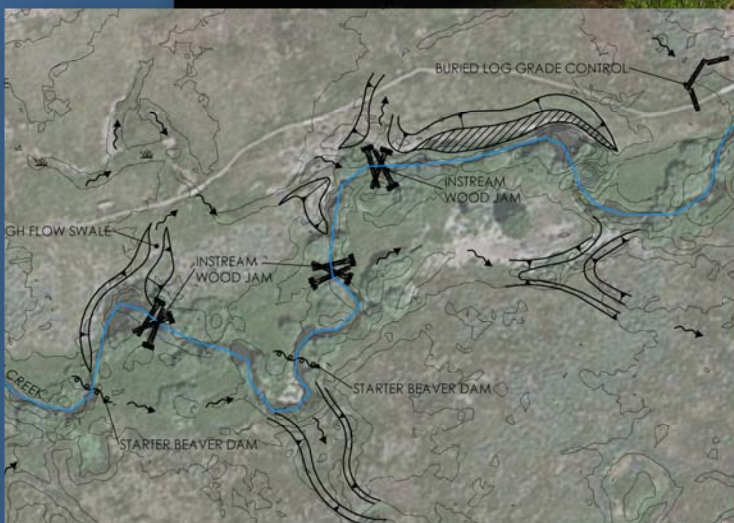

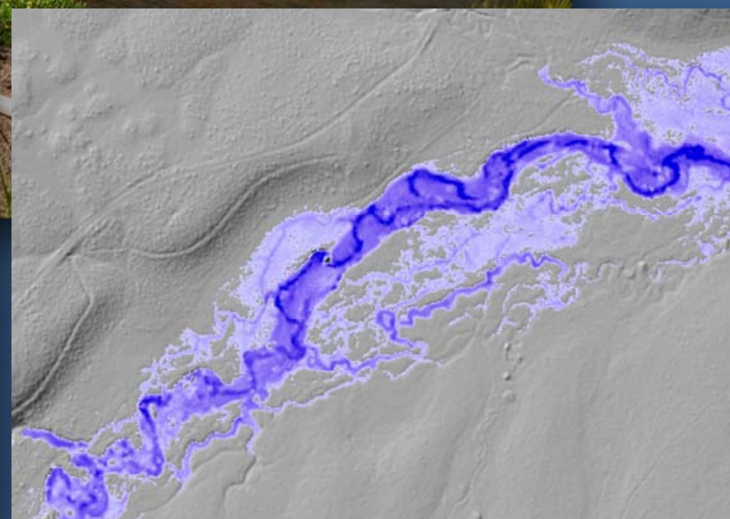

Conceptual Design and Feasibility Study

Mainstem Martis Creek

Placer County, California

Prepared for:

TruckeeRiverWatershedCouncil
Collaborative solutions to protect, enhance and restore the Truckee River Watershed

Prepared by:

Balance Hydrologics, Inc.®

August 2016

August 18, 2016

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PLATES

APPENDICES

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EXECUTIVE SUMMARY

The Truckee River Watershed Council (TRWC) is working with multiple stakeholders in the Martis Valley to implement restoration projects to improve both aquatic and upland habitats. TRWC contracted with Balance Hydrologics (Balance), Western Botanical Services and Auerbach Engineering to develop conceptual plans and evaluate the feasibility of Mainstem Martis Creek restoration. Restoration of Martis Creek supports the management goals and objectives of the landowner, the US Army Corps of Engineers.

A single landowner provides an opportunity to develop reach-scale restoration efforts. The Balance team evaluated alternatives for restoration of over 2.0 miles of stream within a montane meadow. Current and historical land-uses and disturbances resulted in cumulative impacts of Martis Creek and its adjacent montane meadow. The current condition is characterized as an incised channel with a disconnected floodplain, impaired water quality, and meadow conversion. Legacy ranching and logging activities have also influenced overland flow pathways and transportation improvements have impacted meadow habitat and confined segments of channel along levees.

The Balance team conducted a channel reconnaissance, completed channel and vegetation surveys, and evaluated channel conditions in context of historical and cumulative impacts and under the current hydrologic regime. Mainstem Martis Creek was categorized into reaches according to channel condition. Hydraulic modeling analyses were completed to evaluate degree of channel-floodplain connectivity impairment and restoration design elements were identified for each reach based on the prevailing geomorphic conditions in each reach. Restoration elements include: beaver dam analogs, instream wood jams, rip-rap removal, levee removal, meander restoration, and grading to promote inset floodplain habitat. Restoration elements were grouped into two different alternatives for further consideration and cost-benefit analysis.

Restoration of Mainstem Martis Creek will provide opportunities to restore impacts from historical land-uses and disturbances, enhance both aquatic and upland habitats, and provide educational opportunities for the public in an area that is prized as a local resource and area of outstanding beauty. Conceptual plans and feasibility of Mainstem Martis Creek is the first step of several before restoration can be implemented. Stakeholder input, permit applications, and more advanced designs will be required before implementation can occur.

1 INTRODUCTION

This report accompanies conceptual alternatives for restoration of Mainstem Martis Creek in Placer County, California (**Appendix A**). The conceptual alternatives presented herein are focused on restoring floodplain processes and wet meadow functions to the Martis Creek corridor. The purpose of this memo is to outline the project goals and objectives, provide background information, describe field studies completed, identify project constraints and opportunities, and present conceptual alternatives, design elements, and our analyses for design. The design alternatives are suitable for presentation to and discussion among the landowners and stakeholders; however, this report should always accompany the proposed conceptual alternatives when they are distributed.

1.1 Project Goals and Objectives

Based on our field work, analyses, and input from Truckee River Watershed Council and stakeholders, we present two (2) conceptual alternatives that focus on the following goals and objectives:

Goals

1. Protect functioning channel, wet meadow, and associated habitats;
2. Restore wet meadow hydrologic connectivity in degraded areas;
3. Restore floodplain functions in degraded areas including:
    a. overbank flows,
    b. sedimentation,
    c. shallow groundwater recharge, and
    d. peak flow attenuation;
4. Enhance existing and impaired aquatic and wet meadow habitats; and
5. Enhance wetland vegetation (diversity, vigor, cover).

Objectives

a. Define or delineate areas for protection;
b. Remove or modify historical features or watershed disturbances that have altered natural streamflow patterns (e.g., levees, irrigation ditches and diversion structures);

c. Increase frequency of overbank flows in previously abandoned wet meadow surfaces and swales using geomorphically-appropriate in-channel features (e.g., instream wood, analog beaver dams) to elevate water surfaces;

d. Re-establish functioning floodplains and meadow habitats using minor grading for inset floodplain creation with proper biotechnical methodologies (only in areas that are incised from the wet meadow surface more than 3 feet); and

e. Enhance aquatic and meadow habitat by encouraging beaver activities and revegetation efforts.

1.2 Acknowledgements

The work and information presented in this report draws on information and efforts provided by a number of key individuals or stakeholders including: Doug Grothe, Jacqueline Zink, and Taylor Johnson (USACE), Jerusha Hall (Northstar), Mike Staudenmeyer (Northstar Community Services District), and Jeff Cobain (Lahontan Community Association).

1.3 Available Data and Reports Reviewed

The following pertinent data, reports, and/or information were reviewed for this project:

- USACE Master Plan and Update for Martis Creek Lake Dam (2014)
- Light detection and ranging (LiDAR) imagery (2006 and 2013)
- Martis Watershed Assessment (Shaw and others, 2012)
- Historical aerial photographs (1939, 1952, 1966, 1987, 1992, 2005, and 2011)
- Historical maps (1889, 1895, 1940)
- Streamflow gaging station records for WY 2013- partial WY 2016 (CDM and Balance, 2013, 2014, 2015 and 2016; unpublished data)

1.4 Completed Field Studies

Balance, with assistance from Western Botanical Services (WBS), has completed the following field studies for this project:

- Channel reconnaissance (August 2015, September 2015, and February 2016)
- Channel thalweg and cross-section surveys (September 2015)
- Prior assessment, field work and reconnaissance completed as part of Martis Watershed Assessment (Shaw and others, 2012)

2 PHYSICAL SETTING

Martis Creek is located in the Sierra Nevada Geomorphic Province, east of the Sierra Nevada crest, and is a regulated tributary to the Truckee River. Martis Creek drains a 42.7 square mile watershed with elevations between 8,617 feet in the headwaters down to 5,680 feet at the confluence with the Truckee River. The project area lies within the Martis Valley and includes the mainstem of Martis Creek between the operating pool elevation of Martis Creek Dam (5,810 ft elevation) upstream to the property boundary of Lahontan Golf Club and Community (5,858 ft elevation), **Figure 2-1**.

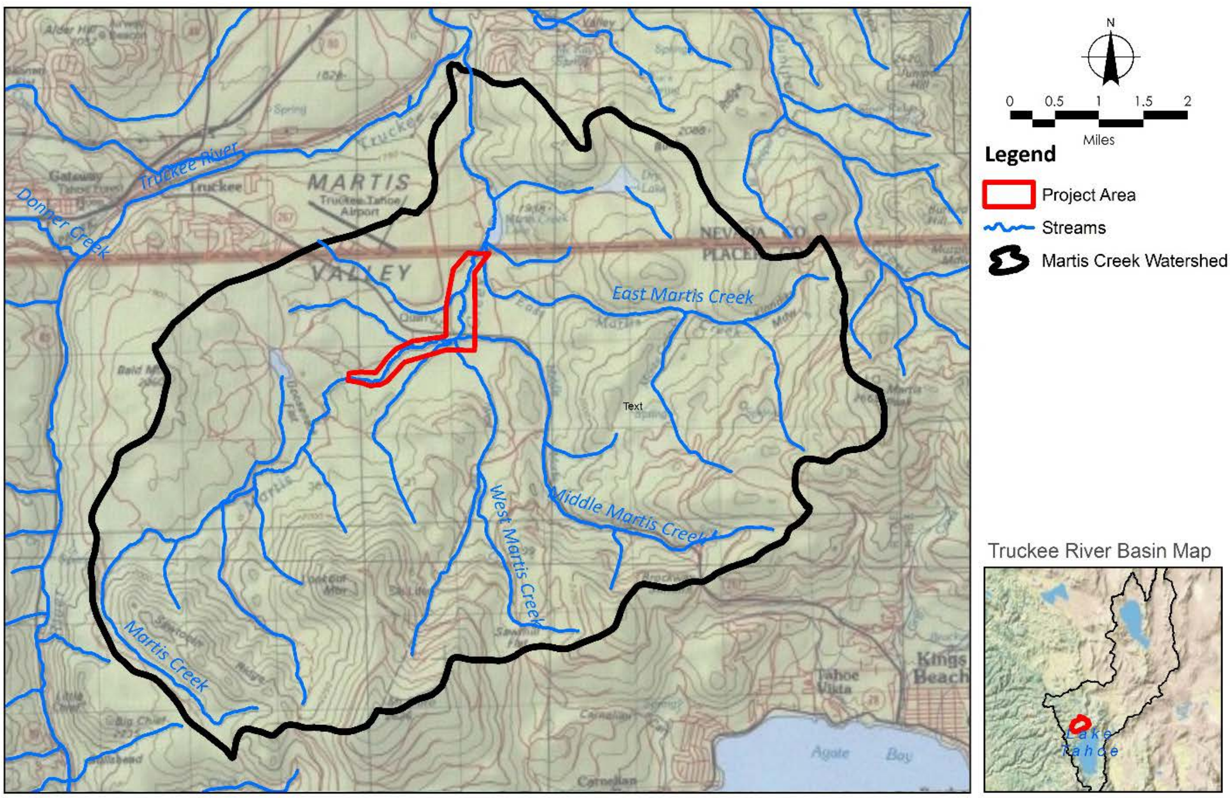

Figure 2-1 Martis Creek Watershed and Project Area, Placer County, California.

2.1 Hydrology

Mean annual precipitation in the Martis Creek Watershed ranges between 30 to 45 inches, depending on elevation with most precipitation falling as snow between the months of October and April. Martis Creek is a snowmelt-dominated, perennial system; however, annual peak flows over the last four consecutive years have been the result of a rain-on-snow event. Annual floods typically occur between March and June, coincident with peak snowmelt runoff with short-lived peak flows generated by summer thunderstorms or during winter months as observed in recent years (CDM Smith and Balance Hydrologics, 2015).

Continuous streamflow and water quality on Martis Creek has been measured since water year 2014[1] (CDM Smith and Balance Hydrologics, 2014, 2015, unpublished data, 2016). Daily streamflow over this period is shown in **Figure 2-2** and illustrates the range of streamflow during both dry years (WY2013, WY2014 and WY2015) and an average precipitation year (WY2016). Daily mean flows for Martis Creek at this station ranged between 0.5 cfs to 120 cfs. The peak flow of 183 cfs for the period of record occurred on March 6, 2016.

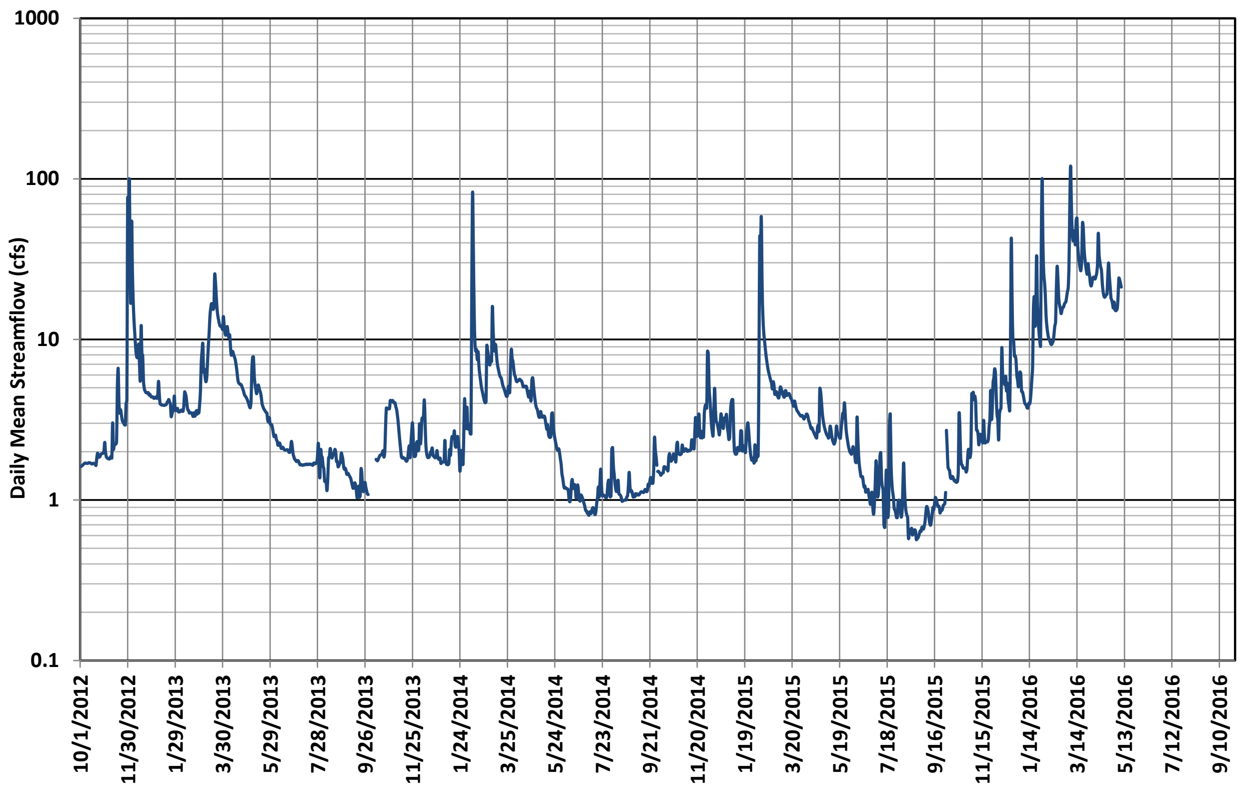

Figure 2-2 Daily Mean Streamflow, Mainstem Martis Creek Upstream of West Martis Creek, Water Year 2013 – Partial Water Year 2016.

2.2 Geomorphology

A general geomorphic map of the Martis Creek project area is provided in **Plate 1**. The Martis Creek Watershed lies east of the Sierra Nevada Crest in a transitional zone

[1] Water year refers to the period measured from October 1 to September 30 of the named water year; water year 2014 began on October 1, 2013 and ended September 30, 2014.

between the Sierra Nevada Geomorphic Province and the adjacent Basin and Range Geomorphic Province. This zone is characterized by tectonic uplift, faulting, early and more recent volcanism, and glaciation; all of which have influenced drainage patterns, landforms, and interactions between surface water and groundwater.

Uplift along active north-south trending faults initially created much of the topography seen today in the Martis Creek Watershed (Birkeland, 1963). Subsequently, Pleistocene volcanic flows formed some of the adjacent terrain and accumulated with interbedded fluvial sediments to raise the existing land surface. One of the last flows blocked the Truckee River below Martis Creek and accelerated the deposition of boulders, cobbles, gravels, sands and silts, known today as the Prosser Creek alluvium (QTtpc of Birkeland, 1963, Sylvester and others, 2012).

More recently, glaciations of the eastern Sierra Nevada, roughly 130,000 years before present (BP) to 70,000 years BP, generated thick outwash deposits (Qdo, Qtao of Birkeland, 1961) at the confluence of Martis Creek and the Truckee River further constricting and forming the Martis Valley. A small alpine glacier eroded the upper West Martis Creek drainage and provided additional sources of fine sediment and flow to the Martis Valley and Basin.

Together these geologic processes created a low-gradient, montane valley (Martis Valley) which today supports a wet-montane meadow, perennial stream system, and an important groundwater aquifer. A profile of Martis Creek and location of the project reach is illustrated in **Figure 2-3**.

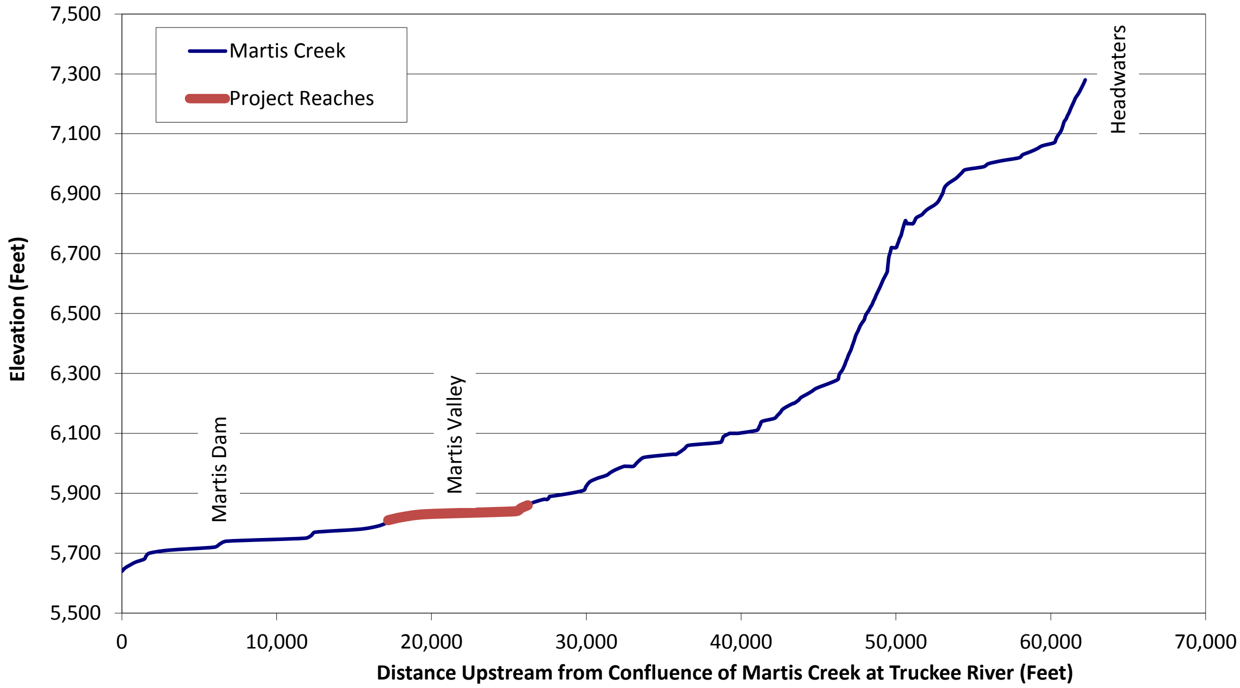

Figure 2-3 **Martis Creek Channel Profile.** Project reaches through the Martis Valley are highlighted and indicate a low-gradient channel relative to other reaches.

Mainstem Martis Creek and its tributaries originate in steep, forested canyon and open into gentle sloping Martis Valley. At this slope transition, Martis Creek and its tributaries have formed a series of overlapping and interfingering alluvial fans, defined as older alluvium (Qoa; see Plate 1). More recently, Martis Creek and its tributaries have dissected the older alluvium and formed narrow inset corridors of recent alluvium (Qa) where recent sediment has been deposited by active fluvial or stream processes. Today, Martis Creek corridor is confined between these older alluvial deposits, volcanic bedrock (QTtbm), Prosser Creek alluvium (QTtpc), and boulder-dominated glacial outwash (Qdo), all more resistant to erosion. It is within the recent alluvium corridor that channel and floodplain processes are active and are the focus of this restoration effort.

Inundation mapping presented in **Figure 2-4** highlights the multiple channel system that has formed within the recent alluvial corridor, as well as the area subject to inundation by very high flows. Historical aerial photographs and field observations provide additional evidence that Mainstem Martis Creek historically maintained many primary and secondary channels, typical of many undisturbed meadow systems found in the Sierra Nevada. Fine sediment deposited within this corridor can support wetland and meadow vegetation, particularly sedges and rushes, with cohesive root networks. As these soils dry and vegetation is converted, these fine-grained soils become more susceptible to erosion and bank failure.

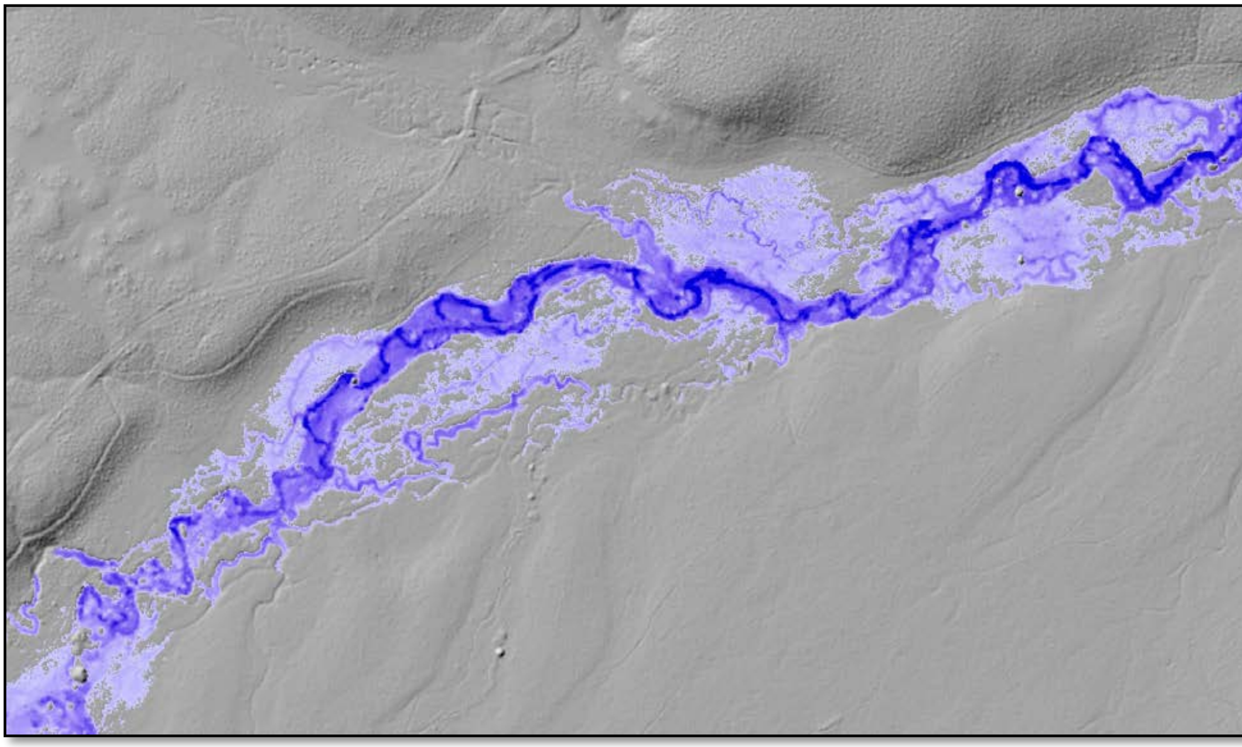

Figure 2-4 Existing Channel Patterns for a Reach of Mainstem Martis Creek. Modeled streamflow using topographic data is shown to highlight multiple channels and define an existing and potential channel corridor.

