SPAWNING GRAVEL IN THE LOWER TUOLUMNE RIVER

STUDY REPORT
DON PEDRO PROJECT
FERC NO. 2299



Prepared for:
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December 2013

Spawning Gravel in the Lower Tuolumne River
Study Report

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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 Background

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

Both TID and MID are local public agencies authorized under the laws of the State of California to provide water supply for irrigation and municipal and industrial (M&I) uses and to provide retail electric service. The 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. The "water bank" within Don Pedro Reservoir provides significant benefits for CCSF's 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 aquatic resources in the lower Tuolumne River, and hydropower generation.

The Project Boundary extends from RM 53.2, which is one mile below the Don Pedro powerhouse, upstream to RM 80.8 at an elevation corresponding to the 845 ft contour (31 FPC 510 [1964]). 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) 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.

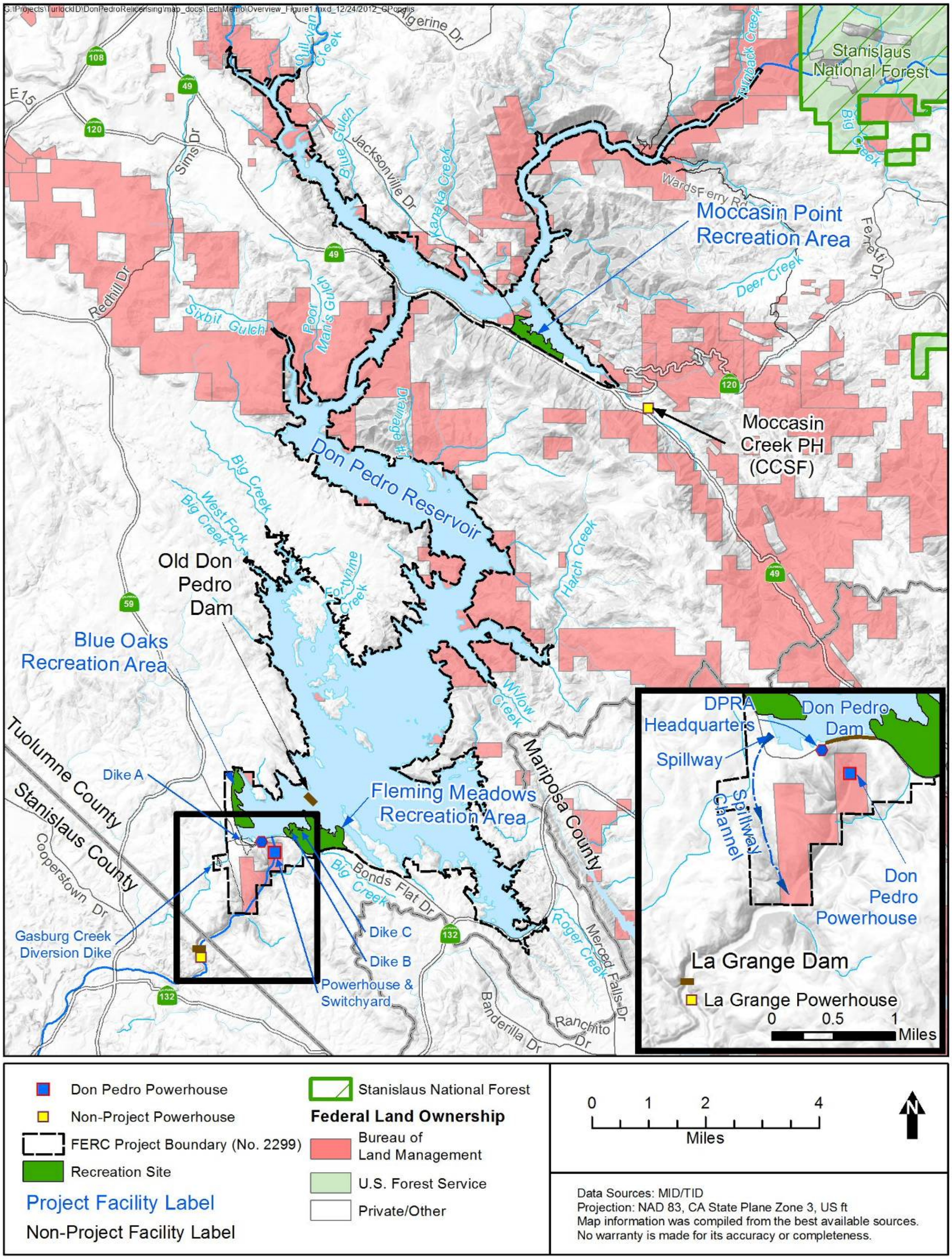

Figure 1.1-1. Don Pedro Project location.

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.

The Districts filed their Initial Study Report (ISR) in January 2013 and the Districts filed a response to ISR comments from relicensing participants on April 9, 2013. FERC issued a determination on study modifications on May 21, 2013. As a result of these filings, the Districts modified the final W&AR-04 study to include the following:

(1) *Modeling using with-Project hydrology.* NMFS and SWRCB requested that the Districts model changes in coarse bed material storage using the Project-related hydrology set (with- and without-Project). The Districts agreed to perform the requested modeling analysis using with-Project hydrology in their April 9, 2013 response to comments in the ISR. The FERC Director recommended in his Determination on Requests for Study Modifications and New Studies for the Don Pedro Hydroelectric Project that the Districts perform an analysis using with-Project hydrologic information (1970-2009).

(2) *Presentation of sediment budget results in subreaches.* Per NMFS request, FERC recommended that the Districts present W&AR-04 results (e.g., changes in bed material storage from modeling and surface differencing) at a finer reach scale than was presented in the ISR. The Districts worked with Relicensing Participants to define subreaches,

analyze results (modeling, surface differencing, and mapping results) in subreaches, and interpret the results within the context of the W&AR-04 study.

(3) *Modeling involving PM&E scenarios*. Relicensing Participants requested that the DREAM-2 sediment transport model be made available for use in evaluating potential PM&E scenarios. The Districts agreed to perform a limited number of DREAM-2 model runs using parameters defined by Relicensing Participants. The Districts will work with Relicensing Participants to define model parameters associated with PM&E scenarios, conduct a limited number of model runs using DREAM-2, interpret the results within the context of the W&AR-04 study, and present the results to Relicensing Participants.

This 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.comwww.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 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 change channel sediment storage, alter channel form, and modify 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 long term average annual sediment delivery to Don Pedro Reservoir via topographic differencing 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 in the Lower Tuolumne River Study Plan with the recommended modifications. The Districts carried out the 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 52.2) 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 52.2): 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. A portion of the material stored in tailings piles was used in constructing Don Pedro Dam. 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 sediment storage, channel form, 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 unregulated portions of 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 annual total and coarse sedimentation rate 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 to the mainstem Tuolumne River (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 in many reaches the channel is wider than would have occurred prior to large-scale anthropogenic disturbance, 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 infiltration into gravel beds (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. An assessment of sediment supply to the lower Tuolumne River, based in part on the size of deltas at each of the tributary mouths following the January 1997 flood event, indicated that Gasburg Creek (RM 50.3) and Peaslee Creek (RM 45.5) have relatively large input potential, while Lower Dominici Creek (RM 47.8) has moderate input potential (McBain and Trush 2000).

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 in downstream reaches of the Tuolumne River (McBain and Trush 2000, 2004). In June 2001, discrete fine sediment deposits in the lower Tuolumne River channel were mapped from the USGS gauging station near La Grange Dam (RM 52.2) 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 events, 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 52.2 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 November 26, 1986 when flow was 230 cfs, and a black and white set taken at a scale of 1:24,000 on January 19, 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 52.2 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 52.2) 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 (yd^3)
50.0 to 50.7	2002	9,600
50.0 to 50.7	2003	5,330
43	2005	10,820
43	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 52.2) 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 provided 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 have been 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 spawning preferences generally decreasing from upstream to downstream (TID/MID 1992a). Data collected since 1997 supports these findings and indicates that over half of the spawning activity occurs in the Dominant Salmon Spawning Reach (Reach 7) from RM 52.2 to RM 46.6 (Table 1.4-2). The Chinook Salmon Population Model Study (W&AR-06) includes more detailed analysis of spawning habitat use in proportion to suitable gravel areas.

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	46.6–52.2	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 and the ongoing effects of upstream diversion 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) 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.

(4) Map current 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).

(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 potential spawning population sizes supported under current conditions.

3.0 STUDY AREA

The overall area encompassed by the W&AR-04 Spawning Gravel in the Lower Tuolumne River Study includes the lower Tuolumne River from La Grange Dam (RM 52.2) downstream to RM 23, which captures the extent of riffle habitats documented in historical surveys (TID/MID 1992a). Within this area, study elements were implemented within different spatial extents and time periods necessary to address the six 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.

(2) Coarse bed material storage changes in the Dominant Salmon Spawning Reach from La Grange Dam (RM 52.2) downstream to approximately Peaslee Creek (RM 45.5) were estimated over the 2005–2012 period by sediment transport modeling and surface differencing. The reach from RM 52.2 to RM 45.5 is where the potential for bed material storage changes is greatest and where most Chinook salmon (*Oncorhynchus tshawytscha*) and *O. mykiss* spawn. Coarse bed material storage changes from RM 52.2 to RM 39.5 over the 1970–2012 period were estimated by sediment transport modeling.

(3) A sediment budget was developed to estimate the potential cumulative effects of the Project on coarse bed material storage changes in five reaches of the lower Tuolumne River from La Grange Dam to RM 39.5. Methods and time frames for estimating sediment budget components vary by reach (refer to Objective 2 above).

(4) Mapping of FBM deposits and analysis of change in FBM storage over the 2001–2012 period occurred from approximately La Grange Dam (RM 52.2) to the Santa Fe Aggregates haul road bridge (RM 36.3), the reach in which historical fine sediment mapping data exists (Stillwater 2002a)) and below which the channel progressively transitions to a predominantly fine (e.g., sand) bed.

(5) Mapping of riffles, spawning gravel, and suitable spawning habitat occurred in the gravel-bedded reach from approximately La Grange Dam (RM 52.2) downstream to RM 23, which includes the extent of riffle habitats mapped in previous surveys (TID/MID 1992a, McBain and Trush 2004).

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

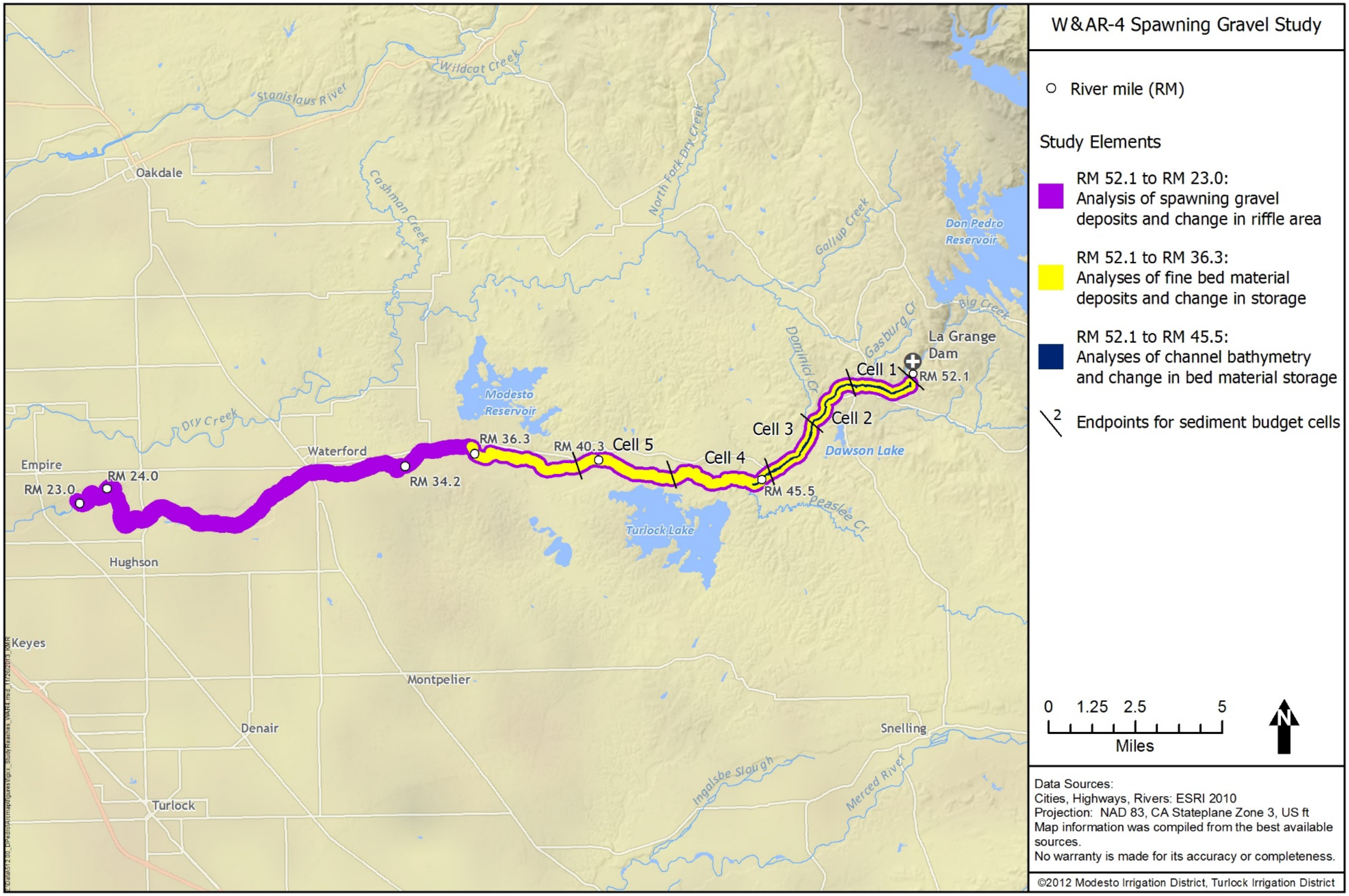

Figure 3.0-1. Spawning Gravel in the Lower Tuolumne River study area.

4.0 METHODOLOGY

Methods implemented to satisfy each of the six 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 capacity using 2011 bathymetry data was compared to the storage capacity estimated in 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

Annual changes in coarse (>2 mm) bed material storage in the 12.4 mi reach downstream of La Grange Dam to approximately RM 39.5 were estimated over the WY 1971-2012 period based on sediment transport modeling conducted within a sediment budget context. Estimates of coarse bed material storage changes from model simulation during the WY 2005–2012 period 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 52.2) 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.

In the Initial Study Report filed by the Districts in January 2013, mass change in coarse bed material storage was computed for two reaches of the lower Tuolumne River channel (referred to as budget cells). Budget cell 1 extended from La Grange Dam to Peaslee Creek (RM 52.2 to 45.5) and budget cell 2 extended from Peaslee Creek to RM 39.7. In response to recommendations from NMFS, the two reaches used in analyses reported in the ISR were subdivided into five reaches that provide greater spatial resolution in sediment budget results (Table 4.2-1).

Table 4.2-1. Lower Tuolumne River reaches used in the updated sediment budget.

Reach	Location (RM)		Length (mi)
	Begin	End	
Cell 1	52.2[1]	49.8	2.3
Cell 2	49.8	47.8	2.0
Cell 3	47.8	45.8	2.0
Cell 4	45.8	42.6	3.2
Cell 5	42.6	39.5	3.1

[1] Upstream extent of topographic differencing is RM 51.6.

The coarse sediment budget from modeling 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 floodplain erosion). Input to each budget cell includes output from the upstream budget cell.

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).

In the Initial Study Report filed by the Districts in January 2013, changes in coarse sediment storage within each budget cell were computed annually for the WY 2000 –WY 2012 period. The 2000-2012 period was selected to include the effects of gravel augmentation that began in 2000, and to allow comparison of coarse bed material storage changes estimated by modeling and by differencing of detailed channel topography surveyed in 2005 and 2012. In response to recommendations from NMFS, changes in coarse sediment storage within each budget cell were computed annually for WY 1971 through WY 2012, the period over which the Project Operations Model simulates “base case” daily average discharge.

Bedload transport 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 and 2012. 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). In response to recommendations from NMFS, bedload fluxes and storage changes were also modeled each year during the WY 1971-2012 using “base case” daily average discharge simulated by the Project Operations Model. Figure 4.2-1 provides a comparison of daily average discharge measured at USGS #11289650 and simulated by the Project Operations Model.

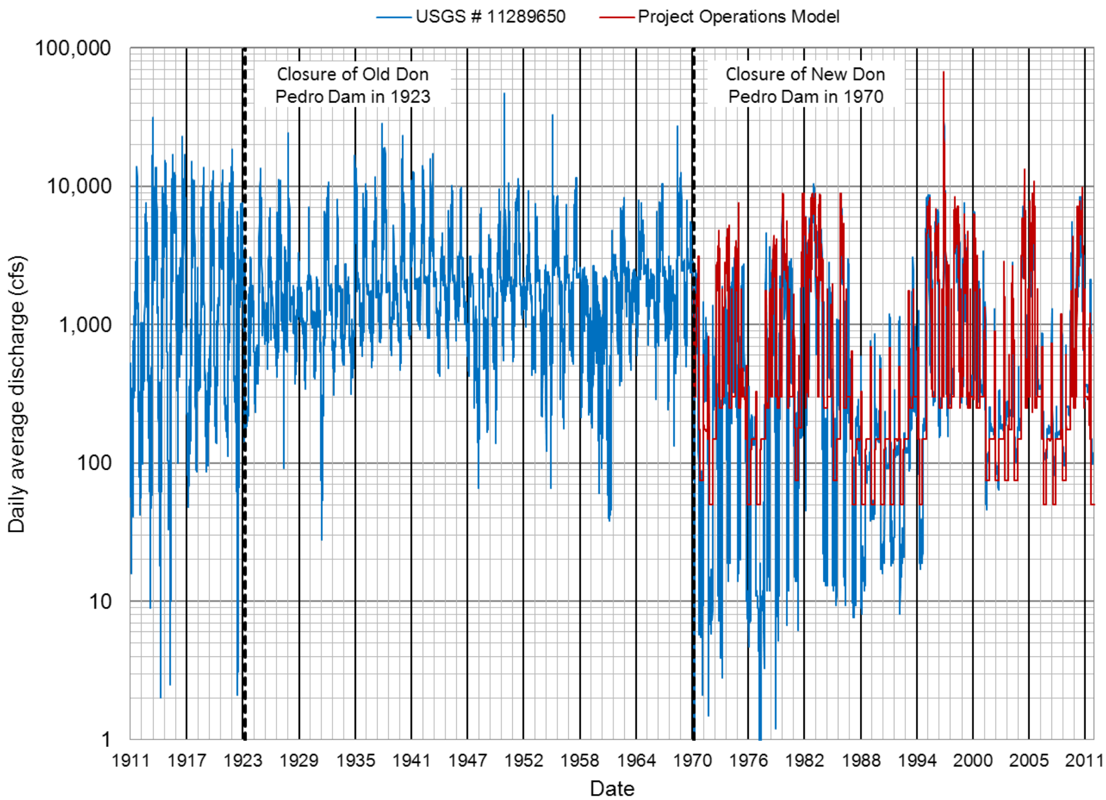

Figure 4.2-1. Daily average discharge in the Tuolumne River near La Grange Dam.

There is little information about the sediment supply rate, longitudinal profile, and bed material grain size distribution 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 model 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.

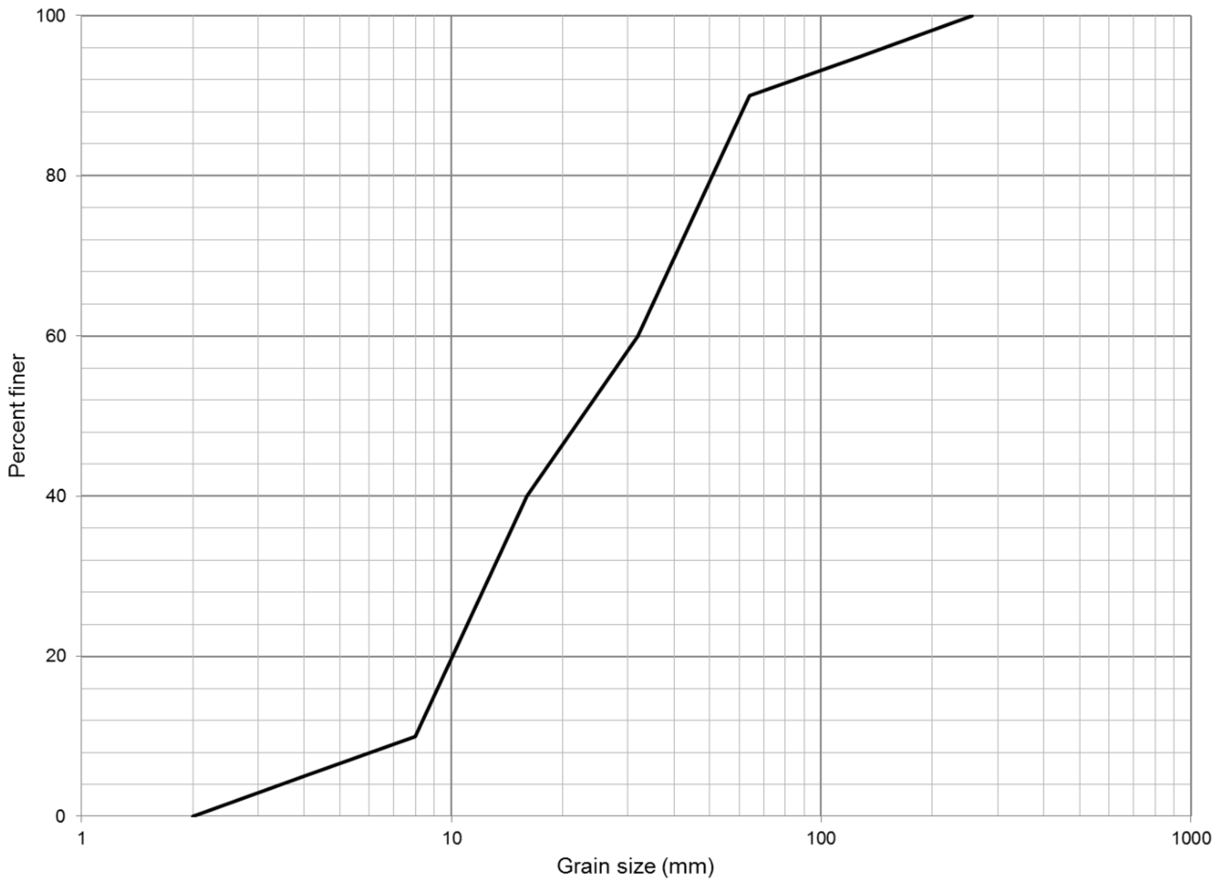

Figure 4.2-2. Assumed initial bed material grain size distribution in the model study reach.

Two DREAM-2 model runs were conducted with the initial conditions discussed above; one that included gravel augmentation implemented from 2002 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 2011 was approximately 44,753 yd^3, or approximately 58,940 tons, assuming a density of 1.30 tons yd^{-3}. The grain size distribution of coarse sediment added during augmentation projects is summarized in Figure 4.2-3.

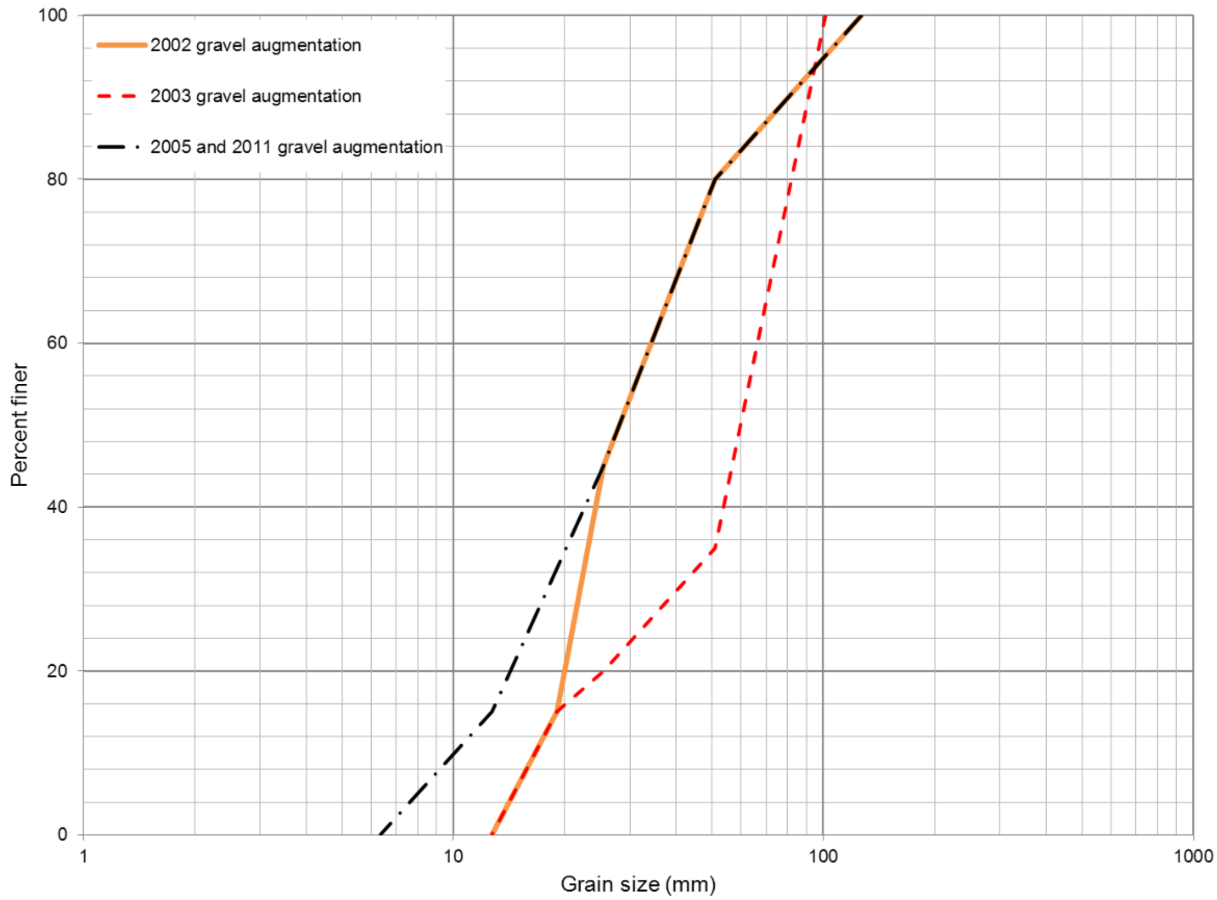

Figure 4.2-3. Grain size distributions of gravel augmentation in the Tuolumne River, 2002–2011.

