Lower Tuolumne River Instream Flow Studies
Final Study Plan

Prepared for
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and

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1 BACKGROUND AND PURPOSE

The Federal Energy Regulatory Commission (FERC) issued a July 16, 2009 order ("Order") directing Turlock Irrigation District and Modesto Irrigation District ("Districts") to develop and implement an Instream Flow Incremental Method/Physical Habitat Simulation (IFIM/PHABSIM) study of the lower Tuolumne River (FERC 2009). The purpose of the instream flow study is "to determine instream flows necessary to maximize fall-run Chinook salmon *(Oncorhynchus tshawytscha)* and *O. mykiss* production and survival throughout their various life stages." This study plan responds to the Order and provides detailed methods for the proposed approach.

Two prior PHABSIM studies of the lower Tuolumne River have been conducted for the Don Pedro Project (FERC Project No. 2299) as part of the approved FERC Fisheries Study Plan. A 1981 study by CDFG (TID/MID 1992, Appendix 4) was focused within a nine-mile reach (river mile [RM] 50.5–42.0) extending from near the town of La Grange to near Turlock Lake State Recreation Area. A reanalysis of the 1981 CDFG data was also completed by EA Engineering, Science, and Technology (EA) in 1991 on behalf of the Districts (TID/MID 1992, Appendix 5). Selected elements of the CDFG study are summarized in Table 1 below.

Table 1. Selected instream flow model details for studies on the lower Tuolumne River in 1981 and 1992.

Study	Upper RM	Lower RM	Total Transects	Calibration Flows (approx. cfs)			Simulation range (cfs)
				Low	Mid	High	
CDFG reanalysis (TID/MID 1992)	50.5	42.0	19	120	260	410	20–600
USFWS (1995)	52.2	0.0	25 (23 used)	250	600	1,050	25–1,200

In 1992, the second PHABSIM study was conducted by the USFWS (1995), which is also briefly summarized in Table 1. The USFWS study reaches included the entire lower Tuolumne River from La Grange Dam (RM 52.2) downstream to the confluence with the San Joaquin River (RM 0.0), although the most extensive field efforts were focused in riffle and run habitats in the 21-mile reach upstream of Waterford (RM 31) that is most heavily utilized for spawning by salmonid species. Using the results of the USFWS study, the Districts previously responded to an August 2003 information request from FERC staff to develop a flow vs. habitat evaluation that incorporated water temperature effects on Weighted Usable Area (WUA) (Stillwater Sciences 2003).

The rationale for the Order's inclusion of an additional IFIM study is not entirely apparent, especially since both prior studies included simulations for various life stages of *O. mykiss*, in addition to Chinook salmon. In addition to the previous IFIM studies and evaluations, the Districts have also reported on flow fluctuation and juvenile salmonid stranding analyses at flows up to 8,400 cfs (TID/MID 1992, Appendices 14 and 15; TID/MID 2000, Report 2000-6; TID/MID 2005, Appendix E), as well as geographic information system (GIS) based mapping of floodplain inundation surfaces at several flows within this range (TID/MID

2005, Appendix F). The GIS inundation maps were used in a recent assessment of variations in inundation areas at high flows by USFWS (2008). Although data collected from a new study could be combined with data from prior investigations (specifically from the USFWS [1995] study), the recommended study plan detailed below assumes independent, standalone investigations that are not dependent on data from the previous IFIM studies.

2 RECOMMENDED STUDY APPROACH

The instream flow studies are proposed to be separated into a 1-D PHABSIM study from 150 cfs up to at least 400 cfs and a 2-D PHABSIM pulse flow study, which will evaluate spring pulse flows of 1,000 to 5,000 cfs and fall pulse flows of up to 1,500 cfs, as specified in the Order. The 1-D PHABSIM model will estimate habitat availability for various lifestages of Chinook salmon and *O. mykiss* over a range of simulated flow releases included in the FERC Order (150 to at least 400 cfs), as well as in-channel flows up to 1,200 cfs, which corresponds to the flow range in the USFWS (1995) study. The proposed model software is the Riverine Habitat Simulation Model (RHABSIM). This model is an adaptation of the PHABSIM software that was originally developed and maintained by the Instream Flow and Aquatic Systems Group of the U.S. Fish and Wildlife Service in Fort Collins, Colorado (Milhous 1973, Bovee 1982, Milhous et al. 1984). The RHABSIM software, which was developed by Thomas R. Payne and Associates, implements the equivalent algorithms of PHABSIM but features expanded input, output, graphic, and calibration capabilities.

Development and implementation of the IFIM study considers a variety of factors, besides just the hydraulic and habitat suitability criteria (HSC) required for the PHABSIM component of the analysis, to evaluate the suitability of a stream and various flows for the species and life stages of interest. Water temperature is of particular interest since it varies with flow (particularly downstream of large impoundments, such as Don Pedro Reservoir). A water temperature study is planned, based on the results of a HEC-5Q water temperature model (RMA 2008) that will be validated as part of a complementary Tuolumne River water temperature modeling study plan (Stillwater Sciences 2009) included in the Order.

The proposed pulse flow assessment will examine potential responses of salmonid and predator species to spatial variations in inundation area, velocities, and depths in relation to the pulse flows specified in the Order within both in-channel areas as well as temporarily inundated portions of the Tuolumne River floodplain. Although the 1-D PHABSIM methodology is the most commonly used method for flow and habitat assessments within confined channels, the proposed pulse flow assessment will examine the effects of pulse flows for the benefit of migratory salmonid life stages using a 2-D hydraulic model of both in-channel and inundated floodplain areas at flows up to 5,000 cfs. The rationale for the two different methods for the instream flow and pulse flow elements of the study is threefold. First, extension of the IFIM analysis to flows exceeding the bankfull channel width, in the range of 1,500–2,500 cfs in some locations (McBain and Trush 2000), will cause a significant shift in the stage-discharge relationship for the channel. This requires a separate modeling analysis in order to develop a reliably predictive (*i.e.*, log linear) estimate of stage. Second, patchy distribution of floodplain areas makes their treatment as separate, discrete areas more precise, since the conditions at these locations cannot be as reliably extrapolated to other areas of the river. Third, pulse flows are typically of shorter duration and intended for either the attraction/migration of fall spawners or to facilitate outmigration of juvenile fish; detailed evaluation of such flows in a PHABSIM study in order to assess and generalize their microhabitat suitability for spawning, adult holding, or rearing (which is what the associated HSC are developed for) is of limited use in refining potential flow recommendations.

3 METHODS

The methodology presented in the sections below discusses in more detail the steps for performing the proposed instream flow study and reporting results.

3.1 Logistics

Instream flow studies are best performed when targeted calibration flows are consistently maintained during hydraulic field measurements. Stillwater Sciences will coordinate with TID/MID to ensure these flows are available and manageable during field measurements. Stillwater will notify TID/MID, FERC and the agencies if substantive changes in the study design, methods or schedule are anticipated.

To facilitate field staff safety, allow for coordinated water operations, and facilitate agency staff awareness of study activities, the parties listed in Table 2 will be notified by email or telephone in advance of the proposed field sampling. Prior to mobilization, planned river operations by the Districts will be checked to determine if field surveys would be safe under the anticipated flow and all parties will be notified of any delay or modification to the survey schedule.

Table 2. Field work notification.

Contact	Affiliation	Address	Phone and Email
Tim Ford	TID	333 East Canal Dr. Turlock, CA 95380	209.883.8275 tjford@tid.org
Greg Dias	MID	1231 11th Street Modesto, CA 95354	209.526.7566 gregd@mid.org
Tim Heyne	CDFG	P.O. Box 10 La Grange, CA 95329	209.853.2533 x1# theyne@dfg.ca.gov
To be determined during agency comment period	USFWS	--	--
To be determined during agency comment period	NMFS	--	--

3.2 Study Area Segmentation

The proposed study reach extends from the La Grange stream flow gage (USGS No. 11289650) at RM 51.7 downstream to the lower end of the Gravel Mining Reach at RM 34.2 (McBain and Trush 2000). This reach includes the downstream extent of summer *O. mykiss* observations in past snorkel surveys (TID/MID 2009) as well as large majority of the spawning reach for Chinook salmon. As a secondary option, CDFG has recommended that the downstream boundary for the study extend to RM 24 to the downstream end of the In-Channel Gravel Mining Reach (Figure 1). Within the proposed study reach, the river would be divided into segments of similar habitat, geomorphic, and hydrologic character and analyzed independently. The study reach and number/location of segments would be determined as part of the scoping process.

