Watershed-Based Assessment of Hydrologic and Geomorphic Conditions in Cache Creek through Capay Valley

Yolo County, California

Prepared for the:

Yolo County Resource Conservation District

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Executive Summary

The Capay Valley segment of Cache Creek flows through a rural area in northwestern Yolo County that supports a productive agricultural community. Resource management issues affecting lands along the stream corridor include: streambank erosion, the spread of invasive, non-native plants, and elevated levels of mercury in the ecosystem. As part of the conservation planning effort to address these issues, the Yolo County Resource Conservation District retained Kamman Hydrology & Engineering, Inc. (KHE) to prepare this assessment of the hydrologic and geomorphic conditions of Cache Creek within Capay Valley. Work was funded through the CALFED Watershed Program, Department of Water Resources and the California Bay-Delta Authority. The assessment describes the physical processes that collectively shape the stream corridor and control channel changes over time. The objectives of the study are to:

- Document the physical characteristics of the stream channel and surrounding watershed;
- Identify the causes of streambank erosion affecting lands along the stream corridor; and
- Evaluate whether the prevailing geomorphic processes and stream channel morphology are indicative of a stable channel.

KHE's approach to the address the study objectives included: compilation and synthesis of existing data, field reconnaissance and site investigations, interpretation of aerial imagery, and evaluation of geomorphic characteristics from a high-resolution topographic dataset. KHE assessed historical changes in the stream corridor from a series of aerial images spanning the period 1937 to 2009. The assessment relates the existing geomorphic features, or landforms, to the historical changes observed between successive sets of aerial imagery to document the physical processes that control streambank erosion and floodplain sedimentation.

The assessment of Cache Creek through Capay Valley documented characteristics representative of a dynamic alluvial river. The present alignment and channel configuration is just one component of a much broader stream corridor through which the channel migrates laterally by natural geomorphic processes. KHE concludes that channel migration processes are an important mechanism essential to the maintenance of a functional river system within Capay Valley. Concurrent processes of streambank erosion and floodplain sedimentation dissipate energy during peak flow events, allow for maintenance of a stable channel profile, and sustain a variety of aquatic and riparian habitats that depend on relatively frequent disturbance. As such, KHE recommends consideration of land management strategies that allow for continued channel migration within an alluvial corridor as opposed to structural or engineered actions that attempt to constrain the stream channel along a specific alignment and configuration.

A series of map sheets depicting the geomorphic features and historical channel alignments accompany the assessment as Appendix A. The map sheets were designed to provide local residents and land managers with a tool to better understand the historical channel dynamics at a given location and identify areas of potential future channel migration. The information can then be utilized to guide development of land management strategies based on the level of risk associated with potential bank erosion and channel migration in future decades.

KHE's primary conclusions about the stream corridor through Capay Valley are supported by the key findings summarized below:

- The channel morphology in Capay Valley is characterized by a slope of about 0.2 percent, a high width-to-depth ratio, and a pattern that is transitional between meandering and braided forms. A primary channel is directed around gravel bar surfaces in a moderately sinuous path that meanders within the stream corridor. Flow is split around mid-channel bars in localized areas.
- Development and evolution of gravel bar surfaces is a key process controlling the channel pattern and shaping the geomorphic features in the stream corridor through Capay Valley. The alignment and configuration of the stream channel and adjacent bar surfaces changes over time due to episodic cycles of sediment erosion, transport, and deposition that frequently rework streambed material. Such changes are associated with processes such as meander migration, chute cut-offs, and streambank erosion. This dynamic physical setting is typical of streams with a channel gradient, hydrologic regime, and sediment load similar to Cache Creek through Capay Valley.
- Evaluation of channel changes from the sequence of aerial photographs reveals that bank erosion and channel migration processes have prevailed at a relatively high rate throughout the study period. The naturally high rate of streambank erosion and channel migration in Cache Creek is associated with a highly variable flow regime and a high supply rate of coarse-grained sediments. Streambed materials are remobilized by high flows which correspond to a flood discharge expected to be equaled or exceeded every 1.5 to 2 years, on average, in the annual flood series. These relatively frequent flood events transport large volumes of sediment through the study reach and produce significant changes to the channel configuration. Larger floods also cause episodic, large-scale shifts in channel alignment; however, the occurrence of large floods is less common.
- Despite the dynamic lateral movements and frequent realignment of the channel position, the streambed has maintained a relatively stable cross-sectional geometry and longitudinal profile through Capay Valley during the historic period. Many other streams in the area, including the reach of Cache Creek below Capay Valley, have been characterized by episodes of streambed incision during the historic period. Common causes of channel incision in this region of California include decreases to the sediment supply associated with dam construction (reservoirs trap sediment that would be transported downstream under natural conditions) and geomorphic changes associated with gravel mining within the stream corridor.
- The reach through Capay Valley has not been significantly impacted by gravel mining because mining has not been undertaken at a commercial scale like it has in the reach downstream. Grade control created by Capay Dam appears to have halted the upstream migration of bed incision which has occurred in the lower (mining affected) reach. Additional grade control is present upstream of Capay Dam such as the boulder-strewn run at the toe of a large landslide in the confined reach near Sugarloaf hill.
- Two dams in the upper watershed affect the streamflow and sediment transport characteristics through Capay Valley. However, the reduction in sediment supply due to sediment trapping in the reservoirs appears to be proportional to the reductions in sediment transport capacity associated with decreasing peak flows. As such, dam construction in the Cache Creek watershed does not appear to have triggered channel incision as it has in many regulated rivers in the region. Sediment impacts from Cache Creek Dam are thought to be

minor because Clear Lake acted as a natural sediment trap prior to completion of the dam. In addition, the distribution of geologic units in the basin is such that the areas of most erodible sediments, and greatest source supply per unit area, are located in unregulated portions of the watershed and along portions of the reach through Capay Valley.

- Streamflow regulation at Cache Creek Dam (below Clear Lake) and Indian Valley Dam (on the North Fork Cache Creek) has affected the hydrologic characteristics of the reach through Capay Valley. Approximately 60 percent of the watershed is regulated and reservoir storage of winter runoff has reduced the magnitude and frequency of peak flows downstream. Subsequent flow releases in the summer months maintain an artificially high base flow period that is sustained until flow releases cease in the fall.
- Environmental changes during the study period have also altered the riparian vegetation characteristics along Cache Creek. Expansion of agricultural activities included land clearance within areas of riparian woodland in Capay Valley. Agricultural activities have transitioned through several different phases but current agricultural production includes orchards, field crops, and livestock grazing. Many of the lands that border the stream corridor are cultivated on floodplain soils or on alluvial terraces formed by fluvial processes (i.e., within the channel migration zone). Farming these low-lying areas includes an element of risk associated with the loss of land due to channel migration and streambank erosion.
- The abundance and distribution of riparian plant communities has been affected by a combination of (1) human encroachment and agricultural land clearance; (2) the spread of invasive, non-native plants; and (3) streamflow regulation that maintains relatively high summer baseflows. The riparian corridor is dominated by early successional stages of development and more mature areas of riparian woodland are notably lacking.
- Areas of recent floodplain disturbance are dominated by non-native plants such as tamarisk, arundo, and ravenna grass. Non-native plants are generally confined to the area of historical channel migration while the more stable areas of the floodplain are utilized for agricultural production. Invasive, non-native plants have been known to alter the ecologic, hydrologic, and geomorphic conditions of the stream corridor. Tamarisk, for example, tends to grow in dense stands which trap and stabilize alluvial sediments and can trigger aggradation on floodplain surfaces which may result in channel narrowing, a decreased channel capacity, and increased overbank flooding. Stabilization of mid-channel or lateral gravel bars can direct flows toward the opposite bank and result in streambank erosion.
- Anecdotal reports suggest that the extent and relative dominance of the non-native plants has increased in recent decades. KHE hypothesizes that there is a threshold at which the thickets of riparian plants become dense enough to increase hydraulic roughness and stabilize floodplain surfaces to an extent which affects stream channel geomorphology. Observations of historical channel changes in Capay Valley suggest that geomorphic impacts associated with invasion of these non-native plants have not affected Cache Creek to the degree observed in other river systems; however, KHE recommends that the RCD and local stakeholders continue efforts to eradicate the invasive, non-native plants and revegetate the riparian corridor with native plant communities.
- The flow regime through Capay Valley appears sufficient to maintain a stable channel geometry and to continue natural channel migration processes. Channel width, sinuosity, and rates of channel migration have remained relatively consistent throughout the study period.