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. (2006b) 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 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 this reach 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 52.2 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 May 8–12, 2012 at flows ranging from 650 to 2,100 cfs as measured at USGS #11289650. Sounding data were 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 were 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 were 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 were imported into ESRI ArcGIS software for final editing and DTM generation. GPS rover and total station survey data were 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 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 plus 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 fine bed material (>2 mm) observed in bulk bed material samples from the lower Tuolumne River. The California Department of Water 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 (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 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 between 2005 and 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 52.2) 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 52.2 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 Studies (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 instream flow 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 instream flow study (TID/MID 2010) and have been used in instream flow 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 were mapped from La Grange Dam (RM 52.2) downstream to RM 23, which includes the maximum 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 base flow 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

Mapping of gravel substrate and hydraulics suitable for Chinook and *O. mykiss* spawning were used within a Physical Habitat Simulation (PHABSIM) model to derive a relationship between flow and usable spawning habitat area in the lower Tuolumne River from RM 52.2 to RM 23. Gravel suitable for Chinook salmon and *O. mykiss* spawning was identified based on the median grain size (D_{50}) of mapped gravel deposits: a D_{50} from 16 to 78 mm defined suitable Chinook spawning gravel and a D_{50} from 10 to 46 mm defined suitable *O. mykiss* spawning gravel (Kondolf and Wolman 1993). Suitable hydraulic conditions for spawning were defined as depths ranging from 0.7 to 2.7 feet and velocities ranging from 1.0 to 3.1 feet per second. These depth and velocity suitability criteria were developed by converting criteria curves used in the current instream flow study to a binary format (i.e., suitable vs. unsuitable) appropriate for field determination (Figures 4.4-1 and 4.4-2). Hydraulic data (i.e., suitable depth and velocity) were collected within a stratified random sample of riffle mesohabitats during November 5–7, 2012 at a flow of approximately 175 cfs. The number of sampled riffles comprised approximately 25% of the total number of riffles mapped in the spawning reach (RM 52 to RM 24) in September 2010 (Table 4.4-1). By wading each sample riffle with a top-set rod and Marsh-McBirney flow meter, polygons of suitable depth and velocity were delineated onto aerial photographic tiles (April 2012, 320 cfs) showing spawning gravel mapped in August 2012. Polygons of suitable spawning habitat area (i.e., areas with suitable gravel, depth, and velocity) in sample riffles were digitized and used in ESRI ArcGIS to calculate suitable spawning habitat area in the study area.

Table 4.4-1. Sample riffles and total number of riffle mesohabitats in spawning reaches of the lower Tuolumne River from RM 52 to RM 24.

Mesohabitat	RM 52.2–46.6		RM 46.6–40.3		RM 40.3–34.2		RM 34.2–24.0		Total	
	Total	Sample	Total	Sample	Total	Sample	Total	Sample	Total	Sample
Flatwater Riffles	8	2	1	1	3	1	12	3	24	7
Bar Complex Riffles	6	1	18	5	19	5	18	5	61	16
Total	14	3	19	6	22	6	30	8	85	23

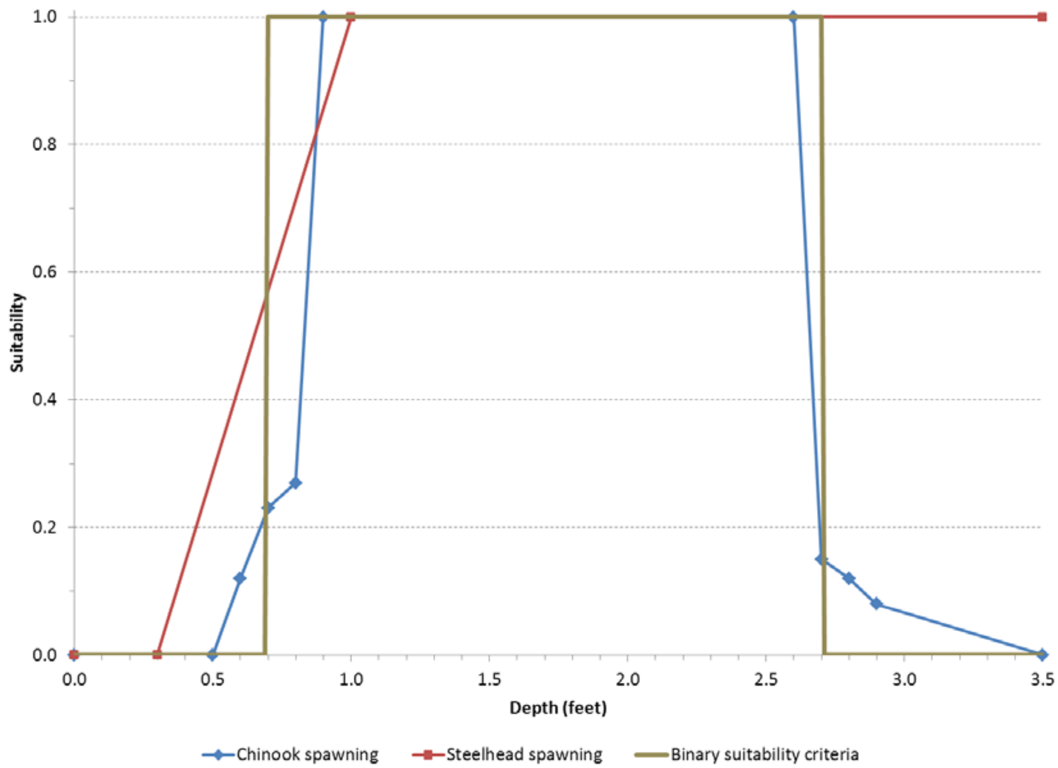

Figure 4.4-1. Depth criteria used for lower Tuolumne River spawning habitat mapping.

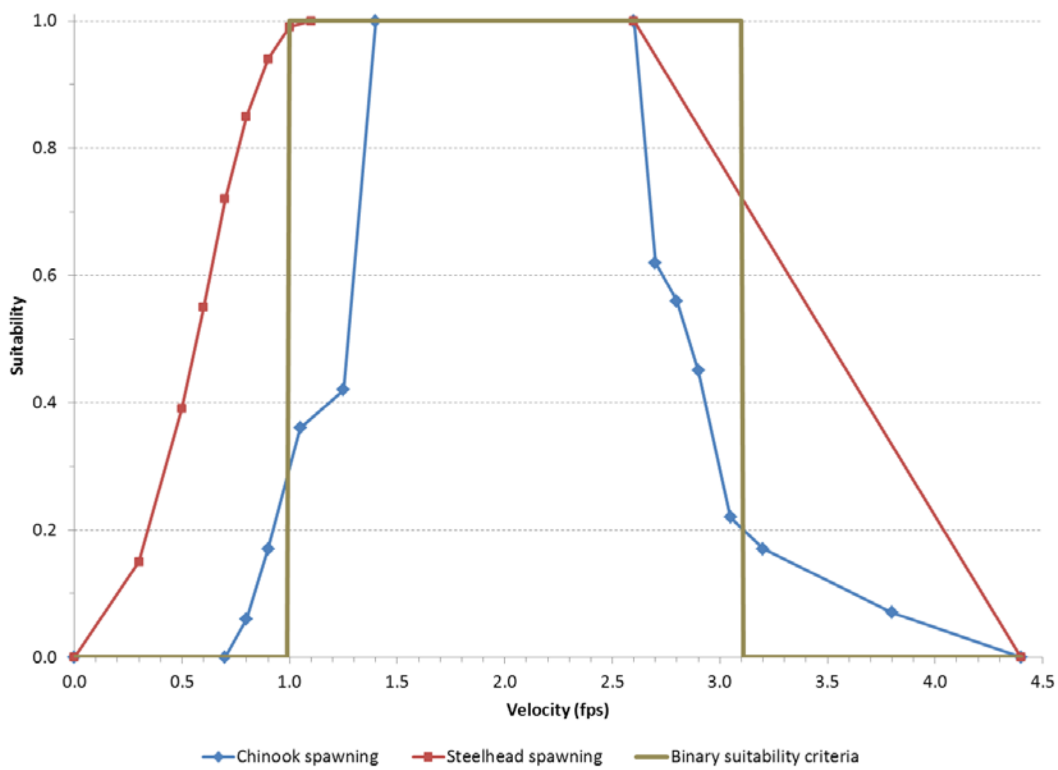

Figure 4.4-2. Velocity criteria used for lower Tuolumne River spawning habitat mapping.

Use of PHABSIM modeling for predicting spawning habitat utilization is based on studies in the Merced and American Rivers by Gallagher and Gard (1999), who found a significant correlation between weighted usable area (WUA) predictions and the observed density of Chinook salmon redds. Since both are based on the same depth and velocity criteria, total suitable spawning area is assumed to change in direct proportion to spawning WUA. On this basis, PHABSIM modeling results from the *Lower Tuolumne River Instream Flow Study* (Stillwater Sciences 2013) were used to re-scale total suitable spawning area sampled at 175 cfs (mapped during summer 2012) to estimate total suitable spawning area within the 320 cfs flow boundary from the April 2012 aerial photography. For the purposes of this study, PHABSIM modeling of WUA at flows of 175 cfs and 320 cfs was based on data from riffle transects and the binary suitability criteria used during field mapping.

The following steps illustrate the process used in calculating riverwide suitable spawning habitat area estimates at any given flow "Y" (100–1,000 cfs) by re-scaling the 320 cfs estimates using the relative changes in spawning WUA results at these other flows.

Step 1. Total wetted spawning gravel area in riffle habitats of a hypothetical reach at 320 cfs = A_{320} ft^2

Step 2. Proportion of spawning WUA at flow 'Y' cfs to spawning WUA at 320 cfs in riffle habitats, P_Y = (spawning WUA at flow 'Y')/(spawning WUA at 320 cfs)

Step 3. Total suitable spawning habitat in riffle habitats of hypothetical reach at flow Y, $A_Y = P_Y \text{ x } A_{320}$ ft^2.

4.5 Maximum Potential Spawning Population Sizes

Estimated maximum potential spawning population size for a specific flow was computed by dividing the total suitable spawning area (i.e., area with suitable substrate, depth, and velocity) by an estimate of the disturbed gravel area (i.e., the area of egg deposition) within completed redds for each species, and multiplying by a factor of two fish per redd. For Chinook salmon redds, total and disturbed area estimates of 80 ft^2 (7.5 m^2) and 52 ft^2 (4.8 m^2) were calculated from detailed measurements (n=354) collected in 1988–1989 (TID/MID 1992, Appendix 6). A comparable set of estimates were made from Chinook salmon redd data collected in 2012 in the *Redd Mapping Study* (W&AR-08). Average total redd size for Chinook salmon was 97.1 ft^2 (9.0 m^2) based on redd measurements (n=286) in fall of 2012, with an average disturbed redd area estimate of 43.1 ft^2 (4.0 m^2) calculated from egg pocket measurements. Maximum potential spawning population size estimates for *O. mykiss* were based on an average disturbed redd area of 3.1 ft^2 (0.3 m^2) calculated using measurements (n=36 redds) collected in spring 2013 as part of the *Redd Mapping Study* (W&AR-08).

5.0 RESULTS

The results of each element in the W&AR-04 Spawning Gravel in the Lower Tuolumne River Study are discussed below within the context of the six study objectives.

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 a coarse-to-total sediment ratio of 0.10 (Snyder et al. 2004), average annual total and coarse (>2 mm) sediment yields to the reservoir 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 coarse bed material storage changes in the Dominant Salmon Spawning Reach based on (1) reach average bed material storage changes simulated by sediment transport modeling and (2) spatially explicit bed material storage changes 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).

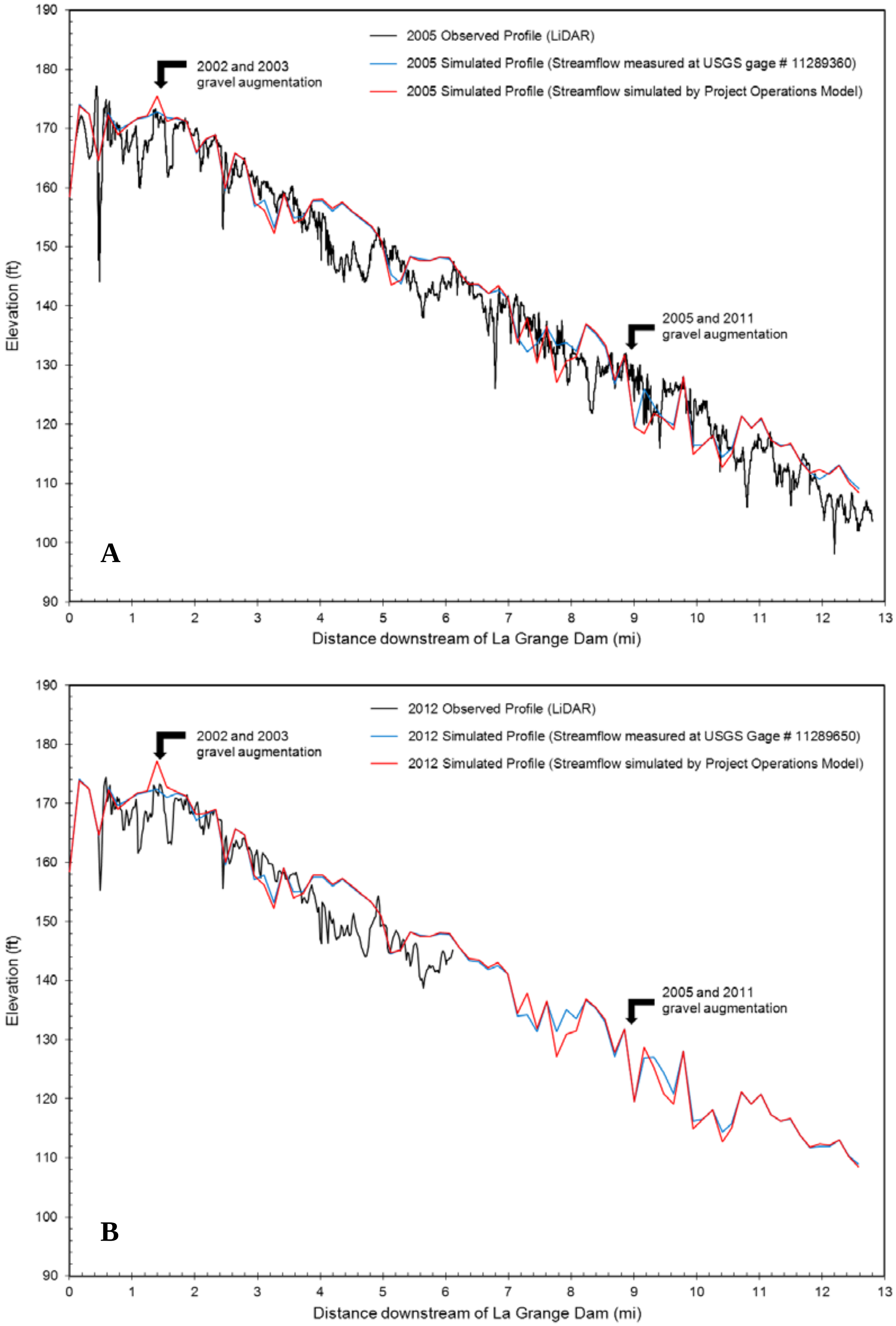

Figure 5.2-1. Simulated (with gravel augmentation) and observed longitudinal profiles of the 12.4 mi model study reach in (A) 2005 and (B) 2012.

Average annual bedload transport rates (with gravel augmentation) in the five lower Tuolumne River sediment budget cells modeled using daily average discharge simulated by the Project Operations Model are reported in Table 5.2-1. Estimates of bedload transport rate in the vicinity of Riffle 4A and 4B are lower than previous estimates (1,412–1,930 ton yr^{-1}) (McBain and Trush 2000, 2004). All of the estimates to date are relatively low compared to bedload transport rates in other rivers channels with similar slope, drainage area, and precipitation.

Table 5.2-1. Average annual bedload transport rate modeled using daily average discharge simulated by the Project Operations Model.

Period	Transport rate into sediment budget cell (t yr^{-1})							
	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 5	Riffle 4A	Riffle 4B
1970–2000	0	499	1022	1032	1828	2886	506	1070
2000–2005	0	180	384	292	173	431	122	116

Model estimates of coarse bed material storage changes differ depending on the source of input streamflow data. Model results using daily average discharge simulated by the Project Operations Model typically indicate a greater loss in storage than results using streamflow measured at USGS #11289650 (Figure 5.2-2). While model results using daily average discharge simulated by the Project Operations Model may be appropriate for evaluating potential future Project effects, model results using streamflows measured at USGS #11289650 characterize flow in the study reach over the study period and are therefore appropriate for making comparisons with spatially explicit estimates of bed material storage changes determined by differencing 2005 and 2012 digital terrain models. Resulting estimates of bed material storage changes from modeling reported hereafter are based on analyses using streamflows measured at USGS #11289650.

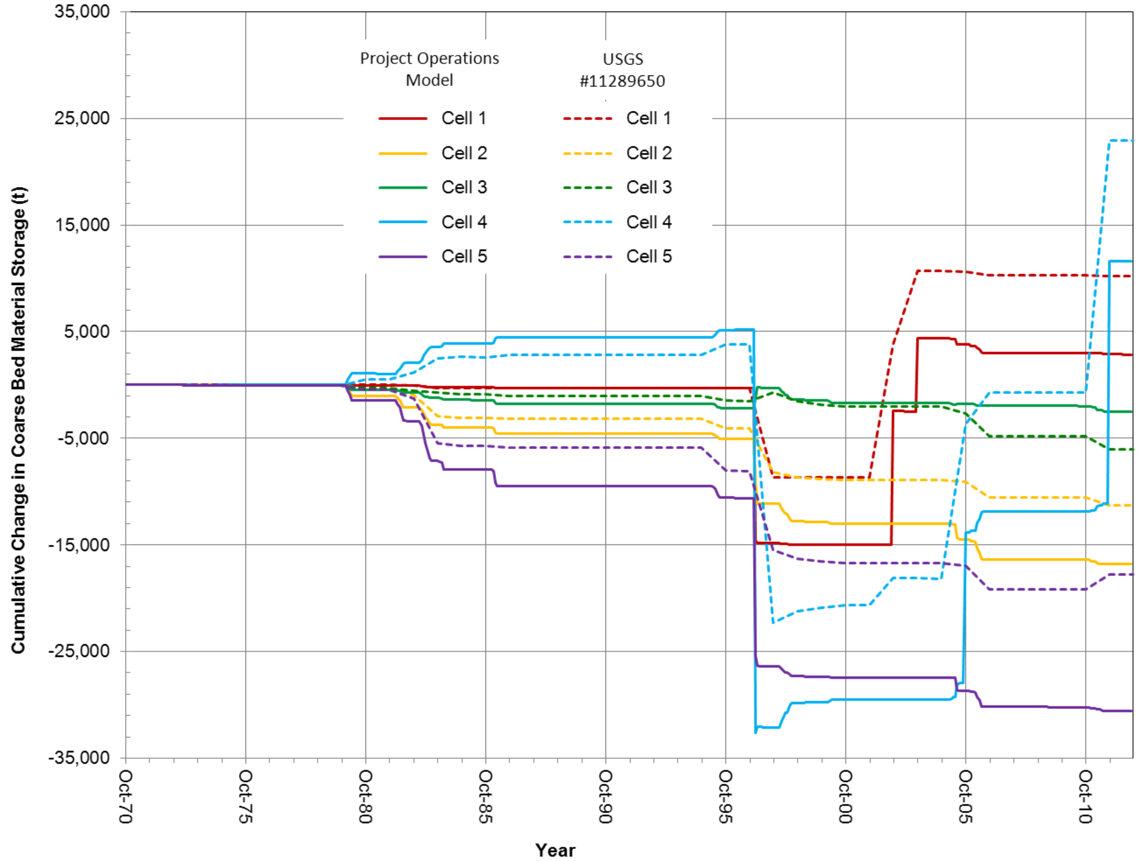

Figure 5.2-2. Cumulative change in coarse bed material storage from WY 1971 – WY 2012 modeled using streamflow measured at USGS #11289650 and simulated by the Project Operations Model.

The model results using measured streamflows indicate that coarse bed material storage changed relatively little from WY 1970 through WY 1996, decreasing most substantially in Cell 5 (Figure 5.2-3). The large flood event in 1997 resulted in substantial losses of coarse bed material in all budget cells except Cell 3. Since the 1997 event, storage would have decreased a small amount in all but Cell 4 without the addition of gravel at augmentation sites. Gravel augmentation in Cell 1 and Cell 4 helped increase cumulative coarse bed material storage by about 14,100 tons since 2000, but 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 Cell 3 and Cell 4, where approximately 1,000 tons would otherwise have been lost from storage without augmentation (Figure 5.2-3). The net increase in coarse bed material storage within all five budget cells increased by approximately 55,600 tons, or approximately 94 percent of the total added by gravel augmentation, indicating most coarse sediment added by augmentation was retained within the reach.

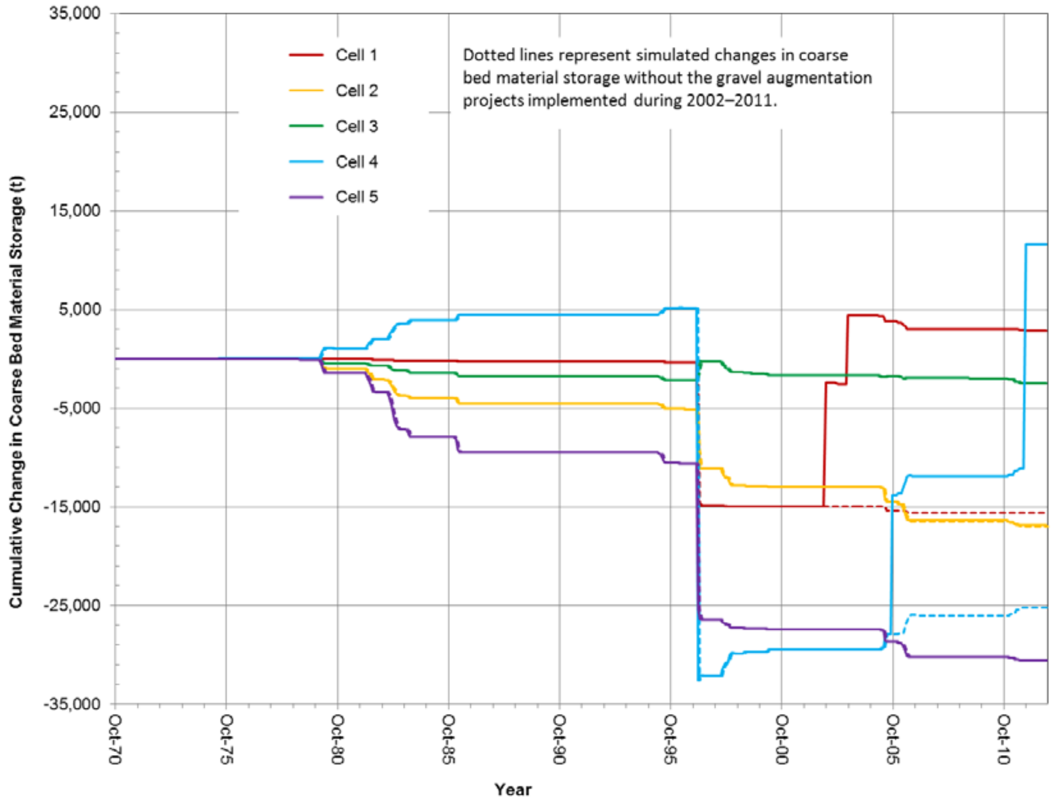

Figure 5.2-3. Cumulative change in coarse bed material from WY 1971 – WY 2012 with and without gravel augmentation.

5.2.2 Topographic Differencing

Topographic differencing of DTMs from 2005 and 2012 indicates a loss of 7,292 yd^3 (-9,478 tons) of bed material from within the 320 cfs wetted channel in sediment budget cells 1–3 (Table 5.2-1). Assuming 92 percent of bed material is coarse (>2 mm), approximately 6,707 yd^3 (8,720 tons) of coarse sediment was lost from channel storage during the period. Although the overall storage change in this 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).

Table 5.2-2. Estimated bed material storage changes from WY 2006 through WY 2012.[1]

Reach	Location (RM)		Change in storage[2] from modeling[1] (tons)		Change in storage from surface differencing[3] (tons)	Average bed elevation change (mm)	
	Begin	End	Measured streamflow	Simulated streamflow		Modeling[4]	Surface differencing[5]
Cell 1	52.2	49.8	-384	-951	820	-1.3	3.1
Cell 2	49.8	47.8	-2,196	-2,325	-4,844	-12	-29
Cell 3	47.8	45.8	-3,334	-720	-4,695	-12	-19
Cell 4	45.8	42.6	26,607	39,520	na	61	na
Cell 5	42.6	39.5	-789	-1,880	na	-2.1	na
Dominant Salmon Spawning Reach	52.2	45.8	-5,913	-3,996	-8,720	-8.0	-13
Total Cells 1–5	52.2	39.5	19,905	33,643	na	13	na

1 Model estimates of storage changes are with gravel augmentation.
2 Model results are reported using streamflow measured at USGS #11289650 and simulated by the Project Operations Model.
3 Change in coarse bed material storage assumes bed material is 92 percent coarse sediment (> 2mm).
4 Lowering based on model result using measured streamflow.
5 Lowering based on change in total bed material storage within the 320 cfs wetted channel area.
6 na = not available.

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).

