UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Turlock Irrigation District	)	
	)	
and	)	Project No. 2299
	)	
Modesto Irrigation District	)	

2004 LOWER TUOLUMNE RIVER ANNUAL REPORT

Report 2004-13

Tuolumne River Floodway Restoration: Project Design Approach and Rationale for Gravel Mining Reach and Special Run Pools 9&10

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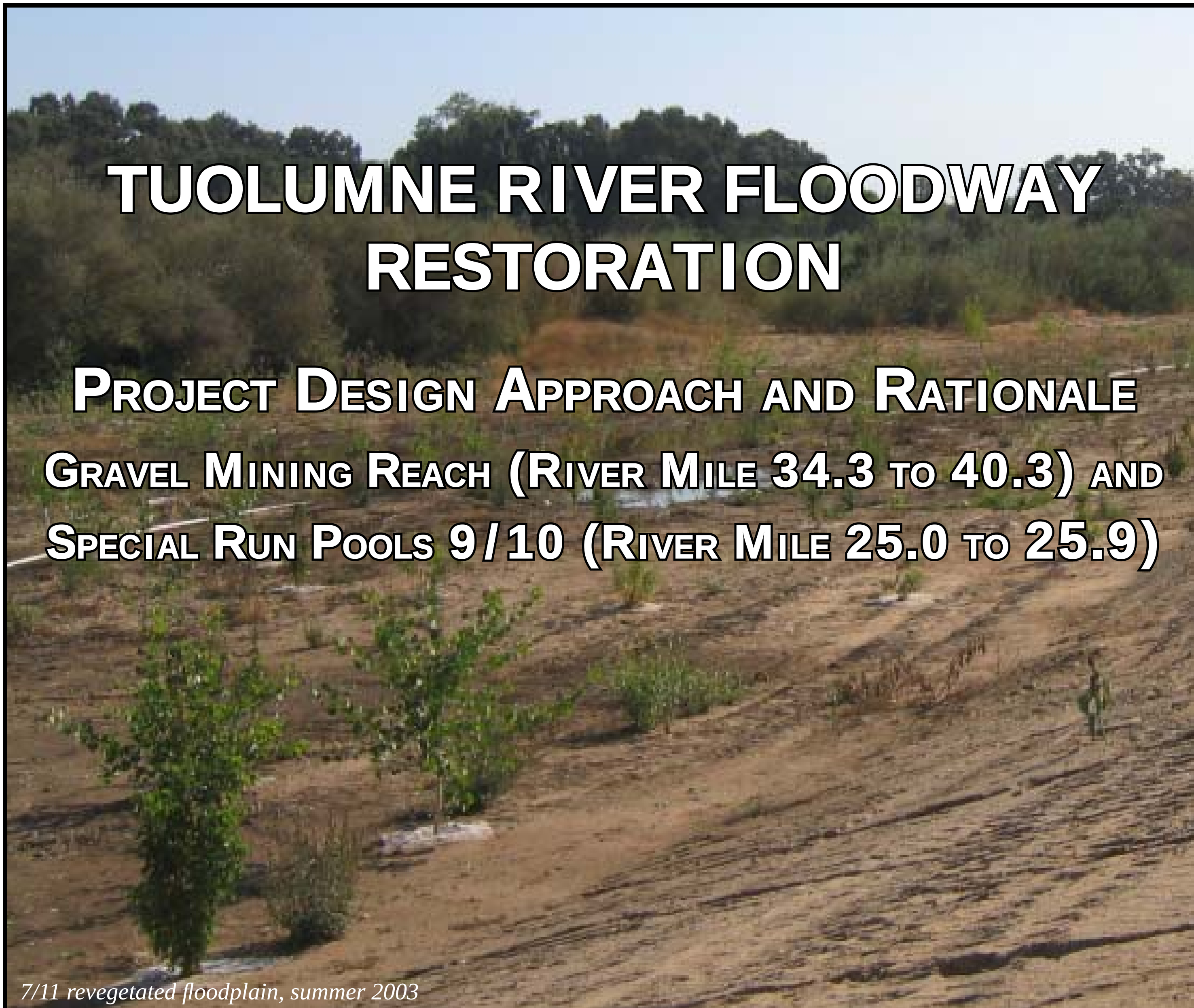
March 2005

TUOLUMNE RIVER FLOODWAY RESTORATION

PROJECT DESIGN APPROACH AND RATIONALE

GRAVEL MINING REACH (RIVER MILE 34.3 TO 40.3) AND SPECIAL RUN POOLS 9/10 (RIVER MILE 25.0 TO 25.9)



7/11 revegetated floodplain, summer 2003

SRP 9 under construction, summer 2001

FEBRUARY 26, 2004

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--PROJECT DESIGN APPROACH AND RATIONALE--

FOR

GRAVEL MINING REACH (RIVER MILE 34.3 TO 40.3)

AND

SPECIAL RUN POOLS 9/10 (RIVER MILE 25.0 TO 25.9)

Prepared for

Tuolumne River Technical Advisory Committee

Funded by

The Anadromous Fish Restoration Program

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ACRONYMS

ACOE	U.S. Army Corps of Engineers
AFRP	Anadromous Fisheries Restoration Program
CALFED	California-Federal Bay-Delta Ecosystem Restoration Program
CCSF	City and County of San Francisco
CDFG	California Department of Fish and Game
CDMG	California Department of Mines and Geology
DWR	California Department of Water Resources
FERC	Federal Energy Regulatory Commission
FSA	FERC Settlement Agreement
MID	Modesto Irrigation District
NDPP	New Don Pedro Project
PHABSIM	Physical Habitat Simulation Model used as part of The Instream Flow Incremental Methology
RM	River Mile, measured upstream from the confluence of the San Joaquin River
SRP	Special Run Pool, which are large instream gravel mining pits that have not been filled after mining.
TID	Turlock Irrigation District
TRTAC	Tuolumne River Technical Advisory Committee of the FERC Settlement Agreement
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WY	Water Year, beginning on October 1 and ending on September 30 of the following calendar year.

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GLOSSARY

TERM	DEFINITION
Accretion	Accumulation of groundwater seeping into a stream or river that increases the surface discharge.
Aggradation	Raising of the channel bed elevation on a reach-wide scale, due to sediment deposition and accumulation.
Aggregate	Commercially mined river-run rock (sand and gravel) extracted and used for road-base, concrete, river restoration, etc.
Alluvium/Alluvial	Sediment transported and deposited by running water. An alluvial river has bed, banks, and floodplain composed of alluvium. An alluvial deposit is composed of unconsolidated or partially consolidated river-laid material in a stream valley.
Alternate bar	Fundamental geomorphic unit of alluvial rivers, composed of an aggradational lobe or point bar, and a scour hole or pool. A submerged transverse bar connects adjacent point bars to form a riffle. An alternate bar sequence, composed of two alternate bar units, is a single meander wavelength, usually 9-11 bankfull channel widths long.
Anadromous	Typical life cycle of salmon, in which fish spawn in freshwater streams and migrate early in their life cycle to the ocean where they grow and mature. Anadromous fish return to freshwater as adults to spawn in the stream or river of their origin, then typically die.
Ascending limb	Component of a winter or spring snowmelt hydrograph in which the discharge rapidly ramps up from a baseflow level to the peak flow magnitude.
Avulsion	Large-scale channel abandonment and planform readjustment resulting from large floods.
Bankfull channel	Channel of an alluvial river that contains flow just prior to overflow onto the floodplain.
Bankfull discharge	Flood discharge that exceeds the capacity of the bankfull channel and begins to spill onto the floodplain. Bankfull discharge tends to occur on a 1.5 to 2 year flood recurrence on alluvial streams.
Bar face	Portion of point bar that is downward - sloped from the floodplain towards the low water edge.
Bedload	Coarse component of sediment transported by a stream. During transport, particles are in constant or frequent contact with the stream bottom. Bedload makes up most of the channel bed and banks of alluvial rivers, but typically represents only 5-15 percent of the total sediment yield (excluding dissolved component).

Boundary shear stress	Force exerted on the channel bed by flowing water. When boundary shear stress (force) exceeds the forces of a particle resisting motion (e.g., particle size and density), the particle may become mobilized and transported downstream.
Braided channel	Channel form having multiple low-flow threads.
Capillary fringe	Zone in which water is drawn into soil pores above the water table by surface tension (capillarity).
Channelization	Straightening of a river channel or containment between levees.
Channel morphology	The shape, size, and particle size of a channel created by the interaction of fluvial, biological, and geomorphic processes.
Channel slope	Longitudinal slope or gradient of the channel, measured, for example, by the water surface elevation or from the crest of successive riffles.
Competence	A measure of overall stream power, determined by the largest grain size the river can transport, for a given flow condition.
Constriction	Significant narrowing of the channel width, forcing flow between banks.
Conveyance	Ability of a channel to pass water downstream.
Critical Habitat	(1) Specific areas within the geographic area occupied by a species at the time it is listed in accordance with the Federal Endangered Species Act (ESA); (2) Specific areas outside the geographical area occupied by a species at the time it is listed under ESA if there is a determination that such areas are essential for conservation of the species.
Critical rooting depth	Minimum root depth that is capable of anchoring a plant firmly enough to withstand channelbed scour.
D_{84}	Particle diameter of which 84% of the bed is finer. Also considered the particle size that forms the structural matrix of gravel bars.
D_{50}	Particle diameter of which 50% of the bed is finer
Descending Limb	Component of a winter or spring snowmelt hydrograph in which the discharge rapidly ramps down (descends) from a peak flow magnitude to a lower flow.
Degradation	Downcutting of the channelbed elevation on a reach-wide scale, caused by an imbalance in sediment supply and transport processes.
Deposition	Process in which a sediment particle in transport comes to rest on the stream bottom, point bar, floodplain, etc., when the competence and sediment transport capacity of a stream are exceeded by the particle's resisting forces.
Dike	A non-engineered structure designed and constructed to confine floodwaters to a specified river corridor, thus protecting adjacent lands from flood inundation.

Drainage basin	Area of land that drains water, sediment, and dissolved materials to a common outlet along the stream channel. Synonymous with "watershed" and "catchment."
Encroachment	Movement of human activities, such as agricultural, urban, and infrastructure, into the river corridor that tends to confine or constrict the rivers ability to flood or migrate without negative consequences to these human activities.
Entrainment	The initiation of motion of sedimentary particles, leading to sediment transport and deposition.
Entrenchment	Ratio of flood-prone channel width to the bankfull channel width.
Exceedance probability (P)	Statistical estimate of the likelihood or probability that a certain discharge will be equaled or exceeded in any given year.
Flood Frequency Curve	The statistical distribution of the annual peak flood discharge for a period of record for a gauging station, typically plotted as discharge verses exceedance probability on a log-probability scale.
Floodplain	Geomorphic surfaces bordering a river channel constructed by the deposition of alluvial material, and inundated by discharges equaling or exceeding bankfull discharge.
Floodway	River channel and adjoining floodplains and terraces that together provide the necessary lateral space (valley width) to convey floods of a range of magnitudes.
Fluvial	Processes involving the physical properties of flowing water.
Flushing flows	Conceptual approach where high-flow dam releases are intended to "flush" fine sediments stored in the bed of rivers and transport them downstream, thus cleaning the riverbed of fine sediments.
GIS	Geographical Information System. A specialized form of computerized, geographically-referenced data bases that provide for manipulation and summation of geographic data. A GIS may also be defined as a system of hardware, software, data, and personnel for collecting, storing, analyzing, and disseminating information about geographical areas.
Groundwater	The saturated subsurface or *phreatic* zone of water, constituting 21% of the world's fresh water and 97% of all the unfrozen fresh water on earth.
Headward erosion	Process of channelbed erosion or migration upstream from an abrupt drop in the longitudinal profile of a stream.
Hydraulic geometry	The relationship between a given discharge and the physical dimensions of channel, including width, depth, velocity, and slope.
Hydraulic Radius (R)	Hydraulic mean depth, expressed as the ratio of cross-sectional area to wetted perimeter of the channel (A/WP).

Hydrograph	Streamflow (discharge) plotted as a function of time. Annual hydrographs show streamflow during and entire year, typically with daily flow averaged, while flood hydrographs may use time increments of 15 minutes or 1 hour for the duration of the flood.
Incision	Vertical erosion or downcutting of the channelbed.
Knickpoints	Abrupt changes or local perturbations in the longitudinal gradient of a river or stream, caused by accumulation of coarse debris or sharp change in the erosional resistance of the bedrock.
Levee	An engineered structure designed and constructed to confine floodwaters to a specified river corridor, thus protecting adjacent lands from flood inundation.
Longitudinal Profile	The morphology and gradient of a river or stream channel, viewed longitudinally from upstream to downstream.
Meander	The approximately sinusoidal planform pattern of a river or stream channel.
Meander Belt	River corridor within which channel migration occurs, indicated by abandoned channels, oxbow lakes, and accretion topography.
Migration (channel)	The process in which rivers change their planform location by the gradual erosion of banks, floodplains, and terraces on the steep, outside portion of the meander bend, with concurrent deposition on the inside portion or point bar.
Mitigation	Activities designed to avoid, minimize, rectify, reduce, or compensate for project or land-use impacts.
Particle facies	A discrete patch or zone of homogenously-sized sediments resulting from natural segregation of particle grain sizes within depositional sites.
Phenology	Botanical periodicity (e.g. flowering, seed dispersal, etc.) related to climate, especially seasonal changes.
Piping	Flow seeping through levees when there is a difference in water surface elevation between the mining ponds and the river, sometimes resulting in levee failure
Planform	Alignment or location of a river viewed from directly above, such as a map view.
Plant assemblage	Group of plant species that form a distinct unit, called a stand, in the vegetation mosaic.
Plant recruitment	Plants that have survived through establishment to reach sexual maturity.
Plant stand	A plant assemblage defined by the presence of one dominant species or co-dominance between a few species

Pools	Geomorphic channel forms (or habitat units) characterized by deep water and flat water surface during low flows, and formed by scouring of the channel bed during higher flows.
Rating Curve	Graph plotting discharge verses the water surface elevation, to establish a regression relationship, then used to predict discharge at any given water surface stage height.
Riparian	The zone adjacent to water bodies, watercourses, and surface-emergent aquifers (springs, seeps, and oases) whose water provides soil moisture significantly in excess of that otherwise available through local precipitation. Vegetation characteristic of this zone depends on the availability of excess water.
Riparian Corridor/Zone	The zone of interaction along a river or stream containing moisture-dependent vegetation, trees, brush, grasses, sedges, etc., that affect the channel and are affected by it.
River Mile	Longitudinal distance on the Tuolumne River upstream from the confluence of the San Joaquin River as indicated on USGS topographical maps.
Receding limb	Component of storm, snowmelt, or dam-release hydrograph that is ramping down from a peak flow magnitude to a lower flow.
Recurrence Interval (T)	The average interval (in years) between flood events equaling or exceeding a given magnitude. Defined as the inverse of the exceedance probability (1/P)
Riffles	Shallow, steep, coarse section of river channel, or topographic high in the longitudinal profile, formed at the cross-over of the sediment transport path (transverse bar) and the water flow path.
Riparian berm	Dune of sand deposited along the edge of the low water channel caused by, then anchored by, encroached riparian vegetation. Riparian berms constrict the channel, isolating the channel from adjacent floodplains, often causing the channel to downcut.
Riparian encroachment	The process of riparian initiation, establishment, and maturity progressing toward the low water channel. Reduction in high flow regime reduces natural flood - induced riparian mortality, which allows riparian vegetation to initiate and survive in channel locations that would normally be scoured by floods.
Riparian establishment	Begins at the end of the first summer and extends through several growing seasons as the plant increases energy reserves and strengthens roots and shoots.
Ramping	Flow reduction by either natural or dam control means.
Riparian initiation	Begins at seed germination and extends through the first summer.

Riparian maturity	Period of life-cycle when a plant first expends energy on sexual reproduction and continues through its maximum reproductive period.
Rooting depth	The maximum depth that a plant's roots grow every year or reach at maturity.
Sapling	A young tree with a trunk less than 4 inches in diameter at breast height (4.5 feet above the ground surface).
Sediment budget	Quantification of sediment yield to a river channel from different contributing sources, including overland flow and gullying, landsliding, bed and bank erosion.
Sediment deposition	The termination of motion or settling-out of sedimentary particles, usually as result of a decrease in flow capacity and competence in the recession stage of a storm hygrograph.
Sediment load	The rate of sediment transported by a river, expressed in tons per day.
Sediment transport	Process or rate of movement of sedimentary particles downstream by entrainment resulting from physical forces of water acting on the channel bed.
Sediment transport capacity	Maximum amount of sediment a river can transport, for a given flow condition.
Sediment yield	Annual production of bedload and suspended load contributed to, and transported by a stream or river as result of erosional processes, expressed as tons per year
Seedling	A plant shortly after seed germination, includes the first plumuoles.
Sinuosity	The irregular, meandering planform pattern of a river, strictly defined as a ratio of the length of the channel axis or thalweg to the straight-line length of the river valley (Sinuosity Index).
Slough	Portion of abandoned channel or meander cutoff that continues to receive flow from the main channel
Snowmelt hydrograph	The annual spring flood (long duration, moderate magnitude) resulting from the seasonal melting of snow at higher elevations.
Special Status Species	Generally refers to species with declining populations, including, but not limited to species listed or proposed for listing as threatened or endangered under the state and federal Endangered Species Acts.
Stage (height)	Elevation of the water surface at a particular discharge.
Subsurface particles	Particles found in the gravel column deeper than one D_{84} diameter below the bed surface.
Surface particles	Particles found in the gravel column from the bed surface to a depth of one D_{84} diameter.

Suspended load	The finer portion of the annual sediment load, transported in suspension above the bed surface
Thalweg	The deepest portion of the channel.
Threatened species	Any species of plant or animal likely to become endangered within the foreseeable future throughout all or a significant portion of its natural range.
Transverse bar	Depositional channel feature representing the path of sediment transport connectivity between two alternating point bars, and location of a riffle.
Turbidity	Cloudiness in water produced by presence of suspended sediments.
Vegetation	Mosaic of different assemblages of plants across a landscape, and wide range of environmental conditions and gradients.
Water year	Period on which streamflow hydrology is computed, extending from October 1 of the prior calendar year to September 30 of the current calendar year. For instance, WY 1989 extends from October 1, 1988 to September 30, 1989
Water yield	Total volume of runoff generated by a watershed over a water year, usually expressed in acre-feet.
Wetlands	A zone periodically or continuously submerged or having high soil moisture that has aquatic and /or riparian vegetation components and is maintained by water supplies significantly in excess of those otherwise available through local precipitation.
Wetted perimeter	Distance from the left edge to right edge of water surface measured along the channel sides and bottom, perpendicular to the flow direction, i.e., along a cross section.

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1. INTRODUCTION

The Gravel Mining Reach and Special Run Pools (SRPs) 9 and 10 projects are the largest restoration projects attempted on the Tuolumne River and are among the largest of their type implemented by CALFED and the Anadromous Fish Restoration Program (AFRP). These projects have been identified as a high priority in the following documents:

- Habitat Restoration Plan for the Lower Tuolumne River (McBain and Trush 2000)
- Federal Energy Regulatory Commission Settlement Agreement (FSA) for the New Don Pedro Project (NDPP) (FERC 1995)
- Restoring Central Valley Streams: A Plan For Action (CDFG 1993)
- Final Restoration Plan for the Anadromous Fish Restoration Program (AFRP) Restoration Plan (USFWS 2001)
- CALFED Ecosystem Restoration Program (CALFED 2000).

Several state and federal agencies have and continue to actively participate in these projects through the Tuolumne River Technical Advisory Committee. Participants include representatives from the Turlock Irrigation District (TID), Modesto Irrigation District (MID), Friends of the Tuolumne Trust, Tuolumne River Preservation Trust, US Fish and Wildlife Service, City and County of San Francisco, and California Department of Fish and Game.

The Gravel Mining Reach and SRP 9/10 Reach have been drastically altered by past and current mining. The Gravel Mining Reach was and continues to be extensively mined for commercial aggregate (sand and gravel). This mining has removed large expanses of the floodplain and associated riparian vegetation and replaced them with deep pits separated from the river by dikes that confine the river to a narrow corridor. In the Gravel Mining Reach, floods often cause these dikes to breach, connecting off-channel pits to the river which can then strand and delay salmon during emigration, divert and trap coarse sediment in transport, raise water temperatures, and expose juvenile salmon to non-native predators such as largemouth bass (Micropterus salmoides) and smallmouth bass (Micropterus dolomieu). In the SRP 9/10 Reach, large pits in the river channel were created by in-channel aggregate mining during the 1930s and 1940s. Excavation of these pits has eliminated salmon spawning and rearing habitat as well as floodplains and riparian vegetation. The pits also trap all coarse sediment carried downstream by high flows and provide warm-water habitat for non-native bass that prey on Chinook salmon smolts as they migrate out to sea. Recent studies have found bass densities as high as 750 adult bass per river mile in the SRPs (McBain and Trush and Stillwater Sciences 1999, 2000). Because SRPs 9 and 10 are located at the downstream end of the gravel-bedded reach, all juvenile salmon produced in the river must pass through them and be subject to predation on their route to the Pacific Ocean.

River restoration involving extensive mechanical reconstruction of the river channel is a relatively recent and rapidly expanding field. The published literature documents many ecologically-based channel and wetland restoration projects, almost all completed since the early 1980s. Many of these projects, particularly those in Europe, have involved restoration of natural meanders in channelized rivers (Binder et al. 1983; Brookes 1987; Jungwirth et al. 1995; Toth 1996; Brookes and Shields 1996; Olsen 1996). Many of these restoration projects were constructed in lowland areas with low stream gradients. Some projects were implemented after catastrophic floods, where restoration actions were intended to jumpstart the natural recovery process. Other projects attempted to either stabilize the stream using bank protection and/or grade control structures or assumed the system is static. These stabilization projects often fail to accommodate the naturally dynamic processes of the river, resulting in expensive maintenance and repairs, and unrealized restoration potential. In California, engineers and landowners have attempted to stabilize dynamic rivers with structural approaches (i.e., concrete and rip-rap). Flood control efforts have also largely focused on structural approaches (i.e., dams and levees). The periodic failure of these structural approaches (e.g., 1997 flood), coupled with tremendous environmental damage caused by these approaches, has led to a different approach that acknowledges and accommodates dynamic river processes and develops solutions that begin to satisfy both environmental restoration objectives as well as flood control and river stability objectives.

This emerging approach has been applied to the recently completed Habitat Restoration Plan for the Lower Tuolumne River Corridor (McBain and Trush 2000). The Restoration Plan's vision for restoring the lower Tuolumne River corridor is to:

> *Utilize an integrative approach to re-establish critical ecological functions, processes, and characteristics under regulated flow and sediment conditions that best promote recovery and maintenance of a resilient, naturally reproducing salmon population and the river's natural animal and plant communities.*

New restoration projects on the Tuolumne River will contribute to that corridor-wide vision by restoring some of the most damaged sections of the river in a way that incorporates natural, dynamic processes into the restoration design. These projects also begin to rely on these processes to maintain the function of each project site after construction is completed. This document describes the restoration design process and design specifications, changes to the projects during their implementation, and project monitoring. The report is intended to illustrate the conceptual models, design approach and assumptions, and risks and uncertainties that underlie these projects to those building them.

2. THE TUOLUMNE RIVER

The Tuolumne River drains a 1,960-square-mile watershed on the western slope of the Sierra Nevada Range and is the largest of three major tributaries to the San Joaquin River (Figure 1). The river originates in Yosemite National Park and flows southwest to its confluence with the San Joaquin River (at San Joaquin river mile [RM] 83.7), approximately 10 miles west of the city of Modesto. The upper watershed is characterized by deep canyons and forested, mountainous terrain. Near the town of La Grange (RM 52), the river exits the Sierra Nevada foothills and flows through a gently sloping alluvial valley that is incised into Pleistocene alluvial fans. Within the alluvial valley, the river can be divided into two geomorphic units defined by channel slope and bed composition: the gravel-bedded reach, which extends from La Grange Dam (RM 52) to below Geer Road (RM 24), and the sand-bedded reach, which extends from approximately RM 24 to the confluence with the San Joaquin River (RM 0).

The watershed experiences a Mediterranean climate, with cool, wet winters and warm, dry summers. At elevations above 5,000 feet, precipitation is predominantly snow. Average annual precipitation in the watershed ranges from 12.6 inches/yr near Modesto to 35.0 inches/yr at Hetch Hetchy in the upper watershed. Eighty percent of annual precipitation at the Hetch Hetchy station falls from October through April (Figure 2). Unimpaired summer flows are characteristically low (300 cfs) in late summer and fall, with increasing baseflows and brief high flow peaks in late fall and winter caused by rainfall and rain-on-snow events. The largest volume of water runoff occurred during the late spring

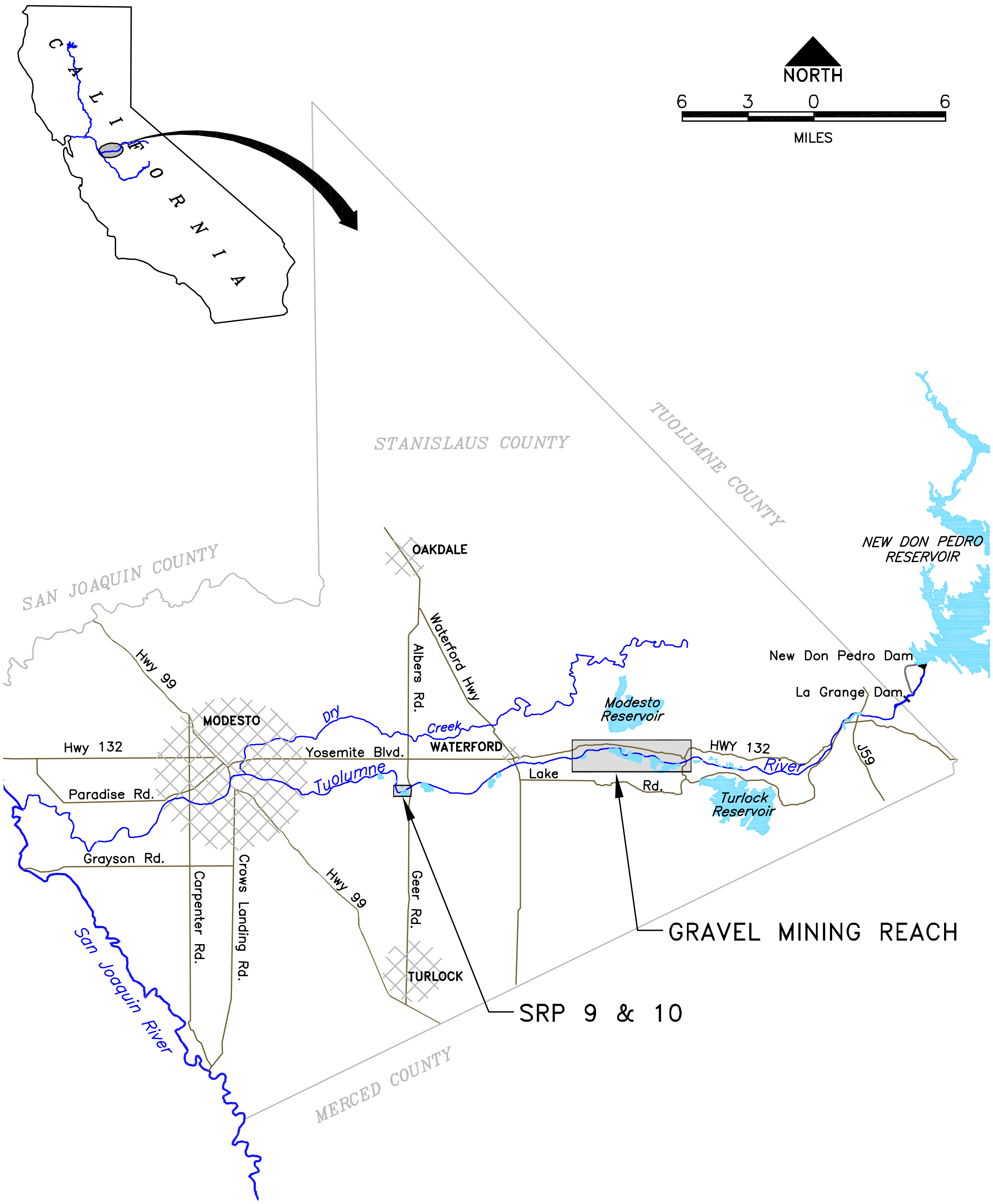

Figure 1. Lower Tuolumne River corridor and location of Gravel Mining Reach and SRP 9/10 project locations.

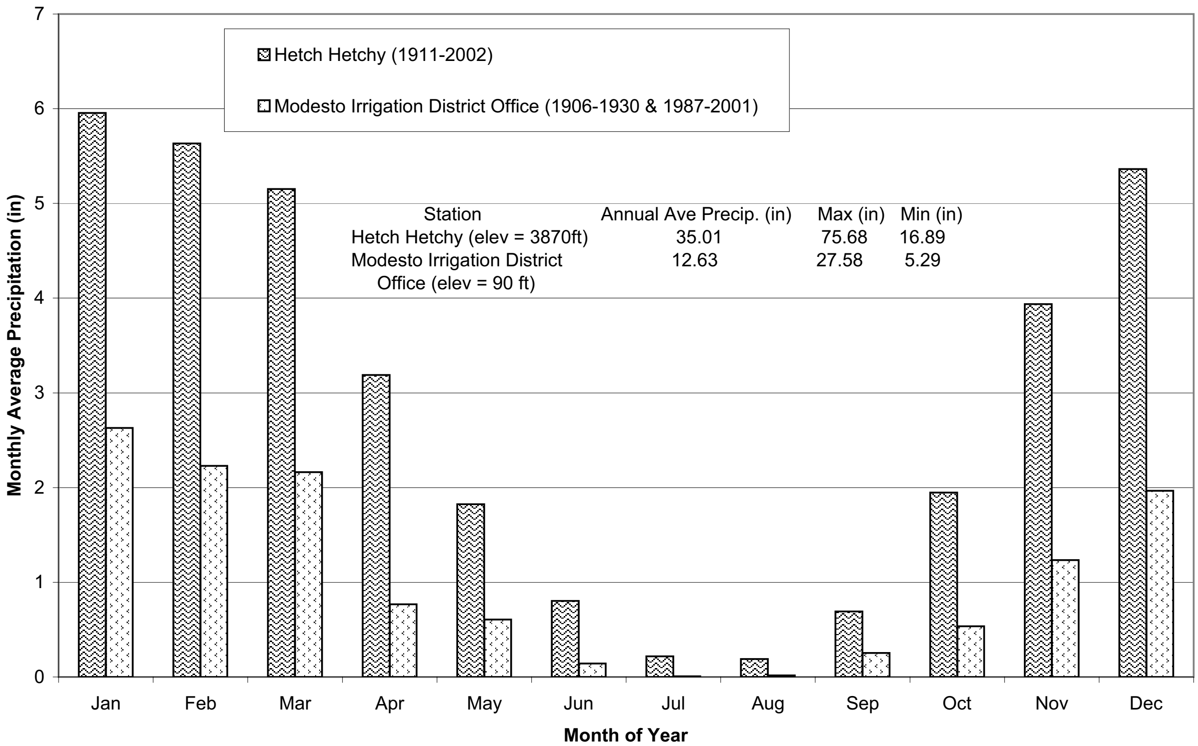

Figure 2. Mean monthly precipitation values for Modesto (from the Modesto Irrigation District records) and Hetch Hetchy.

and early summer months, where prolonged high flows and flooding was caused by snowmelt runoff from the upper watershed. This spring snowmelt typically extended through mid-summer, but in wet years could completely mask summer baseflows and continue through to the fall-winter rainy season. These unimpaired flow conditions are described in more detail in section 2.1.1.

2.1. Pre-Colonial conditions

Under natural (i.e., pre-colonial) conditions, the Tuolumne River was most likely a dynamic, quasi-equilibrium morphology characteristic of alluvial rivers (e.g., Schumm 1977, Knighton 1984). This quasi-equilibrium river channel was maintained by floods, sediment transport, and channel migration events. In the sand-bedded reach of the river, there was a well defined bankfull channel and floodplain (Figure 3). The bankfull channel consists of a low flow channel that conveys baseflows, and alluvial bars that are mobilized by common flows. In the upstream gravel-bedded reach, channel morphology does not appear to consistently follow the two-stage (bankfull channel and floodplain) morphology, but has periodic split low flow channels and numerous high flow scour channels on higher elevation surfaces (Figure 4). Using relationships developed by Lane (1957) and Leopold and Wolman (1957), both predict that the pre-colonial Tuolumne River was in the transitional zone between a meandering and braided channel morphology (Figure 5). A bankfull channel likely existed in many reaches, but in other reaches, the semi-braided channel morphology was typified by more than one low flow channel, and numerous high flow scour channels on the floodplain. Review of historical aerial photographs (Figure 4) and early maps support the predictions of the relationships in Figure 5. In the pre-colonial Tuolumne River, high flows scoured the channel bed and discouraged

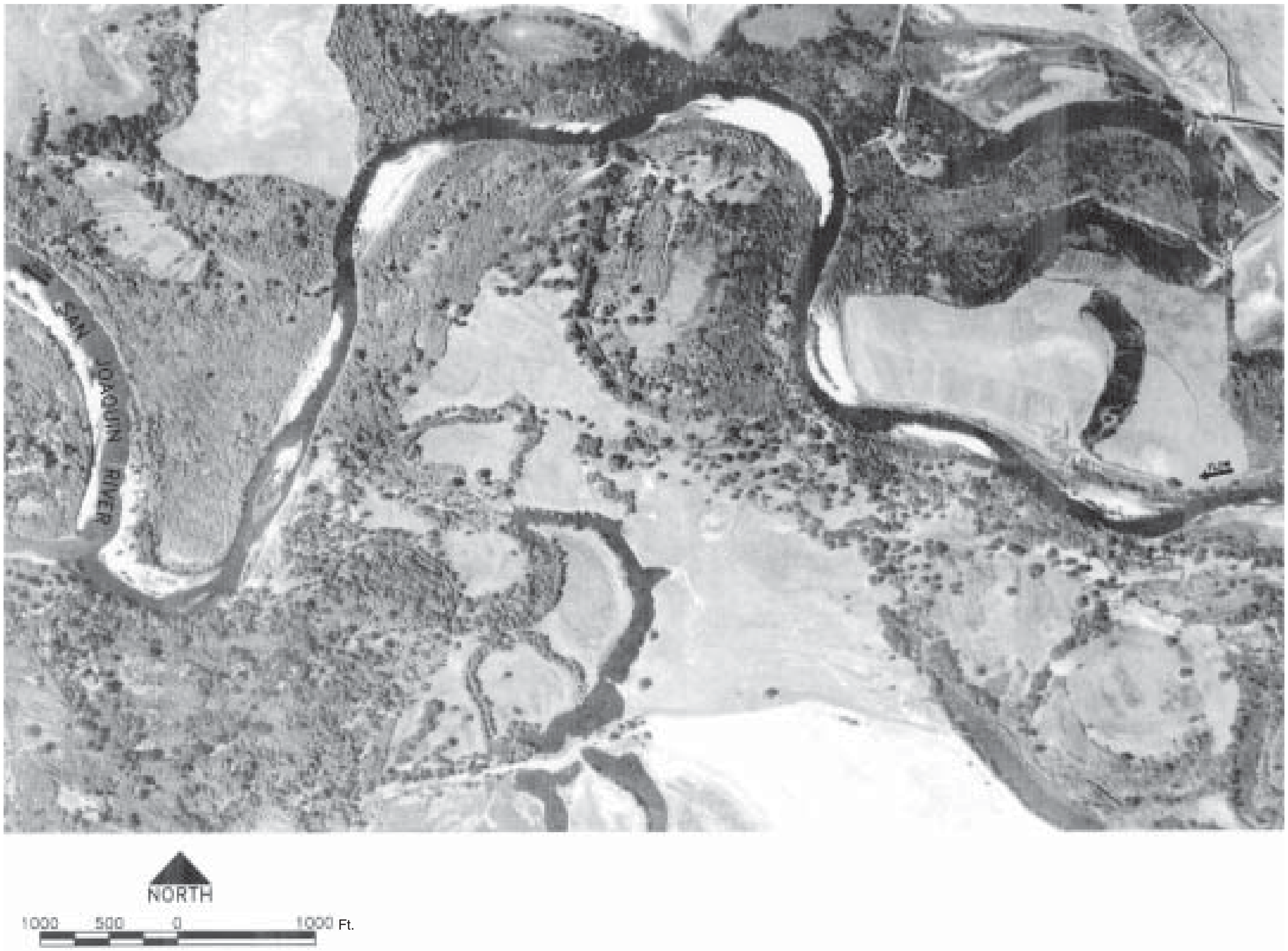

Figure 3. Example alternate bar sequences in sand-bedded reach in 1937, near confluence with the San Joaquin River.

Figure 4. Example floodway and channel morphology in gravel-bedded reach in 1937, near River Mile 42.

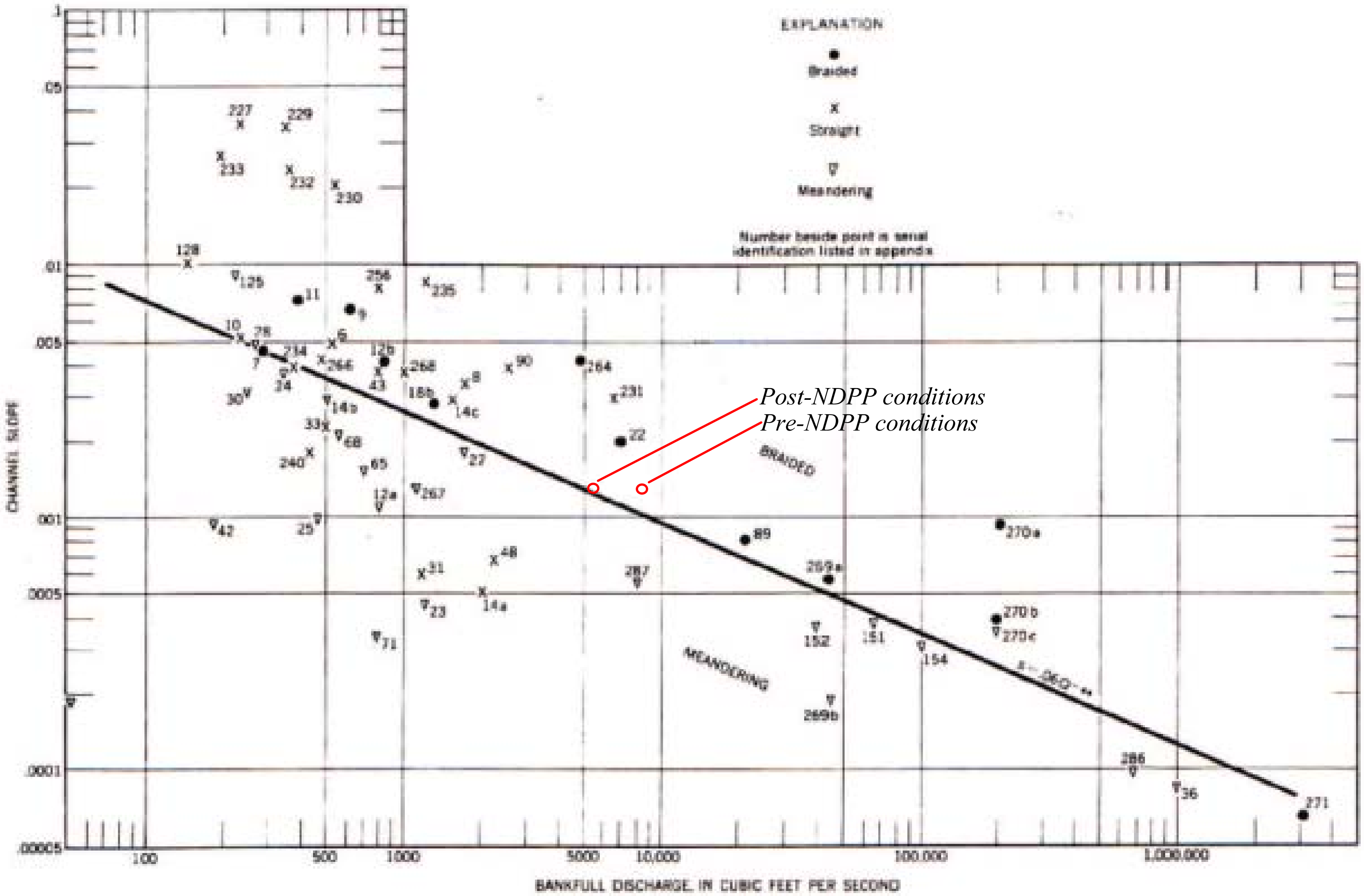

Figure 5. Relationship between braided and meandering channel morphology, illustrating predicted semi-braided channel morphology for the gravel-bedded reach of the Tuolumne River.

encroachment of riparian vegetation onto alluvial bars. Flooding, channel migration, and meander cut-off created complex floodplain surfaces vegetated by mix-aged stands of riparian forest. Channel migration and avulsion was an important fluvial process on the Tuolumne River, creating complex aquatic habitat, creating floodplains, and encouraging riparian regeneration (Figure 6).

Prior to flow regulation, the bankfull flow in the lower Tuolumne River was approximately 8,400 cfs (the pre-dam $Q_{1.5}$) to 10,000 cfs (estimated from historic cross section at RM 36.5) (Figure 7). In the gravel-bedded reach, the channel ranged from a single-thread to a mildly braided morphology. Bankfull channel width was approximately 550 feet (based on channel cross sections and historic aerial photographs) (Figure 8). Meander wavelengths were approximately 2,000 feet to 3,000 feet, had a low amplitude (<400 feet), and large radius of curvature (>1,500 feet). In the sand-bedded reach, the bankfull channel width was approximately 600 feet. Meander wavelengths in this reach were less variable, tending toward 3,000 feet. Meander amplitude ranged from 600 feet to 750 feet. Meander cut-offs were common, forming frequent oxbow lakes (Figure 3).

The native riparian forest canopy was dominated by Fremont cottonwood (*Populus fremontii*), valley oak (*Quercus lobata*), Oregon ash (*Fraximus latifolia*), box elder (*Acer negundo*), white alder (*Alnus rhombifolia*), and several species of willow (*Salix* spp.). In the gravel-bedded reach, the pre-colonial riparian forest was patchy, with trees occurring in silty soils, adequate soil moisture, and protection from harsh flooding conditions (Figure 4). Floodplain vegetation between these patches of cottonwood and willow riparian forest was largely grassland with occasional valley oaks (*Quercus lobata*). Riparian vegetation in the sand-bedded reach was a lush, multi-layered gallery forest of Fremont cottonwood (*Populus fremontii*), valley oak (*Quercus lobata*), Oregon ash (*Fraxinus latifolia*), and western sycamore (*Platanus racemosa*). Many vines (California grape [*Vitus californica*] and poison oak [*Toxicodendron diversiloba*]) connected the canopy tree layer with a dense underbrush of shrubs, grasses and forbs. Prior to 1900, extensive gallery forests extended for a half mile or more on either side of the river from RM 10 to the confluence with the San Joaquin River (Figure 3).

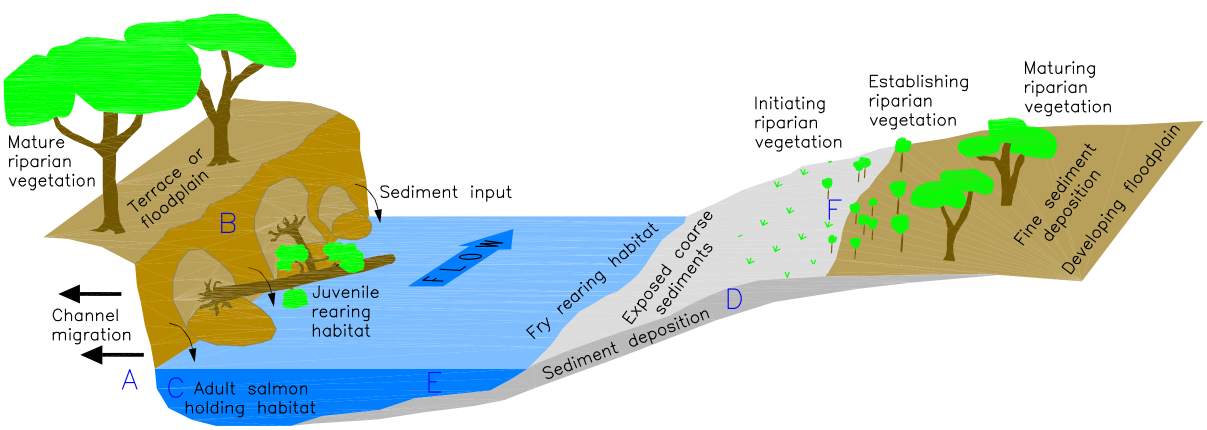

Figure 6. Conceptual role of channel migration in creating spatially and temporally complex riparian corridor and channel morphology.

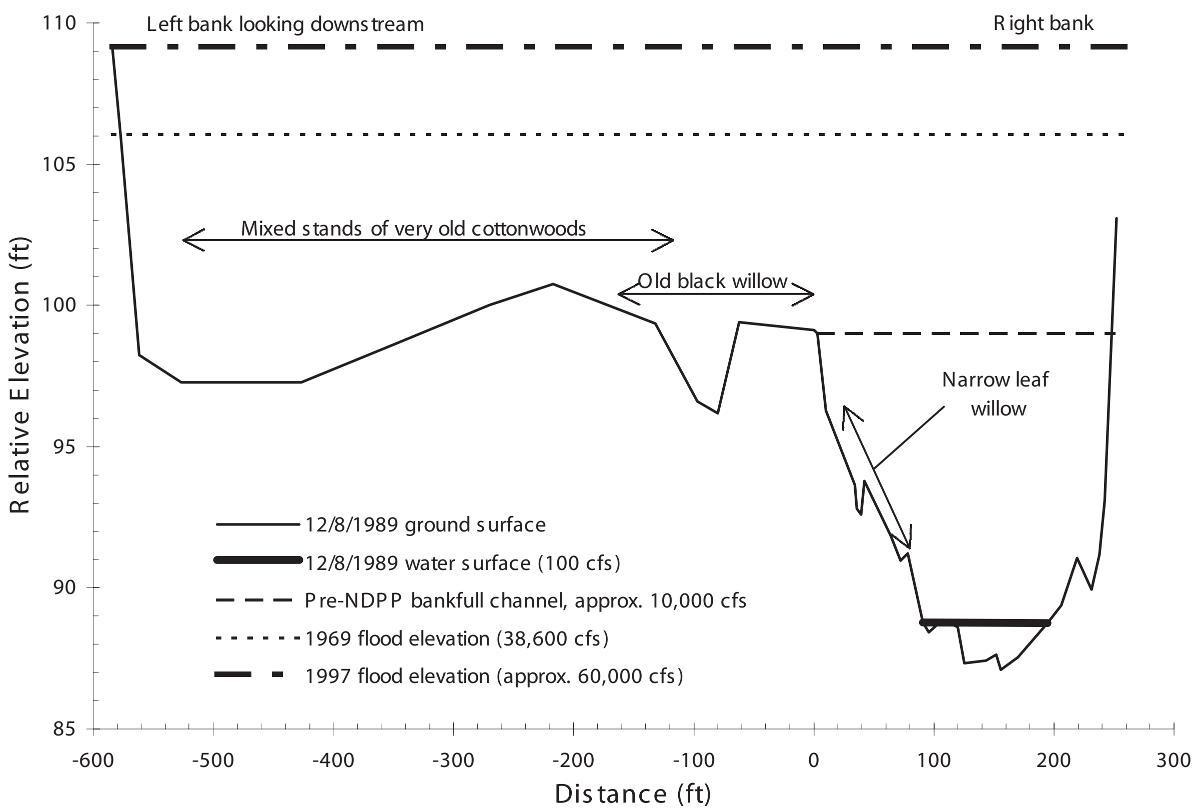

Figure 7. Fossilized pre-NDPP bankfull channel and floodplain surface on cross section at RM 35.5 of gravel-bedded reach.

2.1.1. Flow Diversion and Regulation

Flow diversion began in the mid-nineteenth century with small diversion ditches that carried water to gold mines. Later in the century, irrigation districts constructed larger dams to provide water to the rich agricultural lands of the San Joaquin Valley (Table 1). Wheaton Dam, the first significant dam on the river, was completed in 1871 by the Turlock Irrigation District (TID) and Modesto Irrigation District (MID) and served as the point of diversion for the MID to the south of the river and TID to the north of the river. In 1893, this dam was replaced by the larger La Grange Dam at the same location. These early dams and diversions reduced summer baseflows in the river but lacked sufficient storage capacity to significantly alter high flows.

The first significant storage reservoirs in the watershed to significantly alter the Tuolumne River flow regime were created by Don Pedro Dam and Hetch Hetchy Dam, which were completed in the 1920s (Table 1). By 1955, reservoir storage capacity in the watershed was equivalent to 49% of the watershed's average unimpaired annual outflow. Reservoirs constructed during this period include Don Pedro (290,000 acre-feet), Hetch Hetchy (206,000 acre-feet, later enlarged to 360,000 acre-feet), and Lake Lloyd (268,000 acre-feet). New Don Pedro Dam was completed in 1971. With a reservoir capacity of 2.03 million acre-feet (or 107% of the average annual unimpaired water yield for the Tuolumne River basin), this dam nearly tripled reservoir capacity in the watershed. Today, total reservoir capacity in the watershed is 2.68 million acre-feet, or 1.4 times the average annual unimpaired flow from the basin.

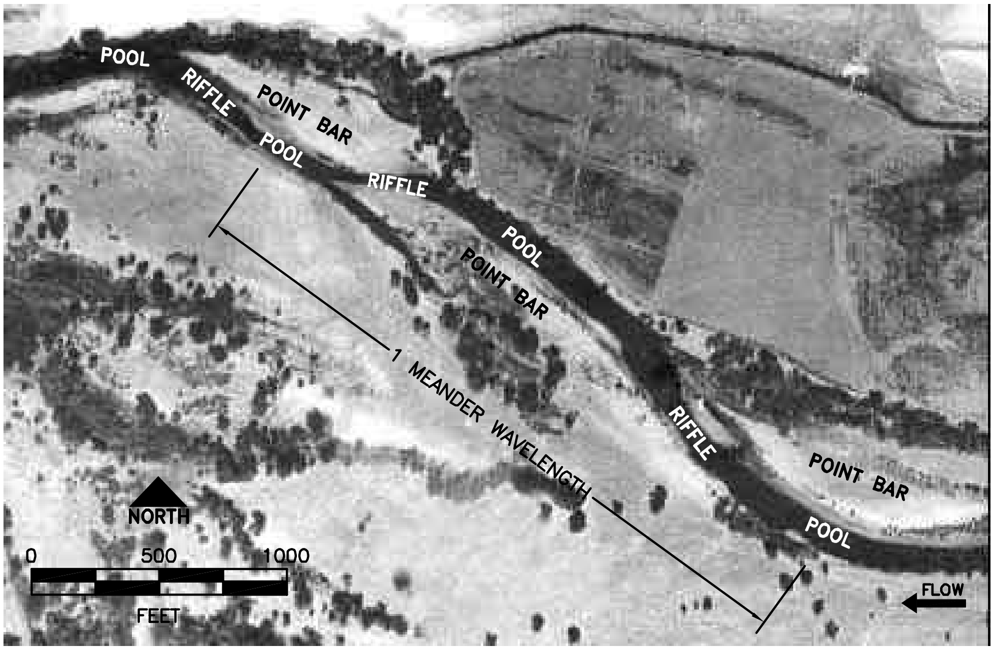

Figure 8. Example alternate bar sequence in gravel-bedded reach in 1937, near RM 38.

In addition to reservoir storage, large volumes of water are diverted from the river for municipal and agricultural uses (Figure 9). MID and TID divert flow from the river for agricultural and municipal uses. La Grange Dam is the point of diversion for both districts. The average annual flow diversion by TID and MID at La Grange Dam is 885,000 acre- (based on 1984-1998 data), or 47% of the average unimpaired outflow from the watershed. The City and County of San Francisco (CCSF) also diverts flow from the river for municipal supply. Average annual CCSF diversion is 230,000 acre-feet (based on 1984-1998 data), or 12% of the average unimpaired outflow from the watershed.

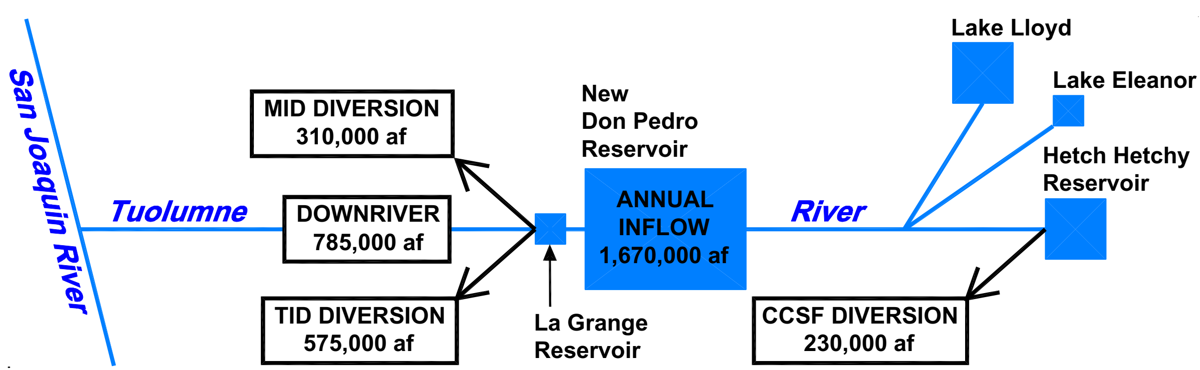

Figure 9. Long-term average inflow, diversion, and instream release volumes on the Tuolumne River.

Table 1. Reservoir Storage Capacity in the Tuolumne River Watershed.

Dam	Year Completed	Reservoir Capacity (acre-feet)	Cumulative Capacity Relative to Unimpaired Basin Yield (percent)
Wheaton Dam	1871	<500	0
La Grange Dam (replaced Wheaton Dam)	1893	500	0
Lake Eleanor (Eleanor Creek)	1918	26,100	1.4
Don Pedro Dam	1923	290,000	17
Hetch Hetchy Dam	1923	206,000	27
	Enlarged 1937	360,000	36
Lake Lloyd (Cherry Creek)	1955	268,000	50
New Don Pedro Dam (replaced Don Pedro Dam)	1971	2,030,000	141
Total		**2,684,600**	**141**

Minimum flows in the lower river were defined by the Federal Energy Regulatory Commission (FERC) license for the New Don Pedro Project (NDPP). Minimum flows required by the original license are shown in Table 2. Minimum flow requirements were revised by a FERC Settlement Agreement (FSA) established in 1995, which significantly increased minimum flows and specified maximum flow fluctuations for ten water year types. The revised minimum flow schedule is shown in Table 3.

Table 2. Minimum Flow Schedule Established in the Original FERC New Don Pedro Project FERC License.

Period	Required Minimum Flow	
	Schedule A: Normal Year (unimpaired flow < 1 million acre-feet)	Schedule B: Dry Year (unimpaired flow between 750,000 and 1 million acre-feet)
Pre-season flushing flow	2,500 cfs	50 cfs
October 1-15	200 cfs	200 cfs
October 16-31	250 cfs	200 cfs
November	385 cfs	200 cfs
December 1-15	385 cfs	135 cfs
December 16-31	280 cfs	135 cfs
January	280 cfs	135 cfs
February	280 cfs	200 cfs
March	350 cfs	200 cfs
April	100 cfs	85 cfs
May-September	3 cfs	3 cfs
Annual minimum release:	123,210 ac-ft	64,041 ac-ft

The Lower Tuolumne River Corridor Habitat Restoration Plan encompasses the area from La Grange Dam to the confluence with the San Joaquin River. Flows in the restoration reach are thus controlled by the operation of the dams and diversions described above. Under natural conditions, the Tuolumne River annual hydrograph can be divided into four hydrograph components: fall and winter baseflows, winter flood flows, spring snowmelt flows and snowmelt recession, and summer baseflows (Figure 10). Flow regulation and diversion have significantly altered each of these hydrograph components. Major effects of regulation and diversion include reduction in total water yield, loss of inter-annual and seasonal flow variability, reduction in peak flow magnitude and duration, and reduction in summer, fall, and winter baseflows. Effects of flow regulation and diversion on hydrograph components are described below and are illustrated in Figure 10. To quantify the effects of flow regulation and diversion on hydrologic conditions in the lower river, McBain and Trush (2000) developed a water year type classification system by plotting exceedence probabilities for annual water yields using data from water year (WY) 1918 through WY 1999. This classification system, which differs from the system used in the FSA shown in Table 3, includes five water year types: extremely wet, wet, normal, dry, and critically dry (Figure 11).

Table 3. Minimum Flow Schedule Established in the 1995 FERC Settlement Agreement.

