Upper Tuolumne River Ecosystem Project

O'Shaughnessy Dam Instream Flow Evaluation Study Plan

McBain & Trush, Inc.

Prepared for:
The San Francisco Public Utilities Commission

July 7, 2009

About the Upper Tuolumne River Ecosystem Project

In June 2006, the San Francisco Public Utilities Commission (SFPUC) adopted the Water Enterprise Environmental Stewardship Policy and directed the Water Enterprise to integrate this policy into the planning and operation of the SFPUC water system infrastructure, including Hetch Hetchy Project dams and diversions. The policy establishes a management directive to protect and rehabilitate ecosystems affected by water system operations, within the context of meeting water supply, power generation, water quality, and existing minimum instream flow requirements. The policy further directs the nature of SFPUC instream flow releases such that they mimic, to the extent feasible, "…the variation of the seasonal hydrology (e.g., magnitude, timing, duration, and frequency) of their corresponding watersheds in order to sustain the aquatic and riparian ecosystems upon which native fish and wildlife species depend."

Subsequent to adoption of the Environmental Stewardship Policy, the SFPUC initiated the Upper Tuolumne River Ecosystem Project with the goal of conducting a set of long-term, collaborative, science-based investigations designed to (1) characterize historical and current river ecosystem conditions, (2) assess their relationship to Hetch Hetchy Project operations, and (3) provide recommendations for improving ecosystem conditions on a long-term, adaptively managed basis.

The Ecosystem Project will provide data and analyses to (1) support implementation of the Water Enterprise Environmental Stewardship Policy on the Upper Tuolumne River, (2) support ongoing Yosemite National Park Tuolumne Wild and Scenic River planning and management efforts, (3) provide the scientific basis for resolving outstanding issues with the U.S. Department of the Interior related to the 1987 Stipulation under the Raker Act, and (4) implement mitigation and monitoring requirements specified in the Final Programmatic Environmental Impact Report for the Water System Improvement Program (WSIP PEIR).

Primary partners include the SFPUC, Yosemite National Park, Stanislaus National Forest, and the U.S. Fish and Wildlife Service. The study area includes reaches of the Upper Tuolumne River mainstem and major tributaries regulated by the Hetch Hetchy Project, from O'Shaughnessy Dam to Don Pedro Reservoir, Cherry Creek downstream of Cherry Valley Dam, and Eleanor Creek downstream of Eleanor Dam.

This document prepared by:

McBain & Trush, Inc., Arcata, CA

Prepared for:

The San Francisco Public Utilities Commission, 1145 Market St., San Francisco, CA

Preferred citation

McBain & Trush, Inc. 2009. Upper Tuolumne River Ecosystem Project: O'Shaughnessy Dam Instream Flow Evaluation Study Plan. Prepared for the San Francisco Public Utilities Commission.

Table of Contents

This page intentionally left blank

1 Introduction

Agreements between the City and County of San Francisco and the US Department of Interior (1985 Stipulation, 1987 Stipulation) govern minimum instream flows in the Upper Tuolumne River between O'Shaughnessy Dam and Early Intake (the "Hetch Hetchy reach"). Instream flow studies focusing on trout habitat in this reach (Figure 1) were performed by the US Fish and Wildlife Service (USFWS) between 1976 and 1990, with a draft report released in 1992 that contained revised recommendations for minimum instream flow releases from O'Shaughnessy Dam (USFWS 1992).

In 2006, the San Francisco Public Utilities Commission (SFPUC) and USFWS agreed to undertake new studies that will (1) address unresolved issues from previous studies, (2) adopt an ecosystem approach, and (3) consider new analytical approaches. The parties intend that these new studies will lead to revised recommendations for instream flows that address a broad range of resource values in this reach.

This new instream flow evaluation will develop: (1) rationale and methods for quantifying the biological and geomorphic relationships between the annual hydrograph and the Upper Tuolumne River ecosystem in the Hetch Hetchy reach, and (2) an analytical protocol for evaluating and synthesizing the outcomes of (1) to recommend instream flow release schedules for O'Shaughnessy Dam as described in the 1987 Stipulation. The instream flow evaluation is a collaborative effort among the SFPUC, USFWS, Yosemite National Park, and Stanislaus National Forest.

This document provides an initial study plan towards developing initial flow recommendations for the Hetch Hetchy Reach by December 2009 and final recommendations by December 2010. An addendum to this plan may be developed based upon the results of 2009 studies.

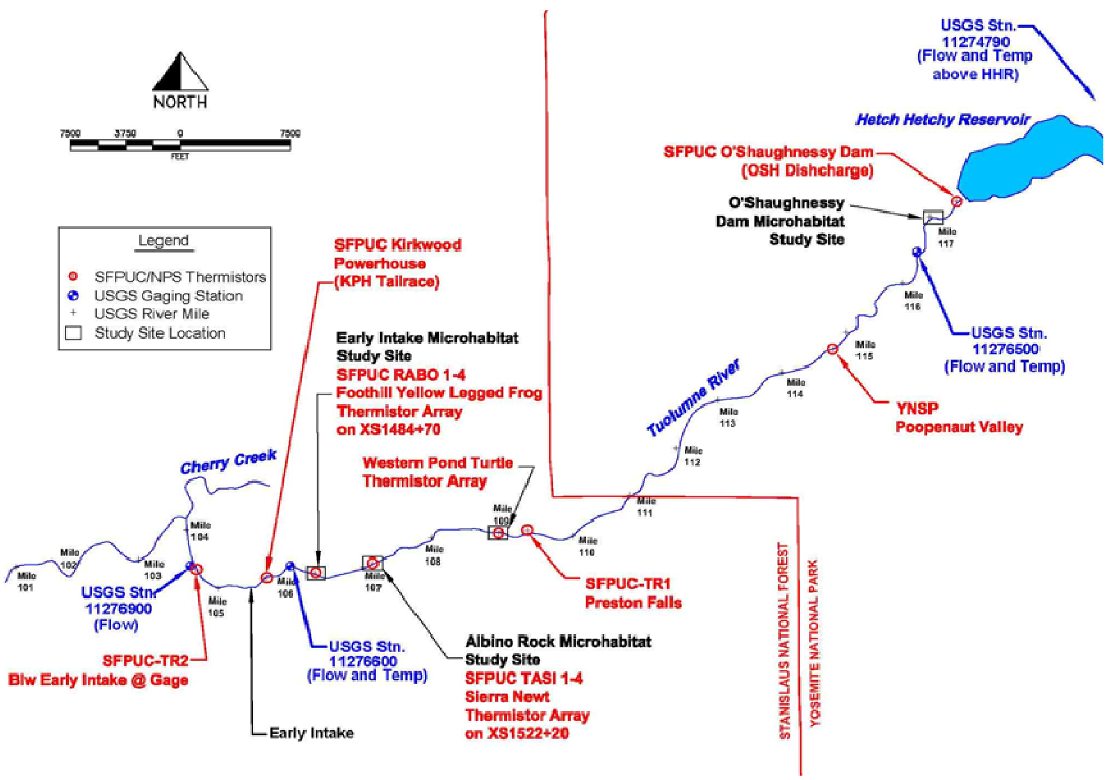


Figure 1. Map of the Hetch Hetchy reach, including river miles, stream gaging sites, thermistor sites, and proposed habitat study sites for the instream flow evaluation.

2 Background

2.1 Pre- and post-regulation hydrology in the Hetch Hetchy reach

All components of the unregulated annual hydrograph were important to how the Tuolumne River ecosystem once functioned. High flow releases still occur during late-winter and spring, with many operational releases in WY1997 through WY2006 resembling the shape and timing of unregulated winter peak flood and snowmelt hydrographs, but at a lower duration, frequency, and magnitude (McBain & Trush, Inc. and RMC Environmental 2007). Several aspects of the operational flow releases between WY1997 and WY2006 differ from the computed unimpaired annual hydrographs (Figure 2), including:

- Summer and fall baseflows (August 15 to September 30) are typically higher than natural, unimpaired flows due to minimum instream flows required under the 1987 Stipulation;
- Winter floods have been eliminated in almost all years (except in some extremely wet years), and winter maximum daily average flow values are typically only slightly higher than, or equivalent to, winter baseflows;
- Winter and early-Spring baseflows have decreased in magnitude;
- Snowmelt peaks have been reduced by 20% to 50% in extremely wet to normal years, and have been eliminated in dry and critically dry years. In addition, operations at O'Shaughnessy Dam have altered the snowmelt hydrograph in the following ways: (1) operational snowmelt hydrographs have a steep ramp-up, abruptly jumping from a baseflow release to a much higher release between mid-May and late-May, (2) the steep operational snowmelt recession limb is shorter and reaches the minimum streamflow release earlier than in the unregulated snowmelt hydrograph, (3) an abbreviated low-magnitude recession limb occurs in wetter years, and a gradual recession limb is largely eliminated in drier years, (4) the operational snowmelt peak streamflow is generally considerably less, though peak streamflow timing seems approximately unchanged, and (5) in many dry years, and all critically dry years, there is no operational snowmelt release hydrograph.