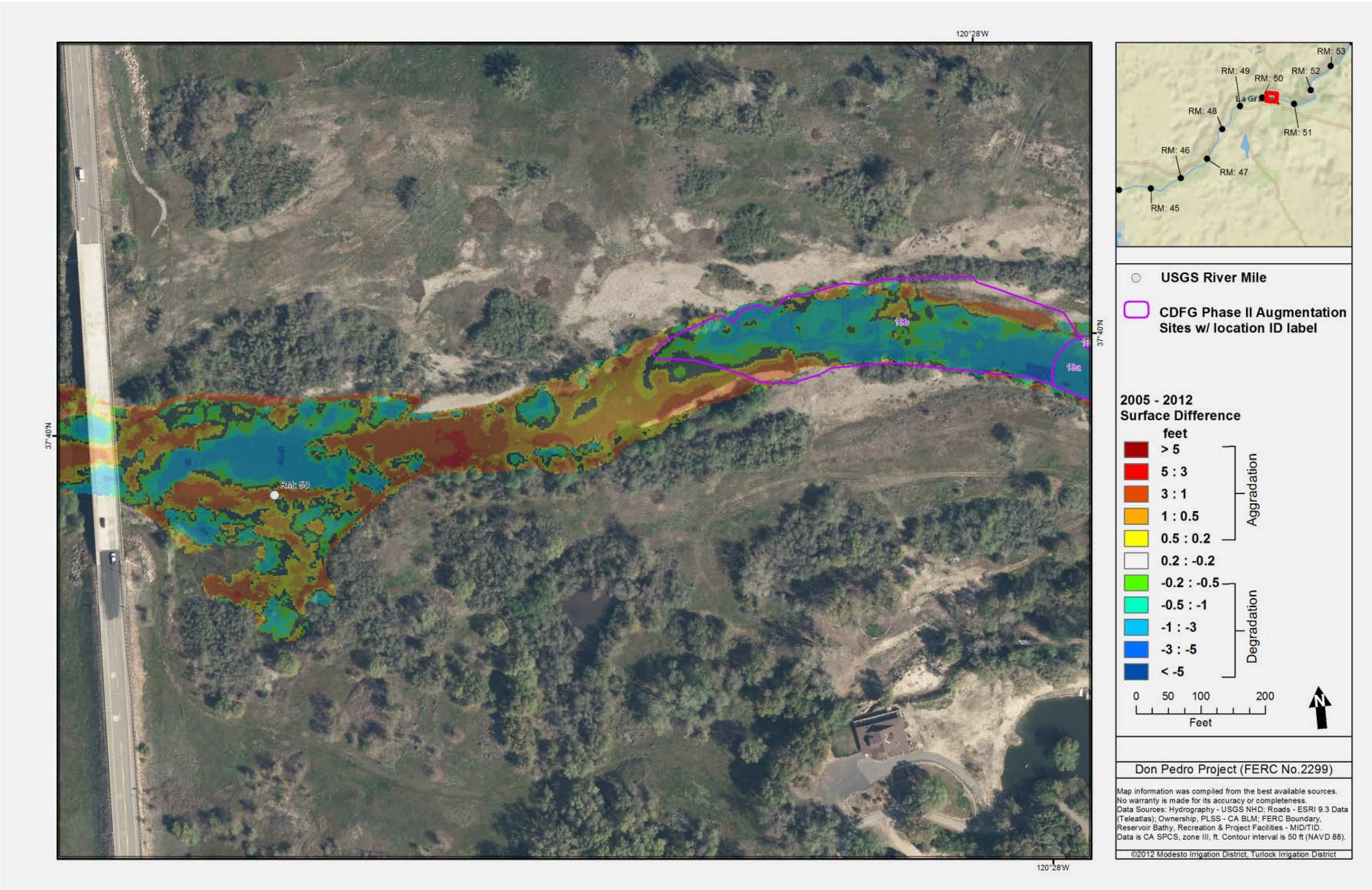

Figure 5.2-4. Bed elevation changes in the lower Tuolumne River from RM 49.9 to RM 50.3 determined from differencing 2005 and 2012 DTM surfaces.

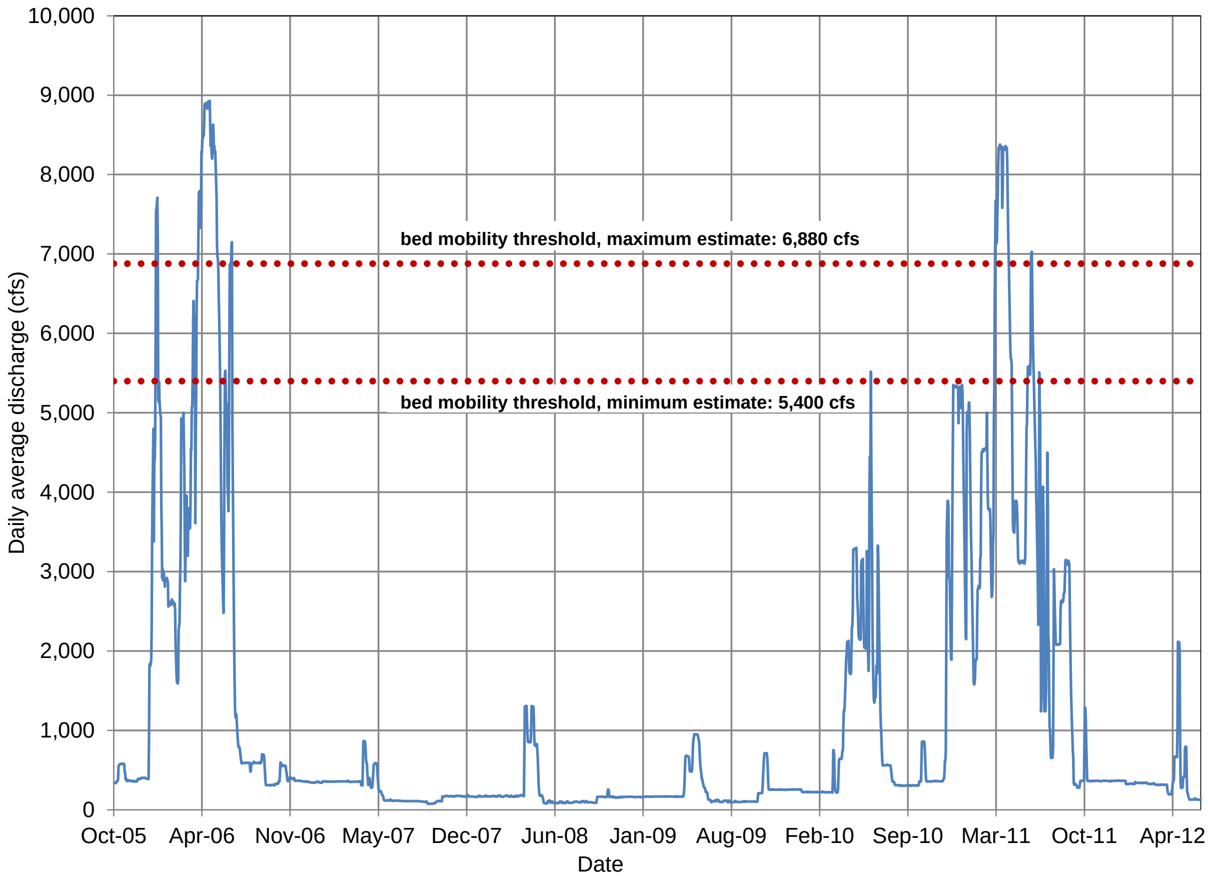

Figure 5.2-5. Hydrograph for WY 2006–2102 at USGS gauge # 11289650 (Tuolumne River below La Grange Dam), and estimated maximum and minimum bed mobility thresholds at Riffle 4b.

In summary, the coarse sediment budget for RM 52.2 to RM 45.5, encompassing the Dominant Salmon Spawning Reach immediately downstream of La Grange Dam, indicates that approximately 4,549–6,707 yd^3 (5,913–8,720 tons) of coarse bed material was lost from storage between 2005 and 2012 (Table 5.2-2). 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 13 mm. The estimated lowering in the reach during the 2005–2012 period is less than half 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.

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 52.2) 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 76,500 tons, of which approximately 63,900 tons (83%) occurred within the 320 cfs inundation area (Table 5.3-2, Figure 5.3-1). The volume of FBM was distributed nearly equally among pool margins, other channel margins, and alcoves and backwaters (Table 5.3-2, 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.

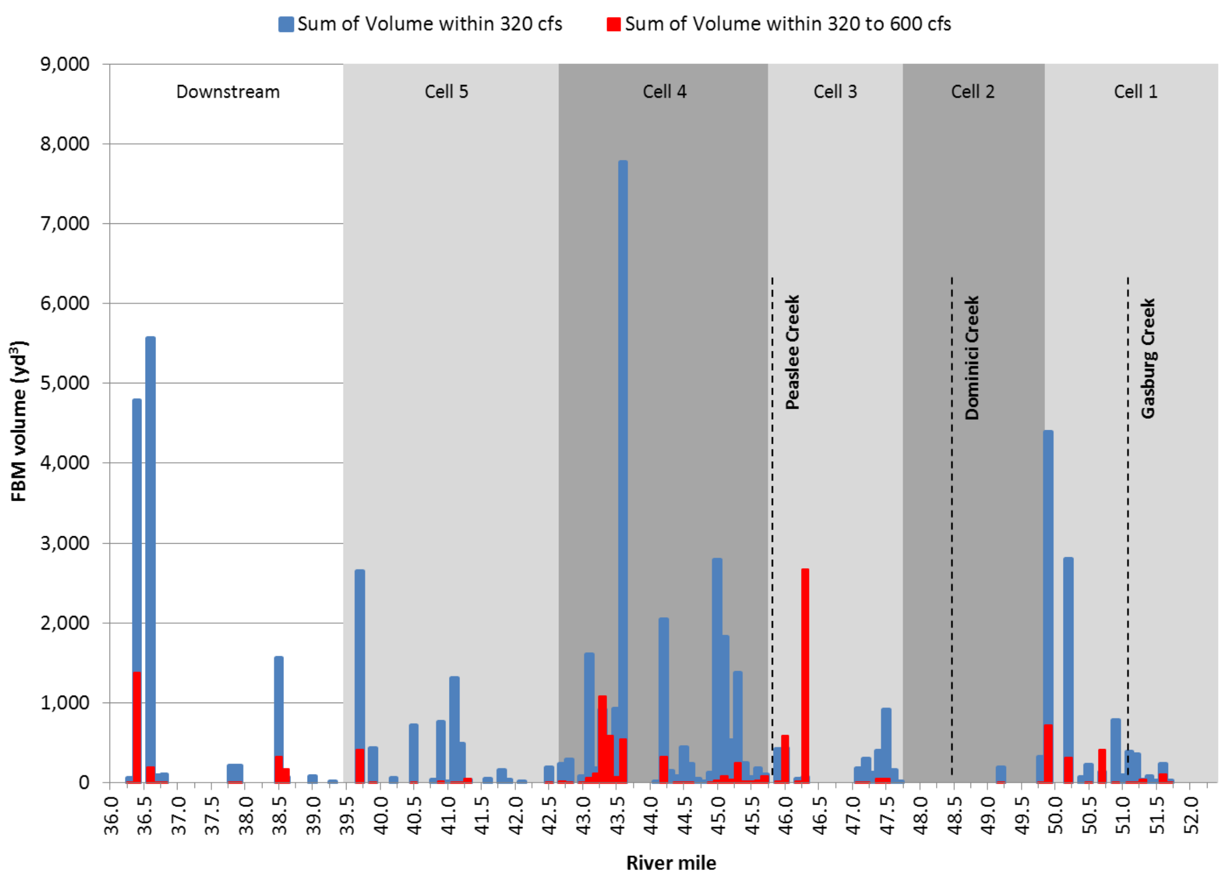

Figure 5.3-1. Distribution of discrete FBM deposits within 320 cfs and 600 cfs inundation areas from La Grange Dam (RM 52.2) to Santa Fe Aggregates haul road bridge (RM 36.3).

Table 5.3-1. Discrete fine bed material deposits mapped in 2012 by reach.

Reach	Volume (yd³)			Mass[1] (tons)		
	In 320 cfs inundation area	In 320–600 cfs inundation area	Total	In 320 cfs inundation area	In 320–600 cfs inundation area	Total
Cell 1	10,029	1,605	11,634	11,533	1,845	13,379
Cell 2	218	1	219	251	1	251
Cell 3	3,377	3,516	6,893	3,884	4,043	7,927
Cell 4	22,144	3,286	25,429	25,465	3,778	29,244
Cell 5	4,344	91	4,435	4,996	104	5,100
Dominant Salmon Spawning Reach[2]	13,624	5,121	18,745	15,667	5,890	21,557
Total Cells 1–5[3]	40,112	8,498	48,609	46,128	9,772	55,901
RM 39.5 to 36.3	15,458	2,496	17,953	17,776	2,870	20,646
Total[4]	55,570	10,993	66,563	63,905	12,642	76,547

1 Assumes sediment density of 1.15 tons yd^{-3}.
2 Includes sediment budget cells 1–3 from RM 52.2 to RM 45.8.
3 RM 52.2 to RM 39.5
4 RM 52.2 to RM 36.3.

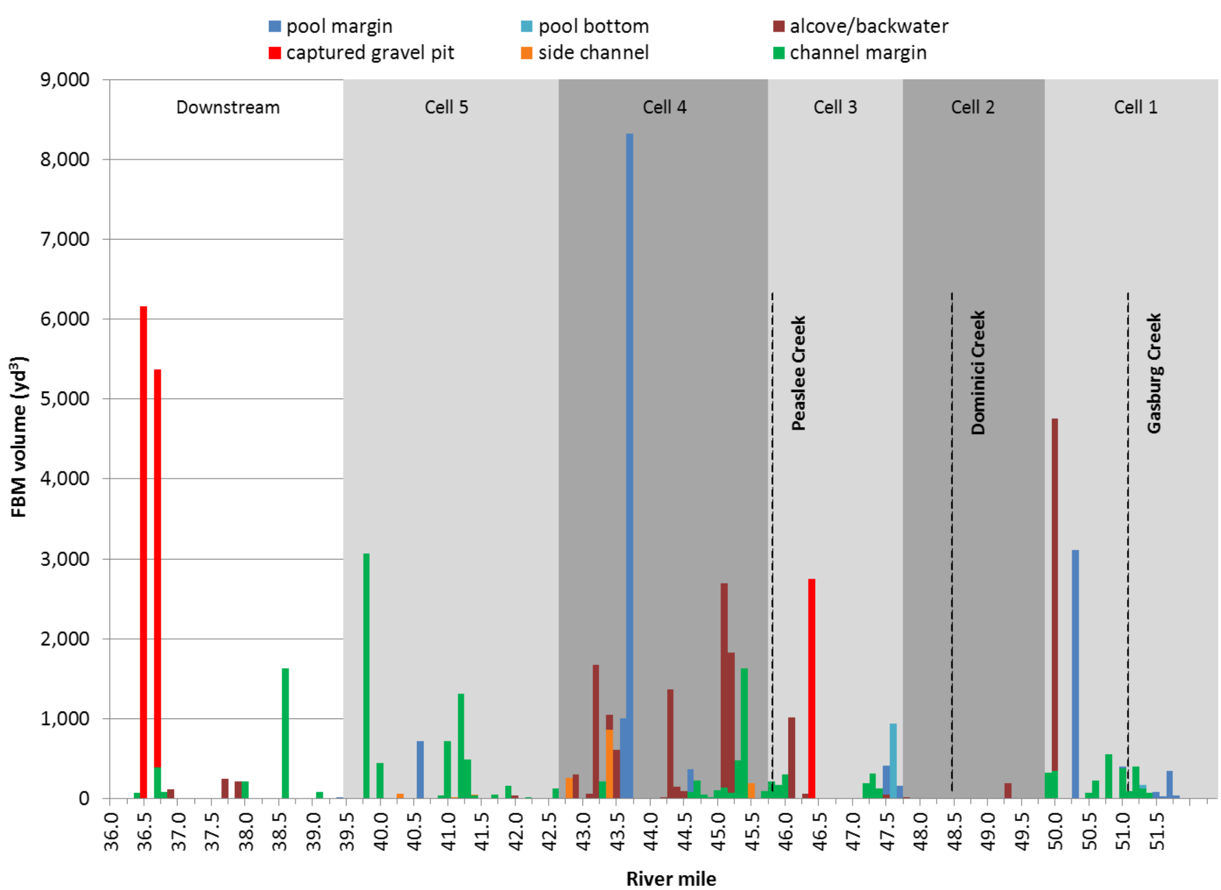

Figure 5.3-2. Distribution of discrete FBM deposits within different geomorphic units from La Grange Dam to Santa Fe Aggregates haul road bridge.

Table 5.3-2. Discrete fine bed material deposits mapped by geomorphic unit.

Geomorphic Unit	Volume (yd^3)			Mass[1] (tons)		
	In 320 cfs inundation area	In 320–600 cfs inundation area	Total	In 320 cfs inundation area	320–600 cfs Inundation Area	Total
Pool bottom	2,022	166	2,188	2,325	191	2,516
Pool margin	14,441	1,140	15,582	16,607	1,312	17,919
Channel margin	14,195	1,816	16,011	16,324	2,088	18,413
Alcove/backwater	14,320	2,717	17,037	16,468	3,125	19,593
Side channel	507	959	1,465	583	1,102	1,685
Captured gravel pit	10,085	4,194	14,279	11,598	4,824	16,421
Total[2]	55,570	10,993	66,563	63,905	12,642	76,547

[1] Assumes sediment density of 1.15 tons yd^{-3}.
[2] RM 52.2 to RM 36.3.

Comparison of FBM storage in the reach from RM 52.2 to RM 39.5 in 2001 and 2012 indicates a 48 percent reduction in total sediment volume, from approximately 92,734 yd^3 in 2001 to approximately 48,609 yd^3 in 2012. Fine bed material storage in the low flow channel diminished 40 percent from approximately 67,229 yd^3 in 2001 to approximately 40,112 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 total estimated 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.

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 Spawning Gravel

A total of 3,527,200 ft^2 of riffle mesohabitat was mapped from RM 52.2 to RM 23 in 2012, of which 2,967,500 ft^2 (84%) 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 52.2 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 52.2 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%). However, comparing the 2001 and 2012 surveys suggests a more significant increase of 709,500 ft^2 (54%). 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 April 6, 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	%
Cell 1	247,032	195,910	141,653	387,993	324,696	140,961	5	192,083	98
Cell 2	459,565	395,034	191,707	342,495	323,831	-117,070	-25	-52,539	-13
Cell 3	222,065	137,500	52,565	138,330	125,893	-83,735	-38	830	1
Cell 4	161,522	144,386	22,631	430,479	342,657	268,957	167	286,093	198
Cell 5	144,874	159,732	31,821	333,265	278,693	188,391	130	173,533	109
Dominant Salmon Spawning Reach[3]	741,357	606,600	410,600	793,400	709,200	52,054	7	186,845	31
Total Cells 1–5[4]	1,235,058	1,032,562	440,377	1,632,561	1,395,770	397,503	-32	599,999	35
Total RM 52.2 to RM 23.6	2,917,200	na	na	3,527,200	2,967,500	606,212	21	na	na

1 Riffle mesohabitats were not mapped in the reach from RM 34.2 to RM 23 in 2001.
2 na = not available.
3 Dominant salmon spawning reach includes sediment budget cells 1–3 from RM 52.2 to RM 45.8.
4 RM 52.2 to RM 39.5

5.4.2 Spawning Habitat

The total suitable spawning habitat area in riffle habitats was calculated by re-scaling habitat mapping from 320 cfs to other flows using PHABSIM modeling results of the binary habitat suitability criteria used for this study (Section 4.4.2). Riverwide (RM 52–23) estimates of total suitable spawning area for Chinook salmon and *O. mykiss* over flows ranging from 50 cfs to 1,000 cfs is shown in Table 5.4-3 and Figure 5.4-1.

Table 5.4-3. Estimated suitable spawning area for Chinook and *O. mykiss* in the lower Tuolumne River from RM 52 to RM 23.

Simulated Discharge (cfs)	Chinook spawning area (ft^2)	*O. mykiss* spawning area (ft^2)	Percent of maximum spawning area
50	316,541	79,897	23
75	562,478	141,974	41
100	845,615	213,439	62
125	1,129,995	285,219	82
150	1,244,925	314,228	91
175	1,314,041	331,674	96
200	1,322,622	333,840	97
225	1,370,917	346,029	100
250	1,353,182	341,553	99
275	1,302,157	328,674	95
300	1,288,574	325,246	94
320	1,305,658	329,558	95
325	1,303,725	329,070	95
350	1,272,067	321,079	93
375	1,215,009	306,677	89
400	1,158,653	292,452	85
450	1,036,844	261,707	76
500	914,703	230,878	67
550	787,745	198,833	58
600	713,976	180,213	52
650	668,954	168,849	49
700	612,356	154,563	45
800	573,454	144,744	42
900	445,104	112,348	33
1000	402,461	101,584	29

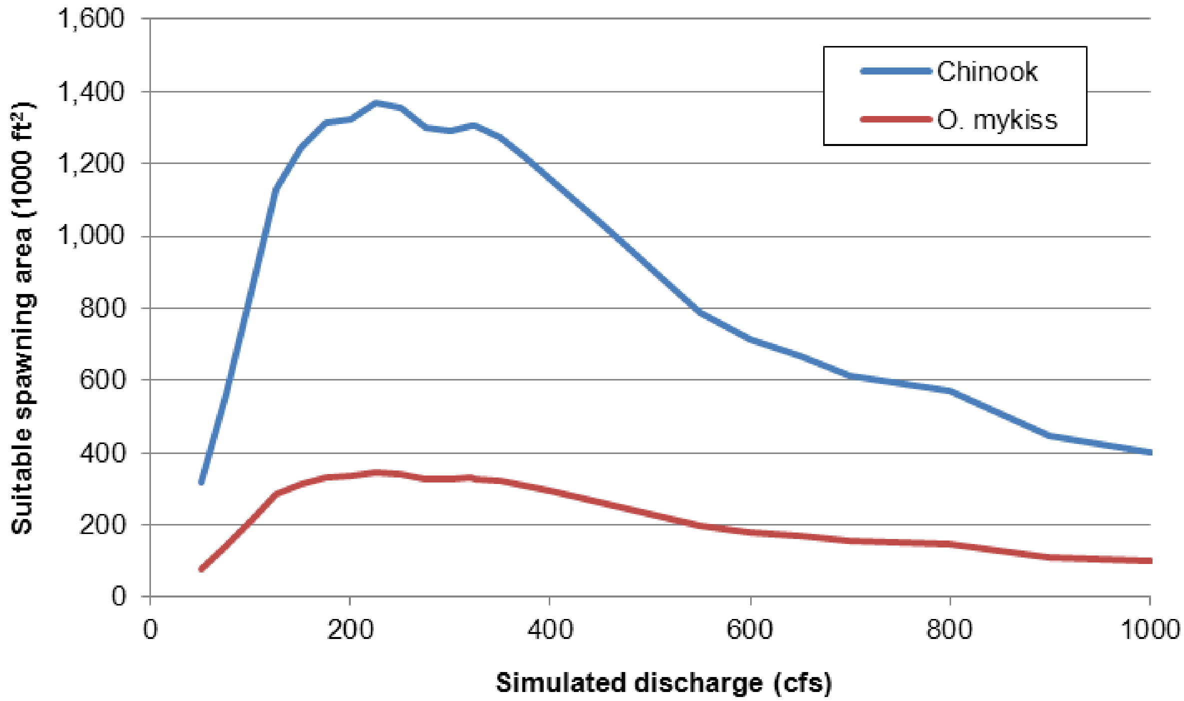

Figure 5.4-1. Estimated suitable spawning habitat area for Chinook and *O. mykiss* in the lower Tuolumne River from RM 52 to RM 23.

5.5 Maximum Potential Spawning Population Sizes

Estimates of maximum potential Chinook salmon and *O. mykiss* spawning population sizes under the current FERC flow schedule (e.g., 150, 175, 180, or 300 cfs) shown in Table 5.5-1 are calculated as the product of two fish per spawning pair multiplied by the ratio of the total suitable spawning habitat area at a given flow to the average disturbed redd area found in the Tuolumne River (Section 4.5). Maximum run sizes under the current FERC flow schedule would range from approximately 47,882–59,795 for Chinook salmon (dependent on redd size) and approximately 803,178–854,547 for *O. mykiss* (Table 5.5-1). These maximum potential spawning population size estimates are based on the average redd size estimates from the Tuolumne River (Section 4.5) and do not take into account factors related to actual spawning site selection (e.g., increased preference for upstream locations, non-uniform habitat selection at the site-scale, redd superimposition, etc.).

Table 5.5-1. Estimated maximum potential spawning Chinook salmon and *O. mykiss* population sizes in the lower Tuolumne River from RM 52 to RM 23.

FERC (1996) spawning flow requirement (cfs)	FERC (1996) Water year type(s)	Estimated maximum potential Chinook spawning population size		Estimated maximum potential *O. mykiss* spawning population size[c]
		1988-1989 redd size data[a]	2012 redd size data[b]	
150	Critical and below through Median Dry	47,882	57,769	803,178
175	Median Below Normal	50,540	60,976	847,769
180	Intermediate Dry-Below Normal	50,944	61,464	854,547
300	Intermediate Below Normal-Above Normal through Median Wet/Maximum	49,561	59,795	831,338

Notes:
[a] Based on average Tuolumne River Chinook salmon disturbed redd area of 52 ft^2 (4.8 m^2) (TID/MID 1992, Appendix 6).
[b] Based on average Tuolumne River Chinook salmon egg pocket redd area of 43.1 ft^2 (4.0 m^2) from the *Redd Mapping Study* (W&AR-08).
[c] Based on average Tuolumne River *O. mykiss* egg pocket area of 3.1 ft^2 (0.3 m^2) from the *Redd Mapping Study* (W&AR-08).

6.0 DISCUSSION AND FINDINGS

Findings from the W&AR-04 Spawning Gravel in the Lower Tuolumne study are discussed below within the context of the six 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 5,913–8,720 tons of coarse (>2 mm) bed material was lost from storage in sediment budget Cells 1–3 (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 was retained.

Differencing of channel topography surveyed in 2005 and 2012 in budget Cells 1–3 shows little change in storage at the reach scale, but field observations indicated 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 1 to 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: 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. A sediment budget was developed to estimate the potential cumulative effects of the Project on coarse bed material storage changes in five reaches of the lower Tuolumne River from La Grange Dam to RM 39.5. Refer to the discussion and findings summarized above under Objective 2.