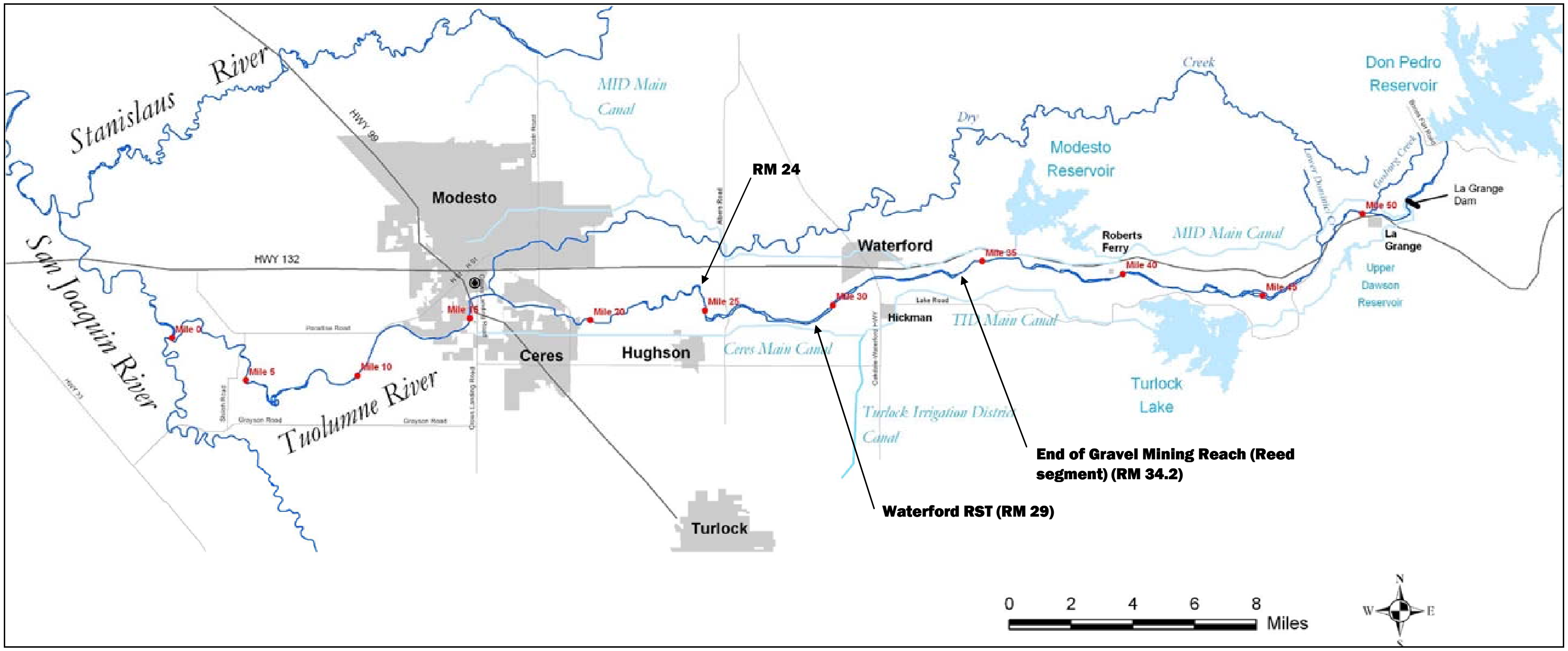


Figure 1. Vicinity map for the lower Tuolumne River IFIM study.

3.3 Habitat Mapping

Within the proposed study reach, existing habitat mapping has been completed down to RM 29.0 below the City of Waterford, as part of *O. mykiss* population estimate surveys being conducted pursuant to the April 2008 FERC Order (Stillwater Sciences, *in prep*.). Data from this current habitat mapping, completed during snorkel surveys during 2008 and 2009, will provide the basis for habitat composition and delineation. Proposed mesohabitat types are listed and described in Table 3.

Table 3. Coarse scale habitat types to be used during instream flow surveys.

Habitat Type	Description
Riffle	Shallow with swift flowing, turbulent water. Partially exposed substrate dominated by cobble or boulder. Gradient moderate (less than 4%).
Run/Glide	Fairly smooth water surface, low gradient, and few flow obstructions. Mean column velocity generally greater than one foot per second (fts^{-1}).
Pool	Slow flowing, tranquil water with mean column water velocity less than 1 fts^{-1} and depths of 10 ft or greater.

The percent composition of these mesohabitat types are shown in Table 4 for the study reach extending from La Grange Gage (RM 51.7) downstream to the end of the Gravel Mining Reach at RM 34.2 (McBain and Trush 2000), along with a secondary reach extending to the location of the existing rotary screw trap (RST) location downstream of the City of Waterford (RM 29.0). Additional habitat mapping would need to be conducted if areas farther downstream are included in the hydraulic simulations (see Study Area Segmentation section above).

Table 4. Mesohabitat types and percentage occurrence.

Habitat Type	# of Units	Total Length (ft)	% of Reach
La Grange Gage (USGS No. 11289650) to end of Gravel Mining Reach (RM 51.7 to RM 34.2)			
Riffle	55	19,195	21%
Run/Glide	55	55,964	61%
Pool	20	16,888	18%
Totals	130	92,046	100.0%
End of Gravel Mining Reach to downstream of Waterford (RM 34.2 to RM 29)			
Riffle	21	6,077	21%
Run/Glide	20	20,885	72%
Pool	2	1,951	7%
Totals	43	28,913	100%

3.4 IFIM/1-D PHABSIM study

3.4.1 Study site selection

Study sites for instream flow data collection will be established in a stepwise process following guidelines from Bovee (1982). First, the study area will be reviewed for possible segmentation into reaches. Reach segmentation will be based primarily on changes in stream gradient (associated with geomorphic condition), and/or hydrology that may cause habitat types in one reach to display significant hydraulic differences from the same habitat type in another reach (*e.g.*, low gradient riffles in one reach have consistently greater depth or velocity than low gradient riffles in another reach). Stream gradient will be determined using existing topographic data and displayed as a longitudinal profile of elevation versus river mile within the study area.

Second, areas for study sites will be identified. Sites that contain the full complement of common (>10–15% of stream length in the reach) and modelable (*e.g.*, not high gradient riffles or other areas with high air entrainment or significantly non-laminar flow) habitat units in a safe and legally accessible section of stream will be identified. Within these areas, study sites will be established via consensus with the fish resource agencies. In the event consensus is not achieved on study sites, they will be determined by randomly selecting a starting habitat unit (using a random number table or similar device) among the least common habitat unit types. From that starting habitat unit, transect locations will be established in adjacent habitat units (heading upstream or downstream) until the requisite transects are placed in the specified habitat units, as described below. Where possible, sites will be co-located in areas where data have been collected for other studies in order to maximize the potential for integrated data analysis.

An exception to the above protocol will be implemented for habitat units at known spawning sites. Analysis for these units will preferentially target historical high-use spawning sites for Chinook salmon, based on prior surveys and redd counts.

3.4.2 Transect selection

Within each study site, transects will be placed in each habitat unit to be sampled either by professional judgment and concurrence of the transect selection team, or based on a stratified random sampling protocol. The stratified random sampling protocol would involve random placement of transects within strata of similar hydraulic characteristics within each habitat unit, except where such placement would result in transects running through a hydraulic anomaly or other feature (*e.g.*, re-circulating or vertical flow, brush in channel, etc.) that cannot be accurately modeled. In these cases, the transect will be relocated (either placing the transect using professional judgment and concurrence among the transect selection team, or by specifying an arbitrary distance up or downstream of the original location). Transects will be distributed in run, riffle, and pool habitat types. No transects will be placed in habitat units located on private property without the consent of the landowner.

Transect placement will target locations where there is no more than a 0.1 foot difference in stage across the transect and where the velocity profile across the transect is dominantly perpendicular to the transect. Areas with transverse flows, across-channel variation in water surface elevations, or flow contractions/expansions will be avoided.

A sufficient number of transects will be established to model approximately three replicates of each major habitat unit type in the reach (*i.e.*, runs, riffles, and pools), with the number of replicates dependent on the relative proportions of the major habitat unit types (*i.e.*, there may be more than three replicates of the most common unit type, and fewer of the least common unit type). It is expected that relatively hydraulically homogeneous habitat units will require 1–3 transects per replicate; relatively heterogeneous habitat units will require 2–5 transects per replicate. The final number of transects proposed for the reach will depend on habitat complexity as well as target resource values in the reach, and will be determined during a field site visit with concurrence of agency representatives. If there is not agreement on the appropriate number of transects, the issue will be referred to FERC for final determination.

3.4.3 Field data collection

Target calibration flows will be relatively evenly spaced (on a log scale) and selected to allow the models to simulate in-channel flows over a range covering the current minimum flow (50 cfs) up to approximately 1,000+ cfs, with a target of having the lowest simulated flow at no less than 0.4 of the lowest calibration flow and the highest simulated flow at most 2.5 times the highest calibration flow. The proposed target calibration flow ranges are as follows:

- low flow calibration: approximately 100 cfs;
- middle flow calibration: 250 cfs; and
- high flow calibration: 600 cfs.

