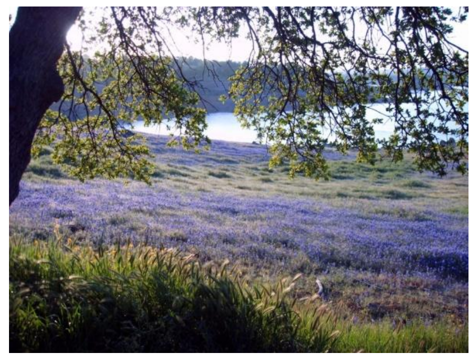
SPAWNING GRAVEL IN THE LOWER TUOLUMNE RIVER

PROGRESS REPORT
DON PEDRO PROJECT
FERC NO. 2299





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

Prepared by:
Stillwater Sciences

January 2013

Spawning Gravel in the Lower Tuolumne River
Study Report

TABLE OF CONTENTS

List of Figures

List of Tables

List of Attachments

List of Acronyms

ac ....acres

ACEC.........................Area of Critical Environmental Concern

AF ....acre-feet

ACOE.........................U.S. Army Corps of Engineers

ADA...........................Americans with Disabilities Act

ADCP.........................Acoustic Doppler Current Profiler

ALJ.............................Administrative Law Judge

APE............................Area of Potential Effect

ARMR........................Archaeological Resource Management Report

BA..............................Biological Assessment

BDCP ....Bay-Delta Conservation Plan

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

CalEPPC ....California Exotic Pest Plant Council

CalSPA.......................California Sports Fisherman Association

CAS............................California Academy of Sciences

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

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
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 ....California Threatened Species
CTR............................California Toxics Rule
CTS ....California Tiger Salamander
CVRWQCB ....Central Valley Regional Water Quality Control Board
CWA ....Clean Water Act
CWHR........................California Wildlife Habitat Relationship
Districts......................Turlock Irrigation District and Modesto Irrigation District
DLA ....Draft License Application
DPRA.........................Don Pedro Recreation Agency
DPS ....Distinct Population Segment
DTM...........................Digital Terrain Model(s)

EA ....Environmental Assessment
EC ....Electrical Conductivity
EFH ....Essential Fish Habitat
EIR ....Environmental Impact Report
EIS..............................Environmental Impact Statement
EPA ............................U.S. Environmental Protection Agency
ESA ....Federal Endangered Species Act
ESRCD.......................East Stanislaus Resource Conservation District
ESU ....Evolutionary Significant Unit
EWUA........................Effective Weighted Useable Area
FBM ....Fine Bed Material
FERC..........................Federal Energy Regulatory Commission
FFS ....Foothills Fault System
FL ....Fork length
FMU ....Fire Management Unit
FOT ....Friends of the Tuolumne
FPC ....Federal Power Commission
ft/mi............................feet per mile
FWCA ....Fish and Wildlife Coordination Act
FYLF..........................Foothill Yellow-Legged Frog
g..................................grams
GIS ....Geographic Information System
GLO ....General Land Office
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
ISR ....Initial Study Report
ITA.............................Indian Trust Assets
kV...............................kilovolt
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
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
NAS............................National Academy of Sciences
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
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
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
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
RMP ....Resource Management Plan
RP...............................Relicensing Participant
RSP ....Revised Study Plan
RST ....Rotary Screw Trap
RTK............................Real-time Kinematic
RWF ....Resource-Specific Work Groups
RWG ....Resource Work Group

RWQCB.....................Regional Water Quality Control Board
SC...............................State candidate for listing under CESA
SCD............................State candidate for delisting under CESA
SCE ....State candidate for listing as endangered under CESA
SCT ....State candidate for listing as threatened under CESA
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
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
SWE ....Snow-Water Equivalent
SWRCB......................State Water Resources Control Board
TAC............................Technical Advisory Committee
TAF ....thousand acre-feet
TCP ....Traditional Cultural Properties
TDS ....Total Dissolved Solids
TID.............................Turlock Irrigation District
TIN.............................Triangulated Irregular Network
TMDL ....Total Maximum Daily Load

TOC............................Total Organic Carbon
TRT............................Tuolumne River Trust
TRTAC.......................Tuolumne River Technical Advisory Committee
UC..............................University of California
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
VRM..........................Visual Resource Management
WPT...........................Western Pond Turtle
WSA...........................Wilderness Study Area
WSIP..........................Water System Improvement Program
WWTP.......................Wastewater Treatment Plant
WY.............................water year
μS/cm.........................microSeimens per centimeter

1.0 INTRODUCTION

1.1 General Description of the Don Pedro Project

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 formed by the dam extends 24-miles upstream at the 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).

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 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 the requirements of the Raker Act passed by Congress in 1913 and agreements between the Districts and City and County of San Francisco (CCSF), the Project reservoir also includes a "water bank" of up to 570,000 AF of storage. CCSF may use the water bank to more efficiently manage the water supply from its Hetch Hetchy water system while meeting the senior water rights of the Districts. CCSF's "water bank" within Don Pedro Reservoir provides significant benefits for its 2.6 million customers in the San Francisco Bay Area.

The 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 Project are recreation, protection of the anadromous fisheries in the lower Tuolumne River, and hydropower generation.

The Project Boundary extends from approximately one mile downstream of the dam to approximately RM 79 upstream of the dam. Upstream of the dam, the Project Boundary runs generally along the 855 ft contour interval which corresponds to the top of the Don Pedro Dam. The Project Boundary encompasses approximately 18,370 ac with 78 percent of the lands owned jointly by the Districts and the remaining 22 percent (approximately 4,000 ac) is 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 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 Project and its primary facilities is shown in Figure 1.1-1.

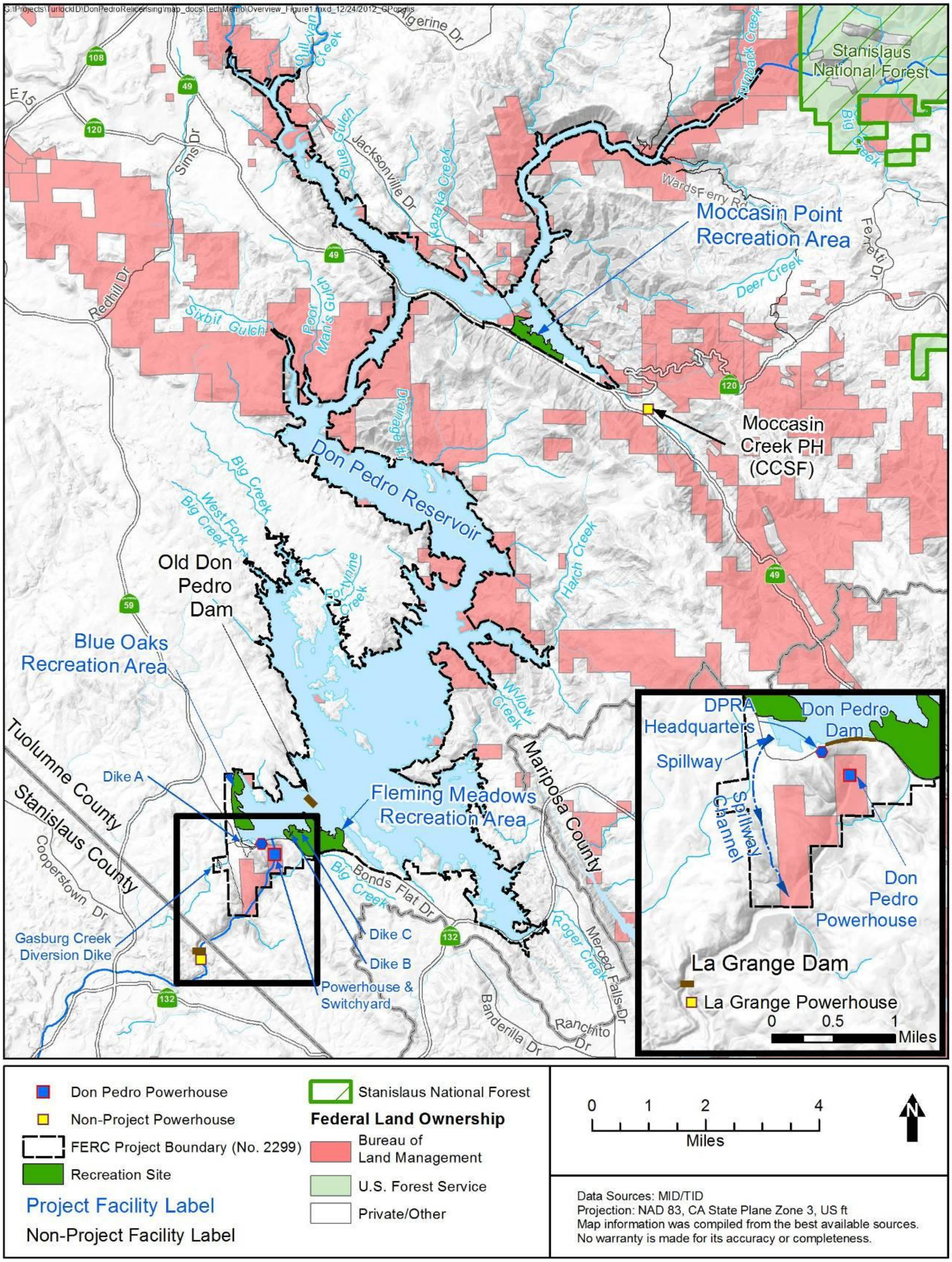


Figure 1.1-1. Don Pedro Project location.

1.2 Relicensing Process

The current FERC license for the Project expires on April 30, 2016, and the Districts will apply for a new license no later than April 30, 2014. 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.

This progress report describes the objectives, methods, and results of the Spawning Gravel in the Lower Tuolumne River Study (W&AR-04) as implemented by the Districts in accordance with FERC's SPD and subsequent study modifications and clarifications. Documents relating to the Project relicensing are publicly available on the Districts' relicensing website at www.donpedro-relicensing.com.

1.3 Study Plan

FERC's Scoping Document 2 identified potential direct, indirect or cumulative effects of the Project on reservoir bathymetry, fluvial geomorphic processes, and fish spawning habitat in in the lower Tuolumne River. The Districts' operation and maintenance (O&M) of the Project may affect spawning habitat by changing streamflow and sediment supply in a manner that may reduce channel sediment storage, alter channel form, and coarsen bed surface textures.

In its SPD, FERC staff recommended that the Districts modify their Revised Study Plan for W&AR-04 according to the following:

(1) Omit the goal of developing average annual gravel transport rates from channel geometry and changes in riffle areas mapped in 1988 and 1999-2000.

(2) Identify changes in riffle areas since 1988 and 1999–2000.

(3) Clarify how spawning habitat mapping will be performed and include a discussion of any differences between the proposed methodology and the methodology used in the studies proposed for comparison.

(4) Include methodology for estimating annual sediment storage in Don Pedro Reservoir via comparison of reservoir bathymetry.

(5) Include quantification of coarse and fine sediment storage in the lower Tuolumne River.

(6) Include a sediment budget for the purpose of determining the annual ongoing cumulative effect of the Project on sediment yield in Project-affected reaches.

FERC approved the Districts' W&AR-04 Spawning Gravel study plan with the recommended modifications. The Districts carried out the W&AR-04 Spawning Gravel study consistent with these directives. Variances and modifications to the final approved study play are discussed in Section 7 of this report.

1.4 Background

The lower Tuolumne River downstream of La Grange Dam can be divided into two geomorphic reaches defined by bed composition: a gravel-bedded reach that extends from La Grange Dam (RM 52.1) to Geer Road Bridge (RM 24), and a sand-bedded reach that extends from Geer Road Bridge to the confluence with the San Joaquin River (McBain and Trush 2000). The gravel-bedded and sand-bedded reaches are further subdivided based on land use, confinement, substrate, slope, and salmonid use (McBain and Trush 2000):

- Reach 1 (RM 0–RM 10.5): Lower Sand-Bedded Reach,
- Reach 2 (RM 10.5–RM 19.3): Urban Sand-Bedded Reach,
- Reach 3 (RM 19.3–RM 24.0): Upper Sand-Bedded Reach,
- Reach 4 (RM 24.0–RM 34.2): In-channel Gravel Mining Reach,
- Reach 5 (RM 34.2–RM 40.3): Gravel Mining Reach,
- Reach 6 (RM 40.3–RM 46.6): Dredger Tailing Reach, and
- Reach 7 (RM 46.6–RM 52.1): Dominant Salmon Spawning Reach.

Prior to widespread European settlement, channel form in the gravel-bedded reach of the lower Tuolumne River was a combination of single-thread and split channels that migrated and avulsed (McBain and Trush 2000). Pervasive, large-scale anthropogenic changes that have occurred in the lower Tuolumne River corridor since the mid-1800s include gold mining, grazing, and agriculture. Stored bed material was excavated for gold and aggregate to depths below the river thalweg, eliminating active floodplains and terraces and creating large in-channel and off-channel pits. By the end of the gold mining era, 12.5 miles of river channel and floodplain from

RM 50.5 to RM 38 were dredged and converted to tailings piles, and much of the gravel-bedded zone of the river was converted to long, deep pools. Large-scale, in-channel aggregate mining in the river began in the 1930s and continues today. Historically, aggregate mines excavated sand and gravel directly from the active river channel, creating large, in-channel pits now referred to as Special Run Pools (SRPs). These SRPs are as much as 400 feet wide and 35 feet deep, occupying 32 percent of the channel length in the gravel-bedded reach. Agricultural and urban encroachment, in combination with a reduction in coarse sediment supply and high flows, have resulted in a relatively static channel within a floodway confined by dikes and agricultural uses.

1.4.1 Coarse Bed Material

The mass balance between coarse sediment supply and bedload transport capacity is a fundamental relationship governing morphologic responses in river channels, including channel form, channel aggradation and degradation, sediment storage, and bed surface texture. La Grange Dam (constructed in 1893), Old Don Pedro Dam (completed in 1923) and New Don Pedro Dam (completed in 1971) trap all coarse sediment (>2 mm) and most fine sediment (<2 mm) historically supplied from the upper watershed to the lower Tuolumne River. These projects also alter the frequency, magnitude, and duration of bed-mobilizing flows that influence bedload transport capacity in the lower Tuolumne River.

Brown and Thorp (1947) estimated that 4,734 acre-feet (7,637,520 yd^3) of sediment accumulated in Don Pedro Reservoir behind Old Don Pedro Dam during the 23 year period from 1923 and 1946 (as cited in McBain and Trush 2004). This estimated annual volume equates to an average total sediment and coarse-grained sediment deposition of approximately 431,601 tons y^{-1} and 43,160 tons y^{-1}, respectively. These estimates assume 100 percent trap efficiency, an average sediment density of 1.30 tons yd^{-3}, and an average coarse-to-total sediment ratio of 0.10 (Reid and Dunne 1996, Snyder et al. 2004). Sediment yield to Don Pedro Reservoir based on more recent bathymetric surveys conducted in 2011 is discussed below in Section 5.1. Small tributaries downstream of La Grange Dam do not supply significant quantities of coarse sediment (McBain and Trush 2004).

The estimated minimum threshold for significant bed mobility in the lower Tuolumne River was estimated to be 5,400–6,880 cfs at Riffle 4B (McBain and Trush 2000, 2004). The average annual bedload transport rate at Riffle 4b was estimated to be 1,930 ton yr^{-1} based on an empirically derived bedload rating curve applied to the WY 1972–2001 flow record (excluding WY 1997) at USGS gage #11-289650 (McBain and Trush 2004). Sediment transport modeling in the reach from Riffle 5a to 4a estimated a similar average annual bedload transport rate of 1,412 tons yr^{-1} (McBain and Trush 2004).

Several indicators suggest a deficit in coarse sediment supply relative to bedload transport downstream of La Grange Dam, a condition affecting both the capacity and productivity of salmonid spawning habitat (CDWR 1994, McBain and Trush 2004):

- Channel cross section surveys indicate that the channel is wider than expected in many reaches, lacks bankfull channel confinement, and has cross sectional dimensions that are not adjusted to the contemporary flow regime.