Objective 4: 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 52.2) to Roberts Ferry Bridge (RM 39.6) decreased by 48 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 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). A total of 3,527,200 ft^2 of riffle mesohabitat was mapped from RM 52.2 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 52.2) downstream to RM 23. Analyses of suitable spawning habitat were instead developed using information collected as part of the *Lower Tuolumne River Instream Flow study* (Stillwater Sciences 2013) and the Redd Mapping Study (W&AR-08). The maximum estimated suitable spawning habitat areas of 1,370,917 ft^2 for Chinook and 346,029 ft^2 for *O. mykiss* occur at a flow of approximately 225 cfs based on criteria developed for this study.

Objective 6: Estimate maximum potential spawning population sizes supported under current conditions. Analyses of maximum potential spawning population sizes were conducted in association with the *Lower Tuolumne River Instream Flow study* (Stillwater Sciences 2013) 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. Flows within the current FERC flow schedule (150–300 cfs) provide approximately 90 to 100 percent of the maximum Chinook salmon and *O. mykiss* spawning habitat using criteria developed for this study.

7.0 STUDY VARIANCES AND MODIFICATIONS

The Districts implemented the W&AR-04 Spawning Gravel in the Lower Tuolumne Study Plan, as modified by FERC in its December 22, 2011 SPD, and the May 21, 2013 Determination on Requests for Study Modifications and New Studies. 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 December 22, 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 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 and maximum potential spawning population sizes presented in this report were instead developed using information collected as part of the *Lower Tuolumne River Instream Flow study* (Stillwater Sciences 2013), the *Redd Mapping Study* (W&AR-08) as well as interrelated salmonid population modeling studies (W&AR-06 and W&AR-10).

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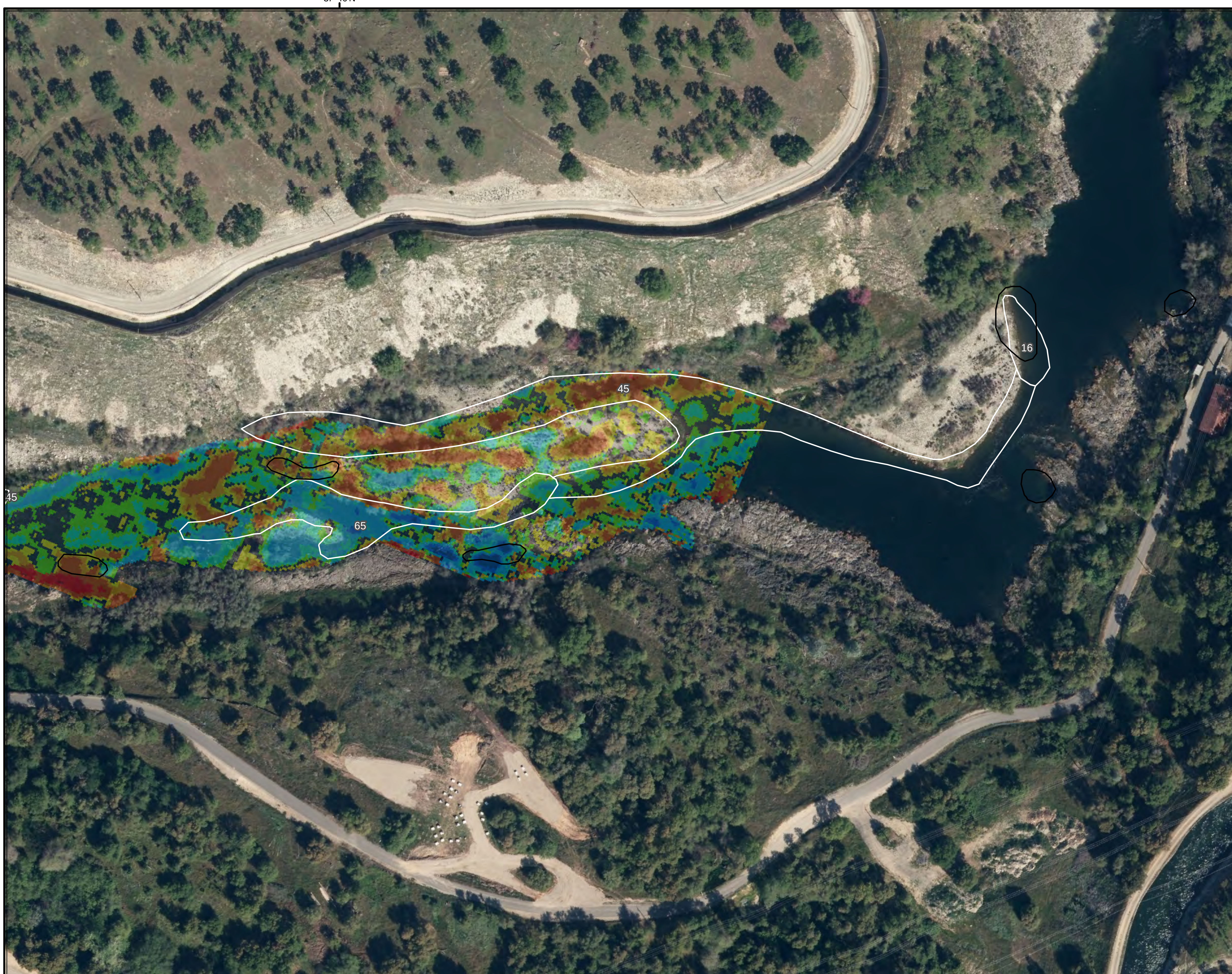
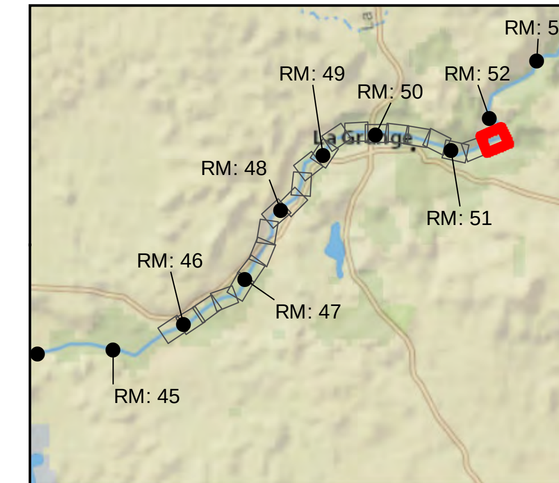
STUDY REPORT W&AR-04
SPAWNING GRAVEL IN THE LOWER TUOLUMNE RIVER

ATTACHMENT A

BED ELEVATION CHANGES IN THE LOWER TUOLUMNE RIVER FROM RM 51.5 TO RM 45.5 DETERMINED FROM DIFFERENCING OF 2005 AND 2012 DIGITAL TERRAIN MODELS





USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Class (feet)	
> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200
Feet

N

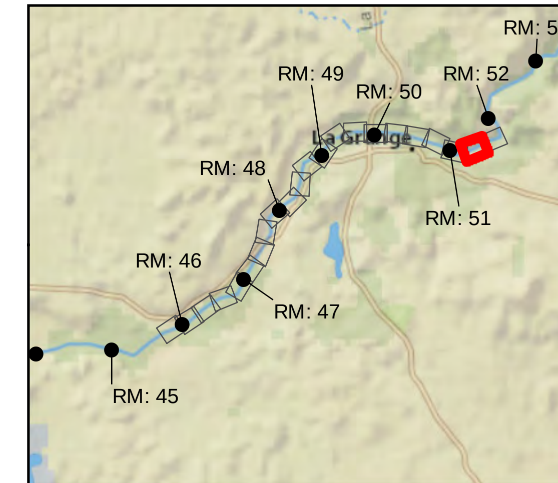
Attachment A

Don Pedro Project (FERC No.2299)

Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.
Data Sources: Hydrography - USGS NHD; Roads - ESRI 9.3 Data (Teleatlas); Ownership, PLSS - CA BLM; FERC Boundary, Reservoir Bathy, Recreation & Project Facilities - MID/TID.
Data is CA SPCS, zone III, ft. Contour interval is 50 ft (NAVD 88).

120°27'W

120°27'W



USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200

Feet

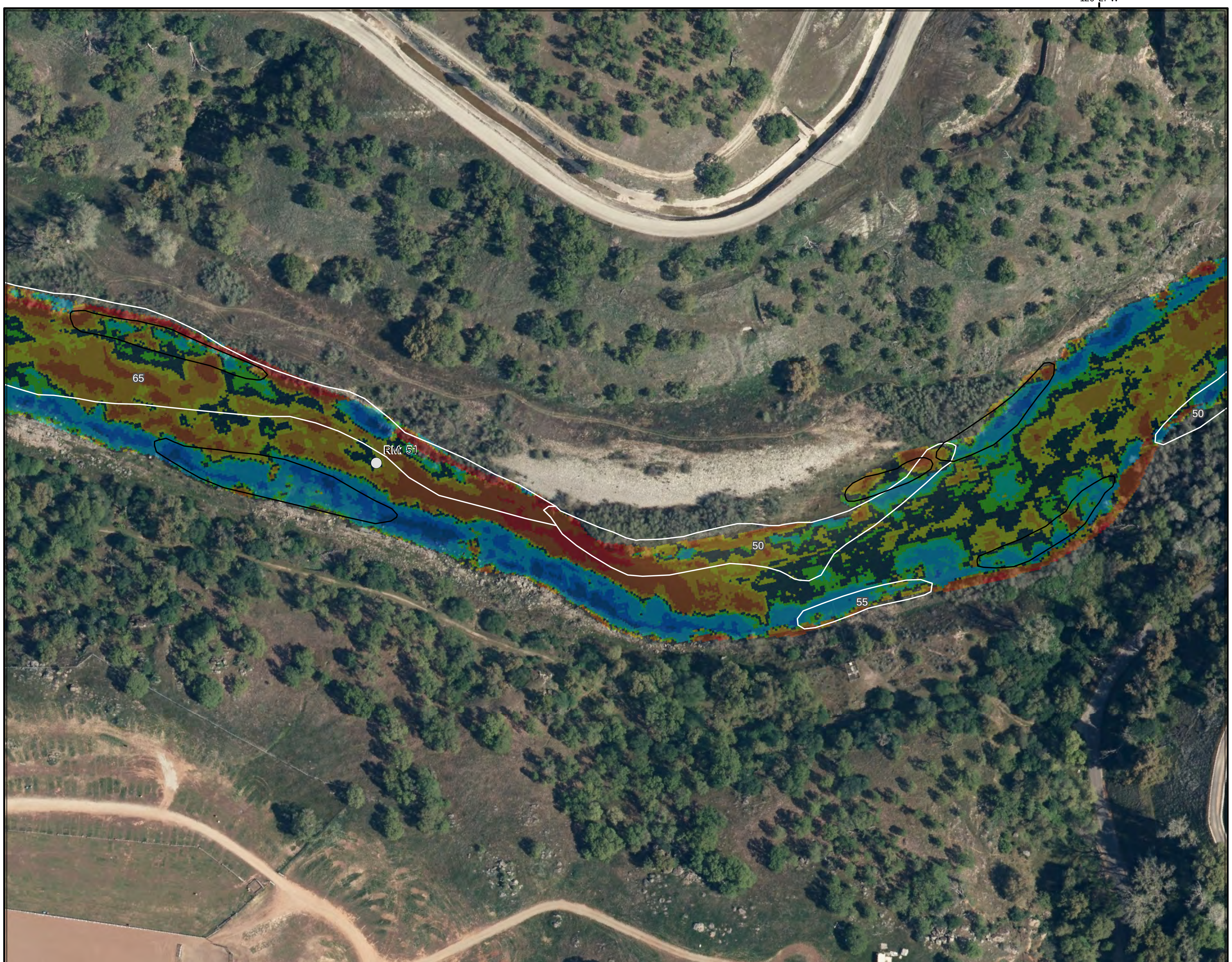
N

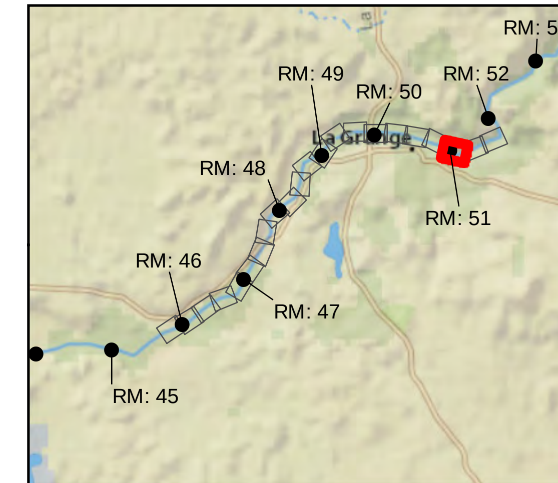
Attachment A

Don Pedro Project (FERC No.2299)

Map information was compiled from the best available sources. No warranty is made for its accuracy or completeness. Data Sources: Hydrography - USGS NHD; Roads - ESRI 9.3 Data (Teleatlas); Ownership, PLSS - CA BLM; FERC Boundary, Reservoir Bathy, Recreation & Project Facilities - MID/TID. Data is CA SPCS, zone III, ft. Contour interval is 50 ft (NAVD 88).

120°27'W





Page 3 of 22

- USGS River Mile
- Discrete FBM Deposit
- Spawning Gravel Deposit w/ D_{50} label (mm)
- CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet	
> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200
Feet

N

Attachment A

Don Pedro Project (FERC No.2299)

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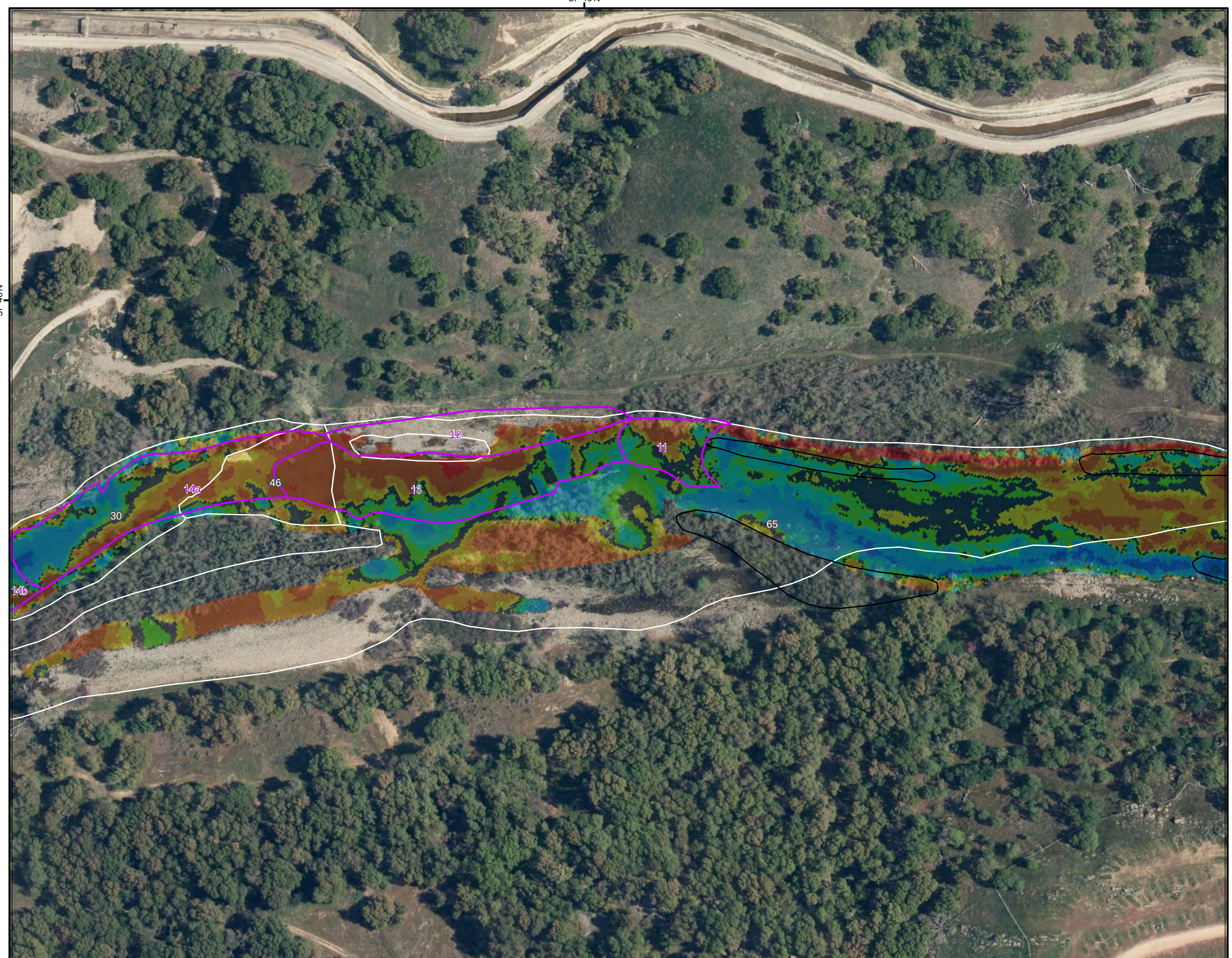
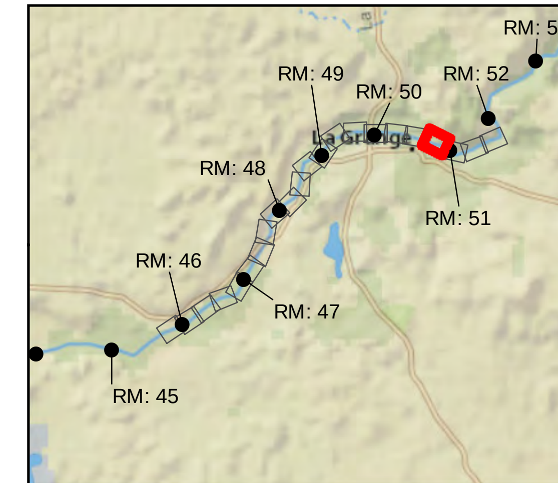
Data is CA SPCS, zone III, ft. Contour interval is 50 ft (NAVD 88).





USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Aggradation:
- > 5
- 5 : 3
- 3 : 1
- 1 : 0.5
- 0.5 : 0.2

- 0.2 : -0.2

Degradation:
- -0.2 : -0.5
- -0.5 : -1
- -1 : -3
- -3 : -5
- < -5

0 50 100 200

Feet

N

Attachment A

Don Pedro Project (FERC No.2299)

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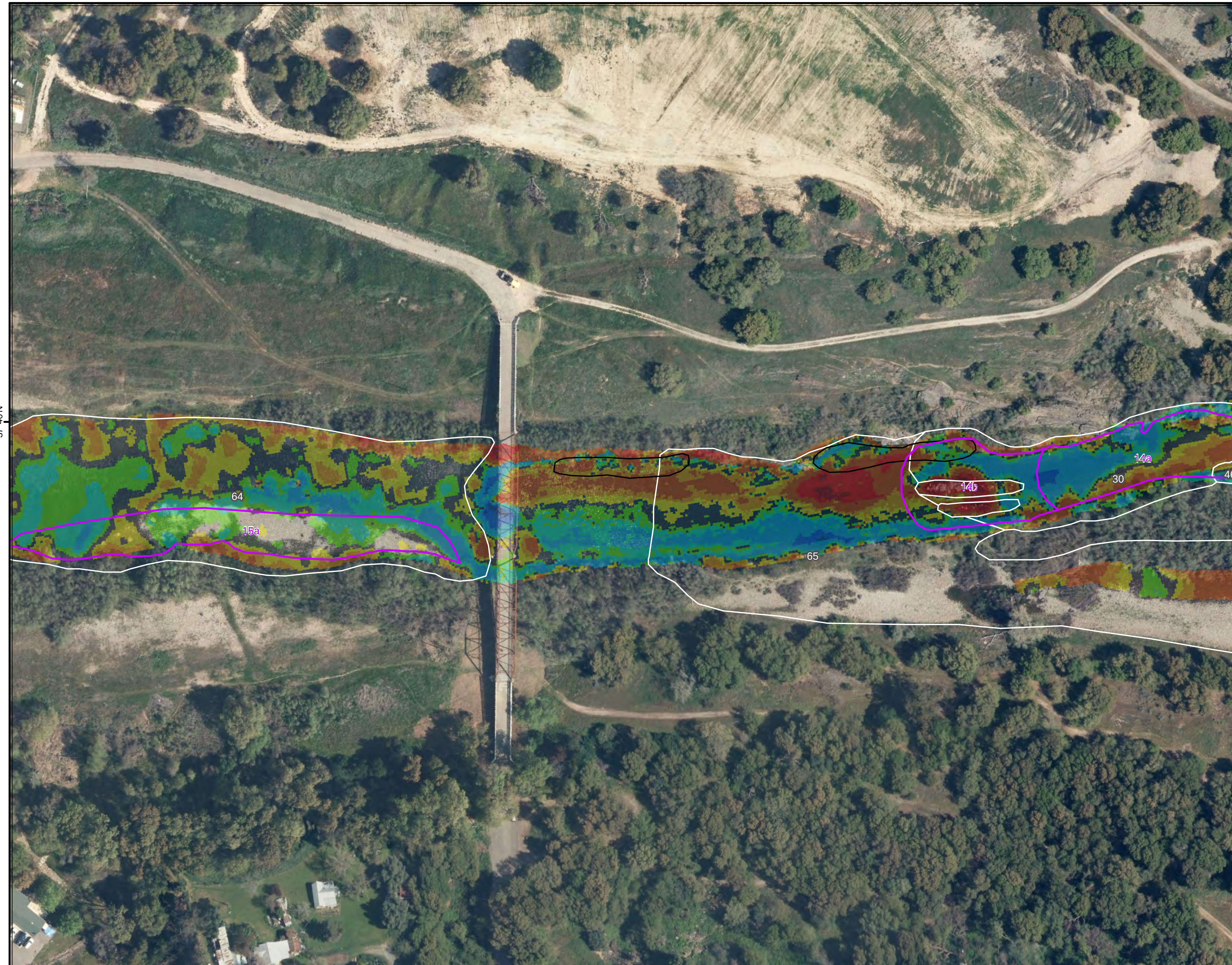

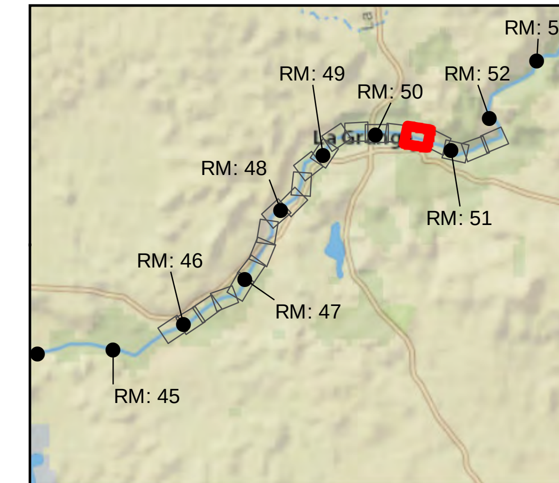

- USGS River Mile
- Discrete FBM Deposit
- Spawning Gravel Deposit w/ D_{50} label (mm)
- CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200

Feet

N

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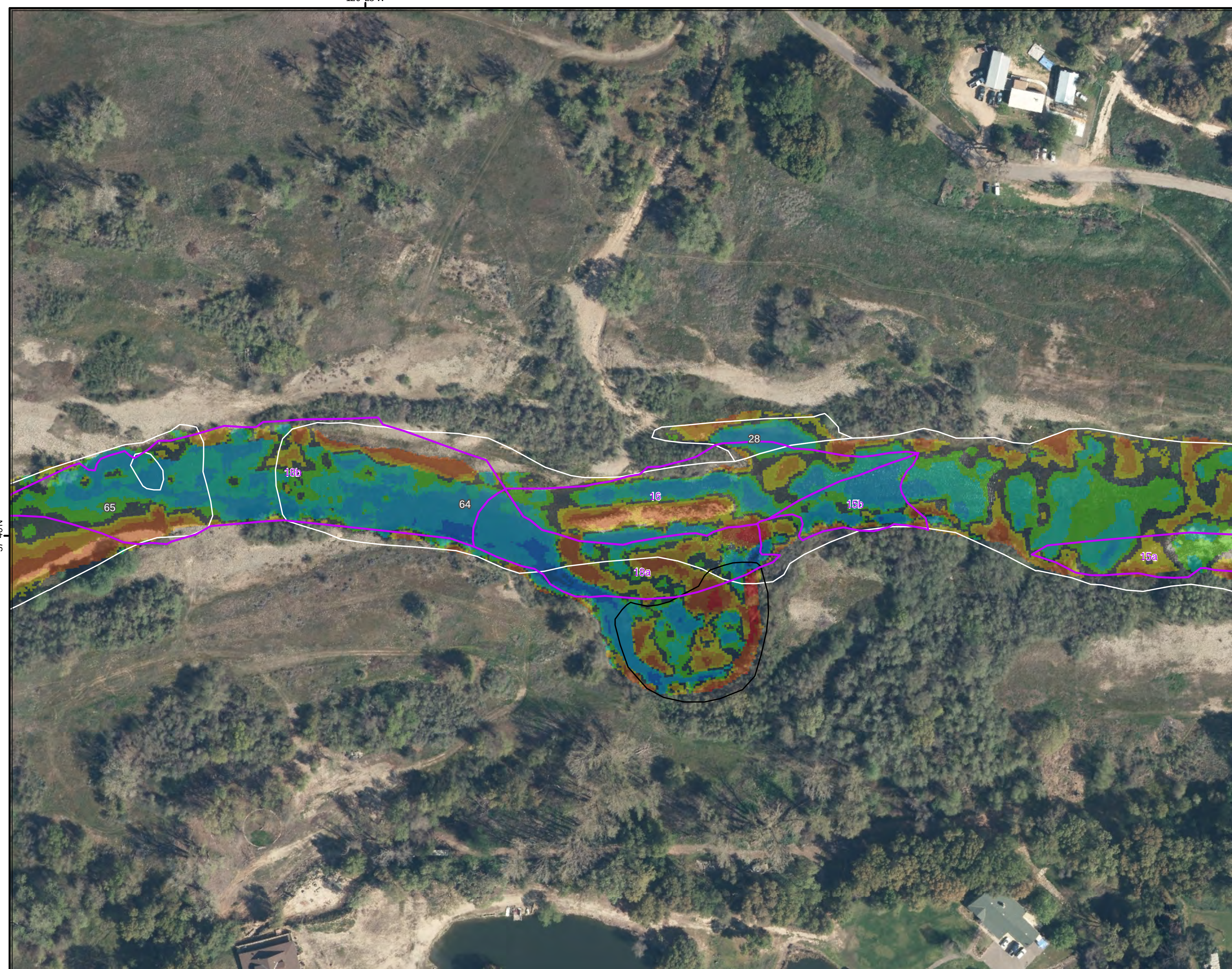
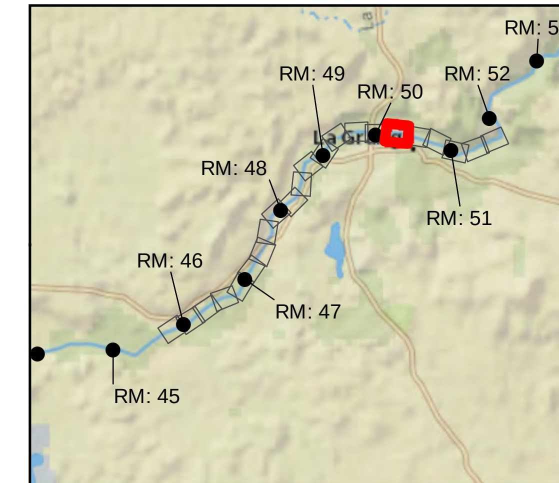
120°28'W