Velocity data sets will be collected at all transects at the middle calibration flow, and water surface elevation (WSE) will be collected along each transect at all calibration flows.

3.4.3.1 Hydraulic data

Hydraulic data collection and recording will use standard procedures and guidelines for PHABSIM field studies (Trihey and Wegner 1981; Milhous et al. 1984). In general, hydraulic data collection includes establishing independent elevation reference benchmarks for level control, as well as semi-permanent headpins and tailpins at each transect. Water surface elevations will be measured using an auto-level and stadia rod along each transect at each calibration flow; WSE will be measured near each bank (to the nearest 0.01 foot), and in mid-channel areas where a significant difference between the near-bank WSE exists. A level loop survey tied to the local benchmark will be conducted at each calibration flow to ensure the accuracy of each survey. Benchmark and transect locations will be recorded with a GPS, where feasible.

The local benchmarks established for each transect will serve as the reference elevations to which all elevations (streambed and water surface) are tied. The benchmarks will consist of items that will not change elevation over time, such as lag bolts driven into trees, painted bedrock points, or local infrastructure. Benchmarks will be tied together, where practical, for the upstream and downstream transects at each site, for efficient analysis and QA/QC procedures.

Channel cross section profiles above the highest measured calibration flow will be surveyed (to the nearest 0.1 foot) with a stadia rod and auto-level or total station to establish the overbank channel profile up to or beyond the water's edge at the highest flow to be modeled, with sufficiently close spacing of verticals to document changes in slope. In-channel profiles will be calculated by subtracting the depth of water measured during the velocity measurements from the average WSE. Additional topographic data collection for each transect will include stage-of-zero-flow (SZF) elevation, which is the controlling elevation within or downstream of the transect line below which flow ceases.

Temporary and permanent staff gage readings and time-of-day will be recorded at the beginning and end of each transect measurement to check that the stage had not changed appreciably during the transect measurement nor the calibration flow measurement for the entire study site.

Depths and mean column water velocities will be measured across each transect at the middle calibration flow. The number of cells sampled for depth and velocity is based on a goal of retaining a minimum of 20–25 stations that would remain in-water at the low calibration flow. Discharge measurements will be collected at each calibration flow following techniques outlined in Rantz (1982). Discharge measurements will be made at each grouping of transects in hydrologically distinct areas using either an existing habitat transect (if deemed suitable) or at some other suitable transect established solely for measuring discharge. These discharge measurements will be used in conjunction with data from the La Grange gaging station (USGS No. 11289650) to determine more precisely the calibration flow and account for accretion, if any, within the study reach.

3.4.3.2 Velocity measurements

Velocity measurements will be made using a Marsh-McBirney Flo-mate pressure transducer-type velocity meters (Hach Corporation, Loveland CO), mounted on standard top-set USGS wading rods. Velocities will be measured at six-tenths of the depth (0.6 depth) when depths were less than 2.5 feet, and at two-tenths (0.2 depth) and eight-tenths (0.8 depth) of the depth when depths equal or exceed 2.5 feet or when the expected velocity profile is altered by an obstruction immediately upstream. In instances of increased turbulence or obstructions, measurements may be taken at all three depths (0.2, 0.6, and 0.8) and a weighted average calculated (Bovee and Milhous 1978). Where transects have a series of water depths greater than approximately 3.5 feet, depth and velocity will be measured using an Acoustic Doppler Current Profiler (ADCP) mounted on a mini-cataraft. The ADCP uses acoustic pulses to measure water velocities and depths across the channel. The ADCP is connected by cable to a power source and a radio modem with data transmitted to a shore-based laptop computer.

3.4.3.3 Substrate data

Data collection at each transect will include substrate and/or cover codes compatible with proposed species HSC. Substrate composition and cover types will be recorded in the field at each cross section location where channel geometry data are collected. Substrate coding, as applicable and feasible (depending on nature of source data), will be adapted to the coding systems specified in Table 5a (from USFWS and CDFG) and/or Table 5b (from prior mapping of the lower Tuolumne River for the Coarse Sediment Management Plan [McBain & Trush 2004]).

Table 5a. Proposed substrate types for the Lower Tuolumne IFIM study. [Use of these codes is subject to final decisions on habitat suitability criteria for substrate]

Substrate Type	Particle Size (inches)
Sand/Silt	< 0.1
Small Gravel	0.1 – 1
Medium Gravel	1 – 2
Medium/Large Gravel	1 – 3
Large Gravel	2 – 3
Gravel/Cobble	2 – 4
Small Cobble	3 – 4
Small Cobble	3 – 5
Medium Cobble	4 – 6
Large Cobble	6 – 8
Large Cobble	8 –10
Large Cobble	10 –12
Boulder/Bedrock	> 12

Table 5b. Coarse sediment size gradation chart showing particle size class descriptions and sizes.

Particle Size Class		Particle Size (mm)	Particle Size (in)
Boulder	**Very Large**	4,096	161.2
		2,896	114.0
	Large	2,048	80.6
		1,448	57.0
	Medium	1,024	40.3
		724	28.5
	Small	512	20.1
		362	14.2
Cobble	**Large**	256	10.1
		181	7.1
	Small	128	5.0
		90.5	3.6
Gravel	**Very Coarse**	64.0	2.5
		45.3	1.8
	Coarse	32.0	1.2
		22.6	0.9
	Medium	16.0	0.6
		11.3	0.4
	Fine	8.00	0.3
		5.66	0.2
	Very Fine	4.00	0.2
		2.83	0.1
		2.00	0.1

Notes:
1. Adapted from McBain & Trush 2004
2. Particle sizes less than 2mm are classified as sand (2-0.063mm), silt (0.063-0.0093mm), and clay (<0.0093mm).

3.4.4 Hydraulic modeling

The hydraulic models used for instream flow studies utilize the data collected in the field for calibration of water surface elevations, discharge, and velocities over a range of flow simulations. The hydraulic modeling will result in output files of hydraulic parameters (depths, velocities, etc.) used in the habitat analysis.

3.4.4.1 Stage-discharge calibration

Stage-discharge relationships are developed from measured discharge and water surface elevation (WSE) using an empirical log/log formula (commonly referred to as IFG-4), or by using a channel conveyance method (referred to as MANSQ). Using the log/log and channel conveyance methods, each transect is treated independently. The IFG-4 method requires a minimum of three sets of stage-discharge measurements and an estimate of SZF for each transect. The quality of the stage-discharge calibration using the IFG-4 method is evaluated by examination of mean error and slope output from the model. MANSQ only requires a single stage-discharge pair, though additional pairs are advisable for validation, and uses Manning's equation to determine a stage-discharge relationship (Bovee and Milhous 1978). In situations where irregular channel features occur on a cross section, for instance bars or terraces, MANSQ is often better at predicting higher stages than IFG-4. MANSQ is most often used on riffle or run transects and is not suitable for transects that have backwater effects from downstream controls, such as pools. It can also be useful as a test and verification of log/log stage discharge relationships.

The Water Surface Profile (WSP) program for use in developing stage-discharge predictions can also be used, but due to its limited application for riffle and run habitat, and its reliance on additional hydraulic control transects, it is not expected to be used extensively in this study, although it may be applicable for certain pool habitat simulations. For the purposes of this study, the IFG-4 program is proposed as the primary method for developing the stage-discharge relationship.

3.4.4.2 Velocity calibration

The preferred method for simulating water velocities is the "one-flow" option. This technique uses a single set of measured velocities to predict individual cell velocities over a range of flows. Simulated velocities are calibrated to measured data and a relationship between a fixed roughness coefficient (Manning's 'n') and depth is developed. In some cases, roughness is modified for individual cells if substantial velocity errors are noted at simulation flows. Velocity adjustment factors (VAFs) are examined to detect any significant water velocity deviations and determine if velocity changes at simulated flows remain consistent with changes in stage and total discharge.

3.4.4.3 Calibration metrics

Various calibration metrics will be used as target values to evaluate performance of the IFG-4 hydraulic model. Although these are not strict thresholds to determine usefulness of the data, an effort will be made to calibrate the model to these standards.

- A beta value (a measure of the change in channel roughness with changes in streamflow) between 2.0 and 4.5;
- Mean error in calculated versus given discharges less than ten percent;
- No more than a 25% difference for any calculated versus given discharge
- No more than a 0.1 foot difference between measured and simulated WSELs
- Mean stage-discharge regression error for all transects less than 10%, and 5% or less for 90% of the transects.
- Velocity Adjustment Factor (VAF) values of 0.2 to 5.0 with a pattern of monotonic increase with an increase in flows and values between 0.90 and 1.10 at the calibration flow.

