition can be an increasing function of egg density in the gravel, such that the total number of eggs successfully deposited approaches stream carrying capacity as the spawner numbers increase (McNeil 1964). In general, *O. mykiss* is considered a pocket spawner; that is females avoid areas of streams where overly larger substrate or the possibility of flood scour impede successful redd construction or incubation and emergence (Montgomery et al. 1999).

Incubation

Fertilized eggs (embryos) sink to the bottom of the redd and develop in the gravel interstices. From much of the research developed in the Pacific Northwest (PNW), egg incubation generally lasts from 40 to 90 days at water temperatures of 4.4 to 12.2 °C (Bams 1970; Heming 1982; Bjornn and Reiser 1991; Geist et al. 2006). Incubation time varies inversely with temperature. Eggs usually hatch within 28 to 40 days (Cope 1957) but may take as long as 49 days (Scott and Crossman 1973). Calhoun (1966) reported increased rainbow embryo mortalities at temperatures < 7° C and normal development at temperatures >7 but < 12° C. However, Myrick and Cech (2001) determined the lower lethal limit for *O. mykiss* incubation was 2°C, but mortality is relatively high. The USEPA (2003) indicates upper lethal limits for spawning and incubation as 13° C. At 4.5°C Rainbow Trout eggs require 80 days to hatch, at 10°C, 31 days and at 15°C, 19 days (Leitritz and Lewis 1980). Eggs are extremely sensitive to handling and shock from 2 days postfertilization until the blastopore is completely closed, 9 days at 10°C. Once the eggs become pigmented (about 16 days at 10°C), the period of sensitivity is over, and the eggs can be handled until just before hatching. At hatching, fry are attached to their large egg-yolk. These fry are called yolk-sac fry, or alevins, and they burrow into spaces within gravel, where they continue to develop and grow, utilizing their yolk-sac for all necessary energy and nutrients to grow.

The optimal water velocity above Rainbow Trout redds is between 30 and 70 cm/sec (Raleigh et al. 1984). Velocities less than 10 cm/sec or greater than 90 cm/sec are unsuitable (Delisle and Eliason 1961; Thompson 1972; Hooper 1973). The combined effects of temperature, dissolved oxygen (DO), water velocity, and gravel permeability are important for successful incubation (Coble 1961). In a 30% sand and 70% gravel mixture, only 28% of implanted *O. mykiss* embryos hatched; of the 28% that hatched, only 74% emerged (Bjornn 1969; Phillips et al. 1975). Optimum incubation substrate is a gravel/cobble mixture (calculated from fish lengths of the expected population) and a composition including less than 5-25% sand and silt (Reiser and Bjornn 1979; Platts et al. 1989). Optimal spawning gravel conditions are assumed to include < 5% fines; > 30% fines are assumed to result in low survival of embryos and emerging yolk-sac fry. Suitable incubation substrate is gravel that is 0.3 to 10.0 cm in diameter (Delisle and Eliason 1961; Orcutt et al. 1968; Hooper 1973; Duff 1980). Optimal substrate size depends on spawner size but is assumed to average 1.5 to 6.0 cm in diameter for rainbows < 50 cm long and 1.5 to 10.0 cm (diam.) for spawners ~ 50 cm long (Orcutt et al. 1968). Doudoroff and Shumway (1970) reported that salmonids that incubated at low DO levels were weak and small with slower development and more abnormalities. Dissolved oxygen requirements for Rainbow Trout embryos are not well documented but are assumed to be similar to the requirements for adults.

Alevins may remain in the gravel for 21 to 42 days after hatching, receiving nutrients and energy from their yolk sac before emerging from gravels to the water column (Moyle 2002). When the yolk-sac is nearly gone and has been surrounded by skin on the ventral side of the fish, the fry are said to be 'buttoned up'. The time needed for alevins to reach this stage depends on water temperature, but at 10°C is ~20 days and at 15°C, 10 days or less from hatching. The fry are then ready to begin exogenous feeding and emerge from the gravel. At this point they are said to be 'swim-up' fry although they may continue to rely on yolk during this feeding transition. The entire sequence from spawning to emergence from the gravel is timed such that the fish emerge when natural food is abundant in spring. Since streams differ in water temperature and food abundance throughout the geographical range of Rainbow Trout, local populations are adapted to local conditions, and spawning and fry emergence are timed appropriately (Hardy 2002).

The incubation period, survival to, and health at emergence are highly dependent on water temperature, DO and substrate permeability (Merz et al. 2004). For successful egg incubation, gravel must be sufficiently free of fine sediment to adequately bring DO to embryos, carry off metabolic wastes, and not hinder emergence (Tappel and Bjornn 1983; and see discussions in Chevalier et al. 1984 and Groot and Margolis 1991). Watershed parameters, such as fine sediment inputs and coarse sediment deficits can influence embryo survival and larval emergence success (Merz et al. 2004; Fudge et al. 2008). Other environmental parameters (e.g. disease, contaminants) can further affect development and survival (Raleigh et al. 1984). Large-scale gravel habitat enhancement projects occur throughout the Central Valley (CV) to enhance and restore quality incubation habitat (Merz et al. 2006; Wheaton et al. 2004). Flow manipulation has also been prescribed to improve the incubation environment (Merz et al. 2008). In regulated streams where access to higher-gradient tributaries and smaller substrate is blocked, redd scour and desiccation can be a major factor in reduced fry production (Korman et al. 2011).

Emergence and Early Fry Rearing

Rainbow Trout embryos emerge 45 to 75 days after egg fertilization, depending on water temperature (Calhoun 1944; Lea 1968); alevin hatch in 3-4 weeks (at 10-15° C) and remain in the gravel for about 2- 3 weeks after hatching (Scott and Crossman 1973; Crisp 1988). Length frequency analysis from monthly seining surveys on the Mokelumne River suggest fry emergence begins in February and is typically complete by the end of July with rapid growth occurring during the summer months (Merz et al. 2015). The fry aggregate in shallow water along the shoreline and gradually move into deeper water as they grow larger (Cramer and Ackerman 2009). If they live in riffles or shallow runs, the fish may be territorial or partially so, but fish in pools tend to congregate in the water column, albeit with some sorting by size (Raleigh et al. 1984).

When moving from natal gravels to rearing areas, Rainbow Trout fry exhibit what appears to be three distinct genetically controlled movement patterns: (1) movement downstream to a larger river, lake, or to the ocean; (2) movement upstream from an outlet river to a lake; or (3) local dispersion within a common spawning and rearing area to areas of low velocity and cover (Raleigh and Chapman 1971). Fry residing in streams prefer shallower water and slower velocities than do other life stages of stream trout (Miller 1957; Horner and Bjornn 1976). Fry utilize velocities < 30 cm/sec, but velocities < 8 cm/sec are preferred (Griffith 1972; Horner and Bjornn 1976). Fry survival decreases with increased velocity after the optimal velocity has been reached (Bulkley and Benson 1962; Drummond and McKinney 1965). A pool area of 40-60% of the total stream area is assumed to provide optimal fry habitat. Cover in the form of aquatic vegetation, debris piles, and the interstices between rocks is critical. Griffith (1972) states that younger trout live in shallower water and stay closer to escape cover than do older trout. Few fry are found more than 1 m from cover (Raleigh et al. 1984). As the young trout grow, they move to deeper, faster water (Cramer and Ackerman 2009). Everest (1969) suggested that one reason for this movement was the need for cover, which is provided by increased water depth, surface turbulence, and substrate that consists of large material. Stream resident trout fry usually overwinter in shallow areas of low velocity near the stream margin, with rubble being the principal cover (Bustard and Narver 1975a). Optimal size of substrate used as winter cover by rainbow fry and small juveniles ranges from 10-40 cm diam. (Hartman 1965; Everest 1969). An area of substrate of this size class that is ~ 10% of the total habitat probably provides adequate cover for rainbow fry and small juveniles. The use of small diameter rocks (gravel) for winter cover may result in increased mortality due to greater shifting of the substrate (Bustard and Narver 1975a). The presence of fines (~10%) in the riffle-run areas reduces the value of the area as cover for fry and small juveniles (Suttle et al. 2004). Brungs and Jones (1977) report a preferred temperature range of 13 to 19° C for fry. Because fry occupy habitats contiguous with adults, their temperature and oxygen requirements are assumed to be similar to those of adults.

Juvenile Rearing

Several PNW studies have documented that native trout tend to remain close to their spawning areas (e.g., June 1981; Moore and Gregory 1988), implying that the distribution of juvenile fish closely reflects the species spawning distribution. Griffith (1972) reported focal point velocities for juvenile cutthroat in Idaho of between 10 and 12 cm/sec, with a maximum velocity of 22 cm/sec. Dickson and Kramer (1971) found that metabolic rates for PNW Rainbow Trout are highest between 11 and 21° C, with an apparent optimal temperature of between 15 and 20° C. Sullivan et al. (2000) define the optimal rearing range as the mean weekly average temperature at which no more than 10% reduction from maximum growth occurs in the rearing stage (13.3-17°C).

Common cover types for juvenile trout are upturned roots, logs, debris piles, overhanging banks, riffles, and small boulders (Bustard and Narver 1975a). Young salmonids occupy different habitats in winter than summer, with log jams and rubble important as winter cover. Wesche (1980) observed that larger cutthroat trout (> 15 cm) and juveniles (~15 cm) tended to use instream substrate cover more often than they used streamside cover (undercut banks and overhanging vegetation). However, juvenile brown trout preferred streamside cover. An area of cover ~15% of the total habitat area appears to provide adequate cover for juvenile trout. Because juvenile Rainbow Trout occupy habitats contiguous with adults, their temperature and oxygen requirements are assumed to be similar. Suttle et al. (2004) found that increasing concentrations of deposited fine sediment decreased growth and survival of juvenile *O. mykiss*. These declines are associated with a shift in invertebrates toward burrowing taxa unavailable as prey and with increased juvenile activity and injury at higher levels of fine sediment.

Sogard et al. (2012) reported that temperature patterns differed markedly between two Central Valley rivers supporting *O. mykiss*. In the American River, the warmest temperatures were in August, with a daily mean of 19.2◦C, whereas in the Mokelumne River, the warmest temperatures were in September, with a mean of 15.2◦C. Coolest temperatures were in January on the American River, with a mean of 9.1◦C, and in February on the Mokelumne River, with a mean of 10.2◦C. Daily maximum summer temperatures regularly exceeded 20◦C on the American River but did so only rarely on the Mokelumne River. In the American River, mean summer–fall growth rates of *O. mykiss* were estimated at 1.12 mm/d. On the Mokelumne River, growth rates in summer–fall had a mean of 0.60 mm/d for 14 years of surveys. Seasonal growth patterns in the Central Valley were slower in winter–spring than in summer– fall, with an estimate of 0.61 mm/d for the single year of data for the American River and a mean of 0.46 mm/d for the 11 years of Mokelumne River data.

Sub-Adult and Adult Residence

Rainbow Trout growth rates depend on water temperature and food abundance, and although males may mature within their first year, wild males and females generally reach maturity at 2+ years of age (Crandall and Gall 1993; Hardy 2002). Most spawning trout are first spawners, but a small proportion of spawners, mainly females, survive to spawn again. Growth and maturation in Rainbow Trout are indeterminate, meaning that there is no set rate or age (Hardy 2002). Rather, environmental factors determine growth and maturation, with fish in cold, harsh environments generally living longer than those in warmer, benign environments. Maximum size is variable, with 17–23 kg Rainbow Trout sometimes being captured in Kootenay Lake, British Columbia. These fish would be 5–6 years old (Behnke 1992). However, Rainbow Trout in streams typically weigh 100 g at 1 year of age and 300–450 g after 3 years (Hardy 2002).

General Physical Requirements of Rainbow Trout

Optimal Rainbow Trout riverine habitat is characterized by clear, cold water; relatively low-silt, rocky substrate in riffle-run areas; an approximately 1:1 pool-to-riffle ratio, with areas of slow, deep water; well-vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes, and stream banks (Raleigh and Duff 1980). They typically thrive in the tailwaters of large dams (Moyle 2002). Rainbow Trout are among the most physiological tolerant of salmonids, which is why they are often the only salmonid found in streams that are thermally marginal. They can live in waters that reach 26 –27° C in summer for short periods of time, provided there is sufficient acclimation time and plenty of food available (Moyle 2002). Thermal refuges (e.g. upwelling ground water) are also important in marginal situations (Brewit and Danner 2014). Optimal temperatures for growth (and preferred temperatures) under ‘normal’ circumstances are usually 15–18° C. At low temperatures, rainbows can survive relatively low dissolved oxygen concentrations although saturation is needed for most activities. They also can survive and grow in a wide range of water chemistry, including water with pH values between 6 and 9. As indicated under life history, different life stages have different habitat requirements as defined by depth, water velocity, and substrate (Moyle 2002). Smaller fish generally require shallower water, lower velocities, and less coarse substrates than larger fish. Given a choice, trout in streams live in areas where they can hold in place with minimal effort, while food is delivered to them in nearby fast water. They also require nearby cover, such as downed trees, to protect them from predators.

Diet of Stream-Dwelling Rainbow Trout

Adult and juvenile Rainbow Trout are basically opportunistic feeders and consume a wide variety of foods. Availability of different foods depends on many factors, including water type, season, and size of the trout (McAfee 1966). The diet of Rainbow Trout consists mainly of aquatic insects (Allen 1969; Carlander 1969; Baxter and Simon 1970; Scott and Crossman 1973), although foods, such as zooplankton (McAfee 1966), terrestrial insects, and fish (Carlander 1969), are locally or seasonally important. The relative importance of aquatic and terrestrial insects to resident stream Rainbow Trout varies greatly among different environments, seasonally and dielly, and with the age of the trout (Bisson 1978). Forty to fifty percent or more of the summer food of trout in headwater streams may be composed of terrestrial insects (Hunt 1971). Adult stream Rainbow Trout occasionally consume significant quantities of vegetation, mostly algae (McAfee 1966). Stream trout have no mechanism to break down cell walls in vegetation and cannot obtain nutrients from it, therefore, vegetation is thought to be consumed because of the invertebrates attached to it (Behnke pers. comm. As cited in Raleigh et al. 1984; Merz 2002). *O. mykiss* in California streams consume primarily aquatic and terrestrial insects that are drifting in the water column, although amphibians, fish, and small mammals may also be consumed on occasion, and benthic feeding also occurs (Sogard et al. 2012; Merz 2002; Merz and Vanicek 1996). Merz (2002) found that zooplankton produced from a large flood-storage reservoir in the Central Valley had a significant effect on the diet of a tailwater *O. mykiss* population.

TASK 2. HYDRAULIC MODELING

Hydrologic Scenarios

Purpose

This task facilitates meaningful discussion of flow scenarios that should be evaluated when estimating habitat availability and future management actions as they relate to Rainbow Trout in the Kings River tailwater fishery. Specifically, we provide an objective and scientific basis for the selection of scenarios evaluated through hydraulic and habitat suitability modeling.

Background

Natural streamflow from the upper watershed above Pine Flat Dam has characteristics of snowmelt-dominated Mediterranean-montane basins (Yarnell et al. 2010). Below Pine Flat Dam, Kings River tailwater hydrology is regulated for flood control, agricultural and municipal water delivery as well as flows for the fishery. To develop a basis for hydrologic scenarios considered for modeling we analyzed daily flow data from Pine Flat Dam from 1953 through 2017. We analyzed these data to identify the timing and magnitude of flow discharges that are relevant for irrigation, a Rainbow Trout fishery, channel maintenance, and flood control to aid in the selection of hydrologic scenarios.

Several tributaries enter the river below Pine Flat Dam, the largest of which are Hughes and Mill creeks. Both creeks are unregulated, and experience seasonal streamflow driven by rain. Thus, both creeks generally exhibit a flashy hydrograph where flow rises and falls relatively quickly. Using United States Army Corp. of Engineers (USACE) daily average data for Mill Creek from WY1958 through 2017 we analyzed data for relative effects on ecohydrology, channel maintenance and flood control. Because of their flashy, rain-driven hydrograph, they are unreliable as irrigation and municipal water sources and, therefore we did not analyze tributary flows related to irrigation needs.

Irrigation Season

Irrigation demand generally begins in May and lasts through August. Irrigation flows are managed to optimize available water with downstream demand. To quantify hydrology for the irrigation season we used computed monthly average flows from Pine Flat Dam for each water year (WY) by WY type for WYs 1954 – 2017 (Figure 12).

Water Year type was based on the Department of Water Resources San Joaquin Valley WY hydrologic classification indices. For simplification, values were rounded up to the nearest 10 cfs. Not surprisingly there is variation in monthly average flows based on WY type. Average flows during the irrigation season for critically dry, dry and below normal years range from 2,750 – 4,230 cfs. Average irrigation flows for above normal and wet years are 5,260 and 7,370 cfs, respectively. The lowest monthly average flow during the irrigation season is 1,390 cfs and occurs in May during critically dry years. Conversely, the highest monthly average flow is 8,800 cfs and occurs in June during wet years.

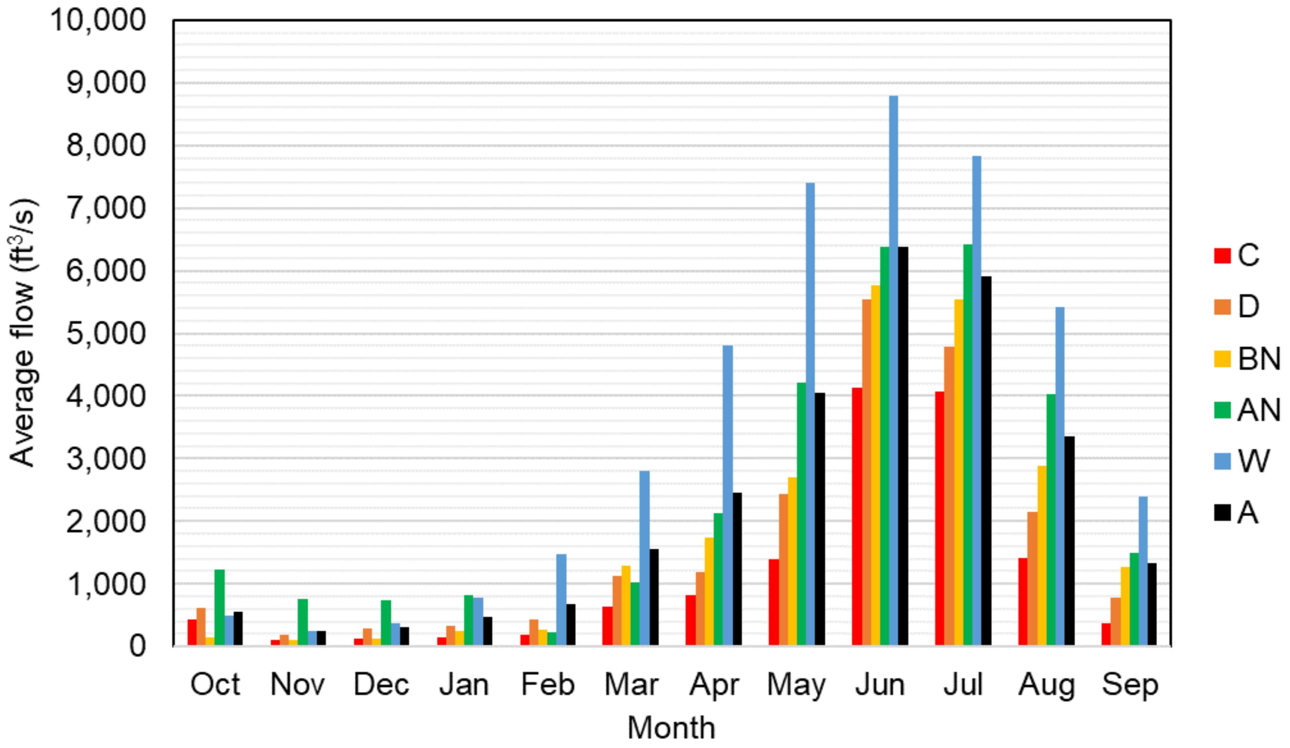


Figure 12. Monthly average flows from Pine Flat Dam for WYs 1954-2017. A=average across all years, C=critically dry, D=dry, BN=below normal, AN=above normal, and W=wet.

Ecohydrology

Minimum flows for the trout fishery are set forth in the KRFMP Framework (KRFMP 1999). Under the framework, flows below Pine Flat Dam are managed for water temperature and enhancing trout stream conditions. The framework was put in place in 2005. Depending on reservoir storage, base flows can range from 100 to 250 cfs, with a minimum flow of 5 cfs to Dennis Cut independent of reservoir volume.

Beyond minimum flows, we determined ecohydrology associated with Rainbow Trout spawning (≥2-yr old) and rearing (fry/parr). Ecohydrology was developed analyzing the same flow data as above using HEC-EFM (Hydrologic Engineering Center Ecosystems Function Model). Rainbow Trout complete their entire life cycle in freshwater. Adult trout typically spawn from December through April in California, but we assume from past redd surveys (B. Beal personal communication) and the temperature regime that most Kings River trout spawning occurs from December through February. Their offspring rear for two or more years before reaching reproductive maturity. The early rearing season (newly-emerged fry and parr) for Rainbow Trout spans the winter and spring months when flow, water temperatures, and food availability, driven by California's Mediterranean climate, create habitat conditions conducive to accelerated growth. With continued parr rearing through the summer and fall as they transition to sub- adults the following year. Note that a Gantt chart for the Rainbow Trout lifecycle was developed for this project (Figure 11). Timing and relative success of each life stage transition should be further researched.

We focused this ecohydrology analysis on spawning/incubation, and fry/parr rearing. For each period associated with these life stages we determined statistics associated with median flows that had durations ranging from 14–21 days and exceedance probabilities of 33 to 67 percent. The 14–21-day duration was considered so that adequate inundation occurs for food production (Jeffres et al. 2008; Merz et al. 2005). Exceedance probabilities were based on the idea that inundation of juvenile trout habitat needs to occur every 1.5–3 years (occurs at least once per generation) to create and maintain high-quality rearing conditions bolstering natural trout production. All relationships are shown in Table 1.

Based on the statistical analysis the average spawning period flow was 125 cfs. For the incubation period the average flow increases to 760 cfs. Notably, Mill Creek can yield ~400 cfs of additional flow during this period. For the fry and parr rearing periods the 14- and 21-day durations are all within 200-300 cfs, suggesting that flows are somewhat steady during those periods. For the three exceedance values the range of flows during the fry rearing period are between ~1,140 and ~2,620 cfs, while for the parr rearing period are between ~2,020 and 4,300 cfs. Both tributaries would contribute at most 59% during the incubation period, followed by 16% during the spawning period. For fry/parr rearing the tributaries would contribute <5% total river flow.

Channel Maintenance

Channel maintenance flows are those that maintain channel form around a state of dynamic equilibrium, as well as those that completely reset the geometry and alignment of the river corridor. Often, the "bankfull discharge" is used as a surrogate for channel maintenance. Bankfull discharge is the flow that just overtops the channel banks on terraces and floodplains in natural channels. Bankfull discharge is less applicable in Western semi-arid landscapes, especially for rivers that are regulated by dams. Currently channel maintenance flows are unknown for the Kings River. For natural Western rivers, recurrence intervals associated with channel maintenance range from 1.2 – 10 years (Keller 1971, Williams 1978, Andrews 1980, Nolan et al. 1987, Sawyer et al. 2010). For context, we estimated the 2, 5 and 10-year flood discharges for the Kings River as ~7,150, 9,900 and 12,610 cfs. Considering coincident peaks from Mill and Hughes creeks these values would be 7,8800, 12,900 and 16,600 cfs.

Table 1. Ecohydrology for spawning and juvenile rearing periods for Pine Flat Dam outflow (PNF), Mill Creek, and Hughes Creek. All values rounded up to the nearest 10 cfs.

Period Length in Days(d), Exceedance Probability (%), and Recurrence Interval	**Pine Flat Dam 1954 - 2017WY**	**Mill Creek 1958-2017WY**	**Hughes Creek (estimated as 12% Mill Creek)**	**Mill and Hughes**	**Percentage of King's River flow**
Spawning peak (Dec-Jan) average flow	130	10	10	20	16%
Incubation peak (Jan- Feb) average flow	760	400	50	450	59%
Fry rearing (Mar-Apr)					
14d 33%	2,430	90	20	110	5%
14d 50%	1,570	40	10	50	3%
14d 67%	1,140	20	10	30	3%
21d 33%	2,620	90	20	110	4%
21d 50%	1,620	40	10	50	3%
21d 67%	1,160	20	10	30	3%
Parr rearing (Apr-May)					
14d 33%	4,010	40	10	50	1%
14d 50%	2,930	20	10	30	1%
14d 67%	2,020	10	10	20	1%
21d 33%	4,300	40	10	50	1%
21d 50%	3,190	10	10	20	1%
21d 67%	2,290	10	10	20	1%
2-year	7,150	650	80	730	10%
5-year	9,900	2,670	330	3,000	30%
10-year	12,610	3,560	430	3,990	32%

Flood Control

Pine Flat Dam is maintained by the USACE. As a flood control structure, it can regulate the entire volume for flood events up to the 1-percent-annual-chance event, or 100-year storm. Based on published flood studies the 100-year storm has a flow discharge of 16,700 cfs at Pine Flat Road and 20,300 cfs at Piedra Road (FEMA 2016).

Rating Curve Analysis

Another way to define relevant flows is to analyze rating curves of water depth/elevation with flow (Figure 13). By identifying visual or quantitative breaks in the rate of change of water depth with flow one can identify flows where there are unique hydraulic responses. Examples could be where floodplains or terraces become activated, causing water to spread out with increased flow, yielding minimal changes in water depth with flow compared to channelized sections.

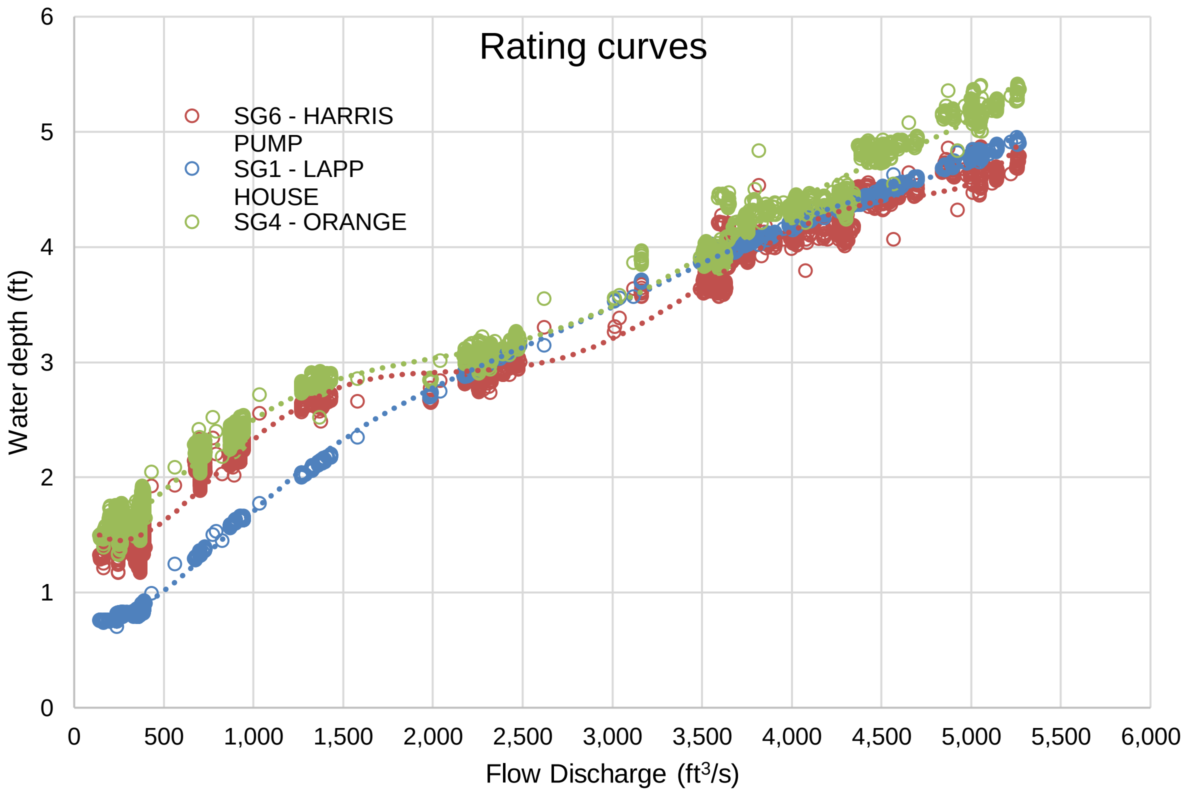


Figure 13. Rating curves for several locations within the study area. Dashed lines are 6th order polynomials.

We utilized rating curve data provided by KRCD for three locations that spanned 30 June through 30 October 2014 and flows ranging from 141 – 5,269 cfs (Figure 14). The SG1 gage flow has one inflection at ~370 cfs. Below this flow water depth does not change appreciably with flow, and beyond this flow water depths increase more rapidly with flow. Visually, both the SG4 and SG6 gages have two inflections. At ~1,500 cfs, where the rate of change of depth diminishes until ~2,000 cfs where it increases again beyond ~2,500 cfs.

Flow Scenarios

Using the analyses above and the Rainbow Trout Gantt chart reviewed by the TSC we created a draft list of flow scenarios to consider for use in hydraulic modeling to test the study hypotheses related to physical habitat for spawning and rearing Rainbow Trout (Table 2). Since 14 and 21-day duration flows for fry and parr rearing were close (e.g. within 200 – 300 cfs) we averaged those values. Further, we used the 33 and 67% exceedance flows and excluded the 50% exceedance flow since they serve to provide bounds on probable flows. For over-summer rearing, we selected an average June-July flow and an August wet year flow. Since the 100-year flood is relatively rare it likely does not provide valuable insight into the current fisheries population. Therefore, the 100-year flood flow is excluded. The highest flow considered is the 5-year flood (13,200 cfs), which we believe is an important flow to assess spawning gravel mobility.

Table 2. Flow scenarios considered for ecohydraulic analysis.

Scenario	PNF outflow (cfs)	Basis	Purpose
1	100	Normal year minimum flow	Estimate minimum spawning habitat flow
2	130	Wet year minimum flow and approximate average spawning flow	Estimate average spawning habitat flow
3	250	Very wet year flow	Determine if additional flow yields additional spawning habitat
4	760	Incubation 50% exceedance	Determination of hydraulic conditions during incubation
5	1,140	Fry rearing 67% exceedance; Parr rearing 67% exceedance	Assess fry and parr rearing habitat
6	2,000	Rating curve inflection at SG4 and SG6 gages	
7	2,525	Fry rearing 33% exceedance	
8	4,000	Parr rearing 33% exceedance	
9	6,000	Approximate average flow for June/July	Assess over summer rearing habitat
10	7,300	Irrigation season flow for wet years and 2-year annual flood	
11	8,800	Average monthly flow for June during wet years	
12	13,200	5-year flood	Assess high flow spawning gravel mobility

Two-Dimensional Hydrodynamic Modeling

Two-dimensional hydrodynamic modeling (2D modeling) was used to evaluate ecohydraulic suitability of Rainbow Trout spawning and rearing habitat. Two-dimensional hydrodynamic models have been used to evaluate aquatic habitat for fish and invertebrates (Waddle and Holmquist 2013) as well as for planning and assessing river rehabilitation designs (Pasternack et al. 2004; Elkins et al. 2007; Brown and Pasternack 2009; Pasternack and Brown 2013). The benefit of 2D models is that they provide information on the spatial distribution of depth, depth-averaged velocity, water surface elevation (WSE), shear stress and other hydraulic variables within a modeled domain for a specific flow or sequence of flows. When input data such as topography and boundary values of flow and water elevation are of good quality, they can yield very good predictions, often within tenths of a foot of observed water elevations (Pasternack 2011; Wright et al. 2017). Since they use model grids, the scale and resolution can be adjusted for a wide range of physical and biological processes over an array of spatial and temporal scales.