- Field surveys indicate that sediment storage features (e.g., lateral bars and riffles) are depleted of coarse sediment, and riffles throughout the gravel-bedded zone have progressively diminished in size.
- SRPs deprive downstream reaches of sediment by trapping all particles larger than coarse sand (4 mm), provide little or no high quality salmonid habitat, and provide suitable habitat for non-native piscivores that prey on juvenile salmonids (McBain and Trush 2000).

1.4.2 Fine Bed Material

Studies of lower Tuolumne River salmon spawning habitat have attributed low salmonid survival-to-emergence to poor gravel quality resulting from fine sediment (TID/MID 1992b, TID/MID 2001, TID/MID 2007b). Fine (predominantly <2 mm) bed material (FBM) is supplied to the lower Tuolumne River primarily by the three largest tributaries downstream of La Grange Dam (Gasburg, Dominici, and Peaslee Creeks) and by bank and floodplain erosion. Gasburg Creek (RM 50.3) and Peaslee Creek (RM 45.5) were assessed as having relatively large input potential, while Lower Dominici Creek (RM 47.8) was assessed as having moderate input potential (McBain and Trush 2000). These assessments were made in part, by the size of deltas observed at each of the tributary mouths believed to have been deposited on the receding limb of the January 1997 flood event.

The January 1997 flood event in the lower Tuolumne River eroded approximately 500,000 yd^3 of sediment from the spillway at New Don Pedro Dam, depositing sediment behind La Grange Dam and a large volume of fine sediment in downstream reaches of the Tuolumne River (McBain and Trush 2000, 2004). In June 2001, discrete fine sediment deposits in the channel were mapped from the USGS gauging station near La Grange Dam (RM 52.1) downstream to Roberts Ferry Bridge (RM 39.6) (Stillwater Sciences 2002a). The survey estimated fine sediment storage in pools and other discrete deposits and estimated the relative contribution of fine sediment from tributaries. Results from the survey indicated that fine sediment constituted a large fraction of the channel bed surface. Discrete fine sediment deposits were more common in pools from Basso Bridge (RM 47.5) to Peaslee Creek (RM 45.5) than in upstream reaches, and the largest volumes of fine sediment were observed from Peaslee Creek to Roberts Ferry Bridge (RM 39.5). Gasburg Creek and Peaslee Creek appeared to be the largest contributors of fine sediment in the surveyed reach.

Sediment source analyses conducted for the Gasburg Creek watershed in 2003 and 2004 indicated that the tributary supplied approximately 1,203 yd^3 of fine sediment annually to the Tuolumne River (Stillwater Sciences 2004a, PWA 2004). The Gasburg Creek Fine Sediment Reduction Project was implemented in 2007 to reduce fine sediment delivery from a deeply incised gully (the dominant erosion feature identified in the watershed) and to modify the Gasburg Creek floodway extending from the MID canal culvert downstream to approximately Old LaGrange Road (Laird 2005, McBain and Trush 2007). Beginning on January 6, 2008, the lower Tuolumne River experienced several episodes of high turbidity resulting from fine sediment input from the Peasley Creek watershed. Following the event, the Districts conducted turbidity monitoring, bulk sediment sampling, photo-monitoring, and benthic invertebrate sampling in the Tuolumne River in the vicinity of the Peasley Creek confluence and Bobcat Flat (located approximately 2 miles downstream of the Peasley Creek confluence) to document any effects related to the increased fine sediment supply (McBain and Trush 2008). In addition to the episodes of elevated fine sediment delivery from Peaslee Creek, several small dams that impounded fine sediment in Lower Dominici Creek failed in February 2006, releasing fine sediment to downstream reaches (CRWQCB 2006 as cited in Stillwater Sciences 2006).

1.4.3 Spawning Habitat

The Districts first assessed potential Chinook spawning habitat area in the gravel-bedded reach of the lower Tuolumne River (RM 52.1 to RM 23) in 1992 (hereafter referred to as the 1988 estimate) (TID/MID 1992a). Spawning habitat was mapped from two sets of aerial photographs: a color set taken at a scale of 1:2,400 on 26 November 1986 when flow was 230 cfs, and a black and white set taken at a scale of 1:24,000 on 19 January 1991 when flow was 100 cfs. Spawning riffles, wetted channel perimeter, and morphological features (e.g., banks, vegetated and unvegetated bars) were identified from the 1986 photography, and changes in the area of spawning riffles and wetted channel perimeter were identified from the 1991 photography. Spawning habitat was delineated by defining the entire areal extent of spawning riffles. Spawning habitat suitability criteria (e.g., substrate size, flow depth, and flow velocity) and other information about spawning use were not incorporated into the mapping criteria. The criteria therefore resulted in a maximum estimate of Chinook salmon spawning habitat (TID/MID 1992a). Total riffle area mapped in 1988 was 1.6 million square feet, 34 percent less than the historical estimate for the reach (TID/MID 1992a, McBain and Trush 2004).

The reach from La Grange Dam to the Santa Fe Aggregates bridge (RM 52.1 to RM 36.3) was resurveyed between September 1999 and February 2001(hereafter referred to as the 2001 estimate) to document changes in riffle area since 1988 and to assess spawning habitat area that met suitable substrate, depth, and velocity criteria during spawning flows (McBain and Trush 2004). Surveys were conducted from La Grange Dam (RM 52.1) to the Santa Fe Aggregates haul bridge (RM 36.3) at flows ranging from 250 to 1,010 cfs. Riffle area and suitable spawning habitat area were mapped onto aerial photographs in the field and later digitized. The portion of the gravel-bedded reach downstream of RM 36.3 was not included in these surveys. Loss of riffle area between 1988 and 2001 in the Dominant Salmon Spawning Reach, Dredger Tailing Reach, and Gravel Mining Reach was 128,000 ft^2 (17 percent), 46,000 ft^2 (11 percent), and 52,000 ft^2 (13 percent), respectively (McBain and Trush 2004). Comparing 2001 spawning habitat area to historical estimates of potential spawning habitat indicated a potential loss of 1.8 million square feet (73 percent) of Chinook salmon spawning habitat. Because suitable habitat area defined by substrate, depth, and velocity criteria is a subset of potential spawning habitat in riffles, these comparisons likely over-estimate loss of potential Chinook salmon spawning habitat (McBain and Trush 2004). Bed mobilization and transport during high flow events in 2005, 2006 and 2011 may have changed channel sediment storage, the distribution of surficial gravel deposits, and associated salmon spawning habitat in the lower Tuolumne River as mapped in 2001.

As directed under the 1995 Settlement Agreement, the Tuolumne River Technical Advisory Committee (TRTAC) developed 10 priority habitat restoration projects separated into three classes based on the project goals and type of restoration activity: (1) channel and riparian restoration, (2) predator isolation, and (3) sediment management (TID/MID 2005a). Gravel augmentation projects aimed at improving spawning gravel availability and quality in the lower Tuolumne River began in 1999. Approximately 178,000 ft^2 of riffle spawning habitat were created through gravel additions implemented by the California Department of Fish and Game (CDFG) from 1999 to 2003 (CDWR 2004, TID/MID 2005, 2006, 2007a). Four gravel augmentation projects were implemented from 2002 to 2011 (Table 1.4-1).

Table 1.4-1. Gravel augmentation projects in the lower Tuolumne River, 2002–2011.[1]

Location (RM)	Year	Volume, yd3
50.0 to 50.7	2002	9,600
50.0 to 50.7	2003	5,330
53	2005	10,820
53	2011	19,000

[1] CDWR 2004, TID/MID 2005, 2006, 2007a, TRC 2011.

1.4.4 Chinook Salmon Spawning

CDFG has conducted fall-run Chinook salmon spawning surveys on the lower Tuolumne River since 1971. The surveys extend from La Grange Dam (RM 52.1) to RM 26.4, and downstream to RM 24 in some years (i.e., 1988, 1989, and 2009 to present). Data collection includes salmon carcass mark-recapture, redd counts, live salmon counts, female counts, fish length measurements, scale and otolith sampling, and recovery of coded-wire-tags. Carcass mark-recapture and observation of redds and live salmon are conducted by drift boat from early October through the end of December or early January. CDFG provides spawning survey results tallied by spawning riffle for inclusion in the annual Article 58 Summary Reports to FERC (e.g., TID/MID 2011, Report 2010-1). Mark-recapture recoveries of carcasses are used to estimate annual escapement, with live counts and redd counts used to help characterize the spatial and temporal distribution of the salmon run.

Early spawning studies showed a nearly linear trend of spawning preferences decreasing from upstream to downstream (TID/MID 1992a). Data collected since 1997 indicate that over half of the spawning activity occurs in the Dominant Salmon Spawning Reach (Reach 7) from RM 52.1 to RM 46.6 (Table 1.4-2).

Table 1.4-2. Average annual redd counts by reach expressed as a percentage of the total annual redd count in the lower Tuolumne River.[1]

Reach	River Mile	1981–1996		1997–2009		1981–2009	
		Average (%)	SD (%)	Average (%)	SD (%)	Average (%)	SD (%)
Reach 4	24.0–34.2	9	6	10	9	10	8
Reach 5	34.2–40.3	17	6	13	5	16	6
Reach 6	40.3–46.6	25	8	23	4	24	7
Reach 7	46.6–52.1	49	11	53	13	51	12

[1] Redd data were derived from the Districts 2009 FERC report (TID/MID 2009) and updated to include the most recent CDFG data available from the 2009 spawning survey.
SD = Standard Deviation

2.0 STUDY GOALS AND OBJECTIVES

Continued Project O&M may contribute to cumulative effects on the supply, transport, and storage of coarse and fine sediment downstream of La Grange Dam, which may affect spawning gravel availability, quality, and use by Chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout/steelhead (*O. mykiss*). The Spawning Gravel study characterizes the cumulative effects of sediment storage in Don Pedro Reservoir, along with ongoing upstream diversion effects on coarse and fine bed material storage and spawning habitat, in the lower Tuolumne River channel. Specific information obtained by this study updates information from prior studies in order to achieve the following objectives:

(1) Estimate average annual sediment yield to Don Pedro Reservoir based on reservoir sedimentation.

(2) Estimate changes in the volume of coarse (>2 mm) bed material stored in the lower Tuolumne River channel over the 2005 to 2012 period.

(3) Map current FBM deposits (predominantly <2 mm) in the lower Tuolumne River channel and compare with results from previous surveys in 2001 (Stillwater Sciences 2002a).

(4) Develop a reach-specific coarse sediment budget for the purpose of determining any cumulative effects of the Project on Projected-affected reaches of the lower Tuolumne River.

(5) Map current riffle area, spawning gravel area, and suitable spawning habitat area in the lower Tuolumne River and compare with results from previous surveys in 1988 (TID/MID 1992a) and 2001 (McBain and Trush 2004).

(6) Estimate maximum spawning run sizes supported under current conditions.

3.0 STUDY AREA

The overall area encompassed by the W&AR-04 Spawning Gravel study includes the lower Tuolumne River from La Grange Dam (RM 52.1) downstream to RM 23, which captures the extent of riffle habitats documented in historical surveys (TID/MID 1992a). Within the overall study area, elements were implemented within different spatial extents and time periods necessary to address the five objectives using the best available information (Figure 3.0-1):

(1) Average annual sediment yield to Don Pedro Reservoir was estimated using information provided by the W&AR-03 Reservoir Temperature Model study and related historical information. No additional field data collection occurred during the W&AR-04 study.

(2) Estimation of the change in coarse bed material storage over the 2005–2012 period occurred in the Dominant Salmon Spawning Reach from La Grange Dam (RM 52.1) downstream to approximately Peaslee Creek (RM 45.5), where most of the Chinook salmon (*Oncorhynchus tshawytscha*) and *O. mykiss* spawning occurs and where the potential for bed material storage changes are greatest.

(3) Mapping of FBM deposits and analysis of change in FBM storage over the 2001–2012 period occurred from approximately La Grange Dam (RM 52.1) to the Santa Fe Aggregates haul road bridge (RM 36.3), the reach in which historical fine sediment mapping data exists (Stillwater 2002) and below which the channel progressively transitions to a predominantly fine (e.g., sand) bed.

(4) Mapping of riffles, spawning gravel, and suitable spawning habitat occurred in the gravel-bedded reach from approximately La Grange Dam (RM 52.1) downstream to RM 23, which includes the extent of riffle habitats mapped in previous surveys (TID/MID 1992a, McBain and Trush 2004).

(5) Maximum spawning run sizes supported under current conditions are estimated for the lower Tuolumne River downstream of La Grange Dam.

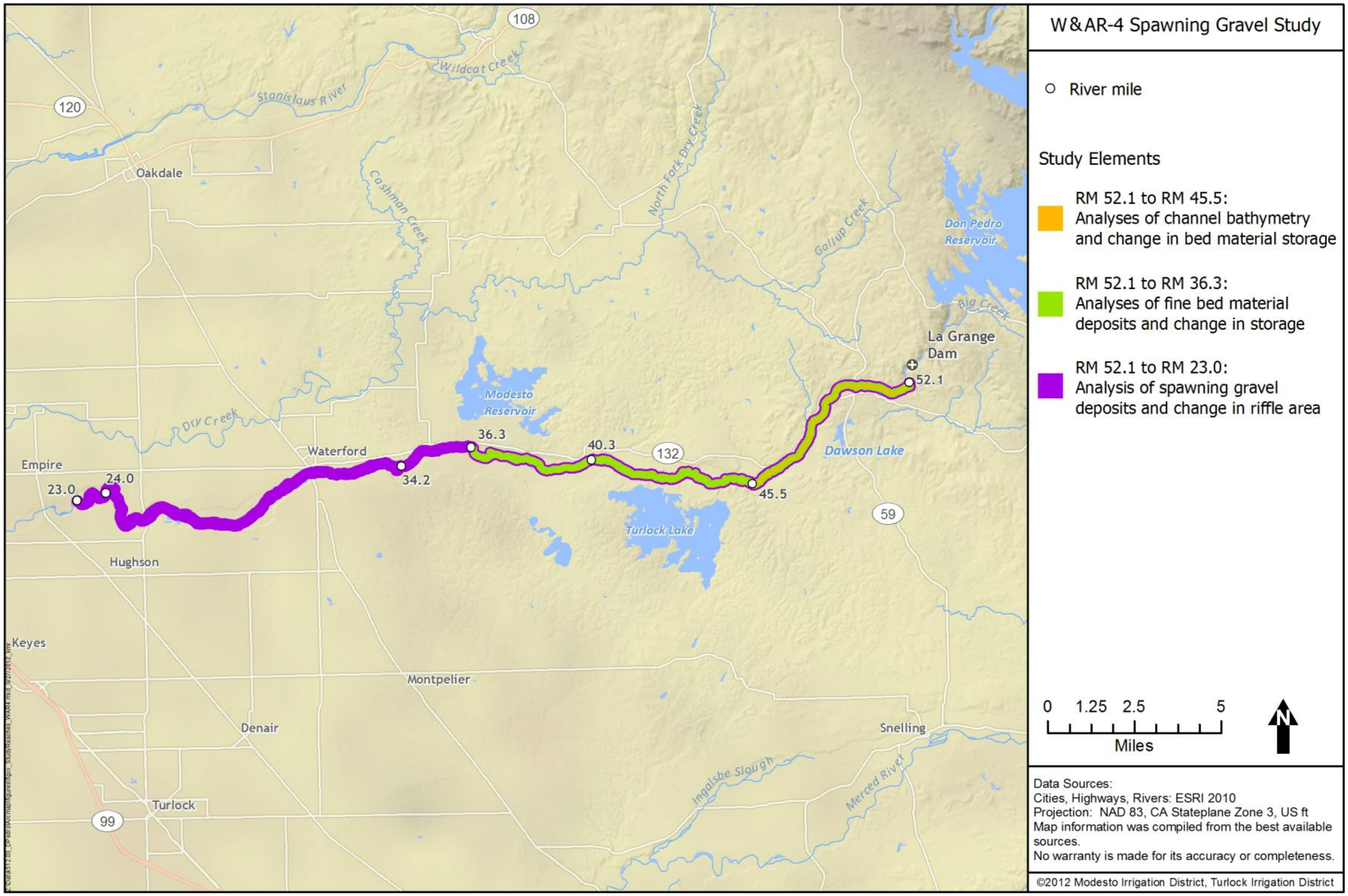


Figure 3.0-1. Spawning Gravel study area.

4.0 METHODOLOGY

Methods implemented to satisfy each of the five study objectives are discussed below.