3.4.5 Target species and habitat suitability criteria (HSC)

Proposed HSC for the current instream flow study will consider the following target species and lifestages:

- *O. mykiss:* adult, spawning, fry, and juvenile.
- Fall-run Chinook salmon: spawning, fry, and juvenile.

Existing HSC data will be compiled for the target species and lifestages, in collaboration with the agencies, to create a database of curves that can be reviewed for applicability to the proposed study. Habitat suitability criteria from prior lower Tuolumne River studies (Tables 6 and 7 will be included in the HSC database for consideration. The database of curves will be reviewed in consultation with the agencies, and screening criteria applied as necessary to minimize the number of curves for further consideration. Proposed screening criteria will include the following, although no single criterion will be used to qualify or disqualify a curve from further consideration.

- Minimum of 150 observations
- Clear identification of fish size classes
- Depth and velocity HSC
- Category II or III data (Bovee 1986)
- Comparable stream size and morphology (*e.g.*, hydrology, stream width and depth, gradient, geomorphology, etc.)
- Source data from the lower Tuolumne River (or other Central Valley streams)
- Habitat availability data collected
- Data collected at high enough flow that depths and velocities are not biased by flow availability
- Availability of presence/absence data

Table 6. Habitat suitability criteria summary from 1981 CDFG IFIM study.

Species	Lifestage	Depth	Velocity	Substrate	Source
Chinook	Spawning	Yes	Yes	Yes	Site-specific
Chinook	Fry	Yes	Yes	All suitable	Unknown
Chinook	Juvenile	Yes	Yes	All suitable	Unknown
Rainbow	Adult	Yes	Yes	Yes	Raleigh et al. (1984)
Rainbow	Juvenile	Yes	Yes	Yes	Raleigh et al. (1984)

Table 7. Habitat suitability criteria summary from USFWS (1995) IFIM study.

Species	Lifestage	Depth	Velocity	Substrate	Source
Chinook	Spawning	Yes	Yes	Combined Substrate / Embeddedness Code	Bovee (1978)
Chinook	Fry	Yes	Yes	All suitable	Bovee (1978)
Chinook	Juvenile	Yes	Yes	All suitable	Bovee (1978)
Rainbow	Adult	Yes	Yes	Combined Substrate / Embeddedness Code	Bovee (1978)
Rainbow	Juvenile	Yes	Yes	Combined Substrate / Embeddedness Code	Bovee (1978)

Following a review and discussion of applicable HSC curves, existing curves may be selected and/or modified for use on the proposed study, or site-specific HSC curves may be developed as deemed appropriate in collaboration with technical experts from the stakeholder group. If there is not agreement on HSC curves to use, the issue will be referred to FERC for final determination.

3.4.6 Habitat modeling

Habitat will be modeled using the HABSIM submodel provided in the RHABSIM software (analogous to HABTAE, HABTAT, etc.). The habitat model combines the hydraulic and HSC components to generate the weighted usable area (WUA), in square feet per 1,000 ft of stream) of the stream for each species and life stage at each simulated flow. The standard option of multiplying individual variable suitabilities (velocity*depth*substrate or cover) for cell centroids will be used to calculate WUA. This output will be proportioned over all habitat types (using the relative abundance of each habitat type and transect as a weighting factor) to obtain the reach-wide estimate of WUA by life-stage. An example of the transect weighting procedure is depicted in Figure 2. WUA versus flow curves will be developed to aid in the interpretation of these habitat flow relationships.

3.4.7 Total habitat time series

A habitat time series (HTS) analysis (Bovee 1982) is proposed for flows up to a maximum of approximately 1,000 cfs (the upper end of the hydraulic modeling range). The HTS analysis uses the WUA versus flow relationship and combines it with current or alternative hydrologic conditions to generate WUA by day under selected flow regimes (including accretion estimates) for different water year types. Figure 3 presents a conceptual example of HTS results. Daily flow values for the study reach under varying water-year types will be obtained from USGS gage records and used for the analysis. The Total HTS results will be used as the first step in calculation of an Effective Habitat Time Series described below.

3.4.8 Effective habitat time series development

In addition to the standard WUA results as described in the Habitat Modeling and Total Habitat Time Series sections, a secondary analysis showing the "effective" WUA (eWUA) will be conducted. This analysis relates to summertime water temperature suitability for *O. mykiss*, and integrates both micro- and macro-habitat considerations. The results from the HEC-5Q water temperature model (Stillwater Sciences 2009) over a range of flows will be combined with the summer WUA results so that areas ("macrohabitats") with unsuitable water temperatures are excluded from the total WUA sum. In other words, if a given reach has 100,000 square feet of suitable habitat (WUA) based on hydraulic microhabitat conditions at flow 'X', but 30 percent of the reach at flow 'X' is above a critical temperature threshold for the species life stage of interest, the eWUA would be 70,000 square feet. This type of analysis was previously conducted, at a coarser level by Stillwater Sciences (2003), using a combination of the 1992 IFIM evaluation for the lower Tuolumne River (USFWS 1995) and the earlier SNTEMP model results (TID/MID 1992, Appendix 18). The methods are explained more fully in Bovee (1982).

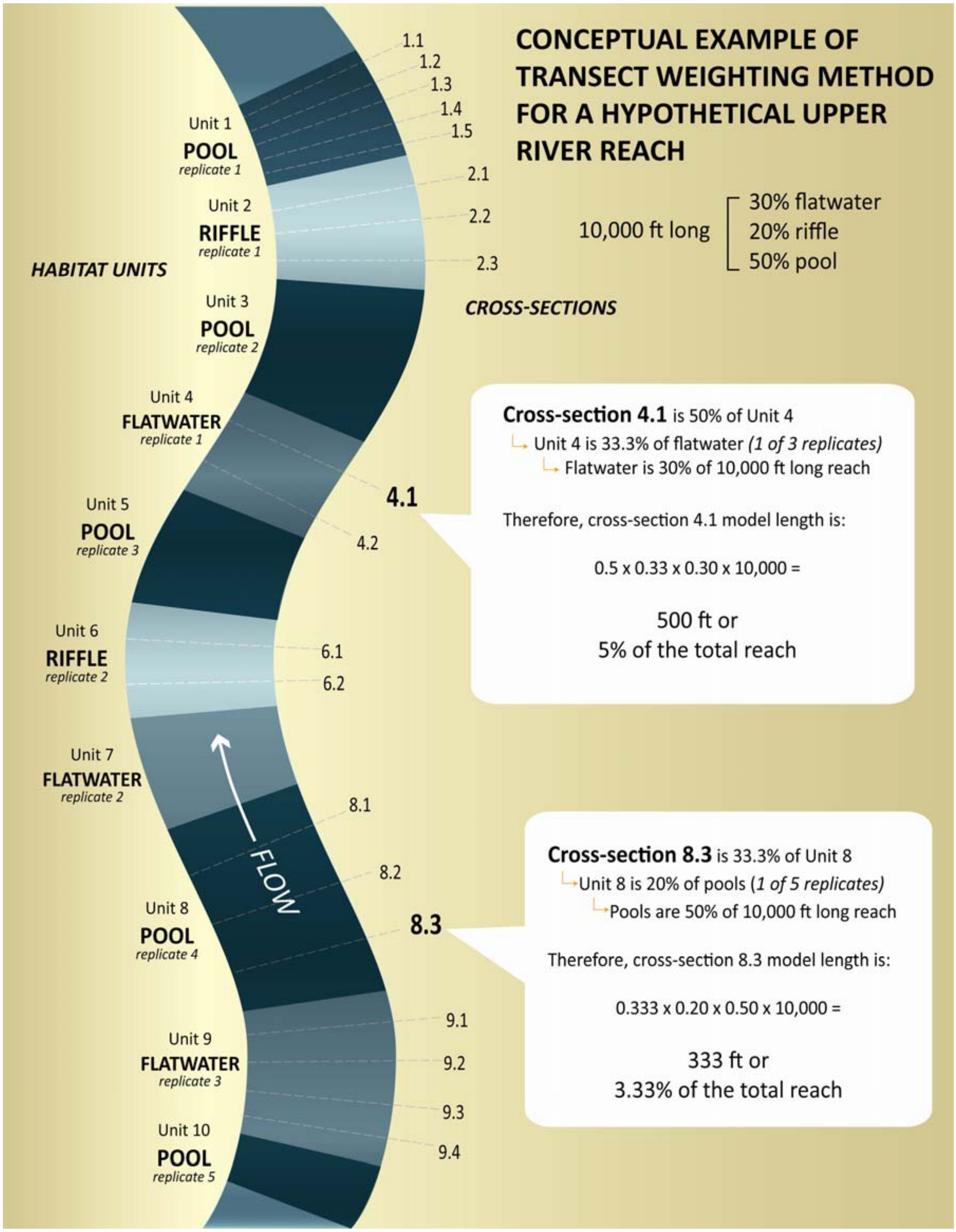


Figure 2. Conceptual example of transect weighting method for reach extrapolations proposed for the lower Tuolumne River IFIM study.