2.2 Previous instream flow studies

Two instream flow studies (but three analyses) have been made for the 12.1 miles of mainstem channel in the Hetch Hetchy reach. The initial USFWS study (1976) measured trout habitat in five representative riffles from stream transects in August/September 1968 and July 1970, using a methodology that assumes riffles are the primary flow-limited habitat for trout. Riffle area "useable" as trout habitat was defined as: (1) riffles with water depths greater than 0.3 ft and (2) water velocities between 0.5 ft/sec and 3.5 ft/sec when measured 0.3 ft from the streambed. The USFWS biologists conclude (USFWS 1976, p.8) that: "Where these physical parameters are met optimum conditions occur for trout spawning and rearing of young, as well as for streambed production of aquatic organisms on which trout feed." Depth and velocity measurements were taken at 8 streamflows: 36, 54, 75, 98, 125, 152, 190, and 211 cfs. Usable habitat was computed for each flow. This 1976 Report concludes: (1) A streamflow reduction from 211 cfs to 75 cfs amounted to a 40% loss of useable trout habitat, (2) because most of the stream channel is pool habitat, not riffle habitat, a 40% loss of riffle habitat "immediately affects the stream's capability to sustain its population of trout", (3) summer flow in excess of 100 cfs is essential for maintaining coldwater habitat close to Early Intake, and (4) the National Park Service (NPS) advocates 75 cfs in winter, a minimum of 150 cfs in summer, and 200 cfs in early summer for wet years to protect recreational and aesthetic values. The 1976 Report recommends a minimum instream flow release schedule for the calendar year of: 75 cfs from

January 1 to April 30, 200 cfs from May 1 to June 30, 150 cfs from July 1 to September 30, and 75 cfs from October 1 to December 31.

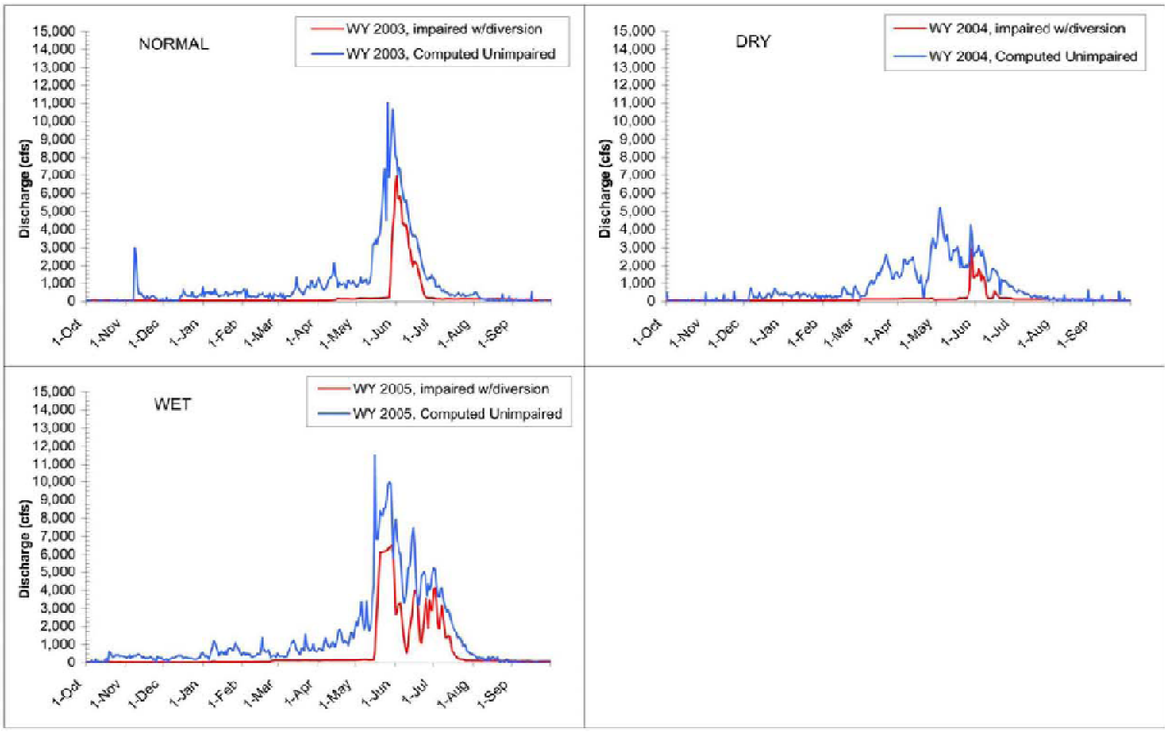


Figure 2. Examples of "impaired" and "unimpaired" hydrographs for normal, dry, and wet years on the Tuolumne River near O'Shaughnessy Dam (USGS Stn 11-276500) (McBain & Trush, Inc. and RMC Environmental 2007).

Another USFWS report with no date, but with a cover letter dated February 6, 1981, provides an additional analysis of the same measured riffle data in the 1976 Report by the USFWS Instream Flow Group (Office of Biological Services) using its instream flow habitat model. Rather than quantifying riffle habitat, as in the 1976 USFWS report, habitat for several rainbow trout life stages were assessed separately: adult, juvenile, fry, and spawning. In Figure 1 of this 1981 USFWS Report, rainbow trout spawning habitat abundance peaks at 125 cfs to 150 cfs, juvenile habitat peaks at approximately 150 cfs, and fry habitat plateaus between 75 cfs and 150 cfs. Adult rainbow trout habitat continues to rise past 200 cfs. No analysis was directed at determining a streamflow - habitat relationship for benthic macroinvertebrates, and no references are provided on how trout habitat was modeled from the 1968 and 1970 transect data.

The USFWS initiated another instream flow investigation, beginning 1988, using PHABSIM for brown trout and rainbow trout juvenile and adult habitat (USFWS 1992). The weighted useable area streamflow relationships for rainbow trout adult habitat reached an asymptote at approximately 100 cfs, while juvenile habitat dropped steeply to approximately 100 cfs before flattening-out. An annual flow allocation of 59,207 ac-ft to 75,363 ac-ft was recommended. Three instream flow schedules were provided "because of the uncertainty of sustaining appropriate water temperatures during the summer and winter months under the recommended flows."

A subsequent analysis by Moyle and Marchetti (1992) on behalf of the San Francisco Public Utilities Commission investigated the potential temperature-related effects on fish assemblages and their distribution in the Hetch Hetchy reach resulting from implementation of the USFWS recommended flow schedule. Moyle and Marchetti hypothesized that (1) brown trout would become dominant over rainbow trout in the downstream-most reach from Preston Falls to Early Intake due to increased flow and therefore decreased water temperatures, (2) Sacramento sucker and California roach numbers would decrease or potentially be eliminated from entire reach due to consistently cool water temperatures, (3) riffle sculpin would probably increase or maintain population densities as a result of reduced water temperatures, and (4) catchable trout numbers would decrease in the uppermost sections of the reach due to colder summer and fall temperatures that would decrease growth rates and possibly survival of juveniles. In summary, Moyle and Marchetti (1992) believed that the flow recommendations would improve the brown trout fishery in the lowermost sections of the reach and reduce the rainbow trout fishery in the upper section. Populations of rainbow trout and other native nongame fish species would decline as the brown trout fish community became dominant.

3 Flow evaluation: approach and initial study plan

No single analytical strategy or field methodology can effectively assess the role of instream flows in sustaining the diversity of habitats present in the Hetch Hetchy reach. To develop and implement the best instream flow study possible, near-term work will evaluate past studies, identify key ecological processes, describe channel complexity, and collaboratively construct an analytical framework for recommending instream flows. Pending results of the initial studies outlined below, additional field investigations and quantification of the roles instream flows have in sustaining an ecologically diverse mainstem Tuolumne River may be conducted.

3.1 Fish and wildlife surveys

Limited information exists regarding the presence, distribution, and condition of wildlife in the Upper Tuolumne River corridor. The majority of existing studies focus on trout and other fish species. Ongoing and planned studies will update and broaden our knowledge of fish and other wildlife, including selected amphibian, reptile, bird, and benthic macroinvertebrate species, will help inform flow-related studies (see Section 3.2), and will provide baseline data for potential future monitoring and adaptive management (Section 3.5.3).

3.1.1 Amphibian and reptile surveys (summer 2008 through fall 2010)

SFPUC, NPS, and USFS staff have been conducted collaborative surveys for amphibians and reptiles in the Hetch Hetchy Reach since 2008. Surveys have been conducted in the reach from O'Shaughnessy Dam downstream through the Poopenaut Valley, and from Preston Falls downstream to Early Intake. These studies will be continued through 2010. Target species may include western pond turtle, bullfrog, yellow legged frog, pacific tree frog, western fence lizard, and garter snake. At least three surveys will be conducted each year: pre-snowmelt release (late April/early May), post-snowmelt release in early summer (late June/early July), late summer (August), and potentially fall (September). A more detailed study plan is currently under development for amphibian and reptile surveys to be conducted in 2009.

3.1.2 Fish surveys (summer 2007 through summer 2009)

Snorkel surveys have been conducted since 2007 at twelve study sites within the Hetch Hetchy reach (Figure 3 and Table 1). The following sites have been surveyed in the past, and will be surveyed in 2009: four sites within the Early Intake subreach, three sites within the Preston Falls subreach, two sites within the Poopenaut Valley subreach, and three sites within the

O'Shaughnessy subreach. A total of five divers will conduct a three-pass method to estimate fish abundance, species, and length. Focal species include rainbow trout (*Oncorhychus mykiss*), brown trout (*Salmo trutta*), Sacramento sucker (*Catostomus occidentalis*), riffle sculpin (*Cottus bairdii gulosis*), and California roach (*Lavinia symmetricus*). A detailed study plan is currently under development for fishery surveys in fall 2009 and 2010; the study plan development process may result in changes to sites and methods described above.