3 ANALYSIS AND ASSESSMENT

3.1 Current Conditions

The analysis presented herein draws upon the assessment of existing or current conditions in the Martis Creek Watershed as detailed in the Martis Creek Watershed Assessment (Shaw and others, 2012) and is augmented by a detailed stream reconnaissance and additional analyses completed as part of this feasibility study. A map summarizing current and historical features within the project area is provided in **Plate 2**. Photo-documentation of current conditions with captions are provided in **Appendix B**. In this section we highlight both functional and impaired areas.

3.1.1 Channel Geomorphology

In an effort to better characterize the current condition of Mainstem Martis Creek and identify appropriate restoration approaches, we conducted the following geomorphic and hydraulic analyses, described in more detail below:

A. Measured existing channel geometry and characterized vegetation changes; and

B. Using field observations, identified stage of channel evolution based on Schumm and others (1986).

Mainstem Martis Creek exhibits impaired channel functions. In many reaches within the project area we observed recent channel down-cutting or incision of more than 4 to 5 feet below the meadow surface (**Figure 3-1**). As a result, frequent floods are confined within a narrow active channel, disconnected from adjacent floodplains and meadow surfaces. Incised channels also appear to have lowered the adjacent groundwater table and vegetation communities in these areas appear to have converted to more dry upland species, with loss of wetland and meadow habitats. Furthermore, where tributaries and swales enter an incised Martis Creek, large headcuts have formed, threatening additional functioning meadow habitat.

Lower reaches of Martis Creek (reaches 5 and 6, see Plate 1) have undergone straightening, bank hardening, and levee construction (**Figure 3-2**).

Figure 3-1 Martis Creek. Current conditions in some reaches exhibit an incised channel with disconnected floodplains.

Figure 3-2 Martis Creek, Downstream of Highway 267. Channel has been straightened with construction of levees along the left bank.

Balance staff conducted a geomorphic investigation of the Mainstem Martis channel to assess the evolution and extent of channel degradation observed in aerial photographs and in the field. Balance staff walked the entire length of the project area during a range of flow conditions to identify and map segments that exhibit active downcutting (i.e., knickpoints in bed erosion) and/or widening (i.e., actively eroding banks). We then compared these conditions to well-documented and supported paradigm of a channel evolution model (CEM) in alluvial systems (Schumm and others, 1984; Simon and Rinaldi, 2006) in response to disturbances (**Figure 3-3**).

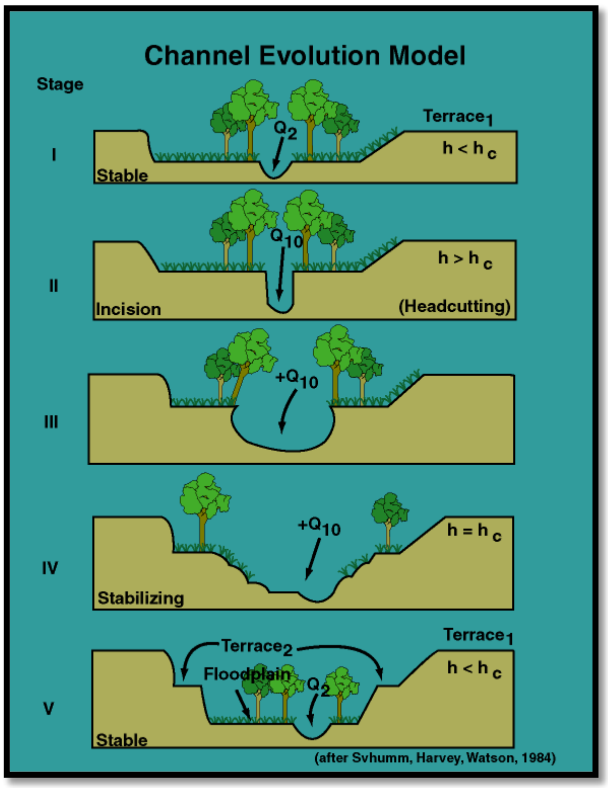

Figure 3-3 Theoretical Channel Evolution Model for Alluvial Systems. Stages of channel evolution are observed in Martis Creek and can be used to evaluate restoration principles.

Based on the CEM presented in Figure 3-3, channel changes can be viewed in both a temporal and spatial context. First, the temporal viewpoint is best ascribed to channel incision initiated by watershed changes or disturbance that affect hydrology or sediment transport processes, in which a new equilibrium may take decades or even centuries to achieve (Fischenich and Morrow, 2000), but follow 5 basic stages of evolution. Typically, rehabilitation of floodplains and habitat should be evaluated with caution if channel conditions are characteristic of Stage II. It is highly recommended to wait until the channel has progressed into subsequent stages since an actively incising channel may cause some restoration elements to fail or success criteria not to be met. Spatially, stages of degradation can migrate up the watershed. Ultimately, incising channels can create a disconnect between active flow in the channel and its connectivity with its floodplain or meadow surfaces leading to meadow habitat loss or deterioration.

Measurement of channel geometry allowed us to characterize each reach to better evaluate stage of CEM and effort required to rewet former meadow surfaces (**Table 3-1**). We did not identify any reaches that are actively incising (Stage II of CEM). Most reaches were characterized as Stage III (widening), Stage IV (deposition), and Stage V (restabilization; new inset floodplain). From Table 3-1 we identified opportunities in Reaches 3 and 4 where small increases (e.g., 2 feet) in water surface elevations may provide the most benefit for increased wetting of meadow surfaces.

Table 3-1 Channel Geometry and Channel Evolution Stage, Mainstem Martis Creek.

Reach	Slope	Bankfull Depth	*Active Channel* Depth	*Active Channel* Width	Floodplain Width	Depth from Meadow or Floodplain Surface	Increase in Bankfull WSE required to rewet meadow surface	CEM Stage
	(ft/ft)	*(ft)*	*(ft)*	*(ft)*	*(ft)*	*(ft)*	*(ft)*	*(I, II, III, IV, V)*
1	0.007	2	3	25	50	5	**3**	III, IV
		1.75	2.5	25	50	5.5	**3.75**	
2	0.006	2	3	8	45	4.5	**2.5**	uncertain; beaver activity
3	0.005	2	2.5	10	55	4	**2**	III, IV
		1.5	2.5	9	25	2.5	**1**	
4	0.004	1.75	2.75	20	60	4.25	**2.5**	IV, V
		1.5	2	10	50	3.5	**2**	
		1.5	2.5	12	20	3.75	**2.25**	
5	0.003	1.5	4	10	25	5.5	**4**	III, IV, V (modified)
		1.5	2	14	30	4.5	**3**	
6	0.006	1.5	1.5	15	35	5	**3.5**	III, IV
		1.75	2.5	20	80	5	**3.25**	

Note: "bankfull" is defined here by: a) observed break in slope, b) change in vegetation, c) absence/presence of vegetation, and d) observation of frequent flow depths
See Figure 3-2 for a description of CEM stages.

3.1.2 HYDROLOGY AND HYDRAULICS

In this section, we describe our analyses and basis for streamflow used for design purposes. Field-collected data (i.e., topography and observation of high-water marks) were used to develop a hydraulic model of the project area. The hydraulic model was then used to simulate effects of existing flows and identify increases in water surfaces required for beneficial restoration approaches.

In the absence of a long-term streamflow record for Martis Creek, we used existing hydrologic data (Interflow, 2003, CDM and Balance Hydrologics, 2014, 2015, and 2016, unpublished data 2016), unit-discharge calculations from a nearby, long-term streamflow gage with similar geology, precipitation, and land-uses (USGS, 10343500, Sagehen Creek near Truckee, CA), USGS Streamstats, and field observations of recent flows to evaluate the range of frequent floods and select a flood appropriate for conceptual planning purposes (**Table 3-2**). For instance, during a regional peak flow event on February 6, 2015 (85 cfs) Balance hydrologists observed flows in Mainstem Martis Creek spilling onto an active floodplain surface. A flood-frequency analysis was completed for the peak flow of the same event measured at Sagehen Creek (USGS 10343500; 31 cfs) using the USGS Bulletin 17B guidelines (US Interagency Advisory Committee on Water Data, 1982). Results suggested that the February 6, 2015 peak flow was approximated to be an annual event and an adequate flow to be used for evaluating current channel conditions to identify impairment. We completed a similar analysis for a peak flow measured to be 130 cfs in Mainstem Martis Creek on June 11, 2014 to identify a less frequent event to bracket our annual flow (see Table 3-2).

Table 3-2 Range of Streamflow Measured and/or Modeled in Martis Creek.

Date	Martis Creek above West Martis Creek		Estimated Flood Recurrence Interval	Comments/Basis
	(cfs)		*(years)*	
Baseflow	3	Measured	n/a	Interflow (2003); unpublished data (2016)
March 21, 2016	60	Measured	<1	frequent flow during snowmelt runoff (unpublished data, 2016)
February 6, 2015	85	Measured	annual (0.5 - 1.5)	Exceeded 7 times in past 4 consecutive years (CDM Smith and Balance, 2014, 2015, 2016, unpublished data 2016); peak flow for same event, Sagehen Creek (31 cfs) calculated to be an annual event based on a 61 year period of record
n/a	197	Predicted	2	USGS Streamstats, v. 4.0 (Gotvald and others, 2012; http://ssdev.cr.usgs.gov/streamstats/)
June 14, 2011	~330	Estimated	2-5	Peak snowmelt runoff, sustained overbank flows, wet year (Google Earth Imagery, 2014; CDM Smith and Balance, 2015); same event for Sagehen Creek (137 cfs) calculated 2 to 5 yr recurrence interval

We developed a hydraulic model [(HEC-RAS software; version 4.1) along with its geospatial extension for ArcGIS, HEC-GeoRAS (version 10.1)] using topographic data from LiDAR (USFS, 2013) and channel surveys to identify reaches where flood flows are confined, and verified the model based on conditions measured and observed in the field (**Plate 3**). Model results illustrated in Plate 3 show that 85 cfs, an estimated annual flood, is confined to the existing channel with limited floodplain connectivity.

3.1.3 Groundwater Conditions

A review of false-color infrared aerial photography shows that Mainstem Martis Creek receives hydrologic support from springs or groundwater in Martis Valley (**Figure 3-4**). Lookout Meadow, southwest of the project area, is one area of concentrated springs that provides year-round hydrologic support to a large area of wet meadow in Martis Valley in most years and supports baseflow in Martis Creek. Other springs have been identified along the valley edge and adjacent to West Martis Creek, as shown in Plate 1. Efforts to protect these areas should be prioritized.

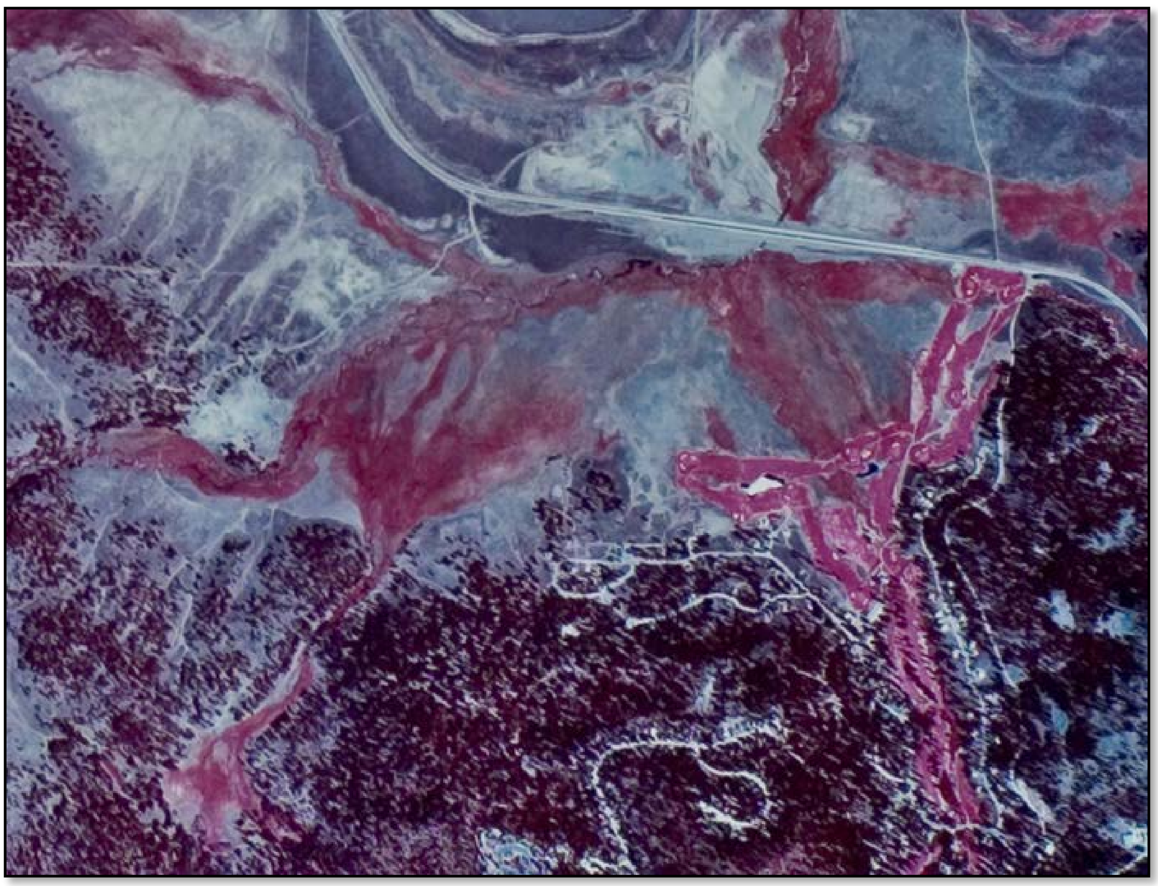

Figure 3-4 False Color-Infrared Aerial Imagery of Martis Valley Including the Project Area. Red colors indicate healthy vegetation or strong hydrologic support from natural spring sources ('Look-out Meadow', lower left). Known groundwater mounds or springs are identified by white circles.

3.1.4 Beaver

An existing colony of beavers remains active in Martis Valley. Approximately 10 beaver dams were identified within the project area (see Plate 2). While the number of beavers is unknown, their activities and ability to alter the physical processes of Martis Creek are resulting in positive outcomes. Beaver dams elevate water surfaces 2 to 3 feet in some areas and encouraging reconnection of high-flow swales and floodplains (**Figure 3-5**). Channel reaches where multiple beaver dams exist appear to be improving channel functions and habitat.

The potential benefits of beaver activity in restoring meadow, stream and floodplain environments are well documented (Pollock and others, 2012, Pollock and others, 2014, Castro and others, 2015). We encourage using beavers for restoration benefits and provide mitigation strategies in **Appendix C** that can be used to minimize potential conflicts with humans and human activities.

Figure 3-5 Active Beaver Dam, Martis Creek.

3.1.5 Instream Wood

Instream wood recruitment and transport (**Figure 3-6**) functions support depositional processes, promote overbank flows, and provide instream habitat in reaches immediately downstream from the forested canyon or adjacent to mature woody vegetation (reaches 1 through 3, see Plate 1). Wood placement could effectively be used as restoration elements within these reaches.

Figure 3-6 Instream Wood Jam, Martis Creek.

3.1.6 Vegetation

In September 2015, Western Botanical Services completed a reconnaissance level survey and identified dominant vegetation communities of the project area. Vegetation within the project area generally corresponds to the following three, broad community types: 1) wetland herbaceous, 2) riparian woody, and 3) upland.

The wetland herbaceous community is dominated by graminoids, particularly *Juncus balticus* (Baltic rush, a FACW species in California); *Carex nebrascensis* (Nebraska sedge, an obligate wetland species in California); and *C. utriculata* (beaked sedge, an obligate wetland species in California). Species in this community type are sorted by hydrology: Baltic rush occurs on drier sites, Nebraska sedge in wetter areas, and beaked sedge in the wettest conditions. Stands of these species occur adjacent to the creek, as well as in disconnected channels. The stands in disconnected channels are generally less vigorous.

In drier soils on the edge of the wetland herbaceous community the following species were identified *Leymus triticoides* (beardless wildrye), *Arnica chamissonis* (Chamisso arnica), *Symphyotrichum spathulatum* var *yosemitanum* (Western aster), Lupinus polyphyllus (Tahoe lupine), *Sidalcea oregana* (Oregon checkerboom), *Potentilla gracills* (slender cinqufoil), *Poa pratensis* (Kentucky bluegrass), *Deschampsia cespitosa* (hairgrass), and *Achnatherum lettermanii* (Letterman's neddlegrass). Also present are the non-natives *Agrostis stolonifera* (creeping bentgrass) and *Alopecurus pratensis* (meadow foxtail), most likely remnants of grazing.

The riparian woody community is dominated by *Salix geyeriana* (Geyer's willow) and *Salix lemonnii* (Lemmon's willow) in even-aged stands with little recruitment of younger material.

The upland plant community is dominated by *Artemisia tridentata ssp. vaseyana* (Mtn. big sagebrush), and *Ericameria nauseosa* (rubber rabbitbrush), along with the nitrogen fixing forb *Lupinus lepidus* (Pacific lupine). Diversity in this community, when surveyed on September 1, 2015 appeared low, although growing conditions in 2015 were unusually dry.

3.2 Hydrogeomorphic Mapping

We classified the existing meadow according to the Hydrogeomorphic Method (HGM) developed by Weixleman and others (2011). The HGM approach uses hydrology, vegetation, and geomorphic characteristics to characterize meadow types along the Mainstem Martis Creek corridor (**Plate 4**), and provides a framework for characterizing the existing condition and function of mapped meadow types. Secondarily, it was used to help link meadow condition to restoration opportunities. For example, field observations indicate areas classified as 'dry meadow' have been converted by channel degradation as evidenced by both wetland species and dry upland species in these areas. Restoration opportunities to rewet these areas and revert the system back to a 'riparian low-gradient meadow' may exist. These meadow types are further described below as mapped in Plate 4.

- A <u>riparian low-gradient meadow</u> defines the Mainstem Martis Creek corridor, and ranges between 200 and 400 feet wide. This area is characterized by a perennial stream with less than 2 percent slope, pool-riffle morphology, and a developed floodplain. This area, which includes the wetland herbaceous community and the riparian woody community described earlier.
- Areas characterized as <u>dry meadow</u> have been mapped near or adjacent to the active channel. This dry meadow is roughly described as a transitional community between the wetland herbaceous and upland plant communities. While a dry meadow is a functioning meadow type, locations where it is mapped along the alluvial corridor of Martis Creek suggest that recent meadow conversion has taken place, likely a result of the incised condition of the adjacent channel. Encouraging overbank flows and shallower groundwater conditions in adjacent dry meadow areas is anticipated to reverse meadow conversion and restore dry meadow to a riparian low-gradient meadow type.
- <u>Discharge slope meadow</u> areas should be protected so they can continue to function as a source for baseflows in Mainstem Martis Creek. Efforts to force overbank flows from Martis Creek to these areas are not anticipated to be feasible or successful.

3.3 Sources of Degradation: Historical Land-Uses and Disturbance

Current and historical land-uses and disturbances likely played a dominant role in modifications to Martis Creek and its adjacent meadow (see Plate 2). The Martis Watershed Assessment (Shaw and others, 2012) describes historical land-uses and disturbances in greater detail. For the purposes of this report, we briefly summarize some of the notable events that may have generated changes specific to Mainstem Martis Creek.

3.3.1 Logging

From the 1850s through the 1920s, timber harvesting and transport methods resulted in a complete change and composition of modern forests and altered stream channels and water quality (Wilson, 1992). In Martis Valley, several large sawmills were operated with active upstream dams with diversions used to transport cut timber from the upper watershed to the mills located in the valley (Lindstrom, 2012). Flumes and other timber transport operations dissected meadows and changed drainage patterns where shown on Plate 2. Additional haul and skids roads in the upper watershed were likely significant sources of sediment. Today, these features remain on the landscape and contribute to alteration of flow pathways and sediment supply.

3.3.2 Ranching

The perennial waters of Martis Creek and lush adjacent meadows supported a livestock industry including both sheep and cattle. Overgrazing activities are well-documented (Shaw and others, 2011), and the remnants of multiple dams and diversions for irrigation are still visible today. Historical accounts of floods washing out these small irrigation dams likely generated points of instability (i.e., knickpoint or headcut erosion) in the creek. Grazing also likely contributed to changes in vegetation including introduction of non-native plant species.

3.3.3 Roads

Historically, Brockway Road (Highway 267) included multiple fords for crossing Martis Creek. Improvements in the 1950s and 1960s straightened segments of the channel, confined the channel corridor along constructed levees, excavated meadows for material used to build a causeway, while the construction of the causeway filled other portions of the meadow. Highway 267 also parallels Middle Martis Creek, a tributary to Martis Creek, and is the source of excess runoff and sediment from impervious surface drainage and road sand applications.

3.3.4 Martis Lake Dam and Operations

The construction of Martis Creek Lake Dam in 1972 has generated more recent impacts to Martis Creek and its environs. Impoundment of flood waters over the last several decades has inundated the creek and meadow areas for extended periods of time. Inundation and a changing base level directly affects sedimentation patterns, vegetation, and habitat. It is possible that periods of channel incision originated from fluctuating base levels or cumulative impacts from the reservoir and other disturbances briefly describe above.

3.3.5 Groundwater Management

The meadows surrounding Martis Creek are supported by both surface water and groundwater. This study identified the many springs feeding meadow and stream habitat in Martis Valley. Interflow Hydrology (2003) identified Martis Creek as a 'gaining' stream or receiving groundwater discharge. Deep groundwater is extracted by several entities in the area, from several water-bearing zones with varying degrees of connectivity between those zones (Bauer and others (2013). Groundwater levels within the vicinity of Martis Creek were relatively steady between 1990 and 2007, but began to decline after 2007. It is not clear to what degree this decline is attributable to groundwater pumping versus below-average precipitation over the last decade. Trustman and Hastings (2016) documented cessation of streamflow in Middle Martis Creek during the drier months of the last few years, but mainstem Martis Creek has recorded flow perennially even during drought periods.

3.3.6 Climate Change

While we do not have evidence to suggest climate change is currently impacting or impairing Martis Creek and its habitats, models in the region (Coats and others, 2010 and 2013) suggest that climate change could be or will be deleterious to stream and meadow functions and habitat. Reduced snowpack, earlier and shorter runoff periods and flashy hydrology from increased rain-on-snow events all translate into less water for meadow habitats and reductions in groundwater recharge. In fact, CDM and Balance Hydrologics (2016, preliminary data) have shown that peak annual flow in the past 4 consecutive years has been the result of rain-on-snow events and not snowmelt runoff. Efforts to retain the water in the creek or disperse over a floodplain or meadow surface will provide resiliency of habitat and minimize the potential consequences of climate change.

Complex, cumulative effects are occurring from legacy logging, road building, ranching, reservoir base-level changes, groundwater withdrawals, drought and climate change. In the absence of identifying any one cause, we find it more effective to understand the processes that are impaired and find solutions to restoring or ameliorating those impairments to support habitat. **Table 3-3** summarizes the links between existing conditions, impairments and restoration objectives for Martis Creek.

Table 3-3 Summary Linking Existing Conditions, Impairments and Restoration Objectives, Mainstem Martis Creek.

	Existing Condition	Effect(s) on Channel Form, Water Quality or Habitat	Source(s) of Degradation	Restoration Objective(s)
Groundwater	Declining water table	Channel incision, meadow conversion, erosion	Groundwater management, drought, channel incision	Increase frequency of overbank flows, increase WSE, re-establish floodplain functions
Beaver	Active colony in some reaches	Positive, natural restoration	--	Protect and work with existing population
Instream Wood	Limited recruitement and transport	Less wood for habitat; opportunity for enhancement	--	Increase instream wood, use strategically to enhance overbank flow
Channel Geometry	Mostly incised	Disconnected floodplains, bank erosion, meadow conversion	Logging, ranching, groundwater management, roads, Martis Lake Dam operations	Remove historical features or watershed disturbances; elevate water surfaces and encourage aggradation of channel; re-establish floodplain functions
Vegetation	Conversion from hydric species to upland species; homogenous community	Loss of habitat, increased erosion	channel incision, groundwater management, drought, non-natives	Enhance habitat by restoring channel functions and revegetation w/ natives

4 DESIGN APPROACH

Restoration activities for the Mainstem Martis Creek have the benefit of land available for restoration with low risks. As displayed in **Figure 4-1,** these factors provide the opportunity to restore or rejuvenate geomorphic processes.

