LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT
STUDY REPORT
DON PEDRO PROJECT

FERC NO. 2299

WATER & POWER
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Modesto Irrigation District

Prepared for:
Turlock Irrigation District – Turlock, California
Modesto Irrigation District – Modesto, California

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Lower Tuolumne River Floodplain Hydraulic Assessment
Study Report

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List of Acronyms

ac ....acres
ACEC.........................Area of Critical Environmental Concern
AF ....acre-feet
ADF............................Area-Duration-Frequency
ACOE.........................U.S. Army Corps of Engineers
AFY............................acre-feet per year
ADA ....Americans with Disabilities Act
ALJ.............................Administrative Law Judge
APE ....Area of Potential Effect
ARMR........................Archaeological Resource Management Report
BA ....Biological Assessment
BAWSCA ....Bay Area Water Supply Conservation Agency
BDCP ....Bay-Delta Conservation Plan
BEA............................Bureau of Economic Analysis
BLM ...........................U.S. Department of the Interior, Bureau of Land Management
BLM-S ....Bureau of Land Management – Sensitive Species
BMI ....Benthic macroinvertebrates
BMP ....Best Management Practices
BO ....Biological Opinion
CAISO........................California Independent System Operators
CalEPPC ....California Exotic Pest Plant Council
CalSPA.......................California Sports Fisherman Association
CALVIN ....California Value Integrated Network
CAS............................California Academy of Sciences
CASFMRA ....California Chapter of the American Society of Farm Managers and Rural Appraisers
CCC............................Criterion Continuous Concentrations
CCIC ....Central California Information Center
CCSF..........................City and County of San Francisco
CCVHJV ....California Central Valley Habitat Joint Venture
CD ....Compact Disc

CDBW........................California Department of Boating and Waterways

CDEC.........................California Data Exchange Center

CDFA.........................California Department of Food and Agriculture

CDFG.........................California Department of Fish and Game (as of January 2013, Department of Fish and Wildlife)

CDMG........................California Division of Mines and Geology

CDOF.........................California Department of Finance

CDP............................Census Designated Place

CDPH.........................California Department of Public Health

CDPR.........................California Department of Parks and Recreation

CDSOD......................California Division of Safety of Dams

CDWR........................California Department of Water Resources

CE ....California Endangered Species

CEII............................Critical Energy Infrastructure Information

CEQA.........................California Environmental Quality Act

CESA ....California Endangered Species Act

CFR............................Code of Federal Regulations

cfs...............................cubic feet per second

CGS............................California Geological Survey

CMAP ....California Monitoring and Assessment Program

CMC...........................Criterion Maximum Concentrations

CNDDB......................California Natural Diversity Database

CNPS..........................California Native Plant Society

CORP ....California Outdoor Recreation Plan

CPI ....Consumer Price Index

CPUE ....Catch Per Unit Effort

CRAM........................California Rapid Assessment Method

CRLF..........................California Red-Legged Frog

CRRF ....California Rivers Restoration Fund

CSAS..........................Central Sierra Audubon Society

CSBP..........................California Stream Bioassessment Procedure

CT ....Census Tract

CT ....California Threatened Species

CTR............................California Toxics Rule
CTS ....California Tiger Salamander
CUWA ....California Urban Water Agency
CV ....Contingent Valuation
CVP............................Central Valley Project
CVPIA........................Central Valley Project Improvement Act
CVRWQCB ....Central Valley Regional Water Quality Control Board
CWA ....Clean Water Act
CWD ....Chowchilla Water District
CWHR........................California Wildlife Habitat Relationship
CWT...........................hundredweight
Districts.......................Turlock Irrigation District and Modesto Irrigation District
DLA ....Draft License Application
DPRA.........................Don Pedro Recreation Agency
DO..............................Dissolved Oxygen
DPS ....Distinct Population Segment
EA ....Environmental Assessment
EC ....Electrical Conductivity
EDD ....Employment Development Department
EFH............................Essential Fish Habitat
EIR.............................Environmental Impact Report
EIS..............................Environmental Impact Statement
ENSO ....El Nino – Southern Oscillation
EO ....Executive Order
EPA............................U.S. Environmental Protection Agency
ERS ....Economic Research Service (USDA)
ESA............................Federal Endangered Species Act
ESRCD.......................East Stanislaus Resource Conservation District
ESU............................Evolutionary Significant Unit
ET...............................Evapotranspiration
EVC............................Existing Visual Condition
EWUA........................Effective Weighted Useable Area
FEMA ....Federal Emergency Management Agency

FERC..........................Federal Energy Regulatory Commission
FFS.............................Foothills Fault System
FL...............................Fork length
FMU...........................Fire Management Unit
FMV...........................Fair Market Value
FOT............................Friends of the Tuolumne
FPC ....Federal Power Commission
FPPA..........................Federal Plant Protection Act
FPC ....Federal Power Commission
ft.................................feet
ft/mi............................feet per mile
FWCA........................Fish and Wildlife Coordination Act
g..................................grams
GAMS........................General Algebraic Modeling System
GIS ....Geographic Information System
GLO ....General Land Office
GPM...........................Gallons per Minute
GPS ....Global Positioning System
HCP............................Habitat Conservation Plan
HHWP........................Hetch Hetchy Water and Power
HORB ....Head of Old River Barrier
HPMP.........................Historic Properties Management Plan
ILP..............................Integrated Licensing Process
IMPLAN ....Impact analysis for planning
I-O..............................Input-Output
ISR ....Initial Study Report
ITA.............................Indian Trust Assets
kV...............................kilovolt
LTAM ....Long-Term Acoustic Monitoring
LTR............................Lower Tuolumne River
m ....meters
M&I............................Municipal and Industrial
MCL...........................Maximum Contaminant Level

mg/kg........................milligrams/kilogram
mg/L..........................milligrams per liter
mgd...........................million gallons per day
mi..............................miles
mi^2.............................square miles
MID...........................Modesto Irrigation District
MOU..........................Memorandum of Understanding
MRP...........................Monitoring and Reporting Program
MRWTP.....................Modesto Regional Water Treatment Plant
MSCS.........................Multi-Species Conservation Strategy
msl.............................mean sea level
MVA..........................Megavolt Ampere
MW...........................megawatt
MWh..........................megawatt hour
mya............................million years ago
NAE...........................National Academy of Engineering
NAHC........................Native American Heritage Commission
NAICS........................North America Industrial Classification System
NAS...........................National Academy of Sciences
NASS.........................National Agricultural Statistics Service (USDA)
NAVD 88...................North American Vertical Datum of 1988
NAWQA....................National Water Quality Assessment
NCCP.........................Natural Community Conservation Plan
NEPA.........................National Environmental Policy Act
ng/g...........................nanograms per gram
NGOs.........................Non-Governmental Organizations
NHI...........................Natural Heritage Institute
NHPA.........................National Historic Preservation Act
NISC..........................National Invasive Species Council
NMFS.........................National Marine Fisheries Service
NMP..........................Nutrient Management Plan
NOAA........................National Oceanic and Atmospheric Administration
NOI...........................Notice of Intent

NPS ............................U.S. Department of the Interior, National Park Service
NRCS ....National Resource Conservation Service
NRHP..........................National Register of Historic Places
NRI.............................Nationwide Rivers Inventory
NTU ....Nephelometric Turbidity Unit
NWI............................National Wetland Inventory
NWIS ....National Water Information System
NWR ....National Wildlife Refuge
NGVD 29...................National Geodetic Vertical Datum of 1929
O&M ....operation and maintenance
OEHHA......................Office of Environmental Health Hazard Assessment
OID ....Oakdale Irrigation District
ORV ....Outstanding Remarkable Value
PAD............................Pre-Application Document
PDO............................Pacific Decadal Oscillation
PEIR ....Program Environmental Impact Report
PGA............................Peak Ground Acceleration
PHG............................Public Health Goal
PM&E ....Protection, Mitigation and Enhancement
PMF............................Probable Maximum Flood
PMP............................Positive Mathematical Programming
POAOR ....Public Opinions and Attitudes in Outdoor Recreation
ppb.............................parts per billion
ppm ....parts per million
PSP.............................Proposed Study Plan
QA..............................Quality Assurance
QC ....Quality Control
RA ....Recreation Area
RBP ....Rapid Bioassessment Protocol
Reclamation ...............U.S. Department of the Interior, Bureau of Reclamation
RM ....River Mile
RP...............................Relicensing Participant
RSP ....Revised Study Plan

RST ....Rotary Screw Trap
RWQCB.....................Regional Water Quality Control Board
SD1 ....Scoping Document 1
SD2 ....Scoping Document 2
SE...............................State Endangered Species under the CESA
SFP.............................State Fully Protected Species under CESA
SFPUC ....San Francisco Public Utilities Commission
SHPO ....State Historic Preservation Office
SIC ....Standard Industry Classification
SJR.............................San Joaquin River
SJRA ....San Joaquin River Agreement
SJRGA ....San Joaquin River Group Authority
SJTA ....San Joaquin River Tributaries Authority
SPD ....Study Plan Determination
SRA............................State Recreation Area
SRMA ....Special Recreation Management Area or Sierra Resource Management Area (as per use)
SRMP.........................Sierra Resource Management Plan
SRP ....Special Run Pools
SSC ....State species of special concern
ST...............................California Threatened Species under the CESA
STORET ....Storage and Retrieval
SWAMP.....................Surface Water Ambient Monitoring Program
SWAP ....Statewide Agricultural Model
SWE...........................Snow-Water Equivalent
SWP ....State Water Project
SWRCB......................State Water Resources Control Board
TAC............................Technical Advisory Committee
TAF............................thousand acre-feet
TC ....Travel Cost
TCP ....Traditional Cultural Properties
TDS............................Total Dissolved Solids
TID.............................Turlock Irrigation District

TIN............................. Triangular Irregular Network
TMDL........................Total Maximum Daily Load
TOC............................Total Organic Carbon
TPH............................Total Petroleum hydrocarbon
TRT............................Tuolumne River Trust
TRTAC......................Tuolumne River Technical Advisory Committee
UC..............................University of California
UCCE.........................University of California Cooperative Extension
USDA.........................U.S. Department of Agriculture
USDOC......................U.S. Department of Commerce
USDOI.......................U.S. Department of the Interior
USFS..........................U.S. Department of Agriculture, Forest Service
USFWS......................U.S. Department of the Interior, Fish and Wildlife Service
USGS.........................U.S. Department of the Interior, Geological Survey
USR............................Updated Study Report
UTM...........................Universal Transverse Mercator
VAMP........................Vernalis Adaptive Management Plan
VELB.........................Valley Elderberry Longhorn Beetle
VES............................Visual Encounter Surveys
VRM..........................Visual Resource Management
W&AR.......................Water & Aquatic Resources
WMP..........................Waste Management Plan
WPT...........................Western Pond Turtle
WSA...........................Wilderness Study Area
WSIP..........................Water System Improvement Program
WTP...........................Willingness to Pay
WWTP.......................Wastewater Treatment Plant
WY.............................water year
µS/cm.........................micro-Siemens per centimeter

1.0 INTRODUCTION

1.1 Background

Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) are the co-licensees of the 168-megawatt (MW) Don Pedro Project (Project) located on the Tuolumne River in western Tuolumne County in the Central Valley region of California. The Don Pedro Dam is located at river mile (RM) 54.8 and the Don Pedro Reservoir has a normal maximum water surface elevation of 830 ft above mean sea level (msl; NGVD 29). At elevation 830 ft, the reservoir stores over 2,000,000 acre-feet (AF) of water and has a surface area slightly less than 13,000 acres (ac). The watershed above Don Pedro Dam is approximately 1,533 square miles (mi^2). The Project is designated by the Federal Energy Regulatory Commission (FERC) as project no. 2299.

Both TID and MID are local public agencies authorized under the laws of the State of California to provide water supply for irrigation and municipal and industrial (M&I) uses and to provide retail electric service. The Don Pedro Project serves many purposes including providing water storage for the beneficial use of irrigation of over 200,000 ac of prime Central Valley farmland and for the use of M&I customers in the City of Modesto (population 210,000). Consistent with agreements between the Districts and City and County of San Francisco (CCSF), the Don Pedro Reservoir also includes a “water bank” of up to 570,000 AF of storage which CCSF uses to more efficiently manage the water supply from its Hetch Hetchy water system while meeting the senior water rights of the Districts. The “water bank” within Don Pedro Reservoir provides significant benefits for CCSF’s 2.6 million customers in the San Francisco Bay Area.

The Don Pedro Project also provides storage for flood management purposes in the Tuolumne and San Joaquin rivers in coordination with the U.S. Army Corps of Engineers (ACOE). Other important uses supported by the Don Pedro Project are recreation, protection of aquatic resources in the lower Tuolumne River, and hydropower generation.

The Project Boundary extends from RM 53.2, which is one mile below the Don Pedro powerhouse, upstream to RM 80.8 at a water surface elevation of 845 ft (31 FPC ¶ 510 [1964]). The Project Boundary encompasses approximately 18,370 ac with 74 percent of the lands owned jointly by the Districts and the remaining 26 percent (approximately 4,802 ac) owned by the United States and managed as a part of the U.S. Bureau of Land Management (BLM) Sierra Resource Management Area.

The primary Don Pedro Project facilities include the 580-foot-high Don Pedro Dam and Reservoir completed in 1971; a four-unit powerhouse situated at the base of the dam; related facilities including the Project spillway, outlet works, and switchyard; four dikes (Gasburg Creek Dike and Dikes A, B, and C); and three developed recreational facilities (Fleming Meadows, Blue Oaks, and Moccasin Point Recreation Areas). The location of the Don Pedro Project and its primary facilities is shown in Figure 1.1-1.

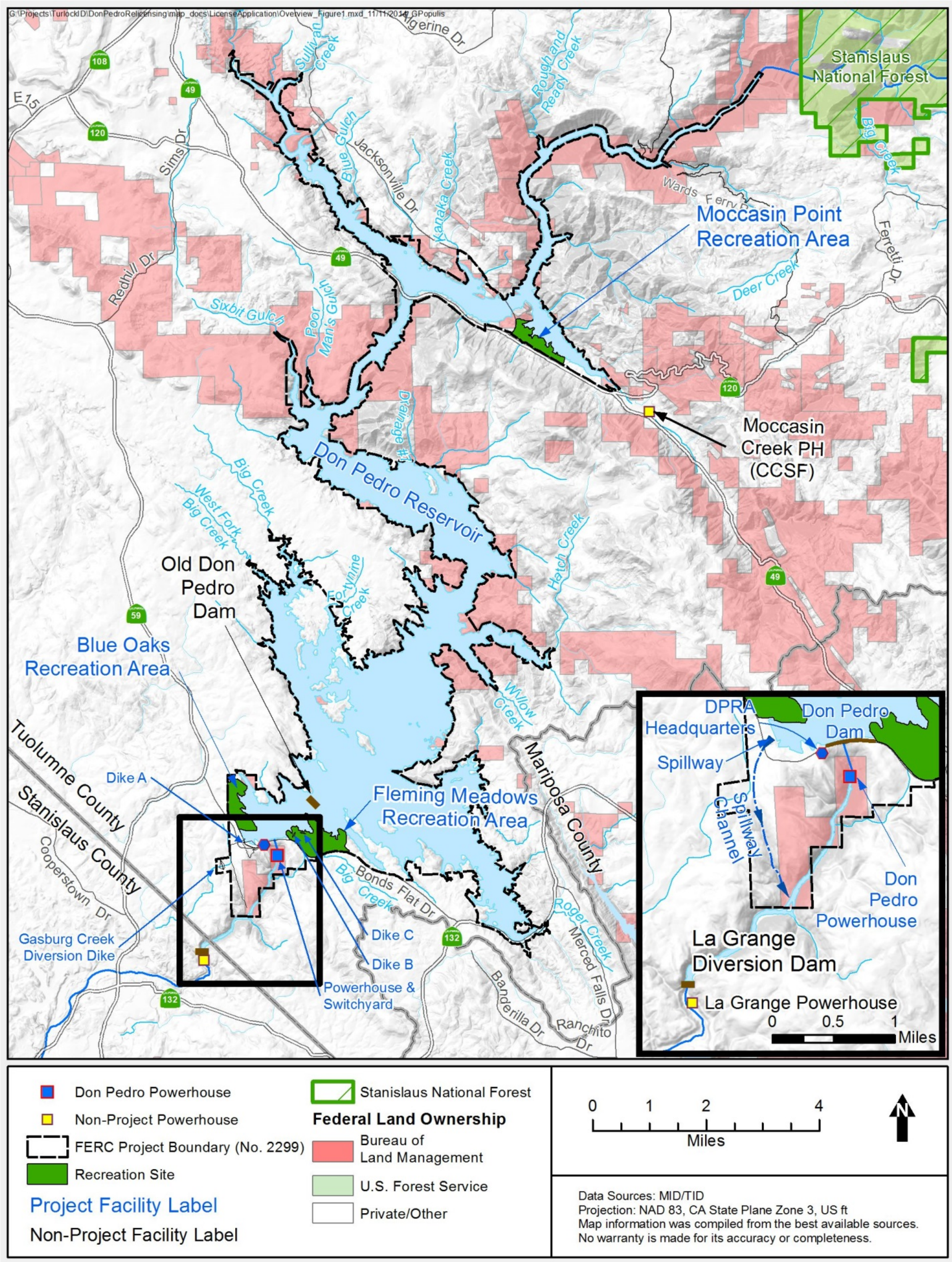

Figure 1.1-1. Don Pedro Project site location map.

1.2 Relicensing Process

The current FERC license for the Project expires on April 30, 2016, and the Districts applied for a new license on April 28, 2014. At that time, and consistent with study schedules approved by FERC through the ILP's study plan determinations, five important studies involving the resources of the lower Tuolumne River were still in-progress. These studies are scheduled to be completed in 2016. Once these studies are completed, the Districts will evaluate all data, reports, and models then available for the purpose of identifying appropriate protection, mitigation, and enhancement (PM&E) alternatives to address the direct, indirect, and cumulative effects of Project operations and maintenance. Upon completion of this evaluation, the Districts will prepare any needed amendments to the license application.

The Districts began the relicensing process by filing a Notice of Intent and Pre-Application Document (PAD) with FERC on February 10, 2011, following the regulations governing the Integrated Licensing Process (ILP). The Districts' PAD included descriptions of the Project facilities, operations, license requirements, and Project lands as well as a summary of the extensive existing information available on Project area resources. The PAD also included ten draft study plans describing a subset of the Districts' proposed relicensing studies. The Districts then convened a series of Resource Work Group meetings, engaging agencies and other relicensing participants in a collaborative study plan development process culminating in the Districts' Proposed Study Plan (PSP) and Revised Study Plan (RSP) filings to FERC on July 25, 2011 and November 22, 2011, respectively.

On December 22, 2011, FERC issued its Study Plan Determination (SPD) for the Project, approving, or approving with modifications, 34 studies proposed in the RSP that addressed Cultural and Historical Resources, Recreational Resources, Terrestrial Resources, and Water and Aquatic Resources. In addition, as required by the SPD, the Districts filed three new study plans (W&AR-18, W&AR-19, and W&AR-20) on February 28, 2012 and one modified study plan (W&AR-12) on April 6, 2012. Prior to filing these plans with FERC, the Districts consulted with relicensing participants on drafts of the plans. FERC approved or approved with modifications these four studies on July 25, 2012.

Following the SPD, a total of seven studies (and associated study elements) that were either not adopted in the SPD, or were adopted with modifications, formed the basis of Study Dispute proceedings. In accordance with the ILP, FERC convened a Dispute Resolution Panel on April 17, 2012 and the Panel issued its findings on May 4, 2012. On May 24, 2012, the Director of FERC issued his Formal Study Dispute Determination, with additional clarifications related to the Formal Study Dispute Determination issued on August 17, 2012. The dispute did not involve the study plan for the *Lower Tuolumne River Floodplain Hydraulic Assessment* (W&AR-21).

On January 17, 2013, the Districts issued the Initial Study Report (ISR) and held an ISR meeting on January 30 and 31, 2013. The Districts filed a summary of the ISR meeting with FERC on February 8, 2013. Comments on the meeting summary and requests for new studies and study modifications were filed by relicensing participants on or before March 11, 2013 and the Districts filed reply comments on April 9, 2013. FERC issued the Determination on Requests for Study Modifications and New Studies on May 21, 2013. As part of that Determination, FERC staff recommended that the Districts undertake an analysis of floodplain inundation and frequency for portions of the lower Tuolumne River to supplement and update information from previous studies conducted by the Districts and the U.S. Fish and Wildlife Service (USFWS). In response, the Districts filed a new study plan with FERC for the *Lower Tuolumne River Floodplain Hydraulic Assessment* (W&AR-21) on September 16, 2013. The Districts addressed all relicensing participant recommended changes to the original draft and FERC approved the study plan without modification on October 18, 2013.

The Districts filed the Updated Study Report (USR) on January 6, 2014; held a USR meeting on January 16, 2014; and filed a summary of the meeting on January 27, 2014. Relicensing participant comments on the meeting summary and requests for new studies and study modifications were due by February 26, 2014. The Districts filed reply comments on March 28, 2014. FERC issued the Determination on Requests for Study Modifications on April 29, 2014.

This study report describes the objectives, methods, and results of the *Lower Tuolumne River Floodplain Hydraulic Assessment* as implemented by the Districts in accordance with FERC's October 18, 2013 Order. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at http://www.donpedro-relicensing.com/.

1.3 Study Plan and Consultation

The Districts' operation and maintenance (O&M) of the Project may contribute to cumulative effects on habitat availability and production of Central Valley fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and *O. mykiss* in the lower Tuolumne River. In the Determination on Requests for Study Modifications and New Studies issued on May 21, 2013, FERC staff recommended that the Districts undertake an analysis of floodplain inundation and frequency for the lower Tuolumne River between RM 52.5 and RM 21.5 to supplement and update information from previous IFIM studies conducted by the Districts and the USFWS. In response, the Districts issued a draft study plan to relicensing participants on August 9, 2013 for a 30-day review period. Timely comments were provided by CDFW and USFWS. Comments from CDFW and USFWS were either incorporated into the final study plan or, if not adopted, responded to in the study plan attachment. Several agency comments resulted in substantive changes to the study plan. In response to a comment from CDFW, the Districts revised the plan to assess the extent of suitable juvenile salmonid rearing habitat. Based on requests from both CDFW and USFWS, the Districts agreed to extend the study area to the confluence of the Tuolumne River and the San Joaquin River. At the request of USFWS, the area-duration-frequency curves produced under Step 5 of the study plan include the determination of the continuous wetted area for periods of 7, 14, 21, and 30 day durations.

On February 13, 2014, the Districts' study team held a consultation Workshop with relicensing participants. The first of two workshops, Workshop No. 1 was held to (1) update relicensing participants on study progress; (2) present modeling approaches and describe the TUFLOW model (BMT Group Ltd. 2013); and (3) solicit input on delineating the boundary between overbank and in-channel areas to be analyzed using two dimensional (2D) and one dimensional (1D) modeling, respectively, downstream of La Grange Diversion Dam (RM 52.2) to the San Joaquin River (RM 0.0). Comments on materials presented at Workshop No. 1 were received from the Tuolumne River Conservancy, Inc. (TRC) on February 20, 2014. On March 4, 2014, draft meeting notes for Workshop No. 1 were provided to relicensing participants (RPs) for review and comment. No additional comments were received during the 30-day review period. TRC's comments did not result in any changes to the draft meeting notes. On July 17, 2014, the Districts filed final meeting notes for Workshop No.1 (Attachment A).

On July 15, 2014, the Districts provided the draft TUFLOW 1D/2D model domain boundary to relicensing participants for review and comment. The Districts requested that all comments be provided by August 29, 2014. No comments were received.

On December 18, 2014, the study team held consultation Workshop No. 2 with relicensing participants. Workshop No. 2 was held to (1) review the TUFLOW hydraulic model development, (2) present calibration and validation results, (3) present preliminary results of the habitat analysis for the completed modeling subreaches, and (4) present the remaining study and reporting schedule. On January 9, 2015, draft meeting notes for Workshop No. 2 were provided to RPs for review and comment. No comments were received during the 30-day review period. Final meeting notes for Workshop No. 2 are included in Attachment A.

On September 3, 2015, the Districts filed the draft study report and requested that relicensing participants provide comments no later than October 6, 2015. Comments on the draft study report were provided by the USFWS on October 1, 2015. In response to those comments, the report has been revised to remove perennially flooded areas within isolated portions of the floodplain from the estimates of usable floodplain area. The Districts provide a response to each USFWS comment in Attachment A.

2.0 STUDY GOALS AND OBJECTIVES

The goal of this study is to develop a hydraulic model for the lower Tuolumne River that simulates the interaction between flow within the main channel and the floodplain downstream of the La Grange Diversion Dam at RM 52.2 to the confluence with the San Joaquin River (RM 0) and to apply the model results to estimate floodplain juvenile salmonid rearing habitat. The TUFLOW model analysis conducted for this study expands the flow range and number of flow regimes evaluated in the 2012 Pulse Flow Study (Stillwater Sciences 2012) and uses recent data on floodplain topography and in-channel hydraulic controls that were not included in either the 2012 Pulse Flow Study or floodplain GIS analysis conducted by the USFWS (2008). The following objectives apply to this study:

- reproduce observed water surface elevations, within reasonable calibration standards, over the sampled range of hydrologic conditions;
- determine floodplain inundation extents for flows at 250 cfs intervals between 1,000 and 3,000 cfs and 500 cfs intervals between 3,000 cfs and 9,000 cfs;
- estimate the area, frequency and duration of inundation over a range of flows for the base case (WY 1971–2012) hydrology; and
- apply modeled water depths and velocities to quantify the amount of suitable salmonid rearing habitat for juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and *O. mykiss* at the designated flow increments.

The TUFLOW model is available for use in future evaluations of inundation and frequency duration under alternative scenarios.

3.0 STUDY AREA

The study area consists of the lower Tuolumne River from below the La Grange powerhouse tailrace at an elevation of approximately 165 ft to the Tuolumne River's confluence with the San Joaquin River (RM 0.0) at approximately elevation 35 ft. For modeling purposes, the Tuolumne River was divided into three reaches, each simulated with a stand-alone model for computational efficiency. The model reach boundaries are based on changes in geomorphic regime and continuity of terrain data sources. A map depicting the study area and the individual model extents is shown in Figure 3.1-1.

3.1 Landform and Land Use

From upstream to downstream, the lower Tuolumne River leaves a steep and confined bedrock valley at the La Grange Diversion Dam (RM 52.2) and enters the eastern Central Valley near the La Grange Regional Park (at Basso Bridge, RM 47.5), where hillslope gradients in the vicinity of the river corridor are typically less than 5 percent. From this point to the confluence with the San Joaquin River the Tuolumne River corridor lies in a broad alluvial valley. The alluvial valley may be delineated into two geomorphic reaches based on channel slope and bed composition: a predominantly gravel-bedded reach that extends from La Grange Diversion Dam to RM 24 near the City of Hughson and a predominantly sand-bedded reach that extends from RM 24 to the San Joaquin River confluence (McBain & Trush 2000).

As summarized in the Tuolumne River Restoration Plan (McBain & Trush 2000), a number of large-scale anthropogenic changes have occurred in the lower Tuolumne River corridor since the California Gold Rush in 1848. Gold mining, gravel mining, grazing, and agriculture had encroached on the lower Tuolumne River channel even before the first aerial photographs were taken by the Soil Conservation Service in 1937. Dredge mine tailings along the river are primarily the legacy of gold mining abandoned in the early 20th century, however, gravel and aggregate mining still continue alongside the river for a number of miles, particularly upstream of the Town of Waterford (RM 34). Excavation of riverbed material for gold and aggregate to depths well below the river thalweg has formed large in-channel pits ("special run-pools" [SRPs]) as well as off-channel ponds. During the construction of the Don Pedro Dam, aggregate was reclaimed from floodplain areas formerly occupied by dredger tailings between RM 51.5 and RM 40.3 (McBain & Trush 2000). These floodplain areas are characterized by floodplains two to three times wider than floodplains in other portions of the lower Tuolumne River corridor. Although some overbank habitat is available over the length of the lower Tuolumne River, most of the river corridor is confined by either natural bluffs or man-made levees, often built to protect active floodplain gravel mining areas (McBain & Trush 2000).

Along the lower Tuolumne River, agricultural and urban encroachment in combination with in-channel excavation has resulted in a river channel contained within a narrow floodway confined by dikes and agricultural fields. Levees and bank revetment extend along portions of the river bank from near Modesto (RM 16) downstream to the San Joaquin River, limiting potential floodplain access for rearing juvenile salmonids. The remnant SRPs, floodplain mining pits and multiple connected backwaters along the lower Tuolumne River have been noted for juvenile Chinook stranding concerns (TID/MID 2001).

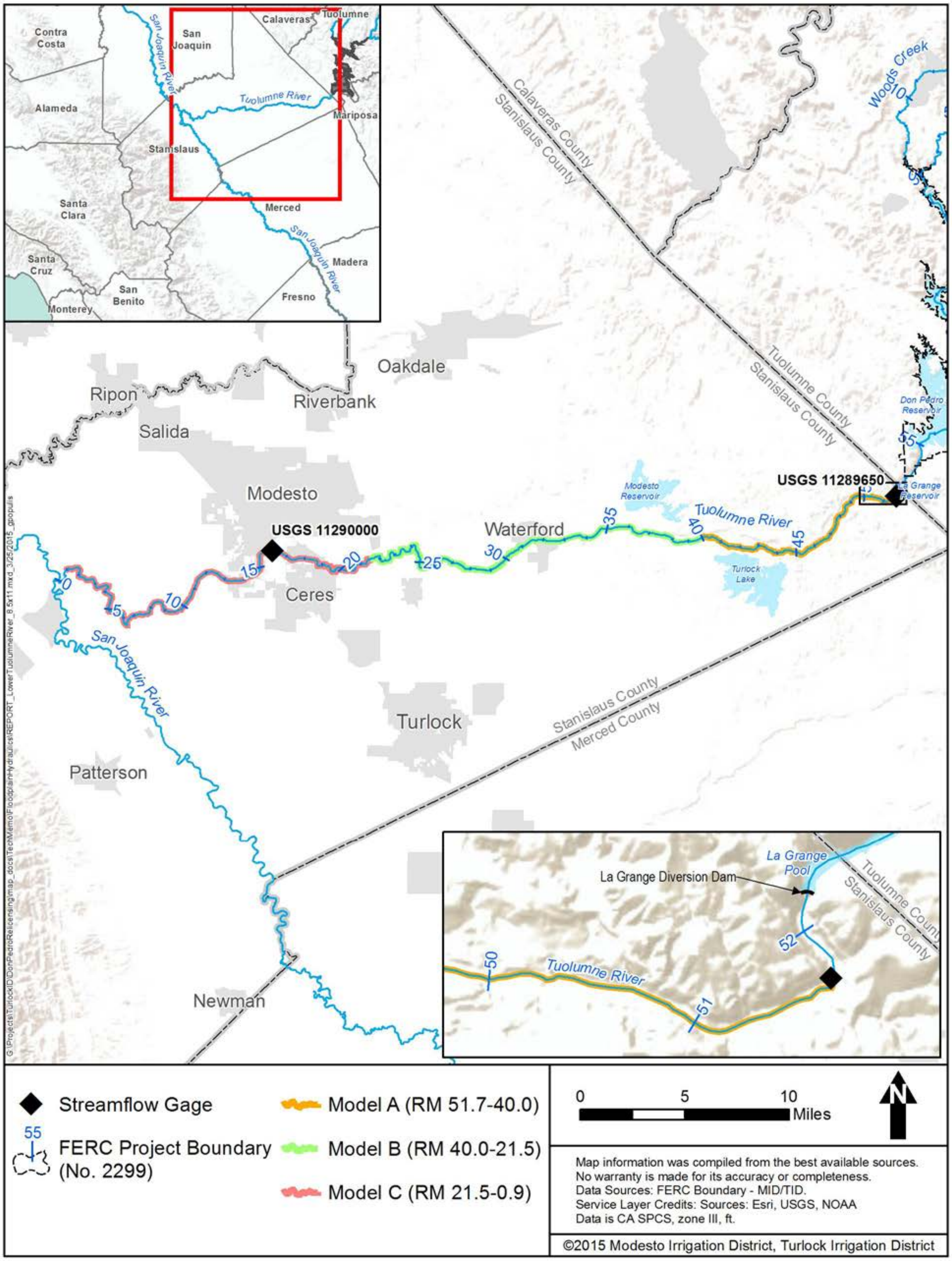

Figure 3.1-1. Lower Tuolumne River study area and model reaches.

3.2 Hydrology

Flow statistics of the mean daily flow for the study period (WY 1971 to 2012) using flows recorded at USGS Gages 11289650 (Tuolumne River below La Grange Diversion Dam) and 11290000 (Tuolumne River at Modesto) are shown in Table 3.2-1. Previous studies estimate that flows as low as 1,000 cfs may reach bankfull within portions of the lower Tuolumne River (USFWS 2008, Stillwater Sciences 2012). The flow frequency curve for the lower Tuolumne River at Modesto for the study period (Figure 3.2-1) indicates that mean daily flows exceed 1,000 cfs approximately 28 percent of the time throughout the year. The highest study flow of 9,000 cfs is exceeded less than 1 percent of the time annually.

Table 3.2-1. Lower Tuolumne River mean monthly flows (cfs) WY 1971-2012.

Month	Mean Daily Flow (cfs)					
	USGS 11289650 - Tuolumne River Below La Grange Dam Near La Grange, CA			USGS 11290000 - Tuolumne River at Modesto, CA		
	Mean	Highest	Lowest	Mean	Highest	Lowest
January	1,440	13,070	10	1,780	15,500	154
February	1,720	8,116	22	2,050	8,782	166
March	1,810	6,636	94	2,150	7,658	239
April	1,790	8,900	41	2,030	9,268	169
May	1,620	9,744	9	1,830	10,420	138
June	940	5,161	8	1,120	5,683	95
July	490	3,808	7	670	4,244	79
August	301	2,498	6	474	2,415	68
September	454	3,491	4	654	4,041	73
October	595	4,187	1	824	4,760	78
November	348	905	8	641	2,089	93
December	864	4,625	10	1,120	5,431	110

Some of the base flow in the reach between the two USGS gages appears to be derived from groundwater inflow and the lower Tuolumne River is generally considered to be a gaining stream[1] (CDWR 2004). A portion of the river flow is also derived from tributary inflows. In addition to Dry Creek (RM 16.4), which joins the lower Tuolumne River upstream of the USGS Modesto gage, minor and unmeasured natural surface inflows come from Gasburg Creek (RM 50.3), Dominici Creek (RM 47.8) and Peaslee Creek (RM 45.2). About 75 percent of the time these tributary inflows occur between December and March, in response to winter rain storm events. Urban and agricultural runoff as well as operational spills from irrigation canals flowing into the river and riparian pumping from the river also contributes to changes in river flow between the two USGS gages.

[1] A gaining stream is a stream whose flow rate increases in the downstream direction, often as a result of groundwater inflows.

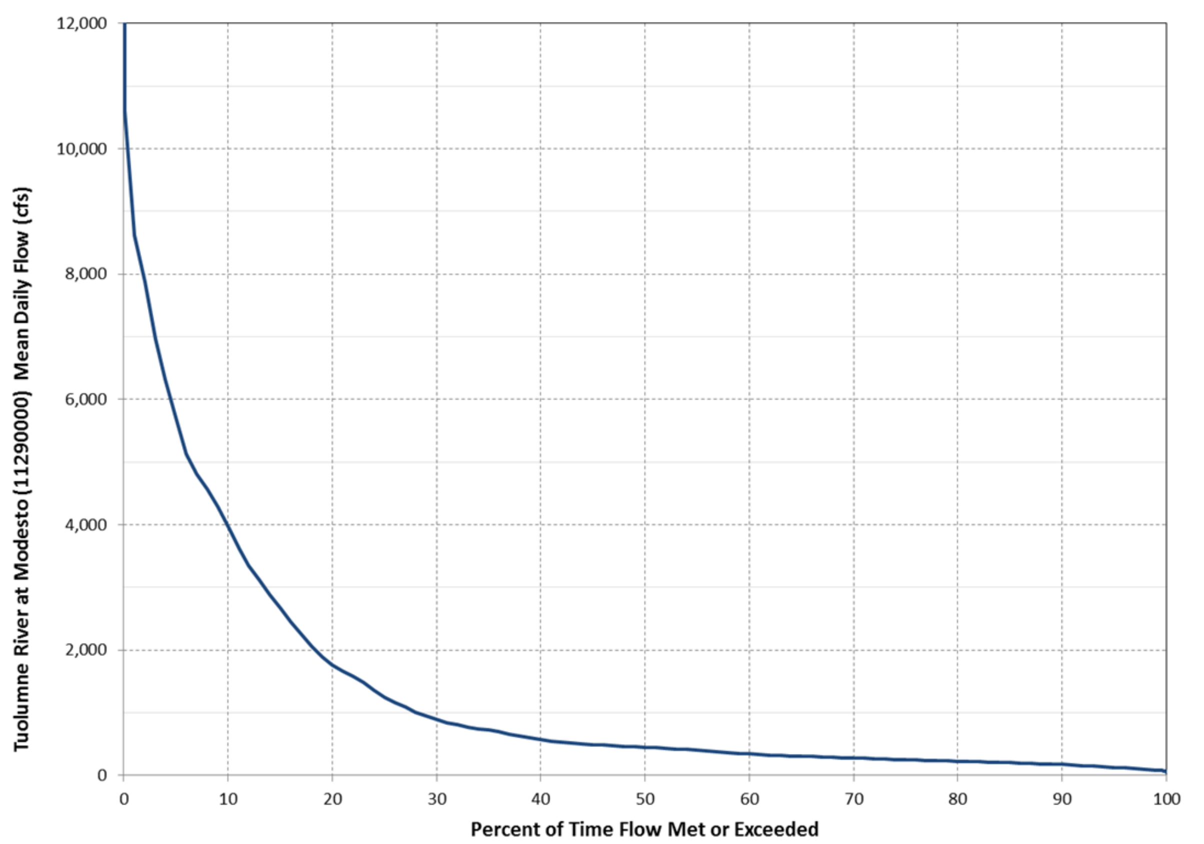

Figure 3.2-1. Flow exceedance at USGS Gage 11290000 Tuolumne River at Modesto CA, WY 1971 to 2012.

4.0 METHODOLOGY

4.1 Hydraulic Model Development

A detailed hydraulic model for 52 miles of in-channel and floodplain areas along the lower Tuolumne River was developed using the best available topographic and bathymetric data. A model platform was chosen that allowed for river-wide modeling while at the same time facilitating detailed modeling for complex features and local riverine hydraulics present in the study area such as ponds, pools, narrow flow paths connecting river and overbanks, flow paths connecting overbank ponds, and hydraulic structures like culverts and weirs. Given the study objectives, the TUFLOW modeling platform was chosen to provide accuracy while also providing efficient model run time.

4.1.1 Hydraulic Model Software

TUFLOW Classic (TUFLOW), a propriety model developed by BMT WBM (BMT Group Ltd. 2013), was chosen to model the channel and overbank hydrodynamics along the lower Tuolumne River. TUFLOW simulates the complex hydrodynamics of channel and overbank through dynamic linking of the solutions of the full one-dimensional (1D) St. Venant equations for in-channel flow and full two-dimensional (2D) free-surface shallow water equations in the overbank regions. TUFLOW uses square computational cells (cells) to represent computational domain. Figure 4.1-1 shows the grid, computational points and a typical 1D-2D model divide used in the TUFLOW model.

The TUFLOW version used for the study was the 64 bit, double precision version TUFLOW.2013-12-AC-w64. Surface-water Modeling System (SMS) software developed by Aquaveo, LLC was used for visualizing TUFLOW output. SMS version 11.1.10 (Build date: November 06, 2013) was used for the study.

4.1.2 Topographic and Bathymetric Data

A Digital Terrain Model (DTM) was created using the LP360 extension (QCoherent 2014) for ArcGIS to process LiDAR data collected March 30, 2012. Flows in the lower Tuolumne River were approximately 320 cfs at the time the LiDAR data were collected, as measured at USGS Gage 11289650 (Tuolumne River Below La Grange Dam Near La Grange, CA) (TID/MID 2013b). The DTM was created with a cell size of 3.125 ft based on a point density of 5.2 returns per square meter and a vertical root mean square error (RMSEz) of 0.15 ft as defined in the associated LiDAR accuracy assessment report (Photo Science 2012). The LiDAR data define overbank land surface geometry and channel geometry to the water surface elevation at the time of data collection. The remaining bathymetric channel data were collected from additional sources (see Table 4.1-1 below).

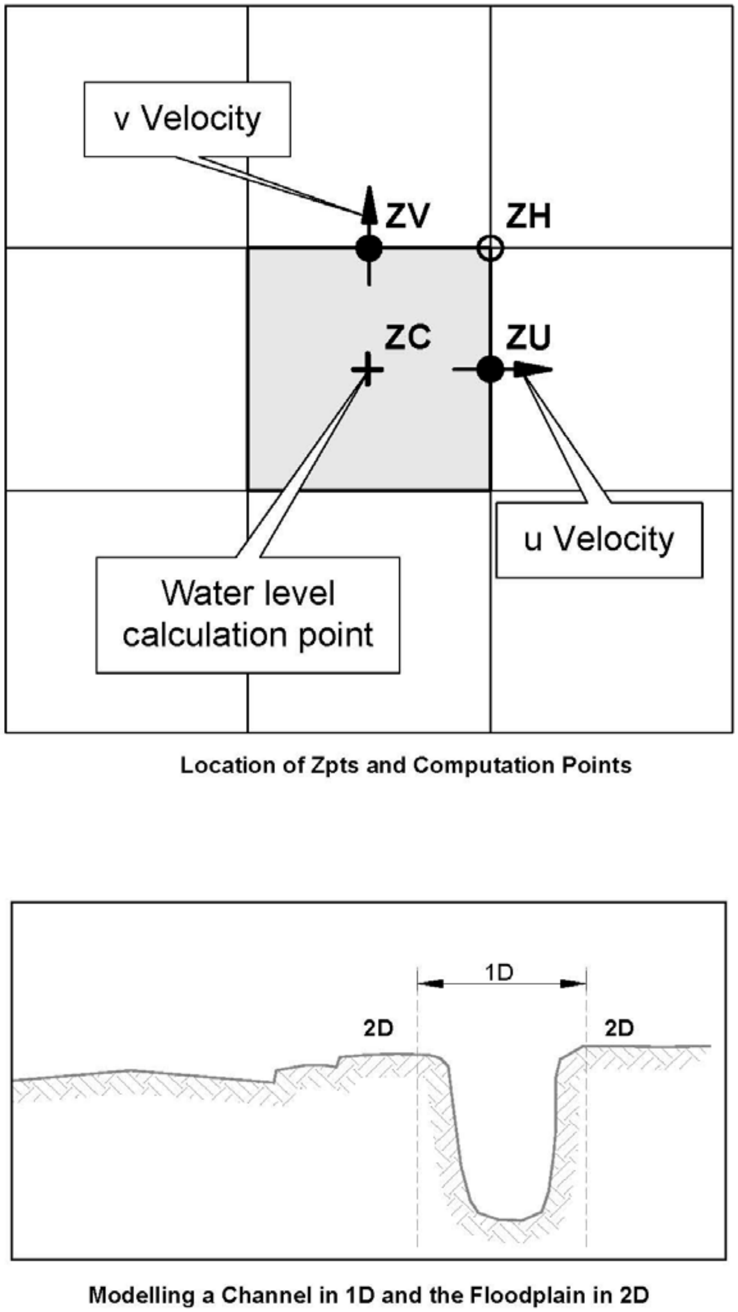

Figure 4.1-1. TUFLOW grid and 1D-2D boundary (TUFLOW Manual 2010).

4.1.3 Model Spatial and Temporal Resolution

TUFLOW computational cell size can be changed to meet specific requirements posed by the hydraulics of the study site and intended application. The size of the cell directly affects computational accuracy and computational effort. For a given model extent, a smaller cell size results in more accurate hydraulic computations but may be computationally expensive (model would require much longer run times). Conversely, a bigger cell size would result in faster model run times but less accurate results. A cell size sensitivity analysis was completed to determine optimal cell size for the study and its intended applications.

At the early stages of the study, the sensitivity of flow hydraulics and habitat analysis to cell size was evaluated using a test reach spanning RM 50 to RM 47 (Attachment B). This reach, which contains complex overbank features such as ponds, pools, narrow flow paths connecting river and overbanks, and flow paths connecting overbank ponds, represents the complexity of the study area well. Water level data for this reach were available for a steady flow of 3,000 cfs from the Pulse Flow Study (Stillwater Science 2012). Sensitivity test model runs were made for cell sizes of 10, 20, 30, 40 and 50 feet square. Hydraulic and habitat results were evaluated and compared for all five cell sizes (Tables 1, 2, and 3 in Attachment B).

The results indicated that a cell size of 30 x 30 ft would be optimal for the study area. Model development and calibration confirmed that the 30 x 30 ft cell size was optimal for producing accurate results and efficient model development and calibration.

TUFLOW model robustness and performance is measured by three key parameters: a time step that produces stable model runs, the absence of excessive negative depths at cells during calculations, and mass errors less than 1 percent of total volume. Regarding the first parameter, the time step for TUFLOW model hydraulic calculations (both 1D and 2D components) was selected before computations began. Time step directly affects model stability, model run time and the accuracy of results. The Courant stability criterion determines the limiting time step value. The computation time was set in accordance with this criterion as given in the TUFLOW Manual (2010). Given a cell size of 30 ft, the required time step for this project was between 2 and 5 seconds. All three models were progressively debugged to run at a 4 second time step for the 2D scheme and a 2 second time step for the 1D scheme. Regarding the second and third parameters, all model runs were stable with no negative depths at cells during calculations and mass errors were well below 1 percent of total volume.

4.1.4 Hydraulic Model Reaches

The lower Tuolumne River study area was divided into three reaches for modeling efficiency and accuracy of results (Figure 3.1-1):

- Model A – RM 51.7 to RM 40.0
- Model B – RM 40.0 to RM 21.5
- Model C – RM 21.5 to RM 0.9 (confluence with the San Joaquin River)

These reach extents define the applicability of each model's results to particular locations. To minimize boundary condition effects, the downstream limit of Model A was extended to RM 37.4 and the downstream limit for Model B was RM 20.5.

Model A falls within the gravel-bedded geomorphic reach regime (McBain & Trush 2000) and covers the area formerly occupied by dredger tailings reclaimed for use in the construction of Don Pedro Dam. This area includes two broad floodplain sites that were modeled in previous floodplain hydraulic assessments (Stillwater Sciences 2012): (1) downstream of New La Grange Bridge (RM 49–50) and (2) at Bobcat Flat (RM 43). River bathymetric data, available from RM 51.7 to RM 40.0, define the channel morphology for Model A.

Model B covers the remaining gravel-bedded regime upstream of Model C, extending from RM 40.0 to RM 21.5. Most of the channel geometry for Model B is based on cross sections surveyed by TID in 2014. These survey data were supplemented with existing data previously collected for IFIM modeling (Stillwater Sciences 2013).

The upstream extent of Model C is defined by the approximate start of the sand-bedded portion of the reach.

4.1.5 1D Channel – 2D Overbank Demarcation (1D-2D Boundary)

The delineation of the 1D/2D domain boundary between overbank and in-channel areas was an important component of the model development process as it defines what is considered to be overbank habitat for the rearing habitat analysis. The 1D/2D boundary was delineated with the objective of maximizing the area considered to be overbank and distinguishing between in-channel sections where 1D flow predominates and regions that provide additional seasonal habitat. This objective was based on the habitat analysis approach which incorporates the 2D velocity and depth results. The 1D/2D line defines the hydraulic control for TUFLOW. The 1D/2D domain boundary is shown in Attachment C. During Workshop No. 1, the criteria for delineating the 1D/2D boundary was presented to relicensing participants (Attachment A). On July 15, 2014, the Districts provided the draft TUFLOW 1D/2D model domain boundary to relicensing participants for review and comment. The Districts requested that all comments be provided by August 29, 2014. No comments were received.

4.1.6 Hydraulic Model Components

The TUFLOW model for this study has several components. A 1D channel was developed using cross sections from multiple sources, and validated using LiDAR flown during low flows. Overbank roughness coefficients were applied to the TUFLOW 2D scheme and refined during model calibration. Backwater pools connected to the river, large overbank ponds, levees, gullies, and hydraulic structures such as culverts and weirs are also represented in the model.

All the features were developed in a GIS format using ArcGIS 10.2 software (ESRI 2013). Automated tools were developed in Python 2.7 to perform labor intensive GIS tasks. The U.S. Army Corps of Engineers (ACOE) HEC-RAS model (Version 4.1) was used to develop cross-sectional input for the 1D components of each TUFLOW model. Separate 1D/2D TUFLOW and associated 1D HEC-RAS models were developed for each reach.