This chapter describes the 2D model development and evaluation for the LKR, from Pine Flat Dam down to the Fresno Weir. We detail how the model was constructed, such as the domain and resolution, flow scenarios and boundary conditions, developing results and model performance evaluation. Lastly, we describe areas of improvement for future studies.

Model Development

We performed 2D modeling using Surface Water Modeling System 12.3 for computational mesh preparation and Sedimentation and River Hydraulics—Two-Dimensional (SRH-2D) for solving the depth-averaged St. Venant equations. Model outputs include point-based water surface elevation, water depth, depth-averaged velocity components, depth-averaged water speed, Froude number, and shear stress in the direction of flow. For more information, see Lai (2009) and Pasternack (2011). While SRH-2D is the "solver", Surface Water Modeling System (SMS) is a graphical user interface used to construct the model mesh and link model components. Model components include the mesh, roughness, boundary conditions and monitor lines and points. The mesh is the structure that calculations are carried out on. Roughness describes the amount of friction to flowing water. Boundary conditions refer to the amount of water entering the mesh during a flow scenario as well as how much is leaving. Monitor points and lines are used to track model progress through a simulation. Below we describe the input topographic data set and methods for developing the mesh, boundary conditions, hydraulic structure modeling approach and roughness.

Topographic data

A prerequisite for any 2D model is relatively high-quality topographic and bathymetric data. For this study a 2013 topo-bathymetric LiDAR (light detection and ranging) survey was made available by KRCD. The dataset was collected in March of 2013 by Fugro using the Optech SHOALS-1000T and the RIEGL VQ-820-G LiDAR sensors operated simultaneously from a Beechcraft King Air A90 aircraft (Fugro 2013). Digital Imagery data (RGB) was collected also as part of this effort. We used a 3ft digital elevation model raster provided by KRCD as input to the 2D model by converting the raster to a point file. The horizontal coordinate system was California State Plane Zone 4 and vertical coordinate system was NAVD88.

Mesh Domain and Resolution

The model mesh domain represents the spatial extent of hydraulic simulations, while the resolution refers to the spacing between nodes that compute water flow (Figure 14). Early on we explored whether the entire ~9-mile study segment could be modeled as one domain with a reasonable resolution. The resolution of 2D models for fish habitat assessment is generally much smaller than that needed for other evaluations (e.g., flood studies). An ideal mesh resolution for ecohydraulic studies is usually less than 3 m (9.84 ft), but this also depends on study scope and objectives.

We did some initial model building to test model run speeds with the size and resolution of the model domain (extents). Using a single domain for the entire 9 miles at 1m resolution generates model files that take several hours to open, and weeks to run a single simulation on a relatively strong computer (3.6GHz processor and 32GB RAM). Based on this testing our approach was to split the study segment into two model domains to decrease model file size and run timing. These domains are termed upper and lower (Table 3). The upper domain begins below the USACE weir structure under Pine Flat Road and extend down past Cobbles Weir to where there is an existing KRCD gage (SG-4). The Lower domain extends from this point down until approximately 1,400 ft above the Fresno Weir. Model domain characteristics are shown in Table 3. The mesh resolution for the upper domain simulations was ~3 ft, while for the lower domain it was ~6 ft. The difference was due to the size and complexity of the model domains. The upper domain is relatively narrow as the river channel is partially confined. The lower domain is much wider because the river flows through the relict alluvial fan and thus has many distributary channels. The lower domain also had more shallow channels of water flow, while the upper domain was mostly channelized. The 76 Channel and Dennis Cut system was excluded from simulations to focus on understanding habitat in the main river channel.

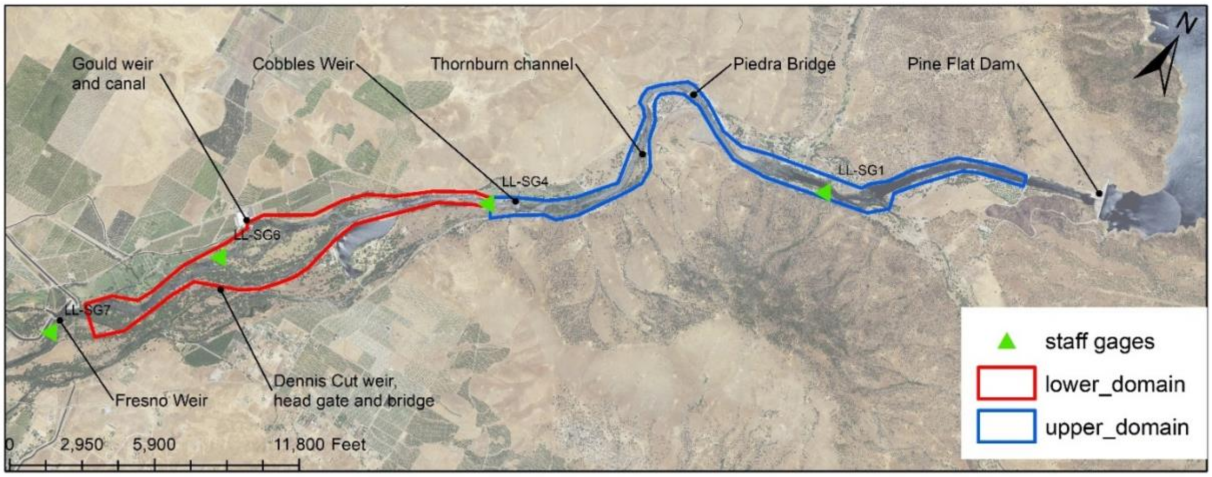


Figure 14. Model domain schematic.

We initially tried patch, paving and hybrid mesh structures within SMS to develop the computational structure of each model domain. We ultimately used a “patch” mesh builder because this type of mesh builder is generally more stable and computationally efficient compared to a “paving” mesh. For more information on mesh types see https://www.xmswiki.com/wiki/SMS:Mesh_Generation.

Table 3. Model domain characteristics.

Domain	Area (ft$_2$)	Resolution (ft)	# elements	# nodes	Avg. run time
Upper	17,772,153	~3	2,755,933	2,290,217	Weeks
Lower	21,477,080	~6	1,378,892	692,588	Days

Modeled Flow Scenarios

For model simulations, a subset of the hydrologic scenarios shown in Table 2 were modeled. These included 100; 250; 658, 3,712; 4,000 and 8,800 cfs. To estimate available spawning habitat 100 and 250 cfs were selected. The 658 cfs flow was selected as a validation run where we compared the aerial extent of modeled inundation versus what was shown in aerial imagery collected during the LiDAR flight. Similarly, 3,712 cfs was selected to perform depth and velocity validation, since that was the flow those data were collected. To model rearing habitat the 4,000 and 8,800 cfs were selected to bracket the range of flow conditions in the river.

Boundary Conditions

For any hydraulic model, basic boundary condition data consists of water flow inputs and a downstream boundary condition. Basically, one needs to tell the model how much water is entering the river and what is happening at the bottom of the reach. The downstream boundary condition is usually water surface elevation for the incoming flow but can also be represented as a water flow leaving the reach. For the latter, some models can also solve for water surface elevation at the downstream boundary, but they can be less accurate, especially if there are downstream hydraulic controls that cause water flow to deviate from normal flow conditions. Based on our hydrologic analysis we anticipate flow inputs from Pine Flat Dam (PNF) only. Since the lower domain begins below Cobbles Weir and the entrance of the 76 Channel, inflow values for the lower domain do not equal the outflow from PNF. For downstream boundary conditions, we utilized data supplied by KRCD and KRWA. For the upper domain, we utilized the KRCD gage SG-4, which is rated for flows between 141 and 5,269 cfs. When a modeled discharge was not found in the measurement data, we used linear interpolation between the closest values to develop water surface elevation values. For example, for flows above 5,269 cfs we developed a linear trend model for the data above 2,460 cfs.

The boundary condition for the lower domain is the KRWA gage at Fresno Weir. These data consisted of gage height at an arbitrary datum, flow values and the date of the flow. To convert gage heights to water surface elevation we used information provided by KRWA that a gage height of 1.6 is equal to the concrete of the Fresno Weir. The weir elevation was derived from the LiDAR data and was used to transform gage height to water surface elevations. We then used interpolation and linear trend models to develop specific water surface elevation values for different flow scenarios. Boundary conditions for both domains are shown in Table 4 and Table 5. It should be noted that this 2D model, as many others, does not explicitly account for groundwater and surface water interactions. Such interactions could be added using inflow and outflow boundary condition nodes, but it is unknown whether groundwater and surface water interactions occur relative to the flow scenarios modeled.

Table 4. Boundary conditions for Upper domain. For the main channel WSE we used the KRCD SG-4 gage as described above. All WSE data is in NAVD88 and units of feet. *All elevations are in NAVD88.

Below Pine Flat Dam (cfs)	Main outflow (cfs)	76 Channel (cfs)	Main channel WSE*	76 Channel WSE
100	100	0	489.1	0
250	250	0	489.28	0
658	658	0	489.92	0
3,712	3,112	600	491.51	use exit-Q
4,000	3,400	600	491.56	use exit-Q
8,800	8,000	800	495.3	use exit-Q

Table 5. Boundary conditions for the Lower domain. All WSE data is in NAVD88 and units of feet.

Below Pine Flat Dam (cfs)	Main outflow (cfs)	Main outflow (cfs)	Gould Canal outflow (cfs)	Main channel outflow WSE
100	100	95	0	436.65
250	250	155	40	436.88
658	658	468	150	437.18
3,712	3,112	2,792	250	438.61
4,000	3,400	3,080	250	438.73
8,800	8,000	7,500	300	440.02

Hydraulic Structures

Hydraulic structures are modeled in SRH-2D as objects that relate the bounding mesh results to the upstream and downstream structure limits. As a result, they can increase model time or affect stability, since the model must communicate with sub routines. Our strategy for modeling structures was avoid them where possible, or use “flow links” in the model mesh. Flow links route water from one part of the mesh to another. Below we describe how each structure was addressed in both the Upper and Lower model domain.

Piedra Road Bridge

Aerial photography spanning the range of flows modeled indicated that Piedra Bridge does not overtop 8,800 cfs. Therefore, we did not use a bridge structure in the model domain. The bridge does have 10 piers, which were modeled as inactive mesh cells so flow could go around the piers. Pier locations and dimensions were based on field measurements by KRCD.

Thorburn Culvert

While information was provided by KRCD for the dimensions of the Thorburn Culvert it was not used. This is because it was more efficient to use a flow link that prescribes specific amounts of flow from the main channel to the Thorburn Channel.

Cobbles Weir

We modeled this structure initially using the weir submodel, with a weir elevation of 494 ft and length of 220 ft. Simulations with and without the weir structure indicated that the structure caused very large lags in computation time, extending model runs from a few days to weeks. Therefore, for the lower domain we represented the weir by modifying the topography of the digital elevation model (DEM) to match the weir elevation. It is important to note that modeling results with and without the weir structure were essentially the same.

Cobbles Headgate

This structure was modeled using an exit boundary condition that takes a specific amount of water (e.g. inflow to the 76 Channel) out of the mesh.

Dennis Cut Weir, Headgate and Bridge

Initially, both the Dennis Cut Weir and Headgate were modeled using the weir and headgate structure boundary conditions in SMS. However, these models were very unstable and often did not run to completion. To simplify the structures in this area, the Dennis Cut Headgate was modeled as an internal sink. An internal sink is a boundary condition that specifies when flow is added or removed from a model, for example at diversions. The Dennis Cut Weir was modeled by modifying the topography of the DEM to match the weir elevation. A constant weir elevation of 461.3 was used based on ground surveys by KRCD. While boards are used to modify the hydraulic head for the Dennis Cut Headgate, this was not necessary, since we could specify exactly how much flow was going into Dennis Cut using an internal sink. The bridge north of Dennis Cut does not overtop during model simulations, but it does have piers. We used photographs and field sketches from KRCD to determine the size and location of two piers located under the bridge. To model this, we added an ineffective hole in the mesh where the piers would go.

Gould Weir

Simulations with and without the weir structure indicated that the structure caused very large lags in computation time, extending model runs from a few days to weeks. Therefore, for the lower domain we represented the weir by modifying the topography of the DEM. We initially assumed a weir elevation of 471 based on a drawing of the structure from 1985 supplied by KRWA. After running several simulations, we found several reasons to lower the weir elevation. First, the measured difference between modeled and observed (WSE) was ~1.7’ indicating the weir was potentially too high. Second, we noticed inundation patterns that deviated from 2014 NAIP imagery at ~3,730 cfs. This included flow flanking the weir structure as well as inundation on the river islands. Third, the model showed only 775 cfs going over the weir, while ADCP data showed that actual flow to be closer to ~1900 cfs. Because of this we lowered the weir elevation. To do this, we took the measured WSE at Gould Bridge and subtracted the elevation gain from the WSE from the weir to the bridge. Then we back calculated the depth needed to obtain the modeled flow over the weir. Finally, we subtracted this depth from the projected WSE using measured data. This yielded a weir elevation of 467 ft. Due to uncertainty in the actual elevation of the weir the value was kept constant since a flow link was used to set the amount of flow in Gould Canal.

Gould Bridge

Gould Bridge does not overtop during the range of flows analyzed, nor does it have any piers. Therefore, no boundary condition structures were used for this structure.

Harris Bridge

The Harris Bridge also does not overtop during the range of flows analyzed, although it does have 2 piers. To model this, we added an ineffective hole in the mesh where the piers would go.

Gould Canal

To model flow into Gould Canal we used an internal sink boundary condition. This type of boundary condition takes a specified amount of flow from the simulation.

Roughness

The interaction of flowing water over land and river channels creates friction, often termed roughness. Hydraulic calculations and numerical models all require an estimate of this roughness. Roughness represents not only friction, but also complex losses of energy associated with the transfer of momentum within water. Because of this estimating roughness in natural river channels is largely empirical, while drawing on some analytical relationships.

Numerical models require a spatially explicit estimation of roughness. Because of this, it is usually not necessary to develop a composite value as done for analytical and one-dimensional hydraulic models. Due to limited data availability at the time hydraulic modeling was performed we assumed values of roughness from the literature as well as our experience in similar rivers (Table 6). To help bracket the lower range of roughness, we estimated grain roughness (n) using the Strickler equation, which has the form:

$$n = 0.015{D_{50}}^{1/6} \tag{1}$$

Where n is the Manning's roughness coefficient and D_{50} is the median grain size in mm. We initially assumed a median sediment size of 150 mm, which would yield a roughness of 0.035[1]. Thus, this was considered the lowest value of roughness to be used for the river channel.

Table 6. Manning's roughness values used in model simulations.

Feature	Value(s)	Source
Channel	0.035-0.045	Chow 1959; Barnes 1967; Hicks and Mason 1991
Banks	0.06-0.1	Klaassen and Van Der Zward 1974
Islands	0.05-0.07	
Floodplain (open grass)	0.06	

Data Processing

The following steps were taken when a model was completed: (1) We checked monitoring lines to see if the appropriate amount of flow was being routed through the model. (2) When possible, we checked modeled versus observed water surface elevations. (3) When satisfied, model results were exported as a CSV file and imported into ArcGIS. (4) We then created a polygon reflecting the extent of inundation. (5) Finally, each inundation polygon and corresponding results point file was used to create a triangular irregular network surface (TIN) of depth and velocity, which were then converted to 3-ft raster grids.

Calibration and Validation

For model validation, we used three separate tests. First, we checked whether the model was allocating the correct amount of flow discharge at the model exit, and where applicable, flow splits. Mass conservation seeks to understand if the same amount of water leaving a reach as is entering. Second, we compared the aerial extent of inundation for 658 cfs. The LiDAR flight had an accompanying aerial image at this flow, so we calculated the percent difference in aerial extent. Lastly, we compared modeled versus observed depth, velocity and WSE from a data set collected in August 2018 for several locations.

Normally one assumes a value of roughness and adjusts it based on calibration data. However, we did not do this owing to the time difference between when the LiDAR was flown and validation data collection (>5 years). During this period, there was a wet water year (2017), with maximum Pine Flat release flows of approximately 14,900 cfs. Therefore, we assumed that channel adjustment may have occurred. For reference the FEMA 100-year flood at Piedra Road is 20,300 cfs (FEMA 2016), so this is a significant flood likely capable of channel change.

[1] Actual median sediment size was 125 mm, which yields a roughness value of 0.034. Given that the initial value of 0.035 is within 3% of 0.034 we did not alter roughness beyond the initially assumed value.

Mass Conservation

Mass conservation results were generally in very good agreement with the desired outflow for each simulation. Eleven out of twelve simulations were within 3% of the desired model outflow (Table 7). The lower250mod model had an additional 33 cfs leaving the model exit. Upon inspection that was due to more water being routed around the topography of the upstream flow split and into the main channel. Since a flow link was used for the Thorburn and 76 channels the specified versus modeled flow amounts were exact.

Table 7. Mass conservation checks for each 2D model.

Scenario model name	Q out	Q out modeled	Percent
Upper100mod	100	100	100%
Upper250mod	250	254	101%
Upper658	658	663	101%
Upper3712	3,112	3,108	100%
Upper4000	3,400	3,282	97%
Upper8800	8,000	7,999	100%
lower100	95	92	97%
lower250	155	188	121%
lower658	468	468	100%
lower3712f2	2,792	2,719	97%
lower4000	3,080	3,072	100%
lower8800	7,500	7,493	100%

Inundation Extent at 658 cfs

For the upper and lower model domains, the ratio of modeled to measured inundation extent was 91.6 and 100.1%. This indicates that for the upper domain the model under-predicted the inundation extent, while for the lower domain it over-predicted it. Differences could be attributed to the hand digitization of inundation extent and the mesh size of the models.

Acoustic Doppler Current Profiler (ADCP) data collection

On 1 August 2018, KRCD and KRWA collected data for the purposes of model validation. KRWA contracted with Sierra Hydrographics to collect depth, velocity and discharge measurements at seven locations using an acoustic doppler current profiler (ADCP). An M9 unit was used, which has a depth range, accuracy and resolution of 0.2 to 0.8m, 1%, and 0.001m, respectively (https://www.sontek.com/riversurveyor-s5-m9). Velocity accuracy is listed at +/- 0.25% of the measured velocity. At the same locations KRCD collected WSE data as well as elevation data at certain structures. This data was used to evaluate model performance, and where possible adjust to improve performance. The daily averaged flow from Pine Flat Dam on 1 August 2018 was 3,712 cfs and this value was used for the 2D model.

We compared modeled versus observed WSE, depth and velocity. The ADCP data was exported from the RiverSurveyorLive software. Specifically, the coordinates of each observation and the depth and average vertical velocity were exported. A shapefile was created in ArcGIS and the modeled depth and velocity were sampled at the ADCP sample locations. Comparing 2D model and ADCP derived velocity is not straightforward. This is because the ADCP collected three-dimensional flow data, while a 2D model uses depth-averaged velocity. We utilized the mean speed from the RiverSurveyorLive software as a measure of the depth-averaged velocity.

Deviations in WSE were mixed between the two model domains (Table 8). In the lower domain deviations were between 0.032 – 1.088 ft, while they were relatively large in the upper domain, ranging from ~2.6 to 3.5 ft. This could be attributed to a change that occurred in the river channel from 2013 to 2018 Figure 15; Table 8) or other factors. The WSE predicted by the model for the upper domain was consistently higher than the surveyed depths by up to 3.5 feet. Given the sensitivity of the habitat suitability indices for water depth, and the magnitude of unexplained variation in depth predicted by the model, caution should be applied when interpreting model results for habitat on an absolute scale. As with many similar flow and habitat models relative comparisons among alternatives are expected to provide more reliable results than when comparing absolute differences.

Table 8. Surveyed versus modeled WSE at 3,712 cfs.

Domain	Location	Survey	2D Model	Unsigned deviation
Lower	Harris	458.133	457.6	0.533
	Below DC	460.792	461.88	1.088
	Gould	470.568	470.6	0.032
Upper	Piedra	518.567	522.07	3.503
	Choinumni	536.81	540	3.19
	Winton	508.932	511.641	2.709
	Frustration	548.69	551.269	2.579

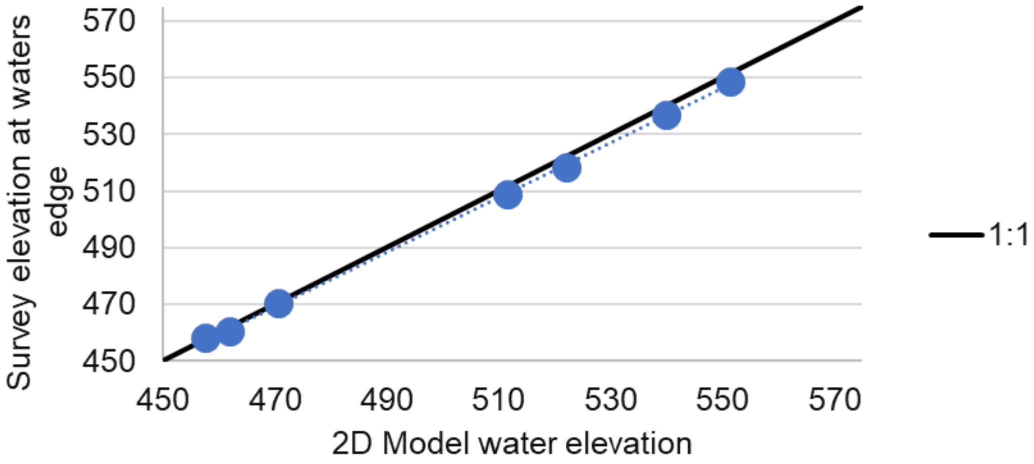


Figure 15. Observed versus modeled WSE. Units are feet NAVD88.

Measured versus modeled discharges indicate that in the upper domain flow amounts were generally close to the daily averaged flow of 3,712 cfs (Table 9). In the lower domain, the Harris Bridge transect was within 80 cfs, but the other locations were more variable. At Gould, flow in the model was almost 600 cfs less than what was observed. Given that WSE values were relatively close in this location (Table 8), it is likely that the upstream hydraulic control shifted, putting more flow down the southern braid into the Dennis Cut (DC) entrance. At the Below Dennis Cut location, there was in fact almost 100 cfs more flow observed than predicted by the model.

Table 9. Comparison of observed versus modeled flow discharge at each transect.

Domain	Location	Observed	Q (cfs) Model	Obs-model	% (mod/obs)
Lower	Harris	1,970	2,050	-80	104.10%
	Below DC	574	669	-95	116.60%
	Gould	1,958	1,368	590.25	69.90%
Upper	Piedra	3,856.50	3,712	144.5	96.30%
	Choinumni	3,717.25	3,712	5.25	99.90%
	Winton	3,724	3,712	12.25	99.70%
	Frustration	3,656.50	3,712	-55.5	101.50%

Depth and velocity comparisons were generally in good agreement but suggest channel change occurred between 2013 and 2018. The Choinumni transect for example, was on average within 0.76 ft, but the transect depth pattern is different indicating channel change. Also, the Gould transect in the lower domain shows significant channel change, with ~6 ft of scour since the LiDAR data was collected.

Piedra and Frustration show that model depth is deeper. One way to reduce water depth would be to lower the roughness. Yet, the value used was on the lower theoretical end for roughness given the grain size of the river. Confounding this is that the Winton transect showed channel deepening in the center of the channel, although it could be due to the model grid size and interpolation. The Below Dennis Cut (DC) transect shows deeper depths, but that is also because there is more flow going in that location in the model than what was observed (Table 9). In the upper domain, mean velocity deviations between ADCP and 2D model data sets were between 0.38– 1.09 ft/s, which indicates good model performance (Table 10).

Table 10. Mean and standard deviation of unsigned deviations in depth and velocity and observed and modeled discharges.

		% Predicted (Observed Model)		Unsigned deviation			
				Mean		Standard	
Domain	Location	Depth	Velocity	Depth (ft)	Velocity (ft/s)	Depth (ft)	Velocity (ft/s)
Lower	Harris	85%	159%	0.66	0.72	0.61	0.82
	Below DC	61%	78%	1.02	1.24	0.28	0.8
	Gould	291%	51%	4.78	2.8	3.16	1.65
Upper	Piedra	92%	96%	0.55	1.09	0.23	0.81
	Choinumni	93%	97%	0.76	0.47	0.38	0.37
	Winton	102%	105%	0.4	0.71	0.27	0.51
	Frustration	94%	94%	0.7	0.38	0.28	0.23

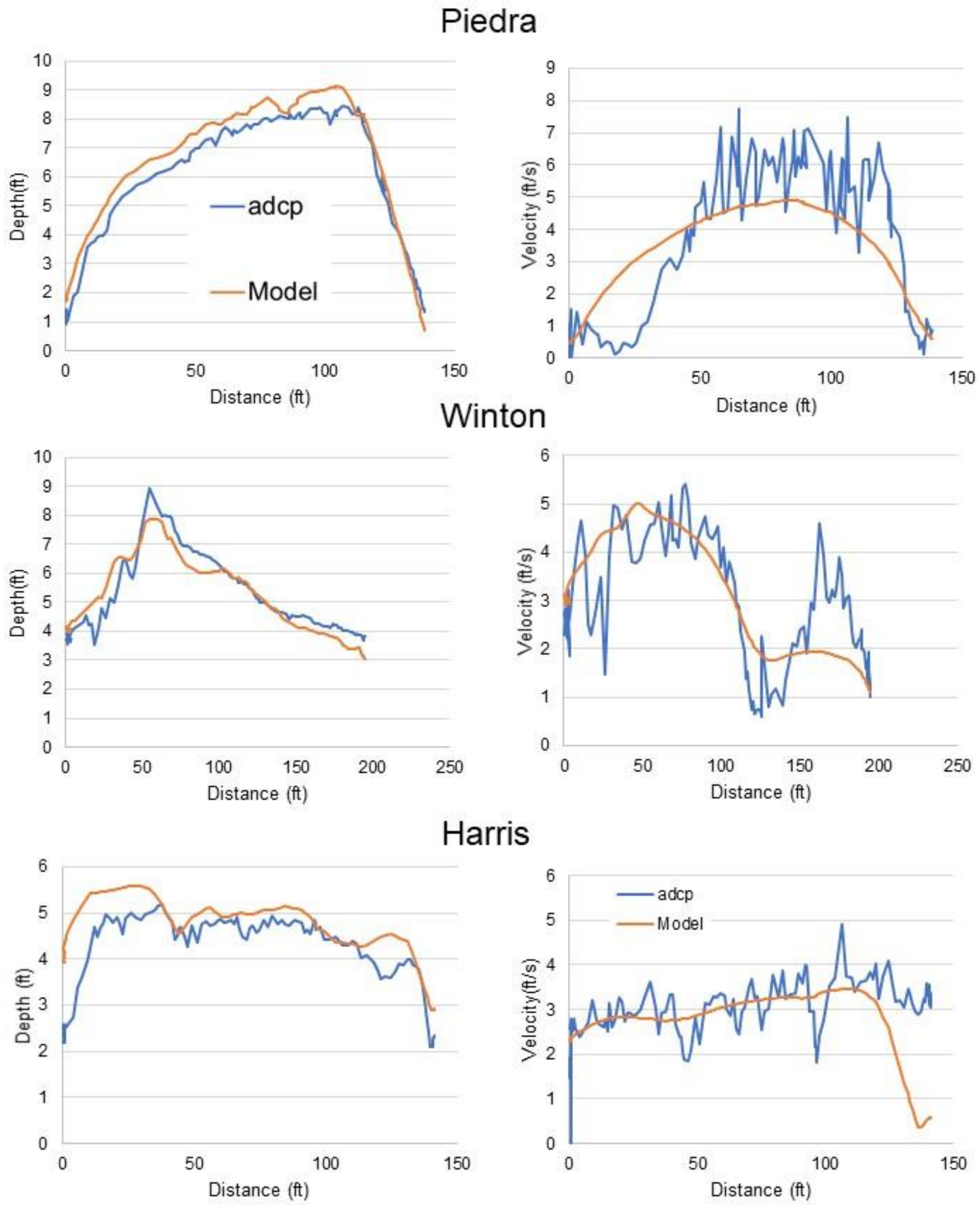
Further, velocity was predicted within 6% for all locations, and depth within 8%. Most of the upper domain model transects for velocity had the same general pattern, although the river left bank of the Piedra transect was different (Figure 16). In the lower domain, Gould and Below DC velocity transects did not show good agreement. For Gould, this is likely due to channel change, while for Below DC it could be due to channel change or due to excess flow in that area in the model compared to what was observed. It is important to note, that deviations in mean depth are not similar to deviations in WSE. This could have been the result of several effects including bank failures or datum inconsistencies during the LiDAR flight or data collection.

Overall Model Assessment

Since 2D models are used for so many different applications there are no overarching model performance standards (Pasternack 2011; Wright et al. 2017). However, most published studies do show that with accurate topographic data, WSE elevations can be predicted within 0.25 ft. Depths are usually predicted within 90%. Mass conservation checks are usually greater than 90%. For water velocity, the common performance benchmark is visual and aims to see if the model captures patterns of velocity along a transect.

Overall, the 2D hydrodynamic model performed well compared against model tests, except for WSE in the upper domain. Mass conservation values were all within 3% except for the lower 250 cfs simulation. The comparison of aerial inundation extent for both upper and lower model domains were within 10%. Model comparisons against field data collected in August 2018 were good. Deviations in modeled versus observed WSE were relatively high in the upper domain, yet mean depth deviations were much lower. This suggests that erosion may have occurred in the upper domain, but the model is still capturing the general variation in depth and velocity. For the lower domain, deviations in modeled versus observed WSE were very good. Another indication of change was that model depths tended to be over-predicted. This is usually parameterized with Manning's Roughness Coefficient (Manning's n), but since Manning's n was at the theoretical lower limit it implies that erosion and channel change occurred. The highest deviation, located Below DC, could be due to channel change or more flow being routed through that area compared to when the surveys were performed (Figure 16).

The water surface elevations at the top of the lower domain and bottom of the upper domain do not match. Upper domain model runs were started first, because it is a simpler model domain with less structures and diversions. We considered re-running Upper domain models using the upstream water surface elevation of the lower domain. Ultimately this was not done because of uncertainty in boundary condition data for both domains, as well as overall uncertainty on the topographic model matching conditions during validation. For example, the Lower domain rating curve was constructed with several assumptions that may be incorrect depending on the accuracy of channel bathymetry.



Piedra

Winton

Harris

Figure 16. Example transect comparisons of depth and depth-averaged velocity for 3,712 cfs.

One could continue to refine the models to achieve even better performance, but this is not recommended for three reasons. One, as stated above it is likely that channel change occurred between LiDAR and field data collection. Quantifying channel change was outside the scope of this project but given that DEM data was collected in 2013 and floods in 2017 peaked over 20,000 cfs, which is greater than a 10-year flood. Corroborating this was the difference in depth/elevation profiles at some of the cross sections where ADCP data was collected in 2018. Second, differences could be related to the quality of downstream rating curve information, which were limited. Lastly, changes to the model are unlikely to alter the gross amounts of habitat predicted, and more importantly their relative effects on understanding limitations to the Rainbow Trout fishery.

For future ecohydraulic or hydrodynamic studies we recommend that boundary condition, calibration and validation data be collected close to the acquisition of topographic data, so they are paired. This will help resolve potential sources of error, such as found in this study. In addition, uncertainty in natural and managed flow splits is a potential source of error that confounds model validation (Figure 17). Natural flow splits above managed diversions can yield more or less water into the receiving channel following channel altering floods. In addition, managed flow splits associated with the ecohydrology flow scenarios represent average conditions. However, depending on the sequence of water years and demand these values can be higher or lower. The more these types of uncertainties can be reduced the better ecohydraulic modeling can help managers understand the relationships between flow and habitat.

