SCOTT RIVER HYDRAULIC HABITAT MODELING

1.0 Study Goals and Objectives

The overall goal of the study is to quantify or characterize fish habitat as a function of flow in the Scott River using either one-dimensional (1D) or two-dimensional (2D) hydraulic habitat modeling.

The specific objectives of the study include:

- Determine the relationship between streamflow and fish spawning and/or rearing habitat, on a seasonal or annual basis using hydraulic habitat models.
- Use habitat index versus flow relationships to develop habitat duration or time series analyses of fish habitat over time under unimpaired, existing, and potential alternative flow scenarios.

2.0 Existing Information/Literature Review

In the early 1970s CDFG conducted a flow study in the Scott River Basin "…to determine minimum flow needs for preserving fishery values in this drainage" (CDFG 1974). Flow need determinations were made based on single measured cross sectional profiles for spawning and rearing (cross sections were established in what was considered representative of the "best" or "key" habitat), utilizing empirical measures of flow volume and velocity and power function relationships to assess larger and small flows than measured. Based on data collected, monthly minimum instream flow recommendations were made for a number of tributaries and at river mile 21 (USGS gage) and river mile 53.4 (Farmer's Ditch) on the mainstem Scott River. Hydraulic modeling and habitat suitability criteria for velocity, depth and substrate were not employed.

Interim fishery flow recommendations were made in 2010 by CDFG in 2010 for the Scott River and several east and west side tributaries (CDFG 2010) using the regression equation method of Hatfield and Bruce (2000). These regional-based flows were recommended as a starting point until such time when more intensive instream flow studies could be implemented. A recent application of the Ecosystem Diagnostic and Treatment model commissioned by the Yurok Tribe (Lestelle 2015) should be reviewed as a supplement to this study plan.

Water rights in the Scott River watershed were adjudicated in the late 1970s, resulting in the Scott River Decree (CSWRCB 1980). The decree spells out the various rights of dozens of claimants in detailed allotments along with their respective seniority. Consideration for non-consumptive instream flow was granted to the U.S. Forest Service within the Klamath National Forest. High flows for fisheries were also reserved pending further development of reservoir storage. This decree and subsequent State Water Board rulings in the watershed may be affected by application of the public trust doctrine as defined in the Mono Lake decision of the California Supreme Court (1983).

3.0 Study Areas

During project scoping, the Scott River was segmented into study reaches using criteria such as hydrology, length, geomorphology, and others (Normandeau Associates 2013; Figures 1 and 2). The study areas for proposed for hydraulic habitat modeling are presented in Table 1 (see Scott River Potential Studies Matrix; http://www.normandeau.com/scottshasta/project_materials.asp).

Table 1. Scott River reaches identified for hydraulic habitat modeling, and estimated priority.

Reach #	Reach Description	Priority
1	Mouth to Shackleford/Mill Creek	High
2	Shackleford/Mill to Oro Fino Creek	High
3	Oro Fino Creek to Moffet Creek	High
4	Moffett Creek-Etna Creek	High
5	Etna Creek to French Creek	High
6	French Creek to Lower Tailings	High
7	Lower Tailings to SF/EF Confluence	High
EF1	East Fork (Lower)	High
EF2	East Fork (Upper)	High
ET1	Etna Creek (Lower)	High
ET2	Etna Creek (Upper)	Low
FR1	French Creek (Lower)	High
FR2	French Creek (Upper)	Low
KD1	Kidder (Middle)	High
KD2	Kidder (Upper)	Low
KP1	Kidder/Patterson (Lower)	High
ML1	Mill Creek (Lower)	High
ML2	Mill Creek (Upper)	Low
MT1	Moffett Creek (Lower)	Low
MT2	Moffett Creek (Middle)	Low
MT3	Moffett Creek (Upper)	Low
PT1	Patterson (Lower)	High
PT2	Patterson (Upper)	Low
S/W	Sugar Creek/Wildcat Creek	High
SF	South Fork	High
SH1	Shackleford Creek (Middle)	High
SM1	Shackleford/Mill Creek (Lower)	High

