From: Rose Staples
To: John Devine, Jesse Deason
Date: Jul 16, 2015, at 1:08 PM

Just received a phone call from Catherine Groves, with Hanson Bridgett (legal representing BAWSCA) who was following up to confirm if what she is hearing is correct, that the dates for the remaining Don Pedro studies and the new La Grange studies had changed or the Districts were going to be requesting to change dates.

I advised that I did not have specific information on that, except that the dates on the 2014 Predation Study for Don Pedro had been extended—and that I would ask and that someone would get back to her—most probably not until the first or mid-next week. Her phone is 415-995-5171.

Rose Staples, CAP-OM, MOS
Executive Assistant

HDR
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Portland ME 04103
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rose.staples@hdrinc.com

hdrinc.com/follow-us

From: Staples, Rose
Sent: Tuesday, August 18, 2015 2:59 PM
To: HORACIO FERRIZ
Subject: RE: Inquiry about water quality in Don Pedro and Turlock Lake reservoirs

Thank you for your inquiry. I know there were water quality data included in the Final License Application (document 53: Water & Aquatic Resources Study W&AR-01 Water Quality Assessment) on the relicensing website at www.donpedro-relicensing.com and on FERC's E-Library at www.ferc.gov. But I will also forward your query to the Districts for a more definitive answer. Thank you.

Rose Staples, CAP-OM, MOS
D 207-239-3857

hdrinc.com/follow-us

From: HORACIO FERRIZ [mailto:HFERRIZ@envres.org]
Sent: Friday, August 14, 2015 5:39 PM
To: Staples, Rose
Subject: Inquiry about water quality in Don Pedro and Turlock Lake reservoirs

Hello Rose,

I have been asked about the water quality at Lake Don Pedro and Turlock Lake (e.g., nitrates, phosphates, and pathogens) by the Regional Water Quality Control Board. Would you happen to have public domain water quality testing results for the water in these reservoirs? I think the concern is about some swimming kid swallowing raw reservoir water.

Thanks,

Dr. Horacio Ferriz, PG CEG
Stanislaus County Geologist
Stanislaus County Dept. of Environmental Resources
3800 Cornucopia Way, Suite C
Modesto, CA 95358
Tel. (209) 525-6724
hferriz@envres.org

From: Staples, Rose
BCC: Don Pedro Relicensing Participants Email Group
Sent: Thursday, September 3, 2015 4:57 PM
Subject: Don Pedro Draft W-AR-21 Lower Tuolumne River Floodplain Hydraulic Assessment Study Report Released for 30-Day Review

To Don Pedro Relicensing Participants:

The Districts are releasing for your review and comment the draft W&AR-21 ***Lower Tuolumne River Floodplain Hydraulic Assessment Study Report***.

The goal of this study was 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. This study was undertaken in accordance with the FERC-approved (October 18, 2013) study plan.

The Draft Study Report is available for your viewing and/or downloading on the Don Pedro Relicensing website at www.donpedro-relicensing.com. Please click on the CALENDAR tab, and then on the notice on today's date, September 3, 2015. The Draft Study Report and Attachments A,B,C,D,E,F,G,H,I are attached to the notice.

Please provide comments to me at rose.staples@hdrinc.com by Tuesday, October 6, 2015.

Thank you.

Rose Staples, CAP-OM, MOS
Executive Assistant

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LOWER TUOLUMNE RIVER FLOODPLAIN HYDRAULIC ASSESSMENT

DRAFT REPORT

DON PEDRO PROJECT

FERC NO. 2299

Prepared for:

Turlock Irrigation District – Turlock, California

Modesto Irrigation District – Modesto, California

Prepared by:

HDR, Inc.

and

Stillwater Sciences

September 2015

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.

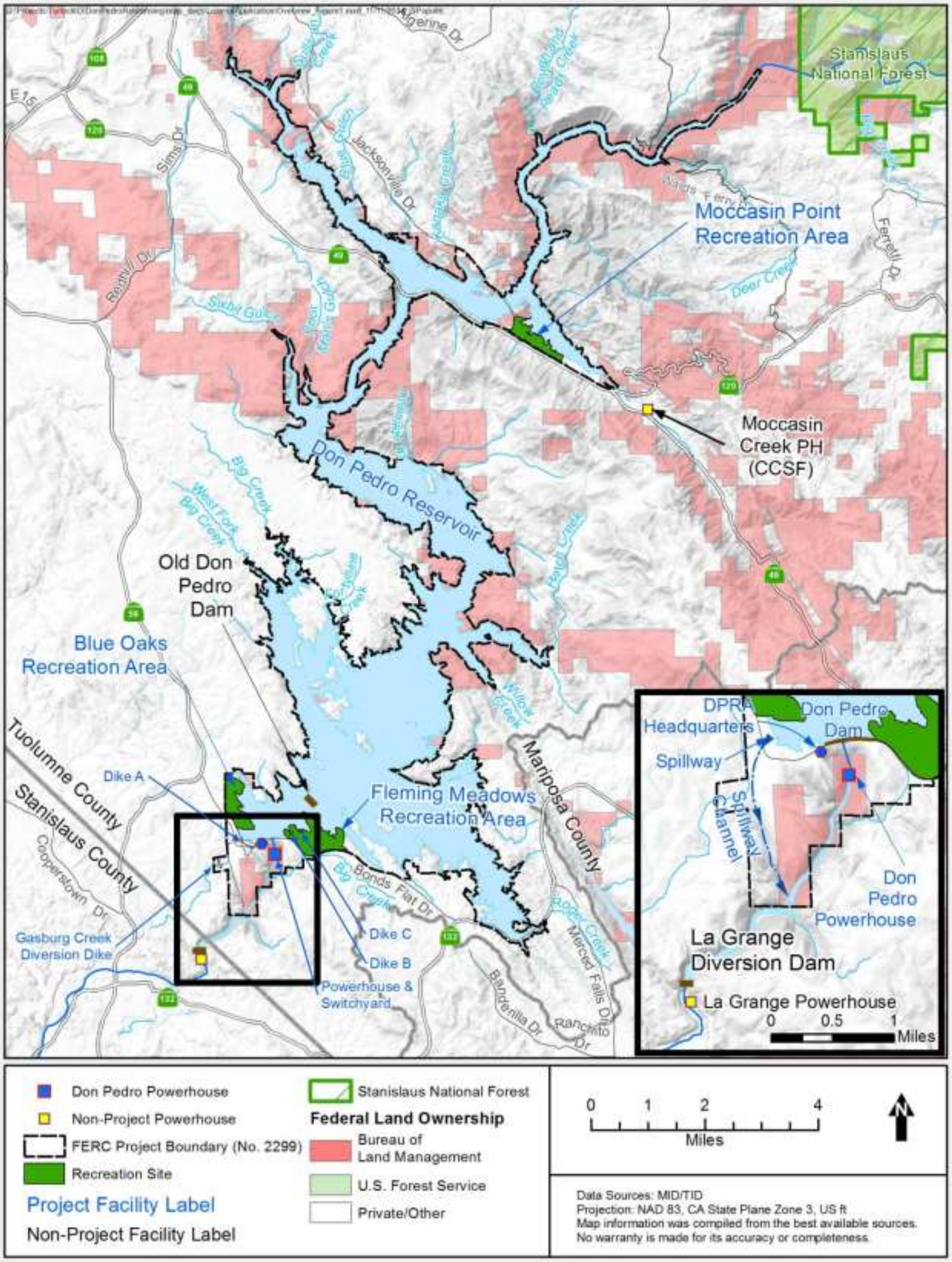


Figure 1.1-1. Don Pedro Project site location map.

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. The final meeting notes for Workshop No. 2 are being filed with this report (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).

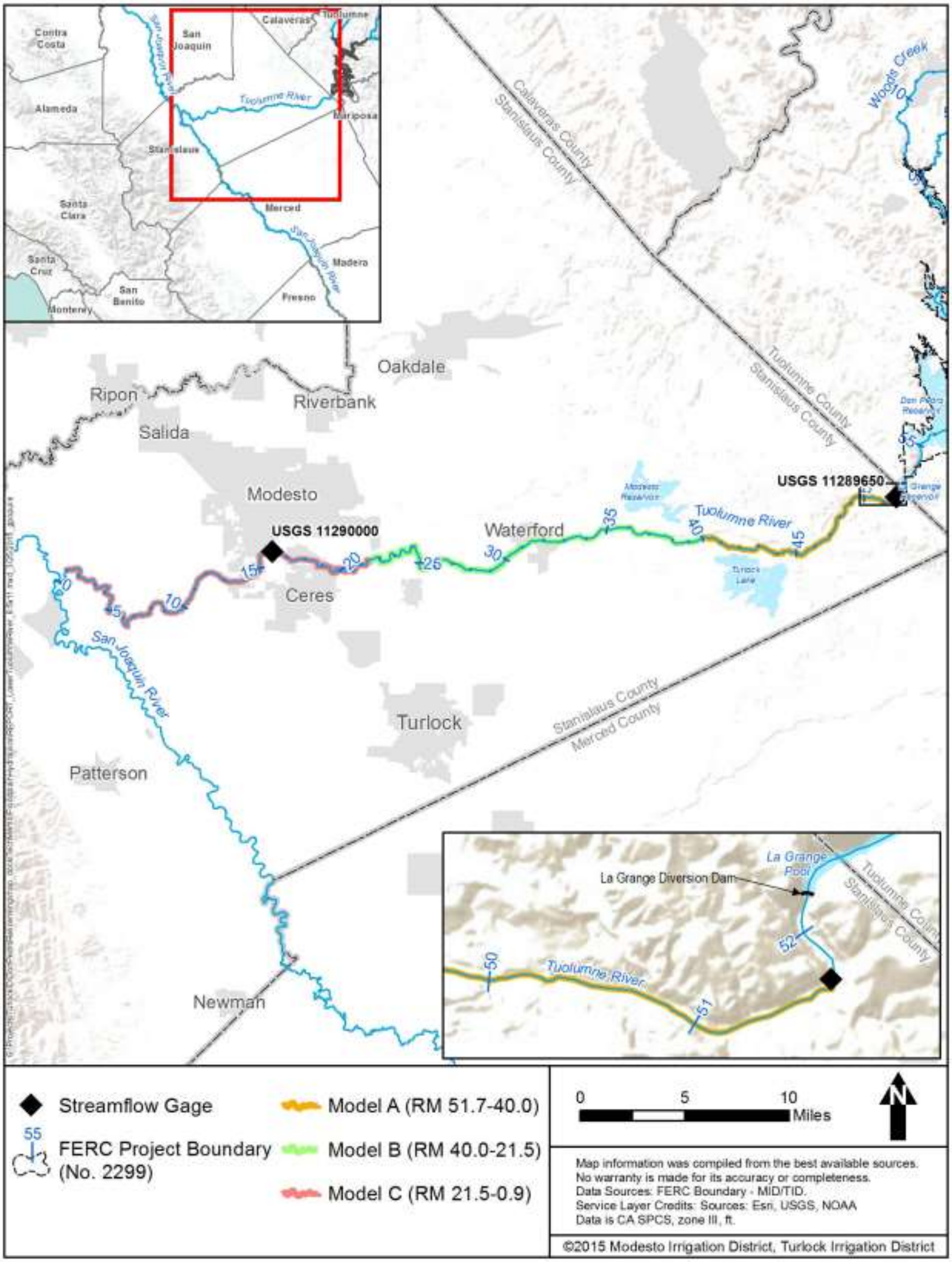


Figure 3.1-1. Lower Tuolumne River study area and model reaches.

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.

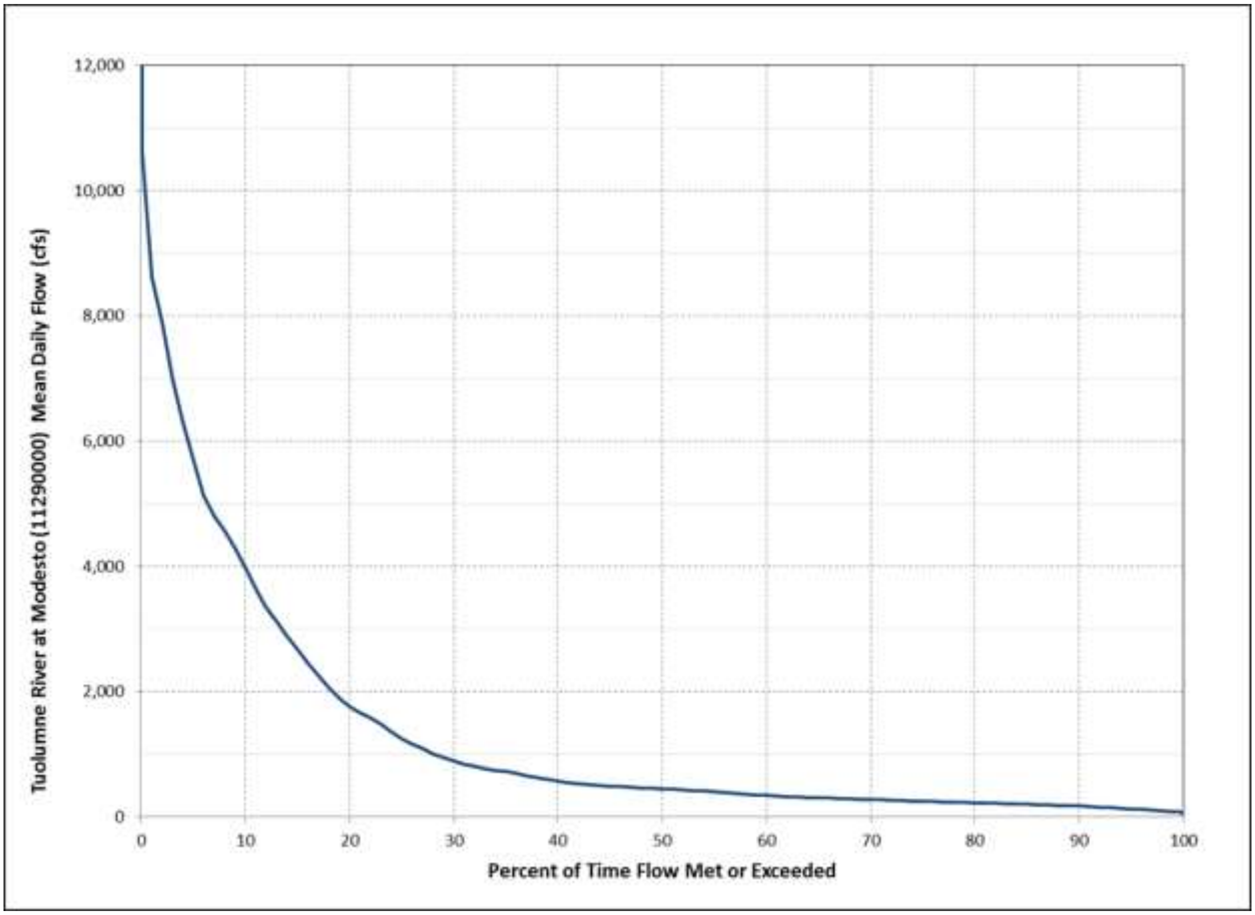


Figure 3.2-1. Flow exceedance at USGS Gage 11290000 Tuolumne River at Modesto CA, WY 1971 to 2012.

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.

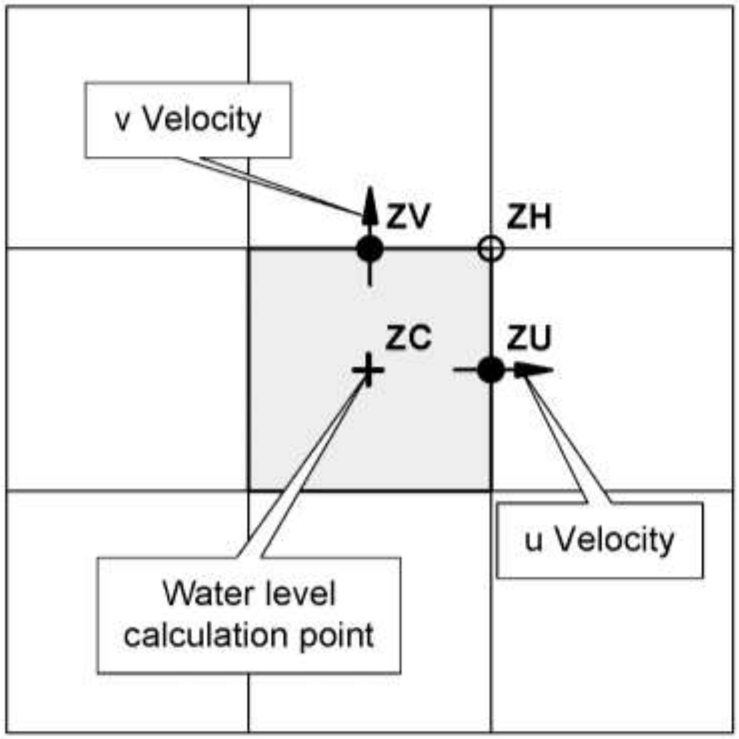
4.1.1 Hydraulic Model Software

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.

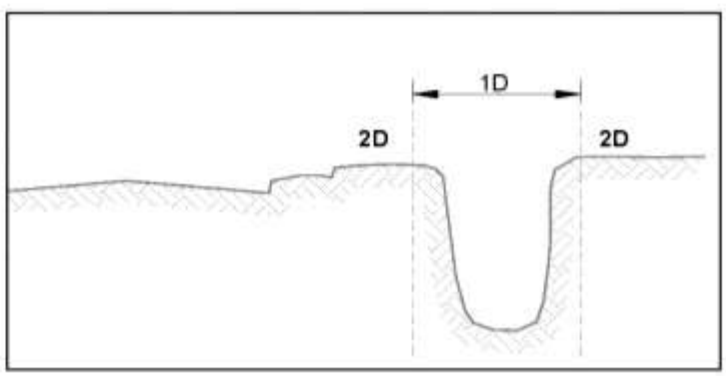
The TUFLOW version used for the study was the 64 bit, double precision version TUFLOW.2013-12-AC-w64. Surface-water Modeling System (SMS) software developed by Aquaveo, LLC was used for visualizing TUFLOW output. SMS version 11.1.10 (Build date: November 06, 2013) was used for the study.

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).



Location of Zpts and Computation Points



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

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.

4.1.8.5.1 Model A

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

4.1.8.5.2 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.

4.1.8.5.3 <u>Model C</u>

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.

