Appendix 7A Fluvial Geomorphic Setting Information

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7A.1 Introduction

This appendix provides detailed fluvial geomorphic setting information for the watercourses and other waterbodies in the study area. The study area for fluvial geomorphology consists of the local drainages associated with the Sites Reservoir (e.g., Funks, Stone Corral, and Hunters Creeks), as well as downstream waterbodies such as the Sacramento River, CBD, Delta, and Yolo Bypass. Figures 1-1, 1-2, and 1-3 identify these various locations.

7A.2 Drainages in Proximity to Antelope Valley

7A.2.2 Geologic and Topographic Setting

The geologic setting of the Antelope Valley is based on the geologic technical memorandum prepared for the dams and reservoir portion of the Project (AECOM 2020:6–7). The geologic framework is important for understanding the landforms and potential geomorphic processes operating in the Antelope Valley.

The Antelope Valley and surrounding hills are underlain by Upper Cretaceous sedimentary rocks of the Great Valley sequence (Cortina and Boxer Formations) and alluvium (Figure 12-1A in Chapter 12, *Geology and Soils*). Within the Cortina and Boxer Formations, the two primary rock units are sandstone and mudstone, with some interbedding of these two units occurring to varying degrees. The primarily sandstone portions are commonly ridge-formers, and the primarily mudstone portions are generally expressed as topographic lows. Downslope of the reservoir (in the areas with flatter topography, Figure 12-1B), surficial geologic units include Pliocene-age deposits of the Tehama Formation, the Quaternary alluvial terrace deposit (the Riverbank and Modesto Formations), alluvium, and Basin Deposits.

7A.2.3 Drainage Geomorphic Characteristics

The geomorphic characteristics of the creeks upstream and within Antelope Valley, as well as those downstream of the valley, are described below.

7A.2.3.2 Upstream and Within Antelope Valley

Upstream of Sites Reservoir and within its footprint, the creeks discussed below (Grapevine, Antelope, Funk, Stone Corral, and Hunters Creeks) (Figure 1-3) are incised (entrenched), ephemeral channels (U.S. Bureau of Reclamation and California Department of Water Resources 2013:4-12) that frequently experience low to no flows in the summer. They closely resemble “dry washes” in their lower reaches in Antelope Valley. Eroding cutbanks are common and the channels all appear to be somewhat degraded as a result of direct trampling by cattle. Water depths are most likely minimal, based on the abundant algal presence in the channels upstream and within Antelope Valley as visible on aerial imagery at select time intervals.

Grapevine Creek

Grapevine Creek is an ephemeral watercourse with a slightly sinuous[1] planform (sinuosity of 1.3). A tributary to Funks Creek, it flows north/northeast for approximately 14.5 miles until its confluence with Funks Creek. Most of Grapevine Creek is extensively confined by the surrounding valley walls. Various unnamed swales and ephemeral drainages join Grapevine Creek at different locations, the largest of which occurs close to the Sites Lodoga Road.

Habitat unit mapping in 1999 on Grapevine Creek (between its confluence with Funks Creek and the reservoir inundation boundary) showed primarily pool habitat in the creek. Small cobble and gravel were the most common substrate, and banks were composed primarily of silt and clay with star thistle (*Centaurea* sp.) and grasses as the dominant bank vegetation types. (Brown 2000:35–36.)

Antelope Creek

From its confluence with Calvins Creek in the Blanchard Valley (southwest of the proposed reservoir), Antelope Creek flows through the southern part of the Antelope Valley for approximately 9.9 miles and joins Stone Corral Creek near the community of Sites. It is an ephemeral watercourse with a slightly sinuous planform (sinuosity of 1.3). Numerous unnamed swales and ephemeral drainages join up with Stone Corral Creek from the west.

Habitat unit mapping in 1999 on Antelope Creek (between its confluence with Stone Corral Creek to the reservoir inundation boundary) showed primarily flatwater habitat in the creek with minimal riffle habitat. Silt and clay were the most common substrates, and banks were also composed primarily of silt and clay with star thistle and grasses as the dominant bank vegetation types. (Brown 2000:39–40.)

Riparian vegetation is scarce or absent in many locales, although well-developed, native riparian vegetation occurs in small remnant patches along Antelope Creek in the southern portion of the inundation area.

Funks Creek

After its headwater tributaries converge northwest of the reservoir footprint, Funks Creek flows in a southeasterly direction for approximately 3.7 miles until its confluence with Grapevine Creek. The distance between this confluence location and the Golden Gate Dam is approximately 5.4 miles. Funks Creek appears to transition from an ephemeral watercourse in its headwaters to possibly an intermittent watercourse (in its lower reaches of Antelope Valley), with an overall slightly sinuous planform (sinuosity of 1.3).