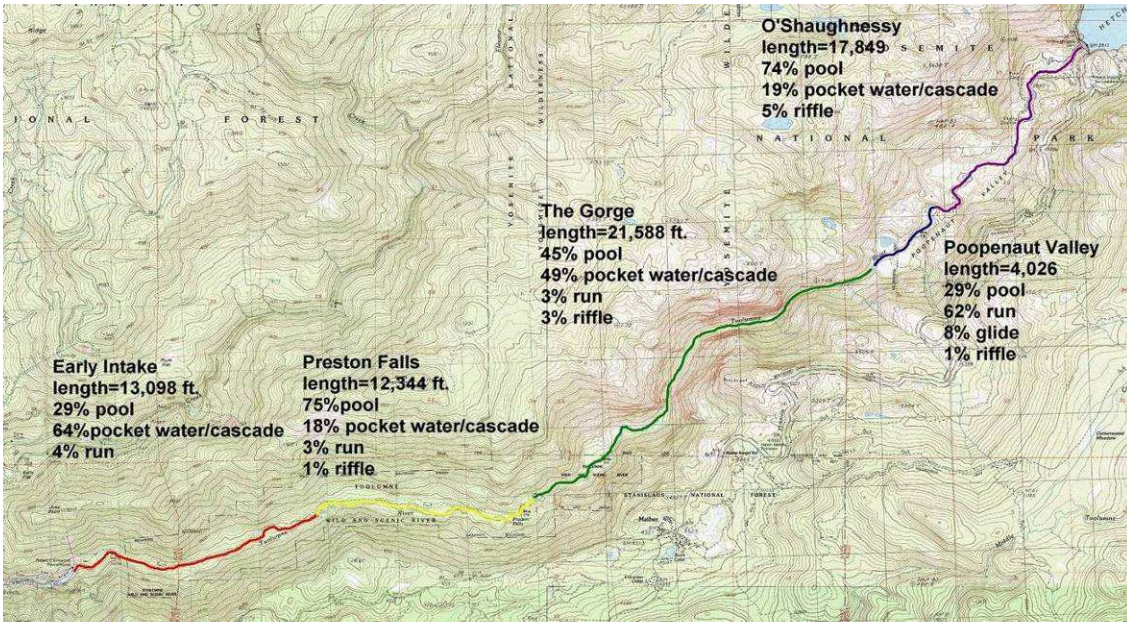


Figure 3. Hetch Hetchy Reach map, showing fish survey mesohabitats for each entire subreach. Fish surveys conducted in portions of all subreaches except for the Gorge reach. Mesohabitat proportions included in the fish surveys are shown in Table 1. The mesohabitat classification used for the fish surveys is different than that used in USFWS (1992).

	Subreach name				
Mesohabitat in the fish survey portion of each subreach	**Early Intake**	**Preston Falls**	**Gorge**	**Poopenaut Valley**	**O'Shaughnessy**
Pool	30%	47%	N/A	61%	63%
Pocket water/cascade	44%	0%	N/A	0%	0%
Run/riffle/glide	26%	53%	N/A	39%	37%
Total length of subreach	13,098 ft	12,344 ft	21,588 ft	4,026 ft	17,849 ft
% of total subreach snorkeled	14%	9%	0%	41%	8%
Length of subreach snorkeled	1,830 ft	1,110 ft	0 ft	1,650 ft	1,425 ft

Table 1. Summary of mesohabitats within the mapping unit for each subreach within the Hetch Hetchy Reach map. Note that pocket water and steeper boulder riffles/glides/pools are considered equivalent mesohabitats.

3.1.3 Avian surveys (spring 2007 through spring 2010)

The NPS is conducting standardized area search surveys and point count surveys to estimate baseline bird community species abundance, composition, and habitat use in Poopenaut Valley wet meadow and montane riparian habitats as part of the NPS Looking Downstream Project. Area searches are conducted in five distinct areas, each comprising approximately 3 hectares. In 2008, there were two point count locations, one on either side of the river in Poopenaut Valley. Standardized point count protocols for monitoring landbirds (Ralph et al. 1993, Nur et al. 1999) are used. Use of standardized methods will allow data to be compared among point count survey results in subsequent years, as well as in areas outside of Poopenaut Valley.

3.1.4 Benthic macroinvertebrate surveys (summer 2007 through fall 2010)

Scientists from the University of California White Mountain Research Station, in collaboration with the NPS and the SFPUC, are collecting baseline data on the benthic macroinvertebrate (BMI) assemblages in the Upper Tuolumne River corridor between O'Shaughnessy Dam and the downstream end of Poopenaut Valley as part of the NPS Looking Downstream Project. The goal is to develop an understanding of current riffle BMI assemblage structure in this reach. To this end, spatially and temporally extensive sampling protocols have been designed to capture year-round variability and to include as many taxa as possible. These baseline studies may be expanded to include study sites in the Early Intake Reach.

3.2 Flow-habitat relationship studies

There has been considerable discussion in the scientific literature of the strengths and weaknesses of various method(s) in developing flow-habitat relationships for aquatic species, and a wide range of methods are currently in use today.

The SFPUC proposes to apply a variety of methods based on the strengths of those methods and use the results to paint a more complete picture of how flow releases translate into ecological benefits. A combination of Microhabitat Mapping, 2-D Habitat Modeling, transect-based evaluations, and temperature monitoring and modeling will be used.

3.2.1 Proposed focal species and habitat suitability criteria

We propose to analyze habitat-flow relationships for rainbow trout, Sacramento sucker, foothill yellow-legged frog, and benthic macroinvertebrates. Habitat suitability criteria (HSC) for these focal species were developed based on review and synthesis of PG&E (2003), USFWS (2004), USFWS (2006), USFWS (2008), and Lind and Yarnell (2008). We also propose to focus analysis of rainbow trout habitat on the adult life stage because resident salmonid populations typically are limited by their adult habitat, given that the species is relatively long-lived (Elliot and Hurley 1998, Morita and Yokota 2002).

Microhabitat Mapping and 2-D Habitat Modeling will focus on adult rainbow trout, foothill yellow-legged frog, and benthic macroinvertebrates. Binary HSC will be used for the Microhabitat Mapping and 2-D Habitat Modeling to allow comparisons. The binary criteria were selected based on habitat suitability values ≥ 0.75 (Table 2). The resulting HSC for adult rainbow trout may include additional criteria (in addition to depth and average velocity), based on research into critical adult habitat components such as specific velocities in the water column, vertical and lateral shear zones, and cover specific to holding and foraging requirements. Snorkel surveys and remote observations via underwater camera are proposed to observe trout habitat use in at least one pool to determine if these additional HSC refinements are warranted.

The transect-based, reconnaissance-level habitat evaluation in the long backwater reaches will focus on Sacramento sucker and western pond turtle habitat in 2009 (see Section 3.2.3), with greater habitat quantification in 2010 if warranted. The binary HSC for Sacramento sucker shown in Table 2 will be used and HSC for western pond turtle are currently being developed from regional field observations and the literature.

Species	Life stage	Parameter	Criteria
Rainbow trout	Adult	Depth	2.4 – 16.6 ft
		Velocity	0.68 – 1.68 ft/s
Sacramento sucker	Adult	Depth	≥3.5 ft
		Velocity	1.27 – 1.62 ft/s
	Juvenile	Depth	1.95 – 2.9 ft
		Velocity	0.06 – 0.65 ft/s
	Fry	Depth	0.9 – 1.5 ft
		Velocity	0 – 0.24 ft/s
Foothill yellow-legged frog	Egg mass	Depth	0.20 – 1.5 ft
		Velocity	0.0 – 0.30 ft/s
	Tadpole	Depth	.07 – 1.4 ft
		Velocity	0.0 – 0.11 ft/s
	All	Substrate	Gravel-boulder
Benthic Macroinvertebrates	All	Depth	1.1 – 3.2 ft
		Velocity	1.1 – 3.3 ft/s
		Substrate	Large cobble 6 – 8 in, 8 – 10 in, 10 – 12 in
Western pond turtle	Adult	Velocity	Under development

Table 2. Proposed habitat suitability criteria for rainbow trout, Sacramento sucker, foothill yellow-legged frog, and benthic macroinvertebrates.

3.2.2 Microhabitat Mapping and 2-D Habitat Modeling (summer 2009 and 2010)

We propose to use Microhabitat Mapping as the foundation for quantifying habitat-flow relationships because (1) it can reliably estimate habitat under complex hydraulic conditions typical of the Upper Tuolumne River mainstem and (2) it can economically quantify habitat over a substantial channel length. We also propose to conduct 2-D Habitat Modeling to support the Microhabitat Mapping. A 2-D model would be constructed for a subreach (e.g., pool/glide/tailout) within the Early Intake Microhabitat Mapping site as a pilot to explore the feasibility of using 2-D Habitat Modeling in a typical complex channel morphology within the Hetch Hetchy Reach. The 2-D Habitat Modeling will be compared (1) to depths and velocities measured at several flows within the study site and (2) to the microhabitat mapped polygons for the same flows.

We propose to conduct the Microhabitat Mapping and 2-D Habitat Modeling in close collaboration with the USFWS. While the Microhabitat Mapping will be the foundation of the flow-habitat relationships based on its strengths in complex channels, the SFPUC and USFWS will collaboratively review preliminary results of both the Microhabitat Mapping and 2-D Habitat Modeling and collectively develop recommendations for additional data needs to support final Instream Flow recommendations. Results from the 2-D Habitat Modeling may be used to: (1) support Microhabitat Mapping results by providing a comparison with established 2-D Habitat Modeling approaches, (2) confirm that Microhabitat Mapping can effectively evaluate habitat-flow relationships, and (3) if needed, to interpolate between or extrapolate beyond data points gathered from the Microhabitat Mapping effort.

3.2.2.1 Microhabitat Mapping methods

Microhabitat Mapping is a useful method to quantify flow-habitat relationships in riverine environments where 1-D and 2-D hydraulic modeling is challenged to accurately predict the complex hydraulics in steep bedrock/boulder channels. Most portions of the Hetch Hetchy Reach are steep, confined, and complex; thus, Microhabitat Mapping is a useful tool to evaluate habitat under these conditions.