120°28'W



USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Aggradation:
- > 5
- 5 : 3
- 3 : 1
- 1 : 0.5
- 0.5 : 0.2

- 0.2 : -0.2

Degradation:
- -0.2 : -0.5
- -0.5 : -1
- -1 : -3
- -3 : -5
- < -5

0 50 100 200

Feet

N

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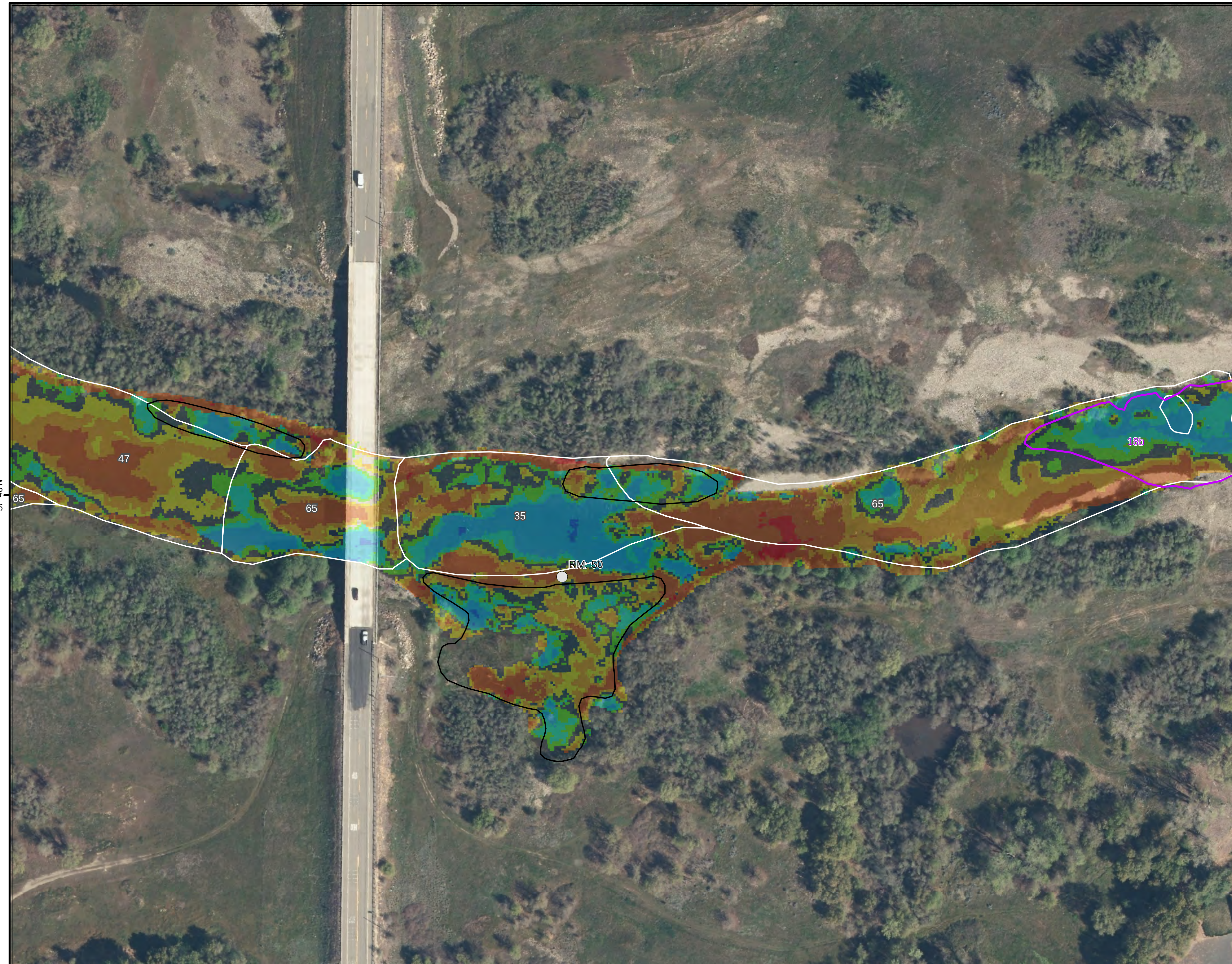

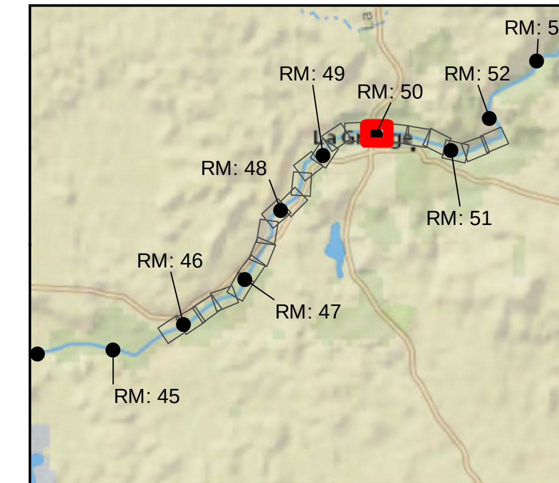

USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200

Feet

N

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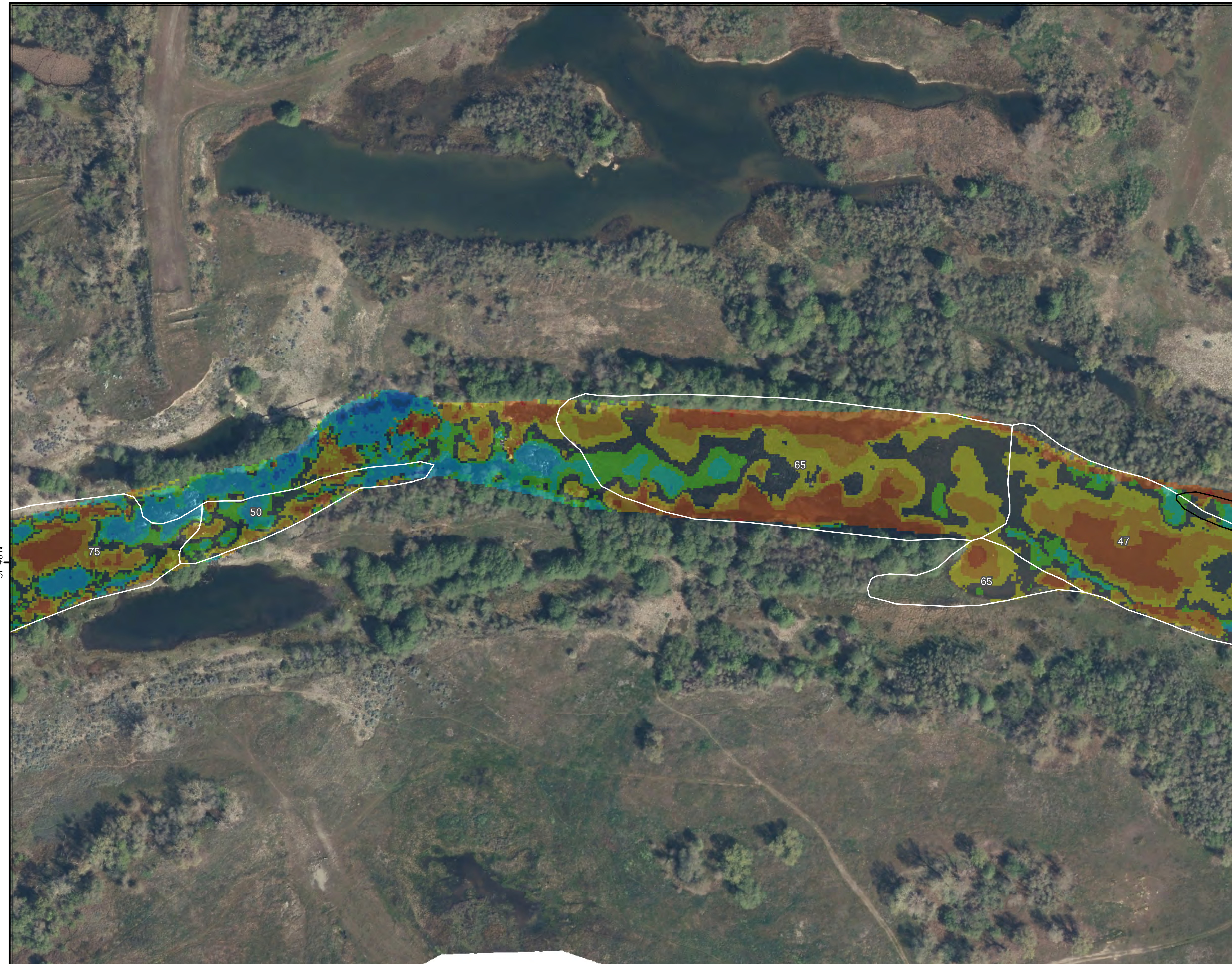

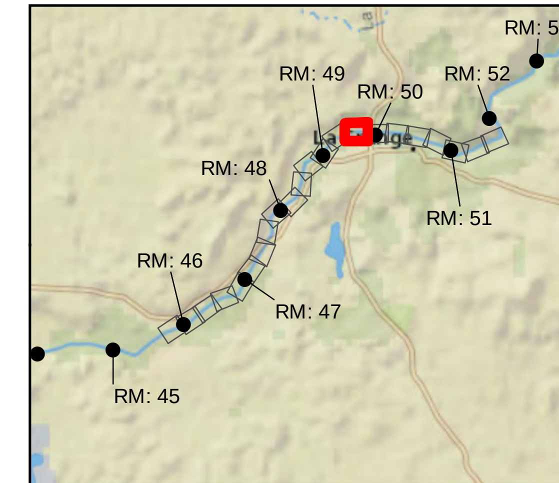

USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Class (feet)	
> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200

Feet

N

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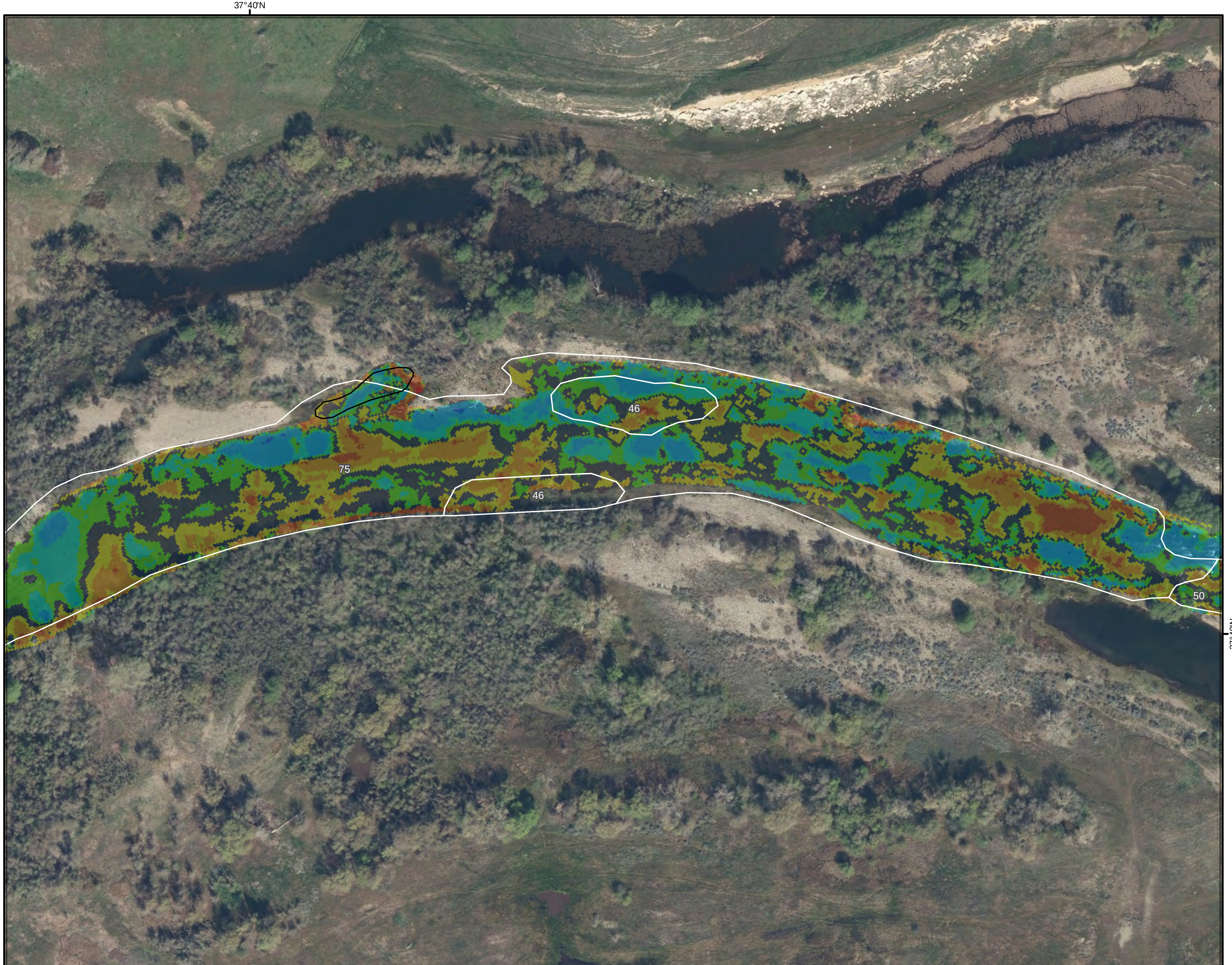

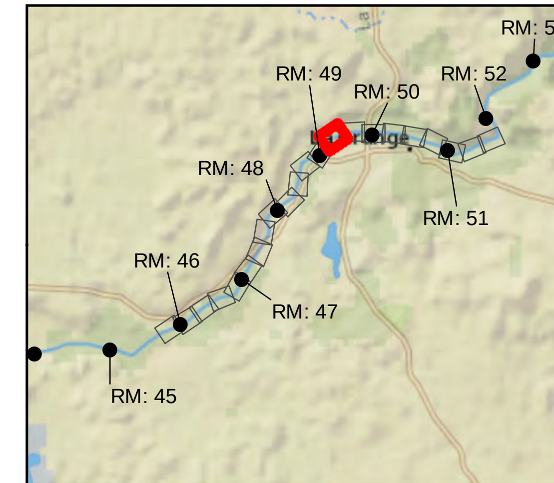

USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Aggradation
- > 5
- 5 : 3
- 3 : 1
- 1 : 0.5
- 0.5 : 0.2

- 0.2 : -0.2

Degradation
- -0.2 : -0.5
- -0.5 : -1
- -1 : -3
- -3 : -5
- < -5

0 50 100 200

Feet

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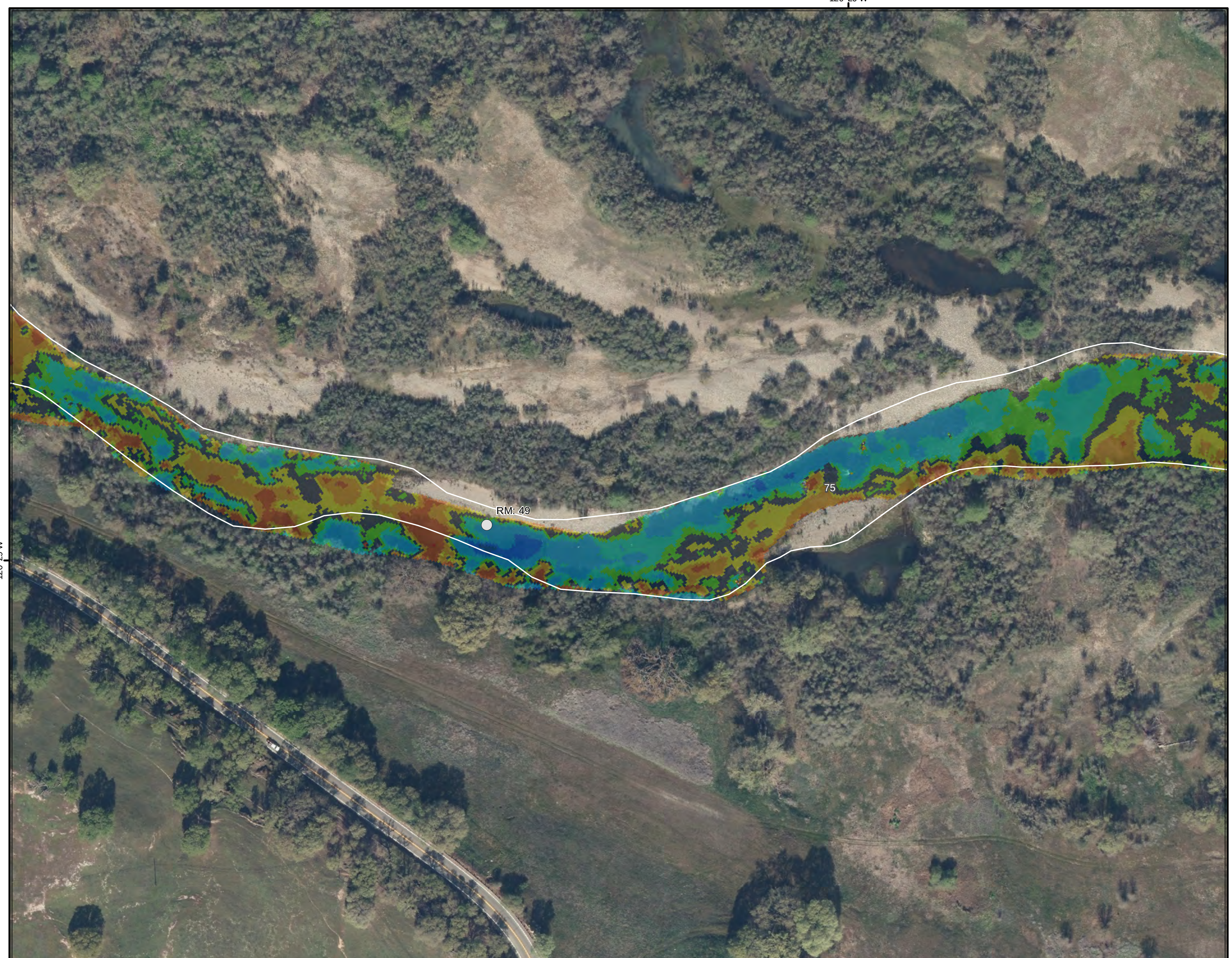

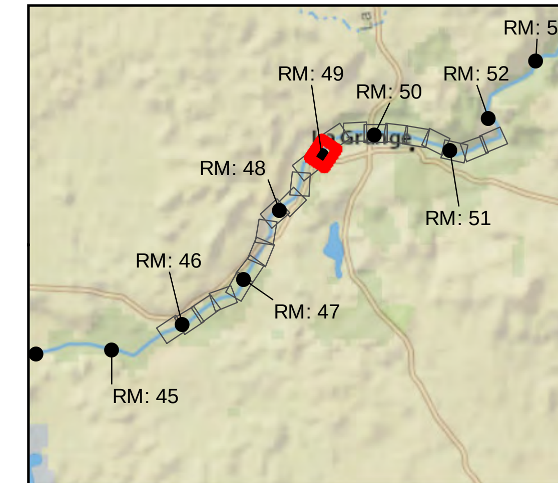

USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

> 5		Aggradation
5 : 3		
3 : 1		
1 : 0.5		
0.5 : 0.2		
0.2 : -0.2		
-0.2 : -0.5		Degradation
-0.5 : -1		
-1 : -3		
-3 : -5		
< -5		

0 50 100 200

Feet

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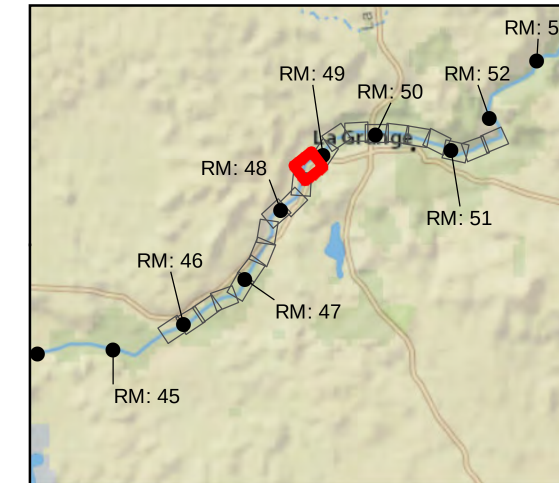

USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
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< -5	Degradation

0 50 100 200

Feet

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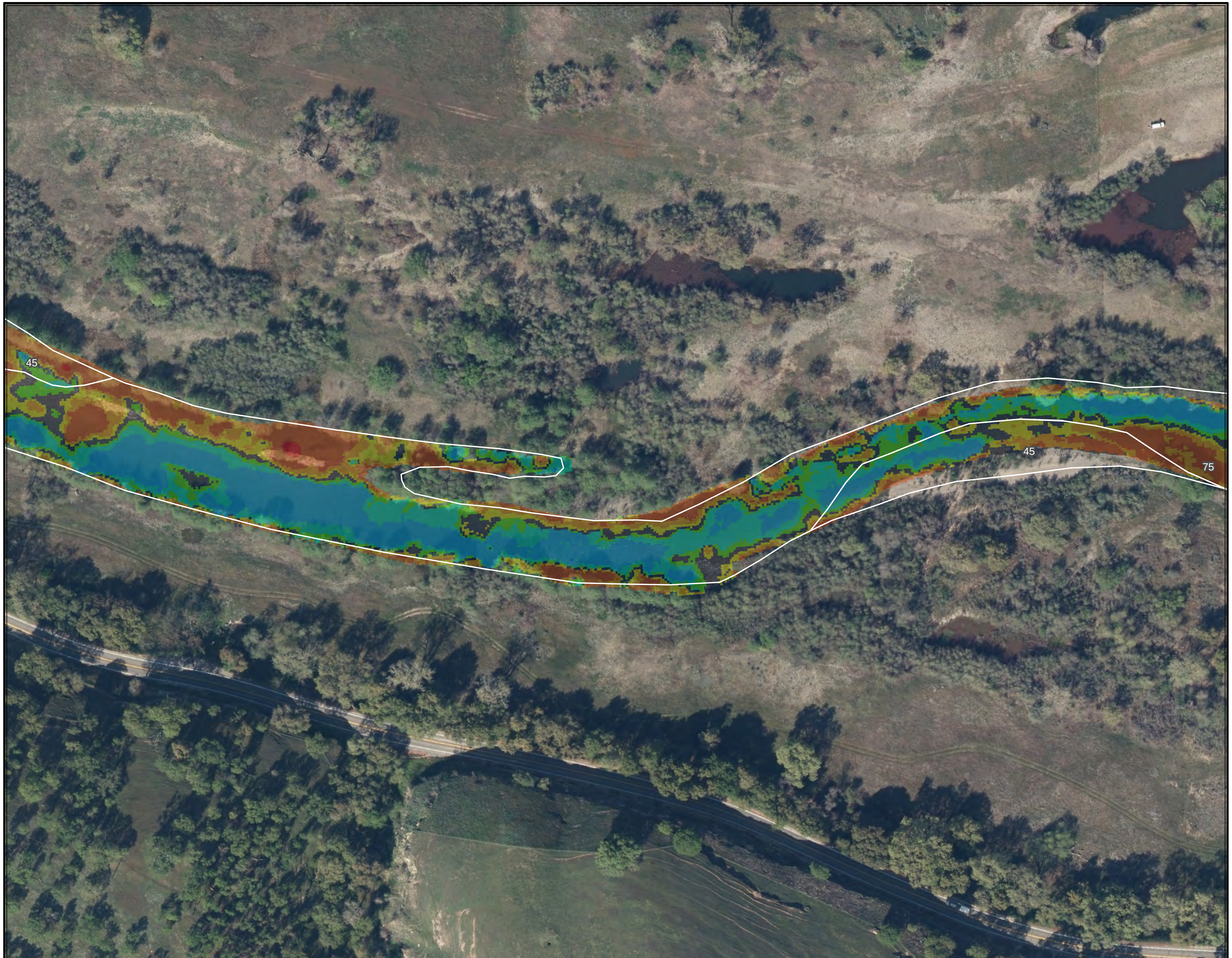

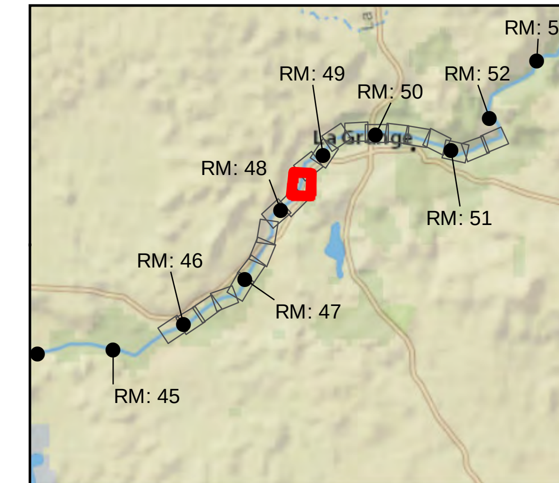

USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Range (feet)	
> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200