Water Year Type	% Exceedence	Oct. 1-Oct. 15 (cfs)	Attraction pulse flow (ac-ft)	Outmigration pulse flow (ac-ft)	Oct. 16 - May 31 (cfs)	June 1 - Sept. 30 (cfs)	Total Flow (ac-ft)
Critical and below normal	93.6	100	none	11,091	150	50	94,000
Median critical	85.6	100	none	20,091	150	50	103,000
Intermediate critical/dry	79.5	150	none	32,619	150	50	117,016
Median dry	68.7	150	none	37,060	150	75	127,507
Intermediate dry/below normal	59.6	180	1,676	35,920	180	75	142,502
Median below normal	49.3	200	1,736	60,027	175	75	165,002
Intermediate below normal/above normal	33.8	300	5,950	89,882	300	250	300,923
Median above normal	28.7	300	5,950	89,882	300	250	300,923
Intermediate above normal/wet	13.3	300	5,950	89,882	300	250	300,923
Median wet/maximum	0	300	5,950	89,882	300	250	300,923

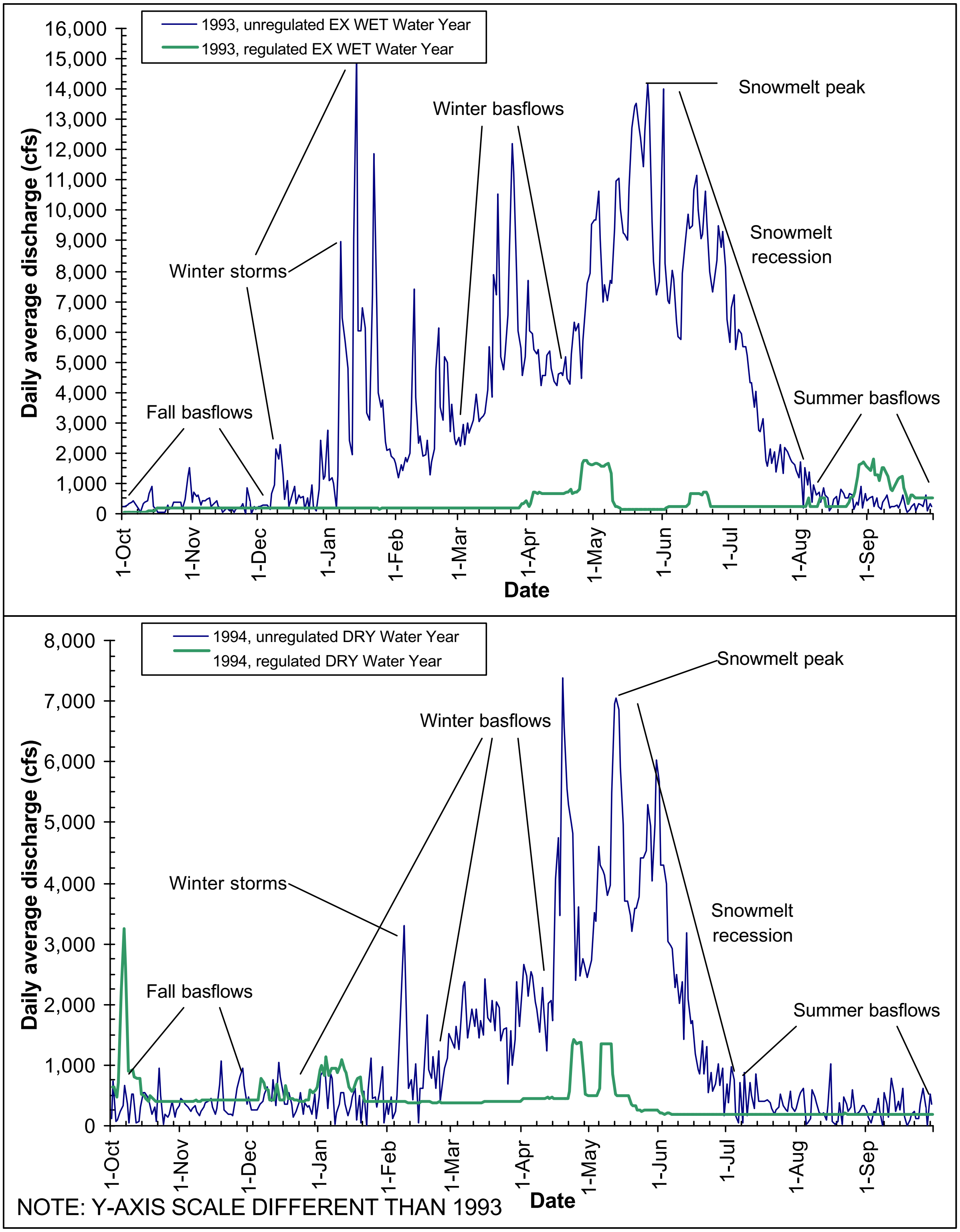

Figure 10. Illustration of unimpaired hydrograph components and in-river releases on the Tuolumne River at LaGrange (RM 52), using WY 1993 and WY 1994 as examples.

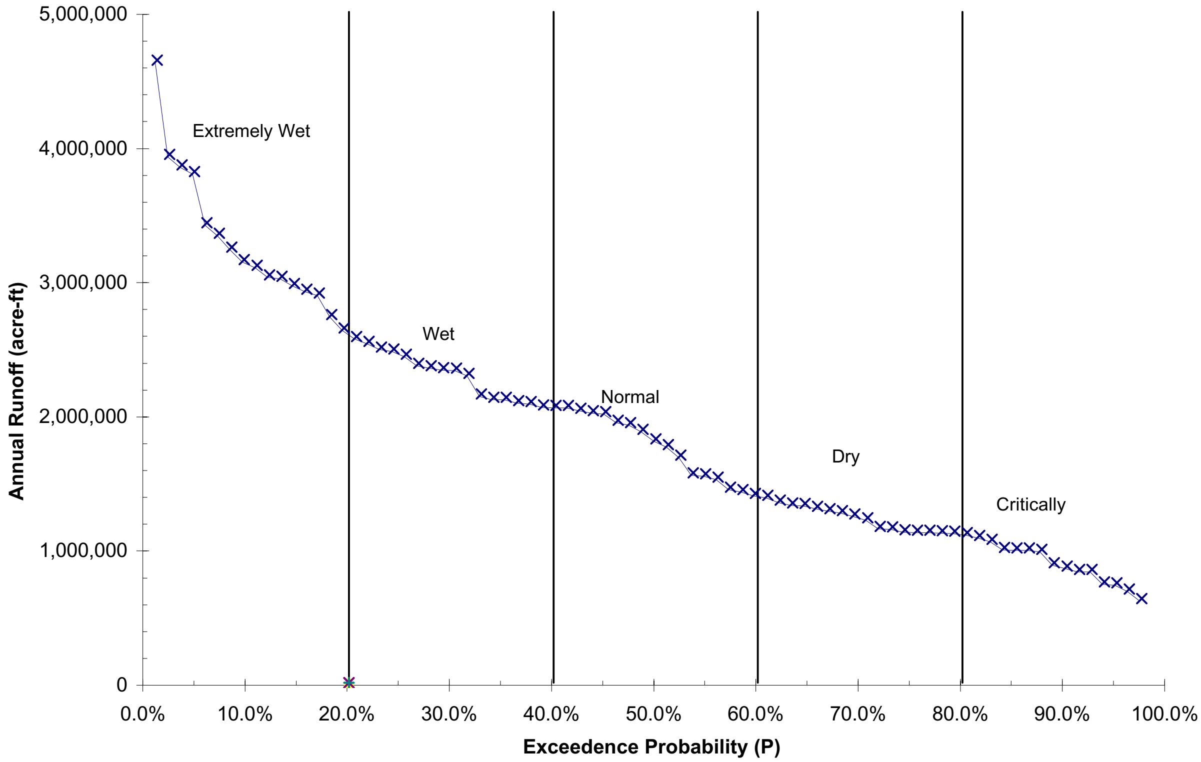

Figure 11. Water year classification describing hydrograph components on the lower Tuolumne River. This water year classification is different than that used in the FERC Settlement Agreement.

2.1.1.1. Annual Water Yield

From WY 1897 through WY 1999, average unimpaired annual water yields from the Tuolumne River (measured at La Grange) ranged from 454,000 acre-feet (WY 1977) to 4.6 million acre-feet (WY 1983) and averaged 1,906,000 acre-feet (Figure 12). The FSA requires minimum flow releases from the NDPP ranging from 94,000 acre-feet to 300,923 acre-feet, depending on water year type (Table 3). Since completion of the New Don Pedro Project (NDPP), annual water volume releases to the lower river has ranged from 61,029 acre-feet (WY 1989) to 3.46 million acre-feet (WY 1983), and has averaged 785,000 acre-feet, or 62% less than unimpaired conditions.

2.1.1.2. Fall and Winter Baseflows

Fall and winter baseflows are the stable flows between fall and winter storm events (Figure 10). Occurring between October 1 and December 20, fall baseflow is relatively low and is punctuated by small magnitude fall peaks. Winter baseflows occur between December 21 and March 20 and are low flows between individual storm events. Winter baseflows are maintained by the receding limbs of storm hydrographs and shallow groundwater discharge, which generally increases in magnitude throughout the winter as soils in the watershed become saturated.

For unimpaired conditions (WY 1918 to WY 1999), fall baseflows ranged from 300 cfs to 550 cfs and frequently exceeded 1,000 cfs during wetter years. Fall baseflows required by the FSA range from 100 cfs to 200 cfs for median below normal and drier years to 300 cfs for wetter years. For unimpaired conditions (WY 1918 to WY 1999), winter baseflows ranged from 300 cfs in critically

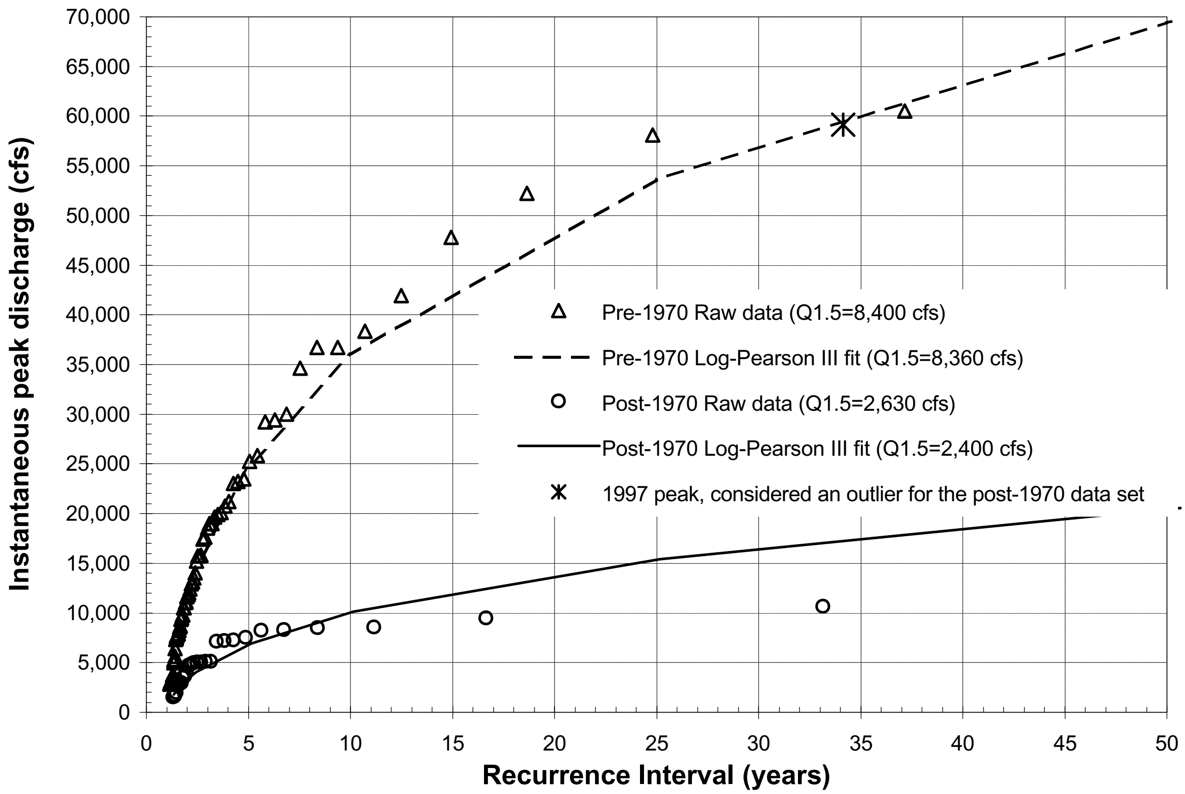

Figure 12. Annual maximum flood frequency curves for Pre-NDPP (1897-1970) and post-NDPP (1971-2003) periods at LaGrange gaging station (STN 11-289650).

dry years to 4,400 cfs in extremely wet years. The FSA requires minimum winter flow releases 150 cfs to 300 cfs. Flow regulation has replaced the previously variable fall and winter streamflows with relatively constant flow conditions in an effort to maximize "weighted usable area" for Chinook salmon spawning. Typical fall and winter baseflows are dictated by minimum flow requirements (Table 3). In wetter years, however, flood control releases result in flow conditions in the lower river that exceed minimum instream flow requirements, increasing the median winter baseflow since completion of the NDPP to 1,080 cfs, which is comparable to winter baseflow conditions in a dry water year under unimpaired flow conditions.

2.1.1.3. Fall and Winter Floods

Fall and winter flood peaks occur between early October and mid-March and are generated by rainfall or rain-on-snow events. Under unimpaired conditions, larger magnitude, short duration floods caused by rain and rain-on-snow events typically peaked in late December through January, with moderate magnitude floods extending through March (Figure 10). The magnitude of these floods sometimes reached 130,000 cfs (1862, 1997), while the 1.5-year flood was 8,600 cfs (Figure 12). In general, winter peaks were larger than fall peaks and were typically shorter in duration than snowmelt peak flows.

Operation of the NDPP has greatly reduced peak flow magnitude in the lower river. Flood releases from the NDPP are dictated by three factors: maximum releases through the dam outlet works, the Army Corps of Engineers (ACOE) flood control rules, and maximum release capacity through the powerhouse turbines. Maximum controlled flow release through the dam outlet works is approximately 14,000 cfs. Flow releases exceeding 14,000 cfs pass over the dam spillway, which has been used only once since completion of the NDPP (in the January 1997 flood). ACOE flood control rules limit flood flows in the river to 9,000 cfs as measured at the Modesto gauge, which includes inflows from Dry Creek. This peak flow magnitude is approximately equal to the pre-dam bankfull discharge measured at La Grange (i.e., without inflow from Dry Creek), and is a 6-year flood at the Modesto gaging station under the post-NDPP flow regime. The ACOE flood control rules have been exceeded four times since completion of the NDPP, with flows at Modesto reaching 12,000 cfs (WY1983), 11,100 cfs (WY1995), 55,800 cfs (WY 1997), and 11,800 cfs (WY 1998). This flood control limitation hinders flood control operations during wetter water years. Efforts are currently underway to re-evaluate flood management on the Tuolumne River to reduce the risk of a flood event similar to the 1997 flood. The turbine capacity of the NDPP powerhouse, however, is about 5,500 cfs. High flow releases, therefore, are often kept in the range of 4,500 cfs to 5,500 cfs to maximize power generation.

Pre- and post-NDPP peak flow magnitudes for various recurrence intervals are shown in Table 4. The floods of record occurred in 1862 and 1997; both peaked at approximately 130,000 cfs (unimpaired). The resulting 1997 peak flood release as measured at the USGS gaging station "Tuolumne River below LaGrange Dam, near LaGrange" was 58,900 cfs, which was estimated by the ACOE to be an 80-year flood (ACOE 1998). For the purposes of this design document, we use the post-New Don Pedro Project flood frequency data "near LaGrange" rather than "at Modesto" because the restoration projects are upstream of Dry Creek. We also exclude the 1997 flood for channel design purposes, keeping in mind larger floods similar to the 1997 flood when designing the floodway width.

Table 4. Pre- and Post-New Don Pedro Project Peak Flow Magnitudes using a Log-Pearson III fit of measured peak flows at USGS gauging station "Tuolumne River below La Grange Dam near La Grange", Stn. No. 11289650 (RM 51.5).

Recurrence Interval (years)	Flow Magnitude at La Grange (cfs)			Percent Reduction[2]
	Pre-NDPP (1897-1969)	Post-NDPP[1] (1970-2003)	Post-NDPP[2] (1970-2003)	
1.5	8,360	2,490	2,400	71
2.0	12,100	3,690	3,350	72
5	25,000	8,200	6,700	73
10	36,000	12,700	9,900	73
25	54,000	20,400	15,200	72

[1]Includes January 1997 flood

[2] Excludes January 1997 flood

2.1.1.4. Spring Snowmelt Hydrograph

Historically, the spring snowmelt hydrograph occurred between mid-March and mid-to-late August and typically was lower magnitude and longer duration than winter floods (Figure 10). Snowmelt flows typically peaked in late April to early June. The median peak ranged from 6,000 cfs in critically dry years to 17,000 cfs extremely wet years, but was historically as high as 52,000 cfs. During most years, unimpaired snowmelt peaks were large enough to transport the coarsest fraction of the channel bed in the gravel-bedded reach and were the largest contributor to the total annual water yield. The snowmelt recession historically extended into July in critically dry years and August in extremely wet years. During extremely wet years, recession rates ranged from 780 cfs/day to 112 cfs/day. During normal and dry years recession rates ranged from 400 cfs/day to 95 cfs/day.

Operation of the NDPP has eliminated spring snowmelt floods from the annual hydrograph, with the exception of flood control releases (Figure 10). The FSA has replaced snowmelt floods with mandated spring pulse flows intended to stimulate Chinook salmon smolt emigration. Required spring pulse flow releases range from 11,091 acre-feet (comparable to 5,600 cfs for one day) to 89,882 acre-feet (comparable to 5,040 cfs for 9 days) depending on water year type. This loss of the spring floods has contributed to the drastic reduction of native riparian vegetation recruitment establishment along the river, particularly for Fremont cottonwood, black willow, and valley oak. It has also reduced Chinook salmon rearing habitat and degraded salmon outmigration conditions.

2.1.1.5. Summer Baseflows

Summer baseflows begin at the end of the snowmelt recession and end with the first fall storm (Figure 10). Under unimpaired conditions, summer baseflows averaged 220 cfs during normal rainfall years and 152 and 637 cfs during critically dry years and extremely wet years, respectively. During some extremely wet years, the later snowmelt recession merged with early fall floods, obscuring the summer baseflow component.

Prior to the FSA, operation of the NDPP reduced summer baseflows to three cfs. The FSA now requires minimum summer instream flows from June 1 through September 30 ranging from 50 cfs and 250 cfs for critically dry and normal-wet water years, respectively (Table 3). The maximum required summer flow for NDPP operation is equivalent to summer baseflows during a pre-dam normal water year. Summer flows for median and drier years, however, are one third to one half the average summer flow conditions for pre-dam critically dry years. Operation of the NDPP, therefore, maintains summer flows typical of critically dry years in the river for approximately half of all years.

2.1.2. Gold Dredging

During the nineteenth century, the upper Tuolumne River was mined for placer (alluvial gold deposits). In the early twentieth century (after hydraulic mining was banned in California), mining shifted to the lower, river, where the channel and floodplain were dredged for gold. Dredging occurred primarily from the town of La Grange downstream to approximately RM 40 near the Roberts Ferry Bridge (Figure 13). The gold dredges excavated channel and floodplain deposits to the depth of bedrock (approximately 25 feet) and often realigned the river channel. After recovering gold from the excavated alluvium, the dredges deposited the remaining tailings back onto the floodplain, creating long, cobble-armored piles that replaced the deep, rich soils of the alluvial valley floor (Figure 13). By the end of the gold mining era, the floodplain adjacent to 12.5 miles of the river (from RM 50.5 to RM 38) had been dredged and converted to tailings piles.

Figure 13. Dredge tailings upstream of Roberts Ferry (RM 43) in 1950 showing the impact of the dredge mining on channel morphology, and illustrating the static nature of the channel due to upstream flow and sediment regulation.

Much of the tailings was excavated and removed from the floodplain to provide construction material for New Don Pedro Dam in the late 1960s. Where these tailings were removed, excavation created flat floodplain surfaces marked by intermittent remnant dredger ponds (Figure 13). The surface of these excavated floodplains is covered by very coarse cobbles. The coarseness of the substrate combined with the near-elimination of natural spring snowmelt runoff does not support recruitment and establishment of riparian vegetation on these excavated areas. These floodplain surfaces thus remain barren, vegetated primarily by exotic annual grasses. The dredger ponds left on the floodplains provide isolated open water and wetland habitats, but can also strand fish during flood recession. Tailings piles remain in the reach from RM 45.4 to RM 40.3. Miners continue to remove tailings as a source of commercial aggregate.

2.1.3. Aggregate Mining

Downstream of La Grange Dam, large-scale aggregate mining 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 and occupy 32% of the channel length in the gravel-bedded reach (Figure 14). More recent mining operations have excavated sand and gravel from floodplains and terraces adjacent to the river, usually to a depth greatly exceeding the thalweg elevation of the Tuolumne River (Figure 15). These floodplain and terrace operations excavate deep pits that are typically separated from the river by narrow dikes consisting of alluvium is left in place during the excavation (Figures 14 and 15). These dikes have failed even during moderate flows (i.e., flows exceeding 8,000 cfs, equivalent to the post-NDPP Q_{10}), resulting in direct connection of the pits to the river channel and/or capture of the river channel by the pits (Figures 14 and 15). The January 1997 flood (which peaked at 60,000 cfs downstream of the NDPP) breached nearly every embankment, resulting in extensive channel capture through aggregate pits. After the flood, aggregate miners completed emergency repairs to separate some pits from the river and place the river back into it's pre-flood channel. Most of these emergency repairs, however, were only a temporary solution.

2.1.4. Clearing Riparian Forests

The riparian forest along the Tuolumne River has been cleared for gold dredging, aggregate mining, agriculture, and urban development. Land clearing for gold dredging, aggregate mining, and agricultural and urban development has eliminated 85% of the Tuolumne River's pre-colonial riparian forest (McBain and Trush 2000). Historic and current riparian vegetation widths along the river are shown in Figure 16. Vegetation that once extended from bluff to bluff prior to the gold rush era is now limited to a much narrower band, and in many locations riparian vegetation is nonexistent or confined to a narrow band along the active channel margins. The current riparian vegetation along the Tuolumne River consists of 22 vegetation types or "vegetation series" (following the definition of vegetation series used by Sawyer and Keeler-Wolf 1995), with the most common series being valley oak (621 acres), narrow-leaf willow (515 acres), Fremont cottonwood (457 acres), and black willow (321 acres). The total area of current riparian vegetation mapped along the 52-mile lower Tuolumne River corridor is about 2,385 acres.

2.2. Anadromous Salmonids in the Tuolumne River

Prior to construction of La Grange Dam, the Tuolumne River supported fall and spring Chinook salmon (*Onchorhyncus tshawytscha*) and steelhead (*O. mykiss*). Spring Chinook salmon were extirpated from this watershed when dams eliminated access to upstream habitats (Yoshiyama et al. 1998). The historic distribution of steelhead in the San Joaquin Basin, including the Tuolumne River, is poorly known. Escapement counts conducted by the California Department of Fish and Game conducted at Dennett Dam (RM 16.2) near Modesto documented 66 steelhead in 1940 and five in 1942 (CDFG unpublished data). Individuals of this species, however, can be very plastic in their life history, and recent studies indicate that resident *O. mykiss* adults can produce anadromous young and vice versa. The National Marine Fisheries Service considers all *O. mykiss* individuals potentially to be anadromous steelhead. *O. mykiss* occur in the upper reaches of the Tuolumne River, and recent increases in summer flows required by the FSA will likely support increasing numbers of *O. mykiss*.

The Tuolumne River currently supports the largest population of fall Chinook salmon in the San Joaquin Basin. Population abundance has fluctuated widely in recent decades, declining severely during prolonged droughts. Since 1953 (when annual counts began), the number of adult Chinook salmon returning to spawn in the Tuolumne River has ranged from less than 100 (1990-1992) to 40,300 in 1985 (Figure 17). The average estimated escapement for the years 1967–1991 is 8,900 fish and for 1967-2002 is 8,000 fish. The goal of the Anadromous Fish Restoration Program is to double the 1967-1991 average escapement, resulting in a target escapement of 17,800 adult salmon and a target production (escapement+harvest) of 38,000 adult salmon (USFWS 1995a, USFWS 2001).

Adult Chinook salmon arrive to the Tuolumne River to spawn from September through December, with arrivals typically peaking in November. The age of return for adult salmon generally ranges from 2 to 4 years, and abundance varies by year-class depending on juvenile survival and ocean harvest. While spawning may occur throughout the gravel-bedded reach, almost all spawning occurs upstream of Hickman Bridge (RM 32) and is most heavily concentrated in the reach between Basso Bridge (RM 46.6) and Old La Grange Bridge (RM 51.5). The period of fry emergence varies depending upon the timing of adult arrival and incubation temperature but typically extends from January through March. Young salmon leave the river as fry, subyearlings, or yearlings. Subyearlings emigrate in late spring; yearlings emigrate in the following winter and spring.

Since 1971, TID, MID and CDFG have researched salmon population dynamics in the Tuolumne River and the San Joaquin Basin (EA Engineering 1992a, 1997). These studies are described in numerous reports submitted to FERC by TID and MID. Based on these studies and other investigations, several factors that potentially limit Chinook salmon escapement, production, and survival in the Tuolumne River have been identified (Table 5). These limiting factors are being addressed by several efforts, including additional studies (e.g., smolt survival studies during varying flow releases), the Lower Tuolumne River Restoration Plan recommendations, and implementing restoration projects (e.g., projects described in this report, gravel introduction).

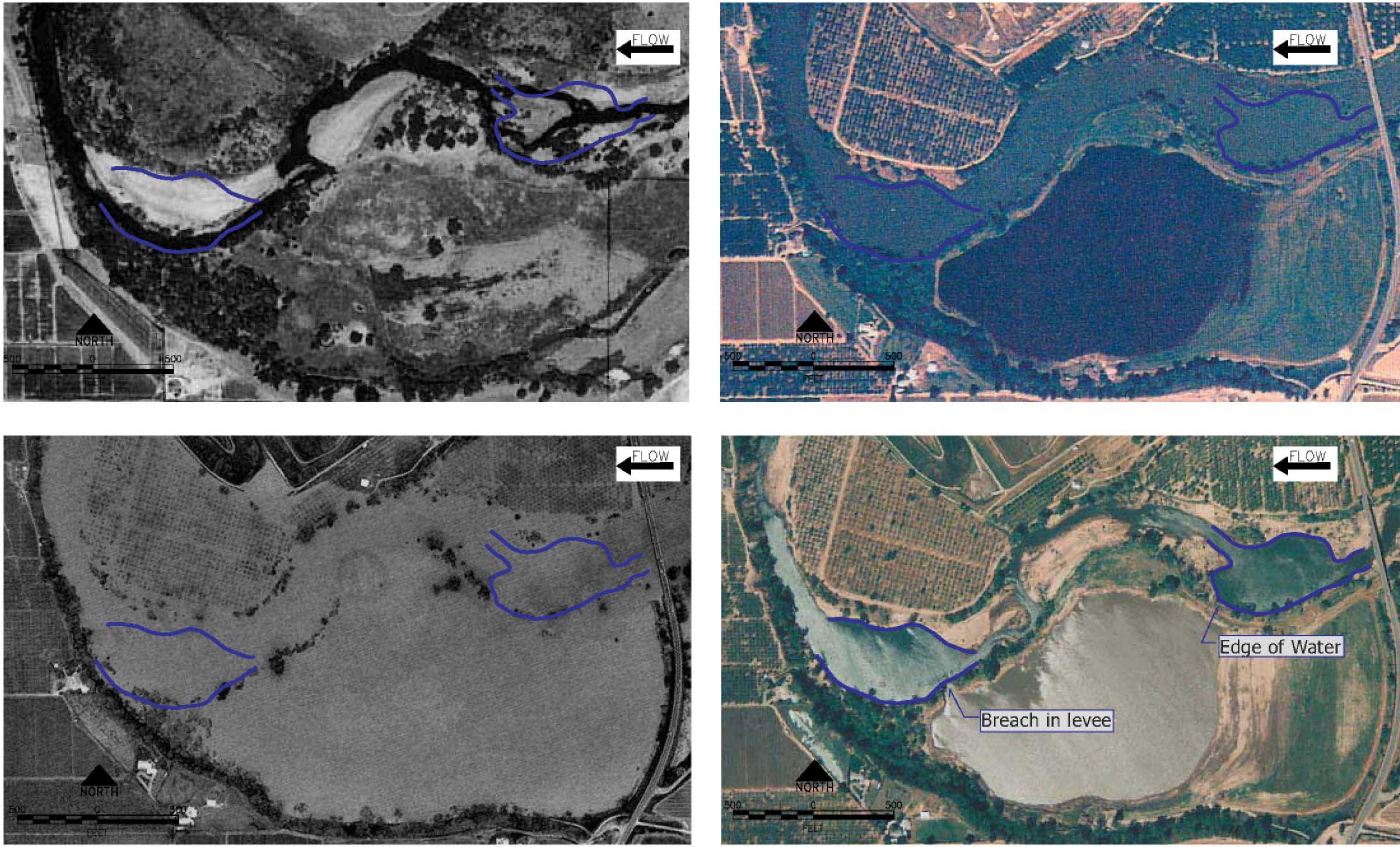

Figure 14. Floodway alterations in the SRP 9/10 Reach project sites since 1937, as well as inundation areas at 8,500 cfs (1995) and 60,000 cfs (1997).

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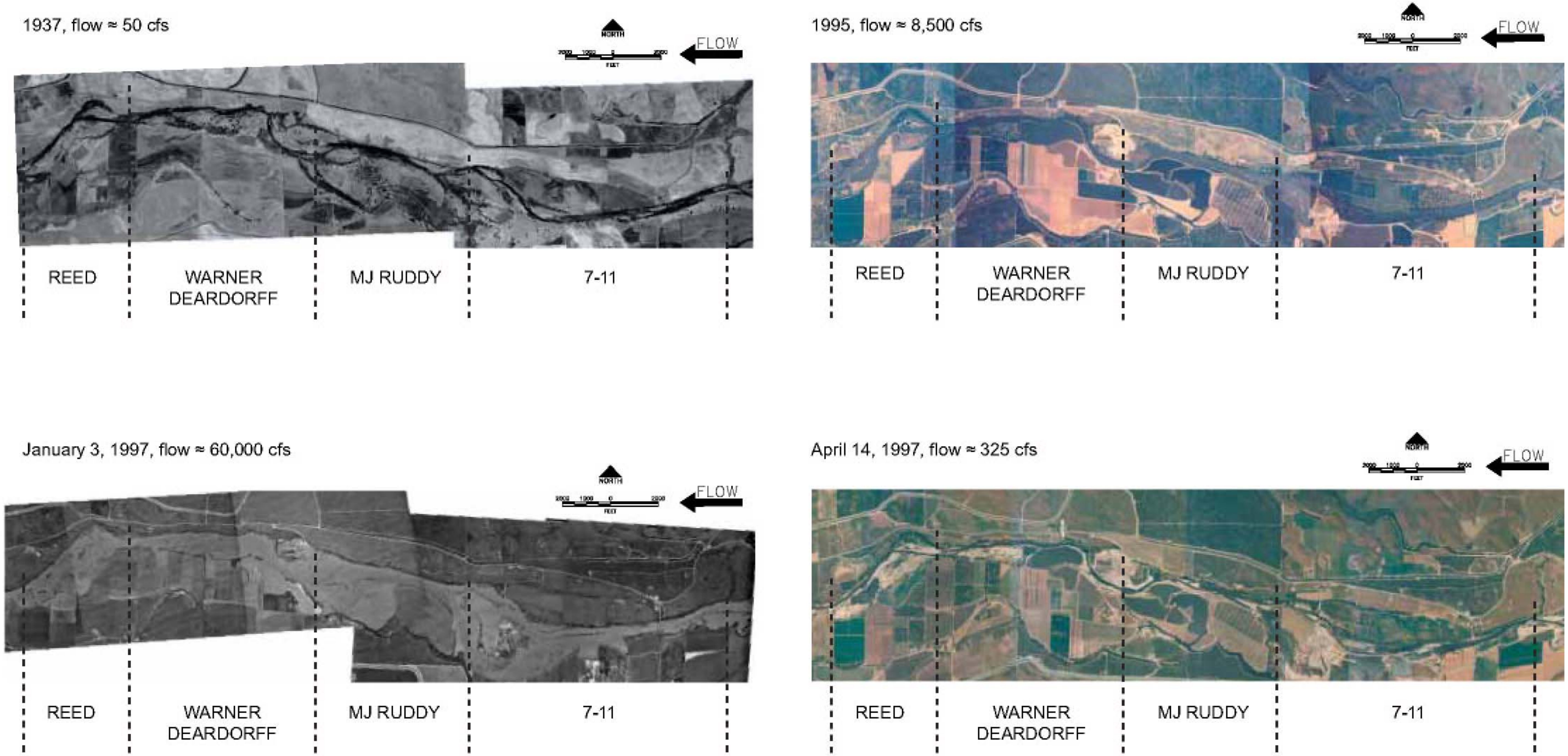

Figure 15. Floodway alterations in the Gravel Mining Reach project sites since 1937, as well as inundation areas at 8,500 cfs (1995) and 60,000 cfs (1997).

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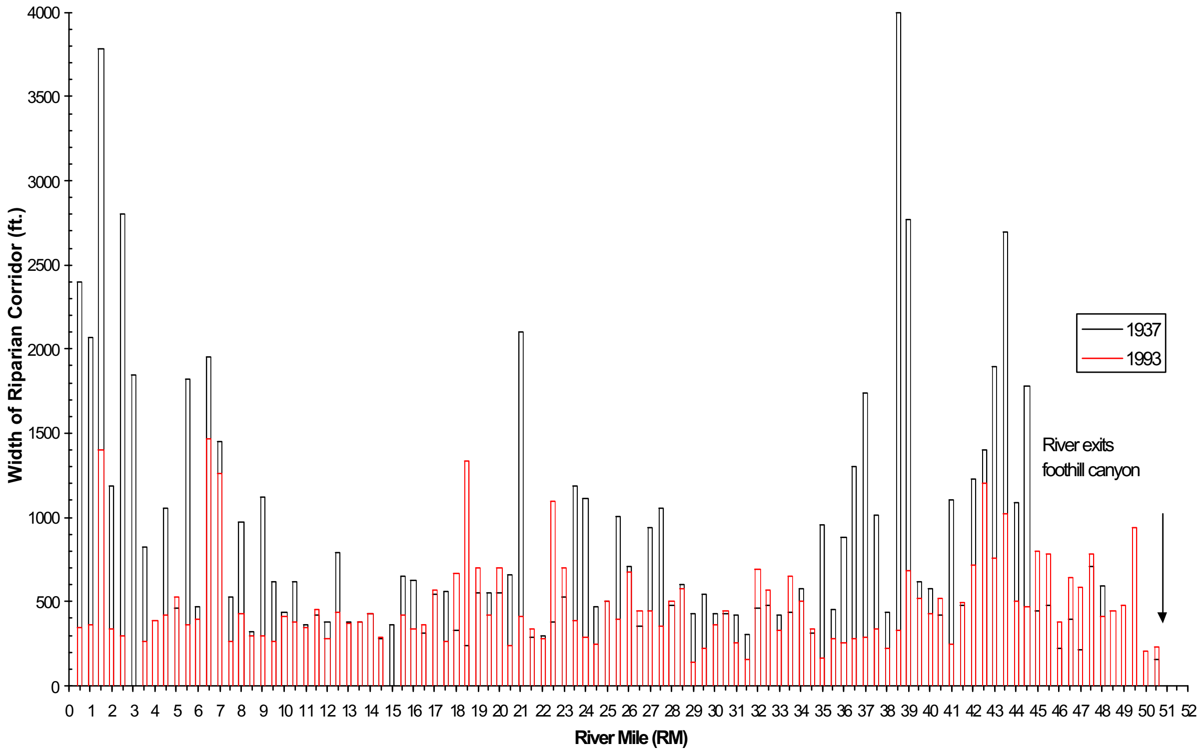

Figure 16. Riparian corridor widths in 1937 and 1993, starting at the confluence of the San Joaquin River (RM 0) and extending just upstream of the New LaGrange Bridge (RM 51.5).

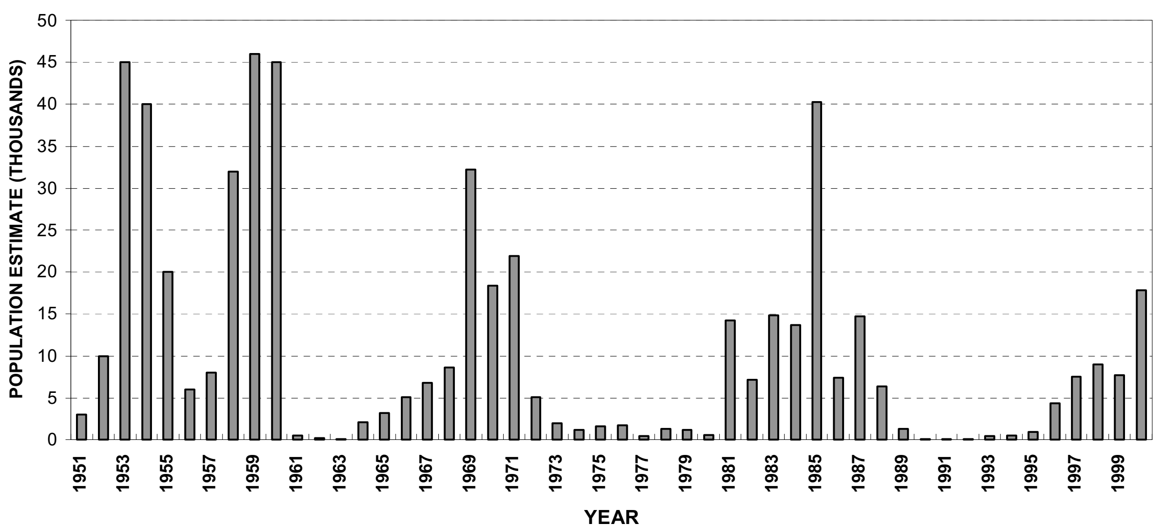

Figure 17. Historical fall-run Chinook salmon escapement estimates on the Tuolumne River.

Table 5. Major Factors Thought to Limit Chinook Salmon Population Abundance in the Tuolumne River.

Ocean/Estuarine Factors	In-river Factors
Ocean conditions: Poor ocean productivity reduces survival to adulthood. **Mortality in the Delta:** Entrainment in State and Federal diversion facilities and predation by non-native species reduces juvenile outmigrant survival. **Harvest:** commercial and sport over-harvest in the ocean and delta reduces adult escapement and spawning.	**Low spring flows:** Low spring flows reduce outmigrant survival, potentially through increases predation rates by largemouth and smallmouth bass. **Predation:** Predation by introduced fish, particularly largemouth bass, reduces outmigrant survival. **Redd superimposition and egg mortality:** Redd superimposition and poor intragravel incubation conditions reduce egg survival-to-emergence.

2.3. Effects of Historical Alterations on Geomorphic Processes and Channel Morphology

In summary, flow regulation and diversion have reduced total flow volume in the lower river, reduced summer, fall, winter baseflows, and virtually eliminated winter and spring flood flows. The reduction in flow peaks has reduced the frequency of bed scour, which has allowed riparian vegetation to encroach into the formerly active channel bed. In addition, historic (i.e., pre-NDPP) floodplains have been abandoned and are now functionally terraces that are farmed and rarely inundated by post-NDPP floods. Currently, floodplain inundation occurs only in a narrow area bordering the river that is only slightly broader than the pre-dam active channel. Recruitment of riparian vegetation on the historic floodplains (now converted to terraces) has ceased due to the lack of inundation, and the remnant cottonwood forests that occur on these terraces are becoming senescent. Lacking cottonwood recruitment, these forests will likely convert to valley oak woodland. Cottonwood recruitment is also extremely limited on current floodplains (i.e., areas that are inundated under post-NDPP flow conditions). Under natural conditions, high flows in spring dispersed cottonwood and other riparian vegetation seeds and deposited them on floodplain surfaces appropriate for their germination and recruitment. Flow regulation has nearly eliminated spring peak flows, thus eliminating the mechanism for riparian seed dispersal and creation of suitable germination sites. In addition, flow regulation has increased the rate of spring flow drawdown. Current rates typically exceed the rate of root development for young cottonwoods. Seedlings that do germinate following flood events, therefore, are susceptible to desiccation and do not survive through the summer. Combined, these effects have narrowed the river channel, reduced in-channel habitat complexity, and reduced the spatial extent and complexity of riparian forests. Reduced flows also affect aquatic biota. Some effects that have been studied in the Tuolumne River include reduction in Chinook salmon rearing habitat, reduced juvenile salmon outmigrant survival, and infiltration of sand into spawning gravels. Effects on channel and floodplain processes and morphology are summarized below.

2.3.1. Sediment Supply

Under pre-dam conditions, most coarse sediment supplied to the lower Tuolumne River originated from the upper watershed. Since 1923, Don Pedro Dam (and since 1971, the New Don Pedro Dam) has blocked coarse sediment supply to the lower river. Under current conditions, coarse sediment sources to the lower river are limited to tributaries downstream of La Grange Dam and bed and bank erosion. Tributaries entering the river downstream of La Grange Dam do not supply significant coarse sediment to the mainstem channel. Reduction in high flows has virtually eliminated coarse sediment recruitment from bank erosion. In addition to the loss of coarse sediment supply, dams and flow regulation have eliminated much of the fine sediment supply from the upper watershed, thus reducing sediment deposition on floodplains during flood events.

Most sediment currently contributed to the channel downstream of the dam consists of sand and finer size particles. Three tributaries, Gasburg, Lower Dominici, and Peaslee creeks, are the main sources of sediment to Tuolumne River downstream of La Grange Dam (McBain and Trush 2000). These creeks derive fine sediment from hillslope and orchard erosion. During the 1997 flood alone, at least 1,000 yd^3 of sand was deposited at the mouth of Gasburg Creek. During the first significant runoff event after the flood, this sand was delivered to the mainstem channel. This single event represented an introduction of fine sediment equivalent to many years of sand contribution to the low-flow channel of the Tuolumne River. In addition, during the 1997 flood, approximately 200,000 yd^3 of sediment were eroded from the New Don Pedro spillway channel. Much of the coarser component of the sediment was deposited behind La Grange Dam. The finer component of the sediment (sand and silts) was transported downstream and deposited within active channel and on the floodplain, or was transported downstream to the San Joaquin River and the Delta.

While dams have eliminated upstream sediment supply, aggregate and dredger mining has removed sediment stored in the river channel and floodplain. In-channel mining has excavated deep pits in the river channel. Because these pits are deep, they capture all bedload in transport from upstream, thus acting as semi-permanent sinks for any coarse sediment transport and depriving downstream reaches of bedload supply. Since sediment supply to the lower river has been cut off by upstream dams, the river cannot recover from past in-channel mining. These pits will persist as permanent features in the river channel. Some of the impacts associated with these pits include: replacement of natural channel features such as bars, riffles, and pools with large, lake-like pits; loss or degradation of rearing habitat for juvenile salmonids; elimination of salmonid spawning habitat; creation of habitat for warm-water, non-native fish that prey on juvenile salmonids, and impairment of sediment transport continuity.

2.3.2. Sediment Transport

Flow regulation has reduced sediment transport competence and capacity and the frequency of bed mobilization in the lower river. Under unimpaired conditions, the wide range of flood flows were sufficient to mobilize the gravel bed nearly every year, scour/redeposit the bed and move the channel laterally in many years. These sediment transport and channel migration processes cumulatively maintained active alluvial bars, prevented riparian vegetation encroachment into the bankfull channel, created new floodplains, and created and maintained a complex channel morphology (Figures 3 and 4). Under current regulated hydrologic conditions, the gravel bed is infrequently mobilized, and the sand bed is mobilized during most years. Tracer gravel experiments conducted at six locations in the river indicated that the D_{84} bed particle is not significantly mobilized at flows up to 6,880 cfs, which is less than the pre-dam $Q_{1.5}$ and equivalent to the post-NDPP Q_4 (McBain and Trush 2000). The results of the tracer gravel experiments were further supported by bed mobility models. Models based on the

Shields equation (Shields 1936) and Andrews (1994) predicted that the D_{84} bed particle is mobilized at flows ranging from 7,050 cfs to 8,250 cfs, or the Q_5 to Q_{10}, which is consistent with the tracer gravel observations. These results do not imply significant bed or bar scour occurring at these flows but rather indicate the flow at which the bed mobilization threshold in riffles is reached. In addition, field measurements of bedload transport rates conducted at Basso Bridge in 1997 indicate minimal coarse sediment transport at these flows, <70 tons/day at flows up to 6,000 cfs and <100 tons/day at flows up to 6,900 cfs (McBain and Trush 2000). More recent sampling at a steeper reach one mile upstream indicates that flows exceeding 5,000 cfs begin to mobilize small gravels (McBain and Trush 2003). With the current channel morphology and bed texture, larger flows are required to cause significant bed scour. Since the construction of the NDPP, flows exceeding 6,900 cfs have occurred only seven times.

2.3.3. Riparian Vegetation

In addition to direct clearing of riparian forests described in Section 2.2.4, flow and sediment regulation has indirectly impacted Tuolumne River riparian vegetation by modifying the hydrologic and fluvial processes that influence vegetation establishment, survival, and succession. The operation of the NDPP has eliminated large floods, thus allowing riparian vegetation to encroach into the active channel while discouraging riparian vegetation recruitment and establishment on former floodplains. Vegetation encroaching into the channel is primarily narrow-leaf willow but also includes alder and box elder. The reduction in floods and the shift in the timing of peak floods from spring to winter have also reduced recruitment and establishment of new vegetation on the floodplain. Riparian forests along the river have thus matured into even-aged stands, with little to no recruitment of new vegetation cohorts. In many stands, the older cottonwoods and oaks have become senescent, and there is little or no evidence of recent recruitment of younger cohorts of seedlings and saplings to replace them. Flow reduction has also virtually halted the processes of channel migration and meander cut-off that supported diverse riparian forests in the sand-bedded reach (see Figures 3 and 6). The elimination of these processes has reduced riparian stand complexity throughout the river. Current riparian vegetation along the Tuolumne River is dominated by relic stands on pre-NDPP floodplains and terraces and small patches of newly established (i.e., post-NDPP) vegetation along the low flow channel margins.

Exotic plants have become well established throughout the river corridor. Forty-two exotic plant species have been identified in the corridor, of which 20 are considered invasive. Eucalyptus (*Eucalyptus* spp.), edible fig (*Ficus carica*), giant reed (*Arundo donax*), and tree of heaven (*Ailanthus altissima*) are the most common invasive species found in the corridor. Although exotic plant species dominate only a small portion (2%) of the 2,385 acres of riparian vegetation mapped in the corridor, these species often comprise a significant component of the understory in stands dominated by native species. Once established, many exotic plant species can expand their distribution and abundance in the riparian corridor by outcompeting native species. Furthermore, exotic species are often more effective colonizers than native species and discourage or prevent native species from recolonizing newly created surfaces without an aggressive weeding program.

2.3.4. Channel Morphology

After more than a century of cumulative impacts, the Tuolumne River has been transformed from the complex, dynamic system described in Section 2.2 to a static remnant that is confined by encroaching land uses to a narrow corridor. Facilitated by the flood control operation of the NDPP, agricultural, urban, residential, and industrial (mining) land uses have cleared riparian vegetation and encroached onto the floodplain. These encroaching uses and their required flood protection confine the river between dikes and constrain opportunities for current and future floodplain inundation. As an illustration, the 1937 floodway at RM 38 varied from 1,000 feet to 3,000 feet, whereas in 1997 the floodway was reduced to as narrow as 175 feet (Figure 8). Within the channel, flow regulation has reduced sediment transport, allowing riparian vegetation to encroach into the formerly active channel, reducing average channel width by approximately 350 feet (64%) and reducing cross sectional variability. The reduced magnitude and frequency of bed mobility and scour events combined with the greatly reduced fine sediment transport capacity have also resulted in sand infiltration into the gravel channel bed, which has been identified as a major factor limiting Chinook salmon production in the Tuolumne River (TID/MID 1992, Appendix 2; Stillwater Sciences 2001a).

The effects of these changes can be illustrated by comparing historical and recent aerial photographs (Figures 14 and 15). The earliest photographs available were taken in 1937, long after the onset of flow diversion and riparian forest clearing but before the effects of the NDPP, gold dredging, and aggregate mining. These photographs illustrate changes typical for the reach, including excavation of in-channel mining pits; conversion of floodplains to mining pits, dredger tailings, and/or agriculture; and vegetation encroachment onto formerly active alluvial bars. Comparative photographs from the gravel-bed to sand-bed transition reach are shown in Figure 14. These photographs illustrate changes typical for the reach, including encroachment of agricultural and urban land uses into the floodplain, dike construction, and bank protection.

3. PROJECT DESCRIPTION AND OBJECTIVES

This report describes two projects; the Gravel Mining Reach and Special Run Pool's (SRP) 9 and 10. The upstream reach, named the Gravel Mining Reach, is between RM 34.3 and 40.3. Within this reach, there are four project sub-reaches (Figure 18): the 7-11 reach (RM 37.7 to 40.3), the M.J. Ruddy reach (RM 36.6 to 37.7), the Warner-Deardorff reach (RM 35.2 to 36.6), and the Reed reach (RM 34.3 to 35.2). The downstream-most reach, named Special Run Pool 9 and 10, is just upstream of the sand-bed transition between river mile (RM) 25.0 to 25.9 (Figure 14). Within this reach, there are two project sites: SRP 9 and SRP 10. These reaches are described in more detail in the following sections.

3.1. Gravel Mining Reach

Aggregate extraction in the Gravel Mining Reach began more recently than at the SRP 9 and 10 sites because of the greater distance from the primary aggregate demand in the City of Modesto. Aggregate extraction in this reach began in the late 1960s and continues today. Both in-channel and floodplain mining have occurred in this reach, and the river corridor has been dramatically altered by mining activities, as well as agricultural encroachment onto the floodplain (Figure 15). As a result, much of the floodplain and terraces in this reach has been converted to open water pits, and the river channel and riparian corridor are confined between dikes left from mining activities. Within the reach, the river channel is bordered by 11 mining pits and one captured settling pond on the left (south) bank and three settling ponds on the right (north) bank. On the left bank, dikes constitute 17,500 feet (55%) of the total river bank length. On the right bank, dikes constitute 735 feet (2%) of the total river bank length. Mining continues in this reach outside the restoration area and will continue to convert floodplain and terrace areas to open water pits in the future.

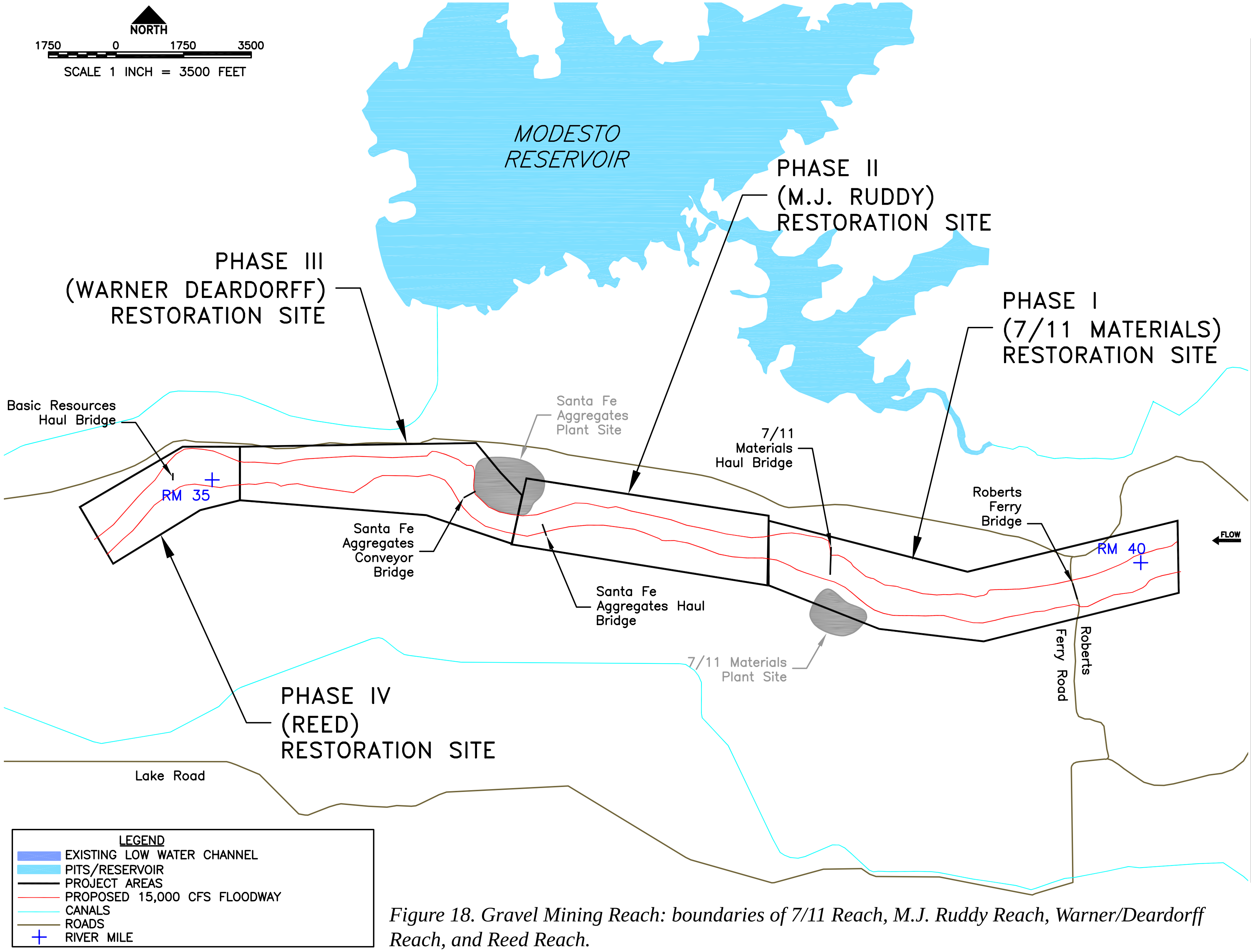

Figure 18. Gravel Mining Reach: boundaries of 7/11 Reach, M.J. Ruddy Reach, Warner/Deardorff Reach, and Reed Reach.

Failure of dikes separating the river channel from mining pits is a major impetus for restoration in this reach. These pit embankments repeatedly fail during moderate-to-large floods (i.e., floods exceeding 8,000 cfs, or floods greater than a post-dam 5-year flood). The January 1997 flood caused extensive damage in this reach, not only to the river channel and dikes but also to aggregate extraction facilities. Damage included multiple dike failures, complete capture of the river channel by aggregate pits in the 7/11 Reach, loss of the M.J. Ruddy conveyor bridge, irreparable damage to the Roberts Ferry Bridge, and damage to other plant operation structures.

3.1.1. Goals and Objectives

The primary goal of the Gravel Mining Reach project is to re-define a riparian floodway that will improve flood conveyance, geomorphic processes, riparian vegetation, and aquatic habitat throughout the reach. The project objectives were presented in the Habitat Restoration Plan for the Lower Tuolumne River Corridor (McBain and Trush 2000) and were reiterated in the proposals to CALFED to fund restoration implementation. These objectives are to:

- restore a floodway width that will safely convey floods of at least 15,000 cfs, which corresponds to a controlled release capacity from New Don Pedro Dam of 14,000 cfs plus 1,000 cfs of tributary accretion;
- improve salmon spawning and rearing habitats by restoring an alternate bar (pool-riffle) morphology, restoring spawning habitat within the meandering channel, and filling in-channel mining pits;
- prevent salmon mortality that results from frequent connection between the Tuolumne river and off-channel mining pits;
- restore native riparian communities on appropriate geomorphic surfaces (i.e., active channel, floodplains, terraces) within the restored floodway;
- restore habitats for other native species (e.g., egrets, ospreys, herons);
- allow the channel to migrate within the restored floodway to improve and maintain riparian and salmonid habitats;
- remove floodway constrictions created by inadequate dikes (e.g., dike failure above a certain discharge threshold); and
- decrease risk of flood damage to aggregate extraction operations, bridges, and other human structures.

3.1.2. Restoration Opportunities and Constraints

Several restoration opportunities and constraints affect the range of potential restoration alternatives in this reach. Key opportunities and constraints are listed below.

3.1.2.1. Opportunities

- Having recently faced the effects of the 1997 flood, mine operators and land owners are generally supportive of restoration measures that would also reduce flood hazards to their operations, structures, and properties.
- The reach is used by Chinook salmon for spawning and rearing but is the most vulnerable reach in the upper portion of the restoration planning area to future habitat degradation resulting from capture of the river channel by mining pits.

- Significant improvements in the quality and extent of habitat for Chinook salmon and riparian-dependent species can be achieved by isolating mining pits from the channel and constructing a functional floodplain and channel.
- Large quantities of aggregate needed for restoration construction are available from operators within the project reach.
- Because mine operations border the project, aggregate can be delivered to the site and construction can be implemented without heavy equipment accessing public roads.
- Due to the expected future mining activity, the restoration project will establish a permanent corridor that will contain a majority of riparian forest along this reach of the river.

3.1.2.2. Constraints

- All land in the reach is privately owned, and all restoration implementation will depend upon the participation of willing landowners.
- Mining will continue in the reach, though it will be set back farther from the river. Mine pits, therefore, will border the site and may have unknown effects on ground water dynamics, wildlife movement (i.e., migration routes), and other processes that could affect restoration project performance.
- The California Department of Mines and Geology (CDMG) has designated almost the entire valley floor within the gravel-bedded reach as “aggregate resources” or “aggregate reserves” and estimates that 217 million tons of commercial grade aggregate could be harvested from this area (Higgans and Dupras 1993). The CDMG estimates assume continuation of current pit mining practices, which would result in continued creation of deep pits along the river and continued impacts to the river ecosystem. As of 2000, mine operators have obtained permits from Stanislaus County to mine 27.7 million tons of aggregate from the reach.
- In addition to purchasing easements to protect the restoration project, mineral rights for unmined parcels within the restoration site must be purchased.
- The project will require large volumes of fill to construct the floodplain and river channel. Although this fill is available from on-site, which reduces transport cost, fill must be purchased at significant cost.
- The project cannot increase flood hazards to private property or structures outside the restoration area.
- The project cannot increase the vulnerability of private property to vandalism or trespass.