4.1.7 1D Channel Development

The 1D TUFLOW model components were developed using HEC-RAS, which simplified the geometry development processes and model calibration. HEC-GeoRAS, an ArcGIS extension tool, was used to develop model cross sections and facilitate combining multiple data sources into a single geometry. The HEC-RAS model output was evaluated, reviewed, and revised, if needed, based on 2014 survey data. Automated tools were then used to import the 1D geometry into the TUFLOW model.

4.1.7.1 Cross Section Development

Representative model cross sections were cut from the DTM developed from the March 2012 LiDAR data collected during flows of approximately 320 cfs. The cross section end points were bounded by the 1D/2D domain boundary. Bathymetric data were required to supplement the LiDAR surface below the 320 cfs water surface elevation (Table 4.1-1). A map of model cross sections identified by data source is provided in Attachment C.

Table 4.1-1. Hydraulic model 1D channel data sources.

River Mile	Data Source	Basis for Collection
51.7 to 29.0	Stillwater Sciences (2012 and 2013)	Cross section data at select sites collected for IFIM modeling (Stillwater Sciences 2012 and 2013).
51.2 to 45.5	TID/MID (2013b).	2012 Bathymetric Data. Bathymetry created using ADCP at flows ranging from 650 to 2,100 cfs May, 2012 for the Spawning Gravel Study (W&AR-04).
48.0 to 24.0	TID Field Survey 2014	Supplemental in-channel cross sections surveyed by TID in 2014 using Real Time Kinematic (RTK) GPS. Locations chosen to supplement other cross section data sources for purposes of this study.
45.5 to 37.9	McBain & Trush (2004a)	2005 Bathymetric Data. Bathymetric data originally collected for an update of the lower Tuolumne River Coarse Sediment Management Plan. A vertical shift was applied to the bathymetry data to match geoids with the 2012 bathymetry data (TID/MID 2013b) for this study.
39.9 to 33.6	HDR Field Surveys 2003-2006	Developed from the Ruddy Segment (RS 177300-21074) data developed by HDR Engineering between 2003 and 2006 for the Tuolumne River Floodway Restoration; survey files included stitched TIN surfaces originating from LiDAR and ground truthed bathymetric soundings. More than 100 transects were measured, anywhere from 50 to 100 ft apart. (AD Consultants et al. 2009).
31.5 to 14.0	HDR Field Survey 2012	Field Survey collected every half mile in support of the W&AR-16 Lower Tuolumne River Temperature Model (TID/MID 2013d).
25.9 to 24.4	McBain & Trush (2004b)	Data collected for the lower Tuolumne River Floodway Restoration.
16.1 to 16.4	USGS (2014a, 2014b)	Geometry of three cross sections used to develop rating curves for USGS Gage 11290000. Cross section data are from 2009 to 2014.
13.8 to 6.7	FEMA (2013)	Developed for FEMA HEC-RAS modeling of the lower Tuolumne River and Dry Creek.
6.3 to 0.9	CDWR (2014)	Developed for the HEC-RAS models developed for the CDWR Central Valley Flood Evaluation and Delineation (CVFED) program.

1D model cross sections were placed at locations to capture the pools, constrictions or expansions in river width, islands, riffles and other identifiable changes in gradient within the river that have potential to have significant hydraulic impact. Cross sections were placed at a higher density in high gradient sections.

4.1.7.2 Channel Roughness Coefficients - Manning's 'n'

1D in-channel roughness was estimated based on channel substrate, channel irregularity, cross-section variation, obstructions, aquatic vegetation, and sinuosity (Cowan 1956). Substrate measurements were taken during spawning gravel surveys (TID/MID 2013b) and the coarse sediment study (McBain & Trush 2004a). A reach average D_{84} of 58 mm, based on the set of measurement locations, was used to estimate the base 'n' value of 0.0198 based on USGS Water-supply Paper 1898-B (Limerinos 1970). Modifiers for irregularity, cross sectional changes, and vegetation resulted in a final channel Manning's 'n' value of 0.04 for the reaches upstream of RM 23. Dense riparian vegetation within the 1D boundary was assigned a roughness value of 0.08 based on comparison to reference photos in USGS Water-supply Paper 2339 (Arcement and Schneider 1989).

4.1.7.3 Cross Section Processing

Using the HEC-GeoRAS extension, cross sections were cut from the DTM and then supplemented with the in-channel bathymetric geometry. Output from HEC-RAS model runs at 320 cfs (steady state) was compared to the water surface profile developed from the 2012 LiDAR water return points along the river centerline. Locations requiring additional survey data were identified based on discrepancies between measured and modeled water surface elevations. This iterative process of data collection and cross section revision was used to develop the 1D geometry such that model channel hydraulics adequately matched the 320 cfs profile.

4.1.8 2D Overbank Component Development

The TUFLOW model consists of dynamically linked 1D and 2D components which solve separate hydraulic equations on each side of the 1D/2D domain boundary and provide continuous results across the boundary. The cross sections developed in HEC-RAS provided the required data for the 1D TUFLOW model component. Some additional inputs required for the TUFLOW 2D solution include the gridded model elevation data developed from the DTM, the overbank Manning's 'n' roughness coefficients, boundary conditions, and model run-time parameters.

4.1.8.1 Model Geometry Development

The lateral boundary of the input geometry extends to approximately the 100-yr floodplain to provide adequate coverage for all study flows. The DTM was created using only the bare-earth ground return points from LiDAR surveys conducted in 2012 and did not contain bathymetric data for off-channel ponds, backwaters, and side channels. These features were identified, processed and added to the TUFLOW model as described in the following sections.

4.1.8.2 Ponds and Pools

Ponds, backwater areas, and side channels considered to have little impact on model hydraulics because of limited or no hydraulic connection with the main channel were assigned an elevation 0.2 ft below the water surface elevation at the time the LiDAR was flown to ensure behavior as a sink, an area surrounded by higher elevation that acts to collect water.

To supplement the DTM, bathymetric surfaces were developed for backwater areas and side channels within the 2D domain with considerable interconnectivity to the 1D main channel. The supplemental bathymetric surfaces were developed using several data sources (Table 4.1-2). Side channels were created by connecting bathymetric points into a Triangular Irregular Network (TIN) with breaklines added to increase the triangle density of the surface where necessary for topographic accuracy. The final TIN was then exported with the model grid size of 3.125 ft and incorporated into the DTM.

Table 4.1-2. Hydraulic model bathymetric data sources.

River Mile	Feature Type	Data Source
50.0	Backwater	2012 Bathymetric Data (TID/MID 2013b)
45.3	Backwater	2005 Bathymetric Data (McBain & Trush 2004a)
44.4	Backwater	2005 Bathymetric Data (McBain & Trush 2004a)
43.3	Backwater	2005 Bathymetric Data (McBain & Trush 2004a)
40.4	Backwater	2005 Bathymetric Data (McBain & Trush 2004a)
45.2 to 44.3	Side Channel	2005 Bathymetric Data (McBain & Trush 2004a), Stillwater IFIM Studies (Stillwater Sciences 2012 and 2013), TID Field Survey 2014
43.4 to 42.8	Side Channel	2005 Bathymetric Data (McBain & Trush 2004a), TID Field Survey 2014
42.5 to 42.3	Side Channel	2012 LiDAR (Photo Science 2012)
40.4 to 40.3	Side Channel	2005 Bathymetric Data (McBain & Trush 2004a)
36.7	Side Channel	TID Field Survey 2014
30.8 to 31	Side Channel	TID Field Survey 2014
30.6	Backwater	TID Field Survey 2014
16.2	Dry Creek	FEMA Study 2014

4.1.8.3 Overbank Roughness Coefficients – Manning's 'n'

Roughness coefficients, or Manning's 'n' values, represent flow energy friction losses and were defined using a geospatial dataset. Manning's 'n' values were derived from land cover and land use data for the entire study area. The riparian vegetation shape file developed as part of the Lower Tuolumne River Riparian Information and Synthesis Study (TID/MID 2013a) provided cover information for most of the natural areas adjacent to the main channel and much of the natural floodplain. Delineation of urban, rural residential and agricultural areas was obtained from CALVEG land use data (USDA 2014) to supplement the riparian cover.

A geospatial layer combining the Riparian Vegetation and CALVEG land use layers was updated through visual comparison against 2012 aerial imagery (USDA 2014). Vegetation and land use designations irrelevant to roughness determination were revised, removed, or merged into more appropriate categories. The final classifications of vegetation type or land use were associated with representative Manning's roughness values estimated through interpretation of aerial photos, field photos, and river helicopter videography. The geospatial layer was used to assign Manning's 'n' values at all 2D model locations. In accordance with the recommendations of TUFLOW authors, the Manning's 'n' values were assigned based on Table 10-1 in report "Australian Rainfall & Runoff, Project 15" (Engineers Australia 2012). Land cover/ land use categories and associated Manning's 'n' values used for the overbank areas are provided in Table 4.1-3. Representative photos of cover and land use and associated Manning's 'n' values are provided in Attachment D.

Table 4.1-3. 2D overbank Manning's 'n' designations.

Roughness Value	Description
0.03	Smooth and flat – pavement
0.04	Bare earth with gravel or finer substrate
0.05	Some herbaceous vegetation, grass, or large cobbles
0.06	Backwater areas choked with Water Hyacinth, agriculture, or irregular bedrock
0.07	Sparse permanent vegetation or low lying shrubs
0.08	Oak woodland, cottonwood, or aspen with some canopy spacing
0.09	Dense young riparian vegetation
0.10	Permanent dense forest (riparian or upland)
0.15	Low density residential
0.20	Industrial/Commercial
0.35	High density residential or Industrial/Commercial

4.1.8.4 Levees, Embankments and Narrow Channels

Additional model layers were created to represent features such as levees, embankments, and gullies that would otherwise be poorly represented by 30 ft cells. The gully input feature of TUFLOW was used to define the elevation and width of narrow channels, natural low spots along ridges, narrow flow paths connecting river and overbanks, flow paths connecting overbank ponds and side channels bypassing the river. The ridge input feature was used to define levees, roadways and natural ridges.

4.1.8.5 Hydraulic Structures

Only hydraulic structures that severely constrict flows were modeled. Bridges were not explicitly modeled because river stages at the modeled study flows do not reach bridge chord elevations and increases in stage due to frictional effects of piers were considered negligible.

Model A

No structure was found to be significant enough to include in the model.

Model B

The 12 barrel culvert on the left overbank of the river near RM 38 was included in the model (Figures 4.1-2 and 4.1-3). The dimensions of the culverts were surveyed by TID in August 2014.

Figure 4.1-2. Culverts near RM 38 (Google 2013).

Figure 4.1-3. Culverts near RM 38 - Field survey by TID/HDR in 2014.

Model C

Dennett Dam, located near the City of Modesto (RM 16), was included in the model (Figures 4.1-4 and 4.1-5). This structure is a remnant metal sheet pile that acts to control water levels at low flows. Dennett Dam was surveyed in 2014 (FEMA 2014).

Figure 4.1-4. Dennett Dam near 9th Street Bridge in the City of Modesto (Google 2013).

Figure 4.1-5. Photo showing downstream face of Dennett Dam (FEMA 2014).

4.2 Hydraulic Model Boundary Conditions

The study plan called for 21 steady-state model runs: eight flows at 250 cfs intervals from 1,000 cfs up to 3,000 cfs, and 13 flows at 500 cfs intervals from 3,000 cfs to 9,000 cfs. The upstream boundary condition for all three models consists of a constant flow hydrograph for each of the study runs.

The downstream boundary condition for each model was different due to differences in bed slope. The bed slope of the Tuolumne River is relatively steep until approximately RM 31 and less steep from that point downstream to the confluence (Figure 4.2-1). This necessitated different approaches for Model A and Model B.

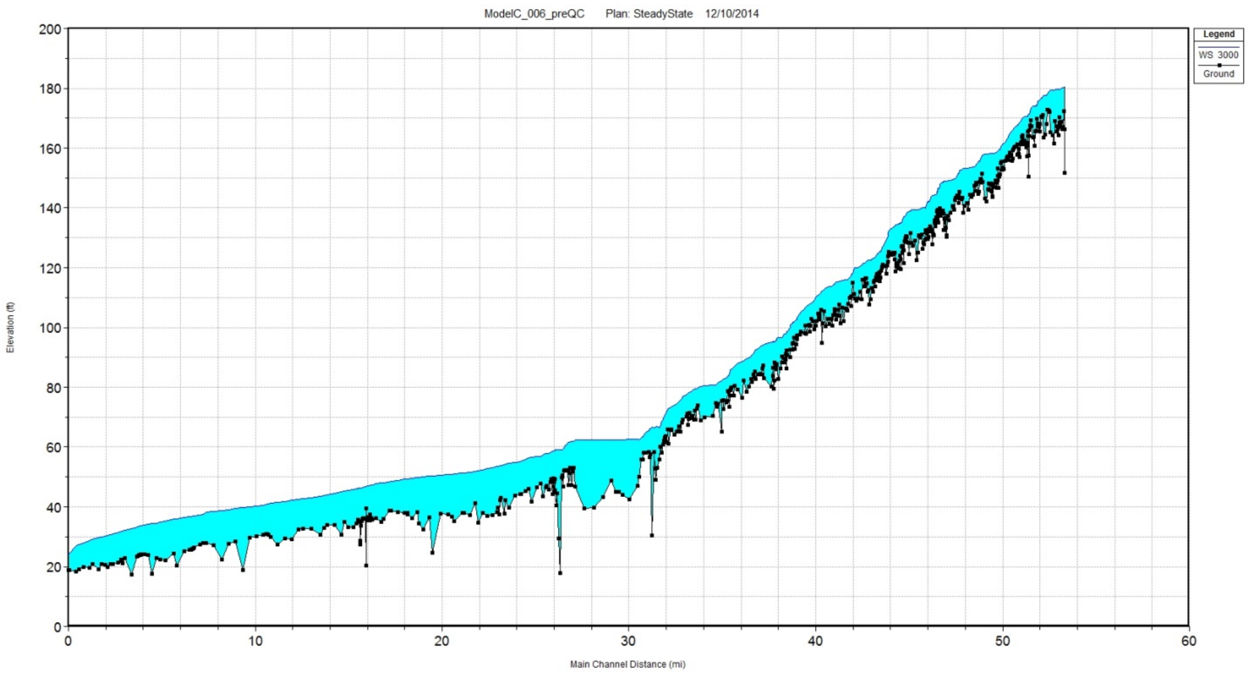

Figure 4.2-1. Bed slope of lower Tuolumne River.

4.2.1 Model A

The relatively steep bed slope in this reach allowed the use of a normal depth boundary condition by extending the model boundary downstream of RM 40 (the applicable downstream model extent) to RM 37.4, such that conditions at the boundary did not affect results at RM 40.

The boundary set-up included a 1D elevation-discharge rating curve developed from the associated HEC-RAS model and a normal depth rating curve for the 2D boundary computed by TUFLOW for a specified steep slope. A sensitivity analysis of the downstream boundary condition was performed for flows of 2,000 and 10,000 cfs (Figures 4.2-2 and 4.2-3). The analysis indicated that varying the 1D rating curve by as much as 5 ft has no impact on results at RM 40.0.

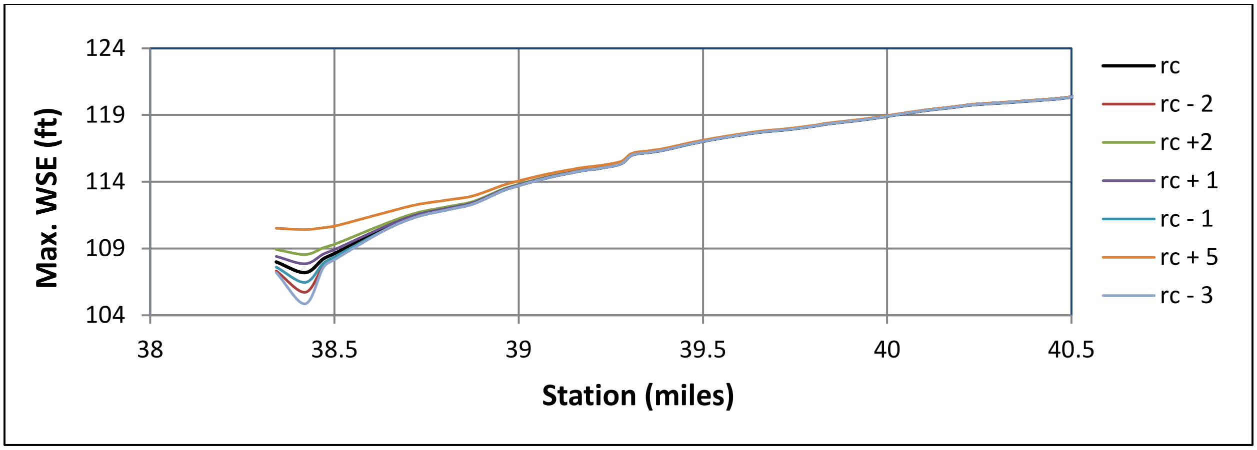

Figure 4.2-2. **Model A - Sensitivity analysis for the boundary condition rating curve at a steady flow of 10,000 cfs. In the legend, "rc" means boundary rating curve elevation and "-" or "+" means minus or plus feet of elevation. For example, "rc-2" means boundary rating curve elevation minus two feet.**

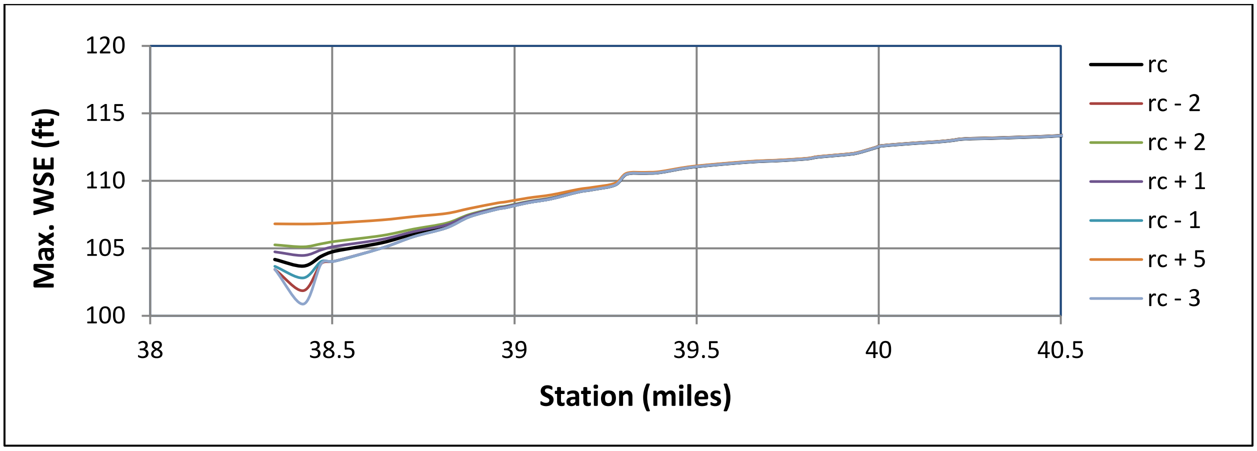

Figure 4.2-3. **Model A - Sensitivity analysis for the boundary condition rating curve at a steady flow of 2,000 cfs. In the legend, "rc" means boundary rating curve elevation and "-" or "+" means minus or plus feet of elevation. For example, "rc-2" means boundary rating curve elevation minus two feet.**

4.2.2 Model B

A normal depth boundary condition was not used for Model B due to the bed slope of this reach of the river. A sensitivity test indicated that boundary effects travel nearly 10 miles upstream, close to RM 31. Because of this, Models B and C were developed simultaneously. Model C was then used to develop an elevation-discharge rating curve for use in Model B. By following this process, differences in results at the model boundaries of B and C were avoided. Figure 4.2-4 shows the rating curve developed for Model B.

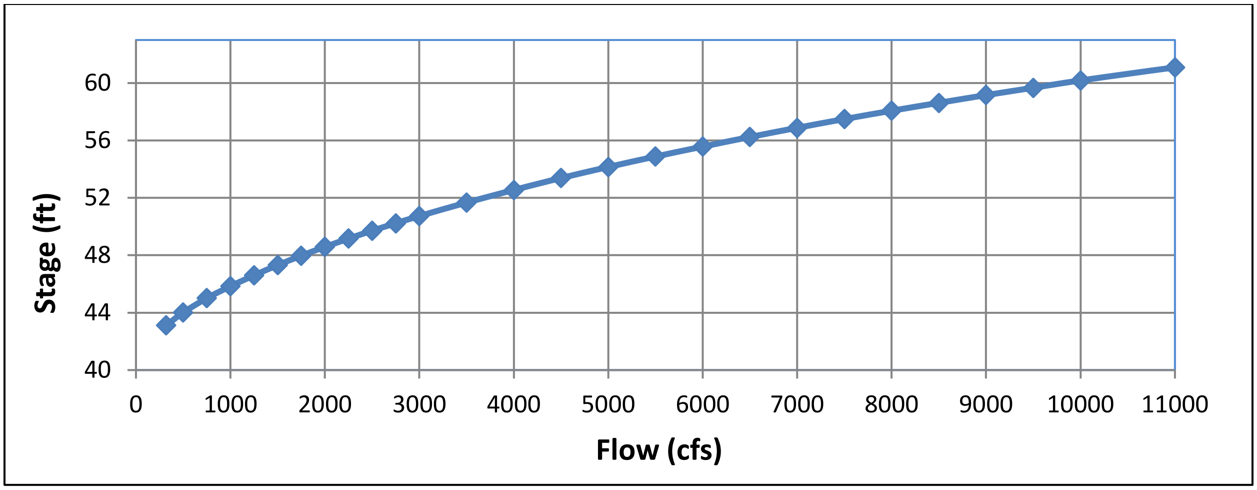

Figure 4.2-4. Model B - Boundary condition rating curve.

4.2.3 Model C

Model C captures the confluence of the lower Tuolumne River with the San Joaquin River. The water surface elevation at the confluence (the boundary condition for Model C) is heavily influenced by the combination of flows in the two rivers.

Backwater effects from the San Joaquin River were determined by an extensive hydrologic and hydraulic analysis (Attachment E). The analysis showed that the potential backwater effects from the San Joaquin River could extend up to approximately RM 13 for the range of flows used in this study. The backwater analysis yielded an elevation-discharge rating curve for the Model C downstream boundary condition (Figure 4.2-5).

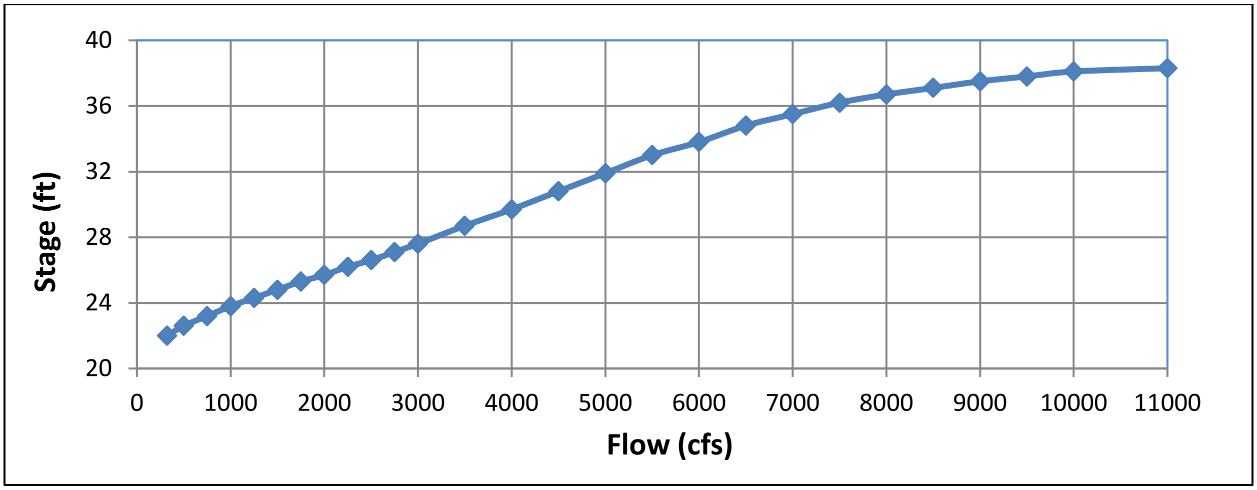

Figure 4.2-5. Model C - Boundary condition rating curve.

4.3 Hydraulic Model Calibration and Validation

The hydraulic model was calibrated and validated to observed physical data such as historical flood inundation extents, high water marks, stage and flow measurements at gaging stations, and other observed stage and flow measurements (Table 4.3-1).

Table 4.3-1. Calibration and validation data.

No.	Data Source
1	USGS Gage 11289650 in the lower Tuolumne River below La Grange Dam near the upstream limit of Model A at RM 51.5
2	Measured water levels for a constant 3000 cfs flow between RM 50 and RM 43 from Pulse Flow Study (Stillwater Sciences 2012)
3	USGS Gage 11290000 in the lower Tuolumne River near City of Modesto in Model C near RM 16
4	Aerial imagery of inundation extents for multiple near-steady flows from Google Earth Pro, Version 7.1.2.2041 (Google 2013)
5	Historic aerial imagery (TID/MID 1997) of inundation extents for multiple near-steady flows collected in 1993 and 1995

4.3.1 Calibration Methodology

The calibration process followed these general steps:

(1) All available calibration data were thoroughly evaluated for quality and applicability.

(2) Significant morphological changes in the river and floodplain between 1993 and 2012 were noted. Identifying and understanding these changes was crucial to establishing calibration data. Locations of morphological changes are identified in Attachment F.

(3) Reaches were calibrated at multiple calibration flows such that each model was calibrated for the entire range of study flows (1,000 – 9,000 cfs).

(4) Flows less than 1,000 cfs were used to calibrate the 1D low flow channel.

(5) To adequately calibrate the 1D channel capacity, calibration flows were selected that exited the channel and entered the floodplain.

(6) Flow travel time was taken into account when interpreting flows associated with aerial images.

(7) The contribution of Dry Creek just upstream of the Modesto gage was taken into account when interpreting flows and associated aerial images.

(8) Model components and parameters were refined without affecting their consistency and reasonableness. This typically included:

- adding cross sections at hydraulic controls that were not obvious;
- obtaining additional field data on split-flow locations and other troublesome areas identified during model runs;
- capturing small islands located in the river that are hydraulically significant using additional cross sections;
- adjusting Manning's 'n' of the 1D channels and 2D overbanks;

- adjusting the 1D-2D line;
- adding and/or adjusting narrow channels and levees to improve flow paths and connections; and
- adjusting the weir coefficient of Dennett Dam.

(9) Models were calibrated by sub-reaches when necessary.

(10) Model reaches were validated using events that were not used for calibration to ensure acceptable performance across the range of study flows.

(11) The lower reach of Model B (below RM 30) and upper reach of Model C (from RM 21.5 to RM 13) were calibrated simultaneously.

4.3.2 Model A Calibration Methodology

Model A was divided into five sub-reaches for calibration and validation. The divisions were based on characteristics of channel-floodplain interaction and local hydraulics. Table 4.3-2 describes the sub-reach extents, areas of interest related to important habitat included in each sub-reach, and the flow events used for calibration or validation at each location. Areas of interest occupying smaller portions of the sub-reaches are designated by the sub-reach number and a letter. Table 4.3-3 lists the historical aerials considered for calibration and validation, associated dates, approximate flows, and whether the data were used for calibration, validation, or limited validation only for each sub-reach location. Aerial imageries from 1993 and 1995 were used only for limited validation.

Measured water levels for a constant 3,000 cfs flow for a small reach between RM 50 and RM 43 from the Pulse Flow Study (Stillwater Sciences 2012) were used in conjunction with aerial images for validating the reach.

Calibration was required for three of the five sub-reaches as the other two reaches provided suitable hydraulic results without model revision. All five sub-reaches were validated.

Table 4.3-2. Model A - Calibration sub-reaches.

Calibration/Validation Sub-reach No.	USGS River Mile	Areas of Interest	Calibration Event No.[1]	Validation Event No.[1]
1	RM 51.6 to RM 48.5	Riffle 4A/4B	2, 6	3, 9
1A	RM 50	Side Channel	--	4
2	RM 48.5 to RM 46	Riffle 5A (Basso Bridge)	1	3, 6, 9
3	RM 46 to RM 44	Zanker Property	6	1, 3, 9
4	RM 44 to RM 42	Bobcat Flat	--	1, 3, 6, 9
4A	RM 43	Bobcat Flat Restoration	--	7, 8
5	RM 42 to RM 40	--	--	3, 6
5A	RM 42 to RM 38	--	--	1, 5

[1] See Table 4.4-3 for calibration and validation event descriptions associated with each number.

Table 4.3-3. Model A - Calibration and validation data.

Event No.	Date	Flow (cfs)	Calibration Sub-reach Number[1]	Validation Sub-reach Number[1]	Limited Validation
1	June 11, 2005[2]	4,030	2	3, 4, 5A	--
2	June 29, 2005[2]	2,680	1	--	--
3	February 23, 2006[2]	1,590	--	1, 2, 3, 4, 5	--
4	May 24, 2009[2]	490	--	1A	--
5	April 24, 2010[2]	1,960	--	5A	--
6	May 30, 2010[2]	2,040	1, 3	2, 4, 5	--
7	June 13, 2010[2]	5,400 to 6,000	--	4A	--
8	June 16, 2011[2]	5,900 to 5,000	--	4A	--
9	July 24, 2011[2]	1,020	--	1, 2, 3, 4	--
10	October 7, 1993[3]	3,100	--	--	All sub-reaches
11	February 16, 1995[3]	5,300	--	--	All sub-reaches
12	April 22, 1995[3]	8,400	--	--	All sub-reaches

[1] See Table 4.4-2 for sub-reach descriptions.
[2] Google Earth Images.
[3] Aerial images from Report 96-14 in TID/MID 1997.

4.3.3 Model B Calibration Methodology

The 1D component of Model B was calibrated along with Model C using USGS Modesto gage information. Model B did not require any model revision based on aerial images referenced during the calibration process. Tables 4.3-4 and 4.3-5 provide the calibration and validation data used for Model B.

Table 4.3-4. Model B - Calibration and validation data – Google Earth Images.

S. No.	USGS River Mile	Approximate Steady Flow* / Image Date			
		654 cfs	2,130 cfs	2,620 cfs	4,050 cfs
1	RM 20 to RM 40	28-Jul-11[2]	24-Apr-10[2]	-	11-Jun-05[2]
2	RM 20 to RM 25			10-Feb-06[2]	

[2] Validation data.
* Previous day average flow to account for travel time from USGS La Grange gage.

Table 4.3-5. Model B - Validation data – TID/MID Images.

S. No.	USGS River Mile	Approximate Steady Flow* / Image Year		
		3,100 cfs	5,300 cfs	8,400 cfs
2	RM 20 to RM 40	1993[3]	1995[3]	1995[3]

[3] Limited validation.
* USGS La Grange gage.

4.3.4 Model C Calibration Methodology

Model C was calibrated in two stages; the reach above RM 13 (which is free of any backwater effects from the San Joaquin River) was calibrated separately from the reach below RM 13. Tables 4.3-6 and 4.3-7 provide the calibration and validation data used for Model C.

Table 4.3-6. Model C - Calibration and validation data – Google Earth Images.

S. No.	USGS River Mile	Approximate Steady Flow* / Image Date		
		900 cfs	3320 cfs	4130 cfs
1	RM 0.88 to RM 16	28-Jul-11[1]	-	11-Jun-05[2]
2	RM 12 to RM 16		10-Feb-06[2]	

[1] Calibration data.
[2] Validation data.
* USGS Modesto Gage (near RM 16).

Table 4.3-7. Model C - Validation data – TID/MID Images.

S. No.	USGS River Mile	Approximate Steady Flow* / Image Year
		8322 cfs
1	RM 0.88 to RM 21.5	22-Apr-95[3]

[3] Limited validation.
* USGS Modesto Gage (near RM 16).

The reach of Model C between the USGS gage near Modesto (upstream of the confluence with Dry Creek) and RM 21.5 was validated using the data in Tables 4.3-4 and 4.3-5 of Model B, due to the possibility that this reach may be affected by inflows from Dry Creek.

Figure 4.3-1 shows the comparison of TUFLOW model results with the USGS Modesto gage rating curve and the USGS flow measurements at the gage.

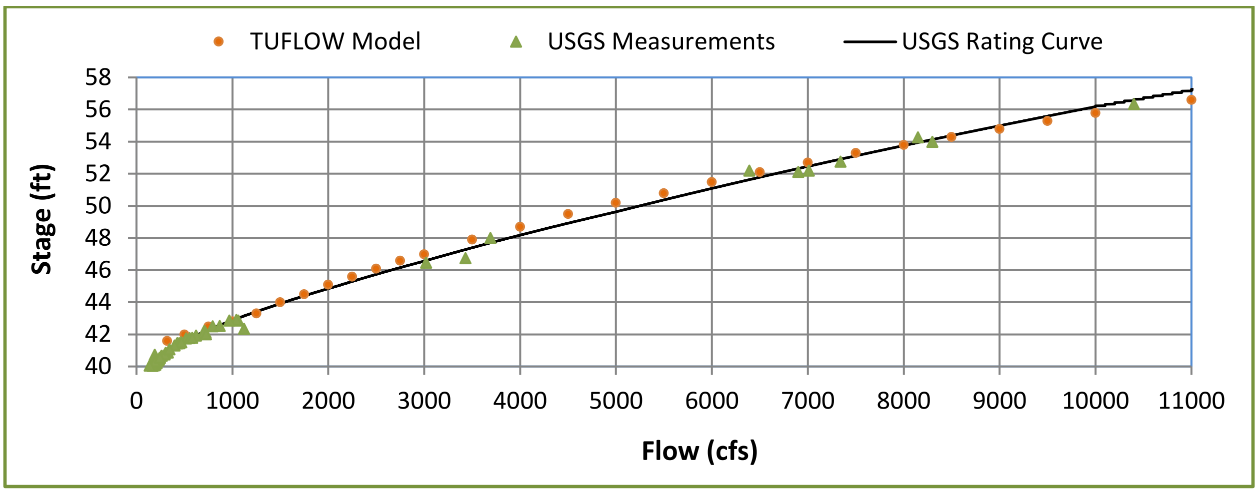

Figure 4.3-1. Model C - Calibration comparison at USGS Gage near Modesto.

4.4 Fish Habitat Suitability Analyses

Habitat Suitability Criteria (HSC) for juvenile life stages of Chinook salmon and *O. mykiss* were selected as part of the completed Instream Flow Incremental Method (IFIM) study (Stillwater Sciences 2013) during workshops held on September 20, 2010, October 20, 2010, and February 3, 2011. So called "Envelope" HSC curves, representing a range of suitable depths and velocities on the lower Tuolumne River, were developed for Chinook salmon fry (Aceituno 1990; USFWS 1988, 2010a), Chinook salmon juveniles (Aceituno 1990), *O. mykiss* fry (Hampton 1997; Moyle and Baltz 1985, TRPA 2004, and USFWS 2010b) and juvenile (TRPA 2000, USFWS 2004) life stages from selected references. The HSC workshop summaries and documentation for selected curves were filed electronically with FERC in the IFIM study progress reports on December 8, 2010 and July 29, 2011.

4.4.1 In-channel habitat suitability

To provide a comparison of the relative amounts of in-channel and floodplain habitat over a range of flows, TUFLOW modeling within the 1D model domain was conducted for flows from 500 cfs up to 9,000 cfs, with additional HEC-RAS model runs at flows of 100 cfs and 250 cfs. Model predictions of depth and velocity within each TUFLOW model grid cell were used to provide a cell-specific prediction of usable habitat area calculated as the product of cell area and a composite suitability index (CSI) for each species/life stage combination at the corresponding depth and velocity estimates. Total usable habitat area within the 1D model domain was calculated for each discharge as the sum of cell-by-cell usable habitat areas throughout the model domain. From the accumulated estimates of usable habitat area for each species/life stage combination, reach specific or river-wide relationships of in-channel usable habitat area vs. discharge are summarized.

4.4.2 Floodplain habitat suitability

The availability of suitable floodplain habitat for juvenile life stages of Chinook salmon and *O. mykiss* was based upon TUFLOW model predictions of depth and velocity as a function of discharge. Inundation area, velocity and depth predictions were made at 250 cfs intervals between 1,000 and 3,000 cfs and 500 cfs intervals between 3,000 cfs and 9,000 cfs, resulting in a total of 21 model runs. Computation of usable area estimates commonly used in PHABSIM analyses was completed in GIS using the following methodology:

(1) At each discharge, total inundated area was calculated by the sum of all modeled grid cells within the 2D domain that have a non-zero depth. Depth and velocity data were accumulated at every point within the 2D model domain.

(2) Usable habitat area for each cell was computed as the product of cell area and the CSI for each species/life stage combination at the corresponding depth and velocity estimates.

(3) CSI range from zero (unsuitable) to 1.0 (suitable) was calculated by the joint product of the appropriate fish HSC curve (depth or velocity) for an individual fish species/life stage combination.

(4) Total usable habitat area was the sum of cell-by-cell usable habitat areas throughout the model domain.

From the accumulated estimates of inundated area as well as usable habitat area for each species/life stage combination, reach specific or river-wide relationships of inundated area vs. discharge or usable habitat area vs. discharge are summarized. Areas within isolated portions of the floodplain created by topographic depressions, backwater areas and ponds, and that were inundated at the lowest flows modeled, were subtracted from the total and usable floodplain area estimates.

4.5 Area-Duration-Frequency Analysis for Base Case (WY 1971–2012) Hydrology

Using the estimates of fish habitat suitability vs. flow in combination with discharge records in the lower Tuolumne River, the quantity of seasonally inundated floodplain habitat may be estimated as a function of duration and frequency. Traditionally, flood frequency analyses are conducted from a record of annual maximum flows or other measures of floods using ranking methods or fitted to particular distributions to estimate probabilities of occurrence or annual return periods (Dunne and Leopold 1978). To determine the maximum continuous wetted area for periods of 1, 7, 14, 21, and 30 day durations, an area-duration-frequency (ADF) analysis was conducted as follows:

(1) Define flow "events" as a combination of discharge as well as duration. For a given flow 'q' and duration 'D', an "event of magnitude (q,D)" is defined as an interval of 'D' consecutive days (within a season of interest) during which mean daily flow is at least 'q'.

(2) Hydrology may be examined on an annual water-year basis, as well as periods representative of rearing periods of Chinook salmon (February through May) and *O. mykiss* juveniles (March through September).

(3) The "recurrence interval (in years) for an event of magnitude (q, D)" is defined as 'N/M', where 'M' is the number of years in which such an event occurred, out of the 'N' (=41) years of record (1971–2012).

(4) For each duration 'D' of interest, 'q' is plotted against the recurrence interval for events of magnitude (q, D).

To allow for examination of alternative scenarios in the current study, a synthetic hydrologic record was previously developed for "base case" conditions contained in the *Project Operations/Water Balance Model Study* (W&AR-02). The Base Case (1971–2012) depicts the operation of the Project in accordance with the current FERC license, ACOE flood management guidelines, and the Districts' irrigation and M&I water management practices since completion of Don Pedro Dam in 1971. Flow frequency and ADF relationships for the current study are based upon the Base Case hydrology.

5.0 RESULTS

5.1 Hydraulic Model Results

TUFLOW model simulations were carried out for 21 flows identified in the Study Plan, from 1,000 cfs to 9,000 cfs. Appropriate downstream boundary conditions were applied and the models were run at a time step of 2 seconds for the 1D component and 4 seconds for the 2D component for a sufficiently long period of time for the models to reach steady-state condition. Model results were thoroughly reviewed for consistency and reasonableness.

Hydraulic outputs were generated at a 15 ft cell size (half the cell size). TUFLOW computes water surface elevations at a model cell size of 30 ft and computes depth and velocity at the center of the cell. This enables TUFLOW to generate results at half the cell size. Outputs were generated in binary grid (flt extension) format which can be viewed and processed in ArcGIS and similar software. These results were used for habitat analysis.

Flood inundation extents for 21 steady flows for the study area are presented in the form of 20 animations (*.avi files) (Attachment G). Using SMS software, animations were developed for the entire study area except where flows were completely contained within the river and significant floodplain inundation was absent.

5.2 Fish Habitat Suitability Analyses

The TUFLOW model results were used to estimate total wetted area as well as usable habitat area within in-channel and floodplain habitats for juvenile life stages of Chinook salmon and *O. mykiss* as a function of flow. Attachment H provides plots comparing total wetted areas and usable habitat in both in-channel and overbank areas for each species/life stage combination as a function of flow within each of the three model reaches and as a river-wide estimate of usable habitat area variation with discharge. Attachment I provides color plots showing overall floodplain inundation at representative sites within each model reach as well as spatial variations in relative habitat suitability (0.0 to 1.0) for the identified species at several intermediate flows.

5.2.1 Floodplain Area vs. Discharge Relationships

Inundated floodplain areas for each of the three TUFLOW model reaches are shown in Figure 5.2-1 as a function of discharge. At the lowest flows modeled, substantial amounts of inundated area within isolated portions of the floodplain were created by topographic depressions and backwater areas (Attachment I). As mentioned in Section 3.1, these off channel ponds and topographic depressions have also been associated with increased incidence of stranding and entrapment of juvenile Chinook salmon (TID/MID 2001). As flows increase, habitat connectivity between ponded habitats and the main channel occurs. Model A (RM 51.7 – 40) shows the largest increase of inundated area with discharge, consistent with the presence of areas that were graded following reclamation of tailings piles during the construction of Don Pedro Dam. However, not all sub-reaches are inundated at the same flows. Although some overbank habitat is available over the length of the lower Tuolumne River, diked areas adjacent to off-channel mining operations within Model B (RM 40–21.5) limit the potential increase in floodplain inundation with increasing discharge. In contrast, and depending on the flow of the San Joaquin River, agricultural areas near the San Joaquin River confluence are subject to broad floodplain inundation at flows in excess of 6,000 cfs and Model C (RM 21.5–0.9) exhibits the highest modeled increase in inundation area with discharge at flows in excess of 8,000 cfs) (Figure 5.2-1).

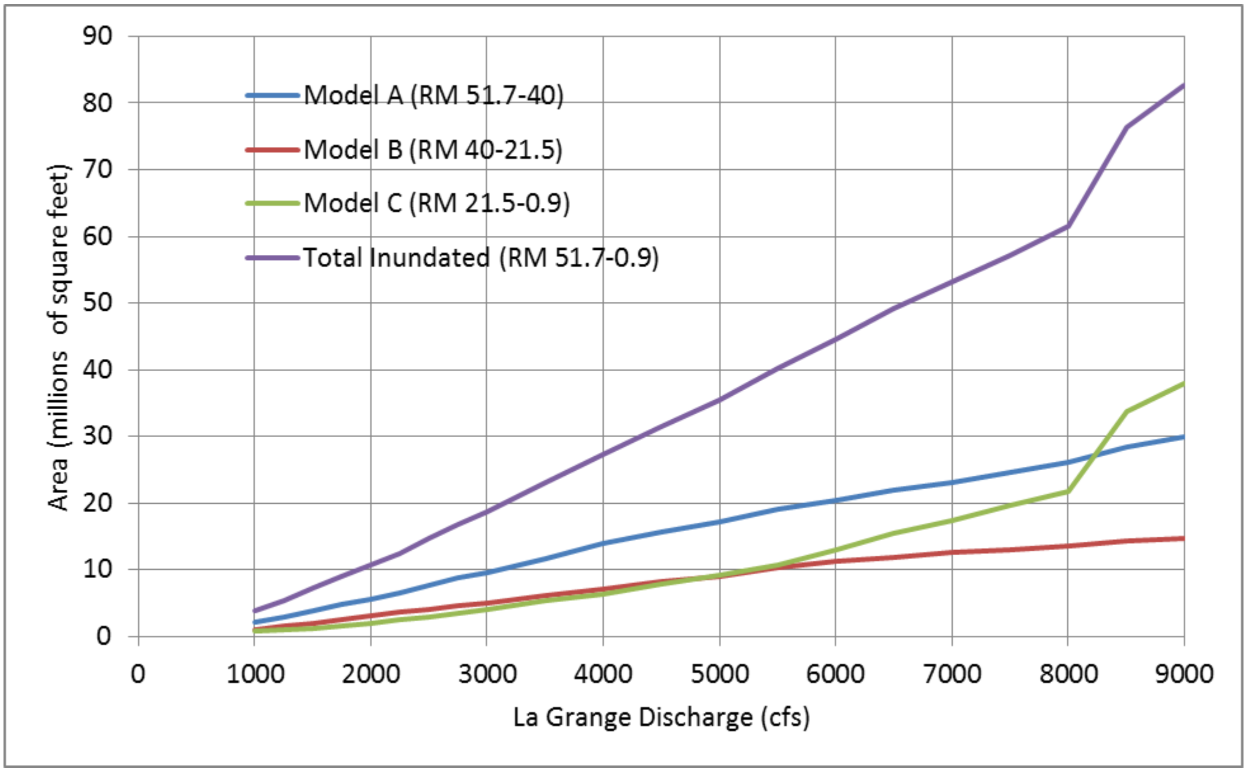

Figure 5.2-1. Total inundated floodplain area as a function of discharge within three modeled reaches of the lower Tuolumne River.

5.2.2 Usable floodplain habitat for juvenile Chinook salmon and *O. mykiss* rearing

Using GIS analysis of inundation areas developed from aerial photography conducted by the Districts (TID/MID 1997), the USFWS (2008) previously developed a report on flow-overbank inundation relationships for fall-run Chinook salmon and steelhead/rainbow trout (*O. mykiss*) juvenile habitat in the lower Tuolumne River. Although GIS analysis used for the development of the USFWS (2008) report excluded areas within isolated portions of the floodplain created by off-channel ponds, topographic depressions, and backwater areas, since habitat suitability for juvenile salmonid rearing was not estimated, flow vs. area relationships developed by the USFWS (2008) study over-estimated the amounts of potential habitat for salmonid rearing as a function of flow. As described below, habitat suitability criteria (HSC) for juvenile salmonids developed for the 2013 IFIM Study (Stillwater Sciences 2013) were used in combination with depth and velocity predictions to estimate total usable habitat as a function of flow.

Table 5.2-1 provides the results of habitat suitability modeling within floodplain areas of the lower Tuolumne River outside of the low flow (1D) channel boundary, with estimates of total available rearing habitat combining both in-channel and over-bank areas found in Attachment H.

At 1,000 cfs, inundated areas outside of the low flow channel boundary provide approximately 1.2 million ft^2 of usable habitat for Chinook salmon fry in Model A (RM 51.7–40.0), with lower amounts of 0.6 million ft^2 and 0.4 million ft^2 within Model B (RM 40–21.5) and Model C (RM 21.5–0.9), respectively. Estimates of usable overbank habitat expand rapidly at higher flows above bankfull discharge, with corresponding increases in habitat carrying capacity for rearing Chinook salmon. On a usable habitat area basis, over half of the usable habitat for Chinook salmon fry is located in the uppermost 12 miles of the lower Tuolumne River (Model A) at flows below 5,000 cfs. Usable habitat expands rapidly between 7,000 cfs and 9,000 cfs in the lowermost reach (Model C) due to backwater influences of the San Joaquin River, assuming simultaneous occurrence of high flows in both rivers.

Table 5.2-1. Hydraulic modeling results of total inundated and usable floodplain habitat for salmonid juveniles at selected flows in the lower Tuolumne River.