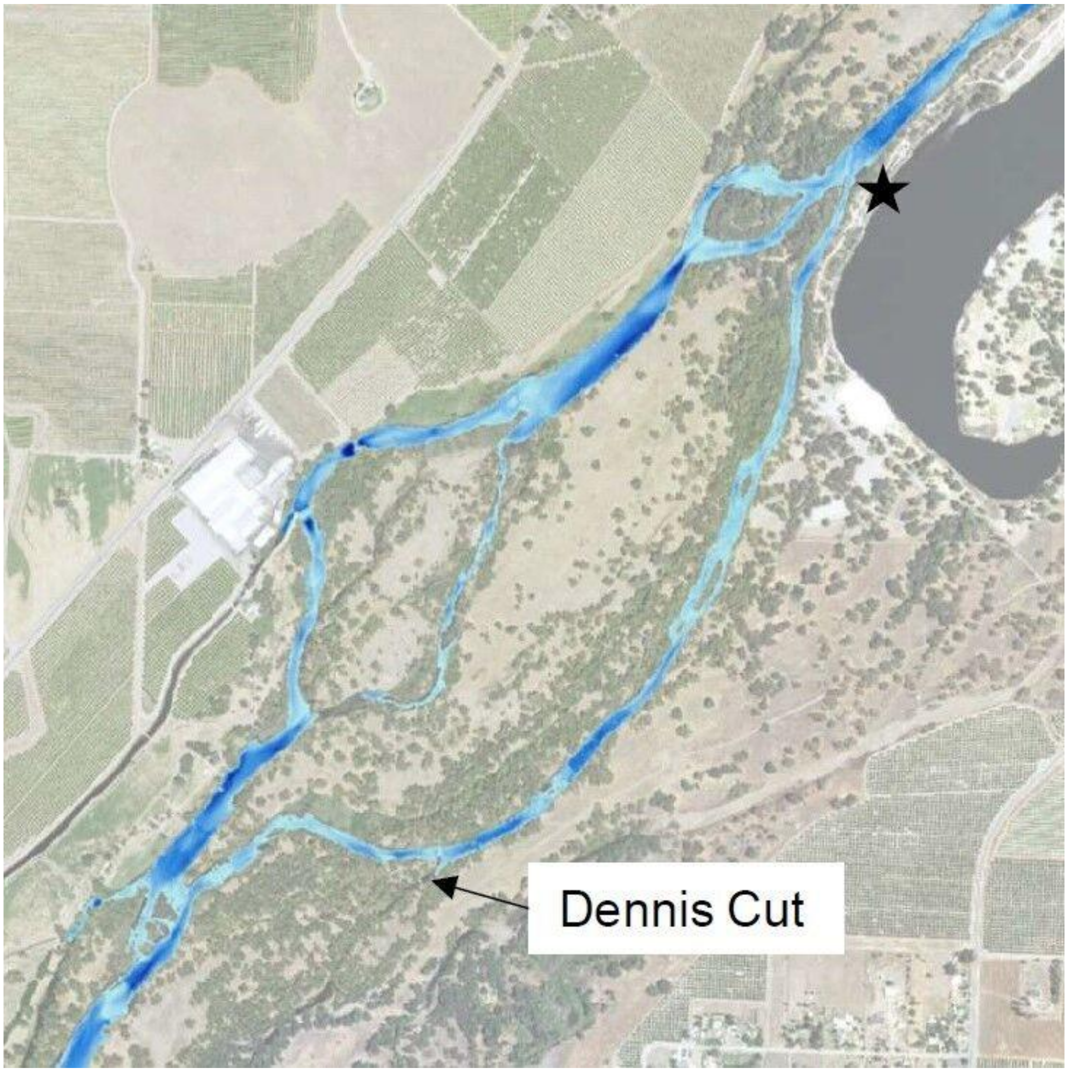


Figure 17. Example of how a natural flow split (e.g. near the black star) can alter flow routing into a managed flow split at Dennis Cut at 250 cfs. In this example an additional 33 cfs is being routed into the main channel and not towards Dennis Cut. This could be due to channel change or DEM errors. Not to scale.

TASK 3. HABITAT SUITABILITY MODELING

Models predicting the spatial distribution of species, often termed habitat suitability models, support our understanding of species niche requirements, predicting species potential distribution, and habitat availability (Hirzel et al. 2006). Their use has been especially promoted to tackle conservation issues, such as managing species distribution, assessing ecological impacts of various factors (e.g. pollution, climate change), risk of biological invasions or endangered species management (Scott et al. 2002; Guisan and Thuiller 2005). These models statistically relate field observations to a set of environmental variables, presumably reflecting some key factors of the niche, like climate, topography, geology or land-cover. They produce spatial predictions indicating the suitability of locations for a target species, community or biodiversity.

To support modeling of suitable habitat, habitat suitability criteria (HSC) are used to translate physical parameters, such as depth and velocity, into terms that inform the modeling process (Bovee et al. 1998).

The focus of this task is the use of HSC and 2D model results to predict the available habitat associated with spawning/incubation and rearing of Rainbow Trout in the 9-mile tailwater below Pine Flat Reservoir. Specifically, we provide the basis for HSC curves used, and together with a range of flows identified by the TSC, assumptions, calibration and validation approach to support modeling results on the estimated habitat available at the time of the LiDAR surveys.

In addition to 2D modeled physical habitat we performed two other analyses related to the spawning and rearing life stages. First, we also collected and evaluated information related to bed substrates. This was done because while adequate hydraulics may exist for spawning there also must be substrate within a specific size class distribution for them to construct a redd. Second, we analyzed water temperature data at the upper and lower study limits relative to published values of thermal tolerances for salmonids.

Methods

Habitat Suitability Curve Basis

Based on habitat suitability information discussed under Task 1, two different habitat suitability indices for depth and velocity were selected for the adult spawning and juvenile rearing life stage (Figure 18). For adult spawning we selected suitability curves from Cummings (2015), while for juvenile rearing we selected suitability curves from Kammel and Pasternack (2014). Adult spawning habitat was evaluated at 100 and 250 cfs, while juvenile rearing habitat was evaluated at 4,000 and 8,800 cfs. During meetings with KRFMP it was requested to also analyze 100 and 250 cfs for juvenile rearing to see if under lower flow conditions habitat became limited.

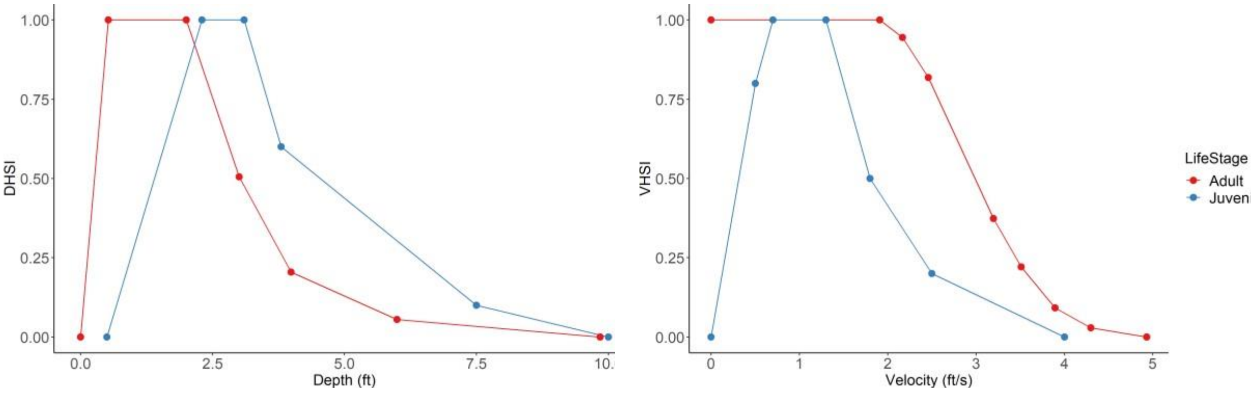


Figure 18. Depth habitat suitability index (DHSI) and velocity habitat suitability index (VHSI) used in habitat suitability modeling (Cummings 2015; Kammel and Pasternack 2014).

Technical Modeling Approach

Habitat suitability maps were created in ArcGIS from 2D model outputs (Task 2) of depth and velocity for adult and juvenile Rainbow Trout. For each flow scenario model results were exported as comma separated values (CSV) with the following variables: X/Y coordinates, shear stress, Froude, velocity, depth, and water surface elevation. CSV files were imported into ArcGIS and a shapefile of the point data generated. A wetted extent polygon was created by generating a 3 ft raster grid of water surface elevation, which was converted to a polygon. The polygon was then used to clip out the points in the model domain that were not wet. Using the inundation polygon, a triangular irregular network (TIN) surface of depth and velocity was created and then converted into a 3 ft raster. For each depth habitat suitability index (DHSI) and velocity habitat suitability index (VHSI) a set of piecewise regressions were developed.

This is a necessary step so suitability indices can be mapped to raster grid data generated from the 2D model. Using these equations, the DHSI and VHSI was determined in ArcGIS using “Con” statements. The hydraulic habitat suitability index (HHSI) was calculated as the geometric mean of the DHSI and VHSI. Since HHSI is an index of suitability a decision needs to be made as to what constitutes “suitable” habitat. We chose a HHSI greater than or equal to 0.5 as suitable habitat (Figure 19 A, B, C).

Normally for spawning habitat, local substrate would be incorporated into the model, as results can demonstrate good hydraulic suitability, while substrate can be poor (e.g. see Brown and Pasternack 2009). Because of this we ultimately sampled substrates associated with polygons of HHSI greater than 0.5 in the field. This information is presented in the Substrate Analysis section.

Juvenile Rainbow Trout typically take advantage of microhabitat features, such as edge habitat to avoid predation and energy-intensive velocity of the main channel (Quinn and Kwak 2000). We analyzed the juvenile HHSI rasters relative to distance from cover. Since cover data was lacking for the study reach, we assumed that the channel margins would be an adequate cover surrogate. Next, we determined the area from the bank that could be used as habitat by juvenile Rainbow Trout. Juvenile salmonid burst speeds were used to define appropriate distances to edge cover. Burst speed typically determines how far into open water juvenile salmonids will move from cover to forage (i.e., maximum range of taking prey if a prey item is detected). This tradeoff represents a combination of “safety” and optimal foraging strategy and can be used to quantify habitat based on fish size and corresponding burst speed. A position that allows juveniles to remain near cover and dart into open water to forage is considered optimal and can be defined in terms of darting time. Bell (1990) suggested that a maximum darting time of 7.5 sec should be used for fish, because after this period fish are unable to pass water over their gills at a rate necessary to obtain the increased oxygen levels required for additional energy expenditure. The distance from optimal holding positions that juveniles can travel in 7.5 sec (out and back to holding position) becomes the optimal foraging distance (3.75 sec). Therefore, suitable habitat can be considered open water habitat that meets depth and velocity criteria within 3.75 sec of cover. Based on NMFS fish passage criteria, this distance is 0.90 m (3.75 sec • 0.24 m/sec) for juvenile size fish (>50 mm). Therefore, a rough approximation of usable rearing habitat area is the area which meets depth and velocity suitability criteria within ~1.0 m of cover. These values are similar to those reported by Hardin et al. (2005) in an observational study of juvenile Chinook Salmon (*O. tschawytscha*) in the Klamath River, California (~0–3 ft). Further, Engle et al. (2006) show that most age 1+ and YOY salmonids occupied habitat within 7.4 ft (2.25 m) of bank edges. A basic relationship that estimates darting distance (L_{dart}) based on fork length (FL) is

$$L_{dart}\,(m) = 9 \bullet FL(m) \bullet 3.75s \qquad (2)$$

Where the number 9 is empirical and is an average value from Bell (1986).

We used the time of year for the two higher flows of 4,000 and 8,800 cfs to estimate Fork Length (FL) for rearing fish from the life cycle model (Figure 35). For example, the 4,000 cfs flow that was modeled is the average flow in May that is exceeded 33% for at least two weeks. We expect juvenile trout during this month to be approximately 37.8 mm (fry). Similarly, the 8,800 cfs flow is the average June flow during wet years, and we expect fish to be approximately 49.5 mm (fry/parr). The smallest FL in any month is 27.7 mm. Using the darting distance equation above we determined the edge distance for these FL and compared them to the 2.25 m edge distance used in initial modeling. The darting distances for 27.7, 37.8, and 49.5 mm fish are 0.9, 1.3 and 1.7 m, respectively. Since all these values were less than 2.25 m, we calculated HHSI using the edge distance of 0.9 m to provide a lower estimate of available juvenile rearing habitat, representative of the early, fry/parr period (e.g., spring-early summer). Therefore, after calculating the “raw” HHSI (e.g. using depth and velocity only) for juvenile rearing we applied buffers of 0.9 and 2.25m (July – September) and used the new polygon to clip the raw rasters of juvenile HHSI for each flow (Figure 19D, E,F). The final amount of habitat area was determined by converting HHSI raster grids for spawning and rearing into polygons where the HHSI was greater than or equal to 0.5 (Figure 20).

After initial results were made available there was a desire by the KRFMP to account for uncertainty in the hydraulic modeling and how that may propagate to estimating physical habitat area. There are no peer reviewed accepted methods of propagating uncertainty from 2D modeling to HHSI estimates. We considered accounting for sampling limitations of the ADCP unit, but the unit’s error is relatively low (e.g., Depth Accuracy 1%; Depth resolution 0.001 m; Velocity accuracy +/-0.25% of measured velocity +/-0.2 cm/s). To incorporate potential error introduced from the 2D model to final estimates of suitable habitat we developed a simple method that accounts for potential error in predicted depth and velocity, using depth to drive error propagation. The mean deviation in predicted depth (e.g. ~0.7 ft) was added and subtracted to each cell and calculated the DHSI for both cases, termed $DHSI_{low}$ and $DHSI_{high}$. We then adjusted velocity at that node based on continuity (e.g. unit cell discharge = cell depth/ cell velocity) and calculated the VHSI for both, termed $VHSI_{low}$ and $VHSI_{high}$. We then calculated several additional estimates of HHSI using different combinations of DHSI and VHSI that were used to develop error bars for habitat area: $HHSI_{low} = (DHSI_{low} \bullet VHSI_{low})^{1/2}$ $HHSI_{high} = (DHSI_{high} \bullet VHSI_{high})^{1/2}$ $HHSI_{low\ 2} = (DHSI_{low} \bullet VHSI)^{1/2}$ $HHSI_{high\ 2} = (DHSI_{high} \bullet VHSI)^{1/2}$ $HHSI_{low\ 3} = (DHSI \bullet VHSI_{low})^{1/2}$ $HHSI_{high\ 3} = (DHSI \bullet VHSI_{high})^{1/2}$

Therefore, there were (7) estimates of potential spawning habitat for 100 and 250 cfs: HHSI (using raw DHSI and VHSI) and the (6) estimates listed above. Note that we did not alter the water inundation polygons for this analysis, as that would amount to changing the model domain beyond what the initial results were derived for. This was done for spawning habitat and edge-buffered rearing habitat.

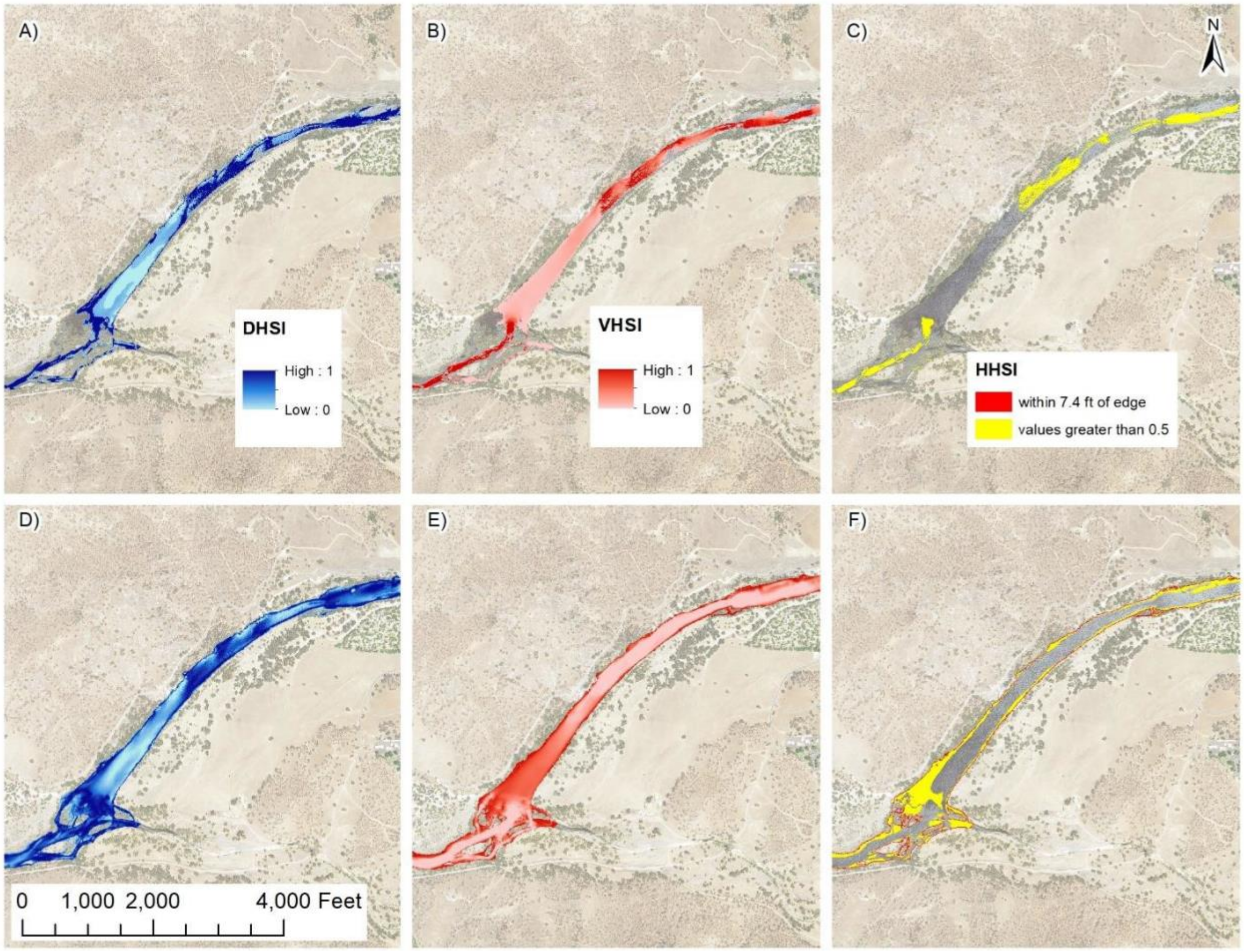


Figure 19. Examples of DHSI, VHSI and HHSI for spawning habitat at 100 cfs (A, B,C) and rearing habitat at 4,000 cfs (D,E,F). Spawning DHSI (A) and VHSI (B) are combined to create the HHSI, which is then subsampled to values greater than or equal to 0.5 (C). A similar workflow is used for juvenile rearing habitat with DHSI (D) and VHSI(E), but the HHSI (F) is clipped to areas within 7.4 ft from the water’s edge.

Results

Adult Spawning Habitat

Habitat suitability modeling predicts between ~41 and 71 acres of habitat meets the depth and velocity requirements of spawning Rainbow Trout at 100 cfs, with a mean of ~58 acres (Figure 20). The amount of hydraulically suitable habitat increases at 250 cfs, with between ~70 and 104 acres available and a mean of ~86 acres of suitable habitat. See Substrate Analysis section for further discussion of spawning habitat availability.

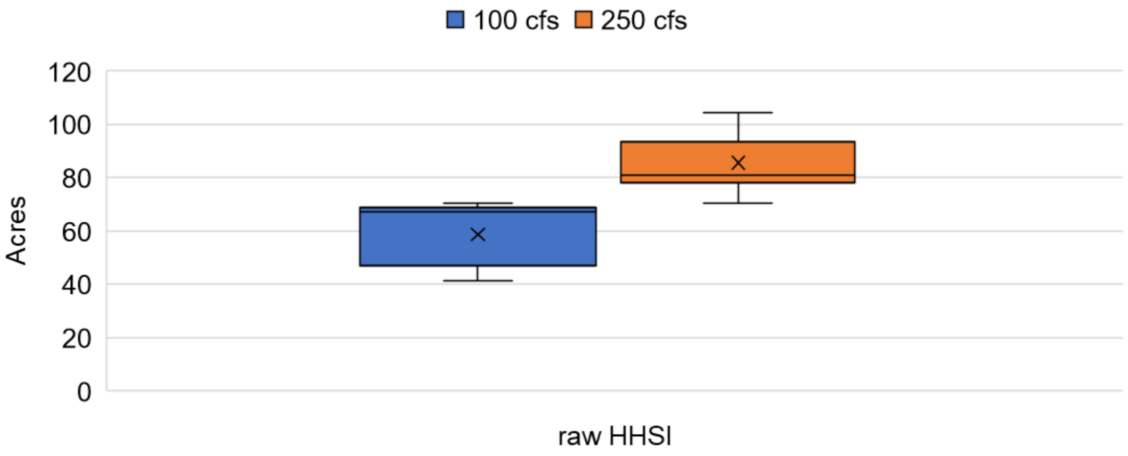


Figure 20. Box and whisker plots of modeled estimate of hydraulically suitable spawning habitat at 100 and 250 cfs. Box shows inclusive median. Box lines are 1st and 3rd quartiles. X = mean and line inside box is median.

Juvenile Rearing Habitat

Habitat suitability modeling predicted between ~96 and 155 acres of hydraulically suitable (meets depth and velocity suitability) juvenile rearing habitat for the range of flows modeled (Figure 21).

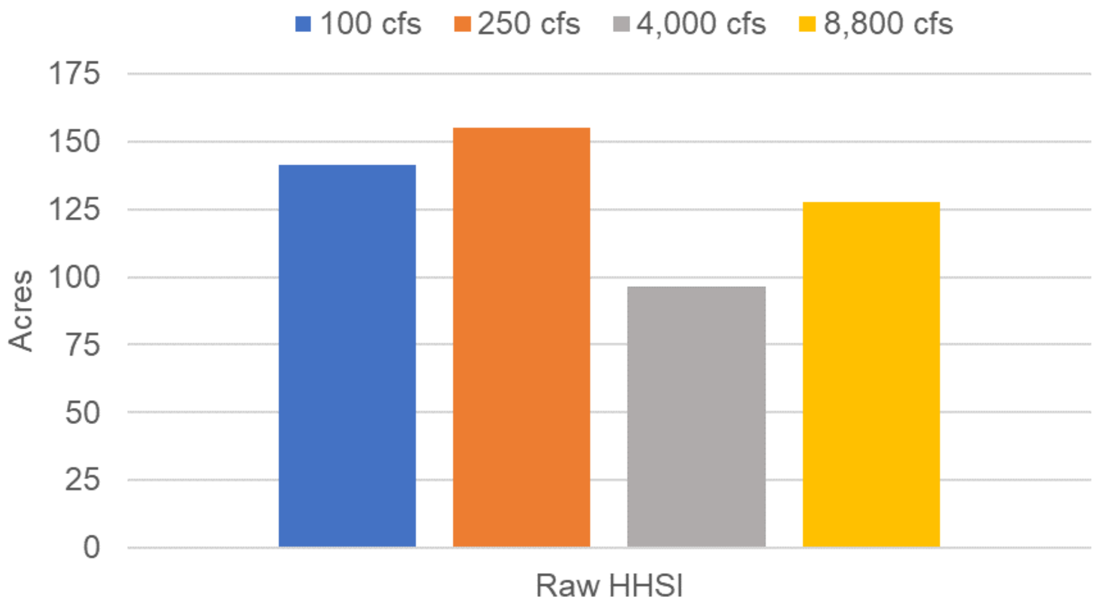


Figure 21. Modeled area of raw hydraulically suitable rearing habitat (e.g. considering only depth and velocity) for juvenile Rainbow Trout at 100, 250, 4,000 and 8,800 cfs assuming cover is sufficient.

When considering the distance to edge potential habitat decreases since less area is considered (Figure 22). Box-whisker plots of the area of hydraulically suitable rearing habitat at 100, 250, 4,000 and 8,800 cfs were calculated for edge buffers of 0.9m (left) and 2.25m (right). Box shows inclusive median. Box lines are 1st and 3rd quartiles. X = mean and line inside box is median. For the 0.9m buffer potential suitable habitat ranges from 1.4 to 18.5 acres with an average between ~7 and 8.5

acres. For the 2.25m buffer potential suitable habitat ranges from 3.4 to 46 acres with an average between ~17 and 21 acres.

Substrate Analysis

Streambed gravel sizes can limit salmonid spawning success (Groot and Margolis 1991; Kondolf 2000). Bed sediment may be too large for spawning females to mobilize and this can particularly be a problem where dams eliminate supplies of smaller, mobile gravels (Parfitt and Buer 1980; Kondolf 1997). Because of this potential issue, we incorporated an assessment of spawning gravel quality to determine whether gravel size limits Rainbow Trout spawning success in areas we predict would meet depth and velocity requirements below Pine Flat Reservoir.

Cramer Fish Sciences and KRCD conducted LKR substrate surveys on 16 and 17 August 2018 to estimate the availability of spawning gravels for adult Rainbow Trout. We hypothesized that spawning gravels are lacking in areas of suitable depth and velocity for spawning *O. mykiss*, resulting in suboptimal spawning habitat.

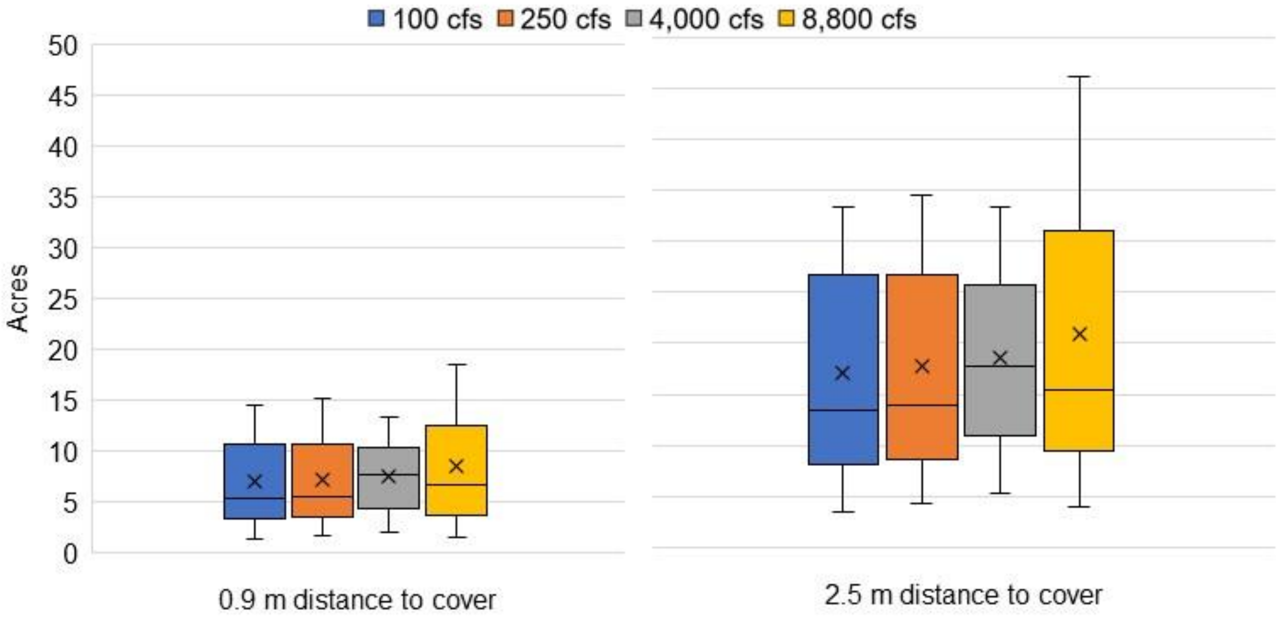


Figure 22. Box-whisker plots of the area of hydraulically suitable rearing habitat at 100, 250, 4,000 and 8,800 cfs for edge buffers of 0.9m (left) and 2.25m (right). Box shows inclusive median. Box lines are 1st and 3rd quartiles. X = mean and line inside box is median. median.

Field Methods

We assessed substrate sizes by conducting video transects through areas with suitable depth and velocity for spawning *O. mykiss*. Study sites were selected using the Surface-Water Modeling System (Aquaveo, Provo, Utah) to calculate a global habitat suitability index (GHSI) derived from known depth and velocity preferences of spawning *O. mykiss* (Figure 19). These data were imported into ArcMap to produce GHSI polygons, which were then uploaded onto a handheld Garmin GPSMAP 64s unit for reference in the field. The Garmin was also used to record our track while we were filming to collect GPS coordinates of the video transects.

It was not possible to perform traditional pebble count surveys (Kondolf and Li 1992; Bauer and Burton 1993) within these polygons because many of the areas were too deep for wading, so we instead captured substrate images using a GoPro Hero 5 underwater video camera. The GoPro was secured in a housing between two lasers spaced 8.5 in. (216 mm) apart and attached to a downrigger on the sampling vessel (Figure 23). Coaxial antenna cable (RG 174) was connected between the GoPro and a Samsung tablet to maintain Wi-Fi connection while the GoPro was underwater, which allowed the crew to see the video in real-time. We oriented the boat upstream into the current to optimize stability and clarity of the lasers and imagery while recording video transects of the substrate. During video collection, we adjusted the downrigger in response to changes in depth, observed from the real-time video on the tablet.

Figure 23. GoPro housing with lasers mounted on either side (left). GoPro and housing attached to downrigger on the sampling vessel (right).

Image Processing

Still images were extracted from every fifth video frame using Free Video to JPG Converter (Softonic, Barcelona, Spain). After extraction, images were linked to the GPS track collected by the Garmin with a time stamp. Any images that fell within polygon boundaries were examined for laser presence, since the distance between them functioned as the scale (Rizzo et al. 2017). Images of poor quality, in which lasers could not confidently be distinguished, were not used (n= 126); images captured outside of polygons were also not used (n= 440). A total of 1,908 substrate measurements were made from 89 images collected within 31 polygons.

Images were processed with ImageJ (National Institutes of Health, Bethesda, Maryland). Depending on the orientation of the image, individual pebbles were randomly selected using either a grid or line. If the GoPro was aimed directly downwards toward the bed surface (i.e., substrate depth was the same throughout the image), a grid was generated over the image and pebbles touching the line intersections were measured (Figure 24 left). If the GoPro was aimed at an angle (i.e., substrate varied in proximity from the camera), a line was drawn between the lasers over the image and any pebble touching the line was measured (Figure 24 right).

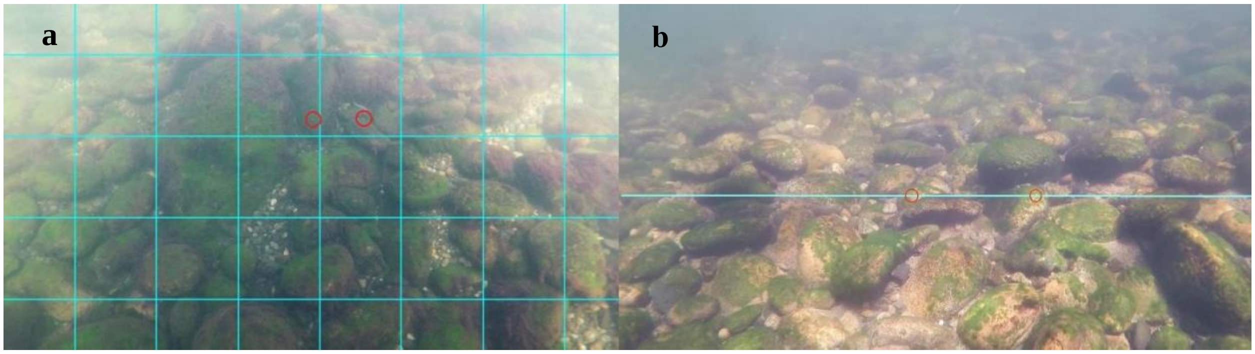


Figure 24. Grid intercept method used for downward-facing image (left) and line intercept method for image taken at an angle (right). Laser points are circled in red for reference and are 8.5 in. (216 mm) apart at point center.

We followed Wolman's pebble count technique of measuring the intermediate axis of each particle using the measuring tool in ImageJ, after setting the scale using the distance between the two laser points (Wolman 1954).