Acknowledging that accuracy and precision are important considerations for any scientific study, we identified four general sources of potential uncertainty associated with Microhabitat Mapping:

1. Selection or development of habitat suitability criteria (accuracy);
2. Delineating boundaries for individual habitat polygons (precision);
3. Translating those located points onto a map or computer (precision);
4. Extrapolating curves from study site to river reach scales, without quantifying reach-wide habitat variability (accuracy and precision).

Selecting or developing habitat suitability criteria is probably the most critical type of uncertainty. Application of habitat suitability criteria that poorly represent actual habitat utilization will lead to inaccurate habitat-flow curves. This is a potentially significant source of uncertainty common to all methods that utilize habitat suitability criteria. Other issues associated with conventional habitat suitability criteria have been described in the scientific literature (e.g., correlation among habitat variables, the requirement of estimating habitat variables in a fully seeded system, and the assumption that higher quality habitat supports higher density of fish, among others) (also see Bovee 1986, Bovee et al 1998, others). The habitat suitability criteria listed below (Table 2) represents our recommended synthesis from other field-based studies.

The second source of uncertainty is the crux of the lack-of-precision issue associated with Microhabitat Mapping. Microhabitat Mapping methods that employ criteria as general guidelines that are tempered with professional judgment are likely less reproducible, because different professionals may interpret 'what is habitat' in different ways based on their own set of experiences. If mapping methods adhere strictly to measured values to identify habitat area boundaries, then this uncertainty is avoided and the method is presumably rendered more reproducible and, potentially, more precise.

A core team of four field biologists will be formed prior to field mapping. The core mapping team should be professional fisheries scientists with field experience observing habitat utilization for one or more targeted species. The mapping team will conduct a field calibration session to orient everyone to field conditions and the habitat suitability criteria. At least two core team biologists should be present at each Microhabitat Mapping event. The mapping team will first visually identify habitat based on the habitat suitability criteria, then using a Marsh-McBirney flow meter on a topset wading rod, the mapping team will identify and survey the specific habitat boundaries based on depth, velocity, substrate, and cover criteria listed in Table 2. This approach combines the strengths of field biologists training with the reproducibility gained by measuring polygon boundaries.

The third source of uncertainty, translating habitat boundary points onto a map or into digital format, is a technological issue. This source of uncertainty can be overcome either by obtaining higher resolution aerial photographs to map habitat in the field (i.e., increasing the practitioner's ability to visually identify reference points on the aerial photo), or by using 3-dimensional survey techniques such as a total-station or GPS equipment. The SFPUC proposes that the primary Microhabitat Mapping method utilize GPS. Habitat polygons will be mapped using a Trimble GeoXH GPS receiver and digital range finder compass. This methodology requires two field personnel: one field biologist to verify the habitat suitability criteria and determine habitat polygon location, and another to operate the GPS, tablet PC, and range finder compass.

The Trimble GeoXH GPS receiver with Zephyr antennae is capable of producing sub-decimeter real time positioning. The field biologist measuring habitat suitability criteria will locate points along the polygon boundary with a rangefinder compass. Each point location on a habitat polygon boundary is then visible in the Terrasync Pro software. Using orthorectified imagery as a backdrop, the operator can determine if a point's location is correct or not. Each point is then attributed with habitat type (species and life history stage). All points determining the boundary of habitat polygon are then brought into GIS software from which polygon area is computed. This approach is identical to that used by the USFWS to develop flow-habitat relationships on the Trinity River (Chamberlin et al 2007). As a backup in the event of equipment malfunction or interruptions in satellite coverage, mapping on high quality aerial photographs will be conducted. Low altitude, high quality air photos were obtained for the Hetch Hetchy Reach in 2007, orthorectified, and plotted at a large scale suitable for field mapping.

The fourth source of uncertainty results from reliance on precision in measurement at the site scale at the expense of the accuracy in assessing habitat variability over longer reach scales. For example, mapping methods may strictly adhere to measured criteria to identify habitat boundaries, and thus achieve a high level of precision. But the effort required to attain this precision is often achieved at the expense of a broader reach-wide assessment to quantify habitat variability over larger spatial scales. Uncertainty associated with extrapolation from study site to reach scale is rarely addressed in instream flow modeling or criteria mapping approaches. For this study, it will be possible to quantify variance based on the inclusion of multiple hydraulic units and several mesohabitat types. It will also be determined if a stratified sampling approach, where the strata are mesohabitat types (i.e., pocket water, deep pools, shallow pools), will improve or magnify this potential variation. Microhabitat Mapping should improve the accuracy of flow-habitat relationships by incorporating a substantial length of the entire Hetch Hetchy Reach and thus measure more habitat variability within its boundaries.

For summer 2009, we propose Microhabitat Mapping at seven flows: 35 cfs, 60 cfs, 80 cfs, 100 cfs, 125 cfs, 150 cfs, and 200 cfs (Figure 4). The core mapping team will typically be split into two teams, with one team mapping at the longer Early Intake site, and the other team mapping at O'Shaughnessy Dam and Albino Rock sites in parallel. Typically, two flow-habitat data points will be collected. With the exception of the first mapping flow (80 cfs), each mapping period shown in Figure 4 will have either a 2-day or 4-day bench per flow, such that each mapping period will be four or eight days.

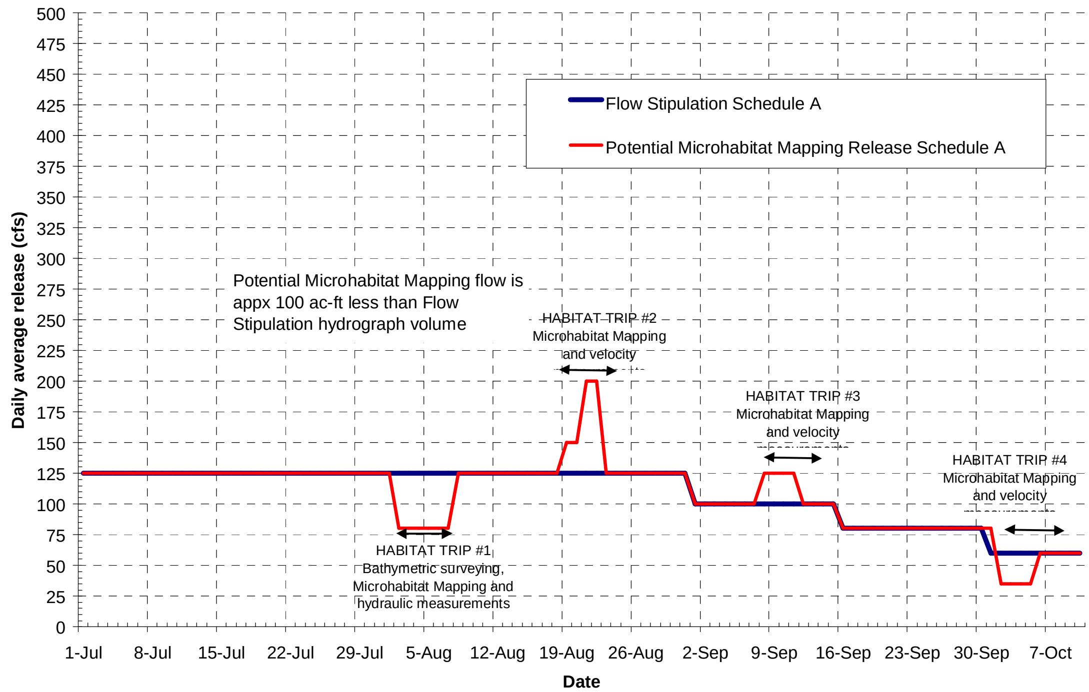


Figure 4. Proposed summer 2009 release schedule for microhabitat data collection and hydraulic model calibration in the Hetch Hetchy Reach.

The 80 cfs bench has a 6-day duration to accommodate bathymetric surveys and hydraulic measurements. After the first three mapping periods, the Microhabitat Mapping data will be reduced/digitized, and initial flow-habitat curves developed for each site. Results of this initial data reduction will inform the specific release schedule for the last mapping period (i.e., gather data at the lowest flows, add resolution between points gathered in the first two mapping periods). Data gathering in 2010 will further refine or extend curves (if needed).

3.2.2.2 2-D Habitat Modeling methods

Two dimensional hydraulic and habitat modeling is proposed at a subsite within the Early Intake Study Site. The Multi-Dimensional Surface Water Modeling System (MD-SWMS) developed by the US Geological Survey will be used to predict 2-D hydraulic (depths and velocities) parameters at the subsite described below in an appropriately spaced grid, and when combined with substrate information and cover, each node will be compared to the binary habitat suitability criteria (Table 2) to determine whether the node can be classified as habitat. Running the hydraulic model will require high quality topographic information and roughness estimates through the site, and computing habitat will require substrate and cover information. Water surface elevations through each site will be collected during the flow release shown in Figure 4 to help calibrate the hydraulic model, and roughness patches will be mapped on the low-altitude aerial photographs. Additionally, depths and velocities will be measured at the upstream and downstream boundaries of the 2-D Habitat Modeling subsite at each flow to assist with model calibration.