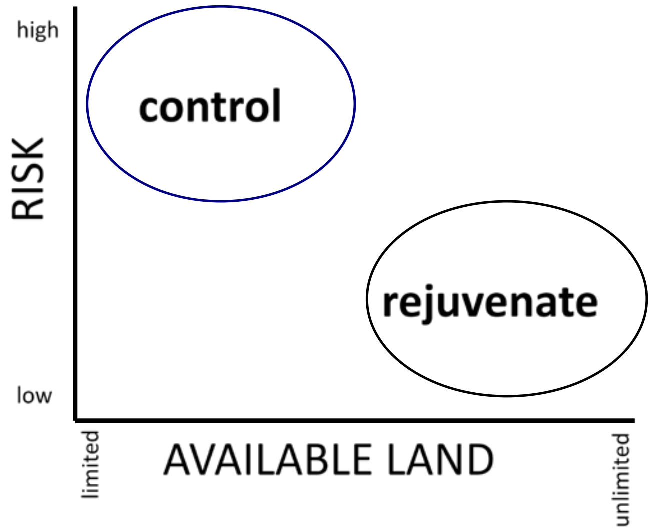

Figure 4-1 Conceptual Schematic of Geomorphic Design Approach.

The above concept helps to only identify the initial design approach. Therefore, we find it useful to further identify project constraints and opportunities to help guide restoration elements and feasibility.

4.1 Design Constraints

Identification of site-specific constraints is a critical step to help establish restoration feasibility and a basis for design. Based on available background information described above and site reconnaissance visits carried out between the Summer of 2015 and Spring of 2016, we identified the following site constraints. Our proposed alternatives attempt to incorporate design elements to address, mitigate for, minimize or outright avoid these constraints.

<u>Martis Lake Dam Operations</u>

Martis Creek Lake Dam is not currently operated as a flood-storage facility, but does provide some flood control benefits under its current operations. Under both the current scenario as well as in potential future configurations, much of the project area could be inundated under impounded waters in a low-frequency, high-magnitude flood. Plate 2 shows the current operating pool elevation and potential inundation area that would result from a large magnitude flood. As such, restoration design elements need to consider the risk for buoyancy (e.g., instream wood) and/or effects of inundation which may promote rapid channel incision and/or floodplain sedimentation.

Geomorphology

The watershed above the project site is confined by steep topography and offers limited storage for excessive sediment that may originate from excess runoff and erosion or debris flows resulting from a severe wildfire. If such an event were to occur, it could directly alter the future channel morphology/patterns and hydrology in the project area or render design elements nonfunctional.

Infrastructure

Box culverts under Highway 267 established a fixed bed elevation or grade control. It does not allow for natural adjustments in channel bed elevations in response to changes in streamflow and/or sediment supply. In addition, restoration design elements need to maintain flood conveyance under Highway 267.

Archeologic Resources (Prehistoric and historic)

The project area is close proximity to several prehistoric (Native American) areas, and includes remnant historic features. Restoration activities should avoid prehistoric areas, and restoration objectives explicitly call for modification of historic features to improve ecological functions (i.e., filling of irrigation ditches, removal of diversion structures). Detailed mapping of these features will require further evaluation, beyond the scope of this study.

Access

Segments of the project area will require temporary access for equipment to place design elements or execute grading. Temporary access should use existing access roads as much as possible and meadow access will require low-impact methods to be used with revegetation strategies applied upon equipment removal. As part of this strategy, grading in wetland areas, although generally optimum during the driest part of the season, should allow enough time for re-establishment of vegetation during the growing season. This is essential to prevent erosion and site failures during spring run-off.

4.2 Design Opportunities

Similar to design constraints, we find it helpful to identify site opportunities where design elements may serve multiple objectives or facilitate restoration of stream and meadow functions. Based on our assessment, we have identified the following opportunities:

<u>Adequate Open Space</u>

The project area is primarily located on open space managed by the USACE. Most of the project area and adjacent lands contain little in the way of infrastructure or private property.

<u>Cut/Fill Quantities, Re-Use and Disposal</u>

It is highly desirable to balance cut and fill materials such that off-site hauling of excess materials can be avoided or minimized. Historical features, such as old irrigation ditches, could potentially be candidates for re-use in an effort to restore local topography and overland flow pathways and minimize off-haul and disposal. Former quarry pits could also provide a location for placement and rehabilitation of excess soil cut and re-establishment of vegetation on what is currently marginally vegetated and disturbed lands.

If inorganic subsoils are used as backfill in restoration, soil testing will be required to evaluate the suitability of soils for revegetation.

<u>Proximity to Materials or Reuse Needed for Construction</u>

Abundant willow stands within the project area allow for dispersed collection of willow for construction of beaver dam analogs or willow post plantings for areas identified for grading and replanting. Furthermore, conifers encroaching on the meadow can be removed and used as instream wood jams and also serve to reverse meadow conversion.

Willows can be used in a great variety of biotechnical applications, depending on age, size, and vigor. Such methods are likely to include willow wattles (fascines), poles, layering, and fencing. Brush mattresses can be considered in areas with permanently moist soils, including the slopes on which they are installed.

Wetland sod can be salvaged from areas selected for grading and re-used, especially in an inset floodplain. Other excavated materials that are unconsolidated may be re-used as an organic material backfill and growth media.

4.3 Design Options and Analysis

The rehabilitation of an incised or incising channel can include one of three options:

1. Allow the channel to establish a new equilibrium condition on its own (i.e., an inset floodplain);
2. Accelerate the process characterized by the CEM and assist the channel in reaching a new equilibrium (preferred after stage II); and/or
3. Restore the hydraulic grade of the system to re-establish the hydrologic connection to its historical floodplain.

Options 1 and 2 will result in the re-establishment of floodplains, but inset within the degraded or enlarged channel and historical floodplain or meadow. Option 1 can take years and possibly decades to achieve and may not address the source of degradation. Creation of Inset floodplains (Option 2) provides many functions of the historic floodplain (which becomes a terrace), but often at diminished levels. Option 3 can restore the hydrologic interactions between the stream and floodplain over a longer continuum, but often fails to restore the physical and hydraulic conditions within the channel (Fischenich and Morrow, 2000). For example, instream wood jams or beaver dam analogs used for increasing the hydraulic grade will result in more ponded or backwatered conditions, potentially inundating pool-riffle sequences. However, over time, the channel may evolve under Option 3 to re-establish natural channel morphology.

In an attempt to synthesize an increase in water surface elevations or the hydraulic grade (Option 3) that might be achieved using restoration elements (e.g., beaver dam analogs, instream wood jams, etc.), our hydraulic model was run with both 1.0 foot and 2.0 foot WSE increases (**Plate 5**). This analysis highlighted opportunities and benefits for restoring floodplain/meadow connectivity by introducing in-channel features to raise the hydraulic grade (Reaches 3, 4, and 6), and also highlighted reaches that may require grading to establish an inset floodplain (Reaches 1 and 5).

Rewetting meadow surfaces more frequently will also provide increases in shallow groundwater recharge and, in turn, benefit vegetation. Given wetter conditions, dry meadow may revert to low-gradient riparian meadow. In Plate 5, we show potential surface water enhancements relative to areas mapped as dry meadow to better realize these benefits.

Selection of one option or a combination of options may restore many of the functions that are lacking under the current channel condition in Mainstem Martis Creek.

4.4 Design Alternatives

Two conceptual design alternatives have been developed to meet the project goals, objectives, and design criteria outlined above. These alternatives also consider project area constraints and opportunities, and use information gained from evaluation of channel evolution and hydrogeomorphic mapping. Overall, the proposed alternatives are intended to promote the form and functions associated with a montane meadow and perennial, low-gradient channel system.

Alternative #1 includes the introduction of natural instream features (i.e., instream wood jams, beaver dam analogs) to restore hydraulic gradients or achieve increases in water surfaces to restores overbank flows and gain more frequently wetted meadow/floodplain acreage; removal of targeted levees, recontouring of relic, abandoned irrigation ditches, removal of old irrigation diversion structures, and restoration of targeted plant communities.

Alternative #2 includes all design elements described under Alternative #1 plus targeted grading to achieve additional floodplain functions and habitat in reaches classified as incised (CEM, stages IV and V).

Alternatives #1 and #2 are similar in that they both:

- Improve channel and floodplain connectivity;
- Increase the frequency of dispersed flow across currently infrequently occupied high-flow swales and secondary channels;
- Reduce streambank sediment sources;
- Restore natural flow pathways by removing relic, abandoned irrigation ditches;
- Arrest headcutting or knickpoint erosion in the tributary swales/channels;

- Work with existing wildlife to increase surface water and groundwater elevations; and
- Use natural materials to improve function.

Alternatives #1 and #2 are also different.

A table comparing different active floodplain acreage under existing conditions and both proposed alternatives is provided below:

Table 4-1 Floodplain Acreage Under Existing Conditions and Proposed Alternatives.

Reach	Existing Conditions (85 cfs)	*Additional Proposed Conditions* Alternative #1	Alternative #2
	acres	*acres*	*acres*
1	0.4	0.2	0.6
3	1.8	2.6	3.6
4	1.1	1.1	3.0
5	0.6	0.4	1.0
6	0.8	0.1	1.6
TOTAL	4.8	4.3	9.8

While both alternatives include many similar design elements, Alternative #2 creates new additional floodplain areas by grading an inset floodplain. Grading is targeted for reaches that are incised greater than 2 to 3 feet below the former meadow surface (Stages IV, V of CEM, see table 3-1). In these reaches, promoting overbank flows using natural features are difficult to achieve. Instead, grading is used to achieve an inset floodplain.

Alternative #1 roughly doubles active floodplain acreage (additional 4.3 ac) when compared to existing conditions (4.8 ac), whereas Alternative #2 provides an additional 5.5 acres of floodplain and associated functions relative to Alternative #1 increasing the total to 9.8 acres.

4.5 Design Elements

Appendix A includes conceptual design drawings of each of the following alternatives and associated elements.

Alternative #1: Instream elements designed to increase the overall hydraulic gradient or water surface through the project area (Sheets 2.1-3.2):

- Reach 1 (Upper; Sheet 2.1): Filling (recontouring) of abandoned irrigation ditches;
- Reach 1 (Lower; Sheet 2.2): Removal of old diversion works and filling abandoned irrigation ditch; addition of at least three instream wood structures to elevate water surfaces;
- Reach 2 protect, existing beaver colony and beaver dams;
- Reach 3 (Upper; Sheet 2.3): Introduction of instream wood jams and beaver dam analogs;
- Reach 3 (Middle; Sheet 2.4): Introduction of instream wood and beaver dam analogs;
- Reach 3 (Lower; Sheet 2.5): a) Log grade-control features will be strategically located across existing intermittent channels currently exhibiting headcutting; log grade-control features will be augmented with live willow plantings and willow fascines to enhance long-term stability; b) beaver dam analogs installed to increase water surface elevations;
- Reach 4 (Upper; Sheet 2.6): a) Log grade-control features will be strategically located across existing intermittent channels currently exhibiting headcutting; log grade-control features will be augmented with live willow plantings and willow fascines to enhance long-term stability; b) beaver dam analogs installed to increase water surface elevations;
- Reach 4 (Lower; Sheet 2.7): a) Log grade-control features will be strategically located across existing intermittent channels currently undergoing headcutting; log grade-control features will be augmented with live willow plantings and willow fascines to enhance long-term stability; b) beaver dam analogs installed to increase water surface elevations;
- Reach 5 (Upper; Sheet 2.8): a) Log grade-control features will be strategically located across existing intermittent channels currently undergoing headcutting; log grade-control features will be augmented with live willow plantings and willow fascines to enhance long-term stability; b) removal of rip-rap banks and replace with sod mats and other revegetation strategies;
- Reach 5 (Lower; Sheet 2.9): a) Restore channel meander in straightened reach; encourage overbank flows to wet meadow surfaces; b) beaver dam analogs; and

- Reach 6 (Lower; Sheet 2.10): a) Remove levees to increase areas subject to overbank flow; b) minor bank grading to reduce streambank erosion; and c) analog beaver dam installed to increase water surface elevations.

Alternative #2 includes design elements included under Alternative #1 above plus active grading to create inset floodplains. Additional targeted grading is included to encourage more frequent flows to swales and secondary channels that are currently abandoned or infrequently active. Finally, sod plugs are planned in selected secondary channels to further encourage dispersed and dynamic flow across relatively dry meadow surfaces (shown in red on all sheets of Appendix A).

The overall approach to revegetation, under both alternatives, is to minimize import, rely on site material as much as possible, and select the appropriate target plant community using the most suitable, cost effective, and available native species. To reduce the import of soil amendments in subsoils, design will emphasize the use of colonizing species that help develop soil structure and enhance the establishment of later seral stage species. All designs will also focus on immediate erosion control.

Restoration may include a variety of biotechnical solutions, as discrete treatments or in various site-specific combinations. These solutions include salvage and replacement of wetland sod and/or organic matter; the possible use of coir fabrics as a propagated mat or planted material; use of erosion control blankets, use of willows, placement of coir logs (pre-vegetated or not); placement of pre-planted logs; planting of containerized stock; seeding, and mulching.

Site restoration may also include stabilization of borrow or fill sites, and stabilization of banks where riprap will be removed. Bank stabilization will consider biotechnical willow treatments in combination with erosion control blankets.

4.6 Design Elements to be Avoided

Mainstem Martis Creek, through the project area, is a dynamic, alluvial, pool-riffle channel primarily functioning to support a riparian, low-gradient meadow. Channel bed and bank materials and sediment transport is dominantly fine-grained (clay, silt, sand and gravels). Placement of large rock or boulder structures would be geomorphically inappropriate. Such structures are likely to induce bank and bed erosion and degrade the channel in an unpredictable manner.

Furthermore, Martis Creek exhibits an overall channel slope less than 1 percent with pool-riffle channel morphology. Imposing a step-pool form or including drop structures to increase water surface elevations would also potentially introduce instability and risk.

4.7 Proposed Restoration Approach and Consistency with USACE Master Plan

Martis Creek Lake Dam, reservoir, and the project area are under the ownership and management of the U.S. Army Corp of Engineers (USACE). The USACE had developed a Master Plan for Martis Creek Lake Dam and adjacent lands, as required for civil works projects (USACE, 2014). The Master Plan provides a programmatic approach to the management of lands including areas proposed for restoration. **Figure 4-2** shows where we identify the key management units within the USACE Master Plan overlap with the area proposed for restoration.

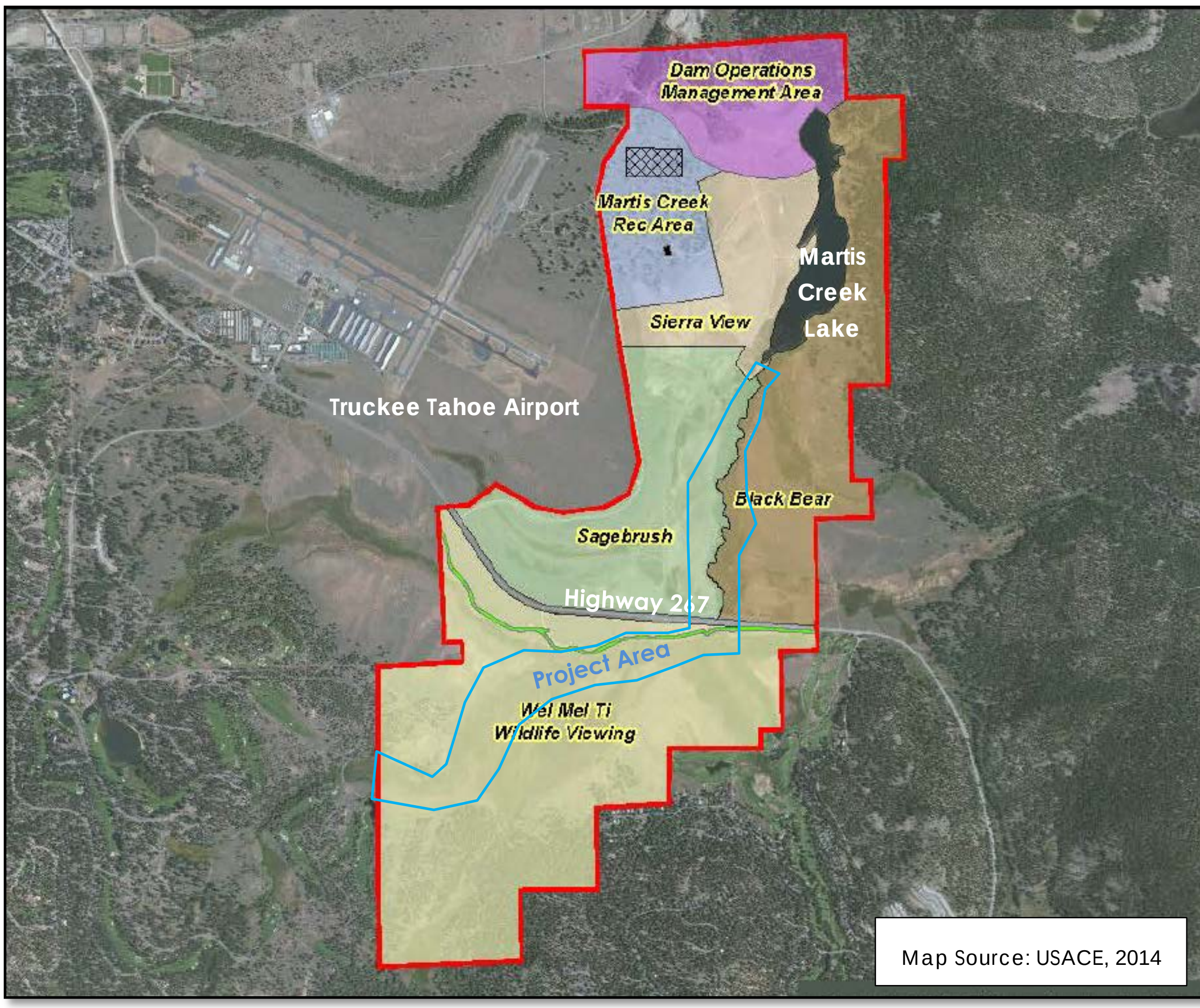

Figure 4-2 US Army Corps of Engineers Management Units, Martis Creek Lake, California.

For each management unit, we describe how the goals and objectives for the restoration of Mainstem Martis Creek support the current and future management of these management units.

USACE Management Unit #6- Sage Brush Day-Use Area

This area is defined as the land north of State Route 267 (SR 267), west of Martis Creek and east of Martis Dam Road. This management unit is primarily allocated to low-impact, non-motorized recreation and open space and protects a diversity of habitat types including upland game birds. USACE characterizes this unit as “greatly impacted and includes abandoned borrow pits and historic roads used for construction of the dam”. Resource objectives include recreation, natural and cultural resources management, and visitor information and education.

Proposed restoration elements include removal of levees, regrading and revegetation of former borrow pits. Removal or modification of these constructed features will permit overbank flows to inundate former wetland/riparian habitat. Removal of invasive species and revegetation of upland areas will enhance existing upland habitat. Inclusion of new trails and educational kiosks are not proposed as part this this project, but can be included in future design. Review and protection of cultural resources will also be required under future design.

USACE Management Unit #7- Black Bear

This area is defined as land north of SR 267 and east of Martis Creek and Martis Lake, adjacent to Waddle Ranch Preserve. This management unit is primarily used for low-impact, non-motorized recreation and open space to preserve and protect wildlife habitat and cultural resources. These lands also include current and former wetlands and intermittent drainages and straightened reach of Martis Creek from construction and upgrades to SR 267 crossing.

Proposed restoration elements include restoring Martis Creek sinuosity in the segment that was previously straightened and minor grading to encourage overbank flows to augment or restore flows to current or former wetlands. Beaver dam analogs are also proposed to work with existing beaver populations and help elevate water surfaces to promote overbank flows.

USACE Management Unit #9- Wel Mel Ti Wildlife Area

This area includes most of the Martis Valley lands under USACE management south of SR 267, and north of the Lahontan Golf Club and Community. Similar to the above units, this unit is primarily used for low-impact, non-motorized recreation. This unit has also been designated as an environmentally sensitive area with natural resource values, scenic values, historic values and fish and wildlife habitat. Preservation, restoration, and interpretation are the primary management goals in this area. Currently, recreational trails have shown to cause some impacts to Martis Creek (e.g., bank erosion and sedimentation of the creek, habitat disturbance). The USACE specifically calls out an objective to continue creek restoration projects in accordance with 40 CFR 230 404(b)(1) Guidelines and in coordination with the Truckee River Watershed Council (USACE, 2014).

Proposed restoration of Martis Creek in this unit is consistent with the management objectives and guidelines outlined for all three management units (#6, #7, and #9) described above. Specifically, restoration elements include working with existing beaver populations and instream wood to promote overbank flows to augment or restore meadow and wetland habitats. Furthermore, some grading is proposed as an alternative to enhance floodplain habitat.

In addition to the specific management unit goals and objectives described above, the USACE has some overall goals that are consistent with the objectives of proposed restoration:

Flood Control

The primary goal of Martis Creek Dam is to provide flood control. Low pool storage is estimated to be 72 acres and extended to 312 acres under the current operating plan (USACE, 2014). Proposed restoration of floodplain connectivity will function to reduce timing and magnitude of flood flows entering Martis Creek Lake and may extend the time period upon when Martis Creek Lake reaches its storage capacity during high-flows under its current operating plan.

Water Quality Improvements

A secondary goal of the Martis Creek Lake is for storage for future water supply (USACE, 2014). However, Martis Creek is on the Lahontan Regional Water Quality Control Board (LRWQCB) ‘Watch List’ for excess nutrients. Martis Creek Lake has the potential for algae blooms during dry years. Proposed restoration of floodplain connectivity provides additional opportunities to slow nutrient laden runoff, infiltrate runoff, and encourage sediment/nutrient deposition and nutrient uptake by riparian/meadow/wetland vegetation. On-going water quality monitoring activities by Placer County (CDM Smith and Balance Hydrologics, 2016) will provide both a baseline and, if the project continues, post-project tool for evaluating reductions of excess nutrients.

4.8 What We Have Not Analyzed or Assessed

Because design elements described in this feasibility report and illustrated in Appendix A are conceptual, we find it prudent to list what assessments or analyses we have not conducted for this project, but are likely to be needed for complete development of designs.

a) Detailed survey of bed elevations to support accurate depiction of water surfaces throughout project area;

b) 2-dimensional hydraulic model to identify accurate channel depths, velocities and shear stress;

c) Bedload sediment transport measurements;

d) Subsurface investigations to evaluate characteristic of materials at depth, depth to bedrock and depth to groundwater;

e) Investigation of utility alignments;

f) Quantification of available and suitable wetland sod or other wetland and riparian vegetation; and

g) Detailed botanical survey focusing on site availability of desirable seed.

5 ESTIMATED COSTS

We anticipate the construction costs associated with these alternatives to potentially be as low as $700,000 and as high as $1,400,000. However, conceptual designs lack the detail necessary to develop engineering-level estimates of project design, permitting and construction costs. Types, quantities and/or volumes of materials are not provided at this level of design. The following implementation elements will greatly influence the cost of each alternative:

Alternative #1:

a. Cut volume (minor, can likely be used on-site);
b. Off-haul of rip-rip and gabions removed from banks;
c. Size, type, and source of trees for instream wood jams and log grade control;
d. Size type and source of willow for beaver dam analogs;
e. Revegetation materials, erosion control materials; and
f. Labor and equipment for installation.

Alternative #2:

In addition to those under Alternative #1 above:

a. Additional cut volume;
b. Additional Off-haul and disposal of any unused cut material; and
c. Additional revegetation and erosion control materials and efforts.

6 CONSTRUCTION CONSIDERATIONS

A wetland delineation has not been completed for the project site. However, impacts to existing wetland are probable during construction of both alternatives and will be further evaluated during later phases of this project. The location of the project provides ample opportunity to mitigate for these impacts though restoration, re-establishment, and functional lift of impacted wetland areas.

