SHASTA RIVER FLOODPLAIN HABITAT CONNECTIVITY

1.0 Study Goals and Objectives

The goal of this study is to identify streamflows in the Shasta River that provide sufficient connectivity and inundation of floodplain/off-channel habitat to support and promote the growth of juvenile salmonids. This requires an understanding of the spatial and temporal dynamics of floodplain connectivity and availability relative to the habitat needs of the key evaluation species and life stages. The specific objectives of the study include:

1) Review and summarize the key ecological functions and attributes of floodplain and other off-channel habitat associated with juvenile salmonid rearing success in the Shasta River.

2) Identify the key species/life stages and floodplain inundation attributes (e.g., water depth, water velocity, vegetative cover and hard substrate components, inundation area, timing/duration of inundation) for evaluating connectivity and quantity/quality of floodplain habitat in the Shasta River.

3) Identify representative study sites for evaluating the relationship between hydrology, connectivity, and habitat quantity/quality of floodplain and other off-channel habitat.

4) Use empirical data and hydraulic modeling to determine the relationship between flow and floodplain habitat connectivity and quantity/quality for target species/life stages.

5) Use hydrological and hydraulic data to describe the frequency and extent of floodplain and other off-channel habitat availability under natural unimpaired (see *Shasta River Hydrology and Integrated Surface Water/Groundwater Modeling* study plan) and alternative flow physical restoration scenarios.

The floodplain habitat connectivity study plan will need to be developed in coordination with the California Department of Fish and Wildlife (CDFW) and the data collection, analysis, and modeling tasks described in the *Hydrology and Integrated Surface Water/Groundwater Modeling, Hydraulic Habitat Modeling, Habitat Suitability Criteria,* and *Water Temperature Assessment* study plans. Potential coordination needs with other study plans are referenced below under each of the study tasks.

2.0 Review of Existing Information

Published and unpublished literature on the floodplain and off-channel habitat needs of anadromous salmonids in the Shasta River will be compiled, reviewed, and summarized. During the initial phase of study plan development, specific study reaches were identified where floodplain connectivity is a primary resource issue, and relevant documents that discuss the status or need for such studies were identified in the Shasta River Potential Studies Matrix; (http://www.normandeau.com/scottshasta/project_materials.asp).

The objectives of this task are to identify the key evaluation species/life stages and the physical, hydrologic, and hydraulic variables affecting connectivity, quantity, and quality of floodplain and off-channel habitat for these species/life stages. This task should include a review of the available published and unpublished information, including the following sources:

- Habitat restoration and recovery plans for salmon and steelhead ESUs/DPSs and populations in the Shasta River.

- Records and studies of historic and current use of floodplains and off-channel habitat (including irrigation flow returns) by salmon and steelhead in the Shasta River.

- Documents identifying key ecological functions (e.g., spring/summer rearing, winter refugia), attributes (e.g., minimum passage depth for young-of-year salmonids [0.3 feet]), and processes (e.g., food production) defining the connectivity and suitability of floodplain habitat for growth, survival, and production of juveniles.

- Hydrologic, water quality, and biological factors (e.g., distribution of rearing juveniles) potentially affecting floodplain and other off-channel habitat use in the study reaches (*Hydraulic Habitat Modeling, Hydrology and Water Balance Modeling,* and *Water Temperature Assessment*).

- Floodplain inundation modeling and photo-documentation in the Shasta River canyon (McBain & Trush 2014) and the Big Springs Complex (McBain & Trush 2013).

This task also includes telephone and email correspondence with CDFW to review results and agree on data gaps and the specific study reaches or sites where field surveys will be conducted.

3.0 Study Areas

The study area includes the Shasta River watershed, Siskiyou County, California. During project scoping, the Shasta 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 where floodplain and off-channel juvenile rearing habitat connectivity was identified as a primary resource issue were described in the Shasta River Potential Studies Matrix (http://www.normandeau.com/scottshasta/project_materials.asp) and are listed in Table 1.