Despite the fact that the non-native vegetation is widespread throughout the stream corridor through Capay Valley, the riparian changes have not yet created any system-wide impacts to geomorphic conditions. Localized areas along the stream corridor appear to have been affected by such impacts and further spread of these invasive species could potentially exceed a threshold and trigger widespread geomorphic changes.

- KHE delineated the width of the historic migration zone (HMZ) by mapping the various channel alignments observed in aerial imagery for the period 1937-2009. Evaluation of the topographic characteristics along the channel boundary, in conjunction with observations of historic channel migrations, suggests that the creek requires a significantly wider channel migration zone (CMZ) to maintain a stable profile through Capay Valley. Locations of emergency streambank protection, typically provided by rock riprap or other rock structures, tend to correspond to areas where human activities and infrastructure have encroached within the CMZ.

1.0 Introduction

The Capay Valley segment of Cache Creek flows through a rural area in northwestern Yolo County that supports a productive agricultural community. Local residents, working together as the Cache Creek Watershed Stakeholders Group, collaborated with the Yolo County Resource Conservation District (RCD) to develop the Capay Valley Watershed Stewardship Plan in 2003. The plan compiled a list of resource issues of concern and developed goals and objectives focused on enhancing and protecting natural resources in the watershed. The resource management issues identified in the plan include: streambank erosion, invasive plants, and the effect of mercury on human and ecological health. Streambank erosion has resulted in the loss of agricultural land and has presented threats to infrastructure along the stream corridor. Invasive, non-native plants such as tamarisk (*Tamarix* spp.; also known as saltcedar), arundo (*Arundo donax;* also known as giant reed), and ravenna grass (*Saccharum ravennae*) have spread along the creek and pose a threat to the ecological health of riparian areas. Alluvial soils and floodplain sediments contain elevated levels of mercury released from historic mining activities in the upper basin.

As part of the future implementation of the Stewardship Plan, Yolo County RCD will assist stakeholders with development of conservation and riparian enhancement projects. Such projects are likely to include efforts to revegetate riparian areas with native plants and to stabilize eroding streambanks. Yolo County RCD retained Kamman Hydrology & Engineering, Inc. (KHE) to assess the hydrologic and geomorphic characteristics of the Capay Valley segment of Cache Creek. The assessment is needed to determine the underlying causes of channel instability and the prevailing mechanisms of streambank erosion and lateral channel migration. Results of this assessment will guide future bank stabilization and stream enhancement projects. The assessment was funded by a grant from the CALFED Watershed Program.

This report documents the hydrologic and geomorphic conditions along the Capay Valley segment of Cache Creek. The study area is defined as the stream corridor covering approximately 21 river miles in Capay Valley between Camp Haswell (approximately 1 mile northwest of Rumsey, CA) and the Capay Diversion Dam (Fig. 1-1). The primary objectives of the hydrologic and geomorphic assessment are to:

1. characterize the basic physical conditions of the stream channel and surrounding watershed;
2. identify the prevailing reach-based processes (both natural and human-induced) that cause streambank erosion and drive lateral channel migration; and
3. evaluate whether the prevailing geomorphic processes are indicative of a stable channel and, if they are not, identify the cause(s) of instability.

The desired outcomes of the assessment focus on improving the overall condition of the stream channel and riparian areas and assisting stakeholders with development of streambank protection strategies. The assessment of hydrologic and geomorphic conditions evaluates and quantifies the physical conditions of the stream corridor such that stakeholders can make informed management decisions that protect property and infrastructure from bank erosion while maintaining natural processes that are characteristic of dynamic river systems and essential to maintain healthy riparian and aquatic habitats. The assessment describes the hydrologic and geomorphic responses to historical changes in land-use and water development (e.g., diversions, reservoir construction, groundwater pumping, etc.), identifies existing conditions that are trending towards or away from geomorphic equilibrium, and examines how human-induced changes in hydrologic and geomorphic conditions have affected riparian ecology in terms of the lost or altered floodplain area and inundation frequency. A key goal of this assessment was to distinguish between “natural” and “accelerated” bank erosion, and to identify the underlying causes (both natural and anthropogenic) so that appropriate solutions can be developed. KHE utilized historic and recent aerial photographs to describe historical channel conditions and to document channel changes and mechanisms of stream channel adjustment.

The present study builds on information compiled in previous investigations and describes the hydrologic and geomorphic conditions in the Capay Valley segment of Cache Creek. Existing sources of information were synthesized in order to establish the basic physical conditions for the study area. Three previous investigations contributed substantial information to the present understanding of geomorphic processes along Cache Creek. Lustig and Busch (1967) compiled an early study that investigated the sediment transport characteristics of streams in the Cache Creek watershed. The report discusses the relationship between the environmental characteristics of the watershed (i.e., the climate, geology, soils, and vegetation characteristics) and characteristics of sediment supply and transport within different components of the drainage network. A second series of investigations were developed in the 1980’s in response to a proposal to expand the outlet channel of Clear Lake. Two investigations were completed in tandem during this period. Simons, Lee, and Associates (1987) prepared a geomorphic analysis of Cache Creek for the U.S. Army Corps of Engineers (USACE) to evaluate the potential impacts to the proposed changes in flow regulation at Clear Lake on geomorphic conditions downstream. Results were later summarized in a USACE (1988) sediment engineering investigation. Concurrent with the Simons, Lee, and Associates assessment, the U.S. Geological Survey compiled information on streamflow, sediment transport, and cross-sectional profile characteristics of the stream channel in Capay Valley (Harmon, 1989). More recently, Northwest Hydraulic Consultants (NHC, 1995) prepared the Cache Creek Streamway Study to guide the development of the Lower Cache Creek Resource Management Plan. The NHC investigation describes the watershed conditions and is directly relevant to the present study. The focus of the NHC investigation, however, was limited to the area downstream of Capay Diversion Dam and the geomorphic conditions within Capay Valley were not addressed.

This report is organized to address the objectives listed above. The assessment approach is based on a watershed-scale framework and follows an outline defined in the Watershed Assessment Study Plan (KHE, 2008). Section 2 describes the existing conditions of the Cache Creek drainage basin including the physical controls on the streamflow characteristics and sediment load in Cache Creek. Section 3 presents the surface-water and groundwater hydrology in the study area. Section 4 describes physical conditions within the stream corridor such as the stream channel morphology, sediment load, and characteristics of the floodplain and riparian vegetation. Section 5 presents details of the geomorphic processes that have shaped the stream corridor through a sequence of historical channel changes. The report concludes by summarizing key findings as they relate to the assessment objectives and recommends guidelines that attempt to reduce the socioeconomic impacts of bank erosion and maintain the long-term ecological health of the ecosystem.