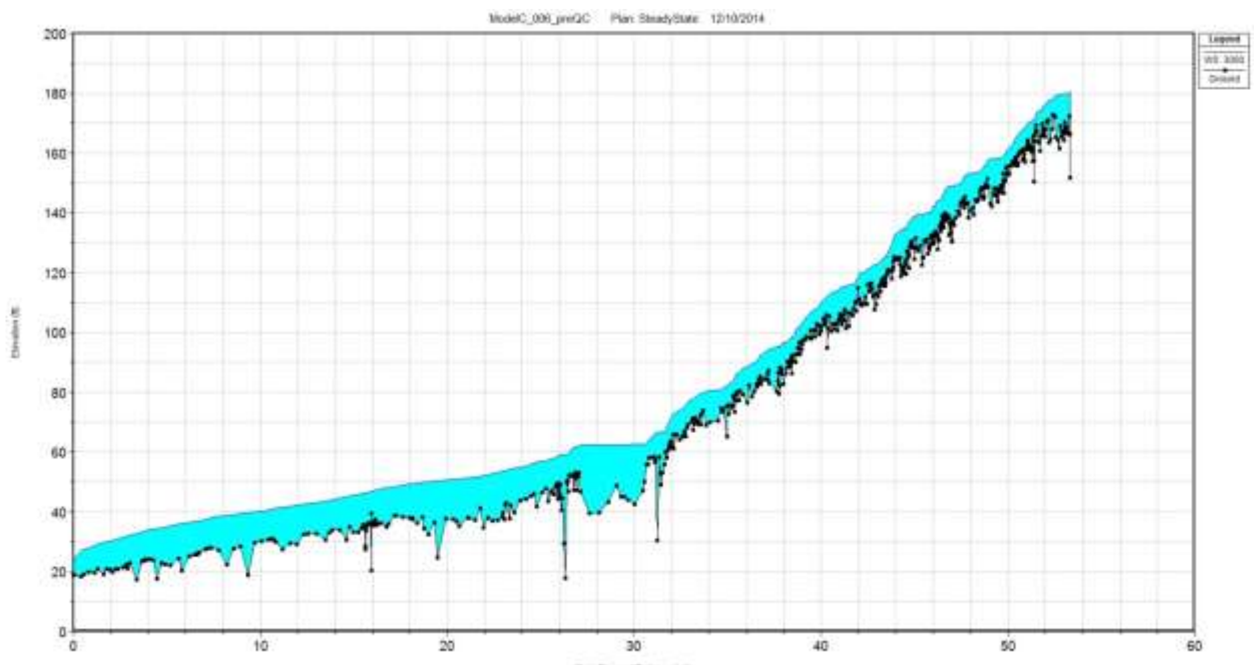


Figure 4.2-1. Bed slope of lower Tuolumne River.

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.

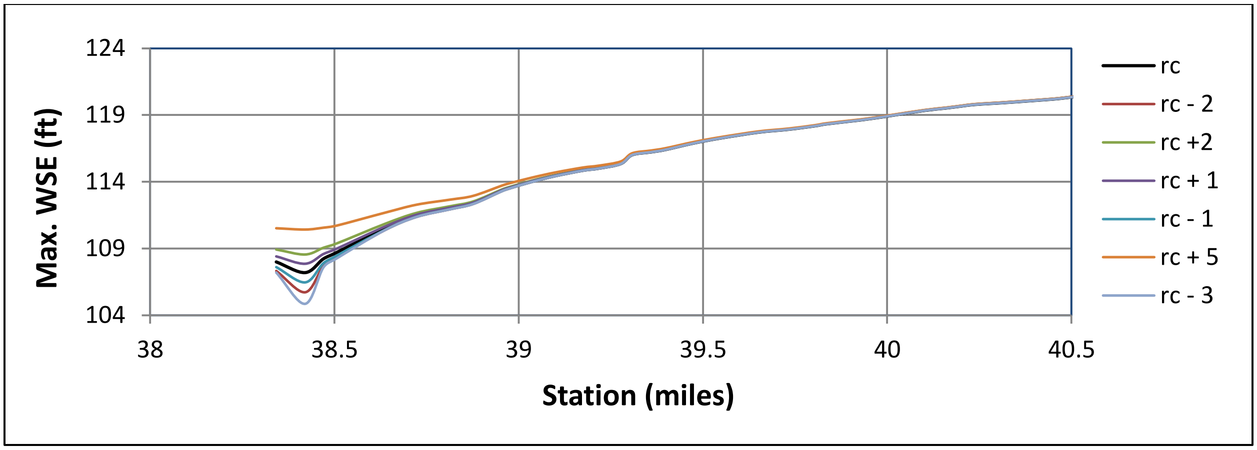


Figure 4.2-2. Model A - Sensitivity analysis for the boundary condition rating curve at a steady flow of 10,000 cfs. In the legend, "rc" means boundary rating curve elevation and "-" or "+" means minus or plus feet of elevation. For example, "rc-2" means boundary rating curve elevation minus two feet.

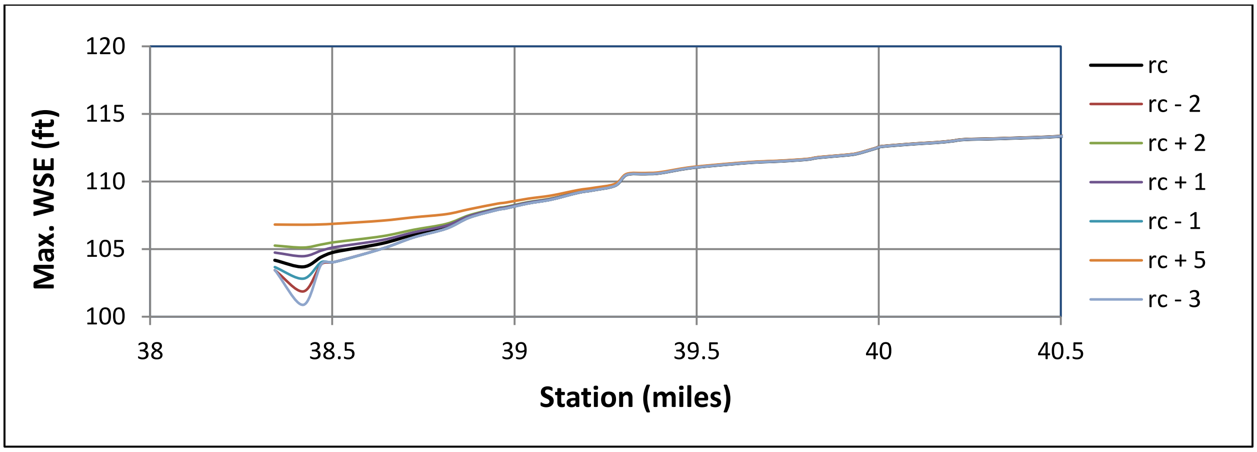


Figure 4.2-3. Model A - Sensitivity analysis for the boundary condition rating curve at a steady flow of 2,000 cfs. In the legend, "rc" means boundary rating curve elevation and "-" or "+" means minus or plus feet of elevation. For example, "rc-2" means boundary rating curve elevation minus two feet.

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.

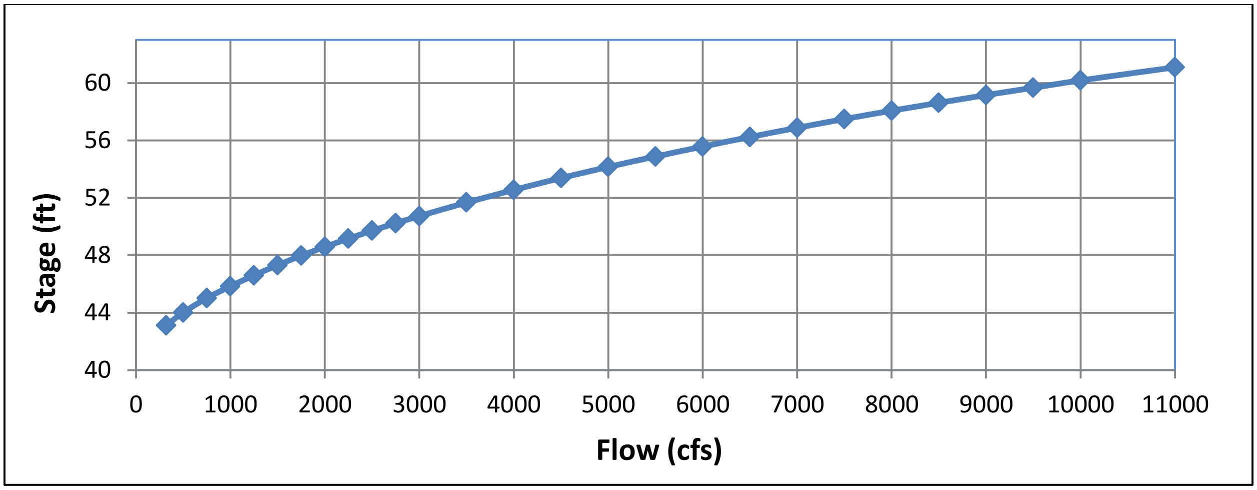


Figure 4.2-4. Model B - Boundary condition rating curve.

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).

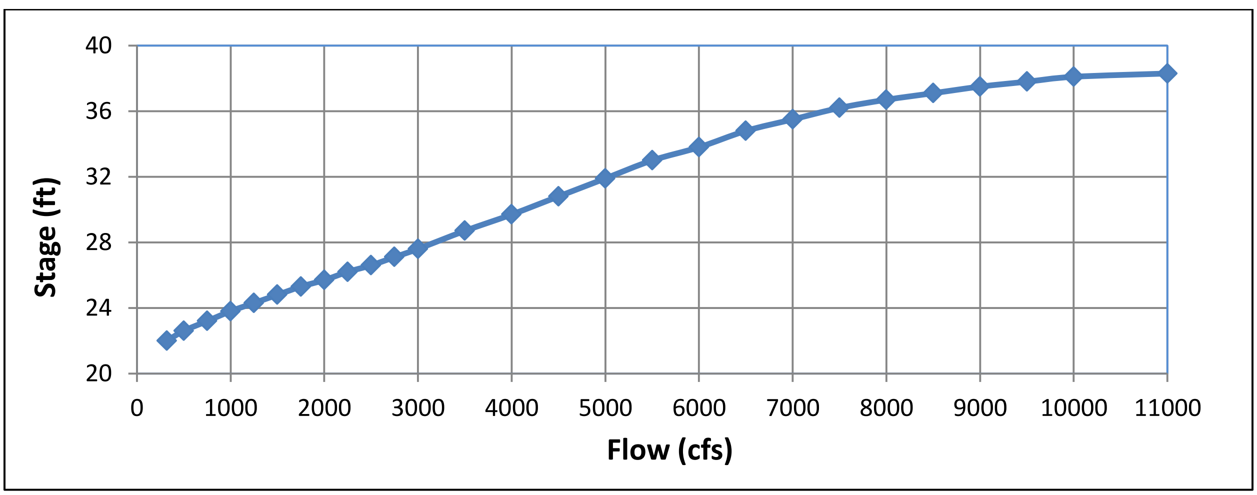


Figure 4.2-5. Model C - Boundary condition rating curve.

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 4.4-1).

Table 4.4-1. 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:

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

b) 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.

c) 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).

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

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

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

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

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

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

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

i) Models were calibrated by sub-reaches when necessary.

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

k) 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 4.4-2 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 4.4-3 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 4.4-2. 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 4.4-3. 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	1993[3]	3,100	--	--	All sub-reaches
11	1995[3]	5,300	--	--	All sub-reaches
12	1995[3]	8,400	--	--	All sub-reaches

[1] See Table 4.4-2 for sub-reach descriptions.
[2] Google Earth Images.
[3] TID/MID Images.

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 4.4-4 and 4.4-5 provide the calibration and validation data used for Model B.

Table 4.4-4. Model B - Calibration and validation data – Google Earth Images.

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

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

Table 4.4-5. 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 4.4-6 and 4.4-7 provide the calibration and validation data used for Model C.

Table 4.4-6. 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 4.4-7. 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 4.4-4 and 4.4-5 of Model B, due to the possibility that this reach may be affected by inflows from Dry Creek.

Figure 4.4-1 shows the comparison of TUFLOW model results with the USGS Modesto gage rating curve and the USGS flow measurements at the gage.

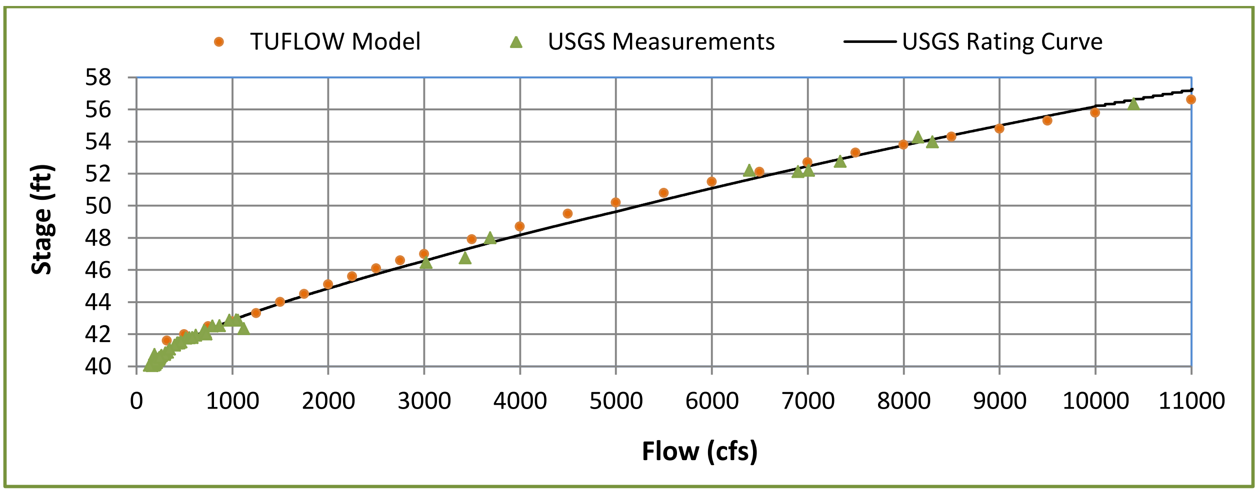


Figure 4.4-1. Model C - Calibration comparison at USGS Gage near Modesto.

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:

a) 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.

b) 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.

c) 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.

d) 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.

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:

a) 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'.
b) 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).
c) 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).
d) 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. 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 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, off channel ponds and topographic depressions have 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).

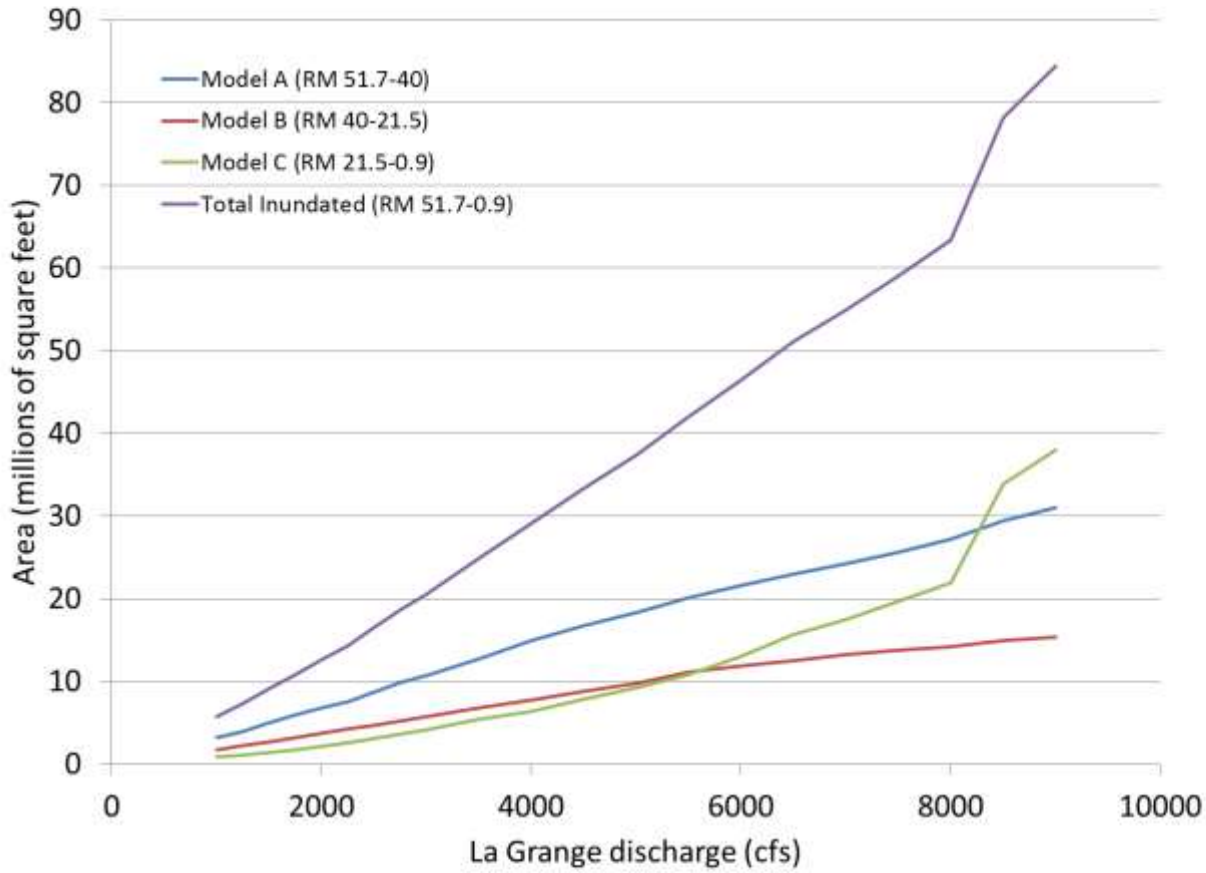


Figure 5.2-1. Total inundated floodplain area as a function of discharge within three modeled reaches of the lower Tuolumne River.

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. However, since the USFWS (2008) study did not examine habitat suitability or habitat use of overbank habitats by juvenile salmonids, flow vs. area relationships developed by the USFWS (2008) study greatly over-estimated the amounts of suitable 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 1.9 million ft^2 of usable habitat for Chinook salmon fry in Model A (RM 51.7–40.0), with lower amounts of 1 million ft^2 and 0.5 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.