Analysis

Program R (R Core Team 2018) was used for data summary and analysis. We calculated cumulative grain size distribution, D_T, median particle size (D_{50}), and 84th percentile of particle size (D_{84}) for each section separately. We also calculated the percent of substrate for each reach that is smaller than: D_T, suitable 100 mm (Orcutt et al. 1968; Raleigh et al. 1984), preferred 60 mm (Orcutt et al. 1968), and unusable 101.6 mm (Orcutt et al. 1968).

Adult *O. mykiss* have depth, velocity, and particle size preferences in which to construct redds, and the substrate size a female is physically able to move is limited by her total length. A range of suitable spawning sediment sizes has been reported in the literature. Orcutt et al. (1968) and Raleigh et al. (1984) determined that suitable Rainbow Trout spawning gravel size is 100 mm. Orcutt et al. (1968) reported preferred substrate to be 60 mm and unusable to be 101.6 mm. Kondolf and Wolman (1993) concluded that female salmonids generally spawn in gravels with a median diameter up to about 10% of their body length. However, Riebe et al. (2014) argue the "10% rule" fails to capture grain-size limitations on salmon spawning and that it may be overly simplistic for evaluating overall salmonid spawning habitat quality. They argue the more appropriate estimate should be the largest particle size that an average- sized female salmonid can move (D_T) which is calculated as follows:

$$D_T = 115[L/600]^{0.62} \tag{3}$$

Where *L* is fork length (FL). Fork lengths used to calculate D_T were gathered from electrofishing surveys conducted by KRCD from 2008 to 2017. Since *O. mykiss* typically reach maturity in their second or third year of life (Moyle 2002), only lengths of individuals at least two years old were used in our analysis (Figure 25).

To estimate D_T, we used FL data from diploid Rainbow Trout collected between 2007 and 2017 during LKR fall electrofishing surveys. We performed a histogram of length frequencies of all fish to estimate all fish at age 2+ or greater (Moyle 2002). Because spawning occurs in winter, we added 12 mm (0.2 mm per day for 60 days; see Sogard et al. 2013) to all fish larger than ~140 mm. In short, most LKR natural spawners were estimated to be ~150-300 mm FL; Because precocious males are often the smallest of the adult salmonid population, we assumed all individuals in the lowest 10 mm of the estimated Age 2+ fish were males and removed them from the analysis (Titarev 1975; Gross 1984). These data suggested the length of spawning Rainbow Trout within the study area ranged from 160 – 462 mm FL (mean 210.8). Therefore, D_T was estimated to be 59.6 mm.

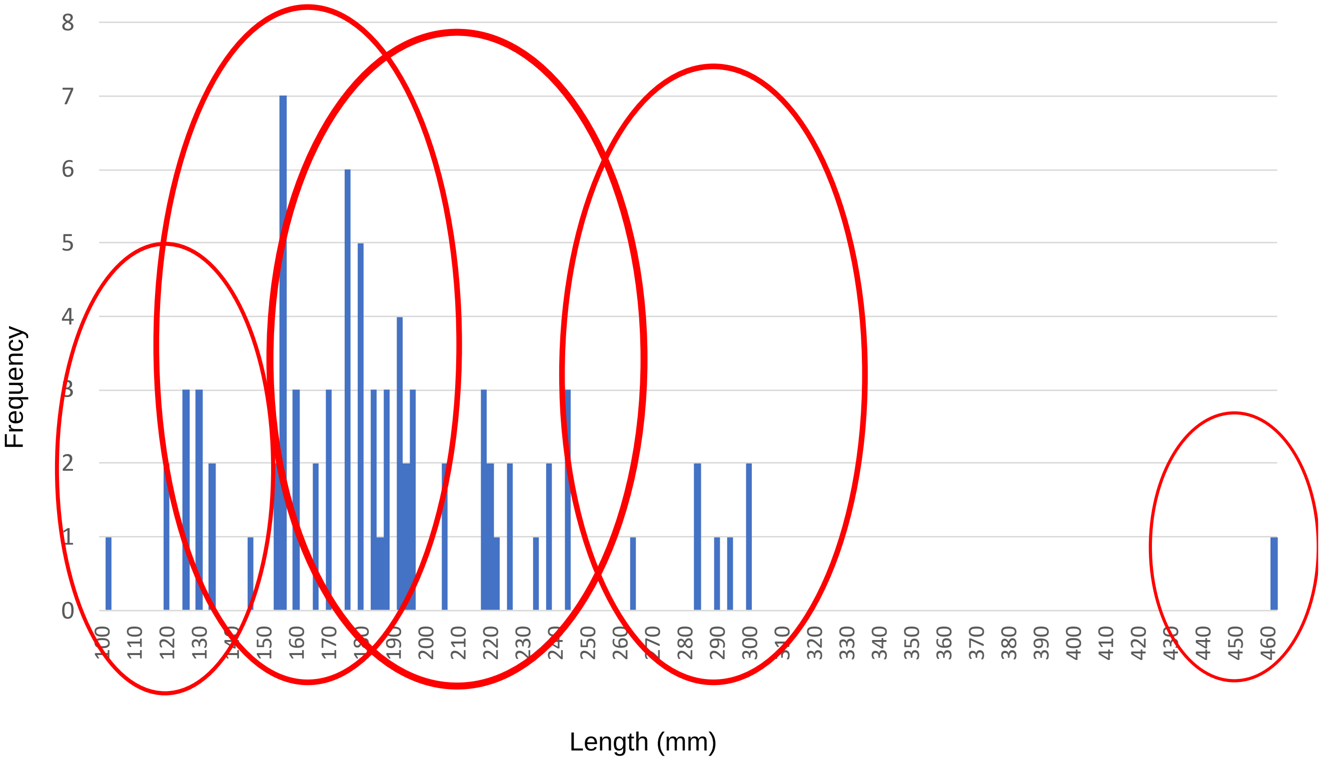


Figure 25. Fork lengths estimated from diploid Rainbow Trout collected during Fall backpack electrofishing surveys in the lower Kings River California. Red circles indicate roughly where ages classes separate based on visual determination of histogram breaks. For Instance, age 1+ Rainbow Trout are ~145-210 mm and age 2+ Rainbow Trout are ~185-260 mm in Fall**.**

Results

A total of 1,908 grain size measurements was recorded from 215 video points of images that fell within polygons estimated to meet depth and velocity requirements for spawning Rainbow Trout during the typical spawning period (see Habitat Suitability Modeling section). Results indicate >76% of surface substrates were larger than the largest particle that LKR Rainbow Trout (age 2+) can move (D_T) and >58% were above the threshold considered generally usable for Rainbow Trout in the literature (Figure 26). Although some variability in grain size was observed along the stream corridor, the overall outcome suggests oversized material is a chronic issue throughout the entire 9 miles (~15 km) of the study reach (Figure 27).

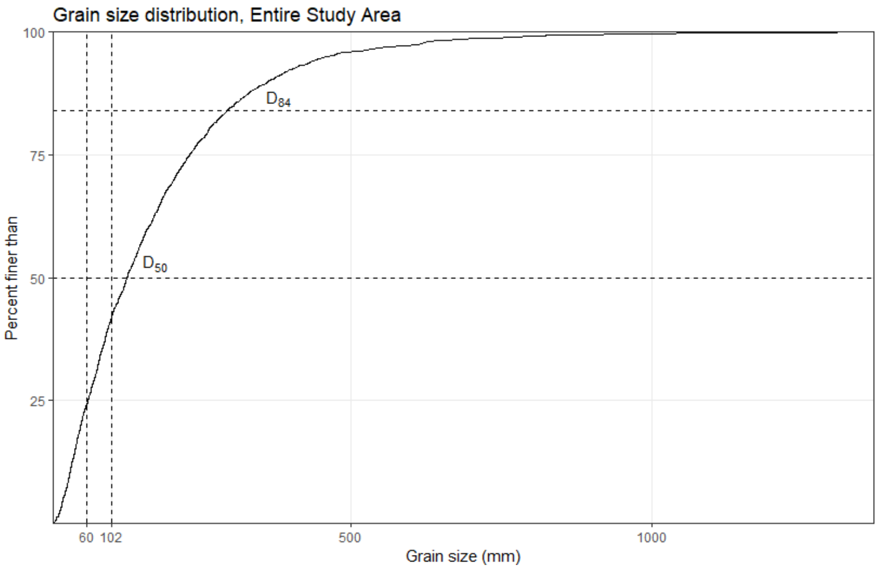


Figure 26. Grainsize distribution (D_{50} = 127; D_{84} = 294) collected from 1,908 particles measured along the ~15km study reach of the Kings River below Pine Flat Reservoir. D_T is the estimated largest particle size that an average-sized Kings River Rainbow Trout can mobilize (D_T = 60 mm), and generally unusable grain sizes (102 mm) for Rainbow Trout (Orcutt et al.1968).

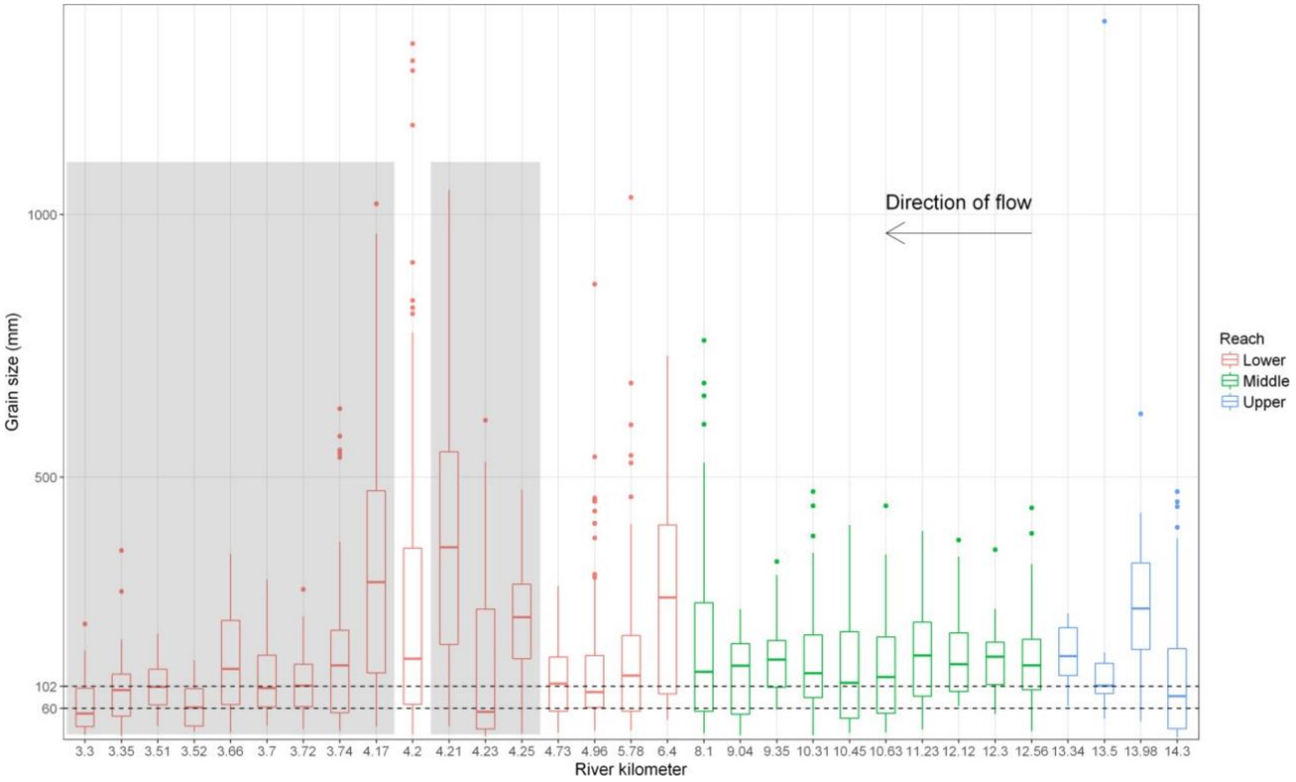


Figure 27. Grain size distribution estimated from underwater video within the study reach of the lower Kings River. Bar and whiskers indicate mean, range and standard deviation in relationship to estimated largest particle size that an average-sized Kings River Rainbow Trout can mobilize (D_T = 60 mm), and unusable grain sizes (102 mm). The reach was divided into three sub-reaches from Fresno Weir to Cobbles Weir (Lower), Cobbles Weir to Mill Creek (Middle), and Mill Creek to Pine Flat Dam (Upper). Gray boxes indicate where limited boat access required surveys in secondary channels.

Water Temperature Analysis

This sub-task of the habitat suitability modeling provides a coarse evaluation of general water temperature suitability for Rainbow Trout in the study area. The sub-task goal is to assess whether there are changes in water temperature that may shift the focus of where habitat enhancement should take place. We assume that the potential benefits of habitat enhancement are limited when water temperatures might cause Rainbow Trout to avoid areas of the river. We utilize existing temperature records located below Pine Flat Dam and adjacent to the Fresno Weir.

According to a USEPA (1999) review of the scientific literature, salmonids may avoid areas where maximum temperatures exceed approximately 22–24°C. Note that this does not consider thermal requirements for egg incubation. Optimal ranges for incubation, defined as the range in which eggs had the highest survival (Myrick and Cech 2001), are between 5–10°C, well below the general limit for suitability. Instead we focus on juvenile and adult life stages where fish can move in response to unsuitable conditions.

While the above provides general ranges of water temperature, several factors have been identified that affect temperature tolerance and response of different life stages of trout including acclimation history, dissolved oxygen concentrations, food supplies, nighttime cooling, stress, genetics, thermal history, swimming energy, and overall health and condition. It has also been hypothesized that Rainbow Trout demonstrate a clinal gradient in temperature tolerance with stocks from the Pacific Northwest and Alaska having the lowest thermal tolerance and stocks from warmer climates (e.g., central and southern California) having greater thermal tolerance. For example, Matthews and Berg (1997) reported Rainbow Trout holding in pool habitat where summer water temperatures were as high as 28.9 °C; substantially greater than the 22–25 °C temperature frequently cited as the threshold for unsuitable rearing habitat. Matthews and Berg (1997) noted that the pool where trout resided throughout their observation period had a vertical temperature gradient with surface water (27.9 °C) substantially warmer than temperatures near the pool bottom (17.5–21 °C). They attributed this to groundwater seeps that introduced cooler water with reduced dissolved oxygen, into the bottom creating a microhabitat that served as a thermal refuge where trout would accumulate during the day. Again, the focus of this sub-task is to prioritize future potential habitat enhancement activities and more rigorous temperature analyses are beyond the scope and availability of data for this project.

Methods

Temperature data were collected from a KRWA temperature gauge at the Fresno Weir from 2002–2017 and at the USACE Bridge below Pine Flat Dam from 1984–2017 (Figure 28). Median weekly water year type temperatures (minimum median, median, and maximum median) for the USACE Bridge location were calculated by assigning a water year to average daily temperature data from 1984–2017 and calculating the median values across all water year types. Values for the Fresno Weir location were calculated in a similar way; however raw data were given in 30–minute increments for portions of the year from 2002–2017. There was no temperature data available for April-August in wet water years. The three water year types used in this report were created by combining the five categories defined by the California Department of Water Resources; Critically Dry, Dry, Below Normal, Above Normal, and Wet. Dry consists of Critically Dry and Dry, Normal combines Above Normal and Below Normal, and Wet.

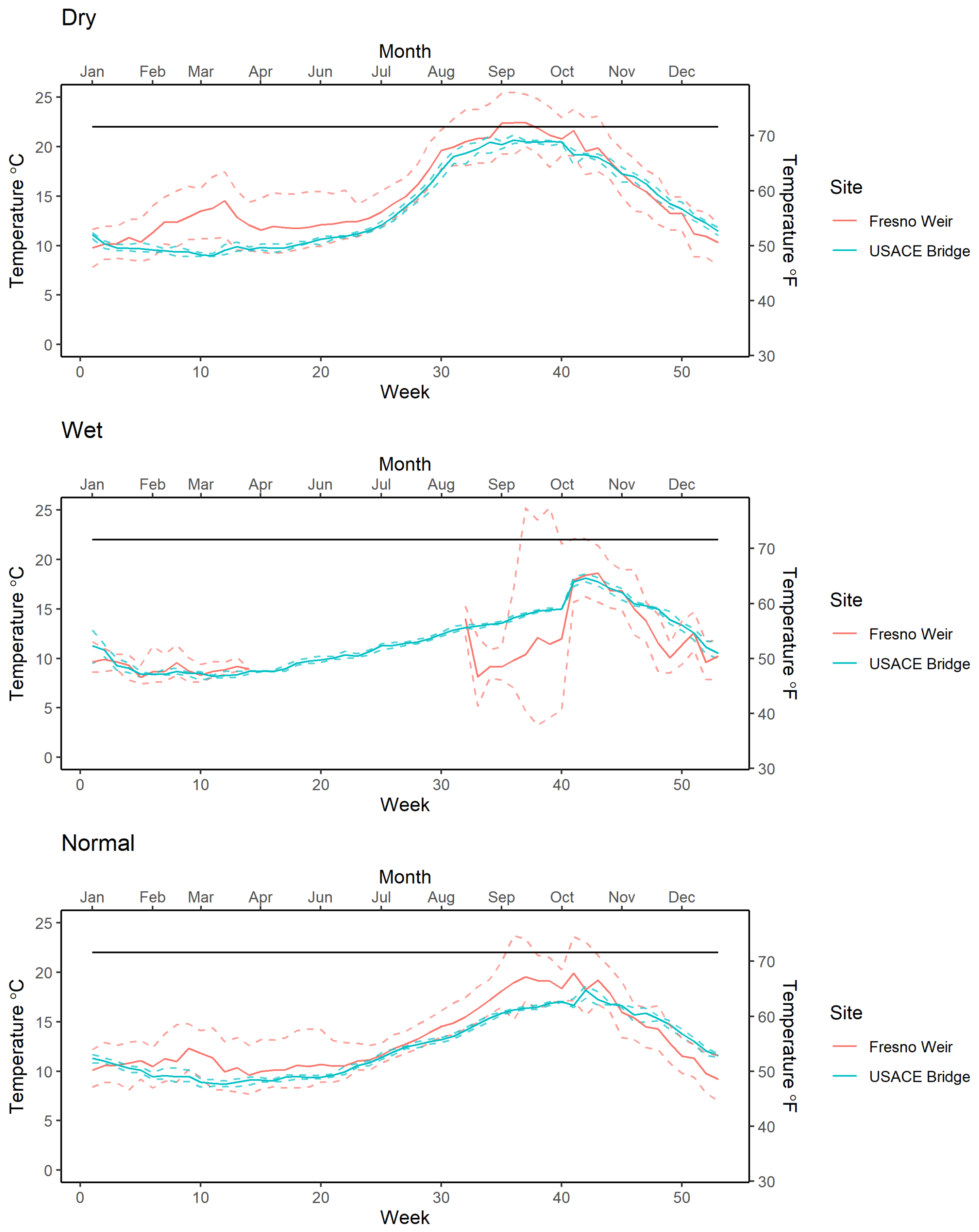


Figure 28. Median weekly water temperatures by water year type at the USACE Bridge below Pine Flat Dam from 1984–2017 and at the Fresno Weir from 2002–2017. The solid black line (horizontal) conservatively represents the 22°C upper limit for suitability discussed in the text. The lower broken line = minimum median, solid line = median, and the upper broken line = maximum median water temperature.

Observations related to general salmonid habitat suitability and habitat enhancement

Visually assessing the plots of water temperature at both locations by water year type, only maximum median values exceed or come close to the 22°C–24°C range at the Fresno Weir, and generally in the Fall (Figure 28). During dry years mean temperature values at the Fresno Weir exceed ~22°C during weeks 31-43, a total of 13 weeks (Table 11). During wet years the mean temperature values exceed the suitable range during weeks 37-39 and 41-42, a total of 5 weeks. For Normal water years, maximum values exceed the suitable limit during weeks 36-37 and 41-42, a total of 4 weeks.

The implications to potential habitat enhancement are that it would be more beneficial to focus actions in the upper portions of the Study area, at least initially. It is important to note that the logger located at Fresno Weir is at the extreme downstream end of the Rainbow Trout fishery. It also occurs at the downstream end of a relatively large glide/pool. This may exaggerate temperatures, especially at the upper range trout are exposed to in this area. Even so, only maximum values tend to exceed suitable limits at the Fresno Weir. Spatially explicit water temperature measurements would help constrain exactly where along the river water temperatures begin to exceed suitable ranges.

Table 11. Number of weeks per water year that exceed 22°C at the Fresno Weir.

Location	Water Year Type	Week Number(s)	Total Number of Weeks
Fresno Weir	Wet	37-39, 41-42	5
	Normal	36-37, 41-42	4
	Dry	31-43	13

Conclusions

- ***Spawning Habitat Suitability Modeling*** – At flows of 100 cfs, the model predicts ~40 –70 acres of river channel meet spawning depth and velocity preferences of Rainbow Trout. At 250 cfs, this increases to ~70 –100 acres. These results do not include substrate as summarized below.
- ***Rearing Habitat Suitability Modeling*** – Habitat suitability modeling predicted ~96 –155 acres of hydraulically suitable (meets depth and velocity suitability) juvenile rearing habitat for the range of flows modeled. However, when considering modeled edge cover needs, potential habitat ranges from 1.4 – 46 acres with an average between ~7 and 21 acres depending on the flow and trout size.
- **Substrate mapping -** Results indicate >76% of surface substrates were larger than the largest particle that LKR Rainbow Trout (age 2+) can move (D_T) and >58% were above the threshold considered generally usable for Rainbow Trout in the literature Although some variability in grain size was observed along the stream corridor, the overall outcome suggests channel hydraulics at the modeled flows are adequate, but that substrate is generally too large for salmonids to construct redds.
- **Water temperature -** In general water temperatures are both warmer and more variable at the Fresno Weir location compared to the USACE Bridge. Water temperatures exceed suitable ranges only at the Fresno Weir for maximum median values, and only in the Fall. Based on this, habitat rehabilitation is likely to yield more benefits towards the upstream study limit.

TASK 4. QUANTITATIVE LIFE CYCLE MODEL AND ASSOCIATED HABITAT NEEDS – LOWER KINGS RIVER RAINBOW TROUT POPULATION

This task uses life cycle modeling, in concert with ecohydraulic analysis to inform LKR fisheries management. Life cycle modeling is an invaluable tool for informing population management (Doak et al. 1994; Beissinger 2002), particularly for species that have distinct life stages. A major advantage of life cycle models is that they can translate changes in demographic rates (survival, capacity, or fecundity) in specific life stages into measures of population viability metrics (e.g., long-term abundance, productivity, or probability of extinction), which are more relevant for population management. Additionally, life cycle models allow for the examination of impacts across several life stages and in concert with other factors such as habitat variability and climate change. This can further facilitate the estimation or prediction of specific habitat requirements for each key life stage which allows for habitat rehabilitation and maintenance planning for target populations (Zabel et al. 2013).

The KRFMP is dedicated to enhancing the LKR watershed, including fish habitat, while maintaining other beneficial uses, recognizing that a healthy river is essential to the region’s well-being and quality of life. Accordingly, we have focused on developing relationships between spawning, juvenile productivity, rearing potential and associated habitat conditions for the primary angling resource, Rainbow Trout in the LKR. Therefore, the goal of freshwater habitat enhancement actions in the LKR include changing the state of the river ecosystem in such a way as to improve conditions for Rainbow Trout spawning, embryo incubation and juvenile rearing. Habitat enhancement actions can take on many forms, including moderating water temperature by increasing riparian vegetation, restoring stream structure, or allowing better access to or increasing the amount of productive habitat. In addition, other anthropogenic impacts, such as climate change, can alter freshwater ecosystems, and can consequently change population performance, either positively or negatively. The economic and cultural importance of a fishery and the potential high cost for large-scale habitat enhancement, increase the need for tools to direct enhancement efforts within the LKR where they will be most effective (KRFMP 2004).

A major challenge of developing fish/habitat relationships is understanding the mechanistic pathways linking mitigation actions with ecosystem changes and, ultimately, a fish response (Zabel et al. 2013). Establishing these linkages requires detailed field data, both in terms of fish response and habitat conditions. However, when done properly, such models can be informative in determining possible habitat enhancement or enhancement actions and determining potential outcomes of such actions to inform management decisions.

Our objective was to model and evaluate potential effects of habitat availability and potential habitat enhancement targeting spawning and rearing habitat for the LKR Rainbow Trout fishery given population and angling expectations. It is important to note that while this document offers a level of precision that would suggest precise quantitative information is available, this is not the case. These models were developed as a first step in determining relationships between environmental conditions and population responses. Future LKR-specific research should inform and improve this first attempt at developing these relationships.

Model Assumptions

To investigate the response of wild Rainbow Trout to habitat change resulting from rehabilitation or degradation, we adapted a spatially explicit, life stage specific, population-habitat relationship model (Scheuerell et al., 2006; Battin et al., 2007), to address the following questions for an LKR population:

- Is spawning or summer rearing habitat limiting population goals?
- How does the population change in response to alternative scenarios of habitat enhancement?
- Which individual habitat characteristics have the potential to substantially influence population status, through improvement?
- Which life stage(s) has/have the largest population status effect?

Since little biological information is available for Rainbow Trout specifically within the LKR, application of this population dynamics model involved developing relationships between habitat characteristics specific to the LKR and population vital rates (survivorship or carrying capacity) available from the literature. Where available, we used region-specific information (see references in methods section) addressing variability and uncertainty in the assumptions.

The model includes direct effects of harvest, population age structure, and life-stage-specific survival relative to the LKR. We used this model to compare the relative influences of important habitat characteristics on population size and to describe where in the basin those habitat characteristics may be altered by landscape changes; particularly habitat enhancement/rehabilitation actions.

In-Channel Fish Habitat Improvements

The governing KRFMP document (Framework Agreement; KRFMP 1999) provides several recommendations that aim to improve and maintain the LKR fishery. These include guidelines for minimum target instream flows, Pine Flat Reservoir coldwater pool management, an annual stocking program, and fish habitat improvements (KRFMP 1999; 2011). The overarching aim of these efforts is to create and maintain recreational fishing opportunities in a year-round, high-quality trout fishery (KRFMP 1999). Successful habitat improvement projects are designed to activate under contemporary hydrologic conditions and create, increase or enhance habitat types, features, or processes that are limiting the productivity of a target population. Therefore, it is imperative that habitat enhancement practitioners and resource managers answer the following questions:

1) What is the goal for the target population (e.g., population size, abundance of adults, etc.)?
2) How much habitat is currently available for the target species? (*Is that amount of habitat sufficient for meeting fishery management goals?*)
3) What is the type and deficit of habitat limiting the population’s productivity and ability to reach the desired goal?

Resource managers will be able to clearly identify how to measure success for a given habitat enhancement action or management strategy by defining these three key elements of their fishery. The intent of the modeling activity presented here is to answer these questions and thereby to inform future projects and monitoring efforts in the basin. It is important to note that this modeling exercise is dependent on adaptive management: As more data are collected, specifically relevant to LKR enhancement actions and relative population changes, the model and the data that inform the model, will also change, improving the value of this effort.

Population - Habitat Modelling

It is necessary to translate the KRFMP goals into quantifiable terms to evaluate alternative habitat enhancement actions for inclusion in the KRFMP and establish measurable objectives for adaptive management. Quantifiable habitat objectives are essential for guiding the development and implementation of habitat enhancement/rehabilitation efforts and establishing a means to measure progress and evaluate success (Rosenfeld and Hatfield 2006). To this end, we determined (1) abundance goals for each of (a) a minimum abundance to support a viable population; and (b) a population with sufficient abundance to support a harvestable surplus, then (2) estimated the minimum habitat required to support the minimum estimated number of individuals at each lifestage necessary to support each of the two population goals. Within each iteration, we define this minimum habitat as "critical habitat" or "H_{crit}." We also provide general rules for determining habitat needs to support these different "book-end" populations represented by the minimum viable population (MVP) and harvestable surplus population (HSP).

This analysis is intended to form the basis of a simple life cycle model that can be used to optimize habitat requirements to meet multiple resource use needs, including management of a healthy LKR Rainbow Trout fishery. Our approach is to pair information about minimum fish territory requirements with a simple model that can estimate the number and size of Rainbow Trout from adult spawning, through embryo development and fry emergence, rearing, and ultimately back to spawning again in the next generation, and thus provide estimates of habitat required to support identified population abundances. We created a deterministic simulation model that tracks spawning, incubation, and rearing of two Rainbow Trout populations with different management objectives, i.e., an MVP versus an HSP. Whenever possible, we used data and literature values derived from LKR to inform model relationships. When local data were lacking, we applied the best available laboratory or out-of-basin data sources. The analysis is based on two core assumptions: First, there is a positive relationship between habitat and population size (Figure 29). Second, a minimum habitat area is required for each life stage to meet a recovery target (Figure 30).

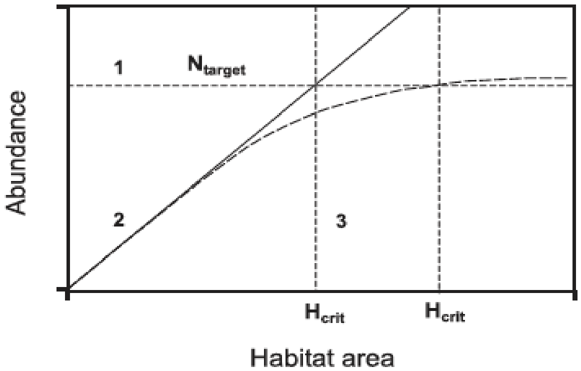


Figure 29. Defining critical habitat is illustrated as a three-step process. (1) A population recovery target is determined (N_{target}). (2) A relationship between habitat and abundance is developed. (3) The recovery target and the habitat–abundance relationship is used to define the quantity of habitat required to meet the recovery target (H_{crit}). H_{crit} will differ depending on the form of the habitat–abundance function. Habitat–abundance relationships will be linear if the number of recruits to a habitat increases proportionally with area (solid line). If the number of recruits is fixed, the relationship will asymptote and display nonlinearity because of density-dependent effects on survival (broken line). High-quality habitat will generally have higher survival rates, resulting in a steeper abundance–habitat area relationship. Note that the horizontal axis can be any measure of habitat quantity (area, volume, stream discharge, etc.). Reproduced from Rosenfeld and Hatfield (2006).

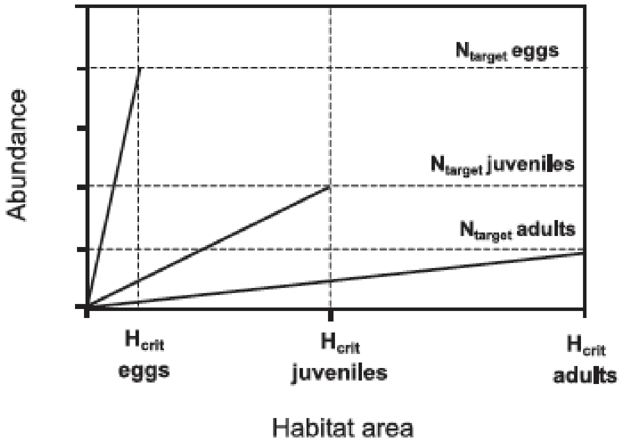


Figure 30. For species with multiple life history stages, sufficient individuals need to recruit to each life history stage to meet the adult recovery target. When life history stages are dependent on different habitats, separate habitat–abundance relationships, stage-specific population targets, and critical habitat areas need to be defined to meet the adult population recovery target. Population targets for early life history stages will depend on stage- specific survival rates. Note that the habitat area required by different lifestages will depend on species ecology, although this figure assumes that individual and cohort area requirements increase from eggs to juveniles to adults. Egg-to-juvenile and juvenile-to-adult survivals are set at 25% and 40%, respectively, for illustration purposes. N_{target}, a population recovery target; H_{crit}, the quantity of habitat required to meet the recovery target. Reproduced from Rosenfeld and Hatfield (2006).