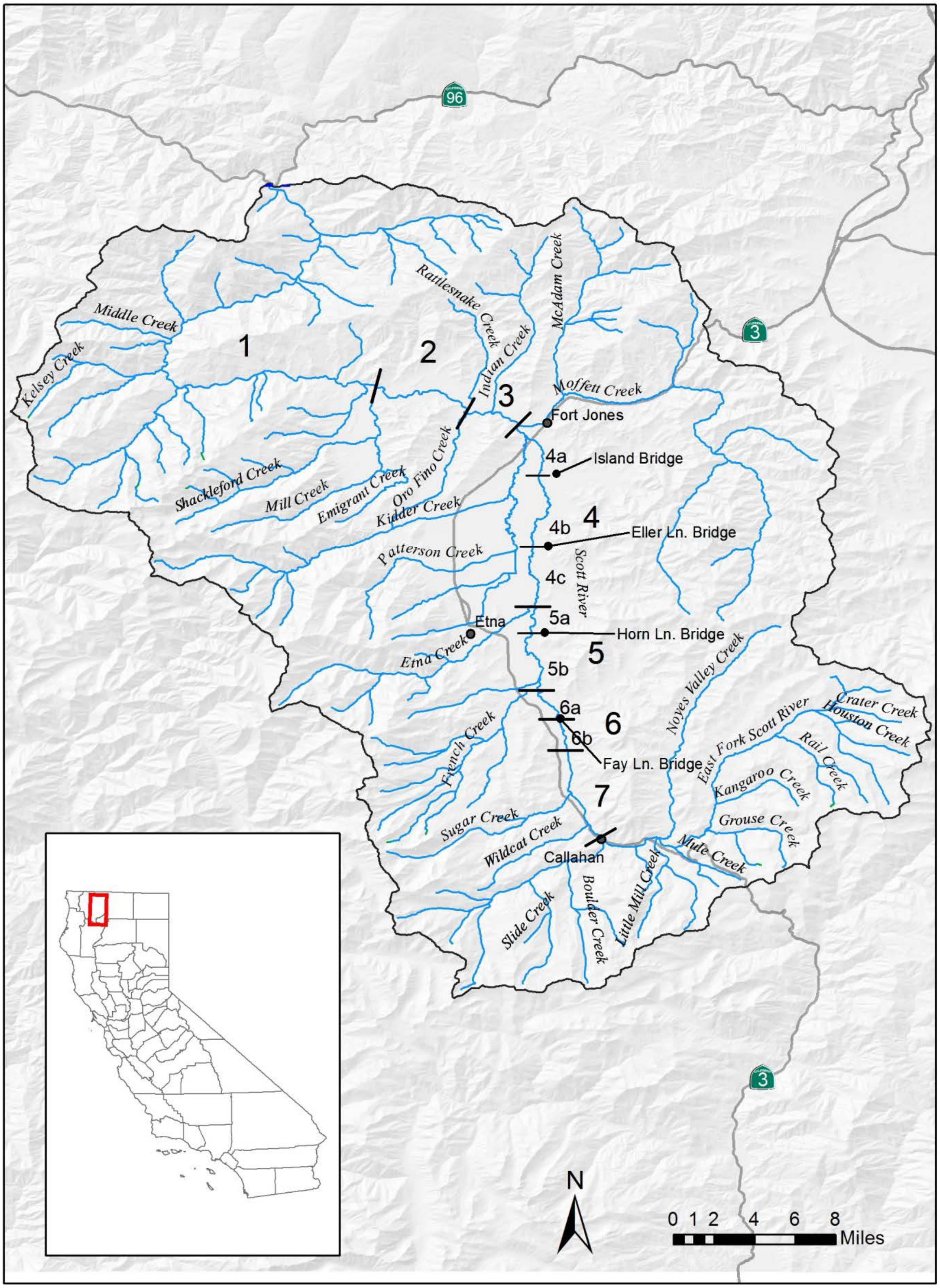

Figure 1. Scott River Mainstem Reaches.