[1] Sinuosity is defined as the ratio of actual channel distance between identified points compared to straight/down-valley distance. The following represent possible ratios that define sinuosity: straight (1); slightly sinuous (1.1–1.3); sinuous (1.4–1.7); meandering (1.8 and above).

Habitat unit mapping results (conducted in 1999) on Funks Creek (between the Golden Gate Dam to just above its confluence with Grapevine Creek) showed primarily flatwater habitat in the creek (e.g., glides and runs) with minimal riffle habitat. Gravel was the most common substrate, and banks were composed primarily of silt and clay with star thistle and grasses as the dominant bank vegetation types. (Brown 2000:34–35.)

Stone Corral Creek

After its headwater tributaries converge along the Sites Lodoga Road, Stone Corral Creek flows in a southeasterly direction for approximately 4.1 miles until its confluence with Antelope Creek. The distance between this confluence location and the Sites Dam is approximately 1.1 miles. Stone Corral Creek is an ephemeral watercourse with a sinuous planform (sinuosity of 1.4).

Habitat unit mapping in 1999 on Stone Corral Creek (between the Sites Dam to just above its confluence with Antelope Creek) showed primarily flatwater habitat in the creek with minimal riffle habitat. Bedrock was the most common substrate, and banks were composed primarily of silt and clay with star thistle and grasses as the dominant bank vegetation types. (Brown 2000:37–38.)

Hunters Creek

The various forks of Hunters Creek originate in the uplands to the north of Antelope Valley and flow east into the Sacramento Valley (Figure 5-2). Four of these forks are discussed below. They include the north fork of Hunters Creek (which would not be affected by project-related activities), and the three main contributing channels downstream/downslope of Saddle Dams 3, 5, and 8B.

After its headwater tributaries converge northwest of the reservoir footprint, the north fork of Hunters Creek flows in a southeasterly direction for approximately 9.0 miles until it reaches the TC Canal, after which it continues past the GCID Main Canal, and then terminates in the vicinity of the CBD. Its confluence with the "8B fork" of Hunters Creek is approximately 6.6 miles downstream from its headwaters. The "8B fork" of Hunters Creek is approximately 5.7 miles long.

The "5 fork" of Hunters Creek is approximately 3.2 miles long. It joins the "8B fork" of Hunters Creek approximately 0.4 mile upstream of its confluence with the north fork of Hunters Creek. The "3 fork" of Hunters Creek is approximately 2.4 miles long. It joins the "5 fork" of Hunters Creek at about its halfway point between the location of the proposed Saddle Dam 5 and its confluence with the "8B fork" of Hunters Creek.

These four forks of Hunters Creek appear to be ephemeral watercourses with slightly sinuous planforms. Similar to Grapevine, Antelope, Stone Corral, and Funks Creeks, these creeks are generally incised and experience low to no flows in the summer. Each fork is highly confined by the surrounding topography.

Downstream (east of) the GCID Main Canal, the mainstem of Hunters Creek has been partially altered for water conveyance and agricultural purposes.

7A.2.3.3 Downstream of Antelope Valley

The only two drainages that exit Antelope Valley are Funks and Stone Corral Creeks. Each creek continues through the steeper, foothill environments and then transitions to the Sacramento Valley floor, where they are generally shallow creeks that have been highly altered, primarily for water conveyance and agricultural purposes. Although the channels of these creeks are not actively managed, their straight channels and angular turns associated with agricultural fields and roads indicate that their natural channels have been modified. Along their reaches on the valley floor, these creeks are confined to narrow channels between berms adjacent to agricultural fields and road prisms.

Funks and Stone Corral Creeks are largely devoid of riparian habitat in their upper reaches (foothill environments) due to heavy livestock use. In the lower reaches where the creeks run through and around agricultural fields, riparian habitat is sparse and consists mostly of low shrubs, grasses, and occasional oak (*Quercus* sp.) and cottonwood (*Populus* sp.) trees.

Funks Creek

Beyond (downstream of) the Golden Gate Dam, Funks Creek flows approximately 1.8 miles before it enters Funks Reservoir. The creek is considered intermittent within this reach, and the channel width decreases in the downstream direction as a result of the backwater effect from Funks Reservoir. Funks Reservoir is approximately 230 acres in surface area and is where the TC Canal has its northern and southern entry and exit points (at the easterly side of the reservoir). Beyond (to the east of) Funks Reservoir, Funks Creek continues another 3.8 miles to the GCID Main Canal (the location of TRR East), after which it continues to Interstate 5 (I-5) (2.4 miles from the GCID Main Canal). Funks Creek’s confluence with Stone Corral Creek is approximately 3.5 miles downstream and southeast of I-5.