6.1 Access

We have evaluated access considerations for both alternatives. In most cases, project elements will require a heavy track vehicle. All access will need to be carefully coordinated with landowners:

Reach 1. Access can be gained from either: (a) an existing two-track road (Old Cavitt Ranch Road) with minor improvements and wetland protection measures or (b) from Lahontan Golf Club with over 500 feet of new temporary road required.

Reach 3. Access can be gained from the existing two-track road (Old Cavitt Ranch Road) with minor improvements to the road.

Reach 4 and 5. Access can be gained from the future improved Martis Trail, a paved recreational trail wide enough for track equipment. Minor improvements will be required to access the creek.

All Reaches. Access will require careful coordination with USACE to identify access with the least impacts or over existing disturbed areas.

7 LIMITATIONS

This report and its contents have been developed solely as an assessment of geomorphic conditions for a proposed habitat enhancement project along the Mainstem Martis Creek, Placer and Nevada Counties, California above Martis Creek Lake for the exclusive use of the Truckee River Watershed Council. Data, interpretations and analyses developed for this report may not be directly applicable to other uses. Balance Hydrologics, Inc. should be consulted prior to applying the contents of this report to future projects, dam operations, or for other purposes not specifically cited in this report.

As is customary, we note that readers should recognize that interpretation and evaluation of physical factors affecting the hydrologic context of any site is difficult and an inexact art. Judgements leading to conclusions and recommendations are generally made with an incomplete knowledge of the conditions present. More extensive studies or increased level of design can reduce the inherent uncertainties associated with such studies.

We have used standard environmental information such as precipitation, streamflow, topographic mapping, and soil and vegetation mapping, in our analyses and approaches without verification or modification, in conformance with local custom. New information or changes in regulatory guidance could influence the plans or recommendations, perhaps fundamentally. As updated information becomes available, the interpretations and recommendations contained in this report may warrant change. To aid in revisions, we ask that readers or reviewers advise us of new plans, conditions, or data of which they are aware.

Data developed or used in this report were collected and interpreted solely for developing an understanding of the hydrologic context at the site as an aid to conceptual planning and restoration design. They should not be used for other purposes without great care, updating, review of sampling and analytical methods used, and consultation with Balance staff familiar with the site.

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PLATES

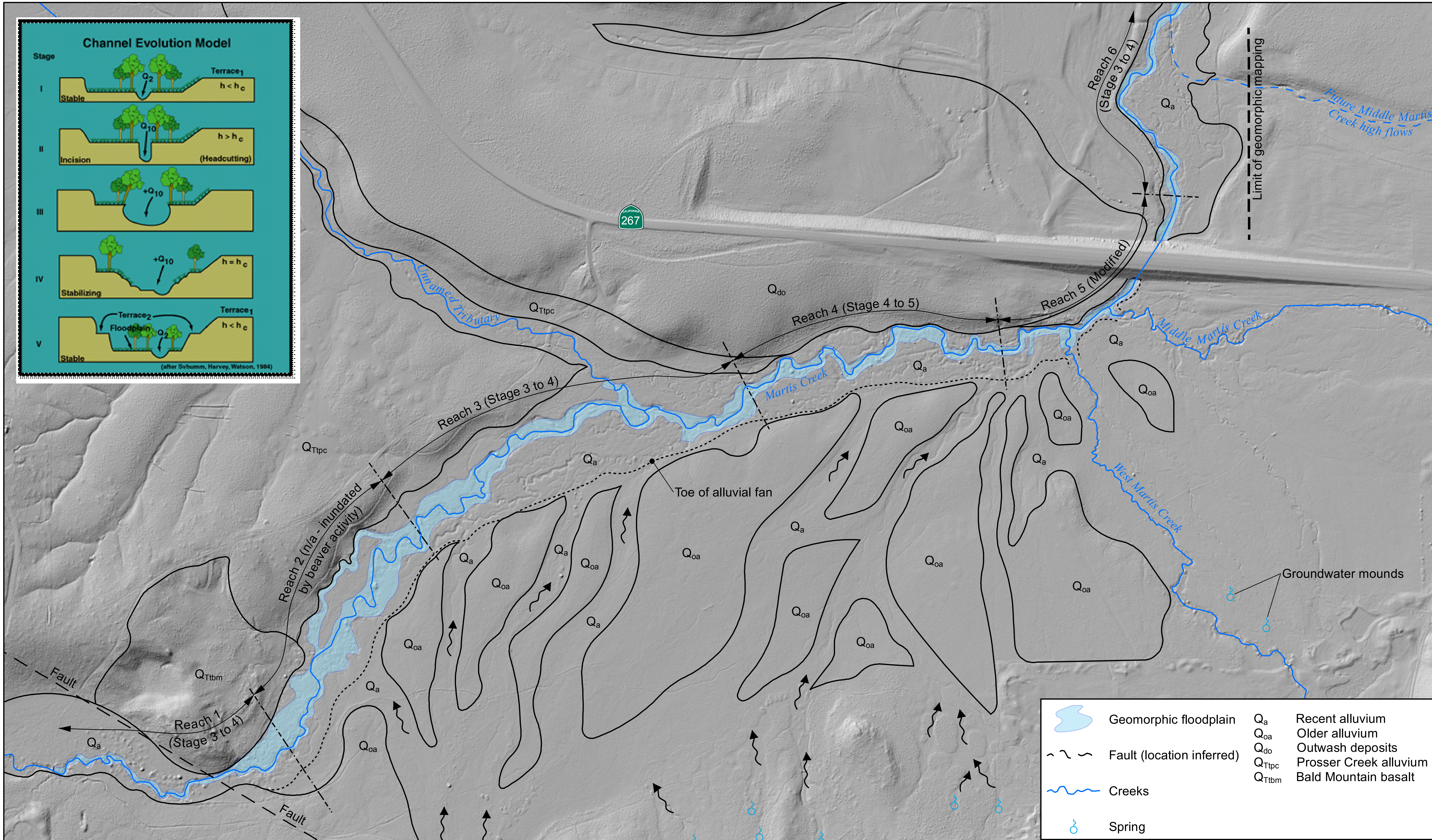

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Plate 1. Mainstem Martis geomorphic map, showing project reaches and channel evolution stage, Placer County, California

Hillshade basemap based on LiDAR-derived data provided by the U.S. Forest Service
Geologic units are based on Sylvester and others (2012)

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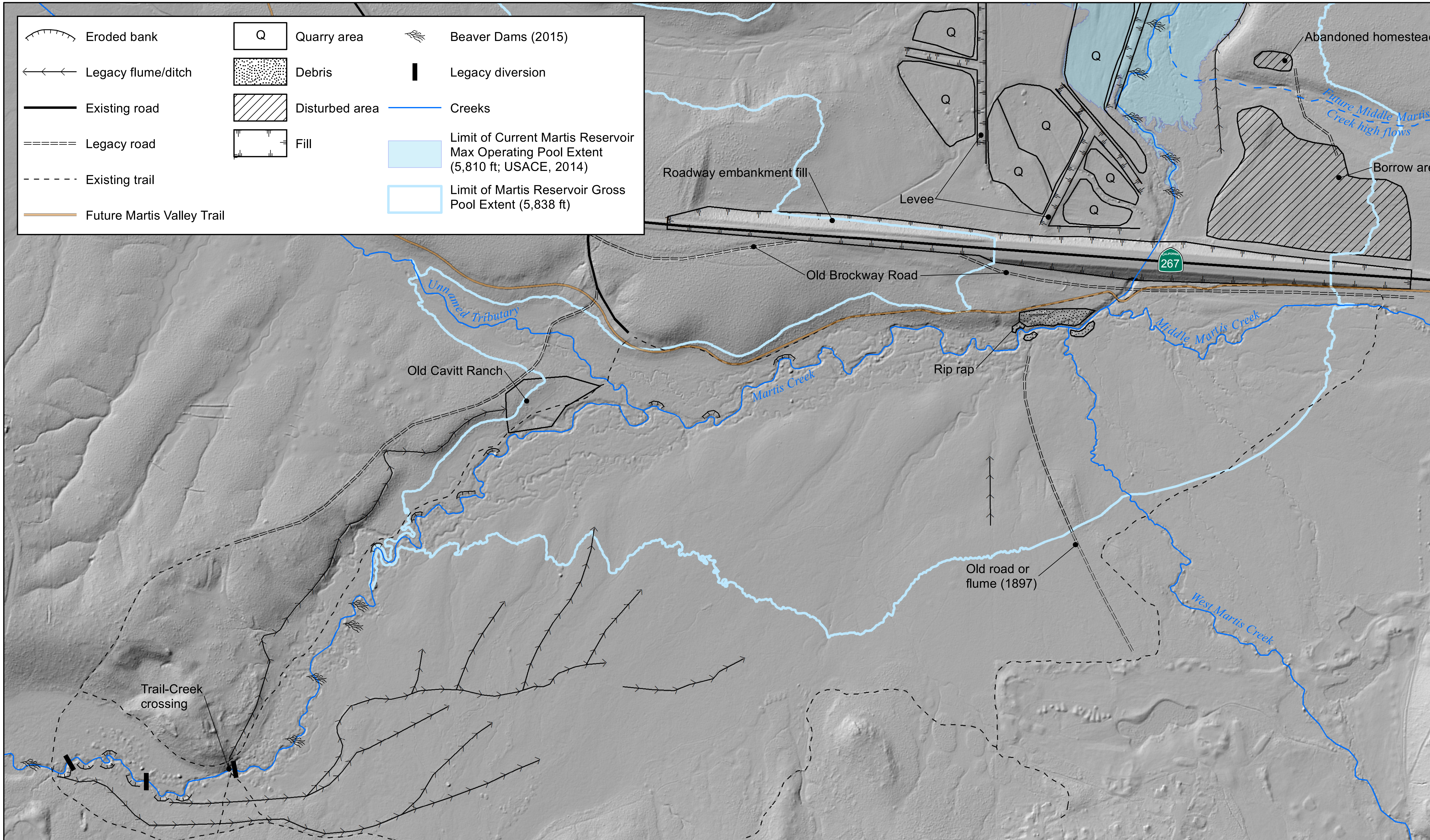

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Plate 2. Mainstem Martis existing conditions and historical features, Placer County, California

Hillshade basemap based on LiDAR-derived data provided by the U.S. Forest Service
Historical features are from Lindstrom (2011)
Future Martis Valley Trail alignment provided by Auerbach Engineerin Corporation (2016)
All other features mapped during field work by Balance (2011 and 2015)

0 250 500 1,000 Feet

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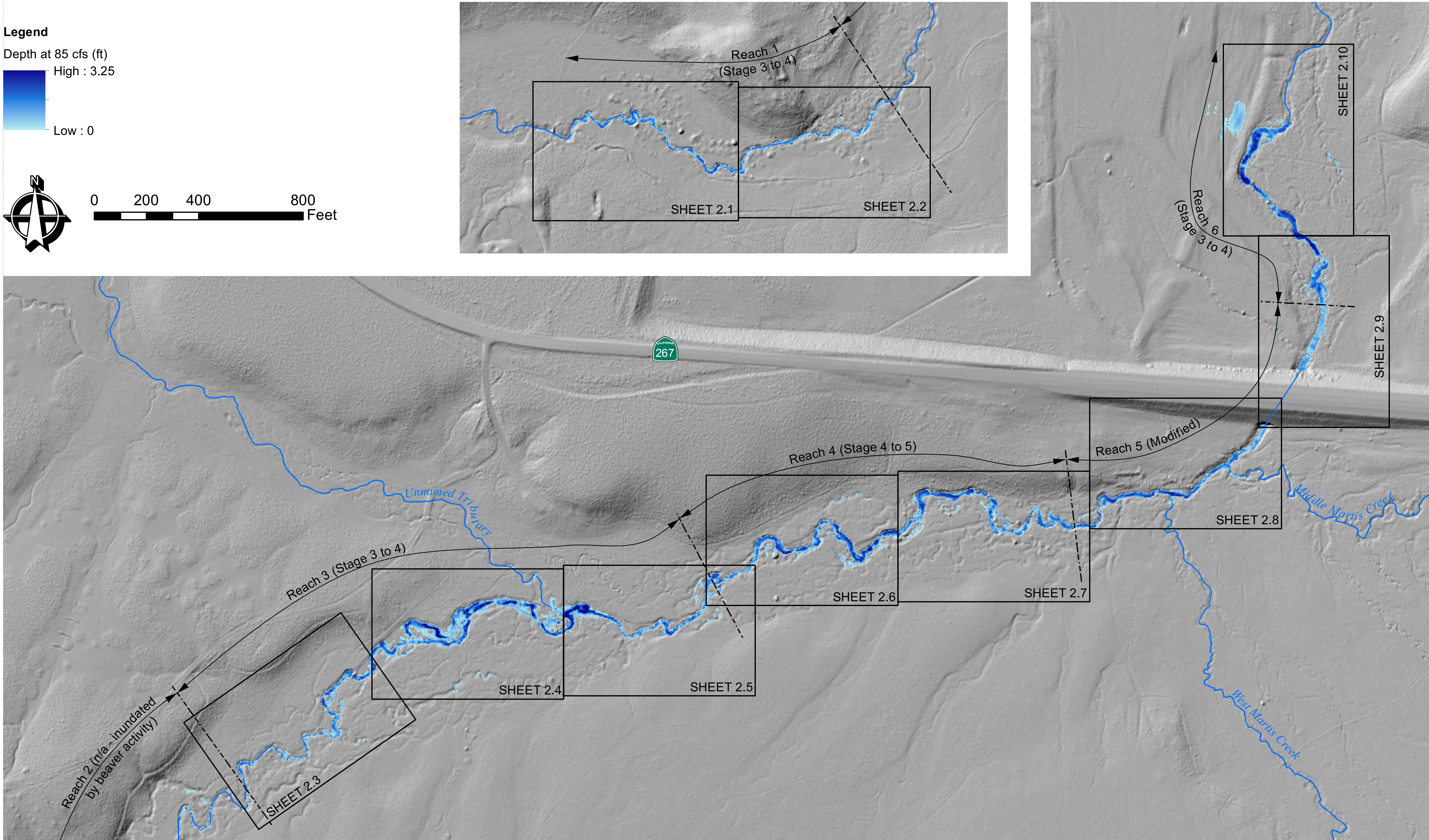

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Plate 3. Existing inundation areas and depths at 85 cfs, Mainstem Martis Creek, Placer County, California

Hillshade basemap based on LiDAR-derived data provided by the U.S. Forest Service
Flow depths are based on hydraulic modeling completed for this study

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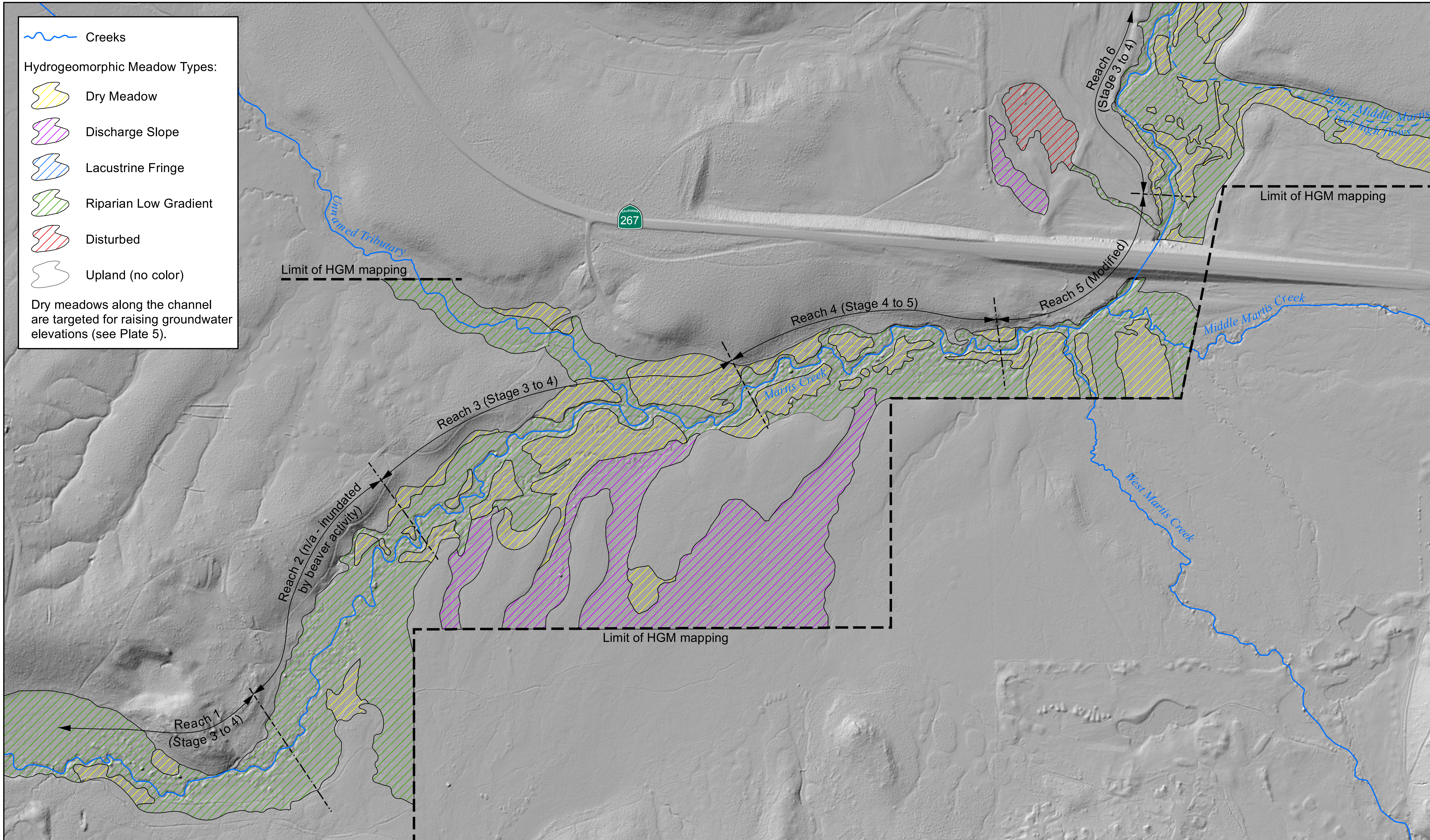

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Plate 4. Mainstem Martis hydrogeomorphic map for project reach, Placer County, California

Hillshade basemap based on LiDAR-derived data provided by the U.S. Forest Service

0 250 500 1,000 Feet

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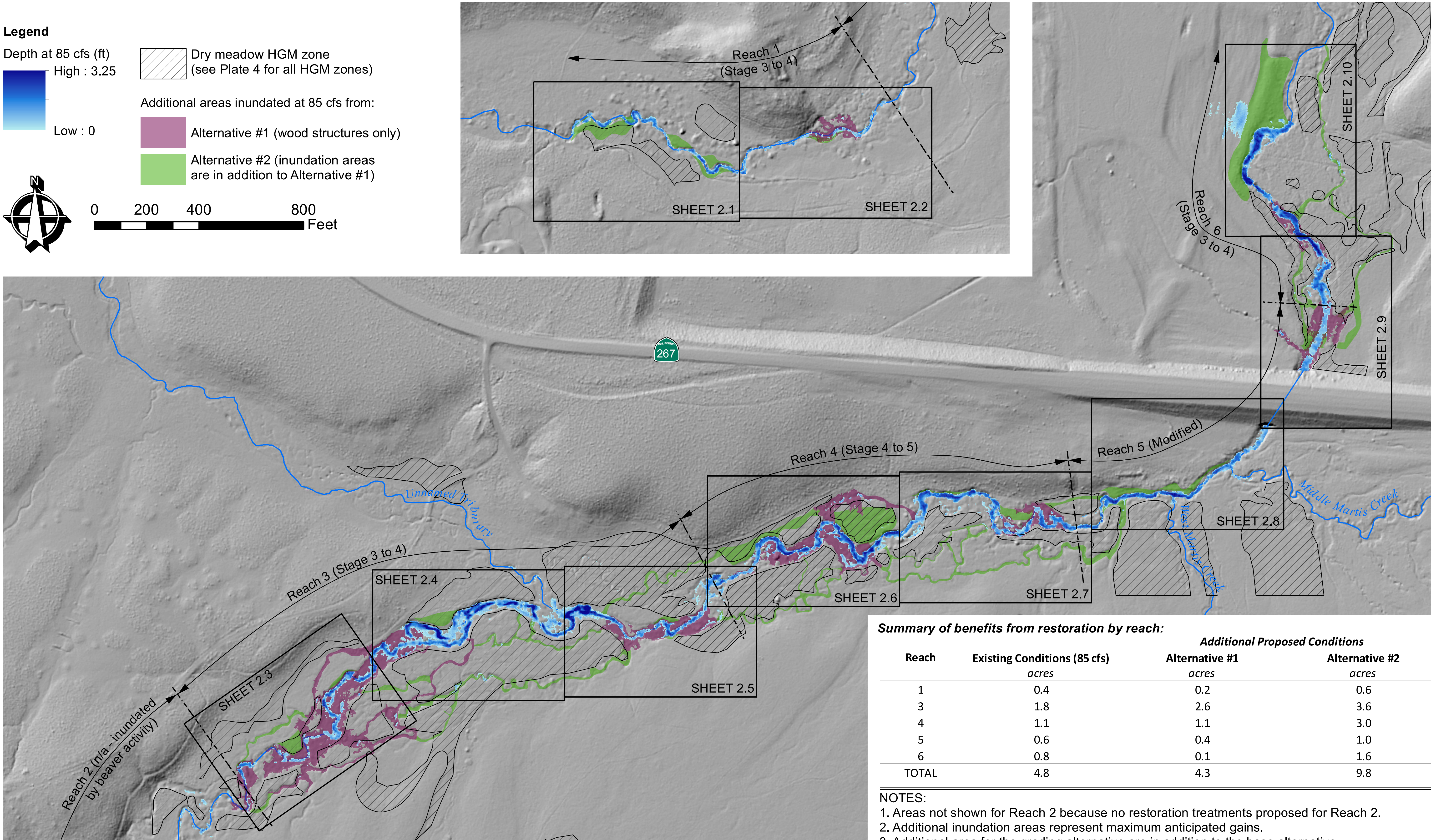

Summary of benefits from restoration by reach:

Reach	Existing Conditions (85 cfs)	Additional Proposed Conditions Alternative #1	Alternative #2
	acres	*acres*	*acres*
1	0.4	0.2	0.6
3	1.8	2.6	3.6
4	1.1	1.1	3.0
5	0.6	0.4	1.0
6	0.8	0.1	1.6
TOTAL	4.8	4.3	9.8

NOTES:
1. Areas not shown for Reach 2 because no restoration treatments proposed for Reach 2.
2. Additional inundation areas represent maximum anticipated gains.
3. Additional area for the grading alternative are in addition to the base alternative.