Table 1. Reaches of the Shasta River and tributaries where floodplain and off-channel habitat connectivity will be evaluated.

REACH DESCRIPTION	Reference(s)	Studies Status
Mainstem Shasta (1-7)	CDFW (2014)	Partial
Little Shasta Confluence to Lower Shasta Road (LS1)	CDFW (2014)	Needed
Little Shasta Lower Shasta Road to Cold Bottle Springs Creek (LS2)	CDFW (2014)	Needed
Parks Creek Shasta River to I-5 (P1)	CDFW (2014)	Needed
I-5 to the MWCD Diversion (P2)	CDFW (2014)	Needed
MWCD Diversion to East Fork confluence (P3)	CDFW (2014)	Needed
Yreka Creek Confluence to Hwy 3 (Y1)	CDFW (2014)	Needed
Yreka Creek Hwy 3 to Greenhorn Creek (Y2)	CDFW (2014)	Needed
Yreka Creek Greenhorn Creek to Headwaters (Y3)	CDFW (2014)	Needed

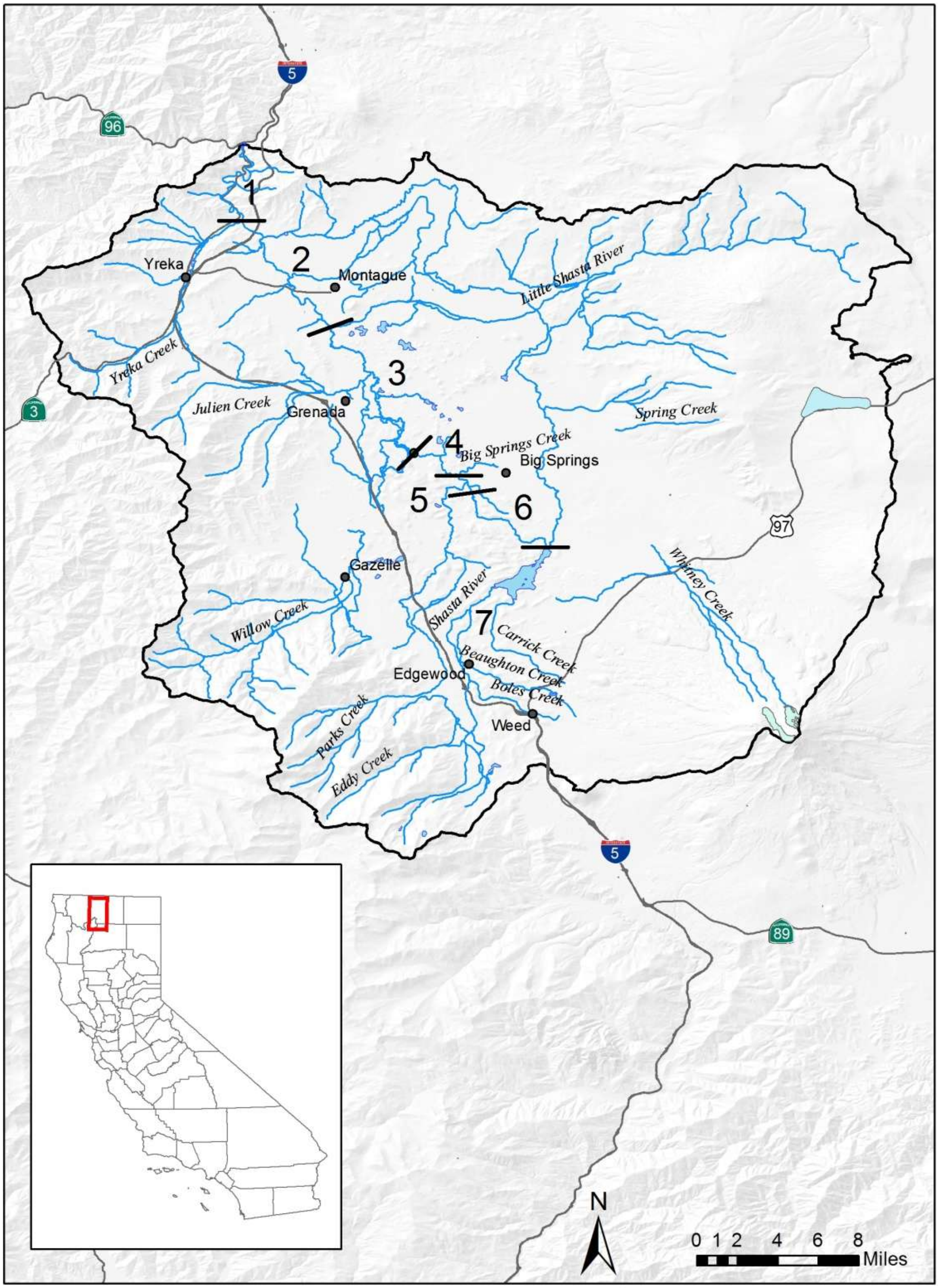

Figure 1. Shasta River Mainstem Reaches.