Stone Corral Creek

Beyond (downstream of) the Sites Dam, Stone Corral Creek flows approximately 4.7 miles to the TC Canal (near Mills Orchards), then another 3.0 miles to the GCID Main Canal, after which it continues to I-5 (4.1 miles from the GCID Main Canal), then approximately 1.4 miles to its confluence with Funks Creek. After the confluence point, the Stone Corral Creek continues approximately 5.6 miles before it terminates at the CBD.

7A.3 Sacramento River Reaches

The four reaches of the Sacramento River, as indicated by their River Mile (RM) limits, that have the greatest potential for change to the geomorphic regime are described below.

Keswick Dam to Red Bluff reach (RM 302 to RM 246)

The river in the upper part of this reach consists of a narrow and deep canyon environment (with a similarly narrow floodplain) below Shasta Lake. Much of the streambed in this reach has coarsened as a result of decreased sediment supply due to dam blockage upstream. Gravel augmentation projects supply suitable spawning gravel for salmonids at select locations below Keswick Dam as part of the Sacramento River Spawning Habitat Restoration Project.

This reach is primarily considered a bedrock system (with various volcanic and andesitic rocks and cemented sedimentary terrace deposits [California Resources Agency 2003:3-2]) with little Holocene alluvium within the river. The overall morphology of this reach is generally not influenced by alternating streamflow and sediment regimes. Large channel substrate (i.e., cobbles and boulders) dominates, because the finer materials have been eroded from the channel bed, and the upstream dams effectively block the replenishment of sediment.

Three large creeks (Clear Creek, Cottonwood Creek, and Battle Creek), as well as numerous smaller tributaries, meet up with the Sacramento River in the Keswick Dam to Red Bluff reach. An anomalously broad alluvial portion of the reach exists between Redding and Balls Ferry, representing an exception to the high degree of confinement that dominates the remainder of the reach.

Red Bluff to Chico Landing reach (RM 246 to RM 194)

Downstream of Red Bluff, the Sacramento River transitions from its canyon environment upstream to the broad alluvial plains of the Sacramento Valley. Within this reach, which terminates at the confluence of Big Chico Creek and Sacramento River at Chico Landing, the Sacramento River displays a highly meandering planform. With a few exceptions, levees are not present and there are relatively large riparian forest remnants and the floodplain shows relict evidence of erosion, deposition, and channel migration processes (California Resources Agency 2003:4-1).

This reach is underlain by sedimentary and volcanic deposits including the Tehama, Tuscan, and Red Bluff formations, and the river is bordered by the terrace deposits of the Modesto and Riverbank formations (erosion-resistant lithologic units) (California Resources Agency 2003:4-4). Within this reach, there are short, narrow, and straight sub-reaches that alternate with longer, more sinuous sub-reaches with higher bank erosion rates (at cutbank locations). Although chute cutoffs at meander bends have decreased the sinuosity of this reach, it displays the highest degree of a meandering planform of all the reaches discussed herein. Major tributaries in this reach include Reeds, Antelope, Mill, Elder, Thomes, and Deer Creeks.

Chico Landing to Colusa reach (RM 194 to RM 143)

Downstream of Chico Landing to Colusa, the planform of the Sacramento River meanders between widely spaced levees, allowing the river to laterally migrate (when possible) within its narrow floodplain. Also included in this reach are the lower reaches of Mud, Deer, and Elder Creeks which join the Sacramento River at RMs 193, 220, and 230, respectively. (Stillwater Sciences 2007:65.)

Within this reach, the Sacramento River is a meandering single-thread channel bordered by setback levees. The average sinuosity is about 1.4–1.5 (Stillwater Sciences 2007) and average energy grade slopes from the U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) modeling ranged from 0.0002 to 0.0003 (Stillwater Sciences 2007:65).