3.2. SRP 9 and 10 reach

The SRP 9/10 reach extends from RM 25.9 to RM 25 (Figure 14). The pit of SRP 9 extends from RM 25.9 to RM 25.75; the pit of SRP 10 extends from RM 25.44 to RM 25.24. The project boundary for the SRP 9 & 10 reach is now proposed to extend downstream to RM 25.0 to allow flexibility in river channel relocation for the SRP 10 project. SRP 9 is separated from SRP 10 by a 2,000 ft long reach of channel that is relatively intact. Instream aggregate extraction on the Tuolumne River likely first began at SRP 9 in the 1930’s. This location was still in the gravel-bedded reach of the river, and was the closest gravel source to the City of Modesto, where the demand for aggregate was greatest. At that time, aggregate was extracted with drag lines within the active channel, resulting in wide, deep pits (Figure 14). SRP 9 is 400 feet wide and ranges from 6 to 19 feet deep. SRP 10 is 400 feet wide and ranges from 10 to 36 feet deep. The south-bank floodplain adjacent to SRP 10 has also been mined. A narrow embankment separates this floodplain mine pit from SRP 10, was breached by the 1997 flood, and connected the pit to the river channel. As these pits were constructed, riparian vegetation was removed. Instream salmonid habitat was destroyed and converted to non-native fish habitat. Two of these non-native species, smallmouth bass (*Micropterus dolomieu*) and largemouth bass (*Micropterus salmoides*), are significant predators of juvenile salmon, and their predation likely causes a substantial reduction in salmon production from the Tuolumne River, particularly during drier water years (EA Engineering 1992b). The pits also trap any sediment transported from upstream reaches and thus function as impediments to restoring long-term sediment routing through the Tuolumne River corridor.

3.2.1. Goals and Objectives

The primary goals of the SRP 9 and 10 projects are to reduce habitat for largemouth bass, improve bedload routing through the reach, and construct a geomorphically functional channel and floodplain. The project objectives were presented in the Habitat Restoration Plan for the Lower Tuolumne River Corridor (McBain and Trush 2000) and reiterated in the proposals to CALFED to fund restoration implementation. These objectives are to:

- reduce/eliminate habitat favored by predatory bass species and replace it with high quality Chinook salmon habitat;
- restore channel and planform morphology scaled to contemporary and future sediment and hydrologic regimes;
- restore sediment transport continuity through the reach; and
- revegetate reconstructed floodplains and terraces with native woody riparian species planted on fluvial surfaces appropriate for each species life cycle.

3.2.2. Restoration Opportunities and Constraints

Several restoration opportunities and constraints affect the range of potential restoration alternatives in this reach. Key opportunities and constraints are listed below.

3.2.2.1. Opportunities

- The reach provides habitat for smallmouth bass and largemouth bass. Reduction in largemouth bass habitat is expected to reduce bass population abundance and thus reduce predation on juvenile Chinook salmon.
- The embankment separating the floodplain pit to the south of SRP 10 from the river channel was breached in the 1997 flood, directly connecting this large pit to the channel. Repair of this embankment will isolate the pit (and its bass population) from the river and will prevent juvenile and adult salmon from entering the pit.
- The primary landowner within the project reach supports implementing the restoration project.
- The site is readily accessible from existing roads.
- Geer Road was identified in the FERC Settlement Agreement as a potential alternate point for diverting irrigation or domestic flows that would normally be diverted at La Grange Dam, 26 miles upstream. Providing a point of diversion downstream of La Grange Dam would increase flows in the primary spawning reach of the river, thus benefiting all life stages of salmonids. Portions of the infrastructure needed for the diversion could be constructed in conjunction with the SRP 9 and 10 restoration.

3.2.2.2. Constraints

- With the exception of Fox Grove County Park, all land is privately owned, and all restoration implementation will depend on the participation of willing landowners.
- The project will require approximately 500,000 yd^3 of aggregate to fill the pits and construct the floodplain and river channel. The aggregate is not available on-site within the river corridor and must be trucked in. The large number of truck trips required would impact local roads, traffic, and air quality. Hauling from off-site sources also greatly increases cost of fill material.
- The project cannot increase flood hazards to private property or structures outside of the restoration area.
- The project cannot increase the vulnerability of private property to vandalism or trespass.
- Low slope of the reach and upstream coarse sediment traps (SRP 7 and 8) discourages ability of project to transport and route coarse sediment.

4. CONCEPTUAL MODELS AND DESIGNS

Conceptual models provide a useful tool for describing our working understanding of reference and current conditions in the river ecosystem and the anticipated effects of restoration actions on ecosystem function. While simplistic, these models present a structured articulation of current hypotheses that link physical processes, habitat structure, and population response. Because our knowledge is imperfect, these models must be revised as we learn from our restoration efforts on the Tuolumne and other rivers.

4.1. Restoration conceptual models

The TRTAC Monitoring Subcommittee developed a series of interconnected conceptual models describing the effects of historical modifications on the Tuolumne River ecosystem, factors affecting the river's Chinook salmon population, and anticipated effects the Gravel Mining Reach and SRP 9/10 projects on the river and its salmon population. These conceptual models were prepared for the Adaptive Management Forum, convened by the Anadromous Fish Restoration Program (AFRP) and CALFED working through the Information Center for the Environment (University of California–Davis) to evaluate the planning and implementation of large-scale river restoration projects in the Central Valley. The suite of models is described in detail in the Adaptive Management Forum Summary Report (Stillwater Sciences 2001b).

The conceptual model of reference conditions for the Tuolumne River is described in Section 2.1. A conceptual model of current conditions for the Tuolumne River is shown in Figure 19, and a summary of reach specific restoration issues is shown in Table 6. The broad-scale conceptual model in Figure 19 illustrates linkages between physical inputs, physical processes, habitat structure, and biological responses and the effects of dams and mining on these linkages. In this model, dams have altered seasonal flow patterns in the lower river, reduced peak flow magnitude, reduced fine sediment supply, and eliminated coarse sediment supply. In addition, aggregate mining and gold dredging have reduced coarse sediment supply by removing stored sediment from the channel and floodplain and by trapping coarse sediment that is transported from upstream sources. These reductions in key inputs to the system (i.e., sediment and water) have reduced sediment transport, channel migration and avulsion, recruitment of large wood, and floodplain inundation, resulting in channel incision, bed

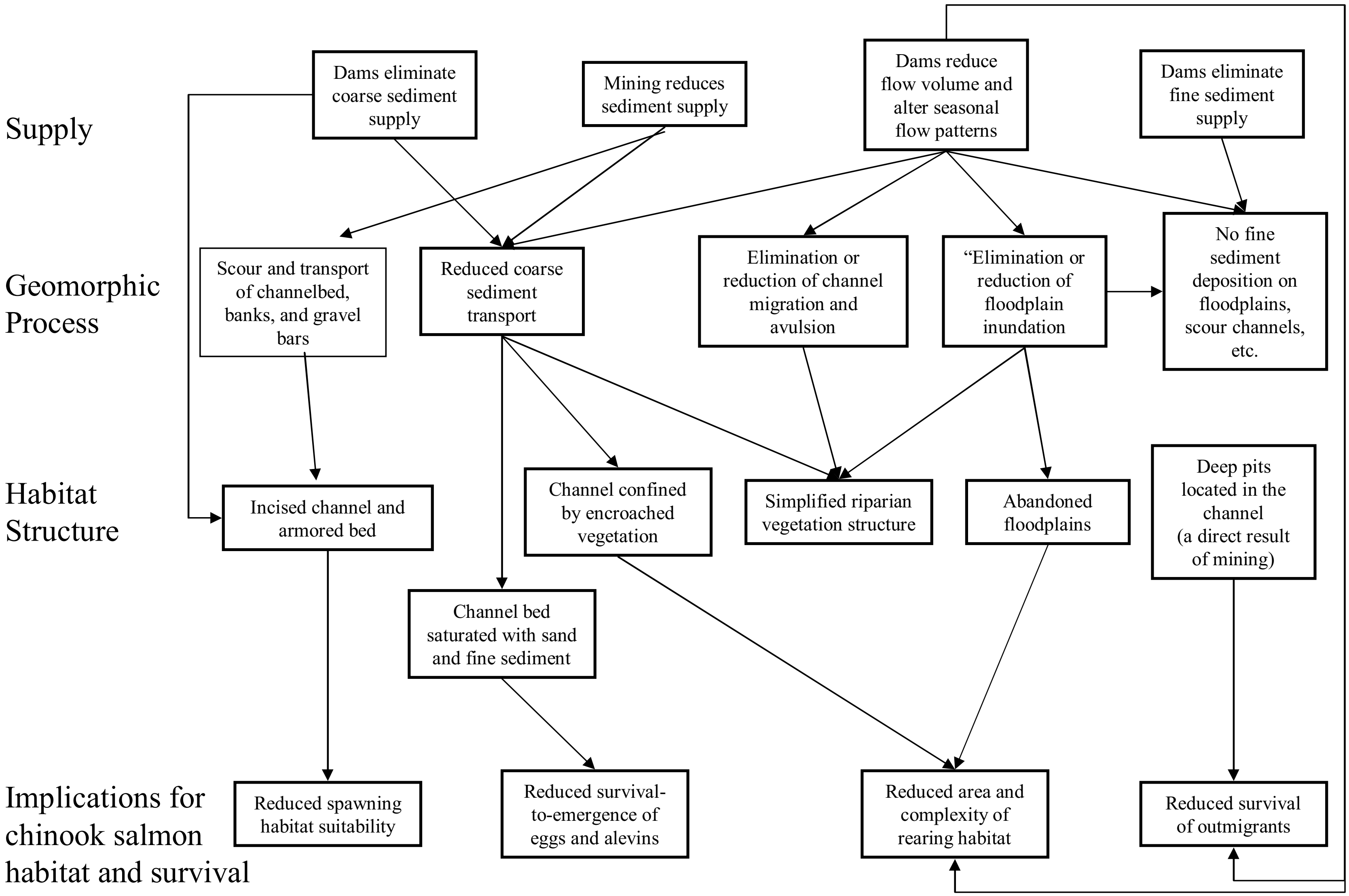

Figure 19. Conceptual model of how land and water management have altered reference geomorphic and biotic conditions along the Tuolumne River corridor (from Stillwater Sciences, 2001b).

armoring, channel narrowing (through riparian vegetation encroachment), and abandonment of pre-dam floodplains. Aggregate mining has also left large, lake-like pits in the river channel. Combined, these alterations to geomorphic inputs and processes have changed aquatic and terrestrial habitat structure and reduced aquatic habitat quality for Chinook salmon spawning, incubation, rearing, and outmigration. These alterations have also contributed to the limiting factors summarized in Table 5.

The restoration projects attempt to improve habitat structure and increase Chinook salmon abundance by addressing the geomorphic inputs and processes components of the model. While modifications to certain flood control releases would greatly benefit the restoration projects and improve their performance, they are not mandated and would be difficult to obtain. The restoration projects have been designed to accommodate and benefit from these flood control release modifications (if they occur in the future), but again do not mandate these flood control release modifications to be successful. The restoration projects attempt to reconstruct the bankfull channel, floodplain, and floodway that is geomorphically functional within the contemporary (i.e., regulated) flow regime. The project significantly increases floodway conveyance from existing conditions, and implementation will remove an important bottleneck that will improve flood control flexibility.

Recommended improvements in flood control releases include:

- increasing allowable flood releases to 15,000 cfs upstream of Dry Creek and 20,000 cfs downstream of Dry Creek;
- enabling flow releases between 9,000 cfs and 15,000 cfs for flood control and ecological restoration after mid-February to reduce scour of Chinook salmon redds;
- extending the duration of flows in the 4,000 cfs to 6,000 cfs range for several days following a larger flood release to transport fine sediment downstream of spawning reaches and initiate fine sediment deposition on floodplains;
- limiting the duration of large flow releases (e.g., 12,000-15,000 cfs) to minimize downstream gravel flux and attenuate flood magnitude in downstream reaches;
- reducing flood releases at the rate specified by the FSA to minimize stranding potential;
- releasing larger magnitude, short duration flows (12,000 cfs to 15,000 cfs) to scour riparian vegetation seedlings from alluvial bars;
- during extremely wet years (such as 1984 and 1998), instead of releasing 5,500 cfs for prolonged periods, release a large enough peak to accomplish geomorphic needs (as shown in Figure 20) and fashion the receding limb of spring flows to support recruitment and establishment native riparian vegetation (as shown in Figure 21).

The need for these improvements became more apparent as a result of the January 1997 flood event, and also as a result of the Lower Tuolumne River Corridor Restoration Plan (McBain and Trush 2000). The 1997 flood resulted in significant damage to the river channel in confined locations, and two proposals were prepared and submitted to CALFED shortly thereafter seeking funding to develop a long-term floodway restoration solution for the Gravel Mining Reach and the SRP 9/10 projects. Significant regulatory issues would need to be resolved to achieve such release modifications.

4.2. Conceptual Designs

These proposals developed conceptual designs that addressed the Chinook salmon limiting factors identified in Table 5, as well as the river corridor restoration goals developed in the Restoration Plan. For both projects, the attributes of alluvial river integrity described in the Tuolumne River Corridor Restoration Plan guide our "geomorphically functional" designs (McBain and Trush

Table 6. Geomorphic, land use, and restoration characteristics of reaches in the lower Tuolumne River.

Reach		**Boundaries**	**Slope**	**Bed and Bank Material**	**Valley Confinement**	**Dominant Land Use**	**Restoration Issues**
1	Lower Sand-bedded Reach	RM 0.0 – 10.5	<0.0003	Sand	None	Agriculture (row crops and dairies)	• Agriculture confines the river corridor. • Levees and rock revetment limit channel migration. • Floodplains have been converted to agriculture and are isolated from the river by levees and mine embankments
2	Urban Sand-bedded Reach	RM 10.5 – 19.3	<0.0003	Sand	Moderate	Predominantly urban, some agriculture	• Urban and agriculture land uses confine the river corridor. • Modesto sewage treatment plant is a major floodway bottleneck. • Inflow from Dry Creek may degrade water quality. • Several bridges span the channel. These bridges limit channel migration and flood conveyance. One bridge, a railroad trestle, also traps woody debris, preventing debris from reaching downstream areas and creating additional flood risk.
3	Upper Sand-bedded Reach	RM 19.3 – 24.0	<0.0003	San	Little	Predominantly agriculture (row crops) and some rural	• Agriculture confines the river corridor. • Levees and rock revetment limit channel migration. • Floodplain forests have been converted to agriculture and are isolated from the river by levees and mine embankments
4	In-channel Mining Reach	RM 24.0 – 34.2	0.0003 - 0.0015	Gravel	Little	Off-channel aggregate mining and agriculture (orchards)	• Deep in-channel mining pits dominate the reach. Pits capture bedload, provide habitat for non-native predatory fishes, and convert potential floodplains to open water. • Agriculture confines the river corridor.
5	Gravel Mining Reach	RM 34.2 – 40.3	0.0010 - 0.0015	Gravel	Little to Moderate	Off-channel aggregate mining and agriculture (row crop and orchards)	• Agriculture and mining pit embankments confine the river corridor. Floodplain is very narrow or absent, lack of alternate bars. • Channel bed is infrequently mobilized. • Channel lacks habitat complexity. • Floodplains have been mined or converted to agriculture.

Table 6. Characteristics of Tuolumne River Reaches, continued.

Reach		**Boundaries**	**Slope**	**Bed and Bank Material**	**Valley Confinement**	**Dominant Land Use**	**Restoration Issues**
6	Dredger Tailings Reach	RM 40.3 – 46.6	0.0010-0.0015	Gravel	Little	Agriculture (grazing)	• Riparian vegetation has encroached into formerly active channel. • Dredger tailings cover floodplain and confine river corridor. • Channel bed is infrequently mobilized. • Channel lacks habitat complexity. • Floodplains are more frequently inundated than downstream reaches but the coarseness of these constructed floodplains discourages riparian vegetation recruitment.
7	Dominant Spawning Reach	RM 46.6 – 52.1	0.0010-0.0015	Gravel	Little	Agriculture (grazing)	• Upper limit of anadromous fish access • Riparian vegetation has encroached into formerly active channel. • Channel bed is infrequently mobilized. • Channel lacks habitat complexity. • Dredger tailings have been removed from floodplain, but excavated floodplain remain barren. • Remnant dredger ponds strand fish during flood recession. • Sand infiltration into bed reduces salmon survival-to-emergence. • Floodplains are more frequently inundated than downstream reaches but the coarseness of these constructed floodplains and lack of fine sediment sources (silts) discourages riparian vegetation recruitment.

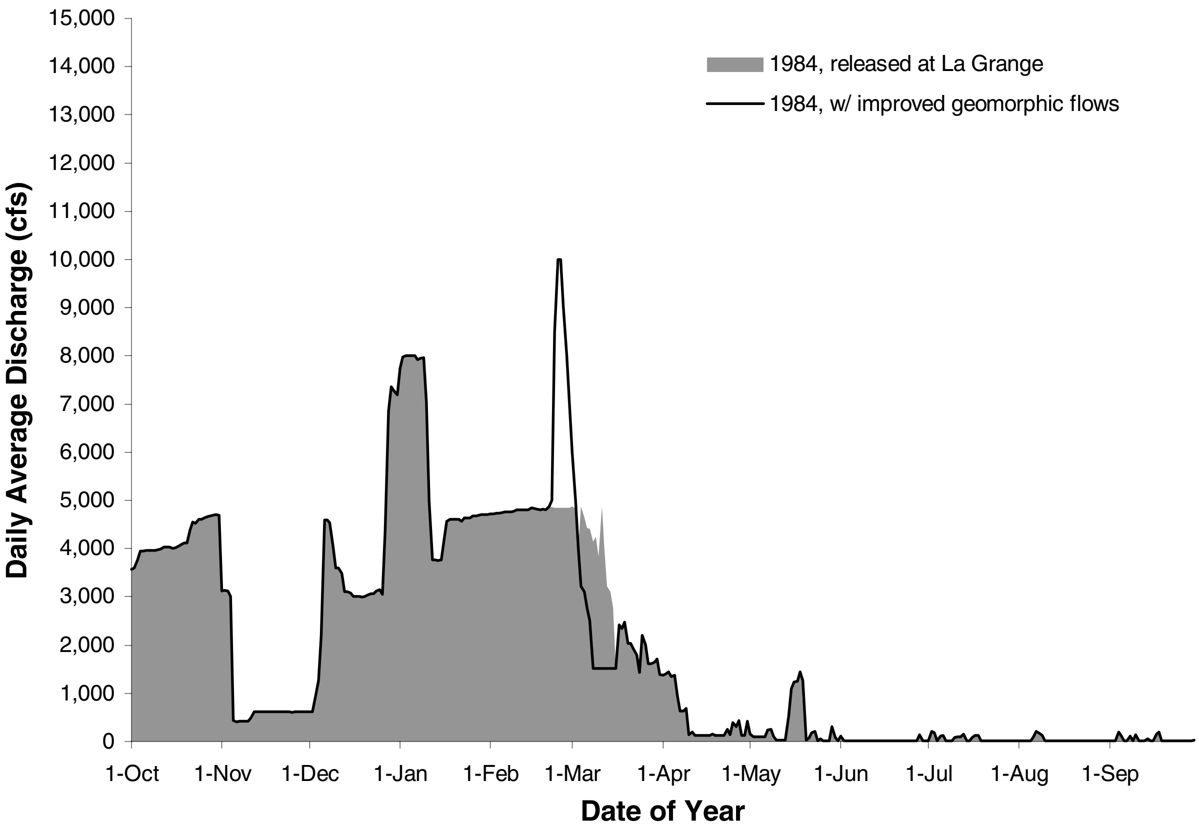

Figure 20. Water year 1984 flood control release hydrograph and example of recommended hydrograph modification to improve geomorphic processes.

2000). Fundamentally, the projects attempted to recreate a well defined floodway capable of safely conveying 15,000 cfs, allowing some lateral channel movement, recreating an initial bankfull channel, reducing salmon predator habitat, restoring sediment transport continuity, and partially revegetating constructed surfaces within the floodway. An important goal of the floodplain reconstruction was to create surfaces where woody riparian vegetation, particularly cottonwood and black willow, could naturally regenerate under post-NDPP flow conditions. As will be discussed later, there were significant differences between design team members regarding the revegetation effort.

4.2.1. SRP 9 and 10

The conceptual model for restoring geomorphic processes, riparian habitat, and aquatic habitat at the SRP 9 and 10 projects is shown in Figure 22, and the conceptual model of potential improvement in smolt production through the SRP 9/10 Reach is shown on Figure 23. Because this reach contains large deep pits that harbor large numbers of predatory piscivores, the primary conceptual design component of this project is to greatly reduce salmon predator habitat by filling the pits and reconstructing a natural channel morphology. Other treatments shown on Figure 23 may occur in the future. The initial conceptual design, as submitted to CALFED in 1997, is shown in Figure 24. For both SRP 9 and 10, the pits would be filled, and a reconstructed mainstem channel and floodplain would be scaled to contemporary flow conditions. In-channel and floodplain geomorphic and riparian processes may be improved somewhat, but the low slope and low sediment supply due to upstream pits would prevent significant improvements in geomorphic processes in the reach. However, filling

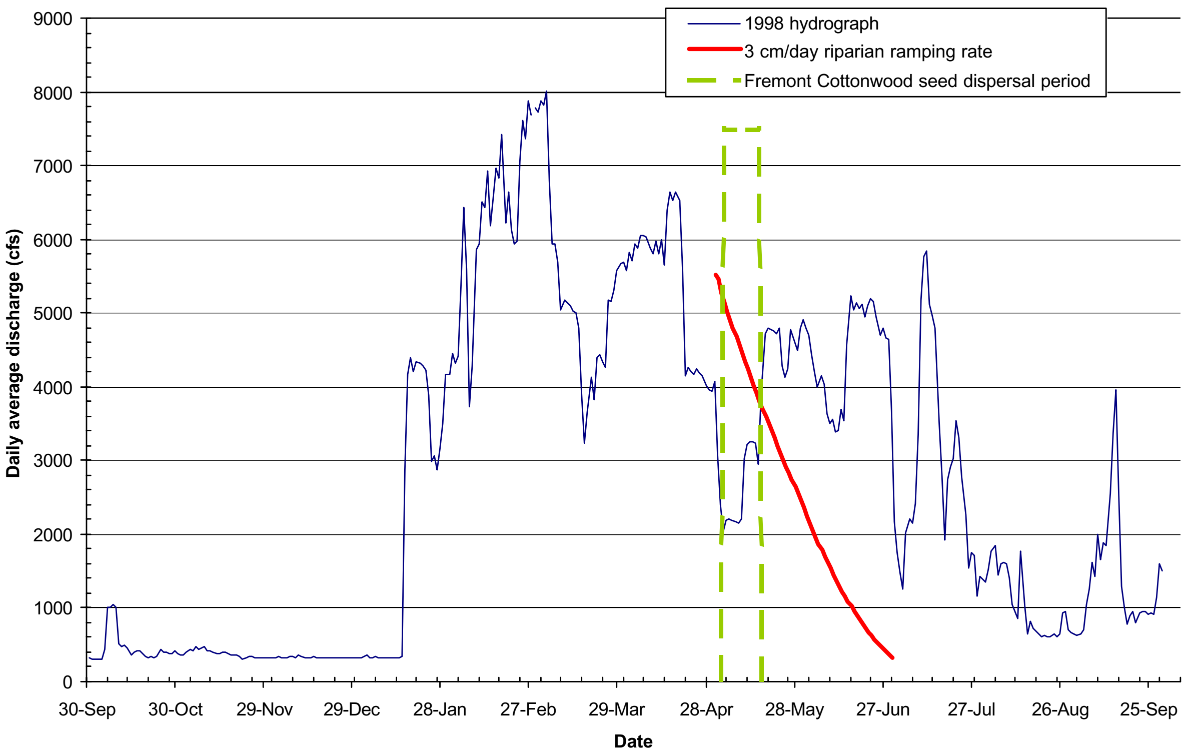

Figure 21. Water year 1998 flood control release hydrograph and example of hydrograph modification to improve riparian regeneration (based on rating curve at the Old LaGrange Bridge, RM 50.5).

the pits would significantly reduce predation on outmigrant Chinook salmon, increase juvenile salmon rearing habitat, and increases juvenile salmon survival. Constructing an appropriately scaled channel may eventually increase the frequency of bed mobilization (particularly if upstream pits are filled), and restores sediment transport continuity through the SRP 9 and 10 reach. As with the Gravel Mining Reach, the channel design avoids use of bank revetment (except at the infiltration gallery location), thus allowing the reconstructed channel to migrate when flows are of sufficient magnitude. The rate of channel migration, however, will continue to be reduced, compared to natural conditions, due to continued flow regulation and low slope of the reach. By constructing a floodplain inundated by small, frequent floods, the project provides a surface for colonization by riparian vegetation. Initial planting and maintenance of riparian vegetation would occur.

4.2.2. Gravel mining reach

The conceptual model for the Gravel Mining Reach project is shown in Figure 25, and conceptual designs are shown in Figures 26 through 29. The key conceptual design for the Gravel Mining Reach is to increase floodway width and hydraulic capacity as the foundation for habitat recovery and long-term preservation. Reconstructing a channel, floodplain, and floodway scaled to contemporary flow conditions, combined with planting native riparian vegetation on the reconstructed floodplain and maintaining coarse sediment supply, improves in-channel and floodplain geomorphic and riparian processes, and improves Chinook salmon spawning and rearing habitat. Constructing an appropriately scaled channel and maintaining coarse sediment supply balances sediment transport capacity with sediment supply and provides a mainstem channel and floodplain that functions

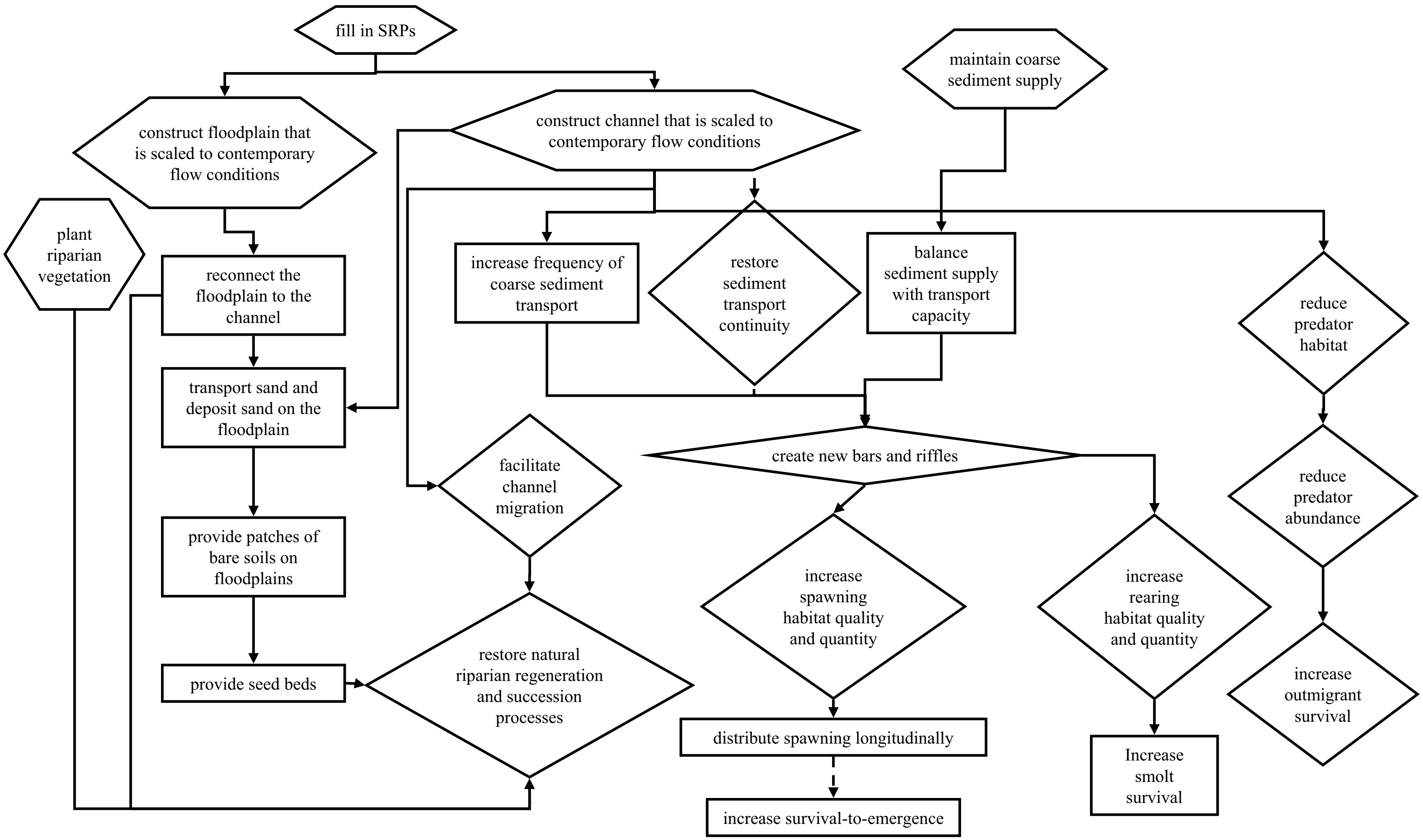

Figure 22. Conceptual model for improving geomorphic processes, riparian habitat, and aquatic habitat at the SRP 9 and SRP 10 restoration project (from Stillwater Sciences, 2001b).

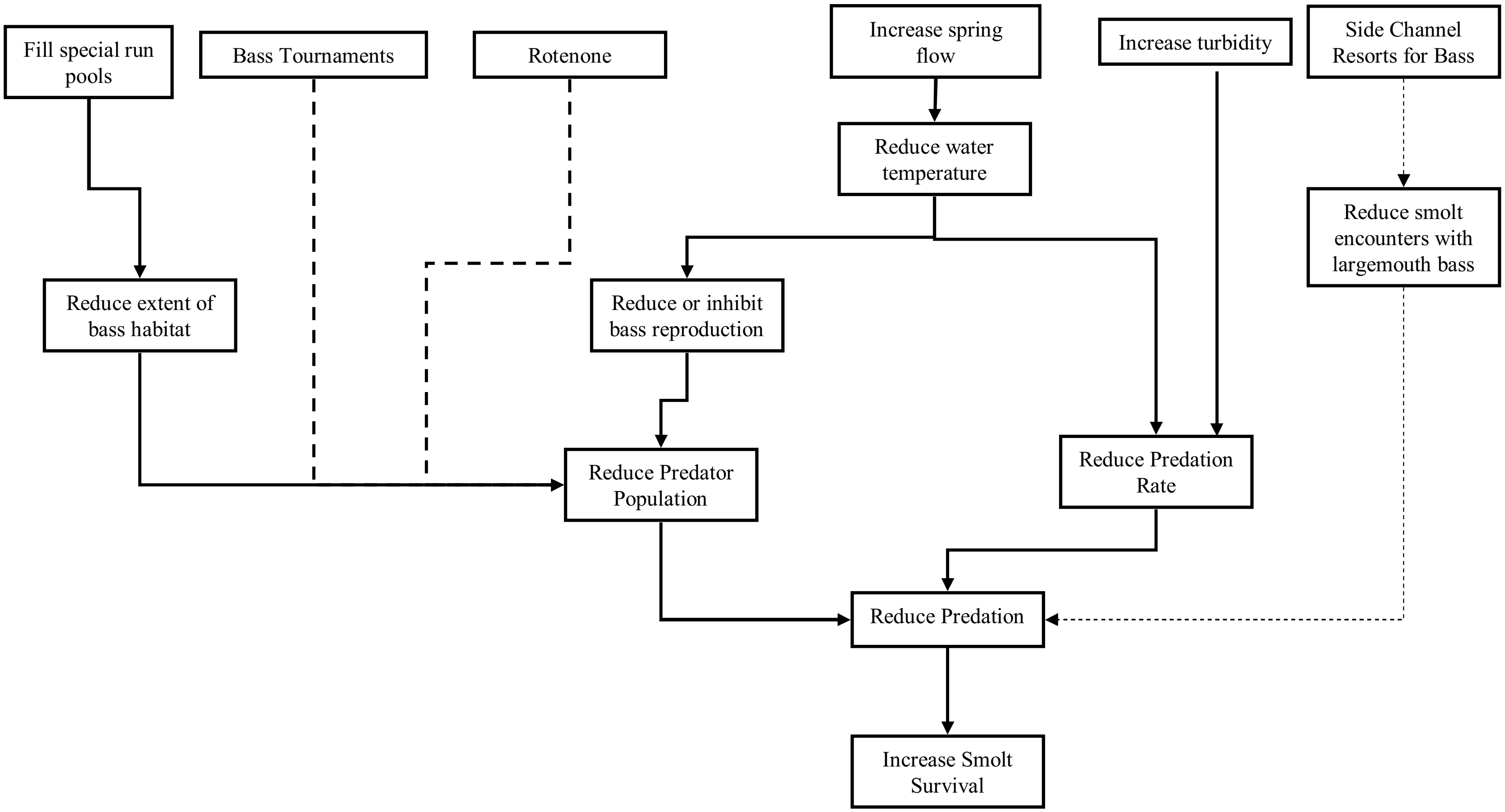

Figure 23. Conceptual model for improving smolt production through the SRP 9 and SRP 10 restoration projects (from Stillwater Sciences, 2001b).

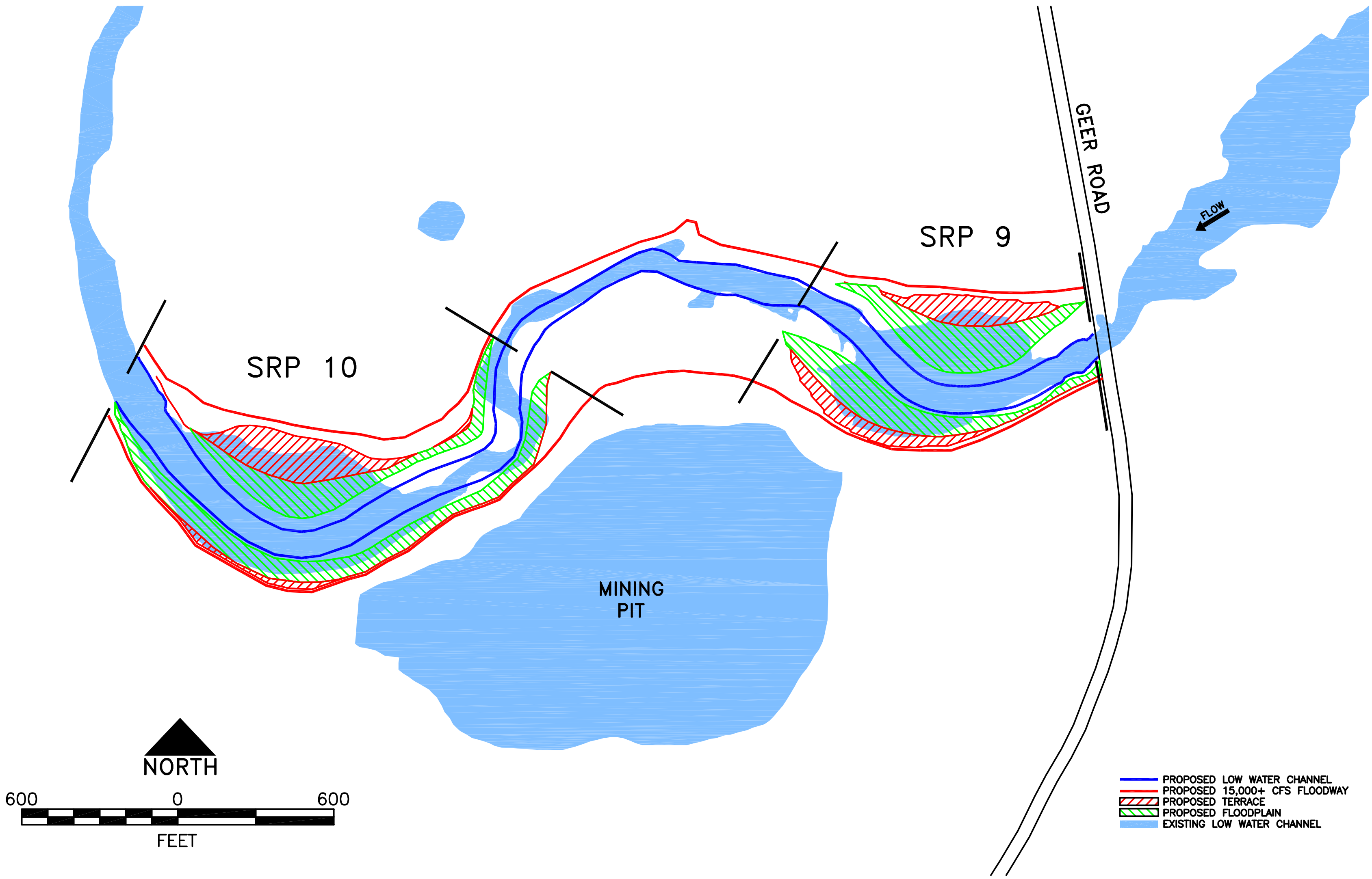

Figure 24. Conceptual design for the SRP 9 and SRP 10 projects, as submitted to CALFED in 1997 (from EA Engineering and McBain & Trush 1997).

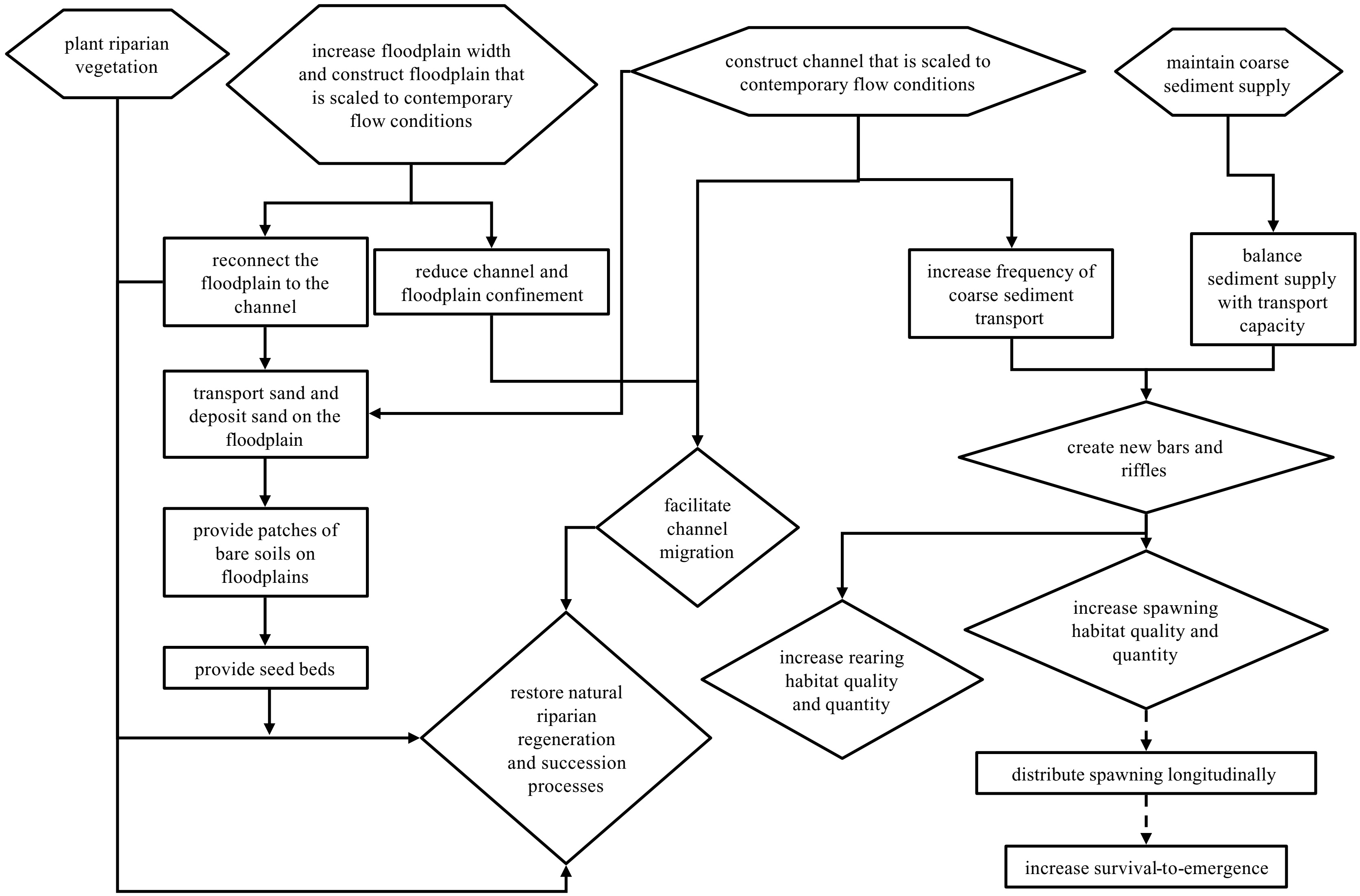

Figure 25. Conceptual model for the Gravel Mining Reach restoration project (from Stillwater Sciences, 2001b).

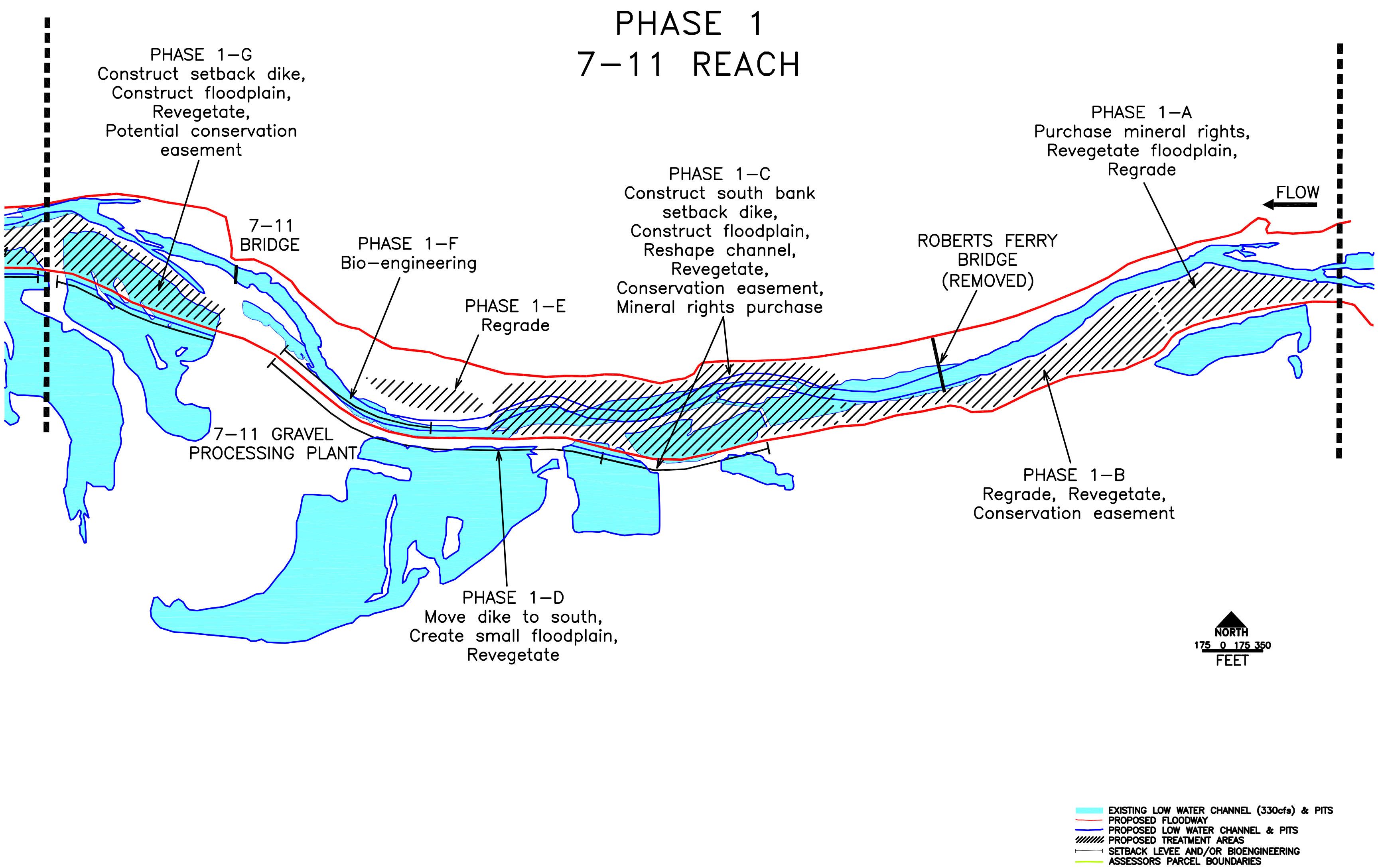

Figure 26. Conceptual design for the 7/11 portion of the Gravel Mining Reach, as submitted to CALFED in 1997.

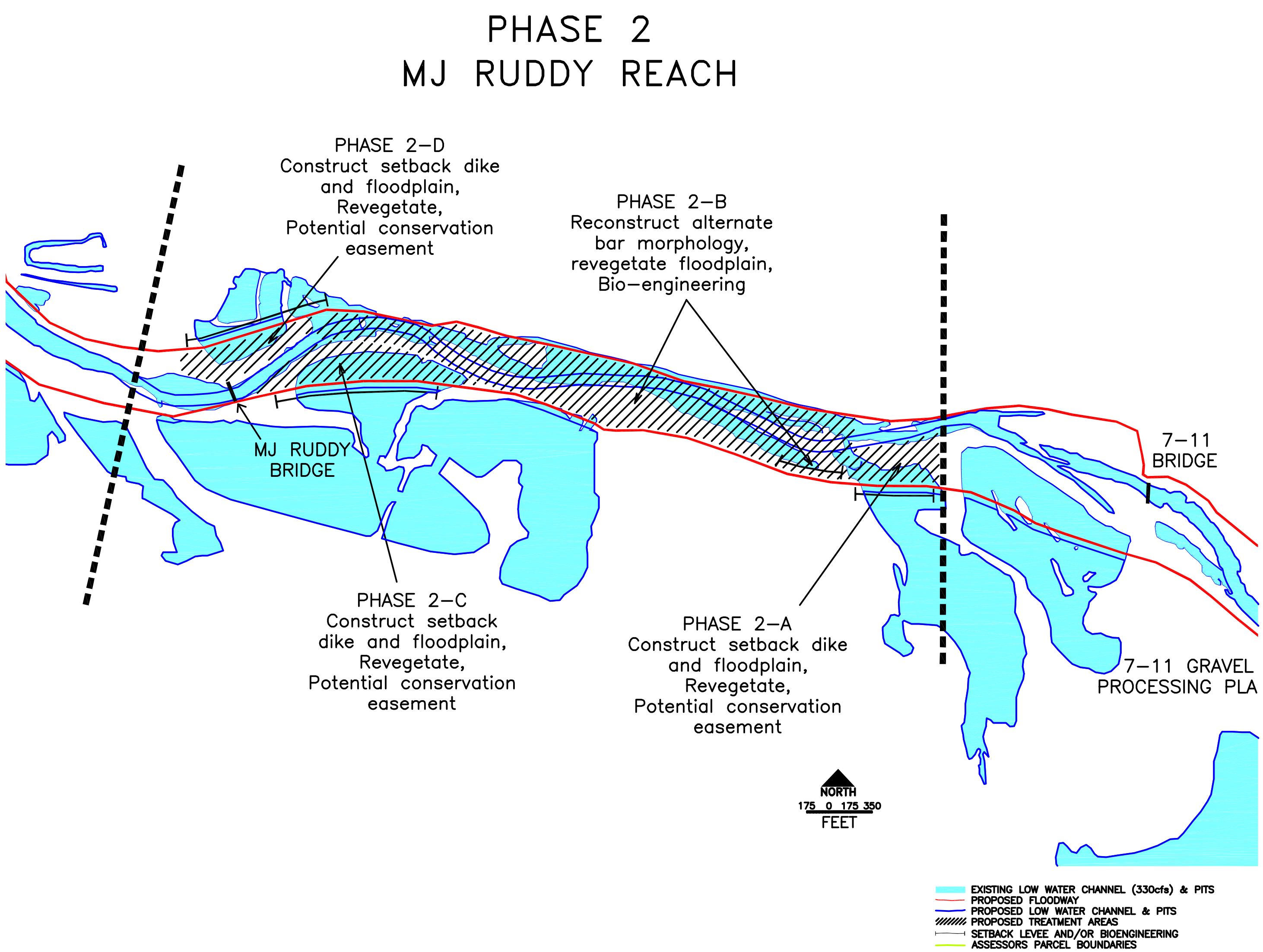

Figure 27. Conceptual design for the MJ Ruddy portion of the Gravel Mining Reach, as submitted to CALFED in 1997.

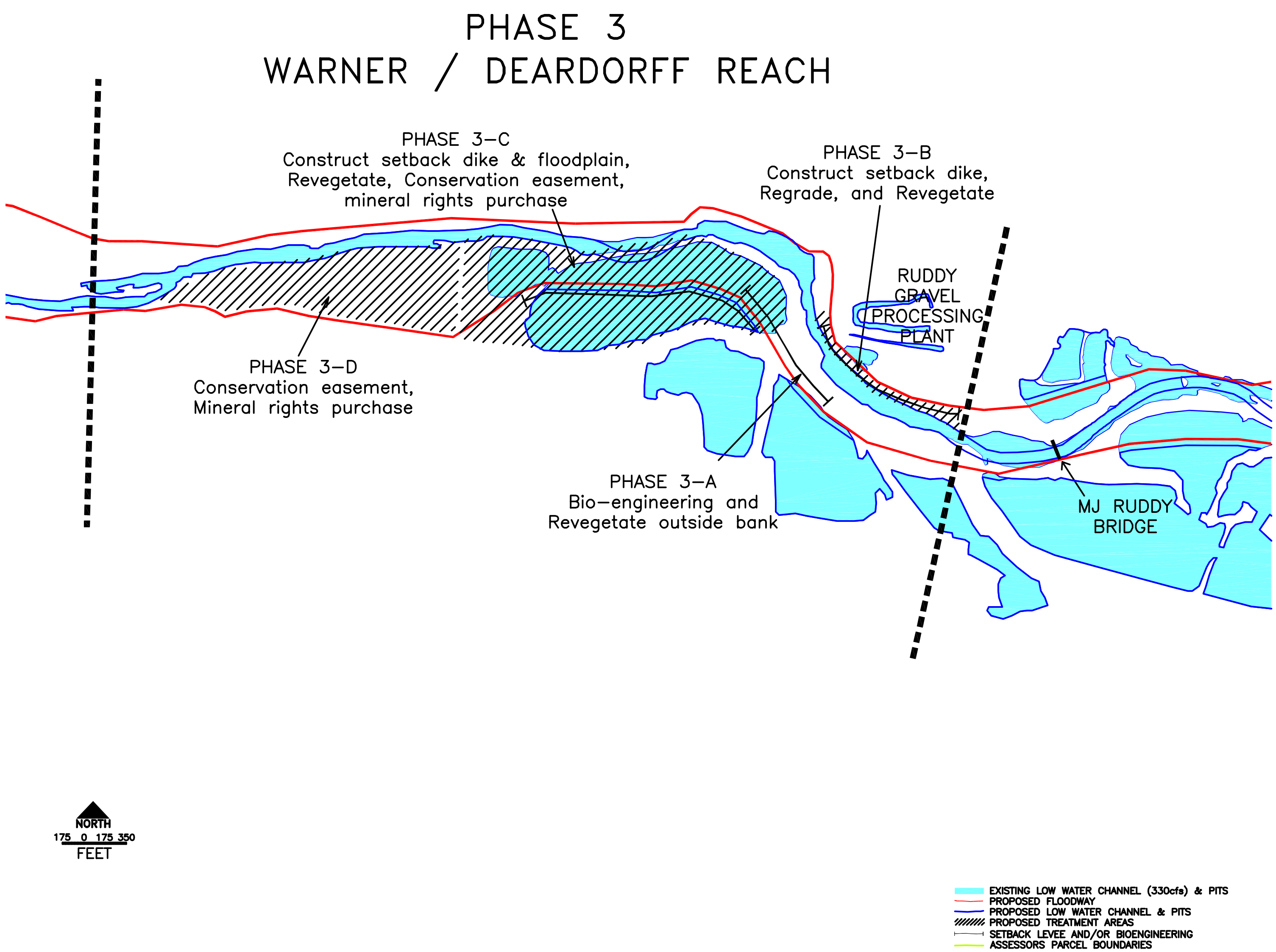

Figure 28. Conceptual design for the Warner/Deardorff portion of the Gravel Mining Reach, as submitted to CALFED in 1997.

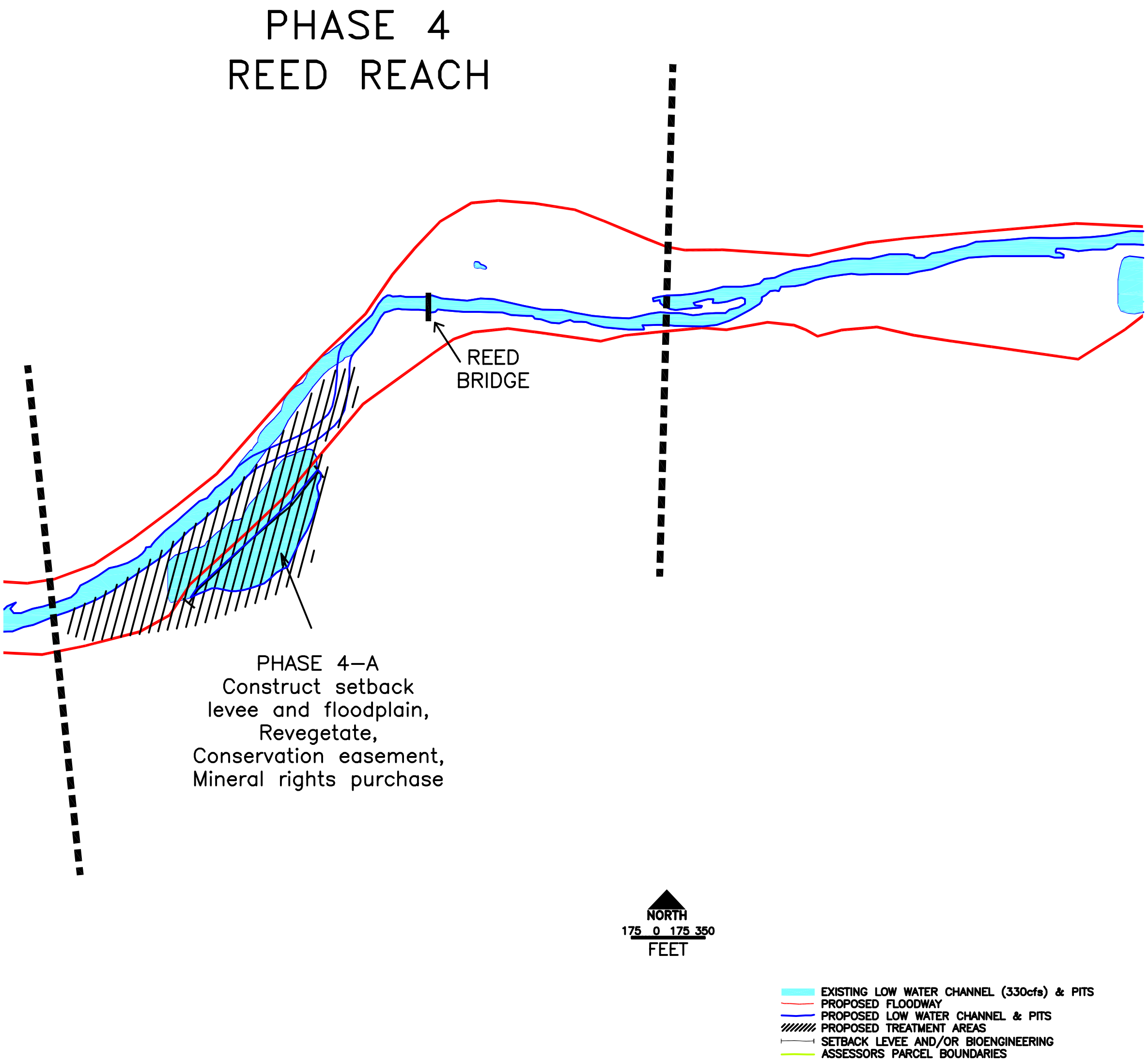

Figure 29. Conceptual design for the Reed portion of the Gravel Mining Reach, as submitted to CALFED in 1997.

together under contemporary, regulated flow conditions. By providing conditions that allow the mainstem channel to construct bars and riffles, the project improves salmon spawning, incubation, and rearing habitats. Increasing floodplain width reduces river stage and flow velocities during floods, provides some flood flow storage that may attenuate short duration flood peak magnitude in downstream reaches, enables complex alternate bars to form, and provides refugial habitats for rearing salmon during high flows. In several locations, the bankfull channel would require reconstruction to reverse damage caused by the 1997 flood, but grade control and bank protection structures are avoided unless absolutely necessary. Due to the available channel gradient in this reach (0.0015), the conceptual design anticipates and encourages a dynamic channel, with frequent gravel transport, frequent floodplain inundation, and some small amounts of lateral channel migration within the defined floodway. Riparian vegetation would be planted, but because the floodplains would be constructed with respect to the post-NDPP flow regime, natural regeneration would be anticipated as well.