Modeled Flow (cfs)	1,000	2,000	3,000	5,000	7,000	9,000
Model A (RM 51.7-40) estimates of total inundated and usable rearing habitat areas (ft^2)						
Inundated Area	2,088,000	5,633,775	9,604,125	17,265,375	23,146,875	29,926,125
Chinook salmon fry	1,222,916	3,193,092	4,756,145	6,419,680	7,108,983	7,618,930
O. mykiss fry	1,741,791	4,318,501	6,639,330	9,167,501	10,124,053	11,863,551
Chinook salmon juvenile	703,341	2,961,988	5,562,806	9,963,276	12,904,300	14,726,723
O. mykiss juvenile	784,686	3,155,993	5,888,722	10,533,523	13,671,567	15,922,373
Model B (RM 40-21.5) estimates of total inundated and usable rearing habitat areas (ft^2)						
Inundated Area	1,059,525	3,055,725	5,024,700	9,061,875	12,527,100	14,743,125
Chinook salmon fry	617,099	1,609,146	2,089,023	2,789,931	2,971,408	2,392,190
O. mykiss fry	885,640	2,222,935	2,994,996	4,007,929	4,393,046	3,668,032
Chinook salmon juvenile	355,594	1,595,783	2,846,802	4,509,524	5,631,474	5,397,445
O. mykiss juvenile	372,266	1,693,502	3,044,601	4,906,282	6,394,684	6,497,518
Model C (RM 21.5-0.9) estimates of total inundated and usable rearing habitat areas (ft^2)						
Inundated Area	724,725	2,015,550	4,044,600	9,141,300	17,406,675	37,903,950
Chinook salmon fry	438,614	1,068,951	1,993,904	3,566,876	6,423,204	14,080,302
O. mykiss fry	616,325	1,506,680	2,757,012	4,971,681	8,765,927	19,833,137
Chinook salmon juvenile	333,783	1,082,079	2,174,819	4,469,145	7,945,966	19,178,555
O. mykiss juvenile	346,295	1,074,538	2,210,151	4,828,970	8,844,476	19,448,788
River-wide (RM 51.7–0.9) estimates of total inundated and usable rearing habitat areas (ft^2)						
Inundated Area	3,872,250	10,705,050	18,673,425	35,468,550	53,080,650	82,573,200
Chinook salmon fry	2,278,630	5,871,189	8,839,073	12,776,487	16,503,594	24,091,422
O. mykiss fry	3,243,756	8,048,116	12,391,338	18,147,111	23,283,027	35,364,719
Chinook salmon juvenile	1,392,718	5,639,850	10,584,427	18,941,945	26,481,740	39,302,723
O. mykiss juvenile	1,503,247	5,924,034	11,143,474	20,268,776	28,910,727	41,868,679

Recognizing that fry and juvenile rearing on floodplains is generally restricted to areas nearest the high flow channel margin, we can contextualize the usable habitat area estimates in terms of a maximum habitat carrying capacity using literature values for rearing density. For example, assuming a maximum density of 1.44 fry/ft^2 found in analyses by Grant and Kramer (1990) would correspond to a river-wide carrying capacity of 3.3 million Chinook fry at 1,000 cfs (i.e, (1.44 fry/ft^2 x 2.28 million ft^2 = 3.3 million fry). At 2,000 cfs, this would correspond to a carrying capacity of 8.5 million fry, with carrying capacity estimates of 12.7 million and 18.4 million at 3,000 cfs and 5,000 cfs, respectively.

Usable habitat for Chinook juveniles at 1,000 cfs, 3,000 cfs and 5,000 cfs is estimated to be 1.4 million ft^2, 10.6 million ft^2, and 18.9 million ft^2, respectively river-wide (Table 5.2-1), which would correspond to a carrying capacity of 0.6 million, 4.9 million, and 8.8 million juveniles using the same calculations as for fry at the maximum density of 0.465 juveniles/ft^2 found by USFWS (1991). Although corresponding estimates of usable habitat for juvenile *O. mykiss* are shown in Table 5.2-1 as a basis of comparison we do not provide a carrying capacity estimate. Floodplain habitat use by juvenile *O. mykiss* has not been observed on the lower Tuolumne River and regional observations of *O. mykiss* rearing on floodplains is limited to incidental observations from the Yolo bypass studies (Sommer et al 2001, USBR 2008) as well as more recent (2011) observations of Age 0 habitat use along higher elevation channel margin habitats created following gravel augmentation along the Lower American River (Sellheim et al 2015).

In addition to the results summary above, variations in total inundation areas as well as total usable area with flow for each of the salmonid life stages within each of the model reaches are depicted in Figure 5.2-2 through Figure 5.2-4, respectively, with spatial distribution of suitable habitat at representative sites shown in Attachment I. At the lowest flows modeled within Model A (RM 51.7–40), approximately 60 to 80 percent of total inundated area is usable by Chinook and *O. mykiss* fry, respectively (Figure 5.2-2). As flows increase, increased depths and velocities in the floodplain areas reduce suitability for fry life stages such that usable habitat falls to 25 to 40 percent of total inundated habitat at 9,000 cfs. Because of the greater swimming performance of juvenile salmonids as compared to fry life stages for a given depth or velocity, usable habitat area for juvenile rearing is approximately 50 to 60 percent of total inundated area at 2,000 cfs and above (Figure 5.2-2).

For Model B (RM 40–21.5), usable habitat area for fry life stages varies from 60 to 80 percent of total inundated habitat at 1,000 cfs, with a lower range of 15 to 25 percent of total inundated habitat at flows of 9,000 cfs (Figure 5.2-3). For juvenile life stages, usable habitat varies from a high estimate of 50 to 55 percent usable area out of total inundated habitat at 1,000 cfs and only 35 to 45 percent usable at flows of 9,000 cfs.

For Model C (RM 21.5–0.9), usable rearing habitat area at flows of 1,000 cfs varies from 60 to 80 percent of total inundated habitat for fry and 50 to 55 percent of total inundated habitat for juveniles (Figure 5.2-4). Although the inundated area increases rapidly at the highest flows modeled due to presence of low gradient agricultural areas and backwater effects of the San Joaquin River confluence, the fraction of usable habitat for rearing at 9,000 cfs decreases to 35 to 50 percent of total inundated habitat for fry and 45 to 50 percent of total inundated habitat for juveniles. It should be noted that floodplain inundation in the areas nearest the San Joaquin River is strongly influenced by San Joaquin River discharge and backwater effects (Section 4.2.3).

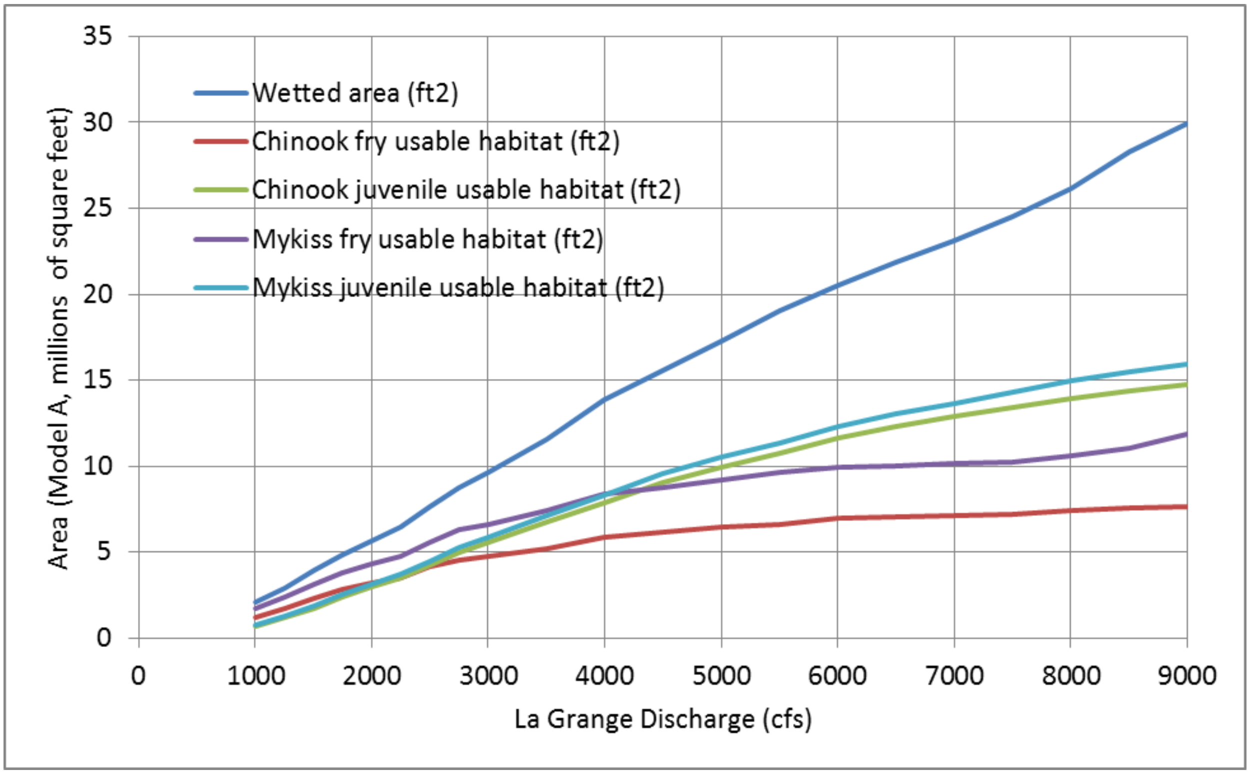

Figure 5.2-2. **Model A results showing total wetted and usable habitat areas for juvenile salmonid life stages in the lower Tuolumne River (RM 51.7–40).**

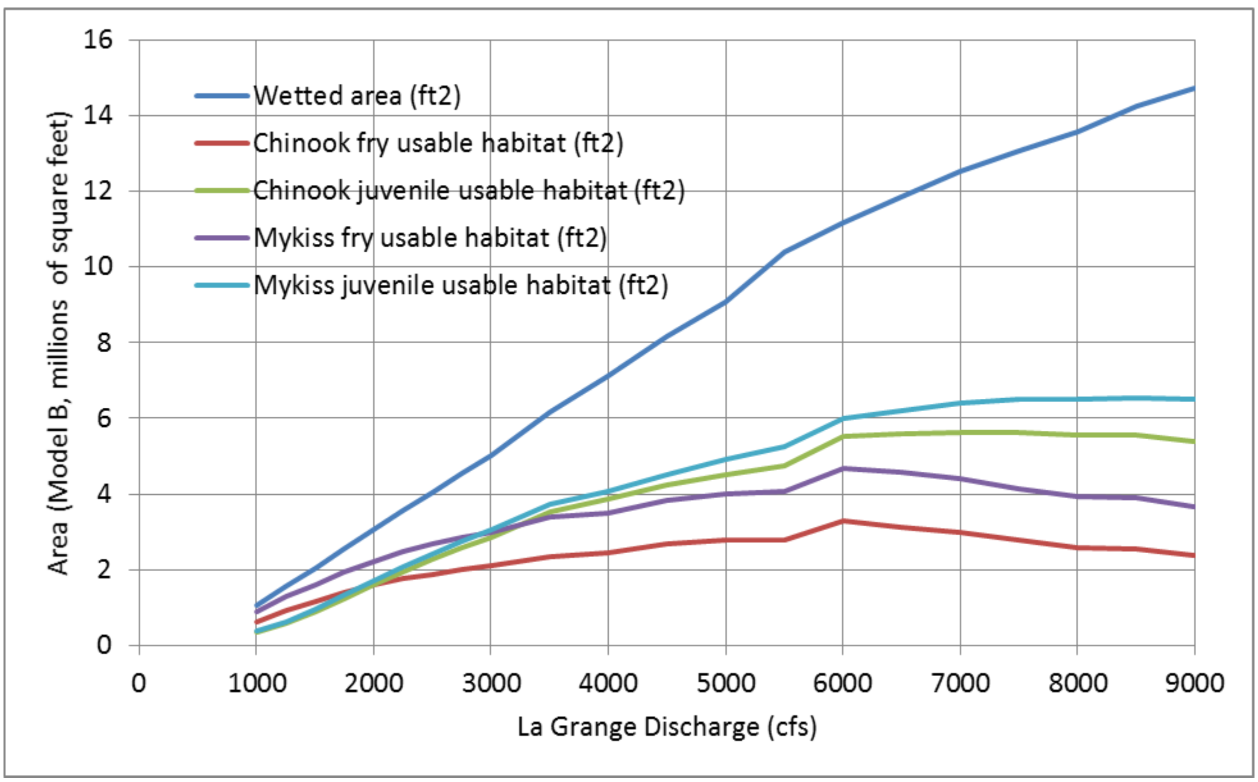

Figure 5.2-3. **Model B results showing total wetted and usable habitat areas for juvenile salmonid life stages in the lower Tuolumne River (RM 40–21.5.)**

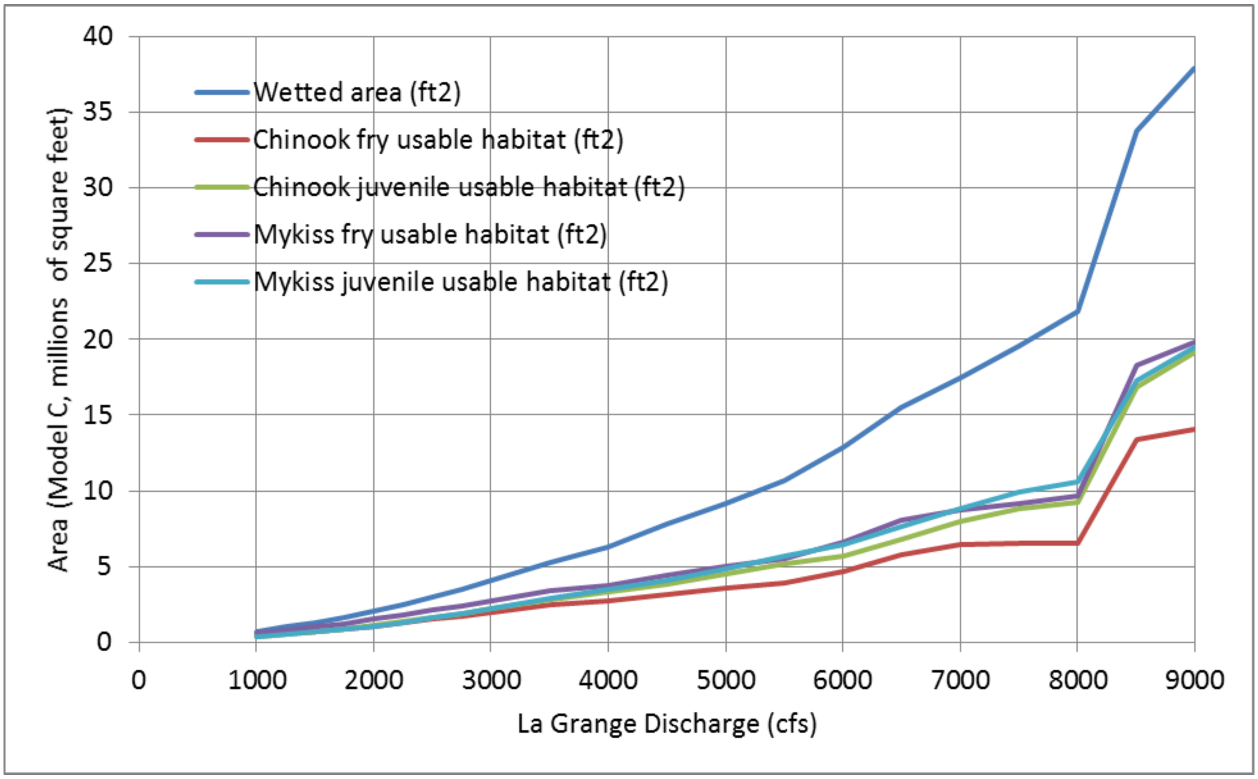

Figure 5.2-4. Model C results showing total wetted and usable habitat areas for juvenile salmonid life stages in the lower Tuolumne River (RM 21.5–0.9).

5.3 Area-Duration-Frequency Analysis for Base Case (WY 1971–2012) Hydrology

5.3.1 Flow Frequency Analysis

Using the Base Case (WY 1971–2012) hydrology from the *Project Operations/Water Balance Model Study* (W&AR-02), an annual exceedance frequency analysis of flow events combining discharge magnitude and duration was conducted. Although flow frequency analyses traditionally use annual hydrology records, we have analyzed the discharge duration-frequency from February through May, months relevant to juvenile Chinook salmon rearing (TID/MID 2013e). Figure 5.3-1 shows the annual recurrence period for these events capturing various flows and durations occurring during the spring time juvenile rearing period for Central Valley Fall-run Chinook salmon. To examine conditions for any rearing Central Valley Steelhead as well as resident *O. mykiss* in the lower Tuolumne River, Figure 5.3-2 shows the annual recurrence period for discharge-duration events occurring between March and September.

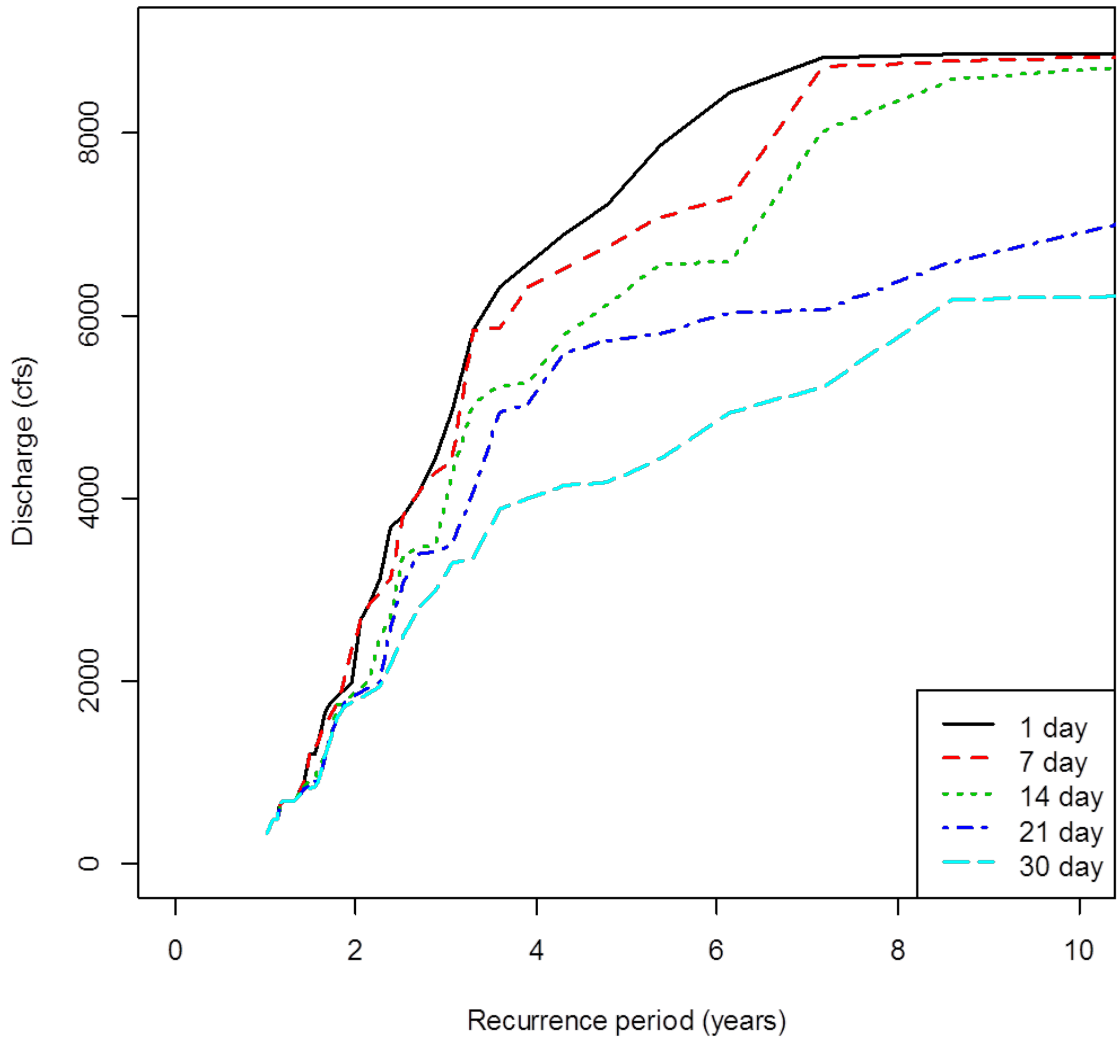

Figure 5.3-1. Annual frequency with which "events", exceeding given flow magnitude and duration thresholds, occur in the lower Tuolumne River from February through May under Base Case (1971–2012) hydrology.

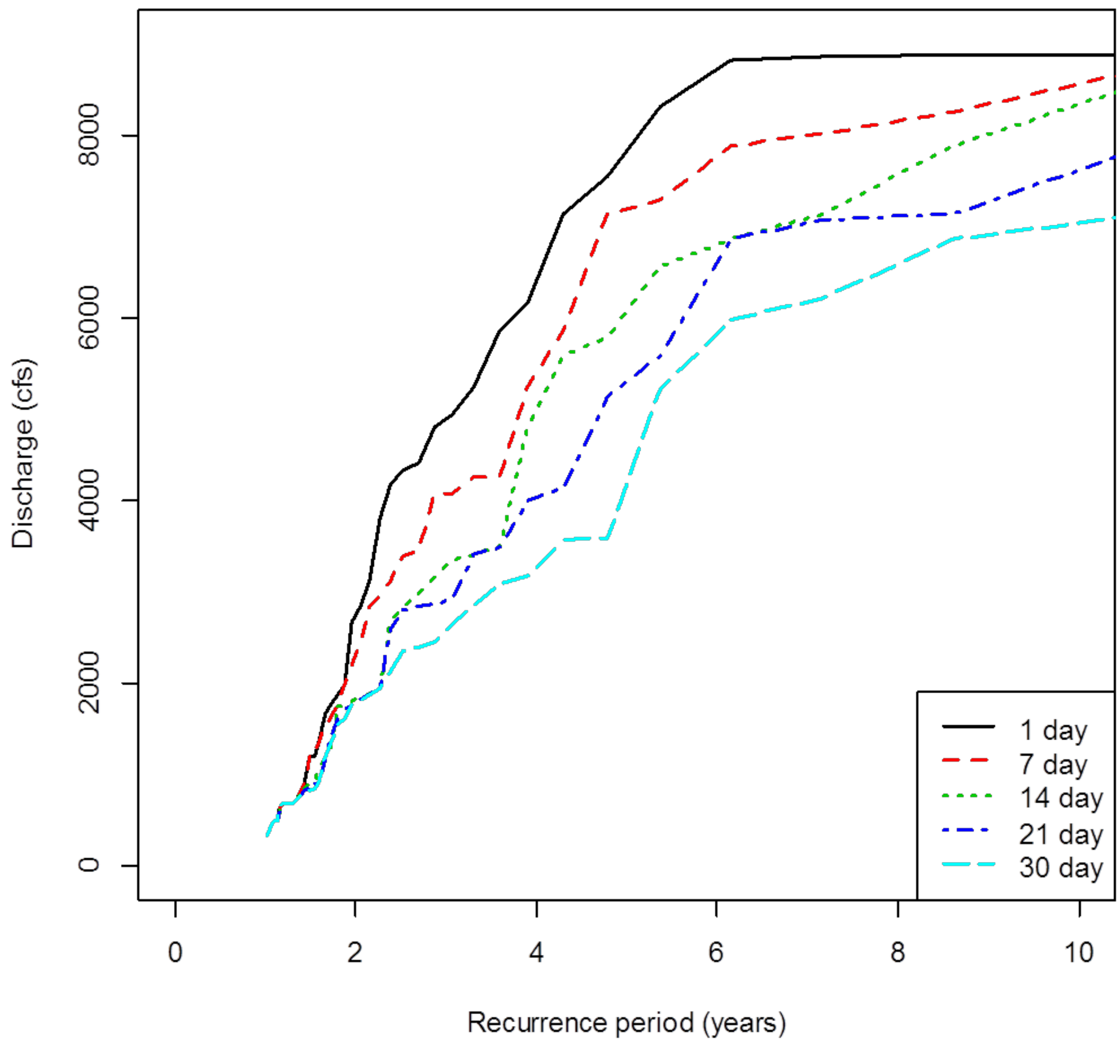

Figure 5.3-2. **Annual frequency with which "events", exceeding given flow magnitude and duration thresholds, occur in the lower Tuolumne River from March through September under Base Case (1971–2012) hydrology.**

5.3.2 Juvenile Chinook salmon floodplain rearing habitat

The potential benefits of general floodplain rearing for juvenile Chinook salmon have been highlighted in recent reports from the Yolo Bypass (Sommer et al. 2001, 2005) and the lower Cosumnes River floodplain (Jeffres et al. 2008). By comparison to the 60,000 acre Yolo Bypass, potentially inundated floodplain areas on the lower Tuolumne are small and would amount to less than 2,000 acres even at the highest flows (i.e., 9,000 cfs) modeled (Table 5.2-1). Nevertheless, to examine potential floodplain habitat availability for the lower Tuolumne River under Base Case (1971–2012) hydrology, the recurrence of floodplain inundation events for Chinook salmon rearing was assessed by combining the flow frequency and habitat suitability analyses discussed in Sections 5.3.1 and 5.2.2 above. Proceeding from the annual discharge frequency analysis (Figure 5.3-1), Figure 5.3-3 shows the annual recurrence period of events exceeding various total inundation area and duration thresholds in the lower Tuolumne River from February through May. For example, consistent with exceedance metrics defining bankfull discharge on the order of 1.5–2 years (Dunne and Leopold 1978), the lowest flows modeled (1,000 cfs) provide approximately 5.7 million ft^2 of inundated area outside of the low flow (1D) channel boundary (Table 5.2-1). Recurrence periods at larger amounts of continuously inundated area are shown in Figure 5.3-3 for the durations analyzed.

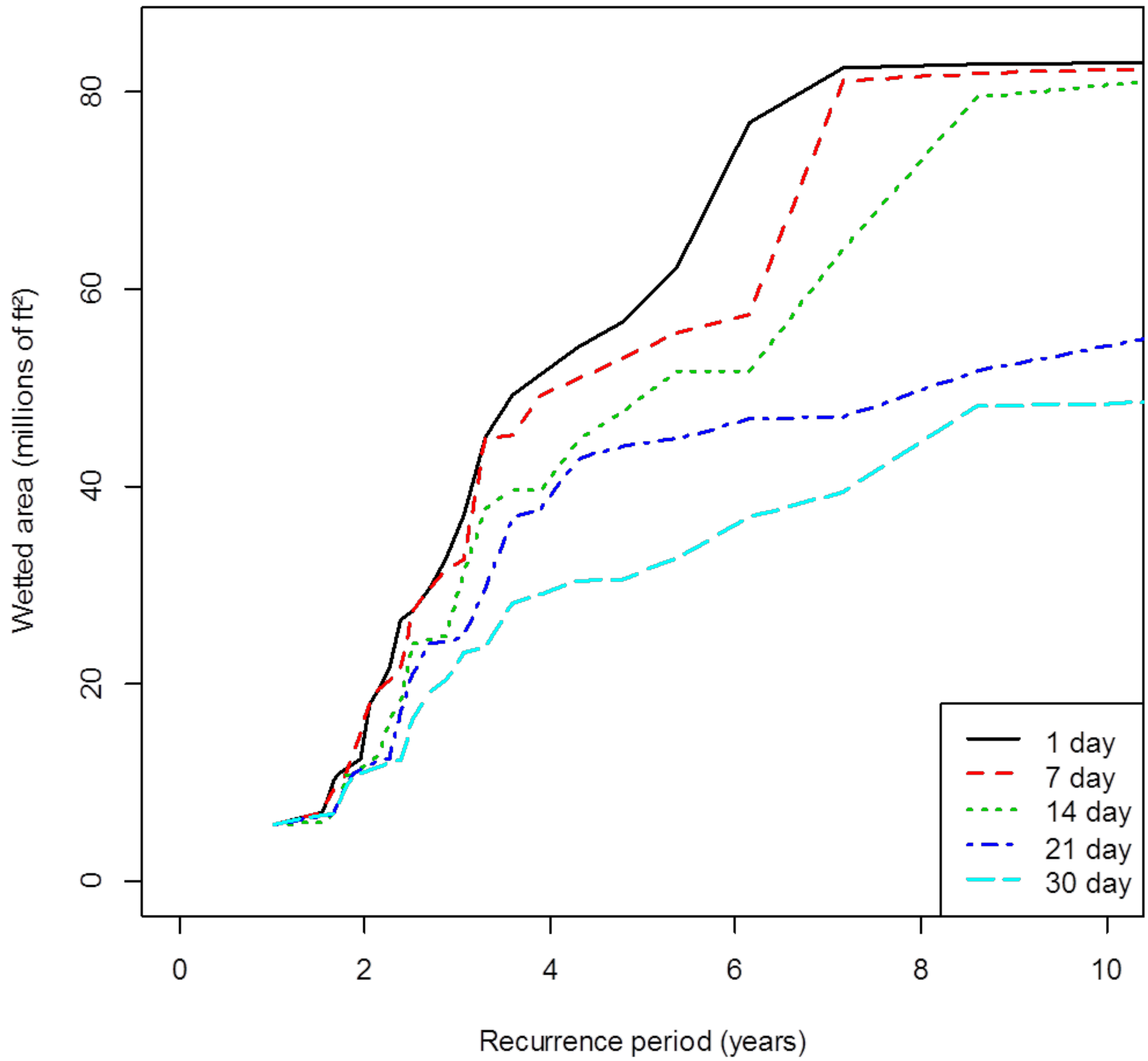

Figure 5.3-3. **Total area-duration-frequency (ADF) plot showing recurrence of events exceeding various total inundation area and duration thresholds in the lower Tuolumne River from February through May under Base Case (1971–2012) hydrology.**

Examining the recurrence of various inundation area relationships of usable habitat for Chinook salmon fry and juvenile rearing, Figures 5.3-4 and 5.3-5 show usable habitat area-duration-frequency (ADF) plots for Chinook salmon fry and juveniles, respectively. These plots analyze the recurrence of events exceeding various usable habitat area (i.e., determined from velocity and depth predictions at a given flow) and duration thresholds (i.e., events lasting 1, 7, 14, 21, and 30 days).

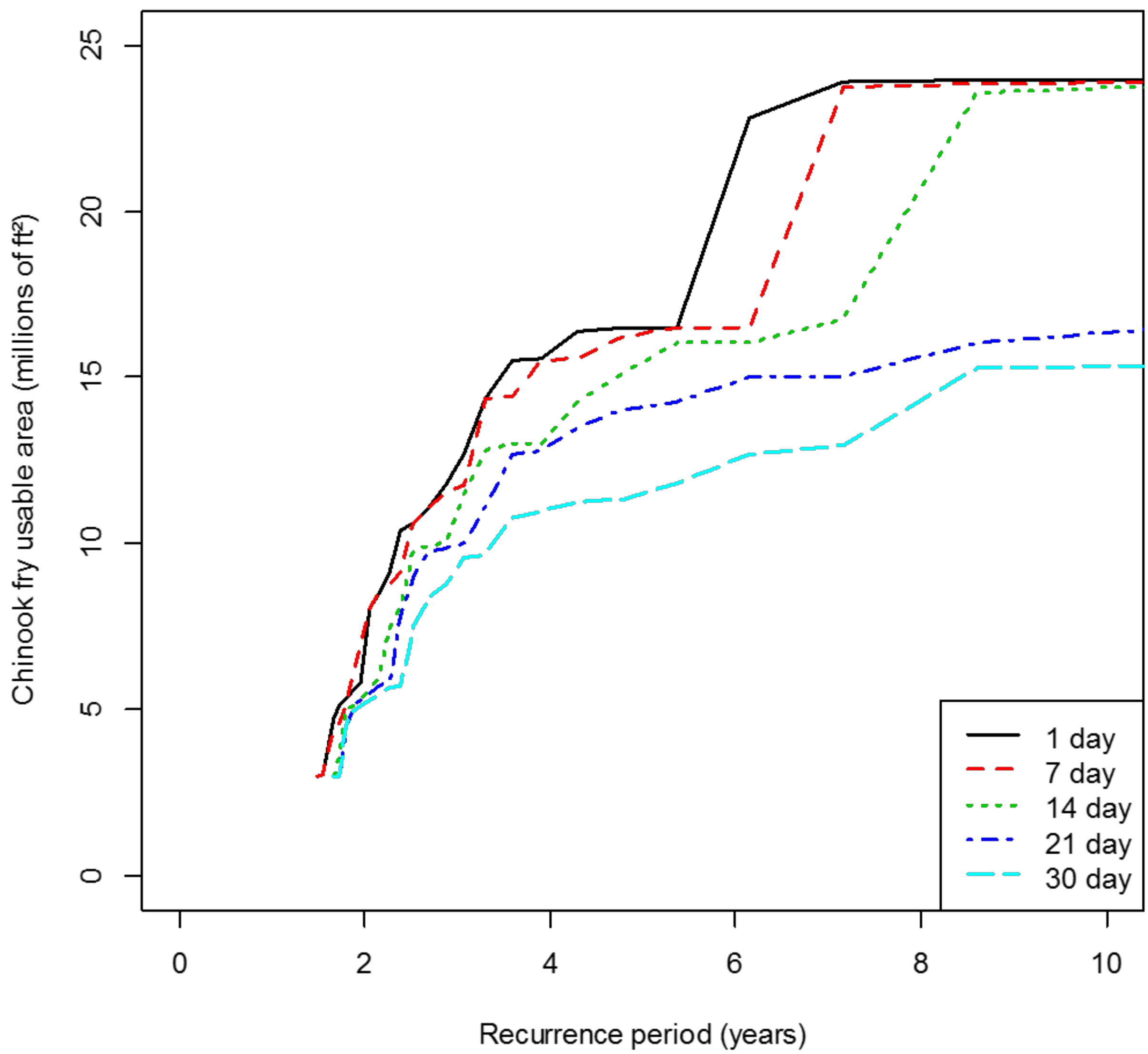

Figure 5.3-4. Chinook salmon fry habitat area-duration-frequency (ADF) plot showing recurrence of events exceeding various usable habitat area and duration thresholds in the lower Tuolumne River from February through May under Base Case (1971–2012) hydrology.

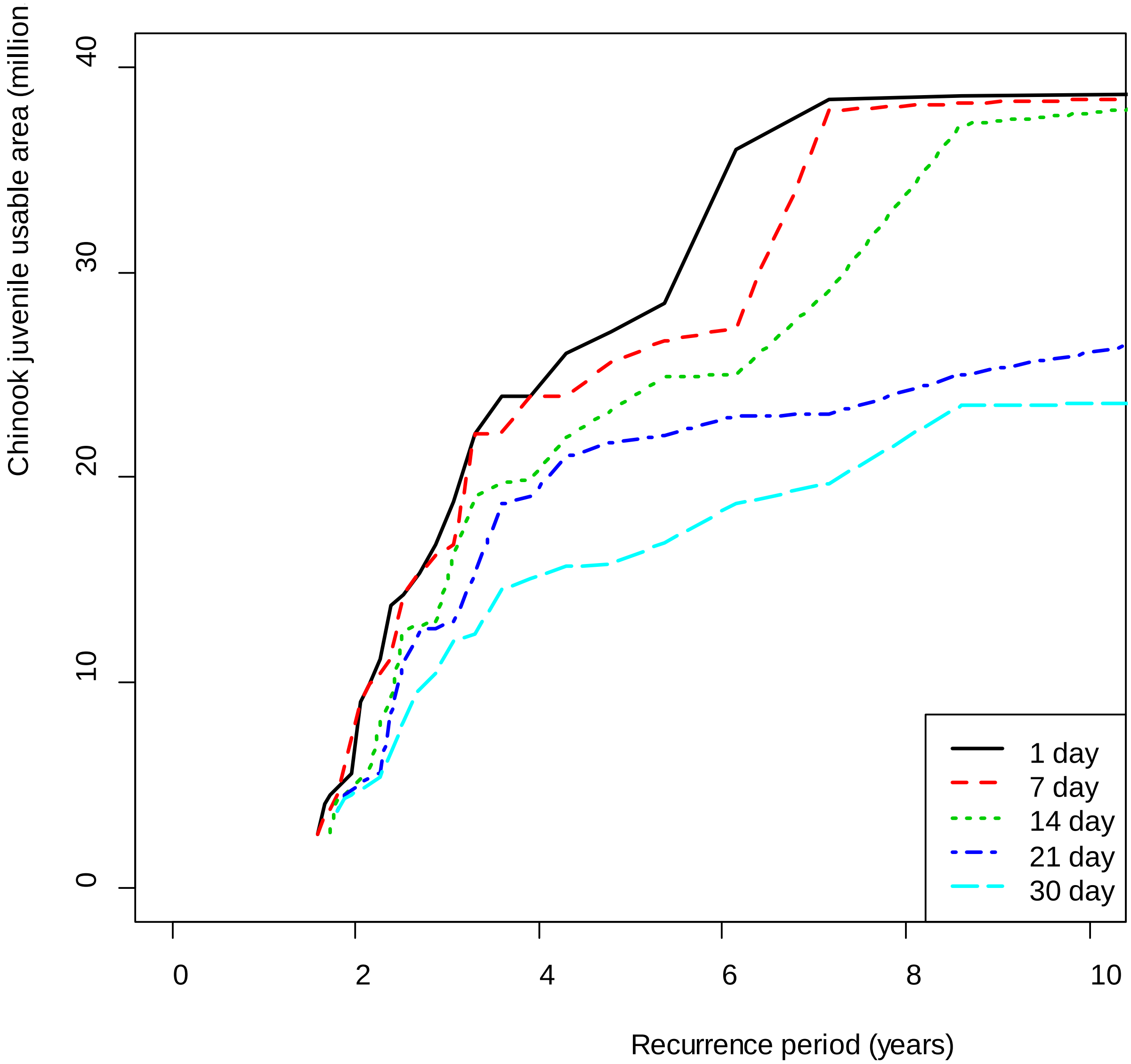

Figure 5.3-5. **Chinook salmon juvenile habitat area-duration-frequency (ADF) plot showing recurrence of events exceeding various usable habitat area and duration thresholds in the lower Tuolumne River from February through May under Base Case (1971–2012) hydrology.**

5.3.3 Juvenile *O. mykiss* floodplain rearing habitat

In accordance the with approved Study Plan, the final report includes analysis of potential floodplain habitat use by fry and parr sized *O. mykiss* on the lower Tuolumne River using the same ADF analysis applied to Chinook salmon rearing (Section 5.3.2). Figure 5.3-6 shows the annual recurrence period of events exceeding various total inundation area and duration thresholds in the lower Tuolumne River from March through September. Because of the period of analyses extends into the summer months for *O. mykiss* rearing with less frequent flood control releases, comparable floodplain inundation area and durations to those examined for

Chinook salmon also occur less frequently. To examine the recurrence of various inundation area relationships of usable rearing habitat for *O. mykiss* juveniles, Figure 5.3-7 and Figure 5.3-8 show habitat ADF plots for fry and juvenile life stages, respectively. In comparison to the corresponding plots for Chinook salmon juvenile rearing period (i.e., February through March), shorter duration events (e.g., 1 and 7 day duration) occur at a similar return period but extended duration events (e.g., 4, 12, and 30 day durations) occur at a greater return period (i.e., floodplain inundation occurs less frequently in spring and summer).

Although this report analyzes potential usable floodplain habitat for juvenile *O. mykiss*, there are no known data that suggest floodplains are an important habitat for the species. Numerous studies of floodplain use by California native and non-native fishes including Chinook salmon have been conducted (e.g., Sommer et al. 2001, 2005). However, other than limited observations of rearing steelhead smolts along the Yolo Bypass (Sommer 2001, USBR 2008) as well as more recent observations of smaller (Age 0) *O. mykiss* rearing at higher elevation channel margin habitats created following gravel augmentation along the Lower American River (Sellheim et al 2015), juvenile steelhead are not known to rear in floodplain habitats to any great degree at any time of year (Bustard and Narver 1975, Swales and Levings 1989, Feyrer et al. 2006, Moyle et al. 2007).

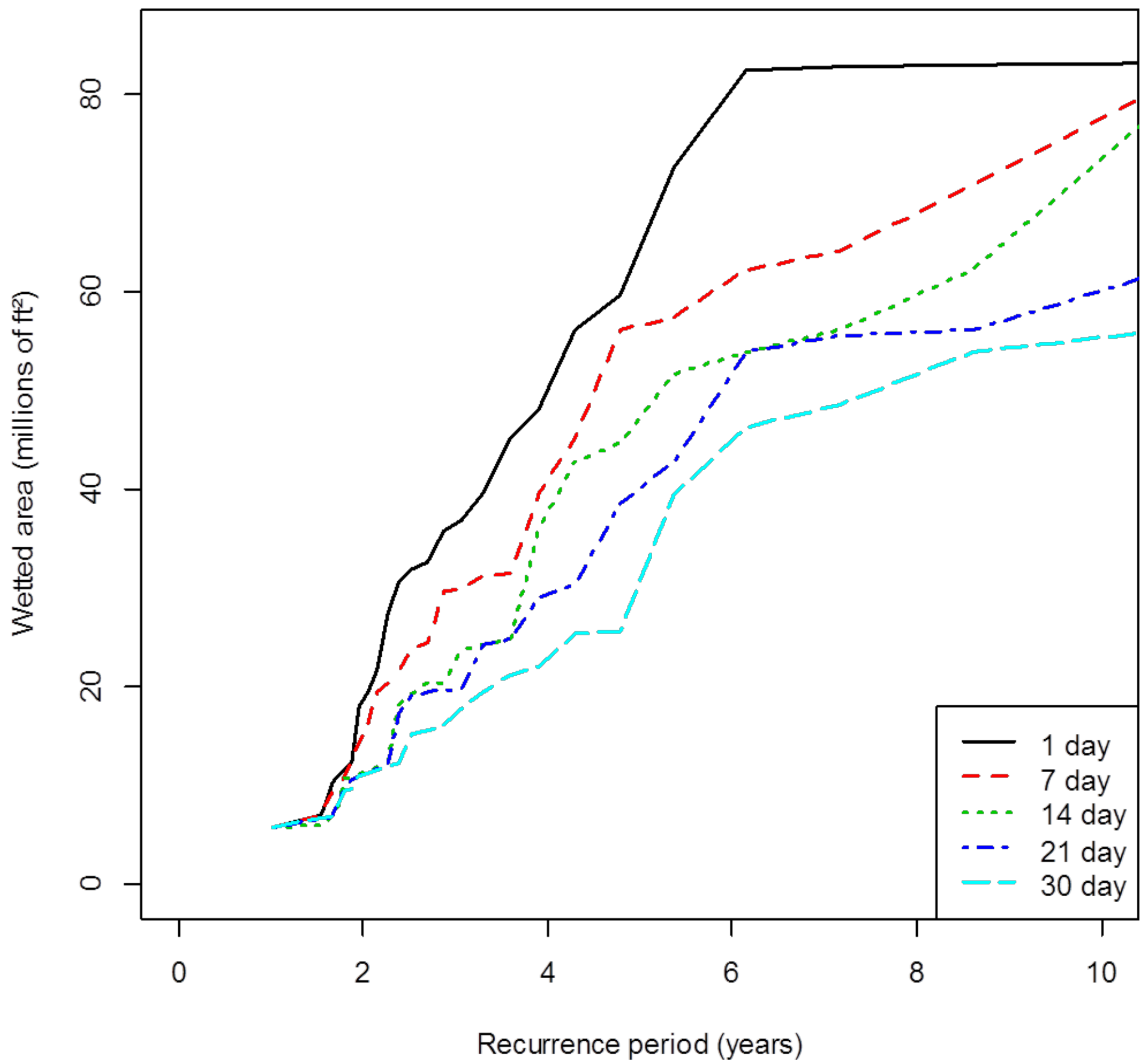

Figure 5.3-6. **Total area-duration-frequency (ADF) plot showing recurrence of events exceeding various total inundation area and duration thresholds in the lower Tuolumne River from March through September under Base Case (1971–2012) hydrology.**

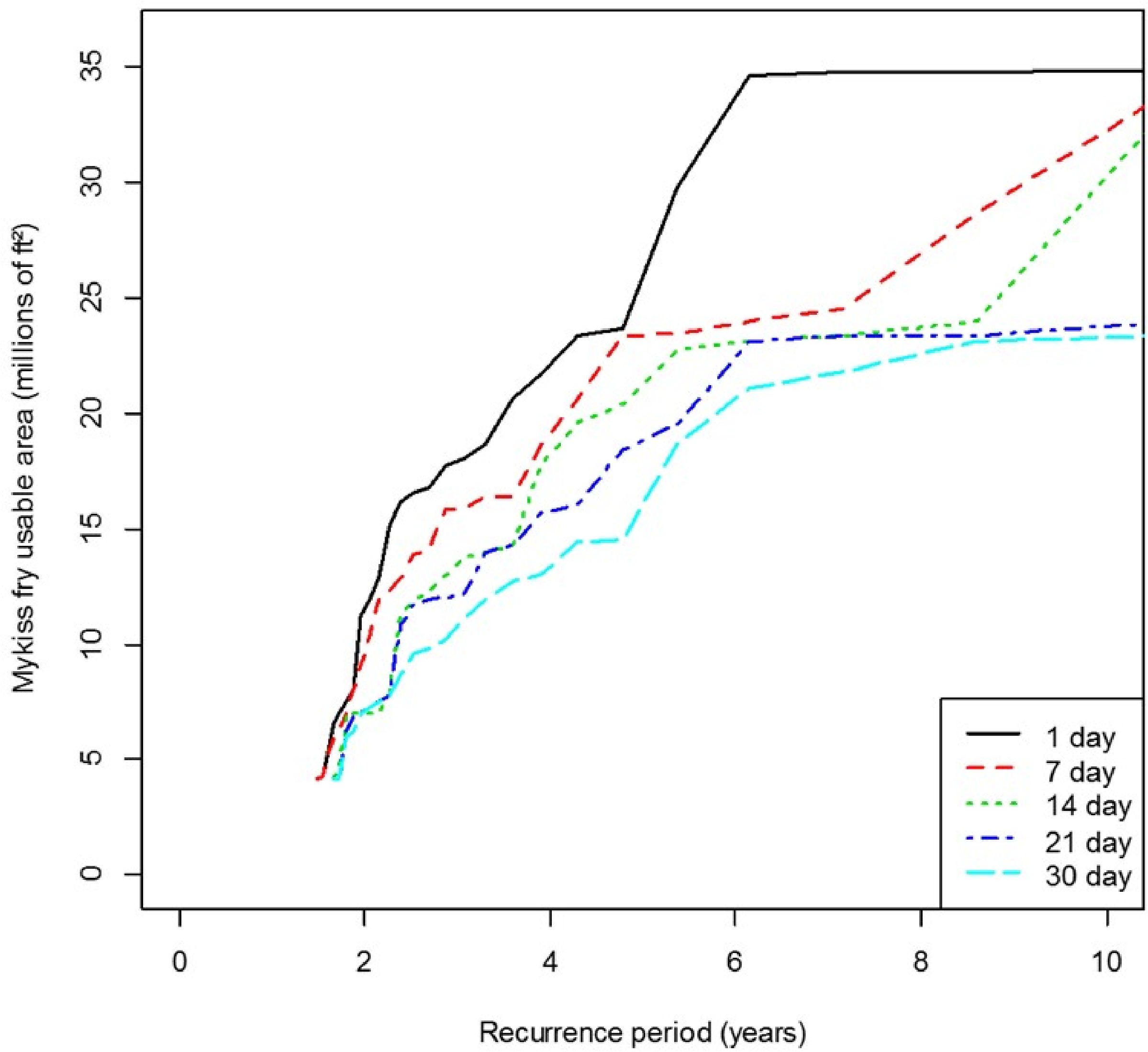

Figure 5.3-7. **O. mykiss fry habitat area-duration-frequency (ADF) plot showing recurrence of events exceeding various usable habitat area and duration thresholds in the lower Tuolumne River from March through September under Base Case (1971–2012) hydrology.**

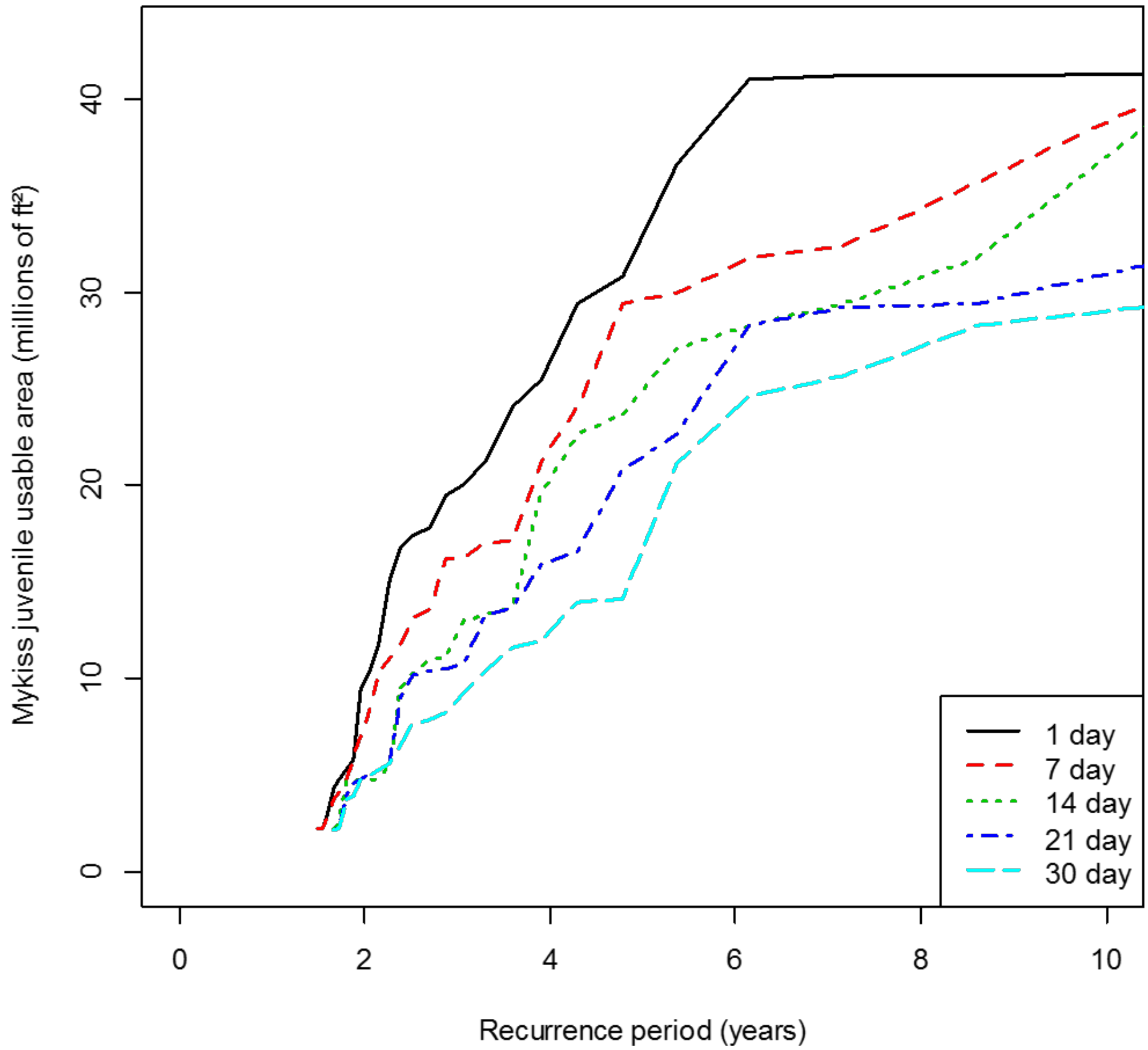

Figure 5.3-8. **O. mykiss juvenile habitat area-duration-frequency (ADF) plot showing recurrence of events exceeding various usable habitat area and duration thresholds in the lower Tuolumne River from March through September under Base Case (1971–2012) hydrology.**

6.0 DISCUSSION AND FINDINGS

6.1 Hydraulic Model

The study required developing a detailed hydraulic model for 52 miles of river and overbank using the best available topographic and bathymetric data and without creating extensive additional data requirements. The TUFLOW modeling platform was used in the study due to the platform's ability to model complex local hydraulics and features present in the study area including ponds, pools, narrow flow paths connecting river and overbanks, flow paths connecting overbank ponds, and hydraulic structures.