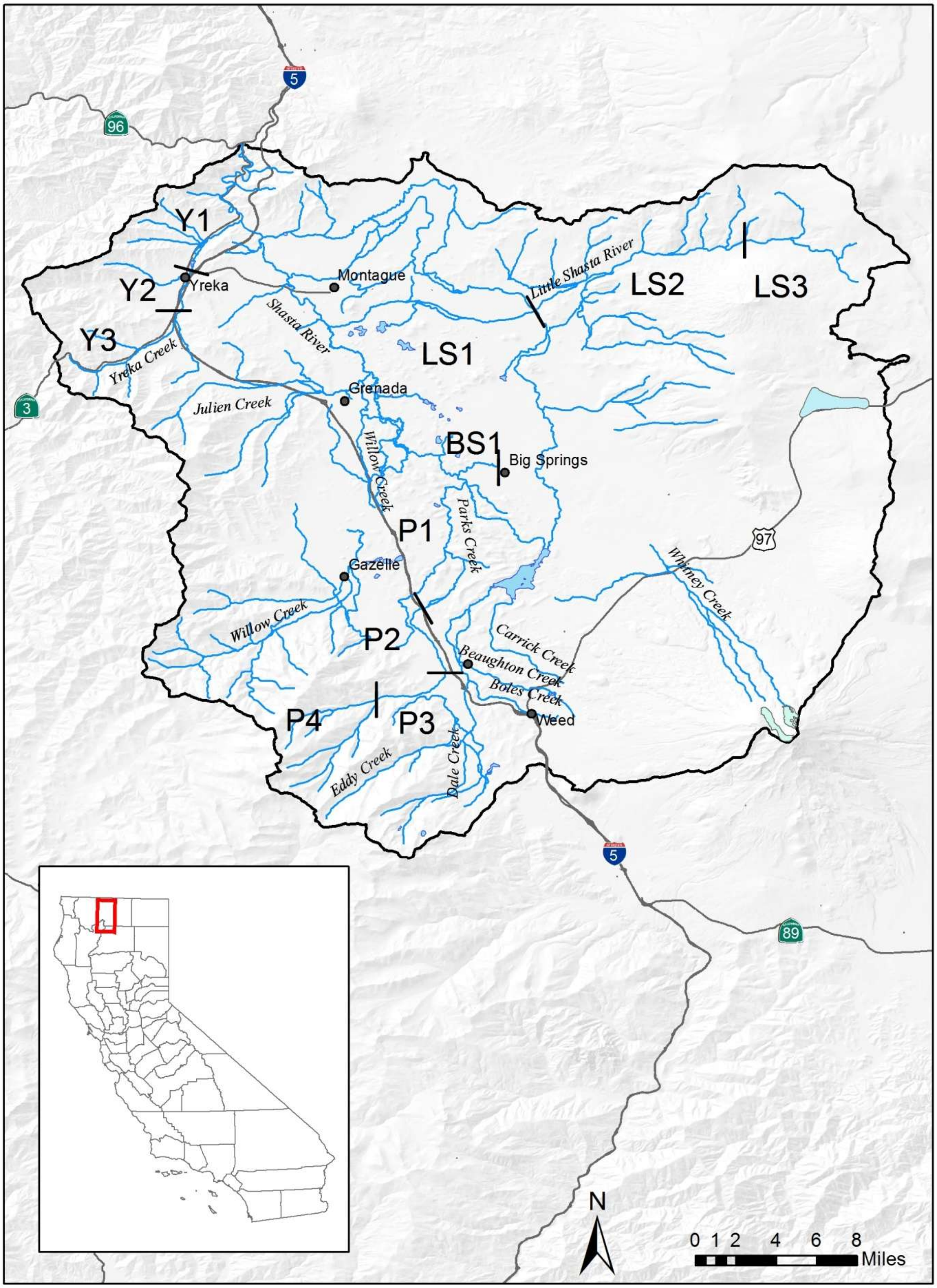

Figure 2. Shasta River Tributary Reaches. Little Springs Creek (Reach BS1a) is a tributary to Big Springs Creek and is not depicted due to its short relative length (0.7 miles).

4.0 Study Methods

Assessment of the relationship between streamflow and floodplain connectivity typically requires a combination of field surveying, data collection, and hydraulic modeling depending on study objectives, site conditions, flow evaluation range, and the target species/life stages. Three primary considerations in identifying an appropriate approach are the target range of flows to be evaluated, the desired level of spatial resolution, and the need to evaluate potential modifications to channel-floodplain morphology to restore or enhance floodplain connectivity and availability. Data collection, modeling, and analytical requirements include:

Hydrologic analysis of the timing, frequency, and magnitude of flows associated with floodplain connectivity and inundation.

- Field surveys of potential off-channel juvenile salmonid rearing habitat locations within irrigation flow returns, including main-channel connectivity, physical characteristics (substrate, fine sediment, water quality), and fish utilization.
- 1-D (transect-based) or 2-D (grid-based) hydraulic modeling to simulate changes in floodplain connectivity and inundation (floodplain habitat quantity and quality) as a function of flow.
- Field measurements of flows, water surface elevations, water depths, and other attributes (i.e. vegetative cover and hard substrate components – conducted consistent with other Shasta River study plans) to calibrate/validate model predictions and characterize other conditions (e.g., water temperature, dissolved oxygen) that may affect the suitability of floodplain habitat for the target species/life stages.