4.1 Sediment Yield to Don Pedro Reservoir

Average annual sediment yield to Don Pedro Reservoir was estimated from the total volumetric storage loss in the reservoir below the normal maximum water level of 830 ft. The calculation assumes the storage loss is due to sediment delivered from the reservoir source area and accumulated in the impoundment during the period since dam closure. The storage loss was estimated by comparing storage capacity information developed for the Don Pedro Project in 1971 with storage capacity information updated in 2011 (TID/MID 2011).

Information documenting development of the initial storage capacity curve in 1971 indicates that the curve was based on topography of the impoundment surveyed prior to closure of Old Don Pedro Dam in 1923. Comparison of the 1971 and 2011 capacity curves therefore accounts for sedimentation that occurred during the 40 year period between closure of New Don Pedro Dam in 1971 and the 2011 survey, as well as sedimentation during the 48 year period between closure of Old Don Pedro Dam in 1923 and 1971.

The storage capacity curve for Don Pedro reservoir was updated in 2011 based on bathymetry surveyed with depth sounding and DGPS technology in 2011. Transects were surveyed approximately perpendicular to the longitudinal axis of the reservoir over the entire reservoir water surface area at the normal maximum water level of 830 ft. Depth measurements were adjusted using reservoir water level elevations measured at three gages. Sounding data were supplemented with topographic information above 792 feet obtained by interferometric synthetic aperture radar (IFSAR) during August 2004. The two data sources were integrated into one surface that was used to calculate reservoir volume in one-foot contour intervals from the bottom of the reservoir to the normal maximum water level. The W&AR-03 Reservoir Temperature Model study report (TID/MID 2011) includes more detailed explanation of these methods and results.

The calculated storage using the 2011 bathymetry data was compared to the storage capacity information from 1971 to estimate the total change in storage volume below the full pool elevation of 830 ft. The total volume change, assumed to be the result of sedimentation, was used to estimate average annual total (all grain sizes) mass sediment yield and coarse (>2 mm) mass sediment yield to Don Pedro Reservoir. Sediment yield calculations assume 100 percent trap efficiency, an average sediment density of 1.30 tons yd^{-3}, and an average coarse-to-total sediment ratio of 0.10 percent (Reid and Dunne 1996, Snyder et al. 2004).

4.2 Changes in Coarse Bed Material Storage

Changes in coarse (>2 mm) bed material storage in the 12.4 mi reach downstream of La Grange Dam to approximately RM 39.7 were estimated for the 2000–2012 and 2005–2012 periods based on sediment transport modeling conducted within a sediment budget context. Estimates of coarse bed material storage changes from model simulation are compared with bed material storage changes estimated by differencing digital terrain models (DTMs) that characterize channel bathymetry in the Dominant Salmon Spawning Reach from La Grange Dam (RM 52.1) downstream to approximately Peaslee Creek (RM 45.5) in 2005 and 2012.

4.2.1 Modeling

Coarse (> 2mm) bed material storage changes (ΔS_y) in a particular reach over a particular time period were calculated according to the following sediment budget equation:

$$\Delta S_y = (I_y + I_a) - E_y$$

in which I_y denotes modeled bedload flux into the area over the time period, I_a denotes coarse sediment added to the area through augmentation during the period, and E_y denotes modeled bedload flux exported from the area during the period.

Mass change in coarse bed material storage was computed for two reaches of the lower Tuolumne River channel (hereafter referred to as budget cells). Budget cell 1 extends from La Grange Dam to Peaslee Creek (RM 52.1 to 45.5) and budget cell 2 extends from Peaslee Creek to RM 39.7. The coarse sediment budget accounts for mainstem bedload fluxes into and out of each budget cell, but does not account for coarse sediment inputs from tributary sources or from bank and floodplain erosion within a cell. The main tributaries to the model study reach (Gasburg, Dominici, and Peaslee creeks) do not supply significant quantities of coarse sediment to the mainstem Tuolumne River (McBain and Trush 2004), nor do within-reach sediment sources (e.g., bank and flood erosion). Input to budget cell 2 includes output from budget cell 1.

Mainstem coarse (>2 mm) sediment fluxes I_y and E_y are estimated using the DREAM-2 sediment transport model of Cui et al. (2006a, 2006b), modified to incorporate the effects of coarse sediment additions. Two millimeters is typically the smallest grain size that travels predominately as bedload rather than in suspension. DREAM-2 applies Parker's surface-based bedload equation (Parker 1990) to calculate bedload transport capacity and is appropriate for gravel-bedded rivers like the study reach. The model and its predecessors have been applied in numerous projects with satisfactory results (Cui and Parker 1999; Hansler 1999; Sutherland et al. 2002; Cui 2007a; Cui et al. 2003, 2006a, 2007b, 2008, 2011, 2012; Cui and Wilcox 2008; Downs et al. 2009; Stillwater Sciences 2000, 2004b, 2008, 2010, 2012; Gomez et al. 2009).

Changes in coarse sediment storage within each budget cell are computed for the 2000–2012 and 2005–2012 periods. The 2000-2012 period was selected to include the effects of recent gravel augmentation that occurred in the reach prior to WY 2006, and the 2005–2012 period was selected to allow comparison between modeled estimates of coarse bed material storage changes and storage changes estimated by differencing channel bed topography surveyed in 2005 and 2012. Model runs started in 1883 to numerically establish a quasi-equilibrium channel profile at the start of the period of interest (year 2000) that exhibits sediment transport characteristics influenced by the altered hydrology and sediment supply. The quasi-equilibrium channel bed theoretically experiences little cumulative aggradation or degradation over time, and any changes in bed profile thereafter are assumed to be the result of disturbances introduced in modeling simulations (e.g., changes in sediment supply, hydrology, or gravel augmentation)(Cui et al. 2006a, 2006b).

Longitudinal profiles and cross sections of the lower Tuolumne River study reach were extrapolated from DTM surfaces developed from LiDAR, bathymetric, and topographic data surveyed in 2005 (approximately RM 51.5 to RM 38.0) and 2012 (approximately RM 51.5 to RM 45.5). Development of DTM data is discussed in more detail in Section 4.2.2 below. Daily average discharge records for WY 1912–1970 at USGS #11288000 (Tuolumne River above La Grange Dam) describe the period prior to closure of New Don Pedro Dam, and discharge records for the period WY 1971–2012 at USGS # 11289650 (Tuolumne River below La Grange Dam) describe the period following closure (Figure 4.2-1).

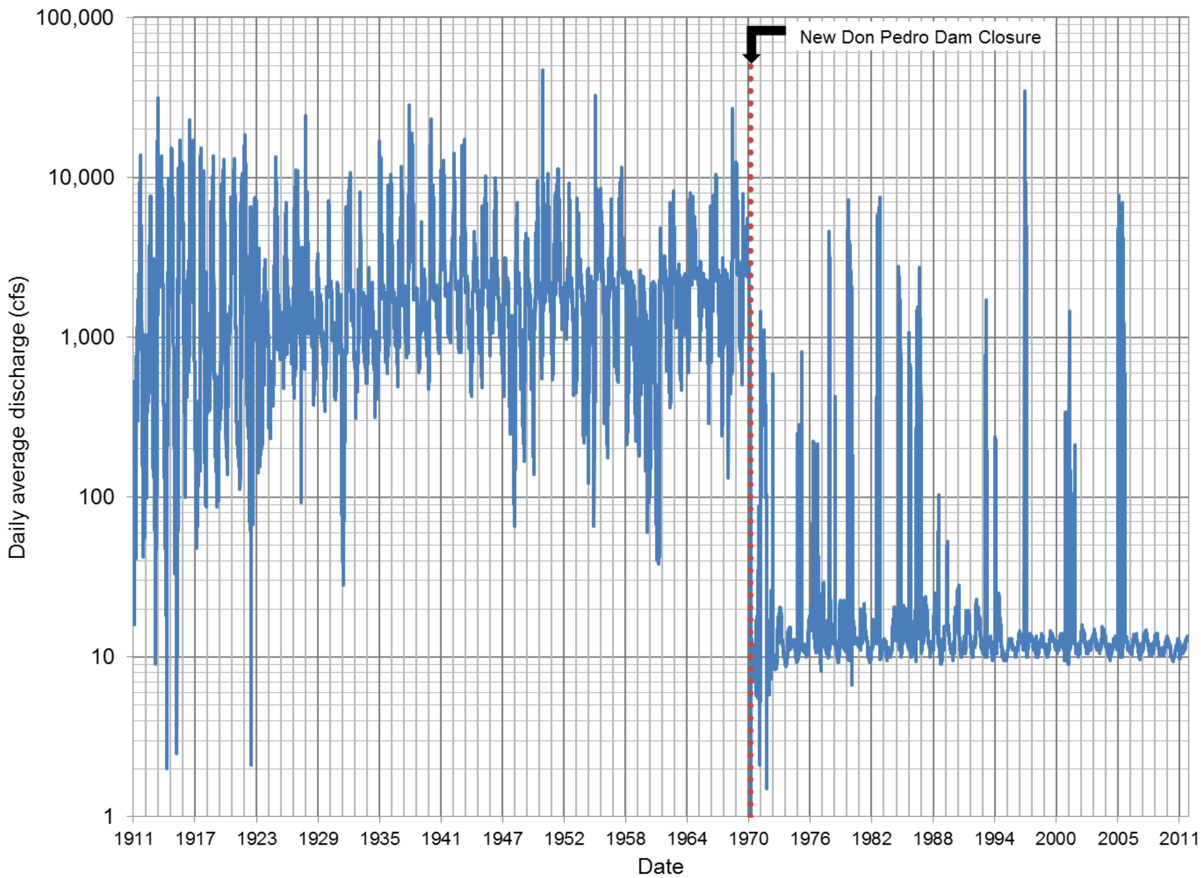


Figure 4.2-1. Daily average discharge in the Tuolumne River near La Grange Dam.

There is little information about the sediment supply rate, longitudinal profile, and surface and subsurface grain size distributions in the study reach prior to the construction of La Grange Dam and Old and New Don Pedro dams. No systematic bed material grain size sampling was conducted for the current modeling simulations, although surface pebble counts conducted at select locations during spawning gravel mapping in 2012 were used in the analysis. Based on the expectation of bed degradation during the long time period (over 100 years) between model initiation in year 1883 and the 2000-2011 period of interest, the initial profile in 1883 was assumed to be 1.6 ft higher than the bed profile obtained from recent DTM data. Modeling also assumed an initial bed material grain size distribution shown in Figure 4.2-2. Different assumptions about initial bed elevation and grain size would likely affect the absolute value of the results but would not change the relative magnitude of the predicted transport capacity or change in coarse bed material storage.

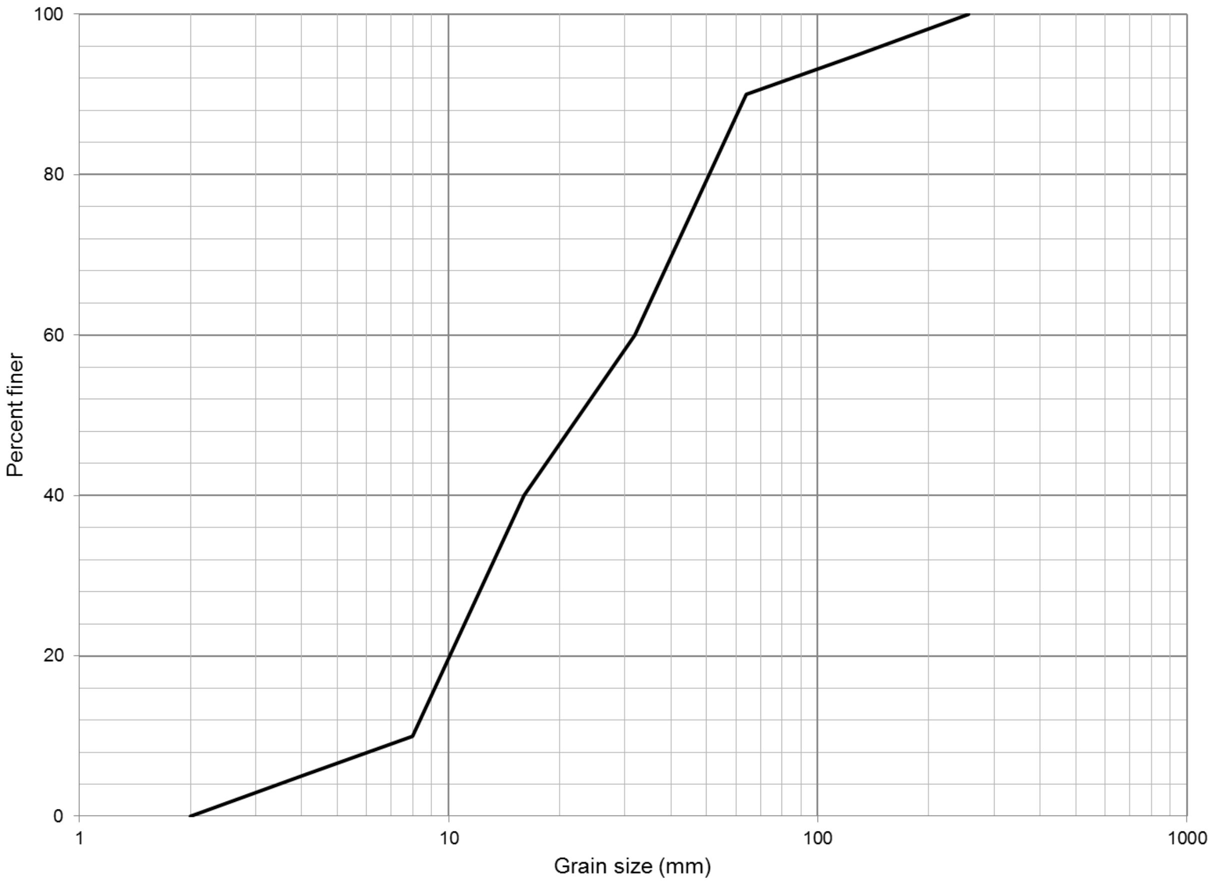


Figure 4.2-2. Assumed initial bed material grain size distribution in the model study reach.

Two DREAM-2 model runs were conducted with the initial conditions discussed above; one that included gravel augmentation implemented from 2005 to 2011 (discussed in Section 1.4.3 above), and another simulating a scenario without gravel augmentation. Since the future location and quantities of gravel augmentation are uncertain, these two different runs were conducted to address the potential cumulative effects under future conditions with and without augmentation. The total amount of gravel added during augmentation projects in the model study reach from 2002 to 2012 was approximately 44,753 yd^3, or approximately 58,940 tons, assuming a density of 1.30 tons yd^{-3}. The grain size distributions of coarse sediment added during augmentation projects in 2002, 2003 and 2005 are summarized in Figure 4.2-3. For modeling purposes, the grain size distribution of coarse sediment added in 2011 was assumed to be identical to that added in 2005.