Another important geomorphic process that the restoration approach attempts to achieve is periodic mobilization of the gravel bed to support formation for complex in-channel habitats and to prevent encroachment of riparian vegetation into the river channel. Under current conditions, reduced peak flows combined with the coarseness of the gravel bed have severely reduced the frequency and magnitude of bedload transport in the gravel-bedded reach of the river. Reinitiating bedload transport processes in the river, therefore, must address both flow conditions and bed texture. Because dams have cut off upstream supply of coarse sediment, restoration actions must also accommodate the reduction in coarse sediment supply by increasing supply via the restoration project and upstream augmentation, and by reducing the particle size of introduced coarse sediments. The particle size downstream of dams often reflects the flow regime that occurred prior to the dam, such that gravel augmentation needs to introduce a smaller gravel size that is commensurate with the post-dam flow regime (as well as spawning preferences for targeted salmonids). The increased frequency of bed mobilization and deposition of new bars and riffles improves Chinook salmon spawning and incubation conditions, which may stimulate spawning in downstream reaches that are currently underutilized, thus reducing redd superimposition and increasing survival-to-emergence. The restoration projects are also designed to benefit from potential future improvements in high flow releases. These variable flows will further enable self-maintenance of a dynamic complex channel morphology, and the variable flows will mobilize, scour, and redeposit different scale alluvial features within the floodway (e.g., small gravel patches, pool tails, riffles, point bars, floodplains). Filling instream and off-channel aggregate extraction pits will also help restore coarse sediment routing capability through the river corridor, allowing coarse sediment to be "recycled" through different reaches over the years. Elimination of in-channel pits also reduces habitat suitable for largemouth bass, thus reducing predator abundance and increasing salmon outmigrant survival.

5. RESTORATION DESIGN CRITERIA

The goals and objectives for the Gravel Mining Reach and SRPs 9 and 10 projects are discussed in Sections 3.1.1 and 3.2.1, respectively. These goals and objectives, which were developed as part of the Habitat Restoration Plan (McBain and Trush 2000), are fairly broad in nature and do not provide a comprehensive suite of quantitative criteria to support restoration design or evaluate project performance. The Habitat Restoration Plan focused on recreating the physical structure of the channel and floodplain and reinitiating geomorphic processes to maintain that structure. The fundamental assumption of this approach is that it is possible to create a geomorphic form and reinitiate geomorphic processes that are scaled in size to the modern flow regime of the river and that doing so will translate into improved ecosystem function and increased abundance of native fish and wildlife populations. This focus on restoration of geomorphic form and processes to improve habitats and, thus, increase species abundance is reflected in the conceptual models for these projects presented in Section 4.3.

In their review of the Tuolumne River restoration projects, the Adaptive Management Forum (AMF) identified the need to establish quantitative criteria for determining project success. Such criteria would also support restoration design. The AMF recommended: (1) selecting quantitative metrics of ecosystem response that encompass an array of structural elements and functional processes, (2) selecting appropriate indicator species, and (3) developing protocols for monitoring the key processes and functions that have been identified as being important indicators of healthy aquatic and riparian ecosystems (Adaptive Management Forum Scientific and Technical Panel 2002).

This section describes criteria used to design the restoration projects. These include geomorphic criteria that define certain aspects of channel and floodplain morphology, as well as biological criteria define habitat suitability for key species. These criteria define physical conditions to be targeted by restoration implementation. For example, one objective of the restoration is to eliminate largemouth bass habitat at SRP 9 and 10 and replace it with Chinook salmon spawning and rearing habitat. The criteria described below define the largemouth bass habitat to be eliminated, as well as conditions for Chinook salmon spawning and rearing to be created. These criteria also provide a metric with which to evaluate project performance. For instance, the area of channel that meets the Chinook salmon spawning habitat suitability criteria can be measured in the field to document project effects on the extent of suitable spawning habitat.

5.1. Geomorphic Design Criteria

Geomorphic design criteria for each restoration project were developed using a combination of observations in a reference reach in the Tuolumne River, attributes of alluvial river integrity from the Restoration Plan, and application of numerical models and empirical data found in the literature. Channel and floodplain design criteria included bankfull discharge, bankfull cross section, channel meander geometry, sediment transport thresholds, floodplain width and elevation, and riparian vegetation species composition and elevations (relative to the channel elevation and inundation frequency). General criteria were developed for the river then applied at each restoration site in combination with site-specific channel conditions to develop final three-dimensional conceptual designs. Design objectives include:

- The mainstem channel conveys the bankfull discharge. Floodplain inundation begins at flows exceeding the bankfull discharge.
- The D_{84} bed particle is mobilized at flows slightly less than the bankfull discharge.
- Sediment is routed through the reach, without encountering impediments to transport (such as pits).
- Bedload transport, scour, and deposition creates and maintains alternate bars, riffles, and pools.
- The bankfull discharge or larger floods occur frequently enough and are of sufficient magnitude and duration to prevent encroachment of riparian vegetation into the active channel.
- The bankfull discharge or larger floods are of short enough duration to prevent excessive loss of coarse sediment from restoration reaches.
- Fine sediment is deposited on floodplains during high flows.
- Floodplain inundation and channel migration support recruitment of native riparian vegetation and diverse age-class vegetation structure.
- Floodplain microtopography supports diverse riparian vegetation assemblages.

The process for developing design criteria for these objectives is described below. Specific designs for each project are discussed in Sections 6 and 7.

The channel cross section analysis relied heavily on the reference reach. The design reference reach was the M.J. Ruddy Four Pumps Project. This reach, which extends from RM 36.7 to RM 37.6, was the location of a restoration project completed in 1992-93 by the California Department of Water Resources. The project attempted to reconstruct an alluvial channel, floodplains, and terraces sized to inundate under post-dam flow conditions. This site was resurveyed in 1996, by which time it had experienced several large flows, ranging from 5,000 cfs to 9,000 cfs that were sufficient to mobilize the bed and initiate channel adjustment. Surveys were conducted in this reach to document channel slope, cross section, and meander geometry. A HEC-RAS model was also developed and calibrated using field data collected during a 5,410 cfs flow. These field data allowed the Manning's roughness coefficient to be back-calculated. Calculated roughness coefficients for surveyed cross sections ranged from 0.027-0.029, lower than values typically used for rivers with vegetated floodplains. Tracer particle experiments were also conducted to document bed mobility thresholds, and bed mobility model was applied to compare predicted thresholds with those observed in the field. Numerical models and other data and empirical relationships available in the literature were used to test the application of the reference site to channel design and to refine channel design criteria.

It is important to recognize that, while the channel will be constructed to these design criteria, it is not expected to remain static after construction. Rather, the channel is expected to adjust (within acceptable ranges) in response to flow conditions and sediment transport and deposition. Anticipated channel adjustments include lateral migration within reconstructed dikes, formation of mobile alluvial bars, and recruitment of large woody debris (and resultant sediment deposition and scour). This adjustment should drive the system toward a quasi-dynamic equilibrium, as described for a natural river in Section 2.1 and should be relatively minor in magnitude. For instance, bank erosion associated with lateral migration is an acceptable adjustment as long as the channel width remains relatively constant (i.e., the channel does not widen significantly). Similarly, deposition of mobile gravel bars is expected to occur, and the channel is expected to create and maintain an alternate bar morphology. Deposition throughout the reach resulting in conversion from an alternate bar to a plane-bed or braided morphology is not indicative of development of an equilibrium state and would be beyond acceptable ranges.

5.1.1. Channel design process overview

The channel design process focuses on the following large-scale components: (1) the bankfull channel and corresponding floodplain elevation, (2) the floodway width, and (3) the dike elevations. Bankfull discharge is often used as a primary design component for sizing the channel geometry and planform location. We use the bankfull concept in our design process as well, but only use it to generate a rough channel template upon which to add layers of complexity. Planform location and geometry was determined by a combination of professional experience on planform morphology and location, meander geometry relationships in the literature (e.g., meander wavelength as a function of bankfull discharge), and physical constraints in the field (e.g., bridges, dikes). A repetitive sinusoidal meander geometry was avoided to the greatest degree possible, and numerous high flow scour channels were created on the floodplain to simulate a semi-braided channel morphology.

The bankfull width and depth was designed to: (1) convey the bankfull discharge, and (2) mobilize the bed surface. An iterative process was used to develop the width and depth. First, bed mobility modeling was used to estimate the depth necessary to mobilize the bed surface given the reach-wide slope. Then, the width necessary to convey the bankfull discharge at the bed mobility depth was computed. This rudimentary channel geometry was then compared to regional relationships of bankfull dimensions, as well as compared to observations of channel geometry evolution at the M.J. Ruddy 4-pumps project between 1993 and 1996 (McBain and Trush 2000). This simple channel geometry was smoothed to develop template cross sections for riffles and pools. Bar morphology and pool depths measured at the M.J. Ruddy 4-pumps project was used in developing these templates, and pool depths were adjusted based on the radius of curvature of each meander bend (the smaller the radius of curvature and roughness on the outside of the bend, the deeper the pool). A longitudinal profile was then created to join the pools and riffles together, and then the design topography created in AutoCAD Land Development Desktop 2.

The floodway width was primarily designed to "safely" convey the design flood discharge, but some consideration was also given to minimum widths for ecological significance. The design flood discharge is 15,000 cfs, which is the sum of the maximum controlled outlet works capacity of New Don Pedro Dam (14,000 cfs) plus a moderate volume of accretion during a storm event (1,000 cfs). Aerial photographs were used to identify floodway widths that were less prone to flood damage, and were used as initial floodway width targets. Simple hydraulic computations were then used to evaluate average flow velocities at the design discharge, and to estimate the height of reconstructed dikes needed to contain the design flood with 3 feet of freeboard. In locations where the floodway width was wider than this design width, the existing (larger) width was retained.

5.1.2. Bankfull Discharge

Channel design parameters (i.e., bankfull channel width and depth, channel sinuosity, meander wavelength, and radius of curvature) are driven by a combination of the channel maintaining flow, channel slope, sediment supply, and sediment particle size. The primary independent variable in the bankfull channel design analysis is the channel maintaining flow. In unregulated alluvial rivers, the bankfull discharge has been found to be an influential flow in determining channel and planform geometry. Bedload begins to move at discharges slightly less than the bankfull, and as discharge increases towards bankfull, the bedload transport rate increases.

Ideally, reference reaches can be used to identify the bankfull channel, and either direct flow measurement during a bankfull discharge or hydraulic computation can be used to compute the bankfull discharge. The degree of flow regulation, sediment regulation, and physical manipulation of the channel (agriculture, urban encroachment, aggregate mining) has prevented any reasonable post-NDPP bankfull channel indicators. Therefore, a hydrologic indicator was considered. In unregulated rivers, the bankfull discharge typically falls within the range of the $Q_{1.5}$ to Q_2. For the Tuolumne River, the pre-dam $Q_{1.5}$ to Q_2 was 8,360 cfs and 12,100 cfs, respectively. Excluding the 1997 flood in computing flood frequency, the post-NDPP $Q_{1.5}$ to Q_2 at LaGrange is 2,640 cfs and 3,750 cfs, respectively. However, peak flow conditions in the lower Tuolumne River are heavily influenced by power generation. Except as needed to meet flood control rules, peak flows that exceed the NDPP maximum generation capacity of 5,500 cfs are rarely released. If the flood flow management modifications described in Section 4.1 are implemented, $Q_{1.5}$ to Q_2 would increase to 2,700 cfs and 5,000 cfs, respectively. Because of the grouping of peak flows at 5,000 cfs to 5,500 cfs due to power generation and the potential changes in flood flow management, a flow of 5,000 cfs was chosen as the design bankfull discharge. As will be discussed in later sections, the discharge that caused overbank flows on design floodplains (bankfull discharge) was subsequently lowered in certain reaches due to implementation budgetary constraints.

5.1.3. Design flood discharge, floodway width, and dike height

The 1997 flood exceeded the outlet works capacity of New Don Pedro Dam, allowing an uncontrolled spill of 60,000 cfs over the spillway. This was the first time that the spillway was used since the NDPP was completed, and the flood caused extensive damage to downstream infrastructure, as well as instream habitat. To improve future flood management, this project attempts to enable flood releases that are at the maximum of the outlet works capacity, and allows for downstream tributary accretion between the dam and the project sites. The maximum outlet works capacity of the New Don Pedro Dam is 14,000 cfs, and assuming 1,000 tributary accretion between New Don Pedro Dam and the project sites, the selected design discharge is 15,000 cfs. This discharge has a variety of flood frequency estimates depending on the method used (Table 7), but still does not provide either 50- or 100-year flood protection to the project. Increasing floodway width to provide greater protection was considered, but because of the very large costs and the funding source (CALFED restoration funds), the 15,000 cfs design flood was not increased.

Table 7. Flood frequency estimates for a 15,000 cfs design flood discharge using a variety of sources.

Method/Source	Flood recurrence
Log Pearson III, excluding 1997 flood	40
Log Pearson III, including 1997 flood	12
Peak Rain flood frequency (ACOE, 1999)	40

The project attempts to have sufficient floodway width to keep average water velocities at the 15,000 cfs discharge below 8 ft/sec to minimize damage to dikes, the rehabilitated channel, and infrastructure in the floodway. A floodway width of 500 ft or greater was chosen in the conceptual design process. In the 1997 proposal to CALFED, three approaches were used to develop the minimum design floodway width of 500 ft: (1) a simple hydraulic analysis was used for a 15,000 cfs discharge to achieve desired average water velocities at that discharge, (2) review of the 1997 flood aerial photographs to identify minimum floodway widths that showed signs of minimal damage to the floodway, and (3) desire to have at least 150 ft of riparian forest on each side of the channel (assuming the 200 ft wide bankfull channel was in the center of the floodway) for a wildlife migration corridor and to provide meaningful habitat value. The design criterion for dike height was two feet of freeboard above the 15,000 cfs water surface elevation as determined by the hydraulic model (Figure 30). This simple cross section and floodway width design criteria was then applied to the entire reach, and where the existing floodway width was wider than 500 feet, the wider width was retained. This resulted in variability in the actual floodway design width due to opportunities (e.g., wider, less disturbed sections) and constraints (e.g., bridges) (Figures 25-29). Assuming a high water slope of 0.0014, in-channel as-built Manning's roughness of 0.028, and floodplain as-built Manning's roughness of 0.035 (with planted vegetation), the corresponding average velocities at 15,000 cfs were 3.2 ft/sec on the floodplains and 7.5 ft/sec in the main channel. Using future roughness values of 0.035 for the channel and 0.07 for the floodplain reduced average velocities to 2.0 ft/sec on the floodplain and 6.6 ft/sec in the main channel. Corresponding water surface at 15,000 cfs was 1.3 ft higher (9.3 ft versus 8.0 ft). Within this floodway, the specific dimensions and details of the channel was refined well beyond the simple template shown in Figure 30, largely based on observations on the M.J. Ruddy 4-pumps project from 1993-1997. There has been concern raised over whether a 500 ft wide floodway will be sufficient to provide meaningful riparian habitat and allow sufficient room for lateral channel migration (Kondolf 1997). The riparian habitat values are discussed in Section 5.3. The designers agree with Dr. Kondolf and others that a 500 ft wide floodway leaves little room for lateral migration; however, due to the depth of the off-channel mining pits, bridge locations, and other infrastructure, expanding the floodway width beyond 500 ft in certain areas would be cost prohibitive. As will be discussed in Chapter 6, there are some locations where constraints force the floodway to be less than 500 ft wide.

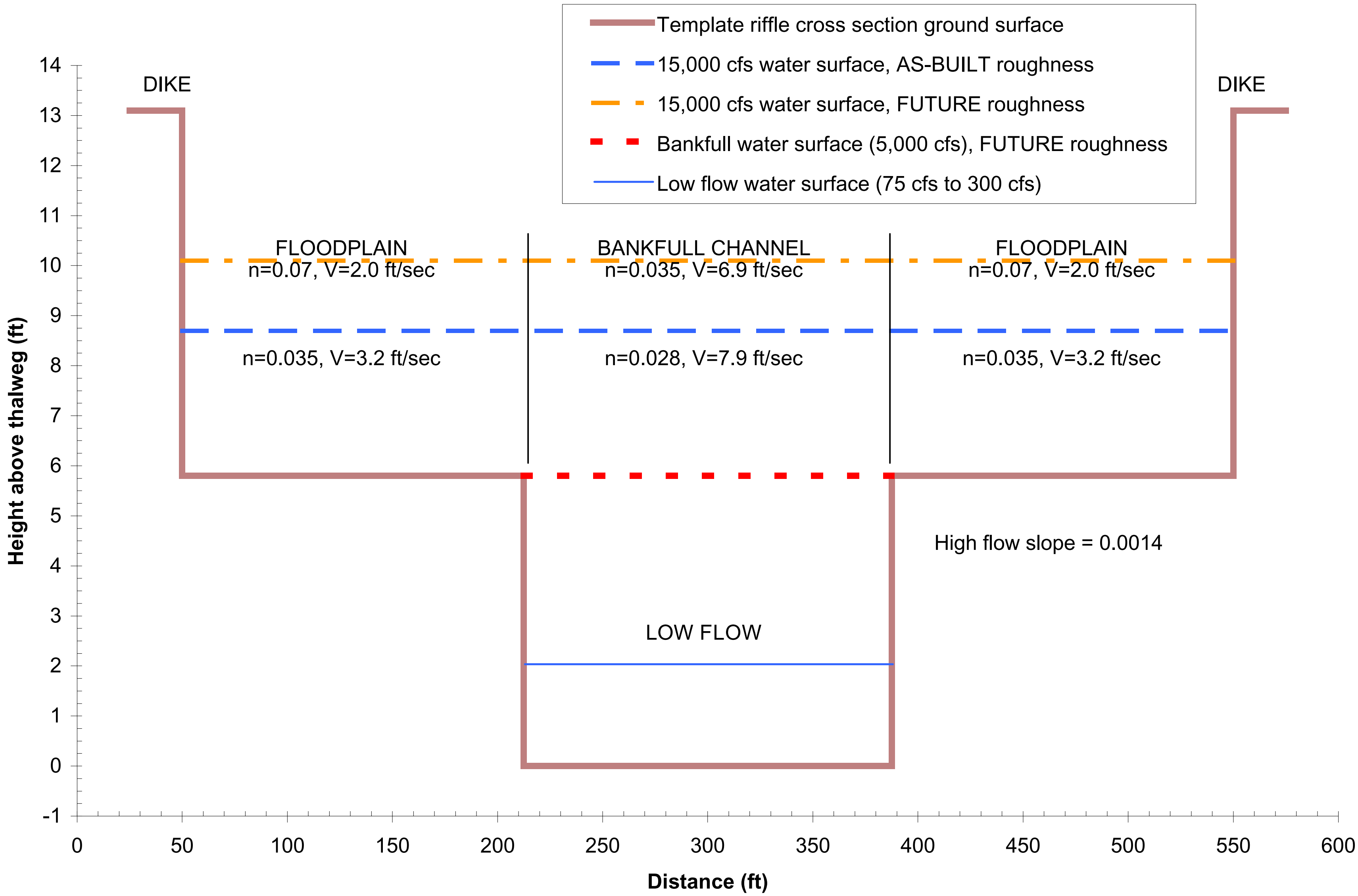

Figure 30. Simple template cross section used for developing the minimum floodway width in the Gravel Mining Reach in the 1997 CALFED proposal.

5.1.4. Hydraulics and sediment transport

Dramatic differences in channel slope occur between the SRP 9/10 Reach and the Gravel Mining Reach; however, channel confinement by the valley walls remains similar between the two reaches. The change in slope is a natural geomorphic feature (not human induced), and occurs near RM 31 (Figure 31). This drastic change in slope marks the beginning of the gravel-bed to sand-bed transition on the river, and greatly limits the degree of geomorphic processes that can be restored at SRP 9 and 10. The following sections develop design criteria based on hydraulic and sediment transport considerations. In these computations, we considered modifying the reach-scale slope to better achieve geomorphic objectives, but the manipulation would be infeasible due to cost. Therefore, we considered slope as a hard constraint that could not be changed.

5.1.4.1. Valley slope and confinement

A hydraulic model was constructed through the lower portion of the Tuolumne River between Roberts Ferry Bridge (RM 41) and the San Joaquin River by USGS in 1969 (USGS 1970). No other river-wide hydraulic model has been developed, but the USGS model provides an illustrative perspective on slope between the Gravel Mining Reach and the SRP 9/10 Reach (Figure 31). The profiles from the model suggest that a large-scale slope break occurs at RM 31, between the Gravel Mining Reach (Slope=0.0015) and SRP 9&10 (Slope less than 0.0003). While valley confinement is similar between the two reaches, the valley walls no longer influence hydraulics due to the reduced flow regime. Dikes now provide that confinement in the Gravel Mining Reach, and orchards provide confinement at SRP 9 and 10.

Local slopes were also measured at each reach during high flows in 1996 and 1997. At SRP 9, the local 7,600 cfs water surface slope was 0.00043 (Figure 32), while the riffle crest slope through SRP 9 and SRP 10 (including the riffle between SRP 9 and SRP 10) was 0.00084 (Figure 33). Slopes in the Gravel Mining Reach vary between 0.0015 in the M.J. Ruddy reach, to 0.00064 in the Warner-Deardorff Reach, and back up to 0.0013 in the Reed Reach (Figure 34). These slopes appear to be consistent with the USGS study, with the exception of the Warner-Deardorff portion of the Gravel Mining Reach (slope=0.00064). The design considered large scale slope manipulation to remove this slope discontinuity, but the cost and effort were found to be too large. Therefore, slope at both reaches were treated as a constant, and the project design began and ended on fixed slope controls at the upstream and downstream end of the project reaches.

For each design reach, HDR Engineering prepared a HEC-RAS hydraulic model for both existing and design conditions. The Manning's roughness values were back-calculated using the high flow water surface slopes shown in Figures 31 and Figure 33. This calibrated model was then used to predict water surface elevations at the design bankfull discharge and design floodway discharge (15,000 cfs) for the Gravel Mining Reach. Roughness values at the SRP 9/10 Reach were based on professional judgment. These model predictions, combined with the empirical water surface measurements in 1996, were then used to design floodplain elevations, floodway widths, and dike surface elevations.

5.1.4.2. Sediment Routing

A sediment routing model was not developed due to several factors. First, the benefit of the model output was considered low in light of the cost necessary to perform the modeling. Sediment supply to the reaches is extremely low, as are sediment transport rates under the post-dam flow regime,

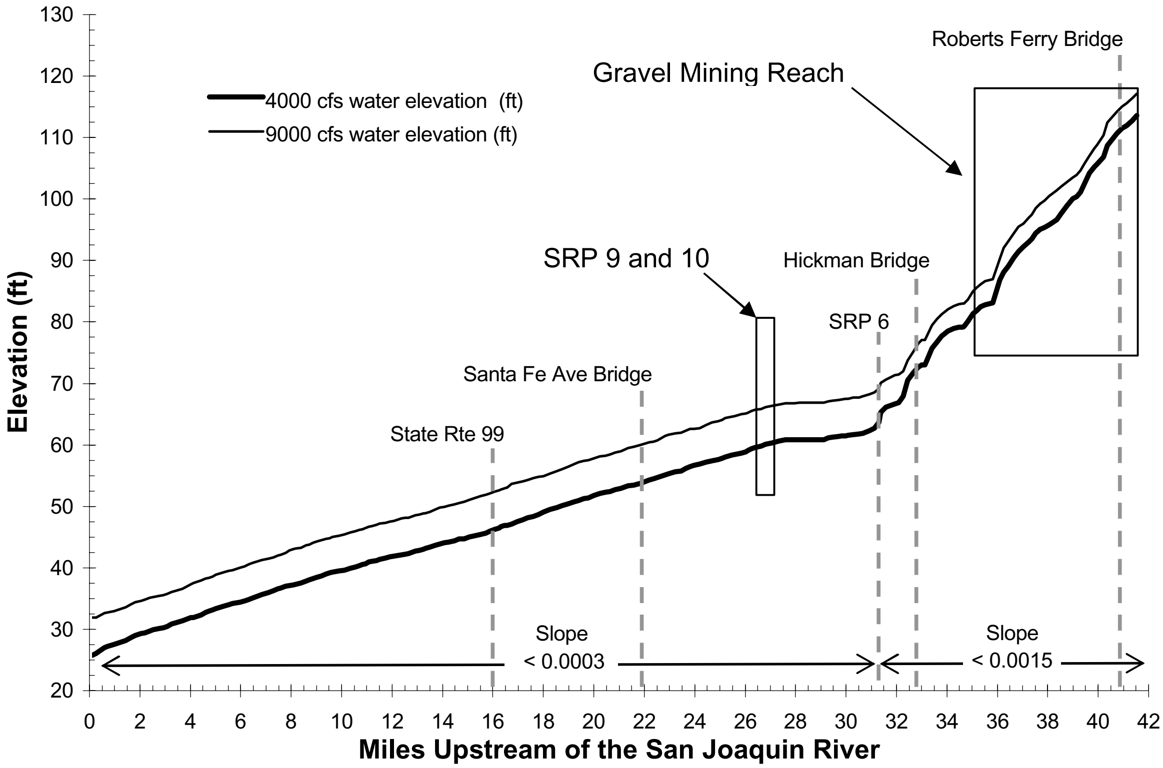

Figure 31. Tuolumne River water surface profile generated by the 1969 USGS channel capacity study (USGS 1970). Note that the distance are from the floodway length, not the low water channel length, thus differ from commonly used river mileage markers.

such that we do not expect large-scale scour/depositional changes at most locations in the SRP 9/10 Reach and Gravel Mining Reach by flows under 15,000 cfs. Bridge constrictions, particularly the 7/11 Haul Road Bridge (RM 37.8) and the Santa Fe Aggregates Haul Road Bridge (RM 36.6) may be exceptions; however, the hydraulic conveyance at these bridges were increased to the maximum feasible under project budget constraints and objections by the landowners. Therefore, local sediment scour and deposition may still occur at these locations, but the restoration project will reduce local deviations in sediment transport capacity by increasing floodway conveyance, thus the potential for local scour and deposition should be much lower than current conditions. In retrospect, sediment routing modeling would have been a useful qualitative illustration of improvements in sediment routing through the reach, and should be considered in future phases of design.

5.1.4.3. Bed Mobility Thresholds

One of the fundamental functions of alluvial river channels is to transport sediment. The threshold for coarse sediment transport in relatively unimpaired alluvial rivers often ranges from 80% to 100% of the bankfull discharge. Sediment transport is a broadly a function of energy slope and water depth for a given flow. As discharge approaches the bankfull discharge, water depth increases and sediment transport initiates. As flows continue to increase, water depth increases and sediment transport increases. When flows exceed bankfull discharge and water spills onto the floodplain, the rate of increase in water depth slows, such that the rate of sediment transport ascent also slows. Therefore, a primary design criteria for the bankfull channel dimensions is that coarse sediment transport should be initiated at or slightly less than bankfull discharge.

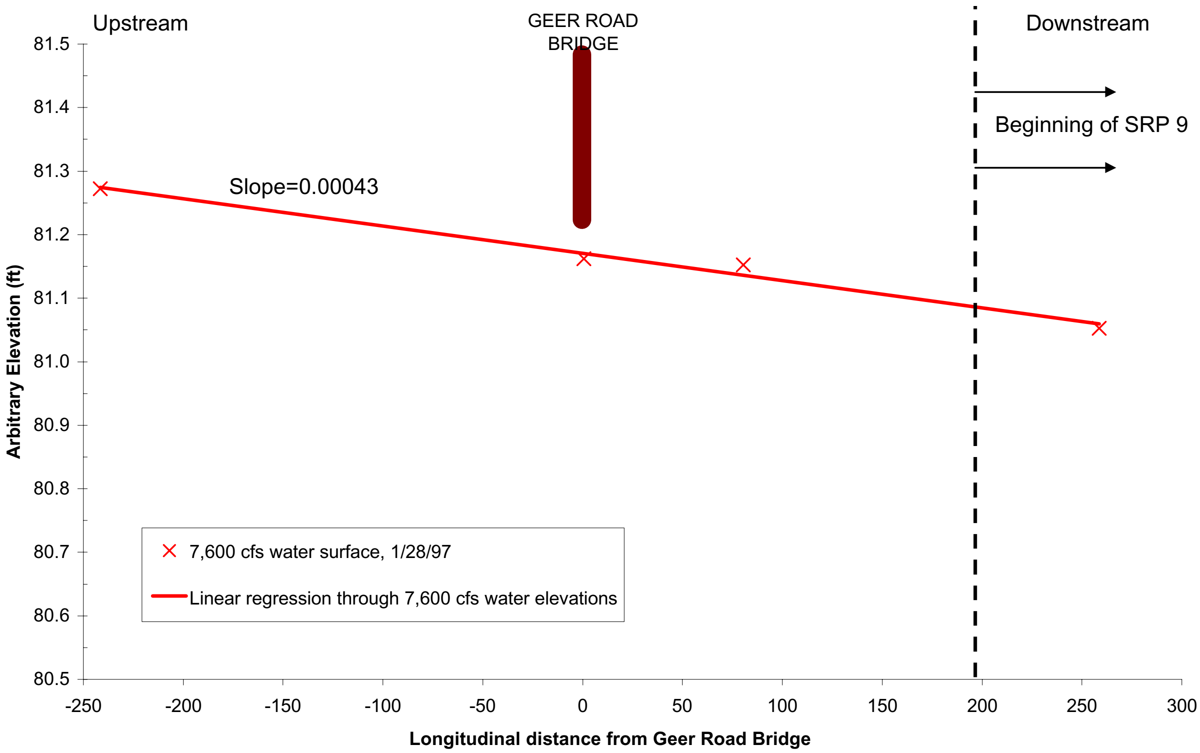

Figure 32. Measured 7,600 cfs water surface profile on the Tuolumne River in 1997 at the entrance to SRP 9, illustrating extremely low slope (S=0.00043).

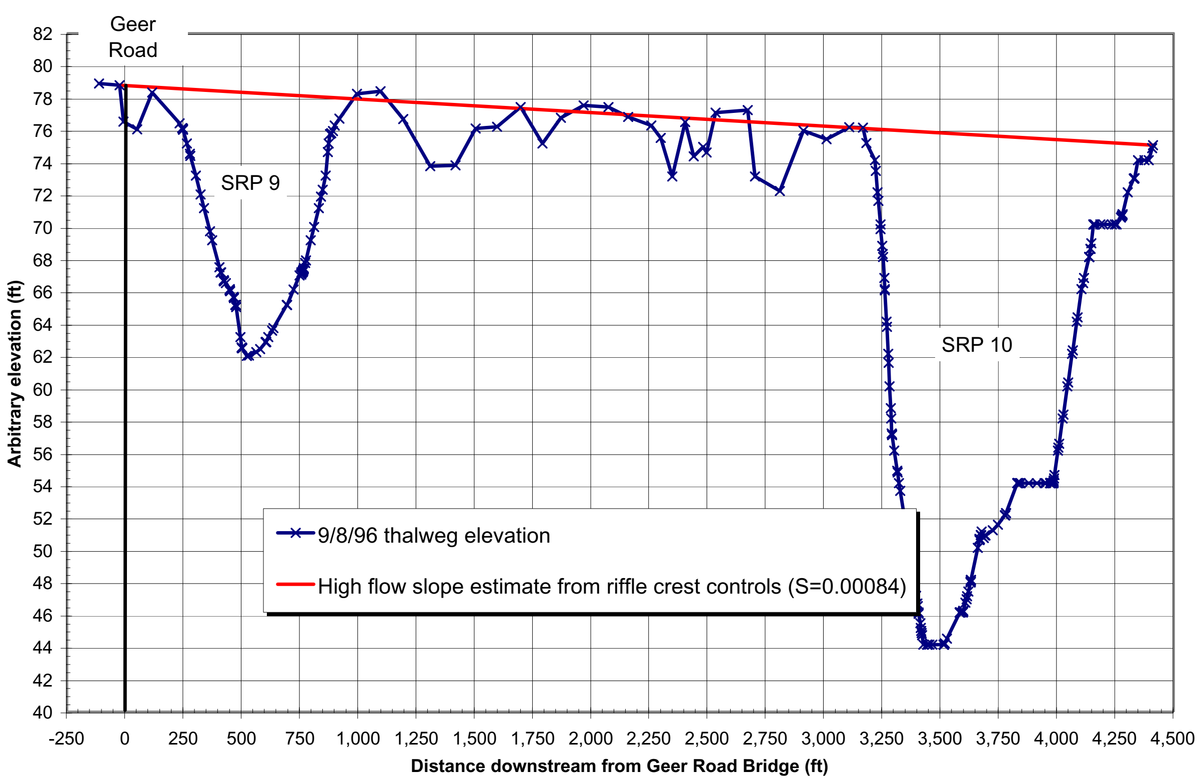

Figure 33. Tuolumne River invert profile through SRP 9 and SRP 10, corroborating low slope measured in 1997. Steeper slope in the invert profile (S=0.00084).is largely due to the riffle between SRP 9 and SRP 10.

Design bankfull channel depth is initially determined based on the flow depth needed to mobilize the channel bed. Critical depth (i.e., the flow depth at which the bed is mobilized) is calculated using Shields equation (Equation 1):

$$(1)\quad \text{Critical Depth} = \frac{(\rho_s - \rho_w)(\tau_c^*)(D_{84})}{\rho_w (S)}$$

where ρ_s is the specific gravity of the sediment (assumed to be 2.65 g/cm^3), ρ_w is the specific gravity of water (1.0 g/cm^3), τ_c* is critical shear stress for a given particle size, D_{84} is the particle size diameter where 84 percent of the bed surface is finer, and S is energy slope (approximated by the water surface slope for template channel computations). We use the D_{84} as the design particle size because it represents the matrix particle of the gravel bed, and if the D_{84} is mobilized, it is safe to conclude that general bed mobilization has occurred. A value of τ_{cD84}*=0.02 is used based on back-calculations on the Trinity River (McBain and Trush 1995) and predictions in Andrews (1983). The D_{84} diameter of 2.9 inches (74 mm) was defined using a desired post-restoration bed texture considered to be suitable for salmonid spawning (McBain and Trush, 2003).

The energy slope used for reach-wide bed mobility calculations in the Gravel Mining Reach was 0.0014 based on 1996 field surveys of water surface profile during the 5,400 cfs flow in the M.J. Ruddy Reach and Reed Reach (Figure 34). The energy slope used for SRP 9 was 0.00043 based on 1997 field surveys of water surface profile at SRP 9. Water depths to achieve bed mobility under different particle size assumptions were computed (Table 8).

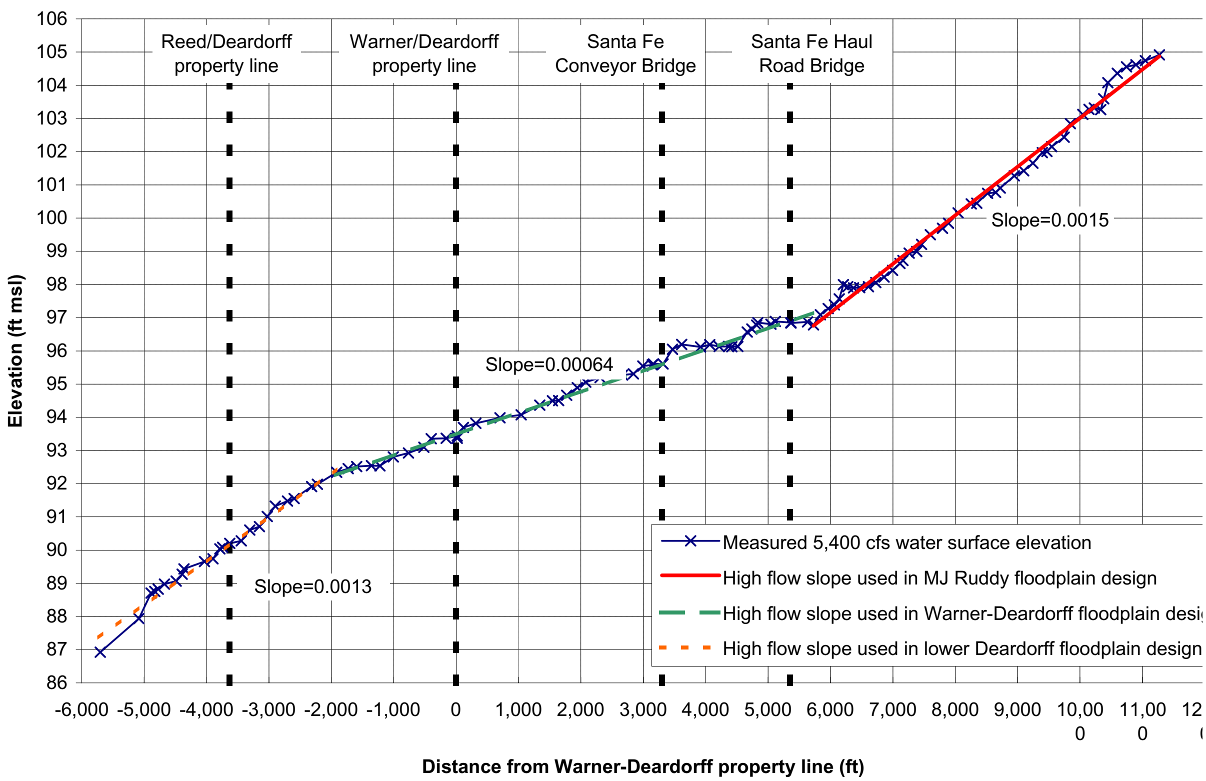

Figure 34. Measured 5,400 cfs water surface profile on the Tuolumne River in 1996 through the M.J. Ruddy, Warner-Deardorff, and Reed reaches, illustrating higher slopes than at the SRP 9/10 Reach. Note the local decrease in slope in the Warner-Deardorff Reach.

The discharge needed to create the depth of flow needed to mobilize the bed surface D_{84} is much larger than the 5,000 cfs chosen for bankfull discharge; therefore, the design team has concluded that mobilizing the bed surface by the design bankfull discharge will likely be achieved in the 7/11 Reach, M/J/ Ruddy Reach, and Reed Reach using a particle size distribution similar to that found in the river at the M.J. Ruddy 4-Pumps site in 1996. Bed mobilization will be more problematic within the Warner-Deardorff Reach due to the low slope, but will likely still occur at a reduced rate than the desired 1.5 to 2.0 year flood recurrence. Depending on the particle size used to rebuild the channel in SRP 9 and 10, bed mobilization may rarely occur at these locations due to the low slope (keep in mind that these projects are located at the pre-dam gravel-bed to sand-bed transition).

Table 8. Summary of computed water depths required to mobilize the bed surface assuming different reach slopes and D_{84} particle sizes.

Site	D_{84} size	Assumption	Bed mobilization depth
SRP 9	74 mm (2.9 inch)	Based on D_{84} of desirable spawning gravel per Tuolumne River coarse sediment management plan. Slope=0.00043.	19 ft
SRP 9	43 mm (1.7 inch)	Based on D_{84} particle size from pebble count in riffle upstream of SRP 9 taken in 1997. Slope=0.00043.	10.8 ft
7/11, M.J. Warner, and Reed reaches	74 mm (2.9 inch)	Based on D_{84} of desirable spawning gravel per Tuolumne River coarse sediment management plan. Slope=0.0014.	5.8 ft
7/11, M.J. Warner, and Reed reaches	75 mm (2.9 inch)	Based on average D_{84} particle size of pebble counts taken in M.J. Ruddy 4-Pumps project reach in 1996. Slope=0.0014.	5.8 ft
Warner-Deardorff Reach	74 mm (2.9 inch)	Based on D_{84} of desirable spawning gravel per Tuolumne River coarse sediment management plan. Slope=0.00064.	12.7 ft
Warner-Deardorff Reach	75 mm (2.9 inch)	Based on average D_{84} particle size of pebble counts taken in M.J. Ruddy 4-Pumps project reach in 1996. Slope=0.00064.	12.7 ft

5.1.5. Bankfull Channel Geometry (Width and Depth)

The template channel cross section geometry includes several components: the low flow channel, the bankfull channel, and the floodplains (Figure 30). The sizing of the floodway width is described in Section 5.1.3. No geomorphic models are useful to predict low flow channel width; however, observations of channel evolution at the M.J. Ruddy 4-Pumps project were used to develop low flow channel dimensions (McBain and Trush 2000). Figure 35 illustrates cross section and habitat unit locations at the M.J. Ruddy 4-Pumps Restoration Site, and Figures 36-42 show cross sections as evolved between construction in 1993 and survey in 1996. Table 9 summarizes the high flows that refined the channel geometry at the M.J. Ruddy 4-Pumps project, and Table 10 summarizes the corresponding widths and average depths for the low flow channel.

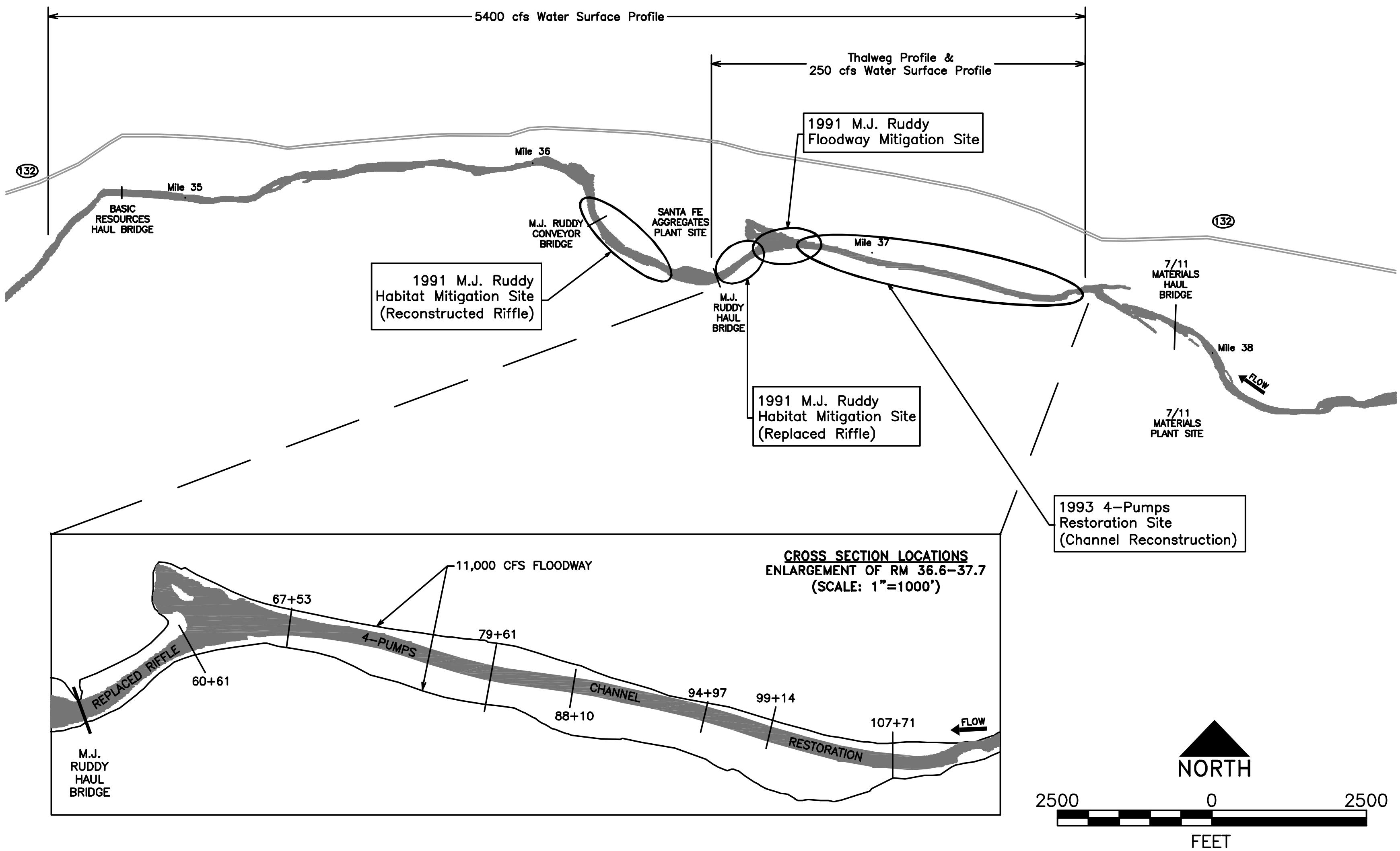

Figure 35. Map of cross section locations at the M.J. Ruddy 4-Pumps restoration site. Site was constructed by DWR in 1993, and evolved to numerous high flow events between 1993 and 1996 before damaged by January 3, 1997 flood.

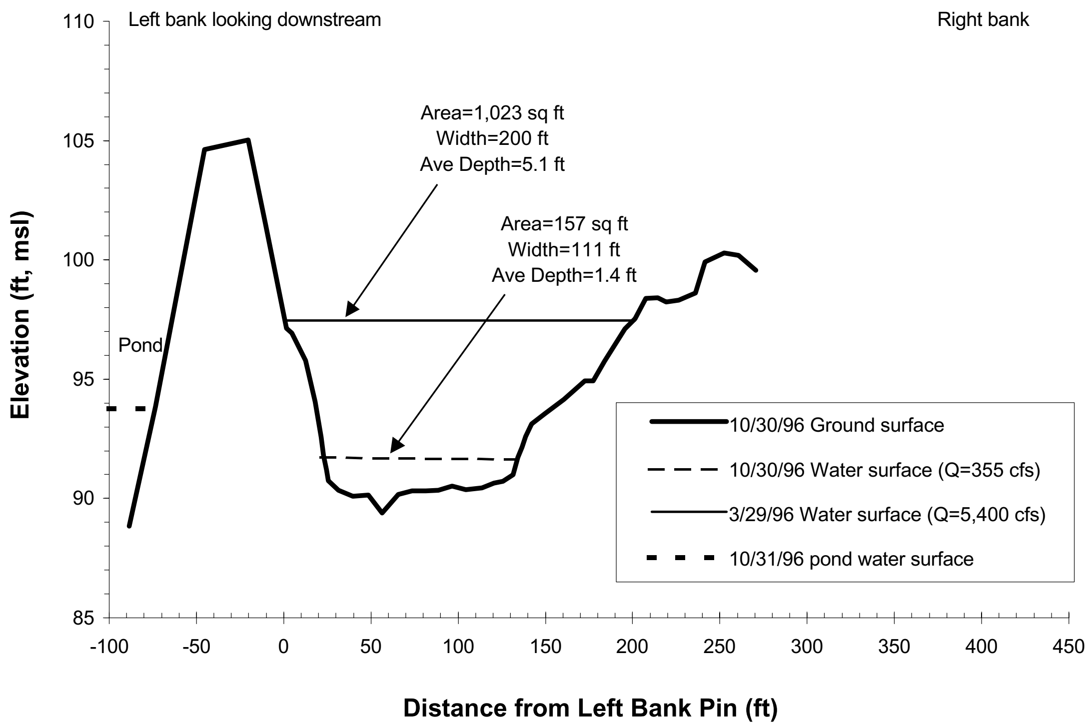

Figure 36. Cross section 60+61 surveyed in October 1996 at the M.J. Ruddy Mitigation Site showing channel dimensions following construction and numerous high flow events between 1993 and 1996.

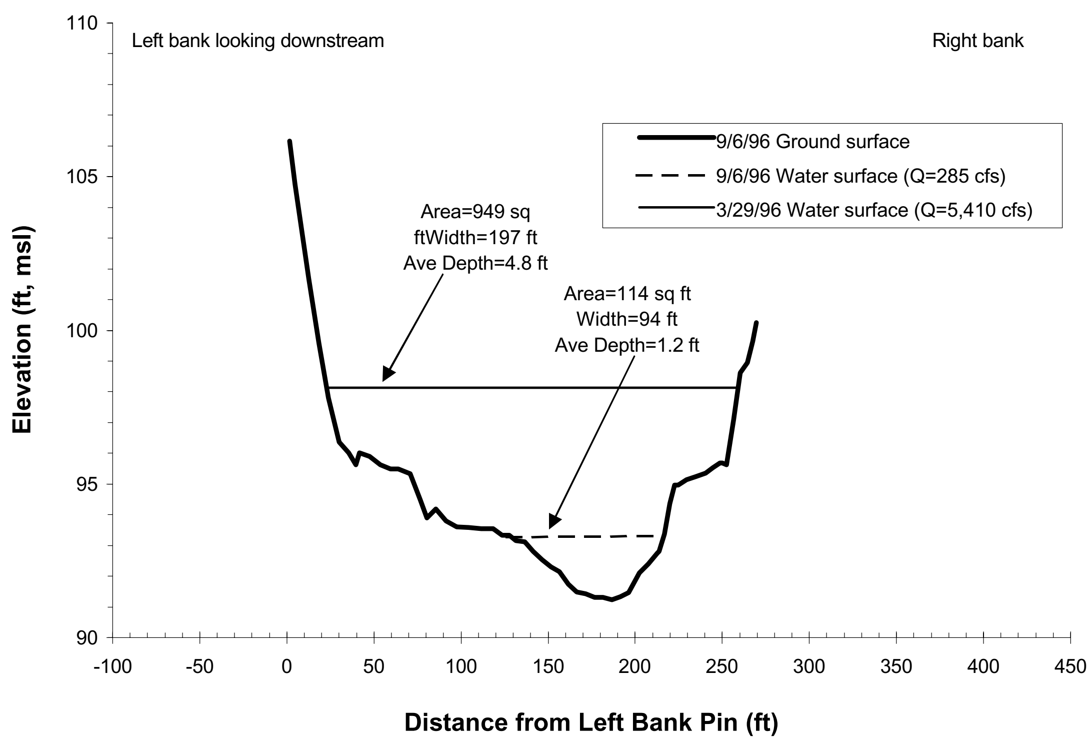

Figure 37. Cross section 67+53 surveyed in September 1996 at the M.J. Ruddy 4-Pumps Restoration Site showing channel dimensions following construction and numerous high flow events between 1993 and 1996.

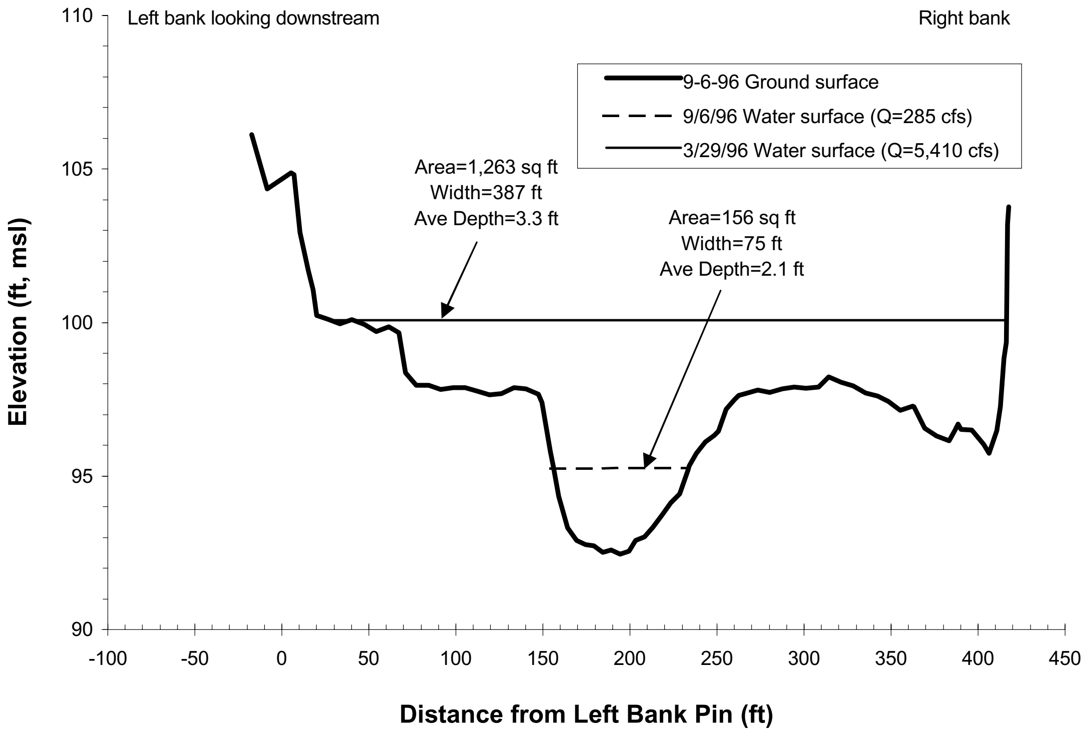

Figure 38. Cross section 79+61 surveyed in September 1996 at the M.J. Ruddy 4-Pumps Restoration Site showing channel dimensions following construction and numerous high flow events between 1993 and 1996.

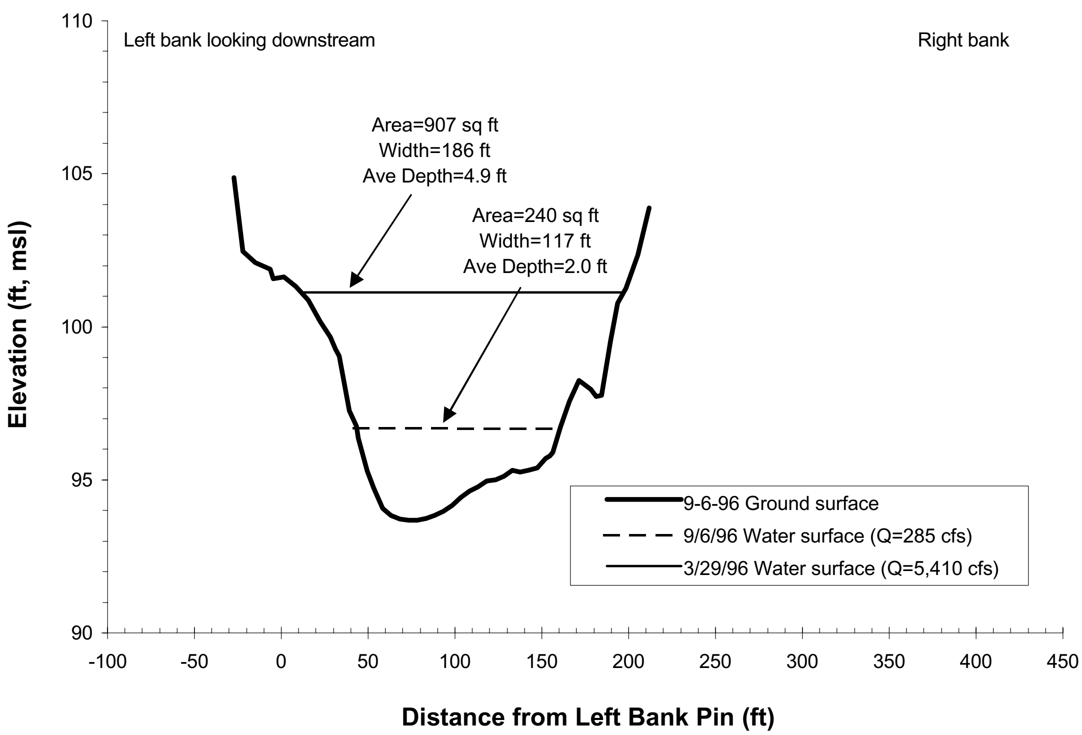

Figure 39. Cross section 88+10 surveyed in September 1996 at the M.J. Ruddy 4-Pumps Restoration Site showing channel dimensions following construction and numerous high flow events between 1993 and 1996.

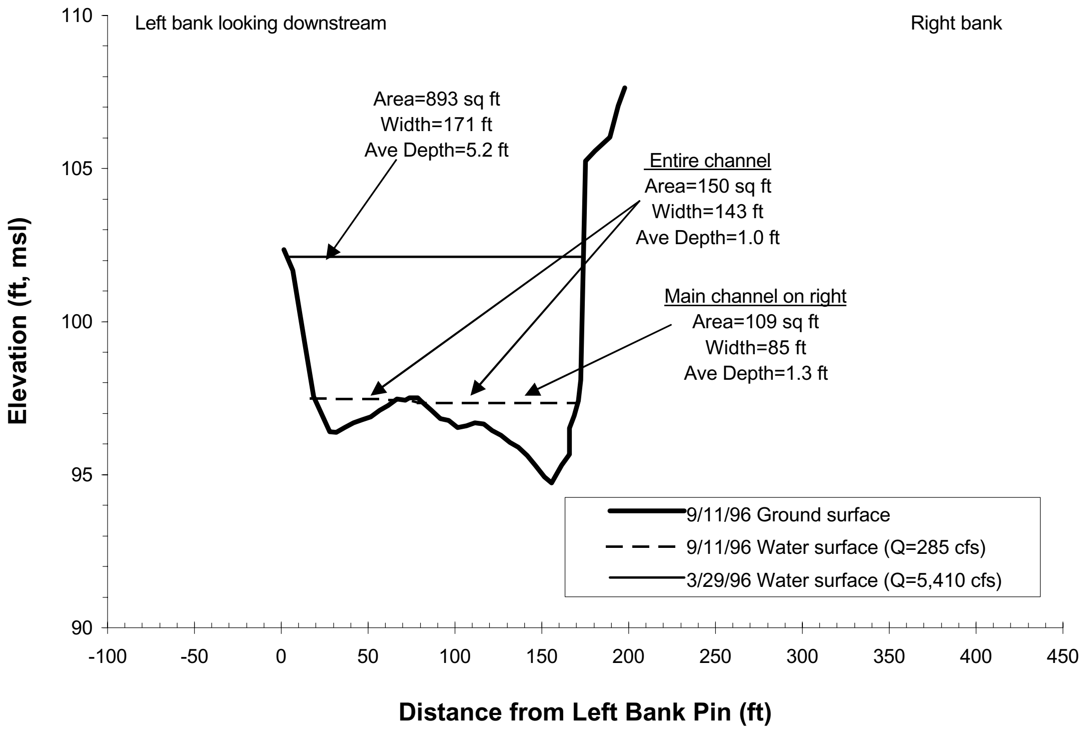

Figure 40. Cross section 94+97 surveyed in September 1996 at the M.J. Ruddy 4-Pumps Restoration Site showing channel dimensions following construction and numerous high flow events between 1993 and 1996.