Salmonid populations in regulated streams are influenced by a complex interplay of factors that range from individual stream flow levels and temperature, to long-term habitat degradation associated with altered sediment budgets, migration routes, and climate conditions. Achievement of management goals relies on rehabilitation actions that involve both discharge (e.g., dam releases) and non-discharge (e.g., gravel augmentation) components, and these are inter-related (Merz et al. 2016). Therefore, successful attainment of KRFMP goals requires that:

- A quantifiable measurement of a "healthy Rainbow Trout population" is defined (healthy populations) for purposes of analysis;
- Enough individuals *for each lifestage* can access and exit habitat when appropriate (adequate passage) to meet population goals including harvest rates;
- Sufficient quantity and quality of habitat is available for each lifestage to meet population targets (suitable habitat);
- Sufficient habitat must function at the appropriate time, location, and duration for each lifestage (suitable habitat).

With this in mind, the relationship between flow, and habitat quantity and quality for the target LKR population, must be determined (note that this modeling exercise identifies the population size per lifestage, and the corresponding habitat area needed; this informs the 2D modeling which is done in a separate study using the green LiDAR. Within this modeling exercise, two fundamental concepts relating Rainbow Trout production to LKR habitat are (1) stream-dwelling salmonids either defend or rely on food from a territory, and thus maximum number of individuals that an area of habitat can support is limited by the interaction of fish territory size and the amount of available suitable habitat;

and (2) salmonids must be able to access and exit habitats as they develop and transition between lifestages.

There are a variety of methods for modeling and investigating habitat impacts on fisheries needs, including capacity-based limiting factors models (e.g., Reeves et al. 1989; Beechie et al. 1994; Cramer and Ackerman 2009), multi-stage spawner-recruit life cycle models (e.g., Schuerell et al. 2006; Zeug et al. 2012), net-rate of energy intake (NREI) models (Wall et al. 2015), and habitat suitability models based on hydraulic modeling and fish habitat preferences (Ghanem et al. 1996; Lacey and Millar 2004; Pasternack et al. 2004). As capacity, NREI, or habitat suitability all rely on derivatives of depth and velocity (or cover, substrate, or other hydraulic factors), flow modeling can support any of these approaches.

Multi-stage spawner-recruit life cycle models, while used to evaluate flow options (e.g., Zeug et al. 2012), are complex, time-consuming efforts that require lifestage specific data not available for the LKR. Similarly, NREI and other food web-based models require collection of not only fish data, but also primary (periphyton) and secondary (macroinvertebrates) production. In contrast, capacity-based limiting factors and habitat suitability models have been widely used for modeling changes in usable habitat at various flows or under proposed habitat improvement scenarios. Capacity-based limiting factor models use estimates of habitat area and fish densities to estimate capacity at different lifestages with fixed survival estimates between lifestages, effectively converting lifestage- specific capacity to potential fish production (Roni et al. 2018). In contrast, habitat suitability models simulate the physics of water flow (hydraulics) along with habitat suitability preferences, to determine eco-hydraulic effects such as how water forces impact fish ecology. Then, areas of suitable habitat are related to territory size (typically for juvenile fish) or assumed densities (for spawners) so that capacity can be estimated. These two approaches are complementary, with the capacity-based model being coarser than the habitat suitability modeling, but less precise in terms of predicting changes in habitat. An option that combines both approaches would provide a comprehensive evaluation, as the former would estimate total capacity, and the latter would estimate changes in habitat suitability for each target species at various flows. Development of this modeling effort allows us to estimate habitat rehabilitation strategies, within the context of the managed hydrology, that support each lifestage along the entire LKR corridor accessible to Rainbow Trout. We can then identify potential habitat enhancement scenarios that would provide physical habitat components (e.g., water depth and temperature) adequate to support each lifestage and achieve the desired Rainbow Trout population for the LKR.

This analysis is intended to form the basis of a simple life cycle model that can be used to estimate habitat needs to support a Rainbow Trout population. This optimization effort follows a general process for determining the ability of the LKR to support a target trout population (Figure 31). Within this document, we specifically define:

1) A population target - quantify viable Rainbow Trout abundance;
2) Basic life history information, including identification of different life stages and their habitat associations (general demographics);
3) Availability of suitable habitat (present and potential);
4) Spawning habitat needs;
5) Incubation and emergence requirements;
6) Rearing habitat needs.

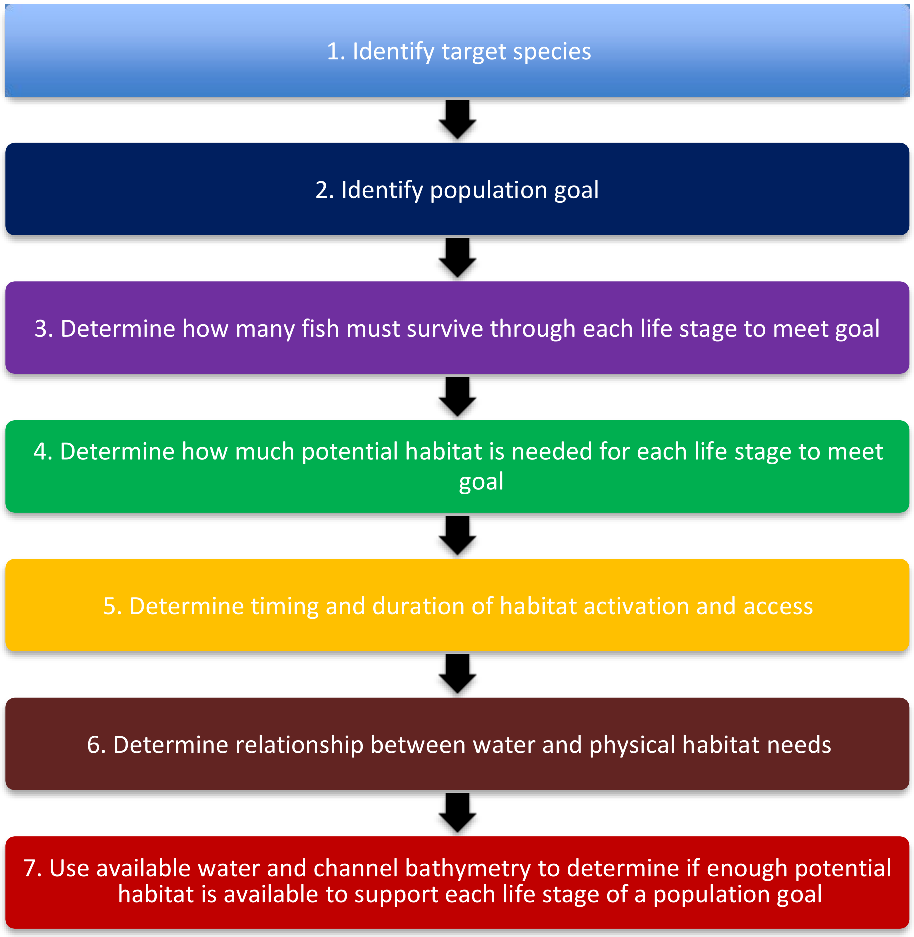


Figure 31. General process for determining watershed ability to support target fish populations assuming a viable population goal is identified, habitat needs are quantified and a general relationship between potential habitat and flow is known.

Once the seven steps are accomplished, a secondary process is undertaken to determine watershed potential to support the target species population. This process is iterative, altering the relationships between flow, channel bathymetry and the range of species capabilities available in the literature and evaluating model output (gaming). Note, it is possible that Rainbow Trout fishery goals (e.g., harvest rates, fish sizes, etc.) may surpass the habitat carrying capacity of the Kings River management area. In such a case, numerous management action options, including trout stocking (hatchery production), altered angling regulations, and habitat enhancement might be implemented to bring angling opportunities, harvest rates, and habitat productivity into alignment. These concepts are incorporated into the flow chart depicted in Figure 32 which facilitates an adaptive management framework which has been, to date, supported by a combination hatchery and natural population structure.

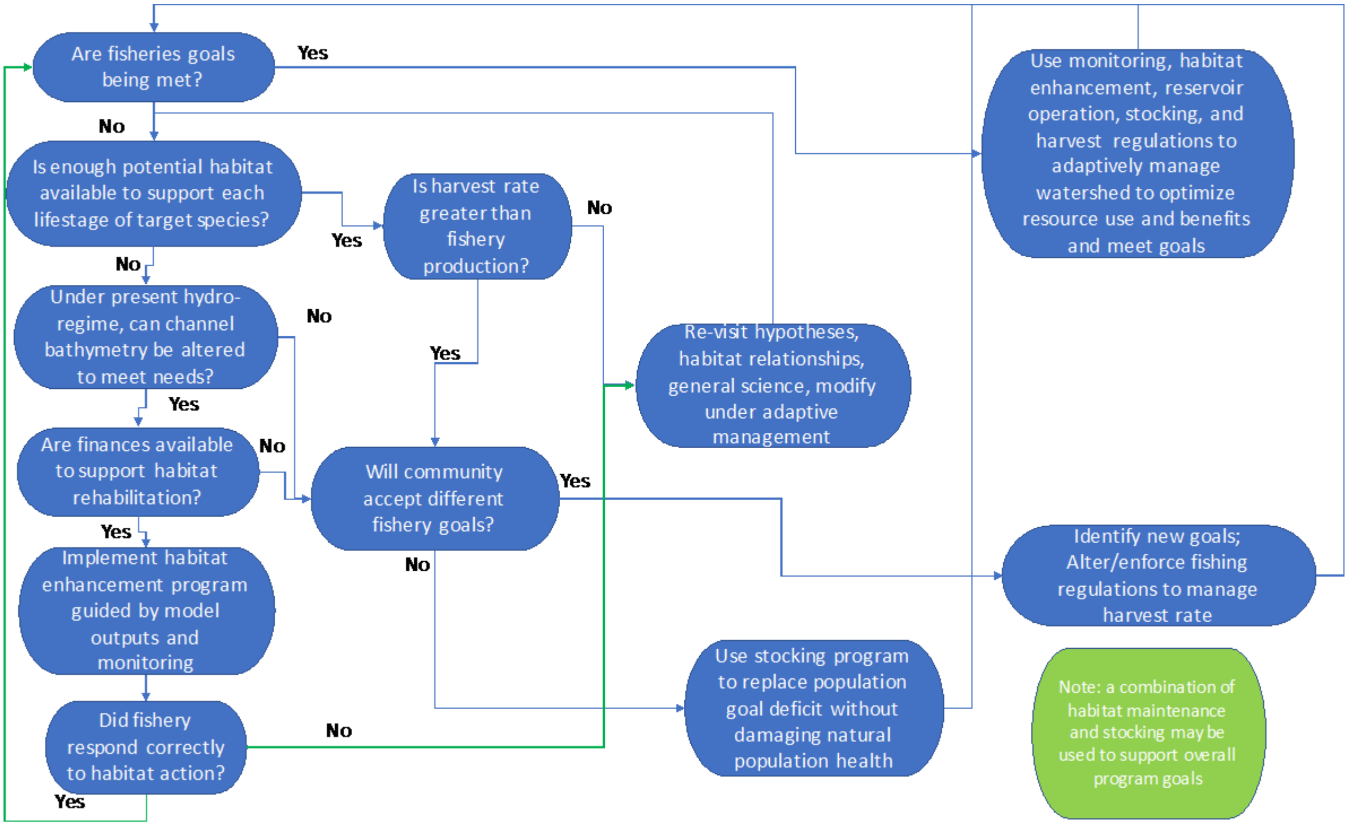


Figure 32. General flow chart for determining watershed potential to support target species population. Target species population is identified by fisheries management as a quantifiable goal. This goal may change over time.

Population structure

To date, the LKR Rainbow Trout have been divided into three distinct groups:(1) wild, (2) KRFMP egg incubation, and (3) CDFW/Other hatchery. The KRFMP egg incubation group is produced in an incubation facility using LKR water, typically released at the sub- catchable fry stage. The CDFW/Other hatchery group, produced to support a recreational fishery production, are stocked as “catchable” fish that are generally larger than 6 inches (~152mm). Up to 2014, most, if not all, of the CDFW/Other hatchery fish were non-reproductive (triploid) trout (KRFMP 2015). As of mid-2018, CDFW returned to stocking of diploid Rainbow Trout.

Group-specific differences in survivorship may result when hatchery fish differ phenotypically and genetically from local wild fish. Such differentiation may occur when the original broodstock were taken from another basin (Murdoch et al. 2006), and when selection pressures differ between hatchery and natural habitats (Busack and Currens 1995; Knudsen et al. 2006; McClure et al. 2008a).

While there is potential for substantial influence on hatchery produced trout, the wild population effect is beyond the scope of this habitat assessment project. Therefore, we did not include the hatchery groups in the model; our interest is in the status of the wild population in response to changes in habitat condition. Therefore, all model output (e.g. productivity, mean number of smolts or spawners) is expressed in terms of wild fish. Future iterations could be developed for inclusion of the LKR mixed (wild and hatchery origin) fishery.

Population Size

Previous interpretations of “good condition” under California Department of Fish and Game Code section 5937 have been applied at the population level to single species (Moyle et al 1998). For example, during testimony at the 1993 Mono Lake trial, the California Department of Fish and Game defined it in relation to the principal fish species present. The Department considered good condition to mean that each population must have (1) multiple age classes (evidence of reproduction), (2) a viable population size, and (3) healthy individuals. Viable population size is difficult to quantify, so two surrogate indicators were relied on in the case of Putah Creek: (1) extensive habitat should be available for all life history stages;(2) all life history stages and their required habitats should have a broad enough distribution within the creek to indefinitely sustain the species by multiple trophic levels (barring stream-long catastrophes) (Moyle et al. 1998).

For management purposes, population targets are usually set at a level that will ensure the long-term persistence of a species (Rosenfeld and Hatfield 2006). This target may be arrived at in several ways. If sufficient data exist to parameterize a population model that incorporates temporal variability in demographic and environmental conditions, then a formal Population Viability Analysis (PVA) (Morris and Doak 2002) can be performed to establish a minimum recovery target. Although PVA has come under intense scrutiny (Coulson et al. 2001; Ellner et al. 2002; Reed et al. 2002), it remains a useful quantitative tool for setting recovery targets and exploring different management scenarios (Brook et al. 2000; Haight et al. 2002), provided the results are interpreted with caution (Brook et al. 2002; Lindenmayer et al. 2003). However, sufficient information to perform a PVA is often lacking (Morris et al. 2002). In this case, interim population targets need to be set based on available data until more accurate targets can be derived. One simple approach is to set population targets based on generic Minimum Viable Population (MVP) sizes (Roloff and Haufler 1997).

Per Lindley et al. (2007), population management plans should have quantitative, objective criteria. Significant work has been done on defining a viable population size for Pacific salmonids. McElhany et al. (2000) suggested that the viability of Pacific salmon populations should be assessed in terms of abundance, productivity, spatial structure, and genetic and life-history diversity. Gerber and Hatch (2002) found a positive relationship between the number of well-defined biological recovery criteria and the trend in abundance for a species. This empirical finding supports the concept that well-defined population goals are important for long term population health (Lindley et al. 2007).

Following this logic, Rainbow Trout management planning under the KRFMP should start with defining MVP abundance estimates (i.e., threshold abundance values associated with high and low risk of extinction) for LKR trout populations. This approach is conservative and protectionary; it uses the lower end of “good condition” as the starting point. An alternative approach would be to develop population numbers based on the production potential of the watershed, which represents the upper end of “good condition.” For example, the “intrinsic potential” concept might be used to bookend the upper end (Bjorkstedt et al. 2005). Approaches based on the watershed potential are more resource intensive. Regardless of the starting point for purposes of analysis, “good condition” ultimately defines a viable fishery, not just a marginally self-sustaining population (Bork et al. 2011).

Spence et al. (2008), establish extinction risk criteria based on total population size per generation (N_g), which reflects the harmonic mean of spawner abundance per generation, and on effective population size (N_e), which reflects the number of breeding individuals within a population (Wright

1931) and which is directly proportional to spawner abundance (Ford et al. 2004).[2] These criteria are intended to address risks associated with inbreeding and the loss of genetic diversity within a population. The criteria for salmonid populations in general are $N_g > 2500$ for low extinction risk and $N_g < 250$ for high extinction risk. Effective population size (effective spawners to total spawners) is assumed to be 20% of N_g (Spence et al. 2008). Therefore, N_e targets would be $N_e > 500$ for low risk and $Ne < 50$ for high-risk thresholds. Since both effective and total population targets are generational, to relate these abundance goals to annual run size, one would divide the total population size by the average age at reproduction (Brian Spence pers. comm.). In doing this for federal recovery planning purposes, Spence et al. (2008) assumed an average age of 3 years for *O. mykiss*, which we take here for resident populations of this species. The resulting low-risk population estimate, expressed as annual population size, would be calculated as follows:

$$N_e = 500 \bullet 0.2 \bullet 3 = 833 \text{ reproductive adult trout.} \quad (4)$$

We developed two populations for this modeling exercise to “bookend” conceptual ideas for fisheries management goals identified in Figure 6. Population 1 was the low extinction risk population to maintain into the long-term future with no harvest pressure. Population 2 was the population needed to support the low extinction risk population and harvest rates associated with a “successful” sport fishery. Note these populations are meant to provide a starting point for discussing long-term LKR fishery management goals and should not be misinterpreted as accepted or specific annual population targets.

Demographics

Demographic models can track change over time in the number of individuals at different ages or stages given a schedule of age- or lifestage-specific reproductive output and mortality (Gotelli 1998; Caswell 2001). Models can be constructed assuming continuous or annual reproduction and, in the latter case, assuming abundances pertain to the period just before or after breeding occurs (Gedamke et al 2007). A useful method for understanding when and how different habitat factors limit populations is to construct realistic models of population dynamics. Population models for species with discrete lifestages use information on individual-scale habitat requirements to parameterize sub-models for different lifestages, which are then sequentially linked to provide a whole life cycle model for a population [e.g., Holtby and Scrivener 1989; Nickleson and Lawson 1998; sometimes referred to as habitat supply models (Minns et al. 1996)]. Sub-models for different lifestages can be understood simplistically in terms of the extent and quality of available habitat, which is related to cohort size by fitness functions relating organism growth and survival to habitat characteristics (Rosenfeld 2003). This method is what we propose to support fisheries management in the LKR management area. However, it is important to note that successful populations typically utilize multiple life history strategies to be successful, including residency and migratory (Schindler et al. 2010). Dam operations, including artificial, year- round suitable habitat, can lead to much higher rates of resident life history expression (Sogard et al. 2012). Future research on the LKR could help inform management that supports the variability of life history strategies that may maintain healthy populations. We used the following demographic parameters to populate the habitat supply model: age class; age at maturity; sex ratio; fecundity; timing; population mortality and growth; habitat needs; spawning; incubation; and rearing (Figure 11).

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[2] NMFS’ extinction risk criteria are available at https://swfsc.noaa.gov/publications/TM/SWFSC/NOAA-TM-NMFS-SWFSC-423.pdf.

Age Classes

For modeling purposes, we assume four (4) age classes occur in the LKR (fish live into their 5th year). This was determined from length frequencies collected during LKR electrofishing surveys (Figure 25).

Age at Maturity

We used the general life history of Coastal Rainbow Trout (Moyle 2002) that suggests LKR trout should reach spawning stage at Age 2+.

Sex Ratio

There is little information on sex ratios for California *O. mykiss* populations. While the LKR population is non-anadromous (resident Rainbow Trout), most studied populations are characterized by partial migration in which non-anadromous and anadromous (steelhead) life-history forms are sympatric in freshwater habitats with access to the ocean (McPhee et al. 2007). Long-term datasets of adult steelhead, for which the most data exist, show that sex ratios of returning spawners can fluctuate considerably among years (Shapovalov and Taft 1954; Ward and Slaney 1988; Savvaitova et al. 2002) and over longer periods (Ardren and Kapuscinski 2003). This variation notwithstanding, sex ratios of adult steelhead were approximately 1:1 in some systems (Shapovalov and Taft 1954; Ward and Slaney 1988) but female-skewed in others (Savvaitova et al. 2002; Ardren and Kapuscinski 2003). Shorter-term studies have paralleled these results, with some finding balanced sex ratios in adult steelhead (Pautzke and Meigs 1941; Chapman 1958) and others showing female-dominated returns (Hayes et al. 2004; McMillan et al. 2007; Pavlov et al. 2008). Under similar circumstances, other modelers have assumed a 1:1 ratio (Nickelson and Lawson 1998). Given the lack of consistent data, we used a 1:1 sex ratio.

Fecundity

The number and size of eggs laid by *O. mykiss* are highly variable, among both individuals and populations (Lister 1990; Healey and Heard 1984; Healey 2001; Beacham and Murray 1993; Moyle 2002). Females often mature later than males but a portion of females may mature after they enter their second year (Schill et al. 2010). Carlander (1969) states that the average fecundity of Rainbow Trout is related to length, but is highly variable, ranging from 500 to 3,161 eggs per stream resident female (Carlander 1969). Mean fecundities of 130–400 have been reported for populations with females maturing at relatively small sizes (120–250 mm TL; Schill et al. 2010). The fecundity of 105 Rainbow Trout from the Athabasca River, Canada, varied from under 150 to over 600, and the relation between fecundity and length was reasonably well described ($R^2 = 0.77$) by fecundity = (3.9316• FL) - 350.34 (Caskenette and Koops 2018). To estimate the number of embryos available to the population, we used the length to fecundity relationship of Caskenette and Koops (2018) and the mean FL for Rainbow Trout estimated to be 2+ and older from unpublished KRCD electrofishing data. Therefore, depending on spawner month and female age, estimated fecundity ranged from ~590–1300 eggs per female.

Timing

Estimating habitat availability for a species and lifestage over the appropriate time-period is dependent on the lifestage-specific temporal distribution (i.e., the time-period when a specific lifestage may be present). Therefore, we used a combination of data from LKR-specific surveys (e.g. electrofishing and creel surveys) and published information from Central Valley studies to provide a general lifestage-specific life history for Coastal Rainbow Trout (Moyle 2002) in the LKR. It is generally understood that regional and river-specific environmental conditions influence inter- and intra-annual freshwater lifestage periodicities of a salmonid population. However, for evaluation purposes, a generalized life history periodicity was required for each lifestage of Rainbow Trout within the LKR. Figure 11 presents the lifestage-specific temporal periods used to quantify life-stage specific physical habitat needs depending on population and harvest goals. General Rainbow Trout information is further explained in the Life History Section of this document.

- Spawning onset from CDFW observations and completion from American River Steelhead spawning surveys (CFS 2013–2017); CDFW states some early spawning happens in December. For modeling simplicity, we assumed most spawning occurred from end of December to beginning of May with most occurring in January-February (Figure 11);
- Embryos hatch in 3–4 weeks (at 10–15° C) and the fry emerge 2–3 weeks later (Moyle 2002). For simplicity, we assumed emergence occurred approximately 2 months following redd completion;
- Fry emergence begins in February and is complete by August- suggested by Mokelumne River length frequency analysis (Merz et al. 2016);
- Since February is the onset of most emergence, we assume each year-class begins in February.

Population, Mortality, and Growth

For the purposes of discussing potential enhancement actions, we hypothesized two Rainbow Trout populations that bookend a range of potential future management scenarios within the LKR.

Population 1- For the minimum viable population (Figure 33), mortality occurs at a rate of 21% per month to reach 833 adult spawners by February (this is for modeling purposes only; not assumed to represent actual mortality rate). Fecundity, growth and survival through each life stage are described further below. The largest monthly modeled population occurs in May (~107,000). Roughly 93% of these May fish are newly emerged fry.

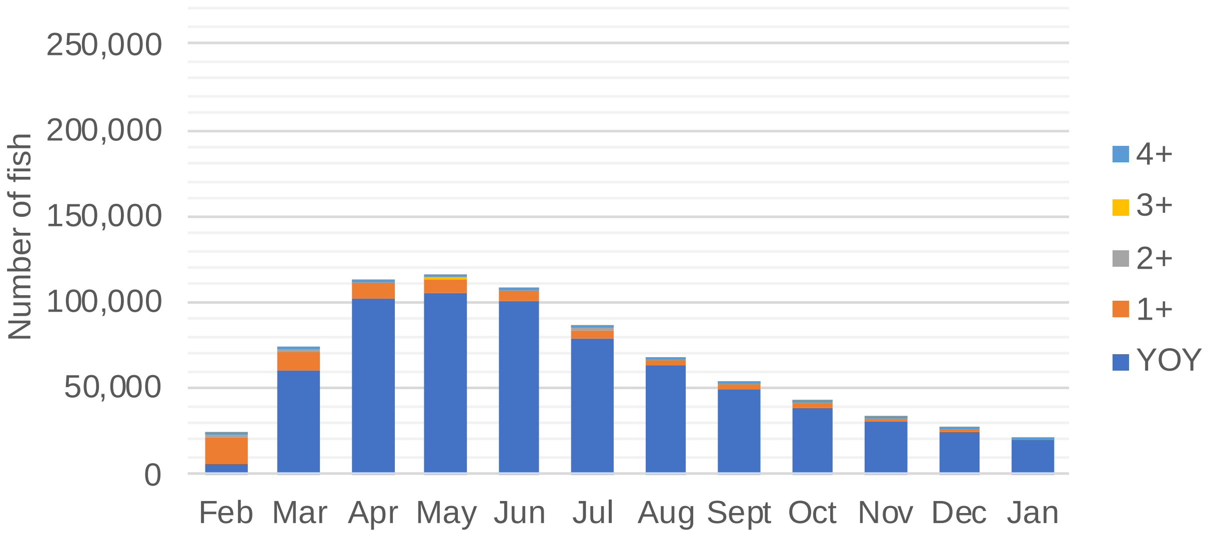


Figure 33. Population 1. Minimum viable population with no harvest. Assumes minimum population of 833 spawners and no harvest. Mortality is kept at 21% monthly to reach minimum population at spawning onset.

Population 2- For the harvested population, we used a daily mortality rate of 0.35% (Hokanson et al. 1977) for the non-harvested portion and adjusted daily mortality down to 0.25% to facilitate monthly harvest goals (Table 12). Fish larger than ~6 inches (>160mm) were considered in the "catchable range". Therefore, harvest mortality occurs for age 1+ and older trout in addition to the daily mortality rate (Figure 34). We ensured that enough catchable-sized trout were available each year to meet catch expectations and maintain at least a minimum population of 833 spawners in January. To quantify catch expectations, we used the average annual "catchable fish" release numbers from 1956–2016 (59,000 catchable trout). We then used the estimated average historic LKR harvest rate of 59.7% (Butler and Borgeson 1965) as the basis of 35,000 fish as an annual harvest goal. Note, this is comparable to the 27% harvest rate (as high as 59% if missing trout included) reported in KRFMP (2012).

Table 12. Modeled annual and monthly harvest rates from Butler and Borgeson (1965) broken down by age class. The proportion of fish per age class was determined from historical Kings River electrofishing surveys. Annual numbers were rounded to the nearest 100. See Population 2 discussion above.

Age	Total Annual	Monthly
1+	33600	2800
2+	1000	83
3+	300	25
4+	100	8
Total	35000	2917

The greatest monthly modeled population occurs in April (~250,000). Roughly 76% of these April fish are newly emerged fry (Figure 34).

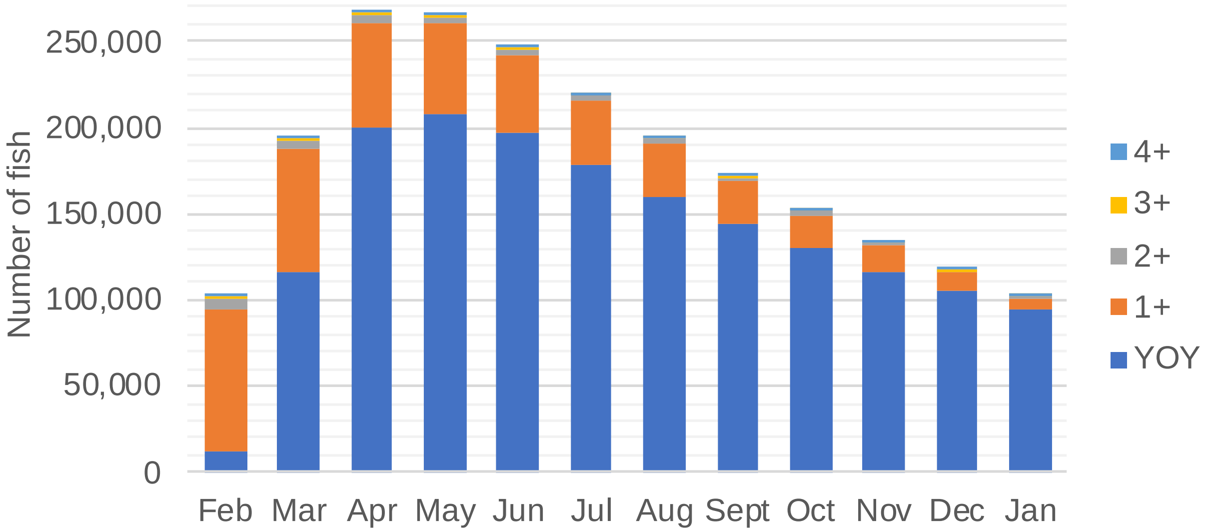


Figure 34. Population 2. Minimum viable population plus catchable fishery. Catchable fishery assumes 59.7% (Butler and Borgeson 1965) of the annual average stocking number from 1956 to 2016 (~35,000 fish) removed annually from the population. Daily mortality rate for non-harvested fish is 0.25 - 0.35% (Hokanson et al. 2011).

For Populations 1 and 2, we used young-of-the-year (YOY) monthly length frequencies from the lower Mokelumne River (Merz 2015; Figure 35). After juveniles reach 1+, we used the growth rates of 3mm per month (0.1–0.2mm per day) from Sogard et al. (2012). KRCD fall electrofishing data support these length and growth rate assumptions (KRCD unpublished).

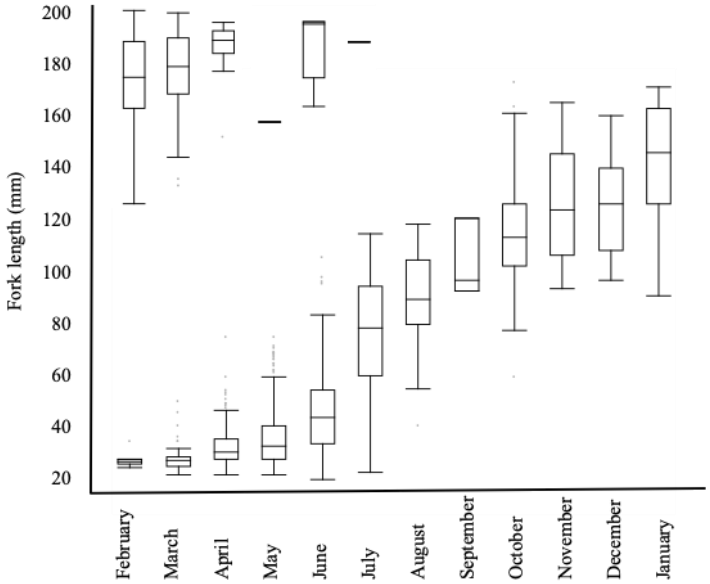


Figure 35. Length estimates for lower Mokelumne River *O. mykiss* captured by month. Box and whisker plots include mean, standard deviation and range. Data compiled from Merz et al. (2015).

Habitat Needs

Physical habitat that successfully supports a specific lifestage typically requires an area of habitat that provides the physiological needs of that lifestage (Figure 36). During these stages, a territory is often developed by individuals, to reduce competition for resources (e.g., food, cover) and density-dependent stressors such as disease, oxygen consumption, redd superimposition and energy wasted on aggressive behavior, etc.

We developed a simple model relationship between a hypothesized population and the area of habitat needed to facilitate spawning, incubation and rearing for that population. The model estimates the amount of suitable habitat required to sustain the number of fish of each lifestage present for each month throughout the seasonal period that each lifestage is expected to be present (Figure 11). The 2-D modeling associated with the Green LiDAR component of this project can then be used (in conjunction with Habitat Suitability Indices for that life stage) to estimate the amount of potential inundated habitat for each reach where that lifestage is expected to occur for each of the calculated monthly habitat needs.