Feet

N

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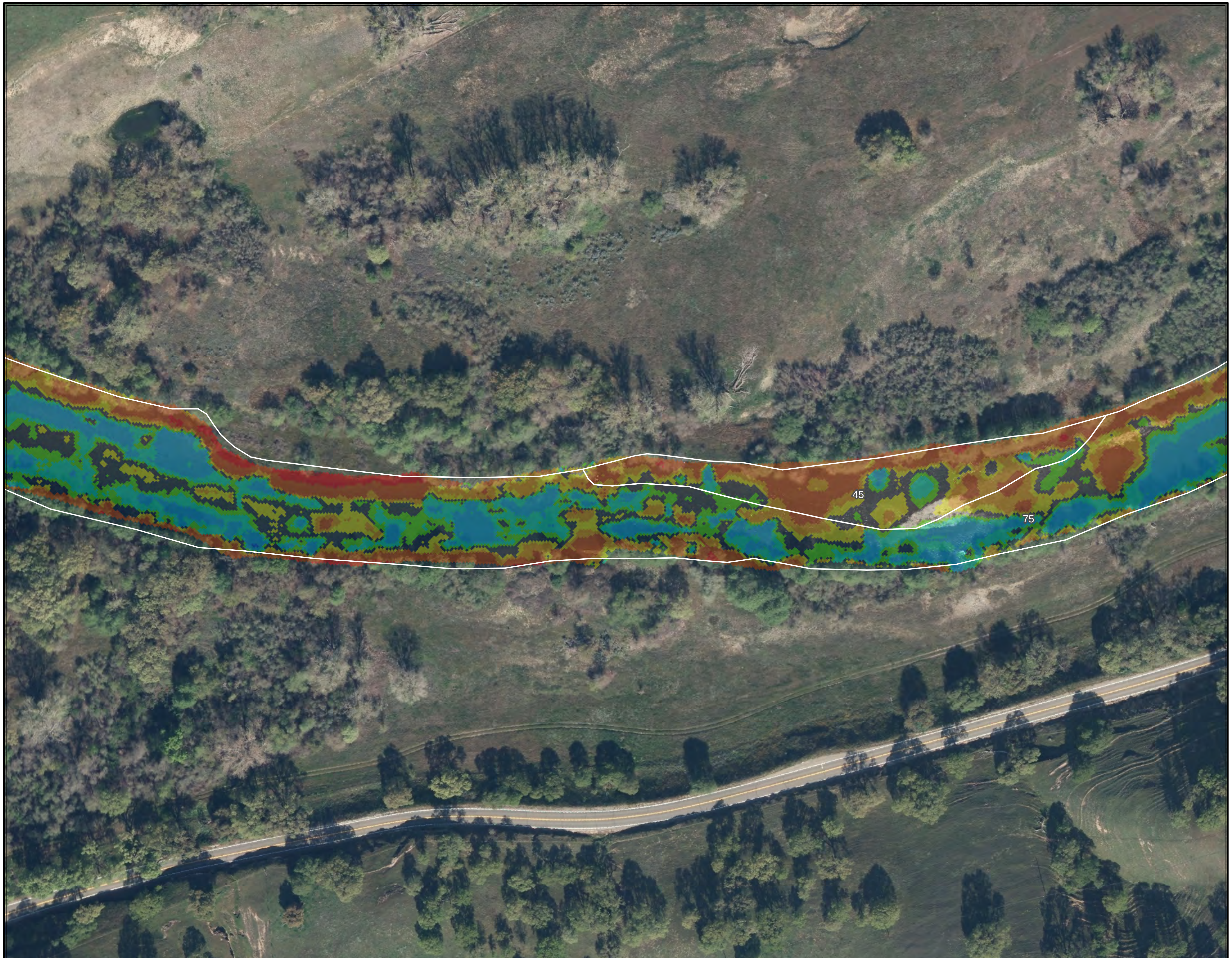

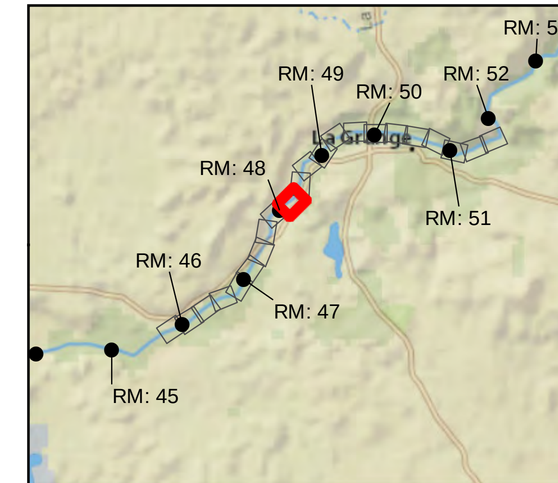

Page 13 of 22

USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Aggradation:
- > 5
- 5 : 3
- 3 : 1
- 1 : 0.5
- 0.5 : 0.2

0.2 : -0.2

Degradation:
- -0.2 : -0.5
- -0.5 : -1
- -1 : -3
- -3 : -5
- < -5

0 50 100 200
Feet

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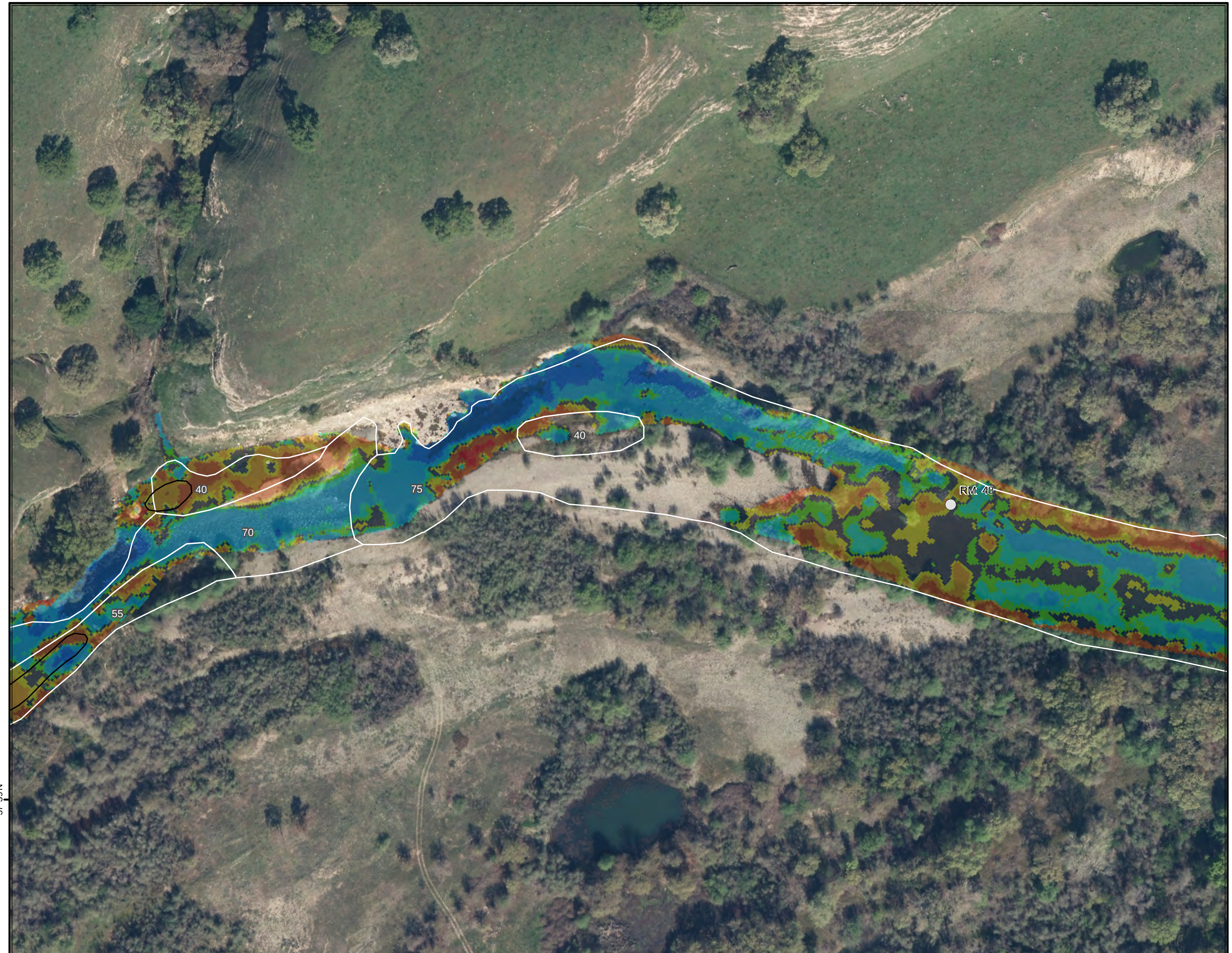

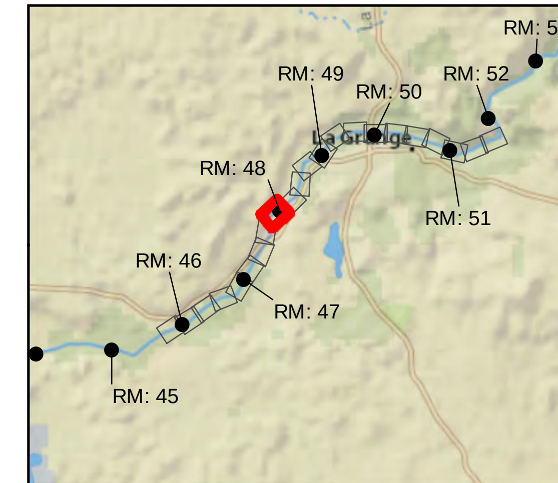

USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Class	
> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200

Feet

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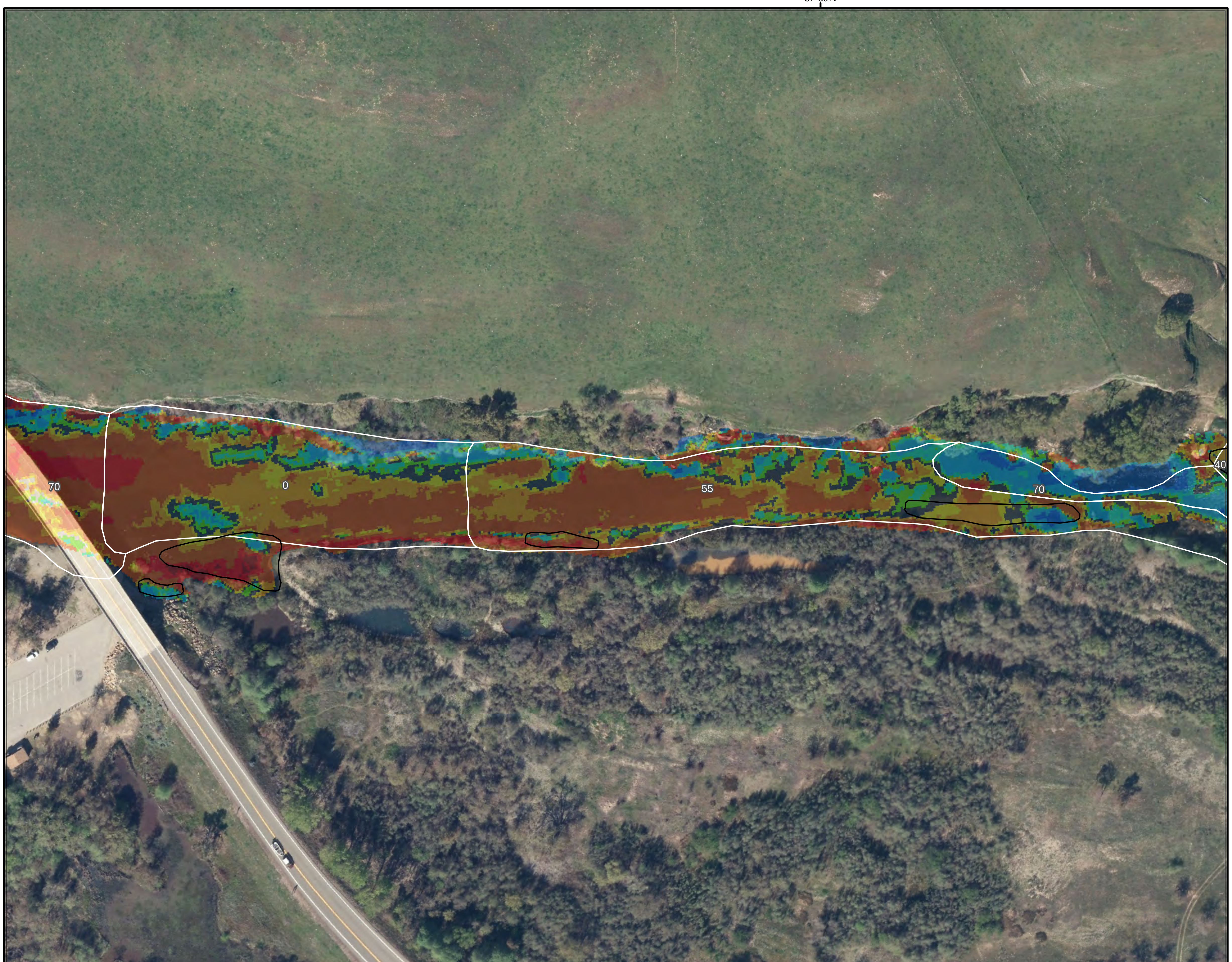
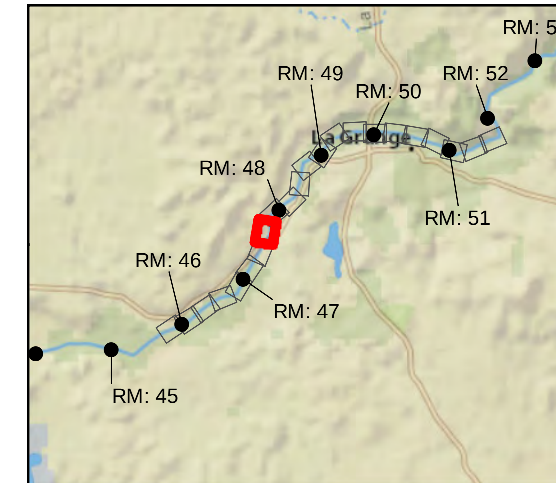
37°39'N



37°39'N



USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Class (feet)	
> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200

Feet

N

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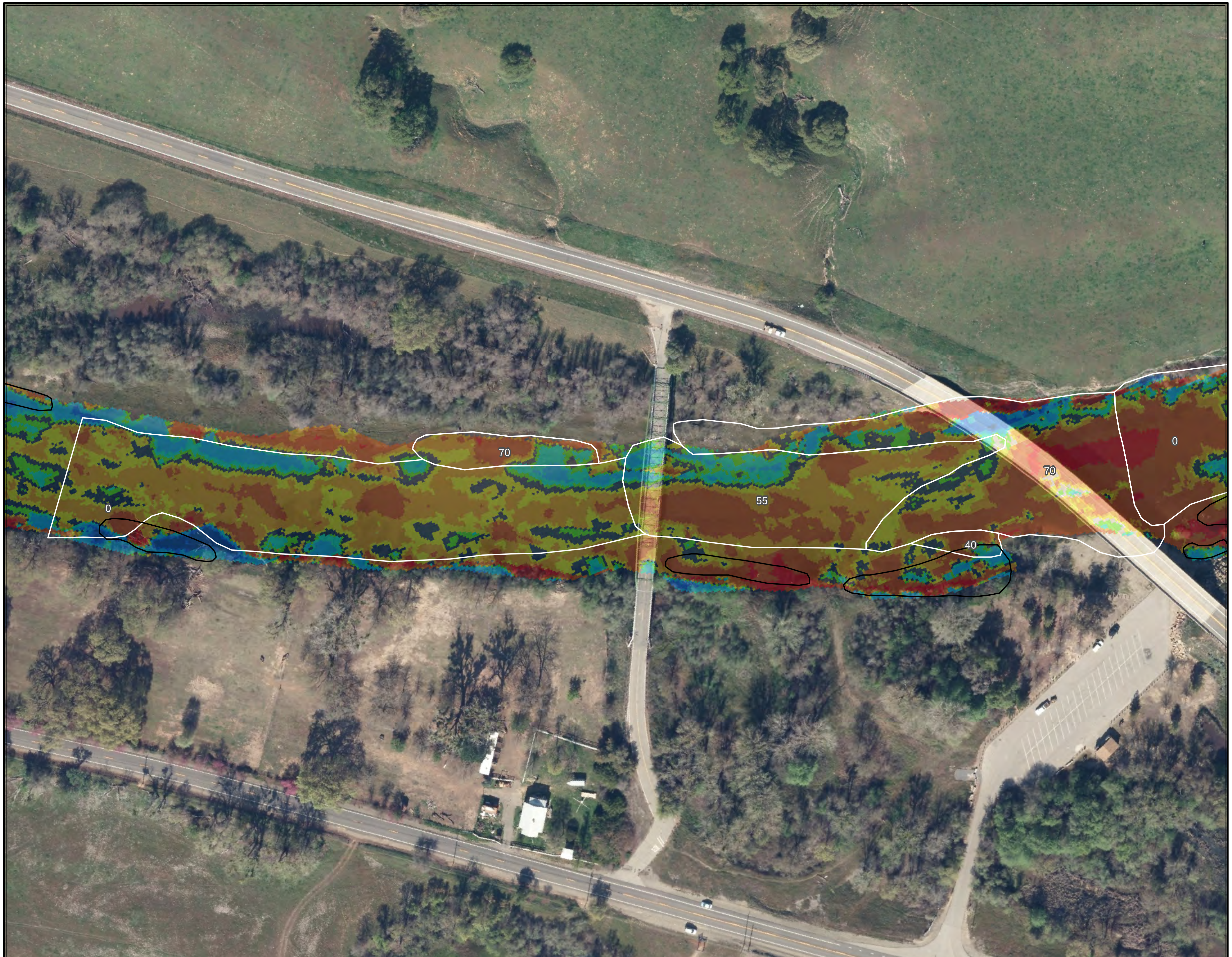

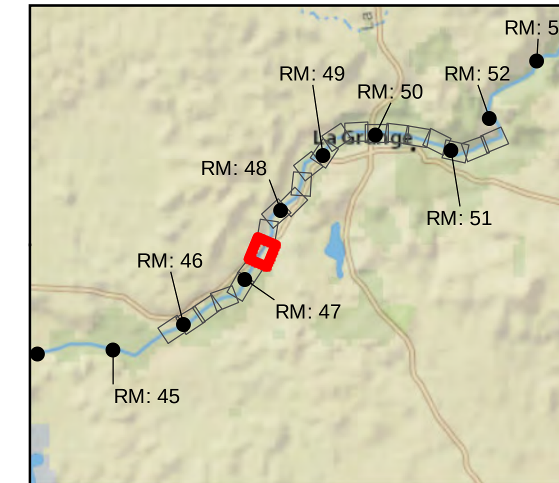

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USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

> 5	Aggradation	
5 : 3		
3 : 1		
1 : 0.5		
0.5 : 0.2		
0.2 : -0.2		
-0.2 : -0.5	Degradation	
-0.5 : -1		
-1 : -3		
-3 : -5		
< -5		

0 50 100 200

Feet

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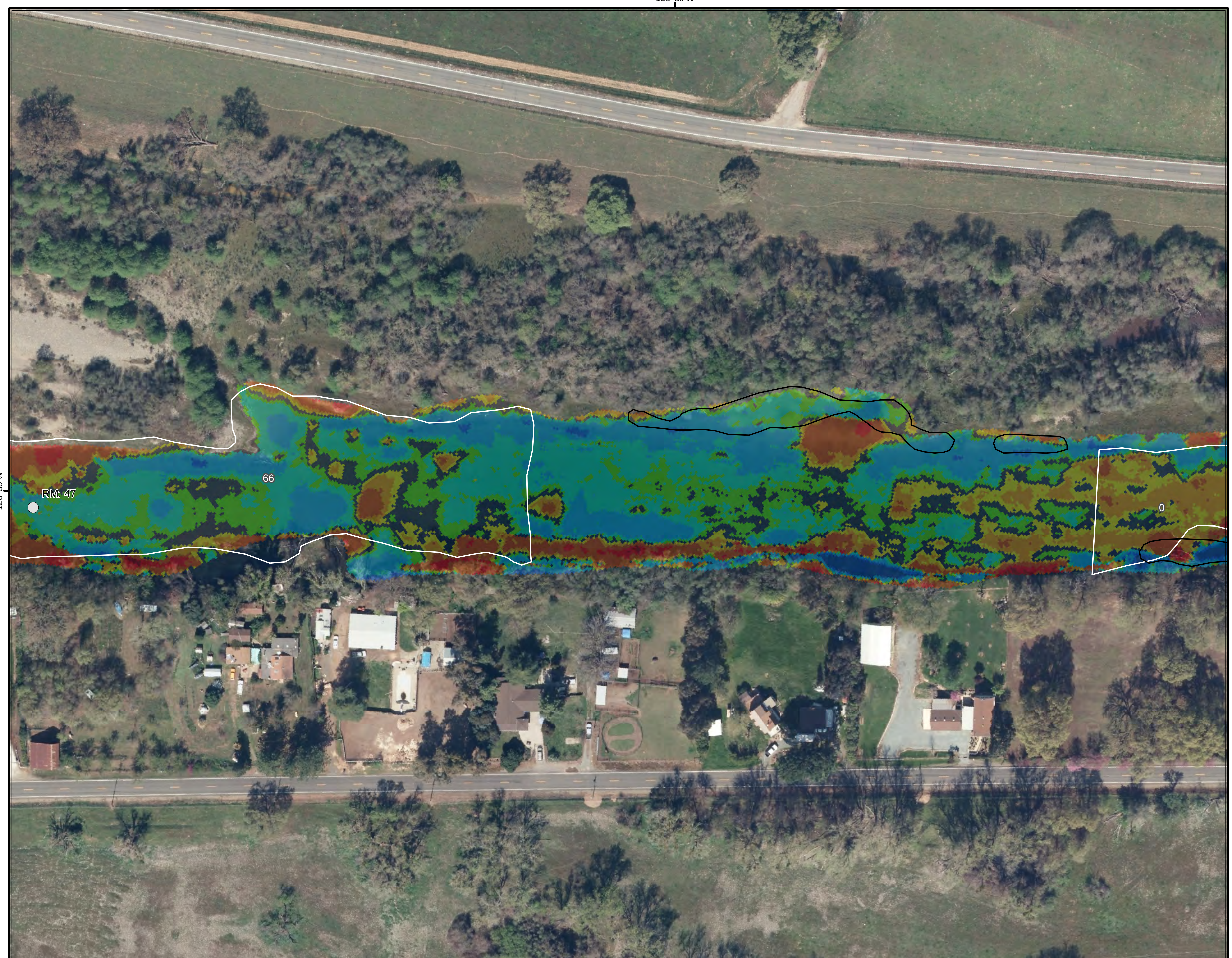
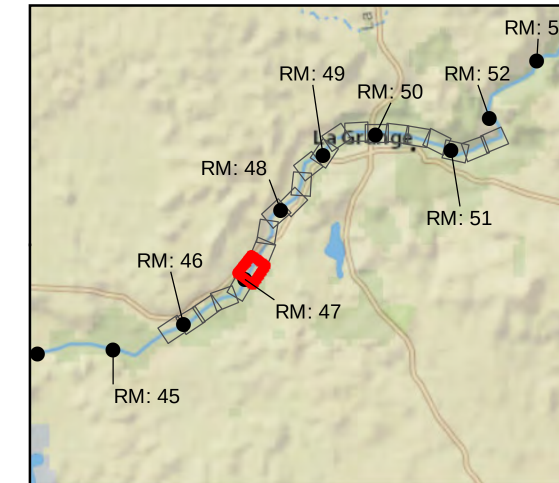
120°30'W





USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Aggradation:
- > 5
- 5 : 3
- 3 : 1
- 1 : 0.5
- 0.5 : 0.2

- 0.2 : -0.2

Degradation:
- -0.2 : -0.5
- -0.5 : -1
- -1 : -3
- -3 : -5
- < -5

0 50 100 200
Feet

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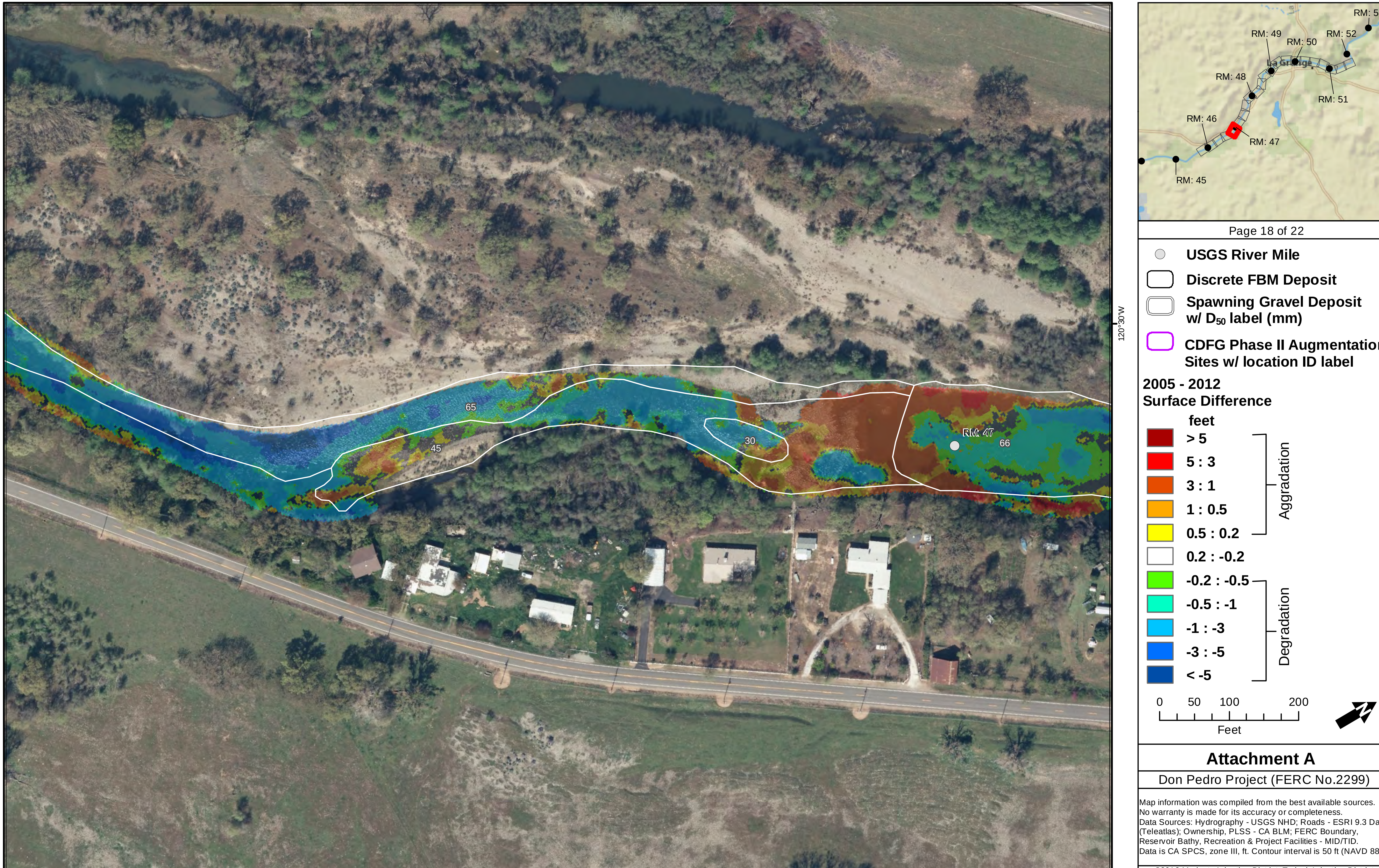