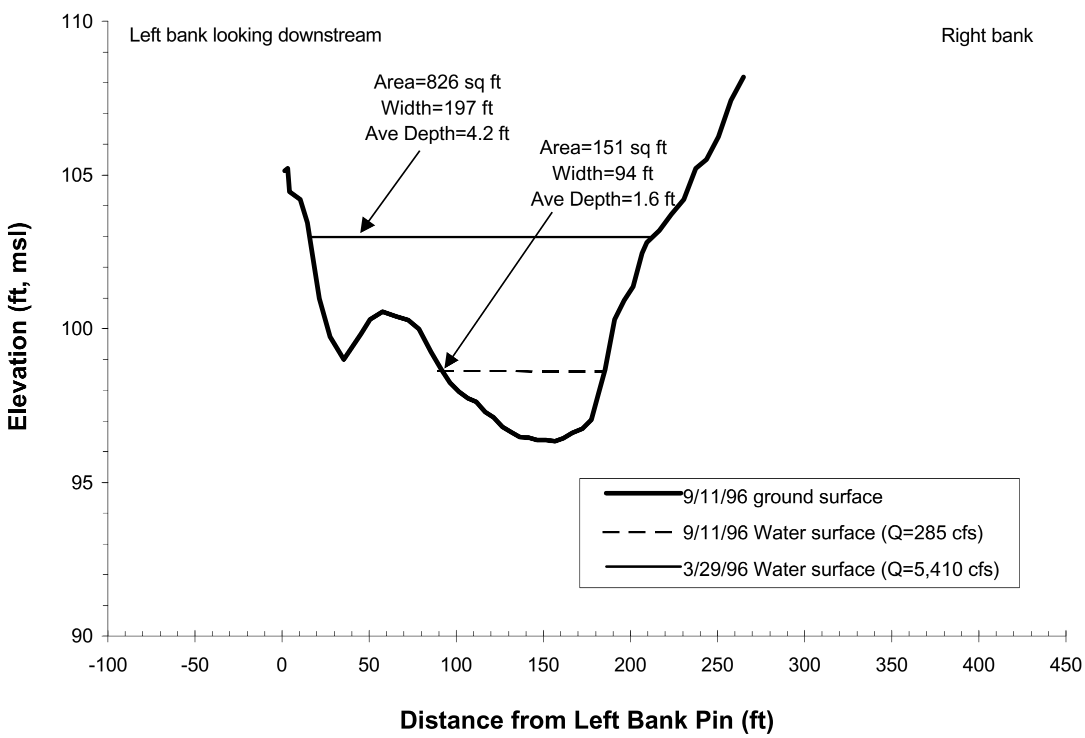

Figure 41. Cross section 99+14 surveyed in September 1996 at the M.J. Ruddy 4-Pumps Restoration Site showing channel dimensions following construction and numerous high flow events between 1993 and 1996.

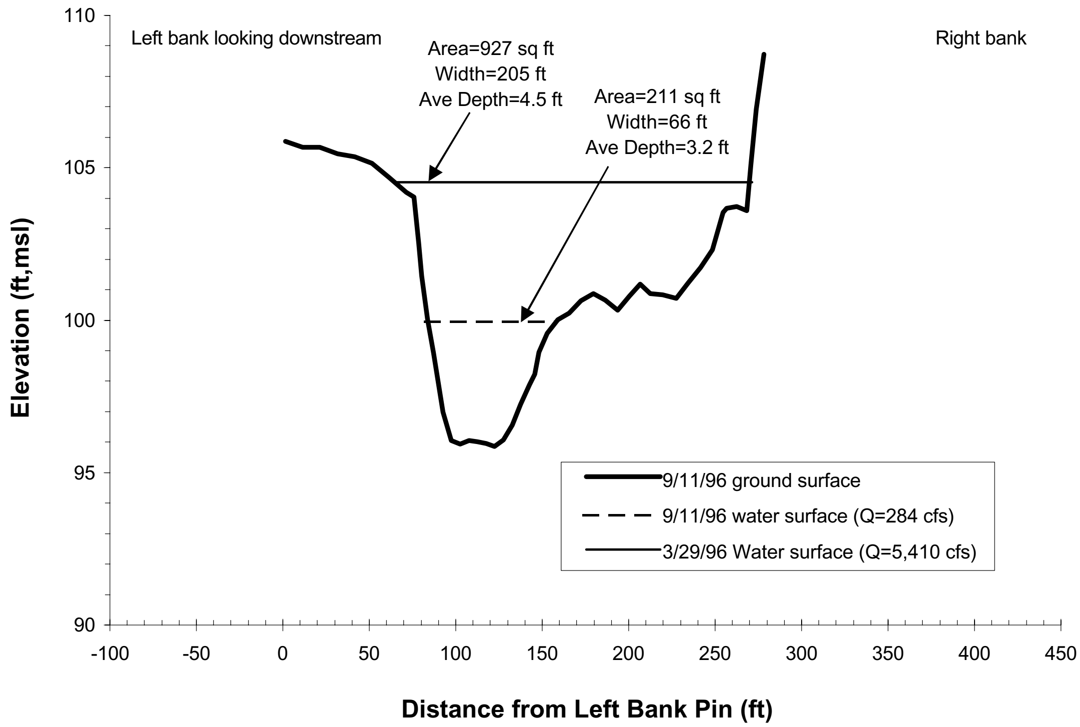

Figure 42. Cross section 107+71 surveyed in September 1996 at the M.J. Ruddy 4-Pumps Restoration Site showing channel dimensions following construction and numerous high flow events between 1993 and 1996.

Table 9. Water years 1995-1997 flood histories for the M.J. Ruddy 4-Pumps restoration site based on the Tuolumne River at LaGrange gaging station. Channel geometry monitored in September 1997 (thus prior to 1997 flood).

WATER YEAR 1995	DISCHARGE
January 30-February 17	4,000 cfs to 5,070 cfs
March 18-19	8,200 cfs
March 25-31	8,000 cfs to 8,300 cfs
April 1-23	6,800 cfs to 8,300 cfs
May 4-June 6	7,600 cfs to 8,700 cfs (peak=9,260 cfs)
July 10-12	8,000 cfs to 8,600 cfs
WATER YEAR 1996	**DISCHARGE**
February 7-March 28	4,500 cfs to 5,500 cfs
May 17-22	6,700 cfs (peak=6,880 cfs)
WATER YEAR 1997	**DISCHARGE**
December 13-21	5,500 cfs to 5,800 cfs
January 3	51,000 cfs (peak=60,000 cfs)
January 11-March 3	7,000 cfs to 9,000 cfs

The M.J. Ruddy 4-Pumps Restoration Site was designed with a low water channel width exceeding 100 feet, a subtle meander wavelength, and subtle pools and point bars. Based on 1996 field observations, the channel evolved considerably as a result of the high flow events listed in Table 9. While no as-built surveys were conducted, surveys in 1996 indicated that pools evolved and deepened, point bars formed, and the meander amplitude increased slightly. This evolution was documented in the Tuolumne River Corridor Habitat Restoration Plan, and several channel dimensions were obtained from this monitoring effort.

Table 10. Low water channel widths, average depths, and habitat units for cross sections at the M.J. Ruddy 4-Pumps Restoration Site.

CROSS SECTION	DISCHARGE	WIDTH	AVERAGE DEPTH	HABITAT UNIT
60+61	355 cfs	111	1.4	Riffle with replaced spawning gravel (1989)
67+53	285 cfs	94	1.2	Subtle point bar leading into old mining pit
79+61	285 cfs	75	2.1	Developing pool and right bank point bar
88+10	285 cfs	117	2.0	Developing pool in center of channel
94+97	285 cfs	84.5	1.3	Riffle with median bar
99+14	285 cfs	94	1.6	Developing pool and left bank point bar
107+71	285 cfs	66	3.2	Developing pool and right bank point bar
60+61	5,400 cfs	200	5.1	Riffle with replaced spawning gravel (1989)
67+53	5,400 cfs	197	4.8	Subtle point bar leading into old mining pit
79+61	5,400 cfs	387	3.3	Developing pool and right bank point bar
88+10	5,400 cfs	186	4.9	Developing pool in center of channel
94+97	5,400 cfs	171	5.2	Riffle with median bar
99+14	5,400 cfs	197	4.2	Developing pool and left bank point bar
107+71	5,400 cfs	205	4.5	Developing pool and right bank point bar

The cross sections and measured 5,400 cfs water surface elevations at the M.J. Ruddy 4-Pumps site were used in a HEC-RAS hydraulic model to back-calculate Manning's roughness values of 0.027 to 0.029 for the cross sections under as-built conditions (no riparian vegetation roughness). This roughness was used for the initial design conditions, and a Manning's roughness value of 0.035 was used for future conditions (Figure 30). Floodplain roughness values of 0.035 and 0.07 were used for as-built conditions and future conditions, respectively (Figure 30). Using Manning's equation and the estimated future roughness values, the channel width that conveys 5,000 cfs at a depth of 5.8 feet (see table 8, D_{84}=75 mm) was determined to be 175 feet. The 5,400 cfs channel widths at the M.J. Ruddy 4-Pumps site were constructed to be approximately 200 ft, and field observations of cross section evolution at several cross sections suggest slight narrowing of the bankfull channel is occurring. A 175 ft to 200 ft bankfull channel width is also consistent with regional observations of channel widths as a function of bankfull discharge (Dunne and Leopold 1978). Therefore, a target bankfull channel width between 175 ft and 200 ft was chosen for the Gravel Mining Reach. Because the slope in SRP 9 and 10 is so low that satisfying the bed mobilization objective under the post-NDPP flow regime is infeasible, the same template channel dimensions were used as at the Gravel Mining Reach.

The rectangular channel and floodway geometry shown in Figure 30 was further refined and smoothed for pools and riffles. The riffle template and pool templates in Figure 43 and Figure 44 respectively were used to develop the design Digital Terrain Model for the 7/11, M.J. Ruddy, and Reed reaches. The maximum depth was increased slightly to 6.5 ft, increasing the average depth to 4.2 ft. This will enable bed mobility in the center of the channel to occur at discharges slightly less than bankfull discharge (5,000 cfs). Because channel slope is lower in the Warner-Deardorff Reach than in the remainder of the Gravel Mining Reach (Figure 34), floodplain confinement was increased to improve the ability of high flows to achieve bed mobility thresholds. Therefore, separate riffle and pool templates were developed for the Warner-Deardorff Reach that had greater confinement (Figure 45 and Figure 46). The maximum depth of riffles was increased to 8.0 ft, thereby increasing the average depth to 5.4 ft.

The low flow channel dimensions were obtained by (1) monitoring the channel geometry adjustment at the M.J. Ruddy 4-Pumps Restoration Site (Table 10), and for riffle cross sections, (2) ensuring that preferable Chinook salmon spawning depths and velocities were obtained at the range of spawning flows (150 cfs to 300 cfs as shown in Table 3). Criteria used to delineate Chinook salmon spawning and rearing habitats were derived from suitability criteria used in the instream flow study conducted on the Tuolumne River in 1995 (USFWS 1995b). These criteria were comparable to habitat criteria identified in a literature review conducted prior to the field work in 1998, and were selected to maintain consistency and comparability with previous Tuolumne River studies. Depth and velocity criteria with suitability indices greater than 0.1 were used to define suitable spawning habitat, which resulted in favorable depths between 0.6 ft and 2.8 ft, and favorable velocities between 0.9 ft/sec and 3.2 ft/sec.

The FERC Settlement Agreement established spawning flows ranging from 300 cfs to 150 cfs based on water year type. Under a 300 cfs spawning flow and riffle slope of 0.0019 and channel width of 90 ft, the corresponding average water velocity is 2.15 ft/sec, maximum depth is 1.7 ft, and average depth is 1.5 ft. At a 150 cfs spawning flow, the corresponding average water velocity is 1.7 ft/sec, maximum depth is 1.2 ft, and average depth is 1.1 ft. Therefore, this riffle cross section template provides preferable depths and velocities over the range of spawning flows identified in Table 3. The above depth and velocity computations are average values; local values will vary to provide good habitat for fry rearing, juvenile rearing, and spawning habitat over the expected range of baseflows. However, because the floodway restoration project is being designed to allow natural adjustment to channel geometry during periods of high flow, we expect the template cross sections in Figure 43 and Figure 45 to evolve in the future. Suitable Chinook salmon habitat should persist and improve as the channel evolves from the as-built template conditions shown in Figures 43-46 into a more complex geometry.

5.1.6. Channel Meander Geometry

Historical conditions suggest that the lower Tuolumne River was a meandering semi-braided channel with a floodway exceeding 5,000 ft width (Figure 4). Meander geometry was extremely variable, with pre-dam meander wavelengths in the gravel-bedded reach ranging from 2,800 feet to 4,000 feet and averaging about 3,400 feet. After completion of New Don Pedro Dam, the flow regime was reduced to the point where the channel geometry was not able to adjust from its pre-dam dimension. One notable exception was at the M.J. Ruddy 4-Pumps Restoration Site, where over a mile of floodway was reconstructed. After construction, a series of high flow years (Table 9) caused evolution of the meander wavelength. The restoration meander wavelength based on observations at the 4-Pumps Restoration Site ranged between 1,600 to 2,000 feet.

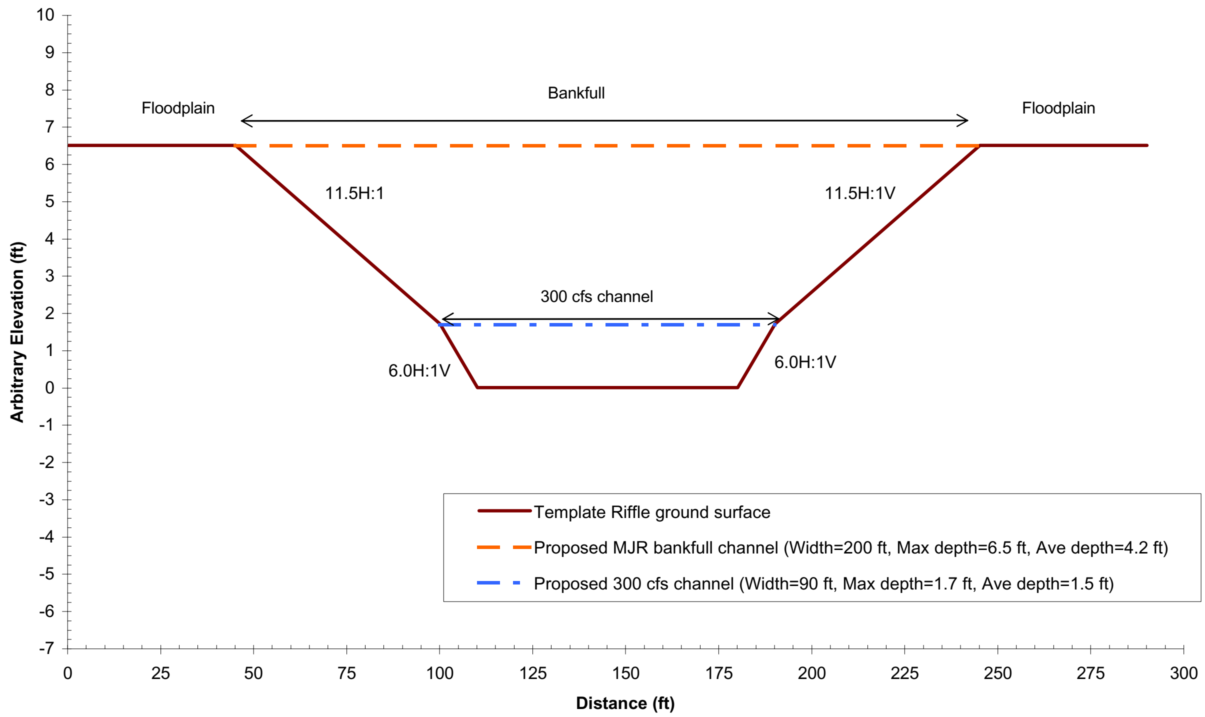

Figure 43. Template riffle cross section used in the 7/11 Reach, M.J. Ruddy Reach, Reed Reach, and SRP9/10 reaches. Floodplain elevations at the SRP 9 reach were subsequently lowered considerably as a cost-cutting measure.

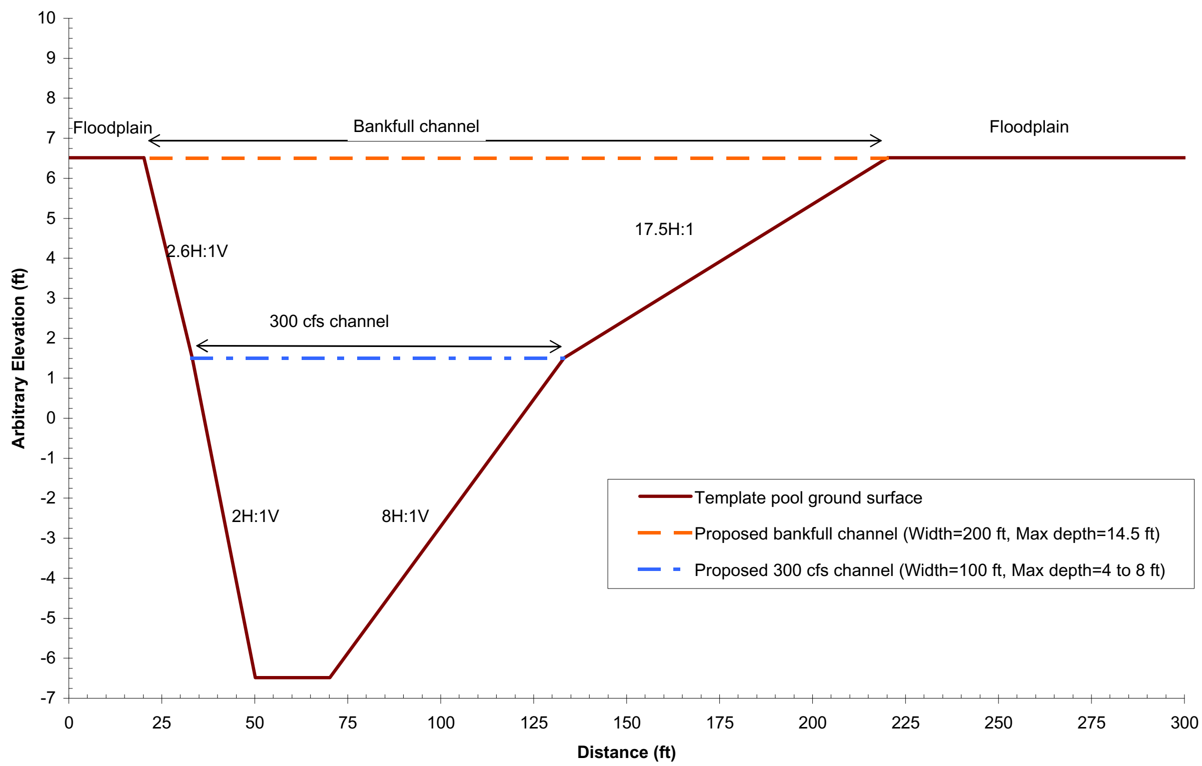

Figure 44. Template pool cross section used in the 7/11 Reach, M.J. Ruddy Reach, Reed Reach, and SRP9/10 reaches. Maximum pool depths were determined based on the M.J. Ruddy 4-Pumps site monitoring, and professional judgment based on the radius of curvature of the pool. Floodplain elevations at the SRP 9 reach were subsequently lowered considerably as a cost-cutting measure.

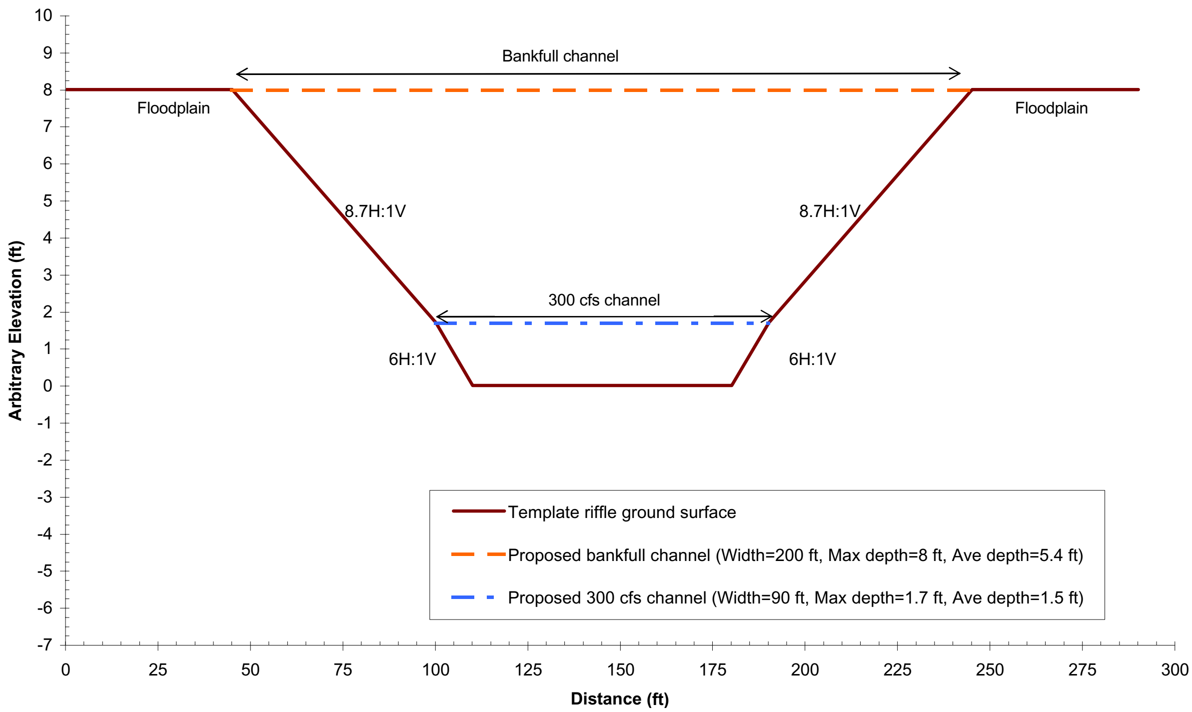

Figure 45. Template riffle cross section used in the Warner Deardorff Reach. Because channel slope is lower in this reach than in the remainder of the Gravel Mining Reach, floodplain confinement was increased to improve ability of high flows to achieve bed mobility thresholds.

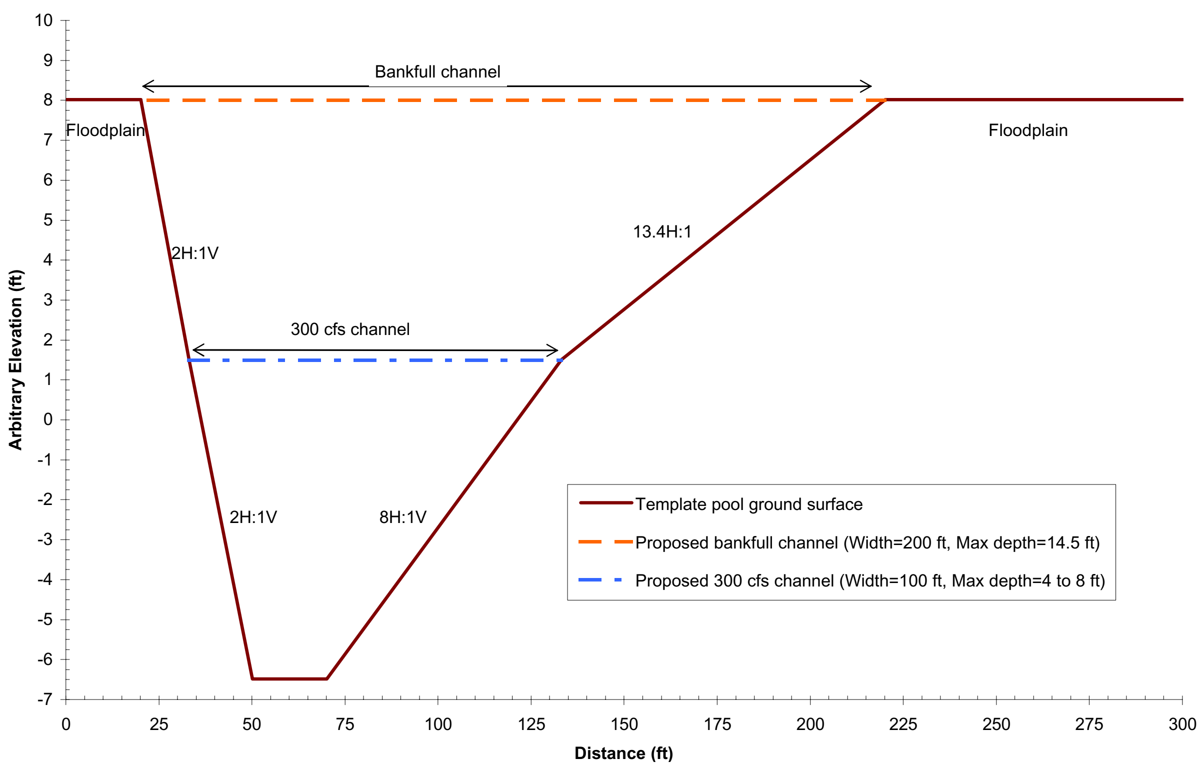

Figure 46. Template pool cross section used in the Warner-Deardorff Reach. Because channel slope is lower in this reach than in the remainder of the Gravel Mining Reach, floodplain confinement was increased to improve ability of high flows to achieve bed mobility thresholds.

The wavelength observed at the 4-Pumps Restoration Site is consistent with meander wavelength predicted by several models. Dury (1976), Leopold and Wolman (1957), and Williams (1986) developed empirically based relationships that can be used to predict meander wavelength based on several variables. These equations are shown below:

A bankfull discharge to meander wavelength relationship compiled by Dury (1976):

(2) $\lambda=15.18Q_{bf}^{0.55}$

A bankfull width to meander wavelength relationship compiled by Leopold and Wolman (1957):

(3) $\lambda=6.5W_{bf}^{1.1}$

A bankfull width to meander wavelength relationship compiled by Williams (1986):

(4) $\lambda=7.5W_{bf}^{1.12}$

where λ is meander wavelength (feet), Q_{bf} is bankfull discharge (cfs), and W_{bf} is bankfull channel width (feet). The results of these estimates for the Tuolumne Designs are shown in Table 11.

Table 11. Summary of Meander Wavelength Estimates.

Method	**Discharge (cfs)**	**Bankfull channel width (ft)**	**Predicted Wavelength (ft)**
Dury (Equation 2)	5,000	N/A	1,643
Leopold and Wolman (Equation 3)	N/A	175	1,907
Leopold and Wolman (Equation 3)	N/A	200	2,208
Williams (Equation 4)	N/A	175	2,439
Williams (Equation 4)	N/A	200	2,833
M.J. Ruddy 4-Pumps Restoration Site	N/A	N/A	1,600 to 2,400

Based on the above predictions and observations, we are targeting meander wavelengths to be approximately 1,600 ft. As mentioned above, historical meander wavelength was highly variable on the Tuolumne River; some of this variability can be explained by how the channel intersects roughness features or hard points (e.g., valley walls). Therefore, the 1,600 ft meander wavelength was used as a general guideline, not a fixed design parameter. Design meander spacing will vary depending on available space, designer judgment based on local site conditions, and fixed hardpoints (forced meander bends). Furthermore, meander amplitude and sinuosity is kept moderately low (amplitude<250 ft and sinuosity<1.1) to allow the channel to adjust to a more natural tendency. Creating a channel morphology with an amplitude and sinuosity that is too large increases the risk of meander cutoff and/or avulsion. Creating a channel morphology with a smaller amplitude and sinuosity will enable the river to gradually increase these values if needed, with reduced risk of catastrophic adjustment. The meander design and associated riparian revegetation acts as a naturally occurring energy dissipation system sized to the current hydrologic conditions.

5.1.7. Summary of design channel morphology dimensions

Based on the evaluations and computations performed in Section 5.1, design parameter guidelines are summarized in Table 12. As mentioned above, it is not the intent of the designers to develop precise channel dimensions that we expect the river to preserve over time. Rivers naturally have variable dimensions both within reaches and between reaches, and performing complex computations in an attempt to develop predict long-term dimensions provides a false sense of precision. While the designers predict expected general trends in channel dimensions (Table 12), we rely on periodic high flows and a coarse sediment supply to enable the channel to adjust its dimensions over time, and improve habitat quality and complexity compared to as-built conditions.

Table 12. Summary of proposed channel design dimensions.

Channel Morphology Parameter	Dimension
Channel width at low water (150 cfs)	75 - 90 feet
Thalweg depth at low water (pools)	4 - 8 feet
Thalweg depth at low water (riffles)	0.5 - 1.5 feet
Width at spawning flow (150-300 cfs)	90 - 100 feet
Average thalweg depth at spawning flow (riffles)	1 - 2 feet
Average water velocity at spawning flow	1.3 - 2.5 feet/sec
Riffle slope at spawning flow	0.0019
Bankfull discharge	5,000 cfs
Bankfull width	175-200 feet
Average bankfull depth	6 feet
Average bankfull water velocity	4.4 feet/sec
Maximum floodway width	>500 feet
Minimum floodway width	500 feet
Maximum design floodway discharge	15,000 cfs
Meander wavelength	1,600 feet
Amplitude	<250 ft
Sinuosity	1.1
Radius of curvature	N/A
High flow energy slope	0.0014[a], .00068[b], .00043[c]

[a] 7/11, M.J. Ruddy, and Reed portion of Gravel Mining Reach

[b] Warner-Deardorff portion of Gravel Mining Reach

[c] SRP 9 and SRP 10

5.2. Fish Habitat Criteria

Improving Chinook salmon production from the Tuolumne River is a primary objective of this restoration project. For the both the Gravel Mining Reach and SRP 9/10 Reach, the project seeks to: (1) reduce periodic salmon predation by reducing the frequency of dike failures with adjacent off-channel mining pits that contain large-mouth and small-mouth bass, (2) reduce chronic salmon predation by filling instream mining pits, and (3) redistributing riffle gradient to increase salmon spawning and rearing habitat. To accomplish these objectives, information is needed to describe habitat for both target restorations species (fall-run Chinook salmon), as well as target reduction species (large-mouth and small-mouth bass). Habitat requirements of each are described in the following sections.

5.2.1. Chinook salmon spawning and rearing habitat

The objectives of the Gravel Mining Reach and SRP 9/10 Reach include improving Chinook salmon spawning and rearing habitat. In the Gravel Mining Reach, one of the primary objectives is to "improve salmon spawning and rearing habitats by restoring alternate bar (pool-riffle) morphology, restoring spawning habitat within the meandering channel, and filling in-channel mining pits" (see Section 3.1.1). For SRPs 9 and 10, one of the primary objectives is to "reduce/eliminate habitat favored by predatory bass species and replace it with high quality Chinook salmon habitat" (see Section 3.2.1). The pathways delineating effects of these changes in habitat structure on Chinook salmon population abundance are described in the conceptual models for the two projects in Section 4.1.

Chinook salmon spawning and rearing habitat suitability criteria for designing and evaluating these projects were derived from PHABSIM criteria developed for the instream flow study conducted in the Tuolumne River for the 1995 FSA (Table 13). Habitat parameters that can be addressed by the restoration design include flow depth, flow velocity, substrate composition, and cover. Water temperature is primarily driven by temperature of flow releases from the NDPP, but flow magnitude and air temperature can potentially be affected by restoration actions the reduce flow residence time (i.e., filling in-channel pits).

Table 13. Summary of Chinook salmon habitat suitability criteria based on USFWS (1995).

Habitat requirement	Fry rearing	Juvenile rearing	Adult spawning
Depth	0.2 ft to 2.0 ft	0.5 ft to 6.5 ft	0.6 ft to 2.8 ft
Velocity	0.0 ft/sec to 1.2 ft/sec	0.1 ft/sec to 2.2 ft/sec	0.9 ft/sec to 3.2 ft/sec
Cover	none	Vegetation and large wood	none
Substrate	All coarse sizes	All coarse sizes	13 mm to 102 mm
Temperature	43°F to 65°F	43°F to 65°F	47.5°F to 57.5 °F

The restoration projects seek to increase the area of Chinook salmon spawning and rearing habitat by filling in-channel pits, redistributing longitudinal gradient, recreating an alternating bar morphology within the floodway, reconstructing spawning riffles, providing suitable floodplain rearing during high flow events, and reducing the risk of stranding on floodplains as flows recede following floods. Much of the Gravel Mining Reach is confined to the point where there is insufficient space for an alternate bar morphology to form. Furthermore, during the 1997 flood, bed scour occurred in areas of confinement and bed aggradation occurred in areas where the confinement ended (dike failures). This has resulted in long pools separated by short, steep riffles that provide little spawning and rearing habitat (Figure 47), and can be one of several reasons for lower spawning density in a reach. This process of riffle steepening occurred during the 1997 flood in the 7/11 Reach at RM 39.0, and occurred at the M.J. Ruddy Reach at RM 37.0. A design criteria is to redistribute the gradient at these locations to a slope of 0.0015 to 0.0020, and create several lower gradient riffles as part of restoring an alternate bar sequence through the reach. Clean spawning gravels will be placed in riffles in the M.J. Ruddy Reach and upstream portion of the Warner/Deardorff reach to a depth of 2 feet to improve spawning habitat for salmonids. The maximum particle size (D_{100}) will be 128 mm (5 inches) and the D_{84} will be 74 mm (2.9 inches) such that spawning habitat will be provided for a range of salmonids per the Coarse Sediment Management Plan (McBain and Trush 2003). Topographic diversity of reconstructed riffles will be considered to provide initial habitat diversity for spawning salmonids.

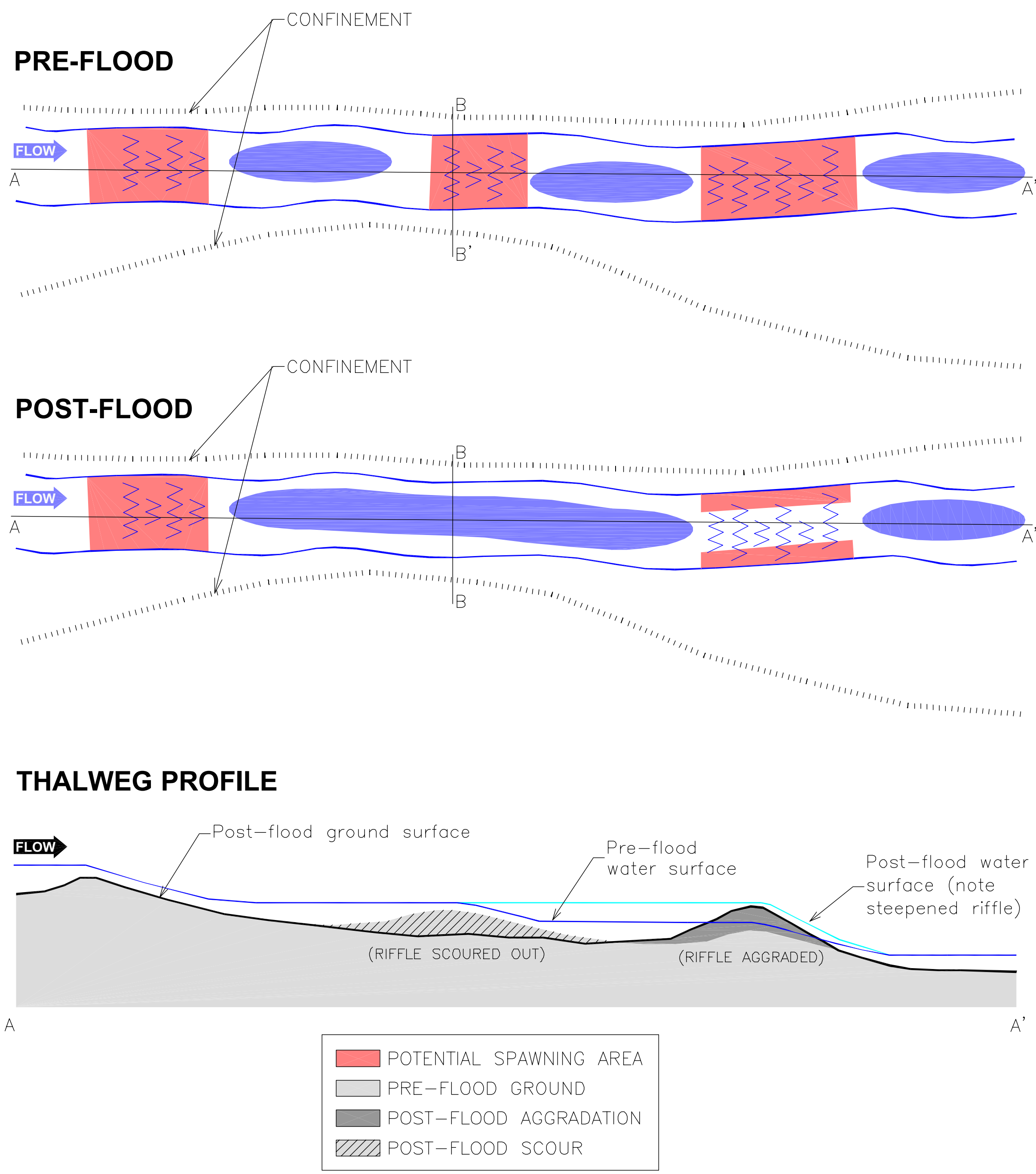

Figure 47. Conceptual illustration of how locally steep gradient will be redistributed to increase spawning habitat quantity.

This topographic diversity will quickly evolve as anticipated fluvial process flows adjust the gravels and cobbles within a specific riffle. Riffle location and existing habitat conditions will be part of the site specific considerations for creating such micro topographic features.

The redd count density shown in Table 14 contains data collected prior to the 1997 flood, and redd count density has likely decreased in the Gravel Mining Reach due to reduced spawning habitat after the 1997 flood. Redd count data for the SRP 9/10 Reach are not tabulated because very little spawning occurs this low on the river.

Table 14. Comparison of spawning riffle areas between the Basso Spawning Reach (desirable) and the Gravel Mining Reach showing lower riffle area density and redd counts. Gravel Mining Reach values have likely decreased as a result of the 1997 flood.

Reach	**River mile**	**Riffle area (ft^2)**	**Riffle area density (ft^2/mi)**	**Average "high" redd counts (1981-1995)**
LaGrange Dam Reach	50.5 – 52.1 (1.6 miles)	68,000[a]	42,400	875[b]
Basso Spawning Reach	46.8 – 50.5 (3.7 miles)	767,000[a]	207,000	5,600[b]
Dredger Mining Reach	41.8 – 46.8 (5.0 miles)	326,000[a]	65,000	3,000[b]
Gravel Mining Reach	33.9 – 41.8 (7.9 miles)	699,000[a]	89,000	2,800[b]
In-channel Gravel Mining Reach	46.8 – 50.5 (7.9 miles)	821,000[a]	104,000	900[b]

[a] Data summarized from EA Engineering, Science, and Technology (1992).

[b] Based on CDFG annual redd counts from 1981-1995. "High" redd counts refer to the highest redd count for numerous redd surveys conducted during each year, and the value shown in the table above is the average of these "high" redd counts from 1981-1995.

The project is also designed such that as-built channel morphology will evolve over time. Therefore, the project has components that target spawning habitat in constructed riffles, but rearing habitat design criteria are not explicitly used in microhabitat design of the project. Rather, fry and juvenile rearing habitat improvements over existing conditions are expected by creating a more sinuous, complex channel morphology (Figure 48). Even greater habitat benefits are expected once high flows begin to refine channel morphology and increase habitat complexity over as-built conditions. In addition, by increasing channel complexity and increasing floodway width, fry and juvenile rearing habitat should be increased over a wide range of flows compared to existing conditions (Figure 48). No predictive modeling was conducted to evaluate the benefits of the project to rearing habitat; however, baseline rearing habitat is being collected as part of the monitoring program in order to evaluate our assumed improvements in rearing habitat once the project is completed and high flows refine the channel morphology.

5.2.2. Largemouth and smallmouth bass habitat

One of the primary objectives of the SRP 9/10 Reach is to reduce the area of suitable habitat for largemouth and smallmouth bass. This objective is also applicable to the Gravel Mining Reach, but the degree of salmon predation by these species is less in this reach than the SRP 9/10 Reach. Smallmouth and largemouth bass are introduced species that prey on juvenile Chinook salmon.

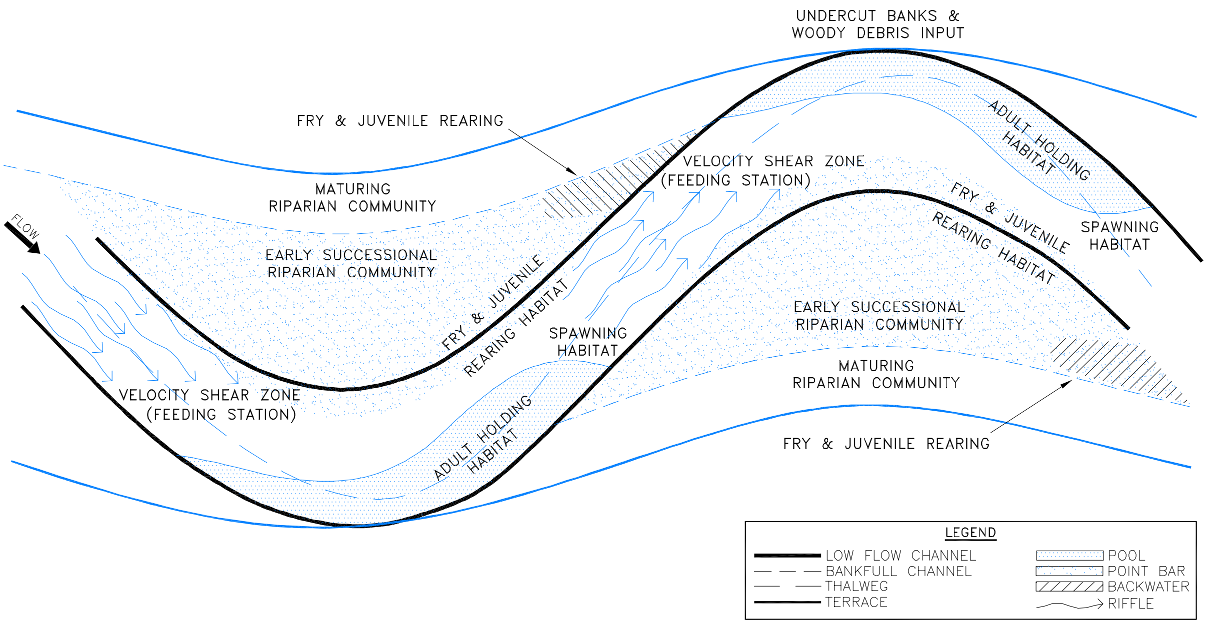

Figure 48. Alternate bar sequence, showing benefits to Chinook salmon fry rearing, juvenile rearing, and spawning habitat.

Largemouth bass prefer lower velocity, warmer water temperatures, and deeper habitats (e.g., instream mining pits), whereas smallmouth bass can tolerate cooler water temperatures, higher velocities, and shallower depths (Table 15).

The restoration projects will attempt to reduce largemouth bass habitat by filling in large in-channel pits and isolating floodplain pits from the restored channel, and increase Chinook salmon habitat by reconstructing a more complex alternate bar morphology as described above. Smallmouth bass, however, will utilize and can reproduce in habitats similar to those used by Chinook salmon. Replacing deep pits with a flowing channel, therefore, may not necessarily decrease the extent of habitat suitable for smallmouth bass.

Table 15. Habitat Suitability Criteria for Largemouth and Smallmouth Bass.

Habitat Parameter	Largemouth Bass	Smallmouth Bass
Flow Depth	no maximum depth identified in literature	Optimal depth = 2 to 10 ft
Velocity	0.0 to 0.75 ft/s	0.0 to 1.5 ft/s
Substrate	No substrate avoided	Strong preference for coarse gravel and cobble; no sand or silt
Cover	Availability of overhead cover is beneficial but not essential	Availability of overhead cover is beneficial but not essential
Temperature	Optimum range = 75°F to 86°F	Optimum range = 68°F to 78°F

Sources: Hardin and Bovee (1978), Stuber et al. (1982), Studley et al. (1986), Todd and Rabeni (1989), Barrett and Maughan (1994)

5.3. Riparian Vegetation Criteria

The existing extent of riparian vegetation at the Gravel Mining Reach and SRP 9/10 Reach is narrow and longitudinally fragmented, with much of the riparian vegetation one tree canopy width wide. Obviously, species dependent on riparian habitat would benefit from increasing the width, area, and longitudinal connectivity, but quantitative criteria on incremental benefits of increasing width, area, and connectivity is sparse in the scientific literature. The following sections describe some of these criteria based on: (1) indicator species habitat needs (e.g., yellow-billed cuckoo), and (2) observed relationships between certain riparian species and inundation patterns on certain geomorphic surfaces. Lastly, the riparian restoration approach has evolved somewhat over the conceptual design to final design phase of the project, thus the vegetation design criteria has also evolved. There were significant differences of opinion on how the riparian revegetation should be conducted, and some of the changes that occurred from conceptual design to actual design are discussed.

5.3.1. Riparian corridor width and patch size

Riparian vegetation performs numerous functions important to terrestrial and aquatic ecosystems. These functions include, but are not limited to, the following:

- filtering runoff and nutrients;
- providing habitat for terrestrial wildlife;
- stabilizing stream banks and reducing erosion;
- providing shade and cover in near-bank aquatic habitats;
- contributing large wood to the channel that, in turn, provides cover and habitat complexity for fish, amphibians, and reptiles;
- contributing to riverine and terrestrial food webs;
- providing nesting, rearing, foraging, and breeding habitat for native terrestrial species; and providing dispersal corridors for aquatic invertebrates and a variety of terrestrial plants and animals

The capacity of the riparian corridor to perform these functions depends, in part, on corridor width and patch size. Depending on the functions desired to be performed by the riparian corridor, corridor widths have been proposed ranging from as narrow as 12 feet for improving water quality (Doyle et al. 1977) to more than 1,800 feet to support the western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) (Laymon et al. 1997). Based on review of the literature on recommended riparian buffer widths in lowland alluvial rivers, Stillwater Sciences (2003) developed three classes of riparian buffer widths for the San Joaquin River, defined as “minimal,” “moderate,” and “enhanced” (Table 16).

In addition to corridor width, patch size is an important consideration in restoring and managing riparian habitats. As part of the San Joaquin River Restoration Program process, yellow-billed cuckoo was used as an indicator species for patch size required to support a range of native species (Stillwater Sciences 2003). The western yellow-billed cuckoo, a willow-cottonwood riparian forest obligate species, was used as an indicator species because habitat criteria have been well quantified and modeled (Greco 1999). Patch sizes are also intended to represent habitat needs of multiple riparian-obligate species, such as yellow warbler, willow flycatcher, and black-headed grosbeak. Patch size criteria for the yellow-billed cuckoo are shown in Table 17, and are considered applicable for the Tuolumne River. There are many other ecosystem functions that are related to floodway width, including floodplain inundation characteristics (e.g.,depth, velocity, duration), residency time, nutrient exchange, and juvenile salmonid rearing habitat (e.g., Sommer et al. 2001) that have not been incorporated into the floodway width criteria.

Table 16. Riparian buffer width classes and corresponding functions.

Class	Width (ft)	**Functions**
Minimal	0-100	• Stream shading • Micro-climate change within riparian vegetation • Sediment trapping • Large woody debris recruitment • Trapping/assimilating nutrients and sediments
Moderate	100-300	• All functions listed above • Additional nutrient and sediment reduction • Reduced stream temperature for narrow streams • Flood peak attenuation • Riparian bird nesting
Enhanced	>300	• All functions listed above • Landscape-level habitat corridors • Food web support • Improved flood peak attenuation • Habitat for yellow-billed cuckoo

Source: Stillwater Sciences 2003

Table 17. Habitat suitability of willow-cottonwood patch sizes for western yellow-billed cuckoo.

Habitat Suitability	Area (acres)	Width (feet)	Patch distance from water (feet)
Optimal	>198	>1,970	<330
Suitable	101-197	660-1,970	--
Marginal	42-100	330-660	--
Unsuitable	<42	<330	> 330

Source: Stillwater Sciences 2003

The riparian width design criteria adopted in the Gravel Mining Reach and the SRP 9/10 Reach conceptual design was based on having at least 100 ft of riparian vegetation width on both banks to: (1) create a visual buffer to allow longitudinal migration corridor, (2) enough canopy closure to create a micro-climate within the riparian band to encourage natural regeneration of understory plants, and (3) provide a roughness buffer to discourage rapid channel migration and potential damage to reconstructed dikes. Given that the proposed bankfull channel width (which would ideally have small amounts of riparian vegetation) was 200 ft, a 500 ft wide floodway would allow a riparian band width of 150 ft if the bankfull channel was within the center of the floodway. This riparian band width would be connected to riparian vegetation on the upstream and downstream ends of the project reaches to improve migration corridor connectivity. This 500 ft wide floodway would allow some riparian patches to be up to 250 ft wide, and as narrow as 50 ft wide. A wider floodway and corresponding riparian patch width was considered, but the implementation costs due to filling additional off-channel mining pits made this cost-prohibitive. The proposed riparian patch widths generally increase from "minimal" under existing conditions to the "moderate" category under design conditions (Table 16). The proposed riparian patch widths are all in the "unsuitable" category for yellow-billed cuckoo (Table 17). Historic riparian patch widths in this reach were rarely larger than the "Unsuitable" category in this reach because of the semi-braided channel morphology, and most of the larger riparian patches and associated yellow-billed cuckoo habitat were likely located downstream in the sand bedded reach that had extensive contiguous riparian forests (Figure 3).

Because healthy riparian systems in California are extremely dynamic, Greco (1999) recommends that conservation and restoration efforts recognize that large areas (i.e., areas exceeding minimum patch size requirements) are needed to allow for changes to and loss of riparian habitat at a particular site. To incorporate the dynamics of riparian habitats in avian conservation and restoration, Greco (1999) recommends using "minimum dynamic areas" (Pickett and Thompson 1978, as cited in Greco 1999) over conservation of minimum patch size areas. The design philosophy of the Gravel Mining Reach and SRP 9/10 Reach designs adopts this principle as well, but the floodway space allocated for "dynamic areas" are likely much smaller than needed to create and maintain habitat for yellow-billed cuckoo. Many other bird species do not require the extent of riparian patch size of yellow-billed cuckoo, and should greatly benefit from the riparian revegetation effort. No quantitative predictions of population numbers for these other species have been attempted.

5.3.2. Riparian hydrodynamics

Riparian investigations conducted for the Lower Tuolumne River Corridor Habitat Restoration Plan evaluated hydrogeomorphic influences on riparian vegetation planting locations, and assessed factors limiting natural vegetation recruitment under the post-NDPP flow regime (McBain and Trush 2000). Riparian vegetation recruitment and establishment in healthy river ecosystems is strongly dependent upon patterns of inundation and characteristics of geomorphic surfaces. There are few sites on the Tuolumne River, however, that can serve as models to define these hydrogeomorphic relationships upon which to base restoration design because of extensive change to geomorphic surfaces (e.g., agricultural and urban encroachment), as well as significant change to streamflow hydrology. The Restoration Plan used three vegetation transects to illustrate relationships between riparian vegetation species, geomorphic surfaces, and inundation characteristics. One transect was located in the gravel-bedded reach, one in the upper sand-bedded reach, and one in the lower sand-bedded reach. Each transect was chosen in a reach where the geomorphic surface and riparian vegetation was minimally disturbed by mechanical means (clearing, mining, agriculture). The results illustrate that the post-NDPP flood recurrences to inundate the riparian species of interest are much larger than one would expect from natural conditions (Table 18). This result is typical in highly regulated systems; riparian vegetation observed today (particularly cottonwood) was established during the pre-dam flow regime, and are now perched on surfaces that are no longer geomorphically active due to the reduced flood flow regime. The Basso Bridge transect (RM 47) is upstream of the Gravel Mining Reach, and the Santa Fe transect (RM 22.5) is near the SRP 9/10 Reach. The proposed inundation characteristics illustrated in Table 18 attempt to rescale the geomorphic surfaces and riparian species plantings towards a more natural relationship, such that constructed surfaces better support natural regeneration of these native riparian species (Table 18).

Table 18. Inundation characteristics for native riparian vegetation species/series based on transects at RM 47 and RM 22.5, and proposed riparian vegetation planting on downscaled geomorphic surfaces.

	Existing inundation characteristics at monitoring transects		Proposed inundation characteristics at Restoration Reaches[3]	
Species/Series	**Flood recurrence interval (post-NDPP)**	**Flow (cfs)**	**Flood recurrence interval (post-NDPP)**	**Flow (cfs)**
Sedges	Summer baseflow to winter baseflow	150 - 1,000	Summer baseflow to winter baseflow	150 - 1,000
Narrow-leaf willow	Summer baseflow to 1.5-year flood	150 - 3,000	Not planted[1]	N/A
White alder, Box elder, and mixed willow	1.5-year to 5-year flood	3,000 – 7,500	1.4-year to 2.2-year flood	2,500 – 4,000
Fremont cottonwood and black willow	5-year to 20-year flood[2]	7,500 – 12,800	2.2-year to 5-year flood	4,000 – 7,000
Valley oak	20-year to 100-year flood[2]	12,800 – 18,000	>5-year flood	7,000 – 15,000

[1] Narrow-leaf willow is an aggressive native species that has encroached into the former active channel and is not a target species to be planted in the restoration effort, as it will naturally establish without planting.

[2] Many of the plants on the transects were established prior to completion of the New Don Pedro Project

[3] From McBain & Trush and EA Engineering, 1997

5.3.3. Riparian Planting Strategies

The challenge of developing a riparian planting strategy involves how to balance the objectives of the Habitat Restoration Plan with the constraints imposed by a severely regulated river system. The Habitat Restoration Plan emphasizes natural regeneration whenever possible. Historically, natural riparian establishment most likely occurred during a small number of years when the spring snowmelt hydrograph and high flow regime provided adequate conditions. In most years, potential riparian recruitment sites were predominately dry, with less than 12 inches of rain per year. The Tuolumne River is now a very highly regulated reservoir system that is not likely to be releasing spring flows at a time and magnitude to match the needs of seed dispersal and germination. We are pragmatic about riparian revegetation at the project sites; we cannot rely solely on natural riparian regeneration due to the severely regulated conditions and naturally dry climate during the riparian establishment period. Artificial revegetation must be done. Low water levels in the river and shallow groundwater table may necessitate irrigation during the first year or two of planting. Funding agencies want successful establishment of riparian forest species within the time frame of the funding for the project. They have indicated a preference for understory planting being included in the planting mix as a methodology to reduce the impacts of invasive non-native weeds on the success of the revegetation effort. Site competition from invasive non-native weeds cannot be underestimated when implementing effective riparian revegetation. Additionally, implementation of riparian revegetation would occur during favorable times of the year when the vegetation is dormant. However, construction management often needs flexibility in the planting window, requiring irrigation of container stock in the event the construction window is delayed beyond the period when dormant cuttings and seeding would be successful.

As stated in Section 5.3.2, many riparian species are associated with specific geomorphic surfaces due to certain hydrologic and geomorphic tolerances by each species. In many portions of the restoration projects, there is a limit to the diversity of geomorphic surfaces that can reasonably be constructed with heavy equipment along the narrow corridor due to volume of fill material (cost), space, and available funding. As a result, the floodway benches constructed to date have tended to be flat with constructed high flow scour channels providing the only micro topography outside of the riffle pool sequence in the main channel. Planting on this flat floodway bench can produce a mix of riparian species being planted on what is essentially the same geomorphic surfaces. Between the time that the projects were initially proposed to the funding agencies and the time they began to be implemented, there were several iterations of revegetation strategy discussions, including comments from the Adaptive Management Forum. Floodway reconstruction methodology, and associated revegetation methodology, will continue to evolve as the remaining segments of the projects are implemented.

Two basic revegetation methodologies were identified for the Gravel Mining Reach and SRP 9/10 Reach, but only one has been implemented. Both methods incorporate topsoil into the construction design to improve both natural and artificial riparian revegetation, as well as to acknowledge that the New Don Pedro Project traps fine sediment supply (silts) from the upper watershed. Both methods look to some form of irrigation to sustain the planting in the first year or two if possible because the site conditions are dry and the water table is not a reliable supply of water for container stock plantings (there is disagreement whether the water table would limit cutting plantings). The method adopted for implementation uses planting modules with overstory and understory plants, using exclusively container stock. Sprinkler irrigation was used because of the planting density. The alternative revegetation strategy involved fewer species of only overstory plants and the use of cuttings to the extent possible with planting in rows to take advantage of drip irrigation. Both methods are discussed below.

5.3.4. Riparian planting modules

Using the inundation characteristics described in Section 5.3.2, planting designs and layouts were established for each restoration project. Hexigon planting modules were developed to portray plantings on a 2-dimensional surface and avoid linear plantings. Each hexagon module contained from one to nine plant species, and from 13 to 166 individual plants. All plantings will be irrigated for two years. Nineteen module types were developed by Hart Restoration (Table 19), and typical hardwood, shrub, and herb modules are shown in Figure 49a and Figure 49b. The mix of modules was varied with the intent to match micro topography and to provide a diverse mosaic across the area planted. The modules were planted contiguously across the floodplain at each site, resulting in very dense, yet diverse initial plantings. The intent of contiguous planting was to achieve canopy closure early in the revegetation growth to reduce weed competition.

A large portion of the plantings are root container stock, comprising both overstory plantings and understory plantings. Because the reconstructed surfaces are primarily cobbles and gravels, the container stock plantings will require topsoil placement to improve survival success (Figure 50). Based on other revegetation projects in the Central Valley, willow and cottonwood cuttings can be less dependent on topsoil to ensure survival; nevertheless, the revegetation design recommends adding topsoil to improve survival success (Figure 51). In rock slope protection zones sedges and rushes will be installed as “ballast buckets” in the lower zones near the edge of the river with, with topsoil placed around the ballast buckets to improve survival (Figure 51). In areas requiring softer, non-riprap bank protection, willow brush matting will be installed along the low water line and

Table 19. Proposed revegetation modules for the Gravel Mining Reach and SRP 9/10 Reach constructed surfaces.