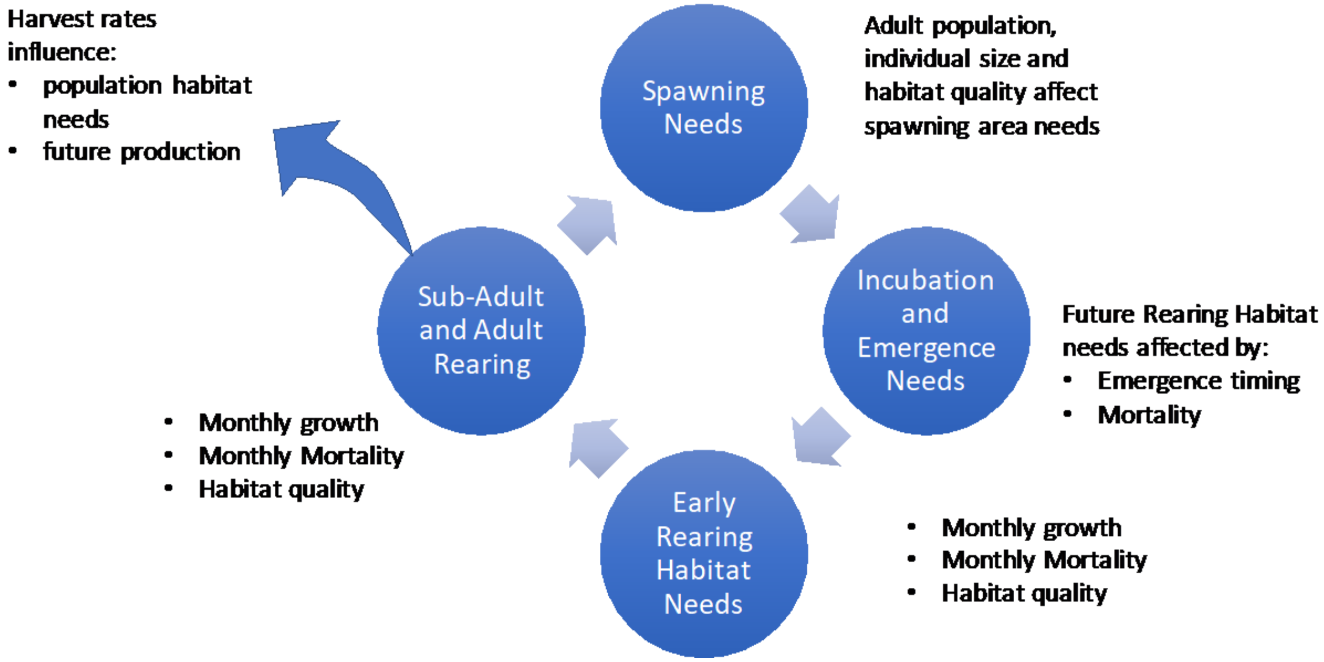


Figure 36. Conceptual Model of estimating Rainbow Trout spawning, incubation, and rearing needs to support a sport fishery in the LKR.

Spawning

Spawning stream salmonids require water deep enough over suitable spawning substrates to facilitate redd construction and redd defense and adjacent pools deep enough to provide spawning gravel downwelling and shelter from perceived threats (Wheaton et al. 2004; Buss et al. 2009). Minimum temperature requirements must also be met through the spawning period (see section on temperature modeling). The objective of the model is to determine the habitat area needed within each reach to support at least 416 spawning females but aim for enough to support a population at low risk of extinction (Na = 833).

Estimates of sufficient spawning area are also dependent on fish and redd size. Because we do not have long-term, complete population data for Rainbow Trout in the LKR, we estimated the acreage of spawning habitat needed each month during the spawning season using the redd size area from Holecek and Walters (2007). They found that adfluvial Rainbow Trout redds in a north Idaho stream were on average 1.4 (range = 0.3–2.9; SD = 0.74) yards^2. Because the spatial requirements for each spawning pair may exceed the area of a completed redd (due to habitat quality and spawner behavior), we used the assumption of Burner (1951) that a conservative estimate should assume four times the average area of a redd. Therefore, we multiplied the number of 2+ females by 0.3, 3+ by 1.4 and 4+ females by 2.9 yards^2. We then multiplied the sum area by 4 (Burner 1951). It is important to note that future data collected specifically from the LKR may alter these outcomes.

Incubation

Since YOY fish (e.g. embryos and alevin) cannot move during the in-gravel incubation period, reaches that can facilitate spawning must have sufficient flow to keep spawning areas sufficiently cool and oxygenated to support incubation to successful emergence. For example, if the last redd is constructed in the lowest reach during the second week of April, then water and temperatures must be kept deep and cool enough so that 850 thermal units (TU) is reached (and TU of species is not exceeded) so fry can emerge and move into rearing areas. The model goals are to provide enough habitat to support the offspring of at least 416 spawning pairs but shoot for enough to support a larger, more sustainable population. We assume the same area for spawning is needed for incubation.

To calculate the number of embryos we used the length to fecundity relationship calculated from the data of Caskenette and Koops (2018):

$$\text{fecundity} = (3.9316 \bullet \text{FL}) - 350.34 \tag{5}$$

The average Rainbow Trout fecundity was 710 eggs per female by end of February. With a population of 833 adults (416 females), we assumed ~250,000 embryos available for Population 1 of LKR Rainbow Trout (Table 13). For Population 2, 1,600– 2,300 spawners (~800–1,110 females) were needed to support expected harvest rates. Using 800 females with length ratios from past electrofishing surveys and length-fecundity relationships, ~523,000 embryos were available for LKR Rainbow Trout.

Table 13. The modeled number of ova per female Rainbow Trout for each age class and estimated total ova for modeled population by month. Modeled monthly emergence produced through the spawning season assumes 39% pre-emergence mortality (61% survival to emergence). Pop 1 = Population 1 (minimum viable population); Pop 2 = Population 2 (supports minimum viable population + past harvest pressure).

Female Spawners			**Estimated Fecundity**				
Age	**Pop 1**	**Pop 2**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
2+	312	600	482	512	543	575	608
3+	90	173	912	955	999	1,045	1,092
4+	14	27	1,510	1,568	1,627	1,687	1,749
Total	416	800					

% total emergence	**5%**	**46%**	**86%**	**96%**	**100%**
Pop 1 embryos (1:1 sex ratio)	209,768	221,296	233,197	245,474	258,132
Pop 2 embryos (1:1 sex ratio)	408,916	425,059	447,918	471,499	495,811
Pop 1 emergence assuming 61% survival	127,959	134,991	142,250	149,739	157,460
Pop 2 emergence assuming 61% survival	245,779	259,286	273,230	287,615	302,445

For embryo to emergence survival, we used the estimates of Merz et al. (2004). This provided ~158,000 Rainbow Trout fry to emergence for the Population 1 (min pop) and ~302,000 for Population 2 (harvest pop). To estimate emergence timing, we assumed a ~2-month lag from redd construction (2-month incubation period) for Rainbow Trout based on East Bay Municipal Utility District's spawning surveys (2008-2014).

Rearing

Using incubation and emergence Thermal Units (TU) from the literature, we estimated the fry period, extending from construction of the first redd to completion of the last redd. For reaches expected to support fry rearing, it is important to ensure that minimum depths and temperature requirements are met (at least) for the fry period in each expected rearing reach. As the transition to the juvenile period occurs, it is important to keep depths and temperatures within rearing limits in each reach where potential rearing habitat occurs. It is important to provide enough habitat to support rearing of offspring of at least 833 spawners (e.g., 416 females x fecundity), but provide habitat for larger, more sustainable population when feasible.

Wood et al. (2012) manipulated juvenile Rainbow Trout population density across a range of realistic densities in artificial stream channels, while controlling food abundance, they found a minimum territory radius of 0.2–0.3 m^2 (2.15 – 3.23 ft^2) for 5 cm (1.98 in) fish which could potentially set an upper limit on local population density and help regulate the population size of stream salmonids. To facilitate incorporation of monthly growth into estimating rearing habitat area needs, we calculated the average territory size (m^2) for each monthly modeled FL size using the equation from Grant and Kramer (1990):

$$\log_{10} \text{area} = 2.61 \log_{10} \text{length} - 2.83 \tag{6}$$

This estimate was multiplied by the modeled number of juveniles (and older fish) remaining to rear for each month.

Habitat Results

Spawning

Model outcome for hypothesized Population 1 indicate ~0.5 acres (SD = 0.3) of spawning habitat is needed through the end of the spawning period to facilitate 833 spawners (Figure 37). To enable incubating embryo transition to the fry stage, this habitat must remain inundated and meet water quality requirements through the month of May.

Habitat modeling estimates for Population 2 indicate~2.6 acres (SD=1.9) of spawning habitat is required through the end of the spawning period to facilitate 1,600 – 2,300 spawners. The model assumes habitat must remain inundated and meet water quality requirements through May to enable incubating embryo transition to the fry stage.

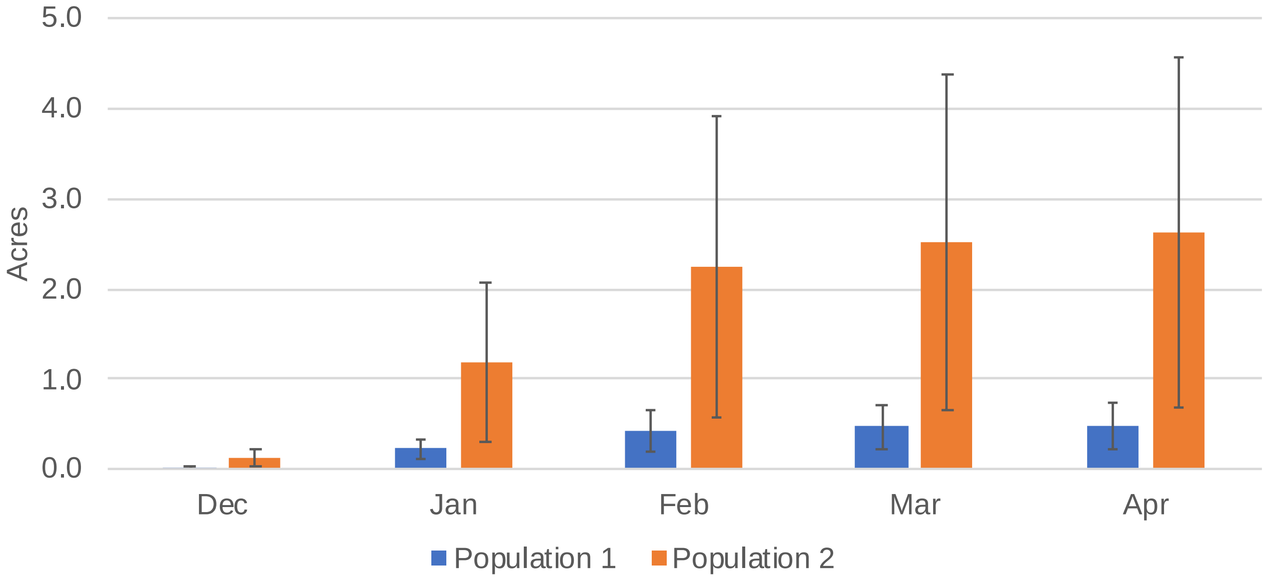


Figure 37. The estimated acreage of spawning habitat needed per spawning season month for two modeled Rainbow Trout population scenarios in the Lower Kings River, California. Modeled Population 1 supports 833 spawners and Modeled Population 2 supports ~1,600 – 2,300 spawners. Whiskers = SD.

Rearing

Habitat modeling outcome for hypothesized Population 1 indicates between 14 and 18 acres of rearing habitat is required to support YOY and Age 1+ juveniles during July – September (Figure 38).

Habitat modeling outcome for hypothesized Population 2 indicates between 55 and 65 acres of rearing habitat is required to support YOY and Age 1+ juveniles during the July – September period (Figure 39).

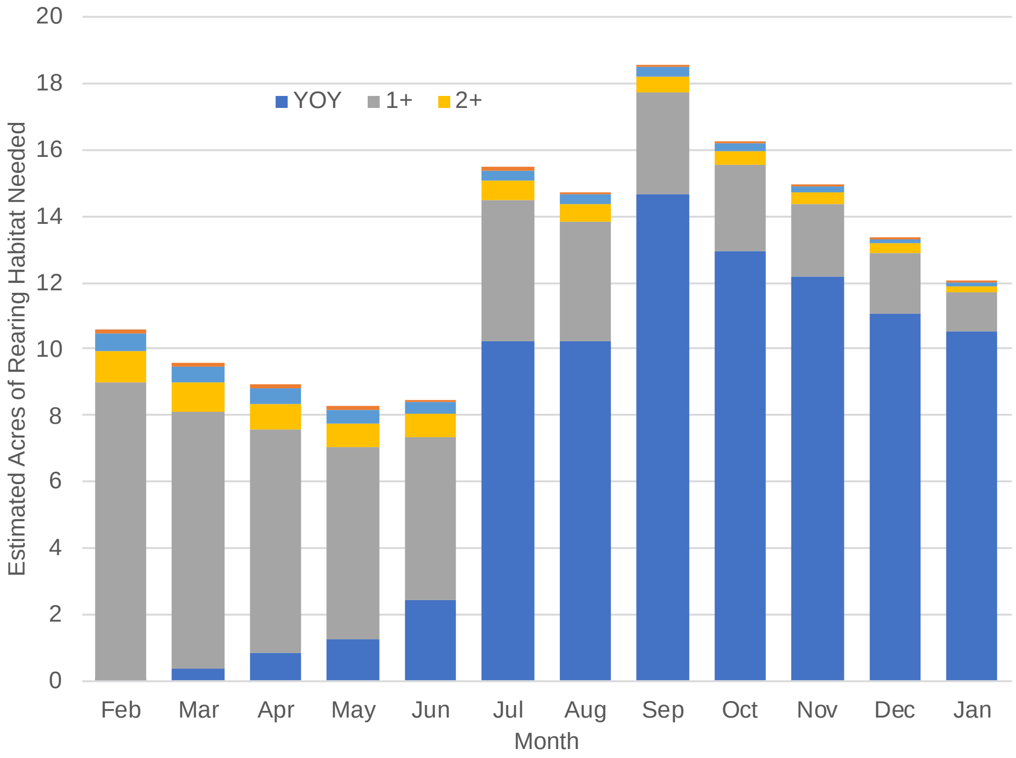


Figure 38. Estimated acres of potential suitable rearing habitat (territory) needed for modeled Rainbow Trout Population 1 in the lower Kings River, CA. Minimum viable population (833 spawners) with no harvest.

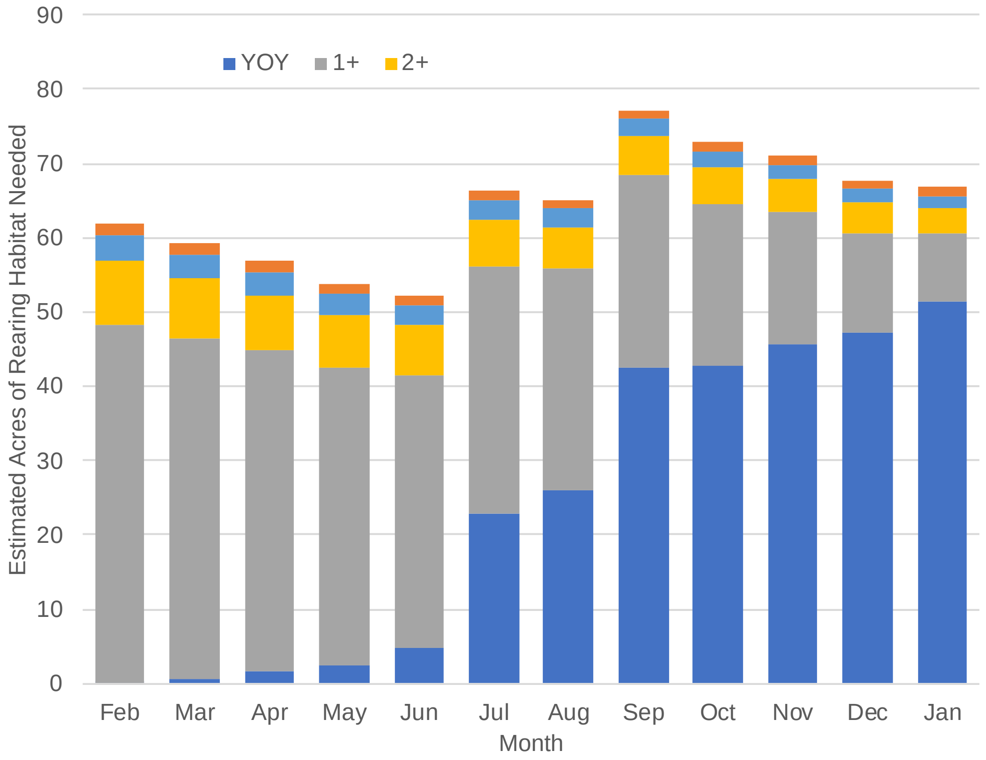


Figure 39. Estimated acres of potential suitable rearing habitat (territory) needed for modeled Rainbow Trout Population 2 in the lower Kings River, CA. Modeled population harvestable at ~35,000 fish annually and 1,600– 2,300 adult spawners to support harvest goal.

Comparison of estimated habitat needs to estimated habitat available

Spawning

Population modeling results indicate that ~0.5 (SD = 0.3) acres of suitable spawning habitat is needed at flows of 100–250 cfs to support the modeled minimum viable population (833 spawners). In contrast, the model predicts 2.6 acres (SD=1.9) of suitable spawning habitat is needed to support a harvestable population that supports historical angling pressure (Butler and Borgeson 1965). Hydraulic modeling results suggest that at 100–250 cfs, 60–78 acres of wetted channel meet spawning Rainbow Trout depth and velocity requirements below Pine Flat Reservoir. However, the substrate analysis indicates negligible suitable habitat due to oversized bed material within the study reach (Table 14).

Rearing

Population model results suggest a range of 14–18 acres of fry/parr rearing habitat is needed in the July – September period to support a minimum viable population (Figure 38). In contrast, population model results indicate 55–65 acres of fry/parr rearing habitat is needed to support the harvestable population during the July – September period (Figure 39). A conservative estimate from the hydraulic modeling suggests that ~15–18 acres of rearing habitat exists; roughly the amount required for early rearing of the minimum viable population at 4,000 – 8,000 cfs. For the harvestable population goal, modeling suggests a 37–50-acre deficit if low quality habitat is assumed (Table 14). If cover is not a limiting factor, sufficient rearing habitat exists to meet both population goals.

Table 14. Modeled habitat needs for Rainbow Trout in the lower Kings River, California. Two modeled populations are used to bookend potential fishery goals. These include a minimum viable population (MVP) of 833 spawners and a population that supports harvest of ~35,000 trout (Harv). Neg = signifies estimated available habitat is negligible due to oversized substrate, even where depths and velocities are appropriate.

Habitat Type	**Modeled Available (Acres)**	**Modeled Need (Acres)**		**Modeled Deficit (Acres)**	
	Acres	MVP	Harv	MVP	Harv
Rearing (pre-July)	7 – 8.5	3 – 10	5 – 22	1.5	13.5
Rearing (July - September)	17 – 21	10 – 15	26 – 43	6	22
Spawning	Neg*	0.5	2.6	0.5	2.6

*See Figures 26–27.

Conclusions

- Spawning Habitat- Hydraulic modeling results indicate that at 100–250 cfs, 60–78 acres of wetted channel meet spawning Rainbow Trout depth and velocity requirements below Pine Flat Reservoir. However, the substrate analysis indicates negligible suitable habitat due to oversized bed material within the study reach.

- Rearing Habitat- Population model results suggest 14–18 acres of fry/parr rearing habitat is needed in the July – September period to support a minimum viable population and 55–65 acres of fry/parr rearing habitat is needed to support the harvestable population during the July – September period. The conservative hydraulic model estimate indicates ~15–18 acres of rearing habitat exists; roughly the amount required for early rearing of the minimum viable population at 4,000 – 8,000 cfs. For the harvestable population goal, modeling suggests a 37–50–acre deficit if low quality habitat is assumed. If cover is not a limiting factor, sufficient rearing habitat exists to meet both population goals.

TASK 5. ALTERNATIVE HABITAT IMPROVEMENT SCENARIOS

Integrating Existing Physical & Biological Data

The Lower Kings River in a Modern Fluvial Geomorphic Context

Before exploring habitat enhancement alternatives, it is important to examine the physical structure of the river corridor in the context of its current hydrogeomorphology. Understanding how the river currently functions is needed to develop and implement potential habitat enhancement actions. Without this, projects may be designed and implemented that are at odds with existing physical processes (e.g. see Kondolf 2000 and Beechie et al. 2010). Understanding these processes allows them, when possible, to be leveraged into passively creating and maintaining physical habitat.

To place the river in a modern fluvial geomorphic context we utilized the LiDAR DEM and results from 2D modeling to draw inferences as to why current habitat is as it is. We do not analyze how the river came to reach its current physical conditions, as that would entail a historical analysis of land use and river channel change. We created datasets of bed profile elevation, inundation extent and widths for selected flows, morphologic units and competent sediment diameter.

Methods

Reach Delineation

Delineating reaches is a useful way to subdivide river segments into areas of similar properties to guide assessment, habitat enhancement and management actions. Reach delineations are most commonly made from geomorphic, land use and vegetation characteristics. Geomorphic factors include changes in gradient, substrate, flow and channel morphology. The goal is to determine reaches that ultimately can be used to link physical changes in river corridor to trout habitat. We used a combination of expert judgement and topographic analysis to delineate representative reaches.

Topographic Analysis

We delineated a hybrid thalweg and centerline profile (reference line) to use as stationing in ArcGIS as well as extract bed elevations, channel width and other attributes. We first delineated a thalweg as the path of minimum bed elevation in a channel along its course. Since we aimed to use this line for stationing and extracting channel properties, we modified the line to approximate the channel centerline in certain locations. Finally, the line was smoothed, and stations were developed at 32.8 ft (10m) for georeferencing. We developed an estimate of inundation width for the flows modeled in both domains using 30m cross sections generated along the reference line. The cross sections were generated to be much wider than the full inundation width and then clipped to the inundation extent at each flow. The cross sections are generated orthogonal to the reference line, which was based on the main channel. Therefore, channel width may be under or overestimated for channel bifurcations since those channels may follow a different downstream orientation than the main channel.

We extracted the longitudinal profile and profiles of inundation width for several flows to understand the physical structure of the river corridor. Channel width variations at bankfull flows can control the formation and persistence of riffle habitats in alluvial rivers (Richards 1976, Brown and Pasternack 2017). We used profiles of channel width at 4,000 and 8,800 cfs to identify relative expansions and contractions. Since riffle bedforms often occur in locally wide areas we looked for regions downstream of local expansions that exceeded the length of average riffle spacing, as calculated above. We also calculated confinement as the ratio of average channel width at 4,000 and 8,800 cfs for each reach.

Competent Sediment Size

The hydraulic model has several outputs that can be used to assess the potential for sediment mobility. We used model outputs of shear stress and the Shields equation to create maps of the competent median sediment diameter (D_{comp}; Figure 40). The competent sediment size is the largest size that would be stable for a given flow based on the Shields equation. Rearranging the Shields equation for the competent sediment diameter (e.g.) yields:

$$D_{comp} = \frac{\tau}{(\gamma_s - \gamma_w)\tau^*} \tag{7}$$

Where τ is the shear stress (lb/ft^2), τ^* is the Shields stress (dimensionless), and γ_w and γ_s are the specific weight of water and sediment (lb/ft^3), respectively. The Shields stress, τ^*, was set at 0.04 following Parker et al. (2007). This output was used to map areas where the current river configuration could support sediment sizes within the preferred size class distribution for Rainbow Trout and areas that could not at 8,800 cfs. The 8,800 cfs flow was used because it was the highest flow modeled, as well as having a frequency similar to bankfull discharge in natural rivers. We also mapped zones of spawning habitat suitability to the 8,800 cfs flow D_{comp}.

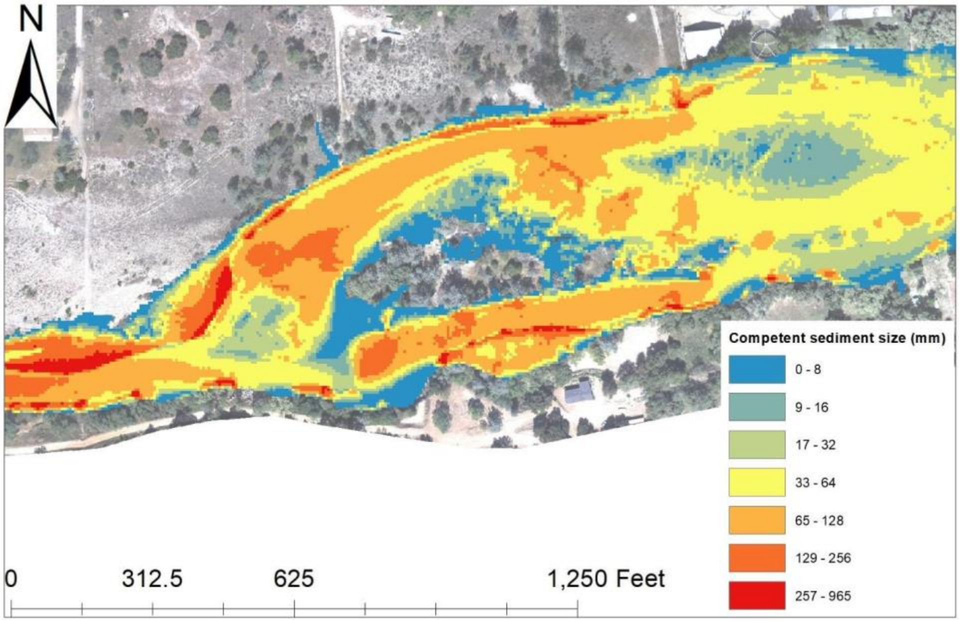


Figure 40. Example competent sediment diameter map.

Morphologic Units

Fish tend to use different habitat units at different lifestages, making the classification of these features a useful way to understand whether they are potentially a limiting factor. We delineated morphologic units (MUs) using depth and velocity outputs from the 2D model. We used morphologic unit descriptions (Table 15) and delineation thresholds (Figure 41) from Wyrick et al. (2014) for model outputs at 100 cfs. Using raster grids of MUs we calculated the percent area comprised by each unit.

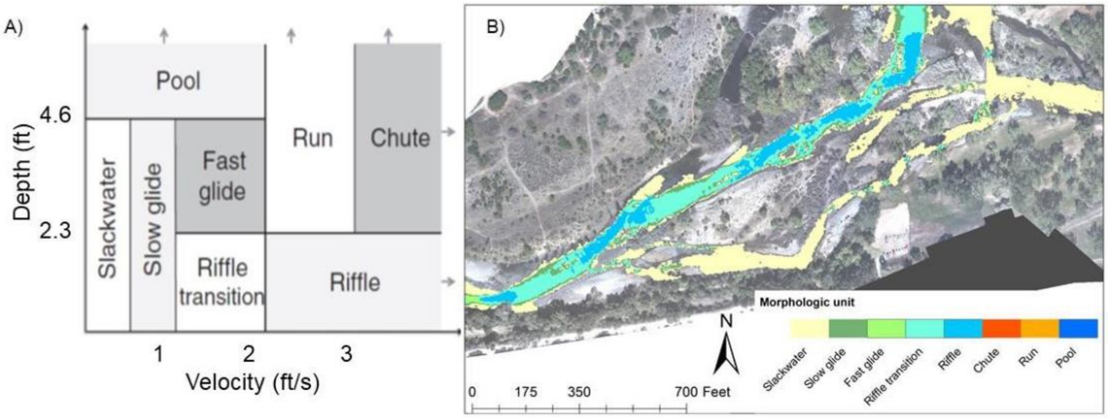


Figure 41. Hydraulic thresholds for delineating morphologic units based on depth and velocity (A), and example map at 100 cfs (B). A is from Wyrick et al. 2014.

Table 15. Morphologic unit descriptions from Wyrick et al. 2014.

Morphologic Unit	Description at base flow
Pool	Topographic low in the channel that exhibits high depth and low velocity, and low water surface slope. This unit covers ‘forced pool’ and ‘pool’. A forced pool is typically along the periphery of the channel and is ‘over-deepened’ from local convective acceleration and scour during floods often associated with static structures such as wood, boulders, and bedrock outcrops. A pool is not formed by a forcing obstruction. The distinction between forced pool and pool cannot be made automatically within GIS.
Riffle	An area with shallow depths, moderate to high velocities, rough water surface texture, and steep water surface slope. Riffles are generally associated with the crest and backslope of a transverse bar (e.g., Knighton, 1998).
Run	An area with moderate velocity, high depths, and moderate water surface slope. Runs typically occur in straight sections that exhibit moderate water surface transverse bar textures and tend not to be located over transverse bars.
Chute	An area of high velocity, steep water surface slope, and moderate to high depth located in the channel thalweg. Chutes are often located at an abrupt vertical expansion.
Fast glide	An area of moderate velocity and depth and low water surface slope. Fast glides commonly occur along the periphery of channels and flanking pools. Fast glides can also exist in straight sections of low bed slope.
Slow glide	An area of low velocity, low to moderate depths, and low water surface slope. Slow glides may be located near water's edge as other MUs along the channel thalweg transition laterally toward the stream margins.
Slackwater	A shallow, low velocity region of the stream that is typically located within adjacent embayments, side channels, or along channel margins. Velocities are near stagnant during base flow conditions and rise more slowly than in other units as stage increases.
Riffle transition	Typically, a transitional area between an upstream MU into a riffle or from a riffle into a downstream MU. Water depth is relatively low. Velocity is also relatively low but increases downstream due to convective acceleration toward a shallow riffle crest that is caused by lateral and vertical flow convergence. The upstream limit is at the approximate location where there is a transition from a divergent to convergent flow pattern. The downstream limit is at the slope break of the channel bed termed the riffle crest.

Results

Reach Delineation

We delineated the study area into two reaches based on channel morphology and water management structures. The Upper Reach extends from the Pine Flat Road Bridge to the Cobbles Weir and is characterized by a confined river channel with nested river islands. The Lower Reach extends below Cobbles Weir down to ~1,500 ft (~457 m) above the Fresno Weir and is characterized by multiple channel bifurcations on the relict Kings River alluvial fan as well as multiple diversions. We considered further subdividing the Upper Reach into two separate reaches, delineated by the confluence of Mill Creek. However, given the relatively short distance of river between Pine Flat Dam and Mill Creek we decided this division would yield little insight into the study area. Therefore, the reach breaks followed the model domain breaks shown in Figure 14.

Topographic Analysis

A plot of riverbed elevation and inundation width at 100 and 8800 cfs is shown in Figure 42 (4,000 cfs was excluded for clarity). The averaged riverbed slope for both reaches is 0.0026. One would expect that bed slopes would naturally decrease with distance downstream, especially where the valley width expands below rkm 6 (rm 3.7). Mean channel width increases for all flow increases from the Upper to Lower Reach, as commonly happens in natural rivers.

One aspect of the study segment that is evident is the difference in valley setting from Pine Flat Dam down to the Fresno Weir. Confined and unconfined valley settings are useful to delineate because of their influence on inundation extent, mean sediment size, channel complexity, allochthonous inputs, aquatic primary producer and invertebrate production, stream retentive capacity, and aquatic invertebrate community composition (McDowell 2001, Bellmore and Baxter 2014). The Upper Reach is a classic case of a partially confined river valley (Brierley and Fryirs 2005), that is, the course of the river is mostly confined but has some space to migrate laterally. The Lower Reach is situated on the relict Kings River fan, where historically the river was unconfined by mountains and able to widen and bifurcate creating most of the current channel network (excluding the 76 Channel). This contrast is evident through visually inspecting two representative cross sections (Figure 42). In these examples, the Upper cross section has a potential valley width of ~2,000 ft, while the Lower cross section has a valley width close to ~4,000 ft.