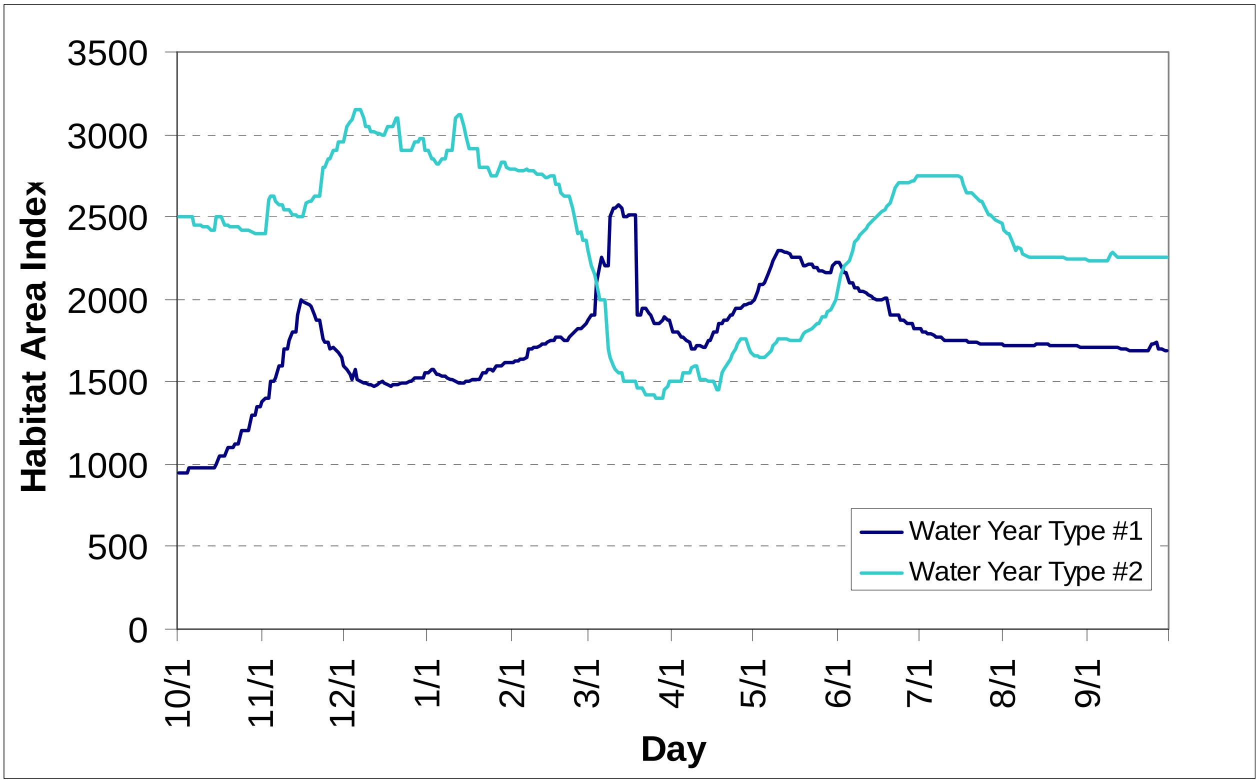


Figure 3. Conceptual example total habitat time series output for the IFIM study.

3.5 Pulse flow assessment

The pulse flow assessment will evaluate spring pulse flows of 1,000 to 5,000 cfs and fall pulse flows of up to 1,500 cfs, as specified in the Order. The detailed approach involves use and expansion of existing topographic maps of the lower Tuolumne River floodplain (RM 52–RM 29), combined with development of a high flow stage-discharge relationship for these same areas as inputs to the River2D hydraulic model (Steffler and Blackburn 2002) or similar two-dimensional modeling software (such as MD-SWMS). The objectives of the assessment are to: 1) gather empirical data on the relationship between water temperature and flow during pulse flow events, and 2) assess habitat usability and habitat segmentation for lower Tuolumne River fish species during pulse flow conditions.

3.5.1 Pulse flow study site selection

Study sites for the pulse flow assessment will include up to four (4) locations upstream of RM 29 (including the gravel-bedded portion of the river used most extensively by salmonids between RM 34.2 to RM 51.7), in addition to other restoration sites (*e.g.*, special run/pool [SRP] 9) where there is existing 2-D modeling data. Study site selection will include areas where significant floodplain inundation is expected at flow ranges up to 5,000 cfs.

3.5.2 Cross section and topography development

Existing LiDAR coverage of the lower Tuolumne River floodplain (RM 52–29), originally developed from aerial surveys of 21 September 2005 at river flows of 321 cfs will be used to for development of the model cross sections and topography. A digital elevation model (DEM) will be used within GIS to develop hydraulic model cross sections, with bathymetric data below the 321 cfs water surface developed (where necessary) using standard survey methods described in Section 3.4.3.1. The existing LiDAR coverage will be point-checked for accuracy, and if significant topographic changes are detected, options for obtaining updated LiDAR coverage will be investigated.

3.5.3 High flow stage discharge relationships

Stage discharge relationships at high flows will be developed at each pulse flow study site within the lower Tuolumne River using either standard survey techniques (where timing and flow conditions allow) or pressure transducers (InSitu® miniTroll) placed in a protective PVC pipe housing and mounted along the active river channel using rebar and foundation stakes. If possible, the pressure transducer elevations will be established using a total station (Sokkia® SET600 or similar) and prism to tie in to an established local benchmark. If this is not possible, the pressure transducer elevation will be tied to an installed temporary benchmark.

The stage recorders will be set at a 15-minute interval and will record corresponding stages to lower Tuolumne River flows of up to 5,000 cfs. Test flows for the pulse flow assessment will include 2,000 cfs, 3,000 cfs, and 5,000 cfs to develop the high flow stage discharge relationship. In the event that the following hydrology conditions are met in the first year of study, tests will occur during the March–May period.

a. The estimated 60-20-20 Index (using 50% exceedance probability) for the then current water year based upon the CDWR within-month March runoff forecast update following March 15 is at least 4.2, provided that (1) daily computed natural flows for both the Tuolumne and San Joaquin Rivers in excess of 50,000 cfs are excluded and (2) the Tuolumne River comprises at least 31% of the index.
b. The 60-20-20 Index for the immediately preceding water year was at least 4.2.
c. The target flow shall be subject to any flow and/or timing limitation required by the VAMP study.
d. The target flow shall be subject to any flow and/or timing limitation required by the Corps of Engineers.

In the event that these high flow conditions are not necessitated by naturally occurring wetter hydrologic conditions (resulting in flood releases in excess of the 301 thousand acre-feet (TAF) annual FERC flow requirements), the Districts will delay data collection for up to 2 years or may alter the intermediate test flows above.

3.5.4 2-D hydraulic model development

River2D model input includes a) topography of the river channel; b) roughness of the channel expressed as a roughness height; c) discharge; and d) downstream water surface elevation. The topography will be developed from the existing LiDAR-derived DEM (subject to the constraints noted in Section 3.5.2 above), whereas elevation data will be developed from the stage discharge relationships described above. Channel roughness will be based on a combination of this topography and professional judgment as a calibration parameter in addition to changes in the finite element network to achieve representative modeled water depths at a given discharge. As an additional calibration, model outputs will be compared to existing flood area inundation maps (TID/MID 2005, Appendix F) previously developed at a wide range of flows (100, 230, 620, 1,100, 3,100, 5,300, and 8,400 cfs).

3.5.5 2-D model simulations and anticipated results

The calibrated 2-D model will be used to simulate flow routing and velocity vectors in both the in-channel areas at pulse flows of 1,000 cfs and 1,500 cfs. In addition, the model will be used to simulate intermediate high flows of 2,500 cfs up to 5,000 cfs. The results of the pulse flow assessment will be used to examine habitat suitability for migratory life stages of lower Tuolumne River salmonids as well as habitat preferences of predators such as largemouth bass *(Micropterus salmoides)* and smallmouth bass *(M. dolomieu)*. During high flows (*e.g.*, spring pulse flows), outmigrating salmon smolts generally use more central portions of the channel, while bass likely seek lower velocities and warmer water near channel margins, as previously examined at individual in-channel restoration sites (McBain & Trush and Stillwater Sciences 2006).