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Plate 5. Maximum anticipated gains from restoration conceptual design, Mainstem Martis Creek, Placer County, California

Hillshade basemap based on LiDAR-derived data provided by the U.S. Forest Service

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APPENDICES

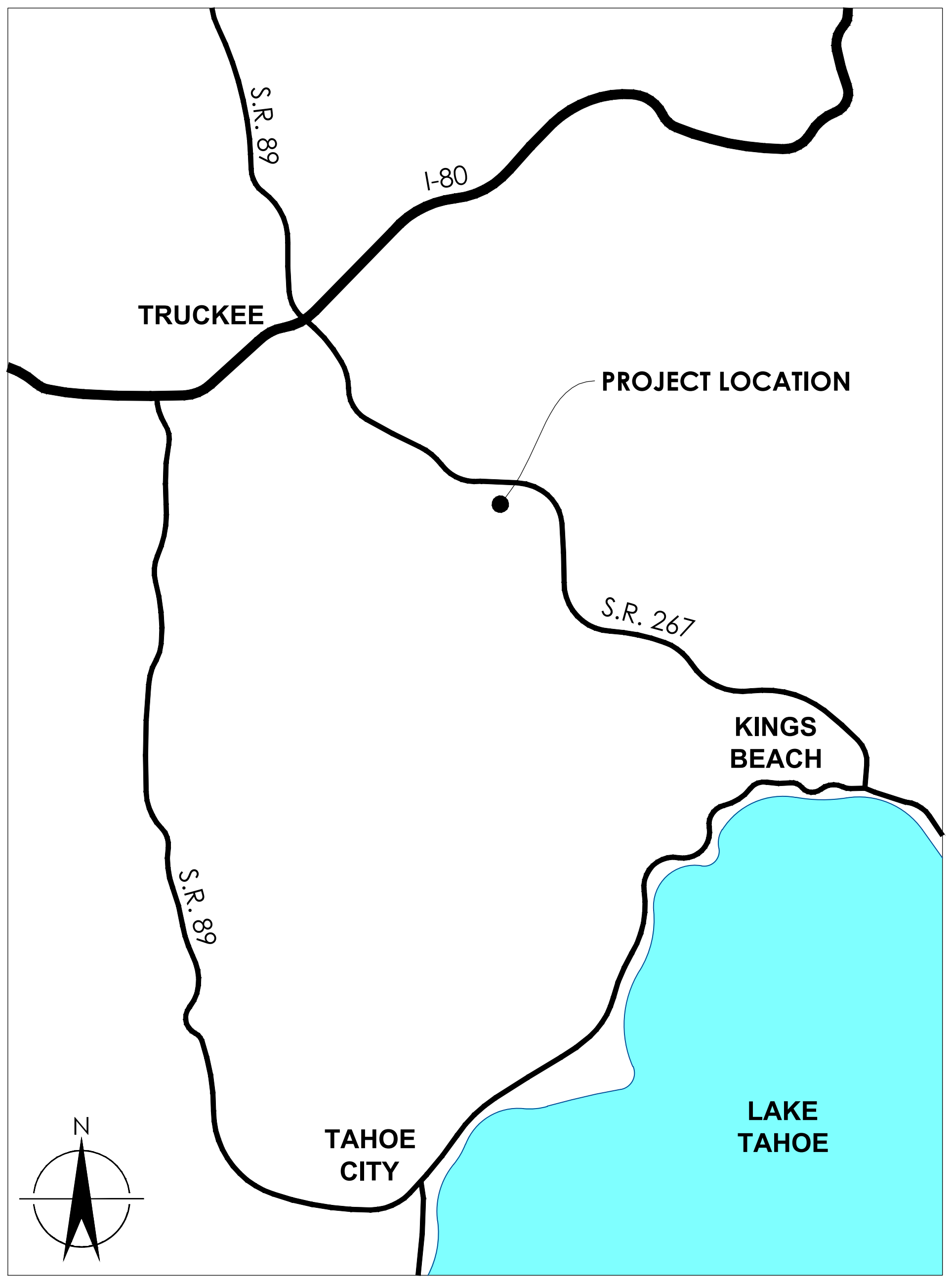
APPENDIX A

Conceptual Plans
Alternative #1 and #2

MAINSTEM MARTIS CREEK RESTORATION

PLACER COUNTY, CALIFORNIA

LOCATION MAP



SHEET INDEX

NOTES

THESE CONCEPTUAL DESIGN PLANS INCLUDE TWO STRATEGIES OR ALTERNATIVES. ALTERNATIVE 1 ADDRESSES DESIGN GOALS USING "LEAST IMPACT" METHODS, WHILE ALTERNATIVE 2 MAXIMIZES HABITAT BENEFITS USING ALL ELEMENTS OF ALTERNATIVE 1 PLUS ADDITIONAL MEASURES.

PROJECT TEAM

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TEL. (775) 849-3223

CONCEPTUAL PLANS - NOT FOR CONSTRUCTION

PREPARED FOR:
Truckee River Watershed Council
Collaborative solutions to protect, enhance and restore the Truckee River Watershed

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DATE	BY	SUBMITTALS / REVISIONS
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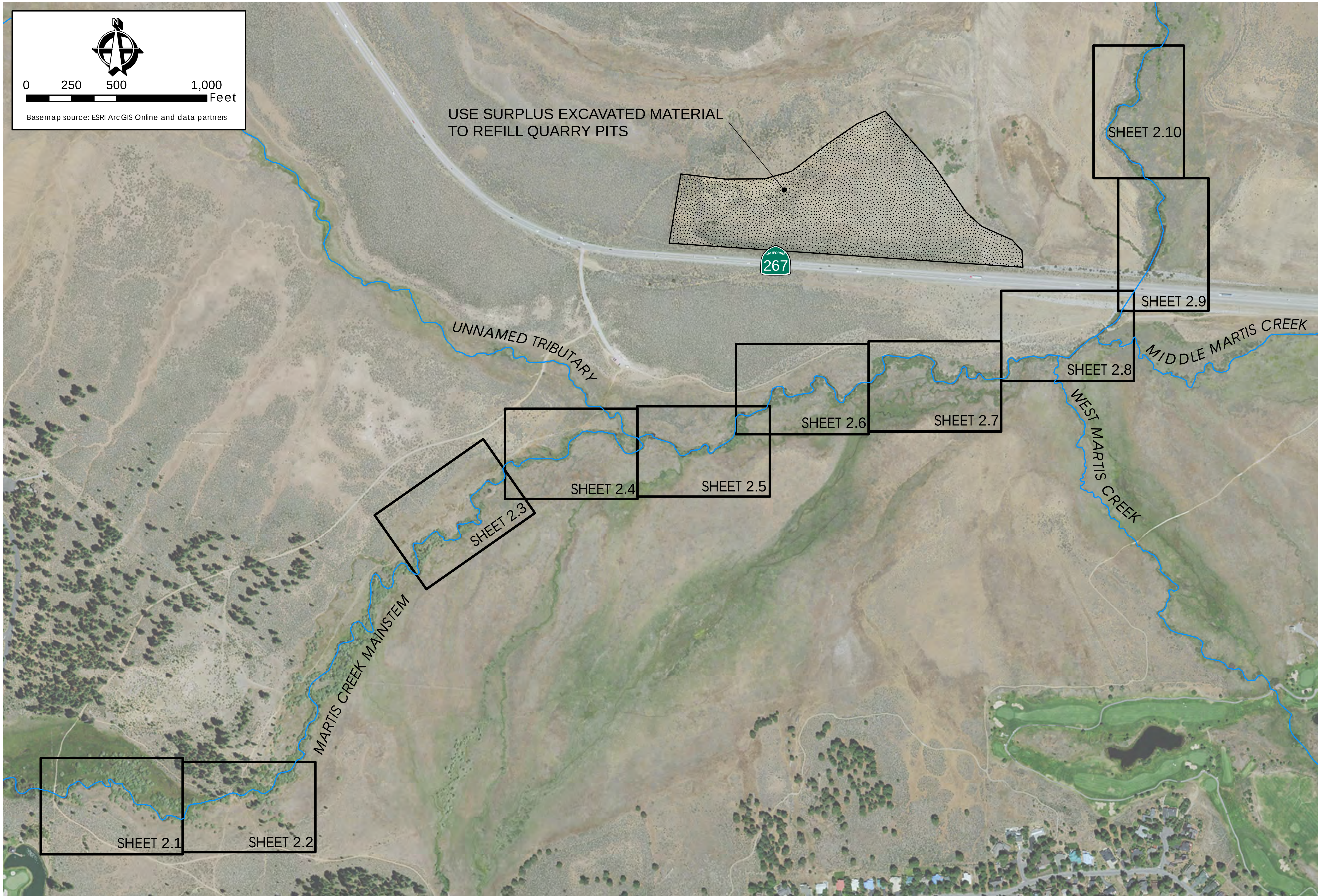
6-10-16	BKH	FINAL CONCEPTUAL PLANS

DESIGNED BY B HASTINGS
DRAWN BY P KULCHAWIK
CHECKED BY D SHAW
IN CHARGE
DATE 6-10-16

COVER SHEET
MAINSTEM MARTIS CREEK RESTORATION
PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063
SCALE --
SHEET 1.0



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IN CHARGE

DATE 6-10-16

OVERVIEW MAP

MAINSTEM MARTIS CREEK RESTORATION

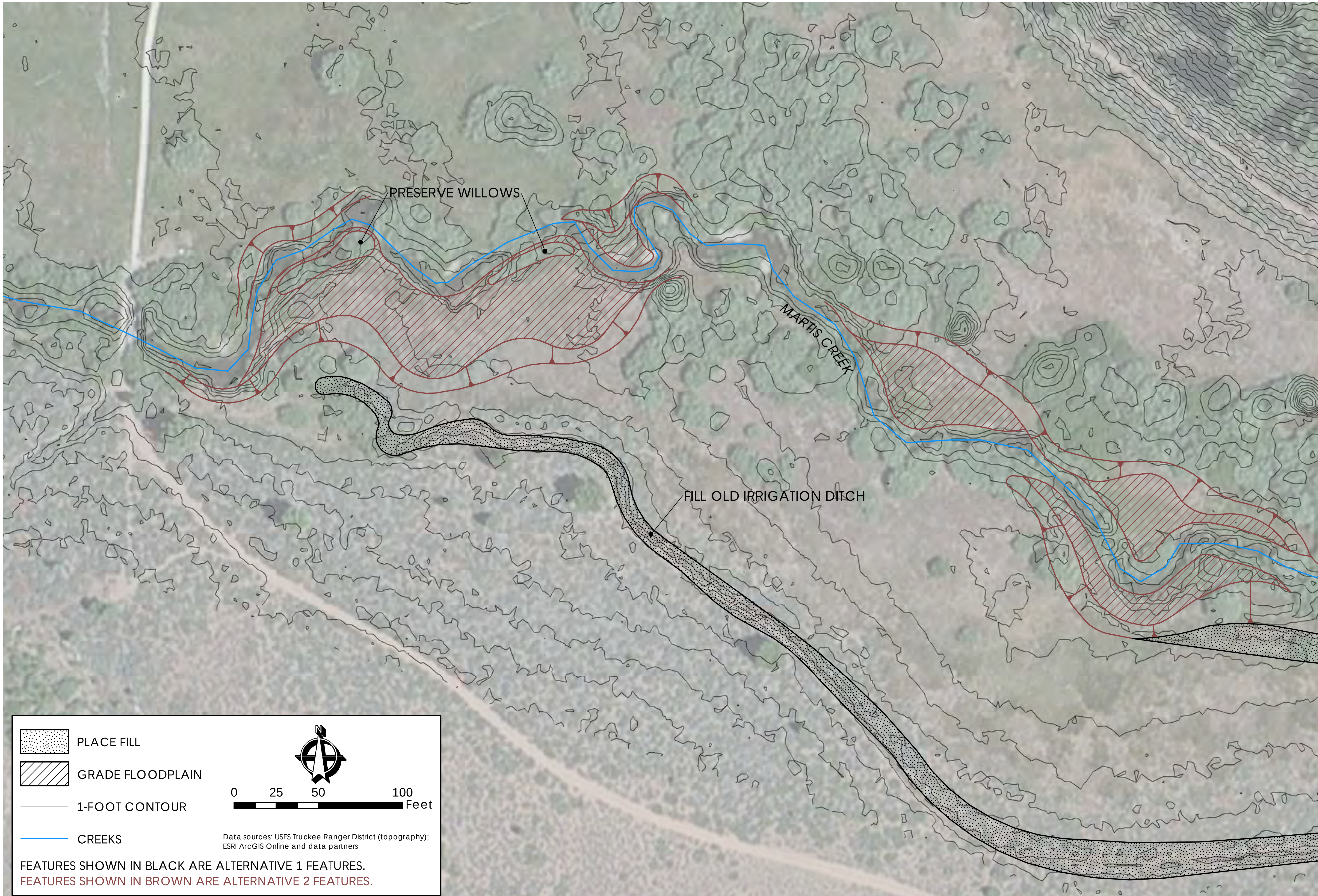
PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063

SCALE 1" = 500'

SHEET

2.0



SEE SHEET 2.2

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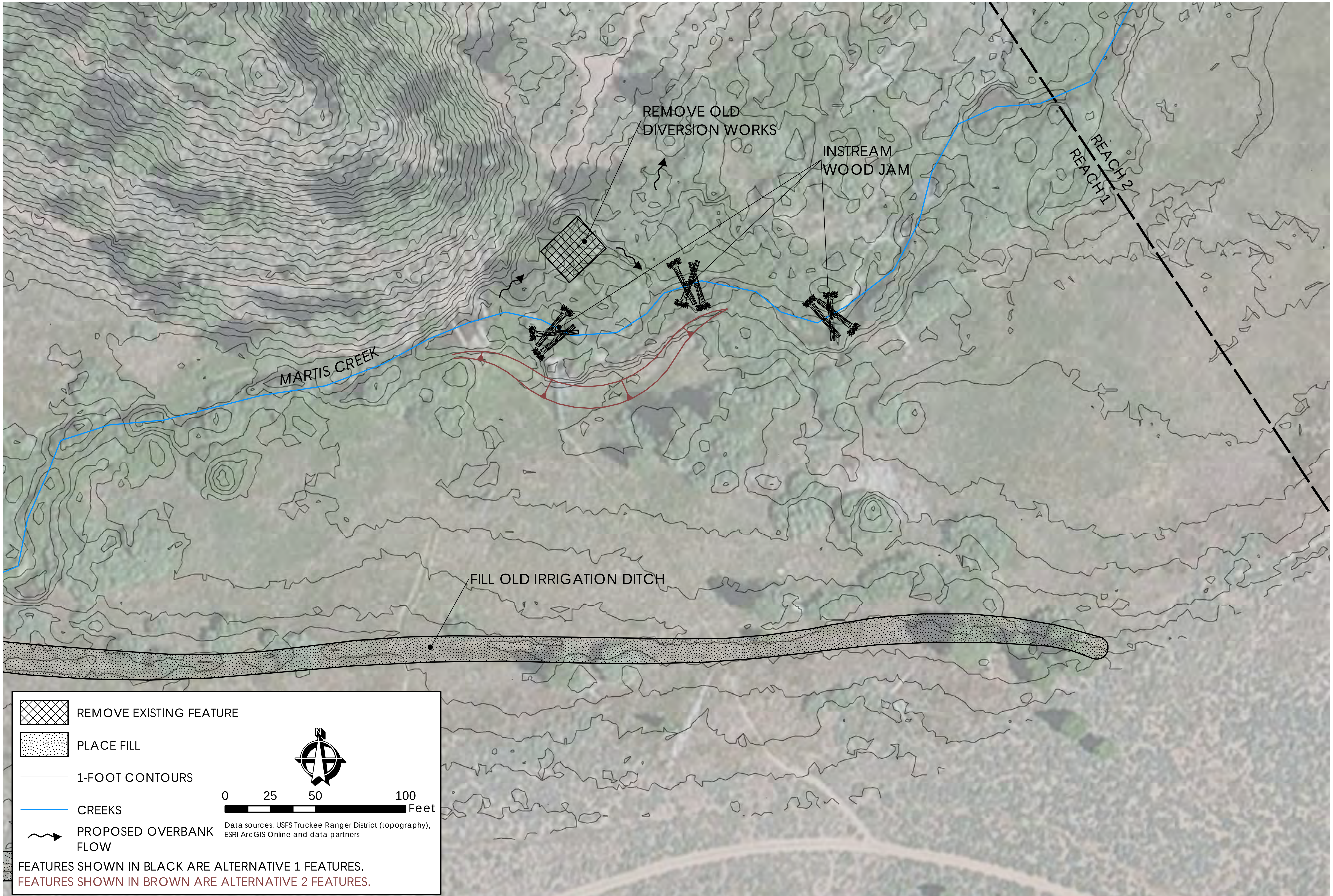
UPPER REACH 1

MAINSTEM MARTIS CREEK RESTORATION

PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063
SCALE 1" = 50'
SHEET 2.1



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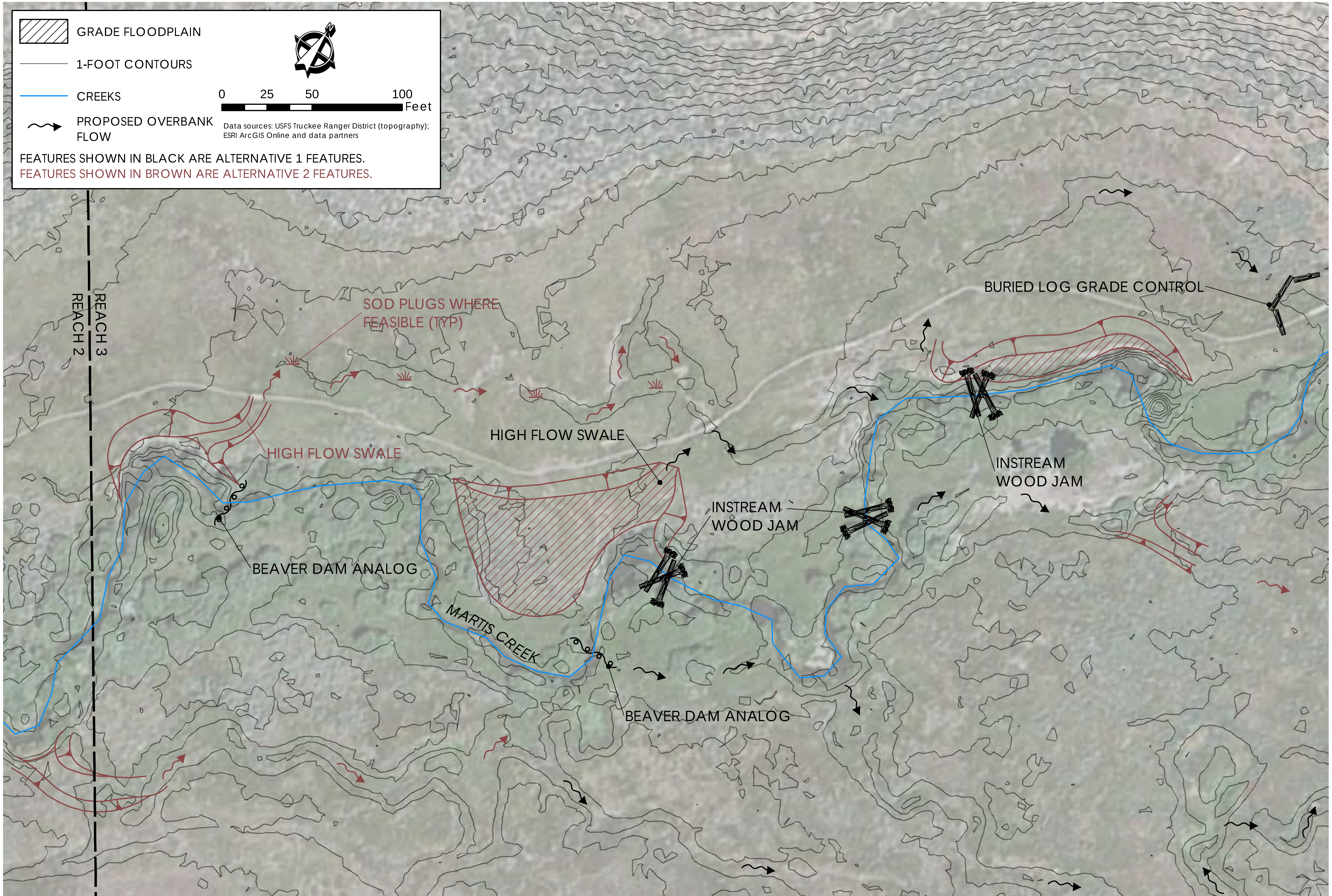
LOWER REACH 1

MAINSTEM MARTIS CREEK RESTORATION

PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063
SCALE 1" = 50'
SHEET 2.2



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IN CHARGE
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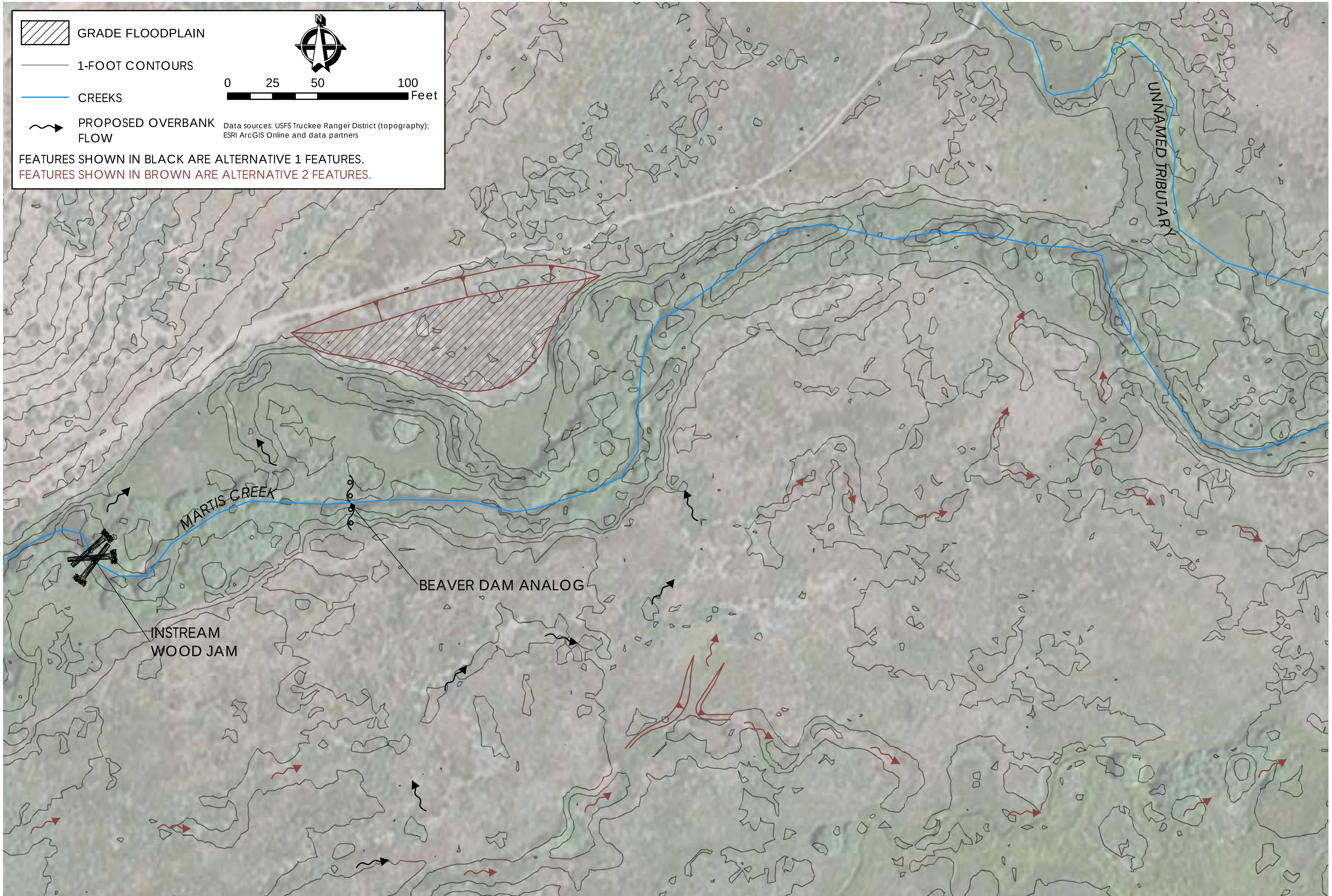
UPPER REACH 3
MAINSTEM MARTIS CREEK RESTORATION
PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063
SCALE 1" = 50'
SHEET
2.3