Module Name	No. species per module	No. plants per module	Planting type
Rush	1	76	Container
Sedge	1	76	Container
Mugwort	1	13	Container
Wild rose	1	13	Container
Blackberry	1	13	Container
Elderberry	2	84	Cutting
Arroyo willow	4	94	Cutting
Button bush	2	128	Cutting
Alder	3	87	Container
Red willow	7	99	Cutting
Shining willow	7	99	Cutting
Black willow	7	99	Cutting
Mixed willow	11	99	Cutting
Cottonwood	7	99	Cutting
Mixed Cottonwood	9	99	Cutting
Ash/box elder	8	99	Container
Western sycamore	7	99	Container
Mixed valley oak	9	99	Seed
Mixed cottonwood alternative planting	9	97	Cutting

anchored with heavy gage wire (Figure 52). Lastly, previous revegetation efforts in the reach have had extensive browse damage to planted riparian vegetation from beaver, and to a lesser degree from deer. The proliferation of gravel pits has increased beaver populations along the Tuolumne River corridor, which has made it more difficult for planted cuttings to grow to a height and girth where they are less prone to beaver browse damage. Many plantings will thus require either wire fence protection in the first few years of growth to reduce riparian planting loss due to browse damage (Figure 53), some form of active beaver reduction measures, or acceptance of anticipated browse damage through the use of heavier planting densities.

5.3.5. Alterations in revegetation strategy and implementation

Many of the design criteria described above were implemented in the 7/11 Reach and SRP 9 project; however, there was disagreement amongst the design team members on several specific aspects of the riparian design and how it was implemented. This resulted in several deviations between the conceptual design proposed to CALFED in the initial two funding applications and the eventual implemented project in those segments. These differences are summarized below:

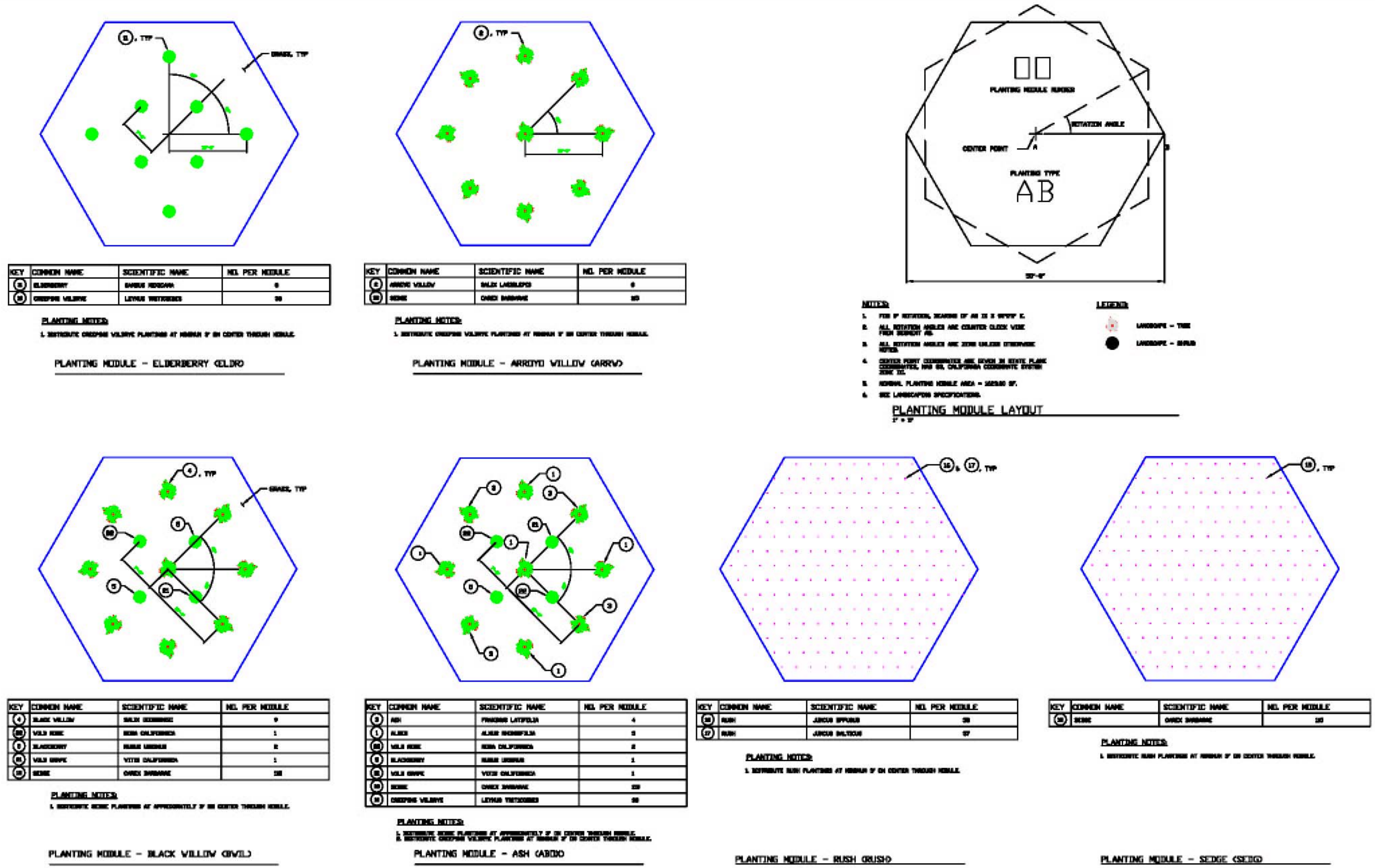

Figure 49. Proposed hexagonal riparian planting scheme for 14 patch types, from Hart Restoration and HDR Engineering.

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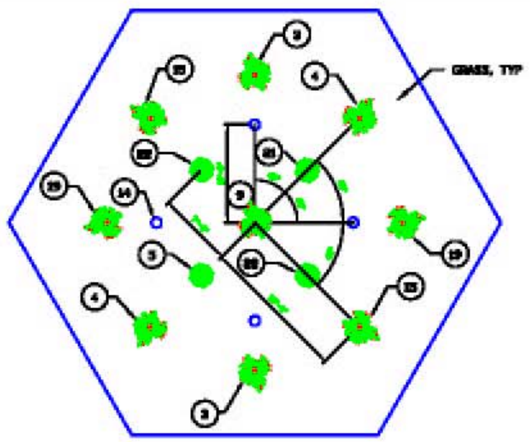
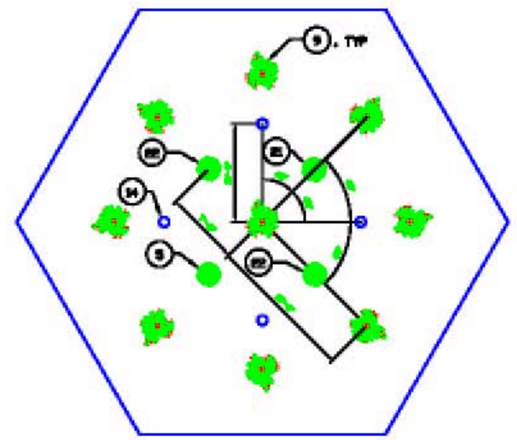


KEY	COMMON NAME	SCIENTIFIC NAME	NO. PER MODULE
20	RED WILLOW	SALIX LAEVIGATA	3
4	BLACK WILLOW	SALIX GOODDINGII	4
19	SHINING WILLOW	SALIX LUCIDA	3
3	ASH	FRAXINUS LATIFOLIA	2
22	WILD ROSE	ROSA CALIFORNICA	2
5	BLACKBERRY	RUBUS URSINUS	1
21	WILD GRAPE	VITIS CALIFORNICA	1
14	MUGWORT	ARTEMISIA DOUGLASIANA	4
18	SEDGE	CAREX BARBARAE	30
16	CREEPING WILDRYE	LEYMUS TRITICOIDES	30

PLANTING NOTES:

1. DISTRIBUTE SEDGE PLANTINGS AT APPROXIMATELY 3' ON CENTER THROUGHOUT MODULE.
2. DISTRIBUTE CREEPING WILDRYE PLANTINGS AT APPROXIMATELY 3' ON CENTER THROUGHOUT MODULE.

PLANTING MODULE – MIXED WILLOW (MWIL)

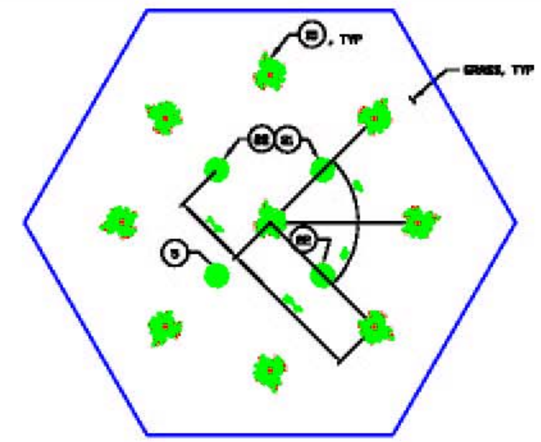


KEY	COMMON NAME	SCIENTIFIC NAME	NO. PER MODULE
9	COTTONWOOD	POPULUS FREMONTII	9
22	WILD ROSE	ROSA CALIFORNICA	2
5	BLACKBERRY	RUBUS URSINUS	1
21	WILD GRAPE	VITIS CALIFORNICA	1
14	MUGWORT	ARTEMISIA DOUGLASIANA	4
18	SEDGE	CAREX BARBARAE	30
16	CREEPING WILDRYE	LEYMUS TRITICOIDES	30

PLANTING NOTES:

1. DISTRIBUTE SEDGE PLANTINGS AT APPROXIMATELY 3' ON CENTER THROUGHOUT MODULE.
2. DISTRIBUTE CREEPING WILDRYE PLANTINGS AT APPROXIMATELY 3' ON CENTER THROUGHOUT MODULE.

PLANTING MODULE – COTTONWOOD (COTN)

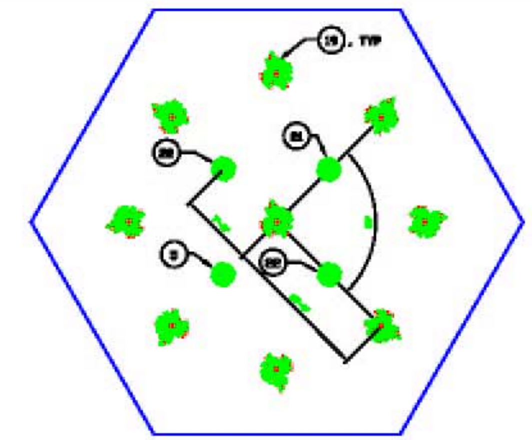


KEY	COMMON NAME	SCIENTIFIC NAME	NO. PER MODULE
20	RED WILLOW	SALIX LAEVIGATA	9
22	WILD ROSE	ROSA CALIFORNICA	8
5	BLACKBERRY	RUBUS URSINUS	1
21	WILD GRAPE	VITIS CALIFORNICA	1
18	SEDGE	CAREX BARBARAE	30

PLANTING NOTES:

1. DISTRIBUTE SEDGE PLANTINGS AT MINIMUM 3' ON CENTER THROUGH MODULE.

PLANTING MODULE – RED WILLOW (RWIL)

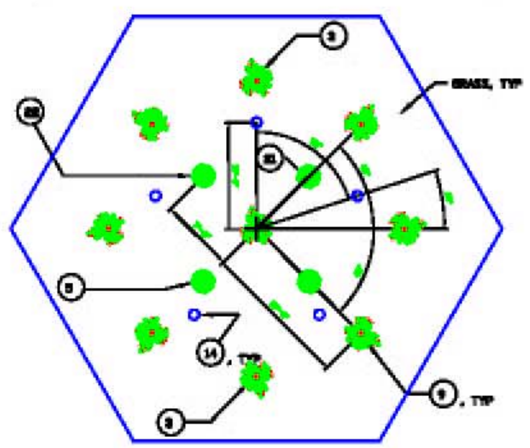


KEY	COMMON NAME	SCIENTIFIC NAME	NO. PER MODULE
19	SHINING WILLOW	SALIX LUCIDA	9
22	WILD ROSE	ROSA CALIFORNICA	8
5	BLACKBERRY	RUBUS URSINUS	1
21	WILD GRAPE	VITIS CALIFORNICA	1
18	SEDGE	CAREX BARBARAE	30

PLANTING NOTES:

1. DISTRIBUTE SEDGE PLANTINGS AT MINIMUM 3' ON CENTER THROUGH MODULE.

PLANTING MODULE – SHINING WILLOW (SWIL)

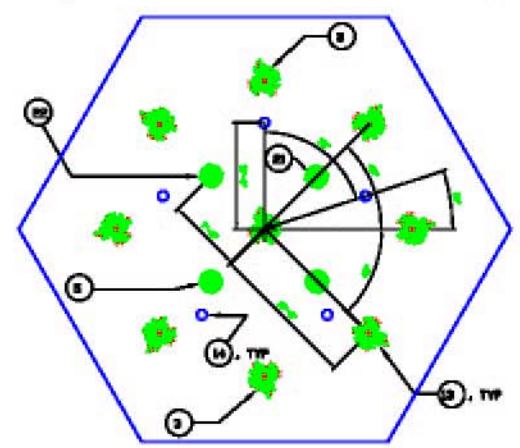


KEY	COMMON NAME	SCIENTIFIC NAMES	NO. PER MODULE
9	COTTONWOOD	POPULUS FREMONTII	7
3	ASH	FRAXINUS LATIFOLIA	2
22	WILD ROSE	ROSA CALIFORNICA	2
5	BLACKBERRY	RUBUS URSINUS	1
21	WILD GRAPE	VITIS CALIFORNICA	1
14	MUGWORT	ARTEMISIA DOUGLASIANA	8
18	SEDGE	CAREX BARBARAE	30
16	CREEPING WILDRYE	LEYMUS TRITICOIDES	30

PLANTING NOTES:

1. DISTRIBUTE SEDGE PLANTINGS AT APPROXIMATELY 3' ON CENTER THROUGHOUT MODULE.
2. DISTRIBUTE CREEPING WILDRYE PLANTINGS AT APPROXIMATELY 3' ON CENTER THROUGHOUT MODULE.

PLANTING MODULE – MIXED COTTONWOOD (MCTN)

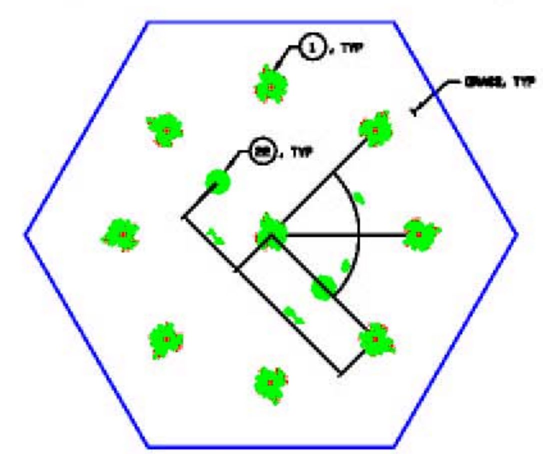


KEY	COMMON NAME	SCIENTIFIC NAMES	NO. PER MODULE
13	VALLEY OAK	QUERCUS LOBATA	7
3	ASH	FRAXINUS LATIFOLIA	2
22	WILD ROSE	ROSA CALIFORNICA	2
5	BLACKBERRY	RUBUS URSINUS	1
21	WILD GRAPE	VITIS CALIFORNICA	1
14	MUGWORT	ARTEMISIA DOUGLASIANA	6
18	SEDGE	CAREX BARBARAE	30
16	CREEPING WILDRYE	LEYMUS TRITICOIDES	30

PLANTING NOTES:

1. DISTRIBUTE SEDGE PLANTINGS AT APPROXIMATELY 3' ON CENTER THROUGHOUT MODULE.
2. DISTRIBUTE CREEPING WILDRYE PLANTINGS AT APPROXIMATELY 3' ON CENTER THROUGHOUT MODULE.

PLANTING MODULE – MIXED VALLEY OAK (MVOK)

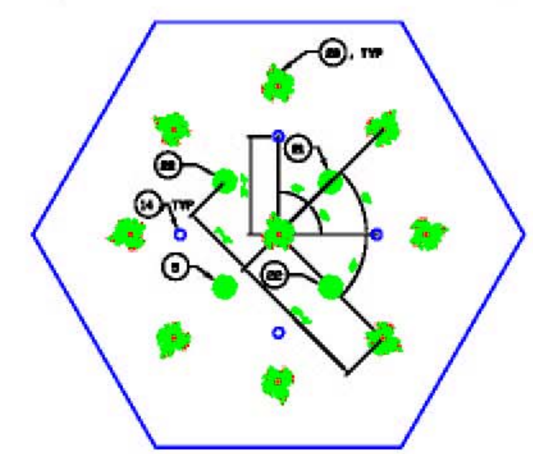


KEY	COMMON NAME	SCIENTIFIC NAME	NO. PER MODULE
1	ALDER	ALNUS RHOMBIFOLIA	9
22	WILD ROSE	ROSA CALIFORNICA	8
18	SEDGE	CAREX BARBARAE	100

PLANTING NOTES:

1. DISTRIBUTE SEDGE PLANTINGS AT MINIMUM 3' ON CENTER THROUGH MODULE.

PLANTING MODULE – ALDER (ALDR)



KEY	COMMON NAME	SCIENTIFIC NAME	NO. PER MODULE
23	WESTERN SYCAMORE	PLATANUS RACEMOSA	9
22	WILD ROSE	ROSA CALIFORNICA	8
5	BLACKBERRY	RUBUS URSINUS	1
21	WILD GRAPE	VITIS CALIFORNICA	1
14	MUGWORT	ARTEMISIA DOUGLASIANA	8
18	SEDGE	CAREX BARBARAE	30
16	CREEPING WILDRYE	LEYMUS TRITICOIDES	30

PLANTING NOTES:

1. DISTRIBUTE SEDGE PLANTINGS AT MINIMUM 3' ON CENTER THROUGH MODULE.
2. DISTRIBUTE CREEPING WILDRYE PLANTINGS AT MINIMUM 3' ON CENTER THROUGH MODULE.

PLANTING MODULE – WESTERN SYCAMORE (WSTC)

Figure 49. Proposed hexagonal riparian planting scheme for 14 patch types, from Hart Restoration and HDR Engineering.- continued

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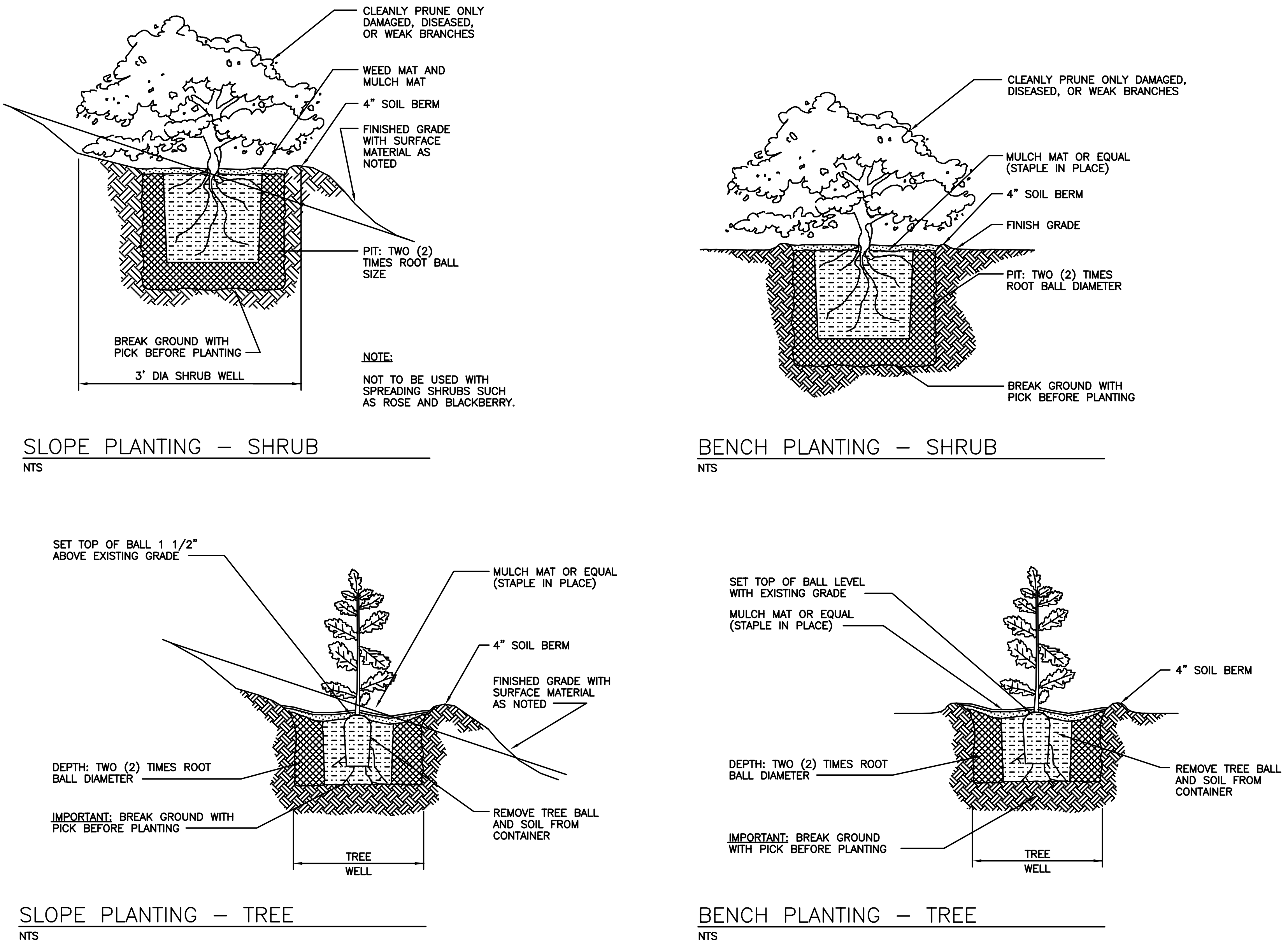


Figure 50. Recommended details for container stock plantings, from Hart Restoration and HDR Engineering.

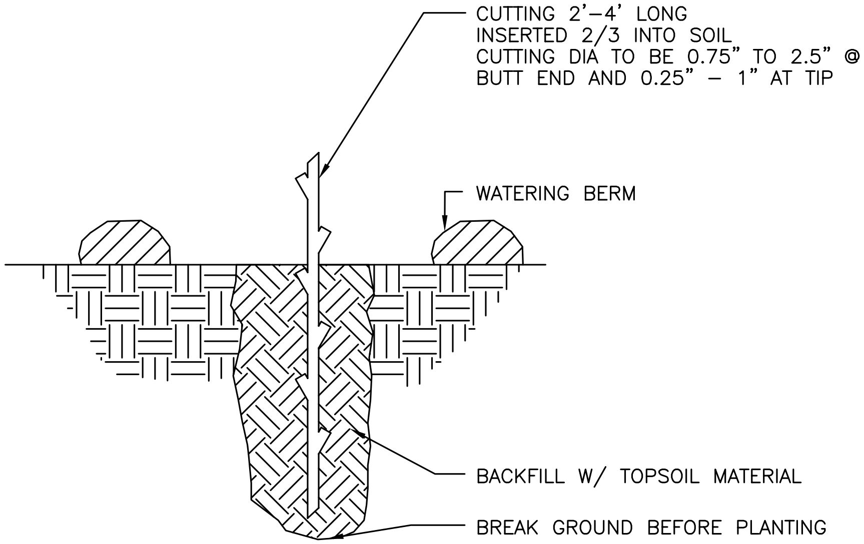
NOTES:

1. BALLAST BUCKET SOIL MIXTURE SHALL BE:
   33% SAND (SM)
   33% CLAYEY LOAM (OL)
   33% SCORIA LAVA ROCK 1/2" – 3/4" IN SIZE
   THOROUGHLY BLEND THE SOIL MIXTURE TO A UNIFORM CONSISTENCY BEFORE USING IN THE BALLAST BUCKET.

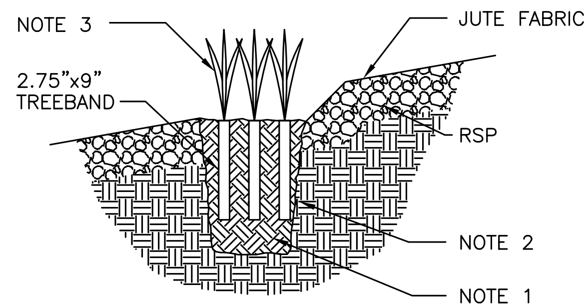
2. BALLAST BUCKET SIZE SHALL BE AS FOLLOWS:
   SHALLOW FLATS – 7"x9" PULP POT
   DEEP REVETMENT – 6"x16" PULP POT
   LARGE, WOODY PLANTS – 12"x12" PULP POT
   PLANTING CONTAINER SHALL BE A BIODEGRADABLE PLANTING CONTAINER MADE FROM TIMBER PULP.

3. INSTALL 2–3 TREEBANDS OF PLANTS AS INDICATED ON THE DRAWINGS PER BALLAST BUCKET (PULP POT).

4. PLACE BALLAST BUCKET INTO PREPARED SPACES IN THE SLOPE REVETMENT. LOWER BUCKET AREAS SHALL BE IN CONTACT WITH NATIVE OR SUBGRADE SOILS. PACK ADDITIONAL COIR, JUTE, OR BURLAP FABRIC BETWEEN THE BUCKET AND THE RSP WITHIN 6 FEET OF THE REVETMENT TOE.



CUTTING PLANTING DETAIL



SEDGE PLANTING DETAIL

Figure 51. Recommended details for cutting (willow and cottonwood) and sedge plantings, from Hart Restoration and HDR Engineering.

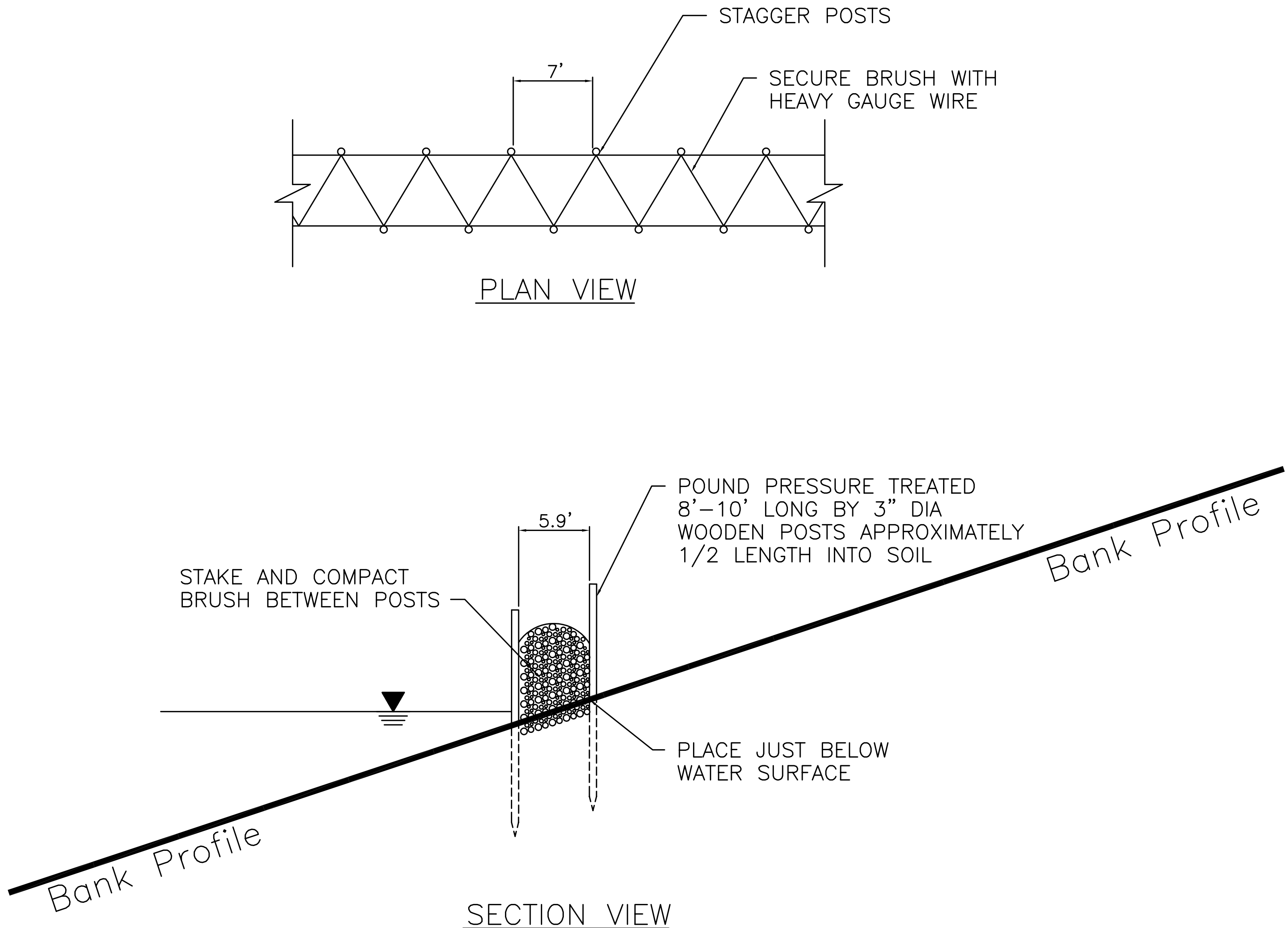


Figure 52. Recommended details for brush matting for bank protection at selected locations, from Hart Restoration and HDR Engineering.

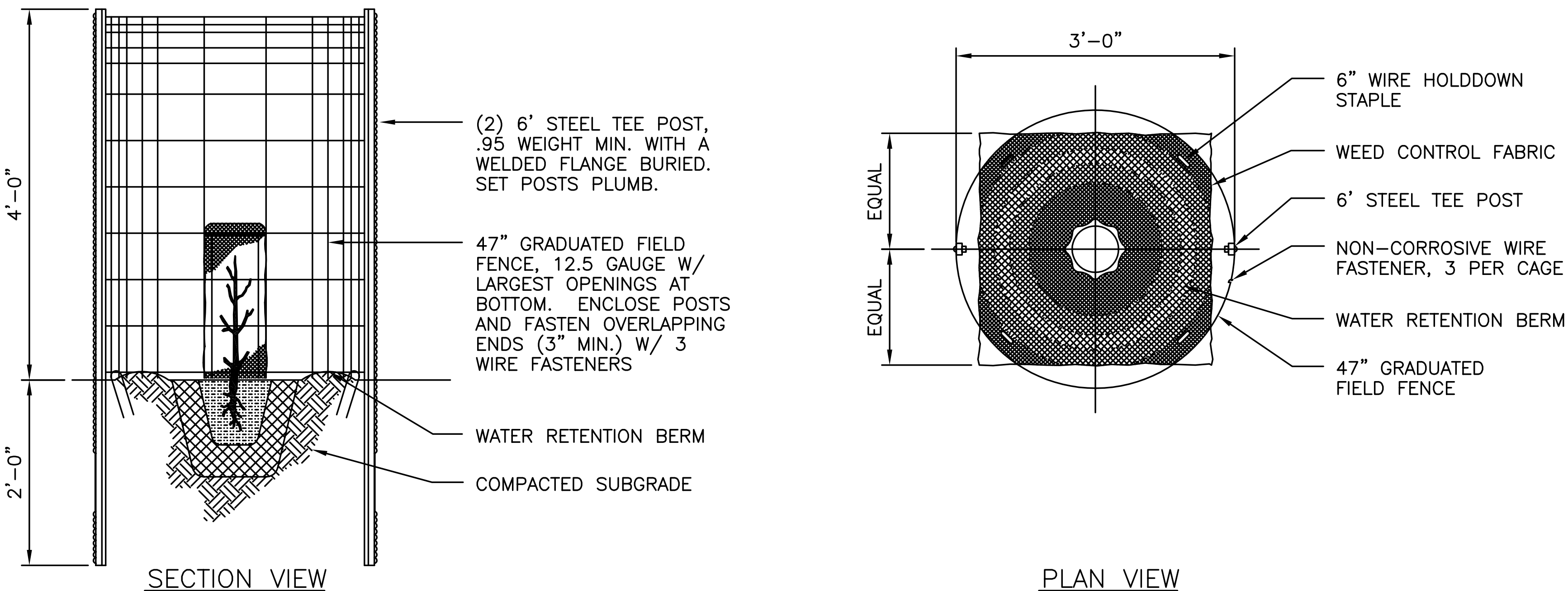


Figure 53. Recommended details for protecting plantings from herbivory browse, from Hart Restoration and HDR Engineering.

5.3.5.1. *Long-term morphology*

The initial conceptual approach was to revegetate portions of constructed floodplains as patches or stringers similar to that observed in the 1937 aerial photos (Figure 4), when the river had the characteristic of a semi-braided channel morphology. This photograph certainly does not illustrate pristine riparian conditions on the Tuolumne River; extensive riparian clearing, grazing, and agriculture had been occurring since the 1850's. However, the photo represents less disturbed conditions that contemporary conditions, does provide some insights on general riparian morphology along the river corridor if interpretation is done with caution. Open spaces were envisioned with no planted riparian vegetation in between patches of riparian vegetation other than grasses established both artificially and naturally.

From a design perspective, there are two approaches being considered: (1) emphasize natural regeneration on constructed surfaces and (2) do not rely on natural regeneration on constructed surfaces and plant these surfaces. The Restoration Plan leans towards the first approach, but acknowledged that we cannot rely on natural regeneration alone, and plantings must occur at restoration projects. The riparian contractor leans towards the latter approach, arguing that given the considerable expense of reconstructing floodplains and level of flow and sediment regulation, that one should revegetate as much of the reconstructed surface as possible to achieve canopy cover and reduce invasive weeds in the newly disturbed floodway reconstruction. Just as the river construction is intended to adjust over time, so is the mix of riparian plants.

These two approaches have been controversial in the design process to date. The Tuolumne River Corridor Habitat Restoration Plan recommended restoring natural ecosystem processes as a basis for restoring aquatic and terrestrial habitats within the Tuolumne River corridor, which will require a change from the status quo since the magnitude and scale of these processes have decreased due to upstream flow and sediment regulation. Natural riparian regeneration is one critical ecosystem process desired in the Restoration Plan. This natural regeneration was intended to occur during infrequent years where flood control releases occur in the late spring (e.g., WY 1998). However, a large portion of natural riparian regeneration would require that (1) riparian regeneration flows would periodically be available in time and quantity under the highly regulated nature of the Tuolumne River system to create conditions for regeneration in the open spaces, (2) the reservoir operations could legally be changed to allow such flows to take place, and (3) impacts from invasive species would be over taken by natural regeneration processes. Second, based on review of the 1937 aerial photographs, a floodplain surface completely covered with riparian hardwoods is not natural, and is not a riparian morphology that can be sustained over the long-term. Lastly, a diverse mosaic of large patches and edges of riparian hardwoods separated by areas of native grasslands was felt by the conceptual designers to be preferable habitat for several species of migratory songbirds.

The tradeoffs of these two implementation philosophies have not been resolved, but perhaps the difference between these two approaches is narrower than it seems. As stated above, riparian plantings are an integral part of both approaches. The main differences appear to be: (1) being proactive in making subtle adjustments in rare wet year hydrographs to achieve natural riparian regeneration, and (2) leaving some constructed areas unplanted to evaluate whether the adjusted hydrographs in rare wet years can result in natural regeneration, and what factors are most important to achieve natural regeneration (adaptive management). Natural regeneration should be evaluated via experimentation and monitoring in the future.

5.3.5.2. Riparian planting on improper geomorphic surfaces

Under natural conditions, certain riparian species tend to establish on unique geomorphic surfaces (Table 18). For example, Fremont cottonwood are typically found on upper bar and floodplain surfaces, while narrow-leaf willow are found on active bars within the bankfull channel. These species associations to geomorphic surfaces occur because of the plant life history and physiology is adapted to the hydrologic and geomorphic environment of a particular surface (e.g., narrow-leaf willow are more adapted to survive scour on lower bar surfaces than Fremont cottonwood). As shown on Table 18, the conceptual approach recommended maintaining these species associations to reconstructed geomorphic surfaces, with the hypotheses that the associations would continue under a scaled-down reconstructed floodway. The implementation plan for the 7/11 Reach and SRP 9 Reach was to have full planting coverage on all surfaces outside the bankfull channel. Natural regeneration was anticipated on surfaces within the bankfull channel. However, in several instances the nearly flat nature of the floodway benches results in some plantings ending up on geomorphic surfaces that could be considered inappropriate (e.g., Fremont cottonwood in the thalweg of shallow scour channels that are closer to the anticipated low flow water table elevation). Plans for the M.J. Ruddy Reach target rush and sedges for scour channel plantings, but also include large numbers of rush and sedge plantings on higher floodplain surfaces with valley oaks and cottonwoods. Many species are planted on floodplains and terraces are still scattered among the remaining bench surfaces without an appropriate association to geomorphic surfaces. The concerns are that many of the plantings will not be successful because they are planted on a geomorphic surface that is inappropriate for their life history and physiology needs, and that irrigation may allow many of these plants to initially establish in a location where they naturally might no have established.

5.3.5.3. Understory species

An alternative approach would replant overstory species (e.g., Fremont cottonwood, black willow) as cuttings, and allowing natural colonization of understory species (e.g., mugwort, buttonbush, etc) once the overstory species became established. This would make revegetation less expensive and more efficient to implement in fine-grained soils. Planting cuttings into an aggregate surface (cobbles and gravels) as opposed to a topsoil surface is much more difficult for augers, trenching equipment, backhoes, and excavators. However, newer technology is becoming available that makes planting cuttings and container stock into aggregate more efficient (e.g., see www.nwrer.com). There is a limited time of the year when cuttings can be successfully installed, particularly if relying on the receding spring water table to sustain the cutting without summer irrigation. A delay in finishing construction in the spring can result in a delay in planting of one year when cuttings are planned. Invasive non-native weeds are a significant problem on restoration sites in the dryer San Joaquin Valley river systems. The riparian contractor felt it important to jumpstart the understory regeneration process and reduce risk of non-native weeds out competing native understory species. Therefore, understory species were replanted at nearly all locations. An adaptive management study should be developed and monitored to evaluate the use of cuttings as an alternative revegetation methodology. To date, one small experimental plot where understory species would not be planted is planned in the M.J. Ruddy Reach (Figure 54). It may be possible to utilize an entire north bench on the M.J. Ruddy project as an experiment in natural regeneration.

We had concern over beaver herbavory of cottonwood and willow saplings; deer and rodent browse of understory plantings was evident at some locations of the 7/11 project, and may need to be addressed in future project phases. Topsoil texture and nutrient quality is another important issue on understory success for both planted and naturally recruited plants. Topsoil quality variation should also be incorporated into adaptive management experiments.

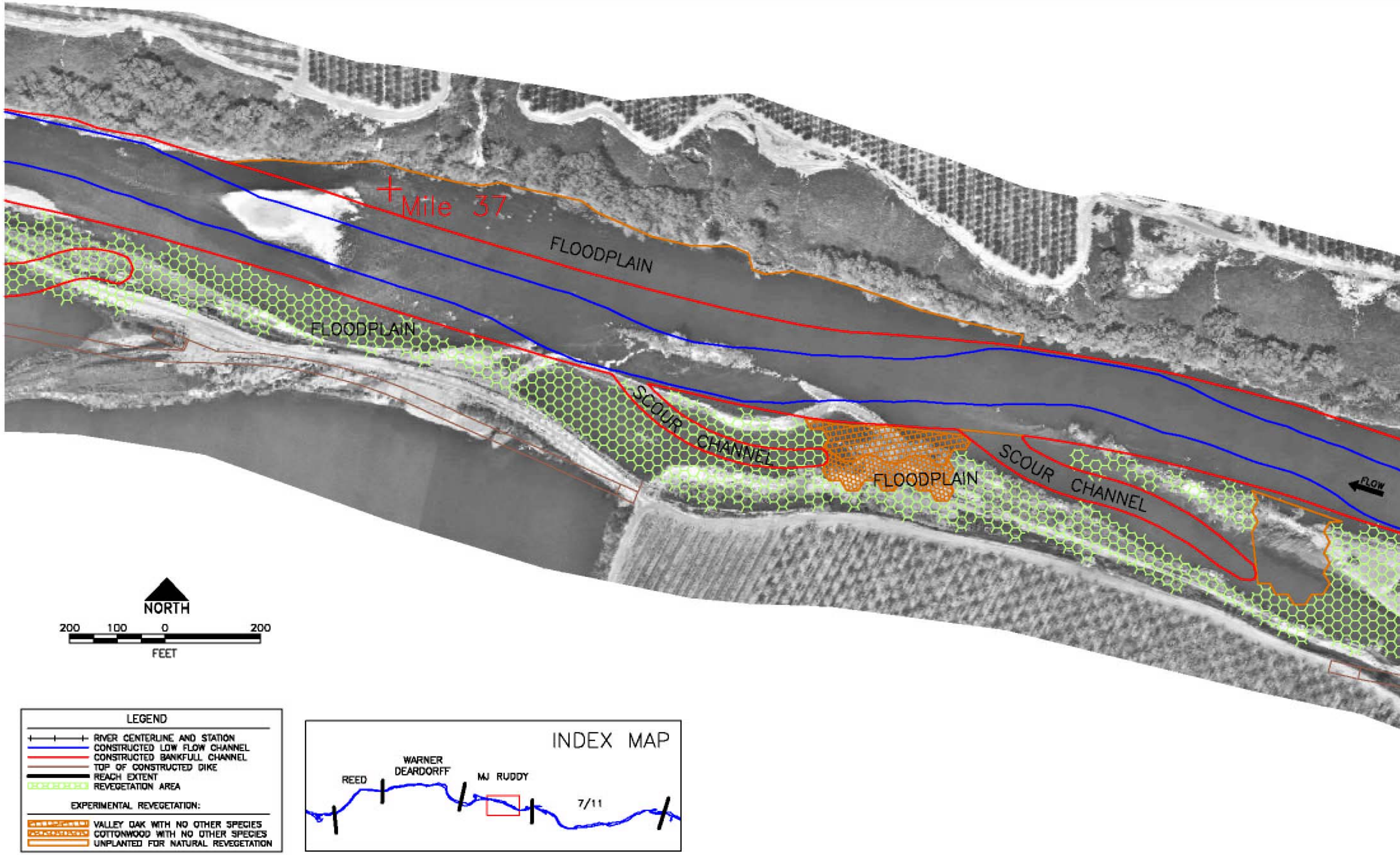


Figure 54. Proposed experimental plots on the M.J. Ruddy Reach showing unplanted areas to test natural regeneration, and cottonwood and valley oak plantings to test natural understory colonization.

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5.3.5.4. Cuttings versus bare root container stock

A simple approach of planting overstory species as cuttings was envisioned for implementation efficiency and probable cost-savings. Most target riparian species can be planted as cuttings (e.g., willows, cottonwood, elderberry, buttonbush) or seeds (e.g., valley oak, native grasses) in an economical manner. However, the time of year, water table elevations, soil conditions, and seed viability are critical to the success of this method. Grass seeding and competition with invasive weeds can be problematic. Other species, such as white alder, box elder, and several understory species can only be planted as container stock. Container stock provides greater flexibility in the time of planting, if there are delays or changed ground conditions as a result of construction. These concerns led to the riparian contractor using extensive amounts of container stock, which probably increased project implementation costs and required irrigation. However, longer-term plant survival is expected with this method, such that the short-term costs may offset by improved long-term planting success. When using container stock, using good quality plants is far more important than the number of plants. Additionally, container stock that are cultivated to a larger size when planted have a greater initial investment, but often have a greater chance of survival, particularly for valley oak. As done for understory species, a small experimental plot is being planned in the M.J. Ruddy Reach to compare some of these differing approaches (Figure 54).

5.3.5.5. Irrigation

The original approach of using only cuttings and seeds anticipated installing the cuttings down to the winter groundwater table as a way to eliminate the need for irrigation and thus reduce project implementation costs. This approach has been successfully applied on Clear Creek, but the water table conditions on Clear Creek were different, and construction timing on the Tuolumne River projects caused difficulty in planting during the dormancy period. The constructed floodplain elevation on Clear Creek is slightly lower than on the Tuolumne River (thus shallow groundwater table on the Tuolumne projects is deeper from constructed surface); however, the difference is very small (1-2 ft). Insertion of cuttings to the shallow groundwater table became problematic due to the cobbles under the topsoil mix layer on the floodway benches. Planting understory species and container stock generally requires irrigation of those plantings for the first few years. The planting design influences the choice of irrigation method, sprinkler or drip. Both methods can be operated to provide periodic deep irrigations to force the new roots deep towards the water table. The use of cuttings and planting in rows lends itself very well to drip irrigation. The density and disperse nature of the over and understory planting in the module system favors the use of sprinkler irrigation. Sprinklers are a simpler approach, but tend to water many areas with no plants and may encourage exotic weeds on constructed surfaces. However, sprinkler irrigation during the June and July period has resulted in natural cottonwood regeneration in some areas. Drip irrigation provides water more precisely at each plant to reduce area wide weed growth outside of where the target plants are located, but is more complex and costly to set up and keep operating. A sprinkler system was adopted, and experimentation with the two irrigation methods would provide a useful cost and success comparison.

The different riparian planting approaches described above are to be tested in several small plots in the M.J. Ruddy Reach. The M.J. Ruddy Reach experimental plots shown on Figure 54 has several small plots on the south bank floodplain and scour channel, as well as a larger floodplain plot on the north side of the river. Of the total planted acreage of 22.2 acres in the M.J. Ruddy Reach, there is concern that the aerial extent of experimental plots may not contain sufficient acres to provide sufficient comparison of planting and irrigation methods to guide adjustment in future planting plans, particularly when considering the entire revegetation area (86.3 acres) of the 7/11, M.J. Ruddy, and Warner/Deardorff reaches (Table 20).

Table 20. Summary of experimental riparian plot acreages for the M.J. Ruddy Reach.

Plot	Acreage	% of M.J. Ruddy revegetated area	% of 7/11, M.J. Ruddy, and Warner-Deardorff revegetated area
North bank unvegetated floodplain	3.47 acres	15.6%	4.02%
South bank unvegetated floodplain	0.65 acres	2.9%	0.75%
South bank unvegetated scour channel	0.82 acres	3.7%	0.95%
South bank cottonwood only	0.36 acres	1.6%	0.42%
South bank valley oak only	0.43 acres	1.9%	0.50%
TOTAL	5.73 acres	25.8%	6.6%

6. THE GRAVEL MINING REACH PROJECT DESIGN

The proposed approach attempts to restore a functional floodway capable of conveying a 15,000 cfs discharge through the project reach by acquiring control of the lands within the project footprint isolating off-channel mining pits, constructing a functional floodplain and channel, and re-planting riparian vegetation on restored floodplain surfaces. The project requires importing large volumes of aggregate to construct the channel and floodplain (including low flow and bankfull channels) and to construct setback dikes that will protect adjacent properties from flooding. The low flow channel width is approximately 75 to 90 feet, and the bankfull channel width is 175-200 feet (Table 12). Bankfull channel conveyance is 5,000 cfs, and flows exceeding 5,000 cfs will spill over onto the floodplain and high flow scour channels. Setback dikes will attempt to be constructed at least 500 feet apart to define the floodway and riparian corridor for the reach. With these channel dimensions, the resulting floodplain/terrace width will be a minimum of 300 feet, for a total combined minimum floodway width of at least 500 feet at nearly all locations. The top elevation of dikes would have at least two feet of freeboard during a 15,000-cfs flow as determined from hydraulic modeling results.

The minimum floodway of 500 ft will allow room for the channel to flood, scour and re-deposit mobile alluvial bars within the bankfull channel. This increased width will enable some channel migration within the floodway, reducing risk of the river capturing aggregate mining pits and damaging human structures. High flow scour channels will be excavated on the floodplain to provide floodplain topographic diversity, high flow velocity refugia, and to encourage natural riparian vegetation recruitment. Because the high flow channels drain back to the river, stranding risk to migrating salmonids will be minimal. The long-term viability of this expanded floodway corridor will be preserved because the mineral rights and project lands are purchased by the TID and MID as part of the New Don Pedro Project. The Districts will enter into a set of restrictive covenants with the US Fish and Wildlife Service to provide the same level of protection as a conservation easement.

The Gravel Mining Reach is being constructed through a design-bid-build process. As discussed in Chapter 4, the conceptual geomorphic and riparian restoration designs are developed by McBain & Trush in accordance to the restoration strategy in the Habitat Restoration Plan for the Lower Tuolumne River. Revegetation designs are developed and implemented by HART Restoration. Detailed designs and strategies are developed by HDR Engineering and McBain & Trush, and final construction drawings and specifications are developed by HDR Engineering. HDR Engineering prepares the 30%, 90%, and 100% construction drawings and develops cost estimates for project completion. The project is then put out to bid to be constructed by a third-party contractor with construction management and inspection performed by HDR Engineering.

6.1. Reach Designs

Due to the large scale of the project, the Gravel Mining Reach will be implemented in four phases during successive years, beginning at the upstream end and working progressively downstream. Each phase is defined primarily by property ownership boundaries as shown in Table 21 and Figure 18. The projected schedule for construction design and implementation is also shown in Table 21.

Table 21. Reach boundaries and projected implementation schedule forGravel Mining Reach Project phases.

Phase	Reach Name	Boundaries (RM)	Projected Implementation Schedule		
			Final Design	Earthmoving	Revegetation
I	7/11 Materials	40.3 - 37.7	2001-2002*	2002-2003*	2003*
II	M.J. Ruddy	37.7 - 36.6	2002-2003*	2003-2004	2004
III	Warner/Deardorff	36.6 - 35.2	2002-2003	2004-2005	2005
IV	Reed	35.2 - 34.3	2003-2004	2005-2006	2006

* completed as of October 2003.

6.1.1. Phase I: 7/11 Segment

The 7/11 segment extends from Roberts Ferry bridge (RM 40.3) downstream to the M.J. Ruddy property line below the 7/11 plant site (RM 37.7) (Figure 18). Restoration includes the following components: removing dredger tailings at the upstream end of the reach and partially filling mine pits and settling ponds on the south bank to create floodplains, constructing two high flow scour channels on the south bank floodplain, constructing or upgrading dikes along the entire south side of the project, reconstructing the channel between Roberts Ferry Bridge and STN 104+00, and revegetating the constructed floodplain surfaces with native riparian vegetation (Figures 55 through 59, Table 22).

7/11 Materials did not wish to have their haul road bridge moved or reconstructed, so the conceptual design recommended a concrete apron ford crossing on the south abutment that would convey flows above 5,000 cfs (Figure 26). After rejection of this approach by 7/11 Materials, a railroad car bridge or CONSPAN bridge was proposed. Subsequent cost constraints resulted in twelve culverts being used to convey bypass flows rather than a bridge (Figure 60).

Construction of this phase requires approximately 420,000 yd^3 of aggregate and topsoil to complete. Most of the fill material needed was obtained from dredge tailings in the upper portion of the reach (Figure 55) and pit-run aggregate from the 7/11 Materials plant. The top two feet of constructed floodplain surfaces was a mixture of aggregate fill and topsoil to improve riparian planting success. All in-channel areas were constructed with tailing materials; no specifically graded spawning gravel was placed as part of the 7/11 Reach restoration project. However, Stanislaus County placed and shaped several thousand cubic yards of spawning gravel in a riffle underneath the Roberts Ferry Bridge as mitigation for the bridge replacement construction activities in 2002. Reconstructed floodplains and scour channels on both the north and south banks will be planted with native riparian vegetation and understory plants, with total revegetation area of approximately 21.8 acres.

Table 22. Original design elements for the 7/11 Reach.

Channel Reconstruction	• Reconstruct channel from Roberts Ferry Bridge (STN 84+00) to STN 42+00. Bankfull channel width is approximately 175 feet and will convey 5,000 cfs. Top of bank elevation ranges from 108 feet to 110 feet at the upstream end of the site.
Floodplain Regrading and Dike Construction	• Remove dredger tailings and regrade floodplain on left bank upstream of Roberts Ferry Bridge (STN 121+66.07 to 104+00). • Construct dike on south side of left bank floodway (to isolate project from mining pit) from STN 121+23 to STN 101+01. • In conjunction with channel reconstruction, construct floodplain on left bank from STN 84+00 to STN 43+00. • Construct floodplain on left bank from STN 29+00 to STN –0+26, including filling the settling pond from STN 16+00 to STN 0+00. • Construct dike on south side of left bank floodway (to isolate project from mining pits) from STN 72+00 to STN 0+00. • Construct high flow scour channel on left bank floodplain beginning at STN 67+00 and joining the mainstem channel at STN 54+00. High flow scour channel is 2 ft deep at the upstream end, 3 ft deep at the downstream end, and 60 feet wide (top of bank).
Slope protection, culverts, and debris removal	• Install vegetated rock slope protection on right bank from STN 22+50 to STN 17+25 and on the left bank from STN 37+75 to STN 33+80. Vegetated rock slope protection consists of 15-pound rock with ½-ton boulders at toe and jute fabric overlay vegetated with sedge, alder and willow ballast buckets, creeping wild rye, coyote bush, box elder and valley oak. • Construct ford-type haul road crossing. Install ½-ton rock slope protection on slopes of haul road crossing and on right bank at STN 19+00. Actual installation was twelve 73" by 55" pipe arch culverts in crossing. • Install 25-pound rock slope protection with ½-ton boulders at toe on left bank STN 33+80 to STN 37+75. • Remove concrete and other debris from channel.
Revegetation	• Upstream of Roberts Ferry Road Bridge, vegetate floodplain surface using cells described in Section 5.3.3. Canopy species include cottonwood, willow, and alder. Revegetation area = 21.8 acres. • Revegetate narrow band on south bank from STN 101 to STN 96+25. • Relocate elderberries to south bank from STN 96+25 to STN 89+00. • Revegetate south bank upstream abutment of Roberts Ferry Bridge. • Revegetate south bank floodplain surface described from STN 84+00 to STN 43+00 above using cells described in Section 4.4. Canopy species include cottonwood, willow, alder, and valley oak. • Revegetate toe of dike and floodplain from STN 29+00 to STN –0+26 using cells described in Section 4.4. Canopy species include cottonwood, willow, alder, and valley oak. • Acquisition of approximately 8 acres of upland bench area on the south bank immediately upstream of the Roberts Ferry Bridge to be planted as valley oak savanna habitat.

Note that stationing in this table reflects project specific river centerline stationing as depicted on the construction design drawings (Figures 55 through 57). STN 0+00 is the downstream boundary of the reach.

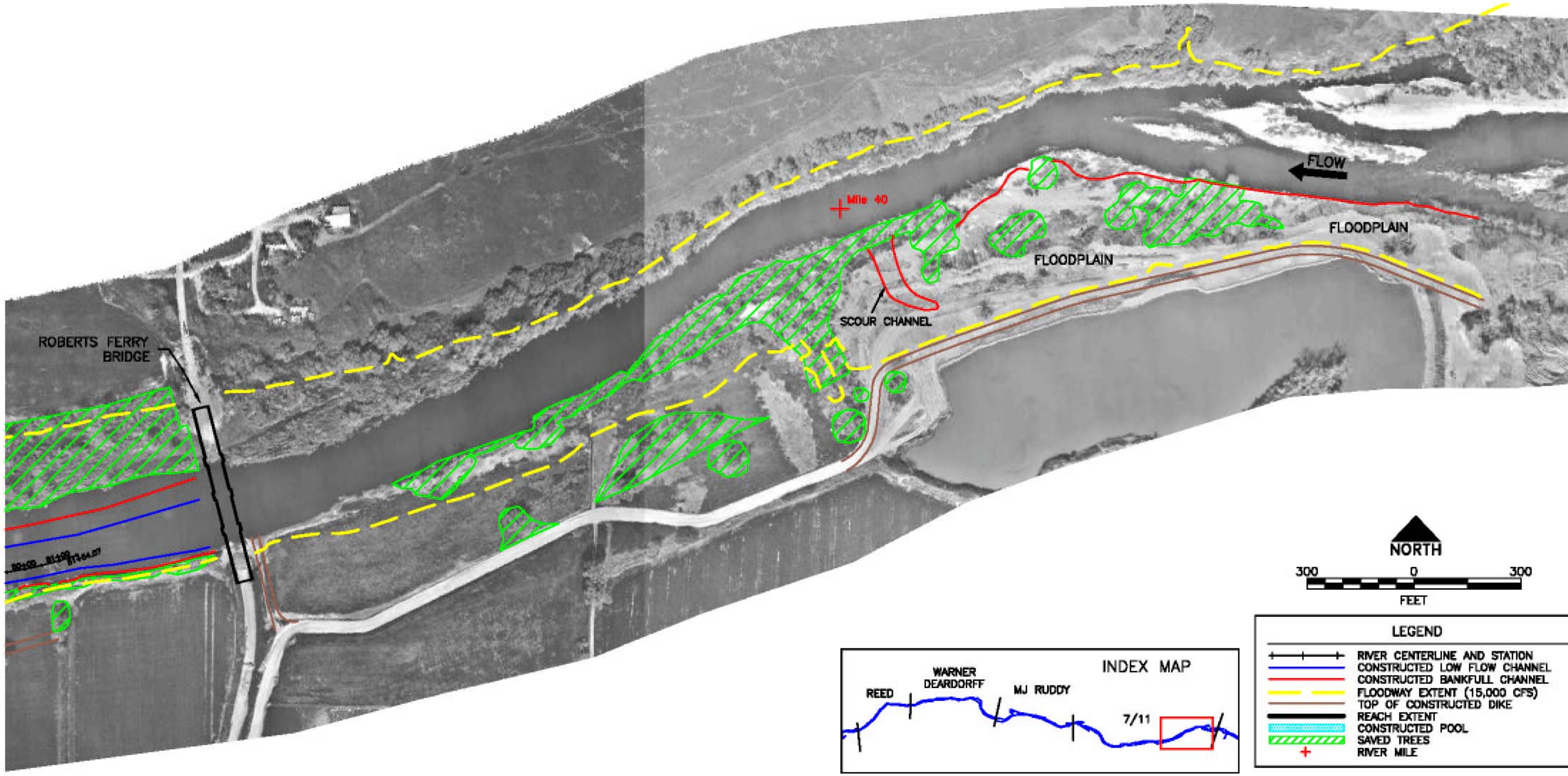

Figure 55. Design planform features for the upper portion of the 7/11 Reach.