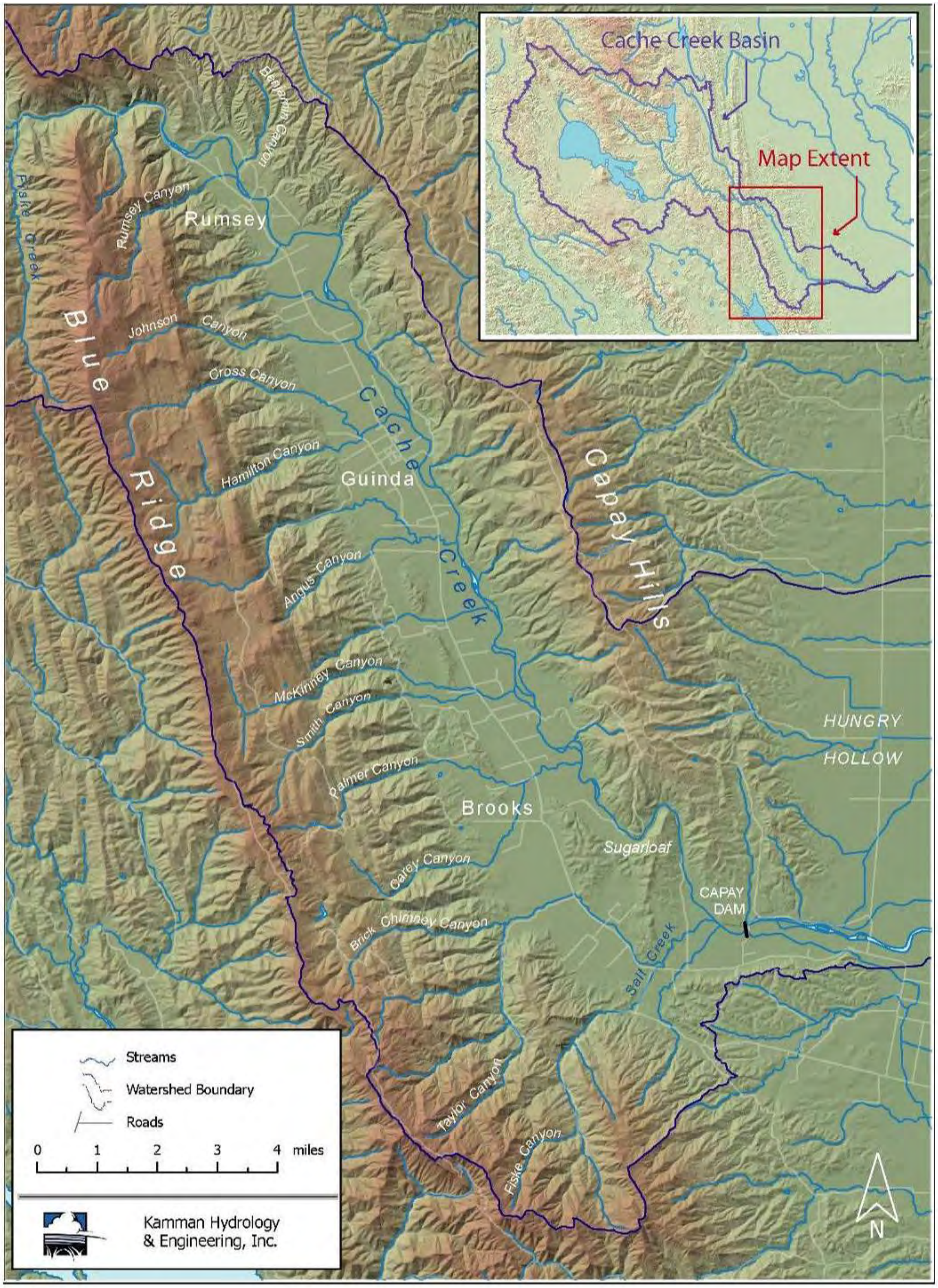


Figure 1-1. Shaded relief map of the Capay Valley region in northwestern Yolo County.

2.0 Drainage Basin Characteristics

The drainage basin is the primary source of runoff and sediment in the fluvial system. The climate, geology, land use, and physiography of the drainage basin collectively determine the magnitude and variability of streamflow in the river channel and the quantity and character of the sediment supply. The watershed characteristics of the Cache Creek basin are summarized below to describe the prevailing conditions that affect the hydrologic conditions and sediment supply of Cache Creek.

Cache Creek is located in the southeastern part of the Coast Range in northern California. The drainage basin encompasses an area of about 1,140 square miles and includes portions of Lake, Colusa, and Yolo Counties (Fig. 2-1). Large variations of topographic relief, climate, and vegetation create a diverse assemblage of landscape features. The watershed extends from the highland regions of the Coast Ranges, where elevation exceeds 4,000 feet along the divide, to the Yolo Basin on the Sacramento River floodplain.

2.1 Physiography

The Cache Creek watershed is composed of three discrete physiographic zones: (1) The upper basin that supplies the majority of runoff and sediment to the study reach, (2) Capay Valley, an intermediate zone within which Cache Creek conveys water and sediment downstream, and (3) the lower basin that naturally functioned as a zone of net sediment deposition.

The watershed of the study area is defined as the collective area contributing drainage to the channel of Cache Creek upstream of the Capay Diversion Dam and encompasses an area of about 1,074 square miles (fig. 2-2). The upper basin includes three major subbasins, Clear Lake, North Fork Cache Creek, and Bear Creek, that collectively account for 80 percent of the watershed. The Clear Lake basin encompasses an area of 525 square miles and accounts for approximately half of the watershed. The level of the lake is maintained by a rock sill, known as the Grigsby Riffle, that spans the outlet channel to Cache Creek. Cache Creek Dam was constructed about three miles downstream of the riffle in 1914 and regulates the outflow from Clear Lake by storing winter runoff and releasing water during the summer. Clear Lake is the primary source of water supplied by the Yolo County Flood Control and Water Conservation District (YCFCWCD)

Cache Creek originates from the outlet channel of Clear Lake and flows approximately 30 miles through a steep, narrow canyon before entering into Capay Valley. Cache Creek Canyon was given environmental protection with designation in the California Wild and Scenic River System in 2005. Two major tributaries, North Fork Cache Creek and Bear Creek, enter Cache Creek within the canyon. The canyon reach has an average channel gradient of about 28 feet per mile (0.5%).

The North Fork Cache Creek basin encompasses an area of 224 square miles and accounts for about 21 percent of the total area in the Cache Creek basin. Indian Valley Reservoir, which formed by the completion of Indian Valley Dam in 1975, stores runoff from about 120 square miles in the North Fork Cache Creek basin and supplements the water supply of the YCFCWCD.

Construction of Indian Valley Dam increased the regulated area of the watershed by 11 percent. Collectively, the Clear Lake subbasin and the subbasin above Indian Valley Dam account for 60 percent of the watershed area.

The remaining area of the North Fork Cache Creek basin (about 104 square miles), the Bear Creek basin (about 103 square miles), and the additional tributary basins draining into the canyon reach (also totaling about 100 square miles) are unregulated. Capay Valley and the tributary drainages that originate from the Blue Ridge or Capay Hills areas encompass about 120 square miles and contribute an additional 11 percent to the watershed area. In total, the unregulated portions of the watershed encompass 427 square miles and account for about 40 percent of the total area.

The Capay Valley segment of Cache Creek is downstream of Cache Creek Canyon in northwestern Yolo County. Channel gradient decreases downstream of the canyon and averages about 10 feet per mile (0.2%) over its course through Capay Valley. The valley axis is oriented southeasterly for a length of approximately 15 miles and the valley width ranges between one and two miles. The valley is flanked on both sides by steep ridges that rise as much as 2,000 feet above the valley bottom. Cache Creek follows a slightly meandering path along the eastern boundary of the valley. Several ephemeral tributaries descend narrow canyons into Capay Valley and join with Cache Creek. Cache Creek enters a more confined reach at the downstream end of Capay Valley that follows a large loop around Sugarloaf Hill and then emerges at the head of a broad alluvial fan.

Below Capay Valley the Cache Creek channel is regulated by the Capay Diversion Dam. Capay Dam is the headworks of a canal system operated by the YCFCWCD. Downstream from Capay Dam, the Cache Creek channel flows eastward across the gentle slope of the alluvial fan and has been heavily impacted by aggregate extraction operations. Mining impacts have triggered channel incision in excess of ten feet for a reach that spans several miles. Downstream of the mining areas the channel is incised and confined by flood control levees for much of its course. Cache Creek reaches its terminus at the Cache Creek Settling Basin and the Yolo Bypass, a component of the Sacramento River Flood Control Project. Historically, streams draining the Coast Range (e.g., Putah and Cache Creeks) spread out across broad distributary areas that ended in “sinks” of tule marsh (Katibah, 1984).