Cross sectional and bathymetric data from multiple sources were obtained, evaluated and supplemented to develop model components. To ensure modeling efficiency and accuracy of results, the study area was split into three models. An appropriate boundary condition for each model was determined. Backwater effects from the San Joaquin River were determined by an extensive hydrologic and hydraulic analysis. This analysis showed that the potential backwater effects from San Joaquin River could extend up to approximately RM 13 in the lower Tuolumne River for the range of flows used in this study.

Models were developed with sufficient topographic resolution and identification of the significant hydraulic features and were calibrated and validated for the range of study flows. Calibrated models were used to obtain depth and velocity information for all 21 study flows for habitat analysis and the extent of flood inundation was calculated.

TUFLOW modeling platform proved to be both accurate and efficient for modeling the lower Tuolumne River to achieve the study objectives. Developed models can be readily applied for evaluating potential alternative flow scenarios.

6.2 Fish Habitat Suitability Analyses

Overall, the results of the study show flows above bankfull discharge are associated with increases in habitat area for juvenile life stages of lower Tuolumne River salmonids. Although some floodplain areas are present over the length of the lower Tuolumne River, because of the history of anthropogenic changes to in-channel and floodplain areas not all portions of the river are inundated at the same flows (Section 3.1). Model A (RM 52.2–40.0) results exhibit the largest increase in inundated floodplain area at low to moderate discharge (Figure 5.2-1). However, the majority of available floodplain habitat in this reach is limited to several disturbed areas formerly overlain by dredger tailings (McBain & Trush 2000). These areas were also associated with the highest frequency of stranding and entrapment of juvenile Chinook salmon in historical stranding surveys (1990–1992, 1994–1996, 1999–2000) at flows between 1,100–3,100 cfs (TID/MID 2001). In the Model B reach (RM 40.0–21.5), the lower Tuolumne River exhibits relatively low amounts of floodplain and little increases in inundated area with discharge. As the valley slope of the lower Tuolumne River corridor decreases between Modesto and the San Joaquin River, Model C (RM 21.5–0.9) results exhibit low floodplain availability at flows less than 6,000 cfs, but also large increases in inundated area as discharge increases above 7,000 cfs (Figure 5.2-1). This large increase is primarily due to the presence of large, low gradient agricultural areas near the San Joaquin River confluence. The lower Tuolumne River is also subject to backwater effects from the San Joaquin River up to RM 13 and this backwater effect also influences the amount of floodplain habitat available at a given discharge in the lower Tuolumne River due to variations in San Joaquin River discharge.

Estimates of usable floodplain habitat area for rearing fry and juvenile life stages of Chinook salmon and *O. mykiss* were conducted using joint habitat suitability indices (i.e., 0–100%) from the Stillwater Sciences (2013) IFIM study along with TUFLOW model predictions of depth and velocity within floodplain areas. Overall, usable habitat for fry life stages suitability ranged from near 60 to 80 percent of total inundated floodplain habitat at 1,000 cfs to as low as 15 to 40 percent of inundated habitat at 9,000 cfs. For juvenile life stages, usable habitat ranged from approximately 50 percent of total inundated floodplain habitat at 1,000 cfs to less than 40 percent at flows of 9,000 cfs. Usable in-channel habitat for rearing salmonid juveniles generally decreases with increased depths and velocities as discharge approaches bankfull within Model A (RM 52.2–40) (Attachment H). Decreases in in-channel habitat suitability are offset by large increases in overbank habitat in Model A (RM 52.2–40) and total usable habitat including both in-channel and floodplain areas steadily increases with increasing discharge. Farther downstream, total usable habitat for Chinook salmon and *O. mykiss* fry and juvenile life stages within Model B (RM 40.0–21.5) and Model C (RM 21.5–0.9) is lower at flows from 1,000–2,000 cfs than for either lower (e.g., 100–500 cfs) or higher (e.g., >3,000 cfs) discharges (Attachment H). These patterns are consistent with observations of floodplain encroachment and channel incision within the gravel mining and sand bedded reaches of the lower Tuolumne River (McBain & Trush 2000) which may limit access to overbank habitat at intermediate flows.

Increased spring river flow is associated with increased amounts of floodplain inundation and it is apparent that inundated floodplains on the Tuolumne River below La Grange Diversion Dam have the carrying capacity to support several million rearing Chinook salmon fry and juveniles, depending upon flow and site specific conditions. The results of the current study, however, are not intended to predict actual fish habitat use on inundated floodplains or whether in-channel rearing habitat is currently limiting salmonid populations. Access to floodplain habitats may provide other benefits than increasing available rearing areas, such as reducing the potential encounter frequency between juvenile salmonids and predatory fish species such as black bass (*Centrarchidae: Micropterus*) and other species, thereby reducing overall predation. However, population modeling sensitivity analyses indicate that increased duration of floodplain access for juvenile salmonids may not necessarily result in large increases in subsequent smolt productivity since in-channel rearing habitat is not likely limiting juvenile salmon production. For example, parameter sensitivity analyses conducted as part of the *Tuolumne River Chinook Salmon Population Model Study* (W&AR-06) showed that large decreases in assumed maximum rearing densities in either in-channel or floodplain habitats were not accompanied by corresponding reductions in modeled smolt productivity.

6.3 Area-Duration-Frequency Analysis for Base Case (WY 1971–2012) Hydrology

Using the Base Case (WY 1971–2012) hydrology from the *Project Operations/Water Balance Model Study* (W&AR-02), an annual exceedance frequency analysis of flow events combining discharge magnitude and duration was conducted. Examining the recurrence of various inundation area relationships of usable habitat for Chinook salmon fry and juvenile rearing, floodplain inundation events lasting 7-days or more occur at return periods of 1.5 to 3 years on the lower Tuolumne River.

It should be noted that many of California's native species have evolved and adapted to take advantage of seasonal floodplain inundation (Moyle 2002). Studies of juvenile Chinook salmon rearing within floodplain habitats of lowland rivers of California's Central Valley (e.g., Sommer et al. 2001, 2005 [Yolo Bypass]; Jeffres et al. 2008 [Cosumnes River]) have suggested that increasing the inter-annual inundation frequency of floodplain habitats may promote the production of food resources for rearing salmonids. Although the lower Tuolumne River floodplain areas are relatively small when compared to large flood bypasses of the mainstem Sacramento and San Joaquin Rivers, the results of this study show that extended periods of springtime floodplain inundation (e.g., 14 to 21 days) regularly occurs at a 2- to 4-year recurrence interval on the lower Tuolumne River under the Base Case (WY 1971–2012) hydrology; this floodplain inundation frequency is consistent with typical return periods of fall-run Chinook salmon. Despite resource agency recommendations to increase floodplain inundation to benefit *O. mykiss*, there are no known data that suggest floodplains are an important habitat for the species. Nevertheless, recognizing the potential for floodplain habitat use by fry and parr sized *O. mykiss* on the lower Tuolumne River, shorter duration events (e.g., 1 and 7 day duration) occur at a similar return period than the corresponding analysis for Chinook salmon rearing but extended duration events (e.g., 4, 12, and 30 day durations) occur at a greater return period (i.e., floodplain inundation occurs less frequently in spring and summer than during winter months).

7.0 STUDY VARIANCES AND MODIFICATIONS

The study was conducted in conformance to the FERC-approved *Lower Tuolumne River Floodplain Hydraulic Assessment Study Plan* (W&AR-21) approved in FERC's October 18, 2013 Determination. There are no variances.

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STUDY REPORT W&AR-21
THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT A

STUDY CONSULTATION

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APPENDIX A

WORKSHOP NO. 1 MEETING NOTES

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Don Pedro Project Relicensing
W&AR-21 Workshop No. 1
Meeting Notes

Thursday, February 13, 2014

Attendees

Nolan Adams – HDR	Matt Moses – SFPUC
Peter Barnes – SWRCB	Bill Paris – MID, *by phone*
Jenna Borovansky – HDR	Pani Ramalingam – HDR
Allison and Dave Bouchet – Tuolumne River Conservancy	Bill Sears – CCSF, *by phone*
Steve Boyd – TID	Maia Singer – Stillwater
Jesse Fernandes – HDR, *by phone*	Ron Yoshiyama – CCSF
Noah Hume – Stillwater	
Rob Sherrick – HDR	
Anna Brathwaite – MID, *by phone*	

Background

- Following introductions, Jenna provided background on the study process to date:
  - This is the first workshop for the W&AR-21 modeling effort, in accordance with the Consultation Process.
  - In January 2013, the Districts received comments on ISR, including a request for additional information. Districts agreed to conduct a floodplain study. Spring - Summer 2013 study plan development.
- The W&AR-21 study goals build on past information (Slide 2).
- The purpose of the first workshop is to present the 2D hydraulic and habitat modeling approach (Slide 3). Actual model results are forthcoming.

Previous Studies

- Noah reviewed previous floodplain studies on the lower Tuolumne River (Slide 4).
- Noah noted that the 2012 2D Pulse Flow Study focused on in-channel predictions of habitat availability.
- Noah presented the study objectives (Slide 5)

Modeling Approach

- Pani is the study hydraulic modeling lead, with Nolan responsible for most of the hydraulic model construction.
- Pani reviewed existing topographic data (Slides 7-11). There are no breaks in the LiDAR data, but there are breaks in the floodplain ponds. The team is currently working to fill these data gaps. Available calibration data is shown on Slide 12.
- Why use the TUFLOW model (Slides 13-14)?
  - TUFLOW was developed in Australia and has been used in numerous river hydraulic modeling studies in Europe and Australia. TUFLOW is being used in studies in the US more often, including multiple USACE and DWR studies.

- We are interested in modeling low to moderate flows in the Tuolumne River study, rather than high flows.
- We also want to link hydraulic conditions to fish habitat availability – so the hydraulic model needs to be able to realistically represent a flow path from main channel to the floodplain. This means that a flexible grid size is important.
- TUFLOW is scalable and can be run using different scenarios as the study develops. In other words, you can make changes in local topography if needed, without re-doing all of the topography.
- TUFLOW has a good 1D modeling component, distinguishing it from most other 2D models, which don't also possess a good 1D component.

- The computational efficiency of TUFLOW decreases with smaller grid size. In other words, the model takes a longer time to run at a smaller grid size.
- We ran TUFLOW for the Pilot Reach (RM 40-52) to determine WSEL sensitivity to grid size. TUFLOW results indicate that there is no benefit to running the model at a grid size lower than 30 ft^2 (Slide 21).
- Habitat Sensitivity to Grid Size – results for Riffle 4A/4B indicate that the smaller the grid size, the higher the estimated area of suitable rearing habitat (Slides 22-23). This is particularly evident for fry. Balancing this with the decreasing computational efficiency as grid size gets smaller, the sensitivity analysis indicates that 30 ft^2 also represents an appropriate grid size for habitat predictions. We can decrease the grid size in particular areas, as needed.
- Question (Allison): does the model distinguish between inundated areas that do have active flow/velocity and areas that do not have flow/velocity? For example, when Legion Park floods, there is no flow. Water sits on the grass, but this does not appear to be good habitat.
- Answer (Noah): The model considers both velocity and depth. Based on the habitat suitability criteria (HSC), areas with no flow would not be considered suitable habitat by the model.
- Reminder that the existing IFIM Study (2012) was a 1D study, covering in-channel habitat at flows up to 1,200 cfs.
- The TUFLOW 1D-2D domain boundary is set in locations that will maximize 2D habitat analysis potential (Slides 24-28). Pani provided example images of the 1D-2D domain boundary location within the Pilot Reach.
- Pani presented the TUFLOW modeling plan (Slides 29-30).
- Noah presented the conceptual steps in the habitat analysis, whereby TUFLOW provides cell-specific velocity and depth predictions. These are run through the habitat suitability criteria (HSC) developed in the 2012 IFIM study and combined with discharge recurrence probabilities to generate area-duration-frequency curves (Slides 31-33).
- Question (Allison): Will the results include consideration of suitable habitat in different sections of the river (i.e., reach-by-reach)?
- Answer (Noah): Yes, the model can do that.

Schedule/Next Steps

- We will distribute electronic links to an updated map book of the Lower Tuolumne River shortly; the map book will show the location of the TUFLOW 1D-2D domain boundary. The agencies should please provide feedback on the model domain delineation approach and we can follow up with a conference call to discuss feedback, if needed.
- As previously noted, this workshop represents the first study consultation, with a second consultation forthcoming following full model calibration.

Questions

Question (Allison): Will the report produce information for four different fish lifestages (i.e., fry and juvenile salmon; fry and juvenile *O. mykiss*)? These species require different habitat types, how does the modeling approach consider the differences?

Answer (Noah): Life history timing for each species is specific, which is an inherent screening tool (i.e., fry and juveniles for each species use the habitats at slightly different times in the year).

Question (Allison): Landowners may like to know what is happening on their property in particular. Will that be that possible?

Answer (Jenna): Potentially with respect to habitat, but reminder that the purpose of the study is not to predict when or exactly how properties will flood. We are running the model out to steady state to obtain habitat suitability information.

Question (Allison): How do you know what the velocity is for a particular floodplain location?

Answer (Pani): TUFLOW models velocity on a cell-by-cell basis.

Question (Allison): How does the model deal with velocity in off-channel areas like flooded roads, bends, etc.? Example is on property downstream of new La Grange Bridge. We have observed large eddies during high flows in this area.

Answer (Pani): Pani showed example model results at 3,000 cfs after running the model for 12 hours. You can see the velocity and depth vectors shift with each time step, and the flow eddies are in fact represented.

Question (Allison): How is roughness associated with different vegetation types, like willow?

Answer (Pani/Nolan): We are still working on this, but we're using the best available information (i.e., survey data, aerial flows) to make the distinctions between vegetation types.

Question (Allison): What is the study output? Can the model be run under different scenarios?

Answer (Noah): The report will include plots and tabulations of inundated area. The model will exist and agencies can run it for different scenarios. If the agencies don't choose to obtain and re-run the model, then they can use the report output to extrapolate to a range of flows, or request that the model be re-run.

At the end of the meeting, workshop participants looked at a recently restored site to see how the restored floodplain surface might respond to flows of 8,400 cfs based on TUFLOW predictions. Dave/Allison: The expected flow re-routing looks like it may occur based on model results, good news! The TUFLOW model is a neat tool. It should really help the decision-making process within the agencies.

Attachments

Attachment 1: Modeling Workshop No. 1 Slides

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Attachment 1

Modeling Workshop No. 1 Slides

Don Pedro Relicensing
Floodplain Hydraulic Assessment Workshop

February 13, 2014

Study Plan Goals

- Analyze the amount of floodplain inundated between RM 52.2 and RM 0 of the Tuolumne River at flows between approximately 1,000 cfs and 9,000 cfs
- Assess the suitability of inundated floodplain habitat for juvenile salmon rearing
- Evaluate the frequency and period of inundation over a range of Project operations representing baseline conditions and alternative operating scenarios

Purpose of Meeting

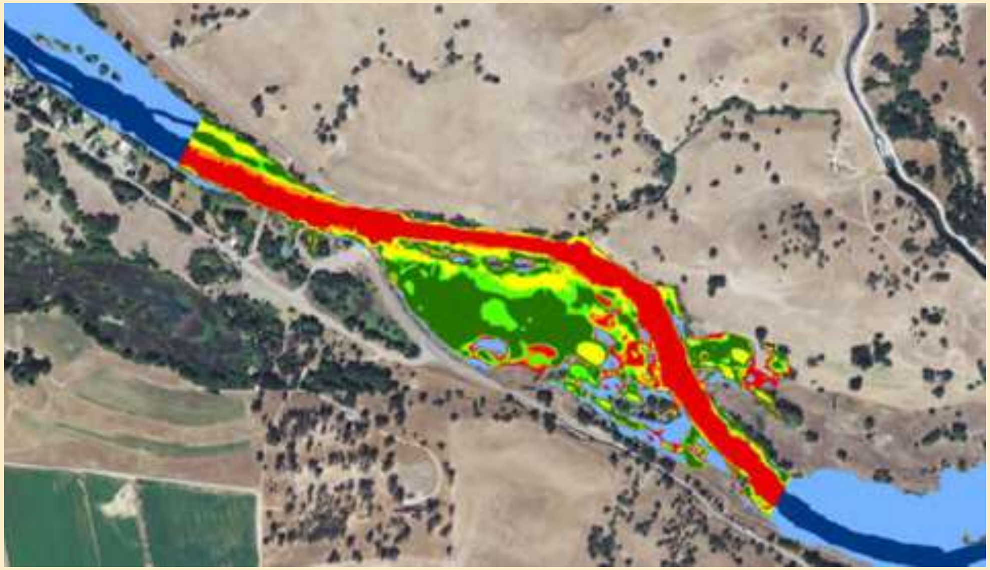
- Hydraulic Modeling Approach
  - Data Sources
  - TUFLOW Model
  - Overbank vs. In Channel Areas

- Habitat Analysis Approach

Photo Credit: Stillwater Sciences

Previous Studies

- TID (1992, 1997, 2010) Inundation Mapping and GIS (100-8,400 cfs)
- USFWS (2008) floodplain analysis of TID GIS data
- Stillwater Sciences (2012) 2D Pulse Flow Study (1,000-5,000 cfs)



Study Objectives

1. Use hydraulic modeling to simulate the interaction between flow within the main channel and within the inundated floodplain at:
   - 250 cfs intervals from 1,000–3,000 cfs
   - 500 cfs intervals from 3,000–9,000 cfs
2. Determine the maximum continuous wetted area for 7, 14, 21, and 30 day durations
3. Evaluate the Base Case scenario (W&AR-02)
4. Estimate depths and velocities in overbank areas from RM 52 to the San Joaquin River and use existing habitat suitability criteria for depth and velocity for juvenile salmonids to quantify the amount of suitable juvenile rearing habitat as a function of flow

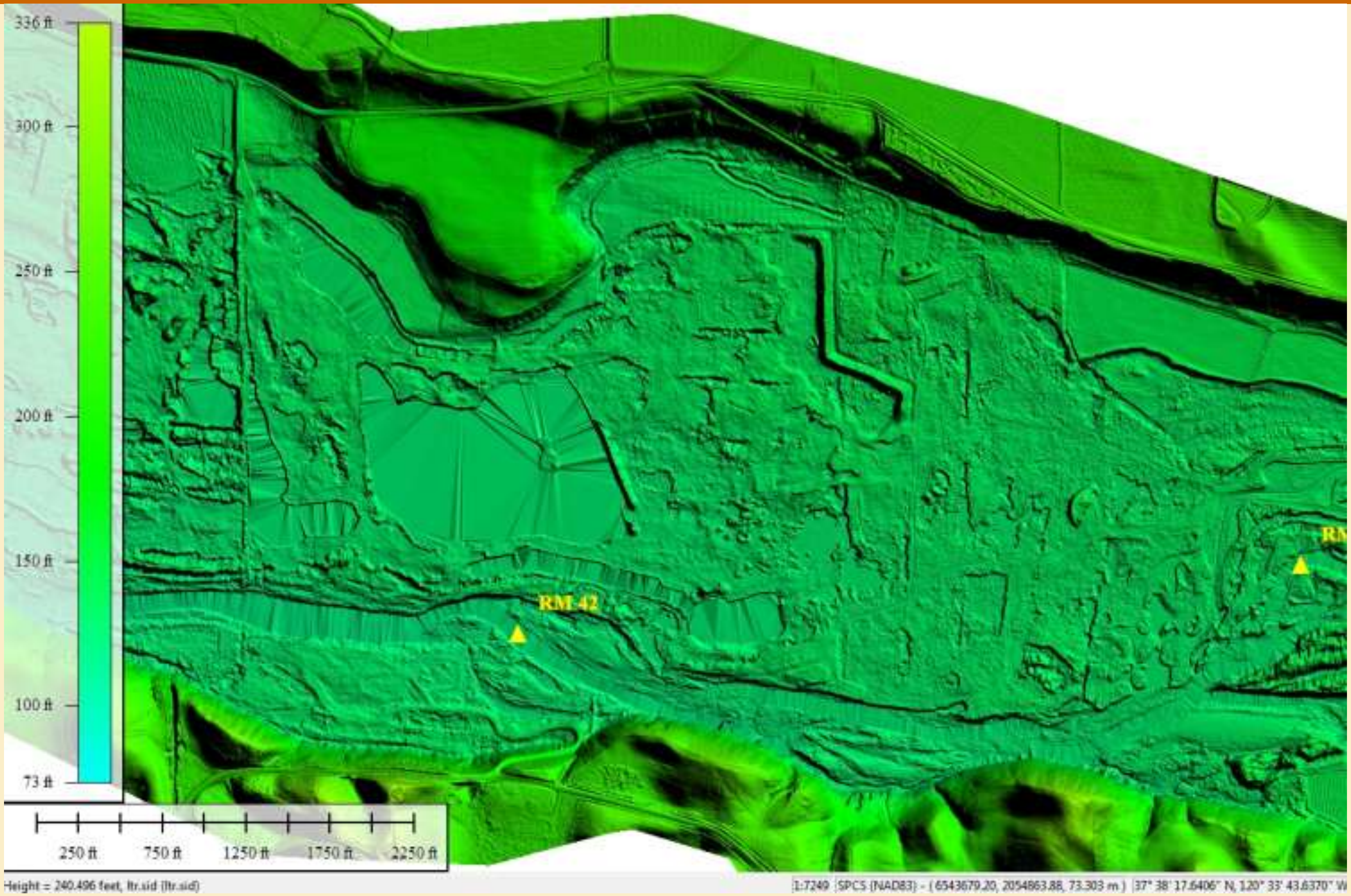
Hydraulic Modeling Approach

- **Topographic Data**
- **Calibration Data**
- **TUFLOW Model**
- **Pilot Model/Sensitivity Analysis**

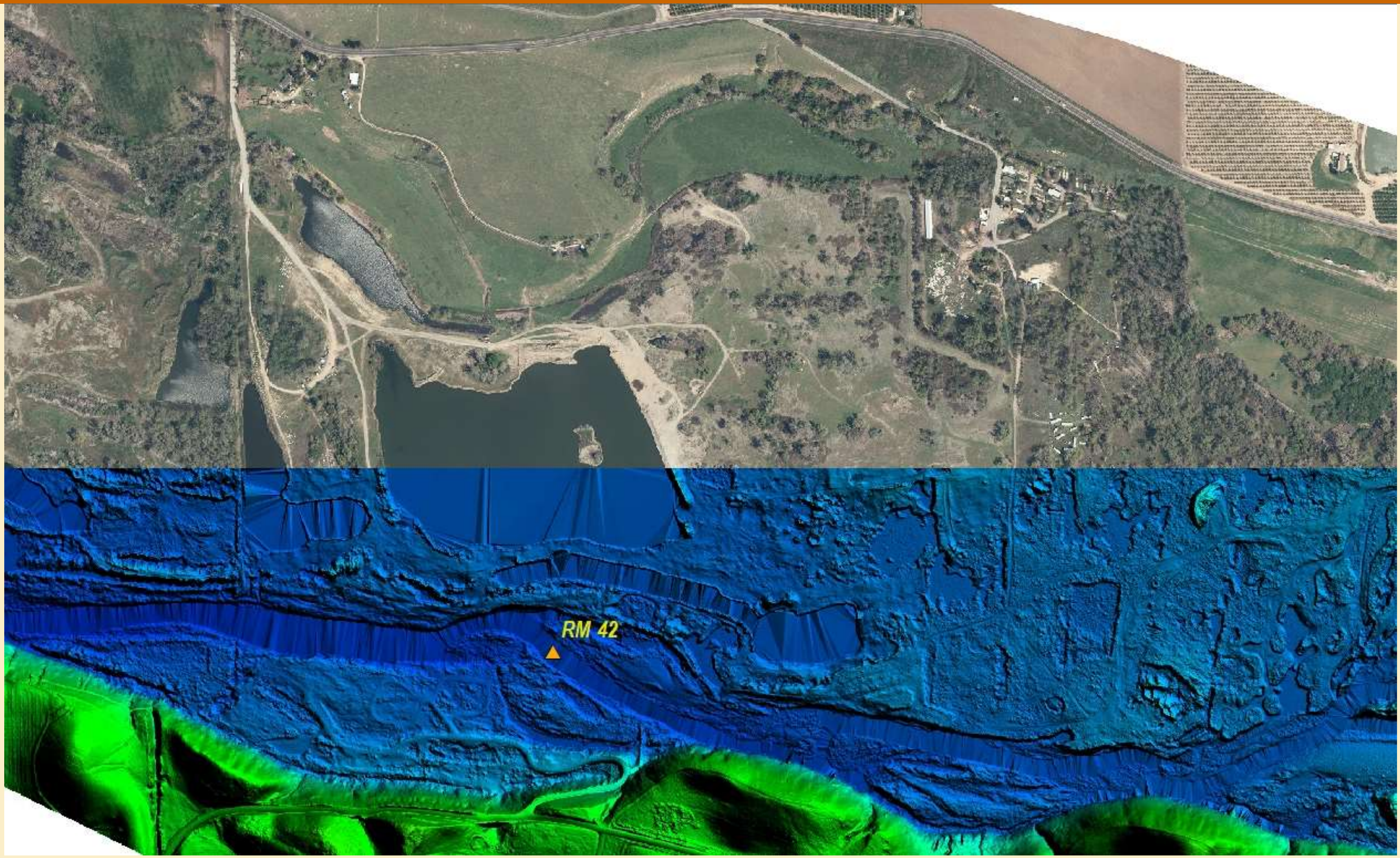
Topographic Data

- **2012 LiDAR Data**
  - RM 54.5 to RM 0.
  - Flown on March 30, 2012
  - Flow in River - Approximately 321 cfs
  - No breaklines
- **1D Channel Bathymetry**
  - Multiple Data Sources

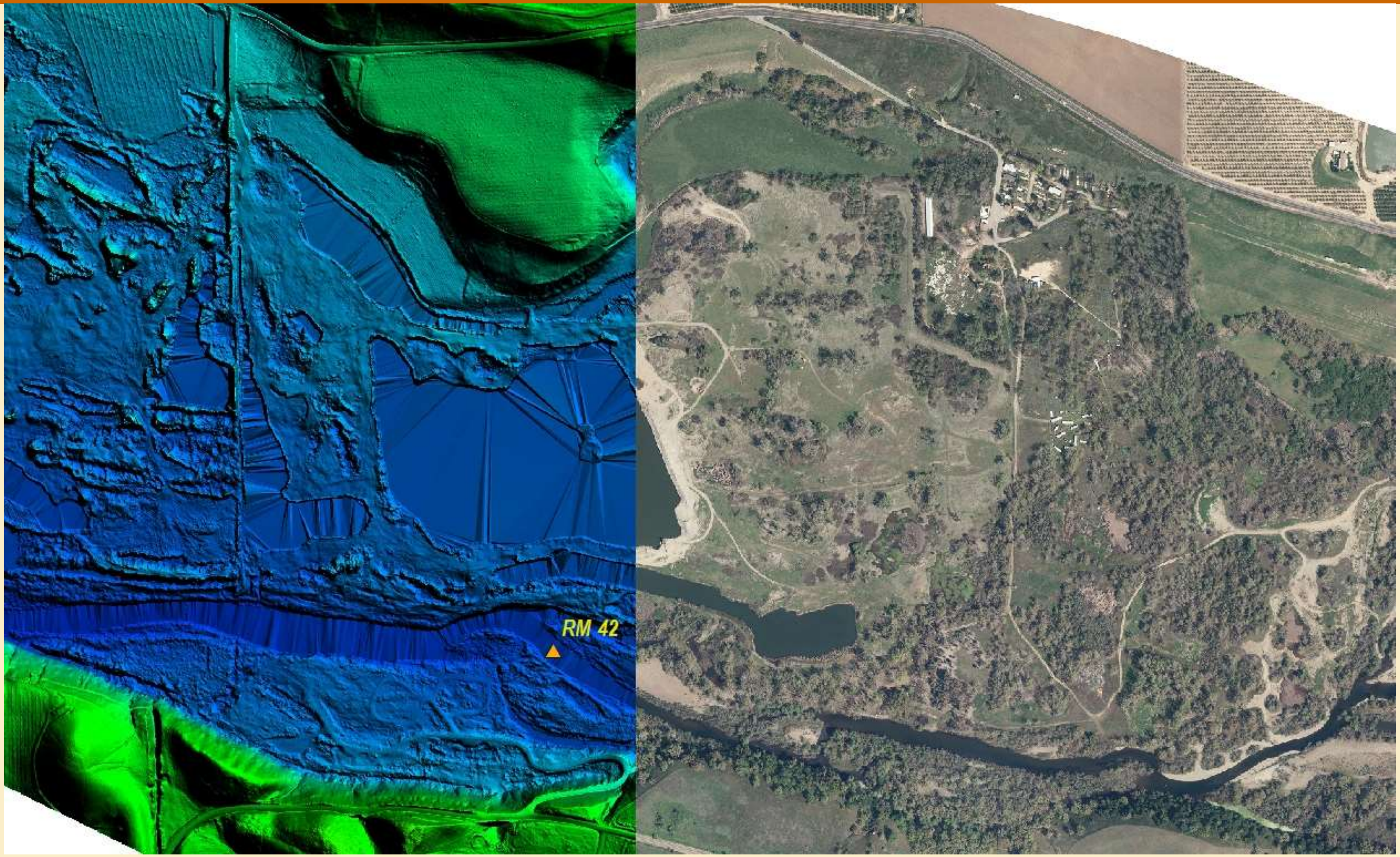
Topographic ASCII Grids



Water Body Details



Water Body Details



1D Low Flow Channel

RM	Source	Original Reason for Collection
0-6.7	DWR (2009)	CVFED HEC-RAS, FLO-2D Models
6.7-24	DWR/FEMA (2012)	FEMA Study, HEC-RAS Model
24-38	HDR (2013), Stillwater (2013)	Temperature HEC-RAS Model, IFIM Study
38-51.5	McBain & Trush (2005)	Coarse Sediment Management
45.5-51.8	Stillwater (2013)	W&AR4 – Spawning Gravel in the Lower Tuolumne River

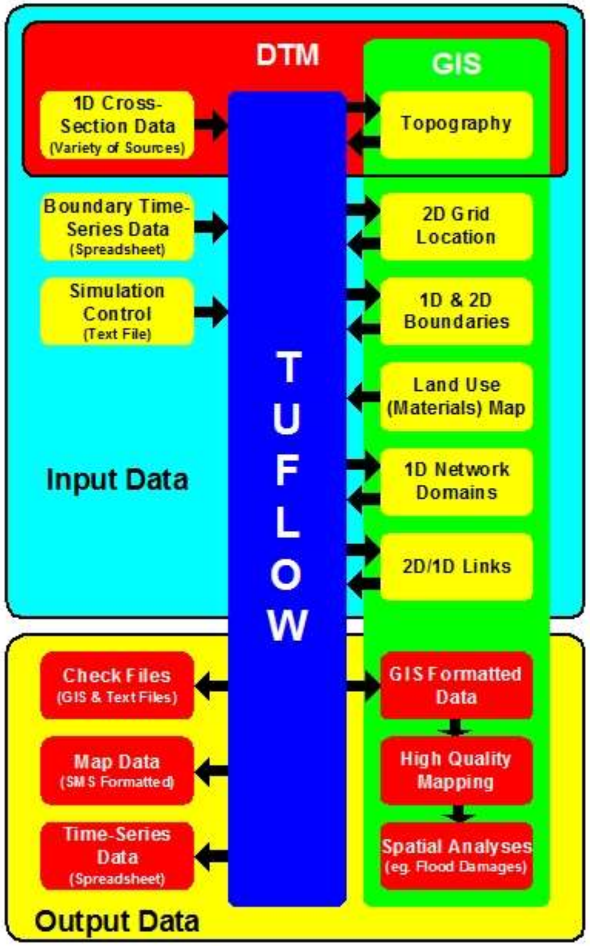
Calibration Data

- Historic Inundation Extent (e.g., 1,070, 3,100, 5,300, 8,400 cfs)

- Water Surface Elevations
  - 2012 Pulse Flow Study
  - 2013 IFIM Study
  - 2012 LiDAR

TUFLOW Model

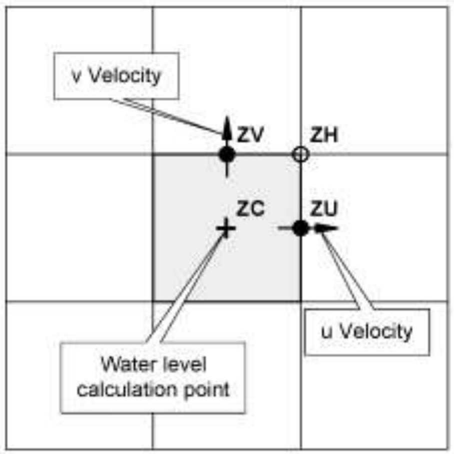
- **Unsteady 2D model**
- **Implicit finite difference scheme – FAST!**
- **2D overbank areas with 1-D low flow channel**
- **River-wide modeling**



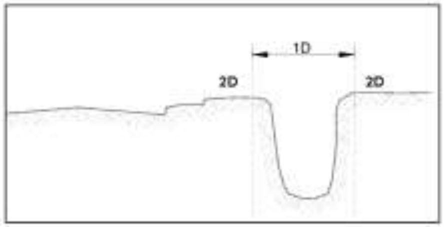
TUFLOW Data Input and Output Structure

Advantages of TUFLOW Model

- Powerful GIS-centric architecture
- Layered data approach
- Flexible grid size
- 1-D low flow channel



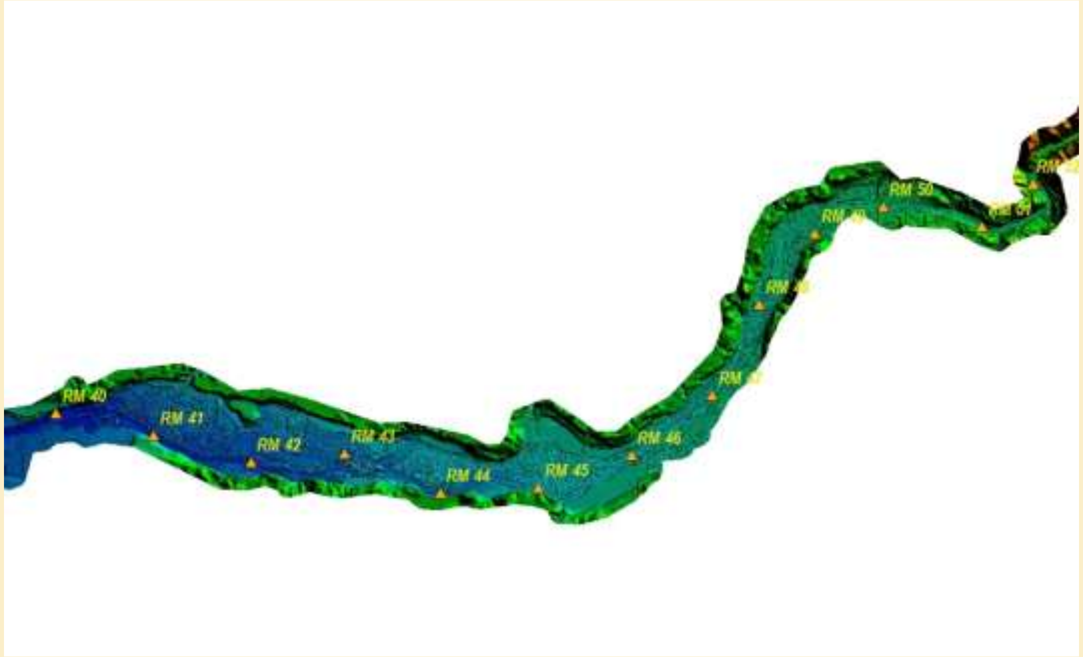
Location of Zpts and Computation Points



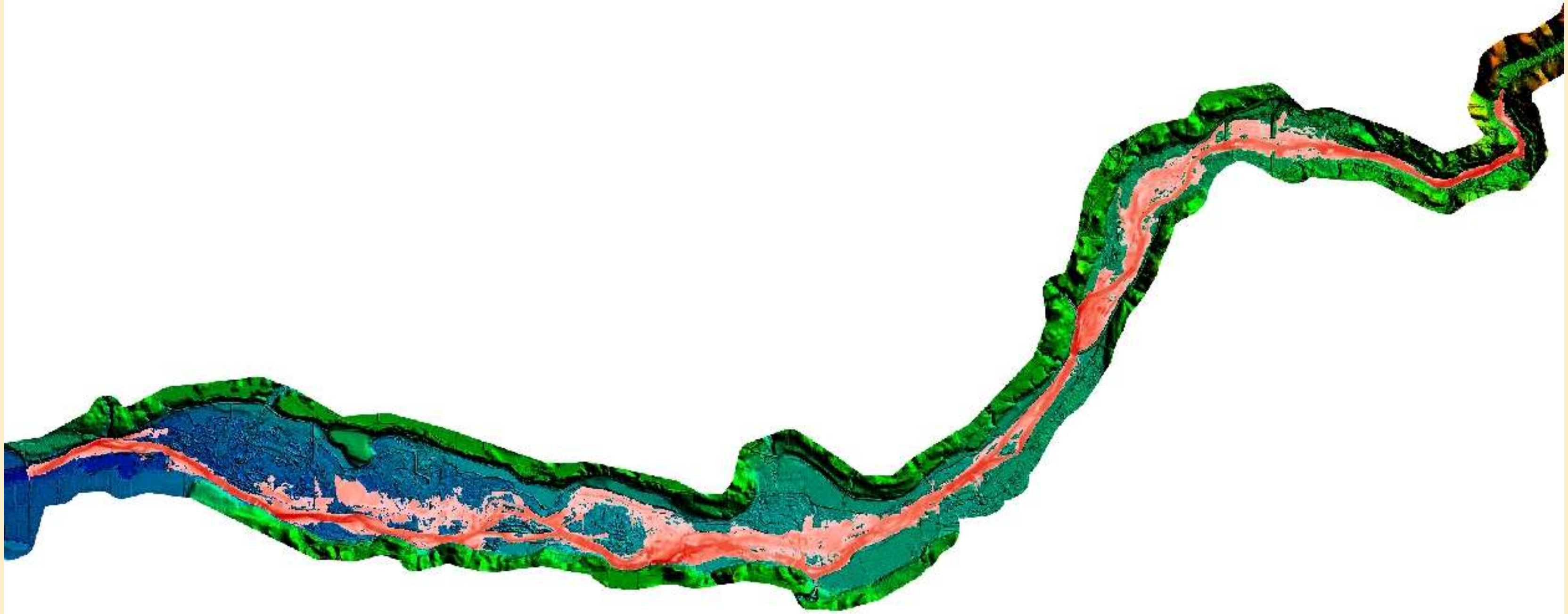
Modelling a Channel in 1D and the Floodplain in 2D

Pilot Model – RM 52 to RM 40

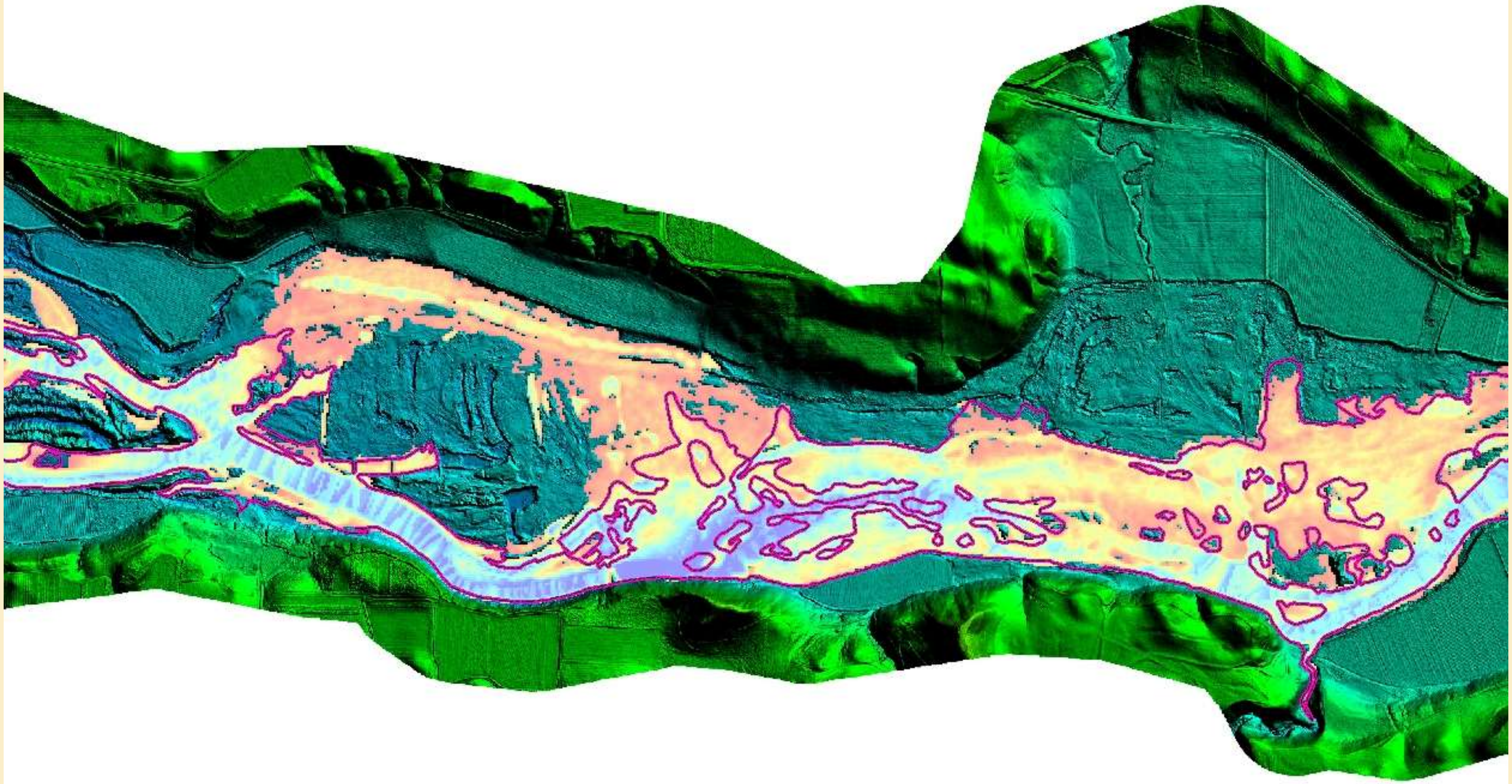
- **2012 Pulse Flow Study**
- **Continuous river bathymetry data**
- **Test Runs**
- **50, 30 & 20 ft cells**



Inundation Extent – 8,400 cfs



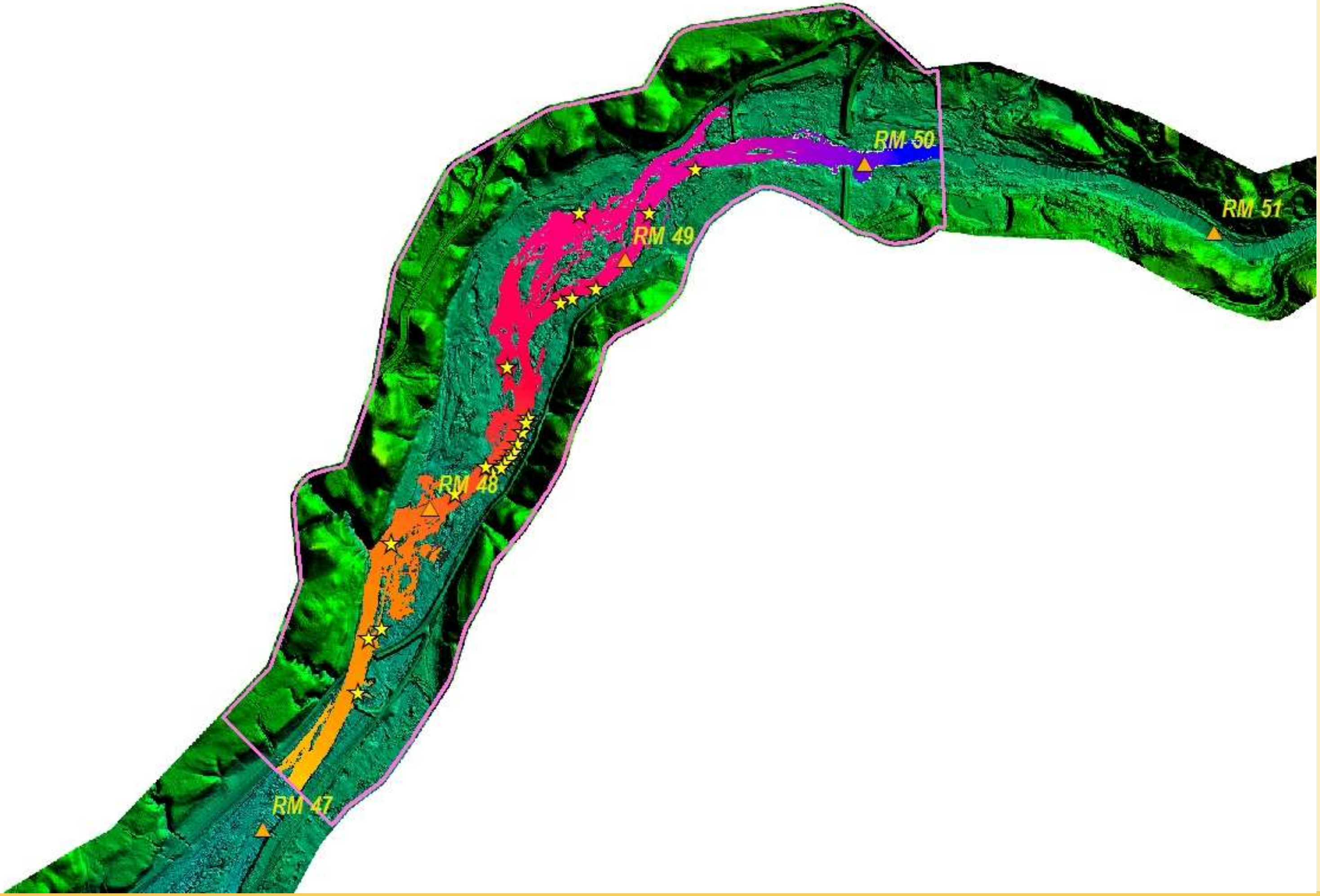
Historical Inundation Extent



Habitat Sensitivity Analysis

- **Small model from RM 50 to RM 47**
- **Cell sizes – 10, 20, 30, 40 & 50 ft**
- **3,000 cfs**
- **Pulse Flow Study WSE calibration data**