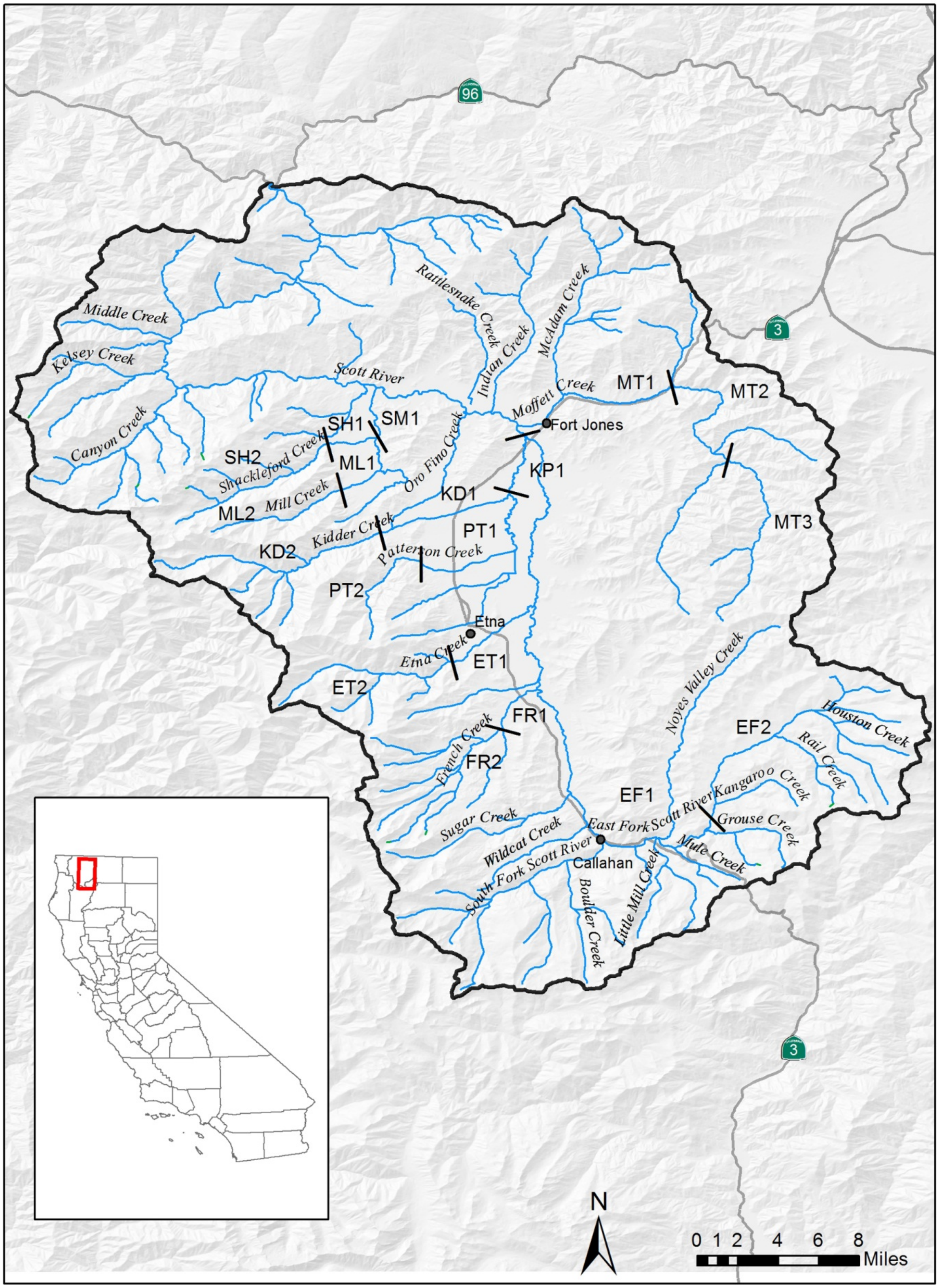

Figure 2. Scott River Tributary Reaches.