2.2 Climate

Climatic conditions in the Cache Creek basin are characterized by cool, moist winters and warm, dry summers. Precipitation falls nearly exclusively as rainfall with more than 85 percent of the annual total occurring between November through March. Rainfall is generally associated with the passage of storm events from the west and is strongly influenced by orographic effects produced by topographic relief. Large variations in rainfall totals are observed in the Cache Creek basin due to its varied topography. Mean annual rainfall is approximately 17 inches in the lowlands of Capay Valley but exceeds 50 inches in the highlands of the Coast Ranges (Fig 2-3). Accounting for this spatial variation, mean annual precipitation for the basin is approximately 32 inches.

2.3 Geology

Development of the Cache Creek basin has occurred relatively recently in earth's geologic history and is attributed to a suite of dynamic geologic processes. During the Jurassic period, about 200 million years before the present (YBP), the continental margin of North America lay near the present location of the Sierra Nevada and the present location of the Coast Ranges was a deep marine environment. By about 160 million YBP, accreted terranes had shifted the continental margin to the existing location of the Coast Ranges. Over the next 150 million years the oceanic Farallon Plate was subducted beneath the continental North American Plate at the convergent boundary. Rock materials scraped from the Farralon Plate during its descent formed an accretionary wedge of sediments that comprise the assemblage of rocks known today as the Franciscan Complex. To the east of the accretionary wedge lay a fore-arc basin in which thick sequences of marine sediments accumulated. The assemblage of marine strata is collectively referred to as the Great Valley Sequence and overlies a layer of oceanic crust known as the Coast Range Ophiolite. Subsequent interactions between the Farallon, North American, and Pacific Plates led a shift in tectonic activity approximately 30 million YBP that triggered the development of a transform plate boundary and created the San Andreas Fault Zone (Irwin, 1990).

The bedrock geology of the Cache Creek basin is composed of a variety of rock types that reflect its geographic position near a dynamic tectonic boundary (Fig. 2-4). The dominant rock types, by areal extent, are the Franciscan Complex and the Great Valley sequence. The Franciscan Complex is a heterogeneous assemblage of igneous, sedimentary, and metamorphic rocks produced near the convergent plate boundary. Franciscan rocks underlie portions of the upper watershed and crop out in road cuts along the north shore of Clear Lake. The Great Valley Sequence is comprised of interbedded layers of shale and sandstone, over six miles thick in places, that have been upturned and dip towards the east. The Great Valley Sequence underlies much of the basin to the east of the Franciscan Complex and is visible in the canyon reach upstream of Capay Valley. Components of the Coast Range Ophiolite, which includes Serpentine and other associated rocks, crop out in places between the Franciscan Complex and Great Valley Sequence. Volcanic rocks, produced by extension of a pull-apart basin within the San Andreas Fault system (Wood and Kienle, 1990), are found in and around Clear Lake and include volcanic dome complexes such as Mt. Konacti.

Surficial deposits add important contributions to the basin's geologic history. The Tehama Formation represents deposits from Cache Creek and other streams draining the ancestral Coast Ranges from the middle Pliocene to early Pleistocene, 3.4 to 1.0 million YBP (Steele, 1980). The weakly cemented conglomerates and sandstones of the Tehama Formation are clearly exposed in Capay Valley at the Blue Cliffs, located approximately two miles downstream of the Rumsey Bridge. The Cache Formation consists of similar-aged deposits that accumulated in structural depressions east of Clear Lake and in the North Fork Cache Creek subbasin. The Pliocene to Pleistocene deposits are very erodible and contribute large volumes of gravel to the sediment budget of Cache Creek (Lustig and Busch, 1967).

The most recent geologic history of the basin has been driven by tectonic uplift, folding, and faulting. Uplift and tilting of the Tehama Formation, approximately one million YBP, records renewed movement of a blind-thrust fault system in the southwestern Sacramento Valley including the present location of Capay Valley (Unruh and Moores, 1992). The recent thrust fault activity has led to uplift of the Blue Ridge and Capay Hills which border Capay Valley (Unruh et al., 1995) on the west and east, respectively. This renewed uplift appears to have shifted the alignment of Cache Creek from one that prevailed eastward toward the Sacramento Valley to its present course which heads southeasterly through Capay Valley. The alignment of Cache Creek within the canyon above Capay Valley is likely antecedent to the recent uplift.

Thrust fault activity and deformation of the bedrock units has tilted the strata underlying Capay Valley towards the east (Unruh and Moores, 1992; Unruh et al., 1995). Tilting of the underlying strata may account for the prevailing tendency of Cache Creek to follow an alignment that favors the eastern side of Capay Valley; however, physical evidence (alluvial deposits and terrace surfaces) indicates that the channel has occupied a wider corridor, including large area in the center of the corridor, under previous conditions. The valley floor is blanketed in alluvial deposits that are relatively recent in age. Sediment accumulating at the foot of the steep hillslopes, where tributary streams emerge from relatively steep canyons onto the valley floor, form large alluvial fan deposits that extend into the valley. Alluvial terraces representing former floodplain surfaces of Cache Creek are extensive throughout the valley. The elevation of terrace surfaces are of various heights above the modern floodplain.

2.4 Vegetation

The vegetation communities in the drainage basin generally fall into one of three categories: (1) chaparral, (2) woodland; or (3) grassland. Agricultural lands occupy about 3 percent of the watershed area and an additional 6 percent are categorized as developed lands. The spatial distribution of vegetation communities varies throughout the watershed and is affected by environmental conditions such as elevation, precipitation, soil characteristics, and fire history (Fig. 2-5). Chaparral vegetation is the most prevalent vegetation type (covering greater than half the watershed area) and is composed of a variety of dense shrubs. Grasslands occupy about 14 percent of the watershed area and are primarily composed of non-native grasses and forbs that have replaced the native prairie species. Woodland areas occupy about 20 percent of the land surface in the watershed. Woodlands include both evergreen and deciduous species of trees, however, much of the woodland areas are dominated by oak. The woodland vegetation is two-storied – with an upper canopy and an understory blanketed with grasses and forbs. The density of the tree canopy changes across the landscape and increases in density at higher elevations and higher rates of rainfall. Spatial variation of the vegetation cover is important to the characteristics of the sediment load in Cache Creek. The middle part of the watershed, including the lower reaches of North Fork Cache Creek, parts of the canyon reach of Cache Creek, and parts of the Capay Valley segment, is characterized by areas of relatively steep slopes that are sparsely vegetated due to the decrease in rainfall at lower elevations in the basin. Slopes most affected by the erosive action of surface runoff in these sparsely vegetated areas are carved up by steep gullies that have developed a badland-type topography where large volumes of sediment are added to the stream channel.

2.5 Land Development History

Land-use history information presented in this section is excerpted from the Capay Valley Vision website (http://capayvalleyvision.org/capayvalley.html).

The Cache Creek watershed was home for Native American tribes for centuries before the Capay Valley entered modern history, but these indigenous and nomadic people left little physical evidence of their way of life. In 1846 the government of Mexico granted lands in the Capay Valley to three Berryessa brothers, beginning the period of settlement. Portions of this land grant were sold to Americans beginning in the 1850s. In 1887 land speculators organized the Capay Valley Land Company in conjunction with the construction of the Vaca Valley and Clear Lake Railroad, and subsequently this company and others divided up areas of the valley into parcels to sell to potential fruit farmers. The railroad served the valley from 1888 until the 1930s, while the valley was developed into various agricultural uses.

Agriculture in the Capay Valley has passed through several distinct phases, but remains the primary land use. The fruit colonies established around the turn of the century gradually declined because local climate and soils do not favor commercially dependable fruit production. Around 1920 some farmers began to plant almond orchards, a number of which have been converted over the years to walnuts. Other farmers continue to grow field crops, while ranchers continue to graze livestock in the hills. More than two dozen organic fruit and vegetable growers are currently expanding and diversifying their operations.