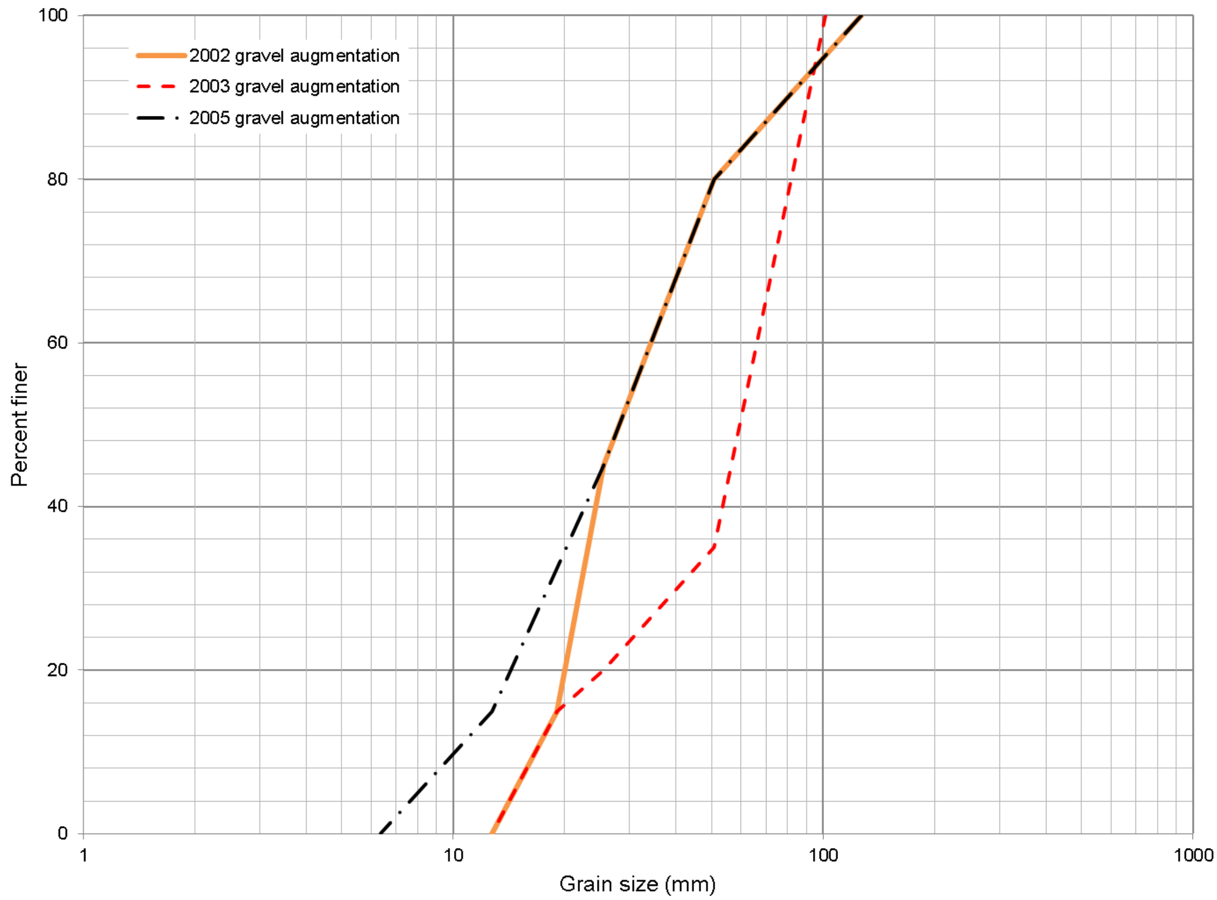


Figure 4.2-3. Grain size distributions of gravel augmentation in the Tuolumne River, 2002–2005.

In addition to longitudinal profile, cross section, discharge, and grain size information, DREAM-2 model simulation requires bankfull channel widths within the study reach. Channel widths were measured approximately every 500 feet from color aerial photography dated 24 July 2011. Channel widths were delineated based on the active flow path that was free of vegetation, high water marks, and other geomorphic evidence of bankfull flow (e.g., surfaces with evidence of bankfull scour and fill). Using a sediment transport modeling approach similar to the current study, Cui et al. (2006) found that simulations are relatively insensitive to variations in channel width.

4.2.2 Topographic Differencing

Digital terrain models of the lower Tuolumne River channel created in 2005 and 2012 were used to calculate bed elevation changes and estimate bed material storage changes in sediment budget cell 1 from approximately La Grange Dam to Peaslee Creek (RM 51.5 to RM 45.5) over the 2005-2012 period. The predominantly single-thread channel with bankfull confinement in budget cell 1 is well-suited for estimating changes in bed material storage using DTM data because bathymetry and LiDAR surveys can accurately measure topographic changes in most areas where significant storage changes occur due to bedload transport. Further downstream in the Dredger Tailing Reach, the less confined and more complex channel with multiple connected backwaters, low valley confinement, and in-channel gravel pits is poorly suited for estimating changes in bed material storage using DTM data because small storage changes related to coarse and fine sediment deposition occur over broad, heavily vegetated areas that are infeasible to accurately survey using sonar bathymetry and LiDAR. To focus calculation of sediment storage changes in areas where the majority of the volumetric storage change occurs due to scour and fill of coarse sediment and to minimize uncertainty related to inaccurate survey data in vegetated floodplain areas, surface differencing was limited to the 320 cfs wetted area digitized from 2012 aerial photography.

The 2005 DTM was created from LiDAR, bathymetric, and terrestrial topographic data collected from RM 51.8 to RM 37.9. The 2005 DTM data was available as a series of CAD drawing files with topographic contours at one and two-foot intervals. The 2005 contour lines were converted to a 3-foot raster using ESRI 3D Analyst. The raster was processed without enforcing hydrologic drainage or significant topographic smoothing. The 2005 survey data is reported as NAD83 (1998), NAVD88. A geoid model was not specified in the metadata, and because GEOID03 was the most current geoid model available in 2005, it was assumed that GEOID03 was used to convert ellipsoidal heights to the NAVD88 vertical datum. The 2005 DTM data was adjusted to the 2012 datum in order to make an accurate assessment of surface change. The NGS Horizontal Time Dependent utility was used to evaluate the predicted horizontal displacement between NAD83 positions at Epoch 1998.00 and Epoch 2002.00 at the primary control point location. The resultant 0.1-foot horizontal displacement was insignificant to topographic modeling. The 2005 elevations were adjusted by +0.15 feet to account for conversion from GEOID03 to GEOID09 (+0.04 ft) and differences in the elevations of fixed features (bedrock, legacy in-channel infrastructure, and road surfaces) in 2005 and 2012 (+0.11 ft).

The 2012 DTM was developed using updated LiDAR, bathymetric, and terrestrial topographic data collected from RM 52.1 to RM 45.5. All survey data is reported in California State Plane Coordinate System, Zone III, NAD 1983 (epoch 2002.00) horizontal datum. Hybrid geoid model GEOID09 was used to convert NAD83 ellipsoidal heights to the NAVD88 vertical datum. Updated LiDAR data was acquired on March 30, 2012 at a discharge of approximately 320 cfs at USGS #11289650. Post-processed LiDAR data provided by the contractor as class 8 model key points (a subset of bare earth ground points) was used to represent topography at the desired scale and resolution. The LiDAR accuracy assessment reports that a root mean square of 0.15 feet was achieved when comparing elevations from the LiDAR bare-earth DTM to surveyed ground control points.

Bathymetry and terrestrial topographic surveys to characterize channel bed elevations in areas below water during LiDAR data acquisition were conducted during two separate field efforts in 2012. Bathymetric surveys were conducted 8–12 May, 2012 at flows ranging from 650 to 2,100 cfs as measured at USGS #11289650. Sounding data was collected with a Teledyne RDI 1200 kHz Workhorse Rio Grande acoustic doppler current profiler (ADCP) and an Ohmex Sonarmite echosounder mounted to a 15 ft Lowe Jon boat. Position and elevation were surveyed with Trimble R8 GNSS (GPS) survey equipment operating in real-time kinematic (RTK) survey mode. Positions measured by the bottom tracking function of the ADCP were used to fill position gaps that occurred when the GPS antenna was obstructed by dense overhead vegetation or bridges. The GPS rover antenna was mounted at a fixed height directly above the ADCP or echosounder transducer. The GPS rover was configured to output standard National Marine

Electronics Association (NMEA 0183) format GGA (positioning), VTG (heading), and ZDA (time-stamp, clock syncing) data strings and connected to a field laptop that simultaneously processed ADCP, GPS, and echosounder data in WinRiver II (ver 2.08) software. At transects where the ADCP was not deployed for safety considerations, continuous RTK GPS survey points and echosounder readings were recorded in a Trimble TSC2 field data controller. Bathymetric surveys were also conducted between June 2–7, 2012 at flows ranging from 125 to 150 cfs to characterize channel bed elevations in areas not covered by LiDAR or the high-flow bathymetry survey. During the low flow bathymetry survey, ADCP and GPS rover equipment were mounted to a small tethered trimaran. Supplementary terrestrial and shallow water surveys were conducted with a GPS rover and a Trimble S6 robotic total station.

ADCP data was initially processed with WinRiver II (Version 2.08) software and screened for erroneous positions and depth measurements that occur due to turbulent flow or dense aquatic vegetation. The WinRiver II data was exported to ASCII format files and imported into the beta Velocity Mapping Software (VMS) for further processing. VMS allows for simultaneous review of multiple ADCP transects, as well as processing of the four individual ADCP beam depth and position solutions. The multi-beam data was imported into ESRI ArcGIS software for final editing and DTM generation. GPS rover and total station survey data was processed in Trimble Business Center software and exported to ESRI Geodatabase format. Raw GPS base station files were submitted to the NOAA NGS Online Positioning User Service (OPUS) for processing and the solutions used to adjust base station coordinates.

A 2012 DTM surface was generated in budget cell 1 from RM 51.5 to RM 45.5 by combining the processed LiDAR, bathymetry, and terrestrial survey data using ESRI ArcGIS 3D Analyst software. A Triangulated Irregular Network (TIN) was generated from the survey data as mass points. Longitudinal profile and cross-section data were extrapolated from the TIN surface. The TIN was converted to a raster with a three foot cell size for surface differencing. Topographic differencing and cut and fill calculations were performed by subtracting the 2005 DTM raster from the 2012 DTM raster. The topographic surface differences show areas that are above (positive values reflecting aggradation), below (negative values reflecting degradation), or unchanged from the 2005 surface.

Topographic differencing provides an estimate of the total (coarse and fine) change in bed material storage. To facilitate comparison with estimates of the change in coarse (>2 mm) bed material storage from model simulation, the total change in bed material derived from topographic differencing was corrected to account for the fraction of bed material >2 mm observed in bulk bed material samples from the lower Tuolumne River. The California Department of Resources reported that bulk samples from 20 riffle sites in the 15-mile reach of the lower Tuolumne River downstream of La Grange Dam contained an average of approximately 6 percent fine sediment <1.2 mm (CDWR 1994). Shovel sampling methods used during the study may under predict the fine sediment fraction. A similar average fraction of 8.0 percent is reported for fine sediment < 2 mm in 100 random bulk samples taken at Riffle 5a in 1993 using standard methods (Stillwater Sciences 2002b). Based on the results of these studies, coarse sediment was assumed to be 92 percent of the total bed material by mass. The calculation assumes an average coarse sediment density of 1.30 tons yd^{-3}.

Bathymetric survey data collection and processing contains both measurement errors and surface processing errors (Byrnes et al. 2002). Sources of measurement error fall into three categories: *blatant error* (e.g. operator mistake), *systematic error* that can be estimated or measured (e.g. instrument calibration), and *random error* related to survey equipment limitations (e.g., manufacturer equipment tolerances, RTK GPS precision, natural streambed variation within the acoustic footprint, sound velocity profile and water temperature stratification). Interpolation error occurs when creating a continuous streambed elevation surface from discrete survey points and was minimized, to the extent feasible, by increasing survey data point density in areas with high natural variability. The total survey measurement and interpolation error may influence site-specific estimates of topographic change, but does not have a significant effect on overall estimates of aggradation and degradation from 2005 to 2012.

4.3 Changes in Fine Bed Material Storage

All discreet FBM deposits (predominantly <2 mm) within the approximate 600 cfs inundation area were mapped from La Grange Dam (RM 52.1) to the Santa Fe Aggregates facility (RM 36.3). Downstream of RM 36.3, the channel progressively transitions to a predominantly fine bed where discrete FBM patches are no longer mappable. Patches were delineated on orthorectified aerial photographs flown on April 6, 2012. Mapping occurred on field tiles at a scale of 1:2000, with a minimum mappable unit of approximately 100 ft^2. FBM deposits were noted as occurring in one of six different geomorphic units: pool bottom, pool margin, other channel margin, alcove/backwater, side channel, and captured gravel pit. The dominant and subdominant surface texture was recorded for each FBM patch, and the depth of the deposit was estimated by probing multiple locations with a Silvey rod. The maximum measureable depth was limited to the length of the Silvey rod (approximately 5 ft). Few patches were greater than 5 feet in depth. Areas of coarse channel bed with a matrix of fine sediment or that were embedded with fine sediment were not mapped as discrete FBM patches due to the coarse overall median grain size. A thin veneer of fine sediment occurred over many low-velocity zones within the 300 cfs inundation area but was not mapped as discrete FBM patches due to the presence of coarse deposits at shallow depth under the thin fine sediment layer.

The aerial photographic map tiles were scanned and georeferenced in ArcGIS. Fine bed material patches delineated in the field were digitized from the scanned field maps. Fine bed material patch volumes were calculated within the 320 cfs and 600 cfs inundation areas by multiplying the area of each patch by the average patch depth. Volume was converted to mass using a bulk density 1.15 tons yd^{-3}. The volume and spatial distribution of fine sediment among geomorphic units were compared between the 2001 and 2012 surveys from RM 52.1 to RM 39.6, the longitudinal extent of the 2001 surveys (Stillwater Sciences 2002a).

4.4 Changes in Spawning Habitat

Methodologies implemented to satisfy the study objectives of mapping current riffle area, spawning gravel area, and suitable spawning habitat area in the lower Tuolumne River and comparison of these results with results from previous surveys in 1988 (TID/MID 1992a) and 2001 (McBain and Trush 2004) are discussed below.

4.4.1 Riffles and Spawning Gravel

The W&AR-04 study updated the boundaries of riffle mesohabitat units delineated in 2010 for the lower Tuolumne River Instream Flow (IFIM) study (Stillwater Sciences 2009a). Mesohabitat typing in 2010 applied a method requested by the USFWS that differs from previous mesohabitat typing on the lower Tuolumne River (Stillwater Sciences 2008). Mesohabitat typing for the IFIM study included two channel forms (flatwater and bar-complex) and four mesohabitat types (pool, riffle, run, glide) (TID/MID 2010). Riffle mesohabitat units mapped in 2010 were defined as shallow features with turbulent flow; partially exposed substrate dominated by gravel, cobble, or boulder; and gradient less than 4 percent. The 2010 riffle boundaries were initially delineated using riffle mesohabitat boundaries mapped in previous years, aerial photography, and depth transitions in the 2005 DTM data. The initial desktop delineation was followed by field validation from La Grange Dam downstream to RM 29 (Stillwater Sciences 2009b). The 2010 riffle boundaries were updated in 2012 using aerial photography flown on April 6, 2012 at a summer baseflow release of approximately 320 cfs. For the purpose of comparing riffle areas over time within a reach, 2012 riffle mesohabitat units were correlated to prior riffle mesohabitat units based on proximity.

Based on published reviews for suitable spawning gravel sizes (e.g., Barnhart 1991, Kondolf and Wolman 1993), considerable overlap in suitable spawning gravel sizes exists for Chinook salmon and *O. mykiss*. All deposits occurring within the approximate 600 cfs inundation area with a D_{50} of 6–102 mm were mapped during the survey, representing a range between the upper limit of optimal Chinook salmon spawning substrate size and the lower limit of optimal resident *O. mykiss* spawning substrate size. These ranges were included in the current IFIM study (TID/MID 2010) and have been used in IFIM studies on other salmon bearing rivers in California (e.g., PG&E 2008, 2009; USFWS 2007).

Using the spawning gravel criteria above, surficial gravel deposits with a particle size distribution potentially suitable for Chinook salmon and *O. mykiss* spawning were mapped from La Grange Dam (RM 52.1) downstream to RM 23, which includes the longitudinal extent of riffle mesohabitats documented in prior surveys. Gravel patches were delineated on ortho-rectified aerial photographs flown on April 6, 2012 at a summer baseflow release of approximately 320 cfs as measured at USGS #11289650. Mapping occurred on field tiles at a scale of 1:2000, with a minimum mappable unit of approximately 500 ft^2. To provide an indication of gravel quality and suitability, grain size parameters (i.e., D_{16}, D_{50}, and D_{84}) were estimated for each spawning gravel patch. Spawning gravel patches were subdivided and assigned separate grain size parameter estimates if the D_{50} or D_{84} varied by at least one phi size class. Wolman (1954) pebble counts were conducted in selected patches to calibrate visual estimates of grain size parameters. The area of coarse sediment deposits within mesohabitats was summarized using riffle boundaries updated to the 320 cfs wetted perimeter in 2012. If FBM deposits were mapped as inclusions within spawning gravel deposits, FBM deposit areas were subtracted from the spawning gravel patch area.