4.0 Study Methods

The study approach is to use 1D and 2D hydraulic habitat modeling methods and to apply hydrologic methods if necessary. The hydraulic habitat studies should follow these general steps (not necessarily in the order shown). Steps 1-5 should apply to all study approaches while items 6 through 9 pertain primarily to hydraulic habitat modeling:

1. Stream reach identification and segmentation
2. Geomorphic delineation (mesohabitat mapping) (separate study plan)
3. Selection of target species and life stages
4. Selection of habitat suitability criteria (separate study plan)
5. Selection and rationale for technical study method (1D, 2D, hydrologic)
6. Selection of target flows for sampling and hydraulic model calibration
7. Study site selection
    a. 1D model transect selection
    b. 2D model reach selection
8. Field data collection
9. Hydraulic habitat modeling
10. Habitat time series analysis

4.1. Stream Reach Identification and Segmentation

Stream reaches (Table 1) were stratified based primarily on hydrology and geomorphology. Detail and rationale of study reach segmentation is presented in *"Scott River and Shasta River Study Reaches"* (Normandeau Associates 2013). Adjustment of reach break locations may occur as part of the study review process or during the Study Site and Transect Selection process. Priority is given to the mainstem and the lower reaches of tributary streams.

4.2. Selection of Target Species and Life Stages

The species and life stages that will be used for 1D and/or 2D modeling are based on management goals and recovery plans (CDFG 2003, CDFG 2009, NMFS 2012) in addition to their importance to local tribes. Target species and life stages are identified in the *Habitat Suitability Criteria Study Plan* and shown in Table 2. As part of this task it will be necessary to develop a life stage periodicity table for each identified reach.

Table 2. Target species and life stages to be analyzed in 1D and/or 2D models.

Species	Life Stages	
Oncorhynchus kisutch **(Coho salmon)**	spawning fry rearing juvenile rearing (0+, 1+)	All identified stream reaches where each life stage occurs.
Oncorhynchus tshawytscha **(Chinook salmon)**	spawning fry rearing juvenile rearing	All identified stream reaches where each life stage occurs.
Oncorhynchus mykiss **(Steelhead)**	adult spawning fry rearing juvenile rearing (0+, 1+)	All identified stream reaches where each life stage occurs.
Entosphenus tridentatus **(Pacific lamprey, formerly *Lampetra tridentata*)**	spawning ammocoete rearing	All identified stream reaches where each life stage occurs.

4.3. Selection and Rationale for Modeling Approach

The preferred approach for determining the relationship between streamflow and habitat suitability is 1D hydraulic modeling in conjunction with depth, velocity, and substrate/cover criteria for target fish species and life stages. A 1D or 2D hydraulic model provides more useful results than an empirical analysis due to a model's capability to interpolate and extrapolate hydraulic conditions. If a given stream reach is either inaccessible for various reasons or better suited to 2D hydraulic modeling, that approach may be used. For reaches that are both inaccessible and unmodelable, a hydrologic analysis may be implemented.

Most reaches of most river channels can be adequately evaluated with standard 1D hydraulic models such as those in PHABSIM (Waddle 2001), SEFA (Payne and Jowett 2012), and similar programs. In highly complex channels such as those with multiple braids or exposed bedrock shoals, the ability of 2D hydrodynamic models to predict flow characteristics and features of ecological importance has been well studied (Crowder and Diplas 2000, Waddle 2010). While virtually any available 2D model can used for hydraulic assessment, River2D (Steffler & Blackburn 2002) has the ability to link with habitat suitability criteria and produce relationships between flow and habitat suitability consistent with the study objectives. Most comparisons of the two modeling approaches have concluded there is little difference in habitat index results when applied to the same study sites (Waddle et al. 2000, Gard 2009, Gast and Riley 2013).