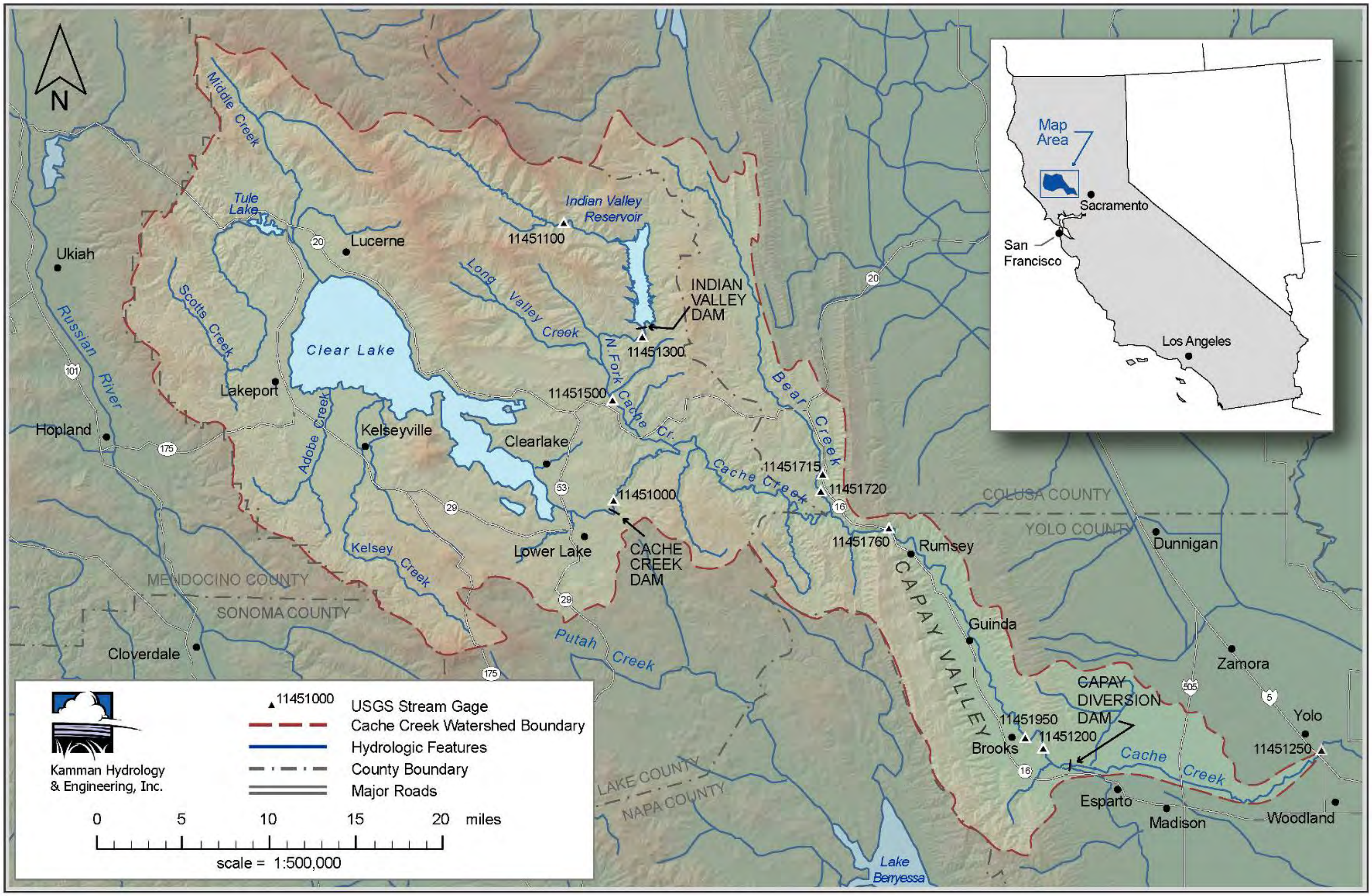
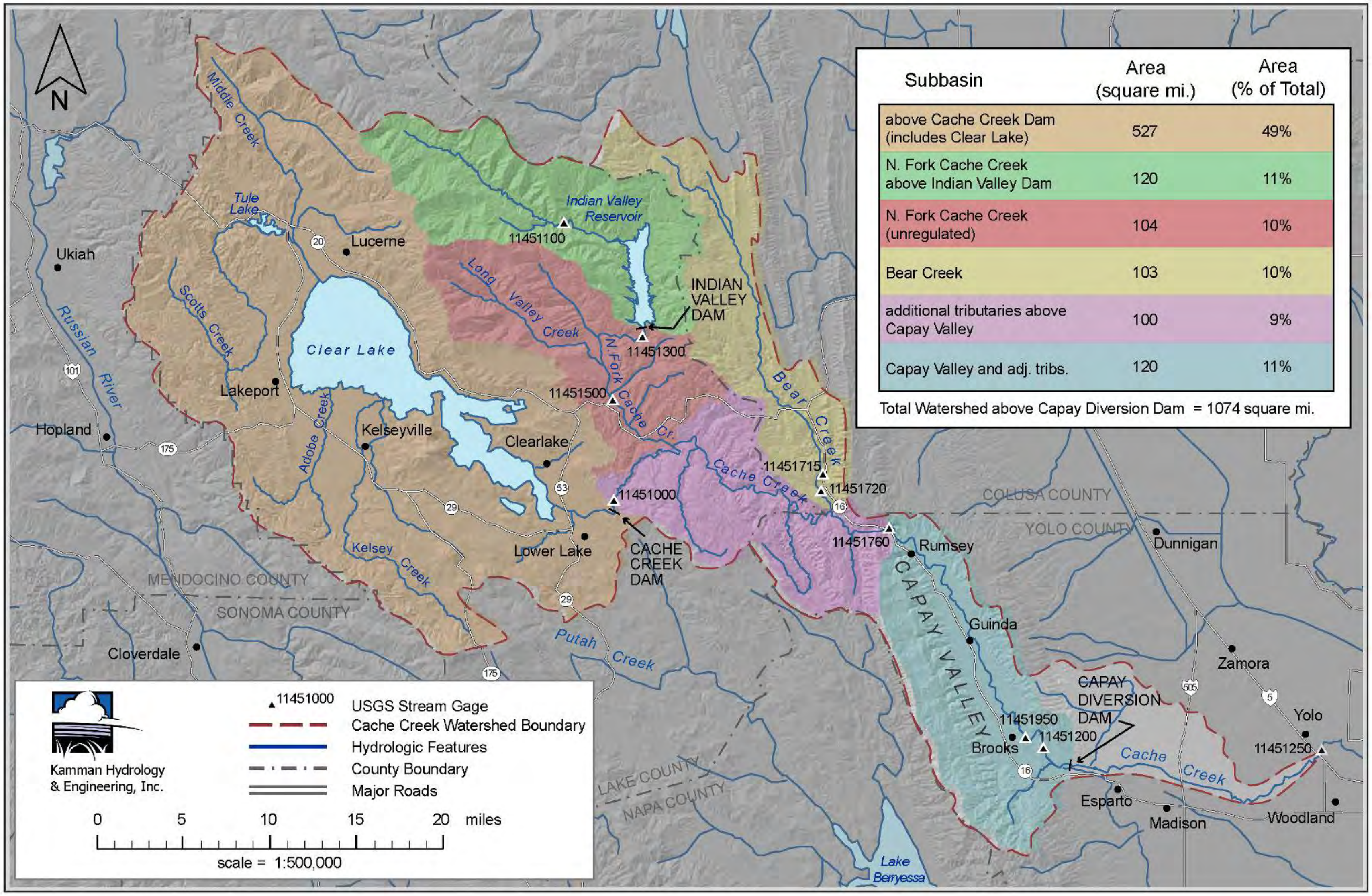


Figure 2-1. Map of the Cache Creek watershed. The watershed area is defined as the drainage basin contributing runoff to a point at the USGS stream gaging station at Yolo. The downstream terminus at the Cache Creek Settling Basin is just beyond the extent of the map.



Subbasin	Area (square mi.)	Area (% of Total)
above Cache Creek Dam (includes Clear Lake)	527	49%
N. Fork Cache Creek above Indian Valley Dam	120	11%
N. Fork Cache Creek (unregulated)	104	10%
Bear Creek	103	10%
additional tributaries above Capay Valley	100	9%
Capay Valley and adj. tribs.	120	11%

Total Watershed above Capay Diversion Dam = 1074 square mi.