4.4.2 Suitable Spawning Habitat

Suitable spawning habitat is a function of gravel size and distribution, addressed in Section 4.4.1 above, as well as hydraulic characteristics such as water depth and velocity. Suitable hydraulic characteristics for spawning could not be mapped during collection of spawning substrate data in summer 2012 due to the dry water year release schedule. Hydraulic data was collected at sample sites in November 2012. This portion of the report will be completed following analyses of suitable spawning habitat using results from the November 2012 surveys combined with prior substrate mapping data and results from PHABSIM modeling. Methods for the assessment of suitable hydraulic conditions and estimation of suitable spawning habitat area are provided in Attachment D.

4.5 Maximum Spawning Run Sizes Under Current Conditions

One of the objectives of this study is to calculate the maximum spawning run sizes supported under current conditions, using the spawning substrate and hydraulic data collected as described above. This calculation will consider the available spawning substrate area, the hydraulic conditions (depth and velocity) over such areas, and the effects of redd superimposition. This information will be relevant for Chinook salmon and *O. mykiss* population models, and the calculations will be completed following collection of the remaining hydraulic field data.

5.0 RESULTS

The results of each element in the W&AR-04 Spawning Gravel study are discussed below within the context of the five study objectives. Data used in conducting these analyses and data generated as a result will be available with the final report.

5.1 Sediment Yield to Don Pedro Reservoir

Comparison of storage capacity curves for Don Pedro Reservoir in 1971 and 2011 indicates 15,694 acre-feet (25,319,653 yd^3) of storage loss due to sedimentation since closure of Old Don Pedro Dam, less than 1 percent of the original storage capacity of Don Pedro Reservoir in 1971. This percentage is within the uncertainty associated with the interpolated surfaces (TID/MID 2012). Using the coarse sediment ratio developed for Englebright Reservoir (Snyder et al. 2004), the average annual total and coarse (>2 mm) sediment yields to the reservoir, calculated over the 1923–2011 period, are approximately 373,966 tons yr^{-1} and 37,397 tons yr^{-1}, respectively. These estimates are within 13 percent of estimates based on changes in reservoir storage capacity over the 1923–1946 period reported by Brown and Thorp (1947) and are comparable to sediment yields estimated for other reservoirs on the western slope of the Sierra Nevada range (Dendy and Champion 1978).

5.2 Changes in Coarse Bed Material Storage

The following sections describe the potential cumulative effects of the Project on changes in coarse bed material storage in the Dominant Salmon Spawning Reach based on simulated reach average changes in bed material storage from sediment transport modeling and spatially explicit changes in bed material storage by differencing 2005 and 2012 digital terrain models.

5.2.1 Modeling

The modeling simulation with gravel augmentation produced simulated longitudinal profiles for 2005 and 2012 that are similar to the observed 2005 and 2012 longitudinal profiles developed from DTM data (Figure 5.2-1). The simulated 2005 and 2012 profiles closely reproduced the general gradient of the DTM channel profiles, although differences in bed elevations occur from point to point. Differences in predicted and observed bed elevations are expected because sediment transport modeling simulates reach-averaged conditions and cannot reproduce local bed elevations attributed to site-specific topographic and hydraulic controls (Cui et al. 2011).

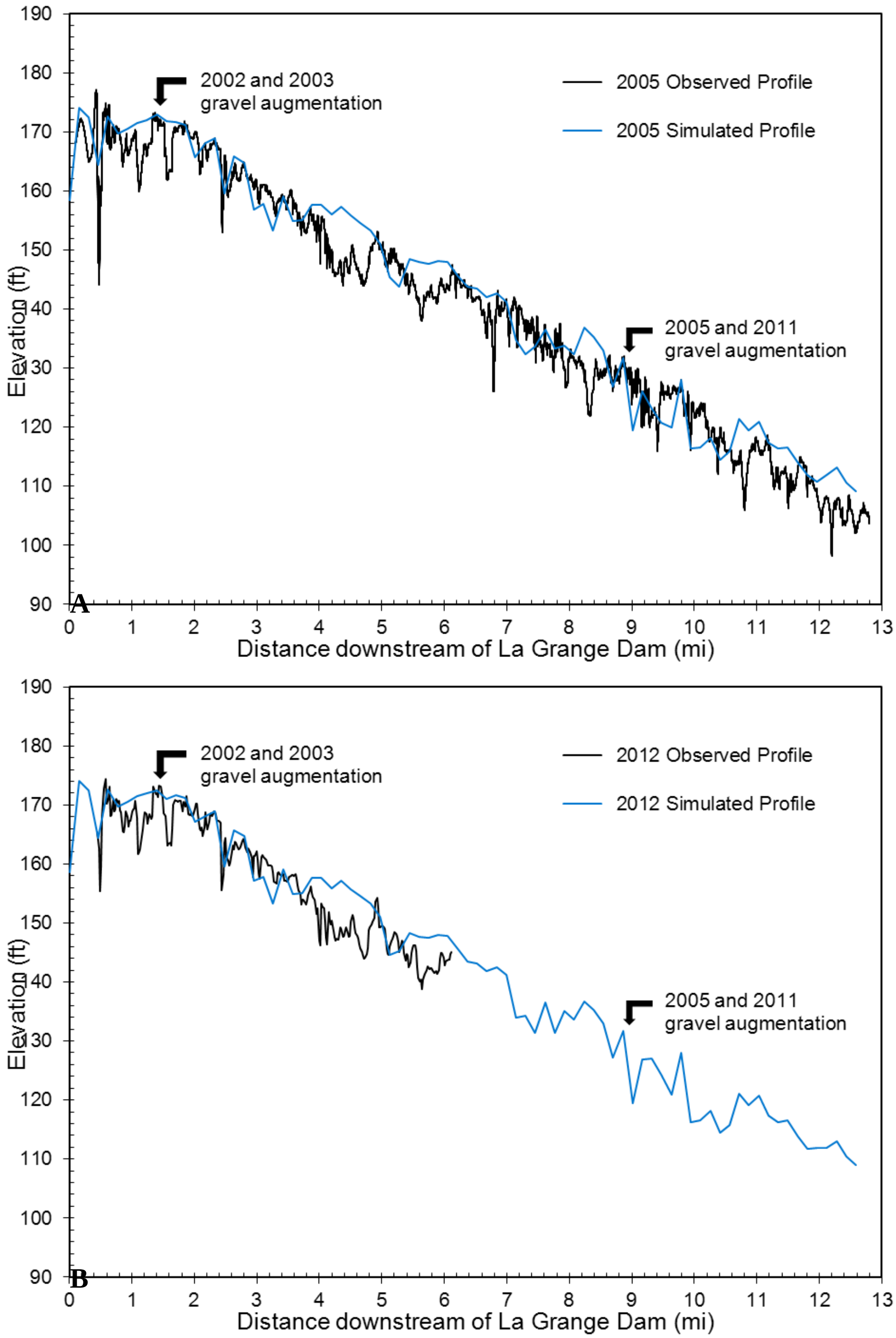


Figure 5.2-1. Simulated (with gravel augmentation) and observed longitudinal profiles of the 12.4 mi model study reach in (A) 2005 and (B) 2012.

The simulated average annual bedload transport rate (with gravel augmentation) in sediment budget cells 1 and 2 was 375 tons yr^{-1} over the 12 year period from 2000 to 2012. The simulated average annual bedload transport rate in the vicinity of Riffle 4A and 4B (approximately RM 48.5), where previous estimates of transport rates exist, was 80 tons yr^{-1} from 2000 to 2005. The current estimate of bedload transport rate in the vicinity of Riffle 4A and 4B is lower than previous estimates (1,412–1,930 ton yr^{-1}), but all of the estimates to date are low compared to bedload transport rates in other rivers channels with similar slope, drainage area, and precipitation.

The model simulations indicated that without gravel augmentation, the channel bed in budget cells 1 and 2 would be slowly degrading and coarsening in response to a reduction in coarse sediment supply due to trapping in Don Pedro Reservoir. Gravel augmentation, however, helped to increase coarse sediment storage. Figure 5.2-2 illustrates the cumulative change in coarse sediment storage in budget cell 1, indicating that gravel augmentation helped increase net coarse sediment storage by about 14,100 tons since 2000, but that approximately 4,550 tons was lost from storage between 2005 and 2012. Similarly, modeling results indicate that gravel augmentation helped increase cumulative coarse sediment storage by about 41,500 tons since 2000 in budget cell 2, where approximately 1,000 tons would otherwise have been lost from storage without augmentation (Figure 5.2-3). Figure 5.2-4 provides a combined coarse sediment budget for budget cells 1 and 2 between 2000 and 2012, showing approximately 55,600 tons of increased coarse sediment storage, all of which can be attributed to gravel augmentation. The increase in coarse sediment storage within the study reach is approximately 94 percent of the total added by gravel augmentation, indicating most coarse sediment added by augmentation was retained within the reach.

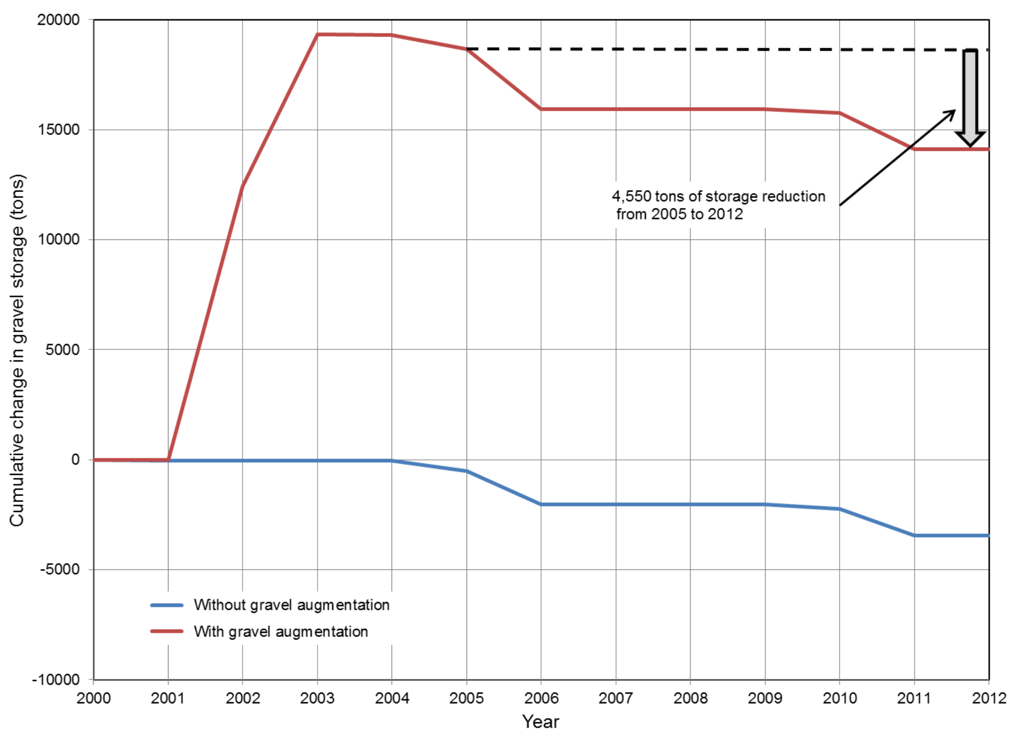


Figure 5.2-2. Simulated cumulative change in coarse sediment storage since 2000 in budget cell 1.

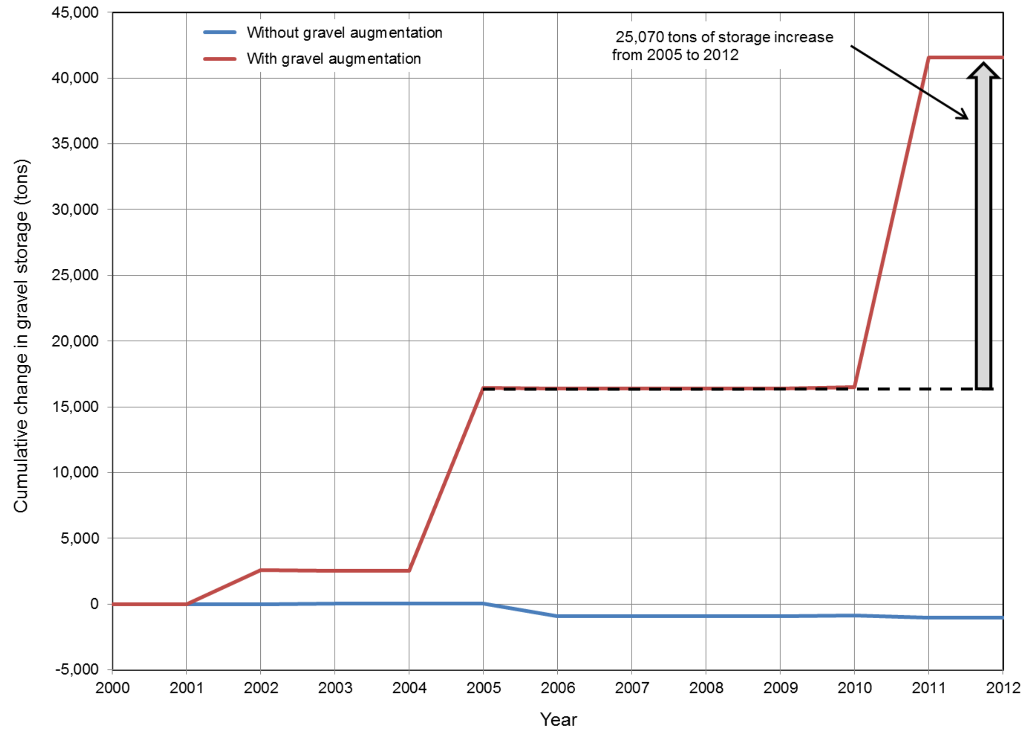


Figure 5.2-3. Simulated cumulative change in coarse sediment storage since 2000 in budget cell 2.

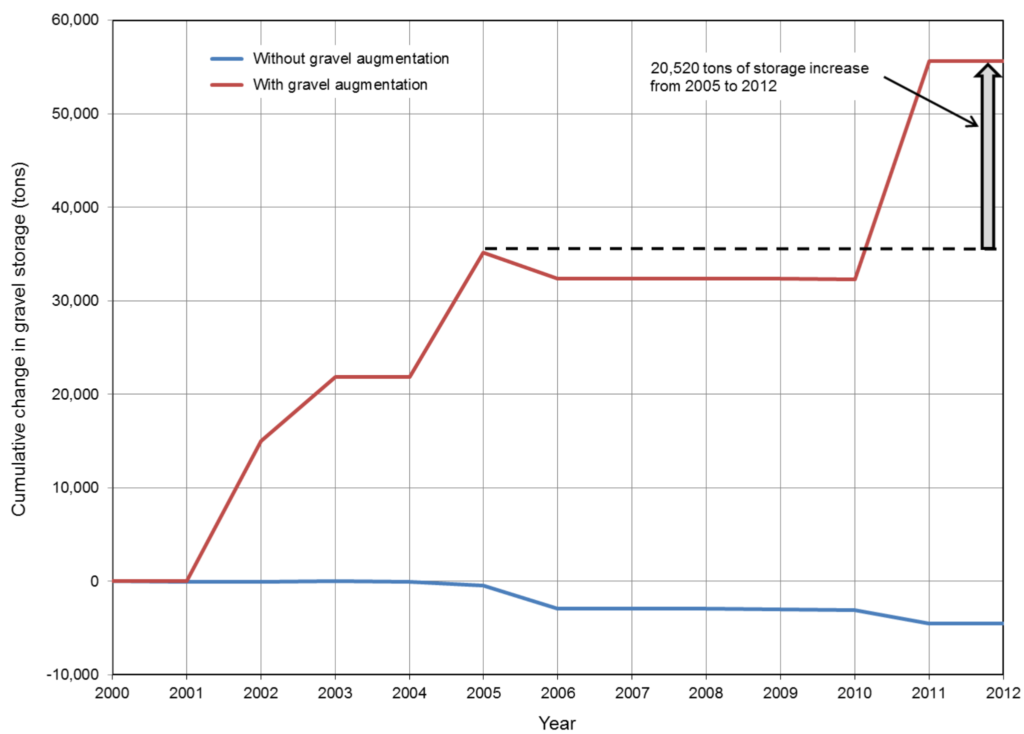


Figure 5.2-4. Simulated cumulative change in coarse sediment storage since 2000 in budget cells 1 and 2.