Topographic data will be collected to an elevation greater than or equal to the 1,000 cfs water surface elevation using a combination of total station, RTK GPS, and echo-sounder techniques. Topographic data will be collected at the lowest flow possible to increase efficiency and improve data quality. In areas that contain water depths greater than 3.0 ft, we will utilize the Navisound 110 200 kHz single-beam echo sounder with integrated RTK GPS. The echo-sounder with integrated RTK GPS will be deployed from a small 8-ft cataraft. The cataraft will be maneuvered by two crew members using ropes, and the bathymetric data will be collected using a 3-ft by 3-ft grid pattern. Crew members will be stationed on opposite banks and the cataraft will be slowly pulled from bank to bank. Wadeable topography in areas shallower than 3.0 ft will be collected by a total station survey. Wadeable topographic data will be collected with sufficient density to produce a 1-ft contour interval map. Topographic data collection will focus on defining topographic breaklines and other features such as large boulders and woody debris that will significantly affect model calibration and performance. Features that typically affect model performance and calibration include objects that are large enough to cause ineffective flow areas or that cause topographic steering. In wadeable areas that do not exhibit a large amount of topographic relief and where no obvious break lines exist, data will be collected using a 3-ft by 3-ft grid pattern.

The MD-SWMS model and habitat computations will be run for the range of 2009 releases, as well as for several flows up to 1,000 cfs. Model development and calibration will be conducted collaboratively with USFWS. Depths and velocities will be measured at the 2-D Habitat Modeling subsite at the first flow release (80 cfs) within the Early Intake Study Site to validate hydraulic predictions from the model, and will enable comparison of Microhabitat Mapping boundaries with more detailed depths and velocity measurements.

3.2.2.3 Proposed study sites

Rather than relying on traditional mesohabitat units to stratify channels, hydraulic units provide a more geomorphically and ecologically grounded stratification strategy. A hydraulic unit is a reach of channel with a common hydraulic setting, such as a half a meander wavelength (a single pool-riffle sequence). Proposed sampling reaches each include 3 to 4 hydraulic units. A typical meander wavelength, comprised of two channel bends and therefore two hydraulic units, will have a channel length often varying from 7 to 10 bankfull widths. Assuming a bankfull width of approximately 175 ft, the study site lengths should be at least 1,800 ft in the absence of a major hydraulic control that could extend the unit length.

Three study sites are proposed to characterize flow-habitat relationships in the Hetch Hetchy Reach (Figure 1, Figure 5-7). These sites attempt to capture boulder riffles/pools/glides that provide high quality habitat for the target species, and are cumulatively long to incorporate the wide variety of mesohabitats observed throughout the reach. Two of the study sites chosen reflect habitat conditions downstream of the gorge and Preston Falls; one study site was located to reflect habitat conditions upstream of Poopenaut Valley. As mentioned above, the low gradient, sand-bedded reaches are not included as a flow-habitat study site, but will be assessed via other methods (water temperatures, inundation thresholds, riparian objectives, etc.). The Early Intake Study Site will also have an approximately 1,000 ft long 2-D Habitat Modeling reach embedded within the site, encompassing a range of geomorphic units and mesohabitats (two pools, riffle/pocketwater, glide, etc). The precise upstream and downstream boundaries will be defined in the field based on hydraulic characteristics required by the hydraulic model. The three proposed study sites are:

Early Intake Study Site:

- Microhabitat Mapping from STN 1460+00 to 1488+50 (2,850 ft)
- 2-D Habitat Modeling from STN 1476+50 to 1486+20 (970 ft)

Albino Rock Study Site:

- Microhabitat Mapping from STN 1517+00 to 1529+50 (1,250 ft)

O'Shaughnessy Dam Bridge Study Site:

- Microhabitat Mapping from STN 2074+00 to 2085+00 (1,100 ft)

TOTALS:

- Total Hetch Hetchy Reach Length = 66,000 ft
- Total Microhabitat Mapping length= 5,200 ft (8% of total Hetch Hetchy Reach length)
- Total 2-D Habitat Modeling length= 970 ft (1.5% of total Hetch Hetchy Reach length)

3.2.3 Transect-based evaluations (summer 2009 through 2010)

A set of transect-based habitat evaluations will be conducted to 1) evaluate whether Sacramento sucker and western pond turtle habitat in the long backwater reaches is sensitive to flow magnitude, and 2) assess foothill yellow-legged frog egg mass scour and desiccation risk under different flow scenarios. The long, flat sand bedded sections of the Hetch Hetchy Reach are important for Sacramento sucker and western pond turtle, yet habitat for these species is likely insensitive to changes in flow in the 30-200 cfs range, and is possibly more sensitive to temperature than hydraulic conditions. Therefore, a transect-based, reconnaissance-level assessment of hydraulic conditions is proposed in these lower-gradient subreaches in summer 2009. This methodology will be refined or ended in 2010 based on results of this reconnaissance analysis. We propose to install three transects in these low gradient backwater areas near RM 168, and measure water depths and velocities across the channel during the summer 2009 flow release benches in order to relate to habitat suitability criteria for Sacramento sucker and western pond turtle.

A pilot transect-based risk assessment will be performed at cross section 1484+70 at the Early Intake study site (Figure 5) and cross section 1522+20 at the Albino Rock study site (Figure 6) to assess the role of flow fluctuation and magnitude on foothill yellow-legged frog egg desiccation and scour under different flow alternatives. At each of the seven flow benches shown in Figure 4, depths and velocities will be measured at 1-2 ft increments on the right bank channel margins in suitable habitat for foothill yellow-legged frog egg masses and tadpole rearing areas (coarse substrate and water depths less than 1.5 ft). Thermistors were also established along the channel margins at each cross section to assess lateral thermal diversity. Velocity measurements, water stage elevations, and water temperature data will be integrated to help assess egg mass scour risk, desiccation risk, development rates, and hatching timing as a function of flow release from O'Shaughnessy Dam.

3.2.4 Associating riparian vegetation to avian species (summer 2009)

The SFPUC will collaborate with NPS to link existing avian habitat conditions to historical flow regimes and facilitate an understanding of how future flow conditions may affect avian habitat. Vegetation patch types at the Microhabitat Mapping study sites will be associated with habitat characteristics used by focal bird species. Patch type polygons will then be digitized into a GIS to determine specific areas of habitats available, and then assign that patch type to each focal bird species. Current vegetation patterns and the associated attributes will describe how contemporary conditions may have changed historical riparian vegetation conditions and what changes in habitat attributes could be expected with future instream flows. Based on peer review, a list of selected focal bird species will be adopted for associating preferable vegetation attributes to riparian vegetation (RHJV 2004). One reference study reach may be established either above Hetch Hetchy Reservoir or on the Merced River in Yosemite Valley, to describe relatively undisturbed riparian vegetation and associated focal bird species.

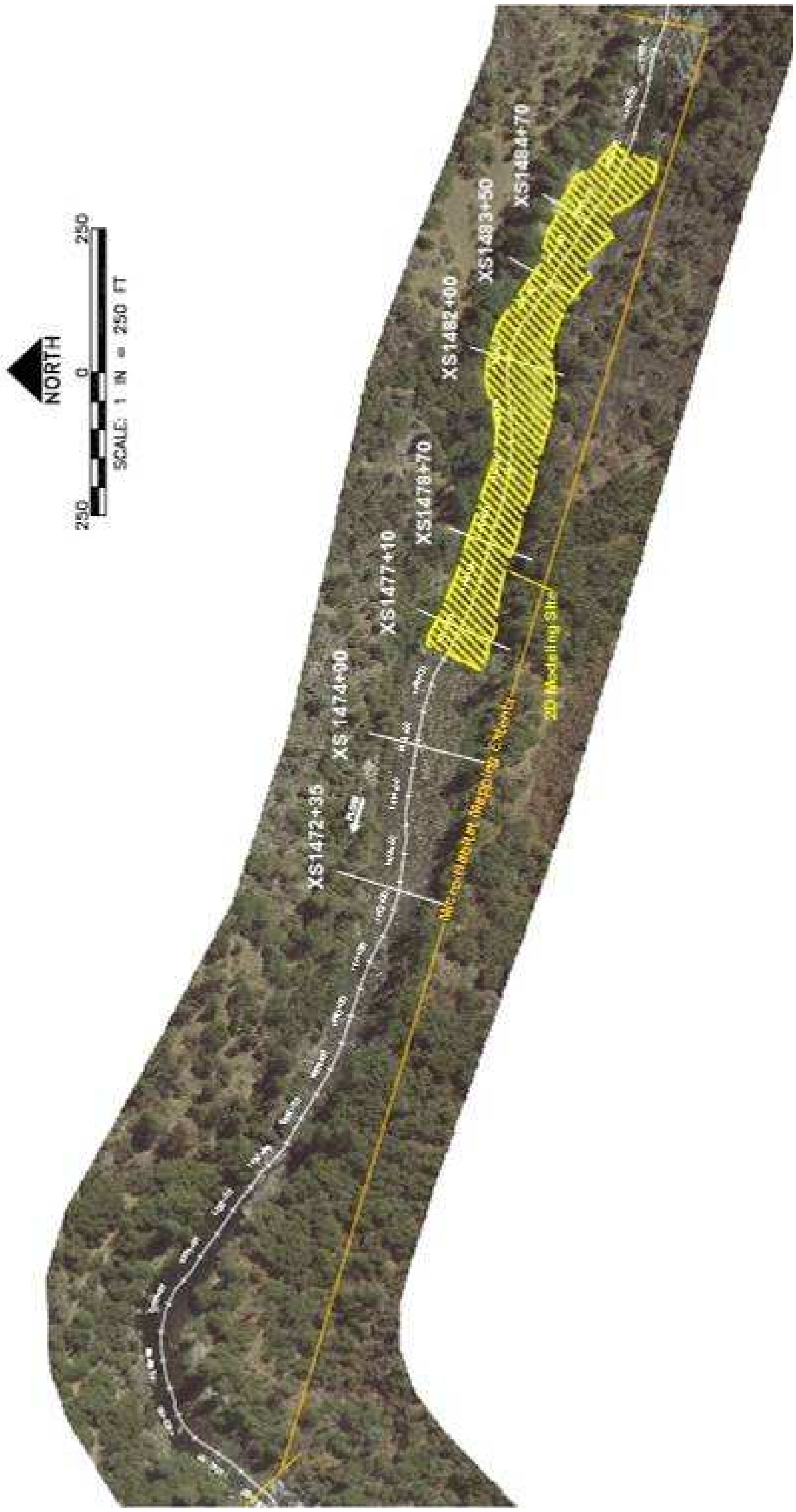


Figure 5. Proposed Microhabitat Mapping and 2-D Habitat Modeling at the Early Intake Study Site.