- USGS River Mile
- Discrete FBM Deposit
- Spawning Gravel Deposit w/ D_{50} label (mm)
- CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

feet	
> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200
Feet

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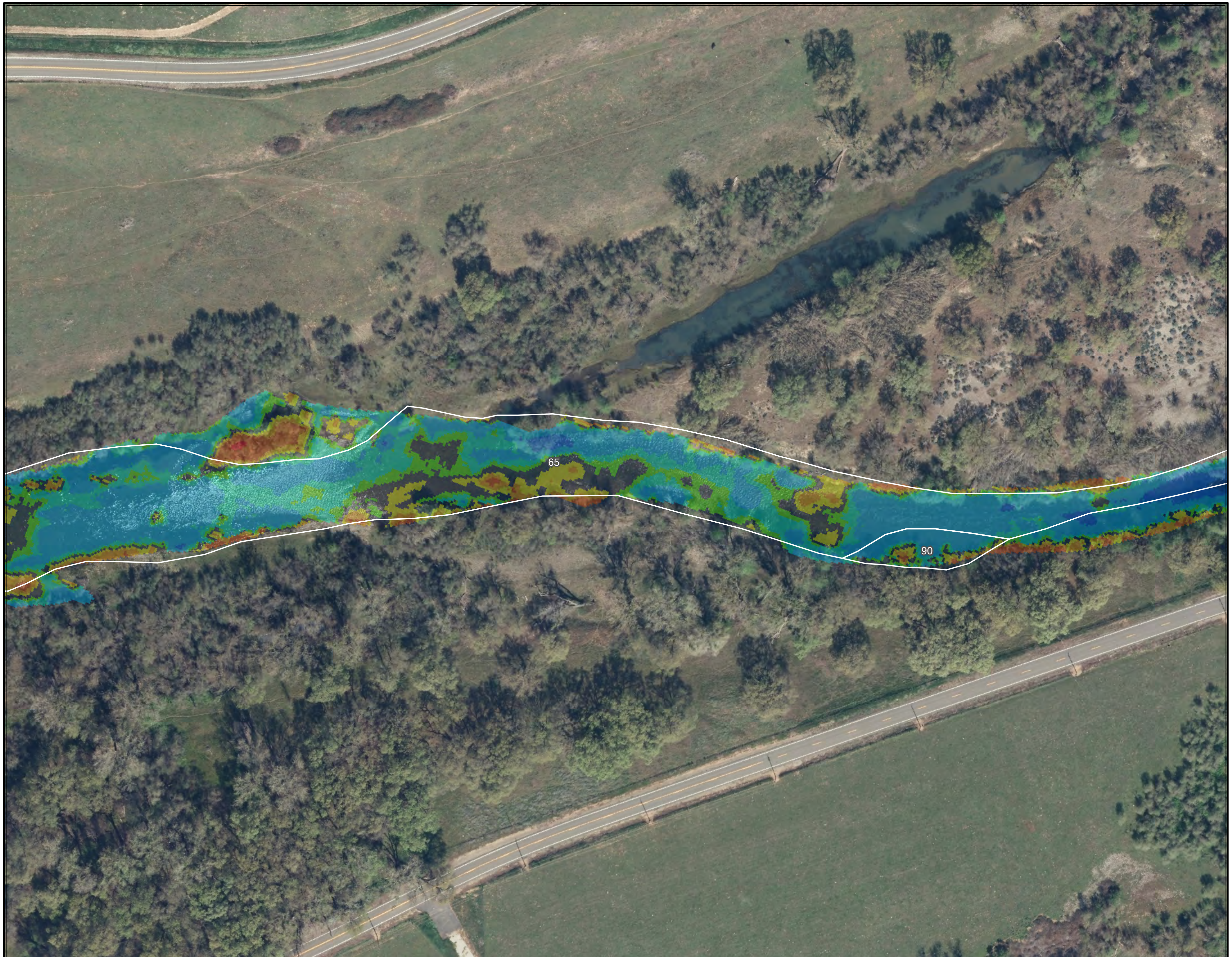

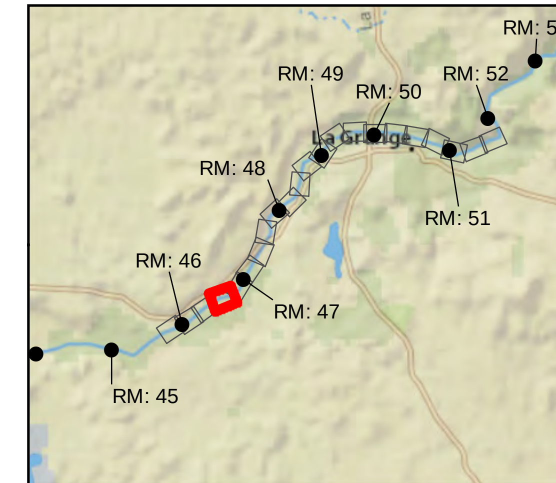

USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

0 50 100 200

Feet

N

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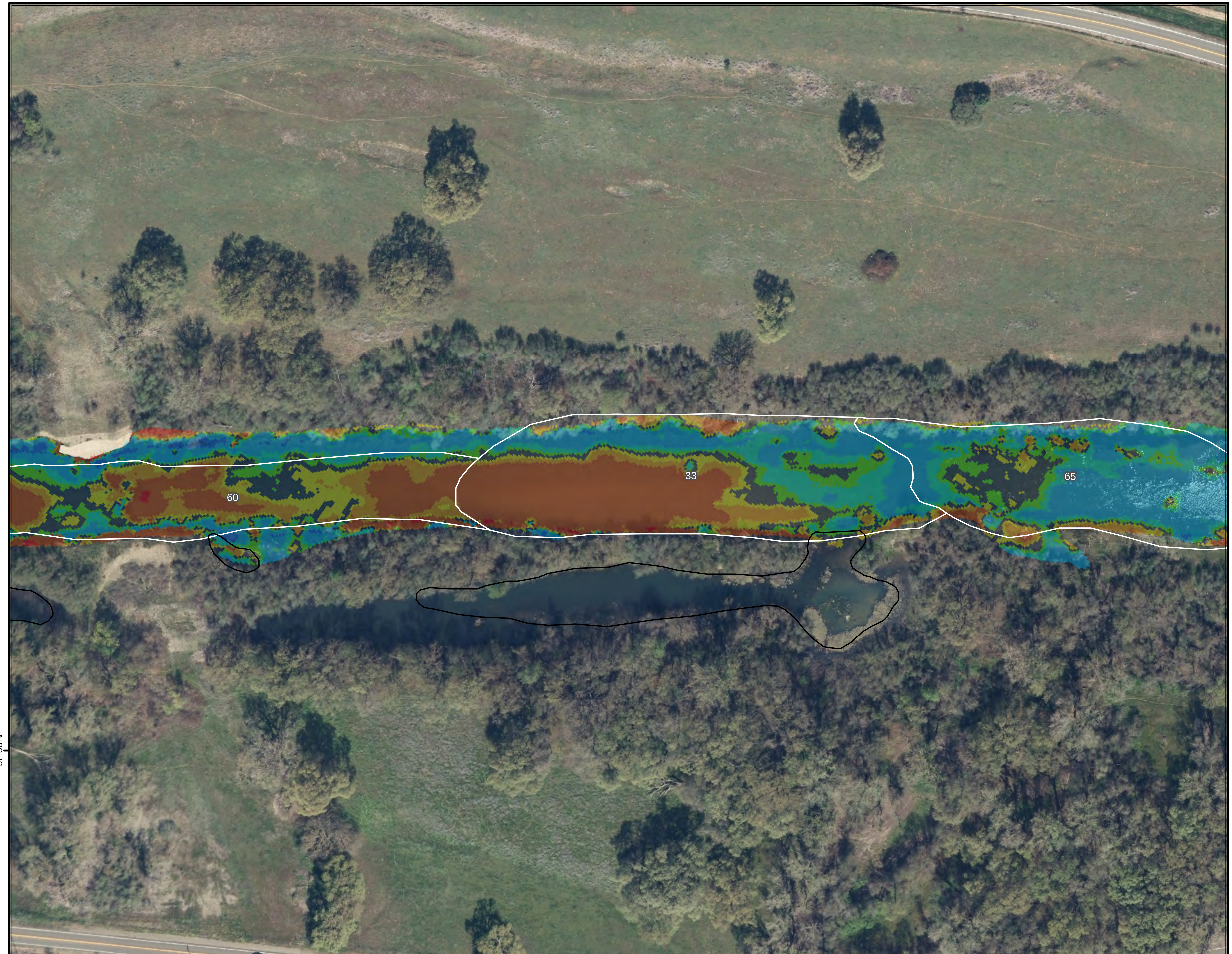
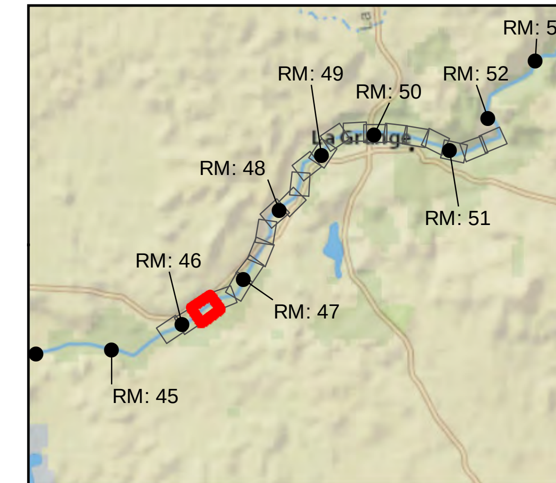
Data is CA SPCS, zone III, ft. Contour interval is 50 ft (NAVD 88).





USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Aggradation:
- > 5
- 5 : 3
- 3 : 1
- 1 : 0.5
- 0.5 : 0.2

0.2 : -0.2

Degradation:
- -0.2 : -0.5
- -0.5 : -1
- -1 : -3
- -3 : -5
- < -5

0 50 100 200

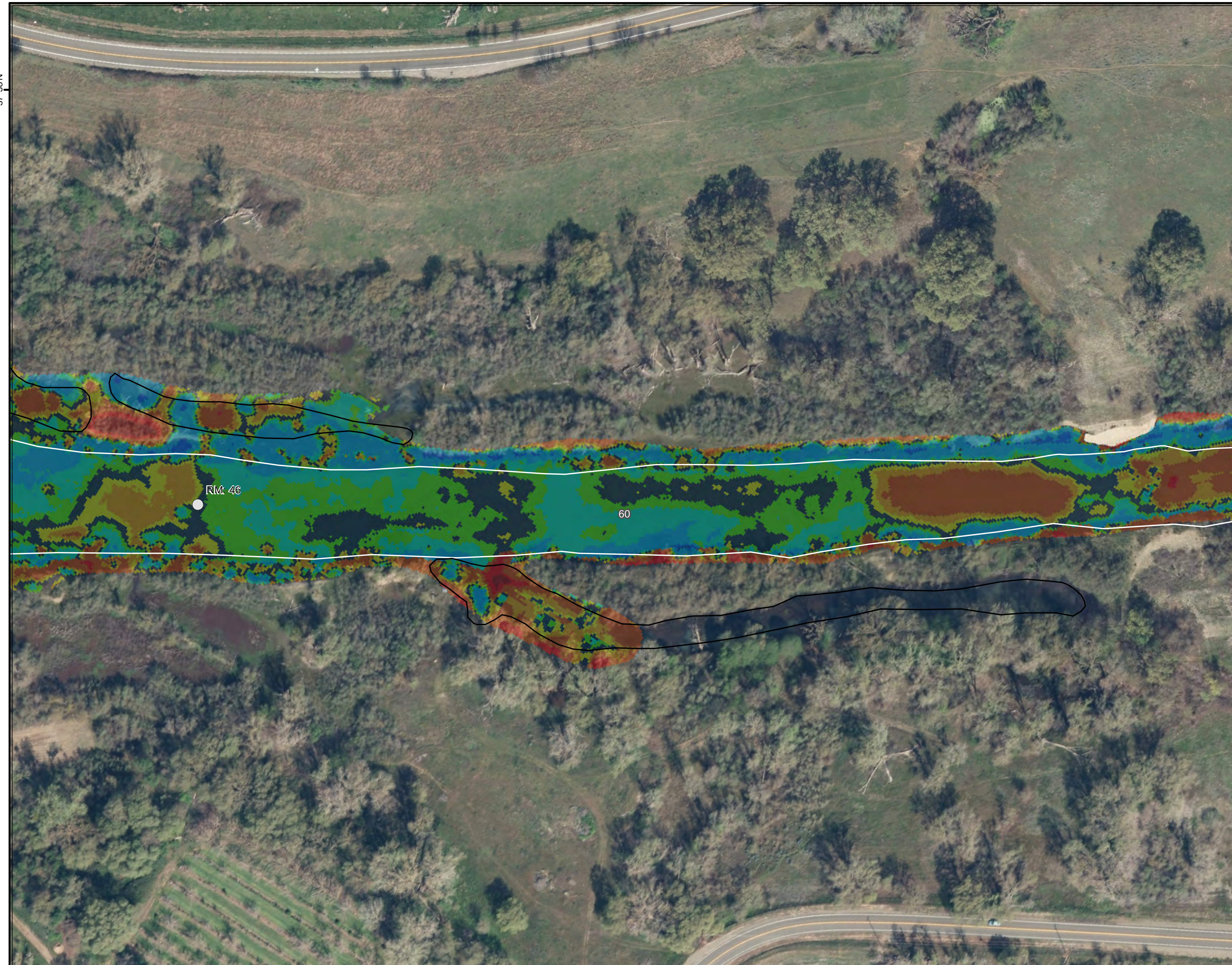
Feet

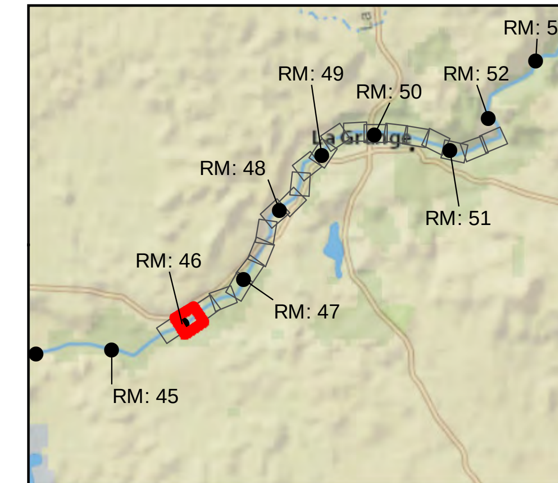
N

Attachment A

Don Pedro Project (FERC No.2299)

Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.
Data Sources: Hydrography - USGS NHD; Roads - ESRI 9.3 Data (Teleatlas); Ownership, PLSS - CA BLM; FERC Boundary, Reservoir Bathy, Recreation & Project Facilities - MID/TID.
Data is CA SPCS, zone III, ft. Contour interval is 50 ft (NAVD 88).





USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

feet	
> 5	Aggradation
5 : 3	Aggradation
3 : 1	Aggradation
1 : 0.5	Aggradation
0.5 : 0.2	Aggradation
0.2 : -0.2	
-0.2 : -0.5	Degradation
-0.5 : -1	Degradation
-1 : -3	Degradation
-3 : -5	Degradation
< -5	Degradation

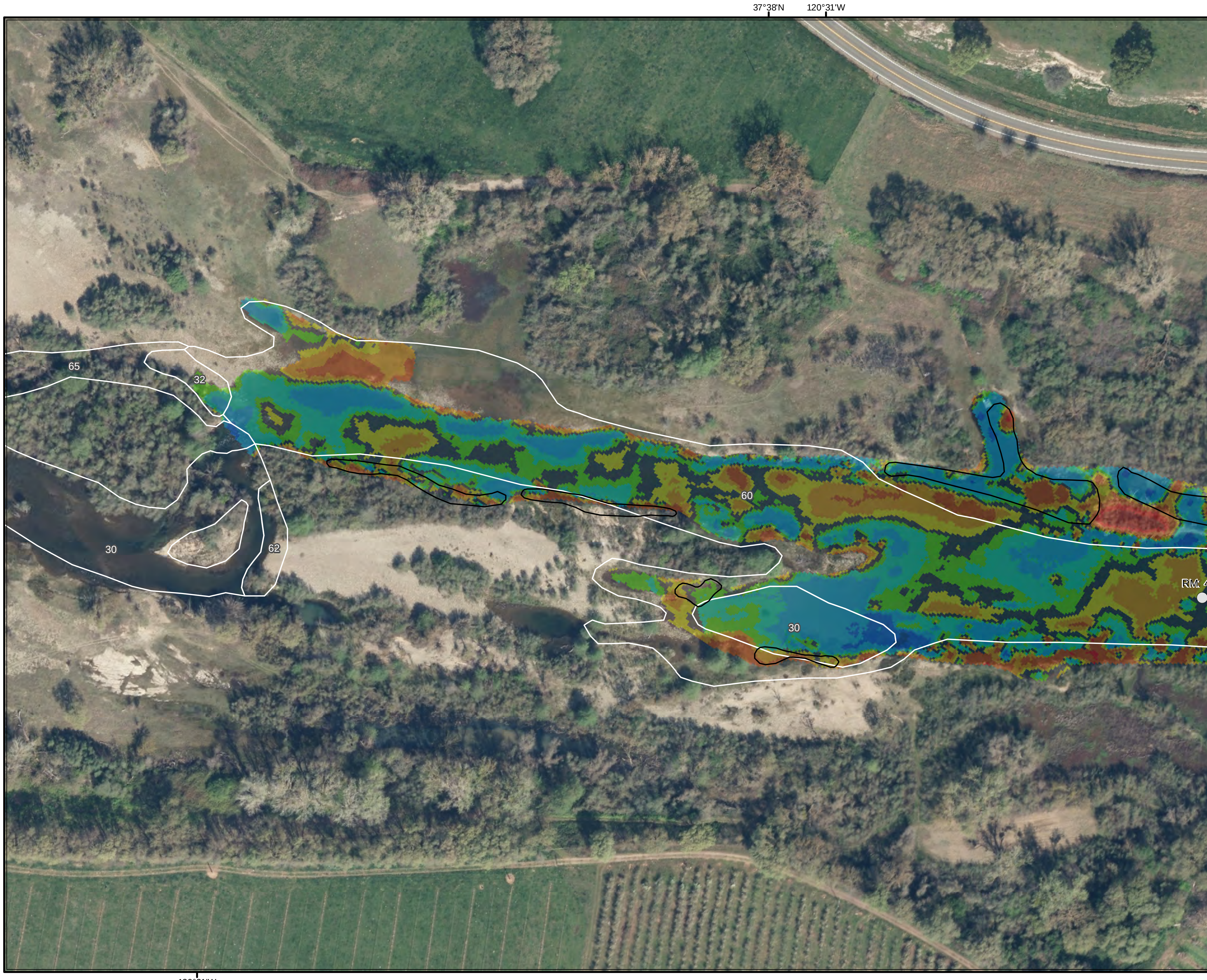
0 50 100 200

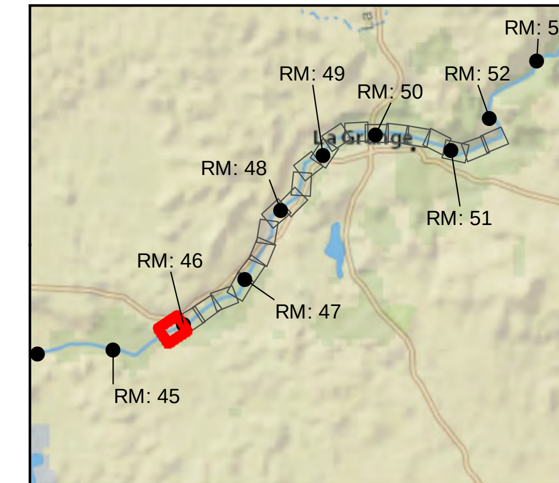
Feet

Attachment A

Don Pedro Project (FERC No.2299)

Map information was compiled from the best available sources.
No warranty is made for its accuracy or completeness.
Data Sources: Hydrography - USGS NHD; Roads - ESRI 9.3 Data (Teleatlas); Ownership, PLSS - CA BLM; FERC Boundary, Reservoir Bathy, Recreation & Project Facilities - MID/TID.
Data is CA SPCS, zone III, ft. Contour interval is 50 ft (NAVD 88).





USGS River Mile

Discrete FBM Deposit

Spawning Gravel Deposit w/ D_{50} label (mm)

CDFG Phase II Augmentation Sites w/ location ID label

2005 - 2012 Surface Difference

feet

Aggradation
- > 5
- 5 : 3
- 3 : 1
- 1 : 0.5
- 0.5 : 0.2

- 0.2 : -0.2

Degradation
- -0.2 : -0.5
- -0.5 : -1
- -1 : -3
- -3 : -5
- < -5

0 50 100 200

Feet

Attachment A

Don Pedro Project (FERC No.2299)

Map information was compiled from the best available sources. No warranty is made for its accuracy or completeness.
Data Sources: Hydrography - USGS NHD; Roads - ESRI 9.3 Data (Teleatlas); Ownership, PLSS - CA BLM; FERC Boundary, Reservoir Bathy, Recreation & Project Facilities - MID/TID.
Data is CA SPCS, zone III, ft. Contour interval is 50 ft (NAVD 88).

STUDY REPORT W&AR-04
SPAWNING GRAVEL IN THE LOWER TUOLUMNE RIVER

ATTACHMENT B

CURRENT AND HISTORICAL RIFFLE MESOHABITAT AREAS AND SPAWNING GRAVEL AREAS WITHIN RIFFLES

Table B-1. Historical and current riffle mesohabitats and spawning gravel areas within riffles.