5.2.2 Topographic Differencing

Topographic differencing of DTMs from 2005 and 2012 indicates a loss of 6,561 yd^3 (8,530 tons) of bed material from within the 320 cfs wetted channel in budget cell 1. Assuming 92 percent of bed material is coarse (>2 mm), approximately 6,035 yd^3 (7,846 tons) of coarse sediment was lost from channel storage during the period. Although the overall storage change in the reach is relatively small, areas of significant scour and fill are apparent in the topographic surface differencing (Attachment A). Pools commonly scoured three to five feet, mobilizing finer sediment to depositional areas in channel margins and coarser sediment to pool tails and riffles. Riffle crests in the vicinity of pools tails commonly aggraded one to three feet. Aggradation is also commonly observed along the channel margins outside of pool units, particularly in areas of expanding channel width. Field observations during the spring and summer of 2012 indicated that pool tails and riffle crests contained little fine bed material, while channel margins contained abundant fine bed material. The channel bed in segments with plane bed morphology and relatively constant width typically changed little (<1.0 foot). Gravel added at augmentation sites from RM 50.1 to RM 50.7 in 2002 and 2003 are apparent as dispersing deposits, with most of the material retained within a short distance downstream from the placement location (Figure 5.2-5).

Erosional and depositional patterns observed in the topographic differencing support hypotheses introduced in the Habitat Restoration Plan for the lower Tuolumne River that infrequent large floods (e.g., exceeding 3- to 5-year annual maximum flood recurrences) scour pools and clean and replenish gravel substrates in riffles (McBain and Trush 2000). The observed erosion and depositional patterns are also consistent with those reported in physical modeling experiments involving sediment transport in gravel bed channels during simulated high flow events of long duration (Parker et al. 2003), similar to those that occurred in the lower Tuolumne River during spring runoff in WY 2006 and WY 2011. Flows exceeded the estimated minimum threshold for significant bed mobility at Riffle 4B (5,400–6,880 cfs [McBain and Trush 2000, 2004]) for 75 days during WY 2006 and 54 days during WY 2011 (Figure 5.2-6).

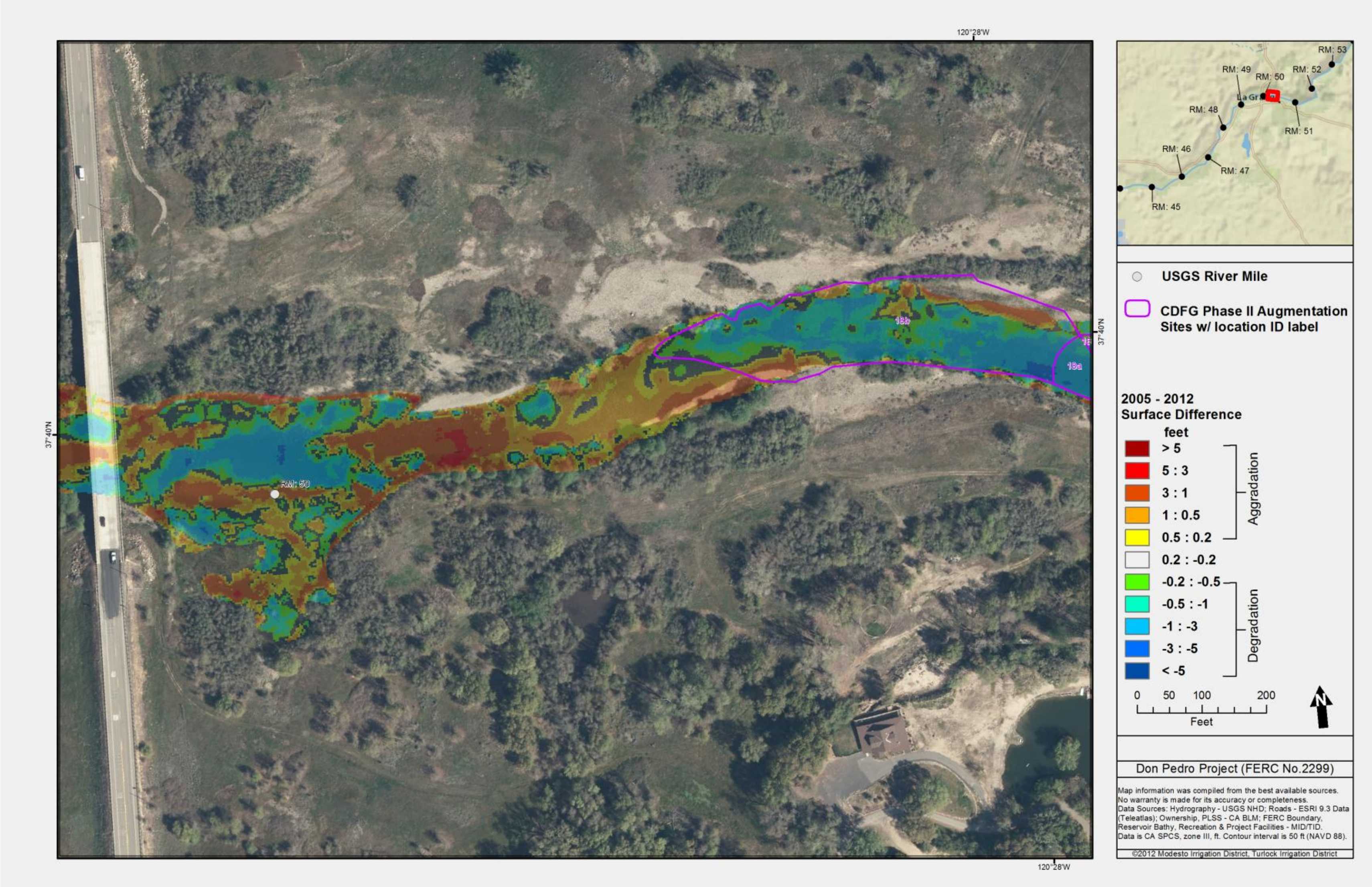


Figure 5.2-5. Bed elevation changes in the lower Tuolumne River from RM 49.9 to RM 50.3 determined from differencing 2005 and 2012 DTM surfaces.

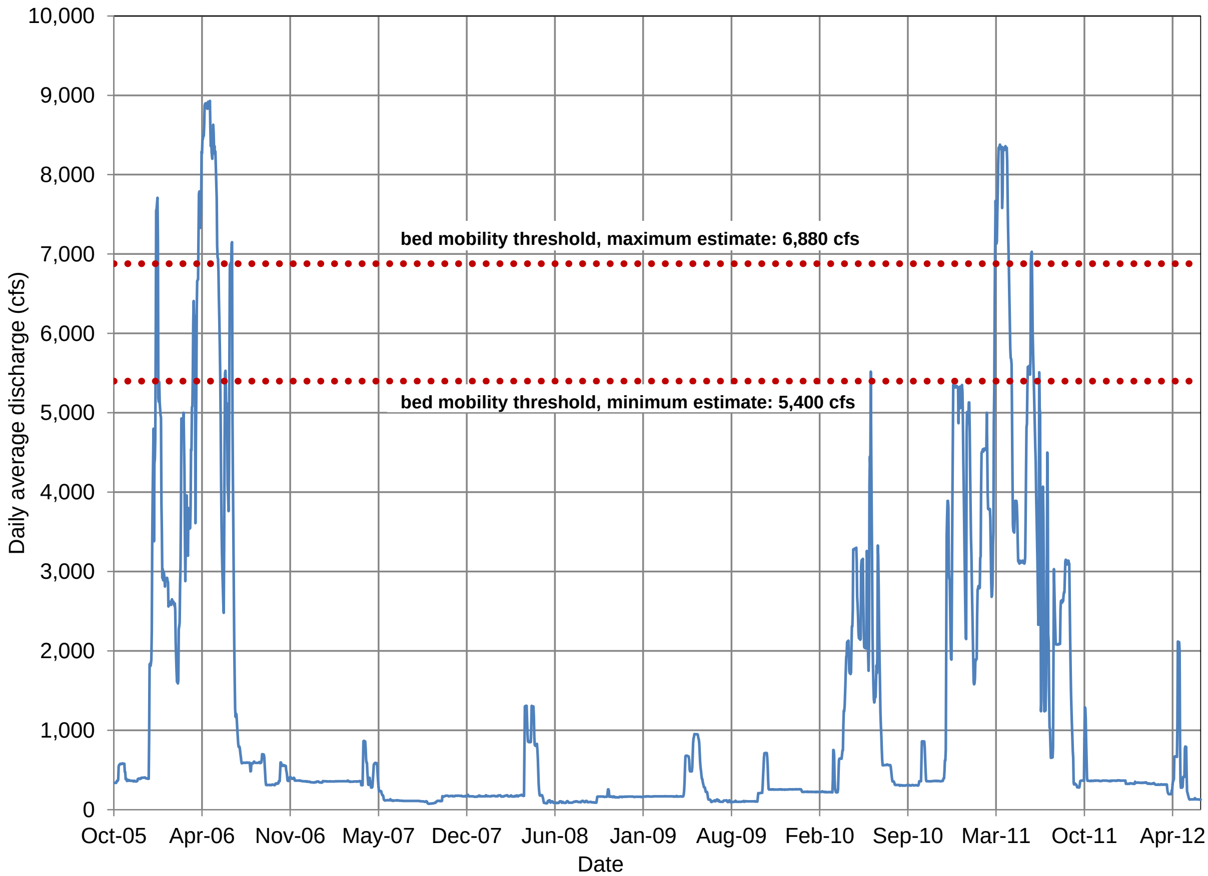


Figure 5.2-6. Hydrograph for WY 2006–2102 at USGS gauge # 11289650 (Tuolumne River below La Grange Dam), and estimated maximum and minimum bed mobility thresholds at Riffle 4b.

In summary, the coarse sediment budget for sediment budget cell 1 (RM 52.1–RM 45.5 encompassing the Dominant Salmon Spawning Reach immediately downstream of La Grange Dam) indicates that approximately 3500–6,035 yd^3 (4,550–7,846 tons) of coarse bed material was lost from storage between 2005 and 2012 (Table 5.2-1). If the estimated total storage change from differencing 2005 and 2012 DTM data is distributed over the total channel area, it equates to an average bed lowering of 12 mm. The estimated lowering in the reach during the 2005–2012 period is less than the average median grain size of the coarse channel bed (approximately 51 mm), and the total estimated volume lost from storage in the reach is comparable in magnitude to the quantity of coarse sediment added during any one of the augmentation projects that occurred since 2002 (approximately 7,000–14,000 tons). Although the results of modeling and topographic differencing indicate little overall change in storage from 2000 to 2012, high flow events in WY 2006 and WY 2011 resulted in substantial pool scour, with coarse sediment redeposited in pool tails and riffles and fine bed material mobilized to channel margins.

Table 5.2-1. Estimated changes in channel sediment storage from 2005 to 2012.

Reach	Change in Coarse Bed Material Storage from Modeling[1] (tons)	DTM differencing		
		Change in Total Bed Material Storage (tons)	Change in Coarse Bed Material Storage (tons)[2]	Average Bed Elevation Change (mm)[3]
0–6.2 mi	-4,550	-8,530	-7,846	-12
6.2–12.4 mi	+25,070	na[4]	na	na

[1] Model estimates of storage changes with gravel augmentation.
[2] Change in coarse sediment storage assumes bed material is 92 percent coarse sediment (> 2mm).
[3] Lowering based on change in total bed material storage within the 320 cfs wetted channel area.
[4] na = not available.

5.3 Changes in Fine Bed Material Storage

Approximately 66,600 yd^3 of FBM deposits occurred in discrete patches in the reach from La Grange Dam (RM 52.1) to the Santa Fe Aggregates haul road bridge (RM 36.3) in 2012 (Attachment C). The volume of discrete FBM deposits in the reach equates to 76,300 tons, of which approximately 63,700 tons (83 percent) occurred within the 320 cfs inundation area (Table 5.3-1, Figure 5.3-1). The volume of FBM was distributed nearly equally among pool margins, other channel margins, and alcoves and backwaters (Table 5.3-1, Figure 5.3-2). Fine bed material storage increased immediately downstream of Gasburg Creek and Peaslee Creek. A large volume of FBM was also stored in captured gravel pits located at the downstream end of the surveyed reach near the Santa Fe Aggregates processing plant. Most FBM patches had a dominantly sandy surface texture.

Table 5.3-1. Volume of discrete fine bed material deposits mapped in 2012 from La Grange Dam (RM 52.1) to Santa Fe Aggregates haul road bridge (RM 36.3).

Geomorphic Unit	Volume (yd3)			Mass1 (tons)		
	320 cfs Inundation Area	320–600 cfs Inundation Area	Total	320 cfs Inundation Area	320–600 cfs Inundation Area	Total
Pool bottom	2,022	166	2,188	2,318	191	2,509
Pool margin	14,441	1,140	15,582	16,561	1,308	17,869
Channel margin	14,195	1,816	16,011	16,279	2,083	18,362
Alcove/backwater	14,320	2,717	17,037	16,423	3,116	19,539
Side channel	507	959	1,465	581	1,099	1,680
Captured gravel pit	10,085	4,194	14,279	11,566	4,810	16,376
Total	**55,570**	**10,993**	**66,563**	**63,729**	**12,607**	**76,336**

[1] Assumes sediment density of 1.15 tons yd^{-3}.

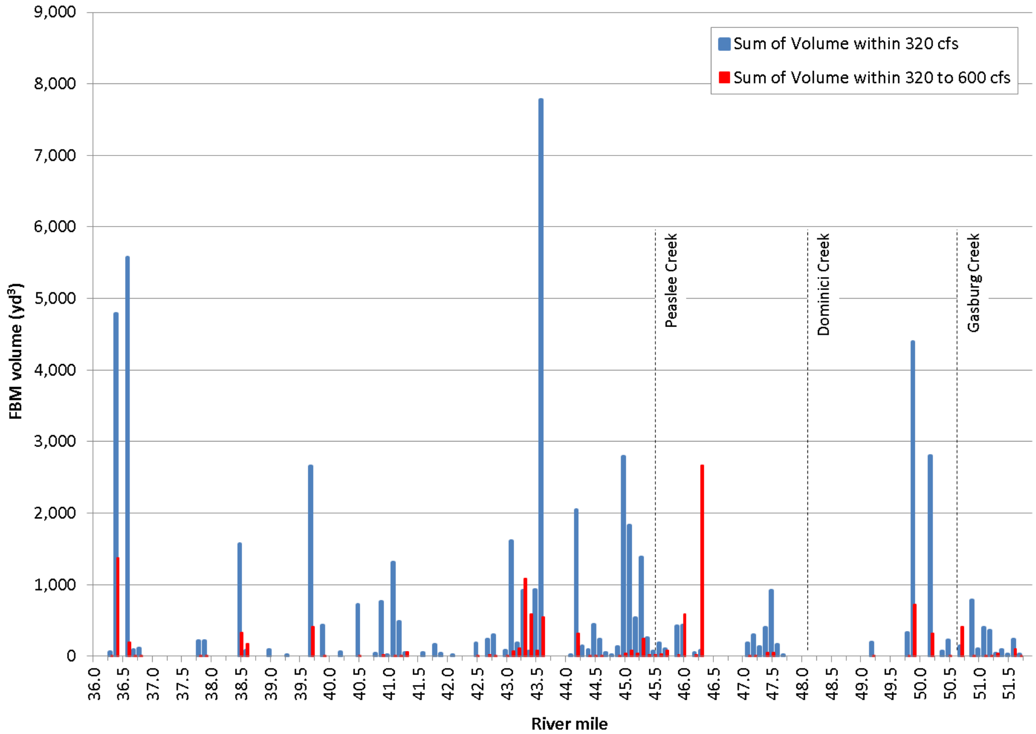


Figure 5.3-1. Distribution of discrete FBM deposits within 320 cfs and 600 cfs inundation areas from La Grange Dam to Santa Fe Aggregates haul road bridge.