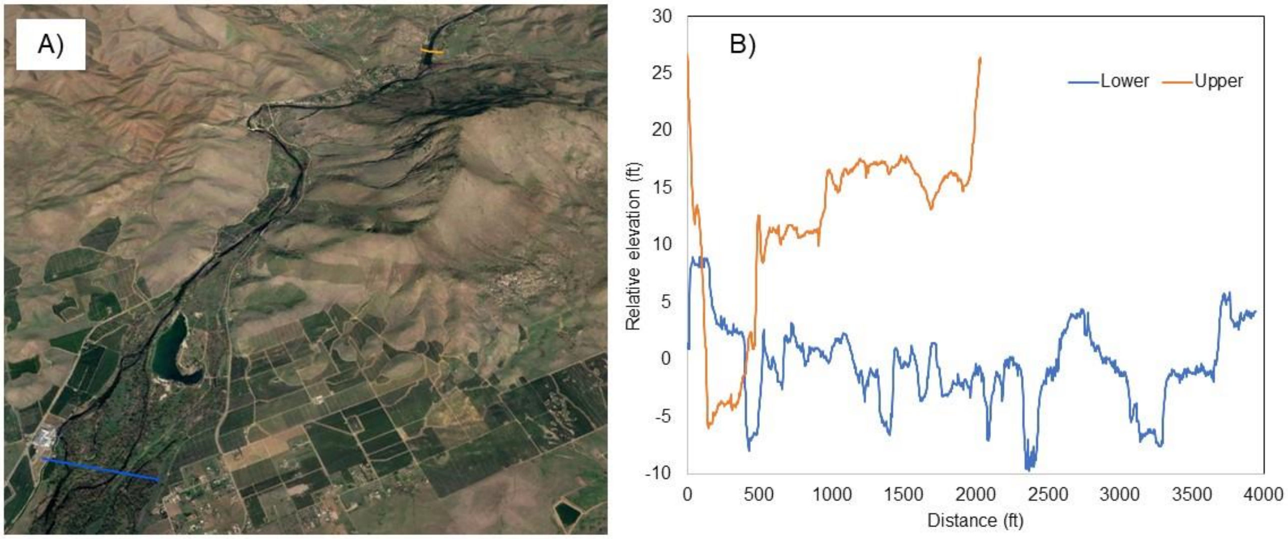


Figure 42. Locations (A) and example cross sections (B) in the Upper (orange) and Lower (blue) reaches illustrating the difference in valley topography. The cross sections are on an arbitrary datum for visualization.

Variability in wetted width is a fundamental attribute of alluvial rivers that can control bed morphology (Brown and Pasternack 2014, 2017, Lane et al. 2017). In simplest terms, anyone who has turned on a garden hose will note that water speed increases when the nozzle is restricted by their thumb. Hydraulic theory posits that decreases (increases) in the area flow has leads to increases (decreases) in the velocity of flow. In alluvial rivers expansions in channel width at flows capable of mobilizing sediment are typically associated with the activation of floodplain terraces and gravel bars. The converse is also true, where relatively narrow zones can be associated with deep pools. This variability is especially important for salmonids, because it is a signature of morphologic variability as well as providing heterogeneity in physical habitat across multiple life stages.

While a benchmark for how much variability a river needs for salmonids is not known, generally more is better. On the LKR, there are many areas where this variability is associated with distinct landforms. For example, two expansions are evident between rkm 11 and 13 (~rm 6.8–8.1) where the width at 8,800 cfs is relatively high (Figure 43;Table 16). The activation of the relict Kings River fan is apparent below rkm 5 (rm 3.1), where the 8,800 cfs width increases significantly. What is most useful in analyzing this type of data is where there is little to no variation in wetted width. Usually these areas have channelized conditions with armored sediments and homogenous flow conditions.

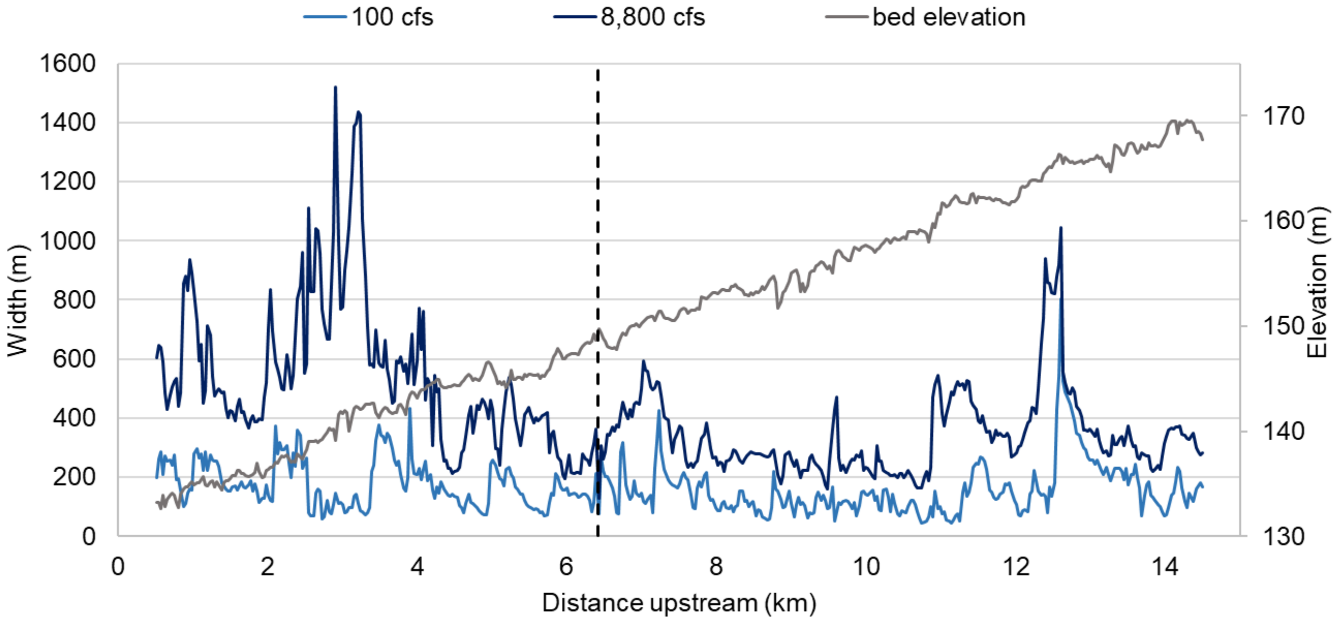


Figure 43. Inundation width at 100 and 8,800 cfs (left axis) and thalweg bed elevation (right axis). The dashed line delineates the boundary between the two reaches.

Table 16. Mean and standard deviation of inundation width for the entire study area and by reach.

	100 cfs		4,000 cfs		8,800 cfs		
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**	**Mean**	**Standard Deviation**	**Confinement**
Lower	177	76	330	140	543	256	0.64
Upper	157	93	278	122	343	140	0.81
All	166	87	300	133	428	221	0.74

Competent Sediment Size

For the full wetted area of 8,800 cfs the competent sediment size mapping indicates that 50% of the river could support of D_{50} of 42 mm (Figure 44). Assuming an optimal range of Rainbow Trout spawning gravels from 13 to 60 mm, 46% of the full wetted extent at 8,800 cfs could support this size class range. When clipping the inundation extent to only include the 100 cfs channel 50% of the river could support the optimal D_{50} for spawning Rainbow Trout.

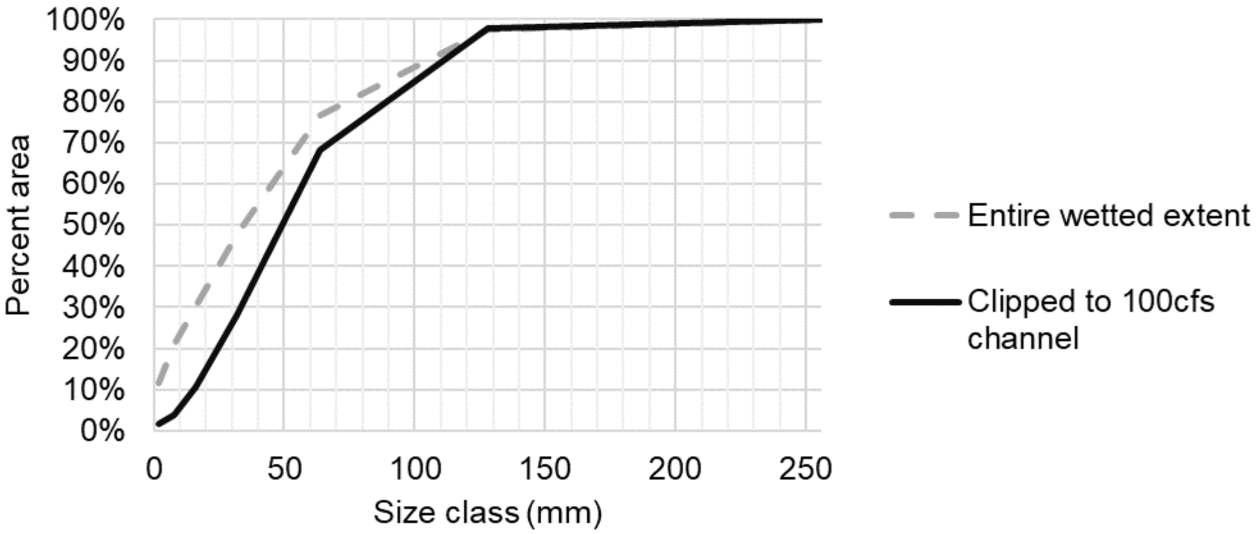


Figure 44. Percent of inundated area and cumulative percent by competent size class at 8,800 cfs (e.g. the largest size not expected to be mobilized). The dashed green line is for the entire wetted domain at 8,800 cfs for both reaches. The black line is the same data but clipped to the extent of the 100 cfs inundated channel.

As an additional analysis, we determined the percent of suitable spawning habitat area that had a D_{comp} value within the spawning size class range for Rainbow Trout. Of the approximately 60 acres of hydraulically suitable Rainbow Trout spawning habitat at 100 cfs, 24 acres, or 40% could support the required spawning gravel size class during flows of 8,800 cfs.

Morphologic Units

Morphologic unit mapping revealed that most of the baseflow channel consists of slackwater, with over 60% comprising both the wetted extent of both the Upper and Lower Reaches. The next most dominant unit by percent area is slow glide (~15%), followed by riffle transition (~10%), pool (~7%) and riffle (~4%). While not shown for brevity, percent occurrence using counts are similar to percent area data shown in Figure 45. There have only been a few other studies in California that have used 2D morphologic units at a similar spatial scale and on valley floor rivers. For the dynamic Lower Yuba River, Wyrick and Pasternack (2012) found a much more even distribution of morphologic units with no single unit occupying more than 20% of the wetted area. The Lower Yuba River is likely much different than the area of the Kings River analyzed because it has abundant sediment supply and quasi-natural flow regime. We have found in our work monitoring a ~0.9-mile reach of the Merced River that pre-habitat enhancement conditions generally consisted of mostly slackwater and post habitat enhancement conditions having a greater balance in the distribution of units (CFS 2019).

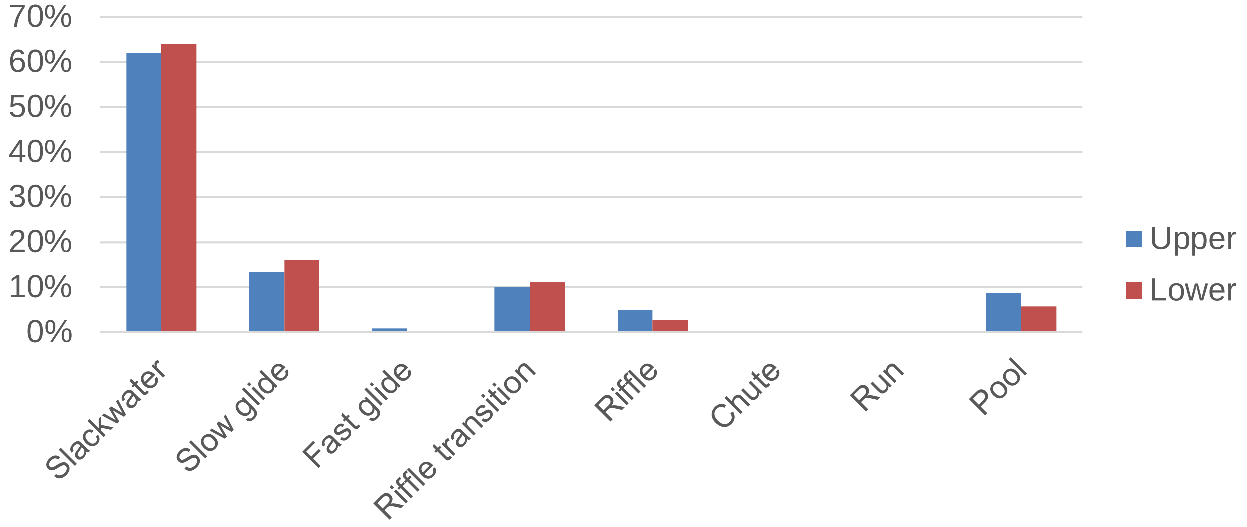


Figure 45. Percent area of morphologic units for both reaches.

Conclusions

- Historically the LKR study segment comprised a section of river at the transition zone between the mountains and lowlands. As runoff, streamflow, sediment and vegetation were supplied from the upper watershed it was routed through the canyon into the lowlands where the bounding mountains expanded and gave way to the relict Kings River fan. While we did not perform a historical analysis of channel change, inspection of aerial imagery from the 1930's show that form associated with historical processes was impacted over 80 years ago from agriculture and land use development.
- Bed slopes between reaches are nearly identical. Given upstream sediment supply reduction from Pine Flat Dam it is possible that incision has occurred and is still occurring, especially in the Upper reach. Another factor could be the multiple diversions and weirs controlling water and bed elevations in the Lower reach. That is, hydraulic structures likely control bed elevation and gradient in the river and mute the tendency for further incision and channel change.
- Channel width increases in the downstream direction, but there are several relatively narrow zones where channel width is constrained by land development.
- Shear stress predictions at the highest flow modeled (8,800 cfs) suggest that the current channel configuration does not support a large amount of area where Rainbow Trout sized spawning gravels would persist. Of the mapped hydraulically suitable spawning habitat only 40% would support spawning gravel in the river's current configuration. Given that there is little to no gravel recruitment this supports field observations that bed sediments are too coarse for Rainbow Trout spawning due to peak flows.
- Morphologic unit mapping at 100 cfs showed that ~60% of both reaches consist of slackwater habitat, which is a habitat unit that is not preferred by Rainbow Trout. The available riffle-pool habitat is much less than what is reported for productive Rainbow Trout streams. Rainbow Trout are most productive in streams with riffle-pool channels, usually at a 1:1 ratio (Raleigh et al. 1984). This is primarily because adult fish tend to spawn at the transition from pool to riffle. The mapped morphologic units show that these habitat units are relatively deficient in both reaches. In fact, we only found 6 locations where a direct pool to riffle transition occurs, and half of these had intermediate slackwater units.

Priority Ranking of Habitat Enhancement Scenarios

Cramer Fish Sciences worked with The KRFMP Technical Steering Committee to identify eight potential hypotheses as to why the LKR was not meeting natural Rainbow Trout population goals. The group agreed upon two most-likely hypotheses that might explain why this is case (possible numerous stressors feed into this result) and use them as a basis for population and habitat modeling associated with this contract:

1) Reproduction- Spawning/Incubation
    a) Habitat limitation
        i) Combination of high summer flows and low sediment recruitment may limit spawning and incubation substrate
        ii) Surface substrate may be too large for spawners to successfully complete redds
2) Fry/Parr
    a) Rearing habitat lacking
        i) In absence of adequate rearing habitat, fry and young parr may be overwhelmed by high velocity during periods of increased flows; no floodplains and limited instream cover

Preliminary results imply both hypotheses have merit and that habitat enhancement may be a viable option to surmount these issues.

The purpose of Task 5 was to identify and analyze 5 habitat improvement scenarios, including 1) type of habitat improvement actions, 2) materials, 3) geographic extent, and 4) estimated carrying capacity for trout at comparable life stages. We also identified potential habitat enhancement areas to facilitate spawning and rearing habitat need requirements identified under Task 4 (Quantitative Life Cycle Model). This report fulfills this task by identifying potential habitat enhancement and creation actions and determining potential action locations.

Results from Task 2 hydrodynamic and habitat suitability modeling predict between 60 and 79 acres of suitable spawning habitat exists at flows between 100 and 250 cfs. However, data on bed substrates indicate overall sediments are too coarse for Rainbow Trout to construct redds, implying suitable spawning habitat is limiting natural LKR Rainbow Trout production. Task 4 Population modeling suggests that between 0.5 and 5 acres of spawning habitat is needed for the modeled minimum viable population and with harvest, respectively (see Task 4 results). Therefore, we considered several spawning habitat enhancement and creation activities. Similarly, hydrodynamic and habitat suitability modeling predicts that on average between about 7 and 21 acres of suitable rearing habitat exists at flows between 4,000 and 8,800 cfs depending on fish size. Population modeling suggests that between 14 and 65 acres are needed to support YOY and Age 1+ juveniles during the August – September period. This suggests rearing habitat is limited by approximately 7 acres for a minimum viable population and is limited by about 44 acres for a population with expected harvest goals. Therefore, we selected rearing habitat enhancement and creation as potential actions to improve habitat. Below we discuss habitat enhancement and creation actions for spawning and rearing habitat.

Habitat Enhancement and Creation Actions

Salmonid stream habitat enhancement has been performed in the United States for well over 100 years (Van Cleef 1885; Hewitt 1931; Mih 1978; Thompson and Stull 2002). It has become more prevalent in the Western United States, since approximately the 1950's, as large dams were constructed that block access to historical spawning grounds, and valley development altered historic floodplains and off channel habitats (Wheaton et al. 2004a). For this project, we identified potential physical actions (e.g. non-flow actions) to improve Rainbow Trout habitat within the two posited hypotheses.

Some important considerations for performing any type of salmonid habitat enhancement are:

1) *Do no harm to existing habitat*
   - Protection of existing habitat is critical to the success of habitat enhancement. To restore habitat in the absence of any overlying conservation program is counterproductive because the ecological integrity of the landscape supporting the habitat enhancement will continue to erode.
   - Consider the geomorphic setting and use natural processes to restore and maintain habitat structure (Beechie et al. 2010)
   - Re-establish the dynamics of hydrology, sedimentology, geomorphology and other habitat-forming processes that naturally create and maintain habitat, rather than simply implant habitat structures at inappropriate or unsustainable locations. Understand and maximize the use of natural processes to achieve goals.

2) *Incorporate target species life history*
   - The extent of habitat enhancement activity must be substantial and habitat enhancement sites must be distributed appropriately to significantly improve ecosystem health, facilitating not only sufficient survival through, but successful transition between each life stage. Distribution of functional habitat throughout the appropriate stream reaches increases resiliency for the population through the variability of seasonal and interannual climatic changes. Analysis of factors limiting salmonid production is a fundamental requirement for planning, designing, implementing, and evaluating habitat enhancement.

The two primary approaches to spawning habitat enhancement are 1) augmentation of spawning gravels (e.g. gravel augmentation, riffle augmentation) and 2) placement of hydraulic structures. Due to the lack of suitable sized spawning gravels, we did not explicitly explore the addition of structure, cover and complexity, instead focusing on gravel augmentation. These could be pursued once a sediment budget is developed later. Actions to improve or create rearing habitat (e.g. rearing habitat enhancement) include gravel augmentation, floodplain, alcove and side channel excavation as well as cover addition. While cover and complexity are important for spawning and juvenile rearing habitat, we did not explicitly consider it as a stand-alone habitat enhancement action. This is because little is known about current cover conditions in the study area. Below we provide a brief overview of six different habitat rehabilitation and enhancement actions considered. While these are discussed individually multiple actions can be combined to improve habitat for an individual life stage, as well as providing benefits for both spawning and rearing habitat.

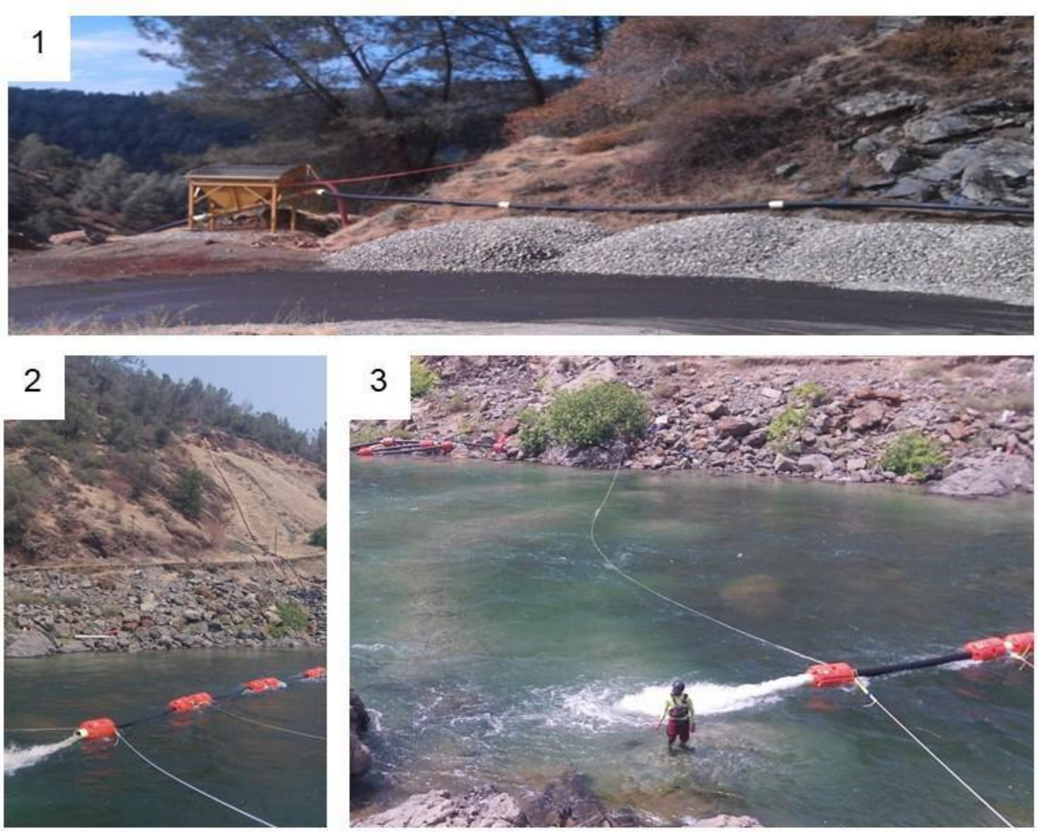
Gravel Injection

The simplest form of gravel augmentation entails the injection or placement of spawning gravels along the bank or in the channel with little to no sculpting of placed material (Kondolf and Matthews 1991). This action seeks to replenish some portion of a regulated river’s sediment budget deficit with imported sediment (Figure 46). In terms of management approach, gravel augmentation can be performed one or more times in a single location, or one or more times in several locations (Figure 47). Whether a single or multiple augmentation locations are needed would require further study from either numerical modeling of bed and sediment evolution (Mosselman 2012; Coulthard and Van De Wiel 2012) or from monitoring (Brown and Pasternack 2013).

Gravel augmentation is typically achieved by placing spawning gravels into piles along a stream's edges at locations upstream of degraded spawning habitat reaches. Pasternack (2010), Bunte (2004), and Kimball (2003) review various methods of gravel injection along with pros and cons. Most common forms of placement utilize dump trucks, conveyor belts or sluicing. Dump trucks can be used to dump sediments on banks or in the channel under the assumption that subsequent flows will mobilize material and route it downstream to create habitat. Cable ways and sediment sluices can also be used to place material more directly in the channel. Gaueman (2014) showed how gravel injection on the Trinity River, CA during high flows can lead to bar creation from sediment deposition. It is assumed that augmented gravels will be entrained during high flows with the competence to transport them downstream. Designs are rarely necessary for gravel injection, but a sediment budget and a monitoring program to enable adaptive management are appropriate.

Several recent studies have demonstrated that within regulated rivers, appropriate implementation of the Spawning Habitat Integrated Rehabilitation Approach (SHIRA) developed by the University of California, Davis (Wheaton et al. 2004a; 2004b; Elkins et al. 2007), including gravel augmentation, can enhance spawning and incubation habitat where spawning beds have degraded (Merz and Setka 2004; Merz et al. 2004; Zeug et al. 2014). While gravel augmentation was discussed above as a method for spawning habitat enhancement research has shown that it can also benefit rearing salmonids. Sellheim et al. (2016) showed that by filling the main river channel it can lead to increased floodplain inundation leading to increased habitat for rearing salmonids.

Figure 46. Bankside gravel injection is one of the older methods of adding gravel to sediment starved rivers to improve spawning habitat. Photographs courtesy of J. Hannon (USBOR). This process relies on the river's energy to mobilize and distributed coarse sediment. Note gravel "dump" during low flow period (left), gravel stockpile (middle), and gravel mobilization during high flow period (right).



1 -Pipe delivers water to screen and gravel is added
2- Water and gravel are sluiced down pipe
3- Pipe is manipulated to place gravel

Figure 47. Photographs illustrating a gravel injection using sediment sluicing below Englebright Dam, Yuba River, CA. Photo by author.

Spawning Riffle Enhancement

Spawning riffle enhancement is a type of gravel augmentation where an existing riffle is supplemented with appropriately sized spawning gravels (Kondolf et al. 1996; Merz 2004; Elkins et al. 2007). This is usually performed in existing riffles where habitat hydraulics are close or within the suitable range for spawning, and a “light fill” of spawning gravels could improve spawning habitat (Figure 48). Research on several rivers including the Mokelumne, Trinity, and Feather rivers shows that this method can significantly increase the quantity and quality of spawning habitat (Merz and Setka 2004; Merz et al. 2004; Elkins et al. 2007; Zeug et al. 2012; Sellheim et al. 2016; CFS 2019). Typically, riffle augmentation is performed using a front-end loader (Sawyer et al. 2009), but this can also be achieved using other methods such as sluicing (Brown and Pasternack 2013). The minimum depth of riffle augmentation should be related to egg burial depths so that water is deep enough for spawning and egg survival. For Rainbow Trout the top of egg pocket is 0.33 ft and bottom of pocket is 0.82 ft (DeVries 1997). Therefore, placed spawning gravels should be at least 0.82 ft deep to provide potential spawning habitat. One would of course need to verify that the addition of this material creates adequate hydraulics for spawning, as well as does not negatively impact adjacent habitat. This can be a concern since riffles are low flow hydraulic controls, so raising bed elevations would raise water elevation and potentially drown out upstream riffles. Further, additional topographic sculpting of the channel bed and banks (e.g. widening) could further enhance habitat and its persistence.

Figure 48. Example of riffle augmentation on the Stanislaus River, CA. The front-end loader is placing spawning gravels for Chinook Salmon and *O. mykiss* over an existing riffle where oversized substrate reduced spawning habitat conditions.

Local Widening and Augmentation

In areas where there are run, chute, riffle or riffle transition morphologic units a combination of local widening and gravel augmentation could enhance or create riffle spawning habitat (Figure 49). The widening is thought to promote energy dissipation at high flows leading to the accumulation and persistence of spawning gravels (e.g. Rhoads et al. 2013; Brown et al. 2016). Benefits could potentially go beyond the spawning life stage by providing rearing habitat. This type of activity would require a SHIRA type design to optimize habitat enhancement and minimize costs.

Figure 49. Example of local widening and gravel augmentation on the Napa River, CA. The left shows a photograph of gravel deposition at a local widening zone. The right image shows where local bank widening occurred at existing riffles. Left image is by author and right image from Google Earth.

Island Creation

Another feature that can be created or enhanced for adult spawning and juvenile rearing salmonids are river islands. River islands are relatively abundant on the river, especially near the confluence of Mill Creek. River islands increase the amount of edge habitat relative to channel length. This is thought to be beneficial to salmonids such as Rainbow Trout that utilize edge habitats. Additionally, when cover is present the inundation of river islands can provide areas of flow refugia when the remainder of the river may have relatively high velocities. Other benefits of constructed and augmented river islands include improved hydraulic and thermal diversity, increased organic matter inputs and hyporheic exchange (Hintz et al. 2015; Ock et al. 2014).

Islands can be created by gravel augmentation in overly wide sections of channel (Figure 50). In the channels that flow around the island riffle or run morphologic units are most common. Islands can also be created by excavating a channel along the inside of an existing bank, leaving the former bank to serve as the island.

Figure 50. Example of constructed river islands. The left photo illustrates river island creation from the augmentation of spawning gravels on the Merced River, Ca. The right photo illustrates river island creation by excavating a channel behind the existing bank on the Napa River, CA.

Channel Morphology Rehabilitation

Other river areas may not have appropriate hydraulics and be too deep and slow. In these areas spawning habitat could be improved by rebuilding the riverbed with alluvial geomorphic units such as riffles, islands, bars and pools with spawning gravels and cobbles (Figure 51). For example, CFS (2019) completed two projects on the Merced River where overly wide and deep sections of channel were rehabilitated. Adjacent mine tailings were excavated and screened to provide a source of gravel, and through excavation create off-channel habitat. Screened gravels and cobbles were then placed in the riverbed to create alluvial river morphology. Analysis of habitat suitability changes from pre- to post- project at one of the sites yielded a three-fold increase in suitable spawning habitat and two-fold increase in rearing habitat (CFS 2019).

This would be most optimal in locations where there is currently no riffle or spawning habitat and where the spacing of riffles exceeds the average range of natural riffle-pool spacing. Additionally, volumes of gravel needed would likely be very high, so a relatively close source of gravel would improve feasibility.

Figure 51. Example of riffle-pool creation on the Merced River, CA. The left image shows the pre-project channel, which consisted of mostly overly deep and coarse channels. The right image shows post project conditions after augmented gravels were placed to create several riffle-pool units with lateral bars and islands.

Off-channel Habitat Excavation

Restoring (i.e., rehabilitation, enhancement) side channel and floodplain connectivity in degraded streams can recover productive rearing habitat for juvenile salmonids (Richards et al. 1992; Morley et al. 2005; Sellheim et al. 2016). Rearing habitat is described as the physical conditions, including water temperature, dissolved oxygen (DO), turbidity, substrate size and composition, water velocity and depth, and available cover (Bjornn and Reiser 1991), which maintain the chemical and biological components (e.g., invertebrate prey resources) critical to habitat productivity for fish (Simenstad and Cordell 2000). The importance of floodplain habitats as productive foraging areas and predator refuge for rearing juvenile salmonids, compared to main river channels, has been well documented (Grosholz and Gallo 2006; Jeffres et al. 2008; Merz et al. 2015). Previous studies in Central Valley streams and other systems have demonstrated that creating or enhancing floodplain habitat can increase the quantity and quality of rearing habitat under a range of flow conditions, and that juvenile salmonids utilize these restored features (Sellheim et al. 2016; CFS 2013; Ogston et al. 2014). Inundated floodplains can enhance juvenile salmonid growth and survival if water temperatures, prey biomass, and velocities are more favorable compared to main channel habitat (Ahearn et al. 2006).

Recently, floodplain rearing habitat has been identified as a limiting factor in meeting California Central Valley salmonid population goals (USFWS 2007). Juvenile salmonids that spend more time rearing in off-channel habitats may grow more quickly, potentially increasing survivorship. Consequently, rehabilitating and increasing rearing habitats has been incorporated into recent watershed management programs (Delta Conservancy 2012; Greco and Larsen 2014).

Floodplain, side channel and alcove excavation are relatively new approaches in regulated rivers (Figure 52). The general concept is that areas outside of the baseflow channel are excavated and lowered to allow for inundation under current flow regimes. It is a promising method in rivers with relatively low sediment supply, especially fine sediments that can potentially fill in excavated areas. Further, in areas where the historic floodplain is present it is possible to screen excavated areas to generate a supply of coarse sediment that can be added to the main channel.