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MIDDLE REACH 3

MAINSTEM MARTIS CREEK RESTORATION

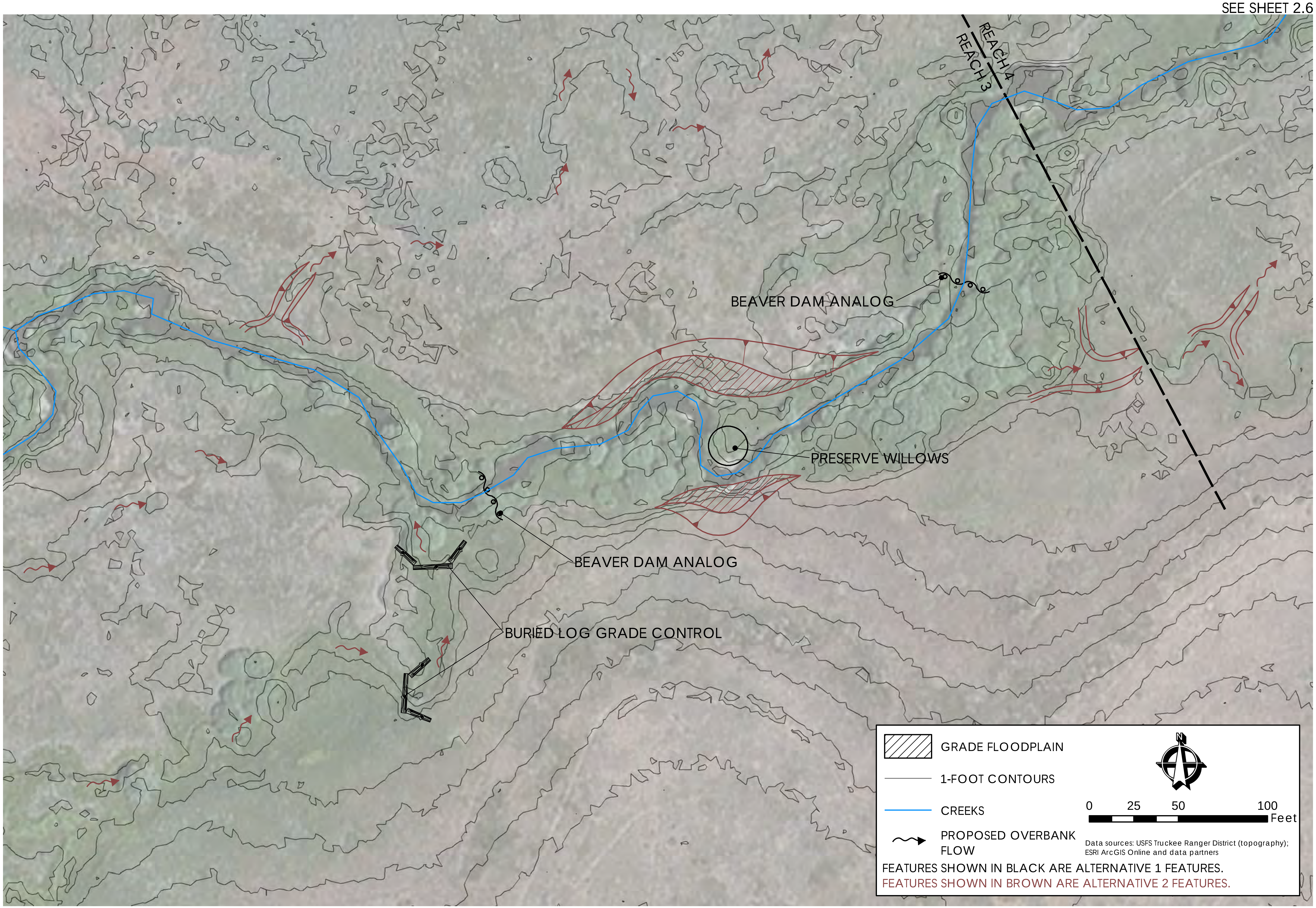
PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063

SCALE 1" = 50'

SHEET

2.4



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LOWER REACH 3

MAINSTEM MARTIS CREEK RESTORATION

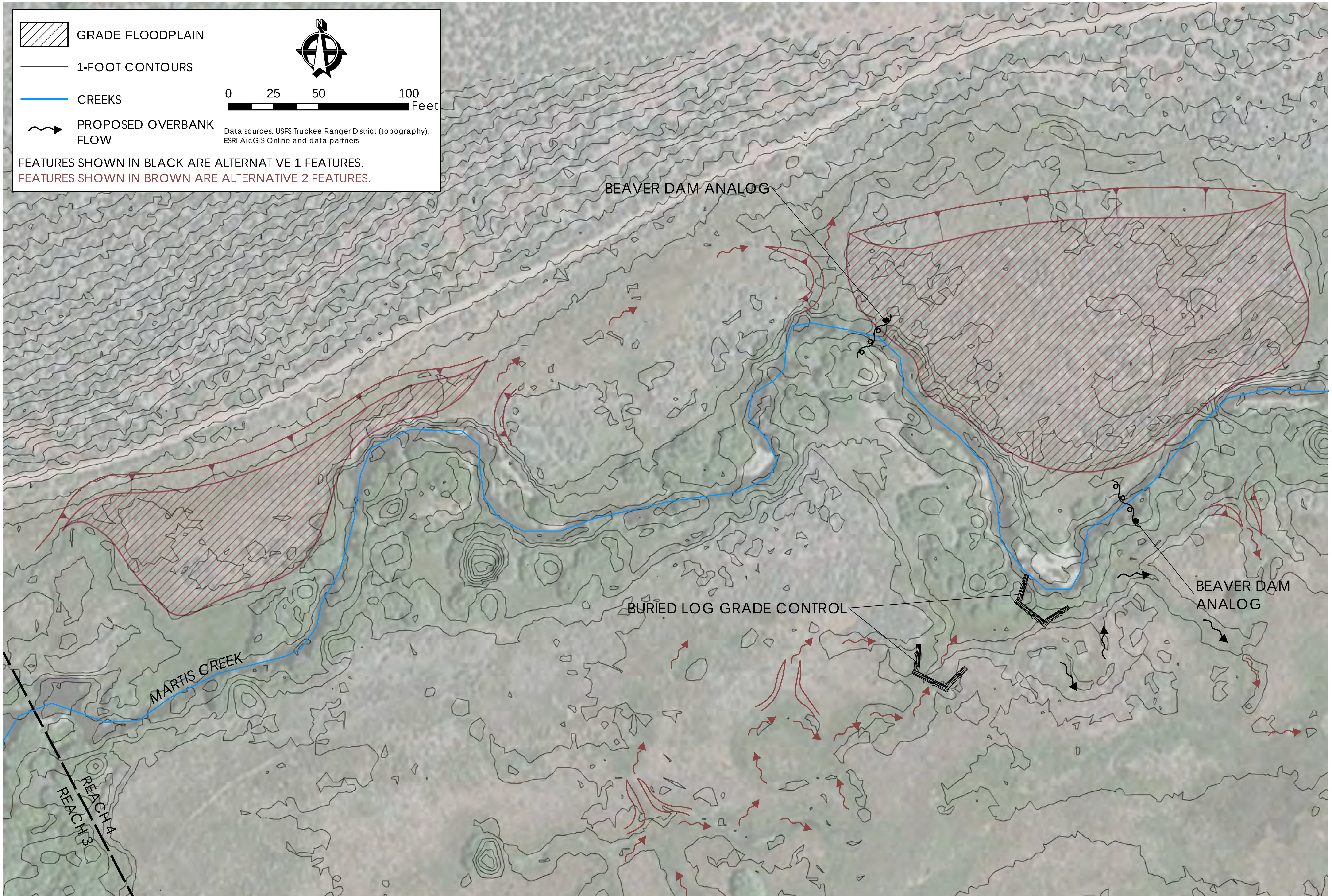
PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063

SCALE 1" = 50'

SHEET

2.5



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UPPER REACH 4

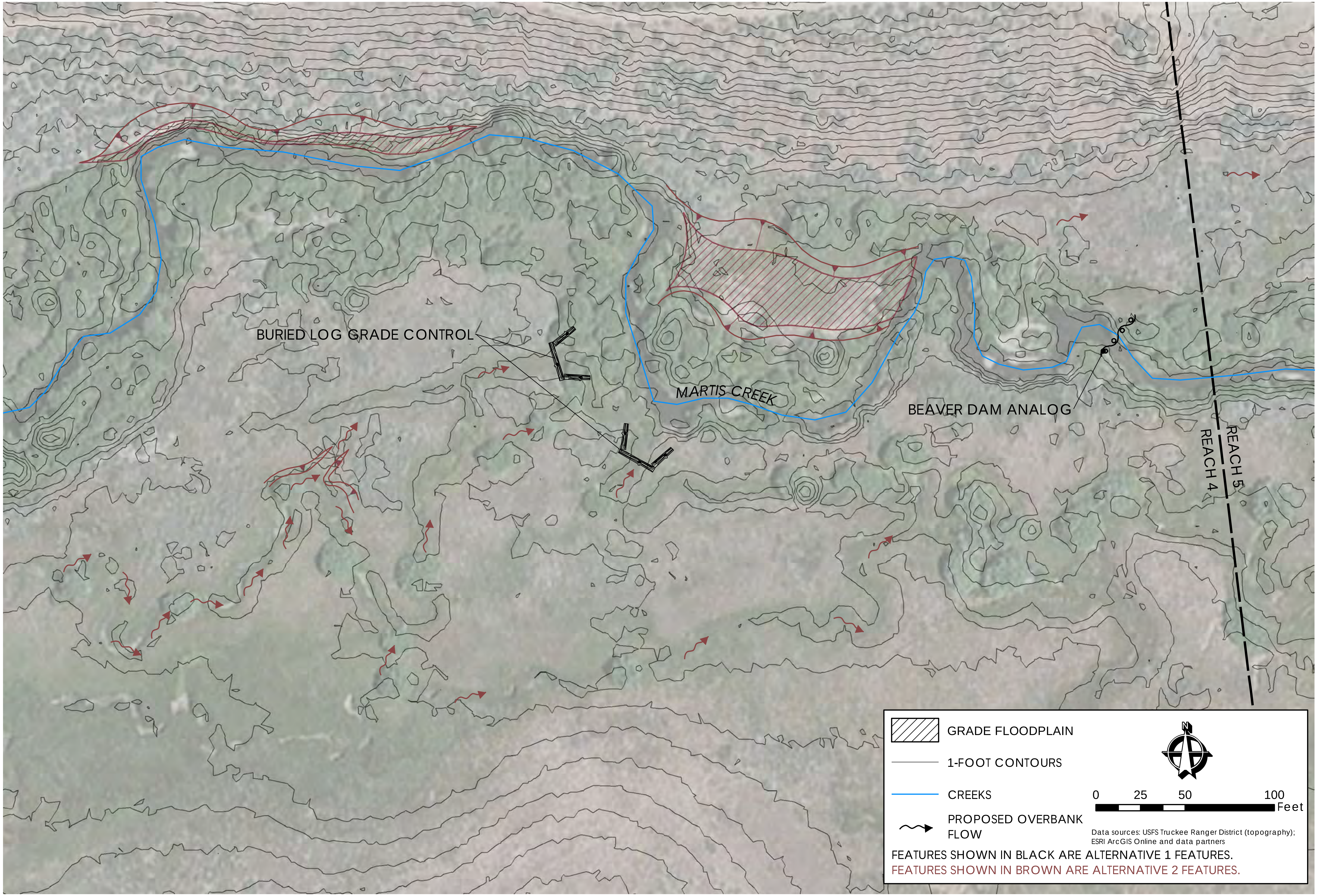
MAINSTEM MARTIS CREEK RESTORATION

PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063

SCALE 1" = 50'

SHEET 2.6



SEE SHEET 2.6

SEE SHEET 2.8

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LOWER REACH 4

MAINSTEM MARTIS CREEK RESTORATION

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SCALE 1" = 50'

SHEET 2.7

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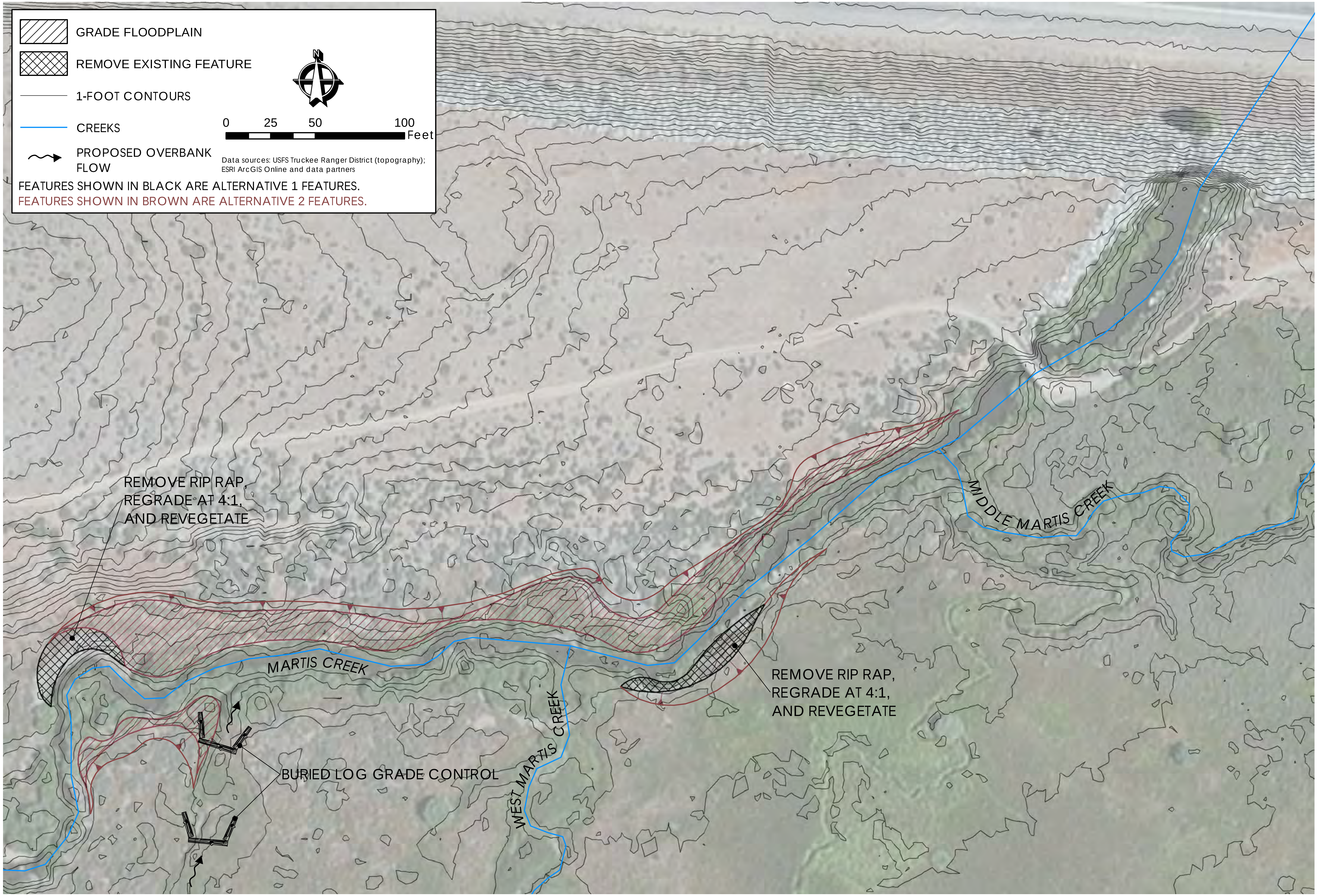

SEE SHEET 2.9

SEE SHEET 2.7

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UPPER REACH 5

MAINSTEM MARTIS CREEK RESTORATION

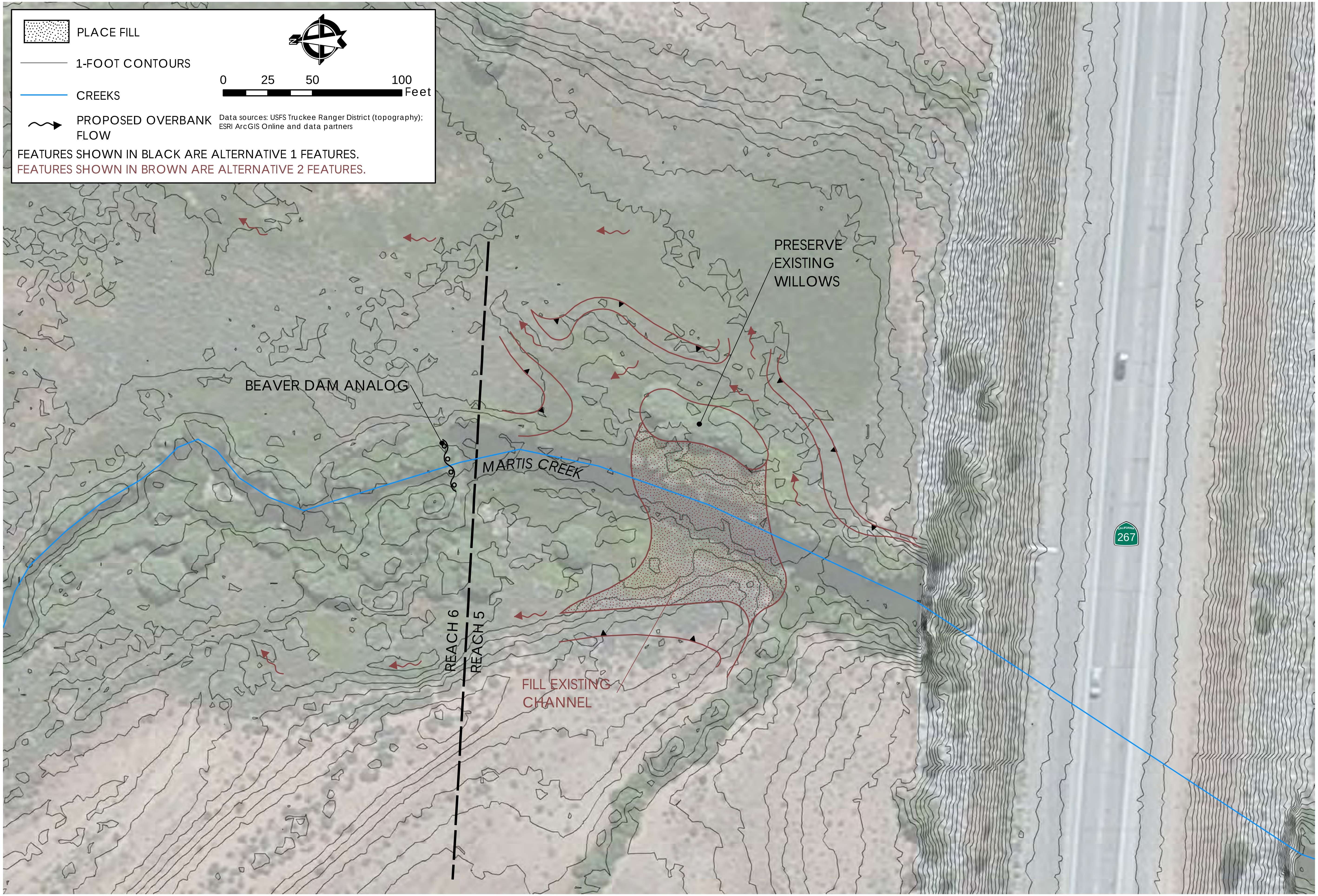
PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063

SCALE 1" = 50'

SHEET

2.8



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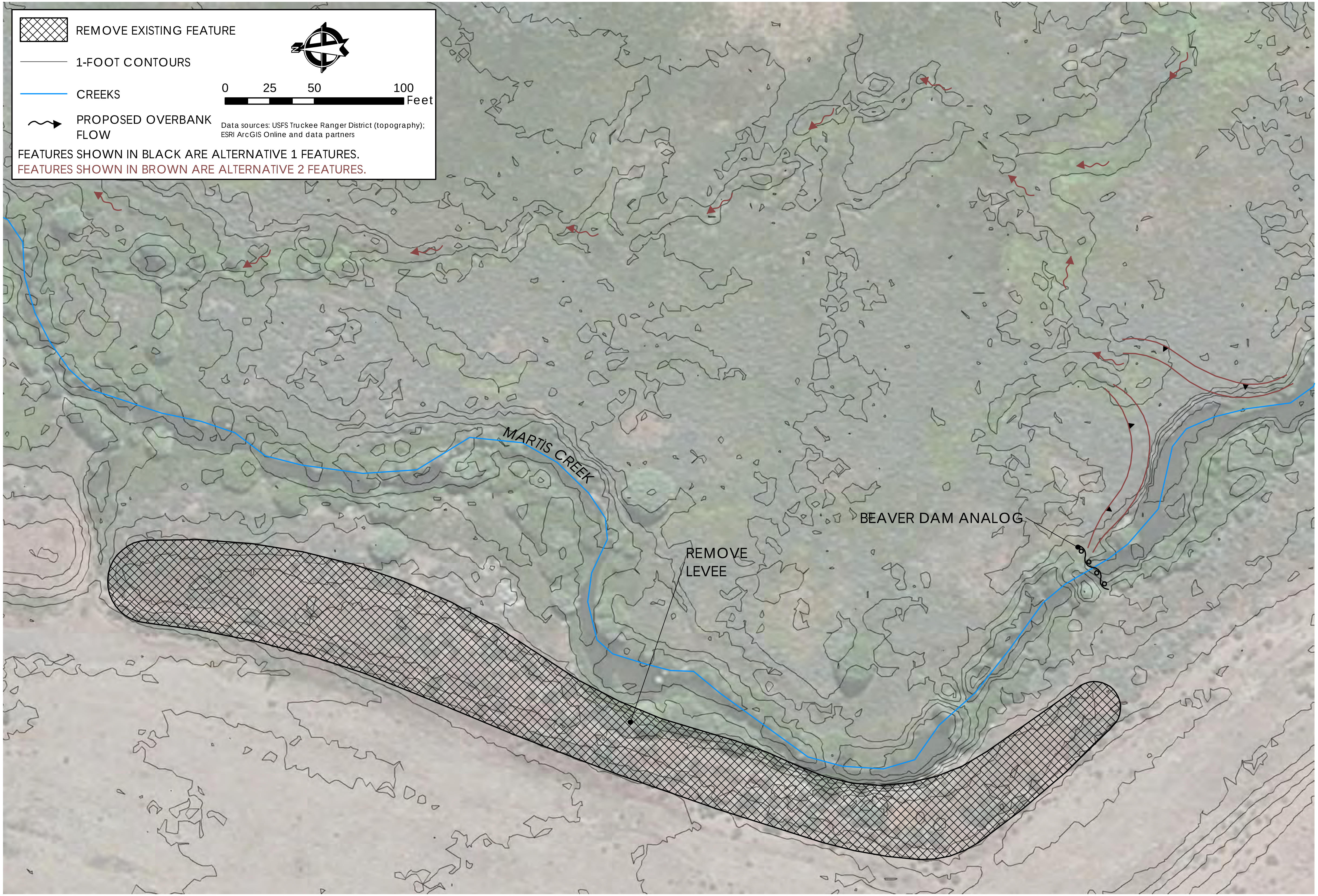
LOWER REACH 5 / UPPER REACH 6

MAINSTEM MARTIS CREEK RESTORATION

PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063
SCALE 1" = 50'
SHEET
2.9



SEE SHEET 2.9

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DATE 5-18-16

LOWER REACH 6

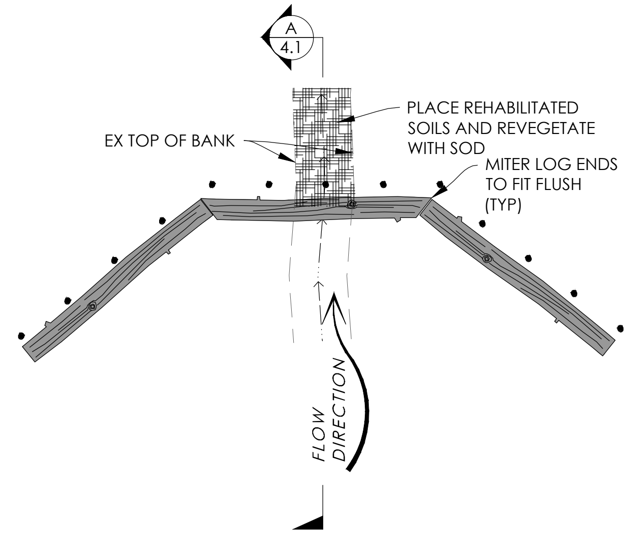
MAINSTEM MARTIS CREEK RESTORATION

PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

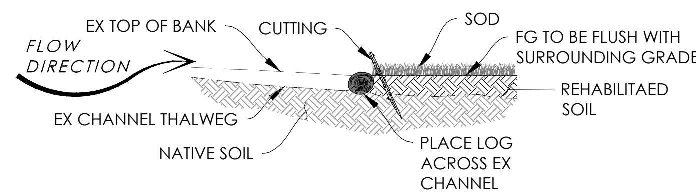
PROJECT NUMBER
215063

SCALE
1" = 50'