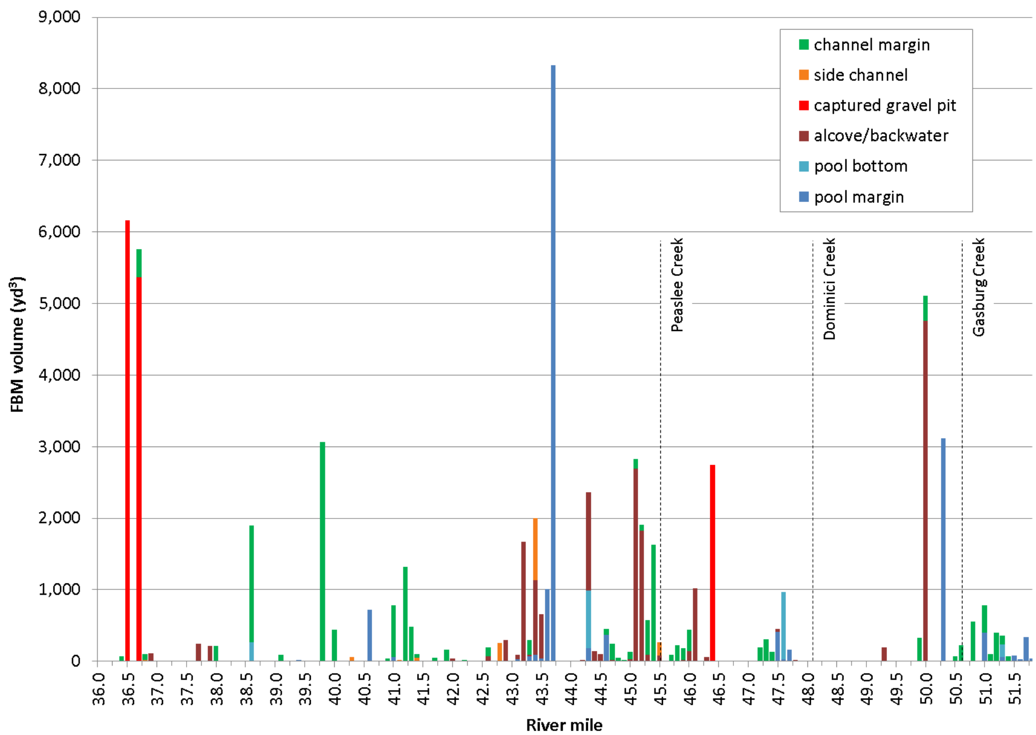


Figure 5.3-2. Distribution of discrete FBM deposits within different geomorphic units from La Grange Dam to Santa Fe Aggregates haul road bridge.

Comparison of FBM storage in the reach from La Grange Dam (RM 52.1) to Roberts Ferry Bridge (RM 39.6) in 2001 and 2012 indicates a 44 percent reduction in total sediment volume, from approximately 92,734 yd^3 in 2001 to approximately 51,664 yd^3 in 2012 (Table 5.3-2). Fine bed material storage in the low flow channel diminished 36 percent from approximately 67,229 yd^3 in 2001 to approximately 42,770 yd^3 in 2012. A spatially explicit comparison by patch or mesohabitat unit was not possible due to a lack of spatial data describing individual patch locations in 2001 or the lateral extent of the 2001 survey.

Differences in the estimated total FBM storage in the reach may be due to mobilization and redistribution of discrete deposits mapped in 2001, changes in fine sediment supply from 2001 to 2012, and/or differences in the mapping extend. Discrete deposits in 2012 were mapped within the approximate 600 cfs inundation area, while discrete deposits in 2001 were mapped within the low flow channel and "to a limited extent and no further than 150 m (approximately 500 ft) away from the low-flow channel boundary" (McBain and Trush 2004). The 2012 survey defined the low flow channel area based on the edge of water mapped from 2012 aerial photographs taken at 320 cfs, while the 2001 survey defined the low flow channel at approximate 90 cfs.

Table 5.3-2. Fine bed material volumes mapped in 2001 and 2012 from La Grange Dam (RM 52.1) to Roberts Ferry Bridge (RM 39.6).

Location	Volume of discrete fine bed material deposits, yd^3				% Change	
	2001		2012			
	Low Flow Channel	Total	320 cfs Inundation Area	600 cfs Inundation Area	Low Flow Channel	Total
Pools	56,922	61,093	40,560	47,561	-29	-22
Other areas	10,338	31,686	2,229	4,138	-78	-87
Total	**67,260**	**92,779**	**42,789**	**51,699**	**-36**	**-44**

5.4 Changes in Spawning Habitat

The results of mapping current riffle area, spawning gravel area, and suitable spawning habitat area in the lower Tuolumne River and comparison of these results with results from previous surveys in 1988 (TID/MID 1992a) and 2001 (McBain and Trush 2004) are discussed below.

5.4.1 Riffles and Spawning Gravel

A total of 3,527,200 ft^2 of riffle mesohabitat was mapped from RM 52.1 to RM 23 in 2012, of which 2,967,500 ft^2 (84 percent) was occupied by spawning gravel (Table 5.4-1, Table 5.4-2, Attachment B). Spawning gravel deposits mapped in the gravel-bedded reach of the lower Tuolumne River in 2012 had a relatively uniform particle size distribution, with an average estimated D_{50} of 51 mm and standard deviation of 17 mm. The maximum and minimum estimated D_{50} for all mapped spawning gravel patches was 15 mm and 100 mm, respectively. It was uncommon to find gravel deposits with a bimodal distribution, such that the D_{50} fell within the suitable spawning range but the D_{84} and D_{max} grain sizes would prohibit spawning in that area. Riffles were not mapped from RM 34.2 to RM 23 in 2001, and comparisons between 2012 and 2001 riffle area are therefore limited to the 17.9-mile reach from RM 52.1 to RM 34.2 assessed by both McBain and Trush (2004) and the current study. A total of 2,342,000 ft^2 of riffle mesohabitat was mapped in this reach in 2012, of which 2,056,600 ft^2 (88 percent) was occupied by spawning gravel (Table 5.4-2, Attachment B).

Table 5.4-1. Spawning gravel area mapped from RM 52.1 to RM 23 in 2012.

Mesohabitat Type	Spawning Gravel Area (ft^2)
Pool	2,285,171
Riffle	2,967,547
Run	5,878,369
Glide	706,357
Bar	426,276
Other[1]	2,129,385
Total	**14,393,106**

[1] Other includes areas outside the mapped extent of mesohabitat units.

Comparing the results of riffle surveys conducted in 1988 and 2012 suggests an increase of 606,200 ft^2 (21 percent). However, comparing the 2001 and 2012 surveys suggests a more significant increase of 709,500 ft^2 (54 percent). Increases in riffle area from 2001 to 2012 are largely attributed to differences in the methods used to map riffles over time (e.g., variability in the discharge and wetted channel area in aerial photographs used in desktop mapping and/or at the time of field surveys, mapping criteria based on flow depth and gravel substrate, accuracy and precision of riffle delineation). Riffles were mapped in 1988 from aerial photography at a scale of 1:2,400 and flow of 230 cfs. In 2001, riffles were mapped onto aerial photographs in the field when flows ranged from 250 to 1,010 cfs. In 2012, riffle mesohabitat boundaries mapped in 2010 during the instream flow study (Stillwater Sciences 2008, Stillwater Sciences 2009a, TID/MID 2010) were updated in GIS based on 2012 aerial photography flown on 6 April 2012 at approximately 320 cfs. Although differences in riffle area are likely attributed to methodological differences, pool scour and associated deposition of coarse sediment in pool tails and riffles during high flow events in WY 2006 and WY 2011 increased the size and modified the distribution of riffle mesohabitats.

Table 5.4-2. Comparison of 1988, 2001, and 2012 riffle mesohabitats and spawning gravel areas in riffles.

Reach	1988 Riffle Area	2001[1]		2012		Change in Riffle Area			
		Riffle Area	Spawning Habitat Area	Riffle Area	Spawning Gravel in Riffles	1988 to 2012		2001 to 2012	
	ft^2	ft^2	ft^2	ft^2	ft^2	ft^2	%	ft^2	%
Dominant Salmon Spawning Reach	741,357	606,600	410,600	793,400	709,200	52,054	7	186,845	31
Dredger Tailing Reach	419,800	373,900	99,300	744,800	601,200	324,991	77	370,888	99
Gravel Mining Reach	412,900	324,500	126,400	533,300	501,200	120,463	29	208,877	64
In-channel Gravel Mining Reach	1,343,200	na	na	1,455,600	1,155,900	112,458	8	na	na
Total RM 52.1 to RM 34.2	1,836,900	1,304,900	636,200	2,342,000	2,056,600	501,347	27	709,525	54
Total RM 52.1 to RM 23.6	2,917,200	na	na	3,527,200	2,967,500	606,212	21		

[1] Riffle mesohabitats were not mapped in the reach from RM 34.2 to RM 23 in 2001.
[2] na = not available.

5.4.2 Suitable Spawning Habitat

Summer baseflows in the lower Tuolumne River during Water Year 2012 occurred under a dry year release schedule and were insufficient to map suitable spawning habitat based on depth and velocity criteria during spawning flows in the 29-mile reach from La Grange Dam (RM 52.1) downstream to RM 23. Analyses of suitable spawning habitat is instead being conducted in association with the ongoing Tuolumne River Instream Flow Incremental Methodology study and other salmon monitoring studies (i.e., W&AR-08 Redd Mapping Study) through Fall 2012. Current spawning habitat area in the lower Tuolumne River and comparison with results from previous surveys in 1988 (TID/MID 1992a) and 2001 (McBain and Trush 2004) will be reported upon completion in accordance with the timeline for other reports and seasonal flow events.

5.5 Maximum Spawning Run Sizes Under Current Conditions

Analyses of maximum spawning run sizes is being conducted in association with the ongoing Tuolumne River Instream Flow Incremental Methodology study and other salmon monitoring studies (e.g., W&AR-08 Redd Mapping Study, W&AR-06 Chinook Salmon Population Model) through Fall 2012. Results estimating spawning run sizes will be reported in accordance with the timeline for other reports and seasonal flow events.

6.0 DISCUSSION AND FINDINGS

Findings from the W&AR-04 Spawning Gravel study are discussed below within the context of the five study objectives.

Objective 1: Estimate average annual sediment yield to Don Pedro Reservoir based on reservoir sedimentation. Comparison of storage capacity curves for Don Pedro Reservoir in 1971 and 2011 indicates 15,694 acre-feet (25,319,653 yd^3) of storage loss due to sedimentation since closure of Old Don Pedro Dam, less than 1 percent of the original storage capacity of Don Pedro Reservoir in 1971. Average annual total and coarse (>2 mm) sediment yields to the reservoir, calculated over the 1923–2011 period, are approximately 373,966 tons yr^{-1} and 37,397 tons yr^{-1}, respectively. These estimates are within 13 percent of estimates based on reservoir storage capacity changes during the 1923–1946 period reported by Brown and Thorp (1947), and are comparable to sediment yields estimated for other reservoirs on the western slope of the Sierra Nevada range.

Objective 2: Estimate changes in the volume of bed material stored in the lower Tuolumne River channel over the 2005 to 2012 period. The coarse sediment budget developed through sediment transport modeling and analysis of changes in bed topography indicates that without gravel augmentation, the channel in the first 12.4 mi downstream of La Grange Dam (sediment budget cells 1 and 2) would be slowly degrading in response to a reduction in coarse sediment supply by New Don Pedro Dam. Approximately 4,550–7,850 tons of coarse (>2 mm) bed material was lost from storage in budget cell 1 (encompassing the Dominant Salmon Spawning Reach) between 2005 and 2012. Gravel augmentation has helped increase coarse sediment storage in the reach, and 94 percent of the coarse sediment added through augmentation has been retained.

Differencing of channel topography surveyed in 2005 and 2012 in budget cell 1 shows that little change in storage has occurred at the reach scale, but that high flow events in WY 2006 and WY 2011 locally scoured the bed and redistributed coarse and fine sediment deposits. Pools commonly scoured three to five feet, mobilizing finer sediment to depositional areas in channel margins and coarser sediment to pool tails and riffles, where 1to 3 feet of aggradation is commonly observed. The total estimated volume lost from storage in the reach is comparable in magnitude to the quantity of coarse sediment added during any one of the augmentation projects that has occurred since 2002 (approximately 7,000–14,000 tons).

The results of sediment transport modeling and topographic differencing suggest that augmentation material is being mobilized short distances during infrequent high flow events (e.g., during WY 2006 and WY 2011), but that routing is slow due to low bedload transport capacity. Prolonged retention of augmented coarse sediment may allow the gravel framework to fill with fine sediment that is not mobilized during infrequent high flow events. Under these conditions, smaller augmentation volumes distributed more widely and more emphasis on improving gravel quality may help achieve the goals of improving spawning habitat in the lower Tuolumne River (McBain and Trush 2004).

Objective 3: Map current discrete fine bed material (FBM) deposits (predominantly <2 mm) in the lower Tuolumne River channel and compare with results from previous surveys in 2001 (Stillwater Sciences 2002a). The total volume of discrete FBM deposits in the reach from La Grange Dam (RM 52.1) to Roberts Ferry Bridge (RM 39.6) decreased by 44 percent from 2001 to 2012. Discrete FBM deposits mapped in 2012 were distributed nearly equally among pool margins, channel margins, and alcoves and backwaters but were more frequent and larger immediately downstream of Gasburg and Peaslee creeks, suggesting that supply from these tributaries may continue to be an important source of fine sediment to the lower Tuolumne River channel.

Objective 4: Map current riffle area, spawning gravel area, and suitable spawning habitat area in the lower Tuolumne River and compare with results from previous surveys in 1988 (TID/MID 1992a) and 2001 (McBain and Trush 2004). A total of 3,527,200 ft^2 of riffle mesohabitat was mapped from RM 52.1 to RM 23 in 2012, of which 2,967,500 ft^2 (84 percent) was occupied by spawning gravel. The particle size distribution of spawning gravel deposits was relatively uniform, with an average estimated D_{50} of 51 mm. Comparing the results of riffle surveys conducted in 1988 and 2012 suggests riffle area increased by 606,200 ft^2 (21 percent). However, comparing the 2001 and 2012 surveys suggests a more significant increase of 709,500 ft^2 (54 percent). Increases in riffle area from 2001 to 2012 are largely attributed to differences in the methods used to map riffles over time (e.g., variability in the discharge and wetted channel area in aerial photographs used in desktop mapping and during field surveys, mapping criteria based on flow depth and gravel substrate, accuracy and precision of riffle delineation). Riffles were mapped in 1988 from aerial photography at a scale of 1:2,400 and flow of 230 cfs. In 2001, riffles were mapped onto aerial photographs in the field when flows ranged from 250 to 1,010 cfs. In 2012, riffle mesohabitat boundaries mapped in 2010 during the instream flow study (Stillwater Sciences 2008, Stillwater Sciences 2009a, TID/ MID 2010) were updated in GIS based on 2012 aerial photography flown on 6 April 2012 at approximately 320 cfs. Although differences in riffle area are likely attributed to methodological differences, pool scour and associated deposition of coarse sediment in pool tails and riffles during high flow events in WY 2006 and WY 2011 increased the size and modified the distribution of riffle mesohabitats

Summer baseflows in the lower Tuolumne River during Water Year 2012 occurred under a dry year release schedule and were insufficient to map suitable spawning habitat based on depth and velocity criteria during spawning flows in the 29-mile reach from La Grange Dam (RM 52.1) downstream to RM 23. Analyses of suitable spawning habitat is instead being conducted in association with the ongoing Tuolumne River Instream Flow Incremental Methodology study and other salmon monitoring studies (i.e., W&AR-08 Redd Mapping Study) through Fall 2012. Current spawning habitat area in the lower Tuolumne River and comparison with results from previous surveys in 1988 (TID/MID 1992a) and 2001 (McBain and Trush 2004) will be reported upon completion in accordance with the timeline for other reports and seasonal flow events.

Objective 5: Estimate maximum spawning run sizes supported under current conditions. Analyses of maximum spawning run sizes is being conducted in association with the ongoing Tuolumne River Instream Flow Incremental Methodology study and other salmon monitoring studies (e.g., W&AR-08 Redd Mapping Study and W&AR-06 Tuolumne River Chinook Salmon

Population Model) through Fall 2012. Estimates of spawning run sizes will be reported in accordance with the timeline for other reports and seasonal flow events.