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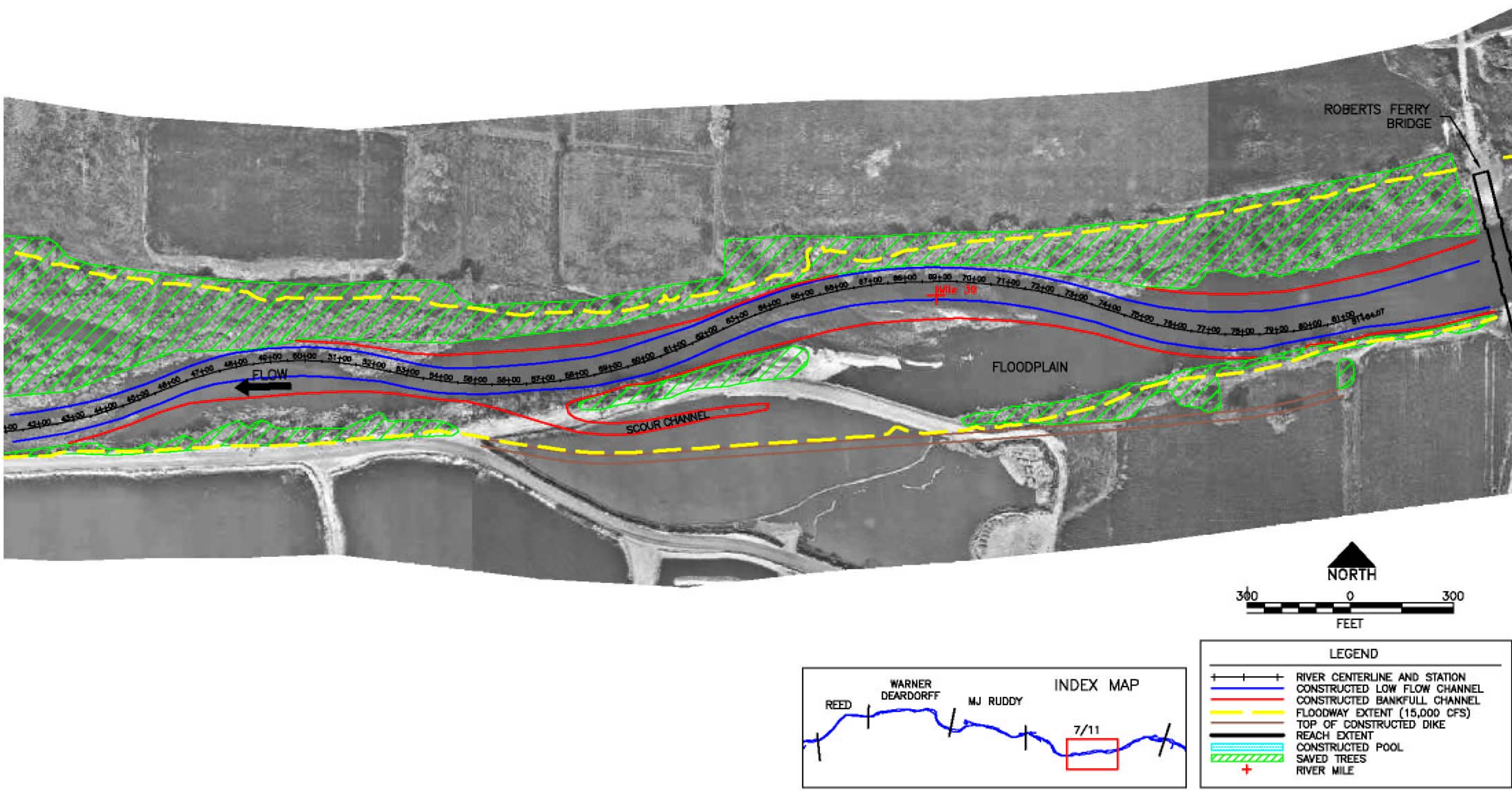

Figure 56. Design planform features for the middle portion of the 7/11 Reach.

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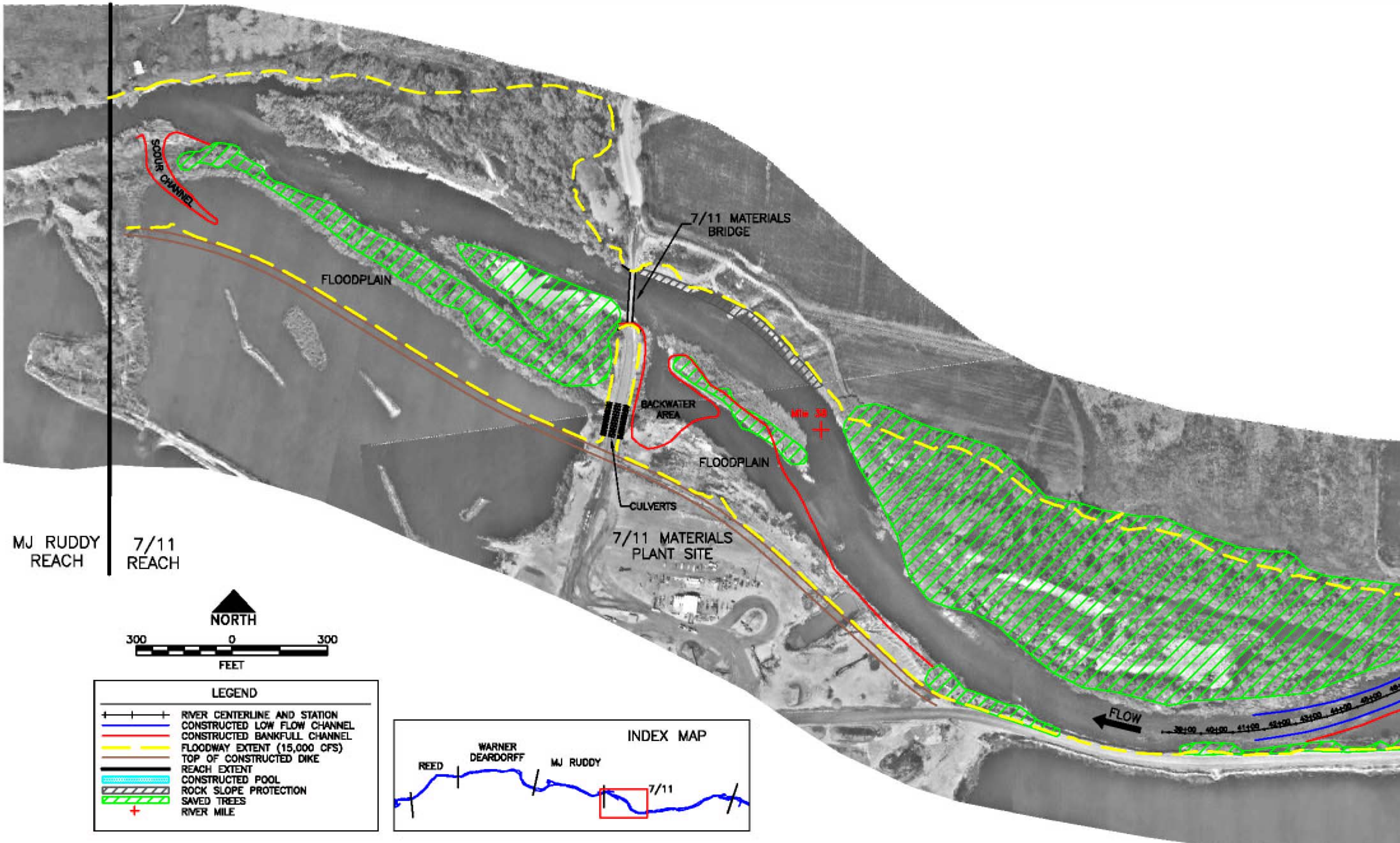

Figure 57. Design planform features for the lower portion of the 7/11 Reach.

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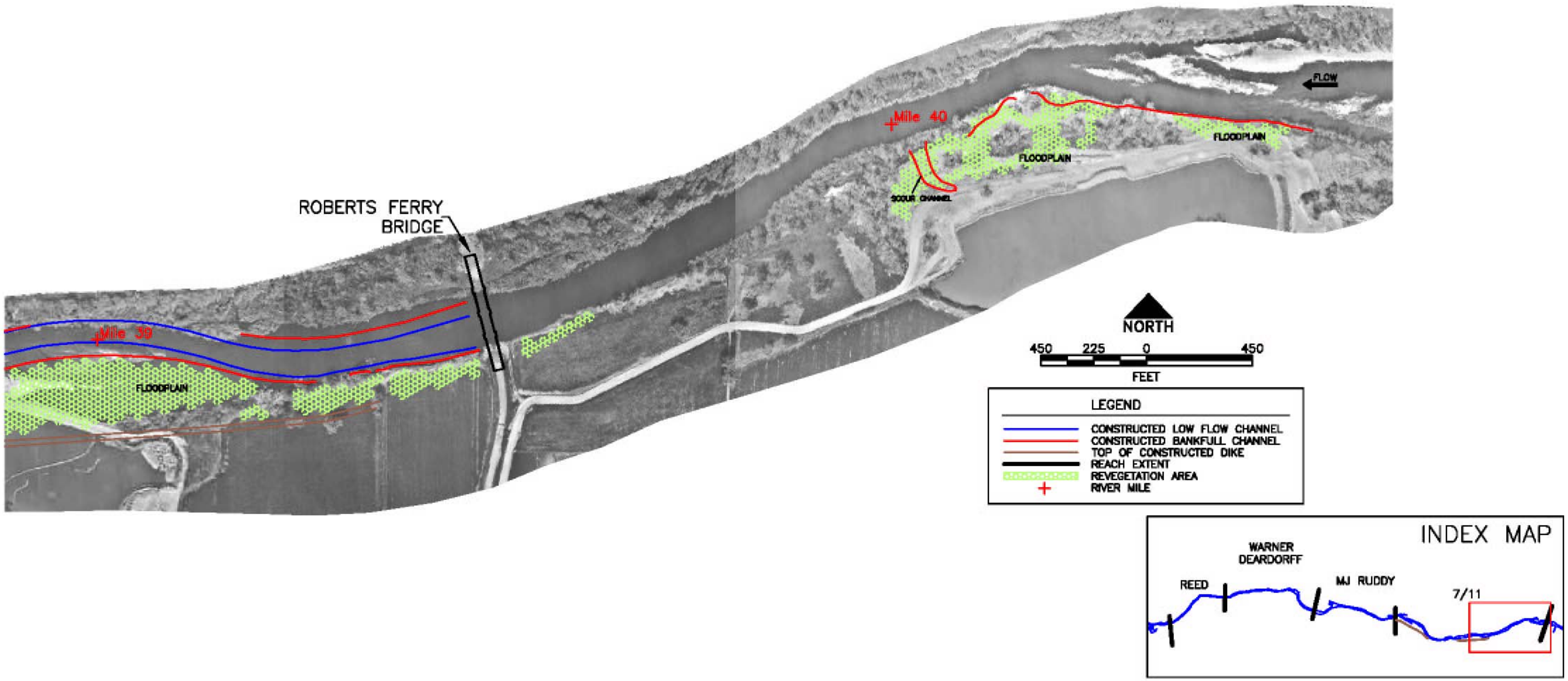

Figure 58. Design riparian revegetation areas for the upper portion of the 7/11 Reach.

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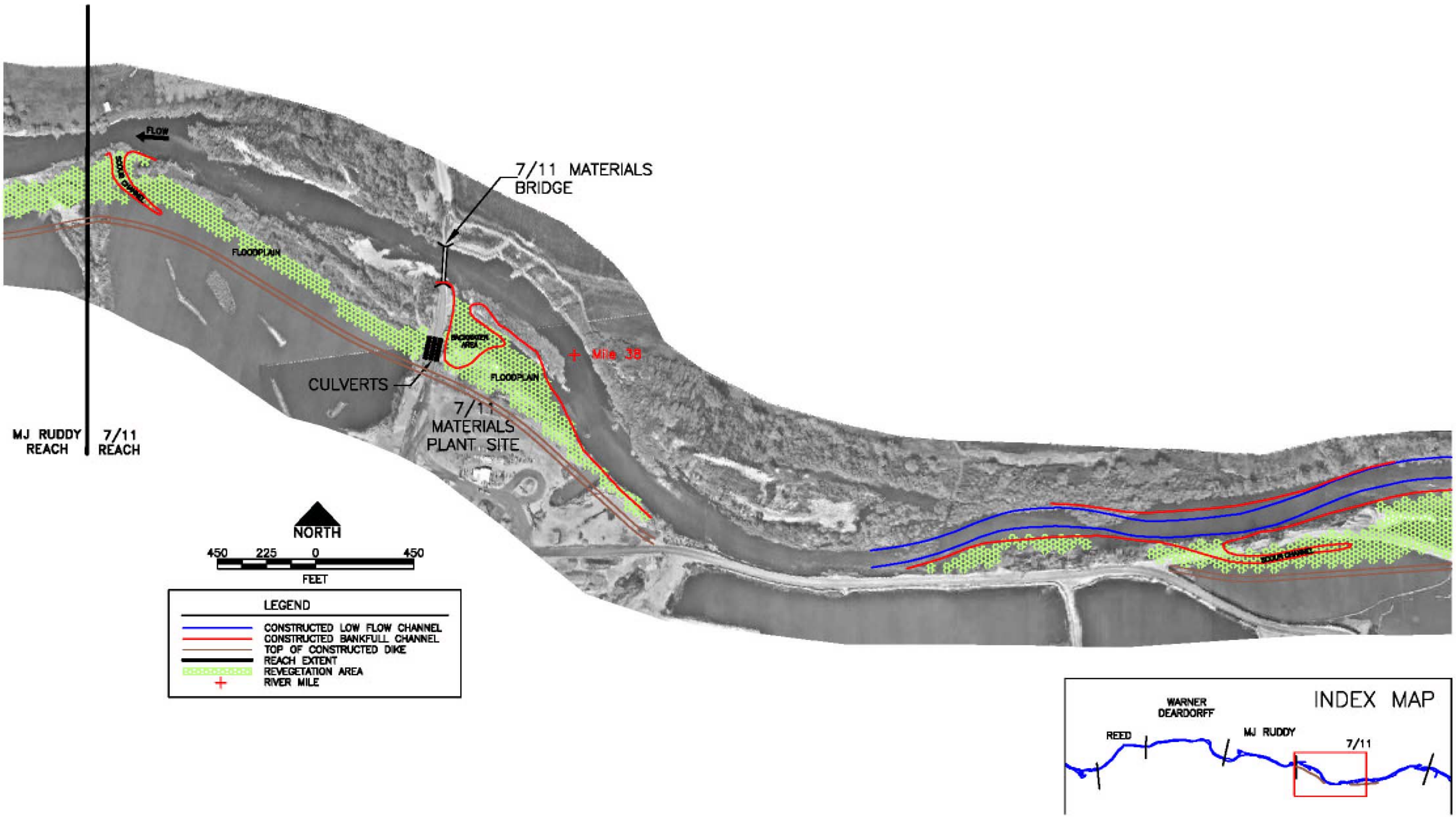

Figure 59. Design riparian revegetation areas for the lower portion of the 7/11 Reach.

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Figure 60. Series of twelve culverts in 7/11 Reach that bypasses high flows on the floodplain through the southern abutment of the 7/11 Materials haul road bridge.

Construction designs for the 7/11 Reach were completed in October 2002 and distributed for bids. Design elements contained in the bid package are summarized in Table 22 and are shown in Figures 55 through 59. Earth work for a majority of the project was completed in October 2001. However, a volumetric shortfall occurred at the downstream portion of the project (Figure 57) where the south bank dike was being moved into the settling pond. A settlement with the contractor was reached in 2002, and construction of the south bank dike and floodplain was completed, although the dike was moved 50 ft to the north as a cost-saving means. Revegetation planting was competed in April 2003, and all constructed surfaces were revegetated.

6.1.1.1. Modification to Construction Design

The two primary modifications to the 7/11 Reach between design and implementation were the 7/11 Haul Road Bridge bypass channel and the southern dike location at the downstream end of the project. The 90% designs included a pre-cast bridge system to allow high flow conveyance from the south bank floodplain through the 7/11 Materials haul road bridge abutment. Cost constraints resulted in twelve culverts being used instead of a bridge (Figure 60). A bridge is a superior approach to high flow conveyance because the opening is larger, roughness less, and is less prone to clogging with woody debris during a high flow event. The culverts can provide flood conveyance, but there is substantial risk that they will not provide intended conveyance due to clogging with debris during a flood. Hydraulic modeling predicts that all flows up to 15,000 cfs could be conveyed through the bridge should the culverts get plugged, without reaching the low chord of the bridge. However, there may be increased risk of damage to the bridge during flows greater than 5,000 cfs, and potential scour and deposition at the 7/11 Materials haul road bridge abutment, if the culverts become blocked and forces all flows underneath the bridge.

The estimated volume of fill required to complete construction for the 7/11 Segment was 420,000 yd^3. Much of this material was required to fill in mining pits to construct functional floodplains and to construct dikes to isolate remaining mining pits from the restoration project (Figure 61). The

Figure 61. View of completed reconstruction of the 7/11 Reach looking downstream from the Roberts Ferry Bridge (RM 40.3).

contractor made a lump sum bid to build the project to the lines and grade. The contractor found this would require more material that they originally estimated and in response to the increased costs to complete the project as designed, the contractor filed a claim against TID for the additional costs. To settle the claim, the dike at the downstream end of the project was shifted toward the river from RM 37.7 to RM 37.8, resulting in a 50 foot reduction in floodway width in the lower portion of the levee. Effects of the modification on project performance are expected to be minor, but the reduction in cross section area of the floodway theoretically may slightly increase velocities within the high flow scour channel area during larger floods (greater than 5,000 cfs). The reduction in floodway width also reduced riparian revegetation by approximately 3 acres.

6.1.2. Phase II: M.J. Ruddy Segment

The M.J. Ruddy segment extends from RM 37.7 downstream to the Santa Fe Aggregates haul road bridge (RM 36.6) (Figure 27). Restoration activities includes: reconstructing the river channel through most of the reach, constructing dikes on the north and south sides of the channel to isolate the river from floodplain mining pits, constructing floodplains with high flow scour channels on the south side of the river, constructing a narrow floodplain on the north side of the river, adding a flat car bridge to convey high flows above 5,000 cfs on the north abutment of the Santa Fe Aggregates haul road bridge, and revegetating constructed floodplain surfaces (Figures 62 through 64).

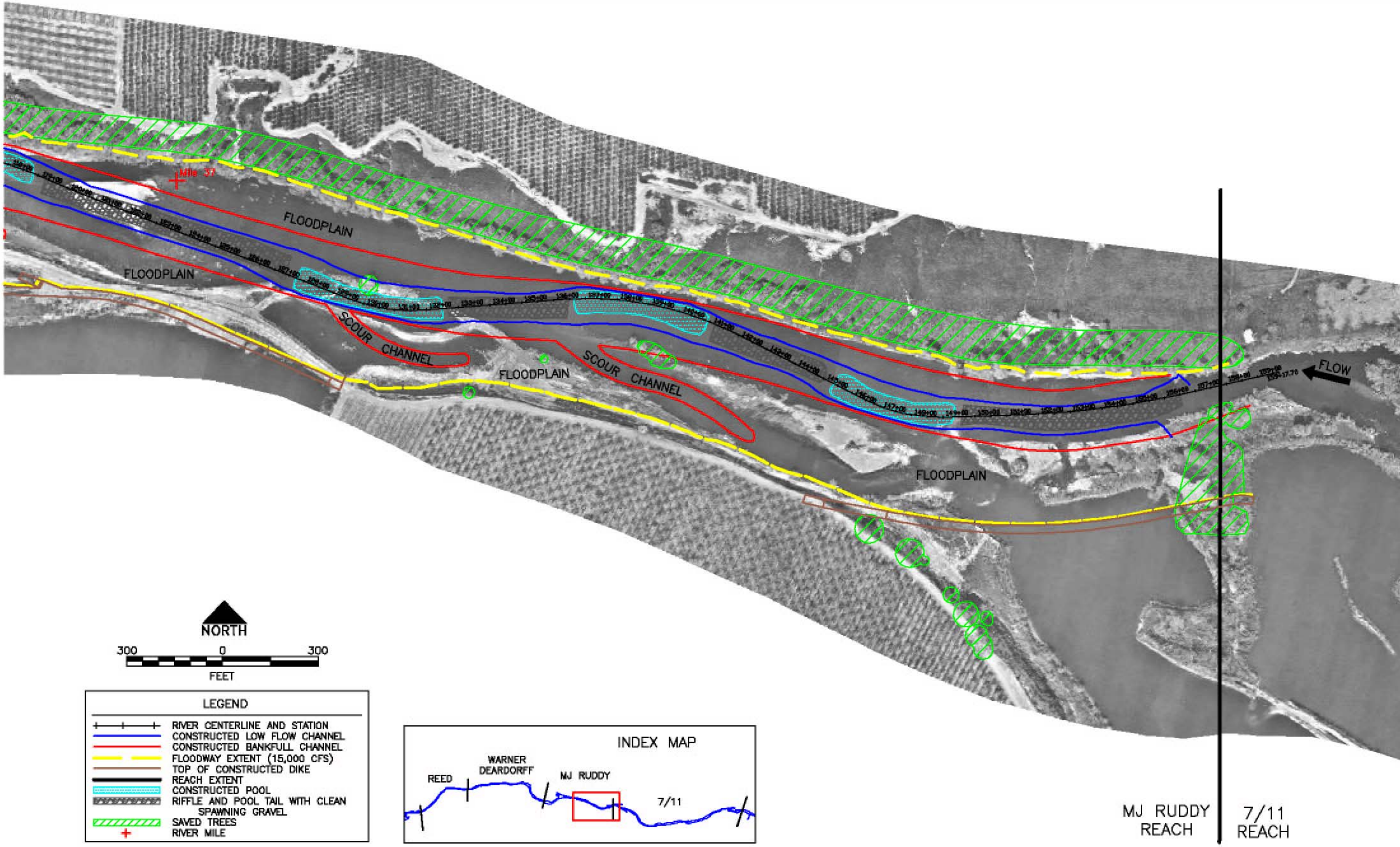

Figure 62. Design planform features for the upper portion of the M.J. Ruddy Reach.

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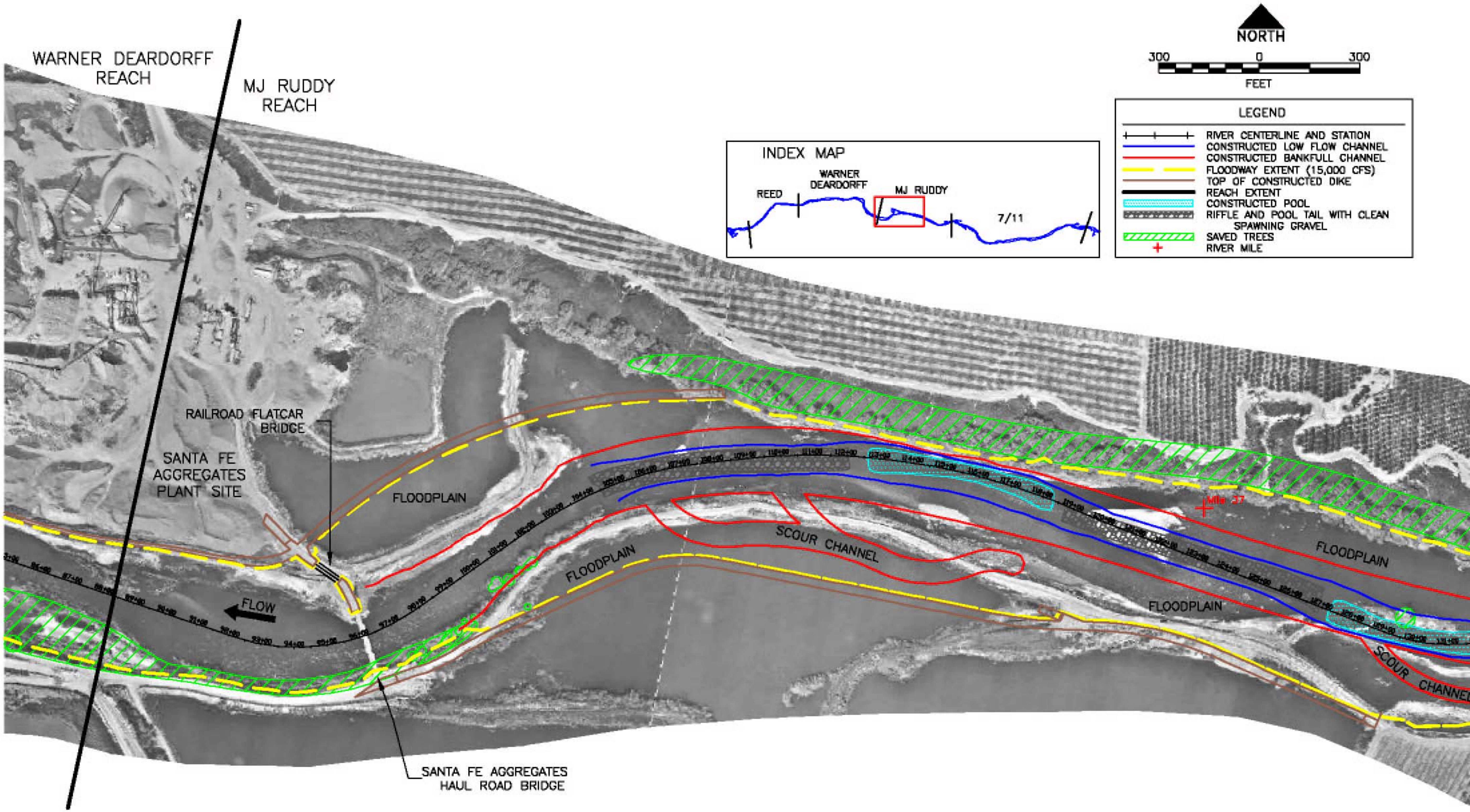

Figure 63. Design planform features for the lower portion of the M.J. Ruddy Reach.

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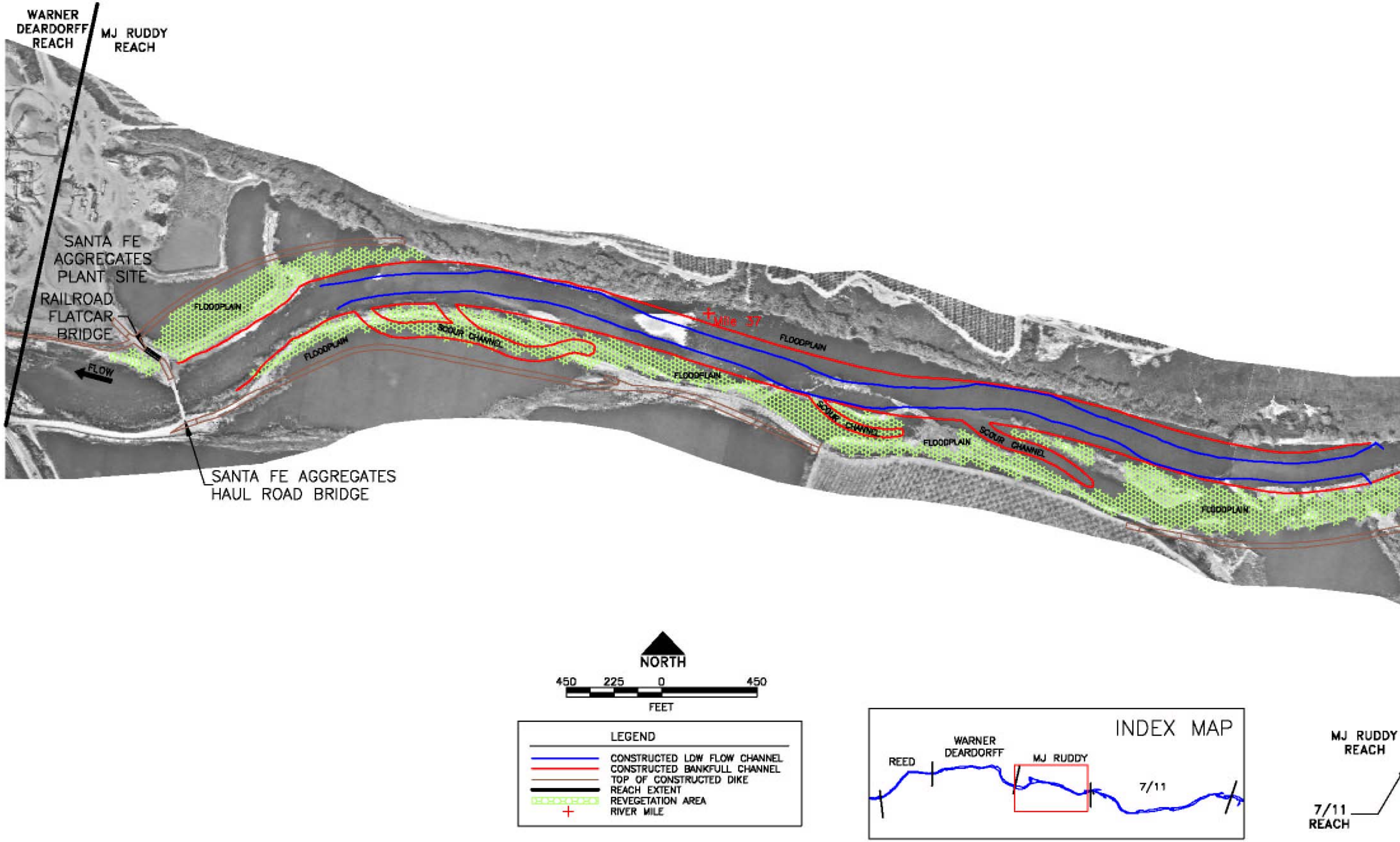

Figure 64. Design riparian revegetation areas for the M.J. Ruddy Reach.

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Construction of this phase was estimated to require 465,000 yd^3 of aggregate and topsoil. All of the aggregate fill material needed will be from pit-run aggregate from the Santa Fe Aggregate plant, and the topsoil will be obtained from wash-water silts that are spoiled as part of the aggregate processing at the Santa Fe plant site. The top two feet of constructed floodplain surfaces will be a mixture of aggregate fill and topsoil to improve riparian planting success. Clean spawning gravel will be placed in five new riffles, and will be sized such that the range of particle sizes will be between 5 inches and ½ inch diameter. Approximately 14,000 yd^3 of spawning gravel will be placed in the five riffles at a depth of 2 feet, resulting in 192,000 ft^2 of spawning habitat. Recent monitoring has documented that there is approximately 103,000 ft^2 of existing riffle habitat, and 38,700 ft^2 spawning habitat (based on depth and velocity preferences for Chinook salmon) in the reach where the riffles will be reconstructed (McBain & Trush and Stillwater Sciences 2000). The restoration project in the M.J. Ruddy Reach will redistribute the slope in the steep cascade at RM 37.0 to create 192,000 ft^2 of additional riffle habitat, nearly a doubling of riffle area (see Figure 47 for conceptual approach at redistributing riffle elevation drop). The increase in spawning area (assuming depth and velocity criteria) should be similarly increased. Reconstructed floodplains and scour channels on the north bank at RM 36.7 and on all south banks will be planted with native riparian vegetation and understory plants, with total revegetation area of approximately 22.2 acres.

A significant cause of dike failure is piping through the dike during a high flow rather than necessarily having a high flow overtop or laterally erode the toe of the dike. The Department of Water Resources (DWR) engineers in the San Joaquin District have developed an "equalization saddle" that enables rapid transfer of water between the river channel and adjacent pond such that hydraulic gradients through the dike are minimized. The DWR design has a rock protected saddle that allows water to safely flow over the levee into a pond, and was considered for the MJ Ruddy Reach. However, it was deleted in favor of cobble trenches, which will be constructed between the floodplain and ponds to allow water to flow through the dike to provide water supply to existing riparian pumps (Figure 65). The cross sectional area and permeability of the cobble trench may also allow enough flow through the dike such that the hydraulic gradient is small during the ascending or receding limb of a storm hydrograph, thereby reducing the risk of piping failure of the dikes. These cobble trenches were not installed at the 7/11 Reach, so the performance of the dikes during a high flow will be closely monitored between the two reaches.

Construction designs for this segment are scheduled to be completed in March 2003 and will be put out to bid in spring 2004. Construction is expected to begin in summer 2004 and be completed by fall 2004. Design elements contained in the bid package are summarized in Table 23 and shown in Figures 62 through 64.

6.1.3. Phase III: Warner-Deardorff Segment

The Warner-Deardorff segment extends the Santa Fe Aggregates haul road bridge (RM 36.6) to the confluence with Dan Casey Slough (Figure 28). The primary components of this segment is: improving the dike on the north bank between the haul road bridge and conveyor bridge to protect the Santa Fe Aggregates stockpile areas, construction of a 2,900-foot-long setback levee on the south bank to isolate the river from an aggregate pit, partial filling of the aggregate pit to create a floodplain, excavation of a pre-NDPP floodplain to create a contemporary floodplain (Deardorff property), and construction of several high flow scour channels on the newly constructed south bank floodplains. Construction of this phase will require moving on-site materials from the Deardorff floodplain excavation into the Warner aggregate pit, which will still require a substantial amount of additional

Table 23. Summary of design elements for the M.J. Ruddy Reach design.

Channel Reconstruction	• Reconstruct river channel from STN 156+00 to STN 104+50, generally shifting the channel to the south. Bankfull channel width is approximately 200 feet (top of bank) and will convey 5,000 cfs. Top of bank elevation ranges from 97.5 feet at the downstream end to 104 feet at the upstream end of the site. • Construct spawning riffles using clean gravel and cobble to a depth of two feet.
Floodplain Regrading and Dike Construction	• Construct south bank dike from (river) STN 158+50 to STN 149+50 and STN 116+00 to STN 100+50 to isolate the floodplain from a mine pit. • Construct north bank dike from (river) STN 97+00 to STN 108+50 to isolate the floodplain from a mine pit. • Reconstruct the south bank floodplain from STN 158+00 to STN 99+00. • Construct narrow north bank floodplain in conjunction with shifting the channel to the south from STN 156+00 to STN 119+50. • Construct north bank floodplain by filling mine pit from STN 108+50 to STN 97+00 • Construct two single branch high flow scour channels on the south bank floodplain, one beginning at STN 143+00 and joining the mainstem channel at STN 135+00 and one beginning at STN 133+00 and joining the mainstem channel at STN 128+50. Construct one bifurcating high flow scour channel on south bank floodplain beginning at STN 118+50 and joining the mainstem channel at STN 109+50 and STN 106+00. High flow scour channels are 3-4 feet deep and 100-150 feet wide (top of bank).
Slope protection, culverts, and debris removal	• Install cobble trench in south bank dike at STN 153+50. • Install cobble trench in north bank dike at STN 104+50. • Install fill abutments for flat car haul road crossing at STN 96+00. Install rock slope protection on fill abutments. • Remove concrete rubble from south bank floodplain between STN 125+00 and STN 120+50.
Revegetation	• Revegetate all floodplain surfaces constructed in the reach using cells described in Section 5.3.3, with the exception of two areas described below. High flow scour channels will be planted with rushes. Floodplain Canopy species include cottonwood, willow, alder, and oak. Revegetation area = 22.2 acres. • No revegetation will occur in the upstream-most high flow scour channel or on the south bank floodplain from STN 144+00 to STN 142+00. These areas will be monitored to assess natural recruitment of native riparian species under several different experimental conditions.

Note that stationing in this table reflects project specific river stationing as depicted on the construction design drawings. STN 0+00 is the downstream boundary of the Warner-Deardorff Reach.

imported aggregate fill to complete. An option being evaluated is to acquire the entire Warner aggregate pit area (Tular Pond, STN 39+00 to 73+00) and use the material between the project dike and the mining permit dike to supply the remainder of the material needs to construct the floodplain. A 2,400 ft portion of the project from STN 63+50 to 39+50 will reconstruct and relocate the bankfull channel slightly to the south, increasing the meander amplitude and sinuosity. The channel gradient in this reach is lower than other reaches (0.00064 compared to 0.0013 in the Reed Reach and 0.0015 in the M.J. Ruddy Reach), such that the two reconstructed riffles will likely provide a small amount

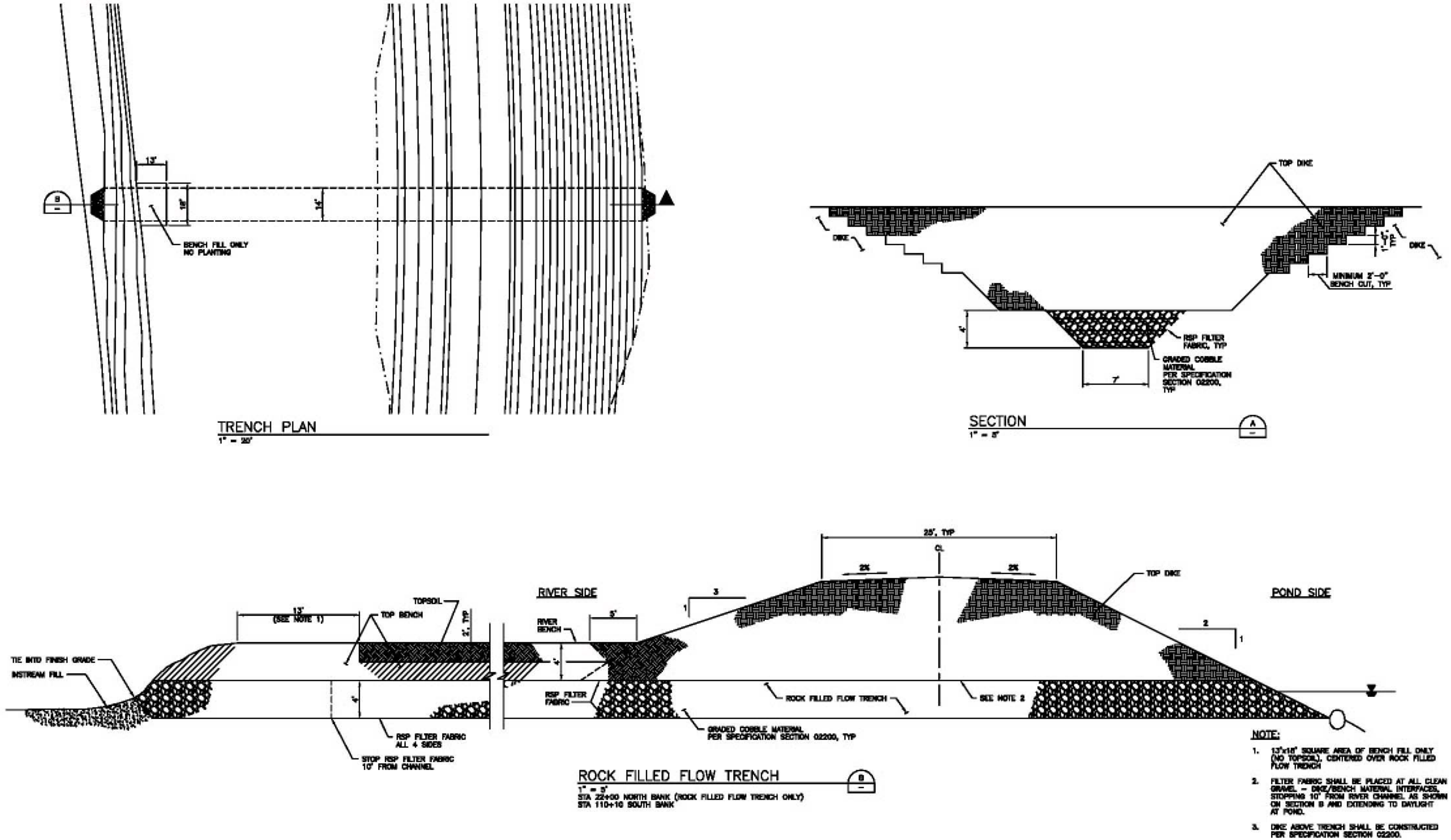

Figure 65. Cobble trench design for the M.J. Ruddy Reach and Warner-Deardorff Reach that will improve water exchange between the river and off-channel ponds, allowing for riparian pumping and reducing the risk of piping failure of the dikes during high flows.

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of spawning habitat compared to the other reaches. The substrate in the riffles will most likely be clean spawning gravels as done for the M.J. Ruddy Reach, but this decision has not yet been made. Reconstructed floodplains and scour channels on both the north and south banks will be planted with native riparian vegetation and understory plants, with total revegetation area of approximately 42.3 acres.

Construction designs for this segment are currently being completed. Design elements contained in the current drawing are summarized in Table 24 and are shown in Figures 66 through 68.

Table 24. Design elements for the Warner-Deardorff Reach.

Channel Reconstruction	• Reconstruct channel from STN 63+50 to STN 39+50. Bankfull channel width is approximately 200 feet (top of bank) and will convey 5,000 cfs. Top of bank elevation ranges from 92 feet at the downstream end to 94.5 feet at the upstream end of the site.
Floodplain Regrading	• Construct setback dike on south side of left bank floodplain from STN 74+00 to STN 39+00 to isolate river from mine pit. • Fill in portion of mine pit from STN 74+00 to STN 39+00 to create a floodplain that will be inundated at flow exceeding 5,000 cfs. • Excavate a south bank current terrace at the downstream end of the site STN 39+00 to STN 13+00 to create a floodplain. • Excavate three networks of high flow scour channels: one beginning at STN 66+50 and joining the mainstem channel at STN 56+00, STN 48+00, and STN 39+50; one beginning at STN 37+50 and joining the mainstem channel at STN 26+50; and one beginning at STN 27+00 and joining the mainstem channel at STN 20+50 and STN 13+00. High flow scour channels are 3-4 feet deep and 50-100 feet wide (top of bank).
Slope protection, culverts, and debris removal	• Install two equalization saddles in the setback dike at STN 46+00 to 47+00 and STN 9+00 to 10+00. • Install 15-pound rock slope protection on left bank at upstream end of site from 54+00 to STN 55+00.
Revegetation	• Revegetate all floodplain surfaces constructed in the reach using cells described in Section 5.3.3. High flow scour channels will be planted with rushes. Floodplain canopy species include cottonwood, willow, alder, and oak. Revegetation area = 42.3 acres.

Note that stationing in this table reflects project specific river stationing as depicted on the construction design drawings. STN 0+00 is the downstream boundary of the Warner-Deardorff Reach.

6.1.4. Phase IV: Reed Segment

The Reed segment extends from the confluence with Dan Casey Slough (RM 35.2) to RM 34.3 (Figure 29). Similar to the Warner-Deardorff segment, the Reed segment will utilize fill material available on–site for channel and floodplain reconstruction. Construction-level designs have not been developed for this reach. Elements included in the conceptual plans for this reach include construction of a setback dike on the south bank to isolate the river from a mine pit, partial filling of the mine pit to create a floodplain, and excavation of a current terrace to create floodplain, and construction of three high flow scour channels (Figure 29). This reach has a recently permitted aggregate extraction operation within the proposed restoration area resulting in a large quantity of material having been mined since the original concept was prepared. Progress from the conceptual designs shown on Figure 29 towards a final design has not yet been initiated. As such, there have not been estimates of revegetation acreages. The conceptual plan limits restoration activities to pit filling and floodplain reconstruction on the south bank only, such that no modifications to the bankfull channel or spawning riffles is anticipated.

6.2. Predicted habitat benefits

One of the recommendations in the Adaptive Management Forum report was for the restoration projects to better predict quantitative benefits of the project (Adaptive Management Forum Scientific and Technical Panel 2002). This section attempts to summarize some of the predicted changes to salmon habitat, bass habitat, and riparian habitat

6.2.1. Fall-run Chinook salmon habitat

The area of spawning habitat in the lower river was estimated using the Physical Habitat Simulation (PHABSIM) model, which was then modified by incorporating water temperature into the model results (USFWS 1995b). Baseline monitoring for the restoration projects also includes mapping-based quantification of suitable spawning habitat at each project site prior to implementation (McBain & Trush and Stillwater Sciences 2000). Habitat mapping is based on meso-habitat unit types developed for the American River (Snider et al. 1992) and the habitat suitability criteria summarized in Table 13. To date, mapping has been completed at the SRP 9/10 Reach, the 7/11 Reach, and M.J. Ruddy Reach. This mapping was conducted during variable flow releases in 1998 ranging from 1,500 cfs to 1,900 cfs, and at a flow of 280 cfs in 1999. Estimated riffle area and spawning area at each project site is shown in Table 25.

Table 25. Estimated pre-project Chinook salmon spawning habitat area for the entire portions of all reaches (reconstructed portions and un-reconstructed portions).

Reach	Riffle Area (ft^2)		Spawning Area (ft^2)
	1998 Field Assessment (1,500 cfs to 1900 cfs)	**1999 Field Assessment (280 cfs)**	**1999 Field Assessment (280 cfs)**
Gravel Mining Reach			
7/11	207,175	65,400	33,475
Ruddy	N/A	167,733	53,195
Warner-Deardorff	N/A	N/A	N/A
Reed	N/A	N/A	N/A
SRP 9/10 Reach			
SRP 9	N/A	N/A	0[a]
SRP 10	N/A	N/A	0[a]

N/A = not assessed to date

[a] No spawning habitat existed with the SRP sites; spawning habitat existing between SRP 9 and 10 is not included in this total

source: McBain and Trush and Stillwater Sciences 1999, 2000

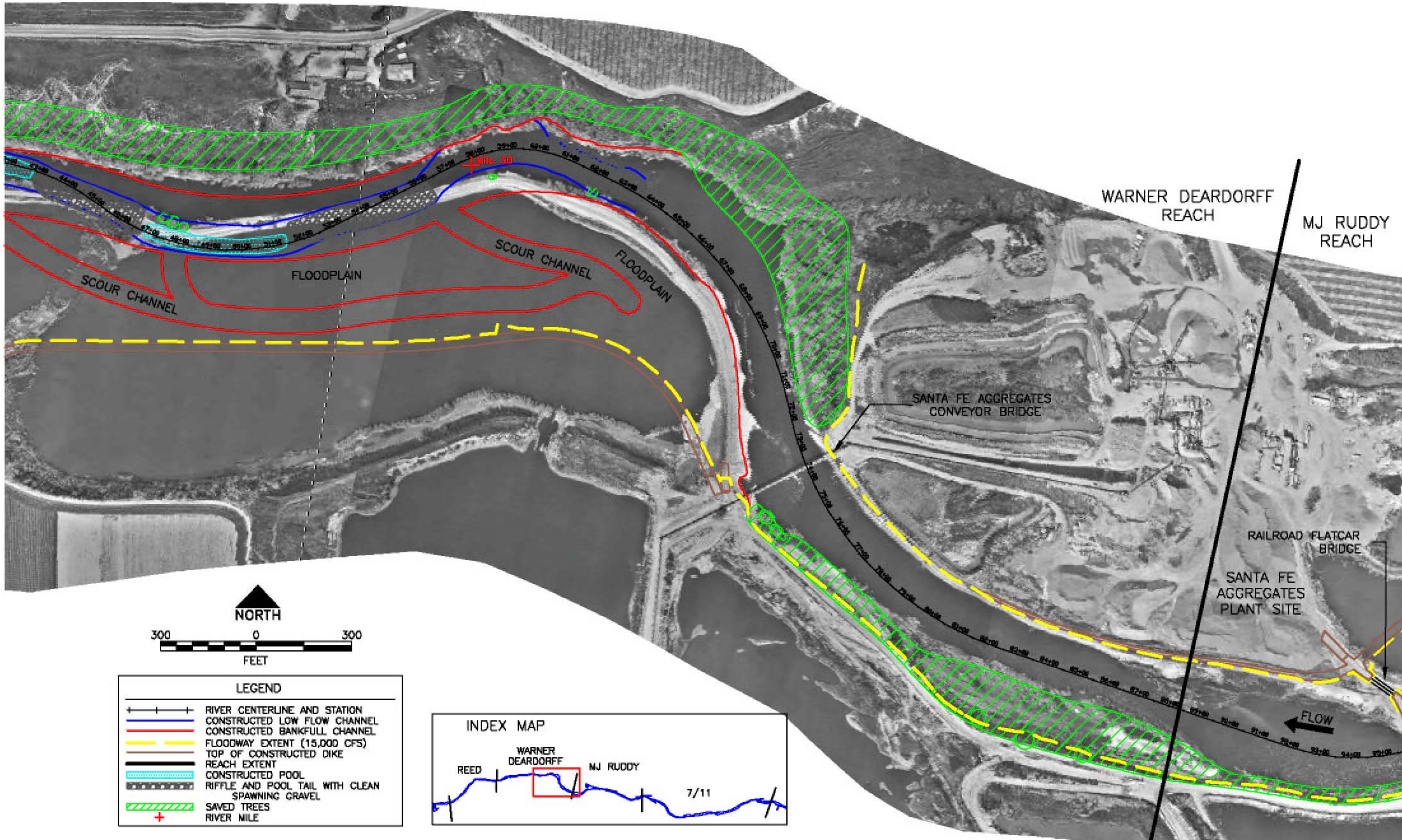

Figure 66. Design planform features for the upper portion of the Warner-Deardorff Reach.

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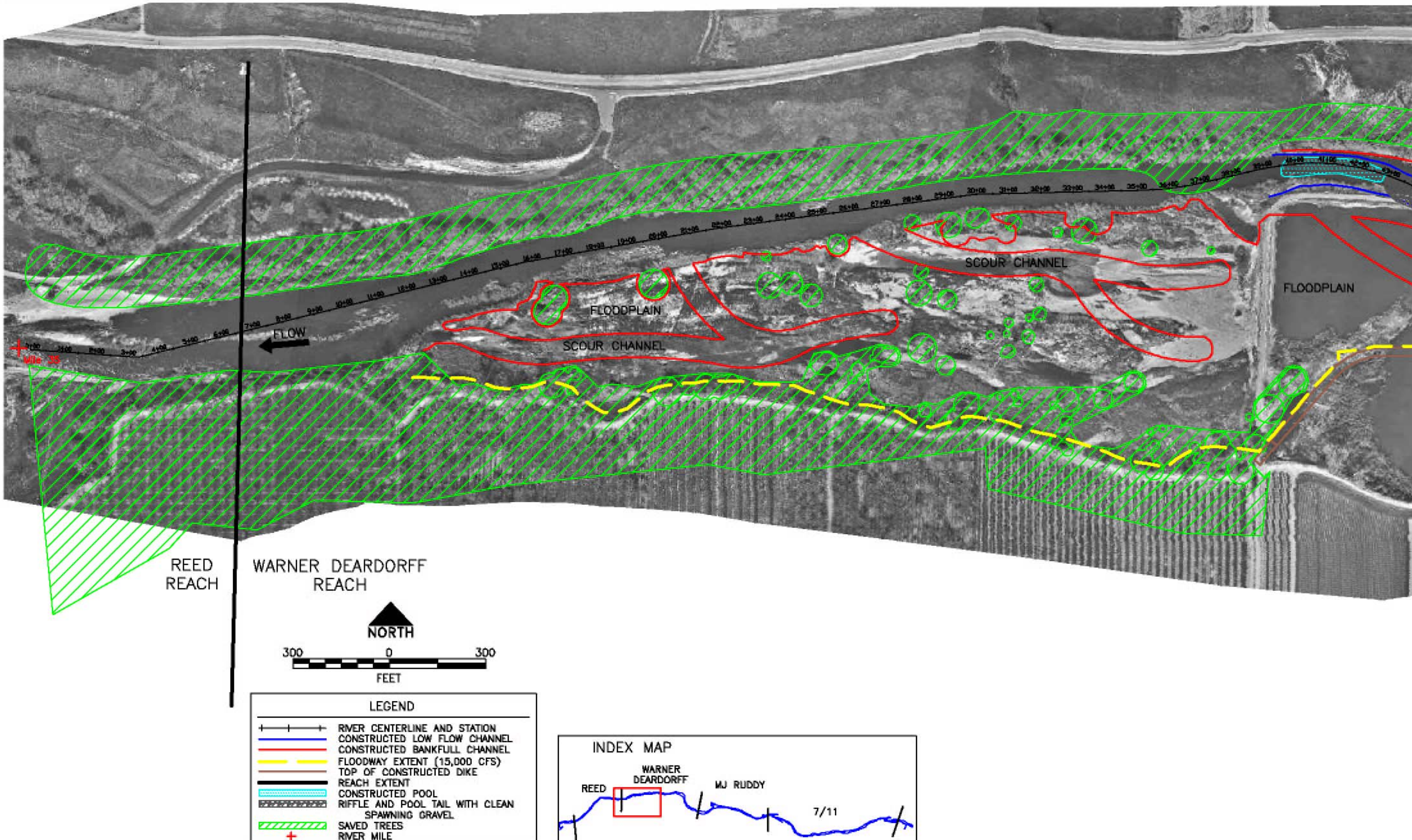

Figure 67. Design planform features for the lower portion of the Warner-Deardorff Reach.

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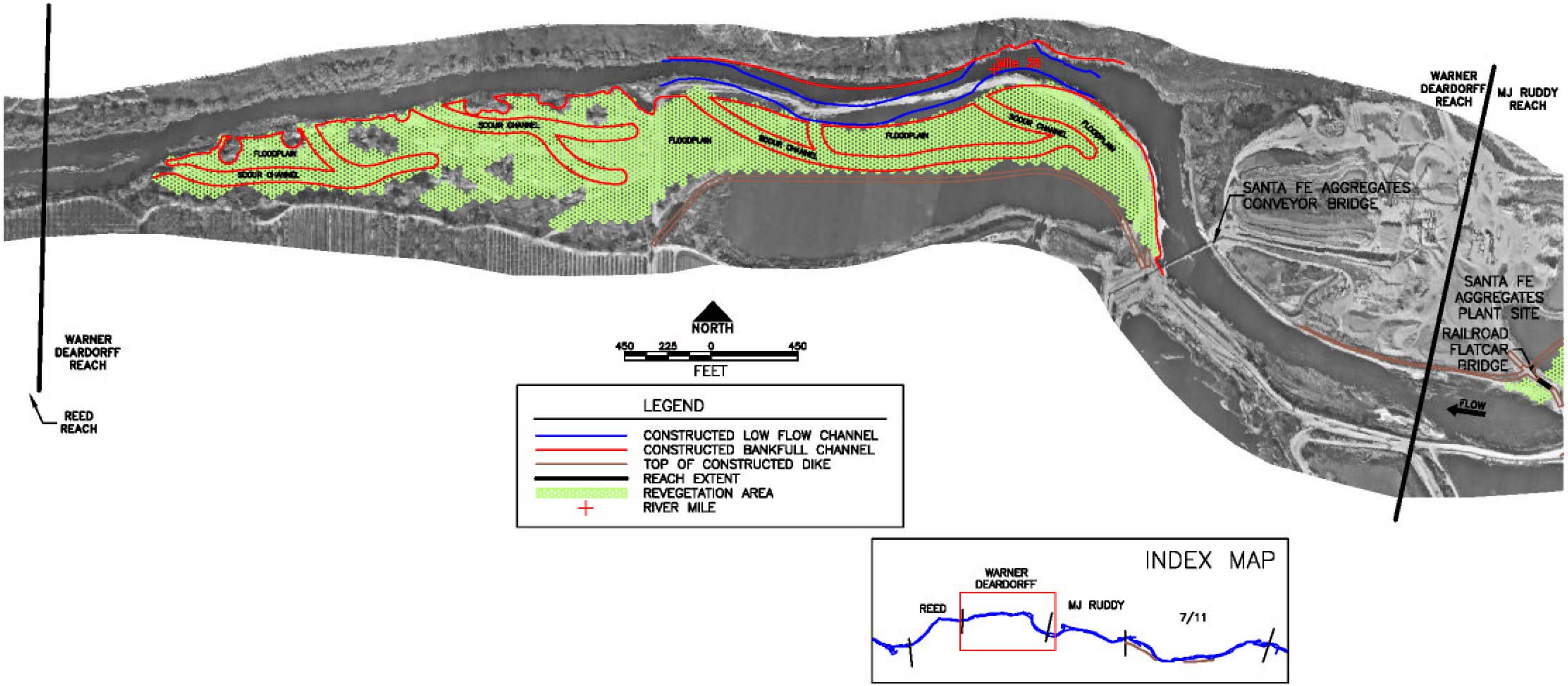

Figure 68. Design riparian revegetation areas for the Warner-Deardorff Reach.

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Project designs for the Gravel Mining Reach include construction of 4 riffles for the 7/11 Reach (38,300 ft^2 actually constructed), five riffles in the M.J. Ruddy Reach (192,000 ft^2 proposed), and two riffles in the Warner-Deardorff Reach (46,000 ft^2 proposed). Design flow depth at these riffles during spawning flows (300 cfs) is 1.7 feet; design average flow velocity at 300 cfs is 2.1 ft/s. After construction of the 7/11 Reach, the surface area of spawning habitat based on depth, velocity, and substrate criteria was 21,240 ft^2 in the reconstructed riffles. The total reconstructed riffle surface area was 38,300 ft^2, such that at a 280 cfs flow when the surveys were conducted, 55% of the riffle area was considered suitable for spawning at 280 cfs when the surveys were conducted. As flows range from 150 cfs to 300 cfs, the integrated percentage of riffle area suitable for spawning habitat should be greater than 55%. Regardless, for predictions of spawning habitat, we'll assume a 55% conversion from riffle area to spawning habitat area. Using this conversion, Table 26 predicts the change in spawning habitat for the 7/11 Reach, M.J. Ruddy Reach, and Warner-Deardorff Reach. Monitoring results from the 7/11 Reach shows that spawning habitat has nearly quadrupled, and predictions at the M.J. Ruddy Reach suggest a tripling of spawning habitat.