Stream reaches where modeling is infeasible may be evaluated using hydrologic statistics, such as mean annual flow, annual, seasonal, and monthly flow exceedance, wet, normal, and dry year stratification, and similar assessments. Creation of the data sets required for statistical analysis will be generated by the *Hydrology and Water Balance Modeling* study plan for the Scott River. Interpretation of the hydraulic habitat modeling or hydrologic statistics and generation of flow recommendations is not part of the current study plan.

4.4. Selection of target flows for hydraulic model calibration

Target calibration flows for each identified reach will be selected based upon natural hydrology from established stream gauging stations or developed from the *Hydrology and Water Balance Modeling* study. The goal is to select flows which will allow hydraulic model extrapolation to at least the 90% and 10% unimpaired annual flow exceedance (AFE) values. Since stage-discharge rating curves can typically be extrapolated down 40% from the low calibration flow and up 250% from the high calibration flow, target low and high calibration flows should be in the range of the 80%-85% AFE and the 15%-20% AFE, respectively, depending on the slope of the AFE curve. These levels of flow are commonly present in normal water years, and neither too low to be rarely present or too high to be unsafe for data collection. Preferably, the middle target calibration flow should be roughly equidistant from the low and high flows on a logarithmic scale to obtain reliable transect rating curves for either 1D or 2D models.

4.5. Study site selection

4.5.1. 1-D Hydraulic Modeling

Study sites (transect or transect cluster locations) should be deliberately selected within the consolidated reach to represent the range of channel and habitat types in the reach (Bovee 1982, Morhardt et al. 1983, Bovee et al. 1998). The characteristic feature of a 1D study reach is homogeneity of the channel structure and flow regime; significant changes in either typically warrant designation of a separate reach. The goal is to characterize the range of hydraulic variability in proportion to its abundance, and thereby generate a relatively accurate representation of the habitat index versus flow relationship for each study reach. This goal will be achieved by distributing transects and transect clusters throughout a study reach in such a way that all modelable habitat types are represented by at least two representative habitat units. Habitat types with a high diversity in a particular reach, such as pool mesohabitat type, may need to be represented by more units even if low in abundance.

Mesohabitat unit and transect selection will be made in conjunction with field review. In general, abundant mesohabitat types should be sampled at a higher frequency than less abundant types, roughly in proportion to their abundance. Adjustments to the proportional sampling may be made based on the biological importance or variability of any particular mesohabitat type. While the total number of transects is dependent on the diversity of channel and habitat types in a study reach, the target number of transects per study reach or sub-reach should be based on CDFW protocols and guidelines (CDFG 2008). The number of transects to represent a reach should be, at minimum, in the range of 17-20 (Payne et al. 2004).

Assuming full access to a reach, the specific locations and lengths of the study sites should be selected in the field as described below. The study sites used for transect placement to represent the different geomorphic and hydraulic conditions should be selected using a stratified random sampling approach based on the least-available sampled mesohabitat type (Payne 1992). Other more-available mesohabitat types will be represented using transects placed in mesohabitat units in close proximity to the least-available selector. This approach minimizes the effect of selection bias, results in transect clustering that limits travel time, and assures transect representation in proportion to habitat availability.

Actual transect selection and placement is typically accomplished with a combination of random selection and professional judgment through the following procedure:

1. All reaches that are accessible and open to study are identified and designated for random transect placement.

2. Within the accessible areas, the habitat type with the lowest percentage of abundance (from the habitat mapping data) is used as the basis for random selection (provided that the habitat type is ecologically significant and modelable). If the distribution of the initial least common selector is too limited to provide an adequate choice of representative habitats, the next least common selector will be used.

3. All habitat units of this type within the accessible distance that were judged to be modelable during the geomorphic mesohabitat mapping are sequentially numbered and a minimum of five units selected by random number.

4. In the field, the first selected unit is relocated and, if it was judged to be modelable and reasonably typical of that particular habitat type within the study reach, one or more transects is/are placed to best represent the habitat type.

5. At least one example of each remaining habitat type is then located in the immediate vicinity of the random transect (upstream or downstream) until transects are placed in all significant types.