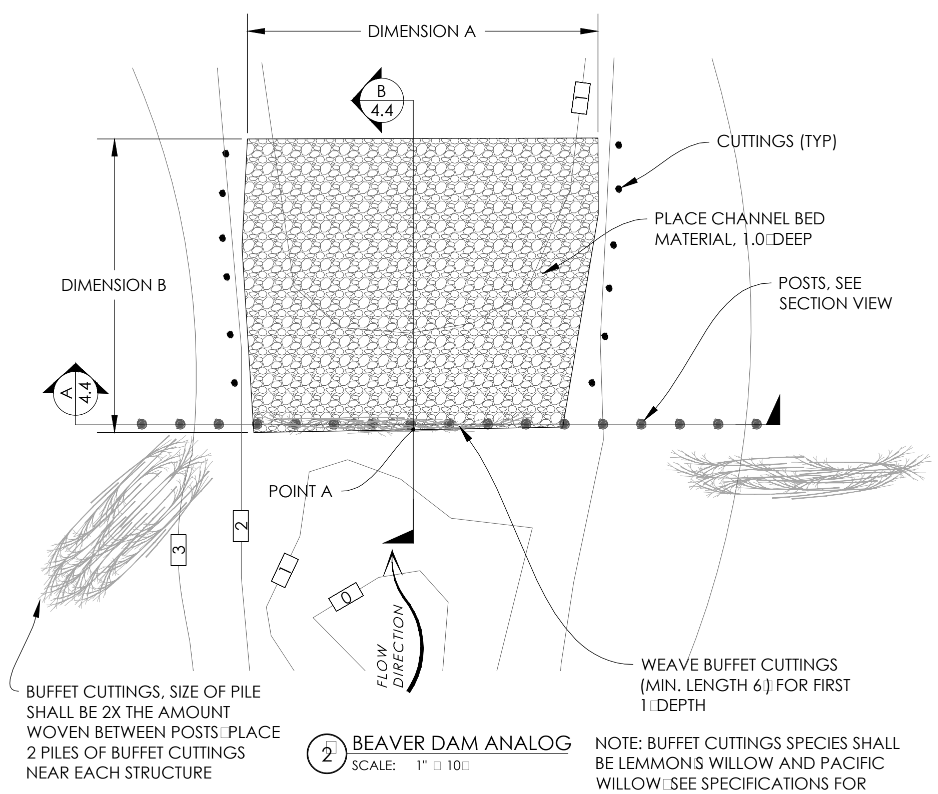
SHEET
2.10



1 BURIED LOG GRADE CONTROL
SCALE: 1" □ 10□

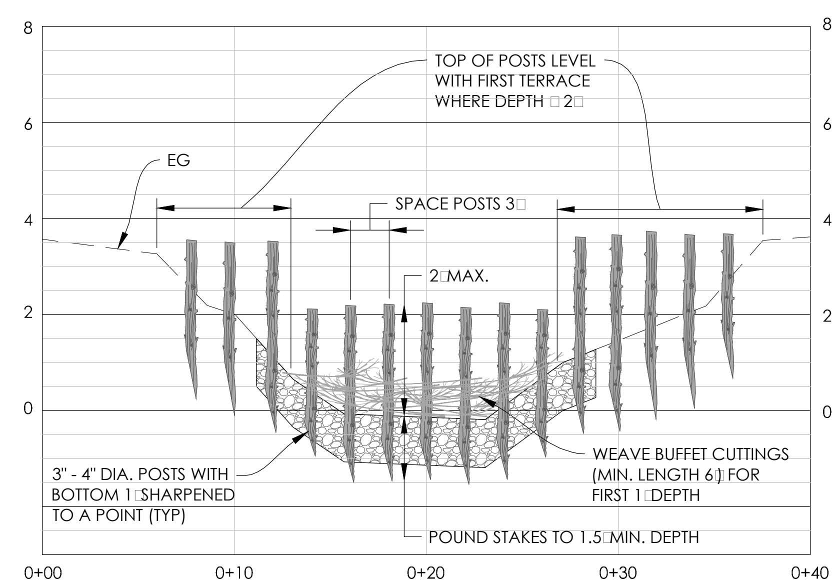


BURIED LOG GRADE CONTROL
PROFILE VIEW
1" □ 10□ A 3.0

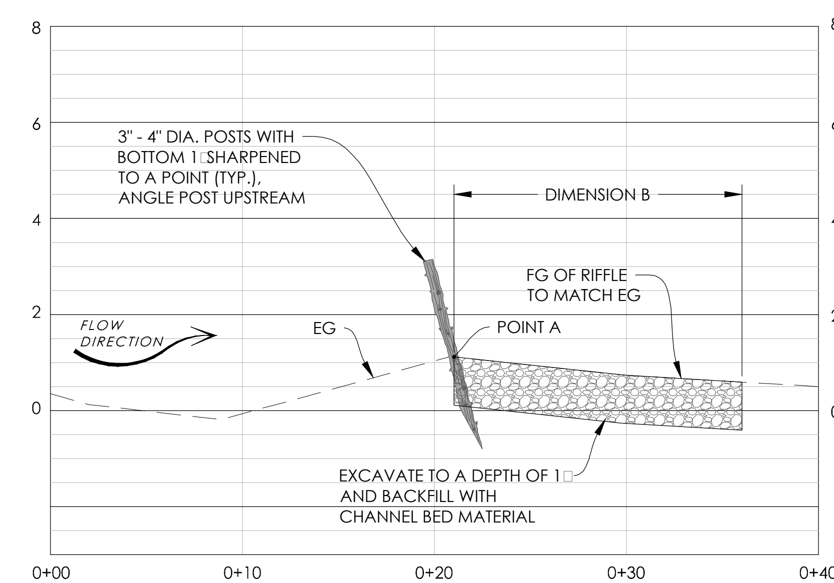


2 BEAVER DAM ANALOG
SCALE: 1" □ 10□

NOTE: BUFFET CUTTINGS SPECIES SHALL BE LEMMON□S WILLOW AND PACIFIC WILLOW□SEE SPECIFICATIONS FOR ADDITIONAL INFORMATION



BEAVER DAM ANALOG
SECTION VIEW
1" □ 10□(H)□1" □ 4□(V) A 3.0



BEAVER DAM ANALOG
PROFILE VIEW
1" □ 10□(H)□1 □□ 4□(V) B 3.0

CONCEPTUAL PLANS - NOT FOR CONSTRUCTION

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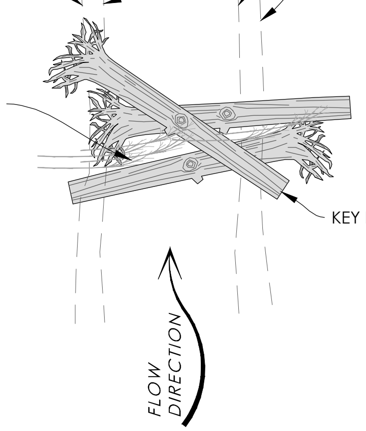
CHECKED BY D SHAW
IN CHARGE
DATE 6-10-16

DETAILS 1

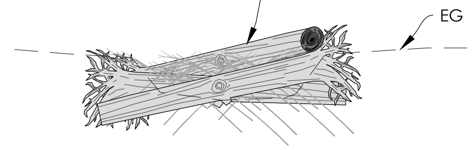
MAINSTEM MARTIS CREEK RESTORATION

PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

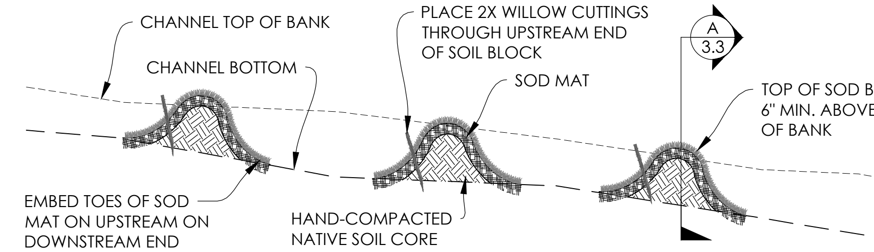
PROJECT NUMBER 215063
SCALE --
SHEET
3.0



(1) INSTREAM WOOD JAM
SCALE: 1" □ 10□



INSTREAM WOOD JAM
CROSS SECTION VIEW 1" □ 10□ A/3.1



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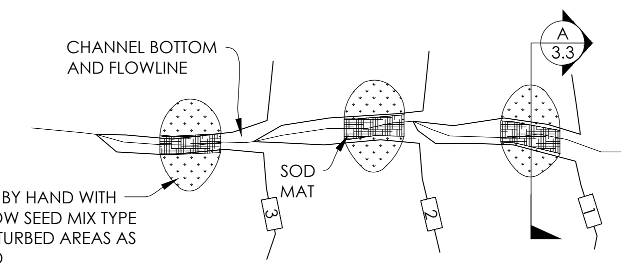

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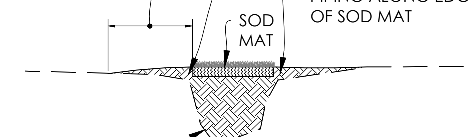

SOD BLOCK
SECTION VIEW 1" □ 10□ A/3.1

PREPARED FOR:
Truckee River Watershed Council

Balance Hydrologics, Inc.
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www.balancehydro.com

DATE	BY	SUBMITTALS / REVISIONS
11-17-15	BKH	CONCEPTUAL PLANS
6-10-16	BKH	FINAL CONCEPTUAL PLANS

DESIGNED BY B HASTINGS
DRAWN BY P KULCHAWIK
CHECKED BY D SHAW
IN CHARGE
DATE 6-10-16

DETAILS 2

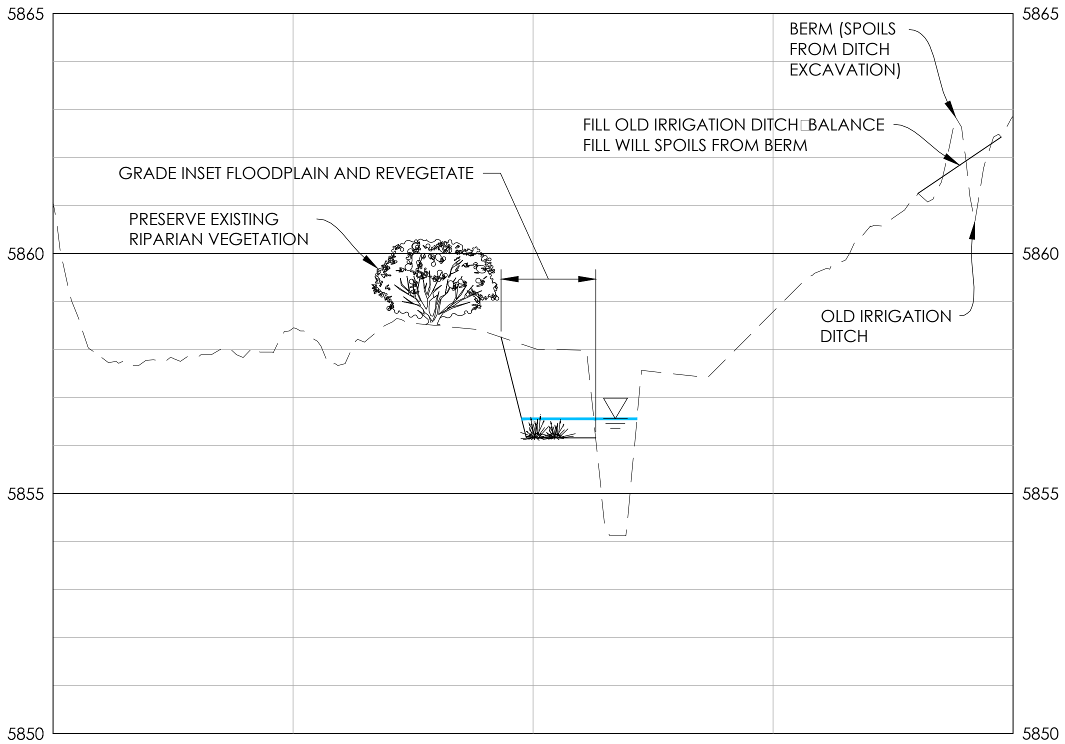
MAINSTEM MARTIS CREEK RESTORATION

PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063
SCALE --
SHEET 3.1

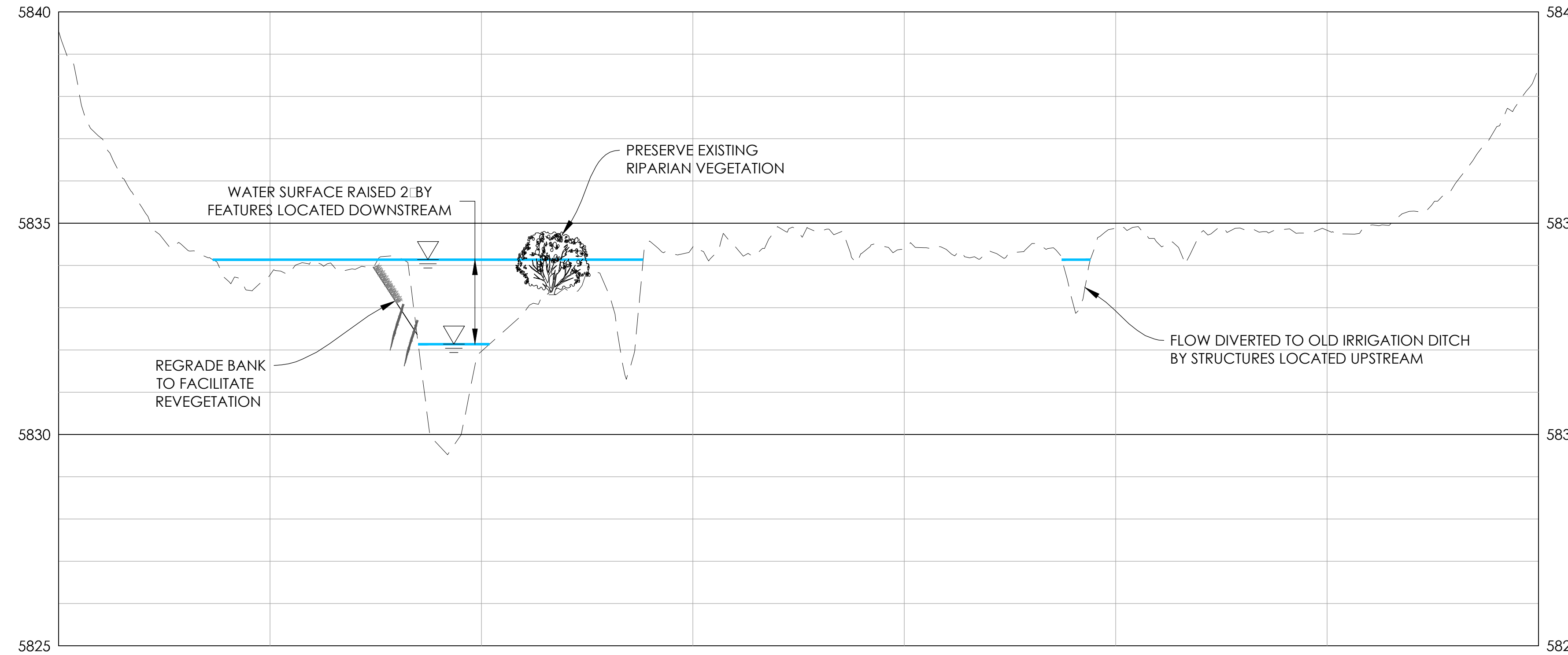
Y:_PROJECTS\215063 MAINSTEM MARTIS RESTORATION\215063 CAD\SHEETS\215063-0301-DETAILS.DWG

CONCEPTUAL PLANS - NOT FOR CONSTRUCTION



REACH 1

HEC-RAS SECTION □15287 1" □ 40□(H)□1□□ 2□(V)



REACH 3

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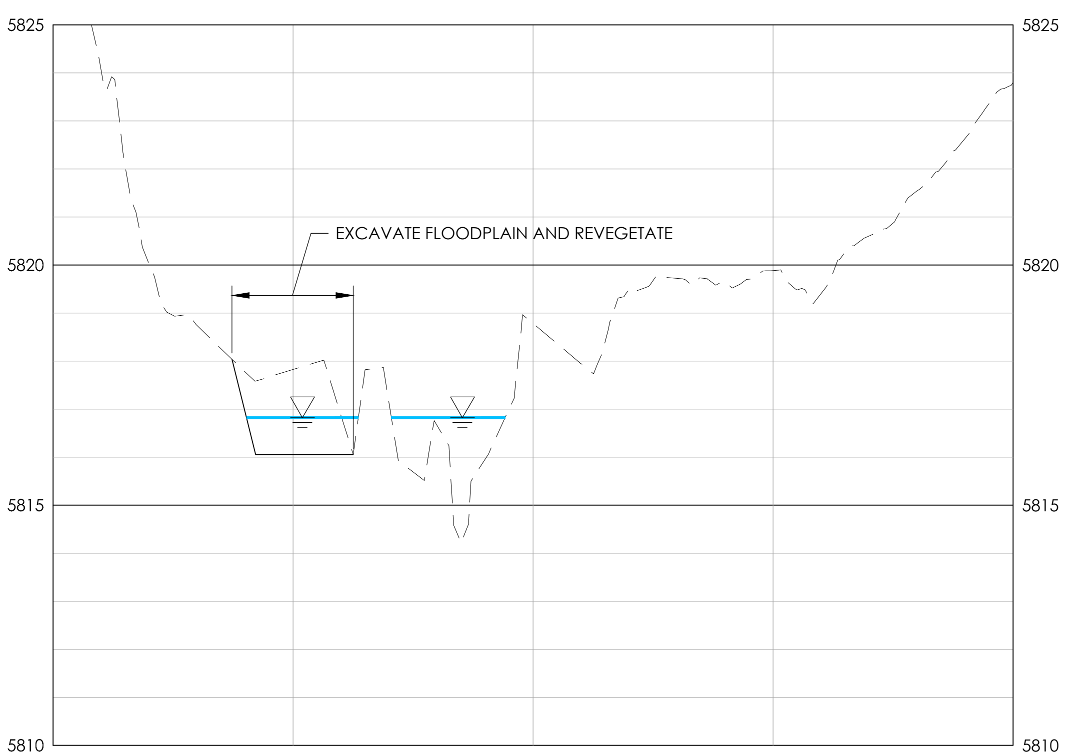

REACH 4

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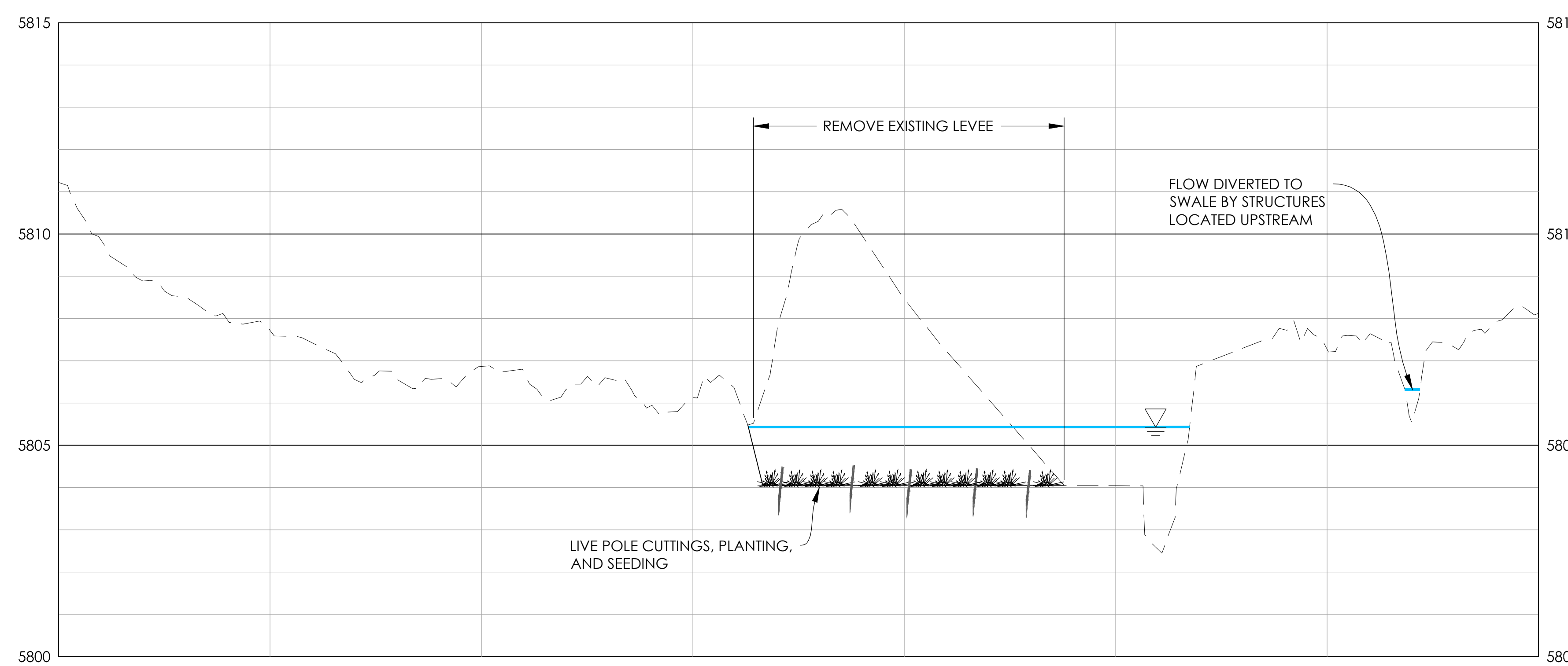

REACH 6

HEC-RAS SECTION □4632 1" □ 40□(H)□1□□ 2□(V)

NOTES:
1. ALL WATER SURFACE ELEVATIONS ESTIMATE THE PEAK OF THE ANNUAL FLOOD (85 CFS) AS SIMULATED BY THE HYDRAULIC MODEL.

CONCEPTUAL PLANS - NOT FOR CONSTRUCTION

Y:_PROJECTS\215063 MAINSTEM MARTIS RESTORATION\215063 CAD\SHEETS\215063-0302-CROSS_SECTION.DWG

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CROSS SECTION VIEWS

MAINSTEM MARTIS CREEK RESTORATION

PLACER COUNTY, CALIFORNIA
TRUCKEE RIVER WATERSHED COUNCIL

PROJECT NUMBER 215063
SCALE --
SHEET
3.2

APPENDIX B

Captioned Photographs of Project Area

Beaver-influenced meadow inundation, Lahontan Golf Club and Community (upstream of project reach)

Incised channel and bank erosion, Mainstem Martis Creek, Reach 1


Incised channel with active bank widening and erosion, Mainstem Martis Creek, Reach 1

Abandoned point of diversion to irrigation ditch, Mainstem Martis Creek, Reach 1

Abandoned irrigation ditch, Mainstem Martis Creek, Reach 1

Incised and widening channel, Mainstem Martis Creek, Reach 1

Abandoned diversion structure, Mainstem Martis Creek, Reach 1

Abandoned diversion structure, Mainstem Martis Creek, Reach 1

Abandoned irrigation ditch, Mainstem Martis Creek, Reach 1

Abandoned irrigation ditch, Mainstem Martis Creek, Reach 1

Unofficial footbridge/trail and bank erosion, Mainstem Martis Creek, Reach 1

Unofficial footbridge/trail and bank erosion, Mainstem Martis Creek, Reach 1

Instream wood recruitement, Mainstem Martis Creek, Reach 1

Instream wood jam, Mainstem Martis Creek, Reach 2

Active beaver dam, Mainstem Martis Creek, Reach 2

Active beaver dam, Mainstem Martis Creek, Reach 2

Inundation from active beaver dam, Mainstem Martis Creek, Reach 2

Inundation from active beaver dam, Mainstem Martis Creek, Reach 2

Active bank erosion, Mainstem Martis Creek, Reach 3

Secondary channel/swale, Mainstem Martis Creek, Reach 3

Abandoned floodplain, Mainstem Martis Creek at 50 cfs, Reach 3

Abandoned floodplain channel, meadow conversion, Mainstem Martis Creek, Reach 3

50 cfs, flow confined to a single channel, Mainstem Martis Creek, Reach 3

50 cfs, flow confined to a single channel, Mainstem Martis Creek, Reach 3

Inset floodplain, Mainstem Martis Creek, Reach 4

Bank erosion and meadow conversion, Mainstem Martis Creek, Reach 4

Active bank erosion, widening and meadow conversion, Mainstem Martis Creek, Reach 4

Knickpiont erosion, swale tributary to Mainstem Martis Creek, Reach 4

Inset floodplain, Mainstem Martis Creek, Reach 4

Bank erosion and widening, Mainstem Martis Creek, Reach 4

Incised channel with active bank erosion, Mainstem Martis Creek, Reach 4

High-flow meadow swale, Mainstem Martis Creek, Reach 4

Former channel crossing, Mainstem Martis Creek, Reach 5

Former channel crossing, Mainstem Martis Creek, Reach 5

Rip-rap bank protection, Mainstem Martis Creek, Reach 5

Inset floodplain, Mainstem Martis Creek, Reach 5

Inset floodplain, Mainstem Martis Creek, Reach 5

Future Martis Trail crossing, Mainstem Martis Creek, Reach 5

Levee and channel straightening, Mainstem Martis Creek, Reach 5

Straightened channel segment, Mainstem Martis Creek, Reach 5

Active bank erosion, channel confined by levee on left bank, Mainstem Martis Creek, Reach 6

Levee, Mainstem Martis Creek, Reach 6

APPENDIX C

Non-Lethal Options for Mitigating Unwanted Effects of Beaver (from Castro and others, 2015)

Chapter 9—Non-lethal Options for Mitigating the Unwanted Effects of Beaver

Michael M. Pollock and Greg Lewallen

Beaver activities that conflict with human interests generally fall into two categories:—tree cutting and dam building—and potentially problematic dams can be further divided into dams that block culverts or irrigation canals and dams that do not. Historically, in many states and provinces throughout North America, lethal removal of beaver has been the method of choice for solving such beaver/human conflicts, but more interest in non-lethal approaches has been growing.