- Integration of hydrologic, topographic, and hydraulic data to describe the frequency and extent of floodplain availability under unimpaired and other flow restoration scenarios, including potential actions to restore or enhance access to floodplain habitat through channel/bank modifications (e.g., agricultural berm removal) or development of side-channel habitat (Rosenfeld et al. 2008).

To the extent feasible, the assessment of floodplain connectivity will be coordinated with the study design, methods, and analysis described under *Hydraulic Habitat Modeling*.

4.1. Reconnaissance Surveys

Reconnaissance-level field surveys will be conducted to further characterize potential study sites in the designated study reaches. The objective of these surveys will be to obtain preliminary field observations and measurements to assist in selecting study sites that are both representative and significant to target fish species. To the extent possible, this task should be coordinated with field surveys, habitat mapping, and data collection tasks described in *Hydraulic Habitat Modeling and Habitat Suitability Criteria*. A floodplain habitat connectivity data sheet will be developed in coordination with the California Department of Fish and Wildlife (CDFW) to document site characteristics and identify important functional habitat types for the key evaluation species and life stage (e.g., winter refuge habitat). Potential data needs include elevation of river-floodplain connections (relative to observed water stage or high water mark), proximity to main channel, potential area of inundation, and important physical characteristics (e.g., side channels). A GPS receiver and camera will be used to document the general characteristics of each potential study site.