Modeled Inundation Extent



Historical Inundation Extent

WSEL Sensitivity to Grid Size

Sensitivity Analysis of Pilot TUFLOW Model* - Basso Reach (RM 50 - RM 47) Results

S No.	Observed WSE (ft) 3000 cfs	Difference in WSE for Various Grid Size					Remarks
		10 ft	20 ft	30 ft	40 ft	50 ft	
1	169.7	0.2	0.2	0.1	0.1	0.0	
2	168.9	0.5	0.4	0.4	0.3	0.2	
3	166.9	-0.3	-0.3	-0.4	-0.4	-0.6	Overbank
4	166.8	0.5	0.4	0.3	0.2	0.1	
5	165.9	0.3	0.3	0.2	0.0	-0.2	
6	165.2	-0.2	-0.3	-0.3	-0.5	-0.8	
7	163.0	0.0	-0.3	-0.6	-0.5	-0.8	Overbank
8	162.7	0.3	0.2	0.2	0.1	0.0	
9	162.5	0.1	0.1	0.0	-0.1	-0.1	
10	162.3	0.1	0.1	0.0	-0.1	-0.1	
11	161.8	-0.1	-0.1	-0.3	-0.3	-0.4	
12	161.6	0.0	0.0	-0.3	-0.3	-0.5	
13	161.5	0.0	-0.1	-0.1	-0.2	-0.2	
14	161.5	0.1	0.0	0.0	-0.1	-0.1	
15	161.3	0.0	0.0	-0.1	-0.2	-0.2	
16	161.1	-0.1	-0.1	-0.2	-0.3	-0.3	
17	161.0	-0.2	-0.2	-0.3	-0.4	-0.4	
18	160.6	0.2	0.1	0.1	0.0	-0.1	
19	158.2	-0.9	-1.0	-1.1	-1.1	-1.0	Downstream area - Observed WSE drops rapidly over a relatively short distance.
20	157.0	-0.9	-0.9	-0.9	-1.0	-1.0	
21	156.9	-0.6	-0.6	-0.6	-0.7	-0.7	
22	156.5	-2.1	DRY	DRY	-1.9	-2.1	
RMSE (ft) (Lines 1 - 21)		**0.4**	**0.4**	**0.4**	**0.5**	**0.5**	
RMSE (ft) (Lines 1 - 18)		**0.2**	**0.2**	**0.3**	**0.3**	**0.4**	

* - Model has only overbank geometry and does not include 1D low flow channel, Manning's n and other necessary components for calibration

Habitat Sensitivity to Grid Size

Salmonid fry usable habitat estimates

Grid size (ft)	Fraction of wetted area (%)					
	Chinook Fry			*O. mykiss* Fry		
	Product	Geo. mean	Limiting	Product	Geo. mean	Limiting
10 by 10	29	40	32	40	48	42
20 by 20	27	39	31	39	47	40
30 by 30	27	38	30	38	46	39
40 by 40	28	39	31	38	47	40
50 by 50	26	38	30	37	46	39

Habitat Sensitivity to Grid Size

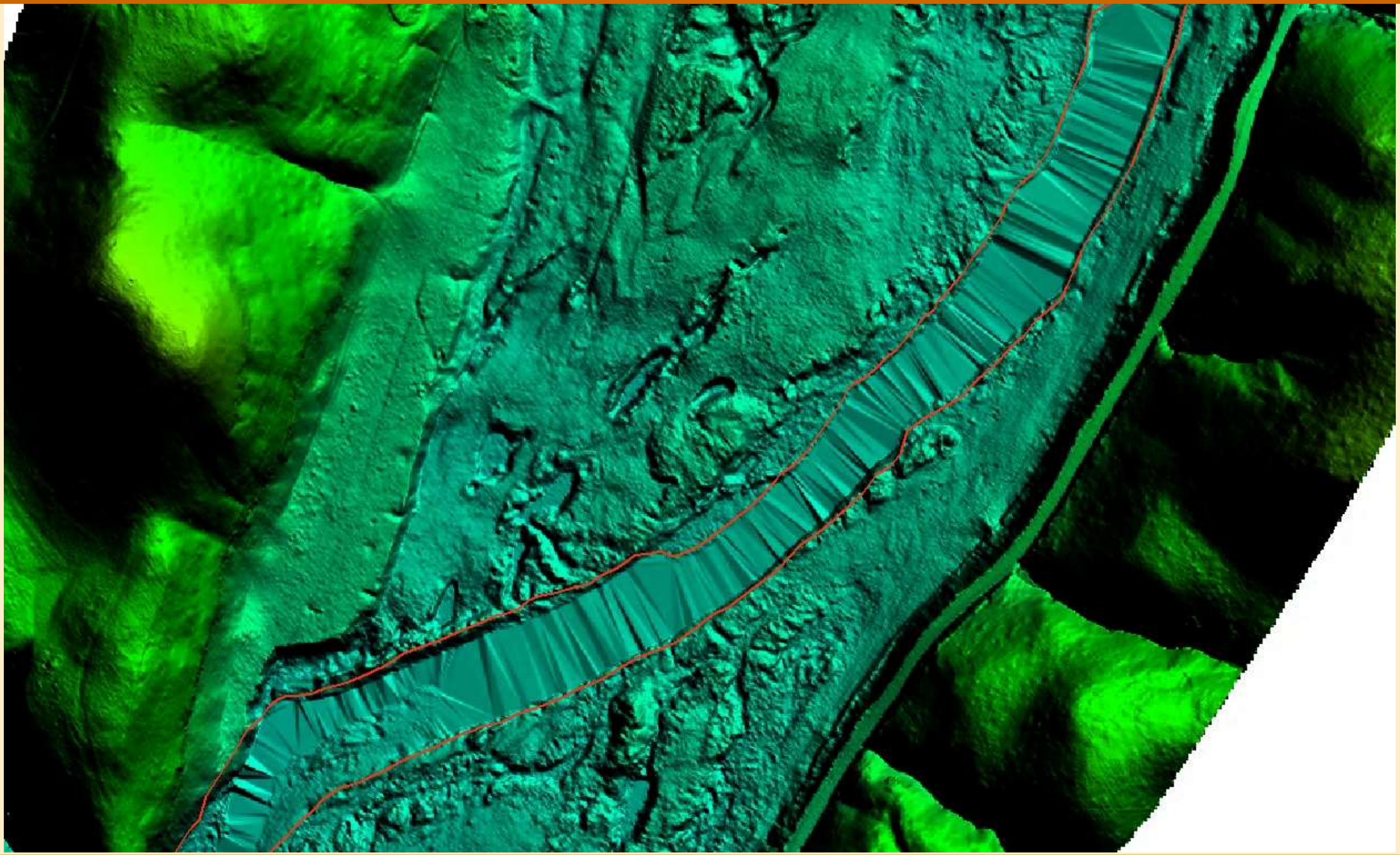
Salmonid juvenile usable habitat estimates

Grid size (ft)	Fraction of wetted area (%)					
	Juvenile Chinook			Juvenile O. mykiss		
	Product	Geo. mean	Limiting	Product	Geo. mean	Limiting
10 by 10	32	42	34	35	43	37
20 by 20	32	42	34	35	43	37
30 by 30	32	41	34	34	42	37
40 by 40	33	42	35	35	43	38
50 by 50	32	41	34	35	43	37

Overbank vs. In-Channel Areas

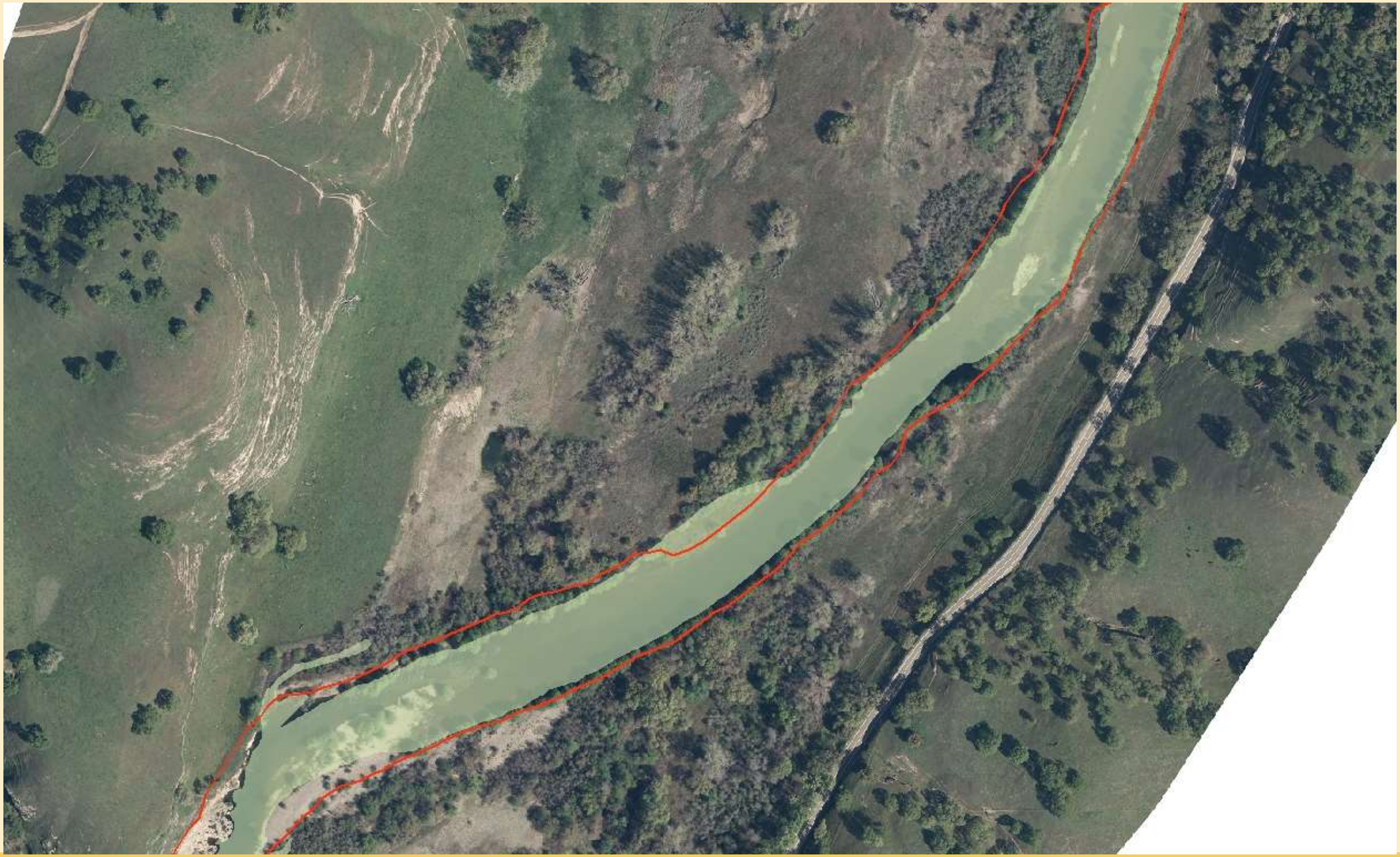
- **2D domain maximized for habitat analysis**
- **1D-2D line defines hydraulic control for TUFLOW**
- **Approximately historic 1,070 cfs inundation extent**
- **Overbank area transitions to riverine area at higher flows**

1D-2D Domain Boundary

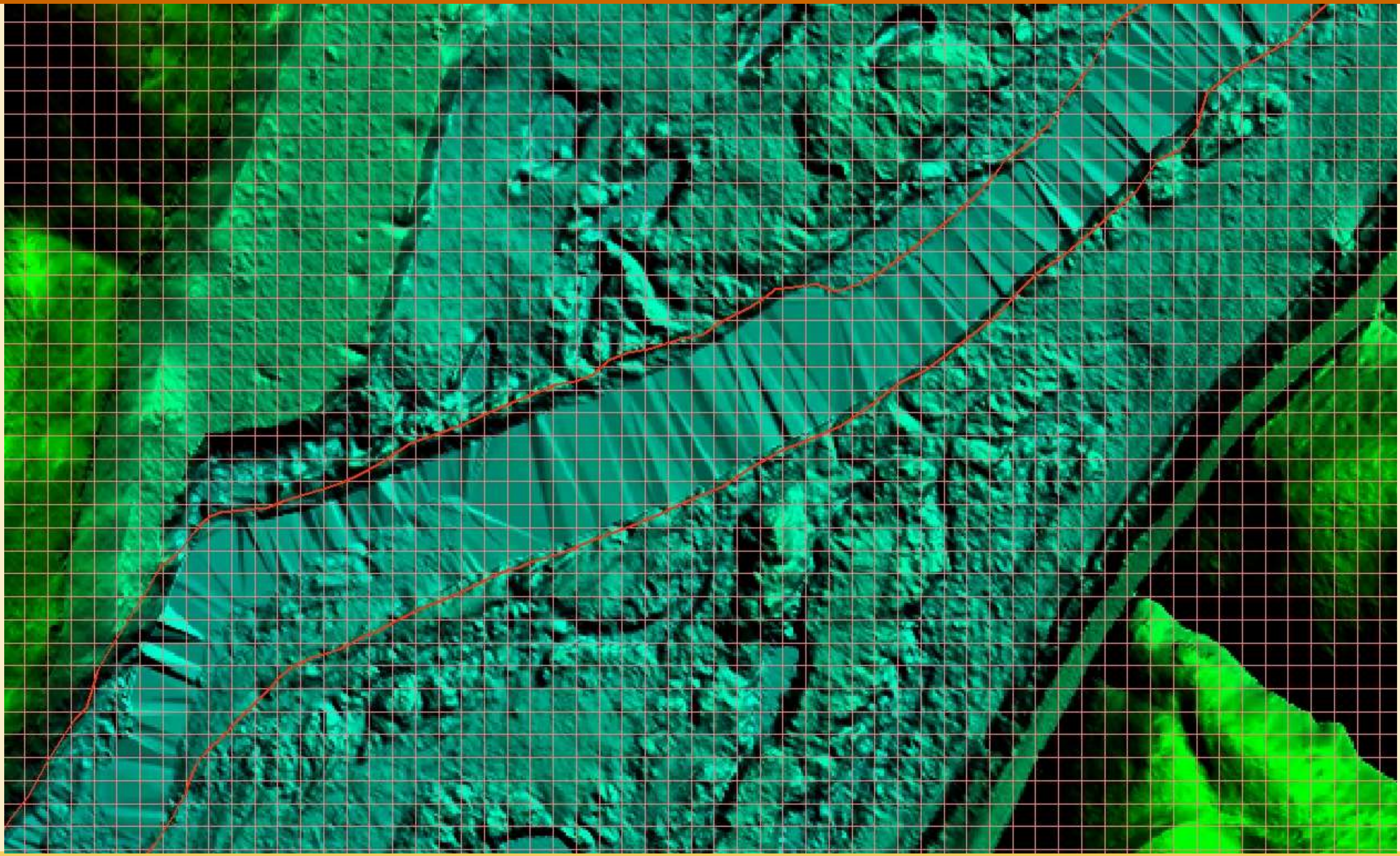


1D-2D Domain Boundary

1,070 cfs Inundation Extent



1D-2D Boundary for 30ft cells



TUFLOW Modeling Plan

- Units: Foot-Pound-Second (FPS)

- Projection : NAD83 California State Plane, Zone III, US Foot

- 3 or more sub-models
  - RM 52 – RM 40
  - RM 40 – RM 24
  - RM 24 – RM 0

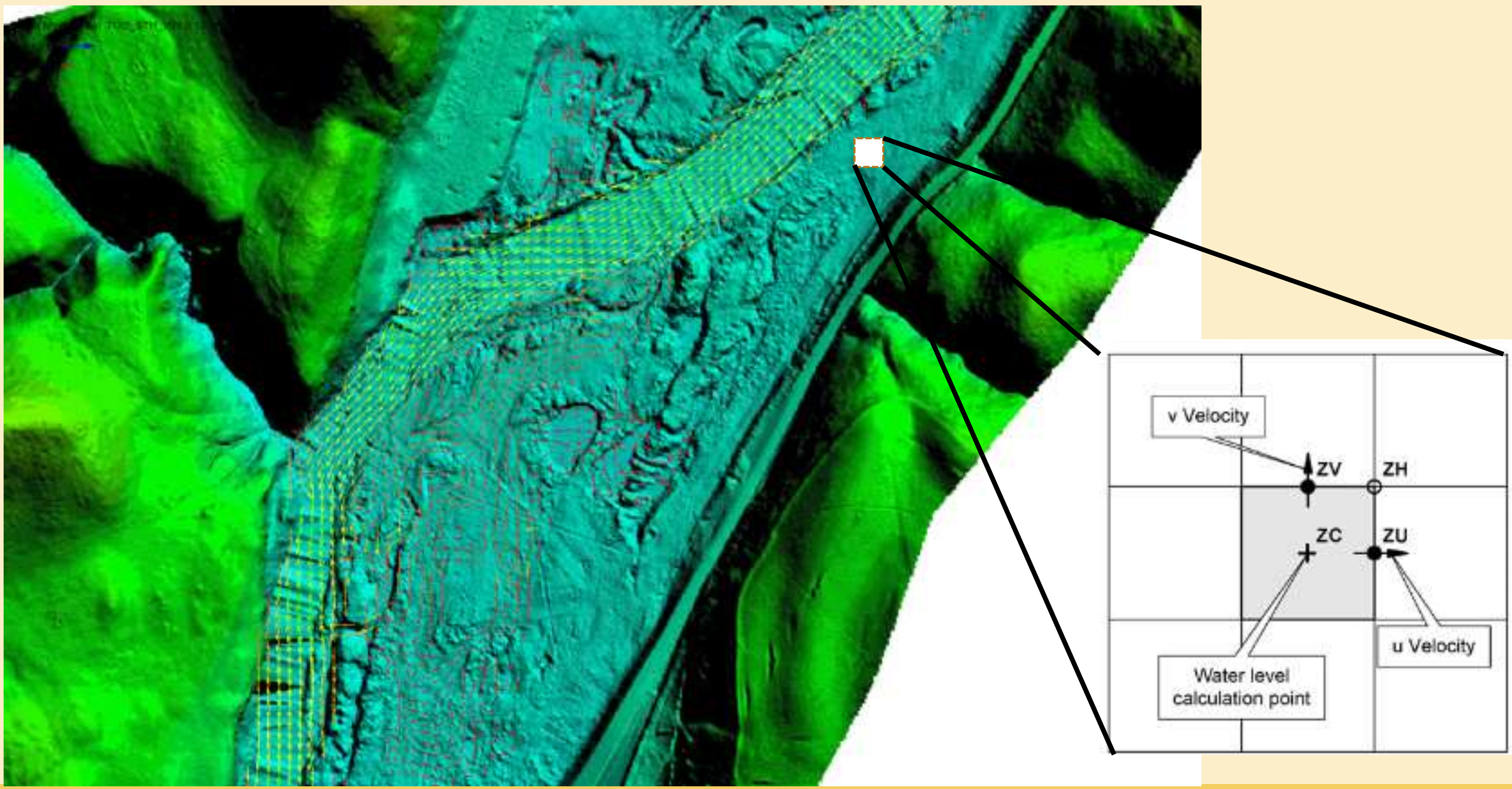
- Cell Size – 30ft or less

Pilot Model - Next Steps

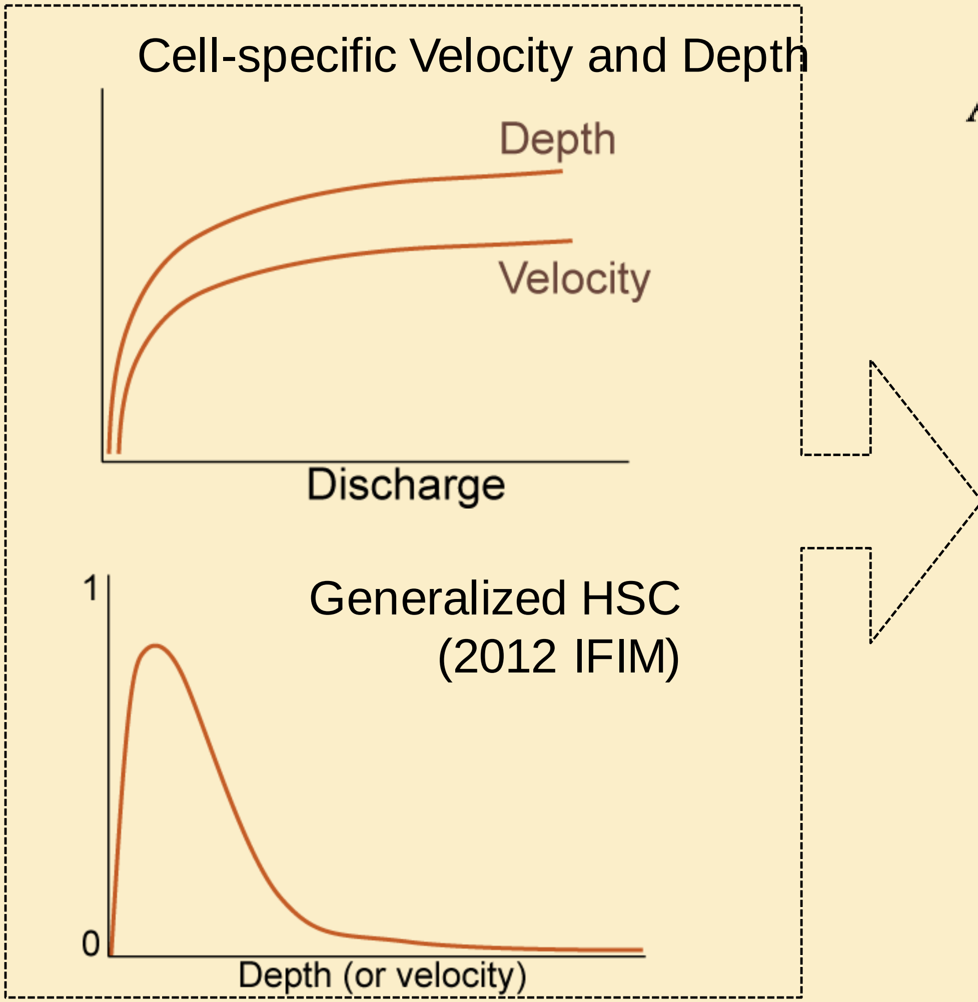
- **Add Manning's "n" to overbank areas**
- **Add embankments using breaklines**
- **Add elevation of ponds & pools using breaklines**
- **Add 1D low flow channel geometry**
- **Calibrate**

Habitat Analysis

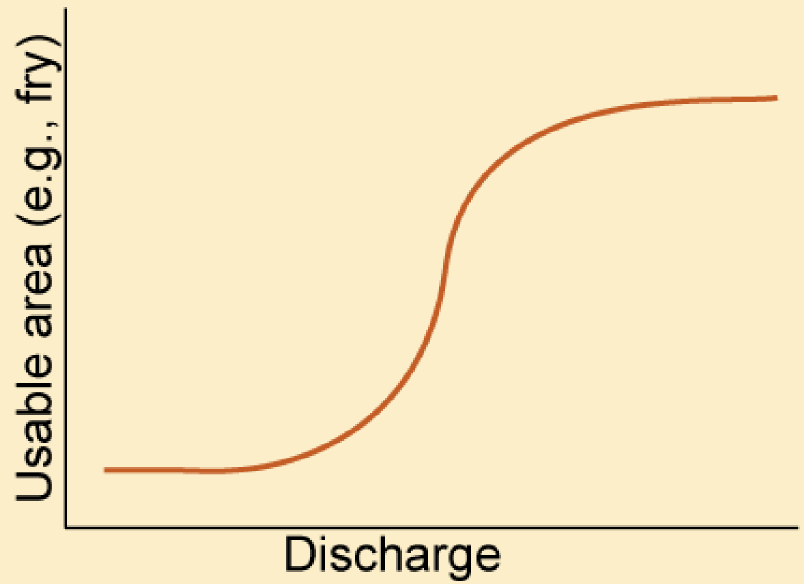
- **Cell-specific Velocity and Depth Predictions**



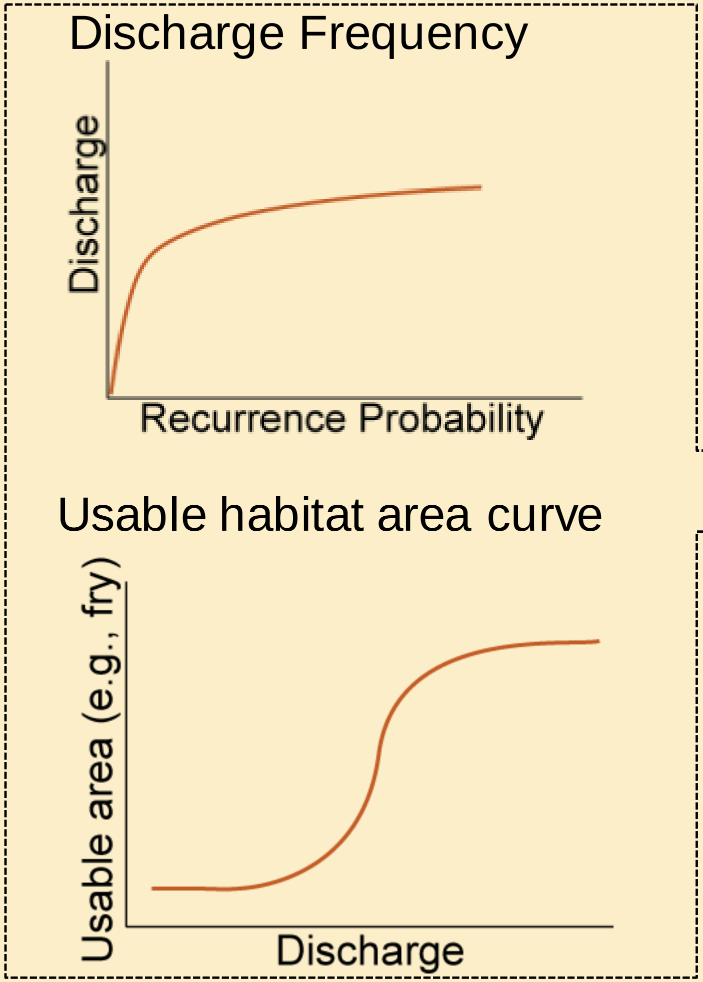
Habitat Analysis

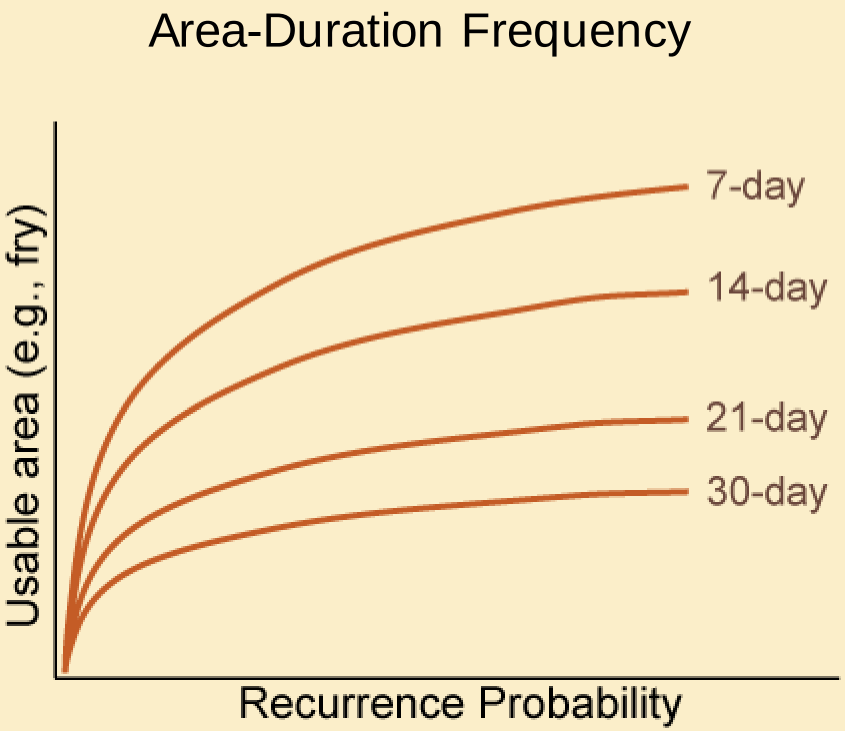


$$Area = \sum_{i=1}^{n} A_i \times HSC(depth, velocity)$$



Habitat Analysis





Questions?

Photo Credit: Stillwater Sciences

Photo Credit: Tuolumne River TAC

Floodplain Hydraulic Assessment Schedule

Model Input Development	October 2013–February 2014
Model Hydraulic Development	January–March 2014
Model Calibration/Validation/RP Consultation	February–March 2014
Map Inundation Extents	March-April 2014
Evaluate Inundation Frequency, Period, Duration and Juvenile Rearing	April-June 2014
Draft Report Preparation	July–August 2014
Draft Report Review by Relicensing Participants	August 2014
Final Report Filing with FERC	November 2014

Attachment B
Tuolumne River Conservancy, Inc.
Comments on Floodplain Hydraulic Analysis Workshop No. 1

From: Allison Boucher <aboucher@bendbroadband.com>
Sent: Thursday, February 20, 2014 8:09 PM
To: 'Staples, Rose'; 'Alves, Jim'; 'Amerine, Bill'; 'Asay, Lynette'; 'Barnes, James'; 'Barnes, Peter'; 'Barrera, Linda'; 'Beeco, Adam'; 'Blake, Martin'; 'Bond, Jack'; 'Borovansky, Jenna'; 'Bowes, Stephen'; 'Bowman, Art'; 'Brenneman, Beth'; 'Buckley, John'; 'Buckley, Mark'; 'Burke, Steve'; 'Burt, Charles'; 'Byrd, Tim'; 'Cadagan, Jerry'; 'Carlin, Michael'; 'Charles, Cindy'; 'Cooke, Michael'; 'Cowan, Jeffrey'; 'Cox, Stanley Rob'; 'Cranston, Peggy'; 'Cremeen, Rebecca'; 'Damin Nicole'; 'Day, Kevin'; 'Day, P'; 'Denean'; 'Derwin, Maryann Moise'; 'Devine, John'; 'Dowd, Maggie'; 'Drake, Emerson'; 'Drekmeier, Peter'; 'Edmondson, Steve'; 'Eicher, James'; 'Fargo, James'; 'Fernandes, Jesse'; 'Ferranti, Annee'; 'Ferrari, Chandra'; 'Findley, Timothy'; 'Fleming, Mike'; 'Fuller, Reba'; 'Furman, Donn W'; 'Ganteinbein, Julie'; 'Giglio, Deborah'; 'Gorman, Elaine'; 'Grader, Zeke'; 'Gutierrez, Monica'; 'Hackamack, Robert'; 'Hastreiter, James'; 'Hatch, Jenny'; 'Hayden, Ann'; 'Hellam, Anita'; 'Heyne, Tim'; 'Holley, Thomas'; 'Holm, Lisa'; 'Horn, Jeff'; 'Horn, Timi'; 'Hudelson, Bill'; 'Hughes, Noah'; 'Hughes, Robert'; Noah Hume; 'Hurley, Michael'; 'Jackson, Zac'; 'Jauregui, Julia'; 'Jennings, William'; 'Jensen, Laura'; 'Johannis, Mary'; 'Johnson, Brian'; 'Jones, Christy'; 'Jsansley'; 'Justin'; 'Keating, Janice'; 'Kempton, Kathryn'; 'Kinney, Teresa'; 'Koepele, Patrick'; 'Kordella, Lesley'; 'Le, Bao'; 'Levin, Ellen'; 'Linkard, David'; 'Loy, Carin'; 'Lwenya, Roselynn'; 'Lyons, Bill'; 'Madden, Dan'; 'Manji, Annie'; 'Marko, Paul'; 'Martin, Michael'; 'Mathiesen, Lloyd'; 'McDaniel, Dan'; 'McDevitt, Ray'; 'McDonnell, Marty'; 'Mein Janis'; 'Mills John'; 'Morningstar Pope, Rhonda'; 'Motola, Mary'; 'Murphey, Gretchen'; 'Murray, Shana'; 'O'Brien, Jennifer'; 'Orvis, Tom'; 'Ott, Bob'; 'Ott, Chris'; 'Pavich, Steve'; 'Pool, Richard'; 'Porter, Ruth'; 'Powell, Melissa'; 'Puccini, Stephen'; 'Raeder, Jessie'; 'Ramirez, Tim'; 'Rea, Maria'; 'Reed, Rhonda'; 'Reynolds, Garner'; 'Richardson, Daniel'; 'Richardson, Kevin'; 'Ridenour, Jim'; 'Riggs T'; 'Robbins, Royal'; 'Romano, David O'; 'Roos-Collins, Richard'; 'Rosekrans, Spreck'; 'Roseman, Jesse'; 'Rothert, Steve'; 'Sandkulla, Nicole'; 'Saunders, Jenan'; 'Schutte, Allison'; 'Sears, William'; 'Shakal, Sarah'; 'Shipley, Robert'; 'Shumway, Vern'; 'Shutes, Chris'; 'Sill, Todd'; 'Simsiman, Theresa'; 'Slay, Ron'; 'Smith, Jim'; 'Stapley, Garth'; 'Steindorf, Dave'; 'Steiner, Dan'; 'Stender, John'; 'Stone, Vicki'; 'Stork, Ron'; 'Stratton, Susan'; 'Taylor, Mary Jane'; 'Terpstra, Thomas'; 'TeVelde, George'; 'Thompson, Larry'; 'Tmberliner'; 'Ulibarri, Nicola'; 'Verkuil, Colette'; 'Vierra, Chris'; 'Villalobos, Amber'; 'Wantuck, Richard'; 'Ward, Walt'; 'Welch, Steve'; 'Wenger, Jack'; 'Wesselman, Eric'; 'Wetzel, Jeff'; 'Wheeler, Dan'; 'Wheeler, Dave'; 'Wheeler, Douglas'; Scott Wilcox; 'Williamson, Harry'; 'Willy, Allison'; 'Wilson, Bryan'; 'Winchell, Frank'; 'Wooster, John'; 'Workman, Michelle'; 'Yoshiyama, Ron'; 'Zipser, Wayne'
Cc: Dave Boucher
Subject: Floodplain Hydraulic Assessment

Floodplain Hydraulic Assessment Study:

Although historic recurrence probability might be interesting, the more important analysis would be unimpaired flows recurrence probability. Please add unimpaired flows recurrence probability to the study and compare it to flows since the 1995 Settlement Agreement excluding the flood of 1997. If the flood of 1997 is included, the graph will be misleading.

Allison and Dave Boucher
Tuolumne River Conservancy, Inc.

APPENDIX B

WORKSHOP NO. 2 MEETING NOTES

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Don Pedro Project Relicensing
W&AR-21 Workshop No. 2
Draft Meeting Notes

Thursday, December 18, 2014

Attendees

Jenna Borovansky – HDR	Ron Yoshiyama – CCSF
Jesse Deason – HDR	Jim Hastreiter – FERC, *by phone*
John Devine – HDR	Robert Hughes – CDFW
Pani Ramalingam – HDR	Dean Marston – CDFW
Rob Sherrick – HDR	Dale Stanton – CDFW
Anna Brathwaite – MID	John Wooster – NMFS, *by phone*
Greg Dias – MID	Mark Gard – USFWS
Bill Johnston – MID, *by phone*	Peter Barnes – SWRCB, *by phone*
Noah Hume – Stillwater Sciences	Chris Shutes – CSPA, *by phone*
Maia Singer – Stillwater Sciences	Peter Drekmeier - Tuolumne River Trust, *by phone*
Jonathan Knapp – CCSF	Patrick Koepele – Tuolumne River Trust, *by phone*
Ellen Levin – CCSF	Nicola Ulibarri – Stanford
Bill Sears – CCSF	

Agenda and Purpose

Following introductions, Jenna Borovansky provided an overview of the meeting agenda. The purpose of the Lower Tuolumne River Hydraulic Floodplain Assessment (W&AR-21) modeling Workshop No. 2 is to review the hydraulic model development, present calibration and validation results, present preliminary results of the habitat analysis, and the study schedule (slide 2).

Background

Jenna provided study background (slide 3).

Study Objectives

Jenna presented the study objectives, namely to analyze floodplain inundation at specified flow intervals and estimate associated floodplain habitat availability for rearing juvenile salmon in the lower Tuolumne River (slide 4). Base case hydrology (1970-2012) from the Operations Model report is used for this study. The completed 2-D floodplain model can serve as a tool for modeling future hydrology scenarios.

Study Methodology

Jenna provided an overview of study methodology (slide 5).

Summary of Workshop No. 1

Jenna presented a summary of material covered at Workshop No. 1, held in February 2014, including recommendations that came out of workshop discussions (slides 6 & 7). The primary recommendations were the following:

- Develop three reaches for TUFLOW model
  - Model A (RM 51.4 – 40)
  - Model B (RM 40 – 21.5)
  - Model C (RM 21.5 – 0.9)
- Based on results of the sensitivity analysis, use a 2-D model cell size of 30 ft or less

Question (Patrick Koepele): What geomorphic characteristics were used to define the three study reaches?

Answer (Pani Ramalingam): Three study reaches were adopted primarily based on run-time considerations for TUFLOW. At a 30-ft cell size, the model run time for the entire lower river would be unreasonably long. Breaking the model into three separate reaches allowed us to optimize model construction, calibration, and run time. Each of the three model segments requires approximately 1-2 hours to run, allowing us to work on them simultaneously.

Answer (Noah Hume): The Tuolumne River has a major slope break from gravel bedded to sand bedded at approximately RM 29. As Pani noted, the river was divided into sub-reaches for computational efficiency.

Hydraulic Modeling Status

Pani Ramalingam presented the model reach extents (slide 8). Rob Sherrick presented a summary of the various cross section data sources used to develop model cross-sections for the 1-D (in-channel) portion of the TUFLOW model (slides 9 &10). While existing data were used where available, a considerable amount of additional cross-section data were collected by TID as necessary. Some of the survey locations of the data sources overlapped in various reaches of the river, allowing for improved spatial accuracy and model validation.

Model Components

Pani presented the TUFLOW hydrologic model components (slides 11-12).

- Ponds and pools – manually digitized and were assigned depths from bathymetry if available or assigned water level from 2012 LiDAR
- Levee like features – derived from LiDAR and captured in the model
- Narrow thin channels – derived from LiDAR and captured in the model
- Mannings 'n' (roughness or friction factor used in modeling) was derived from prior vegetation mapping studies and existing aerial photos, 2012 helicopter video and field visit photos.
- Model B – includes culverts near RM 38
- Model C – includes Dennett Dam (~RM 16)

Model Boundary Conditions

Pani described the order of model segment development. Boundary conditions were set from downstream to upstream in order to appropriately include backwater effects from the Tuolumne River-San Joaquin River confluence.

1. Model C – An analysis of backwater effects of San Joaquin River was performed. A range of USGS gage data sources were used to estimate statistical relationships of San Joaquin and Tuolumne River stages and flows (slides 13-16). This analysis revealed that backwater effects can extend up to RM 13. A discharge - water surface elevation curve (rating curve) was developed for use as boundary condition.

2. Model B - Model C was built simultaneously along with Model B and the section upstream of Modesto gage (near RM 16) was calibrated. Results from this model were then used to develop a rating curve for use as a boundary condition. It should be noted that extents of Model B and C overlap.

3. Model A – Normal depth boundary condition was used by extending the model downstream to RM 37.5 so that boundary effects are insignificant at RM 40. It should be noted that extents of Model A and B overlap.

Model Calibration and Validation

Pani described the calibration and validation steps for TUFLOW (slides 17-21). Calibration was accomplished by using a combination of model results, gage flows, and historical images. The 1-D in-channel portion of the model was calibrated first, followed by the 2-D floodplain portion of the model.

Question (Bob Hughes): How did you use Google Earth to calibrate the model?

Answer (Pani Ramalingam): We used existing images of historical flow events across a range of flows to visualize the channel wetted width. This included digitizing a series of air photos from four high flow events in the 1990s that were used in the USFWS (2008) and Stillwater Sciences (2012) floodplain studies. Google Earth also provides historical aerial imagery which allowed the observed inundation extent to be validated against the gaged flows on the date of the photo.

Question (Bob Hughes): Was there any calibration to water surface elevations?

Answer (Pani Ramalingam): Yes, in Model Segment A for RM 49 – 43, the stage data records for 3,000 cfs collected at two sites in the 2011 Pulse Flow Study was used. Water surface elevations were also used to calibrate Model Segment C using the existing USGS rating curve information at the Modesto gage.

Hydraulic Modeling Results

Pani showed inundation examples (slide 22) for Model Segment A, B, and C stepping through model results in 250/500 cfs increments (not shown in slides).

Question (Noah Hume): Are the flows entering from Dry Creek calculated using the rating curve approach for Model C or are the observed inundation areas simply due to backwater effects?

Answer (Pani Ramalingam): Backwater effects.

Question (Bob Hughes): I don't understand the interaction between the 1-D and 2-D components of the hydraulic model. Is the calibration accomplished primarily on the 1-D portion? How does TUFLOW work in general terms?

Answer (Pani Ramalingam): Calibration is undertaken for both the 1-D and 2-D portions [Pani showed a visual of the break line between the 1-D and 2-D models]. The model first undertakes calculations for the 1-D portion. Every 2 seconds the two models communicate with one another to determine if water should be crossing the break line into the 2-D portion of the model. We must begin with accurate flow predictions for the 1-D model; that is why we spent so much time collecting additional cross-section data for the 1-D model.

Habitat Analysis

Noah Hume discussed the habitat analysis approach (slides 23-24). Once the hydraulic model results were ready, we modeled habitat availability using suitability criteria for depth and velocity from the completed IFIM Study (Stillwater Sciences 2013). Cell-specific depth and velocity predictions from TUFLOW were summed across the 2-D model domain to estimate usable habitat area for juvenile and fry life stages of Chinook and *O. mykiss*. Results for Model Segment A are complete. Results are in development for model segments B and C.

Noah provided example results for Model Segment A at Riffle 4A/4B (slides 25-29):

- Habitat suitability is shown in 2,000 cfs increments
- In-channel habitat was excluded from the analysis (addressed by earlier Stillwater (2013) IFIM Study)
- Although there is a lot of inundated floodplain area, most of the suitable habitat is limited to backwater habitats and margins of flooded areas

Noah provided example results for Model Segment A at Bobcat Flat (slides 30-34):

- Hydraulic modeling is challenging in this reach due to the intact mining tailings piles and numerous deep ponds
- Given that, TUFLOW did a good job of representing flows in this reach
- Model results indicate inundation into captured gravel ponds at 7,000 and 9,000 cfs

Next we summed cell-specific habitat suitability for Model Segment A to produce the usable habitat vs discharge curve shown in slide 35.

- Note that usability of floodplain habitat for juveniles averages about 50% of total inundated area and does not fall off very quickly because they possess stronger swimming performance at increased depths and velocities
- In contrast, fry habitat usability drops off relatively quickly to less than 30% at the highest modeled flows
- The character of the usable habitat vs discharge relationships changes as we move from Model A which has some floodplain habitat; to Model B which has comparatively less floodplain habitat; to Model C nearest the San Joaquin River which has some floodplain habitat that becomes inundated at the highest flows.

O. mykiss fry life stages may be found in floodplain habitats, but generally these fish find flow refuge in gravels in main channel. Nevertheless we have included *O. mykiss* in the habitat analysis.

Area-Duration-Frequency Analysis

Noah discussed the aim of the ADF analysis – to determine the periods of maximum inundation occurring over a certain duration and at a certain frequency in the flow record (slides 36-45). This used base case (WY1971–2012) hydrology from the Operations Model (W&AR-02)

- Note that as in the example animations, even at 1,000 cfs there is a fair amount of floodplain habitat due to the presence of backwaters and pond features (e.g., 2 million ft^2).

- On a fairly regular basis (2-4 yr recurrence interval) floodplain habitat is inundated and usable for juveniles/fry.
- Flows above bankfull discharge are associated with increases in habitat.
- As with the usable habitat curves, each model reach will exhibit a slightly different character for the curves.
- For the final report, we may present habitat curves by reach, or we may combine into one lower river set of curves.
- In general, these results are consistent with prior floodplain modeling efforts.

Questions

Question: (Dale Stanton): Why limit yourself to the base case hydrology?

Answer (Jenna Borovansky): Base case hydrology is specified in the study plan, but conceivably other hydrologic scenarios could be run in the model.

Question: (Mark Gard): Would you compare results of the habitat assessment at unimpaired flows to results for base case flows? USFWS had recommended a set of flows in their comments on the study plan – what about those?

Answer (John Devine): The study plan suggests other flow scenarios, but in the FERC licensing process we are only considering the base case. The unimpaired flows represent a pre-project condition. If after FERC review there is still interest in modeling other flows, the model will be available as a tool.

Question (Bob Hughes): How much of the modeling tool will be publically available?

Answer (Jenna Borovansky): HDR has committed to having the TUFLOW model available for interested parties to run on their own. The Districts will work with agencies on the most efficient method for making the model available for use.

Answer (Noah Hume): The habitat suitability analysis is a little more involved but we could potentially provide the ‘R’ code used.

Answer (Rob Sherrick): The post-processing of the hydrology model results would be different for a new flow series, but TUFLOW results would be the same.

Question: Will the inundation animations be posted on the web?

Answer (Jenna Borovansky): Yes. We have some example animations for Model A that we can post – not all of the animations from today will be available since Pani ran them directly from the model for the workshop presentation.

Action Items

- The Districts will post the PowerPoint and sample animations on the relicensing website, www.donpedro-relicensing.com.
- The Districts will work with agencies to provide the model and habitat analysis files available by request, once the report is finalized.

- Following the meeting, Mark Gard (USFWS) contacted Noah Hume and requested summaries of the inundation area vs. discharge results to be provided in MS Excel format. In addition, when they are available, Mark requested velocity and depth predictions in either spreadsheet or csv format. The Districts will provide this information when the draft report is released for relicensing participant review.