For example, hydraulic modeling conducted at a restored in-channel mining pit ("Special Run Pool" or SRP 9) for pre- and post-project conditions using the River 2D model (Steffler and Blackburn 2002) indicates that the project increases habitat segregation between bass and outmigrating Chinook salmon and may provide a "safe-velocity corridor" for outmigrant salmon during relatively low flow conditions (McBain & Trush and Stillwater Sciences 2006). Modeling for the SRP 9 study suggested that, due to distinct differences in habitat usability between bass and salmon, this effect will occur at predictable flow thresholds in specific habitat types (*e.g.*, riffles and unrestored mining pits habitats). Because high flows may help to spatially separate predators and salmon smolts, the pulse flow study may provide a mechanistic linkage between reductions in the exposure of juvenile salmon to predation at high flows.

Lastly, the pulse flow study will be coordinated with any test flows that examine movement patterns of juvenile Chinook salmon in ongoing rotary screw trap (RST) monitoring, or high flows that are released in relation to fall spawner attraction flows.

3.6 Management alternatives

Management alternatives for the lower Tuolumne River will be considered following completion of the IFIM study and pulse flow assessment detailed in this plan, as well as the Water Temperature study (Stillwater Sciences 2009) included in the Order. Results of these investigations will be evaluated in the context of available information from other studies of the lower Tuolumne River and consideration of other beneficial uses of Tuolumne River water cited in the San Joaquin River Basin Plan (CVRWQCB 1998) and including: agricultural supply (AGR), cold freshwater habitat (COLD), fish migration (MIGR), municipal and domestic supply (MUN), water contact recreation (REC1), noncontact recreation (REC2), fish spawning (SPWN), warm freshwater habitat (WARM), and wildlife (WILD).

4 REPORTING

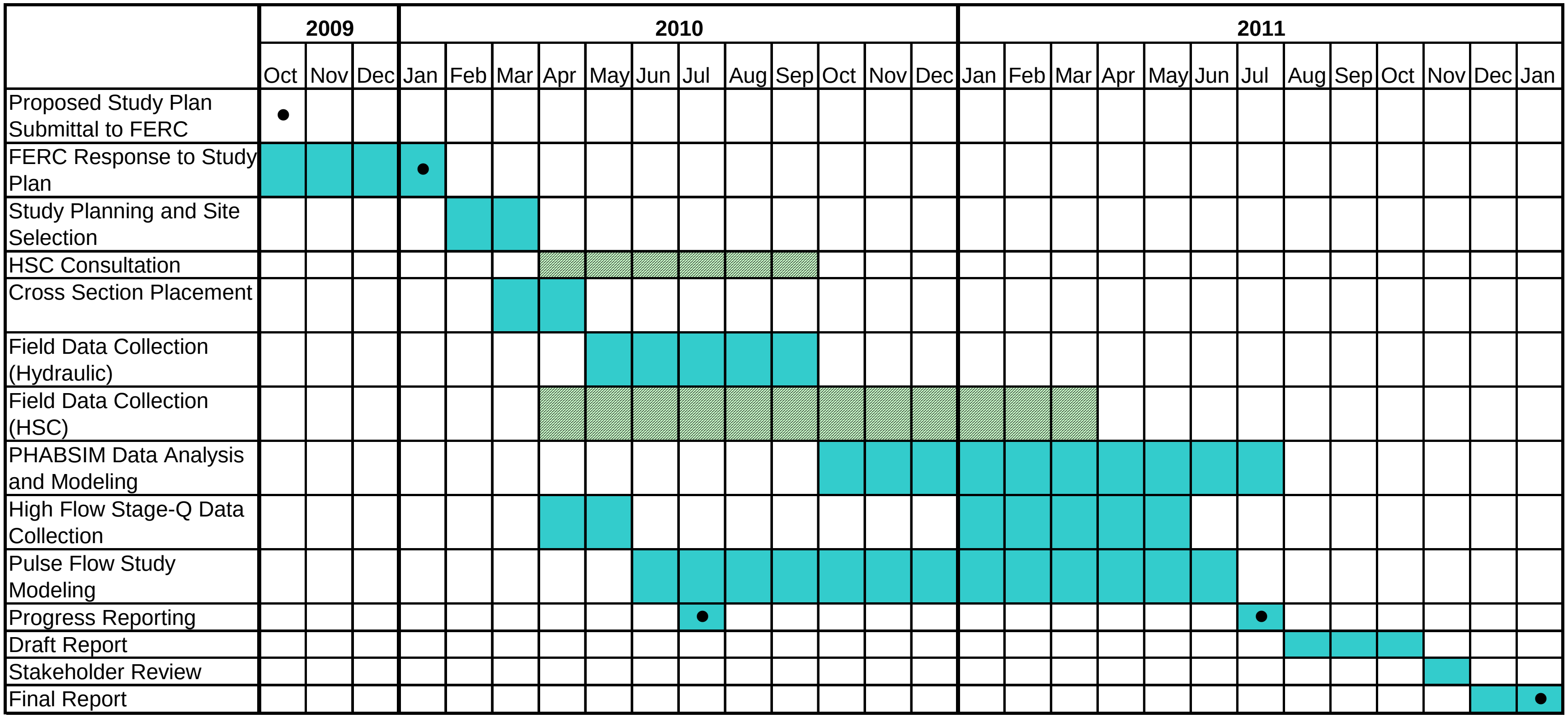
A progress report of the Year 1 and Year 2 data collection efforts, including any changes to the proposed study plan, will be made to the Commission by July 1 in each of two years (2010 and 2011). Following completion of the field studies and analysis, a draft report will be prepared detailing the study methods and results. The draft report will be circulated to the stakeholders for a 30-day review period. Comments will be addressed in a final report that will be filed with FERC within 60 days from the end of the 30-day review period.

5 SCHEDULE

A proposed schedule is provided in Table 8, and graphically represented in Figure 4. The schedule is predicated on an anticipated study plan acceptance date from FERC. A major factor in the proposed schedule is the development of HSC. Although existing HSC are proposed for the lower Tuolumne River, the proposed schedule assumes that site-specific HSC could be necessary for one or more species or life stages, and analytical and reporting tasks are scheduled accordingly. Lastly, for the pulse flow assessment, stage data collection for the highest flow ranges (up to 5,000 cfs) may be delayed from 2010 until appropriate wet year hydrology occurs (flood releases in excess of the 301 TAF annual FERC flow requirements.

Table 8. Proposed schedule for lower Tuolumne River instream flow study implementation.

Item	Dates (duration)	Days from FERC Approval of Study Plan
Proposed Study Plan Submittal to FERC	October 14, 2009	--
FERC Response to Study Plan	January 12, 2010 (90d)	
Study Planning and Site Selection	January 13 to March 13, 2010 (60d)	60
Habitat Suitability Criteria Consultation	March 13 to September 9, 2010 (150d)	240
Cross Section Placement	March 14 to April 27, 2010 (45d)	105
Field Data Collection (Hydraulic)	April 28 to September 24, 2010 (150d)	255
Habitat Suitability Criteria Field Data Collection (if necessary)	April 1, 2010 to March 31, 2011 (365d)	443
Data Analysis (presuming HSC field data collection or 2011 high flow data collection)	April 1, 2011 to July 29, 2011 (120d)	563
High Flow Stage Discharge Data Collection	March 31, 2010 to June 1, 2010 (62d) or January 15, 2011 to June 1, 2011 (137d)	505
Pulse Flow Study Data Analysis and Modeling	June 1, 2010 to June 30, 2011 (394d)	534
Progress Reporting	July 1, 2010 and July 1, 2011	--
Draft Report	October 27, 2011 (90d)	653
Stakeholder Review	November 26, 2011 (30d)	683
Final Report	January 25, 2012 (60d)	743



Note: HSC consultation and field data collection tasks are somewhat independent of other schedule elements of the IFIM Study, but are shown to provide context.

• indicates due date

Figure 4. Proposed schedule for implementation of FERC-ordered instream flow studies.

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Attachment 2
Revised Draft Study Plan (Water Temperature Model)

Lower Tuolumne River Water Temperature Modeling
Final Study Plan

Prepared for
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333 East Canal Drive
Turlock CA 95380

and

Modesto Irrigation District
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Prepared by
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2855 Telegraph Ave. Suite 400
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October 2009

Stillwater Sciences

Suggested citation: Stillwater Sciences. 2009. Tuolumne River Water Temperature Modeling Final Study Plan. Prepared for Turlock Irrigation District and Modesto Irrigation District. Prepared by Stillwater Sciences, Berkeley, California. October.