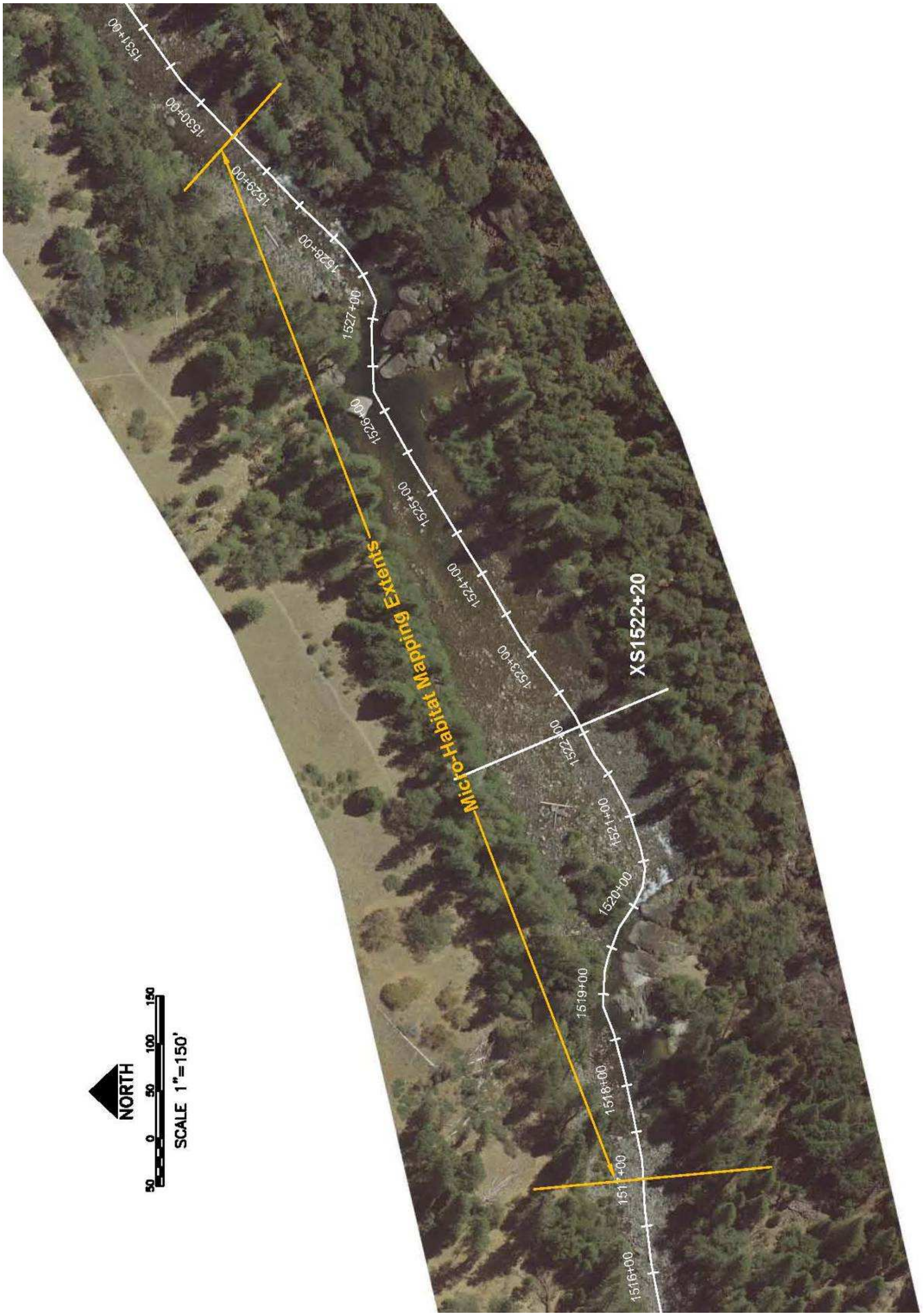


Figure 6. Proposed Microhabitat Mapping at the Albino Rock Study Site.

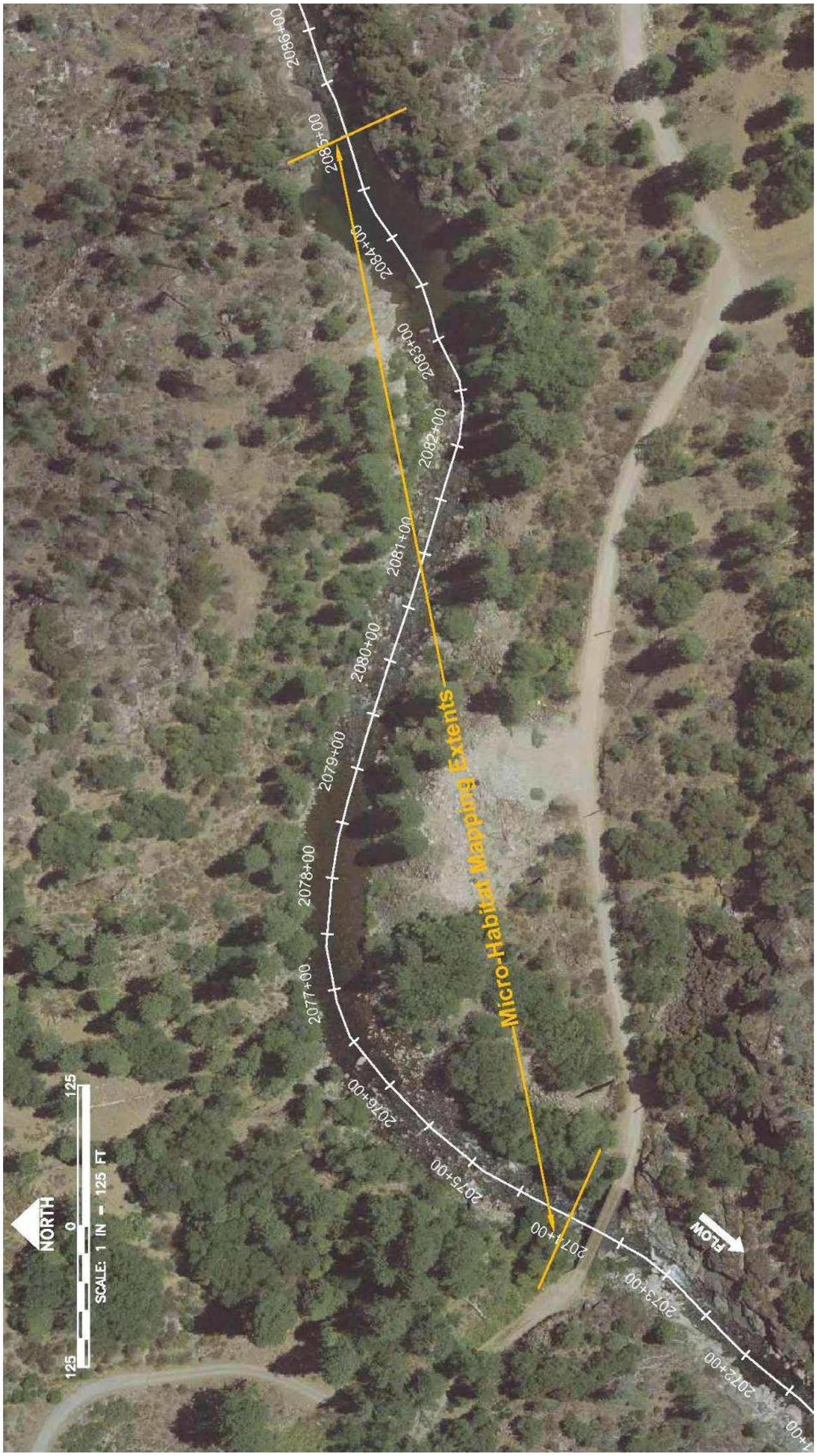


Figure 7. Proposed Microhabitat Mapping at the O'Shaughnessy Dam Study Site.

3.2.4 Photo documentation of streamflows (summer 2008 – spring 2009)

The SFPUC will systematically photograph extensive mosaics from the lowest baseflows up to 6,500 cfs (ideally 8 to 10 streamflows) at specific mesohabitat types for chosen focal species and life stages. These photo mosaics can be reviewed by stakeholders and contrasted with the data collected and analyzed in all the previous tasks to help decide whether, and to what extent, additional habitat quantification would be warranted to adequately characterize the mainstem channel, establish good habitat – streamflow relationships, and to illustrate geomorphic/riparian processes.

3.3 Water temperature monitoring and modeling

Flow-habitat relationships described in Section 3.2 only address whether the physical habitat is present for a range of flows. Yet if water temperatures are unsuitable, then the physical habitat is not available. Temperature is going to be a very important driver given that the reach below Preston Falls is sensitive to thermal warming.