Table 5.2-1. Hydraulic modeling results of total 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) total inundated and usable rearing habitat areas (ft^2)						
Inundated Area	3,185,775	6,731,550	10,701,900	18,363,150	24,244,650	31,023,900
Chinook salmon fry	1,862,541	3,444,543	4,869,105	6,446,877	7,119,815	7,624,482
O. mykiss fry	2,560,952	4,749,804	6,858,724	9,217,775	10,138,965	11,868,922
Chinook salmon juvenile	1,492,554	3,668,897	6,112,661	10,215,191	13,031,099	14,790,965
O. mykiss juvenile	1,560,265	3,894,140	6,467,368	10,905,932	13,958,495	16,144,825
Model B (RM 40-21.5) total inundated and usable rearing habitat areas (ft^2)						
Inundated Area	1,720,350	3,716,550	5,685,525	9,722,700	13,187,925	15,403,950
Chinook salmon fry	996,093	1,720,727	2,124,633	2,796,063	2,974,076	2,393,577
O. mykiss fry	1,376,591	2,432,318	3,073,984	4,012,780	4,393,779	3,668,157
Chinook salmon juvenile	845,844	1,970,584	3,069,094	4,545,171	5,636,807	5,398,679
O. mykiss juvenile	841,897	2,070,949	3,284,073	5,058,377	6,520,626	6,561,410
Model C (RM 21.5-0.9) total inundated and usable rearing habitat areas (ft^2)						
Inundated Area	830,475	2,121,300	4,150,350	9,247,050	17,512,425	38,009,700
Chinook salmon fry	484,748	1,076,305	1,996,085	3,567,612	6,423,316	14,080,325
O. mykiss fry	684,966	1,520,145	2,758,537	4,971,744	8,765,928	19,833,137
Chinook salmon juvenile	413,054	1,113,753	2,180,629	4,469,439	7,946,023	19,178,558
O. mykiss juvenile	412,067	1,109,114	2,238,864	4,835,122	8,845,056	19,449,129

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 riverwide carrying capacity of 4.8 million Chinook fry at 1,000 cfs, 9.0 million at 2,000 cfs, 13 million at 3,000 cfs, and 18 million at 5,000 cfs with 56%, 54%, and 50%, respectively, of the carrying capacity being in the uppermost 12 miles of the river. Large habitat expansion at 9,000 cfs occurs in the lowermost reach due to backwater influences of the San Joaquin River, assuming simultaneous occurrence of high flows in both rivers.

Usable habitat for Chinook juveniles at 1,000 cfs, 3,000 cfs and 5,000 cfs is estimated to be 2.75 million ft^2, 11.4 million ft^2, and 19.2 million ft^2, respectively river-wide (Table 5.2-1), which would correspond to a carrying capacity of 1.3 million, 5.3 million, and 8.9 million juveniles at the maximum density of 0.465 juveniles/ft^2 found by USFWS (1991). Although observations of

O. mykiss rearing on floodplains have been limited to those from the Yolo bypass studies (Sommer et al 2001, USBR 2008), we have provided corresponding estimates of usable habitat for juvenile *O. mykiss* in Table 5.2-1.

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 30 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 (Figure 5.2-2). For Model B (RM 40–21.5), usable habitat for fry life stages varies from 60 to 80 percent of total inundated habitat at 1,000 cfs, falling to only 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 50 to 55 percent of total inundated habitat at 1,000 cfs, falling to 35 to 45 percent at 9,000 cfs. Lastly, in Model C (RM 21.5–0.9), usable habitat for fry and juvenile life stages varies from 60 to 80 percent and 50 to 55 percent of total inundated habitat at 1,000 cfs, respectively (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, usable habitat for fry and juvenile life stages falls to 35 to 50 percent and 45 to 50 percent of total inundated habitat, respectively. Floodplain habitat in the areas nearest the San Joaquin River is strongly influenced by San Joaquin River discharge and backwater effects (Section 4.2.3).

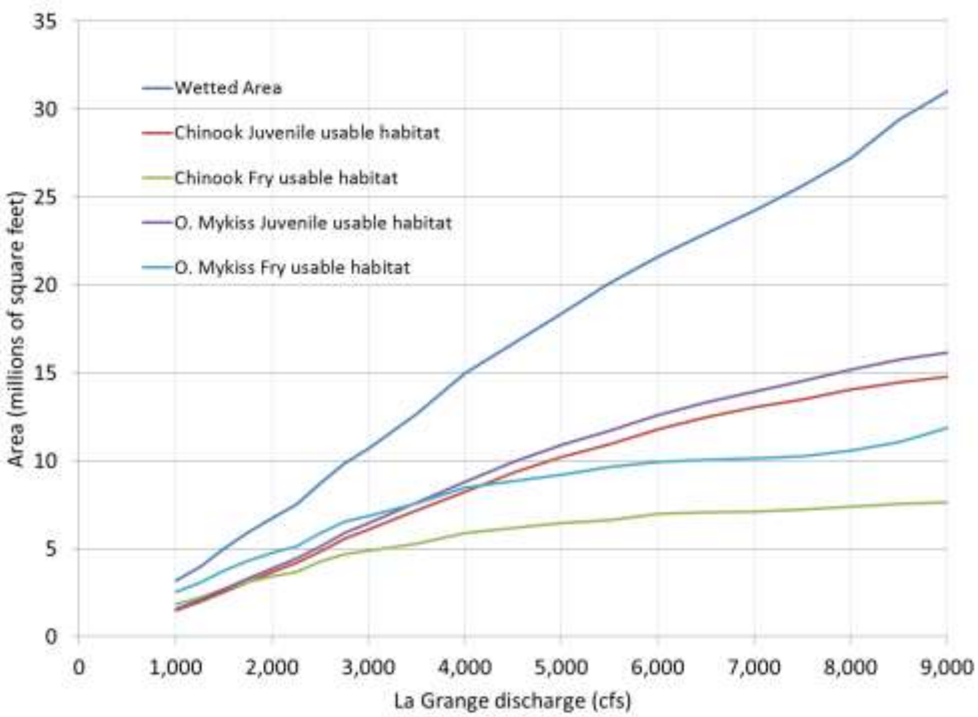


Figure 5.2-2. Model A results showing total wetted and usable habitat areas for juvenile salmonid life stages in the lower Tuolumne River (RM 51.7–40).

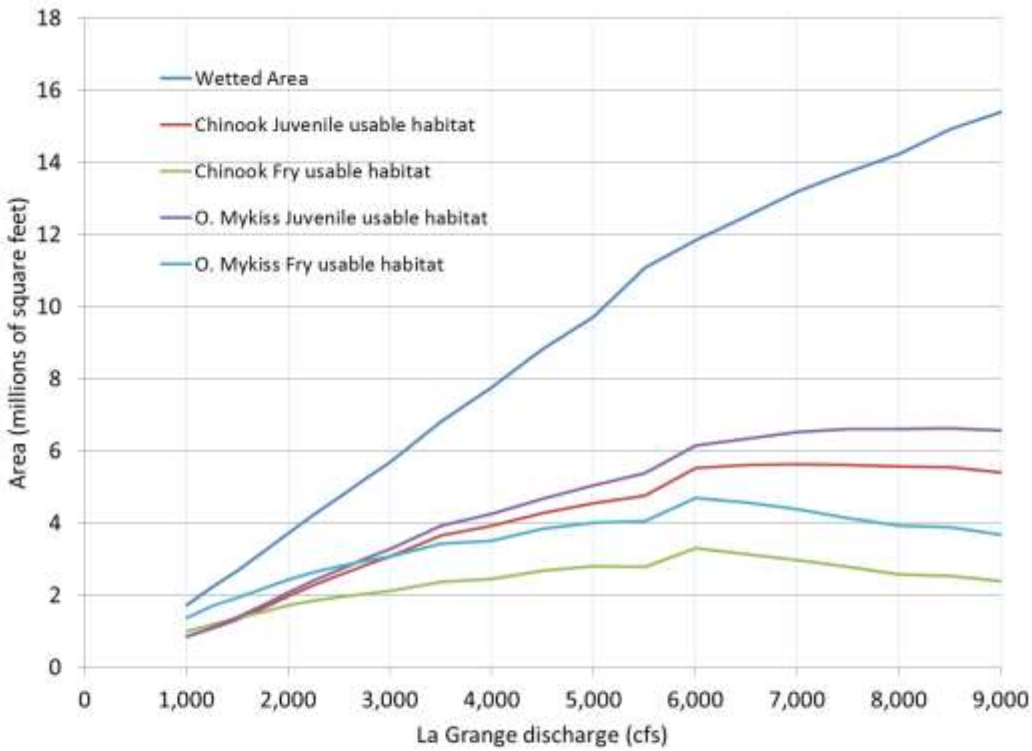


Figure 5.2-3. Model B results showing total wetted and usable habitat areas for juvenile salmonid life stages in the lower Tuolumne River (RM 40–21.5.)

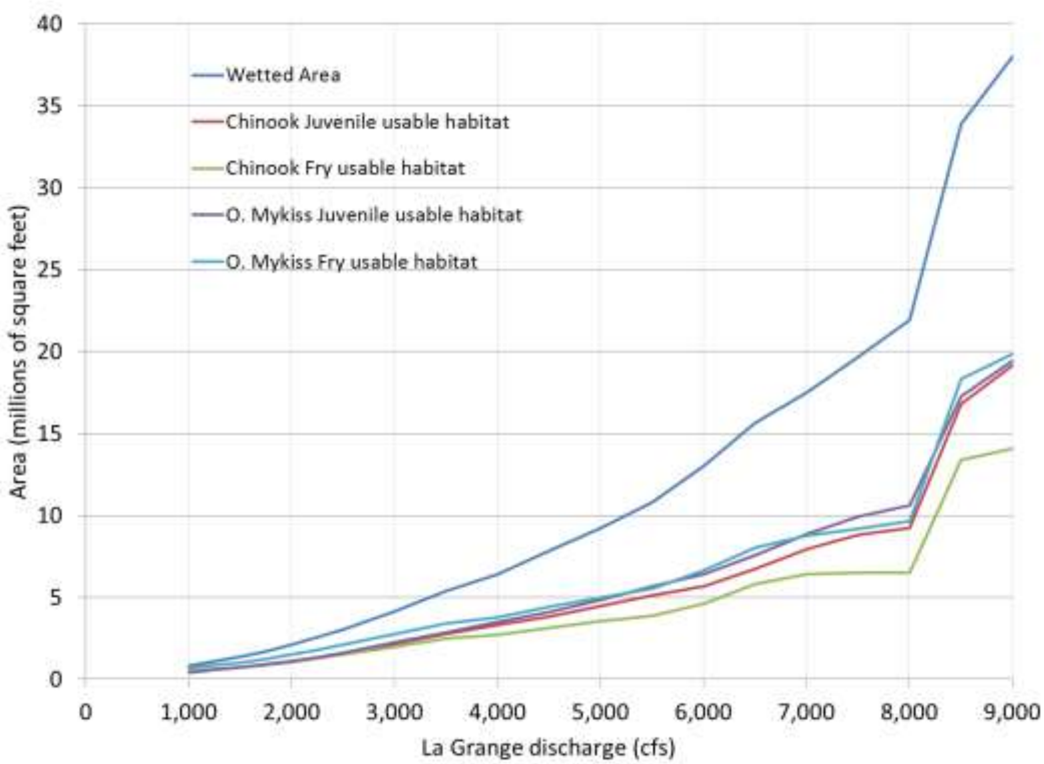


Figure 5.2-4. Model C results showing total wetted and usable habitat areas for juvenile salmonid life stages in the lower Tuolumne River (RM 21.5–0.9).

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.

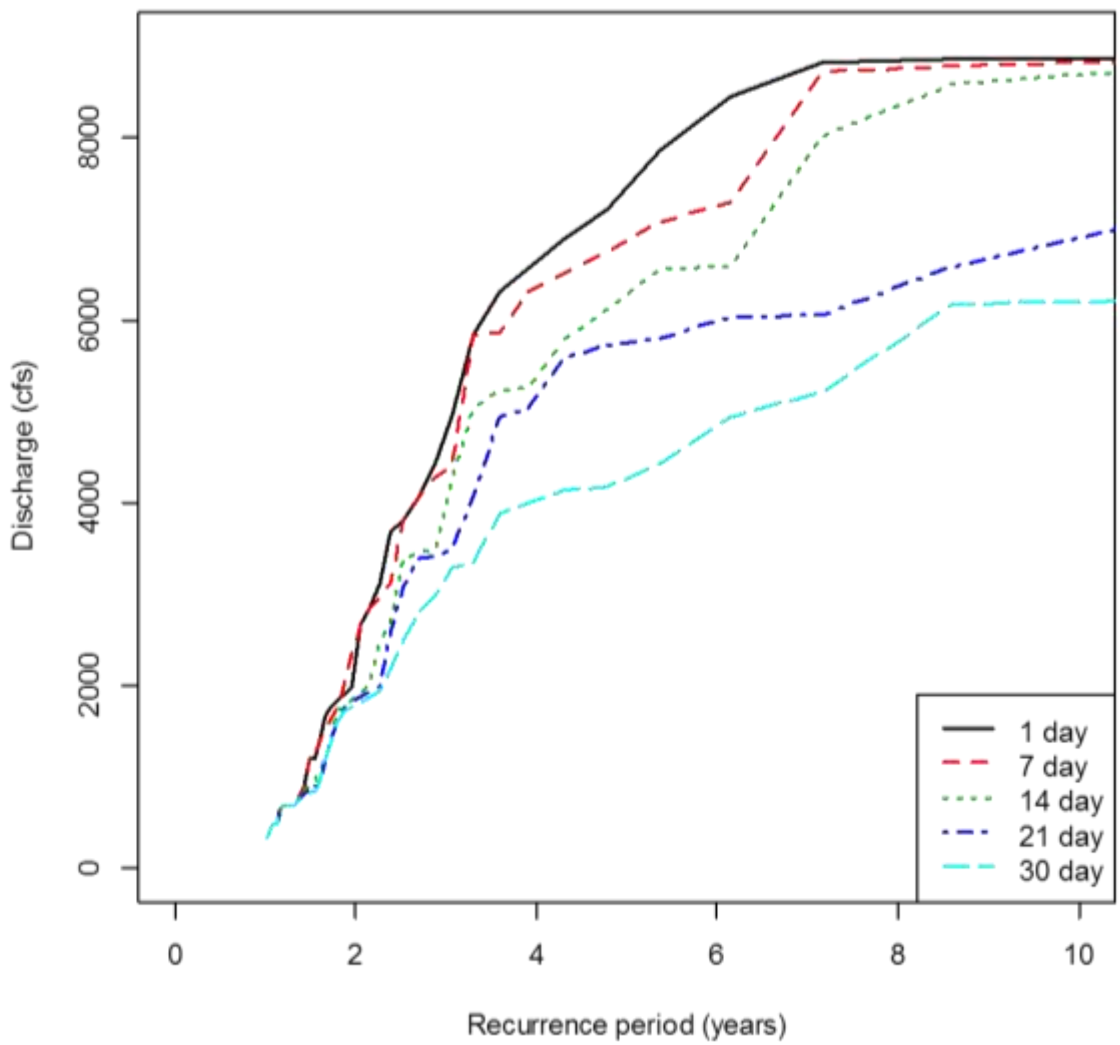


Figure 5.3-1. Annual frequency with which "events", exceeding given flow magnitude and duration thresholds, occur in the lower Tuolumne River from February through May under Base Case (1971–2012) hydrology.

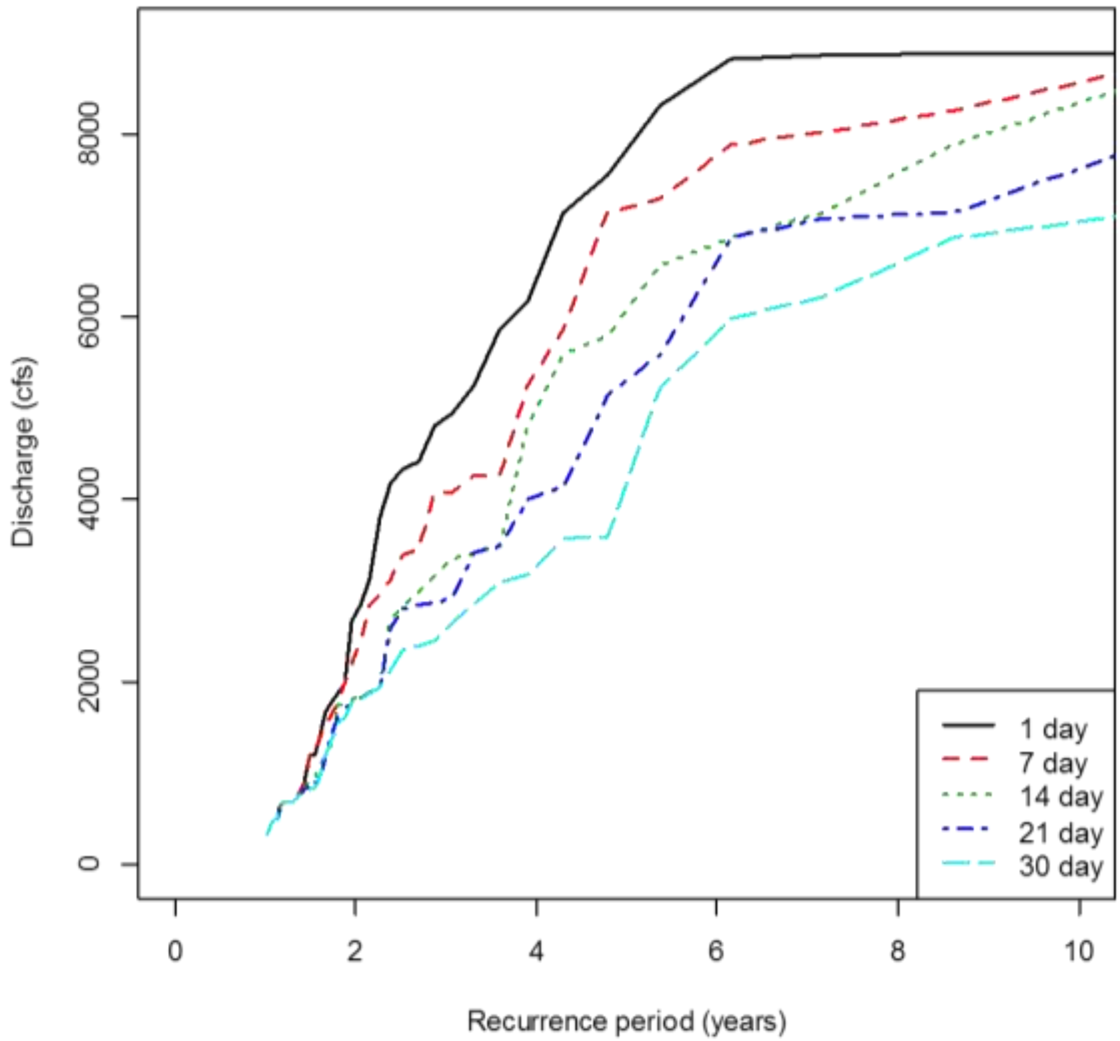


Figure 5.3-2. Annual frequency with which "events", exceeding given flow magnitude and duration thresholds, occur in the lower Tuolumne River from March through September under Base Case (1971–2012) hydrology.