6. This process is repeated with the second, third, fourth or higher random selector to place additional clusters until the different geomorphic and hydraulic conditions are adequately characterized or the target total number of transects is reached.

Although the outlined steps are fairly rigorous, all decisions regarding transect placement are subject to revision through the exercise of professional judgment by study participants, including the specific inclusion of desirable study areas not randomly selected and the placement of transects across appropriate spawning gravels.

In the event only a segment of a reach can be accessed, the study site and transect locations should be selected to represent the reach as a whole (representative reach approach).

4.5.2. 2D Hydraulic Modeling

Study site selection for 2D modeling will depend on reach access, the need for applying a two-dimensional model and channel complexities identified through habitat mapping. The ability of two-dimensional hydrodynamic models to model flow characteristics and features of ecological importance has been well established over the last several years (Crowder and Diplas 2000; Waddle 2010). Depth averaged two-dimensional hydrodynamic models use a detailed topography of the study site to solve governing equations for conservation of mass and conservation of momentum in two horizontal directions to simulate water depths and velocities allowing for the modeling of complex flow patterns. Model inputs are bed topography, channel roughness, as well as the upstream and downstream boundary conditions. The most important data requirements are detailed topographic measurements of the streambed at the site. The upstream boundary requires an inflow amount and the downstream boundary requires the corresponding water surface elevation for the given inflow.

4.6. Hydraulic Model Data Collection

4.6.1. 1-D Field Data Collection

Physical habitat and hydraulic parameters will be measured using a combination of standard techniques of the USFWS methodology (Trihey and Wegner 1981, Bovee 1997, CDFW 2013) and techniques outlined in this study plan. Hydraulic model data collection methods may vary somewhat between study reaches, depending on physical and channel conditions. For example, different velocity meters may be used in deep versus shallow water, in areas with or without aquatic vegetation, or where data collection at the target flow for a given transect is unsafe and either edge-only velocities are collected or a velocity set is obtained at a lower flow.

Surveying and Controls

All elevations will be surveyed by standard differential survey techniques using an auto-level or total station instrument. Headpin and tailpin elevations, water surface elevations (WSE), hydraulic controls, and above-water bed and bank elevations will be referenced to a temporary benchmark serving a single transect or transect cluster. Where reasonable (line of sight or single turning point), benchmarks will be tied together. At a minimum, all transects surveyed in a single mesohabitat unit will have a common datum. Transect locations will be fixed, to the accuracy level possible, using a handheld GPS instrument.

Water Surface Elevation-Discharge

Stage/discharge measurements will be obtained at no fewer than three discharges. Additional stage/discharge measurements may be collected at higher flows (possibly lower also) in order to model habitat over a greater range of the flow frequency curve. When only a stage/discharge measurement is taken, discharge through the study site will be measured using manual velocity meters or a combination of an ADCP (described below) and manual velocity meters at a cross section suitable for accurate discharge determination.

Calibration Velocity Measurement

One velocity calibration set is to be collected at the high target flow for hydraulic modeling and simulation over the complete flow range. The calibration set may be obtained at a middle or even low flow if conditions are unsafe at the high flow. At transects and flows where depths are predominantly greater than 2.5 feet, velocity distributions would be most efficiently measured using an ADCP mounted on a flotation device, although other methods may still be used. According to an extensive evaluation conducted by the USGS (Morlock 1996) and recent application of ADCPs in the field, an ADCP can be used successfully for data collection under a variety of field conditions. In areas that can be successfully measured by wading, measurements will be taken using any calibrated digital, magnetic, or manual velocity meter mounted on standard USGS top-set wading rods. The standard method for determining mean column velocity will be a single measurement at six-tenths of the water depth in depths less than 2.5 feet, a two-tenths and eight-tenths measurement for depths between 2.5 feet and 4.0 feet, and all three depths where total depth exceeds 4.0 feet. Additional measurements at these three depths should be taken where the velocity distribution in the water column is abnormal and fewer points are not adequate to compute an accurate mean column water velocity.