Attachments

Attachment 1: Modeling Workshop Agenda

Attachment 2: Modeling Workshop No. 2 Slides

Attachment 1

Modeling Workshop No. 2 Agenda

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Don Pedro Hydroelectric Project
Floodplain Hydraulic Assessment (W&AR-21)
Workshop No. 2 Agenda

Thursday, December 18
1:00 pm – 4:30 pm
MID Offices, 1231 11th Street, Modesto, CA

Phone number: 866-994-6437
Conference code: 542-469-7994
Link to online meeting: Join Lync Meeting (Lync Meeting Help)

- Review agenda and purpose of the meeting
- Study plan goals and objectives
- Overview of study methodology
  - Study flows
- Summary of Workshop No. 1
- River hydraulic model background
  - 2D TUFLOW model
  - 1D HEC-RAS model
- Model reaches
  - Model A: RM 52.2 to RM 40
  - Model B: RM 40 to RM 21.5
  - Model C: RM 21.5 to the confluence
- Data sources
- River hydraulic model calibration process (RM 52.2 – RM 21.5)
- Habitat analysis status
  - Analysis approach
  - Model A – preliminary results
    - Bobcat Flat example
    - Reach estimated usable area
    - Area-duration frequency analysis
- Next steps and schedule

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Attachment 2

Modeling Workshop No. 2 Slides

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Don Pedro Hydroelectric Project Relicensing

Lower Tuolumne River Floodplain Hydraulic Assessment (W&AR-21)

December 18, 2014

Agenda and Purpose

- Study Background
- Hydraulic Modeling Status
- Habitat Analysis Status
- Study Schedule

Background

- FERC ordered a hydraulic analysis of the amount of floodplain inundated in its May 21, 2013 Determination
- Draft study plan provided to relicensing participants for comment, and final study plan modified based on relicensing participant comments submitted in September 2013
  - Revised plan based on relicensing participant comment, including expanded study area and added habitat analysis
- FERC approved study plan October 18, 2013

Study Objectives

- Analyze the amount of floodplain inundated between RM 52.2 and RM 0 of the Tuolumne River at flows between approximately 1,000 cfs and 9,000 cfs
- Assess the suitability of inundated floodplain habitat for juvenile salmon rearing
- Evaluate the frequency and period of inundation over a range of flows for the base case (WY 1971-2012) hydrology

Study Methodology

1. TUFLOW model to determine floodplain extents at:
   - 250 cfs intervals from 1,000-3,000 cfs
   - 500 cfs intervals from 3,000-9,000 cfs
2. Determine the maximum continuous wetted area for 7, 14, 21, and 30 day durations
3. Evaluate the Base Case scenario (WR 1971-2012)
4. Estimate depths and velocities in overbank areas from RM 52 to the San Joaquin River and use existing habitat suitability criteria for depth and velocity for juvenile salmonids to quantify the amount of suitable juvenile rearing habitat as a function of flow

February 13, 2014: Workshop No. 1

- Hydraulic Modeling Approach
  - Data Sources
  - TUFLOW Model
  - Overbank vs. In Channel Areas

- Habitat Analysis Approach
  - Sensitivity to grid size

Feb.13 Meeting - Recommendations

- **TUFLOW Modeling Plan**
  - **Model A - RM 52 to 40**
  - **Model B - RM 40 to 23**
  - **Model C - RM 23 to 0**

- **2D cell Size – 30ft or less**

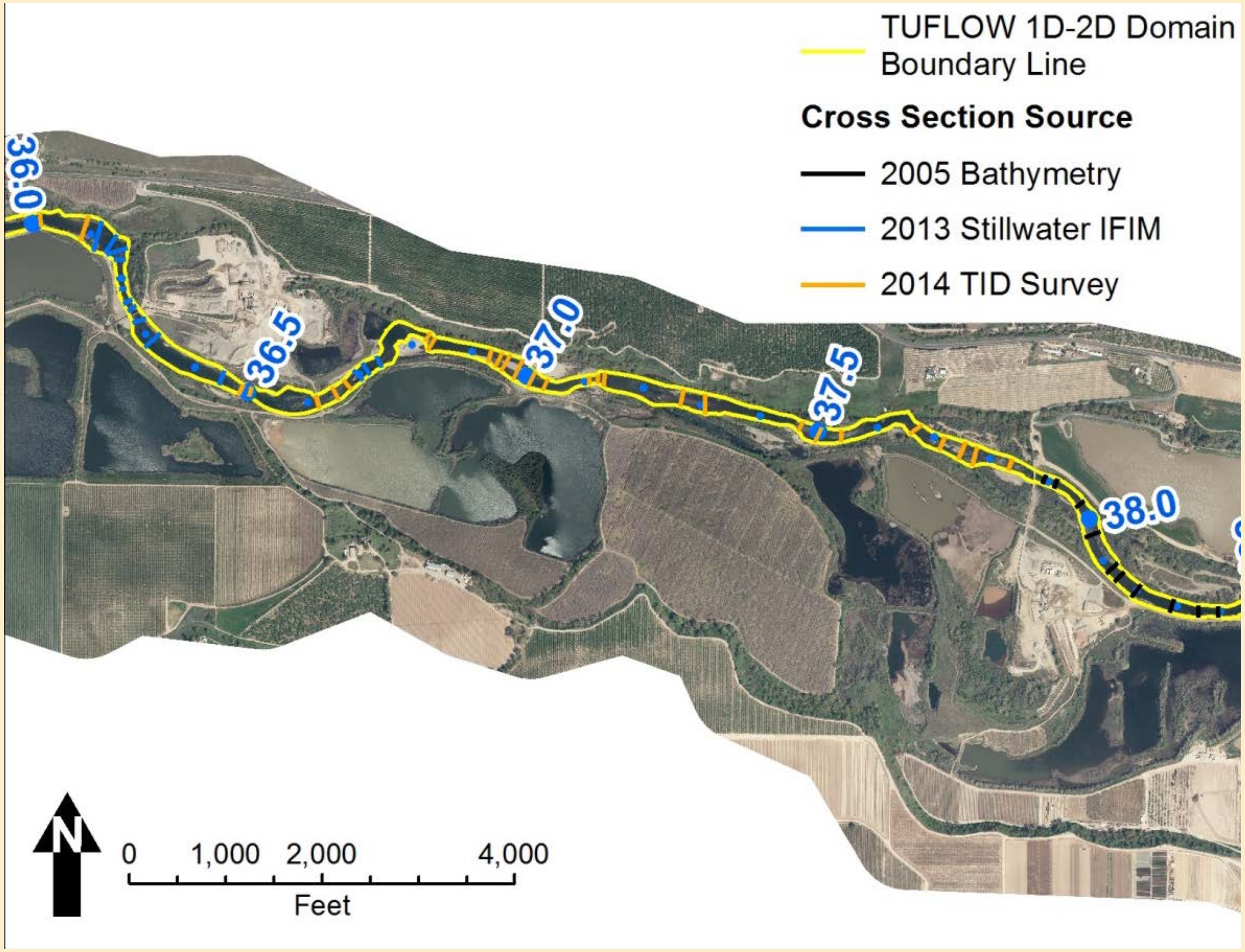
Hydraulic Modeling Status

- **TUFLOW models constructed, calibrated and QCed**
- **Model A – RM 52.2 to RM 40**
- **Model B – RM 40 to RM 21.5**
- **Model C – RM 21.5 to the confluence (RM 0.88)**
  - **San Joaquin River backwater effects analyzed**

1D Cross Section Data Sources

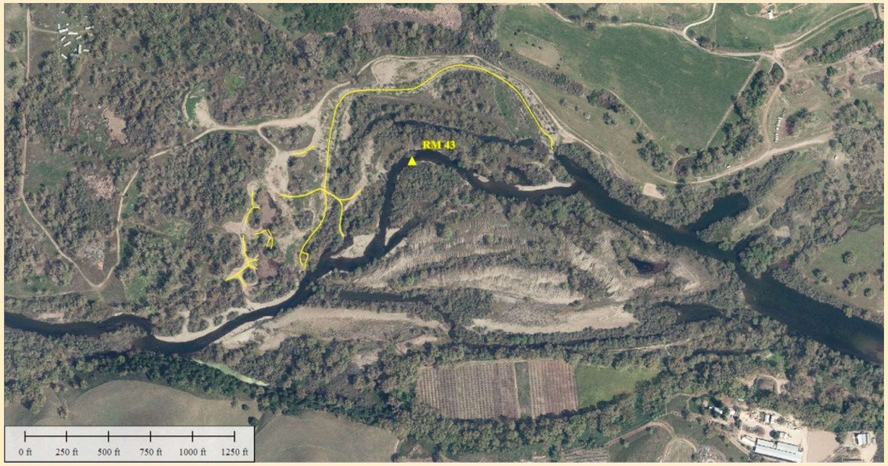
RM (USGS)	RAS Station	Source	Count
0.88-6.31	0.8252-6.3035	2014 DWR-CVFED HEC-RAS Model	28
6.71-22.78	6.715-23.0683	FEMA-CVFED HEC-RAS Model	51
13.99-31.48	13.847-31.9232	2012 HDR Survey	34
4.43-29.54	4.3978-29.98	Interpolated	37
16.13-16.41	15.9601-16.2138	USGS Gage Cross Sections	3
22.59-46.98	22.8536-47.4583	2014 TID Survey	134
24.41-25.86	24.948-26.5125	McBain&Trush SRP 9/10 Restoration	16
30.34-36.74	30.739-37.5818	2013 Stillwater IFIM	19
37.9-45.77	38.9536-46.27	2005 Bathymetry	167
45.78-51.66	46.2985-51.6734	2012 Bathymetry	133
		TOTAL:	622

Sample Cross Section Source Integration



Model Components

- **1D Low flow channel**
- **Ponds & pools**
- **Levee like features**
- **Narrow thin channels**
  - **connecting river and overbanks**
  - **connecting overbank ponds**



Model Components

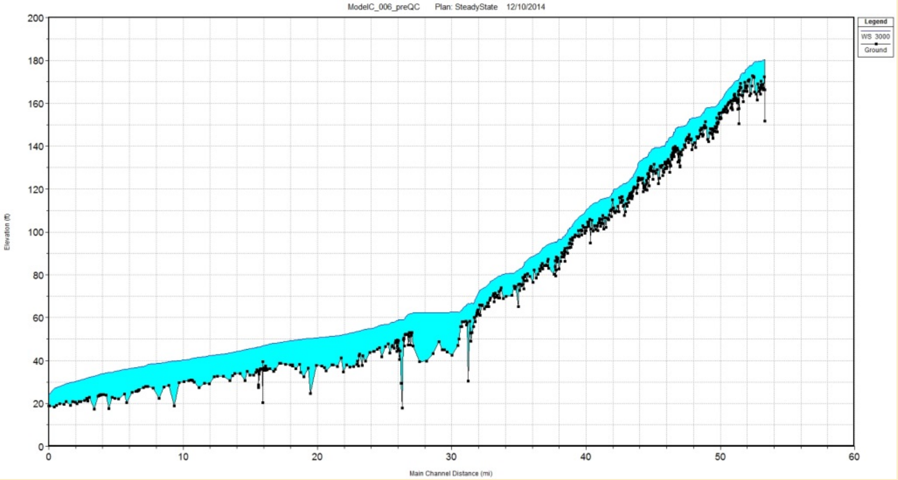
- 2D Manning's "n" for overbank areas

- Culverts near RM 38

- Dennett Dam

Model Boundary Conditions

- **Model A – Normal depth**

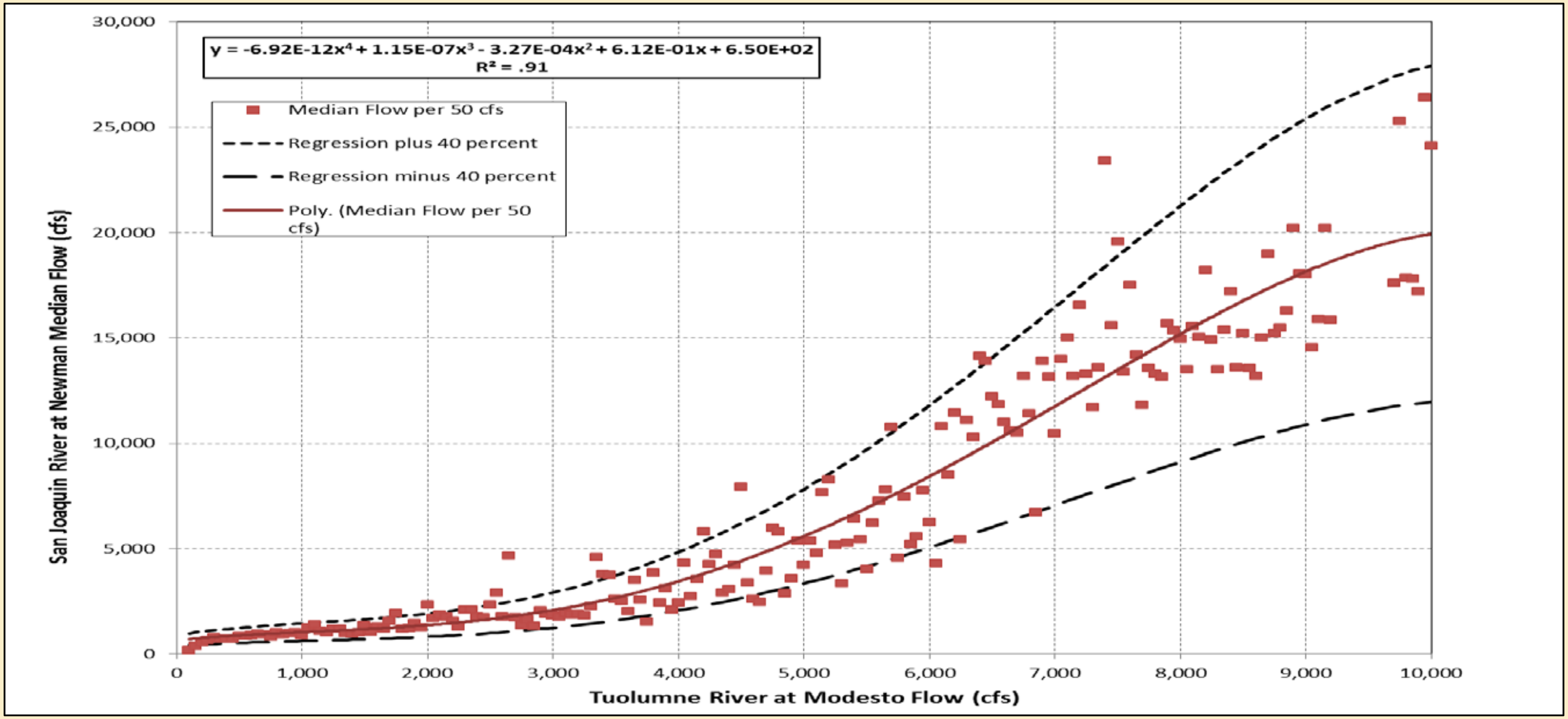


- **Model B – From Model C**
- **Model C – San Joaquin River backwater analysis**

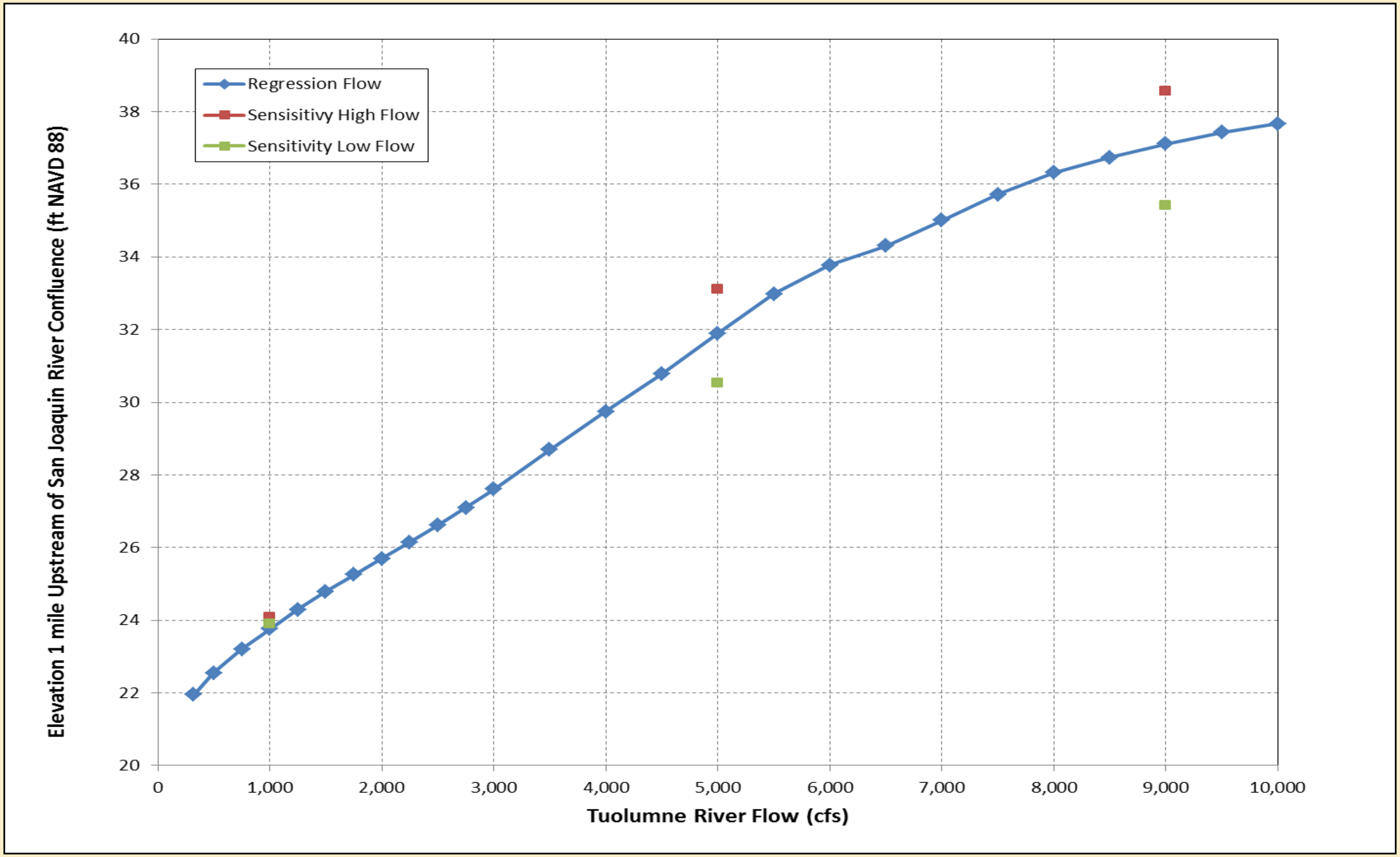
San Joaquin River Backwater Analysis

1. Use existing DWR & FEMA HEC-RAS models
2. Determine extent of backwater effects from San Joaquin River
3. Develop correlated sets of flows for Tuolumne, San Joaquin and Stanislaus Rivers (Water Years 1971 to 2012)
4. Develop a rating curve (elevation-discharge) for downstream boundary condition for Model C

Sensitivity Analysis



Model C Boundary Condition Rating Curve



Model Calibration & Validation

- Google Earth aerial photos (2005-2011)
- TID historic aerial photos (1993-1995)
- USGS gage at Modesto

Model A - Calibration and Validation

TUFLOW Model A - Calibration & Validation Reaches & Data Sources

Primary data set for calibration & validation

S. No.	USGS River Mile	Areas Included	Approximate Constant Flow / Google Earth Imagery Date						RM 50 Side Channel	Bobcat Flat RM 43 Restoration Work	
			1020 cfs	1590 cfs	1960 cfs	2040 cfs	2680 cfs	4030 cfs	490 cfs	5400-6000 cfs	5900-5600cfs
Reach 1	RM 48.5 to RM 51.6	Riffle 4A/4B	24-Jul-11	23-Feb-06		30-May-10	6/29/2005*	-	24-May-09		
Reach 2	RM 46 to RM 48.5	Riffle 5A (Basso Bridge)	24-Jul-11	23-Feb-06	-	30-May-10		11-Jun-05		-	
Reach 3	RM 44 to RM 46	Zanker Property	24-Jul-11	23-Feb-06		30-May-10	-	11-Jun-05	-		
Reach 4	RM 42 to RM 44	Bobcat Flat	24-Jul-11(RM 43 up)	23-Feb-06		30-May-10		11-Jun-05		13-Jun-10	16-Jun-11
Reach 5	RM 38 to RM 42		-	23- Feb-06(RM 40 up)	24-Apr-10	30-May-10 (RM 40 up)		11-Jun-05		-	

*Corrected date per NAIP

Legend

- Calibration Data
- Validation Data
- Limited validation

This data set was used more as a reference. The river/floodplain has changed significantly at several locations since the time of compilation of data.

S. No.	USGS River Mile	Approximate Constant Flow / TID Historic Inundation Imagery Year		
		3100 cfs	5300 cfs	8400 cfs
Reach 1	RM 48 to RM 51.6	1993	1995	1995
Reach 2	RM 46 to RM 48	1993	1995	1995
Reach 3	RM 44 to RM 46	1993	1995	1995
Reach 4	RM 42 to RM 44	1993	1995	1995
Reach 5	RM 38 to RM 42	1993	1995	1995

Model B - Calibration and Validation

TUFLOW Model B - Calibration & Validation Reaches & Data Sources

Primary data set for calibration & validation

S. No.	USGS River Mile	Areas Included	Approximate Constant Flow* / Google Earth Imagery Date			
			654 cfs	2130 cfs	2620 cfs	4050 cfs
1	RM 20 to RM 40		28-Jul-11	24-Apr-10	-	11-Jun-05
2	RM 20 to RM 25		28-Jul-11	24-Apr-10	10-Feb-06	11-Jun-05

*Previous day average flow to account for travel time from USGS La Grange gage

Legend

- Calibration Data
- Validation Data
- Limited validation

This data set was used more as a reference. The river/floodplain has changed significantly at several locations since the time of compilation of data.

S. No.	USGS River Mile	Approximate Constant Flow / TID Historic Inundation Imagery Year		
		3100 cfs	5300 cfs	8400 cfs
2	RM 20 to RM 40	1993	1995	1995

Model C - Calibration and Validation

TUFLOW Model C - Calibration & Validation Reaches & Data Sources

A. Primary data set for calibration & validation

S. No.	USGS River Mile	Areas Included	Approximate Constant Flow* / Google Earth Imagery Date		
			900 cfs	3320 cfs	4130 cfs
1	RM 0.88 to RM 16		28-Jul-11	-	11-Jun-05
2	RM 12 to RM 16			10-Feb-06	

*USGS Modesto Gage (RM 16)

Legend

- Calibration Data
- Validation Data
- Limited validation

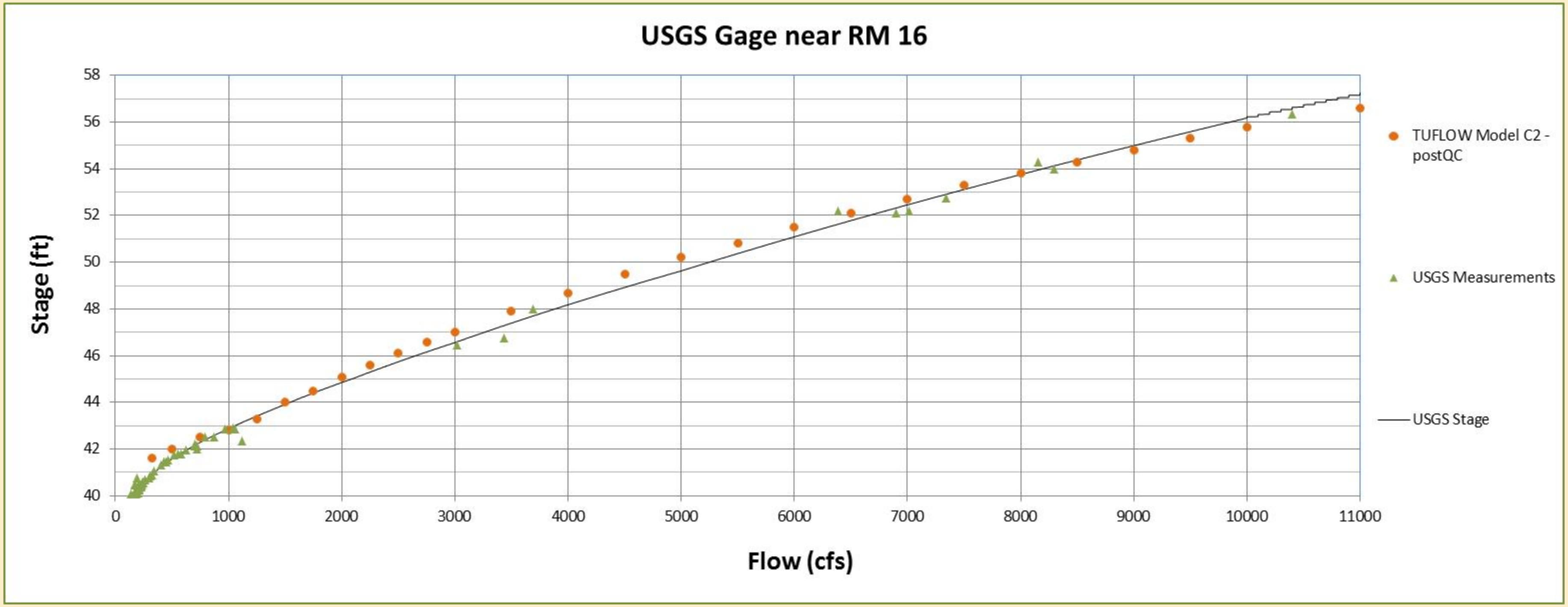
B. TID data set was used more as a reference as the river/floodplain has changed significantly at several locations since the time of compilation of data.

S. No.	USGS River Mile	Approximate Constant Flow* / TID Historic Inundation Imagery Year
		8322 cfs
2	RM 0.88 to RM 21.5	22-Apr-95

*USGS Modesto Gage (RM 16)

C. The rating curve & stage-flow measurements taken at of USGS Gage located near Modesto (near RM 16) were also used to calibrate the model for range of flows.

Model C - Calibration and Validation

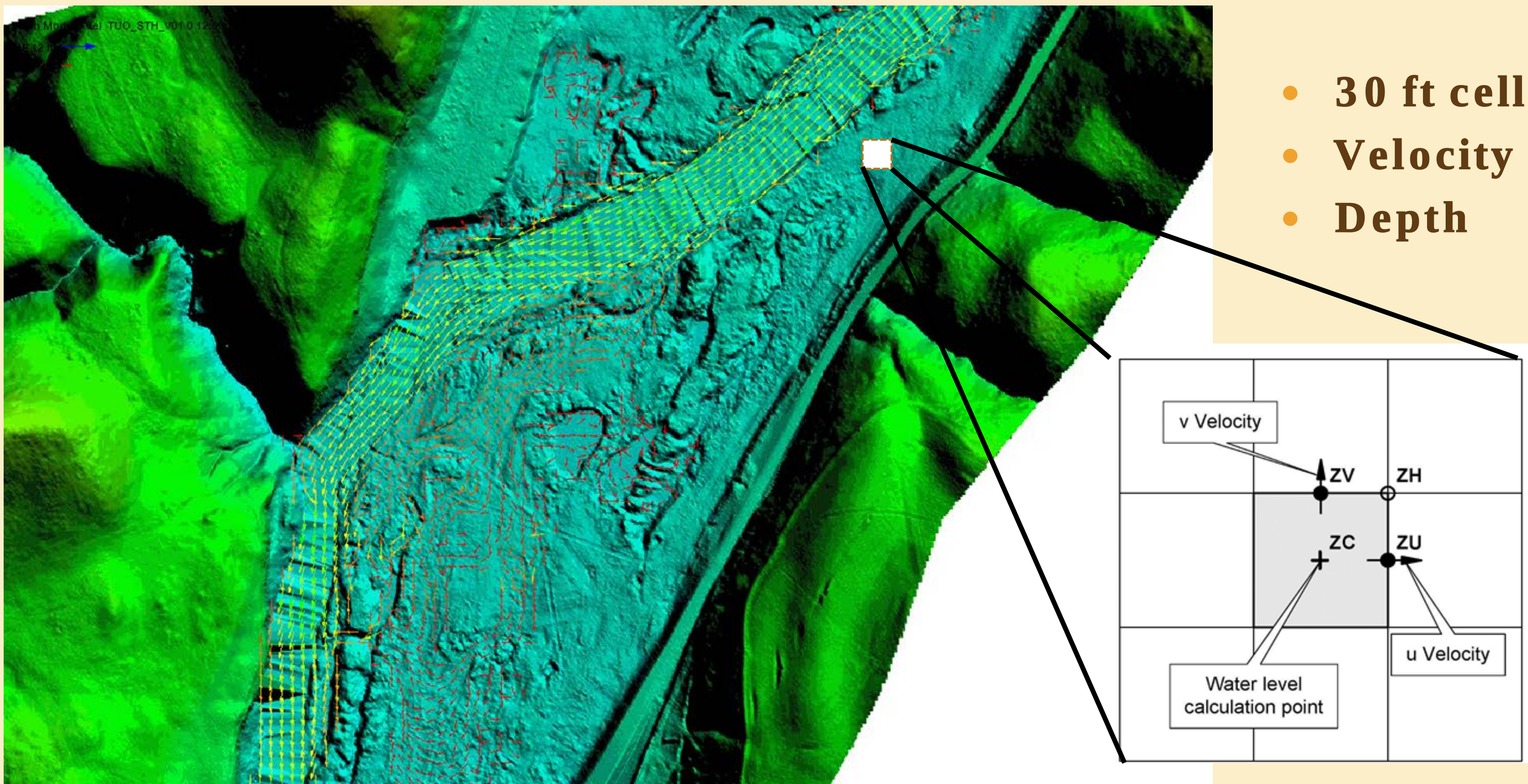


Models A, B & C - Results

- **Inundation Extents at various steady flows** (Animation)
  - **1000 to 3000 cfs @ 250 cfs interval**
  - **3000 to 9000 cfs @ 500 cfs interval**
- **Simulation of time varying hydrograph** (Animation)
  - **1000 to 9000 cfs and back to 1000 cfs**
  - **Shows flow paths, stranding potential etc.**

Habitat Analysis

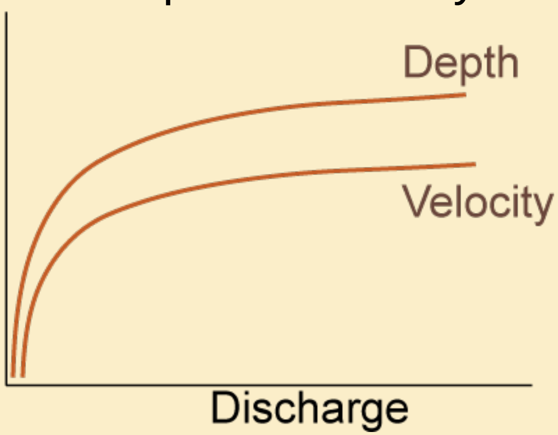
- **Cell-specific Velocity and Depth Predictions**

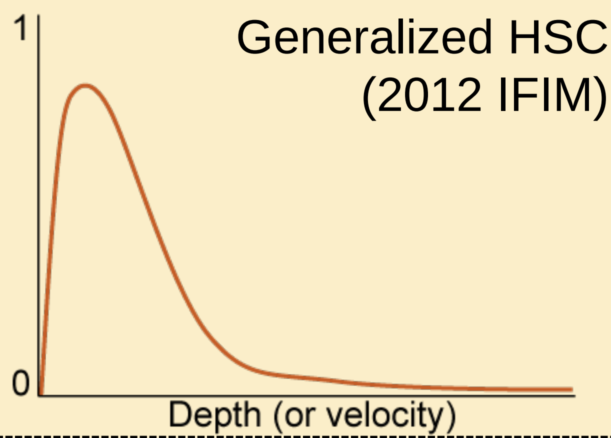


- **30 ft cell size**
- **Velocity**
- **Depth**

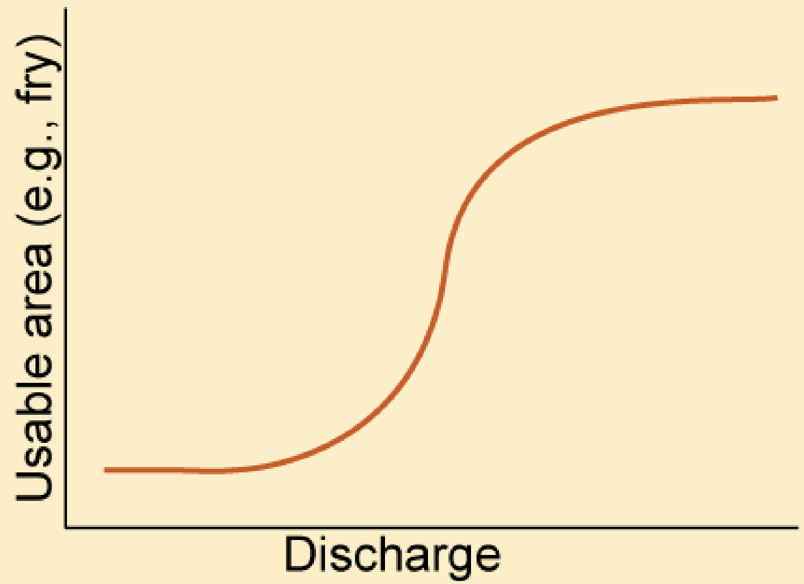
Habitat Analysis

Cell-specific Velocity and Depth



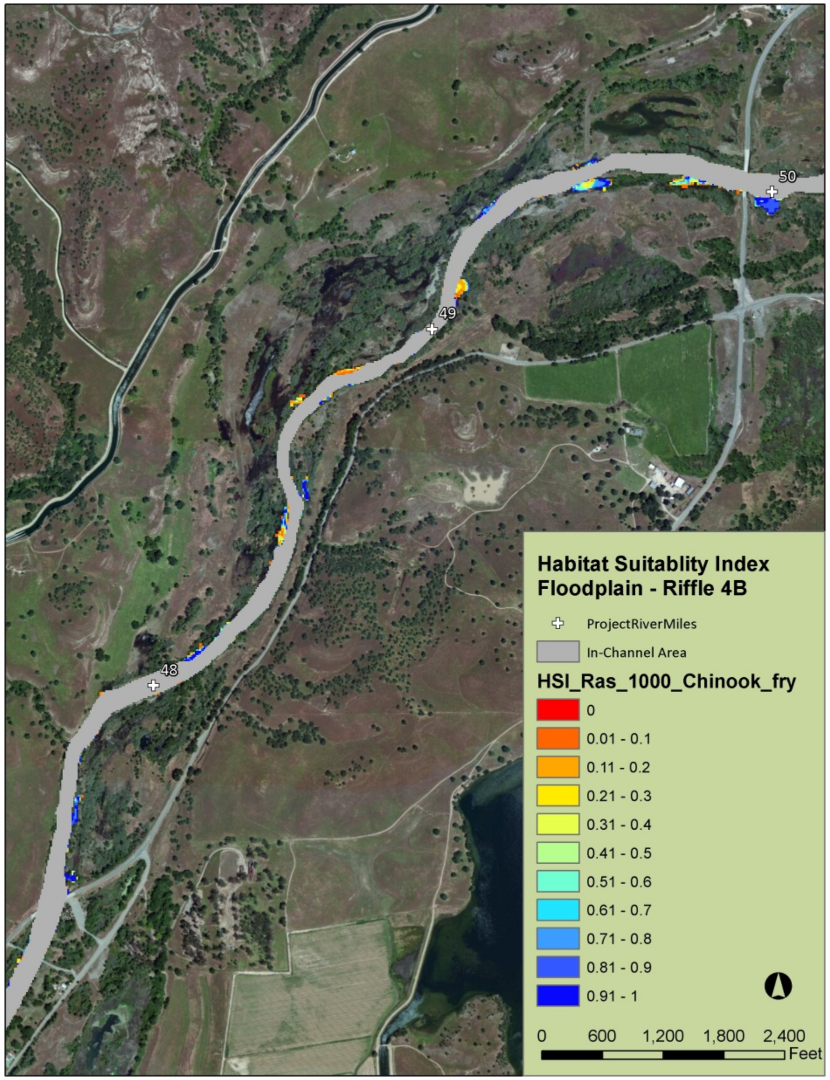


$$Area = \sum_{i=1}^{n} A_i \times HSC(depth, velocity)$$



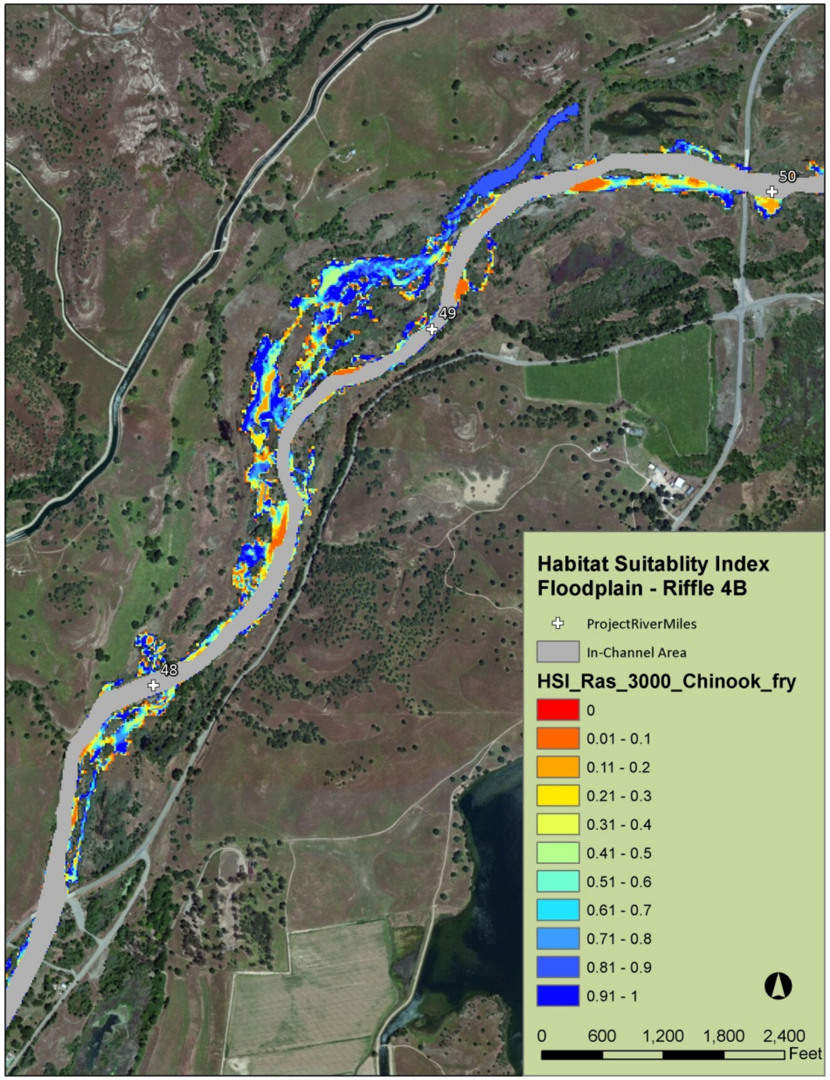
Habitat Analysis Results
Example at Riffle 4A/4B (RM 49)

- **Overbank habitat at 1,000 cfs**
- **Little floodplain inundation evident**



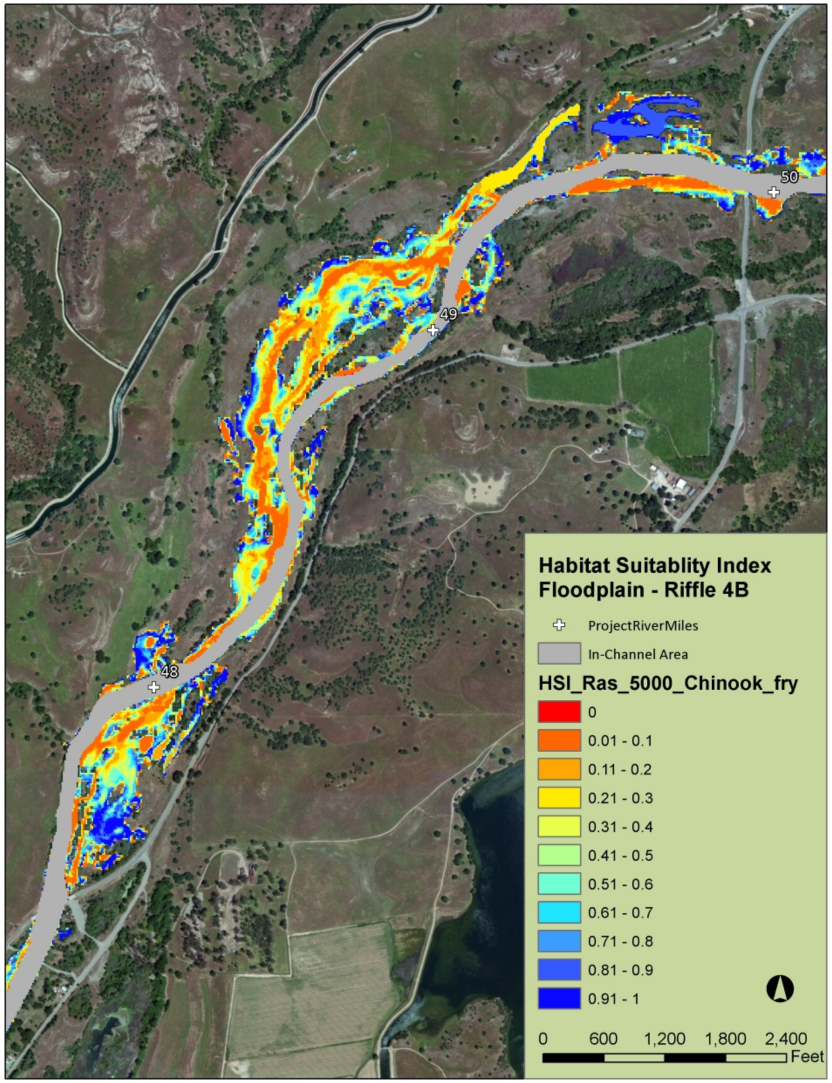
Habitat Analysis Results
Example at Riffle 4A/4B (RM 49)

- Overbank habitat at 3,000 cfs
- Inundation of side-channels and floodplain
- Chinook fry habitat suitability (0-100%) greatest in areas with low velocities



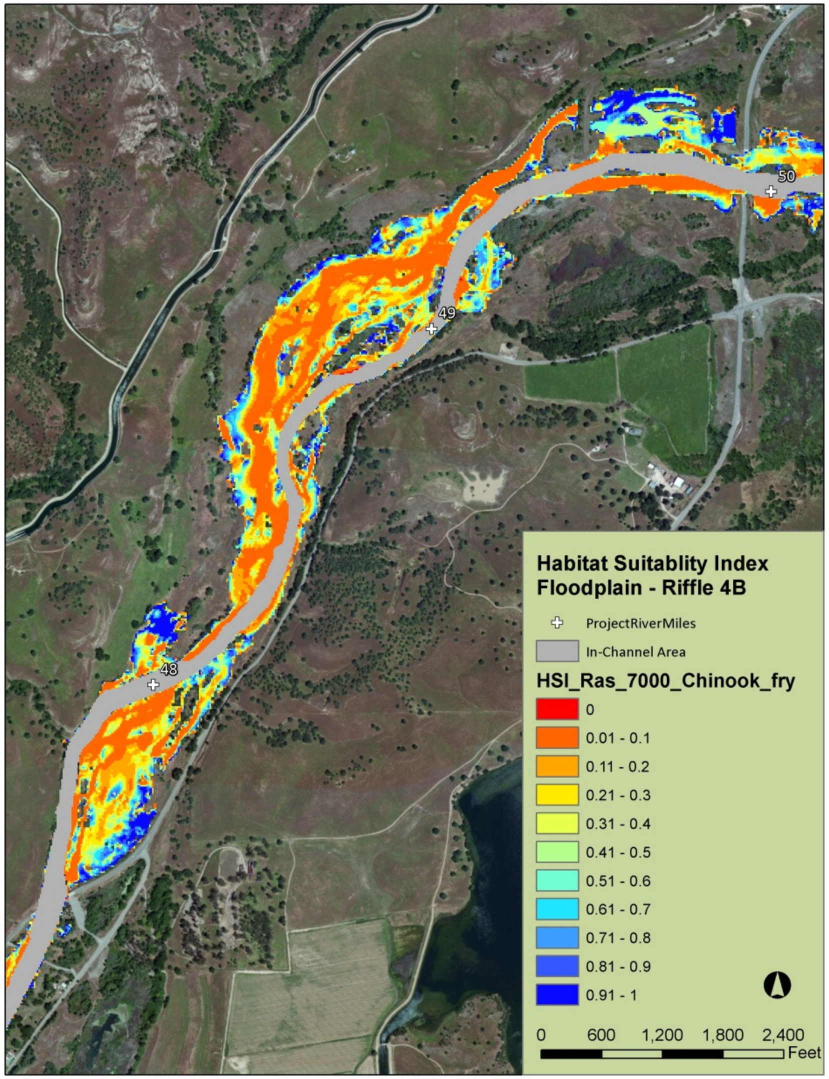
Habitat Analysis Results
Example at Riffle 4A/4B (RM 49)

- **Overbank habitat at 5,000 cfs**
- **Broad inundation of floodplain habitat**
- **Chinook fry habitat suitability (0-100%) greatest in areas with low velocities**



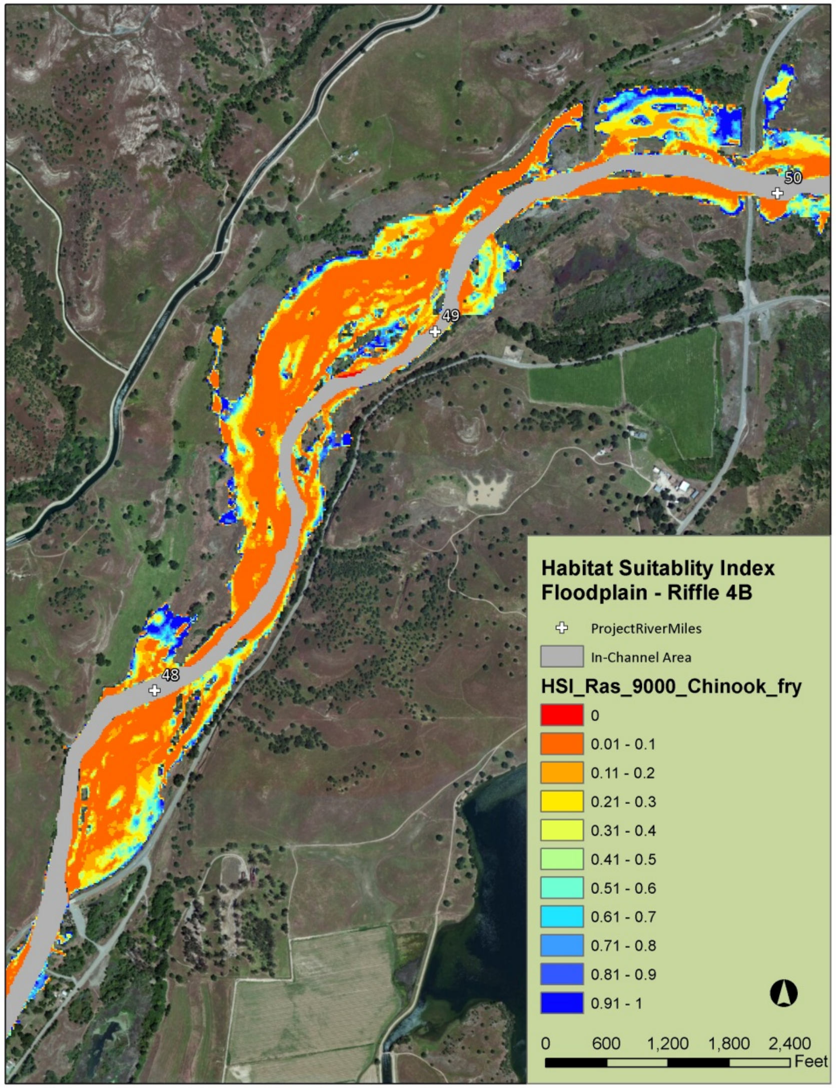
Habitat Analysis Results Example at Riffle 4A/4B (RM 49)

- **Overbank habitat at 7,000 cfs**
- **Broad inundation of floodplain habitat**
- **Chinook fry habitat suitability (0-100%) greatest in areas with low velocities**



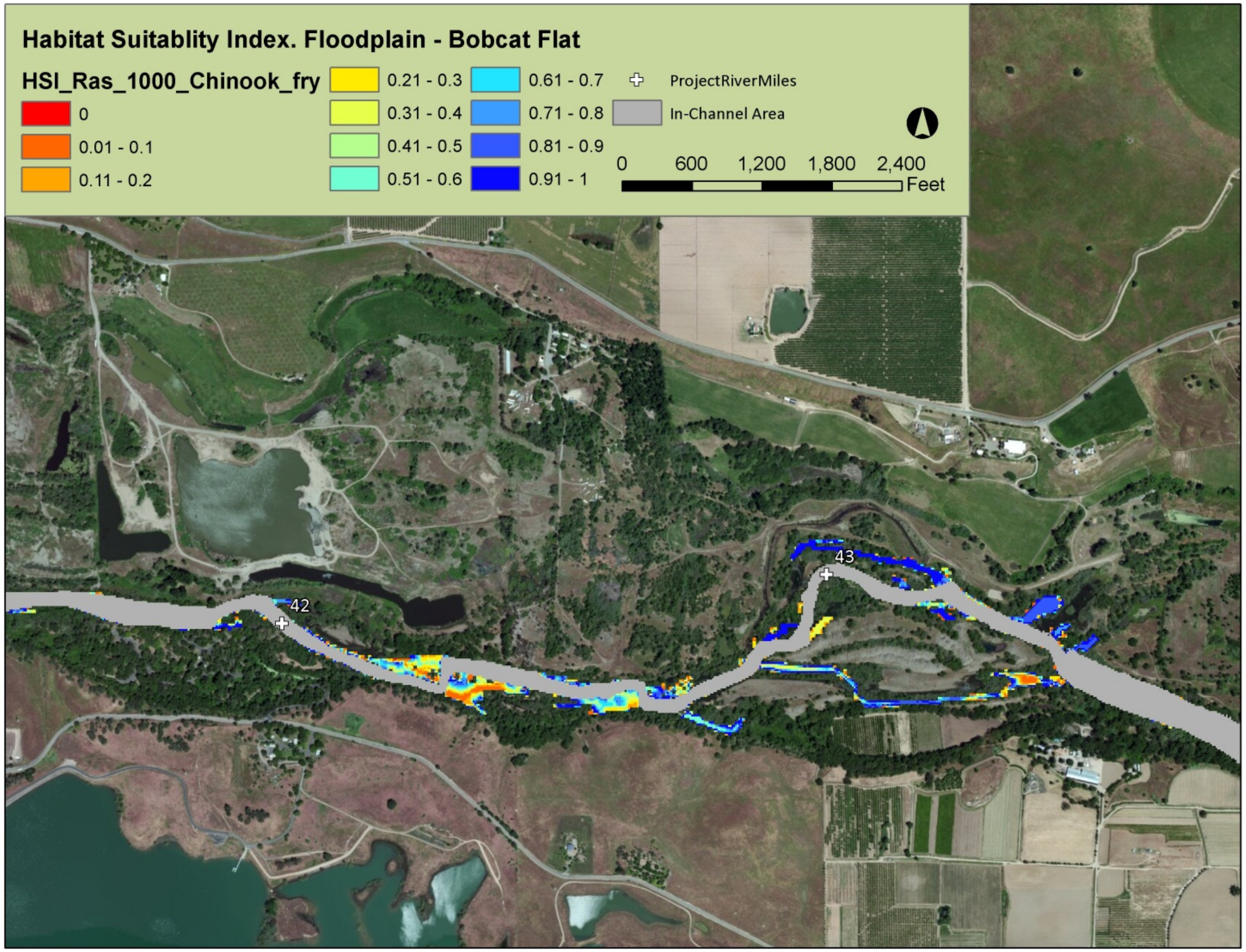
Habitat Analysis Results
Example at Riffle 4A/4B (RM 49)