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 of larger amounts of continuously inundated areas for the durations analyzed are shown in Figure 5.3-3.

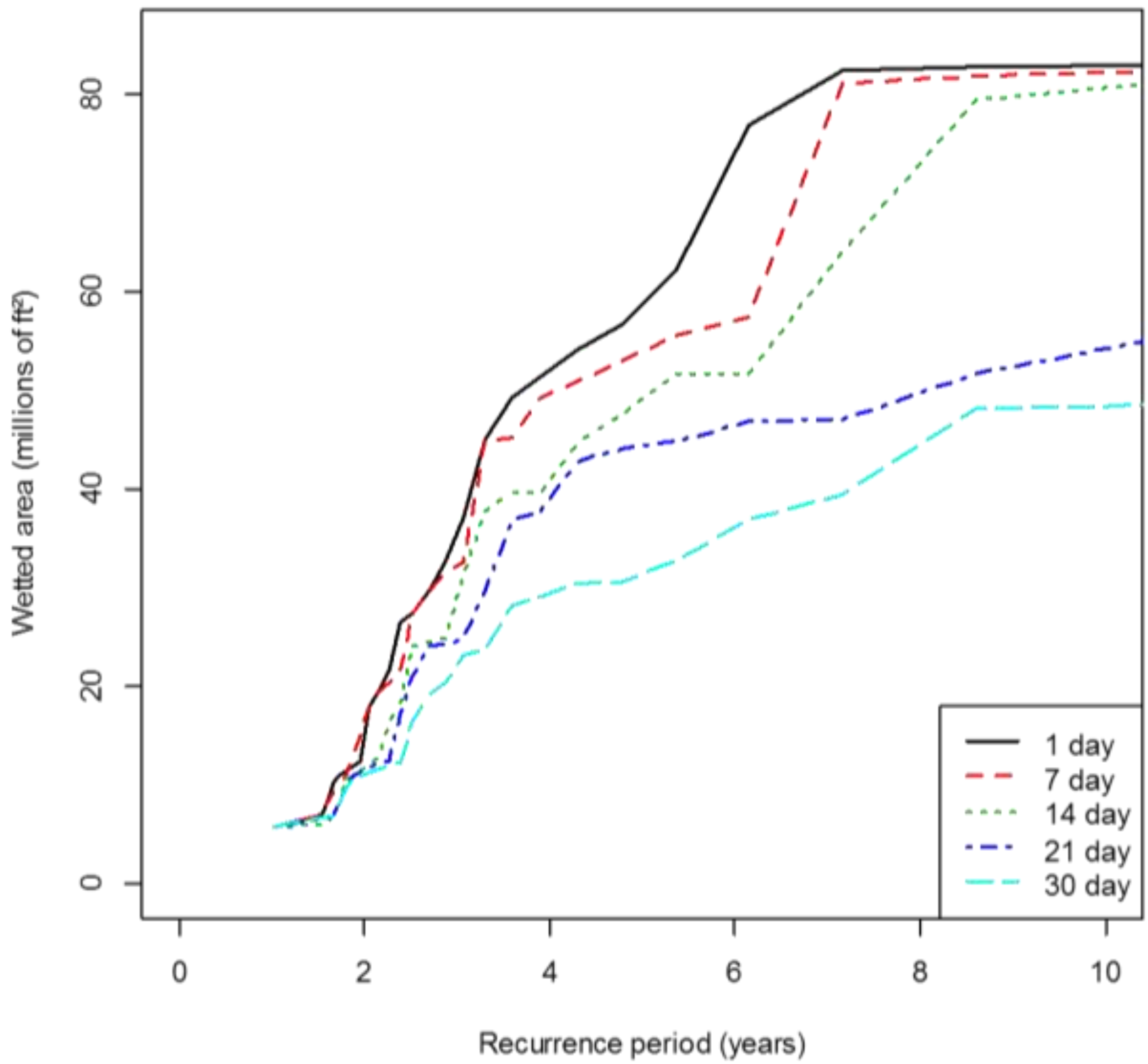


Figure 5.3-3. Total area-duration-frequency (ADF) plot showing recurrence of events exceeding various total inundation area and duration thresholds in the lower Tuolumne River from February through May under Base Case (1971–2012) hydrology.

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).

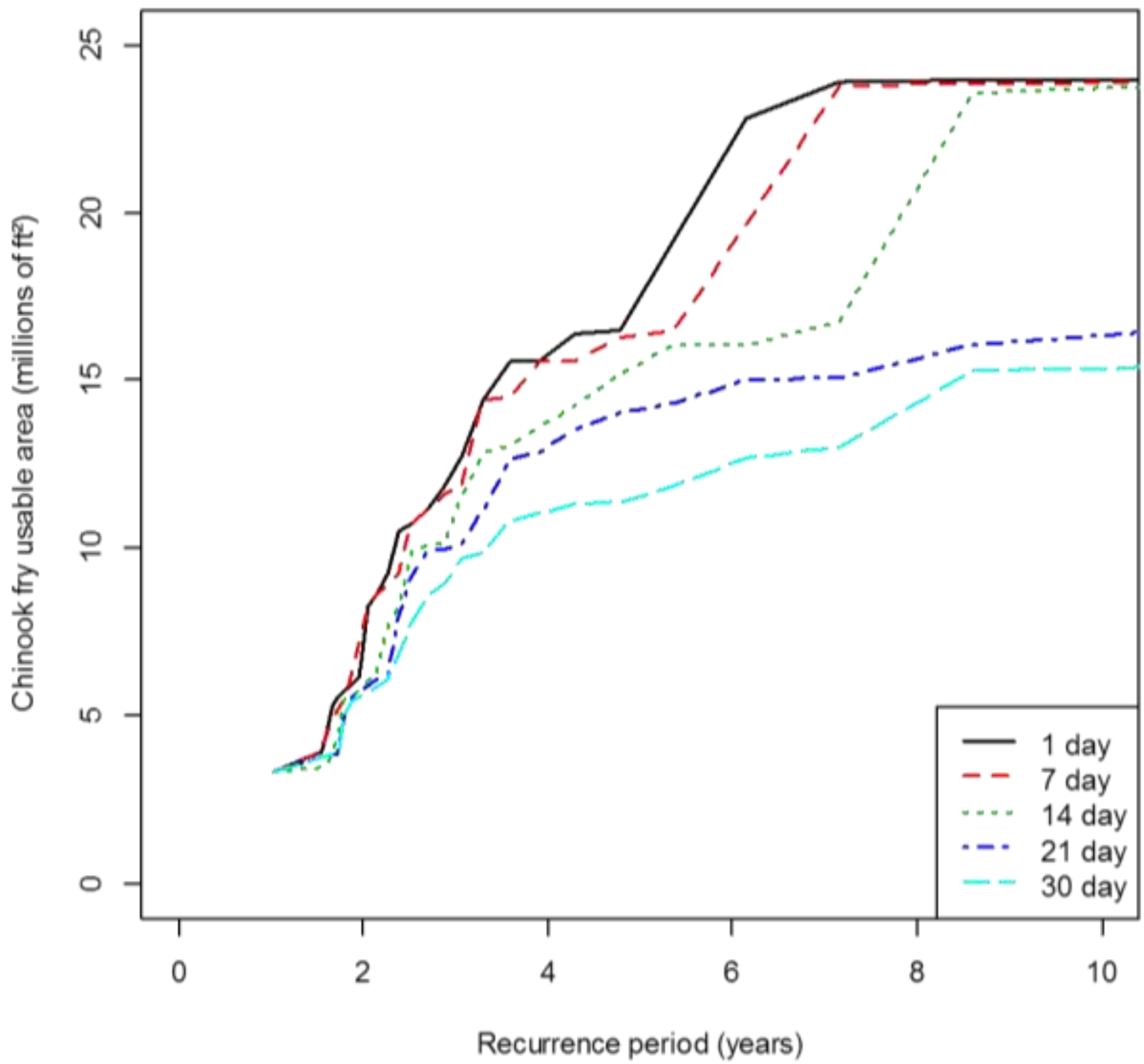


Figure 5.3-4. Chinook salmon fry habitat area-duration-frequency (ADF) plot showing recurrence of events exceeding various usable habitat area and duration thresholds in the lower Tuolumne River from February through May under Base Case (1971–2012) hydrology.

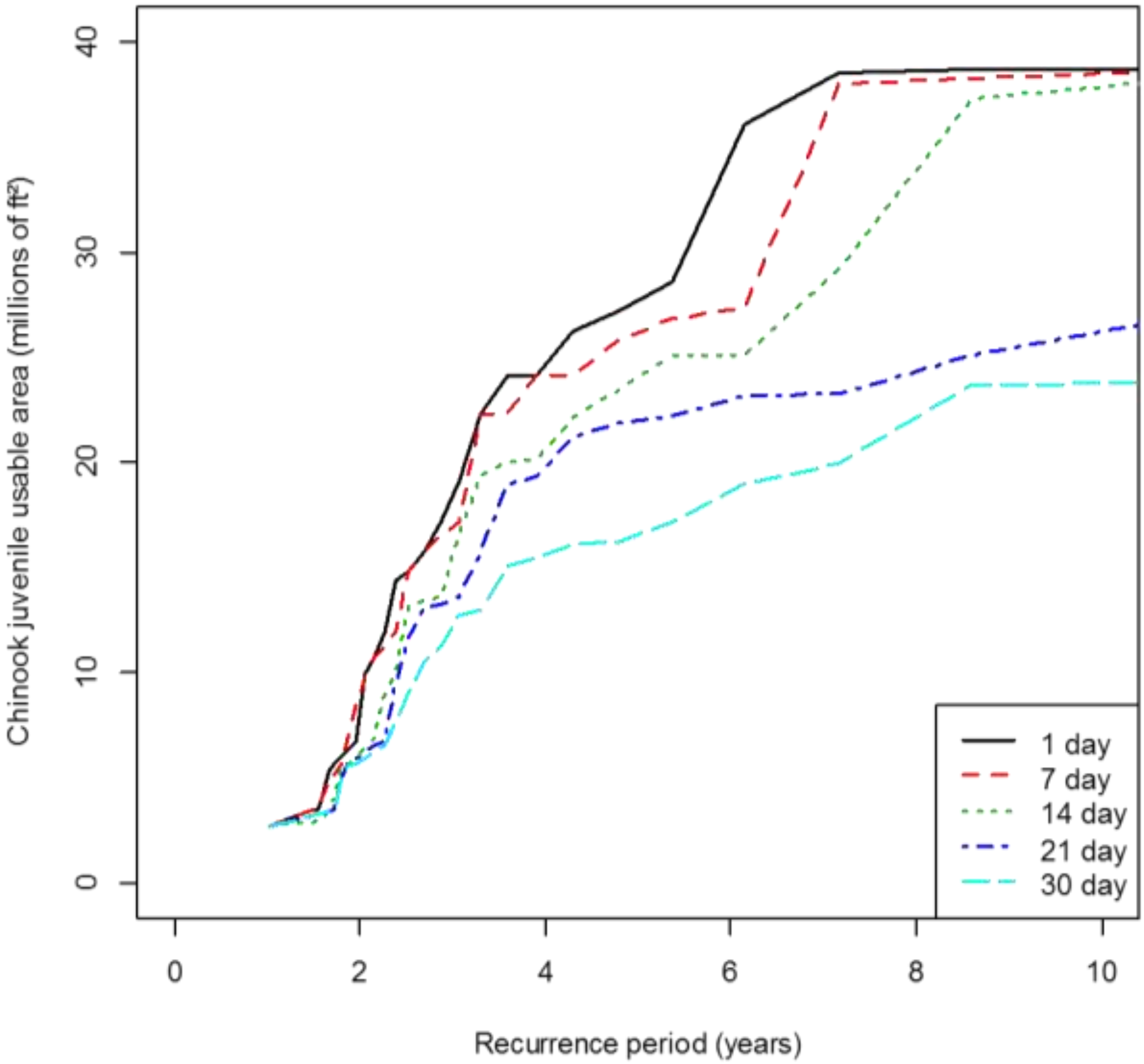


Figure 5.3-5. Chinook salmon juvenile habitat area-duration-frequency (ADF) plot showing recurrence of events exceeding various usable habitat area and duration thresholds in the lower Tuolumne River from February through May under Base Case (1971–2012) hydrology.

5.3.3 Juvenile *O. mykiss* floodplain rearing habitat

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. 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), *O. mykiss* are rarely documented on floodplains. Nevertheless, floodplain habitat for 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) is repeated here for juvenile life stages of *O. mykiss*.

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).

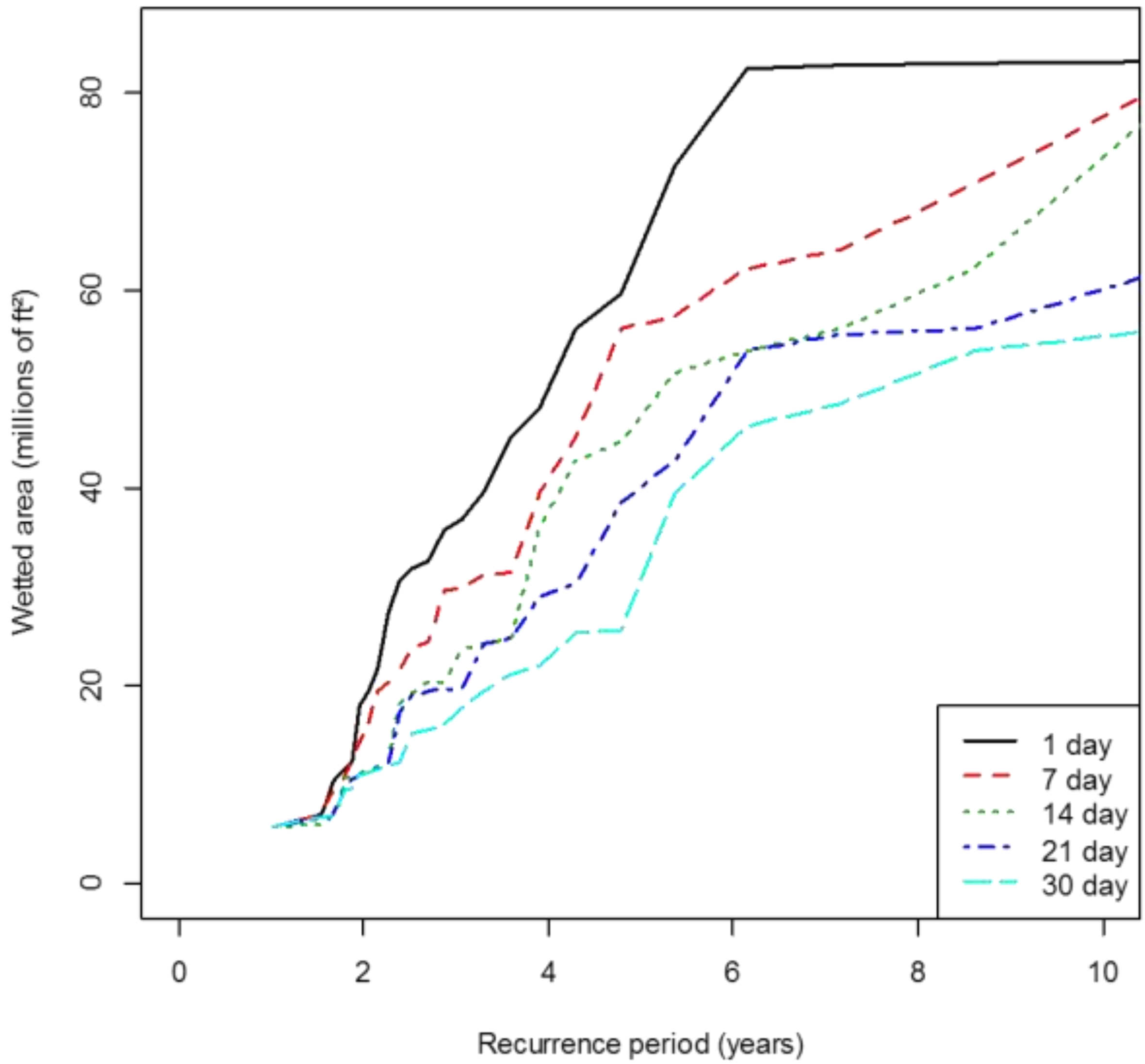


Figure 5.3-6. Total area-duration-frequency (ADF) plot showing recurrence of events exceeding various total inundation area and duration thresholds in the lower Tuolumne River from March through September under Base Case (1971–2012) hydrology.