To assure adequate characterization of micro habitat for all life stages (e.g. adult, fry, juvenile, and spawning), during manual velocity measurements, verticals along a transect will be purposefully placed to describe points where changes in substrate, bed elevation, and velocity occur. The number of verticals will be adjusted in the field to accomplish micro habitat stratification as dictated by site-specific conditions, and will also be increased in stream margin areas where fry or juvenile fish habitat is present. The placement and number of verticals should be designed to limit discharge around any one vertical to no more than 10% of the total discharge. To meet this standard, more verticals can be placed by default in deep, fast sections using professional judgment and experience, or discharge can be calculated in the field at the time of data collection and more verticals added as needed.

Temporary staff gage levels located adjacent to the study site and the time of day should be recorded at the beginning and end of each transect measurement to identify changes in discharge. Continuous recording level-loggers may be deployed in certain reaches to monitor changes in stage during the calibration measurements. A continuous record of stage is useful in modeling if flows do change during calibration measurements. In the event a noticeable fluctuation (>0.05’) in stage occurs it may be necessary to re-measure discharge and WSL at one or more transects. Each cluster of transects should have at least one transect capable of accurately computing discharge, even if it has to be added for the purpose.

Substrate

Substrate will be classified according to a standard procedure, and will be evaluated visually during low flow conditions. Percent occurrence of all substrate sizes within the immediate vicinity of each vertical (1-2 feet radius from vertical) will be recorded. Potential particle size categories are described below, though these could change depending on substrate sizes and suitability determined through the habitat suitability criteria (HSC) study:

Organic debris, permanent vegetation
Clay, silt ....<0.1 inches
Sand ....0.1-0.2 inches
Small gravel ....0.2-1.0 inches
Medium gravel .... 1-2 inches
Large gravel ....2-3 inches

Small cobble ....3-6 inches
Medium cobble.......................6-9 inches
Large Cobble .... 9-12 inches
Boulder ....>12.0 inches
Bedrock

4.6.2. 2D Field Data Collection

Topographic data will be collected, primarily, using manual and robotic total stations. Data should be collected under low flow or dry conditions at a minimum resolution of 3 to 4 topographic points per square meter. Other equipment may be necessary for surveying larger, deeper channels including RTK GPS, as well as an ADCP and/or depth sounder. Each study site will be visited at three flow levels appropriate for creating a stage/discharge relationship at the upper and lower boundaries of the site. During the high, middle, and low flow trips, stage/discharge information will be collected. Additionally, during the low flow trip, topography data, substrate/cover polygon data, and habitat mapping data will also be collected.

Aerial stereo photogrammetry or similar resolution LIDAR may also be used to collect the necessary data, provided there is a level of topographic accuracy matching that of a total station. In areas that lack total access remote sensing may be the only means to collect data with the necessary detail to develop a hydraulic model.

Miscellaneous Field Data Collection Methods

Photographs will be taken of all transects from downstream and other points as necessary at each measured flow. To the extent possible, each photograph should be taken from the same location at each of the three levels of flow if possible.

Data sheets for each study site will be completed as follows:

- Photo Log – for each flow/visit
- Site Documentation – sketch or map showing location, type, and numbering of transects – completed once
- GPS UTM Coordinates for each headpin (or mid-channel if headpin reading could not be obtained) and benchmark – completed once
- Water Surface Elevation and Level Loop – WSE completed at each calibration flow, level loop completed once, pin heights validated at each visit (1-D)
- Cover Description – completed once
- Discharge – for each flow, at one, two or more transects
- Depth and Velocity – at each transect for one calibration flow (middle or high)
- Stage of Zero Flow – collected once for each transect
- Cross Section Profile and Substrate – completed once for each transect
- Task Completion Checklist – in field for every visit