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1 BACKGROUND AND PURPOSE

The Federal Energy Regulatory Commission (FERC) issued a July 16, 2009 order ("Order") wherein Ordering paragraph (F) directed the Turlock Irrigation District (TID) and the Modesto Irrigation District (MID) to develop a water temperature model in conjunction with instream flow studies of the lower Tuolumne River (FERC 2009). The purpose of the temperature model is "to determine the downstream extent of thermally suitable habitat to protect summer juvenile *Oncorynchus mykiss* rearing under various flow conditions and to determine flows necessary to maintain water temperatures at or below 68 degrees Fahrenheit from La Grange Dam to Roberts Ferry Bridge". The Order further directs the Districts to include study plan elements of methodologies, schedules, progress reports, and consultation with fishery agencies ("Agencies", including the California Department of Fish and Game, National Marine Fisheries Service, and U.S. Fish and Wildlife Service) in developing the plan.

To examine potential water temperature management scenarios for the benefit of lower Tuolumne River salmonids, two overall study questions will be examined in response to the July 16, 2009 FERC Order:

1. What flows are required to maintain summer water temperatures (MWAT) of 68°F or less downstream to Roberts Ferry Bridge at river mile (RM) 39.5?
2. What is the relationship between flow and water temperature at various time periods during the year in specified reaches of the lower Tuolumne River?

Two existing water temperature models have been previously developed for the lower Tuolumne River. Using water temperature and meteorological data collected from 1978–1988, a stream network temperature (SNTEMP) model (Theurer et al. 1984) was previously developed for the lower Tuolumne River during the late 1980's (TID/MID 1992, Appendix 18). The SNTEMP model used channel and basin geometry along with local meteorological data (i.e., air temperature, relative humidity, solar insolation, and wind speed) collected at the Modesto CIMIS weather station (with corrections for differences in elevation) to predict 5-day average instream temperatures from La Grange Dam (RM 52.2) to near the San Joaquin River confluence (RM 2.6) at various times throughout the year under different flow release scenarios. This SNTEMP model was used in conjunction with results of the CDFG instream flow study of habitat areas for key salmonid life stages (Appendices 4 and 5, TID/MID 1992) and the USFWS instream flow study (USFWS 1995), both conducted under the Don Pedro Project FERC fisheries study plan, in the development of the current flow schedule under Article 37 of the current Don Pedro Project (FERC No. 2299) license (FERC 1996).

More recently, a HEC-5Q model was developed for the Tuolumne River and other tributaries of the San Joaquin River as part of a CALFED-funded temperature model (RMA 2008). The Tuolumne River HEC-5Q sub-model was calibrated using updated water temperature and meteorological data collected from 1996–2006. Based upon statements at a November 2007 training session provided by the model developer, RMA Associates, the model reproduces this historical temperature record to within 1–2°F (0.6–1.1°C) depending upon river location and time of year. This performance is more precise than the previous SNTEMP Model, which had a predicted error of ± 2.7°F (1.5°C) with a 90% confidence interval of ± 5°F (3.0°C) (TID/MID 1992, Appendix 18). The model also has output on 6-hour intervals, providing more discrete time intervals than the SNTEMP model.

2 RECOMMENDED STUDY APPROACH

In response to the Order, TID and MID (the "Districts") propose to use the existing HEC-5Q model to simulate water temperatures at various flows and times of year. The study approach is to first validate the existing water temperature model against water temperature data not used in the initial model calibration. Second, the validated HEC-5Q model, will be used to test a series of flow scenarios to determine the flows needed to maintain specified water temperatures at particular river locations at various times of the year. Ultimately, the water temperature model predictions developed in this study will be used in conjunction with instream flow incremental methodology (IFIM) predictions of weighted usable area (WUA) developed under a separate study plan (Stillwater Sciences 2009). For example, IFIM estimates of WUA of suitable habitat meeting particular life-stage-specific criteria (i.e., depth, velocity, and substrate) determined at a particular flow and time of year will be superimposed upon areas meeting particular water temperature criteria to create an estimate of effective WUA, or EWUA.

3 STUDY AREA

As shown in Figure 1, the study area extends from La Grange Dam (RM 52.2) downstream to the San Joaquin River confluence (RM 0.0). The upper reach from La Grange to Robert's Ferry Bridge (RM 39.5) specified in the Order represents the downstream extent of most summer *O. mykiss* observations in past snorkel surveys (TID/MID 2009). It also contains the Dominant Spawning Reach (down to RM 46.6) and the Dredger Tailing Reach (down to RM 40.3) which typically have the majority of Chinook salmon spawning activity (McBain and Trush 2000).

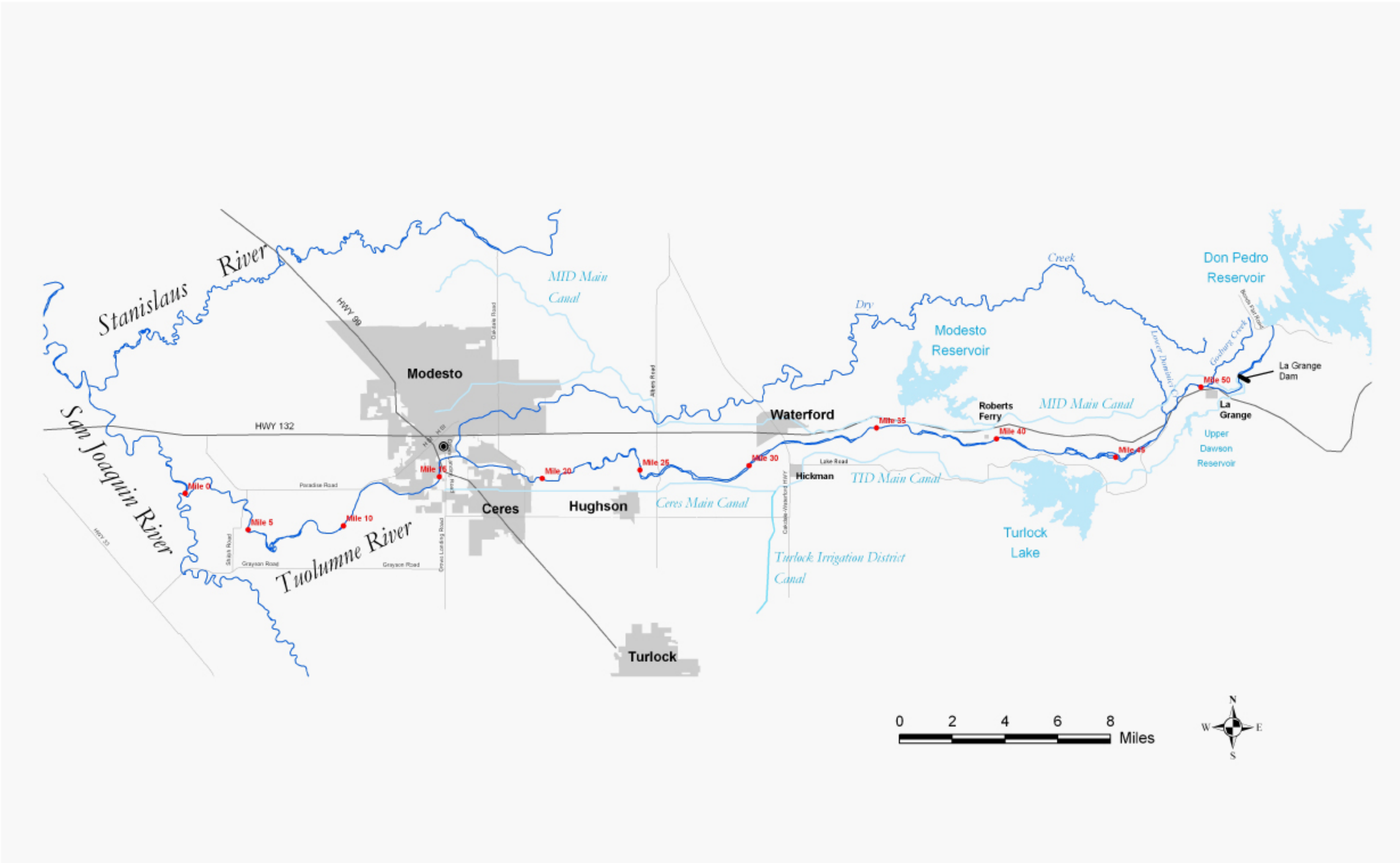

Figure 1. Vicinity map for the Tuolumne River water temperature modeling study.

4 METHODS

The methodology presented in the following sections of this study plan discuss in more detail the steps needed to be performed in order to complete the proposed water temperature modeling study, to inform the complementary IFIM study (Stillwater Sciences 2009), and to report the results to FERC and interested parties.