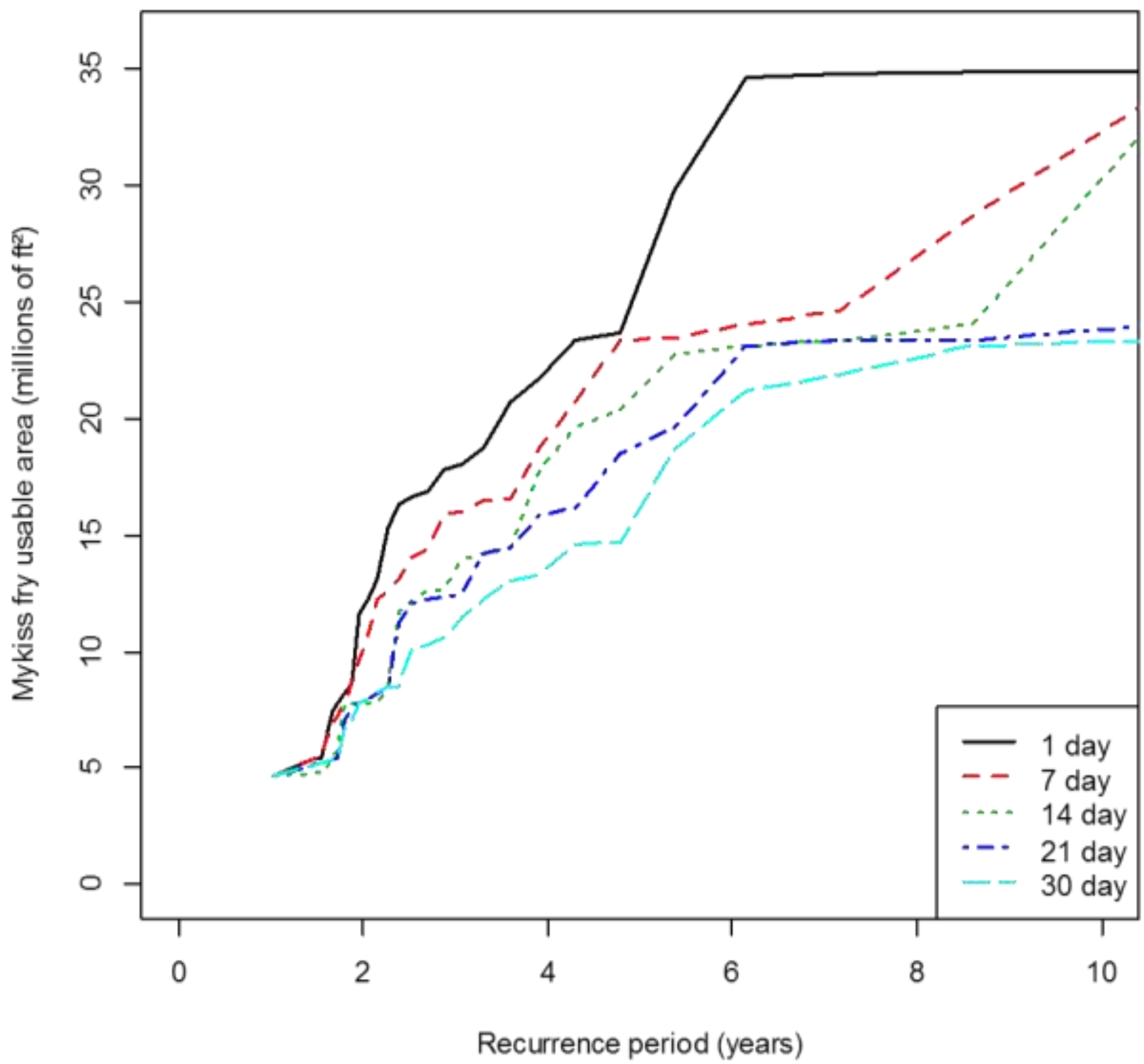


Figure 5.3-7. *O. mykiss* fry habitat area-duration-frequency (ADF) plot showing recurrence of events exceeding various usable habitat area and duration thresholds in the lower Tuolumne River from March through September under Base Case (1971–2012) hydrology.

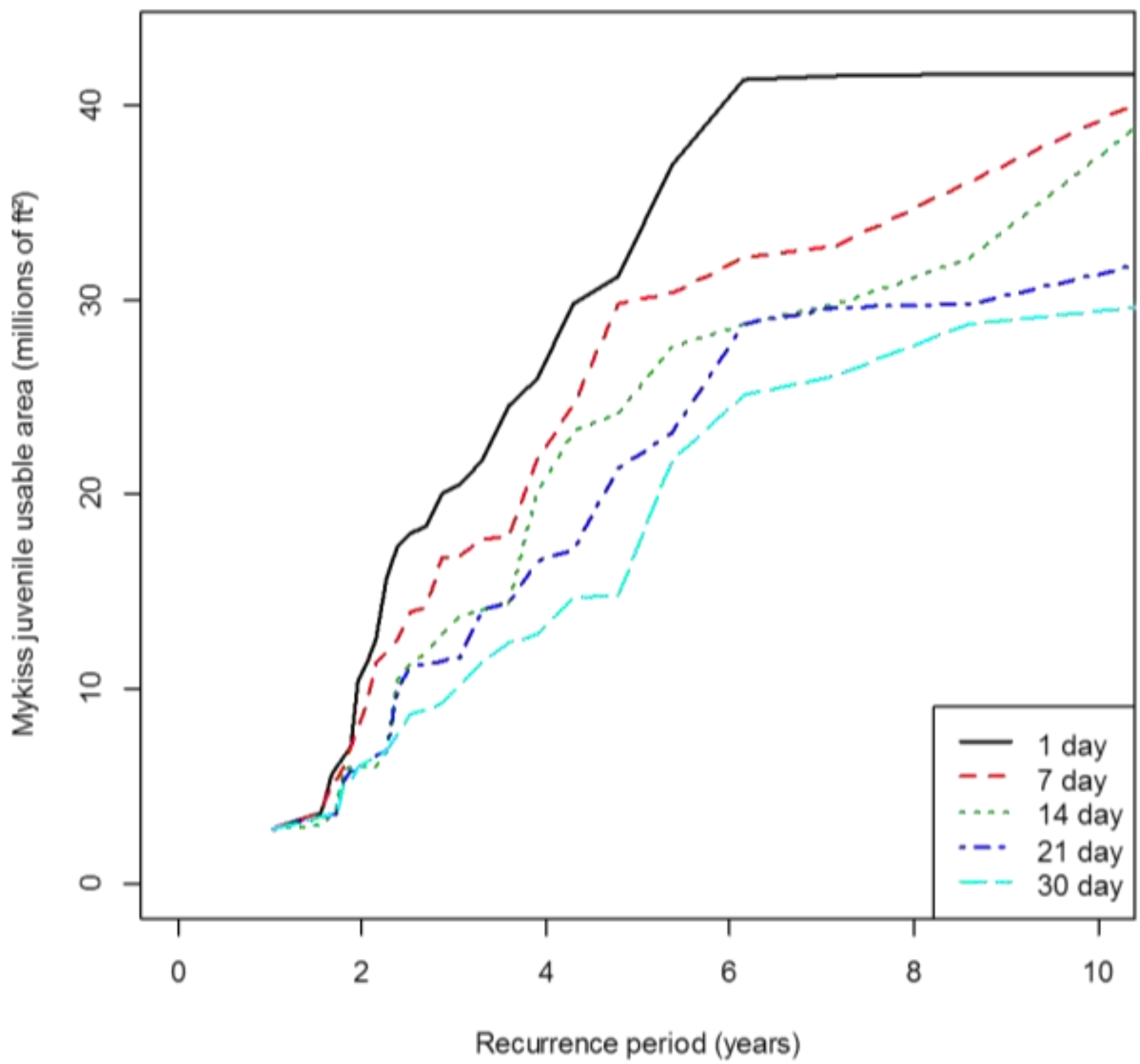


Figure 5.3-8. *O. mykiss* juvenile habitat area-duration-frequency (ADF) plot showing recurrence of events exceeding various usable habitat area and duration thresholds in the lower Tuolumne River from March through September under Base Case (1971–2012) hydrology.

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. 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).

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.

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

WORKSHOP NO. 1 AND NO. 2 MEETING NOTES

APPENDIX A

WORKSHOP NO. 1 MEETING NOTES

Don Pedro Project Relicensing (FERC No. 2299)
W&AR-21 Floodplain Hydraulic Analysis Study
Workshop No. 1
HDR Office in Sacramento
Final Meeting Notes

Thursday, February 13, 2014
1:30 PM to 4:30 PM

Attendees

Nolan Adams	HDR, Inc.
Peter Barnes	State Water Resources Conservation Board
Jenna Borovansky	HDR, Inc.
Allison Boucher	Tuolumne River Conservancy
Dave Boucher	Tuolumne River Conservancy
Steve Boyd	Turlock Irrigation District
Anna Brathwaite (by phone)	Modesto Irrigation District
Jesse Fernandes (by phone)	HDR, Inc.
Noah Hume	Stillwater Sciences
Matt Moses	San Francisco Public Utilities Commission
Bill Paris (by phone)	Modesto Irrigation District
Pani Ramalingam	HDR, Inc.
Bill Sears (by phone)	City and County of San Francisco
Rob Sherrick	HDR, Inc.
Maia Singer	Stillwater Sciences
Ron Yoshiyama	City and County of San Francisco

On February 13, 2014, the Turlock Irrigation District (TID) and Modesto Irrigation District (MID) (collectively, the Districts) conducted Workshop No. 1 for the Don Pedro Hydroelectric Project Floodplain Hydraulic Analysis Study (W&AR-21). This document summarizes items discussed in the Workshop. It is not intended to be a transcript of the meeting. Attachment A provides the slides presented during the Workshop.

Following introductions, Jenna Borovansky of HDR, Inc. (HDR), consultant to the Districts, provided background on the study process to date. She noted that, in accordance with the study schedule, this is a Workshop for the W&AR-21 modeling effort and will follow the Consultation Workshop protocols. In January 2013, the Districts received comments on the ISR, including a request for additional information. The Districts agreed to conduct a floodplain study. She added that the study plan was developed during the spring and summer of 2013. Ms. Borovansky said that the W&AR-21 study goals build on past information and that the purpose of this Workshop is to present the 2D hydraulic and habitat modeling approach, and provide a first cut at describing the demarcation between in-river and overbank habitat.

Noah Hume of Stillwater Sciences, consultant to the Districts, reviewed previous floodplain studies on the lower Tuolumne River. Mr. Hume noted that the 2012 2D Pulse Flow Study focused on in-channel predictions of habitat availability. He then presented the W&AR-21 study objectives.

Pani Ramalingam of HDR reviewed the existing topographic data. He noted that there are no breaks in the 2011 LiDAR data, but that there are some breaks in the floodplain ponds. He said that the study team is currently working to fill these few data gaps. Mr. Ramalingam then presented the calibration data.

During the remainder of the Workshop, Mr. Hume and Mr. Ramalingam alternated as presenter. They explained the advantages of using the model TUFLOW for this study, noting that TUFLOW has been used in numerous river hydraulic modeling studies in Europe and Australia and in multiple studies by the U.S. Army Corps of Engineers and California Department of Water Resources. Mr. Hume and Mr. Ramalingam said that TUFLOW is advantageous because the study will model low to moderate flows in the Tuolumne River, rather than high flows, and will attempt to link hydraulic conditions to fish habitat availability, which requires a hydraulic model that realistically represents a flow path from main channel to the 2D floodplain flows and that has a flexible grid size. They also noted that TUFLOW allows changes to be made to local topography and also has a good 1D in-channel modeling component, an attribute that distinguishes TUFLOW from most other 2D models.

Mr. Hume and Mr. Ramalingam said that the computational efficiency of TUFLOW decreases with smaller grid size. TUFLOW was run for a Pilot Reach (RM 40-52) to determine water surface elevation (WSEL) sensitivity to grid size and the results indicate that there is no benefit to running the model at a grid size lower than 30 ft^2. Mr. Hume and Mr. Ramalingam said that the results for Riffle 4A/4B indicate that the smaller the grid size, the higher the estimated area of suitable rearing habitat. 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. Mr. Hume and Mr. Ramalingam said the grid size in particular areas can be reduced, if needed.

Allison Boucher of the Tuolumne River Conservancy asked if the model distinguishes between inundated areas that have active flow/velocity and areas that do not have flow/velocity. As an example, she said that when Legion Park floods, there is no flow. The water just sits on the grass and does not appear to create good habitat. Mr. Hume replied that 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.

Mr. Hume and Mr. Ramalingam said that the existing IFIM Study (2012) is a 1D study and covers in-channel habitat at flows up to 1,200 cfs. They also said that the TUFLOW 1D-2D domain boundary is set in locations that will maximize the quantity of potential 2D habitat to be analyzed. Mr. Ramalingam provided example images of the 1D-2D domain boundary location within the Pilot Reach.

Mr. Ramalingam presented the TUFLOW modeling plan and Mr. Hume presented the conceptual steps in the habitat analysis, whereby TUFLOW provides cell-specific velocity and depth predictions. He added that the velocity and depth predictions are modeled using the habitat suitability criteria (HSC) developed in the 2012 IFIM study and combined with discharge recurrence probabilities to generate area-duration-frequency curves. Ms. Boucher asked if the results include consideration of suitable habitat in different sections of the river (i.e., reach-by-reach). Mr. Hume affirmed that the model has that capability.

Mr. Hume and Mr. Ramalingam said the study team will distribute electronic links to an updated map book of the lower Tuolumne River, which will show the proposed location of the TUFLOW 1D-2D domain boundary. They requested that relicensing participants provide feedback on the model domain delineation approach. They noted that a follow-up conference call to discuss feedback could be scheduled, if desired.

Ms. Boucher asked if the W&AR-21 study report will provide information on the four different fish life stages (i.e., fry and juvenile salmon; fry and juvenile *O. mykiss*). These species require different habitat types and the modeling approach would need to consider these differences. Mr. Hume replied that life history timing for each species is specific. For example, fry and juveniles for each species use the habitats at slightly different times in the year. He said this is an inherent screening tool in the model.

Ms. Boucher said that landowners may like to know what is happening on their property and asked if it would be possible to provide this information. Ms. Borovansky replied that it may be possible to provide this information with respect to habitat, but reiterated that the purpose of the study is not to predict when or which properties will flood.

Ms. Boucher asked how the model predicts the velocity for a particular floodplain location. Mr. Ramalingam replied that TUFLOW models velocity on a cell-by-cell basis.

Ms. Boucher asked how the model deals with velocity in off-channel areas like flooded roads and bends. She noted that there is a property downstream of new La Grange Bridge where she had observed large eddies during high flows. Mr. Ramalingam replied by showing the model results at 3,000 cfs. He noted that the velocity and depth vectors shift with each time step and that flow eddies are represented.

Ms. Boucher asked how roughness is associated with different vegetation types, such as willow. Mr. Ramalingam and Nolan Adams of HDR replied that the study team is working on this and at this time uses the best available information, such as from survey data and aerial imagery, to make distinctions between vegetation types.

Ms. Boucher asked what the study output is and if the model could be run under different scenarios. Mr. Hume replied that the study report will include plots and tabulations of inundated area. He noted that the model will be available for relicensing participants (RPs) to use to run different scenarios. RPs may also use the study report output to extrapolate results at a range of flows or request that the Districts run the model for a specific scenario.

Mr. Ramalingam showed how a recently restored floodplain surface might respond to flows of 8,400 cfs based on TUFLOW predictions. Dave Boucher of the Tuolumne River Conservancy and Ms. Boucher noted that the predicted flow re-routing appears to mimic what actually occurs in the area they are familiar with, which provided positive feedback on the calibration. They said that the TUFLOW model appears to be a reliable tool that would really help the decision-making process in relicensing.

Appendices

Appendix 1: W&AR-21 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

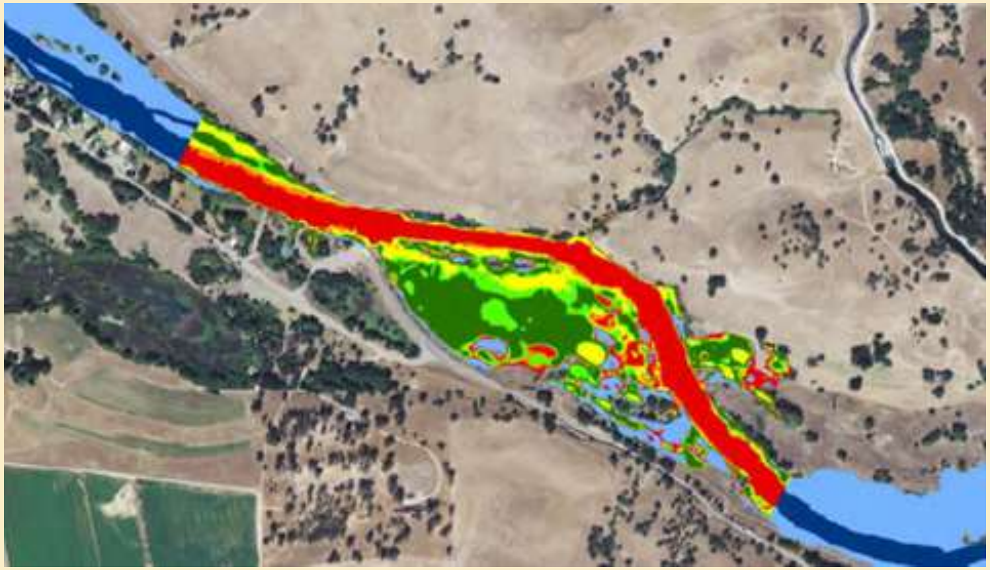
- Hydraulic Modeling Approach
  - Data Sources
  - TUFLOW Model
  - Overbank vs. In Channel Areas