4.2. Floodplain Connectivity Implementation Strategy

Once specific study sites have been identified through review of existing information and field surveys, the contractor will coordinate with CDFW to finalize the selection of study sites and assessment methods and prepare an implementation strategy report. The implementation strategy will include summary descriptions of each study site, including the target species, life stages, and applicable habitat suitability criteria; site attributes potentially limiting floodplain habitat connectivity and suitability; and proposed data collection and analytical methods. A draft implementation strategy report will be submitted to CDFW for review and comment before being revised and submitted to CDFW for approval.

4.3. Flow Duration Analysis

Flow duration analysis (CDFW 2013) should be applied to existing or synthesized long-term daily flow data (*Hydrological and Water Balance Modeling*) to determine the timing, frequency, and extent of floodplain inundation, and identify the range of flows that will be used to guide field data collection and modeling efforts in the designated study reaches of the Shasta River. The range should include frequent flows that inundate portions of the floodplain to less frequent flows that inundate a significant portion of the floodplain. Other available data sources (e.g., aerial photographs, satellite imagery, LIDAR surveys) should be reviewed to define the general relationship between flows and floodplain inundation within each of the study sites.

4.4. Field Data Collection

Field data should be collected at the study sites during two or more floodplain inundation events to evaluate the relationship between flow and floodplain connectivity, and characterize changes in floodplain habitat quantity and quality over the range of target flows. Field data requirements depend on site characteristics, model calibration requirements (see *1-D and 2-D Hydraulic Modeling* below), the desired level of spatial and temporal resolution, and the specific attributes or metrics used to define floodplain connectivity and habitat quality. Key attributes to be measured in the field include river discharge, water surface elevations and depths of river-floodplain connections, area and duration of usable floodplain habitat, availability of cover, water temperatures, and water quality (e.g., dissolved oxygen). If target flows or access are not available during the initial phases of field data collection, aerial photography, LIDAR surveys (TerraPoint 2008), and field or GIS-based delineation of inundated floodplain areas (e.g., USFWS 2008) should be used as an alternative to hydraulic modeling. Photographs, LIDAR, or GIS surveys should be analyzed at multiple flows in order to be sufficient for evaluating changes in connectivity and inundation area with changes in flow. Monitoring of fish presence or utilization of floodplain habitats in relation to physical, hydraulic, and water quality conditions should also be implemented to address uncertainties in defining suitable floodplain habitat.

4.4.1 1-D Hydraulic Modeling

1-D transect-based hydraulic models (e.g. HEC-RAS) can generally be applied to estimate flows resulting in overbank flows or floodplain inundation, and develop relationships between flow and floodplain inundation area (wetted area). General limitations of 1-D hydraulic modeling applicable to floodplain habitat modeling include relatively large data requirements (i.e., intensive sampling at several flows), poor reliability in extrapolating outside the measured flow range, and limitations in describing habitat at scales relevant to fish (Leclerc et al. 1995). Consequently, 1-D hydraulic modeling may not be appropriate for modeling floodplain habitat where relatively high spatial and temporal resolution is needed to accurately describe potential rearing or overwintering opportunities for fish in structurally complex off-channel and floodplain areas.

1-D hydraulic modeling of floodplain habitat will be performed using the general steps described in the *Hydraulic Habitat Modeling* study plan. Step backwater models (e.g., WSP, HEC-RAS) are generally recommended for simulating overbank or floodplain inundation flows (Bovee et al. 1998). Topographic maps derived from aerial photogrammetric techniques or LIDAR can be used to improve the predictive capabilities of 1-D hydraulic modeling (see *2-D Hydraulic Modeling* below).

4.4.2 2-D Hydraulic Modeling

2-D grid-based hydraulic modeling is generally recommended for modeling floodplain connectivity and habitat availability where it is important to accurately model relatively small-scale (microhabitat) spatial and temporal variation in hydraulic conditions resulting from the lateral interaction of river flows with structurally complex floodplains or off-channel areas (LeClerc et al. 1995, USFWS 2011, Kupfer and Meitzen 2012, Bowen et al. 2003).