Figure 2-2. Map delineating subbasin areas of the Cache Creek watershed. The table in the upper right lists the percentage of total area as measured at the downstream extent of Capay Valley (represented by the USGS gaging station 11451200).

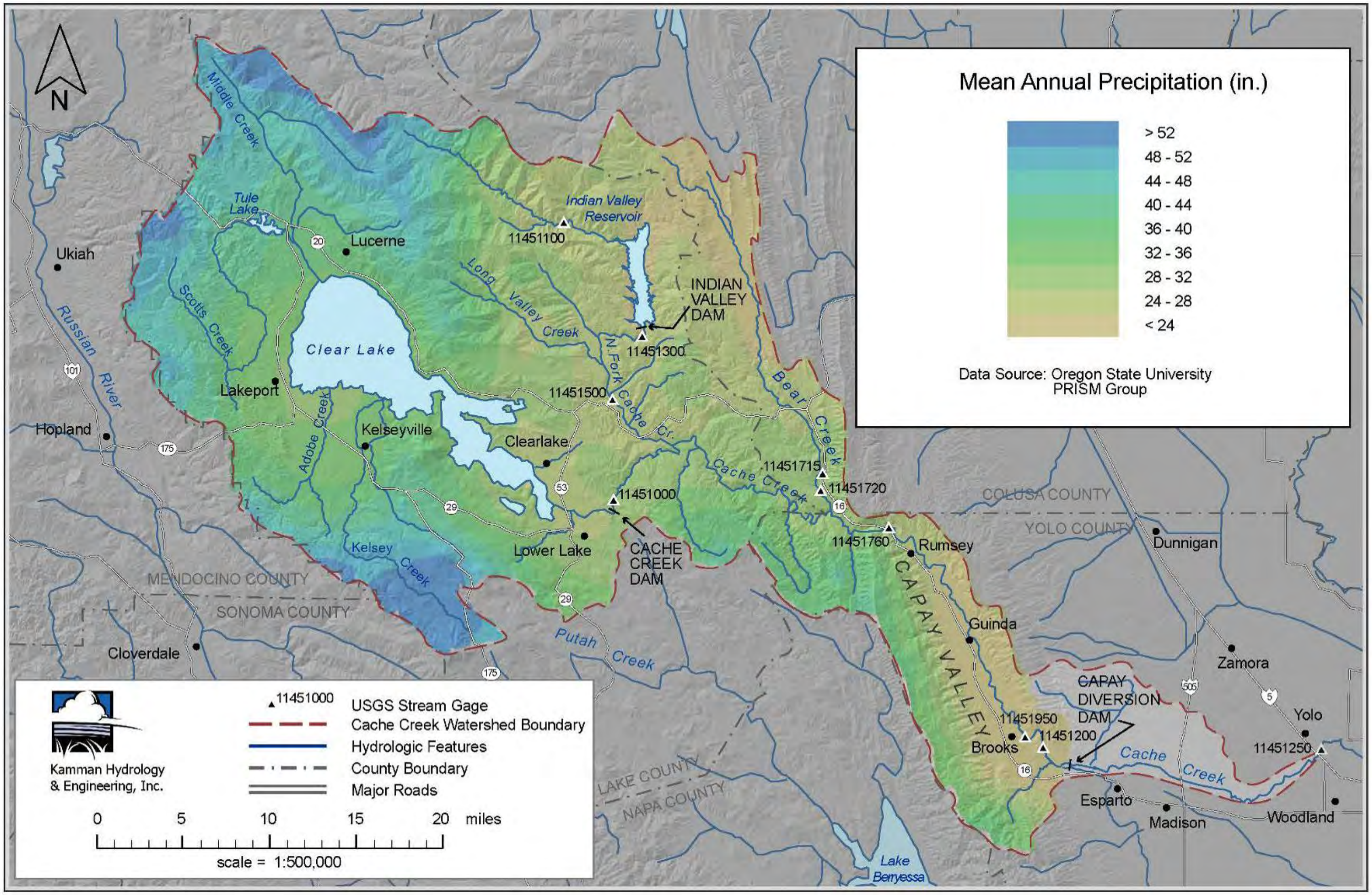


Figure 2-3. Map of precipitation patterns in the Cache Creek watershed. Data source: Oregon State University PRISM Group.

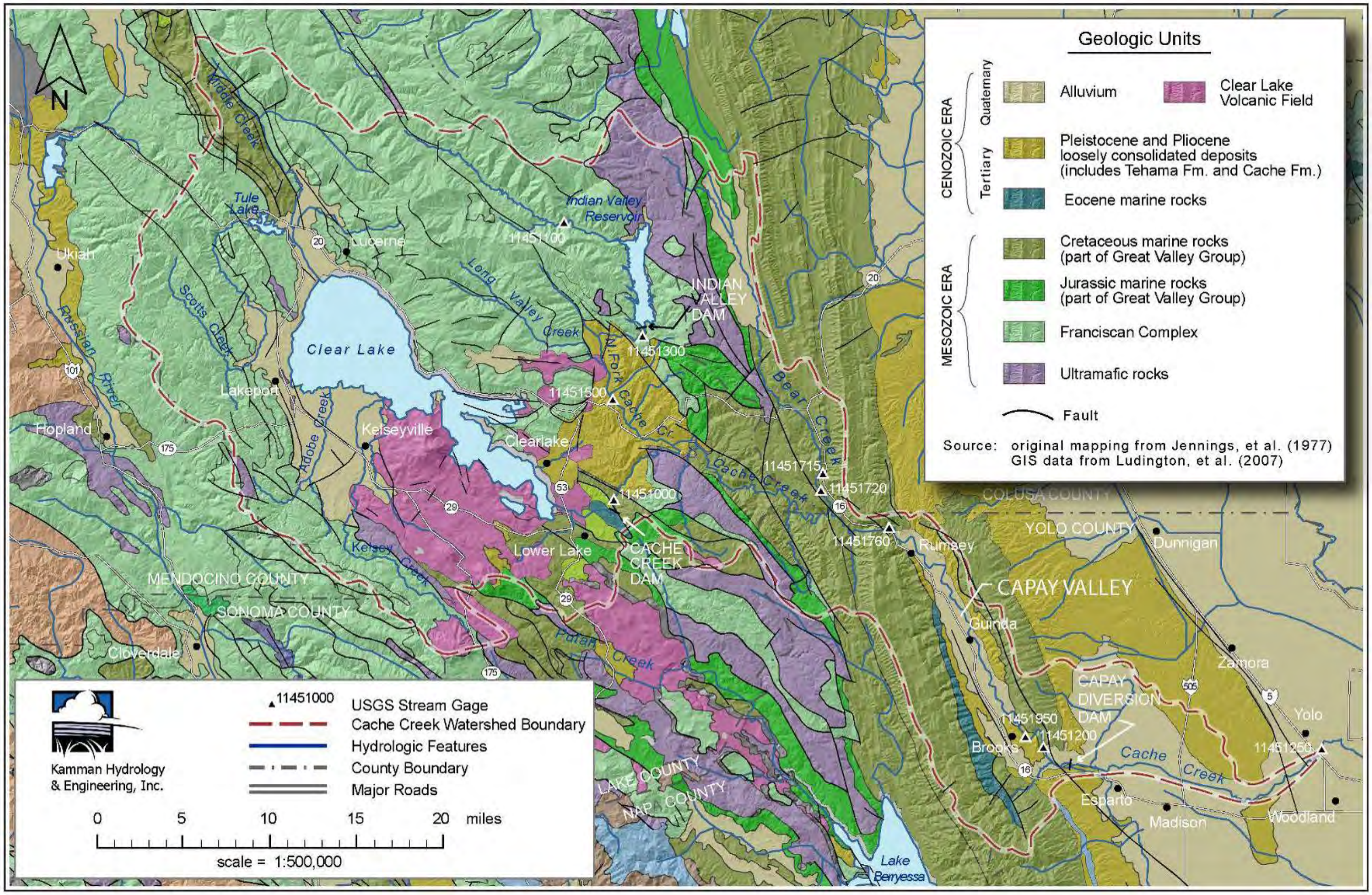


Figure 2-4. Map of geologic units and faults in the Cache Creek watershed. Data source: Jennings et al. (1977).