- 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

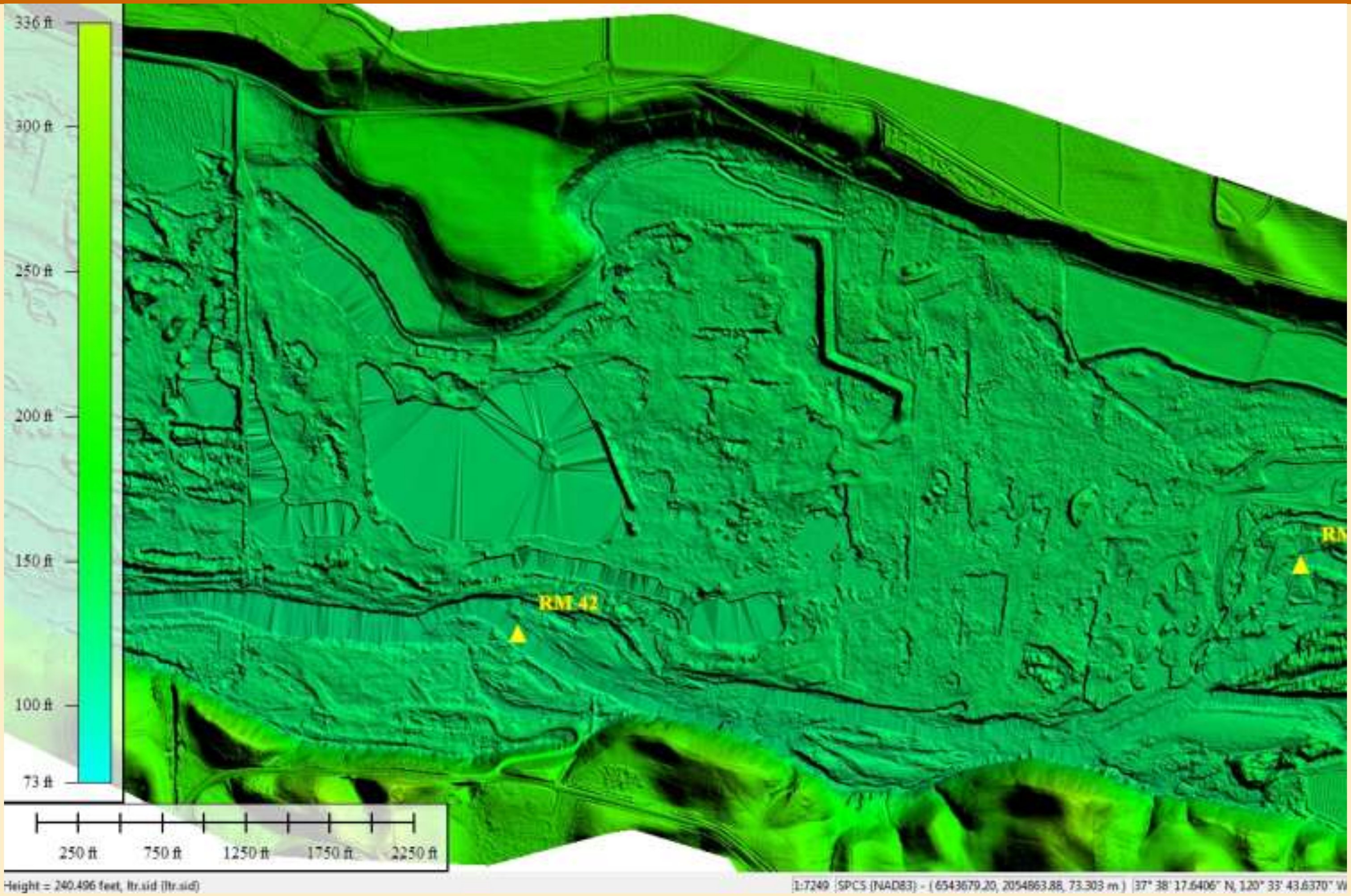
Hydraulic Modeling Approach

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

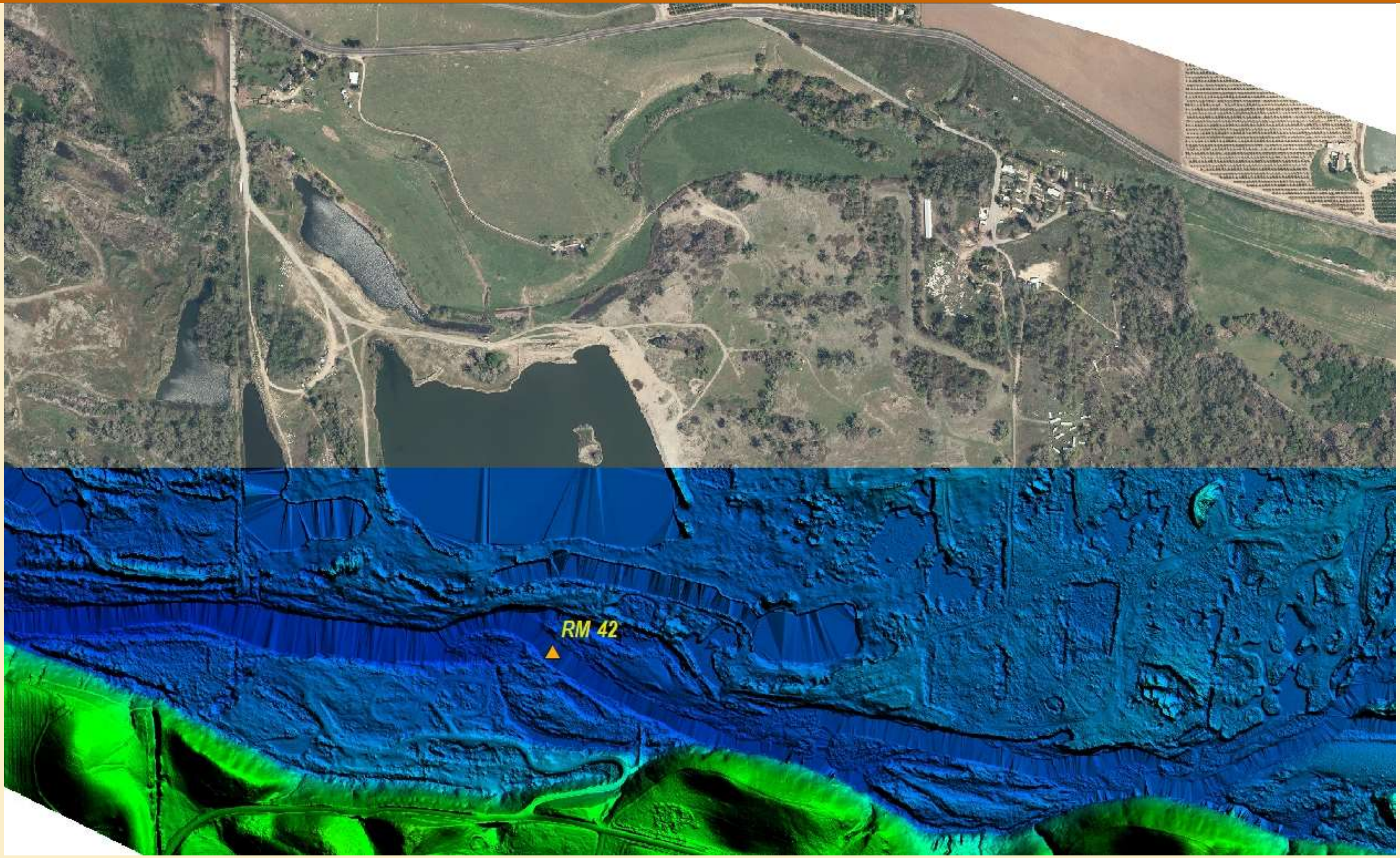
Topographic Data

- **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

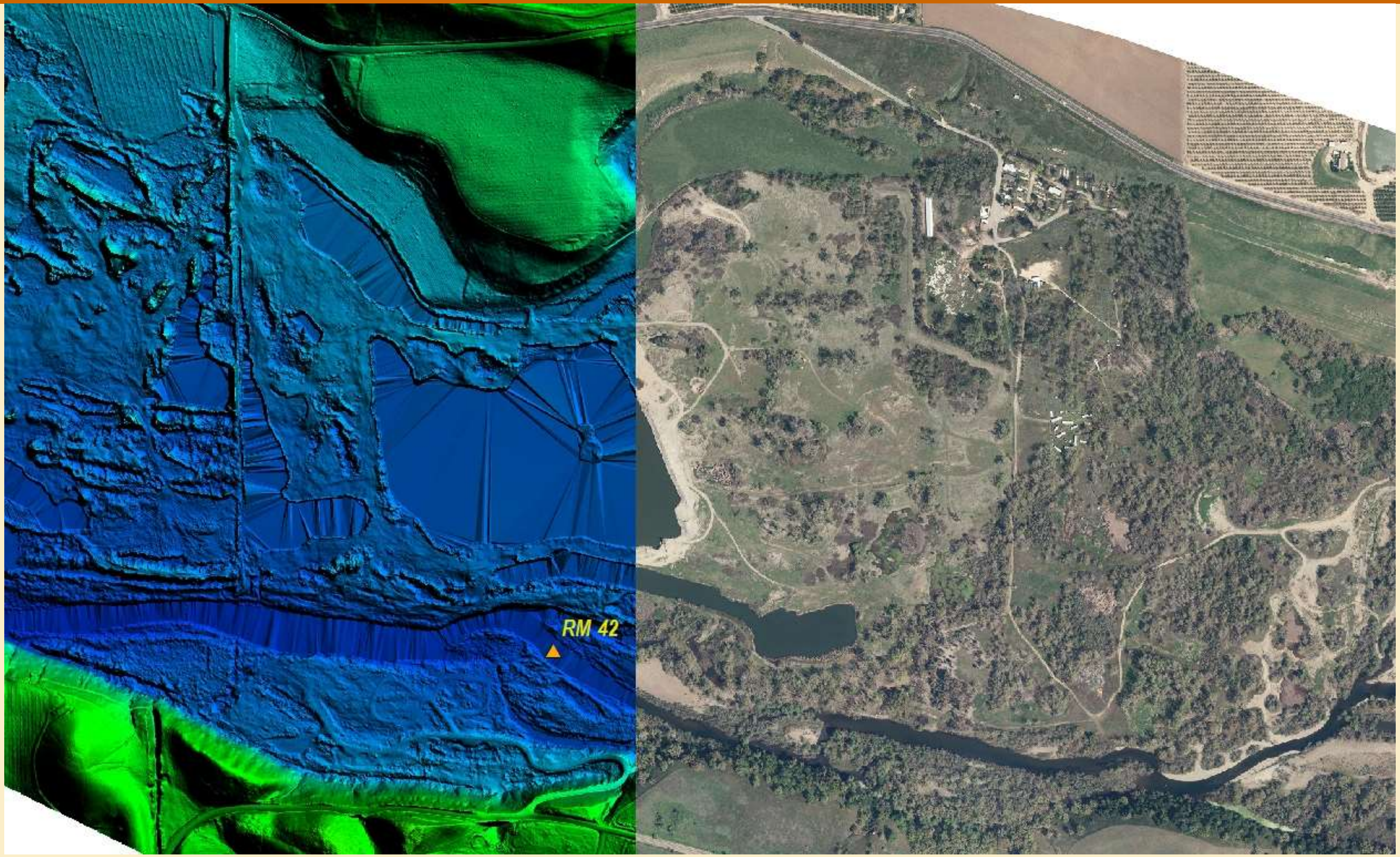
Topographic ASCII Grids



Water Body Details



Water Body Details



1D Low Flow Channel

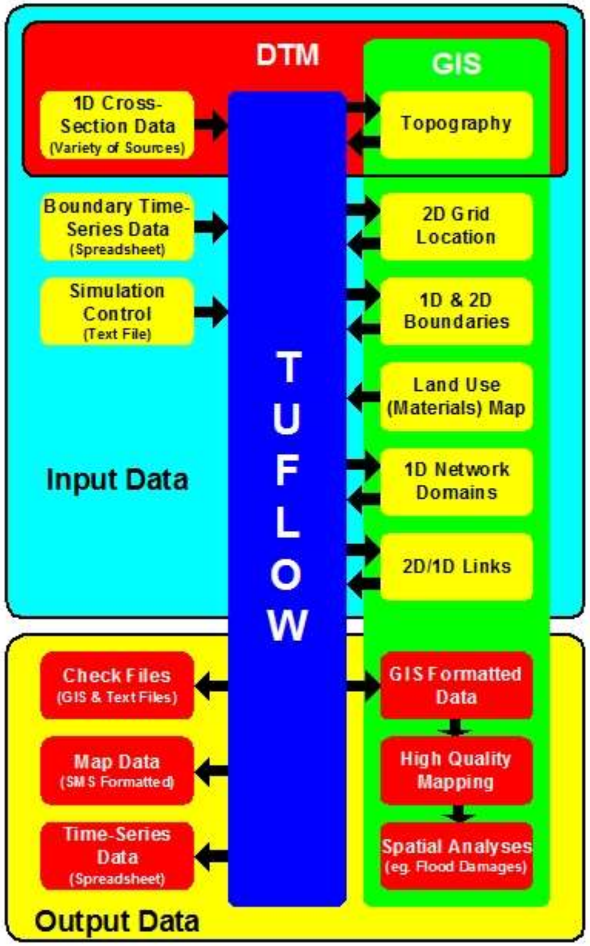
RM	Source	Original Reason for Collection
0-6.7	DWR (2009)	CVFED HEC-RAS, FLO-2D Models
6.7-24	DWR/FEMA (2012)	FEMA Study, HEC-RAS Model
24-38	HDR (2013), Stillwater (2013)	Temperature HEC-RAS Model, IFIM Study
38-51.5	McBain & Trush (2005)	Coarse Sediment Management
45.5-51.8	Stillwater (2013)	W&AR4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

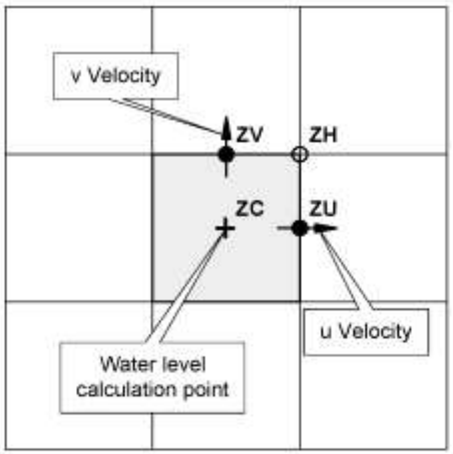
- Unsteady 2D model
- Implicit finite difference scheme – FAST!
- 2D overbank areas with 1-D low flow channel
- River-wide modeling



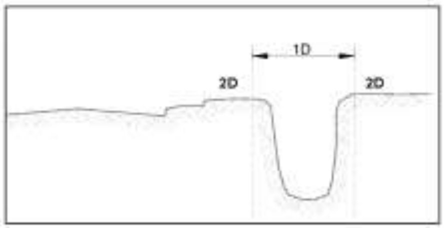
TUFLOW Data Input and Output Structure

Advantages of TUFLOW Model

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



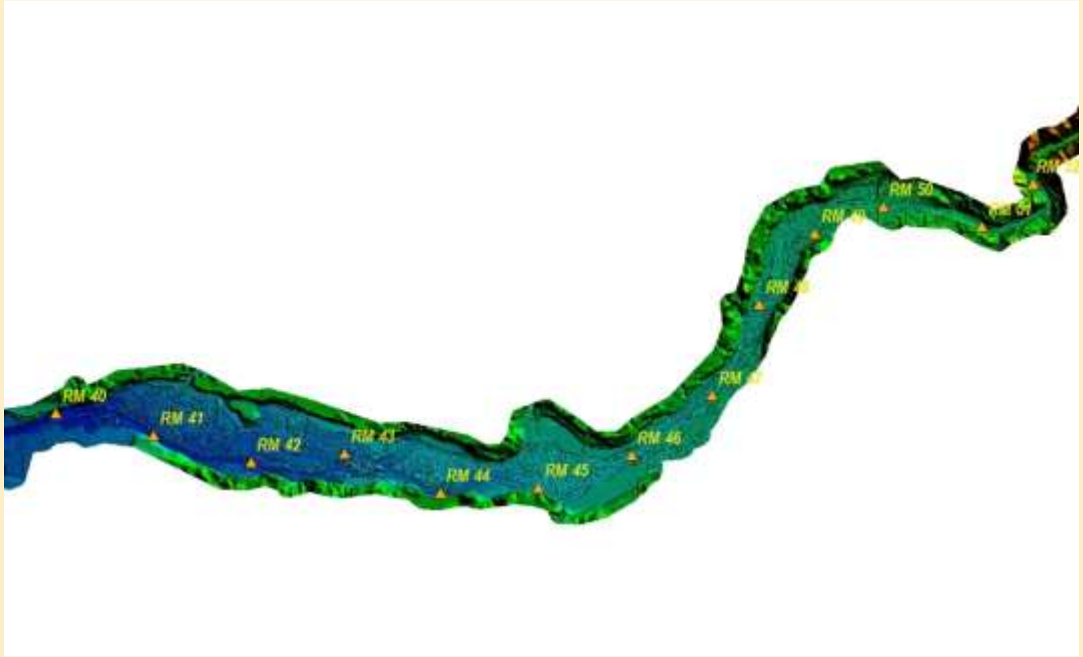
Location of Zpts and Computation Points



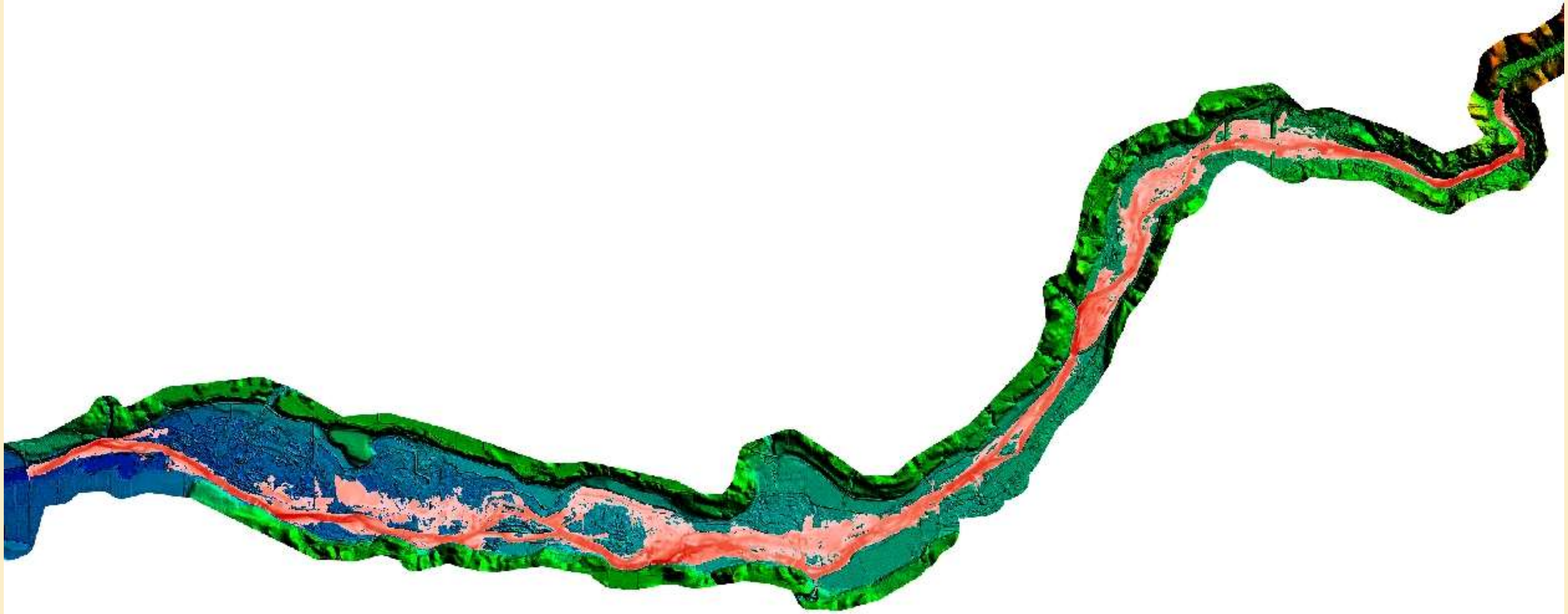
Modelling a Channel in 1D and the Floodplain in 2D