4.1 Validate Existing HEC-5Q Water Temperature Model

Water temperatures have been recorded continuously by the Districts at various locations in the lower Tuolumne River since 1986 (TID/MID 2005). The HEC-5Q model will be validated against 1996–2009 thermograph data not used in the original model calibration. Data used in the original model calibration may be used if no data independent of the model are available. Because no documentation of the original model calibration was provided in the final CALFED summary report (RMA 2008), an initial step in this process will be to request documentation of thermograph locations, temperature data, and periods of record used in the model calibration so that unbiased goodness of fit statistics can be developed (i.e., observed vs. predicted temperatures) and model uncertainties can be identified. As noted in Section 5, delays in collection of the final HEC-5Q calibration data may result in changes to the proposed schedule. All data records and available metadata (i.e., thermograph model, measurement time-step, specified accuracy, etc) used in the validation exercise will be provided as an electronic data Appendix to the final report.

As recommended by the Agencies, the following temperature modeling goodness of fit metrics are adapted from Theurer et al (1984) using both 6-hr averaged (minimum time-step of the HEC-5Q model) as well as daily averaged thermograph data:

- Maximize the correlation coefficient ($R^2 \leq 1.0$) between modeled and observed water temperatures at individual thermograph locations, as well as across all locations not used in the original calibration data set.
- Determine the fraction of observed temperatures deviating from modeled temperatures by more than 0.5°C, 1°C, and 1.5°C
- Determine any trends in the residual errors (observed minus modeled) either spatially (across several locations) or temporally (at individual locations).

If the goodness of fit results indicate large errors between observed and predicted temperatures, updated model uncertainty estimates will be developed for particular locations or times of year.

4.2 Scenario Development

In addition to an evaluation of the current FERC (1996) flow schedules and the actual flow releases during the 1996–2009 periods as part of the model validation exercise (Section 4.1), the initial scenario will use the validated HEC-5Q model to determine the summer flows necessary to maintain 68°F downstream to Roberts Ferry Bridge (RM 39.5). While these flows are expected to range between 100–400 cfs, the initial model scenario flow range will be expanded if necessary.

In addition to the initial scenario included in the FERC Order (Study Question 1), four additional scenarios corresponding to Study Question 2 were recommended by the Agencies in their review of the Draft Study Plan that correspond to their recommended interim conditions for the protection of various life stages of California Central Valley steelhead (*O. mykiss*) and Fall–run Chinook salmon (*O. tshawytscha*).

1. What flows are required to maintain a summer MWAT of 18ºC (64.4ºF) downstream of La Grange Dam to Roberts Ferry Bridge (RM 39.5)?
2. What flows are required to maintain a MWAT of 18ºC (64.4ºF) downstream of La Grange Dam to the confluence with the San Joaquin River (RM 0) from October 15 to December 1?
3. What flows are required to maintain a MWAT of 13ºC (55.4ºF) downstream of La Grange Dam to Roberts Ferry Bridge (RM 39.5) from October 15 to February 15?
4. What flows are required to maintain a MWAT of 15ºC (59.0ºF) downstream of La Grange Dam to the confluence with the San Joaquin River (RM 0) from March 20 to May 15.

In addition, alternative scenarios (i.e., temperature, location, timing, etc.) may also be evaluated that draw upon findings from the literature or field observations, such as information provided to FERC by the Districts, CCSF, and the Agencies.

4.3 Model Simulations and Analysis

The HEC-5Q model will be used to determine the downstream extent of suitable water temperatures for key *O. mykiss* and *O. tshawytscha* life stages under normal and extreme meteorology. As with any temperature model, using the HEC-5Q model as a predictive tool is limited by the availability of meteorological data corresponding to the conditions of interest (e.g., hottest week of spring or summer), However, various reservoir operation and release scenarios may be simulated against the period-of-record meteorology to generate a range of predicted temperatures for various locations in the river under varying meteorologic conditions. It should be noted that since the reservoir operations modeling component of the existing HEC-5Q is not adequately reflective of actual basin hydrology and District operations of Don Pedro Reservoir, corresponding water storage estimates under various scenarios and water-year types will not be addressed as part of this Study Plan.

4.4 Develop Report

A documentation report will be prepared summarizing the results of the temperature model study, describing the HEC-5Q modeling background, validation, scenario development, model simulations and analysis. The report will include graphics depicting the longitudinal flow versus water temperature relationship under varying meteorologic conditions in order to allow a thermal analysis of various flow regimes. The report will be provided to the Agencies for review and comment prior to submittal to FERC. Periodic progress reports will be prepared as milestone steps under Section 5.

5 SCHEDULE

A proposed schedule is provided in Table 1 and Figure 2. The schedule is predicated on an anticipated study plan acceptance by FERC on or about January 12, 2010, and assumes timely response by the model developer and CDFG in providing requested calibration data and documentation (Section 4.1). In the event that the these responses are not received on a timely basis, or in the event that the validation of the existing model reveals major inconsistencies with observed temperatures in the lower Tuolumne River, the schedule below may be adjusted in consultation with FERC and the stakeholders.

Table 1. Proposed schedule for implementation of FERC-ordered Temperature Modeling Study Plan.

Item	Dates (duration)	Days from FERC Approval of Study Plan
Develop Study Plan and Submit to FERC for Approval	October 14, 2009	--
FERC Response to Study Plan	January 12, 2010 (90d)	
Validate Existing Water Temperature Model	January 13 to April 12, 2010 (90d)	90
Scenario Development	January 13 to May 31, 2010 (139d)	139
Model Simulations and Analysis	June 1 to July 30, 2010 (60d)	199
Progress Report	July 30, 2010 (NA)	199
Prepare Report	October 28, 2010 (90d)	289
Instream Flow and Effective Habitat Evaluations	September 27, 2011 (180d)	623

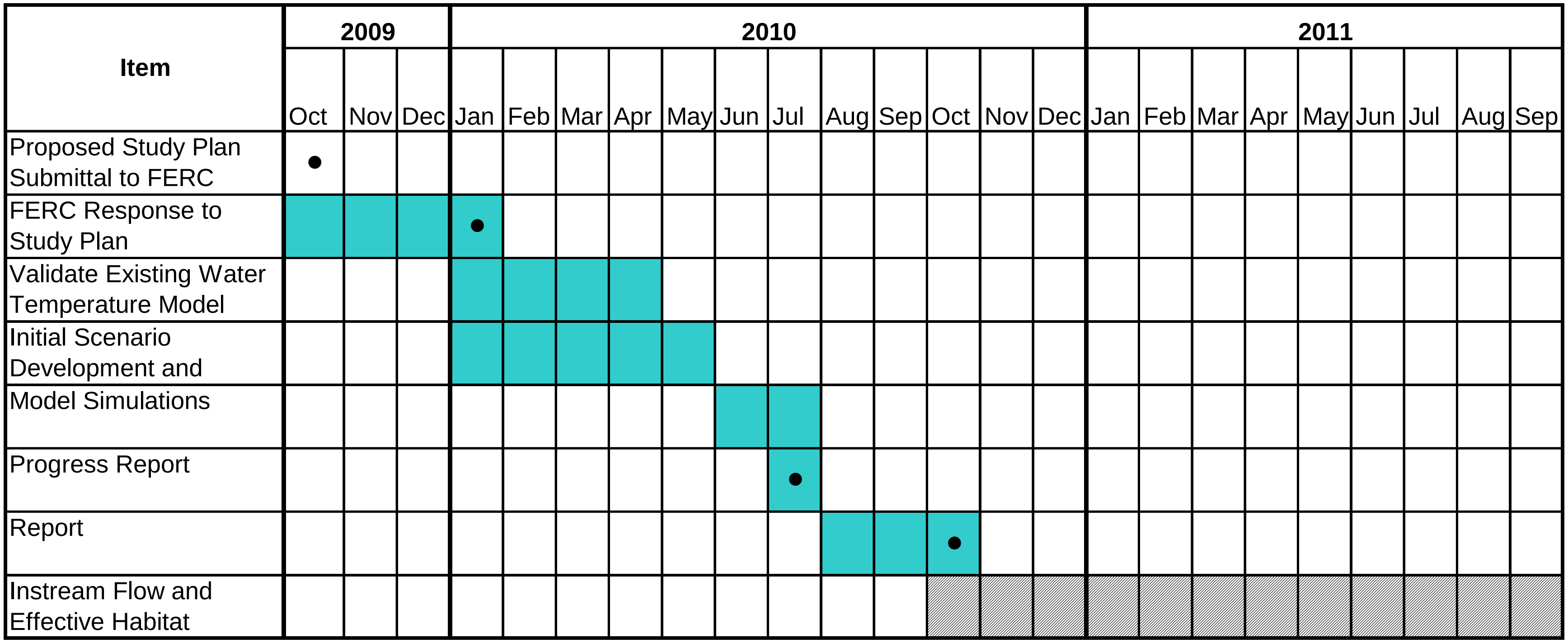

Figure 2. Proposed timeline for implementation of FERC-ordered Temperature Modeling Study Plan.

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