Morphologic landforms present within this reach include natural overflow areas, point bars, cutbanks, islands, and oxbows. The channel is generally bounded by natural stream channel and levee alluvium consisting of unconsolidated silt- to cobble-sized particles (Stillwater Sciences 2007:65). The median bed material size (D_{50}) is roughly 15 millimeters (Stillwater Sciences 2007:65), which provides a non-cohesive sand/gravel bank toe component. Channel migration is limited by bank protection structures within the uppermost portion of this reach. The highest rates of migration occur in the unconstrained sections and appear to depend upon channel cross-section asymmetry and toe scour (Stillwater Sciences 2007:65). Additionally, bank erosion tends to be faster in sections where riparian vegetation has been reduced (Stillwater Sciences 2007:65). Chute cutoffs that lead to the formation of oxbows still occasionally occur within this reach when higher discharges breach and cut off a river bend at a sinuous location (Stillwater Sciences 2007:65).

Despite the relatively higher frequency of channel migration (and therefore a potentially higher frequency of instream woody material [IWM]) recruitment), IWM loading in this reach is relatively low, and is attributable to the conversion of riparian forests to agriculture over the last 100 years (U.S. Army Corps of Engineers 2009:3-139).

Colusa to Verona reach (RM 143 to RM 79)

Within this reach, the Sacramento River flows from Colusa to the confluences with the Feather River and Sutter Bypass at Verona. The channel is mostly confined by levees along the banks with the exception of a few locations where levees are set back to provide overflow across point bars of major meander bends (Stillwater Sciences 2007:63). Contributing flows into this reach are provided by Butte Creek, the Sutter Bypass, and the Feather River.

Within this reach, the Sacramento River is primarily a sinuous single-thread channel with uniform width, an average sinuosity of about 1.8 (Stillwater Sciences 2007:64), and an average slope of 0.00003 to 0.0001 (Stillwater Sciences 2007:64). Levees and bank revetments are located on each side of the river. The adjacent floodplain and bank sediments are alluvial deposits, consisting of clay- to gravel-sized particles. In contrast to the downstream reaches of the river, floodplain sediments in this reach are generally much finer and cohesive. The bank toes are generally composed of fine-grained and cohesive sediments, and bank erosion is the result of both mass failures (gravitational) and fluvial erosion (flowing water) at the contact between the coarser sediment above the cohesive toe material (Stillwater Sciences 2007:64). Floodplain habitat has been significantly reduced compared to historical conditions (Stillwater Sciences 2007:64).

IWM input is currently significantly less than historical rates, due to construction of levees and floodplain forest clearing activities; riparian vegetation is generally limited to older, relict stands and individual large trees (Stillwater Sciences 2007:64). The elimination of channel migration processes, chute cutoffs, and overbank deposition has greatly reduced the availability of adequate riparian recruitment areas that are instrumental in developing and maintaining IWM recruitment to the river (Stillwater Sciences 2007:64). There are, however, several areas north of the Sacramento River’s confluence with the Feather River where setback levees have been constructed (and where channel meander processes and associated geomorphic and habitat diversity still exist) (Stillwater Sciences 2007:64).

The Sacramento River discharge would be located in the Colusa to Verona reach of the Sacramento River between RMs 100 and 101. Geologic units in this area include the upper and lower Modesto Formation to west of the CBD, and Basin Deposits extending to the Sacramento River to the east of the CBD (Figure 12-1C). These units are composed of unconsolidated gravely sand, silt, and clay (Modesto Formation) and the thick Holocene alluvium of the Basin Deposits. Although the channel is mostly confined by levees along the banks within this reach of the Sacramento River there are certain locales where levees are set back to provide overflow across point bars of major meander bends (e.g., Tyndall Landing). The location of the Sacramento River discharge possibly represents an area where historical meandering may have occurred (California Resources Agency 2003:6-4). However, this location does not have setback levees in the vicinity and a review of available aerial imagery (from 1985 to the present) shows no evidence of historical meandering in this reach. Furthermore, a 2010 study by Northwest Hydraulic Consultants (2010:4) concludes that the river channel in this general area is closely bordered by levees with extensive revetment and that lateral channel evolution is limited. There has been an increase in average channel width over time upstream of the Feather River confluence, but this change has been no more than 4% from 1987 to 2005 (Northwest Hydraulic Consultants 2010:4).

7A.4 Colusa Basin Drain

The streams on the valley floor within the Colusa Basin have varying degrees of sinuosity, low channel bedslopes, and are composed of fine grain materials (i.e., sand-, silt-, and clay-bedded). Once abundant within the basin, there are only a few remnants of these “slough” channels or networks remaining. Levee construction and drainage manipulations for flood protection and agricultural purposes have virtually eliminated overflow from the Sacramento River onto the valley floor (H. T. Harvey & Associates et al. 2008:4). The CBD is one such engineered drainage structure.