Table 26. Predicted changes in fall-run Chinook salmon spawning habitat for reconstructed portions of the 7/11, M.J. Ruddy, and Warner-Deardorff reaches.

Reach	Pre-construction riffle area (ft^2)	Pre-construction spawning habitat area (ft^2)	Riffle to spawning habitat conversion	Design or post-construction riffle area (ft^2)	Riffle to spawning habitat conversion	Design or post-construction spawning habitat area (ft^2)
7/11	12,400	5,320	0.43	38,300	0.55[a]	21,240
M.J. Ruddy	103,000	38,700	0.38	192,000	0.55	105,600
Warner-Deardorff	N/A	N/A	N/A	46,000	0.55	25,300

[a] Riffle area to spawning habitat area conversion under future conditions obtained from post-construction ratio at the 7/11 Reach (21,240/38,300 = 0.55)

Fry and juvenile rearing habitat should also be increased with the project; however, predictive modeling has not been conducted for these habitats. Pre-project monitoring for fry and juvenile rearing habitat has been conducted, and post-project monitoring has initiated at the 7/11 Reach and will be conducted at other reaches as well. The potential increase in the number of spawning adults that can be accommodated in this area and their potential juvenile production can be estimated using a redd-superimposition model developed for the Tuolumne River. However, this predictive modeling has not been incorporated into the design process, and has not been conducted for this document.

Gravel placed in riffles at the 7/11 Reach was unscreened, and no size criteria were specified. However, visual observation of the substrate, as well as initial documentation of post-project spawning habitat shows that the particle size is suitable for salmonid spawning. Much of this material was from redistribution of aggregate in the river channel as the floodway benches were constructed. At the M.J. Ruddy and Warner/Deardorff reaches of the Gravel Mining Reach, gravel placed in pool tailouts and riffles will be sorted such that the particle size ranges between ½" and 5" diameter based on the recommendations in the coarse sediment management plan (Table 27).

Table 27. Recommended spawning gravel particle size distribution based on fall-run Chinook salmon preferences (from McBain and Trush 2003).

Percent of total composition	Particle size range (diameter in mm)	Particle size range (diameter in inches)
15%	8 to 12.5 mm	1/4 ” to 1/2”
30%	12.5 to 25 mm	1/2” to 1”
35%	25 to 50 mm	1” to 2”
20%	50 to 128 mm	2” to 5”

6.2.2. Bass habitat

Reduction of bass habitat within the Gravel Mining Reach floodway is not a primary objective because bass habitat and populations are reasonably low in this reach due to the absence of large deep pits (as compared to the SRP sites). Therefore, predicted benefits of the project (as well as monitoring) in reducing bass habitat was not quantified. The primary bass-related objective within the Gravel Mining Reach is to reduce the frequency of (or eliminate) breaching dikes and connection of the Tuolumne River with off-channel mining pits. These large, deep mining pits contain large numbers of bass; therefore, preventing dike failure should reduce most bass predation on salmon.

6.2.3. Riparian habitat

The proposed riparian acreages and maximum riparian widths for the 7/11 Reach, M.J. Ruddy Reach, and Warner-Deardorff Reach are summarized in Table 28. The basic restoration projects focused on salmon related river habitat, yet riparian forest was added to the extent possible within the footprint of the project. When compared to the habitat suitability criteria for yellow-billed cuckoo (Table 17), the restored riparian corridor is well below minimum thresholds for yellow-billed cuckoo habitat at the 7/11 Reach and M.J. Ruddy Reach, but is large enough at the Warner-Deardorff Reach to provide Marginal to Suitable habitat. Yellow-billed cuckoo was used as an indicator species in this exercise; there are other indicator species that could be used (e.g., cowbirds, neotropical songbirds), but the habitat sizes for these other species were not specifically targeted in the design (although the riparian species planted were selected for these species).

Table 28. Summary of proposed riparian acreages and maximum widths for the 7/11 Reach, M.J. Ruddy Reach, and Warner-Deardorff Reach.

Reach	Planted area (acres)	Yellow billed cuckoo area suitability	Maximum widths (ft)	Yellow billed cuckoo width suitability
7/11	21.8	Unsuitable	300	Unsuitable
M.J. Ruddy	22.2	Unsuitable	275	Unsuitable
Warner-Deardorff	42.3	Marginal	690	Suitable

6.3. Design Uncertainty and Risks

Design uncertainties and risks fall into four major categories: construction implementation, geomorphic and hydraulic function, vegetation survival and recruitment, and fish population response. An underlying goal of the restoration construction and revegetation is that once established, the system would be self-sustaining with little or no outside maintenance. Implementation requires balancing constraints which in turn can lead to uncertainties when dealing with a dynamic river system. Evaluation of the long-term success of the projects will require taking these uncertainties into account. Specific uncertainties and risks are described below.

6.3.1. Construction Implementation

The volume of fill needed for project construction was determined based on existing channel and floodplain bathymetry and conceptual design topography. The actual volume required could increase due to settlement/compaction of fill once it is placed in the channel, compaction of the existing channel bed once fill is placed on top of it, or changed site conditions due to active mining between the design survey time and the actual land acquisition. Compaction rates of up to 20% should be expected. Also, volume needs could increase if in-channel cut and fill does not generate as much material as anticipated. As experienced at the 7/11 Segment, unanticipated increases in the volume of fill required during construction can greatly increase project cost and pose potential construction claims. The projects are bid on a lump sum basis for cost containment. However, if funds are not available to accommodate these increased costs, the quantity of fill may need to be reduced to stay within costs resulting in last minute revisions to portions of the project design.

6.3.2. Geomorphic and Hydraulic Function

Channel and floodplain design parameters were developed using observations at the M.J. Ruddy reference reach in the Tuolumne River, a HEC-RAS model, and numerical modeling of bed mobility thresholds. The objective of the design process was to construct a channel with a quasi-stable planform geometry, capacity to convey the bankfull flow (5,000 cfs) and to flood at flows exceeding 5,000 cfs, and a bed that is mobilized at the bankfull flow. There is inherent uncertainty in the application of numerical models in channel design. The Shields equation was used to determine flow depth required to mobilize the channel bed at the project site. Like all models, this model has inherent uncertainty and can over- or under-estimate critical depth. One key uncertainty in using this model is identifying an appropriate dimensionless critical shear stress. Unless field measurements are available, a dimensionless critical shear stress must be assumed. For the design process, the dimensionless critical sheer stress was assumed to be 0.02 based on published literature and observations on the Trinity River. Miscalculation of the critical depth could result in more or less frequent bed mobilization than targeted. The prediction of bed mobility threshold assumes an average shear stress over the channel bottom; however, actual shear stress varies laterally and longitudinally, such that the prediction of bed mobility thresholds using the method described in Section 5.1.4.3 are approximate and should not be interpreted to be precise predictions.

A hydraulic model (HEC-RAS) was used to determine channel width needed to convey the bankfull flow given the critical depth for bed mobilization predicted by the Shields equation. Hydraulic models can over- or underestimate flow velocity and water surface elevations. The channel roughness value (or Manning's *n*) is a critical input to this model. Channel roughness for the as-built conditions at the site was assumed to be 0.028 based on back-calculations from the M.J. Ruddy reference reach.

Manning's *n* once vegetation is established at the site is assumed to be 0.035. If the actual Manning's *n* is different than that used in the model, the frequency and duration of the floodplain inundation will be different than anticipated. This in turn could result in more or less frequent and/or shorter or longer duration inundation of the floodplain than targeted, which would in turn affect survival of planted riparian vegetation and recruitment of new vegetation.

Another uncertainty is whether the assumed bankfull discharge will occur frequently enough to prevent riparian encroachment by narrow-leaf willow. This encroachment process has been studied extensively on Clear Creek (e.g., Pelzman 1973) and on the Trinity River (e.g., Bair 2002). Comparison with observations on the Trinity River would suggest that the assumed bankfull flow (and higher flows) is of insufficient magnitude and frequency to mobilize and scour exposed bar surfaces frequently enough to prevent riparian encroachment in the future. Riparian encroachment should be one of the future riparian and geomorphic monitoring parameters.

There are also a few segments of the Gravel Mining Reach where the target of 500 ft minimum floodway width is not met. The most concerning is the section between the Santa Fe Aggregates conveyor bridge (STN 74+00) to the Santa Fe Aggregates haul road bridge (STN 96+00) where the width is as low as 300 ft (Figure 63 and Figure 66). Space constraints on the Santa Fe Aggregates plant site have precluded increasing the floodway width on the inside of the bend (north bank) and landowner opposition to moving the large dike on the south bank has limited the amount of floodway width expansion on the south bank. At higher flows, average velocities and bank shear stresses will be higher than in the other segments on the Gravel Mining Reach, and consequently, there is a higher risk of bed scour, channel damage, and infrastructure damage because of the narrower floodway. This additional risk has been explained to the landowners and the mining company.

6.3.3. Vegetation Survival and Recruitment

The basis of the revegetation design is planting species on surfaces at which they would be expected to survive given current hydrologic conditions in the river. Irrigation will support the plantings for two years, but future survival will rely on rainfall and flooding. Once the site is established, natural recruitment of native plants is expected to support the continued evolution of the restored floodplain forest. The hydrogeomorphic conditions suitable for the targeted plant species were determined from review of published literature and from observations on the Tuolumne River. Planting locations in the conceptual design were determined based on these hydrogeomorphic conditions and the inundation patterns predicted by of the HEC-RAS model. As discussed in Section 5.3.4, riparian and understory species were planted throughout the site with some locations not well suited to hydrogeomorphic conditions; therefore, there may be die-off of certain species that were planted in hydrologic zones or geomorphic surfaces that conflict with their life history needs (e.g., valley oak planted in scour channels that may be inundated for long duration in certain years and sedges planted on higher benches). The top two feet of floodplains will be constructed using a mixture of cobbles and topsoil to improve riparian planting survival. The mixing of the topsoil with the underlying aggregate fill was intended to vertically distribute the topsoil while providing some erosion protection of the floodplain surface. The mixing may be locally uneven, and this variability in texture and stratification of the floodplain fill may affect local survival of the planted vegetation. Additionally, the nutrient quality of mixed topsoil varied throughout the site, and resulted in significant differences in riparian growth and vigor based on preliminary monitoring observations.

The Habitat Restoration Plan for the lower Tuolumne River proposes an approach that encourages natural riparian regeneration processes for future restoration projects along the river. In most cases, satisfying this objective requires changes in channel morphology and potential riparian seedbeds, as well as modifications to the receding limb of certain flood control release hydrographs (e.g., Figure 21) to supply the water needed for regeneration of new seedlings. Changes in the flood control release hydrograph will not be implemented within the time frame of the current restoration revegetation planting, nor may it be implemented in the future. As a result, the riparian design that is currently being implemented discounts this aspect of natural riparian regeneration processes and artificially plants nearly all reconstructed floodplain surfaces.

Opportunity exists for conducting more active adaptive management experiments to address some of the riparian design disagreements in the remaining portions of the Gravel Mining Reach and SRP 10 project. The large size of the M.J. Ruddy, Warner/Deardorff, Reed, and SRP 10 reaches allows considerable experimentation to occur. The following experiments could be implemented on an equal or larger scale than that presently proposed on the M.J. Ruddy Reach (Figure 54).

1. Natural regeneration: Planting versus non planting. Leave certain areas unplanted to relate streamflow hydrology, soils, and geomorphic surfaces to natural riparian regeneration processes.
2. Irrigation: non-irrigation, drip irrigation, and sprinkler irrigation. Test impacts to weeds, water delivery effectiveness, root growth rates and morphology, plant survival for different species.
3. Planting: cuttings versus container stock. Compare cost effectiveness and plant survival rates for cuttings and container stock plantings for several key species.
4. Understory revegetation: Planting versus non planting. Evaluate cost effectiveness, recovery time, and naturally regenerating understory species in areas planted only with overstory species (cottonwood, valley oak).
5. Topsoil: For economic reasons, fine sediments reclaimed from aggregate mining settling ponds have been used for topsoil mixture. The fertility of these fine sediments is unknown, and differences in nutrient content between these fine sediments and true topsoil should be evaluated. Differences in weed development were noticed between different topsoil sources; therefore, the content of weed seeds of these two sources should also be considered.

These experiments should be done at locations that will have good experimental control (similar shallow groundwater hydrology, similar constructed geomorphic surfaces, and limited disturbance risk by the public). These experiments should be done on both SRP 10 and the remaining portions of the Gravel Mining Reach to evaluate potential differences in experiment results as a function of hydraulic geometry (as a result of the different slopes between the two reaches) and soils between the reaches. There are added planting costs to set up different irrigation and planting experiments; therefore, funding for an expanded monitoring program will be needed to evaluate these types of experiments. Such monitoring needs to be contractually separate from the revegetation contracts. Existing funding grants for the M.J. Ruddy project have been set and might limit the implementation of such experiments and the associated monitoring required.

6.3.4. Fish Population Response

As shown in Section 6.2.1, the Gravel Mining Reach restoration project will greatly increase Chinook salmon spawning habitat, and will likely increase and improve fry and juvenile rearing. Additionally, increase in floodway capacity will reduce the frequency of dike breaches and corresponding juvenile salmon stranding and predator mortality in the pits. However, just because habitat is increased or improved in this reach does not guarantee that smolt production or adult escapement will show improvement in the current spawning and out migration monitoring program. For example, Chinook salmon naturally tend to migrate to upstream reaches closer to LaGrange Dam, and restored spawning habitat in the Gravel Mining Reach may be underutilized except for years with larger adult escapement. It is anticipated that during average and high escapement years, the redd density will stay the same and the increased riffle area will contribute to the increase in salmon spawning use in the restoration area. Likewise, fry and juvenile rearing may be concentrated on upstream reaches in most years, such that the habitat restoration in the Gravel Mining Reach only increases production in those years where habitat is over-utilized in upstream reaches. Therefore, the primary dependent variables being used in the monitoring plan will focus on Chinook salmon rearing and spawning habitat rather than adult escapement or smolt production.

7. SRP 9 AND 10 DESIGN

The approach for SRPs 9 and 10 is to import material to fill in the pits and construct geomorphically functional channel and floodplain. Work will only occur in the SRP 9 and 10 pits, and perhaps the orchard on the north side of SRP 10; no work is planned for the channel reach separating the two SRPs. When the pits were created during aggregate extraction, riffles were excavated at the present pit locations, such that the elevation drop was concentrated in the short reach between SRP 9 and SRP 10. The conceptual design considered reconstructing the reach between SRP 9 and SRP 10 to redistribute the slope through the pit locations, which would have increased spawning habitat. However, because this reach is the downstream extent of spawning, the large added expense of reconstructing the reach between SRP 9 and SRP 10 and limited benefit to spawning habitat caused us to dismiss this option. The project will import large volumes of aggregate and topsoil to fill in the in-channel pits and construct a new channel and floodplain through the pits. Material for SRP 9 will come from off-site sources, but material for SRP 10 may be generated by: (1) purchasing the orchard on the north side of SRP 10, (2) excavating gravel and topsoil from the orchard to create a functional floodplain, and (3) using that cut material to fill SRP 10 and recreate the channel and floodplain through the pit. Design channel dimensions for this reach are the same as the Gravel Mining Reach (Table 12). The floodway will remain the same width as the pit at SRP 9, but the floodway could be expanded significantly at SRP 10 if the north bank orchard is purchased and used for borrow material. No new dikes would be constructed, yet one existing dike on the south side of SRP 10 damaged by the 1997 flood will be repaired.

As at the Gravel Mining Reach, the proposed floodway will allow room for the channel to flood, scour and re-deposit alluvial bars within the bankfull channel, but at a much reduced rate and frequency due to the lower slope in the reach. This increased width will enable some channel migration within the floodway and reduce the risk of capturing the remaining aggregate mining pit on the south side of the river. Again, the low slope of the reach will minimize channel migration. Other than the infiltration gallery installed at the upstream end of SRP 9, there are few human structures in the reach, so potential risk for damage is small. High flow scour channels will also be excavated on the floodplain to provide floodplain topographic diversity, high flow velocity refugia, and to encourage natural riparian vegetation recruitment. Because the high flow channels drain back to the river, stranding risk to juvenile salmonids should be minimal. The long-term viability of this expanded floodway corridor will be preserved by fee title and mineral rights purchases. TID, as operator of the Don Pedro Project, will own these lands and enter into a set of restrictive covenants with the US Fish and Wildlife Service to provide the same protection as conservation easements.

As done at the Gravel Mining Reach, the SRP 9/10 Reach is being constructed through a design-bid-build process. Conceptual geomorphic and riparian restoration designs were developed by McBain & Trush and EA Engineering in 1997. Revegetation designs were developed and implemented by HART Restoration. Draft detailed designs were developed by HDR Engineering and McBain & Trush, and final construction drawings and specifications were developed by HDR Engineering. HDR Engineering completed the 30%, 90%, and 100% construction drawings and developed cost estimates for project completion. The projects are then put out to bid to be constructed by a third-party contractor with construction management and inspection performed by HDR Engineering.

7.1. Reach Designs

The project was originally designed to be implemented in two phases during successive years, beginning with SRP 9 in 2001, and then following with SRP 10 in 2002. The actual funding cycle has resulted in a two-year gap between the two phases, and the anticipated construction schedule is shown in Table 29. The conceptual designs for SRP 9 and SRP 10 are shown on Figure 24. The final design for the SRP 9 project is shown on Figure 69, and ground photos of SRP 9 are shown on Figure 70.

Table 29. Anticipated implementation schedule for the SRP 9/10 Reach.

Reach Name	Boundaries (RM)	Implementation Schedule		
		Final Design	Earthmoving	Revegetation
SRP 9	RM 25.9 to RM 25.75	2001	2001	2001-2002
SRP 10	RM25.45 to RM 25.25	2003	2004	2004-2005

7.1.1. Phase I: SRP 9 implementation and SRP 10 embankment repair

The SRP 9 segment extends from Geer Road to RM 25.75 (Figure 1). The SRP 9 design entails filling the SRP 9 pit with up to 21 vertical feet of aggregate and topsoil to create a functional floodplain and channel. The conceptual design submitted to CALFED in 1997 is shown on Figure 23, and final design elements contained in the project bid package are summarized in Table 30 and are shown in Figure 69 and 70. This design included filling the pit and constructing a bankfull channel that would convey 5,000 cfs (subsequently modified as described in following section), constructing floodplains on the north and south banks of the channel, and installing an infiltration gallery (for future flow diversion) under the channel and floodplain on the south bank. In addition to restoration actions at SRP 9, this phase included patching a dike separating SRP 10 from a large south bank floodplain mining pit. Fill quantity required for the project was estimated to be 146,000 yd^3 based on conceptual designs, and increased to 193,000 yd^3 based on the engineers estimate for the final design (165,000 yd^3 of aggregate, 22,500 yd^3 of topsoil, 5,500 yd^3 of fill for the infiltration gallery).

7.1.1.1. Field Modification to Construction Design

The SRP 9 project was constructed using a design-bid-build process, with a pre-qualified short list of contractors. The 100% construction drawings were completed and released to solicit contractor bids 8 weeks prior to the scheduled date to begin construction. There was a 4 week bid period with mandatory site visit. None of the construction bids received were within the budget available for the project. To reduce costs and allow construction to begin as scheduled, which was necessary to be able to complete construction within the time windows established by various permits, the project was quickly redesigned over a two week period of negotiations with the low bidder to reduce the volume

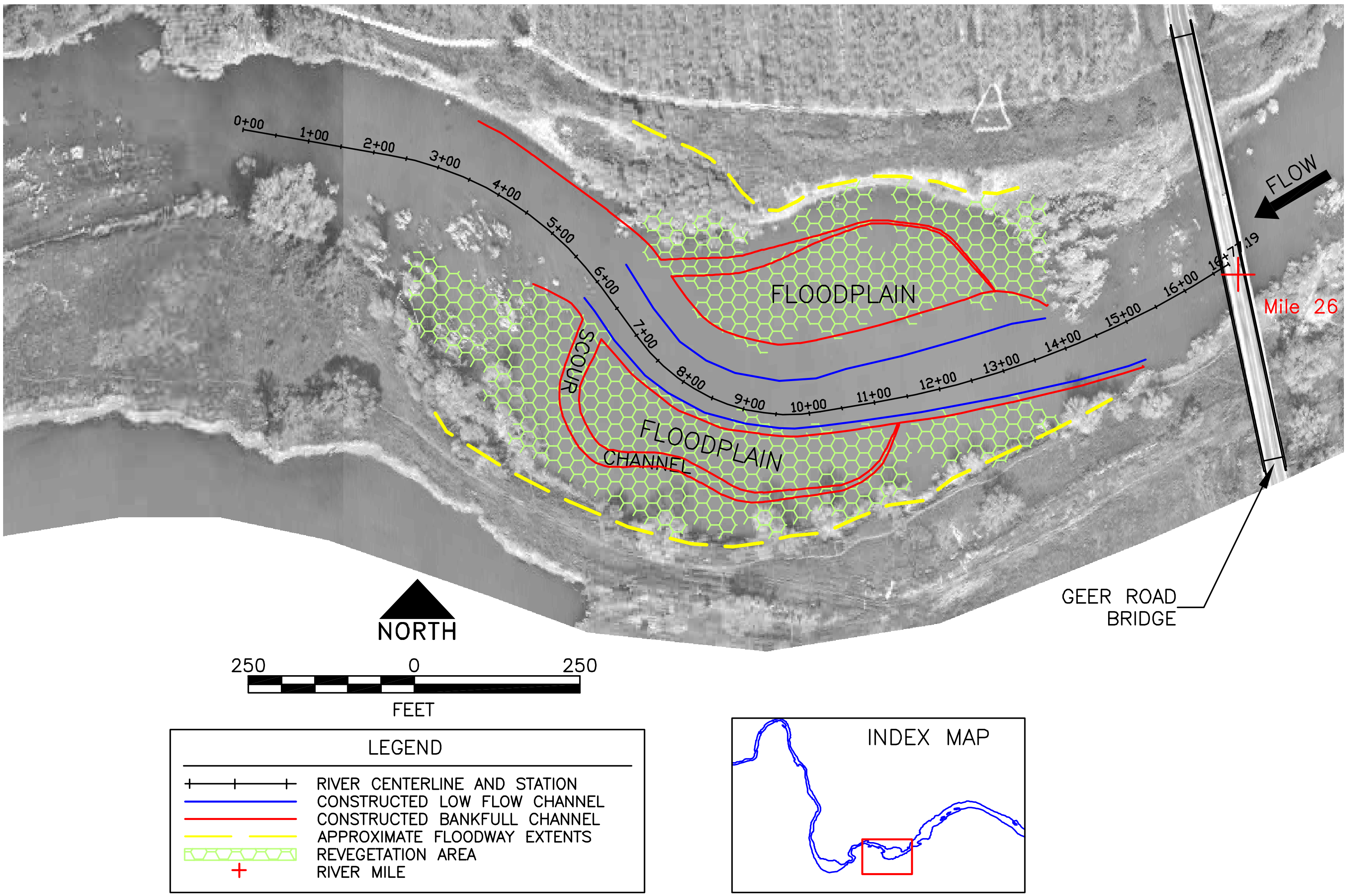

Figure 69. Design planform features and riparian revegetation areas for the SRP 9 Reach.

Figure 70. Construction (summer 2001 and as-built (summer 2003) ground photographs of SRP 9, looking downstream from west side of Geer Road Bridge.

of fill required by 24,000 yd^3. The revised design included lowering the elevation of the floodplains on both sides of the channel by one to three feet and adding high flow scour channels to create topographic diversity on the floodplain. Net fill to construct SRP 9 was approximately 169,000 yd^3.

The channel and floodplain were originally designed so that the floodplain would be inundated at flows exceeding 5,000 cfs. The riparian vegetation design was also based on this level of floodplain inundation. That is, the riparian plantings on the floodplain were based on the inundation frequency expected to occur for the original design. With the revised design, the floodplain will be inundated at flows exceeding 1,500 cfs, slightly less than the $Q_{1.2}$. Because the plants for the project had already been grown, the planting design was not substantially altered, except the high flow scour channels were planted with rushes and sedges. This reduction in channel confinement and increased inundation of the floodplain could affect the performance of the project by:

- Reducing flow depth at bankfull flows, thus reducing sediment transport and scour;
- Causing inundation mortality of planted riparian species that typically establish on higher elevation geomorphic surfaces, such as valley oak;
- Increasing natural regeneration of woody riparian species and associated understory plants because the lowered floodplain surface is closer to the summer baseflow groundwater table;
- Increasing overbank inundation frequency and duration;
- Increasing duration and frequency of time that salmon fry, juveniles, and smolts may have access to floodplain and scour channel surfaces.

The geomorphic objectives may be altered or compromised by this revision (e.g., floodplain inundation frequency and duration, bed mobility, channel migration); however, the low slope of the reach made it difficult to achieve these geomorphic objectives even under the original design. At the time when the design revision was discussed, the project designers felt that: (1) the primary objective of the project was to reduce salmon predator (bass) habitat, and the design revision would not compromise that objective, (2) the geomorphic objectives were secondary to the fishery objectives, and because the geomorphic objectives probably would not be achieved even under the original design, lowering the floodplain surfaces would not lower the geomorphic performance of the project, and (3) lowering the floodplain surfaces would likely provide significant benefits to natural riparian regeneration, improved success of planted vegetation, and improved salmon rearing habitat. To illustrate differences in fry, juvenile, and smolt rearing habitat, we evaluated the percentage of time between January 1 and June 30 (fry to smolt rearing timing) that overbank flows would occur under the post-NDPP project flow regime for the 5,000 cfs floodplain design and the 1,500 cfs floodplain design. If the floodplains were constructed as designed (5,000 cfs inundation), overbank flows during the salmon rearing period would occur 10% of the time (on average, 18 days out of the 181 days between January 1 and June 30), whereas if the floodplains were constructed to inundate at 1,500 cfs, overbank flows during the salmon rearing period would occur 32.5% of the time (on average, 59 days out of the 181 days between January 1 and June 30). Lowering the floodplains causes a dramatic increase in floodplain rearing habitat value. Therefore, the floodplain elevations revisions do not appear to reduce project performance, and are being considered an adaptive management experiment. Revisions to the designs elements are described in Table 30 and are shown in Figure 69. Construction and as-built ground conditions are illustrated in Figure 70.

Table 30. Proposed design elements for the SRP 9 project.

	Original Design	**Revised Design**
Channel Reconstruction	• Reconstruct a low flow and bankfull channel from STN 14+50 to STN 3+00. Bankfull channel width is approximately 200 feet and flow conveyance is 5,000 cfs.	• Reconstruct a low flow and bankfull channel from STN 14+50 to STN 3+00. Bankfull channel width is approximately 160 feet and flow conveyance is 1,500 cfs.
Floodplain Regrading and Dike Construction	• Fill in the right (north) bank of the pit to create a floodplain up to 200 feet in width extending from STN 14+00 to STN 5+50. Floodplain elevation is approximately 5 feet above the low flow water surface. • Fill in the left (south) bank of the pit to create a floodplain up to 150 feet in width extending from STN 14+50 to STN 3+00. Floodplain elevation is approximately 5 feet above the low flow water surface. • Repair a 65-foot long breach in the dike at SRP 10, constructing the new dike section to have 2:1 side slopes on the mining pit and channel side. Armor dike side slopes with 25-pound rock slope protection with ½-ton boulders at the toe.	• Fill in the right (north) bank of the pit to create a floodplain up to 200 feet in width extending from STN 14+00 to STN 5+50. Floodplain elevation is approximately 2.5 feet above the low flow water surface. • Fill in the left (south) bank of the pit to create a floodplain up to 150 feet in width extending from STN 14+50 to STN 3+00. Floodplain elevation is approximately 2.5 feet above the low flow water surface. • Construct two high flow scour channels, one through the north floodplain and one through the south floodplain. Both high flow scour channels are connected to the main channel at both their upstream and downstream ends. • Repair a 65-foot long breach in the dike at SRP 10, constructing the new dike section to have 2:1 side slopes on the mining pit and channel side. Armor dike side slopes with 25-pound rock slope protection with ½-ton boulders at the toe.
Slope protection, culverts, and debris removal	• Install 25-pound rock slope protection with ½-ton boulders at the toe on the left bank from STN 12+50 to STN 6+25. • Install brush boxes and willow mats on north bank between SRP 9 and 10 to protect eroding orchard.	• No change
Infiltration Gallery	• From STN 13+00 to STN 11+00, install infiltration gallery consisting of four main laterals and 16 sub-laterals protruding from the left bank across the channel bed and buried in a select gravel envelope to a depth of five feet below the channel bed.	• No change
Revegetation	• Revegetate all floodplain surfaces constructed in the reach using cells described in Section 5.3.3. Floodplain canopy species include cottonwood, willow, alder, and oak. Revegetation area = 5.5 acres.	• No change, except high flow scour channels planted with rushes and sedges.

Note that stationing in this table reflects project specific stationing as depicted on the construction design drawings (also shown on Figure 69). STN 0+00 is the downstream boundary of the SRP 9 project site.

Channel and floodplain construction was completed using the revised design in October 2001; riparian revegetation was completed in February 2002, and encompassed approximately 5.5 acres.

7.1.1.2. Recommended design improvements

Our preliminary evaluation of the bass habitat availability at SRP 9 indicates that the design was successful in reducing largemouth bass habitat, but actually increased the amount of smallmouth bass habitat. The pre-project surveys showed that, based on depth and velocity criteria, nearly the entire SRP 9 unit was suitable for largemouth bass. In the newly constructed channel, while the channel depth may be suitable for largemouth bass, water velocities in the main body of the unit were generally above the 0.75 ft/s upper velocity threshold for largemouth bass suitability. Largemouth bass habitat was found along the middle section of channel and along the right bank.

Smallmouth bass prefer water velocities up to approximately 1.5 ft/s, channel depths between 2 to 10 ft, and gravel/cobble substrates. While these are generally the conditions created by reconstructing the SRP 9 channel, there does not seem to be much too flexibility to design around these criteria. Depths less than 2 ft are generally not feasible or appropriate for this reach, and depths beyond 10 ft deep begin to allow velocities that are again suitable for largemouth bass. Velocities greater than 1.5 ft/s would require a smaller channel cross section and greater slope, such as at a riffle, which could only be created for a portion of the unit at best.

The 1998 and 1999 Monitoring Reports discussed the feasibility of managing flow releases in spring to reduce water temperatures to suppress bass reproduction. Higher discharge would also increase water velocities and thereby reduce the suitability of habitat conditions in the lower river. Finally, large jumps in water temperatures were documented in this reach in the spring and summer months, and may be attributable to the SRP 9 and 10 units. Reducing residence time in the large SRP ponds may contribute to maintaining colder water temperatures farther downstream along the river. Given this potential opportunity to manage bass predation indirectly by flow management, one primary benefit of the newly constructed channel is that, by eliminating the large pond with extensive backwater areas, much smaller increases in discharge will be required to have an effect on water velocities. The combination of temperature and flow management, in conjunction with reduced channel widths, depths, and surface area, likely offers the best opportunity to reduce bass predation on salmon, and thus meet the restoration project objectives.

7.1.2. Phase II: SRP 10

The SRP 10 segment extends from RM 25.44 to RM 25.24 (Figure 1). Construction designs for this phase have not yet been developed. The original conceptual design for the project described in the Habitat Restoration Plan for the Lower Tuolumne River Corridor (McBain and Trush 2000) is shown in Figure 24 and included placing fill along the north bank of the pit to create a functional floodplain that is inundated at flows exceeding 5,000 cfs and constructing a channel along the south bank of the mining pit. The design channel included three riffle-pool sequences, with a maximum pool depth of 10 feet. The fill quantity required for construction, based on the conceptual design, was estimated to be 293,000 yd^3.

The SRP 10 project is currently being redesigned and the latest conceptual design shown on figure 71. The north bank orchard adjacent to the project has become available for purchase, providing an opportunity to relocate the channel and reduce the volume of fill required from off-site sources to fill SRP 10 (as well as other potential SRP sites in the future). Two design approaches are presently being considered: (1) excavate a new channel and floodplain in the north-bank orchard, and excavated material from the orchard would be used to fill SRP 10 as a functional floodplain (Figure 34), and (2) modification of the conceptual design in Figure 24 such that the north-bank orchard would be lowered to a functional floodplain and the excavated material would be used to construct a new bankfull channel and floodplain through SRP 10. Construction designs for SRP 10 will be completed in winter 2003/2004, and depending on funding timing, construction will likely occur in 2005. Riparian revegetation would occur on reconstructed floodplain surfaces, although the planting strategy and acreages will be developed during the final design.

7.2. Predicted habitat benefits

As done in Section 6.2 for the Gravel Mining Reach, this section summarizes some of the predicted changes to salmon habitat, bass habitat, and riparian habitat in the SRP 9/10 Reach.

7.2.1. Salmon habitat

Spawning habitat does not currently exist within the SRP 9 or SRP 10 project site, although some spawning habitat exists between the project sites. This reach is in the gravel-bed to sand-bed transition and 25 miles downstream of La Grange Dam, and spawning in this reach is extremely low. Some increases in spawning habitat may have occurred at SRP 9 as the riffle on the upstream end was reconstructed and extended slightly downstream using larger sized aggregate than is found at this location. There may also be some increases in spawning habitat in SRP 10 depending on the design option eventually chosen. Because spawning habitat was not a significant objective for this reach, the as-built spawning habitat was not predicted. Baseline monitoring of salmon habitat using mapping-based quantification of suitable spawning habitat has been conducted at SRP 9 and SRP 10. Habitat mapping is based on meso-habitat unit types developed for the American River (Snider et al. 1992) and the habitat suitability criteria summarized in Table 13. This mapping was conducted during variable flow releases in 1998 ranging from 1,500 cfs to 1,900 cfs, and at a flow of 280 cfs in 1999. Estimated riffle area and spawning area at the SRP 9 and SRP 10 project sites is shown in Table 25.

Salmon rearing habitat was also not a significant restoration objective for the project. However, we expect rearing habitat to be increased as: (1) the wide, deep pits are converted to narrower, faster, shallower pool-riffle sequences, and (2) the wide, deep pits are converted to floodplains and scour channels that will be periodically inundated during periods of higher flows. SRP 10 is currently being designed with floodplains that will be inundated by flows greater than 5,000 cfs. SRP 9 was implemented with low floodplains inundated by flows greater than 1,500 cfs, such that the constructed floodplains and scour channels will be inundated with greater frequency and duration than those at SRP 10 (see Section 7.1.1.1). As with spawning habitat, rearing habitat was not predicted due to it being a lower priority objective than the objective of reducing salmon predation by bass. While no prediction has been made, development of a 2-D hydraulic and fish habitat model may allow us to evaluate changes in juvenile rearing habitat.

7.2.2. Bass habitat

A primary objective of the SRP 9/10 Reach projects is to reduce predation on Chinook salmon fry, juveniles, and smolts. During development of the monitoring plan for the SRP 9/10 Reach projects, the TRTAC chose three parameters for evaluating predation: (1) quantifying bass habitat availability at project and reference sites before and after construction, (2) quantifying bass population abundance at project and reference sites before and after construction, and (3) measuring actual predation on salmon migrating through SRPs 9 and 10 before and after construction. Monitoring for these three parameters began in 1998.

Bass habitat availability was estimated in 1998 and 1999 using a combination of aerial photographs, field measurements of depth, velocity, and vegetation distribution, and a set of habitat suitability criteria developed from published literature. AutoCAD Land Development software was used to predict habitat availability based on the depth-velocity criteria for SRPs 9 and 10. Results are presented in monitoring reports (McBain & Trush and Stillwater Sciences 2000). These efforts documented large areas of habitat suitable for largemouth bass in both years, and included SRP 7, SRP 8, SRP 9, and SRP 10. Smallmouth bass habitat was also available, but to a lesser extent within SRP units (Table 31). The distribution of aquatic vegetation was used to distinguish primary and secondary habitat, but this criterion had relatively little effect on the amount of suitable habitat available (less than 10% difference at all sites). The extent of habitat suitable for largemouth and smallmouth bass was mapped in 1998 during flows ranging from 1,500 cfs to 1,900 cfs, and in 1999 during at flows of 280 cfs (Table 31). Based on our observations of the distribution and relative proportions of largemouth and smallmouth bass at project and reference sites, we hypothesized that the net effect of channel reconstruction could be to shift habitat suitability away from largemouth bass, but were unsure about future conditions for smallmouth bass in the remaining habitat.

Post-project monitoring was conducted in 2003, but the data analysis is not yet complete. Preliminary data indicate that largemouth bass habitat was reduced by 78% as a result of the channel reconstruction at SRP 9. Smallmouth bass habitat was nearly tripled, and appears to now make up a larger proportion of the total remaining bass habitat (Table 31). The majority of the habitat now available at the SRP 9 is within the slack water area along the right bank where the channel width increases (Figure 69). Water velocities in the main body and the downstream portions of the pool are also low enough (< 1 ft/s) during the summer to provide suitable habitat for both species of bass; smallmouth bass now have preferable habitat over largemouth bass because smallmouth bass prefer slightly higher velocities and gravel/cobble substrate.

In 1998 and 1999, electrofishing was conducted at the SRP 9/10 project sites, two SRP reference sites, and two channel reference sites. Electrofishing used depletion-removal methods to obtain a population estimate for each of the six sampling sites. These monitoring efforts are also reported in previous monitoring reports (McBain & Trush and Stillwater Sciences 2000). The two years of baseline data were gathered to evaluate the changes to bass population abundance resulting from the channel reconstruction project. Post-project electrofishing was completed in September 2003, but results are not yet available. While both species of bass were relatively abundant in the 2003 effort at SRP 9, the data from post-project habitat mapping and from bass abundance estimates appear to support a shift from largemouth to smallmouth bass habitat suitability and abundance. The ratio of largemouth to smallmouth bass captured at SRP 9 changed from 2:1 (1998) and 10:1 (1999) to 0.6:1 (2003).

The Tuolumne River outmigrant trapping program conducted by the TRTAC and CDFG (TID/MID 1998 and 1999) was designed to provide river-wide and site-specific monitoring of survival and migrational patterns of Chinook salmon juveniles and smolts in specific reaches of the Tuolumne River. These evaluations included the 1.8-mile reach containing SRPs 9/10 (for site-specific evaluations). Smolt survival experiments were conducted in April and May of 1998 and 1999 to test both river-wide survival and survival in specific river reaches, including SRPs 9 and 10. The experiments at SRPs 9 and 10, however, were not successful, and survival in this reach could not be estimated for either year. In both years, marked juvenile Chinook salmon were released

Table 31. Extent of habitat suitable for largemouth and smallmouth bass at SRP 9 and SRP 10.

Site	Largemouth Bass Habitat Area (ft^2)		Smallmouth Bass Habitat Area (ft^2)	
	Primary[1]	Secondary[2]	Primary[3]	Secondary[4]
1998				
SRP 9	227,700	209,100	24,000	22,300
SRP 10	337,100	325,400	17,100	13,700
1999				
SRP 9	275,200	271,400	26,100	22,800
SRP 10	426,200	423,400	22,400	22,200
Predicted future as-built conditions based on 2003 habitat mapping				
SRP 9	NA	34,700	NA	62,500
SRP 10	NA	NA	NA	NA

[1] Includes velocity and cover criteria

[2] Includes velocity criteria only

[3] Includes depth, velocity, and cover criteria

[4] Includes depth and velocity criteria only

NA = Not Available at this time

source: McBain & Trush and Stillwater Sciences 2000

simultaneously at sites upstream of SRP 9 and downstream of SRP 10 and were recovered in a rotary screw trap located downstream of SRP 10. A total of six releases were conducted in this manner. Three different trap locations, all within 0.1 to 0.9 miles of SRP 10, were employed during the 1998 and 1999 sampling in order to provide additional release locations downstream of SRP 10. For all releases except one, fish released at the upstream site were recovered at a significantly higher rate than fish released near the trap. This recovery pattern indicates that the upstream release group and the downstream release group were not equally vulnerable to capture at the trap (i.e., the downstream control groups were less vulnerable than the upstream group). Survival, therefore, could not be estimated based on these releases.

The difficulty of predicting smolt numbers on such a small reach scale has resulted in the monitoring effort backing away from attempting to predict (and monitor) Chinook salmon predation through the SRP 9/10 Reach in favor of predicting and monitoring changes in predator habitat (see Section 7.2.2). Therefore, no prediction is made for reductions in Chinook salmon predation rates or numbers.

7.2.3. Riparian habitat

The SRP 9/10 projects provide opportunities to recreate riparian habitat when the in-channel mining pits are filled in to reduce salmon predator habitat, but no specific riparian or avian species were targeted in the riparian planting design. The proposed riparian acreages and maximum riparian widths for the SRP 9 and SRP 10 project sites are summarized in Table 32. The SRP 9 acreages are as designed and implemented. The SRP 10 design is currently considering two design scenarios. One is based on the original conceptual design in the CALFED proposal (Figure 24), and the other is based on purchasing a portion of the orchard on the north bank of the river and placing the river through the orchard or lowering the orchard surface to reconstruct the channel through the SRP 10 pit (Figure 71). If the orchard on the north bank of SRP 10 is purchased and converted to riparian habitat over the long-term, an addition 20 acres of riparian habitat would be generated (Table 32). If the habitat suitability criteria for yellow-billed cuckoo (Table 17) are used as a benchmark, then the restored riparian corridor is well below minimum thresholds for yellow-billed cuckoo habitat at the SRP 9 project site. The larger size of the SRP 10 project site as shown in Figure 71 greatly increases the amount of riparian habitat and provides suitable widths for yellow-billed cuckoo habitat, but the acreage is not large enough to exceed the "unsuitable" threshold (Table 32).

Table 32. Summary of proposed riparian acreages and maximum widths for the SRP 9 project site, SRP 10 project site, and SRP 10 project site with full riparian restoration of north bank orchard.

Reach	Planted area (acres)	Yellow billed cuckoo area suitability	Maximum widths (ft)	Yellow billed cuckoo width suitability
SRP 9 final design	5.5	Unsuitable	190	Unsuitable
SRP 10 conceptual design	8.2	Unsuitable	310	Unsuitable
SRP 10 + orchard	20	Unsuitable	675	Suitable

7.3. Design Uncertainty and Risks

The design uncertainty and risks for the SRP 9 and 10 projects include those discussed in Section 5.6 for the Gravel Mining Reach. Additional uncertainty and risks are briefly discussed below.

Geomorphic and Hydraulic Function

The SRP 9 project was quickly redesigned to reduce project cost. The redesign no longer satisfied the original bankfull channel design criteria because bankfull channel capacity was reduced and frequency and duration of floodplain inundation was increased. Potential negative effects of this redesign on the project could include reduced sediment transport and channel migration, as well as larger mortality of planted riparian vegetation because they are now planted on geomorphic surfaces that are inappropriate for their life-history needs (e.g., inundation frequency and duration on lowered floodplains could be too great for valley oak and other species to survive).

Vegetation Survival and Recruitment

As discussed above, the redesign of the project altered floodplain inundation characteristics, which will also alter conditions for vegetation survival and recruitment. This more frequent inundation will likely support establishment of pioneer species such as willows and cottonwoods. Species that occur on drier surfaces, such as valley oaks, may not survive at the site.

Fish Population Response

The project is intended to reduce habitat suitability for largemouth bass and thus reduce largemouth bass abundance and predation by bass on juvenile Chinook salmon. This reduction in predation is expected to increase juvenile salmon survival through the project reach. It is unlikely that largemouth bass will continue to occur in the SRP 9/10 Reach in their current numbers because their preferred habitat will be significantly reduced by the projects. However, the projects as constructed may not reduce habitat suitability for smallmouth bass, another introduced predator of juvenile salmon, as much as originally desired. Because smallmouth bass can tolerate shallower depths, faster velocities, and coarser substrates, reducing their habitat will be more problematic. Predation studies on the Tuolumne River have suggested that smallmouth bass predation rates are as high or higher than largemouth bass; however, the data upon which predation rates are estimated have very small sample

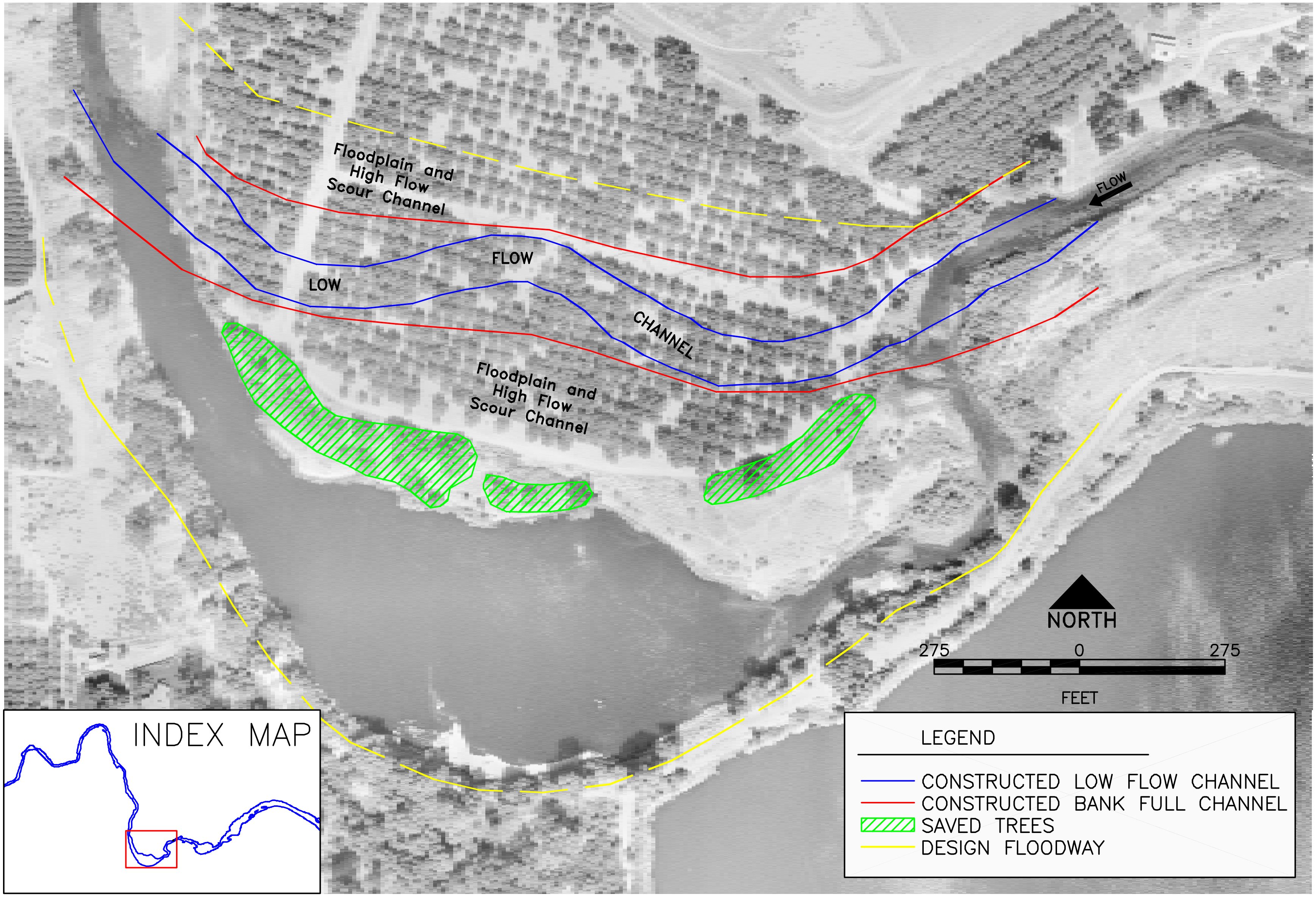

Figure 71. Design planform features for Option A at the SRP 10 Reach, where the channel would be reconstructed through the orchard on the north bank of the river and the SRP 10 pit filled with material excavated from the orchard.

size and should be interpreted with caution (see Appendix 22 Table 3 in EA Engineering 1991). Regardless, smallmouth bass population abundance is generally much lower than largemouth bass, so their overall predation impacts on outmigrating juvenile salmon is smaller. As constructed, the SRP 9/10 projects may shift habitat suitability away from largemouth bass and towards smallmouth bass. Thus, the SRP 9/10 projects will not completely eliminate predation on salmon, but should reduce the level of predation. If the SRP 9/10 projects are locally successful in meeting desired predation objectives, it would eliminate only 12% of the SRP length in the Tuolumne River downstream of the Gravel Mining Reach (SRP 5, 6, 7, 8). Since all spawning occurs upstream of the SRPs, this incremental reduction in SRP area may not be sufficient to significantly increase Chinook salmon outmigrant survival from the river if there are no further SRP projects. A better scientific understanding of both largemouth and smallmouth bass predation rates, population abundance, and distribution would help clarify these issues.

8. PROJECT MONITORING

A primary function of monitoring is to address whether objectives are being met. The Habitat Restoration Plan for the Tuolumne River Corridor recommends a two tier monitoring strategy: (1) Project-specific monitoring that addresses specific objectives of individual restoration projects, and (2) River-wide monitoring that addresses overall goals of the Restoration Plan, as well as the cumulative effects of the individual restoration projects. Project-specific monitoring has been developed for the Gravel Mining Reach and SRPs 9 and 10 projects to assess their performance after construction. Baseline (i.e., pre-project data) collection at these sites began in 1998 and is reported in McBain & Trush and Stillwater Sciences (1999, 2000). For these two projects, site-specific monitoring will assess (1) whether the physical features constructed at the site were completed as designed, (2) geomorphic and riparian response at the project sites, and (3) changes in habitat suitability and utilization by target species.

Another important function of monitoring is to evaluate implementation experiments under an adaptive management framework. Project implementation develops some “hypotheses” (described below), but these are really project-specific objectives rather than testable hypotheses. Most components of the restoration projects are being implemented in a similar manner, such that there are few active experiments being conducted. There are two notable exceptions. First, design changes during the SRP 9 bid negotiation process to reduce project costs resulted in some differences in design implementation. For example, the SRP 9 floodplain was lowered to reduce fill material purchase costs such that the inundation flow was reduced from 5,000 cfs to 1,500 cfs. Likewise, a portion of the 7/11 floodplain was lowered to inundate at 4,500 cfs as a design change to provide a solution to a construction dispute. These changes in floodplain inundation flow have resulted in a functional experiment where floodplain evolution (deposition, inundation frequency and duration, riparian revegetation, etc.) can be compared between the reaches. Second, a small riparian experiment is planned at the M.J. Ruddy Reach. These two exceptions constitute the active adaptive management experiments for these two projects.

The funding for these restoration projects usually had sufficient funds allocated to establish pre-project conditions and make some post-project evaluations. The desire to have more experimental elements in the remaining designs will require longer term funding for monitoring activities that are continued after the projects are constructed. A complete description of the monitoring plan for the Gravel Mining Reach and SRP 9/10 Reach is found in USFWS and TID (1998). The following sections provide a summary of the monitoring plan.

8.1. Gravel Mining Reach

Monitoring of the Gravel Mining Reach project includes assessments of geomorphic conditions, habitat structure, Chinook salmon utilization of the reach, and riparian vegetation. Monitoring falls into two categories: (1) design effectiveness, and (2) project effectiveness. Design effectiveness evaluates how well the design functions as intended. For example, monitoring will determine whether the floodplain is inundated by 5,000 cfs as designed, and if the design did not perform as as intended, monitoring will help evaluate the cause of the discrepancy (e.g., inappropriate roughness values in hydraulic model). Project effectiveness evaluates longer term project performance, such as floodplain evolution, channel evolution, and fish use. Methods being used in the monitoring are shown in Table 33.

The hypotheses (objectives) being tested by the monitoring are as follows:

- H1. The constructed channel conveys 5,000 cfs; flows exceeding 5,000 cfs spill over onto the floodplain (DESIGN objective).
- H2. The channel bed is mobilized at flows of 5,000 cfs (DESIGN objective).
- H3. The constructed bankfull channel morphology is stable, where stable is defined as the longer-term channel dimensions under a dynamic channel morphology (PROJECT objective).
- H4. The channel migrates under the current flow regime, although migration rates will be small (PROJECT objective).
- H5. The extent and quality of Chinook salmon spawning and rearing habitat is increased (PROJECT objective).
- H6. Chinook salmon spawning and rearing will increase in the reach following project implementation (PROJECT objective).
- H7. Planted riparian vegetation will become established on the constructed floodplain (DESIGN objective).
- H8. Natural recruitment of native riparian plant species will occur on the constructed floodplain (PROJECT objective).
- H9. Riparian vegetation will not encroach into the constructed channel (PROJECT objective).

In addition to the project performance monitoring described in Table 33 above, TID will develop and implement a Dike Maintenance and Monitoring Plan (DMOP) that covers all dikes constructed for the project. The DMOP will specify dike inspection and maintenance procedures that will be implemented by TID and will discuss the relationship between these inspections and Department of Conservation requirements for annual inspection reports on the active mining operations adjacent to projects.

8.2. SRPs 9 and 10

Monitoring of the SRPs 9 and 10 project includes assessments channel morphology, geomorphic processes, habitat structure, predator population abundance, juvenile Chinook salmon survival, and riparian vegetation establishment (Table 34). For SRPs 9 and 10, the hypotheses (objectives) being tested for the original design are the same as for the Gravel Mining Reach described above with the addition of two hypotheses as follows:

- H10. Elimination of the pits will reduce habitat suitability for largemouth bass and will increase habitat suitability for Chinook salmon spawning and rearing (PROJECT objective).
- H11. Elimination of the pits will result in reduction of largemouth bass abundance at the project sites and an increase in Chinook salmon outmigrant survival at the project sites (PROJECT objective).

Table 33. Monitoring methods proposed for the Gravel Mining Reach Project.

Hypothesis	Metric	Method	Timing
H3, H9	Channel morphology Channel migration	• Digital terrain mapping • Permanently monumented cross sections • Longitudinal profile surveys • Low altitude aerial photographs	• Digital terrain model: Pre-project and as-built (immediately following construction) • Cross sections and profile: Pre-project and as-built. Post-project surveyed after each of two high flow eents exceeding 5,000 cfs. • Post project aerial photographs: One time following a flow > 10,000 cfs.
H1	Hydraulics	• Monitoring of water surface elevation	• During first high flow after construction that meets or exceeds design discharge[1]
H2	Bed mobility	• Tracer rocks representing D_{50} and D_{84} particle sizes at two riffles in the SRP 9 reach placed at monitoring cross sections (see H3/H9 above) • Pebble counts and bulk samples at two reconstructed riffles in each phase	• As-built pebble counts and bulk samples: As-built • Tracer rocks: Installed immediately following construction and monitored for up to three high flow events exceeding the bankfull discharge.
H5	Habitat structure and suitability	• Habitat mapping at low and high flows • Direct observation (snorkel surveys)	• Baseline: summer 1998 and 1999 • Post-project: 1 year at each site
H5	Habitat utilization	• Chinook salmon spawner surveys (CDFG) • Juvenile seining	• Spawner surveys: Conducted annually by CDFG • Seine surveys: Conducted annually by TID
H8	Riparian vegetation	• Plot-based survival, percent cover, and growth, with plots located along cross sections established for geomorphic monitoring	• Year 0 (as built) • Year 2 (end of irrigation) • Years 3 and 5 and/or following one high flow event that exceeds the bankfull discharge
	Bioengineering	• Photomonitoring stations • Permanently monumented cross sections	• As-built • Years 3 and 5 and potentially following one high flow event > 5,000 cfs.

[1] These data will be used to back-calculate Manning's rough coefficient and test the hydraulic model developed for the site. The results will be applied to improve the hydraulic model developed for the design of subsequent phases.

Table 34. Monitoring methods proposed for the SRP 9/10 Reach.

Hypothesis	Metric	Method	Timing
H3, H9	Channel morphology Channel migration	• Digital terrain mapping • Permanent monumented cross sections • Longitudinal profile surveys • Low altitude aerial photographs	• Digital terrain model: Pre-project and as-built (immediately following construction) • Cross sections and profile: Pre-project and as-built. Post-project surveyed after each of two high flow events exceeding 5,000 cfs (or if overbank flow exceeding 1,500 cfs causes fine sediment deposition). • Post project aerial photographs: One time following a flow > 10,000 cfs.
H1	Hydraulics	• Monitoring of water surface elevation	• During first high flow after construction that meets or exceeds design discharge[1]
H2	Bed mobility	• Tracer rocks representing D_{50} and D_{84} particle sizes at two riffles in the SRP 9 reach placed at monitoring cross sections (see H3/H9 above) • Pebble counts at reconstructed riffles	• As-built pebble counts (immediately following construction) • Tracer rocks installed immediately following construction and monitored after one high flow event exceeding the bankfull discharge.
H5, H10	Habitat structure and suitability	• Habitat mapping at low and high flows • Direct observation (snorkel surveys)	• Baseline: summer 1998 and 1999 • Post-project: 1 year at each site
H5, H10	Habitat utilization	• Spawner surveys (CDFG0 • Juvenile seining	• Spawner surveys: Conducted annually by CDFG • Seine surveys: Conducted annually by TID
H10	Predator abundance	• Depletion electrofishing (at project and reference sites)	• Baseline: summer 1998 and 1999 • Post-project: summer 2003 and 2004
H11	Juvenile Chinook salmon survival	• Mark-recapture at rotary screw traps[2]	• Pre-project (1998 and 1999) • Post-project monitoring abandoned[2]
H8	Riparian vegetation	• Plot-based survival, percent cover, and growth, with plots located along cross sections established for geomorphic monitoring	• Year 0 (as built) • Year 2 (end of irrigation) • Years 3 and 5 and/or following one high flow event that exceeds 5,000 cfs.

[1] These data will be used to back-calculate Manning's rough coefficient and test the hydraulic model developed for the site. The results will be applied to improve the hydraulic model developed for the SP 10 design.

[2] This monitoring was not successful. Implementation was not able to satisfy model assumptions. Results and violations of the assumptions are reported in Stillwater Sciences (1998 and 1999).

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