The general steps in performing floodplain inundation analysis using 2-D hydraulic modeling (RIVER2D) are summarized below. Further details related to the application of 2-D hydraulic modeling to IFIM can be found in Leclerc et al. (1995). Standard methods for the application, calibration, and validation of the RIVER2D model are described by USFWS (2011). An example of the application of this model to floodplain connectivity and inundation mapping can be found in Bowen et al. (2003).

1) Establish a 1-D transect at the upstream and downstream end of each study site and develop stage-discharge relationships for in-channel and overbank conditions to define the boundary conditions for the study site. These transects should include the river channel and floodplain up to the elevation of the highest floodplain inundation flow to be simulated.

2) Develop a topographic map of the study site between the upstream and downstream transects. Record the position, elevation, and dominant substrate and cover type at sampling points distributed throughout the study site. The number and distribution of sampling points depend on the size and structural complexity of the study site, and the desired spatial resolution of the floodplain map by CDFW with respect to elevation, substrate, or cover type, and other macro- and micro-habitat parameters important to the target species and life stages. Topographic data can be collected with a total station, survey-grade GPS or, in unwadeable areas, a total station or survey-grade GPS and Acoustic Doppler Current Profiler (ADCP). Other potential sources or methods for generating topographic (land surface) data include photogrammetric techniques and LIDAR.

3) Process the topographic data using appropriate utility programs to develop a digital model of the river and floodplain surface, and calibrate the 2-D model using the standard methods described by USFWS (2011).

4) During a suitable reference floodplain inundation event (based on flow duration analysis), measure water surface elevations (using an autolevel and/or total station or survey-grade GPS), water depths, and velocities at the upstream and downstream transects as well as a number of random locations within the study site to validate the hydraulic predictions of

the 2-D model. River flow should be monitored at an upstream gage or measured at the time of field measurements.

4.5. Floodplain Connectivity and Habitat Analysis

The 1-D or 2-D hydraulic modeling results will be used to construct relationships between flow and floodplain habitat connectivity and availability at each of the study sites. Water depth will be used as the primary criterion for evaluating accessibility (connectivity) and availability of floodplain habitat for the key evaluation species/life stages. GIS will be used to analyze the hydraulic modeling results and generate habitat classification maps depicting the distribution of water depths and associated changes in connectivity and extent of habitat across the floodplain over the range of floodplain inundation flows (e.g., Bowen et al. 2003). Other variables such as water velocity, cover, and substrate may also be important habitat classification variables.

Habitat duration or time series analysis (HDA; see *Shasta River Hydraulic Habitat Modeling* study plan) will be used to evaluate floodplain connectivity and availability under three different flow or physical restoration scenarios, as identified by CDFW. HDA can be used to compare the performance of these scenarios based on a number of key ecological metrics. Key metrics will likely be the frequency, duration, and magnitude of ecologically-significant floodplain inundation events (i.e., floodplain events of sufficient frequency, duration, and magnitude to result in significant long-term habitat values and associated biological responses). In addition to evaluating the effects of potential flow alterations, the study plan may include application of the 1-D or 2-D hydraulic models to investigate the effects of proposed actions to restore connectivity and functionality of existing floodplains through modifications of floodplain morphology and/or connections with the main river.

5.0 Deliverables

The floodplain habitat connectivity study products will include:

1) Floodplain habitat connectivity data sheets, including observed river flows, water surface elevations and depths of river-floodplain connections, aerial extent of floodplain inundation, and other important floodplain habitat attributes.

2) GPS coordinates, maps, and photographs of potential and selected study sites.

3) An implementation strategy report describing selected study sites and assessment methods.

4) Draft and final floodplain connectivity evaluation reports, including descriptions of field and analytical methods; relationships between river discharge and floodplain connectivity, quantity, and quality; and the results of flow and habitat duration analyses of floodplain connectivity under natural unimpaired and other flow or restoration scenarios.

6.0 Literature Cited

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