Pilot Model – RM 52 to RM 40

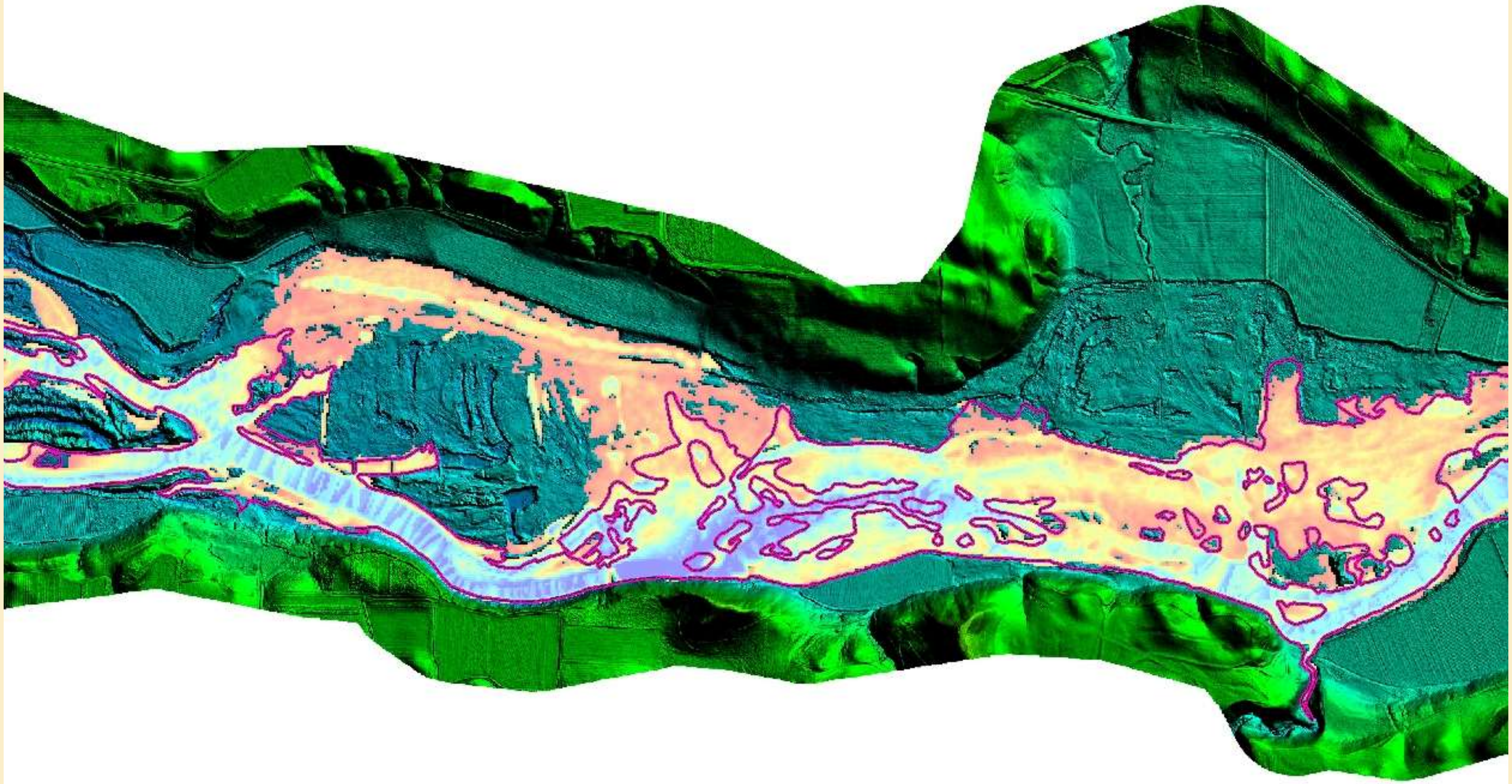
- 2012 Pulse Flow Study
- Continuous river bathymetry data
- Test Runs
- 50, 30 & 20 ft cells



Inundation Extent – 8,400 cfs



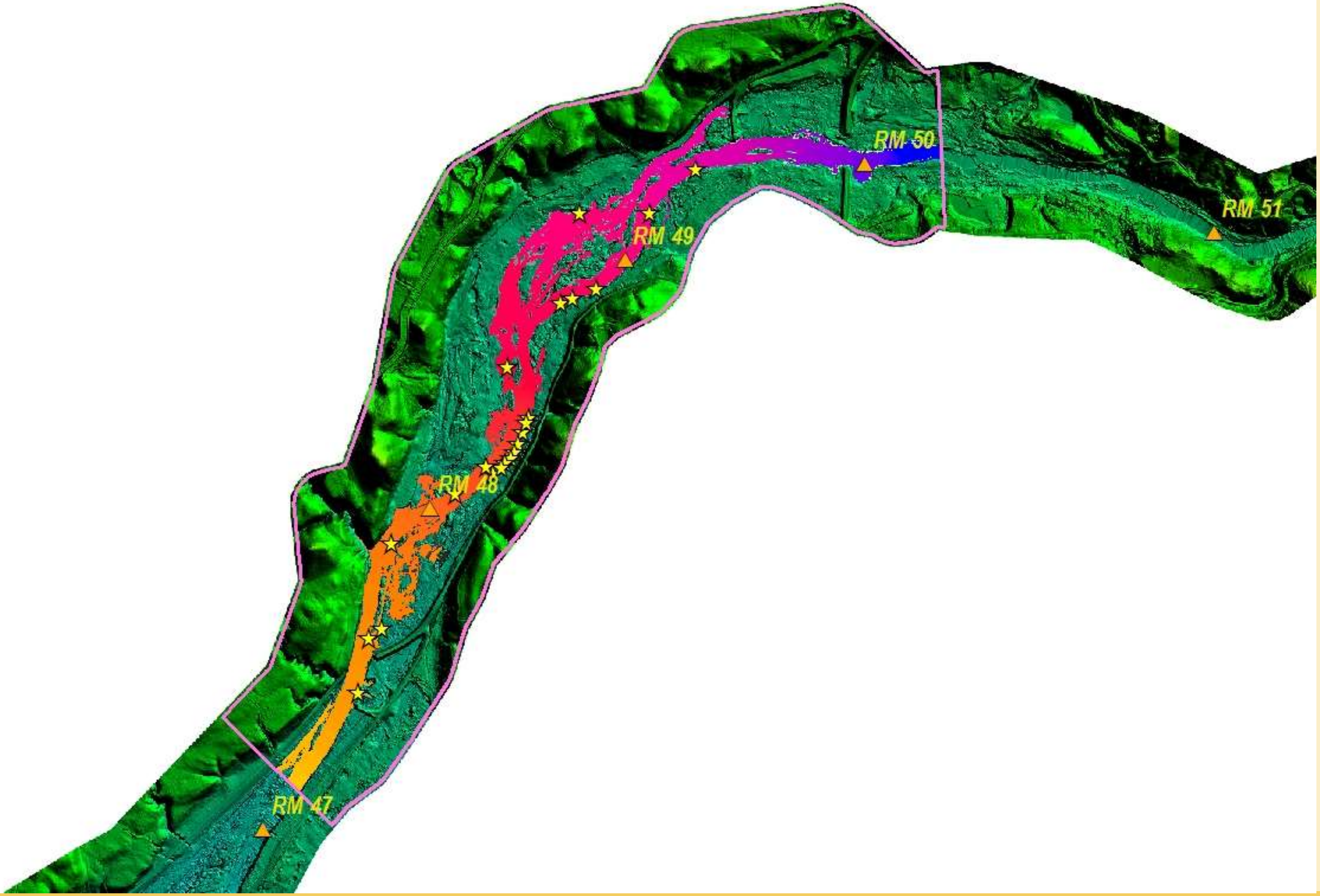
Historical Inundation Extent



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

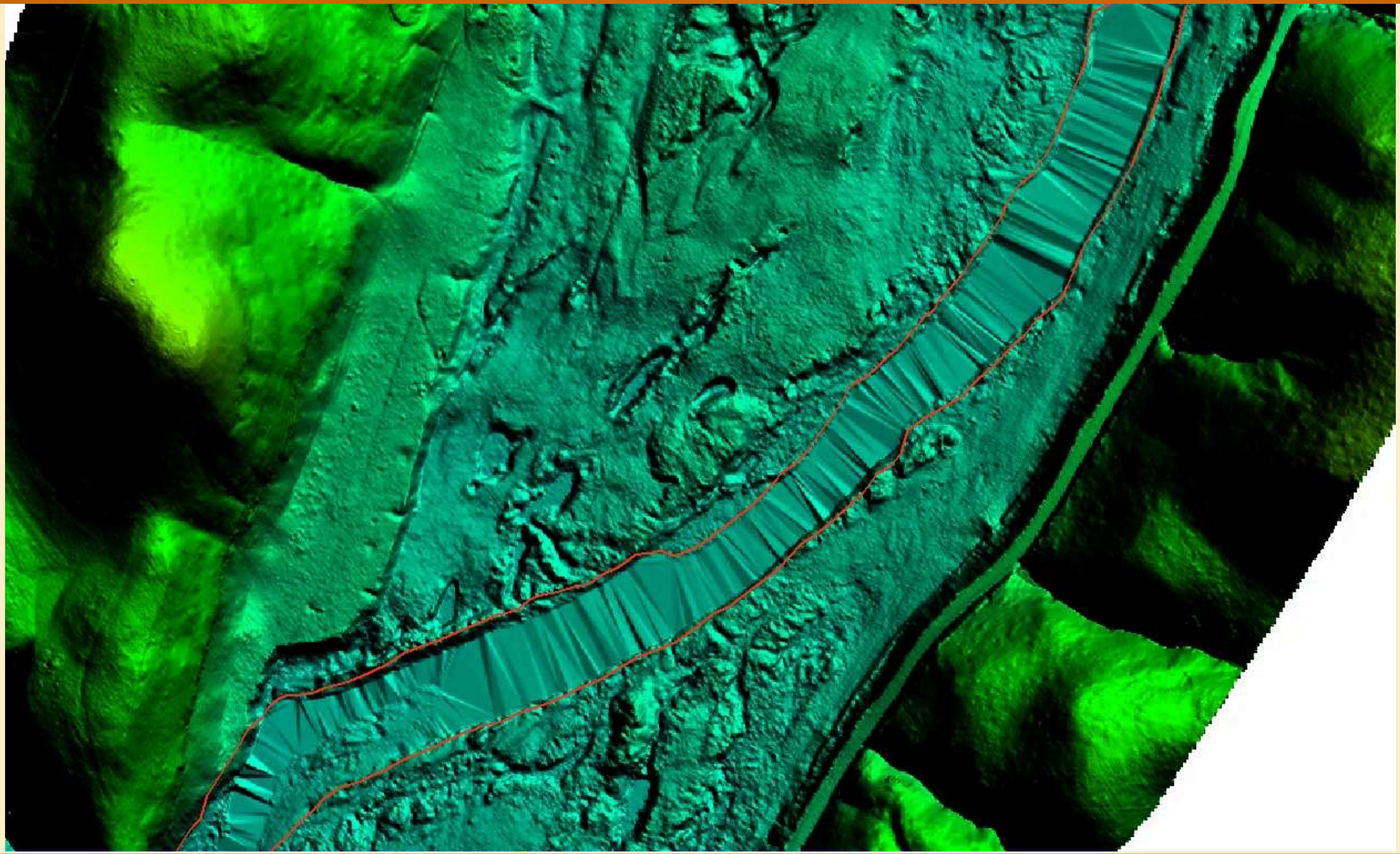
Salmonid juvenile usable habitat estimates