4.7. Hydraulic Habitat Modeling

4.7.1. 1-D Modeling

Hydraulic modeling procedures appropriate to the study site and level of data collection will be used for modeling water surface elevations and velocities across each cross-section. For water surface elevations, these procedures include: the development of stage-discharge rating curves using log-log regression, channel conveyance (MANSQ or similar), and/or step backwater models (WSP, HEC-RAS); direct comparison of results; and selection of the most appropriate and accurate method. If, for example, rating curves using log-log and channel conveyance methods are nearly identical, then log-log will be used to easily allow changes in simulated flows. But, if the two methods diverge and the transect is a riffle or run, the channel conveyance method should be selected for flow simulation. Water velocities will be simulated using the Manning's n method of velocity distribution across all transects, with calibrations generally consisting of correction of over- or under-simulated velocities at individual sample points (i.e. velocity adjustment factors or VAFs). Data file construction, calibration, simulation, reporting, review, and consultation will follow standard procedures and guidelines.

Mesohabitat types will be weighted and combined to develop a representation of hydraulic characteristics and fish habitat suitability for each 1D reach or sub-reach. Mesohabitat weighting will be based on the relative proportion of each of the modeled mesohabitats within the reach or sub-reach. A final habitat index for each study site will be produced by combining hydraulic simulations over a range of flows with HSC for selected species and life stages. Any currently available standard software package that meets the standards set by Waddle (2000) may be used for the 1-D habitat modeling.

4.7.2. 2D Modeling

Model calibration consists of adjusting the roughness values in the model until a reasonable match is obtained between the simulated water surface elevations and the surveyed water surface elevations and water's edge measurements taken along the study site at a given flow. Models may be calibrated at a single flow and then validated at the two other flows, or the model can be calibrated at each measured flow.

Once calibrated, the downstream water surface elevation and the inflow of the model will be changed to simulate the flows of interest. Each modeled flow is run to a steady state solution. That is, for a constant inflow, the model is run until there is a constant outflow and the two flows are essentially equal. Typical convergence tolerance is 1% of the inflow. Another measure of convergence is the solution change. Ideally the solution change will become sufficiently small (0.00001) once converged. In some cases, the solution change will reach a relatively small value and refuse to decrease any further indicating a small, persistent oscillation at one or more points. This oscillation is often associated with a shallow node that alternates between wet and dry. This oscillation may be considered acceptable if the size of the variation is within the desired accuracy of the model (Steffler and Blackburn 2002).

The fish habitat component of River2D is based on the same habitat index utilized in standard 1D models. The habitat index for the entire site is calculated by expanding the composite suitability index for every point in the model domain with the area associated with that point, and then summing those values for all points. The composite suitability is calculated as the product of suitability values for depth, velocity and channel index (cover and substrate codes). Output will include node characteristics of habitat suitability values for depth, velocity, channel index (substrate and/or cover), and combined parameters at a number of flows for each species and life stage of interest. Output will also include image files of the plan view of change in suitability for each habitat parameter at selected flows for each species/life stage.

4.7.3. Habitat Time Series

The habitat index versus discharge function is a static relationship between discharge and habitat that does not represent how often a specific flow/habitat relationship occurs. For this reason, in many cases the index alone should not be considered the final result of a 1D or 2D model. A more complete analysis is the habitat time series (HTS) analysis. An HTS integrates the habitat index versus flow function with hydrology to provide a dynamic analysis of flow versus habitat. Results of the HTS are most useful when the broadest possible range of hydrology is entered into the model. For this reason it may be necessary to extend the stage-discharge flow rating curve beyond 2.5 times the highest calibration flow with additional stage/discharge measurements made during field data acquisition.

4.7.4. Hydrologic Data Sources

Hydrology for some reaches may be dependent on results from *Hydrology and Water Balance Models* and Scott River groundwater models (Papadopulos & Associates 2012, Foglia et al. 2013). The period of record depends on availability of hydrologic data. The HTS analysis should use the same period of record used for basin hydrology models.

5.0 Deliverables

Study products will include: a) a study report that includes a summary of field methods, data analysis, and results; b) all 1D and 2D model digital data on CD; and c) any spreadsheets or other analytical tools used for data analysis.

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