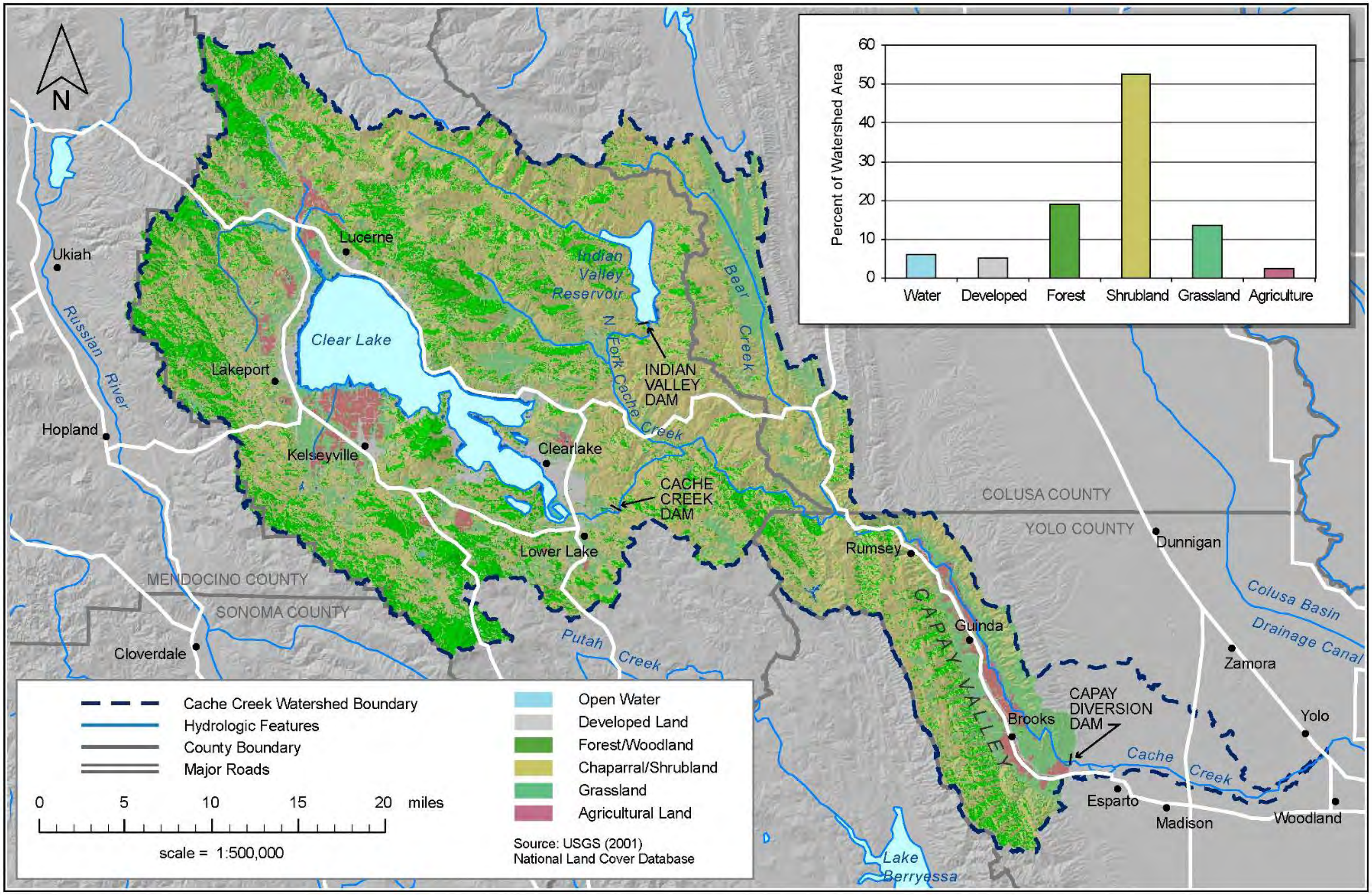


Figure 2-5. Map of vegetation types in the Cache Creek watershed. Data source: U.S. Geological Survey National Landcover Database.

3.0 Hydrologic Conditions

The hydrologic conditions of the Capay Valley segment of Cache Creek integrate the characteristics of upstream controls in the drainage basin (climate, geology, land use, and basin physiography). This section describes surface- and groundwater hydrology and water quality conditions within the watershed and addresses the following questions:

- What is the seasonal variability of flow in Cache Creek?
- How do hydrologic conditions in the basin vary between years (e.g. wet vs. dry years)?
- How do existing hydrologic conditions compare to unimpaired (unregulated by dams) conditions?
- What is the expected recurrence frequency of flood conditions in Capay Valley?
- What are the characteristics of the groundwater hydrology in Capay Valley?

3.1 Summary of Stream Gaging Records

Published records of streamflow were compiled for stream gages in the Cache Creek basin (Table 3-1; Fig. 2-1). The longest available streamflow record is from the U.S. Geological Survey (USGS) gage at Yolo (#11452500) which dates back to 1913 and continues to operate to the present. Streamflow conditions in Capay Valley are presently monitored at the Rumsey Bridge by the California Department of Water Resources (DWR). This station (A81135) has operated since December of 1975, however, records have been poor since 2001 due to channel reconfiguration (L. Fishbain, email communication, November 25, 2008). Additional streamflow observations within Capay Valley are available from discontinued USGS stream gaging stations above Rumsey (#11451760), near Capay (#11452000) and near Brooks (#11451950).

Data from the Capay Valley stream gaging stations, as well as gaging records from stations in the upper basin and near the basin outlet, were utilized to develop a continuous record of daily streamflow for the period 1943-2007. The composite streamflow record utilized flow at the Rumsey gage sites for the periods which data were available. The USGS gage above Rumsey (#11451760) was located approximately 2.5 miles upstream of the present DWR gage (at the bridge) and KHE combined data from the two gage sites without adjustment. Daily observations from the two Rumsey gage sites account for 48 percent (31 years) of the 65-year composite record. An additional 36 percent (23 years) of the record was completed by calculating daily values of streamflow at Rumsey by means of flow correlations to the USGS station at Capay (#11452000). We calibrated the correlation using a regression equation developed from over ten years of concurrent daily flow observations at the two sites ($R^2 = 0.96$).

Remaining gaps of the composite streamflow record, the periods of time for which no streamflow observations were made within the Capay Valley segment, were estimated using a selection of methods chosen to best fit the available data for a given time period. About 11 percent (7 years) of the record was reconstructed by taking the sum of the daily flow at Cache Creek below Clear Lake (#11451000), North Fork Cache Creek below Indian Valley Dam (#11451300), Bear Creek (#11451715) and an estimate of flow contributions from the ungaged area derived as an area weighted proportion of the flow at Bear Creek. A small portion of the record (about 2 percent of the composite record) was estimated by means of a flow correlation using flow at the USGS station at Yolo (#11452500). The regression estimates based on flows at Yolo were limited to the winter season to avoid the large differences in flow that occur between the two stations when water is diverted at Capay Dam. A few dates in the composite record (less than 1 percent) were estimated as the sum of the daily flow at Yolo (#11452500) and the mean monthly diversion at Capay Dam reported for the corresponding month by YCFCWCD. Lastly, a small number of days in the composite record were estimated by linearly interpolating between observed values to fill gaps of a few days when data from gaging stations elsewhere in the basin suggested relatively constant flow conditions (i.e., no significant flood events that would cause the hydrograph to deviate from the linear interpolation).

The 65 year record of mean daily streamflow (1943-2007) was disaggregated into time series of mean monthly and mean annual streamflow. The daily, monthly, and annual records were evaluated statistically to characterize streamflow variability and to document hydrologic changes during the historical period.

Table 3-1. Stream gaging stations in the Cache Creek basin utilized in the streamflow analysis. Locations of stream gaging stations are indicated on the watershed map (Fig 2-1).