Reach	Riffle ID before 2012	2012 Riffle ID	RM (2012 Centroid)	Estimated Historical Spawning Area (ft^2)	1988 Riffle Area (ft^2)	2001		2012		Change in Riffle Area					
						Riffle Area (ft^2)	Spawning Habitat Area (ft^2)	Riffle Area (ft^2)	Spawning Gravel Area in Riffles (ft^2)	1988 to 2001		1988 to 2012		2001 to 2012	
										ft^2	%	ft^2	%	ft^2	%
La Grange Dam to Basso Bridge	RA1	--	--	--	7,603	not surveyed	not surveyed	not surveyed	not surveyed	not surveyed	--	not surveyed	--	not surveyed	--
	RA2	--	--	--	2,965	3,989	not surveyed	not surveyed	not surveyed	1,024	--	not surveyed	--	not surveyed	--
	RA3/4	4 FW Riffle	51.6	--	22,475	11,762	3,702	78,200	38,804	-10,713	--	55,725	--	66,438	--
	RA7A/RA7B	11 FW Riffle	50.7	--	7,596	33,099	16,740	77,046	74,090	25,503	--	69,450	--	43,947	--
	R1A	14 BC Riffle	50.4	--	92,257	23,559	31,989	122,751	117,859	-68,698	--	30,494	--	99,192	--
	R1B	18 BC Riffle	50.1	--	27,269	19,735	13,150	32,468	30,596	-7,534	--	5,199	--	12,733	--
	R2	21 FW Riffle	49.7	--	86,867	103,766	76,072	77,528	63,348	16,899	--	-9,339	--	-26,238	--
	R3A	--	--	--	38,268	15,622	7,076	0	0	-22,646	--	-38,268	--	-15,622	--
	R3B	25 BC Riffle	49.1	--	44,135	77,606	70,137	62,923	60,699	33,471	--	18,788	--	-14,683	--
	R3C	27 FW Riffle	49.0	--	0	0	0	18,171	15,468	0	--	18,171	--	18,171	--
	R4A	30 FW Riffle	48.8	--	125,523	94,827	57,821	120,956	114,769	-30,696	--	-4,567	--	26,129	--
	R4B	33 FW Riffle	48.3	--	178,077	171,421	108,810	165,171	155,935	-6,656	--	-12,906	--	-6,250	--
	R5A	36 BC Riffle	48.0	--	64,395	31,773	18,140	24,545	24,008	-32,622	--	-39,850	--	-7,228	--
	R5B	38 BC Riffle	47.8	--	9,167	19,407	6,936	13,651	13,651	10,240	--	4,484	--	-5,756	--
	RA5A	--	--	--	16,277	0	0	0	0	-16,277	--	-16,277	--	0	--
	RA5B	--	--	--	8,336	0	0	0	0	-8,336	--	-8,336	--	0	--
	RA6	--	--	--	10,147	0	0	0	0	-10,147	--	-10,147	--	0	--
Subtotal	**--**	**--**	**--**	**660,000**	**741,357**	**606,566**	**410,573**	**793,411**	**709,226**	**-134,791**	**-18**	**52,054**	**7**	**186,845**	**31**
Basso Bridge to Turlock Lake State Recreation Area	R6	--	--	--	26,050	0	0	0	0	-26,050	--	-26,050	--	0	--
	R7	41 BC Riffle	46.9	--	67,747	76,643	34,489	71,449	68,536	8,896	--	3,702	--	-5,194	--
	R8	43 FW Riffle	46.7	--	22,023	8,536	5,449	31,425	30,414	-13,487	--	9,402	--	22,889	--
	R9	46 FW Riffle	46.5	--	34,862	0	0	35,455	26,942	-34,862	--	593	--	35,455	--
	R10	--	--	--	7,458	0	0	0	0	-7,458	--	-7,458	--	0	--
	R11	--	--	--	23,206	0	0	0	0	-23,206	--	-23,206	--	0	--
	R12	--	--	--	5,959	52,321	12,627	0	0	46,362	--	-5,959	--	-52,321	--
	R13A	54 BC Riffle	45.7	--	10,551	10,116	779	64,960	55,788	-435	--	54,409	--	54,844	--
	R13B	57 BC Riffle	45.5	--	10,151	6,494	3,103	103,128	96,122	-3,657	--	92,977	--	96,634	--
	R13C	61 BC Riffle	45.4	--	12,283	6,335	1,357	49,521	38,773	-5,948	--	37,238	--	43,186	--
	R14	70 BC Riffle	44.9	--	9,478	7,847	1,064	28,938	20,526	-1,631	--	19,460	--	21,091	--
	R15/16	72 BC Riffle	44.7	--	26,598	24,167	4,456	75,252	47,953	-2,431	--	48,654	--	51,085	--
	R16A	--	--	--	0	0	0	14,114	10,295	0	--	14,114	--	14,114	--
	R17A/17B	81 BC Riffle	44.4	--	15,703	14,099	2,502	32,021	23,334	-1,604	--	16,318	--	17,922	--
	R17C	--	--	--	18,315	0	0	0	0	-18,315	--	-18,315	--	0	--
	R17D	--	--	--	2,072	0	0	0	0	-2,072	--	-2,072	--	0	--
	R18	--	--	--	17,421	12,129	2,181	0	0	-5,292	--	-17,421	--	-12,129	--
	R19	--	--	--	9,736	0	0	0	0	-9,736	--	-9,736	--	0	--
	R20	89 BC Riffle	43.2	--	19,203	26,321	1,766	30,933	22,310	7,118	--	11,730	--	4,612	--
	R21	91 BC Riffle	42.9	--	5,974	18,900	2,469	19,602	16,373	12,926	--	13,628	--	702	--
	R22	94 BC Riffle	42.8	--	4,037	17,978	2,954	12,010	11,183	13,941	--	7,973	--	-5,968	--
	R23A	96 BC Riffle	42.6	--	6,933	12,110	1,016	10,363	7,851	5,177	--	3,430	--	-1,747	--
	R23B	--	--	--	9,091	4,693	612	0	0	-4,398	--	-9,091	--	-4,693	--
	R23C	102 BC Riffle	42.3	--	14,088	18,062	3,454	71,015	57,206	3,974	--	56,927	--	52,953	--
	R23D	107 BC Riffle	41.9	--	22,698	36,229	7,627	54,441	37,954	13,531	--	31,743	--	18,212	--
	R24	109 BC Riffle	41.7	--	18,175	20,935	11,348	40,175	29,689	2,760	--	22,000	--	19,240	--
Subtotal	**--**	**--**	**--**	**936,000**	**419,812**	**373,915**	**99,253**	**744,803**	**601,250**	**-45,897**	**-11**	**324,991**	**77**	**370,888**	**99**

Reach	Riffle ID before 2012	2012 Riffle ID	RM (2012 Centroid)	Estimated Historical Spawning Area (ft^2)	1988 Riffle Area (ft^2)	2001		2012		Change in Riffle Area					
						Riffle Area (ft^2)	Spawning Habitat Area (ft^2)	Riffle Area (ft^2)	Spawning Gravel Area in Riffles (ft^2)	1988 to 2001		1988 to 2012		2001 to 2012	
										ft^2	%	ft^2	%	ft^2	%
Turlock Lake State Recreation Area to Santa Fe Aggregates Bridge	R25	--	--	--	18,785	19,104	0	0	0	319	--	-18,785	--	-19,104	--
	R26	116 BC Riffle	40.9	--	21,214	26,726	7,246	25,918	19,520	5,512	--	4,704	--	-808	--
	R27	--	--	--	4,003	6,747	518	0	0	2,744	--	-4,003	--	-6,747	--
	R28A	120 BC Riffle	40.3	--	29,887	15,126	0	131,352	126,474	-14,761	--	101,465	--	116,226	--
	R28B	--	--	--	0			0	0	--	--	0	--	--	--
	R28C	124 BC Riffle	39.5	--	10,381	11,795	9,060	30,866	28,817	1,414	--	20,485	--	19,071	--
	R29	285 BC Riffle	39.1	--	43,994	9,421	5,262	6,806	6,786	-34,573	--	-37,188	--	-2,615	--
	R29A	126 BC Riffle	38.9	--	0			36,449	36,186	--	--	36,449	--	--	--
	R30A	--	--	--	11,268	8,772	4,158	0	0	-2,496	--	-11,268	--	-8,772	--
	R30B	128 FW Riffle	38.5	--	13,496	8,311	2,757	13,813	13,475	-5,185	--	317	--	5,502	--
	R30C	132 FW Riffle	38.2	--	21,326	0	0	9,215	9,176	-21,326	--	-12,111	--	9,215	--
	R31	135 BC Riffle	38.0	--	25,033	32,902	13,692	60,636	45,119	7,869	--	35,603	--	27,734	--
	R32	--	--	--	3,628	6,605	6,605	0	0	2,977	--	-3,628	--	-6,605	--
	R33	140 BC Riffle	37.7	--	29,472	13,934	25,662	36,258	36,089	-15,538	--	6,786	--	22,324	--
	R34A	144 BC Riffle	37.5	--	16,667	8,704	10,823	42,122	42,122	-7,963	--	25,455	--	33,418	--
	R34B	--	--	--	8,005	0	0	0	0	-8,005	--	-8,005	--	0	--
	R34C	146 BC Riffle	37.3	--	0	--	--	24,624	24,624	--	--	24,624	--	--	--
	R35A/B	148 BC Riffle	37.1	--	66,792	94,316	38,686	63,383	62,688	27,524	--	-3,409	--	-30,933	--
	R36A	156 BC Riffle	36.7	--	34,954	44,690	1,910	37,938	36,182	9,736	--	2,984	--	-6,752	--
	R36B	158 BC Riffle	36.5	--	53,974	17,312	--	13,961	13,904	-36,662	--	-40,013	--	-3,351	--
Subtotal	--	--	--	**801,000**	**412,879**	**324,465**	**126,379**	**533,342**	**501,162**	**-88,414**	**-21**	**120,463**	**29**	**208,877**	**64**

Reach	Riffle ID before 2012	2012 Riffle ID	RM (2012 Centroid)	Estimated Historical Spawning Area (ft^2)	1988 Riffle Area (ft^2)	2001		2012		Change in Riffle Area					
						Riffle Area (ft^2)	Spawning Habitat Area (ft^2)	Riffle Area (ft^2)	Spawning Gravel Area in Riffles (ft^2)	1988 to 2001		1988 to 2012		2001 to 2012	
										ft^2	%	ft^2	%	ft^2	%
	R36C	160 BC Riffle	36.2	--	0	--	--	14,322	14,309	--	--	--	--	--	--
	R37	162 BC Riffle	36.2	--	25,207	--	--	30,224	27,731	--	--	5,017	--	--	--
	R38	165 FW Riffle	35.6	--	26,316	--	--	47,890	37,627	--	--	21,574	--	--	--
	R39	--	--	--	12,972	--	--	0	0	--	--	-12,972	--	--	--
	R40	--	--	--	22,801	--	--	0	0	--	--	-22,801	--	--	--
	R41A	167 BC Riffle	35.2	--	62,483	--	--	49,475	44,029	--	--	-13,008	--	--	--
	R41B	172 BC Riffle	35.0	--	3,739	--	--	13,278	13,278	--	--	9,539	--	--	--
	R42	--	--	--	55,941	--	--	0	0	--	--	-55,941	--	--	--
	R43	175 BC Riffle	34.7	--	7,758	--	--	27,174	21,135	--	--	19,416	--	--	--
	R43A	182 BC Riffle	34.2	--	0	--	--	32,441	32,429	--	--	32,441	--	--	--
	R44/R45	185 BC Riffle	34.1	--	45,643	--	--	55,649	54,462	--	--	10,006	--	--	--
	R46	187 BC Riffle	33.9	--	23,414	--	--	77,766	67,286	--	--	54,352	--	--	--
	R47	--	--	--	20,095	--	--	0	0	--	--	-20,095	--	--	--
	R48A	190 BC Riffle	33.7	--	6,968	--	--	34,998	31,455	--	--	28,030	--	--	--
	R48B	194 BC Riffle	33.3	--	22,020	--	--	55,113	45,803	--	--	33,093	--	--	--
	R49	--	--	--	16,672	--	--	0	0	--	--	-16,672	--	--	--
	R50	--	--	--	20,118	--	--	0	0	--	--	-20,118	--	--	--
	R51	197 FW Riffle	32.5	--	31,594	--	--	47,581	25,154	--	--	15,987	--	--	--
	R52/52B	200 BC Riffle	32.1	--	53,659	--	--	60,008	51,066	--	--	6,349	--	--	--
	R53	206 BC Riffle	31.9	--	13,488	--	--	40,227	28,305	--	--	26,739	--	--	--
	R54	--	--	--	14,611	--	--	0	0	--	--	-14,611	--	--	--
Santa Fe Aggregates Bridge to RM 23.6	R55/R56	209 BC Riffle	31.7	--	108,161	--	--	46,404	42,196	--	--	-61,757	--	--	--
	R57	211 BC Riffle	31.6	--	30,427	--	--	19,365	11,667	--	--	-11,062	--	--	--
	R58	--	--	--	22,193	--	--	0	0	--	--	-22,193	--	--	--
	R59	214 FW Riffle	31.2	--	5,201	--	--	25,154	22,235	--	--	19,953	--	--	--
	R60/60A	216 BC Riffle	31.0	--	46,590	--	--	157,216	144,060	--	--	110,626	--	--	--
	R61	221 BC Riffle	30.7	--	37,389	--	--	43,517	29,697	--	--	6,128	--	--	--
	R62	227 FW Riffle	30.1	--	41,808	--	--	9,107	8,050	--	--	-32,701	--	--	--
	R63	229 FW Riffle	--	--	41,179	--	--	5,379	5,379	--	--	-35,800	--	--	--
	R64	235 BC Riffle	29.8	--	62,384	--	--	28,144	26,243	--	--	-34,240	--	--	--
	R65	--	--	--	95,072	--	--	0	0	--	--	-95,072	--	--	--
	R66	237 BC Riffle	29.6	--	40,814	--	--	48,795	19,403	--	--	7,981	--	--	--
	R67	240 FW Riffle	27.8	--	0	--	--	25,661	6,845	--	--	25,661	--	--	--
	R68	242 FW Riffle	27.7	--	90,824	--	--	31,382	12,750	--	--	-59,442	--	--	--
	R69	244 FW Riffle	25.9	--	51,198	--	--	46,390	44,415	--	--	-4,808	--	--	--
	R70	246 FW Riffle	25.8	--	12,862	--	--	19,839	11,081	--	--	6,977	--	--	--
	R71	248 FW Riffle	25.6	--	22,457	--	--	27,609	16,353	--	--	5,152	--	--	--
	R72	250 FW Riffle	25.5	--	60,905	--	--	111,822	104,566	--	--	50,917	--	--	--
	R73	253 FW Riffle	25.1	--	18,503	--	--	37,111	33,484	--	--	18,608	--	--	--
	R74	255 FW Riffle	24.7	--	14,567	--	--	37,694	37,399	--	--	23,127	--	--	--
	R75	257 FW Riffle	24.5	--	9,265	--	--	40,270	26,956	--	--	31,005	--	--	--
	R76	259 BC Riffle	24.2	--	13,053	--	--	65,619	28,935	--	--	52,566	--	--	--
	R77	261 FW Riffle	23.7	--	16,493	--	--	22,953	17,155	--	--	6,460	--	--	--
	R78	263 FW Riffle	23.5	--	16,307	--	--	20,032	12,972	--	--	3,725	--	--	--
Subtotal	**--**	**--**	**--**	**--**	**1,343,152**	**--**	**--**	**1,455,610**	**1,155,909**	**--**	**--**	**112,458**	**8**	**--**	**--**
Total La Grange Dam to RM 34.2		**--**	**--**	**2,397,000**	**1,574,048**	**1,304,946**	**636,205**	**2,071,556**	**1,811,638**	**-269,102**	**-17**	**497,508**	**32**	**766,610**	**59**
Total La Grange Dam to RM 23.6		**--**	**--**	**--**	**2,917,200**	**--**	**--**	**3,527,166**	**2,967,547**	**--**	**--**	**609,966**	**21**	**--**	**--**

STUDY REPORT W&AR-04
SPAWNING GRAVEL IN THE LOWER TUOLUMNE RIVER

ATTACHMENT C

2012 FINE BED MATERIAL FIELD MAPPING DATA

Table C-1. 2012 Fine Bed Material Field Mapping Data.

RM	FBM No.	2012 Mesohabitat Unit	Geomorphic Unit	Texture Dominant	Texture Subdominant	Average Depth (ft)	Area within 600 cfs (ft^2)	Area within 320 cfs (ft^2)
51.8	2	Pool - 102	pool margin	SA	--	1.0	976	693
51.7	1	Pool - 102	pool margin	SA	--	1.0	1,419	1,398
51.7	3	Pool - 104	pool margin	SA	--	1.9	4,068	2,583
51.6	4	Pool - 110	pool margin	SA	--	0.7	1,380	1,380
51.5	5	Pool - 115	pool margin	SA	--	0.3	1,583	1,583
51.5	6	Pool - 115	pool margin	SA	--	1.3	1,373	1,373
51.4	7	Lateral Bar - 114	channel margin	SI	--	0.3	5,909	2,940
51.3	10	Pool - 115	channel margin	SA	--	0.7	2,641	2,621
51.3	8	Pool - 115	pool bottom	SA	GR	1.3	2,718	2,718
51.3	9	Pool - 115	pool margin	SA	--	1.1	3,939	3,939
51.2	11	Pool - 115	channel margin	SA	SI	0.5	5,547	5,074
51.2	12	Pool - 115	channel margin	SA	SI	1.5	5,562	5,562
51.1	13	Pool - 115	channel margin	SA	SI	1.0	2,747	2,747
51.0	15	Pool - 115	channel margin	SA	--	1.5	6,977	6,977
51.0	14	Pool - 115	pool margin	SA	--	0.8	13,253	13,252
50.8	16	Submerged lateral bar - 125	channel margin	SA	SI	0.8	15,372	1,761
50.8	17	Pool - 115	channel margin	SA	--	0.5	4,974	4,974
50.6	18	Pool - 123	channel margin	SA	--	1.1	5,311	5,311
50.5	19	Pool - 123	channel margin	SA	--	0.5	4,014	4,014
50.3	20	Deep Backwater - 130	pool margin	SA	SI	3.3	25,620	23,039
50.0	22	Deep Backwater - 138	alcove/ backwater	SA	SI	1.1	8,266	8,251
50.0	21	Pool - 135	channel margin	SA	--	3.3	39,188	33,294
49.9	23	Pool - 135	channel margin	SA	--	1.3	6,780	6,780
49.3	24	Pool - 142	alcove/ backwater	SA	GR	1.6	3,269	3,259
47.8	25	Pool - 168	alcove/ backwater	SA	SI	0.3	1,646	1,646
47.7	26	Pool - 168	pool margin	SA	GR	0.8	5,292	5,292
47.6	28	Pool - 177	pool bottom	SA	SI	0.5	1,578	1,578
47.6	27	Pool - 177	pool margin	SA	GR	3.3	7,759	7,361
47.5	29	Pool - 177	alcove/ backwater	SA	--	1.3	961	957
47.5	30	Pool - 177	pool margin	SA	--	1.1	9,586	8,394
47.4	31	Pool - 177	channel margin	SA	SI	0.8	4,254	4,254
47.3	32	Pool - 177	channel margin	SA	SI	2.0	4,239	4,132
47.2	33	Pool - 177	channel margin	SA	SI	0.3	2,051	2,024
47.2	34	Pool - 177	channel margin	SA	SI	0.3	13,846	13,430
46.4	35	Deep Backwater - 189	captured gravel pit	SI	--	1.8	41,088	1,149
46.3	36	Pool - 187	alcove/ backwater	SA	SI	1.0	1,765	1,271

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46.1	37	Shallow Backwater - 191	alcove/ backwater	SI	--	0.8	33,551	14,314
46.0	39	Pool - 187	alcove/ backwater	SI	--	0.3	11,457	11,457
46.0	38	Pool - 187	channel margin	SA	SI	0.7	12,307	11,731
45.9	40	Pool - 187	alcove/ backwater	SA	--	0.4	1,352	1,351
45.9	41	Pool - 187	channel margin	SA	SI	0.5	1,256	1,215
45.9	42	Pool - 187	channel margin	SA	--	1.3	3,009	1,280
45.8	43	Pool - 187	channel margin	SA	SI	1.6	3,628	3,079
45.7	44	Island - 240	channel margin	SA	--	0.5	822	766
45.7	45	Riffle - 243	channel margin	SA	SI	1.6	1,249	994
45.5	46	Pool - 254	alcove/ backwater	SA	--	1.3	1,660	1,660
45.5	47	Pool - 235	side channel	SA	--	1.6	3,120	2,821
45.4	48	Deep Backwater - 255	channel margin	SA	--	2.6	16,741	14,219
45.3	51	Pool - 235	alcove/ backwater	SA	--	0.8	973	973
45.3	49	Pool - 235	channel margin	SA	--	1.1	1,488	803
45.3	50	Pool - 235	channel margin	SA	--	1.3	1,975	1,975
45.3	52	Pool - 235	channel margin	SA	--	0.7	5,574	5,483
45.3	53	Pool - 235	channel margin	SA	--	1.3	5,210	5,052
45.2	56	Deep Backwater - 237	alcove/ backwater	SA	--	1.0	383	383
45.2	54	Pool - 235	channel margin	SA	--	1.1	1,396	1,396
45.2	55	Pool - 235	channel margin	SA	--	1.5	33,481	32,030
45.1	57	Pool - 235	alcove/ backwater	SA	--	1.3	792	792
45.1	58	Pool - 235	alcove/ backwater	SA	SI	1.0	1,121	1,121
45.1	59	Pool - 235	channel margin	SA	--	1.1	1,283	1,283
45.1	60	Pool - 235	channel margin	SA	--	3.3	1,218	1,218
45.1	61	Island - 239	channel margin	SA	SI	2.1	32,255	31,821
45.0	64	Pool - 235	alcove/ backwater	SA	SI	0.5	938	834
45.0	62	Pool - 235	channel margin	SA	--	0.8	812	735
45.0	63	Pool - 235	channel margin	SA	SI	0.7	1,214	1,214
45.0	65	Pool - 235	channel margin	SA	SI	0.8	1,993	1,993
44.9	66	Pool - 235	channel margin	SA	--	0.5	936	936
44.8	67	Run - 256	channel margin	SA	--	0.5	1,166	1,166
44.8	68	Run - 256	channel margin	SA	SI	0.8	923	923
44.7	74	Run - 262	alcove/ backwater	SA	SA	0.3	1,330	506
44.7	69	Run - 256	channel margin	SA	SI	0.8	876	876
44.7	70	Pool - 260	channel margin	SA	SI	1.1	4,825	4,825
44.6	71	Pool - 264	channel margin	SA	SI	0.7	589	589

RM	FBM No.	2012 Mesohabitat Unit	Geomorphic Unit	Texture Dominant	Texture Subdominant	Average Depth (ft)	Area within 600 cfs (ft^2)	Area within 320 cfs (ft^2)
44.6	72	Riffle - 265	channel margin	SA	SI	0.8	1,125	1,023
44.6	73	Run - 269	channel margin	SA	SI	0.7	1,522	1,522
44.6	75	Pool - 266	pool margin	SA	--	0.8	1,802	1,631
44.6	76	Pool - 266	pool margin	SA	--	3.3	2,577	2,577
44.5	77	Run - 198	alcove/ backwater	SA	--	1.1	2,275	2,039
44.4	78	Deep Backwater - 203	alcove/ backwater	SA	SA	1.0	3,970	3,970
44.3	79	Pool - 204	alcove/ backwater	SA	SA	0.7	7,411	7,339
44.3	80	Pool - 204	pool bottom	SA	--	1.3	16,726	14,299
44.3	81	Pool - 204	pool margin	SA	--	1.3	28,198	24,051
44.2	82	Run - 206	alcove/ backwater	SA	--	0.3	1,851	1,851
43.7	83	Special Run Pool - 210	pool margin	SA	SI	1.1	1,529	1,452
43.7	84	Special Run Pool - 210	pool margin	SA	SI	2.5	2,604	2,581
43.7	85	Special Run Pool - 210	pool margin	SA	SI	3.3	66,029	61,546
43.6	86	Special Run Pool - 210	pool margin	SI	SA	0.8	33,267	30,714
43.5	91	Deep Backwater - 305	alcove/ backwater	SA	SI	0.8	641	641
43.5	87	Special Run Pool - 210	pool margin	SA	--	0.3	1,828	1,828
43.5	88	Special Run Pool - 210	pool margin	SA	--	1.0	16,851	844
43.4	90	Deep Backwater - 215	alcove/ backwater	SA	SI	0.7	921	0
43.4	92	Deep Backwater - 305	alcove/ backwater	SI	SA	0.8	815	0
43.4	93	Deep Backwater - 305	alcove/ backwater	SI	SA	3.3	7,107	0
43.4	95	Deep Backwater - 214	alcove/ backwater	SA	SI	1.0	5,865	1,228
43.4	97	Deep Backwater - 213	alcove/ backwater	SA	SI	0.5	4,908	4,836
43.4	89	Special Run Pool - 210	pool margin	SA	--	1.0	6,102	6,003
43.4	94	Deep Backwater - 305	side channel	SA	SI	1.6	9,252	9,252

RM	FBM No.	2012 Mesohabitat Unit	Geomorphic Unit	Texture Dominant	Texture Subdominant	Average Depth (ft)	Area within 600 cfs (ft^2)	Area within 320 cfs (ft^2)
43.3	98	Deep Backwater - 213	alcove/ backwater	SA	--	0.3	1,706	1,706
43.3	96	Pool - 212	channel margin	SA	SI	1.0	1,819	1,223
43.3	99	Pool - 212	pool margin	SA	--	1.6	3,477	1,985
43.2	200	Deep Backwater - 227	alcove/ backwater	SA	SI	2.3	19,681	18,912
43.1	201	Riffle - 228	alcove/ backwater	SA	--	0.3	2,303	2,303
43.1	202	Pool - 225	pool margin	SA	--	0.8	1,927	1,677
42.9	203	Pool - 223	alcove/ backwater	SA	SI	1.0	2,523	2,523
42.9	204	Pool - 223	alcove/ backwater	SA	--	1.0	5,712	5,631
42.8	205	Pool - 223	side channel	SI	SA	3.3	2,100	1,974
42.6	206	Riffle - 219	alcove/ backwater	SA	--	0.8	2,247	2,062
42.6	207	Pool - 220	channel margin	SA	--	1.0	3,451	3,451
42.2	208	Pool - 276	channel margin	SA	--	0.3	1,630	1,630
42.0	209	Deep Backwater - 294	alcove/ backwater	SA	--	0.5	2,019	2,019
41.9	101	Pool - 296	channel margin	SI	--	1.0	4,449	4,449
41.7	102	Pool - 314	channel margin	GR	SA	0.3	4,206	4,206
41.4	104	Special Run Pool - 303	channel margin	SA	--	0.7	2,256	0
41.4	103	Special Run Pool - 303	side channel	SI	SA	0.7	1,675	1,675
41.3	105	Special Run Pool - 303	channel margin	SA	SI	2.0	6,646	6,646
41.2	106	Special Run Pool - 303	channel margin	SA	--	1.8	19,702	19,659
41.1	107	Special Run Pool - 303	side channel	SA	--	0.5	1,051	1,051
41.0	108	Special Run Pool - 303	channel margin	SA	--	0.5	3,048	3,048
41.0	109	Special Run Pool - 303	pool margin	SA	--	0.7	29,756	29,074
40.9	110	Riffle - 320	channel margin	SA	--	0.3	937	937
40.9	111	Riffle - 320	channel margin	SA	--	0.8	1,027	1,027
40.6	112	Pool - 322	pool margin	SA	--	0.3	8,687	8,498
40.6	113	Pool - 322	pool margin	SA	--	1.3	12,693	12,693
40.3	114	Mid-channel Bar - 306	side channel	SA	--	0.9	1,890	1,890
40.0	115	Pool - 54	channel margin	SA	--	1.1	10,472	10,275
39.8	116	Pool - 54	channel margin	SA	--	2.1	38,850	33,630
39.4	117	Pool - 54	pool margin	SA	GR	0.3	1,753	1,753
39.1	118	Glide - 48	channel margin	SA	--	0.7	3,573	3,573
38.6	120	Pool - 45	channel margin	SA	--	0.5	14,525	14,525

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38.6	119	Pool - 45	pool bottom	SA	--	3.3	10,732	10,732
38.0	121	Pool - 27	channel margin	SA	--	0.7	8,701	8,698
37.9	122	Deep Backwater - 20	alcove/ backwater	SA	--	2.0	2,918	2,907
37.7	123	Deep Backwater - 3	alcove/ backwater	GR	SA	0.7	10,181	3,132
36.9	124	Pool - 76	alcove/ backwater	GR	SA	2.0	1,565	1,518
36.8	127	Pool - 57	channel margin	SA	--	1.0	578	391
36.8	126	Lateral Bar - 75	side channel	SA	--	0.8	2,632	2,632
36.7	125	Pool - 57	captured gravel pit	SA	SI	1.3	3,135	2,469
36.7	128	Riffle - 64	channel margin	SA	--	1.6	3,971	3,821
36.7	129	Pool - 63	channel margin	SA	--	3.3	44,185	42,964
36.5	130	Pool - 60	captured gravel pit	SA	--	3.3	50,742	39,408
36.4	131	Pool - 58	channel margin	GR	SA	0.5	3,747	3,314