3.3.1 Characterize pool stratification and lateral thermal diversity (spring/summer 2009)

The SFPUC will measure thermal stratification and identify thermal refugia in 3 to 5 deep pools over a range of low baseflows from Lower Preston Falls downstream to Early Intake. Physical adult rainbow trout habitat may be abundant over the range of streamflows being investigated, but high water temperatures from mid-summer into early fall could reduce habitat availability. Under low unregulated baseflows, thermally stratified pools likely provided refuge for trout in drier runoff years when baseflows would presumably be lower and warmer than during wetter runoff years. In certain reaches during certain seasonal periods, the hypolimnial releases from O'Shaughnessy Dam result in colder water temperatures than naturally occurred, which may have affected the physiology and/or life history trends of amphibians and reptiles. Channel margins, side channels, and poorly mixing areas of large pools may provide thermal diversity (warming) that could be important refugia for certain species. At least twelve thermistors will be placed in a variety of habitats in the Early Intake reach to evaluate the degree of thermal diversity in spring and summer 2009. In addition, a grid-based approach will be used to locate any cold-water thermal refugia in sampled pools.

3.3.2 Develop water temperature model (summer 2009)

A water temperature model for the Tuolumne River mainstem will be developed by the SFPUC for the Hetch Hetchy reach. Water temperature is a key physical variable determining whether the presence of physical habitat on any given day of the annual hydrograph should be considered good habitat or even useable habitat for a particular species and life stage. A water temperature model will be required to predict the annual thermograph on a daily time-step for any given annual hydrograph, a necessary step in for assessing habitat availability. The instream flow assessment needs to estimate the annual thermograph (with daily average and daily maximum water temperatures) at different locations from O'Shaughnessy Dam downstream to Early Intake under: (1) instream flow releases for the annual hydrographs of WY1990 through WY2006 (data measurements, rather than modeled water temperatures, are available and are being collected), (2) different proposed instream flow releases (i.e., if different instream flow releases had been made to the WY1990 through WY2006 annual hydrographs, what would have been their respective annual thermographs), and (3) the computed unregulated annual hydrographs (and therefore not the hypolimnial releases) from WY1990 through WY2006. The last need will be important for determining the range and seasonality of water temperatures aquatic species historically once experienced. None of these modeled annual thermographs will be useful unless directly related to the aquatic species being evaluated. The results from the water temperature model will require species-specific water temperature thresholds before they can be used to evaluate habitat suitability for the various life stages of the target species. Upper and lower thresholds for selected species and life stages will be reviewed from the scientific literature and thermal thresholds proposed for the Tuolumne River.

3.4 Geomorphology and riparian vegetation dynamics

3.4.1 Quantification of fluvial geomorphic processes (winter 2007 – spring 2009)

Fluvial geomorphic process investigations at the USGS gauging station below O'Shaughnessy Dam, in Poopenaut Valley, and from Lower Preston Falls downstream to Early Intake will be conducted by the SFPUC, in collaboration with the NPS. The overall goal will be to associate depositional features with habitat (from several tasks above) and estimate the threshold of high snowmelt or rainfall flood peaks necessary to mobilize and maintain these features. Depositional features (e.g., sand matrix between cobbles and boulders, lee deposits, obstruction deposits, point bars, and others) will first be stratified into nested hydraulic features following McBain and Trush (2007). Bed mobility of depositional surfaces with larger particle sizes, as well as riparian vegetation scour, will be documented over the site using pre- and post-high flow photography. Bed mobility and scour of depositional surfaces will also be documented at a cross section scale by placing tracer rocks and scour cores/chains in each feature and monitoring change before and after high flow events. In some cases, hydraulic and bed mobility modeling may be necessary. At least one reference study reach should be considered either above Hetch Hetchy Reservoir, and/or on the Merced River in Yosemite Valley, to investigate depositional feature morphology and geomorphic processes under unregulated annual hydrographs.

Backwater pool function will be investigated, both hydraulically and as to how their function depends on the annual hydrograph. Poopenaut Valley is the prominent backwater feature, but there are many smaller Poopenaut-like backwaters and other types of more confined but long backwater pools (more like deep runs) as immediately downstream of Lower Preston Falls. Annual flow releases from O'Shaughnessy Dam appear to have sustained these features, but different responses to future instream flows should be anticipated. For example, the long backwater run below Lower Preston Falls has at least two subtle nested hydraulic controls that, if altered, would change riparian and amphibian habitat availability and quality.

3.4.2 Woody riparian field studies (spring 2008 – spring 2009)

The SFPUC will establish 3 mainstem depositional sites to monitor/model woody riparian seedling germination and establishment, as well as consider the possibility of reversing conifer encroachment. Changes in the frequency of small floods (i.e., less than 5-yr pre-dam peak discharge) could be the driving mechanism for this vegetative encroachment. This should begin by collecting hydraulic data at the three sites, then combining this data with seed dispersal and growth data in a recruitment/scour model. This will require periodicity tables for seed release of the willow species among other potential species. Where appropriate, the TARGETS riparian initiation prediction model will be applied to certain cross sections and surfaces to evaluate how certain annual hydrographs (historical, contemporary, and potential future) encourage or discourage natural riparian initiation and establishment. On floodplains, examine whether almost continuous 800 cfs releases at O'Shaughnessy Dam from 1925 to 1967 (prior to completion of Canyon Tunnel) have left their riparian signature on the floodplain, and assess whether more recent diversion operations beginning WY1988 (diversion capacity changed from 670 cfs to 1,400 cfs) and WY1997 flood also left unique riparian signatures. Limited tree coring will be conducted to estimate tree ages.

3.4.3 Poopenaut Valley pond and wetland field studies (spring 2008 – spring 2009)

As part of the Upper Tuolumne River Ecosystem Project and the NPS Looking Downstream Project, the NPS is leading a collaborative effort to characterize ecosystem dynamics in the Poopenaut Valley area, focusing on how flow in the mainstem Tuolumne River and tributaries affects physical habitat in the seasonal wetland on the north side of the river. Specific study elements include continued investigations into: (1) surface, groundwater, and wetland dynamics, (2) relationships between hydrology and vegetation, and (3) key riparian tree species life history timing.

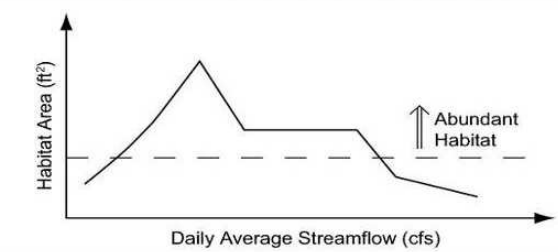
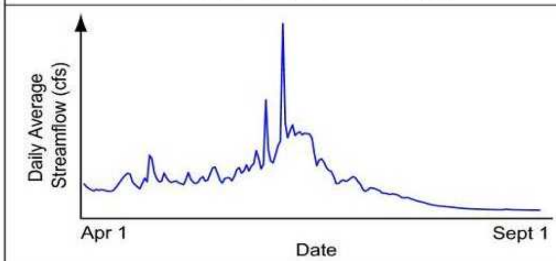
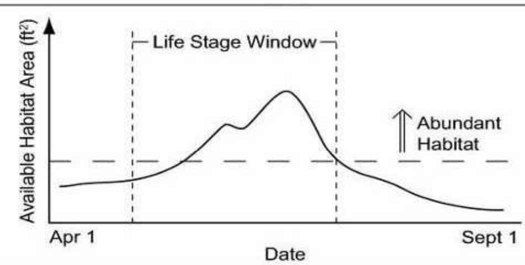
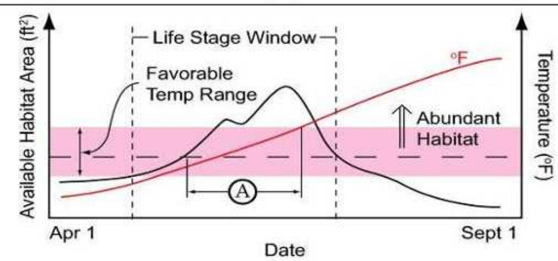
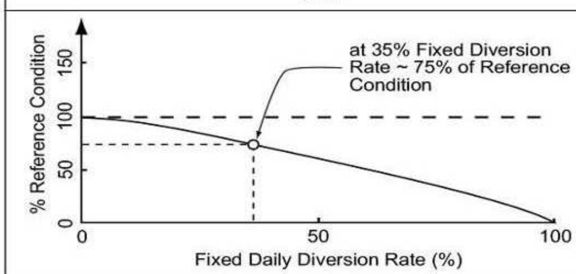
The SFPUC will coordinate with NPS and USFWS to formulate a limnological (i.e., water temperature and dissolved oxygen stratification) and ecological characterization (e.g., timing and abundance of pond turtle habitat) of Poopenaut Valley pond and wetlands that will directly link back to instream flows (and ongoing hydrograph components analyses) in the mainstem channel and shallow groundwater flux.

3.5 Analysis and synthesis: developing instream flow recommendations

3.5.1 Initial framework for assessing instream flows (fall 2009)

The SFPUC will collaborate with the USFWS and NPS to construct an initial analytical framework for evaluating instream flow management scenarios. The previous tasks will emphasize habitat and process quantification, but not explicitly how all these investigations will be integrated to inform instream flow evaluations. Tradeoffs are challenging, but must be addressed as quantitatively as possible, as early as possible. By integrating geomorphic and riparian process evaluations into the habitat assessments, we better understand how habitat is created and maintained as a consequence of sequences of annual hydrographs. More specific hydrograph components for the snowmelt hydrograph might need development (e.g., winter baseflow, winter ramp-up, rapid snowmelt ascension limb, sustained snowmelt base snowmelt peak, fast recession limb, slow recession limb, and late-summer/early fall baseflows). The feasibility of making specific instream flow releases given operational and water supply constraints will also be included in the framework.