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

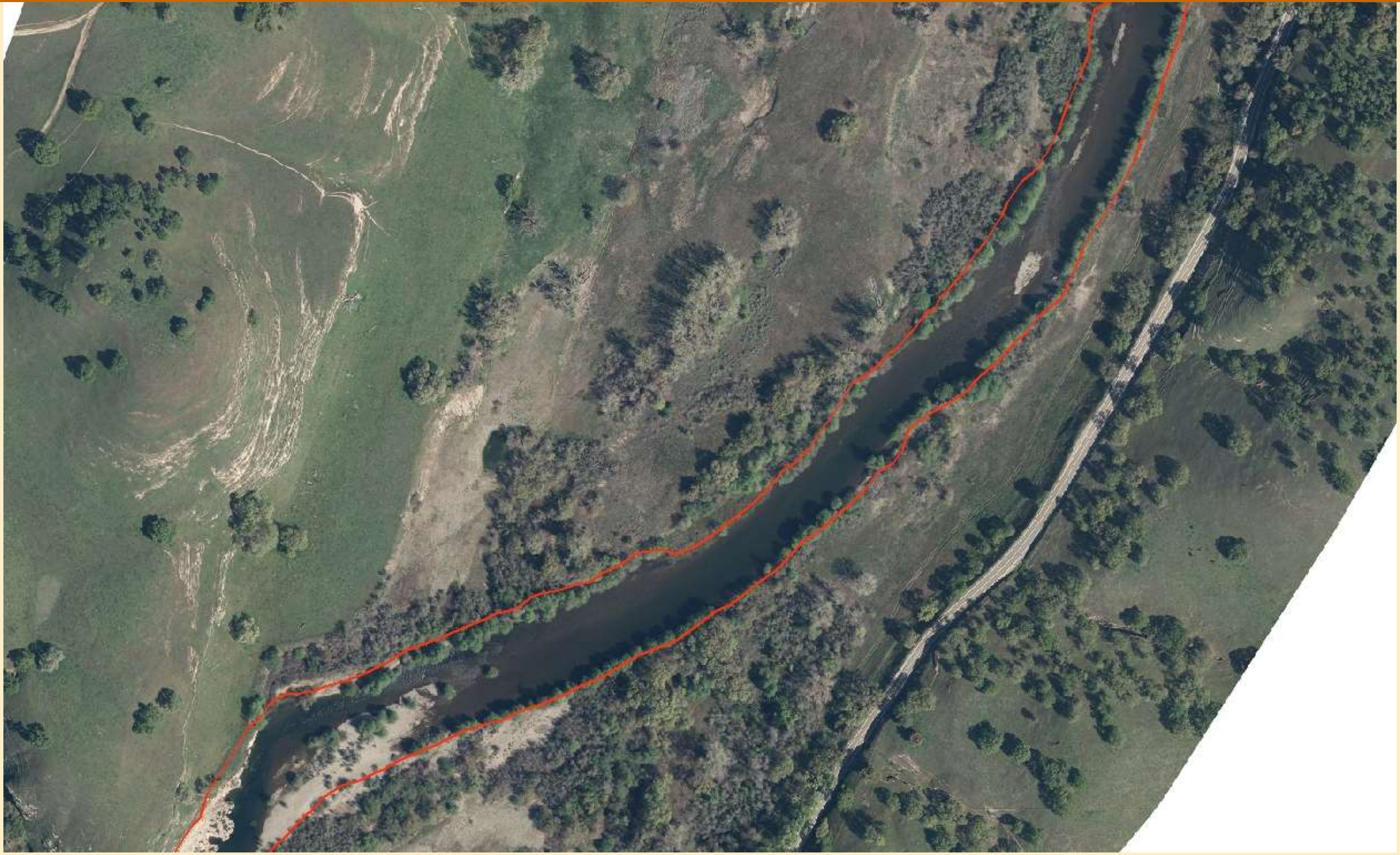
Overbank vs. In-Channel Areas

- **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**

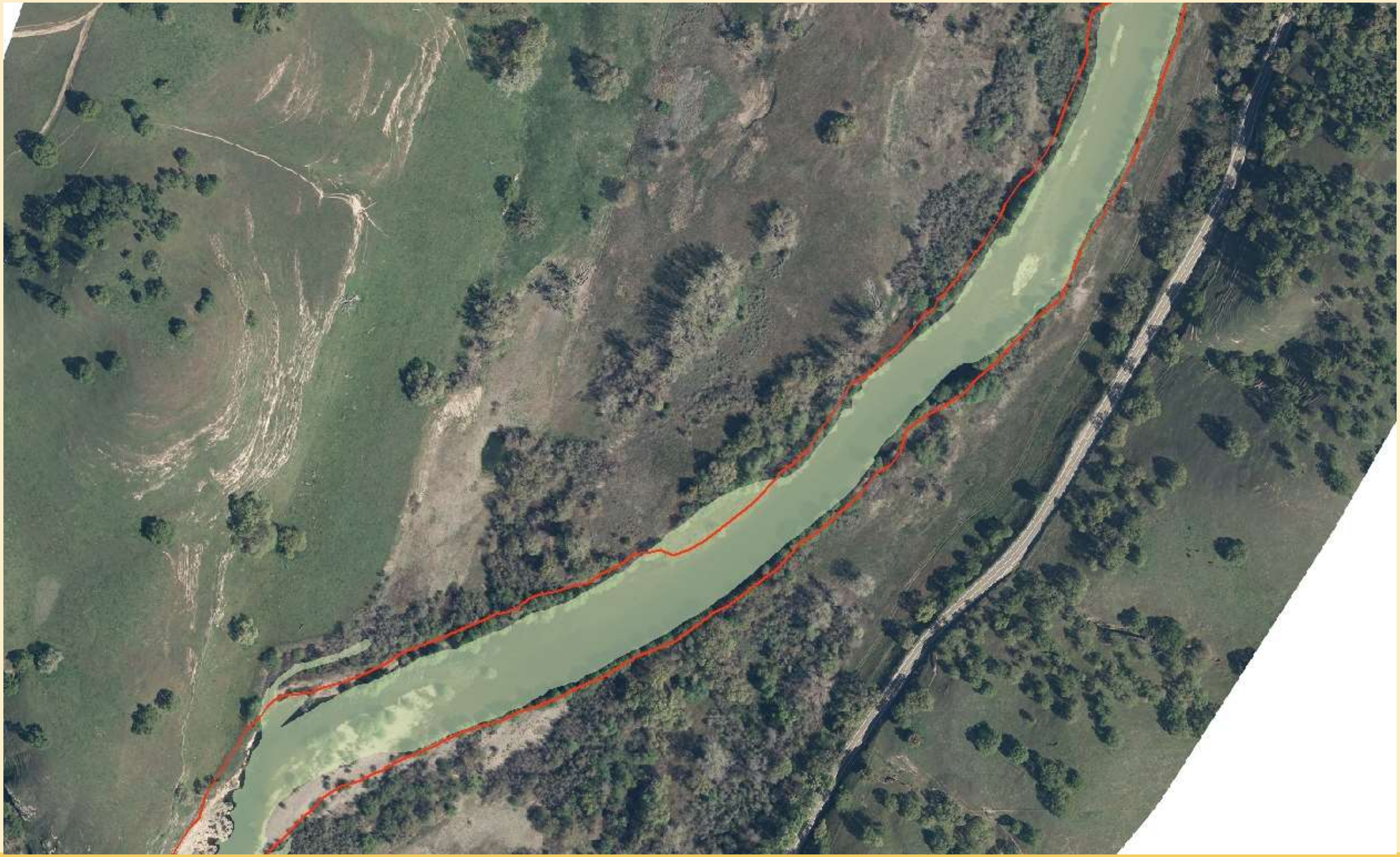
1D-2D Domain Boundary



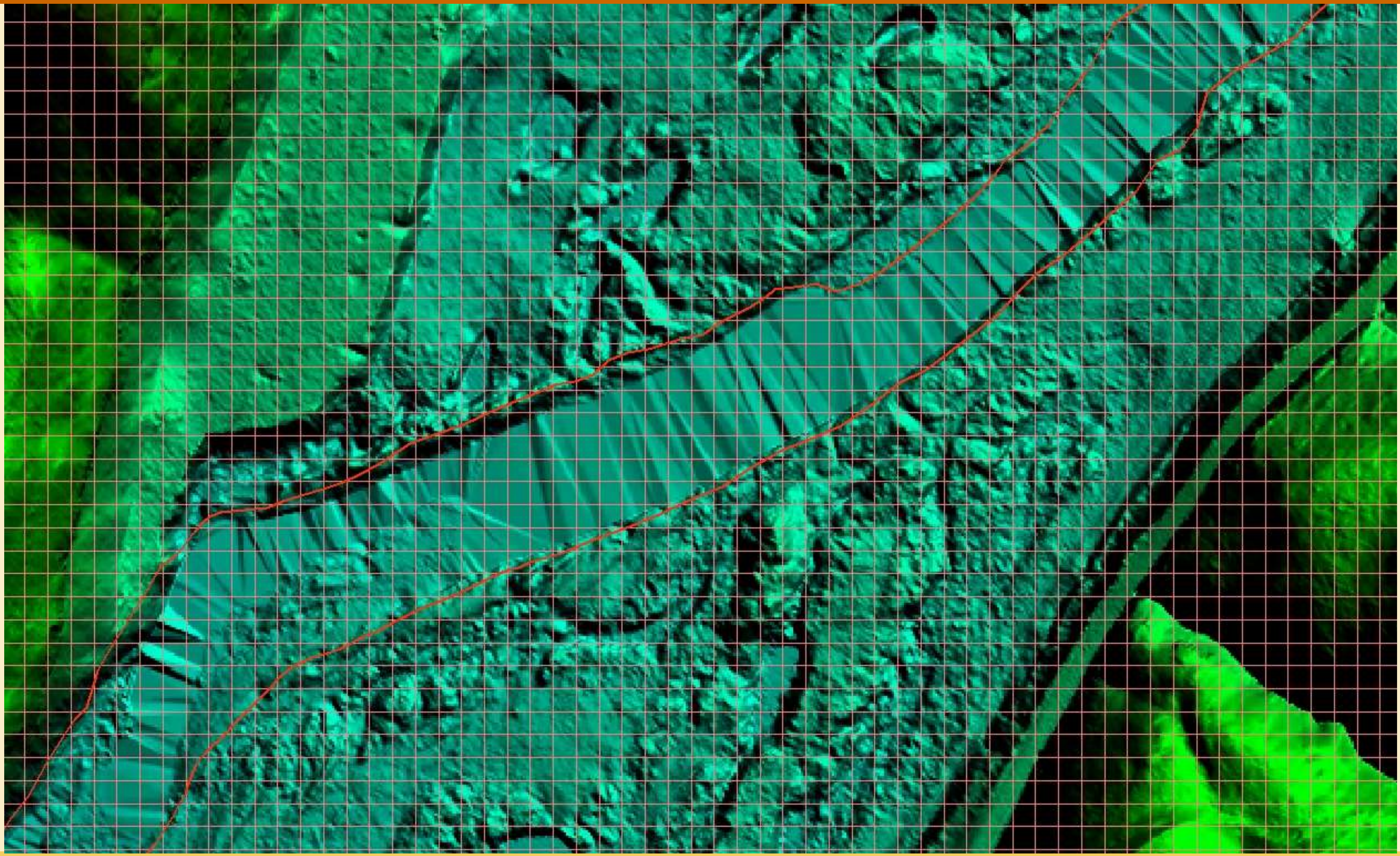
1D-2D Domain Boundary



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

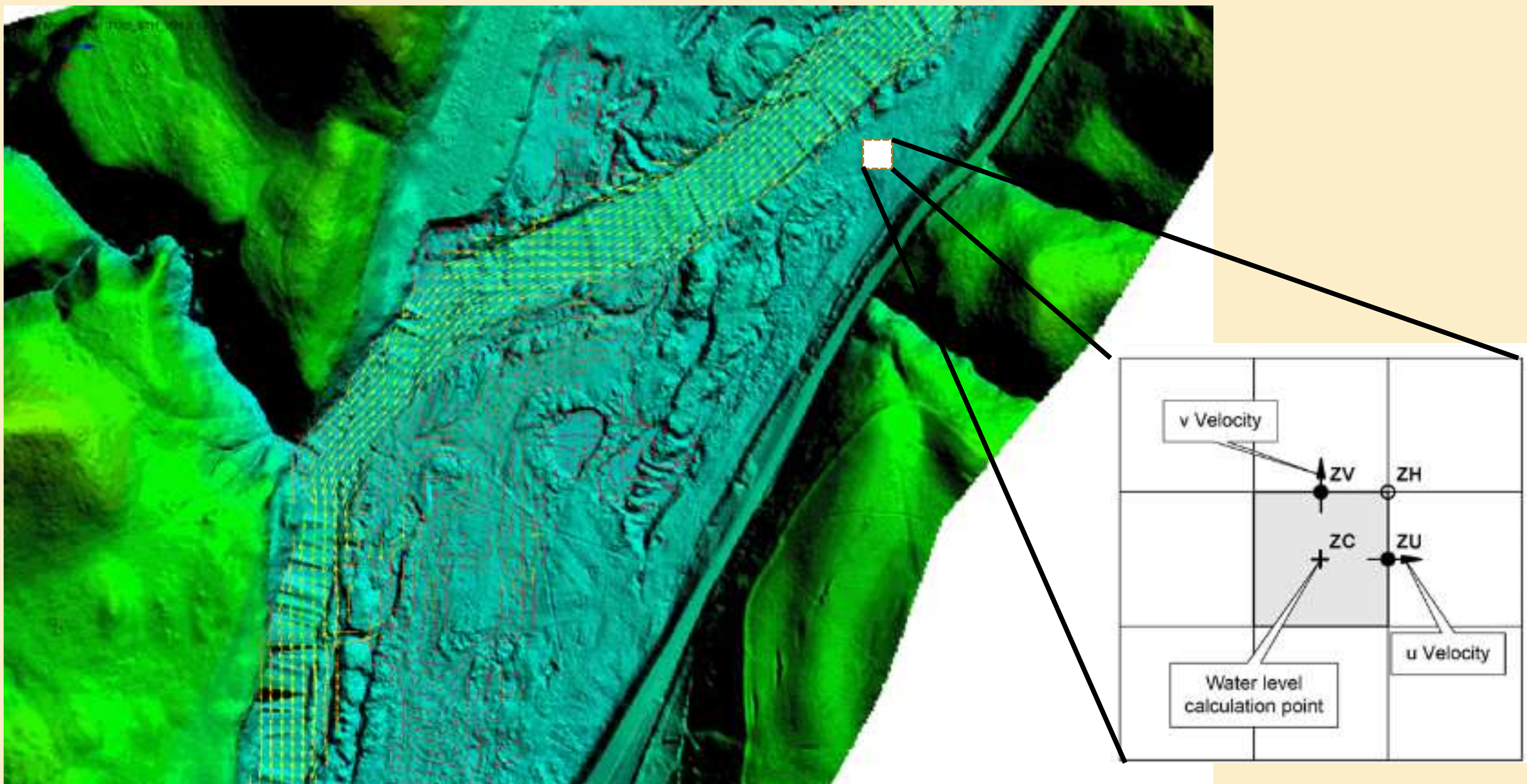
- Cell Size – 30ft or less

Pilot Model - Next Steps

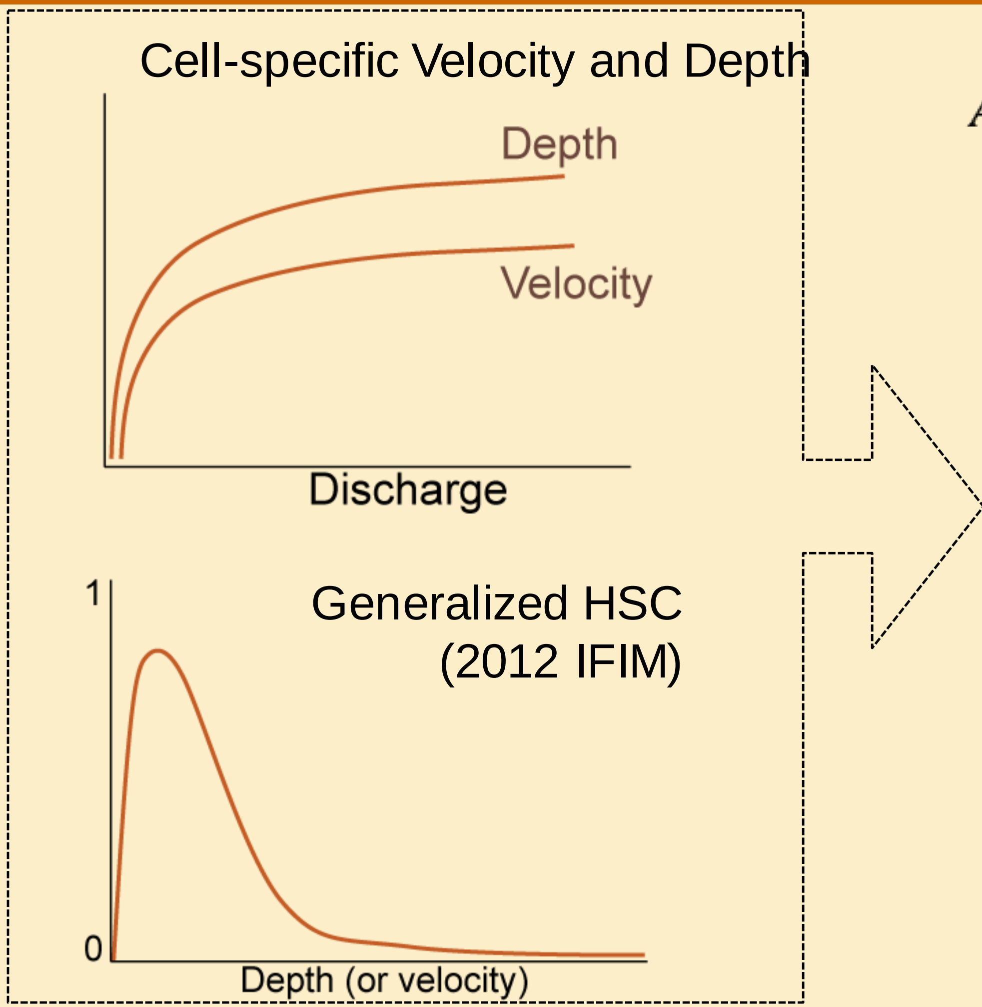
- **Add Manning's "n" to overbank areas**
- **Add embankments using breaklines**
- **Add elevation of ponds & pools using breaklines**
- **Add 1D low flow channel geometry**
- **Calibrate**

Habitat Analysis

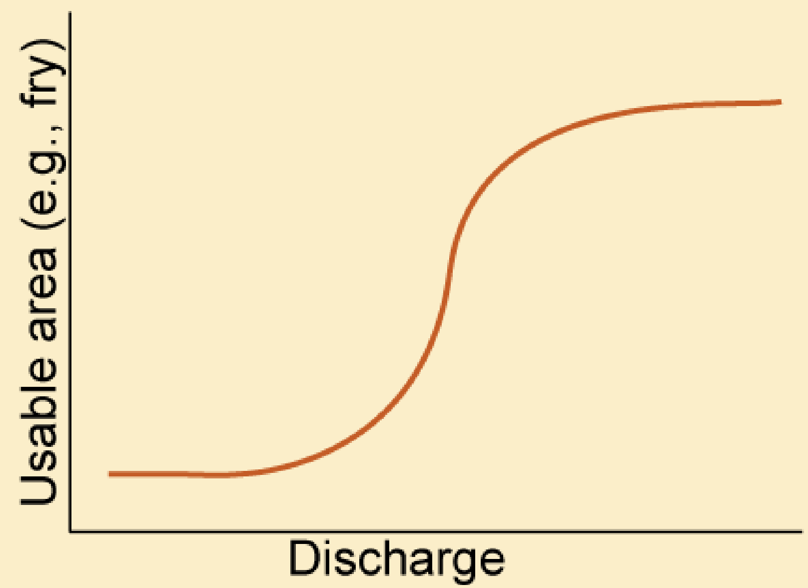
- **Cell-specific Velocity and Depth Predictions**



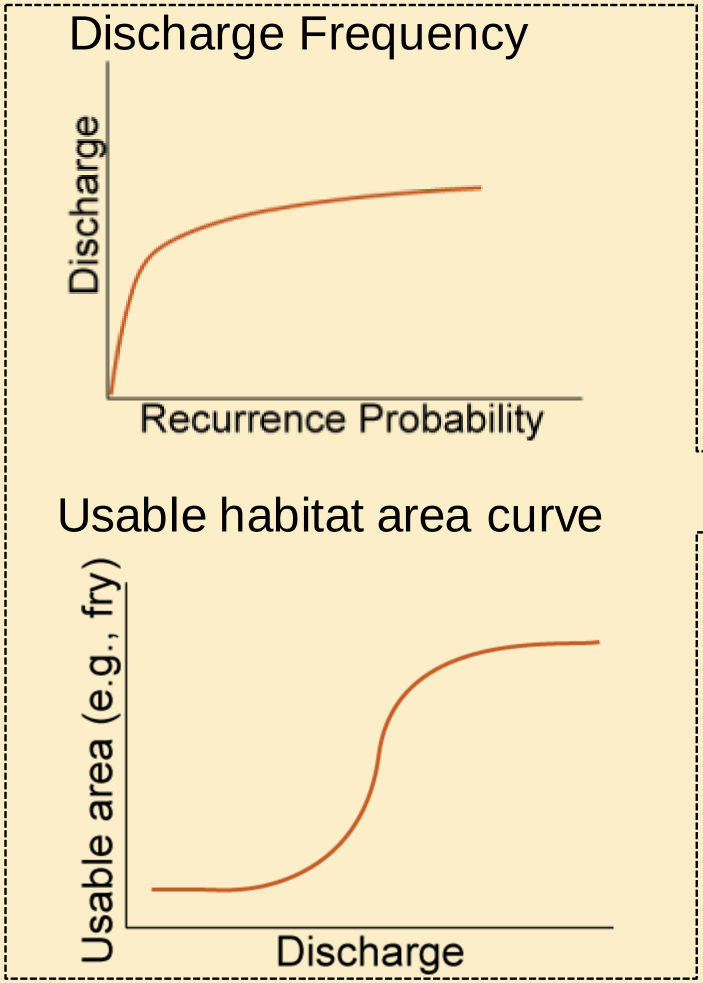
Habitat Analysis

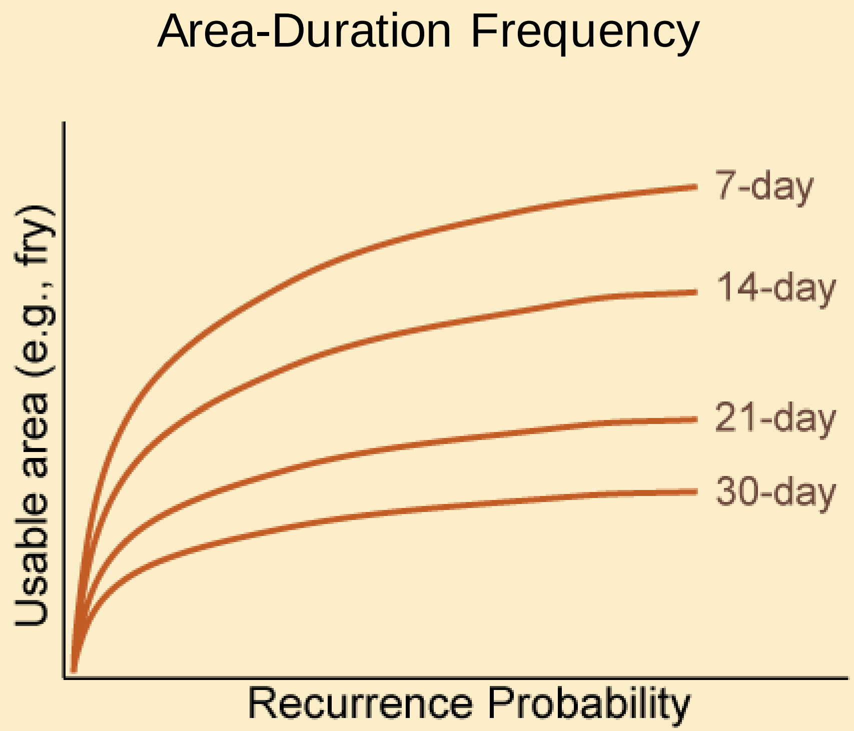


$$Area = \sum_{i=1}^{n} A_i \times HSC(depth, velocity)$$



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