With respect to sediment transport regime, Gray and Pasternack (2016:i) describe how agriculture in the Colusa Basin has increased erosion rates on the valley floor. The eroded sediments are ultimately transported to the CBD. Since the Colusa Basin did not have a discreet outlet to the Sacramento River before the construction of the CBD, sediment delivery to its receiving basins (the Yolo Bypass and the Sacramento River), can be considered entirely anthropogenic, altering the magnitude and duration of sediment transport in the system. Thus, anthropogenic modifications within the Colusa Basin have altered its relationship with the Sacramento River from that of a net sediment sink area to a net sediment source area.

Eroded sediments are deposited and resuspended in the CBD during seasonal and interannual scales. A major control on localized sedimentation within the CBD is the effect of backwater caused by the raising of outfall gates on the Knights Landing Outfall in response to the Sacramento River stage, which result in long periods of ponding and overbank flooding in the lower CBD (Gray and Pasternack 2016:i–ii).

7A.5 Delta and Yolo Bypass

Historical changes in the Delta that have affected channel morphology include land reclamation, levee construction, dredging, hydraulic mining, impoundment of water and sediment by upstream dams and other diversions, and the construction of water diversion facilities and consequent alteration of flow and sedimentation patterns in the Delta. The effects of these changes on channel morphology are summarized below.

- Waterways are mostly confined by levees and able to convey significantly larger sediment and flow discharges than during historical times (Northwest Hydraulic Consultants 2006:15).
- Historical cross-section data indicate that the majority of Delta waterways have experienced some degree of channel incision over several decades and may possibly be experiencing a net sediment loss over time (Northwest Hydraulic Consultants 2006:15).
- Water regulation, diversions, and the impoundment of water (and sediment) via dams has resulted in a decline in the total annual water and sediment outflows to the Delta from the Central Valley (Northwest Hydraulic Consultants 2006:15).
- The construction of large water diversion facilities such as the Delta-Mendota Canal and Delta Cross Canal in 1951 and California Aqueduct in 1973 have altered the historical flow regimes in the Delta, thus affect sedimentation rates and patterns. Water and sediment exhibit a more southerly flow in the Delta, somewhat reducing deposition of sediment in the north and central Delta while increasing sediment deposition in the south Delta (Northwest Hydraulic Consultants 2006:15).

A recent analysis examining future climate scenarios predicted significant increases in large flow events and sediment transport over the next century, which may increase turbidity (Stern et al. 2020:1).

7A.5.2 Regional Geomorphic Description

Below Isleton (RM 17), the Sacramento River flows into the Delta, forming a distribution network of sloughs and channels. Flow is additionally received via the Yolo Bypass, which is a leveed, wide floodplain that flows parallel to the west of the mainstem Sacramento River during high flows. Additional flow comes from several water courses that feed into the Yolo Bypass, including Knights Landing Ridge Cut, Cache Creek, Willow Slough Bypass, the Sacramento Bypass, and Putah Creek. Seasonal high flows enter the Yolo Bypass from the Sacramento River via the Fremont Weir (RM 71) and the Sacramento Bypass Weir (RM 63). Flow velocities are low because flow is distributed throughout the Delta channels and sloughs that are bordered by relatively low levees consisting of both natural bank materials and revetment. These levees and bank protection structures currently prevent the river's access to historical tidal wetlands and islands. Tidal influence extends up the Sacramento River for approximately 80 miles to Verona, with the greatest tidal variation concentrated in the Delta. The major tidal sloughs included within the area are Three-mile, Georgiana, Steamboat, Miner, Lindsay, Cache, Haas, and Sutter Sloughs.

Sloughs and channels in this area are generally confined on both sides by natural levees enhanced by decades of human-made improvements. The individual channels and sloughs are moderately sinuous, of uniform width, and do not migrate. Compared with the upper reaches of the Sacramento River, the impacts of seasonal flood events in the Delta are much less due to both tidal action and the diversion of flow through the upstream flood bypasses and outtakes (Stillwater Sciences 2007). Historically, channel and slough morphology actively adjusted throughout the Delta in response to seasonal variations in flow and sediment load. The decrease in flow velocities caused the deposition of a gradient of coarser to finer material from upstream to downstream (fine sand to clayey silt). The intertidal deposits that border the Delta channels and sloughs are typically characterized by shallow, alternating layers of fine sandy silt and clayey silt, with occasional peaty muds. Artificial fill from hydraulic dredge spoils was placed after 1900 throughout the Delta along channel margins and upon various island surfaces (Stillwater Sciences 2007).

7A.6 References

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