- Overbank habitat at 9,000 cfs
- Broad inundation of floodplain habitat
- Chinook fry habitat suitability (0-100%) greatest in areas with low velocities



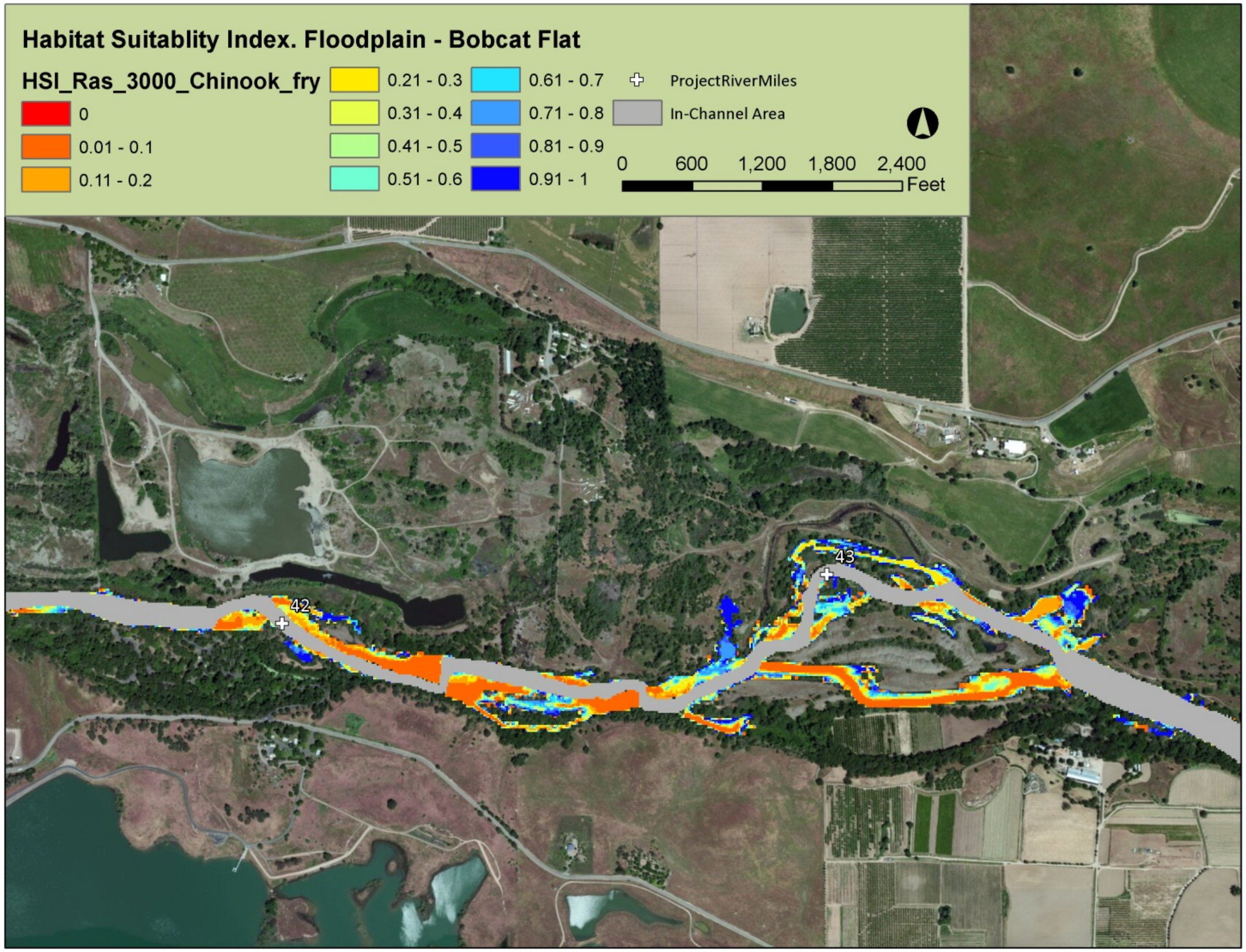
Habitat Analysis Results
Example at Bobcat Flat (RM 43)

- Overbank habitat at 1,000 cfs
- Some side channel and backwater habitat evident



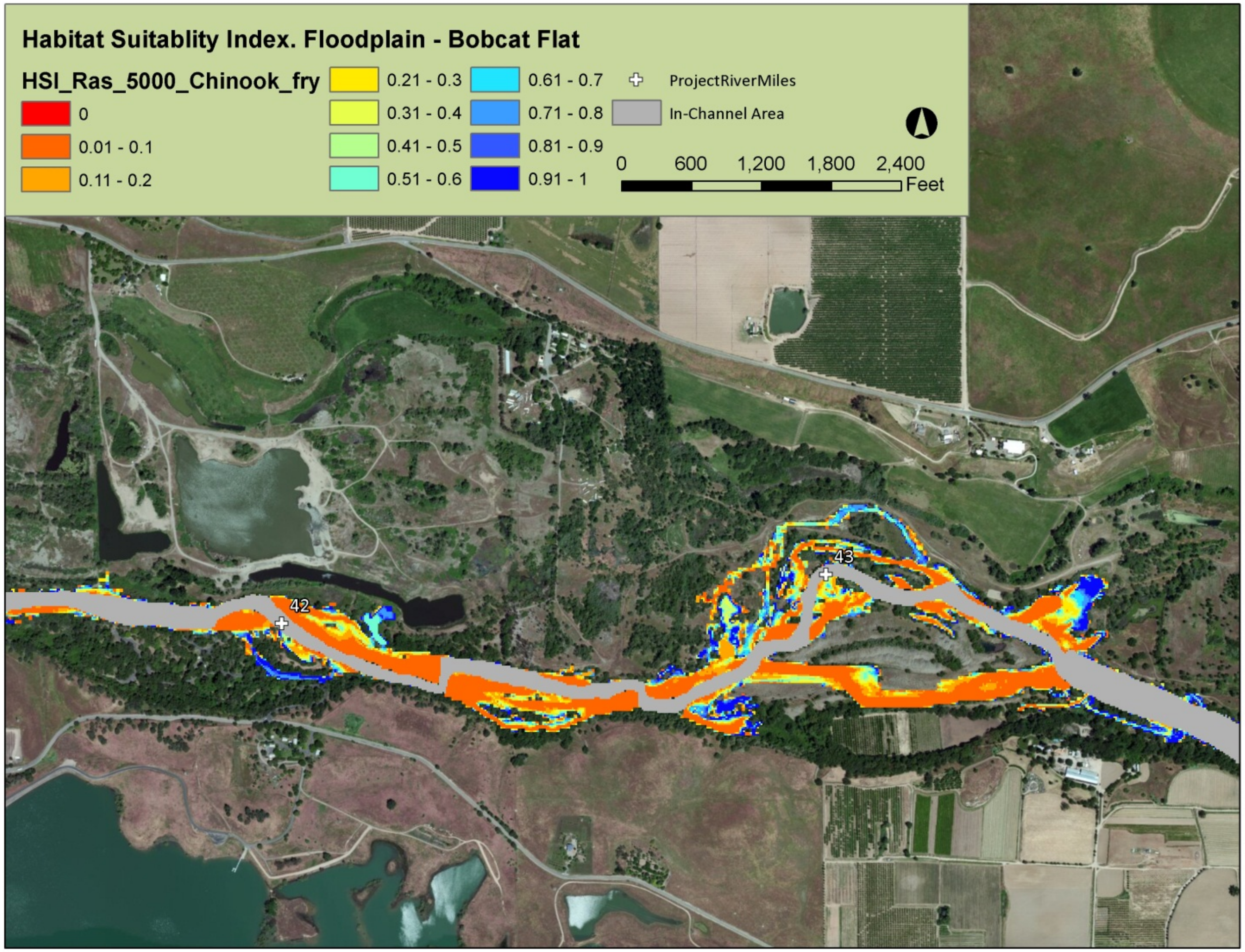
Habitat Analysis Results
Example at Bobcat Flat (RM 43)

- **Overbank habitat at 3,000 cfs**
- **Increasing depths and velocities at channel margins limit Chinook fry habitat suitability**



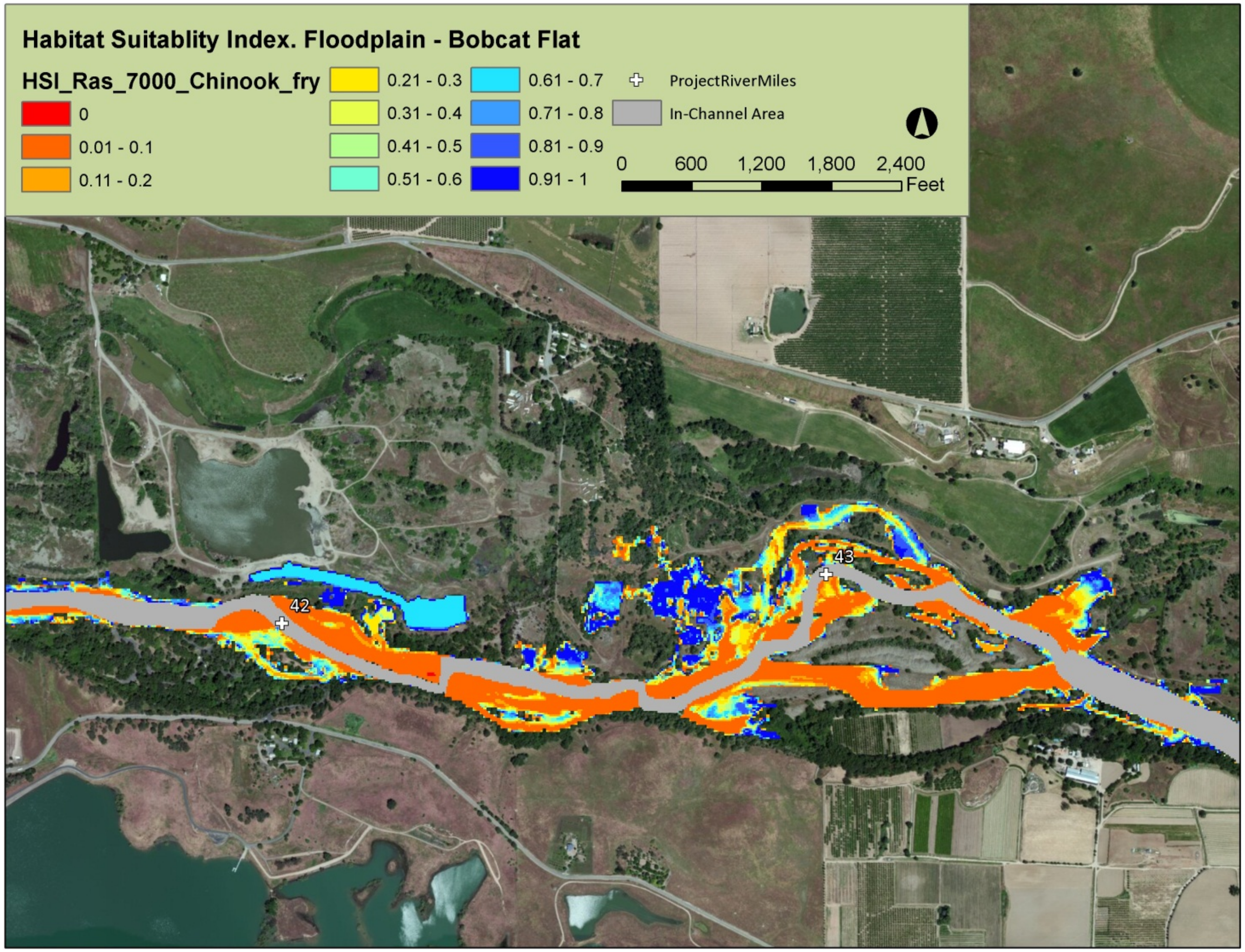
Habitat Analysis Results Example at Bobcat Flat (RM 43)

- **Overbank habitat at 5,000 cfs**
- **Increasing depths and velocities at channel margins limit Chinook fry habitat suitability**



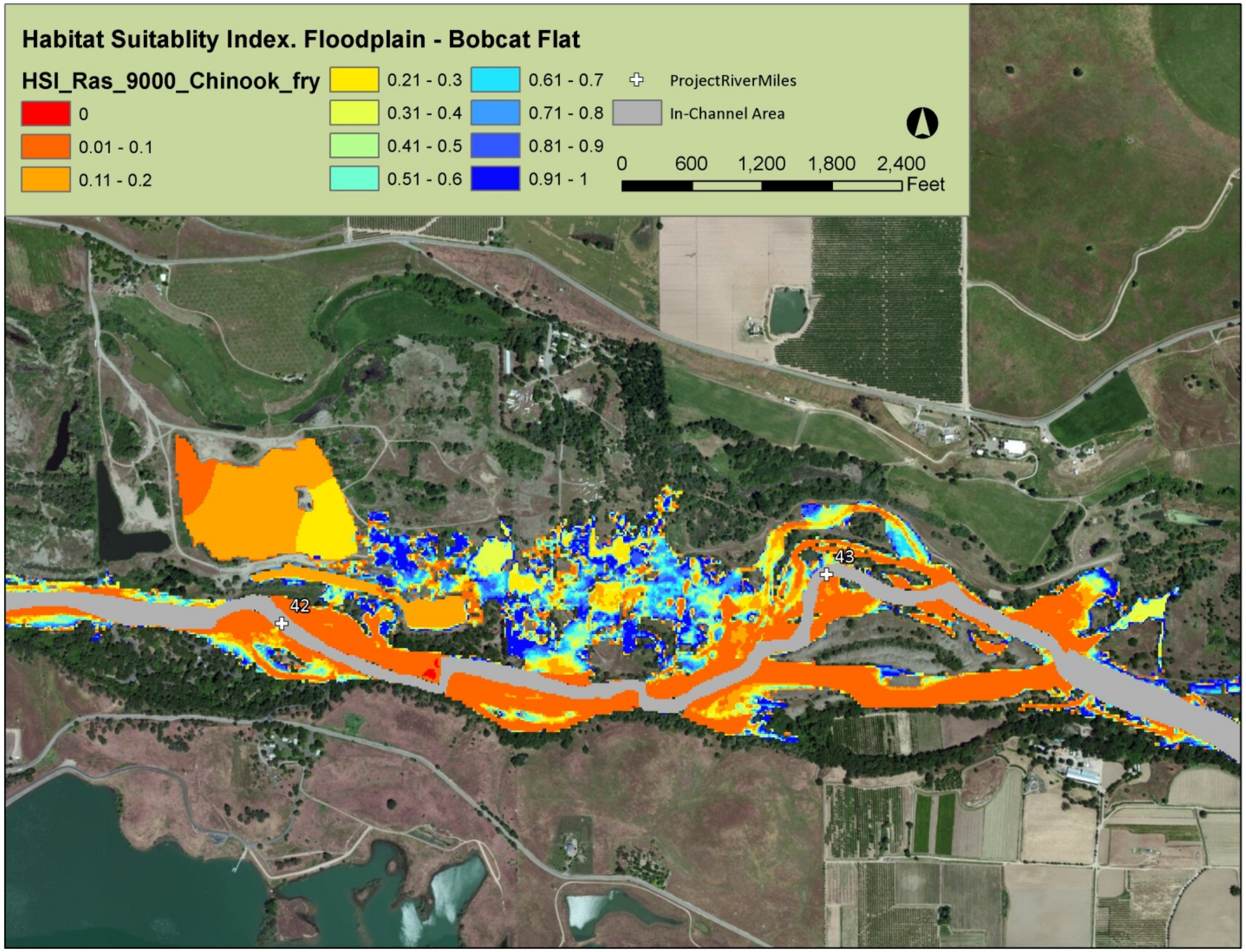
Habitat Analysis Results
Example at Bobcat Flat (RM 43)

- Overbank habitat at 7,000 cfs
- Floodplain inundation in tailings areas
- Chinook fry habitat suitability (0-100%) greatest in shallow areas and low velocities



Habitat Analysis Results
Example at Bobcat Flat (RM 43)

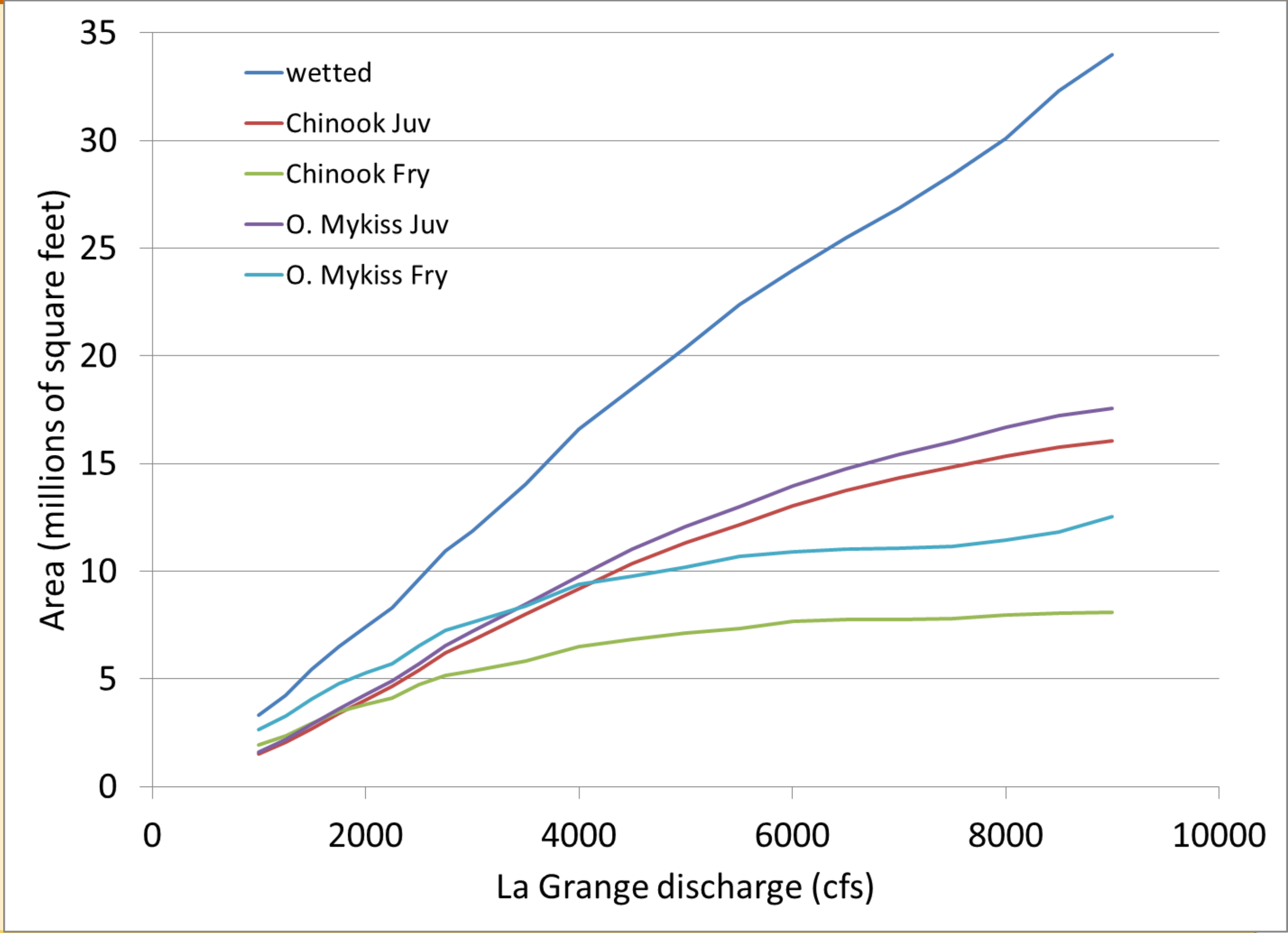
- Overbank habitat at 9,000 cfs
- Floodplain inundation in tailings areas
- Captured mining pit
- Chinook fry habitat suitability (0-100%) greatest in shallow areas and low velocities



Habitat Analysis Results
Model A

- **Approx. 60-80% of inundated area usable by Chinook and *O. mykiss* fry at the lowest flows modeled, falling to 30-40% at 9,000 cfs**

- **Approx. 50-60% of inundated area usable by Chinook and *O. mykiss* juveniles**



Area-Duration-Frequency Analysis

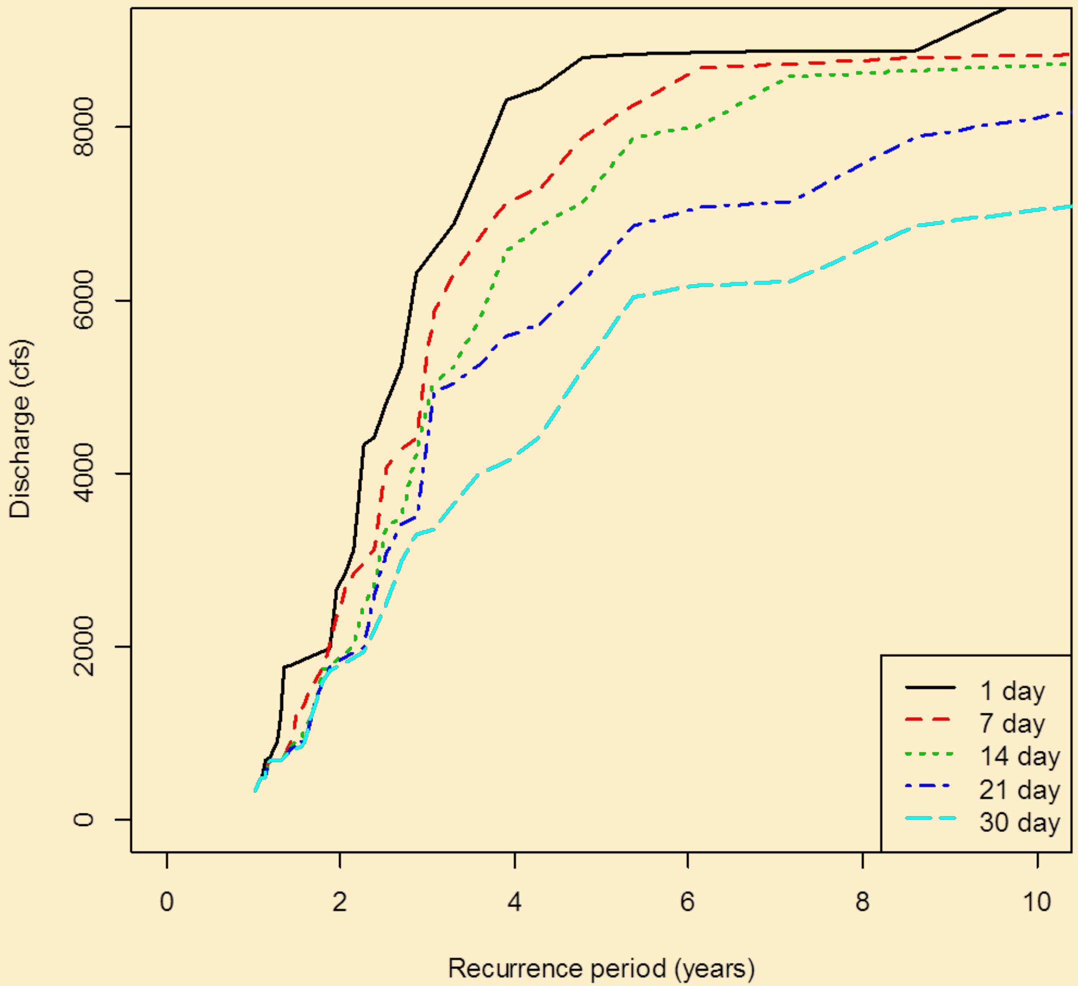
- Using Base Case hydrology (1971-2012), define floodplain inundation “events” by combinations of:
  - Duration (7, 14, 21, and 30 days)
  - Flow magnitude 1,000–9,000 cfs

- Calculate annual recurrence probabilities of each event (i.e., discharge and duration)

- Combine flow-duration frequency with TUFLOW and HSC analyses to show:
  - Total inundation area-duration-frequency (ADF)
  - Usable habitat ADF by salmonid life stage

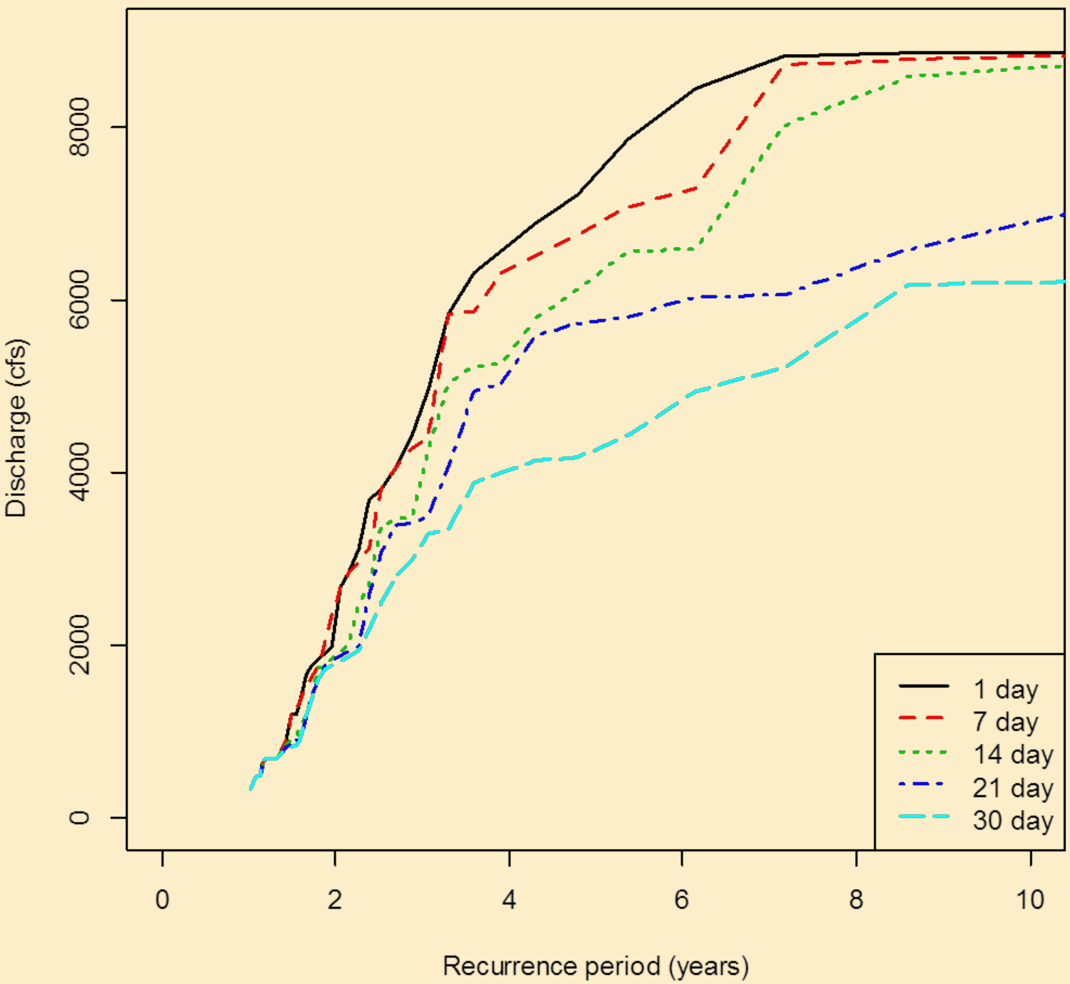
Flow Frequency Analysis Results

- **Base Case hydrology for 1971-2012**
- **Annual recurrence period for 1,000 – 9,000 cfs discharge**



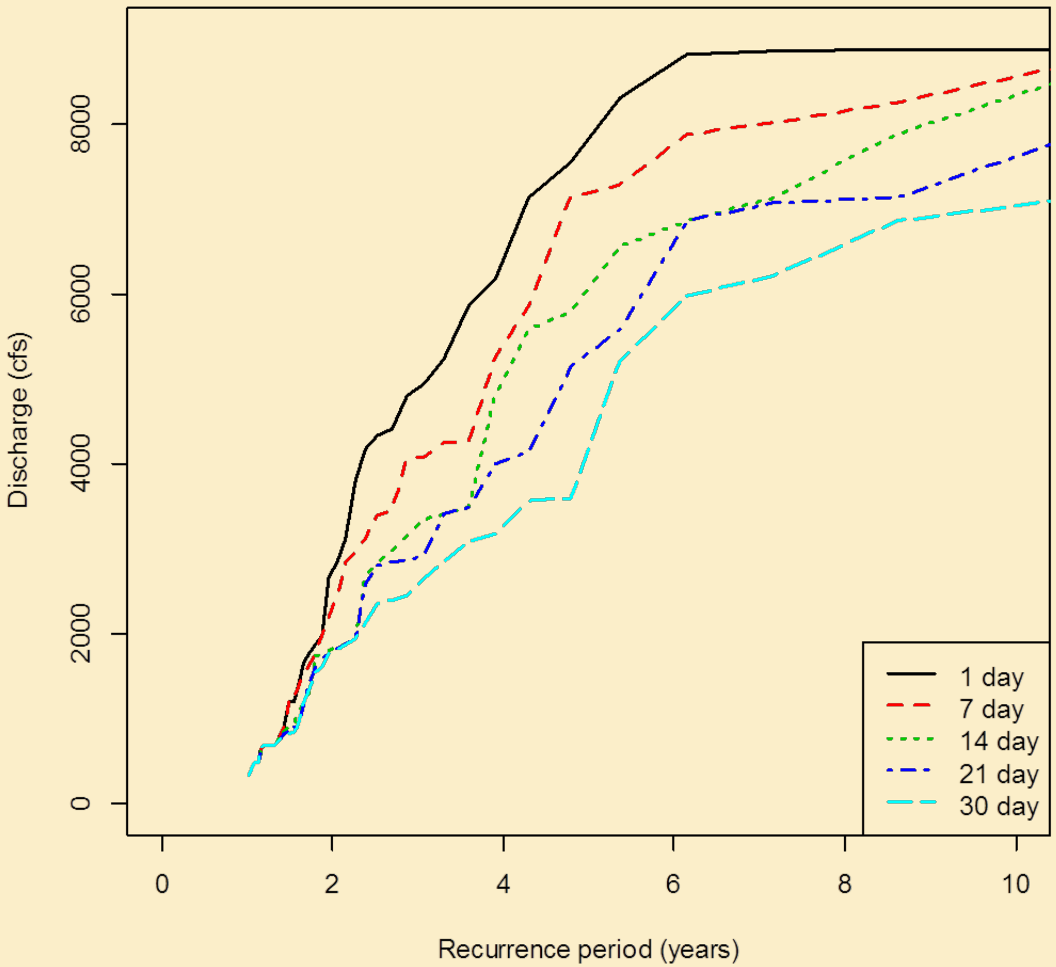
Flow Frequency Analysis Results

- **Base Case hydrology for 1971-2012**
- **Annual recurrence period for 1,000 – 9,000 cfs discharge between February and May**

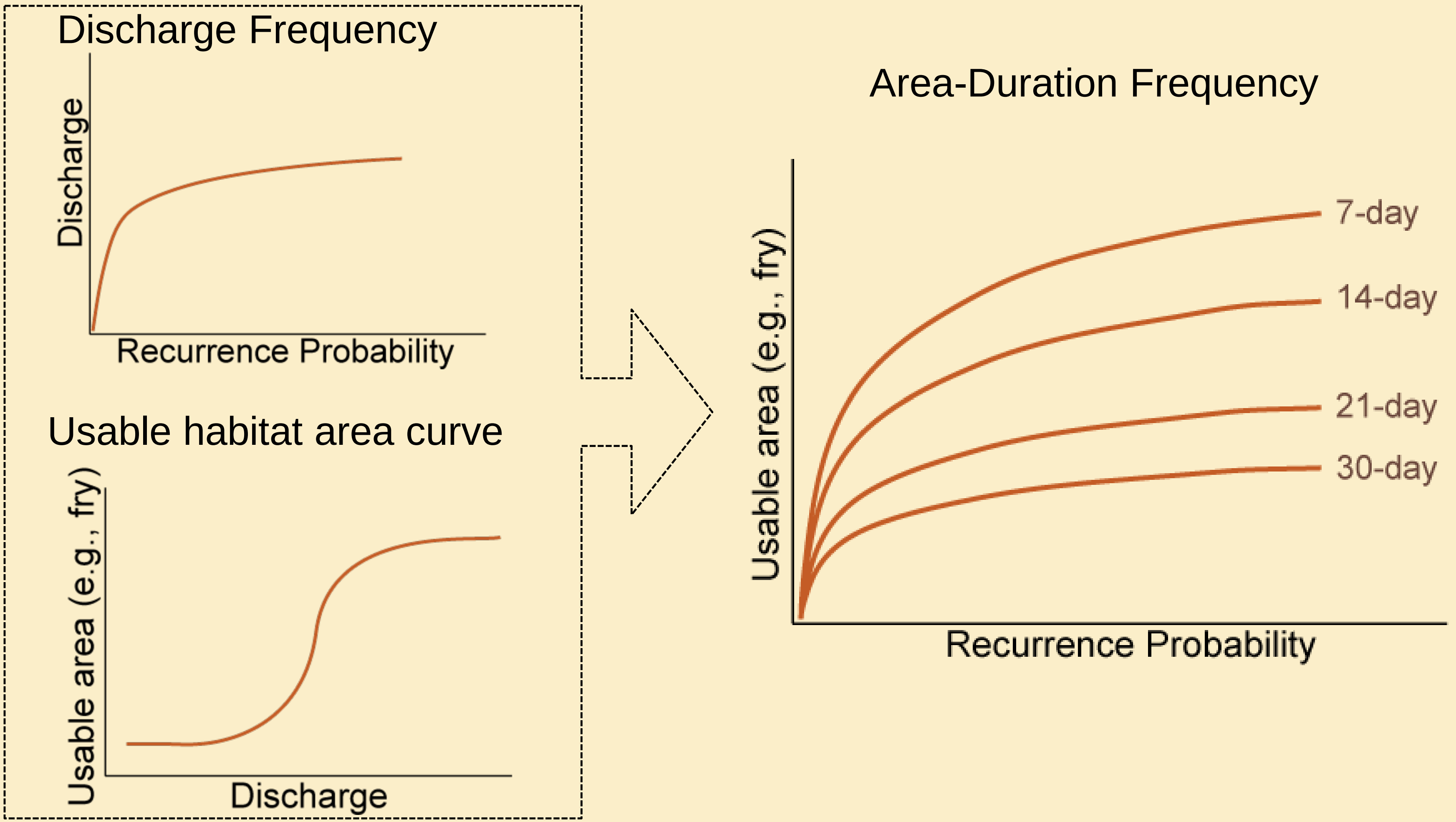


Flow Frequency Analysis Results

- **Base Case hydrology for 1971-2012**
- **Annual recurrence period for 1,000 – 9,000 cfs discharge between March and September**

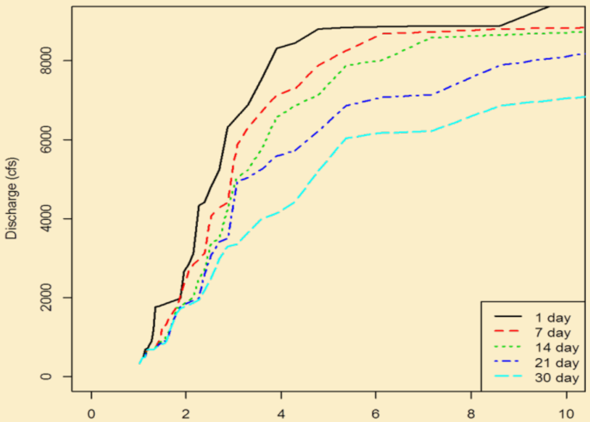


Area-Duration-Frequency Analysis

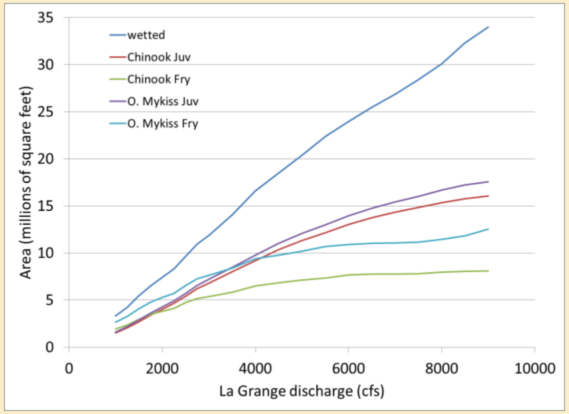


Area-Duration-Frequency Curves to Show Useable Habitat Area

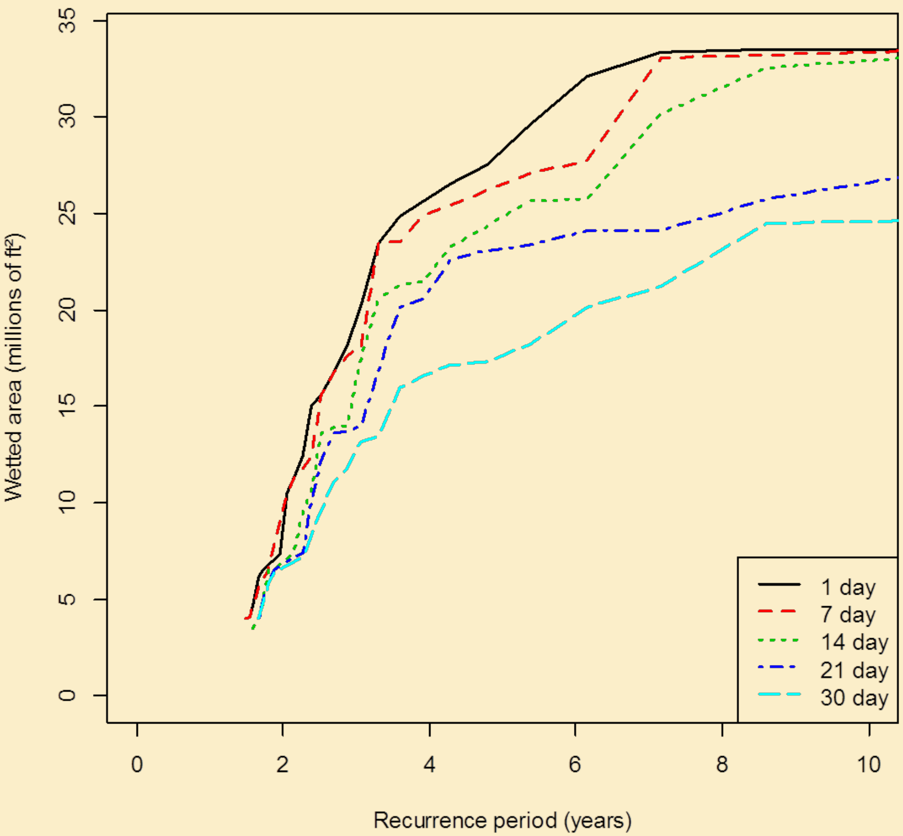
Discharge Frequency



Usable habitat area curve

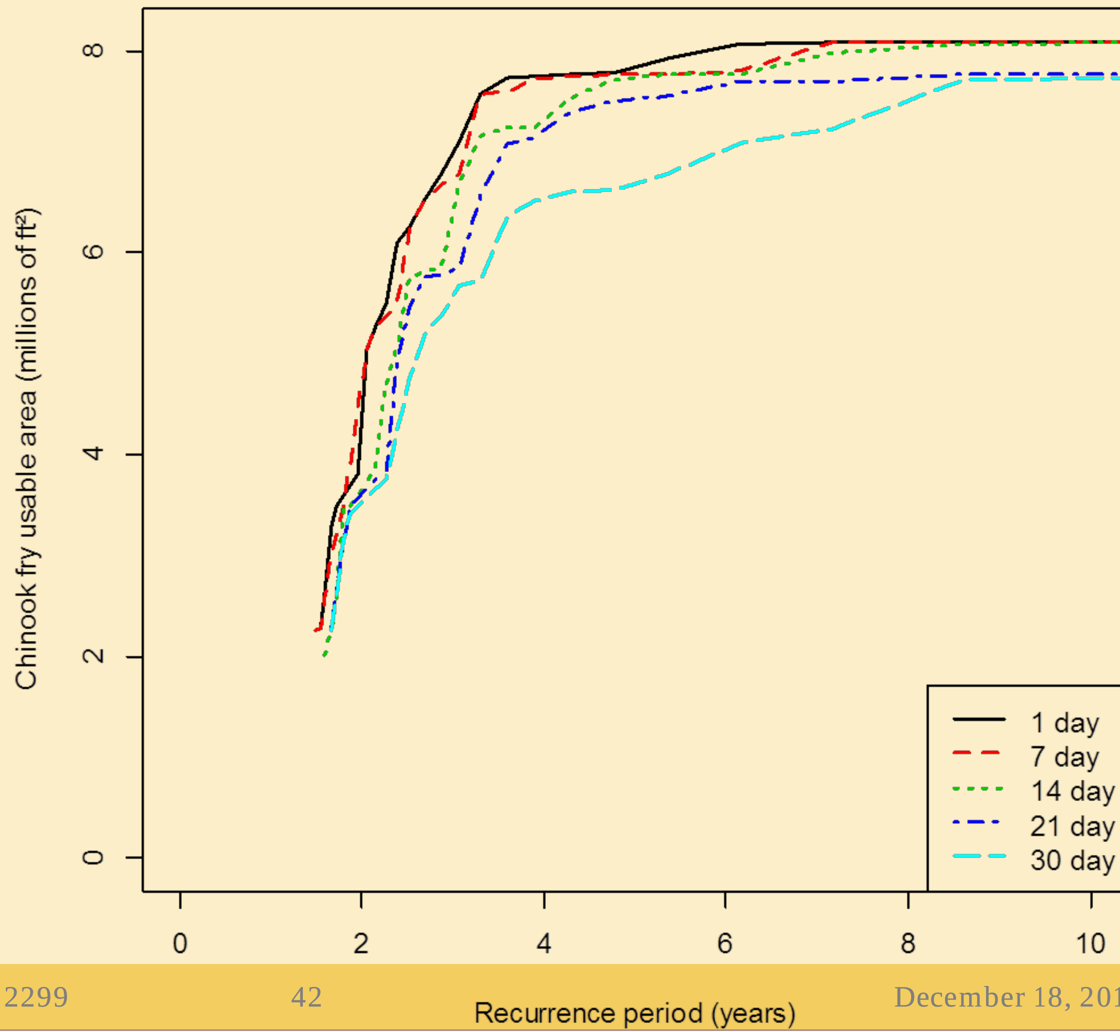


Area-Duration Frequency



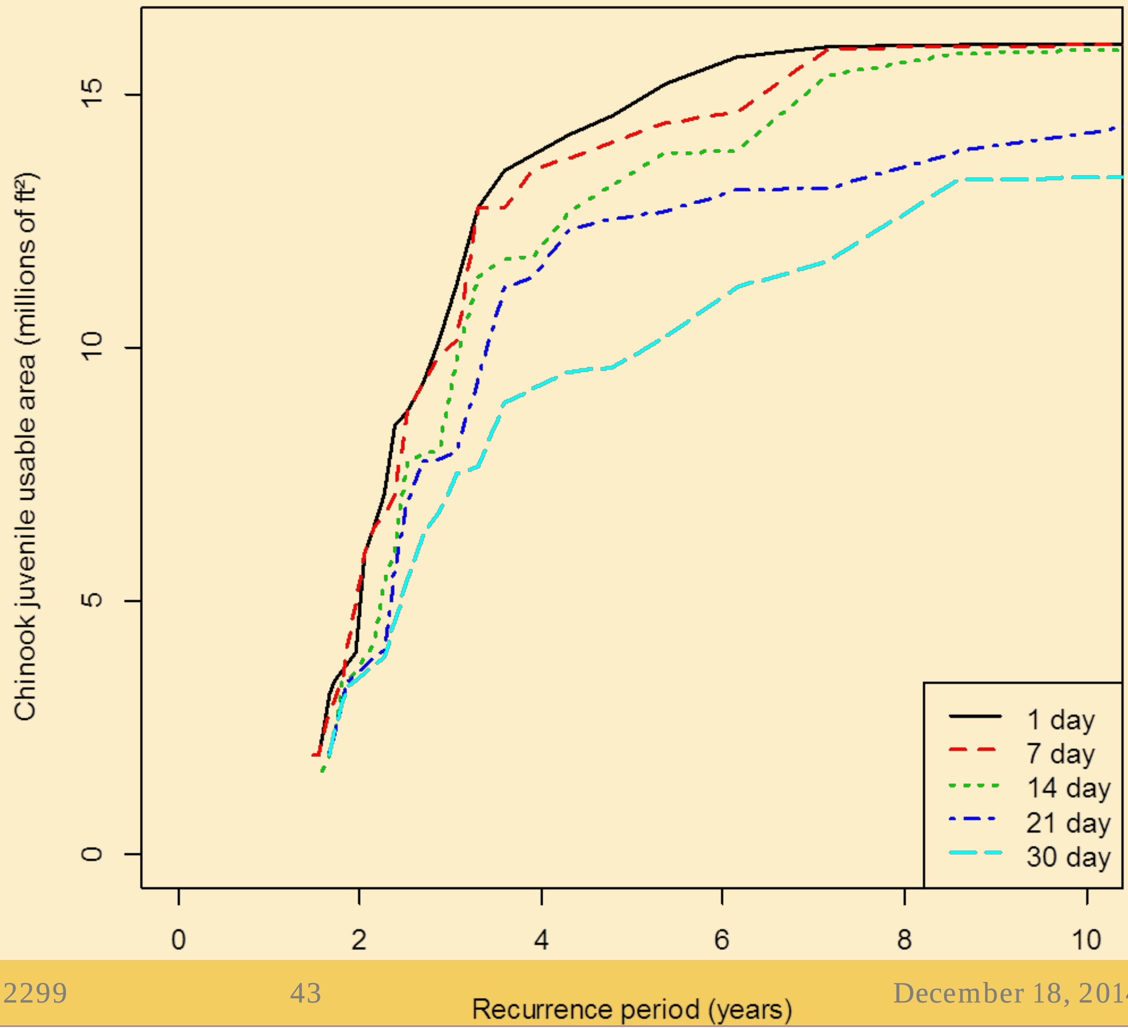
Area Duration Frequency Analysis Results for Model A

- **Base Case hydrology for 1971-2012 between *February and May***
- **Annual recurrence period for inundation of floodplain habitat for *Chinook fry***
- **Large increases in floodplain habitat inundation events (1, 7, 14, 21, 30 days) on a 2-3 yr recurrence period**