As an initial step, we propose conducting a preliminary analysis of how the Tuolumne River ecosystem has been affected by past operations, as a working example of how instream flows can be evaluated. This task should be accomplished in this initial work so that critical data gaps/needs can be remedied the following year. As a first step, the reference condition will be estimated (Figure 8), as outlined in McBain and Trush (2007). From the initial habitat rating curves, each streamflow will be associated with a quantity of good habitat. Each day's streamflow during the hydrograph for a selected runoff year will be assigned square feet of good habitat. A habigraph portrays the daily amount of habitat available each day during the hydrograph, with available habitat (ft^2) on the Y axis and day of the hydrograph on the X axis. For the hydrograph in selected runoff year types, habigraphs will be generated for each species and life stage habitat. Available habitat area is based primarily on flow characteristics (velocity, depth, and other parameters) and channelbed composition. However water temperature, species life stage timing, and species temperature thresholds also determine whether species actually use, and their populations benefit from, that habitat. Individuals will prosper only if water temperatures are favorable, and the population will prosper only if abundant habitat occurs when needed by each life stage. Therefore only portions of the habigraphs provide everything ecologically necessary and relevant for a particular species (Figure 8). For example, abundant rainbow trout fry habitat in August occurs outside the late-spring through early-summer period when fry are in the river. Even if water temperatures were favorable, abundant fry habitat in the habigraph during August would not be relevant, unless that habitat overlaps with the needs of other species at that time of year.

Single Species Life Stage *X* in Water Year *Z*	Name	Data Required and Origin
	Habitat Rating Curve	"Good" habitat area for that species life stage, at various flows Expert habitat mapping
	Annual Snowmelt Hydrograph	Daily average flow at each day of the runoff year (April 1 to Sept 1) for a particular runoff year type USGS gaging station
	Habigraph	Habitat area for species life stage, and day of the runoff year for a particular runoff year type Habitat rating curve and snowmelt hydrograph
	Habigraph with Temperature Thresholds & Life Stages Periodicity	Dates of species life stage window, water temperature, life stage temperature thresholds Thermographs and scientific literature Ⓐ Number of days with abundant and good habitat for Life Stage *X* in unregulated Water Year *Z*. This becomes the Reference Condition for Water Year *Z*.
	Reference Condition Curve	Number of days with ecologically available area, desired snowmelt flow diversion rate in percent Annual habigraphs, habitat rating curve

$$\text{Reference Condition (RC)} = \frac{\text{\# Days Ecological Habitat @ Diversion Rate} = N}{\text{\# Days Ecological Habitat Reference Condition}} \times 100$$

Figure 8. Important physical and biological graphical relationships for recommending instream flows using the reference condition approach (McBain & Trush, Inc. 2007).

To prescribe flow guidelines, the relationship between ecologically necessary/relevant habitat and streamflow can be established over hydrographs representing specific runoff year types. To qualify as ecologically necessary and relevant habitat (as ecologically available habitat), each day's habitat in a given species/life stage habigraph must: (1) occur within the time period for that life stage, (2) fall within the favorable temperature range, and (3) be relatively abundant (Figure 8). The first two qualifiers would be determined from the scientific literature, while the third would be estimated from the habitat rating curves (streamflows providing 60% to 80% or more of peak habitat abundance on the habitat rating curve). For a particular species life stage, a wet runoff year might have 50 days when all three qualifiers were met, whereas a dry runoff year might have only 20 days.

A computed reference condition is the number of days in a particular runoff year's habigraph in which all three habitat qualifiers for a specific species and life stage are met under unregulated streamflows. Under varying managed flow scenarios (e.g., fixed daily diversion rates as an oversimplified example in Figure 8), the number of qualifying days might remain unchanged (remain at 100% reference condition), increase, or decrease. The computed reference condition can be expressed as a percentage: the number of qualifying days in the unregulated habigraph as the denominator and the number of qualifying days in a habigraph created under a specific managed hydrograph as the numerator. In an example from the Clavey River (McBain and Trush 2007), reference condition curves have the percent reference condition on the Y axis and the daily diversion rate on the X axis (Figure 8). With greater diversion rate of the snowmelt hydrograph, the likelihood of diverging either negatively or positively from the 100% reference condition increases. The ecological goal for prescribing flows would be to recommend management strategies that diverge from the reference condition as little as possible. This application of reference condition, as applied to the Clavey River investigation (McBain and Trush 2007), can serve as a starting point for developing an analytical framework specific to the Tuolumne River.

3.5.2 Develop gaming tool (summer and fall 2009)

Many tasks will develop separate numerical models (e.g., water temperature model) and empirical models (e.g., flow-habitat relationships, geomorphic and riparian thresholds) that will be applied to inform preliminary instream flow recommendations. We propose to develop a user-friendly gaming tool to manage and integrate these models to inform instream flow recommendations and facilitate the iterative process of resolving ecological flow recommendations with water supply and management constraints.

The gaming tool will couple flow-habitat curves, ecological thresholds/objectives, a riparian initiation model, and other information to facilitate assessment of water supply operations and constraints. For example, by simulating releases in early May between 100 cfs to 6,000 cfs at 200 cfs increments, a flow-temperature response curve can be developed. This can be repeated on a weekly or bi-weekly basis throughout the warmer period of the year, creating a suite of flow-temperature curves for the entire study reach that reflects time-varying instream flow rates, release temperatures, and meteorological conditions. These data can be readily incorporated into a spreadsheet allowing the user to, for example, enter a flow rate, release temperature, and week of the year (representing meteorological conditions) to obtain a temperature at any location throughout the study reach.

Such a tool can be enhanced to incorporate upstream conditions in Hetch Hetchy Reservoir that may control release temperature (e.g., low storage conditions under multiple year drought that could lead to warmer release temperatures), unseasonable warm or cool meteorological conditions, and other options. The desired end use of the gaming tool will be to enable rapid evaluation of flow alternatives with respect to ecological goals (some of which will be compared via Number of Good Days or Number of Good Years analysis described in Section 3.5), and iteratively re-evaluating ecological performance as the flow recommendations are rectified with water supply and operations constraints.

3.5.3 Preliminary adaptive management and monitoring framework (Fall 2009)

The SFPUC will develop a preliminary adaptive management and monitoring plan in collaboration with the NPS, USFWS, and others. The plan will summarize and prioritize information needs and potential experiments, and link these to priority ecological management objectives. Short and long term monitoring recommendations will be included in the plan, which will be revised in 2010 based upon study findings and NPS, USFWS, SFPUC, and other inputs.

4 References

Elliott, J. M., and M. A. Hurley. 1998. Predicting fluctuations in the size of newly emerged seatrout fry in a Lake District stream. Journal of Fish Biology 53(2): 414-433.

Lind, A. and S. Yarnell, 2008. Habitat Suitability Criteria for the Foothill Yellow-legged Frog (*rana boylii*) in the Northern Sierra Nevada and Coast Ranges of California, DeSabla-Centerville Project Foothill Yellow-legged Frog Habitat Suitability Criteria Report

McBain & Trush, Inc. 2004. Estimating Salmonid Habitat Availability in the lower Oak Grove Fork using Expert Habitat Mapping. Prepared for Portland General Electric, Portland, OR.

McBain & Trush, Inc. and RMC Environmental. 2007. Upper Tuolumne River: Description of River Ecosystem and Recommended Monitoring Actions. Prepared for the SFPUC Land and Natural Resources Division, San Francisco, CA.

McBain & Trush, Inc. 2007. Pulse Flow Guidelines: Managing the Annual Snowmelt Hydrograph and Winter Floods in Regulated Boulder-Bedrock Sierra Nevada Rivers, California Energy Commission, PIER Energy-Related Environmental Research. Sacramento, CA.

Morita, K., and A. Yokota. 2002. Population viability of stream-resident salmonids after habitat fragmentation: a case study with white-spotted char (*Salvelinus leucomaenis*) by an individual based model. Ecological Modelling 155: 85-94.

Moyle, P.B. and Marchetti M. 1992. Temperature requirements of rainbow trout and brown trout in relation to flows between O'Shaughnessy Dam and Early Intake on the Tuolumne River, California. Prepared for Hetch Hetchy Water and Power.

Pacific Gas and Electric. 2003. Fish habitat suitability criteria for the Pit 345 Hydroelectric Project, Federal Energy Regulatory Commission Project No. 233. Pacific Gas and Electric: San Francisco, CA.

Riparian Habitat Joint Venture (RHJV). 2004. The Riparian Bird Conservation Plan: A Strategy for Reversing the decline of Riparian Associated Birds in California, Version 2.0. California Partners in Flight.

U.S. Fish and Wildlife Service (USFWS). 1976. Tuolumne River Flow Study. Canyon Power Project, California. Region I, Portland, OR. August 23, 1976.

U.S. Fish and Wildlife Service (USFWS). 1981. Environmental Assessment: Tuolumne River Flow Schedule Revision (Canyon Power Project). Region I, Portland, OR.

U.S. Fish and Wildlife Service (USFWS). 1992. Instream Flow Requirements for Rainbow and Brown Trout in the Tuolumne River between O'Shaughnessy Dam and Early Intake (rough draft). Prepared by Michael Aceituno. Sacramento, CA.

U.S. Fish and Wildlife Service (USFWS). 2004. Flow-habitat relationships for adult and juvenile rainbow trout in the Big Creek project. U.S. Fish and Wildlife Service: Sacramento, CA.

U.S. Fish and Wildlife Service (USFWS). 2006. Flow-habitat relationships for macroinvertebrates in the Sacramento River between Keswick Dam and Battle Creek. U.S.Fish and Wildlife Service: Sacramento, CA.

U.S. Fish and Wildlife Service (USFWS). 2008. Draft report flow-habitat relationships for juvenile spring/fall-run Chinook salmon and steelhead/rainbow trout rearing in the Yuba River. U.S. Fish and Wildlife Service: Sacramento, CA.