7.0 STUDY VARIANCES AND MODIFICATIONS

The Districts' implemented the W&AR-04 Spawning Gravel study plan, as modified by FERC in its December 22, 2011 SPD. In its SPD, FERC staff recommended, based on NMFS Request Element #3, that the Districts quantify coarse sediment storage in the lower Tuolumne River and develop a sediment budget for the purpose of determining the annual ongoing cumulative effects of the Project in the lower Tuolumne River. The gravel-bedded reach of the lower Tuolumne River contains large, deep stores of coarse sediment that cannot be quantified without geophysical and stratigraphic investigation of the subsurface. These deep sediment stores are not mobilized and/or affected by the Project and are not relevant to the intent of NMFS Request Element #3. The intent of NMFS Request Element #3, as interpreted by the Districts, is to assess the potential cumulative effects of the Project on *changes* in coarse bed material storage and spawning gravel. This objective was effectively achieved by (1) simulating reach average changes in bed material storage through sediment transport modeling, and (2) estimating spatially explicit changes in bed material storage by differencing 2005 and 2012 digital terrain models in the Dominant Salmon Spawning Reach. This approach complied with the intent of NMFS Request Element #3 and is consistent with the direction given by FERC in their 22 December 2011 SPD.

The W&AR-04 study plan states that suitable spawning habitat will be mapped at available spawning flows under the current FERC Flow schedule (e.g., 150, 175, 180, or 300 cfs) from LaGrange Dam to RM 23 using habitat criteria (depth, velocity, and particle size) developed as part of the ongoing Instream Flow Incremental Methodology study of the lower Tuolumne River. Summer baseflows in the lower Tuolumne River during Water Year 2012 occurred under a dry year release schedule and were insufficient to map suitable spawning habitat based on depth and velocity criteria during flows comparable to prior mapping of spawning habitat in the 29-mile reach from La Grange Dam downstream to RM 23. Analyses of suitable spawning habitat, use of spawning riffles, and maximum spawning run sizes are instead being conducted in association with the ongoing Tuolumne River Instream Flow Incremental Methodology study and other salmon monitoring studies (e.g., W&AR-08 Redd Mapping Study) through November 2012. Therefore, results of analyses of suitable spawning habitat, use of spawning riffles, and estimated maximum spawning run sizes will be reported in a draft report for relicensing participant review scheduled for April 2013, and the final report in July 2013.

8.0 REFERENCES

Brown, C.B., and E.M. Thorp. 1947. Reservoir sedimentation in the Sacramento–San Joaquin drainage basins, California, Special Report 10, Soil Conservation Service, Sedimentation Section, Office of Research, Washington, D.C.

CDWR (California Department of Water Resources). 1994. San Joaquin River tributaries spawning gravel assessment: Stanislaus, Tuolumne, Merced rivers. Draft memorandum prepared by the Department of Water Resources, Northern District for the California Department of Fish and Game. Contract number DWR 165037.

CDWR. 2004. Tuolumne River La Grange gravel addition project, Phase II geomorphic monitoring report. Prepared by California Department of Water Resources, San Joaquin District, River Management Section. Report funded by Delta Pumping Plant Fish Protection Agreement and monitoring funded by U.S. Fish and Wildlife Service, Anadromous Fish Restoration Program.

California Regional Water Quality Control Board (CRWQCB). 2006. Executive Officer's Report 26/27 October 2006. California Regional Water Quality Control Board, Central Valley Region, USA.

Cui, Y. 2007a. The Unified Gravel-Sand (TUGS) model: simulating sediment transport and gravel/sand grain size distributions in gravel-bedded rivers. Water Resources Research 43, W10436, doi: 10.1029/2006WR005330.

Cui, Y. 2007b. Examining the dynamics of grain size distributions of gravel/sand deposits in the Sandy River, Oregon with a numerical model. River Research and Applications 23: 732–751, doi: 10.1002/rra.1012.

Cui, Y., and G. Parker. 1999. Sediment transport and deposition in the Ok Tedi-Fly River system, Papua New Guinea: the modeling of 1998–1999. Technical Report. St. Anthony Falls Laboratory, University of Minnesota.

Cui, Y., and A. Wilcox. 2008. Development and application of numerical models of sediment transport associated with dam removal. Chapter 23 *in* M.H. Garcia, editor. Sedimentation engineering: processes, measurements, modeling, and practice. ASCE Manual 110, 995–1,020. ASCE, Reston, Virginia.

Cui, Y., G. Parker, J.E. Pizzuto, and T.E. Lisle. 2003. Sediment pulses in mountain rivers: 2. Comparison between experiments and numerical predictions. Water Resources Research 39: 1,240, doi: 10.1029/2002WR001805.

Cui, Y., G. Parker, C. Braudrick, W.E. Dietrich, and B. Cluer. 2006a. Dam removal express assessment models (DREAM). Part 1: model development and validation. Journal of Hydraulic Research 44: 291–307.

Cui, Y., C. Braudrick, W.E. Dietrich, B. Cluer, and G. Parker. 2006b. Dam removal express assessment models (DREAM). Part 2: sensitivity tests/sample runs. Journal of Hydraulic Research 44: 308–323.

Cui, Y., J.K. Wooster, J.G. Venditti, S.R. Dusterhoff, W.E. Dietrich, and L.S. Sklar. 2008. Simulating sediment transport in a flume with forced pool-riffle morphology: examinations of two one-dimensional numerical models. Journal of Hydraulic Engineering 134: 892–904, doi: 10.1061/(ASCE)0733-9429(2008)134:7(892).

Cui, Y., S.R. Dusterhoff, J.K. Wooster, and P.W. Downs. 2011. Practical considerations for modeling sediment transport dynamics in rivers. Pages 503–527 *in* A. Simon, S.J. Bennett, and J.M. Castro, editors. Stream restoration in dynamic fluvial systems: scientific approaches, analyses, and tools. Geophysical Monograph Series 194. American Geophysical Union, Washington, D. C.

Cui, Y., J.K. Wooster, C. Braudrick, and B.K. Orr. 2012. Marmot Dam removal project, Sandy River, Oregon: lessons learned from model predictions and long-term post-removal monitoring, submitted to Journal of Hydraulic Engineering.

Dendy, F.E., and W. A. Champion. 1978. Sediment deposition in U.S. reservoirs: Summary of data reported through 1975. Miscellaneous Publication 1362, 68 pp., U.S. Department of Agriculture, Washington, D. C.

Downs, P.W., Y. Cui, J.K. Wooster, S.R. Dusterhoff, D.B. Booth, W.E. Dietrich, and L. Sklar. 2009. Managing reservoir sediment release in dam removal projects: an approach informed by physical and numerical modeling of non-cohesive sediment. The International Journal of River Basin Management 7: 433–452.

Gomez, B., Y. Cui, A.J. Kettner, D.H. Peacock, and J.P.M. Syvitski. 2009. Simulating changes to the sediment transport regime of the Waipaoa River driven by climate change in the twenty-first century. Global and Planetary Change 67: 153–166, doi:10.1016/j.gloplacha.2009.02.002.

Hansler, M.E. 1999. Sediment wave evolution and analysis of a one-dimensional sediment routing model, Navarro River, northwestern California. Master's thesis. Humboldt State University, Arcata, California.

Kondolf, G. M., and M. G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29:2275–2285.

Laird, A. 2005. Gasburg Creek fine sediment reduction and habitat restoration project, La Grange, Stanislaus County, California. Prepared by River Planner, Arcata, California for Turlock Irrigation District, Turlock, California and California Department of Fish and Game, Region 1, Fresno, California.

McBain and Trush. 2000. Habitat restoration plan for the Lower Tuolumne River corridor, Final Report. Prepared by McBain and Trush, Arcata, California for the Tuolumne River Technical Advisory Committee with assistance from U.S. Fish and Wildlife Service Anadromous Fish Restoration Program.

McBain and Trush. 2004. Coarse sediment management plan for the lower Tuolumne River. Revised Final Report. Prepared by McBain and Trush, Arcata, California for Tuolumne River Technical Advisory Committee, Turluck and Modesto Irrigation Districts, U.S. Fish and Wildlife Service Anadromous Fish Restoration Program, and California Bay-Delta Authority.

McBain and Trush. 2007. Gasburg Creek fine sediment reduction project: summary of project accomplishments. Final Technical Memorandum. Prepared by McBain and Trush, Arcata, California for W. Fryer, Turlock Irrigation District, Turlock, California.

McBain and Trush. 2008. Monitoring the impacts on the Tuolumne River from Peaslee Creek erosion and runoff events of January 2008. Prepared by McBain and Trush, Arcata, California for T. Ford, Aquatic Biologist, Turlock Irrigation District, Turlock, California.

Parker, G. 1990. Surface-based bedload transport relation for gravel rivers. Journal of Hydraulic Research 28: 417–436.

Parker, G., C.M. Toro-Escobar, M. Ramey and S. Beck. 2003. The effect of floodwater extraction on the morphology of mountain streams. Journal of Hydraulic Engineering 129(11): 885–895.

PG&E (Pacific Gas and Electric Company). 2008. Lower McCloud River instream flow study (FA-S8), Technical Memo 41. McCloud-Pit Hydroelectric Project, FERC Project No. 2106. San Francisco, California.

PG&E. 2009. Lower McCloud River 1-D PHABSIM analysis (FA-S9), Technical Memo 74. McCloud-Pit Hydroelectric Project, FERC Project No. 2106. San Francisco, California.

PWA (Pacific Watershed Associates). 2004. Subject: Gasburg Creek sediment control plan and cost estimate. Memorandum from W. Weaver, PhD, Pacific Watershed Associates, Arcata, California to C. Braudrick, Stillwater Sciences, Berkeley, California. 12 March 2004.

Reid, L.M., and T. Dunne. 1996. Rapid evaluation of sediment budgets. Catena Verlag, GMBH, Reiskirchen, Germany.

Snyder, N.P., D.M. Rubin, C.N. Alpers, J.R. Childs, J.A. Curtis, L.E. Flint, and S.A. Wright. 2004. Estimating accumulation rates and physical properties of sediment behind a dam: Englebright Lake, Yuba River, northern California. Water Resource Research 40.

Stillwater Sciences. 2000. Numerical modeling of sediment transport in the Sandy River, Oregon following removal of Marmot Dam. Technical Report. Prepared for Portland General Electric Company, Portland, Oregon.

Stillwater Sciences. 2002a. Subject: Results of summer 2001 snorkel surveys of fine sediment deposits in the Lower Tuolumne River. Technical Memorandum from M. Trso and N. Hume, Stillwater Sciences, Berkeley, California to McBain and Trush, Arcata, California. 5 January 2002.

Stillwater Sciences. 2002b. Subject: Evaluation of Fine Sediment Removal Methods for use in the Tuolumne River. Technical Memorandum from N. Hume, P. Baker and J. Stallman, Stillwater Sciences, Berkeley, California to McBain and Trush, Arcata, California. 18 November 2002.

Stillwater Sciences 2004a. Gasburg Creek sediment source analysis. Technical Report. Prepared for the Tuolumne River Technical Advisory Committee.

Stillwater Sciences. 2004b. A preliminary evaluation of the potential downstream sediment deposition following the removal of Iron Gate, Copco, and J.C. Boyle dams, Klamath River, California. Technical Report. Prepared for American Rivers, Nevada City, California.

Stillwater Sciences. 2006. Subject: 2002–2003 fine sediment monitoring results for Lower Dominici Creek. Technical Memorandum from N. Lassettre, W. Swaney, and N. Hume, Stillwater Sciences, Berkeley, California to W. Fryer. 16 November 2006.

Stillwater Sciences. 2008. Klamath River dam removal study: sediment transport DREAM-1 simulation. Technical Report. Prepared for California Coastal Conservancy, Oakland, California.

Stillwater Sciences. 2009a. Tuolumne River Instream Flow Studies. Final Study Plan. Prepared by Stillwater Sciences, Davis, California for Turlock Irrigation District and Modesto Irrigation Districts, California.

Stillwater Sciences. 2009b. March and July 2009 population size estimates of Oncorhynchus mykiss in the Lower Tuolumne River. Prepared for the Turlock Irrigation District and the Modesto Irrigation District by Stillwater Sciences, Berkeley, CA. November.

Stillwater Sciences. 2010. Simulating sediment transport in the Patapsco River following dam removal with dam removal express assessment model-1 (DREAM-1). Technical Report. Prepared by Stillwater Sciences, Berkeley, California for Inter-Fluve, Madison, Wisconsin, and American Rivers, Washington, D. C.

Stillwater Sciences. 2012. Modeling sediment transport in Santa Paula Creek California following Harvey Diversion Structure modification. Revised Technical Memorandum.

Prepared by Stillwater Sciences, Berkeley, California for RBF Consulting, Irvine, California.

Sutherland, D.G., M. Hansler-Ball, S.J. Hilton, and T.E. Lisle. 2002. Evolution of a landslide-induced sediment wave in the Navarro River, California. GSA Bulletin 114: 1,036–1,048.

Turlock Irrigation District and Modesto Irrigation District (TID/MID). (Turlock Irrigation District and Modesto Irrigation District). 1992a. Lower Tuolumne River spawning gravel availability and superimposition report. Appendix 6 *in* Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299 Vol. VIII. Prepared by EA Engineering, Science, and Technology, Lafayette, California.

_____. 1992b. Lower Tuolumne River spawning gravel studies report. Appendix 8 *in* Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. Vol. IV. Prepared by EA Engineering, Science, and Technology, Lafayette, California.

_____. 2001. Tuolumne River substrate permeability assessment and monitoring program report. Report 2000-7 *in* 2000 Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. Prepared by P. Baker and J. Vick of Stillwater Sciences, Berkeley, California. March 2001.

_____. 2005 Ten year summary report. Pursuant to paragraph (G) of the 1996 FERC order issued July 31, 1996. Don Pedro Project, No. 2299.

_____. 2006. Bobcat Flat/river mile 43, Phase I project completion report. Report 2005-7 *in* 2005 Lower Tuolumne River annual report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. Prepared by McBain and Trush, Arcata, California.

_____. 2007a. 2006 Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. 2 Volumes. March.

_____. 2007b. Tuolumne River La Grange gravel addition, Phase II annual report. Report 2006-10 *in* 2006 Lower Tuolumne River annual report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project, No. 2299. Prepared by D. Ridgeway, California Department of Fish and Game, Central Region (Region 4).

_____. 2009. Spawning Survey Summary Update. Report 2008-2 to the Federal Energy Regulatory Commission.

_____. 2010. RE: Tuolumne River instream flow study progress report in accordance with ordering paragraph (d) of the May 12, 2010 FERC Order modifying and approving instream flow and water temperature model study plans for the Don Pedro Project (Project No. 2299-072), as modified by Ordering Paragraph (A) of the July 21, 2010 FERC Order. Progress Report to Honorable K.D. Bose, Secretary, FERC, Washington, D. C., from G. Dias, Project Manager, Modesto Irrigation District, Modesto, California and R.M. Nees, Director of Water Resources and Regulatory Affairs, Turlock Irrigation District, Turlock, California. 9 December 2010.

Turlock Irrigation District and Modesto Irrigation District (TID/MID). 2013. Reservoir Temperature Model Progress Report (W&AR-03), Attachment B: Don Pedro Reservoir Bathymetric Study Report. Attachment to Don Pedro Hydroelectric Project Initial Study Report. January 2013.

_____. 2011. Reservoir Temperature Model Study Plan (W&AR-03). Attachment to Don Pedro Hydroelectric Project Revised Study Plan. November 2011.

_____. 2011. 2010 Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 58 of the License for the Don Pedro Project, No. 2299. March.

Tuolumne River Conservancy (TRC). 2011. Bobcat Flat Phase II Restoration Project update. E-mail from Dave Boucher, Tuolumne River Conservancy, Inc. to Noah Hume, Stillwater Sciences. December 7.

Byrnes, M., J. Baker, and F. Li. 2002. Quantifying potential measurement errors and uncertainties associated with bathymetric change analysis. ERDC/CHL CHETN-IV-50. September.

USFWS (United States Fish and Wildlife Service). 2007. Flow-habitat relationships for spring-run Chinook salmon and steelhead/rainbow trout spawning in Clear Creek between Whiskeytown Dam and Clear Creek Road. Sacramento Fish and Wildlife Office, Energy Planning and Instream Flow Branch.

Wolman, M.G. 1954. A method of sampling coarse river-bed material. Transactions of American Geophysical Union 35: 951–956.