Non-lethal approaches have gained popularity for a number or reasons, including the following:

- Non-lethal management is more effective and less costly than lethal removal (Callahan 2005, Simon 2006, Boyles and Savitzky 2008).
- The public is becoming increasingly dissatisfied with lethal removal, in part because of concerns that trapping and drowning or bludgeoning beaver is not humane (IAFWA 1997, AVMA 2000, Hadidian 2003).
- There is growing demand for live beaver, because of organizations' and agencies' renewed interest in re-introducing beaver to locations where they can provide environmental benefits (Apple 1985, Boyle and Owens 2007, Pollock 2012) (Olsen and Hubert 1994, McKinstry et al. 2001).

Non-lethal approaches to solving the major sources of human-beaver conflict are summarized below.

Tree Cutting

Beaver can travel up to 328 feet (100 meters) from a water body to cut and harvest trees, but the probability of harvest decreases exponentially with distance from water (Rutherford 1955, Allen 1983, Gallant et al. 2004). Although beaver generally prefer species in the genera *Populus* or *Salix* (cottonwood, aspen, and willow), they will harvest a wide range of trees and shrubs (reviewed in Boyle and Olsen 2007 and Baker and Hill 2003). Beaver also use the base of large trees of both palatable and unpalatable species as gnawing stations; gnawing can lead to the tree's ultimate demise. As in all burrowing rodents, beaver teeth grow continuously and thus need to be continually worn down, which is done primarily by gnawing on wood.

Solution: Wire Mesh Cages

There is little in the way of peer-reviewed literature on non-lethal methods for preventing beaver from cutting trees, but an extensive review of technical information from various government and private organization websites suggests that surrounding trees with a cylindrical wire mesh cage is the simplest, most effective means of preventing a beaver from cutting down a tree (Figure 39) (e.g. beaversolutions.com, APNM.org, beaversww.org, martinezbeavers.org, www.kingcounty.gov/environment/animalsAndPlants/beavers). Cage specifications vary slightly, but recommendations generally are as follows:

- Wire mesh gauge should be reasonably heavy (e.g., 6 gauge) to prevent beaver from chewing through it. Chicken wire is not recommended.
- Mesh size should be 6 x 6 inches or smaller.
- The cage should be 1 to 2 feet in diameter larger than the tree trunk.
- The cage should extend 3 to 4 feet above the ground or, in colder climates, above the anticipated snow line.
- Wire fencing can be used to encircle multiple trees.

One of this guidebook's authors (Pollock) has noted the effectiveness of exclosure cages using these specifications at various field sites. Not all cages were 100 percent effective. In some cases beaver managed to harvest trees inside of exclosures, presumably by climbing the cages.

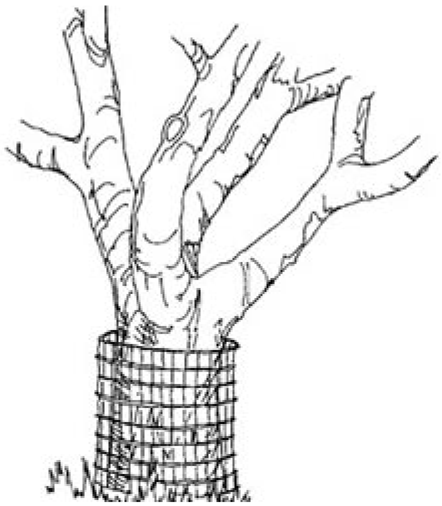
Solution: Paint Mixed with Sand

A number of websites and bulletins also suggest that paint mixed with sand is effective, although repeated application is required. For example, beaversww.org recommends a mixture of 8 ounces (227 grams) of fine sand (30-mil, 70-mil, or masonry sand) mixed with 1 quart (0.94 liter) of oil or latex paint, matched to the color of the tree trunk and painted to 4 feet above ground. Placement of 3- to 4-foot-high fences between streams and the trees that need protecting has also been suggested, presuming that beaver won't travel long distances on the upland side of the fence because they are exposed to predation. Electric fences strung 4 to 6 inches above the ground have also been suggested. We could find no data assessing the effectiveness of these approaches.

Other Approaches

Techniques such as chemical deterrents were considered to be marginally effective because they work only for a few months at most and repeat application is needed. Techniques such as noise and flashing lights appear to deter beaver for a few days at most (Nolte et al. 2003, Kimball and Perry 2008).

(a)



(b)

(c)

Figure 39a-c: Illustrations of a wire cage for protecting trees against beaver. Note that all three examples show caging that is too close to the trunk of the tree, with (c) showing the inevitable result of such a miscalculation.

Flooding Problems

Solution: Flexible Pond Levelers

Where beaver dams raise water levels enough to cause unwanted flooding, a large-diameter flexible pipe inserted horizontally through the dam in combination with a vertical cylindrical wire cage to protect the upstream pipe end from being dammed has also proven highly effective in permanently lowering water levels behind a beaver dam (Figures 40 and 41). Such devices are generically referred to as “flexible pond levelers,” “flex levelers,” “pond levelers,” or “water level control devices.” Callahan (2003) examined the effectiveness of 116 flexible pond levelers on free-standing dams that were causing conflicts with humans but that were not associated with human infrastructure such as culverts. He found that installation of flexible pond levelers resolved human-beaver conflicts 83 percent of the time.

Figure 40: Flexible pond levelers with cylindrical wire cages on the upstream pipe end. Clockwise from upper left (a) and (b) are examples during the construction phase, while (c) is an example just after completion but before dam repair. (b) is a downstream view of a pond leveler after beaver have repaired the dam. Photographs from Boyle (2006).

When the conflict was not resolved, the failure most commonly was attributed to the beaver constructing dams downstream of the installation site; this was the case in 75 percent of the sites where the conflict was not resolved. The few remaining failures were due to vandalism or insufficient pipe capacity.

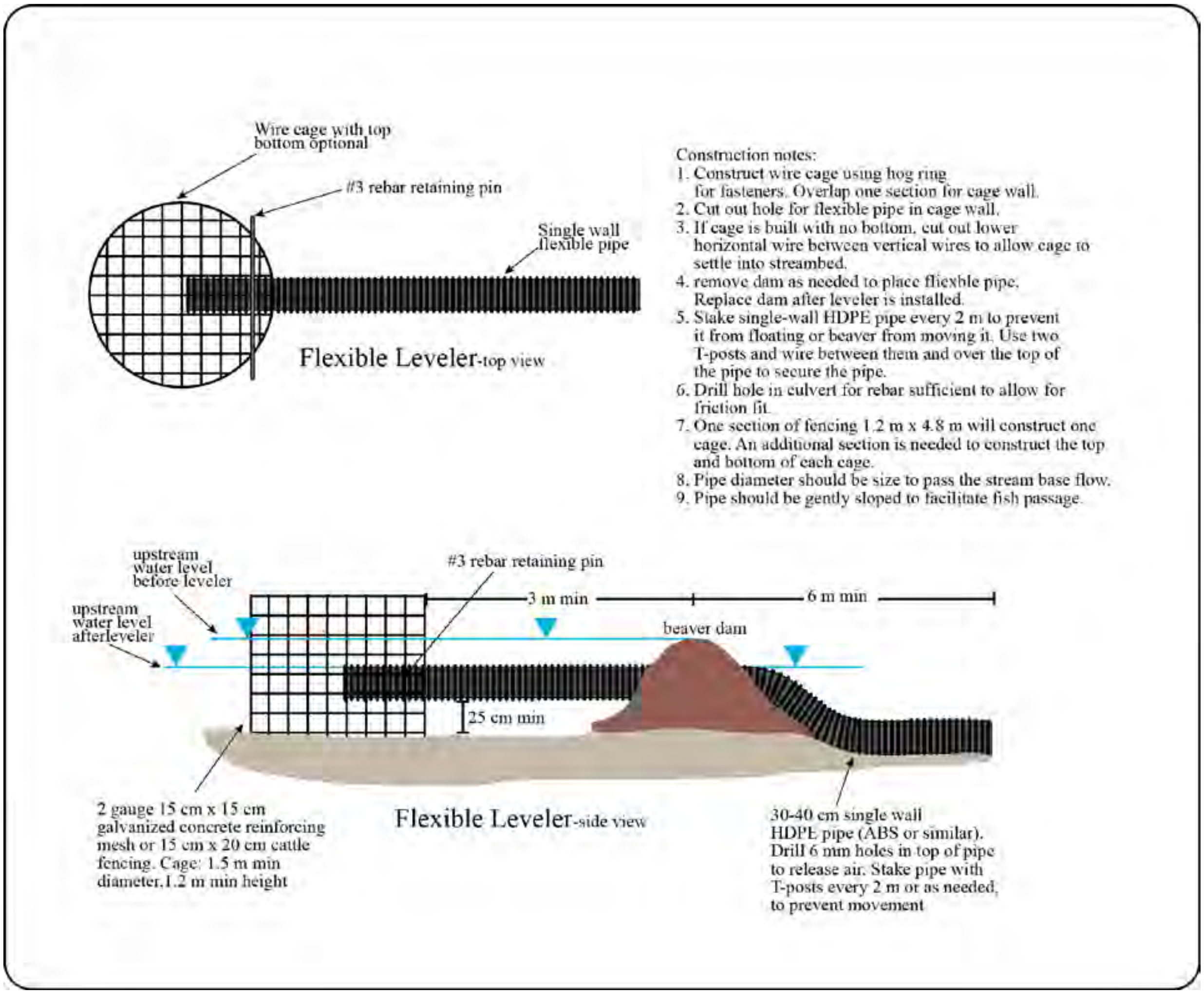


Figure 41: Design specifications for a flexible pond leveler that is used to adjust beaver pond water levels to an acceptable level when there is unwanted flooding. The design allows some pond habitat to remain and is passable to adult salmon. Figure adapted from a design provided by Jake Jacobsen, Snohomish County, Washington Public Works Department, Jacobsen (2010).

Solution: Clemson Leveler

Another popular method of controlling beaver pond levels and preventing culvert plugging is known as a "Clemson leveler." This is a perforated polyvinyl chloride (PVC) pipe whose upstream end is wrapped in wire mesh fencing; the pipe is then inserted horizontally through the dam (see Figure 42). Reported success rates with the Clemson leveler are only about 50 percent (Nolte et al. 2000).

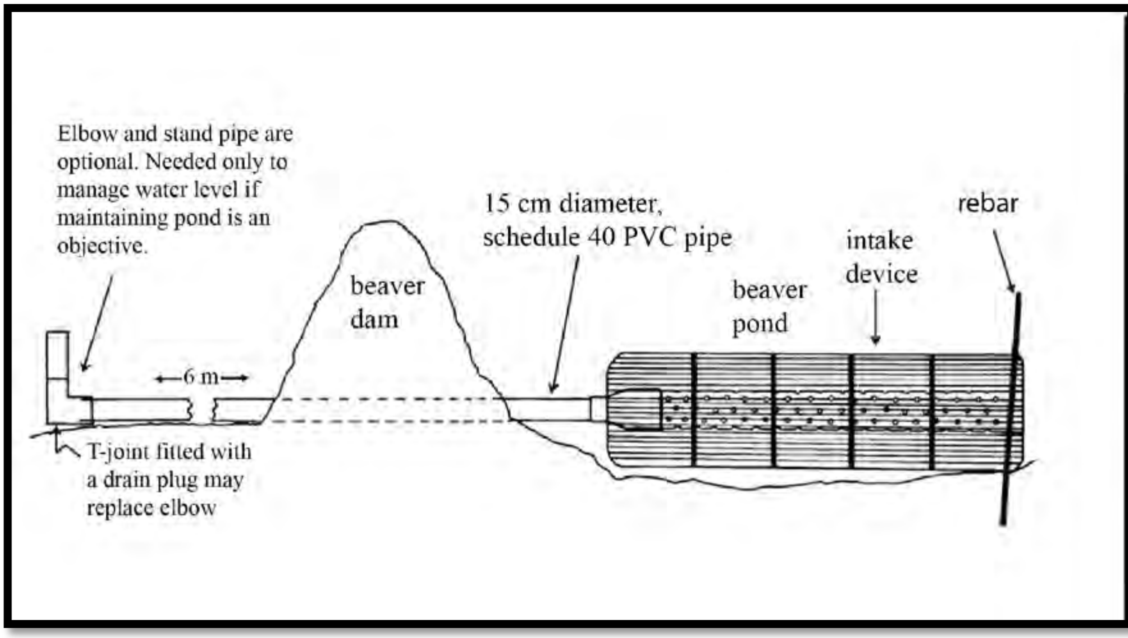


Figure 42: A Clemson leveler-style device is not fish-friendly. The small mesh size, the pipe perforations, an end cap at the upstream end of the pipe, and an elbow on the downstream end are all features that make it challenging for fish to move upstream or downstream. Adapted from Wood et al. (1994).

Other Approaches

More extreme measures, such as the use of heavy equipment or dynamite to remove problem beaver dams have produced mixed results (Dyer and Rowell 1985). Enthusiasm for such approaches seems to be on the decline, presumably because of associated environmental impacts to fish, wildlife, and water resources.

Culvert Blocking

Solution: Culvert-Protective Fencing

Considerable research has gone into the development of non-lethal solutions to the widespread problem of beaver damming culvert inlets and flooding roads. Several studies have evaluated a range of options and found a highly cost-effective solution to be heavy-duty (i.e., 2- to 6-gauge) cattle panel wire mesh fencing installed in a rectangular or trapezoidal configuration upstream of the culvert (see Figure 43) (Jensen et al. 1999, Jensen et al. 2001, Callahan 2003, Boyles 2006, Simon 2006, Boyles and Savitzky 2008).

In Virginia, Boyles (2006) compared the cost of installing and maintaining fencing upstream of culverts with the cost of removing beaver and conducting associated road maintenance and repairs. Boyles found that before fencing was installed, the average annual cost for 14 road maintenance sites with beaver activity was $21,500, compared to $3,200 after culvert fencing was installed. Callahan (2003) extensively examined the effectiveness of culvert protection fences in New England. Out of 131 sites, 126 (96 percent) effectively prevented beaver from damming the culverts. Two sites failed because the entire fence was dammed by beaver, two others failed because proper maintenance was not performed, and another site was considered a failure because a new dam was constructed downstream. Callahan estimated that the average cost of the culvert-protective fences was $654, with an expected life span of 10 years and an average maintenance time of 1 hour per year for an annualized cost of $190 per year (in 2003 dollars). Both of these studies included culverts with protective-fences and pond levelers because of concerns that the fencing, if partially dammed, would provide insufficient flow capacity.

Similarly, in the Pacific Northwest, some observations suggest that culvert-protective fencing alone accumulated enough debris during floods to raise concerns about adult salmon passage, although no data were collected (Jake Jacobsen, Snohomish County Public Works, personal communication). Therefore, pond levelers were installed at some culverts—in conjunction with fencing—to alleviate fish passage concerns.

Simon (2006) expanded upon Callahan's study, examining the effectiveness of various beaver management strategies at 482 sites. Simon found that culvert-protective fences, some of which included pond levelers, were effective 97 percent of the time (at 220 out of 227 sites). Pond levelers not associated with roads were successful 87 percent of the time, cylindrical fences attached to the inlet of culverts were successful 60 percent of the time, and lethal removal by trapping was successful just 16 percent of the time because other beaver quickly occupied the site. Simon found the 10-year annualized installation and maintenance costs of culvert fences, culvert fences with pond levelers, and pond levelers to be $275, $290, and $200, respectively.

Figure 43: Examples of culvert-protective fences. From left to right: (a) and (b) are stand-alone culvert-protective fences, while (c) is a stand-alone fence combined with a flexible pond leveler pipe (underwater and not visible) and a cylindrical wire mesh cage, which provides extra protection against obstruction. Figures from Boyle (2006).

Solution: Right-Sizing Culverts

The right-sizing of culverts is another approach that has been advocated to reduce beaver/road conflicts. Many culverts are undersized or contain design elements that are attractive to beaver. Jensen and Curtis (1999) comprehensively examined factors correlated with beaver damming culverts on streams in New York. On streams with a 3 percent gradient or less they found that the frequency of culvert plugging by beaver decreased exponentially as the culvert inlet opening increased in size, and that size was the most important predictor of culvert plugging (Figure 44). Culverts with an 8.6-square-feet inlet area (i.e., 3.3 feet in diameter) had a 73 percent chance of being plugged by beaver, whereas culverts with a 113 square-foot opening (i.e., 12 feet in diameter) had a 7 percent chance of being plugged.

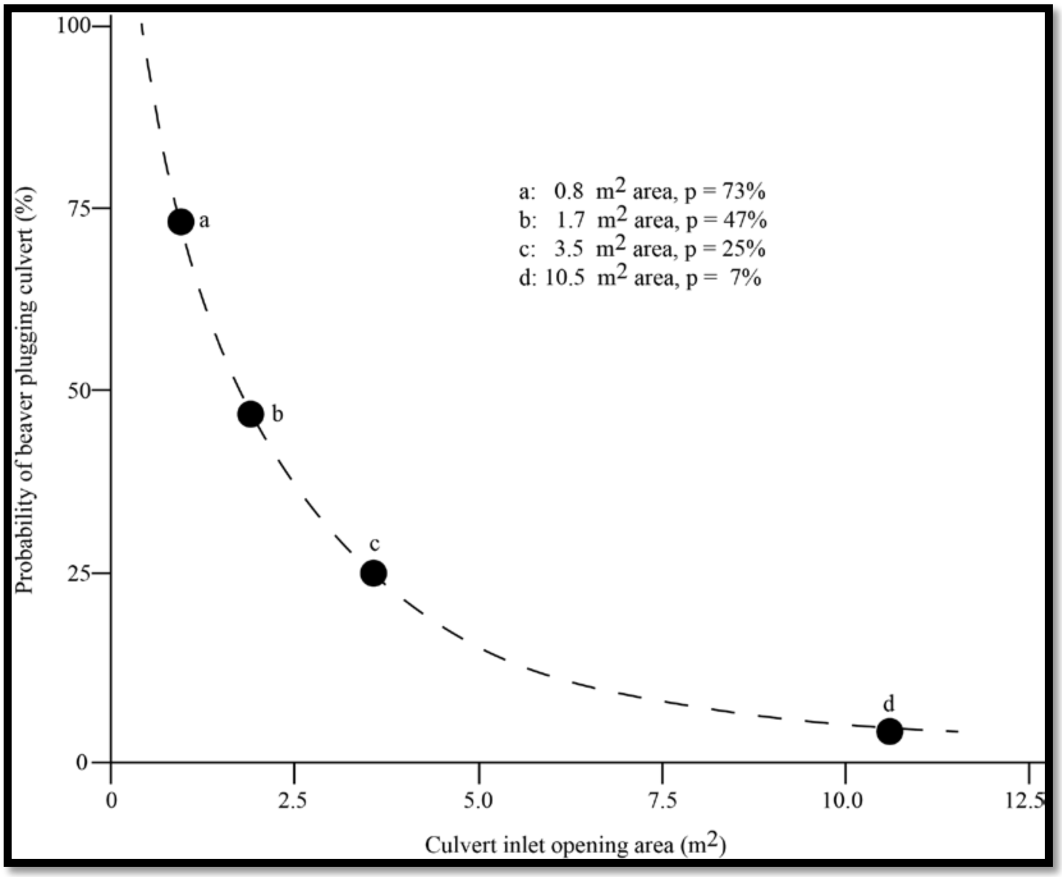


Figure 44: Relationship between the size of a culvert opening and the probability that beaver will plug the culvert, for streams < 3% gradient in New York (adapted from Jensen and Curtis 1999). For reference, the areas of the culvert openings for a, b, c and d approximately correspond to circular culverts with diameters of 3 ft, 5 ft, 7 ft and 12 ft, respectively.

Jensen and Curtis (1999) also found that pipe arch culverts that maintain the stream width are less likely than round culverts to be plugged by beaver. They speculated that round culverts are more attractive to beaver in part because they channel water and reduce stream width; Jensen and Curtis found that, on average, stream width at plugged culverts was twice the width of the culvert inlet opening. Jensen and Curtis thought that round culverts may also generate flow noise that attracts beaver but found that the frequency of plugging did not differ between smooth-walled and corrugated pipes. They further found that culverts that extended beyond the road prism were no more likely to be plugged than culverts that were flush with the road prism. Jensen and Curtis also examined the annualized costs of replacing small culverts with larger ones and found that annualized costs for various pipe arch and box culverts with 10.5-square-meter openings ranged from $881 to $1,717 (1999 dollars), about three to six times the annualized costs estimated by Simon (2006) for culvert-protective fences with pond levelers. There are other potential benefits to using large culverts (with natural streambed bottoms) that should be considered, including improved passage of fish, wildlife, sediment, and organic matter, as well as increased stream habitat.

Fish Passage through Culvert-Protective Fences and Pond Levelers

There is little published research on how pond levelers or culvert-protective fences affect fish passage. A fence with a small mesh size will impede migrating adult salmon. The only study we could find that mentioned mesh size in the context of fish passage was Hall et al. (2005). In their study on the Skagit River, Washington, Hall et al. found that numerous chum salmon (*O. keta*) were able to volitionally pass through a flexible horizontal pipe that had a vertical cylindrical wire cage with 10 x 15-centimeter meshing attached to the upper end. In Snohomish County, just north of Seattle, the Public Works Department built more than 50 flexible levelers using 10 x 15-centimeter mesh or 15 cm x 20-centimeter mesh, which they considered “fish friendly.” Although they did not do a formal study, repeated site visits during the fall when adult salmon migrate never revealed a fish blockage problem and spawning fish were observed upstream of many sites (Jake Jacobsen, Snohomish County Public Works, personal communication).

The mesh size of Clemson levelers is typically too small to pass adult salmon. Mesh sizes ranging from 1 x 2 inches to 2 x 4 iches have been recommended (Wood et al. 1994, Langlois and Decker 1997, Brown 2001, MDNR 2001). Typical pipe diameters for Clemson-style levelers are 7.9 to 9.85 inches, and the levelers may be 20 feet long or longer, which can present an obstacle to the upstream movement of large fish such as adult salmon, particularly if the pipe is capped as is often suggested (Wood et al. 1994, Langlois and Decker 1997, Brown 2001, MDNR 2001). Close (2003) was able to modify a Clemson-style pond leveler on a stream in Minnesota to allow passage of 10 brook trout ranging in length from 6 to 8.6 iches, a size still much smaller than most adult salmon.

Numerous pond levelers and other devices designed to mitigate human-beaver conflicts are described in Gerich (2004). However, many of these devices, such as beaver exclusion fencing with perforated pipes, array piping, pond drain pipes, and wire mesh culverts, appear impassable to fish. Also included are a number of designs for various fencing and pond leveler combinations that appear to be passable to fish.

The movement of both adult and juvenile fish across pond levelers may also be impeded by the placement of the downstream end of the pipe. A number of pond leveler diagrams (particularly for Clemson-type levelers with rigid pipe), have the pipe perched above the streambed on the downstream end. This presents a clear passage obstacle for fish. The location of flexible leveler pipes can also present problems if the outlet is placed in a riffle rather than a pool, or if the outlet is too far downstream of the dam and migrating fish are unable to find the opening. Placing the outlet of a flexible leveler in a pool, with the outlet close to the face of the dam, minimizes fish passage problems.