Figure 52. Examples of side channel (left of image) and floodplain (right of image) creation for juvenile salmon habitat on the Merced River, CA. The side channel has shallower depths and higher velocities compared the floodplain that has moderate depths and relatively low velocities.

Potential Habitat Enhancement Locations

To select potential locations for the above actions we used a combination of expert judgement and quantitative analysis of habitat enhancement potential. We developed separate, but complimentary criteria to select locations for habitat enhancement. The goal was to find locations that could meet the deficiencies in spawning and rearing habitat.

Criteria for Site Identification

We used several datasets to generate criteria for determining potential locations for habitat enhancement actions (Table 17; Figure 53). First, we used a map of morphologic units (MU) derived from 2D model results to consider existing and potential riffle habitat. Second, we used the map of a competent sediment diameter (D_{comp}) for the two highest flows modeled (e.g. 4,000 and 8,800 cfs) and stratified the map to delineate regions where suitable Rainbow Trout spawning gravels could persist under the current channel configuration. We created a GIS layer of local constrictions for the two highest flows modeled (e.g. 4,000 and 8,800 cfs) and stratified the data to delineate regions where channel width was relatively narrow or wide. Lastly, we created a height above river (HAR) digital elevation model (DEM) to find relatively low-lying areas of land for off channel habitat enhancement.

Table 17. Habitat enhancement and creation actions and criteria used in site identification.

Action	**Criteria**
Gravel injection	• Upstream most location free of downstream structures • Above areas where flow routing would promote gravel deposition that would provide downstream benefit
Augment existing riffle	• Existing riffle MU and hydraulically suitable spawning habitat • Competent sediment diameter in range for Rainbow Trout spawning at 8,800 cfs
Local widening and channel augmentation	• Existing hydraulically suitable spawning habitat • Existing riffle, riffle transition, chute or run MU • New riffle spacing would be within range • D_{comp} at 8,800 cfs exceeds spawning substrate size • Relatively narrow section of channel • Amenable land use adjacent to river
Rebuild/create new riffle-pool morphology with spawning gravels	• Slackwater, glide or pool MU occupying length of river channel greater than average riffle spacing • No current spawning habitat
Off channel habitat excavation	• Is location in a relatively narrow section of river • No greater than 2–5 ft above 4,000 cfs water inundation • Amenable land use adjacent to river

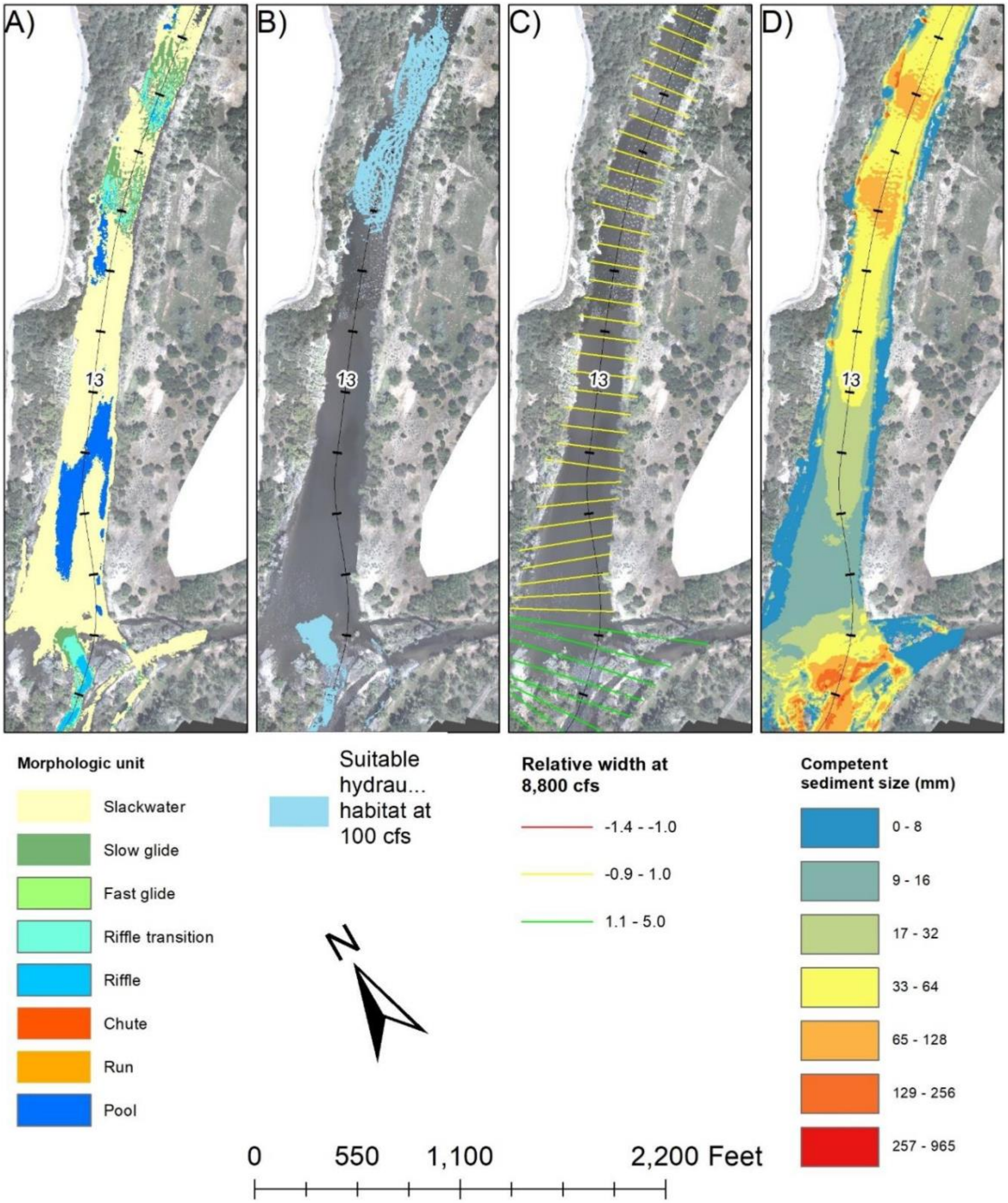


Figure 53. Example datasets derived from hydraulic modeling used to identify potential spawning habitat enhancement locations. Black ticks are 100m stations. For this section of river, the morphologic units (A) are primarily slack water and pool, there is no hydraulically suitable spawning habitat (B), channel widths at 8,800 cfs are relatively narrow (C), and the D_{comp} at 8,800 cfs is between 64 and 9 mm. A potential habitat improvement action would be rebuilding channel morphology.

Gravel Injection

Given that the river is relatively starved of suitable gravels for Rainbow Trout spawning, gravel augmentation below the Pine Flat Road Bridge is a viable option. While the easiest and most economical approach for augmentation would be to dump sediments for subsequent entrainment, significant benefits can be obtained with in channel sculpting of river morphology to meet the specific geomorphic and hydraulic requirements of Rainbow Trout. How much gravel needs to be augmented, and the frequency of augmentation are important questions, but beyond the scope of this study.

Spawning Riffle Enhancement

Where there are existing riffles, they could be augmented with spawning gravels under the assumption they are currently too coarse for Rainbow Trout spawning. An additional consideration is that placed spawning gravels would be persistent during high flows (e.g. 8000 cfs). Therefore, riffle augmentation sites were selected if they were existing riffle or riffle transition MU's as well as had D_{comp} values within the Rainbow Trout spawning gravel size range at 8,800 cfs.

Local Widening and Augmentation

In some riffle MU's the channel may be relatively narrow from channel incision, adjacent land development and encroachment from riparian vegetation. These areas likely have D_{comp} values outside the Rainbow Trout spawning gravel range. These are areas that could be locally widened to reduce flow energy so that placed or augmented spawning gravels would be relatively persistent at high flow. Since local widening can also attenuate spawning gravels by decreasing flow energy, transitional MU's other than pools could be transformed into riffles with gravel augmentation. Therefore, potential riffle augmentation areas with local widening were identified if there was a non-pool MU, in a relatively narrow area at high flow, and the D_{comp} at 8,800 cfs exceeded the spawning gravel size range.

Island Creation

While we listed river islands as a standalone habitat enhancement action, we used criteria for riffle augmentation and local widening as well as riffle-pool creation to identify potential locations for island creation.

Channel Morphology Rehabilitation

Drawing on the same reasoning there are relatively long LKR stretches that are slackwater and glide MU's. If these areas are long enough multiple riffle-pool units could be created. To determine an approximate length threshold for "how long" such areas need to be, we related current riffle spacing to average values from the literature. That is, mapping current riffles and evaluating whether successive riffles are within reported ranges of riffle spacing can help identify areas where riffles could be created. Riffle spacing in natural rivers is variable, occupying an average range of 3–11 bankfull channel widths with a central tendency of 5–7 bankfull channel widths (Keller and Melhorn 1978; Carling and Orr 2000, Thompson et al. 2001; Wyrick et al. 2014). Bankfull discharge has not been explored for the river but based on evaluating flow from Pine Flat Dam from 1953 to 2017 the 2-year flood, a common flow frequency metric for bankfull, is approximately 7,100 cfs. We conservatively used model outputs from a lower flow, 4,000 cfs, to determine the average channel width, which yielded a value of ~300 ft. This value was then conservatively multiplied by 5, which is the lower end of the modal range of riffle spacing from the literature, yielding a distance of ~ 1,500 ft. We then used this value as a check against the length of glide, slackwater and pool morphologic units to estimate potential locations for riffle creation.

Off-channel Habitat Excavation

Potential areas for rearing habitat enhancement and creation were identified using two basic criteria. First, we identified areas of land that are approximately between 0 to 5 feet above the 4,000 cfs water surface elevation. Since excavation volume is the primary cost driver of rearing habitat enhancement and creation, we sought to first find areas where the ratio of material excavated versus area gained is relatively high. Second, we identified areas where the channel is constricted, and modeled habitat is relatively narrow. The reasoning behind this is that relatively narrow zones of rearing habitat could be expanded to more evenly distribute habitat in space so there are not bottlenecks of suitable and unsuitable habitat.

To identify areas of land between 0 and 2 feet above the 3,712 cfs waterline we created a surface in ArcGIS that had the water surface elevation at 3,712 cfs. Next, this surface was subtracted from the LiDAR DEM creating a “height above the river” or HAR DEM. The HAR DEM thus has elevation of 0 in place of the modeled water surface elevation and values greater than zero are relative increments above the water line. Using ArcGIS polygons, we created four areas between 0 to 2 ft of the HAR DEM. These areas can be thought of as being potential rearing habitat if they were lowered to be at least 1 ft below the 4,000 cfs water surface elevation. This polygon was then manually edited to remove polygon areas less than 1 acre as well as areas associated with manmade features such as Avocado Lake. Next, we extracted the width of modeled Rainbow Trout rearing habitat at 4,000 cfs using ~98.4 ft (30m) spaced cross sections to create a spatial series of habitat width versus distance upstream. We visually assessed this plot to identify relatively long stretches of narrow rearing habitat. For example, between rkm 4 and 6.5 (rm 2.5–4) the width of suitable rearing habitat is relatively low compared to the rest of the river (Figure 54).

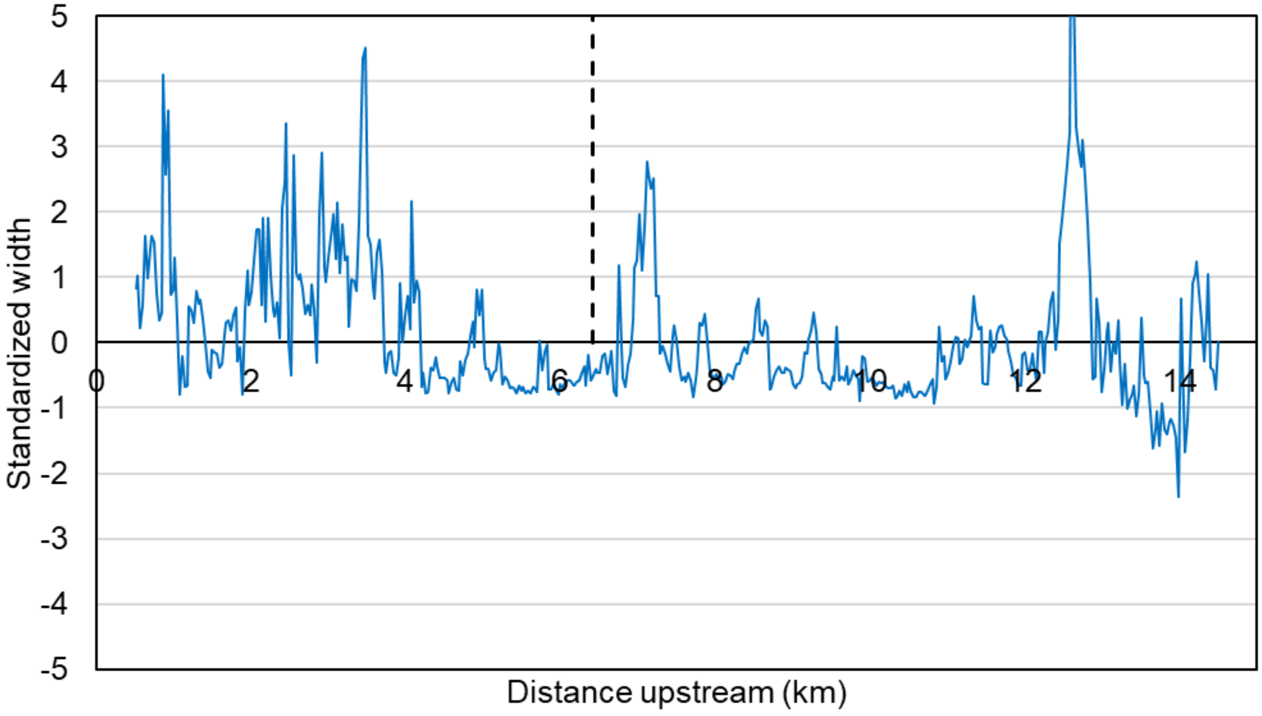


Figure 54. Standardized width series of modeled Rainbow Trout rearing habitat at 4,000 cfs. Values below zero indicate relatively narrow habitat, while values greater than zero indicate relatively wider habitat.

Potential Sites

As a first step, we identified 16 potential sites throughout the study area to improve Rainbow Trout spawning and rearing habitat (Table 18; Figure 55). These locations have been delineated with approximate project areas, which is not the same as the amount of suitable habitat they could provide. To conservatively estimate the amount of suitable habitat for each life stage we discounted the site areas (not shown for brevity) with a multiplier (Table 19). This is a simple way to estimate suitable habitat in the absence of concept designs and 2D habitat suitability modeling.

Table 18. Area multipliers to weight site areas to potential suitable habitat. Values are based on experience with similar projects

Action	Spawning	Rearing
gravel injection/augmentation	0.5	0.2
channel morphology rehabilitation	0.3	0.3
floodplain and side channel excavation	0.3	0.5
side channel creation	0.3	0.5
local widening	0.3	0.3

We identified approximately 25 and 40 acres of potential spawning and rearing habitat improvement, respectively. The amount of potential spawning habitat exceeds initial estimates of habitat need. Potential juvenile rearing habitat is within 95% of initial estimates of habitat need. Of note is that a tremendous amount of potential habitat occurs between rkm 4 and 1 (rm 2.5 and 0.6), on the relict Kings River alluvial fan, so there are enough potential areas to meet the habitat deficit.

Table 19. Potential habitat rehabilitation/enhancement sites for adult spawning and juvenile rearing Rainbow Trout. Actions abbreviations are as follows: GA – gravel augmentation, RCM – channel morphology rehabilitation, SC – side channel creation or enhancement, LW – local widening, FP – floodplain creation or enhancement

ID	Spawning habitat (acres)	Rearing habitat (acres)	US limit (rkm)	DS limit (rkm)	Action(s)
1	2	0.8	14	13.8	GA
2	4.5	4.5	13.2	12.6	RCM
3	2.7	2.7	12.1	11.44	RCM
4	2.4	2.4	10.3	9.84	RCM
5	1.3	2.1	8.6	8.2	SC, GA
6	0	3.6	8.3	7.8	SC (Thorburn channel)
7	2.9	2.9	8.2	7.8	LW
8	1.8	1.8	6.3	5.9	LW, GA
9	0	5.2	5.7	5.4	SC
10	4.1	1	5.35	5.15	GA
11	0	3.6	5	4.1	SC
12	2.2	2.2	4.6	4.2	LW or SC, GA
13	1.2	1.2	3.45	2.8	FP, SC
14	0	2	3.4	2.4	FP, SC
15	0	2.4	1.9	1.5	SC
16	0	1.8	1.8	1.1	SC

Total	25	40

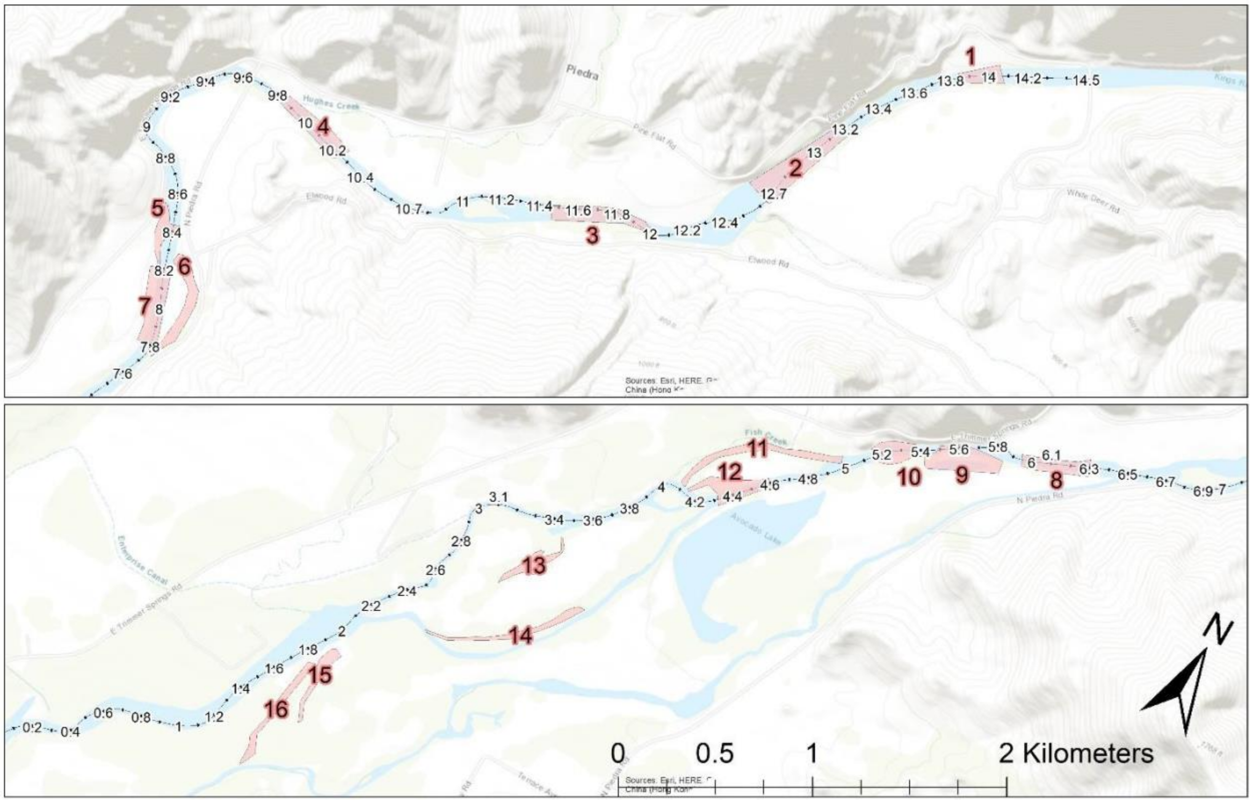


Figure 55. Location maps of potential habitat enhancement sites. See Table 19.

Top 5 Habitat Improvement Projects

Based on the potential habitat enhancement projects shown in Table 19 and Figure 55, we solicited input from KRCD on accessibility. From this information, several projects were eliminated from further consideration. These include Site ID’s: 8,11,13,14,15, and 16.

Given that the study results indicate spawning gravel substrate is deficient, and there is enough juvenile rearing habitat for a minimum viable population, we recommend that gravel augmentation and spawning habitat enhancement projects are prioritized first. Spawning habitat enhancement projects can also yield direct benefits to fry and juvenile salmonids. Therefore, these project types can have life stage benefits beyond spawning. Within those actions, projects located closest to Pine Flat Dam are likely to have greater benefits. This is because (1) placed gravels can be routed downstream through the river during high flows, (2) salmonid spawning tends to be skewed upstream in regulated streams, (3) water temperatures may be less optimum with distance from dam. Based on this reasoning, the top 5 projects would include Site ID’s 1 through 5, although Sites 6 and 7 are adjacent to 5, suggesting they could be considered as a single project. Once one or several projects are implemented it will be important to monitor the biological response at those locations and relative to the overall fisheries to test the fundamental hypotheses generated in this study that drove site selection.

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Kings River Fisheries Management Program
Response to Public Comments Received on the “Lower Kings River Fishery Habitat Characterization and Identification of Habitat Enhancement Opportunities” Report

Name	Date	Letter #	Comment	FMP Response
Public Advisory Group (PAG)	8/14/17	1	The Public Advisory Group (PAG) states that Item 1(j) of the Framework Agreement commits the Kings River Fisheries Management Program (KRFMP) to supplemental stocking more trout than had been provided in 1999. The PAG also states that the 1999 trout estimate was 59,140 - equivalent to near 40,000lbs., therefore the draft stocking plan only meets the perceived obligation by half.	Item 1(j) of the Framework Agreement does not state or suggest any obligation on behalf of the program to meet or exceed any number of rainbow trout as provided in 1999 or any other year.
PAG	8/14/17	2	The PAG restates their position that the intent of the Framework Agreement is to plant more rainbow trout than were planted in 1999. The PAG recognizes that the number of supplemental trout as described in the Framework Agreement is not defined; as such they have assigned a value of +25%. The PAG equates this value to 75,000 additional catchable sized trout. In addition, the PAG request that the KRFMP confirm that the California Department of Fish and Wildlife (CDFW) define "catchable" sized as 1.2 to 2 trout per lb.	The Kings River Fisheries Management Program Framework Agreement was not created to serve a singular purpose. "Among other commitments, the parties committed to: (i) support and pursue in an expeditious manner a cooperative program to improve and manage fisheries and aquatic habitat conditions; (ii) cooperatively seek and develop a broad scope of habitat improvement alternatives, emphasizing opportunities for voluntary conjunctive or sequential water uses for continued enjoyment of the full range of on-stream and off-stream beneficial uses; (iii) to minimize and, where possible, avoid adverse effects of any changes on the holders of water storage and/or use rights, and on the public who beneficially use the waters of the Kings River; and (iv) to co-sponsor projects and programs which further the purpose of the Statement of Intent" (KRFMP Framework Agreement, 1999). Therefore, the program is charged with taking all of these elements into account prior to giving value or preference to a singular task. As mentioned in HI1, no specific quantity of supplemental trout was committed on behalf of the program within the language of the Framework Agreement. It would be irresponsible to commit resources based on a subjective figure and we must therefore reject the 25% recommendation. The program will continue to review and reassess the progress, costs, logistics and success of this endeavor over time. At current the CDFW published definition of "catchable" size is – between 6.0 and 1.0 fish per pound. Most frequently 2.0 fish per pound (about 12" in length).
PAG	8/14/17	3	The PAG points out that there is little in the way of research on the survival rate of sub-catchable sized trout and requests additional information. The PAG proposes that the annual winter allotment of 24,000 sub-catchables be replaced with 4,800 catchable sized trout instead.	There is little in the way of research on the survival rates of stocked sub-catchable trout in the lower Kings River. We are currently investigating how to improve this type of data collection. The allotment of 24,000 sub-catchable rainbow trout which are stocked in the Kings River each December serve as part of the program's commitment to "planting "put and grow" sub-catchable fish … " as outlined in the Framework Agreement G.1(j)(ii). Henceforth this allotment will dually serve as insurance in years where either hatchery or climatic conditions prohibit regular stocking practices or create otherwise uninhabitable conditions for rainbow trout during multiple months of the year. In such instances, said 24,000 sub-catchables will be held and grown out to a catchable size prior to stocking.
PAG	8/14/17	4	The PAG requests that the $30,000 designated for KRFMP Incubator building operations (2017-2018 Annual	The sum of $25,000 (not $30K) has been budgeted and approved by the Executive Committee for the operations and maintenance of the incubator building.

			Implementation Plan budget) be redirected to fund additional catchable sized rainbow trout. The PAG estimates the cost to be $4 per pound, yielding an additional 15,000 trout. The PAG moved on this request with a 9/2 vote	Breakdown of that is as follows: • $15,000 is comprised of reimbursable funds via the Ted Martin family Grant. The grant money is conditional to the terms agreed upon by the Martin family, The Kings River Conservancy (facilitator) and the KRFMP. The funds are exclusively for the purchase of rainbow trout eggs for the incubator building or the direct maintenance of those eggs. As such these funds are non-transferable. Additionally, as of the receipt of these comments 08/15/17, the CDFW San Joaquin Hatchery has not confirmed a price for production with the KRFMP. • $9,000 is to install a standby generator to ensure production upon loss of electrical power. This has been a routine issue, with a high rate of mortality as a result of lost water flow into the rearing raceways. • $1,000 is for routine maintenance and materials that may be needed In regard to the KRFMP incubator building, the KRFMP has seen multiple benefits from the operation of said facility that meet many of the objectives outlined in the Framework Agreement. Along with that, the facility has full support of the Kings River Conservancy (501c3), it serves as a resource for public outreach and education and fulfills or commitment to “plant “put and grow” sub-catchable fish and eggs which can mature into a sustaining population of adult fish whenever appropriate” as listed in section I (j)(ii) of the Framework Agreement. The program continues to work on improving the methods used to monitor the success of this endeavor.
PAG	8/14/17	5	In page 3 of their comments the PAG provided a table of suggested stocking changes as described in comments 3 & 4.	The numbers proposed in the table provided by the PAG have been noted, however the total number of rainbow trout proposed in the draft plan will not change for reasons further explained within the content of these comments. This stands with the exception of a 5% shift in allocation of supplemental trophy trout from Reach 1 to Reach 2 as described below in FMP Response 8.
PAG	8/14/17	6	The PAG has requested that the KRFMP consider the study results from the following documents: *Movement of Resident Rainbow Trout* (KRCD, 2012); *Dispersal and Longevity of Stocked Triploid Hatchery Rainbow Trout in the Silver Fork American River* (CDFW, ?); the *1996 USFWS Coordination Act Report, Pine Flat Fish Turbine Bypass Section 1135 and Restoration Project*. The PAG suggests that the stocking locations are not adequately spaced, causing a concentration of trout to be limited to a few public access points.	A representative of the KRFMP will review the suggested documents. In response to the spacing of CDFW stocking locations, there are actually 12 stocking locations within the 5.5mile put and take section of the tailwater fishery and 5-6 stocking locations in the 4 mile stretch between Alta Weir and Fresno Weir. The map provided in the draft plan did not sufficiently demarcate each individual site and a more comprehensive map will be used in the final plan.
PAG	8/14/17	7	“PAG proposes a significant increase in the number of planting locations”. The PAG has provided the KRFMP with	Six (6) stocking sites recommended by the PAG are located on private property – Frustration Lake (South Bank), Turkey Pens 1 – 3, Upper Riffle and Pool and will not be considered unless private landowners would voluntarily allow public access

			29 GPS locations where they would like for stocking to occur.	It is the policy of the CDFW to allocate time and resources to publicly accessible areas where they will provide the greatest good to the public. Stocking locations are chosen based on public accessibility, the amount of recreational opportunity available, stocking truck accessibility, safety, driver time and the amount of stress placed on the fish per stocking location. Alternate stocking locations will be discussed at the discretion of CDFW.
PAG	8/14/17	8	The PAG request that the KRFMP plant 75% of the supplemental trophy trout in Reach 2 and that 25% be planted in Reach 1. The draft stocking plan currently allocates 20% to Reach 2 and 80% to Reach 1.	The final stocking plan will reflect the following change in supplemental trophy trout allocation as a result of the PAG request: 75% to Reach 1 and 25% to Reach 2 (a change of 5%). Reach 1 includes two county parks and multiple public access locations experiencing an overall greater amount of fishing pressure. Reach 1 is a put and take fishery and is expected to experience greater depletion rates than the catch and release section in Reach 2. Reach 2 includes one county park and far fewer public access fishing locations than Reach 1. Because Reach 2 is a catch and release management zone it is expected that existing trout may be captured multiple times, minimizing the depletion within the reach.
PAG	8/14/17	9	The PAG requests additional public fishing access. The PAG does not believe that access has ever been increased by the KRFMP. Additionally, the PAG requests fishing access on the following privately owned properties – Alta Irrigation District at the head of the 76 Channel and the access area approximately 350yrds. downstream, the orange grove behind the old Sherriff's substation on Trimmer Springs Road, Harris property across from Thorburn channel properties and the Thorburn channel properties to include parking and change in regulations to allow fishing at the channel entrance. The PAG also request use of the closed ACOE recreation area.	Further access can and will be investigated. In response to the comment that the KRFMP has not provided access, the Kings River Conservation District (KRCD) has provided and continues to maintain the All Access Fishing Area (handicapped access) off of Pine Flat Rd.. Additionally, in 2005 the KRFMP built an 8-car parking lot at Green Belt County Park adjacent to Piedra Road and cleared a walking trail from the parking lot to the river. The riparian property was little known and often difficult to access via dirt road. Fishing regulations signs were placed in river access areas and the County owned park became much more accessible to the public for fishing, walking and nature viewing. It is not the policy of the KRFMP to impose or press on the rights of private property owners within our management area and thus we will not pursue access on private lands. . Please refer to B-4 and C-6 of the Framework Agreement under General Aquatic Resource Goals. In the special case of the Thorburn Channel, the property owners entrusted the use of their properties to the KRCD with the understanding that the property would serve as a conservation area demarcated for the spawning/rearing of rainbow trout without the stresses of developed recreational use. Since construction of the channel in 2000, the property has flourished and become a hub of biodiversity providing resources to more than 29 species of wildlife. Foot traffic is allowed on the property and fishing on the river side. The Grantors of Easement who own the North Eastern section of property

				requested a locking gate at the time of easement and maintain that the gates remained locked unless in use by KRCD or official public service (PG&E, Emergency Services, etc.). Altering the existing easements is not justly warranted and would not be prudent.
PAG	8/14/17	10	The PAG requests that the recreational fishery as described in the stocking plan include the section of river from Fresno Weir to 180.	The section of river from the Fresno Weir to Highway 180 is excluded from the supplemental plan. Due to hydrologic diversions and management activities above the Fresno Weir, consistent trout habitat cannot be guaranteed below the weir for any length of time. For that reason, the stretch of river is considered an opportunistic trout fishery. It is not in the best interest to plant in a location that is prone to frequent resource irregularity.
PAG	8/14/17	11	The PAG requests that the 2018-2023 Supplemental Stocking Plan include Pine Flat Reservoir as well as the additional reaches below Reach 2.	The 2018-2023 Lower Kings River Supplemental Stocking Plan is only intended to supplement the tail water fishery below Pine Flat Dam with additional rainbow trout. In the past the program has provided additional game fish for the reservoir and may revisit the idea at a later date. This plan is not part of CDFWs regular stocking plan which includes a greater section of the river, including the Reedley Beach stocking location as described in the document.
PAG	8/14/17	12	The PAG requests that CDFW keep more meticulous records of trout planted at each site	When planting trout, a CDFW hatchery driver takes a number of items into account such as the fishing demand experienced at each site, the number of sites the truck will visit, overall efficiency, and the length of distribution time that the trout are able to handle before becoming stressed. As it is not possible to count each fish individually when stocking large numbers, drivers are asked to estimate the amount stocked per site based on the amount of free area in the tank. Distribution is less a function of equal allocation per site and more a function of each system receiving the allotted poundage distributed according to perceived use as accessed by experienced hatchery personnel.