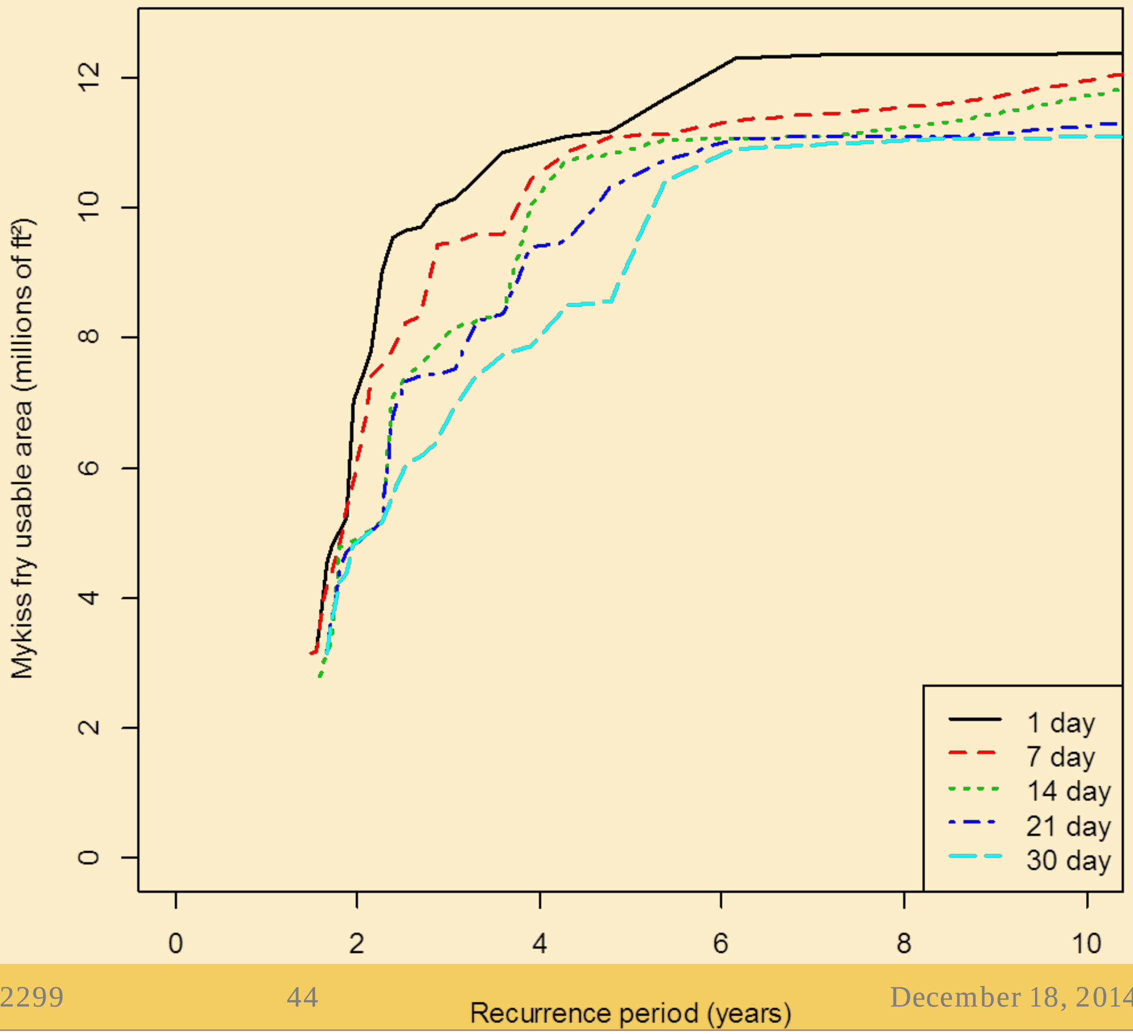
Area Duration Frequency Analysis Results for Model A

- **Base Case hydrology for 1971-2012 between *February and May***
- **Annual recurrence period for inundation of floodplain habitat for *Chinook juveniles***
- **Large increases in floodplain habitat inundation events (1, 7, 14, 21, 30 days) on a 2-3 yr recurrence period**



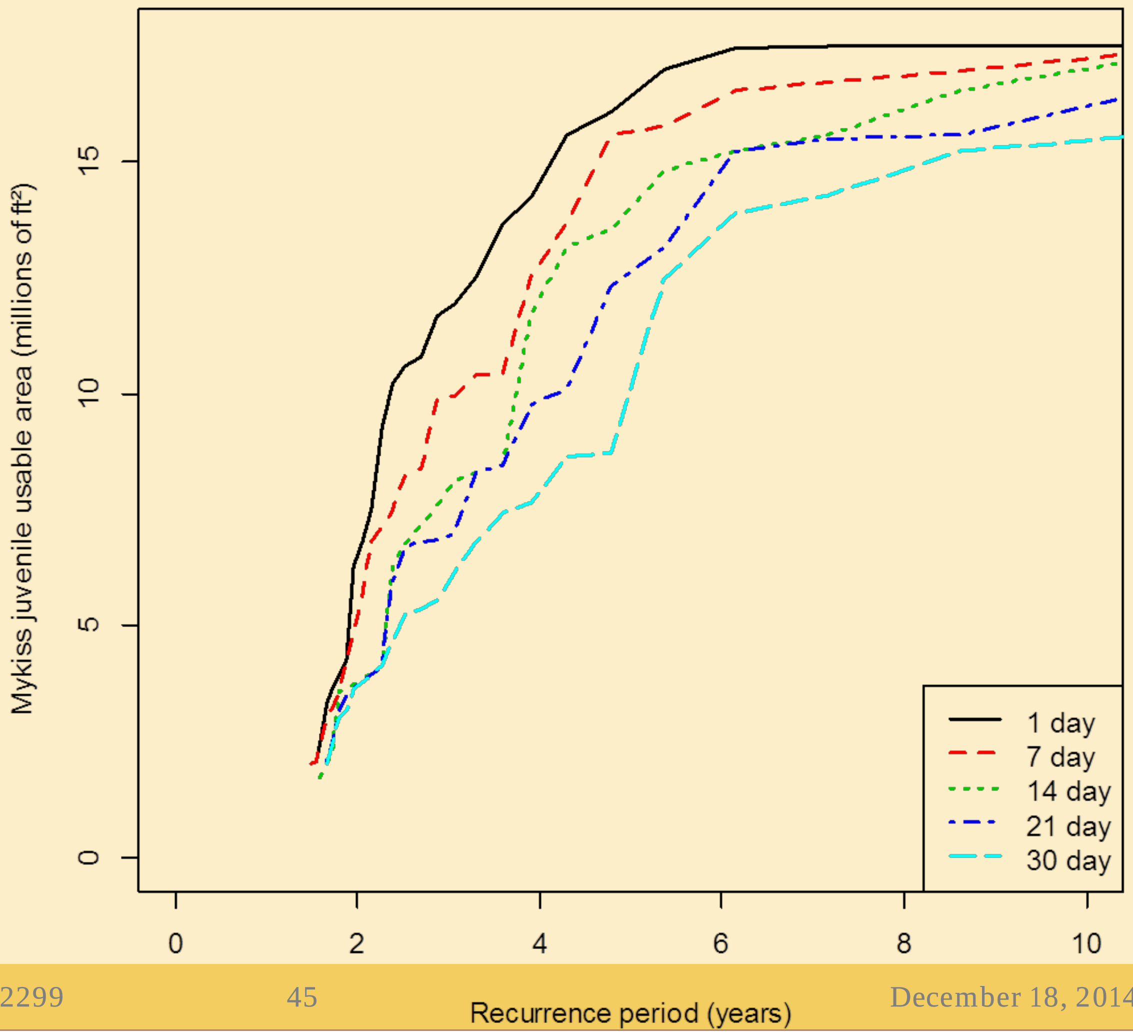
Area Duration Frequency Analysis Results for Model A

- **Base Case hydrology for 1971-2012 between *March and September***
- **Annual recurrence period for inundation of floodplain habitat for *O. mykiss fry***
- **Large increases in floodplain habitat inundation events (1, 7, 14, 21, 30 days) on a 2-3 yr recurrence period**



Area Duration Frequency Analysis Results for Model A

- **Base Case hydrology for 1971-2012 between *March and September***
- **Annual recurrence period for inundation of floodplain habitat for *O. mykiss juveniles***
- **Large increases in floodplain habitat inundation events (1, 7, 14, 21, 30 days) on a 2-3 yr recurrence period**



Habitat Analysis Summary

- **Model A – RM 52.2 to RM 40**
  - **Flows above bankfull discharge (1,500-2,000 cfs) associated with large increases in usable habitat for rearing Chinook salmon and *O. mykiss***
  - **For short duration events (e.g., 1, 7 days), approx. 200% increase in usable habitat area occurs between 1.5 to 2 year recurrence periods under the Base Case (WY1971-2012)**
  - **Longer duration inundation events lasting 14-days and occurring at a 4 year recurrence period are associated with usable habitat area increases on the order of 300%**
- **Models B and C to be provided with Draft study report**

Questions?

Photo Credit: Tuolumne River TAC

Floodplain Hydraulic Assessment Schedule

• Draft Report Preparation	November to December 2014
• Draft Report Provided to Relicensing Participants for 30-day review and comment	January 2015
• Relicensing Participant Comments Due	February 2015
• Final Report Filing with FERC	March 2015

APPENDIX C

RESPONSE TO DRAFT STUDY REPORT COMMENTS BY U.S. FISH AND WILDLIFE SERVICE

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RESPONSE TO DRAFT STUDY REPORT COMMENTS BY U.S. FISH AND WILDLIFE SERVICE

As part of the studies conducted in support of the Integrated Licensing Process (ILP) for the Don Pedro Hydroelectric Project (Project), the Turlock Irrigation District and the Modesto Irrigation District (collectively, the Districts), co-licensees of the Project, conducted a study to develop a hydraulic model for the lower Tuolumne River that simulates the interaction between flow within the main channel and the floodplain downstream of the La Grange Diversion Dam at River Mile (RM) 52.2 to the confluence with the San Joaquin River and to apply the model results to estimate floodplain juvenile salmonid rearing habitat. This study was undertaken in accordance with the FERC-approved (October 18, 2013) study plan. The draft report for W&AR-21 was provided to relicensing participants on September 3, 2015, for 30-day review. Comments on the draft report were provided on October 1, 2015 by the U.S. Fish and Wildlife Service (USFWS) and are repeated as excerpts in **bolded text below**, followed by comment responses. A copy of the USFWS letter is included at the end of this Appendix.

<u>Unimpaired Flows</u> (Fig 3.2-1 on page 3-4): "*…In order to interpret the effect of the Project on the floodplain, this graph should also present the flow exceedance curve for unimpaired flows*."

As stated in the October 18, 2013 FERC Study Plan Determination, "… an evaluation of pre-project flow conditions as requested by FWS would not inform potential license conditions (18 C.F.R Section 5.9(b)(5))."

<u>Modeling Resolution</u> (Page 4-3, 2nd complete paragraph): "*... cell size is at the wrong spatial scale relative to fry and juvenile habitat use, which is generally at a scale of one square foot. Because the data set does not support a one-foot scale, no PM&E measures should be based on this type of analysis of fry and juvenile habitat.*"

The Districts believe that selected cell size and resulting model resolution in their final report represents the best available science to address questions of floodplain habitat suitability in relation to flow. For comparison, the simplified wetted area vs flow relationships used in the older GIS-based study of the Tuolumne River (USFWS 2008) were published to assist in developing instream flow recommendations and yet provide no assessment of usable fry and juvenile habitat, let alone not meeting the 1-ft resolution requested by the USFWS commenter. Even assuming relevant habitat information is captured by simple aerial photo digitization, common mapping standard accuracy estimates (USGS Fact Sheet 171-99) at a photo scale of 1:24000 used in the GIS-based floodplain relationships are on the order of ± 40-ft, well above the 1-ft resolution discussed in the comment relative to Chinook fry and juvenile habitat use. In examining whether the requested modeling resolution has been used in other settings, the Districts found a contemporary 2D modeling effort on the Stanislaus River[1] which was implemented at a resolution of 1 m^2 (11ft^2), which is over ten times the requested resolution.

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[1] Bowen, M. D., M. Gard, R. Hilldale, K. Zehfuss, and R. Sutton. 2012. Stanislaus River Discharge-Habitat Relationships for Rearing Salmonids. Prepared for Central California Area Office, Bureau of Reclamation, Folsom, California

As detailed above, the Districts are unaware of any 2D-modeling studies across as large a model domain as the 52-mile lower Tuolumne River corridor that were implemented at the requested resolution. For the modeling effort in the current study, the computational tradeoffs between reduced cell size, simulation times, and accuracy was discussed with the aid of supporting model simulations presented during Workshop No. 1 on February 13, 2014. Because the alluvial topography of the lower Tuolumne River floodplain does not appear to be hydraulically complex, a decision was made to conduct sensitivity testing which demonstrated little to no differences in predicted areas of suitable habitat across a range of TUFLOW model cell sizes from 10 to 50 ft. On March 4, 2014, draft meeting notes for Workshop No. 1 were provided to relicensing participants, including USFWS, for review and comment. No comments were received about the preferred cell size, or any other subject presented. Final meeting notes for Workshop No. 1 (included as Attachment A of this report) were later distributed to USFWS and other relicensing participants by e-mail on July 17, 2014. Again, no comments were received. Details of the sensitivity analysis presented at Workshop No. 1 are also provided in Attachment B of the study report.

<u>Modeled Study Reach Extent</u> (Page 4-3, Section 4.1.4): "*... analysis needs to be completed with the lower 0.9 miles included, in order to be consistent with the Study Plan*."

The approved Study Plan stated that the Tuolumne River would be modeled from La Grange Diversion Dam (RM 52.2) to the Tuolumne River confluence with the San Joaquin River. The exact location of the confluence is dependent on the flows in each river. To allow results comparisons for all modeled flows, the downstream model boundary was placed at RM 0.88 to represent the Tuolumne River confluence within the San Joaquin River floodway at the highest flows modeled (9,000 cfs). More specifically, during high flow periods the flow direction, depths, and velocities downstream of RM 0.88 are controlled by conditions in the San Joaquin River floodway. No topographic breaks allow for clear separation of the Tuolumne River from the San Joaquin River floodplain habitat in this area and the TUFLOW model does not support more than one downstream model boundary location, thus, the 9,000 cfs model boundary at RM 0.88 was used for all flows modeled. The completed model is consistent with the approved Study Plan.

<u>Modeling Assumptions</u> (Section 4.1.8.2, Page 4-7): "*Assigning ponds, backwater areas and side channels bed elevations of 0.2 feet below the water surface elevation at the time the LiDAR was flown is adequate for simulating the total amount of inundated floodplain area as a function of flow, but ... is expected to greatly over-predict the amount of fry and juvenile habitat, no PM&E measures should be based on this analysis.*"

As summarized in Table 4.1-2, significant hydraulically connected features such as side channels and backwaters included detailed bathymetric data, and did not use a 0.2-ft depth assumption. While this depth assumption was reserved for ponds with little or no connectivity to the main channel, it is recognized that deeper pool habitats are generally unsuitable for fry and juvenile salmonids. Although the amount of ponded habitat makes up only a small proportion of inundated floodplain, the Study Report has been revised to exclude these areas from the final usable habitat area estimates.

<u>Methods Description</u> (Page 4-13): "*It is not clear whether this analysis considered a constant San Joaquin River flow upstream of the Tuolumne River. If a constant San Joaquin River flow was used, it should be reported with an explanation of how the chosen flow was determined.*"

Attachment E of the draft report provides an analysis of backwater effects in the lower Tuolumne River and considered a range of Tuolumne and San Joaquin River flows to develop a statistical relationship between flows in the two rivers. Table 4 of Attachment E shows the stage versus discharge rating curve developed for the downstream boundary condition. Attachment E of the draft report contains a detailed analysis of how it was developed and the sensitivity of the model to the assumptions.

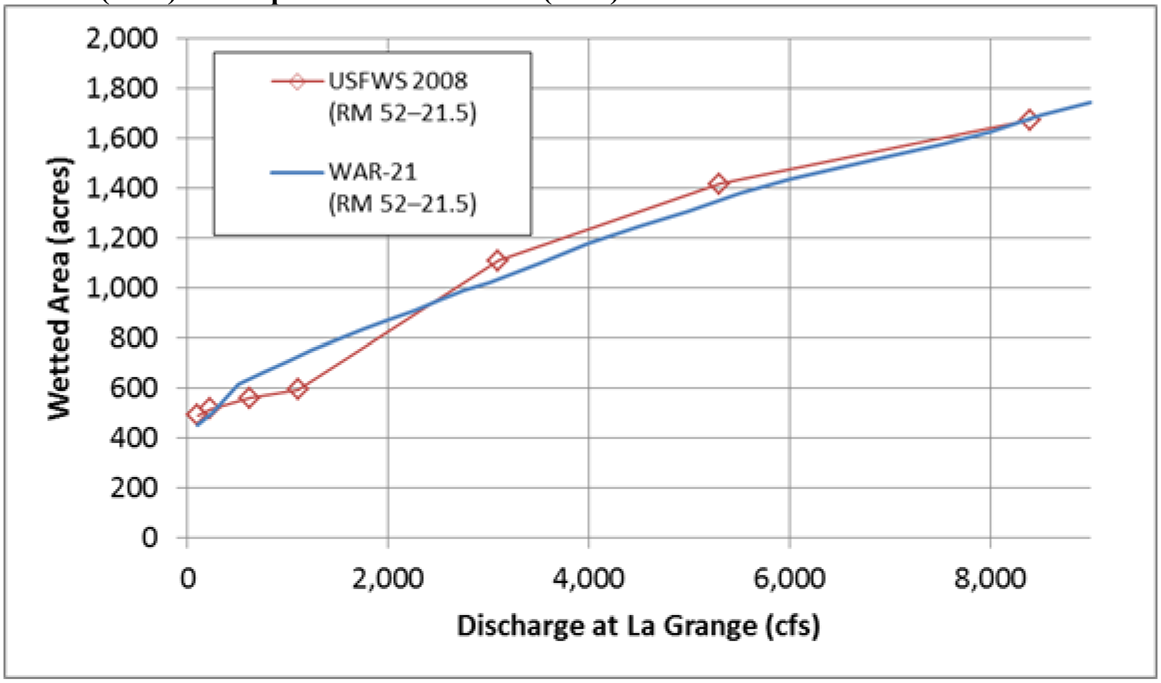
<u>Modeled Floodplain Surfaces in comparison to USFWS (2008)</u> (Section 5.2.1, Page 5-1): "*Areas within isolated portions of the floodplain created by topographic depressions, backwater areas and ponds that were inundated at the lowest flows modeled should be subtracted from the total floodplain area, because they would be perennially inundated off-channel areas, which would not be considered floodplain habitat (USFWS 2014).*"

The Districts compared inundation areas predicted by the completed TUFLOW model and those reported by USFWS (2008) and there do appear to be some differences at the 1,000 cfs level. These apparent differences may be related to isolated areas (e.g., ponds and mining pits) that were clipped out of the GIS shape files in the USFWS report. The Study Report has been modified to exclude these ponded features, resulting in approximately 30% lower usable habitat estimates at the lowest (1,000 cfs) flows modeled when compared to those presented in the Draft Study Report.

<u>Modeled Floodplain Surfaces in comparison to USFWS (2008)</u>(Section 5.2.1, Page 5-2): "*We would have expected that the floodplain delineation from the two reports would be similar for the area in common, because the U.S. Fish and Wildlife Service (2008) assumed that floodplain inundation started at 1,100 cfs, and this report used the 1,070 cfs inundation extent to delineate overbank versus in-channel areas.*"

The Districts have conducted a comparison of the TUFLOW model results with the older USFWS (2008) GIS based estimates corresponding to digitized aerial imagery previously developed by the Districts in the 1990s (TID/MID 1997, Report 96-14). As stated above, there do appear to be some differences at the 1,000 cfs level but the estimates of total inundated area converge at higher flows likely due to reconnection of areas isolated at lower flows (e.g., ponds and mining pits) . The Study Report has been revised to exclude these areas from the usable habitat area estimates. Recognizing that total inundated area is a poor and misleading proxy for actual habitat use by Chinook fry and juveniles or population level benefits of floodplain inundation, the comparisons shown in Figure 1 below across the common reach (RM 52–21) show the two methods are in general agreement, at least with respect to the flow versus wetted area relationship.

Figure 1. Estimates of total wetted area versus flow from GIS analysis of aerial photos in USFWS (2008) as compared with TID/MID (2015) TUFLOW simulations.



<u>Use of Wetted Area vs Usable Habitat Area estimates (</u>**Section 5.2.2, Page 5-2): "*Total floodplain area should be used to develop PM&E measures, rather than fry and juvenile habitat ... for the following reasons: (1) issues raised above concerning cell size and bed elevations of ponds, backwater areas and side channels; (2) the 0.5 foot accuracy of LiDAR data, which can result in significant errors in fry habitat suitability, which can vary substantially with 0.5 foot variations in depth; (3) LiDAR data in areas with heavy ground vegetation, such as blackberry bushes, having elevations that are biased high due to the last return being from vegetation rather than the ground; (4) the lack of cover data to use in calculating fry and juvenile habitat; and (5) the lack of habitat use data from floodplains. With regards to the last item, fry and juvenile may use quite different microhabitat characteristics on floodplains, versus from in-channel areas. In addition, inundated floodplains provide many benefits for fry and juvenile salmonids beyond habitat. Specifically, prolonged flooding affects fry survival by providing autochthonous food resources, providing refuge from predators, reducing water temperatures particularly during downstream migrations in May and June, slowing the rate of disease infestation, diluting contaminants, and reducing entrainment (Mesick et al. 2008).*"**

Although the completed TUFLOW model may be used to report on either total wetted area or usable habitat, we disagree with the USFWS assertion that total floodplain area should be used to develop PM&E measures. Concerns regarding cell sizes and assumed bed elevations of off-channel habitats (Item 1) are fully addressed above. The remaining items raised in the comment above are addressed in the paragraphs below.

1. The vertical accuracy of the LiDAR data is estimated to be 0.15 ft (root-mean-squared)(see section 4.1.2), not 0.5 ft as suggested in the comment. There is broad agreement between

the current TUFLOW estimates and the GIS based USFWS (2008) estimates. This only further supports that there is no reason to suspect model bias regarding estimates of usable habitat.

2. Given the predominance of grassland and oak chaparral vegetation on the floodplains, concerns regarding LiDAR returns in dense vegetation are overstated as there is broad agreement between the current TUFLOW estimates and the GIS based USFWS (2008) estimates discussed above.

3. Because collection of cover data across the 52-mile model domain was considered infeasible during study planning, usable habitat estimates were made based on existing Tuolumne River habitat suitability criteria for depth and velocity, as described in the approved Study Plan.

4. Although collection of habitat use data is an approach to site-specific validation of habitat suitability criteria in instream flow studies, such surveys are not a component of every instream flow study. Extensive effort was made to develop consensus regarding the habitat suitability criteria in the Tuolumne River IFIM Study, including intensive snorkel surveys used to develop site-specific suitability criteria for Chinook salmon fry, as well as for validation of suitability criteria for other juvenile salmonid life stages (Stillwater Sciences 2013). No objections were raised by USFWS or any other party on the suitability criteria proposed to be used by the present study during the study planning phase.

Lastly, it should be noted that none of the generalized benefits of floodplain inundation attributed to Mesick et al (2008) are based on data from the Tuolumne River or other tributaries to the San Joaquin River. As documented in information reviews conducted for the *Salmond Population Information Integration and Synthesis Study* (TID/MID 2013e) and prior site-specific studies on the Tuolumne River, including juvenile health studies conducted by the USFWS[2,3], the commenter is misinformed about conditions on the Tuolumne River when it implies that several cited factors (e.g., disease, contaminants, entrainment, food supplies) are currently negatively impacting juvenile rearing of Chinook salmon within in-channel or overbank habitats. In any event, because the study objectives in the approved Study Plan were limited to examination of the seasonal timing and duration of suitable overbank rearing habitat, the issues raised in this comment do not invalidate

[2] Nichols, K., and J.S. Foott. 2002. Health monitoring of hatchery and natural fall-run Chinook salmon juveniles in the San Joaquin River and tributaries, April - June 2001. FY 2001 Investigation Report by the U.S. Fish and Wildlife Service, California-Nevada FishHealth Center, Anderson, CA

[3] Nichols, K., J.S. Foott, and R. Burmeister. 2001. Health monitoring of hatchery and natural fall run Chinook salmon juveniles in the San Joaquin River and Delta, April - June 2000. FY2000 Investigation Report by the U.S. Fish and Wildlife Service, California-Nevada Fish Health Center, Anderson, California.

the modeling approach used or conclusions drawn for the Base Case hydrology simulation. The completed TUFLOW model represents the best available science to address questions of floodplain habitat suitability in relation to flow.

O. mykiss **Floodplain Habitat Use (Page 5-10): "*Steelhead trout (O. mykiss) are known to benefit from floodplain inundation (Sellheim et al. 2015). Conclusions and statements to the contrary, in Section 5.3.3, should be revised accordingly. Based on the similar floodplain rearing habitat requirements of Chinook salmon and O. mykiss, it is appropriate to do the O. mykiss analysis in the manner applied in the Draft Report.*"**

In accordance with the approved Study Plan, the final report includes analysis of potential floodplain habitat use by juvenile *O. mykiss*. However, the Districts' disagree that. *O. mykiss* are known to benefit from floodplain inundation and disagree that any floodplain-related PM&E measures should be recommended on this basis. Juvenile steelhead are not known to rear in floodplain habitats to any great degree at any time of year (Bustard and Narver 1975, Swales and Levings 1989, Feyrer et al. 2006, Moyle et al. 2007). In addition to the lack of evidence of floodplain habitat use in monitoring and studies of the San Joaquin River tributaries, based on multi-year studies in the Consumnes River, Moyle et al. (2007) concluded that steelhead were not adapted for floodplain use and the few steelhead observed were inadvertent floodplain users (i.e., uncommon and highly erratic in occurrence) that were "presumably…carried on to the floodplain by accident."

The cited Sellheim et al. 2015 report appears to show habitat use of Age 0 salmonids associated with cover and velocity refuge provided by willow species along channel margin areas of the Sailor Bar gravel augmentation site inundated during recent (2011) high flows on the lower American River (LAR). However, this study does not directly examine or reference other studies examining floodplain habitat use by *O. mykiss*. Because the Sellheim et al (2015) report states that the historical LAR floodplain is isolated from the active floodway by levees and the present-day LAR does not provide sufficient connectivity between main-channel and these former floodplain habitats, the report falls far short of supporting a broad conclusion regarding alluvial floodplain habitat use by *O. mykiss*.

Juvenile Chinook survival relationships (Page 6-2):"*... there is a significant positive relationship between juvenile Chinook salmon survival and floodplain inundation downstream of La Grange Dam for the period of February 1 through June 15. We recommend that the following analysis be added to the draft report …*"

The comment and requested analysis does not fall within the scope of the approved Study Plan and does not relate to results or conclusions of the Study Report. The study objectives in the approved Study Plan were limited to examination of the seasonal timing and duration of suitable overbank rearing habitat. While the suggested linkages between floodplain inundation and differences in rotary screw trap (RST) passage are consistent with well-known relationships between discharge and smolt survival included in the FERC record, the regression presented amounts to just two groups of points at high and low inundation and violates standard statistical assumptions of regression analysis. The Districts have strong reservations regarding the suggested ad hoc regression analysis and any inferences to be made regarding the benefits of floodplain inundation on the lower Tuolumne River.

<u>Total Usable Habitat plots</u> (Attachment H, pages 1-2): *"Add figures showing the total combining Models A, B and C."*

Although the plots provided in Attachment H were originally provided to indicate patterns of floodplain inundation and usable salmonid habitat with flow across different river sub-reaches, a combined figure showing river-wide estimates of usable habitat has been added to the Study Report in Attachment H.

BEFORE THE
UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

CERTIFICATE OF SERVICE

I hereby certify that the U.S. Fish and Wildlife Service Comments on W&AR-21 Lower Tuolumne River Floodplain Hydraulic Assessment Draft Report; Don Pedro Hydroelectric Project, P-2299; Tuolumne and Stanislaus Counties, California, has this day been electronically filed with the Federal Energy Regulatory Commission and electronically served on Parties indicating a willingness to receive electronic service and served, via deposit in U.S. mail, first-class postage paid, upon each other person designated on the service list for Project #2299, compiled by the Commission Secretary.

Dated at Sacramento, California, this 1st of October, 2015.

Aondrea Bartoo
San Francisco Bay-Delta Fish and Wildlife Office
650 Capitol Mall, Suite 8-300
Sacramento, California 95814
(916) 930-5621

United States Department of the Interior

FISH AND WILDLIFE SERVICE
San Francisco Bay Delta Fish and Wildlife Office
650 Capitol Mall, Room 8-300
Sacramento, California 95814

In Reply Refer To:

Ms. Kimberly Bose, Secretary
Federal Energy Regulatory Commission
888 First Street NE
Washington, DC 20426

OCT 01 2015

Subject: U.S. Fish and Wildlife Service Comments on W&AR-21 Lower Tuolumne River Floodplain Hydraulic Assessment Draft Report; Don Pedro Hydroelectric Project, FERC Project # P-2299; Tuolumne and Stanislaus Counties, California.

Dear Ms. Bose:

On September 3, 2015, U. S. Fish and Wildlife Service (USFWS) received the *Lower Tuolumne River Floodplain Hydraulic Assessment Draft Report* (Draft Report) for Study W&AR-21 of the Don Pedro Hydroelectric Project (FERC Project No. 2299) (Project), licensed by the Federal Energy Regulatory Commission (FERC or Commission). The following are our comments on the Draft Report.

General Comments

The study was mostly conducted in accordance with the Study Plan. Except for corrections and clarifications needed, as articulated in our comments, the Draft Report is a good starting point for quantifying the relationship between floodplain and flow in the lower Tuolumne River. Information presented in the Draft Report, with the additional information requested herein, should be useful in developing Project protection, mitigation, and enhancement (PM&E) measures.

Specific Comments

Figure 3.2-1 on page 3-4: This graph shows only flow exceedance from current operations. In order to interpret the effect of the Project on the floodplain, this graph should also present the flow-exceedance curve for unimpaired flows.

Page 4-3, 2nd complete paragraph: While the 30 foot by 30 foot cell size is appropriate for simulating the total amount of inundated floodplain area as a function of flow, it is too large for simulating fry and juvenile rearing habitat. Specifically, this cell size is at the wrong spatial scale relative to fry and juvenile habitat use, which is generally at a scale of one square foot. Because the data set does not support a one-foot scale, no PM&E measures should be based on this type of analysis of fry and juvenile habitat.

Page 4-3, Section 4.1.4: The lower 0.9 miles of the Tuolumne River was not modeled. There is no explanation of this omission, which is inconsistent with the commitment in the Study Plan to model the Tuolumne River from RM 0 to 52.2. The analysis needs to be completed with the lower 0.9 miles included, in order to be consistent with the Study Plan.

Page 4-7, Section 4.1.8.2: Assigning ponds, backwater areas and side channels bed elevations of 0.2 feet below the water surface elevation at the time the LIDAR was flown is adequate for simulating the total amount of inundated floodplain area as a function of flow, but is not adequate for simulating fry and juvenile rearing habitat. Specifically, this would result in the model significantly under-predicting depths in ponds, backwater areas and side channels, and thus over-predicting the amount of fry and juvenile habitat in these areas, since fry and juvenile habitat suitability is greatest for shallow depths. Because the analysis in this section is expected to greatly over-predict the amount of fry and juvenile habitat, no PM&E measures should be based on this analysis.

Page 4-13: It is not clear whether this analysis considered a constant San Joaquin River flow upstream of the Tuolumne River. If a constant San Joaquin River flow was used, it should be reported with an explanation of how the chosen flow was determined.

Page 5-1, Section 5.2.1: Areas within isolated portions of the floodplain created by topographic depressions, backwater areas and ponds that were inundated at the lowest flows modeled should be subtracted from the total floodplain area, because they would be perennially inundated off-channel areas, which would not be considered floodplain habitat (U.S. Fish and Wildlife Service 2014). In addition, to the extent that these areas are isolated from the main channel at a given flow, they would not provide any benefit to fry and juvenile salmonids, because they would not be accessible to fry and juvenile salmonids at such flows.

Page 5.2, Figure 5.2-1: We recommend that the Districts overlay the floodplain extent from the floodplain modeling with the empirical floodplain polygons used in U.S. Fish and Wildlife Service (2008), because the amount of floodplain area versus flow in U.S. Fish and Wildlife Service (2008) is generally more than the total in this report combining Models A, B and C. It would be expected that the combined floodplain area from this report, covering over 50 miles of the Tuolumne River, should be significantly more than the floodplain areas in U.S. Fish and Wildlife Service (2008), which only covered 30 miles of the Tuolumne River. We would have expected that the floodplain delineation from the two reports would be similar for the area in common, because the U.S. Fish and Wildlife Service (2008) assumed that floodplain inundation started at 1,100 cfs, and this report used the 1,070 cfs inundation extent to delineate overbank versus in-channel areas.

Page 5.2, Section 5.2.2: Total floodplain area should be used to develop PM&E measures, rather than fry and juvenile habitat, because the model developed in this study cannot be used to develop relationships between flow and the amount of fry and juvenile habitat for the following reasons: (1) issues raised above concerning cell size and bed elevations of ponds, backwater areas and side channels; 2) the 0.5 foot accuracy of LIDAR data, which can result in significant errors in fry habitat suitability, which can vary substantially with 0.5 foot variations in depth; (3) LIDAR data in areas with heavy ground vegetation, such as blackberry bushes, having elevations that are biased high due to the last return being from vegetation rather than the ground; (4) the lack of cover data to use in calculating fry and juvenile habitat; and (5) the lack of habitat use data from floodplains. With regards to the last item, fry and juvenile may use quite different microhabitat characteristics on floodplains, versus from in-channel areas. In addition, inundated floodplains provide many benefits for fry and juvenile salmonids beyond habitat. Specifically, prolonged flooding affects fry survival by providing autochthonous food resources, providing refuge from predators, reducing water temperatures particularly during downstream migrations in May and June, slowing the rate of disease infestation, diluting contaminants, and reducing entrainment (Mesick *et al.* 2008).

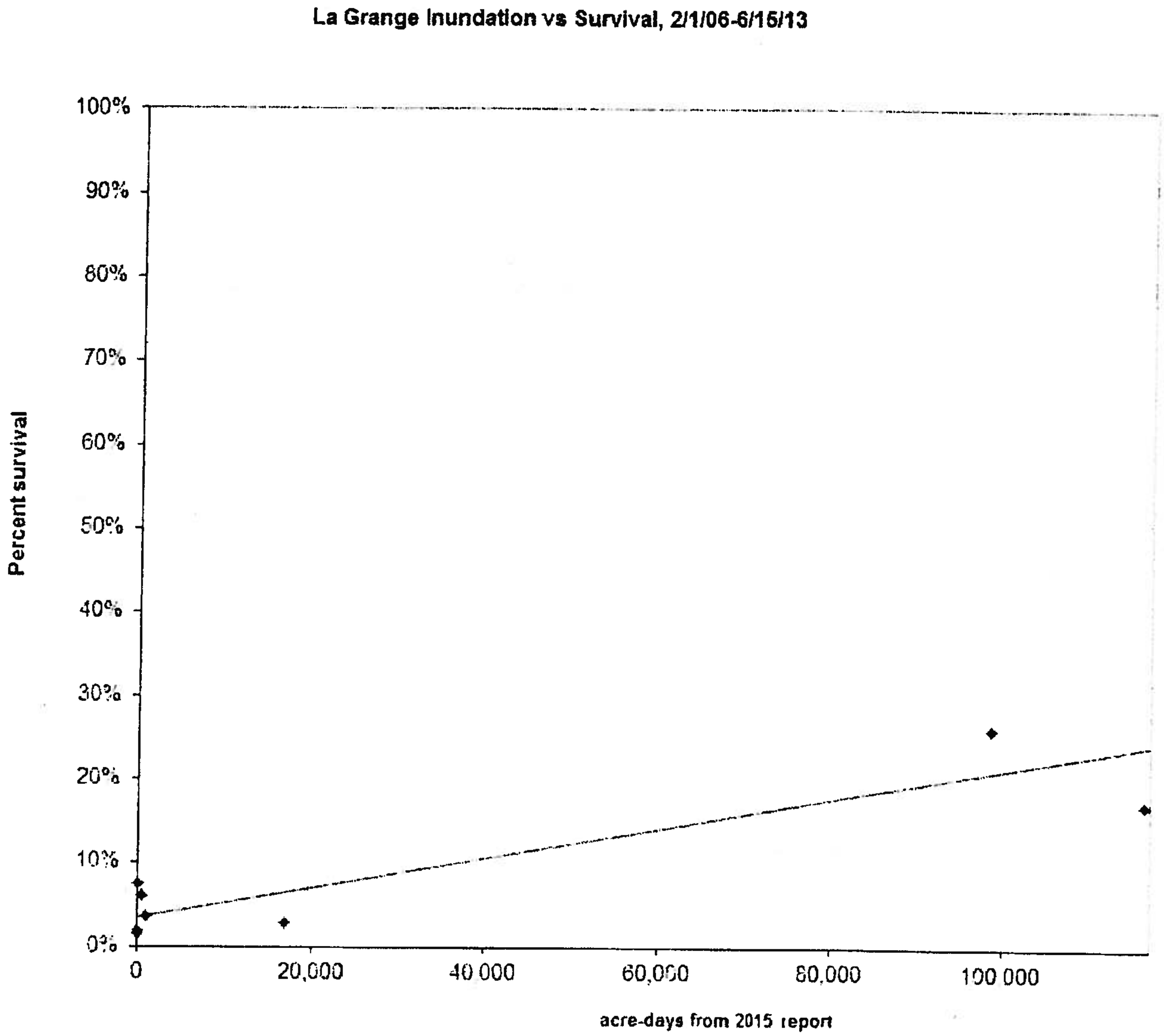


Figure 1. USFWS analysis of Draft Report data: Regression showing the relationship between percent survival of juvenile Chinook salmon in the Tuolumne River and the acre-days of floodplain inundation downstream of La Grange Dam.

Page 5-10: Steelhead trout (*Oncorhynchus mykiss*) are known to benefit from floodplain inundation (Sellheim *et al.* 2015). Conclusions and statements to the contrary, in Section 5.3.3, should be revised accordingly. Based on the similar floodplain rearing habitat requirements of Chinook salmon and *O. mykiss*, it is appropriate to do the *O. mykiss* analysis in the manner applied in the Draft Report.

Page 6-2: Our analysis of the data in this report, combined with Tuolumne River rotary screw trap data, indicates that there is a significant positive relationship between juvenile Chinook salmon survival and floodplain inundation downstream of La Grange Dam for the period of February 1 through June 15. We recommend that the following analysis be added to the draft report: (1) sum the floodplain area versus flow for Models A, B and C; (2) then subtract the floodplain area at 1,000 cfs from the floodplain area at higher flows to compute floodplain area that excluded areas within isolated portions of the floodplain created by topographic depressions, backwater areas and ponds that were inundated at the lowest flows modeled; (3) then use daily average flows from the LaGrange gage, along with the resulting flow-floodplain area relationship, to compute the number of acres of floodplain inundated each day; (4) then sum the inundated acres for the period of February 1 through June 15 each year to compute the number of acre-days of inundated floodplain each year for 2006 through 2013; (5) compute the percent survival of juvenile Chinook salmon for each of these years by dividing the total catch at the Grayson screw trap by the total catch at the Waterford screw trap; (6) then perform a linear regression of percent survival versus acre-days of inundated floodplain. For your convenience, the culmination of this analysis is included as the enclosure: *Excerpt from spreadsheet of FWS analysis of juvenile Chinook salmon survival in the lower Tuolumne River in relation to acre-days of floodplain inundation.*

The resulting regression, as shown in Figure 1, will have an r^2 value of 0.79 and predicted percent survival ranging from 3.67% with no floodplain inundation to 27.49% with 150,000 acre-days of floodplain inundation. The relationship shown in Figure 1 could be used to develop PM&E measures, which could be achieved through a combination of higher flows and floodplain restoration projects which lower floodplain elevations. For example, using the survival goals in the Scientific Evaluation Process Group's 2014 report for the Stanislaus River, the PM&E measures would be 8,400 acre-days in dry years (to achieve 5% survival), 41,000 acre-days in normal years (to achieve 10.18% survival) and 71,350 acre-days in wet years (to achieve 15% survival).

Attachment H, pages 1-2: Add figures showing the total combining Models A, B and C.

Conclusion

We appreciate the opportunity to comment on the Draft Report. If you have any questions, regarding our comments, please contact Alison Willy at (916)414-6534.

Sincerely,

Larry Rabin

Larry Rabin
Acting Field Supervisor

Enclosure

cc:
FERC #2199 Service List
Rose Staples, HDR

References

Mesick, C.F., J. McLain, D. Marston and T. Heyne. 2008. Draft limiting factor analyses and recommended studies for fall-run Chinook salmon and rainbow trout in the Tuolumne River. Report submitted to the Federal Energy Regulatory Commission. March 2007.

Sellheim, K. L., C. B. Watry, B. Rook, S. C. Zeug, J. Hannon, J. Zimmerman, K. Dove and J. E. Merz. 2015. Juvenile salmonid utilization of floodplain rearing habitat after gravel augmentation in a regulated river. River Research and Applications. Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/rra.2876. 12pp.

Scientific Evaluation Process Group. 2014. Administrative draft of the interim objectives for restoring Chinook salmon and steelhead in the Stanislaus River report. Report prepared by Anchor QEA, LLC: Seattle, WA. December 2014.

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Excerpt from spreadsheet of USFWS analysis of juvenile Chinook salmon survival in the lower Tuolumne River in relation to acre-days of floodplain inundation.

year	FWS 2/1-6/15 acre-day	2015 2/1-6/15 acre-day	Waterford	Grayson	% survival
1996	75019	65527			
1997	46573	57403			
1998	100814	99005			
1999	49956	42935			
2000	38471	34392			
2001	4408	3364			
2002	413	354			
2003	495	422			
2004	1811	2018			
2005	78510	69954			
2006	100,627	116,453	499,366	84,987	17.0%
2007	0	0	52,840	952	1.8%
2008	527	487	49,527	3,020	6.1%
2009	0	0	54,517	4,072	7.5%
2010	22,784	16,817	74,520	2,056	2.8%
2011	95,380	98,621	365,904	95,156	26.0%
2012	1,280	877	62,076	2,268	3.7%
2013	24	31	40,387	642	1.6%
2014	29	44			

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THE LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

ATTACHMENT B

TUFLOW MODEL CELL SIZE SENSITIVITY ANALYSIS

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1.0 OVERVIEW

This attachment provides figures and tables referred to in the Model Spatial and Temporal Resolution section of the study report.

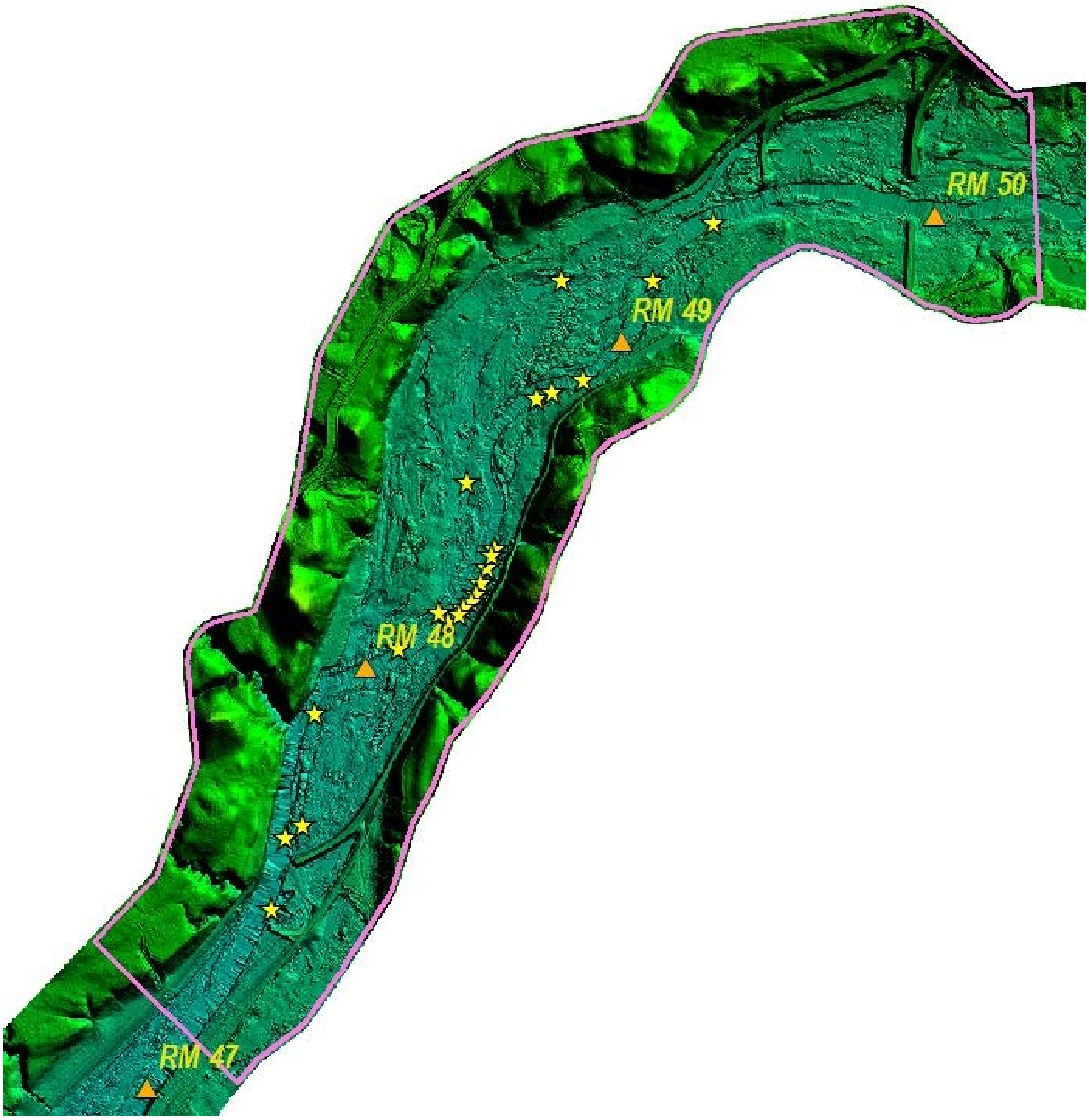

Figure 1. The extent of the TUFLOW model used for cell size sensitivity analysis. Yellow stars represent the locations of water level measurements recorded at a steady flow of 3,000 cfs for the Pulse Flow Study (Stillwater Sciences 2012).

Table 1. Cell Size Sensitivity Analysis – Hydraulic model results.

S No.	Observed WSE (ft) 3,000 cfs	Difference in WSE for Variuos Cell Size Models*					Remarks
		10 ft	20 ft	30 ft	40 ft	50 ft	
1	169.7	0.2	0.2	0.1	0.1	0.0	--
2	168.9	0.5	0.4	0.4	0.3	0.2	--
3	166.9	-0.3	-0.3	-0.4	-0.4	-0.6	Overbank
4	166.8	0.5	0.4	0.3	0.2	0.1	--
5	165.9	0.3	0.3	0.2	0.0	-0.2	--
6	165.2	-0.2	-0.3	-0.3	-0.5	-0.8	--
7	163.0	0.0	-0.3	-0.6	-0.5	-0.8	Overbank
8	162.7	0.3	0.2	0.2	0.1	0.0	--
9	162.5	0.1	0.1	0.0	-0.1	-0.1	--
10	162.3	0.1	0.1	0.0	-0.1	-0.1	--
11	161.8	-0.1	-0.1	-0.3	-0.3	-0.4	--
12	161.6	0.0	0.0	-0.3	-0.3	-0.5	--
13	161.5	0.0	-0.1	-0.1	-0.2	-0.2	--
14	161.5	0.1	0.0	0.0	-0.1	-0.1	--
15	161.3	0.0	0.0	-0.1	-0.2	-0.2	--
16	161.1	-0.1	-0.1	-0.2	-0.3	-0.3	--
17	161.0	-0.2	-0.2	-0.3	-0.4	-0.4	--
18	160.6	0.2	0.1	0.1	0.0	-0.1	--
19	158.2	-0.9	-1.0	-1.1	-1.1	-1.0	Results invalid as this downstream portion is affected by assumed boundary conditions.
20	157.0	-0.9	-0.9	-0.9	-1.0	-1.0	
21	156.9	-0.6	-0.6	-0.6	-0.7	-0.7	
22	156.5	-2.1	DRY	DRY	-1.9	-2.1	
RMSE (ft) (Lines 1 - 21)		**0.4**	**0.4**	**0.4**	**0.5**	**0.5**	
RMSE (ft) (Lines 1 - 18)		**0.2**	**0.2**	**0.3**	**0.3**	**0.4**	

* Model has only overbank geometry and does not include 1D low flow channel, Manning's n and other necessary components for calibration.

Table 2. Cell Size Sensitivity Analysis – Salmonid fry usable habitat estimates.

Cell Size (ft)	Fraction of wetted area (%)					
	Chinook Fry			*O. mykiss* Fry		
	Product	Geo. Mean	Limiting	Product	Geo. Mean	Limiting
10	29	40	32	40	48	42
20	27	39	31	39	47	40
30	27	38	30	38	46	39
40	28	39	31	38	47	40
50	26	38	30	37	46	39

Table 3. Cell Size Sensitivity Analysis – Salmonid juvenile usable habitat estimates.

Grid Size (ft)	Fraction of wetted area (%)					
	Juvenile Chinook			Juvenile *O. mykiss*		
	Product	Geo. Mean	Limiting	Product	Geo. Mean	Limiting
10	32	42	34	35	43	37
20	32	42	34	35	43	37
30	32	41	34	34	42	37
40	33	42	35	35	43	38
50	32	41	34	35	43	37