Site ID	Operator	Location	Drainage Area (mi^2)	Period of Record
11451000	USGS	Cache Creek near Lower Lake	528	1944-2007
11451300	USGS	North Fork Cache Creek near Clearlake Oaks	121	1983-2007
11451500	USGS	North Fork Cache Creek near Lower Lake	197	1931-1981
11451715	USGS	Bear Creek above Holstein Chimney Canyon	95	1997-2008
11451760	USGS	Cache Creek above Rumsey	955	1961-62,1966-73,1984-86
A81135	DWR	Cache Creek at Rumsey	964	1976-2007
11451950	USGS	Cache Creek near Brooks	1041	1984-1986
11452000	USGS	Cache Creek near Capay	1044	1943-1976
11452500	USGS	Cache Creek at Yolo	1139	1903-2007

3.2 Streamflow Characteristics

Characteristics of streamflow in the Capay Valley segment of Cache Creek reflect the regional climate, environmental conditions of the drainage basin, and the effects of flow regulation from Clear Lake and Indian Valley Reservoir. The area contributing drainage to the headward extent of Capay Valley encompasses approximately 955 square miles. An additional area of about 120 square miles drains into Cache Creek between the head of Capay Valley and the Capay Diversion Dam. In total, a watershed area of about 1,074 square miles contributes drainage to Cache Creek at the downstream extent of the study area (Fig. 2-2). The mean annual streamflow of Cache Creek at Rumsey was 746 cfs during the period 1943-2007. Normalized by contributing drainage area (955 square miles), the mean annual streamflow equates to 10.6 inches or about 30 percent of the mean annual precipitation over the basin. The remaining 70 percent of precipitation is lost to evapotranspiration processes and to groundwater recharge.

Hydrology of the Cache Creek basin is characterized by large seasonal and inter-annual variability. The seasonal pattern of streamflow in Cache Creek generally shows a peak between January and March, followed by a period of moderate flows through August, and a decline to very low flows in October and November (Fig. 3-1). Wet season flows are primarily derived

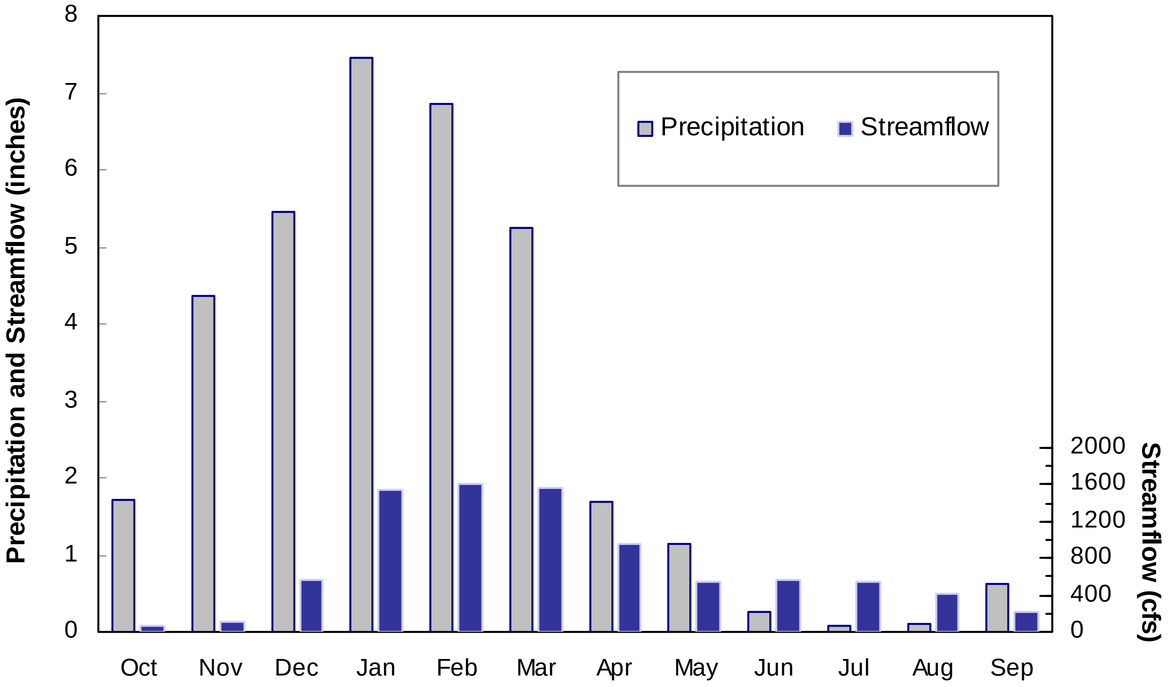


Figure 3-1. Mean monthly precipitation for the Cache Creek basin and mean monthly streamflow for Cache Creek at Rumsey, 1943-2007. Precipitation data from Clearlake (National Weather Service Cooperative Network) is increased by a factor of 1.22 based on the difference between mean annual precipitation at the station (28.7 inches) and the estimate of spatially averaged mean annual precipitation for the basin (35 in.).

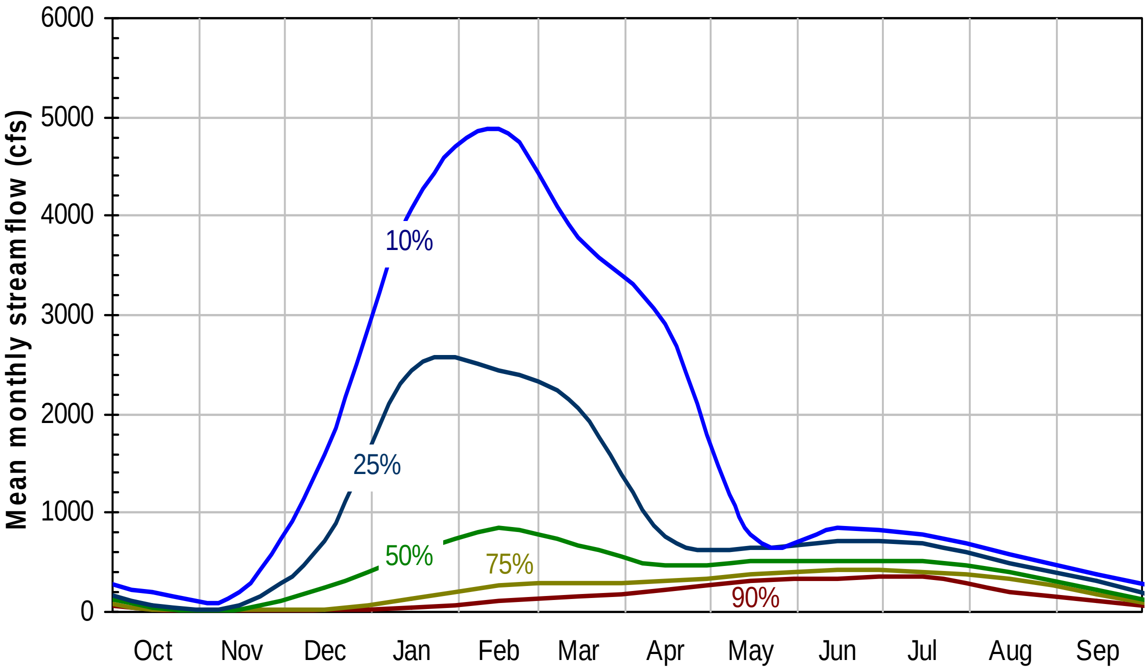


Figure 3-2. Monthly probability hydrographs for Cache Creek at Rumsey show the seasonal trend and inter-annual variability of streamflow during the period 1943-2007. Percentiles represent the exceedance probability, or likelihood that the mean monthly discharge will be exceeded in any given year, of the indicated streamflow value.

from the unregulated portion of the watershed (approximately 40 percent of the watershed area; Fig 2-2). Streamflows during the wet season display a greater range of variability than the typically dry summer months (Fig. 3-2). During most years almost all of the winter runoff from subbasins above the Cache Creek Dam and above Indian Valley Dam is stored in Clear Lake and Indian Valley Reservoir, respectively. Above average water years are an exception; as excess runoff is at times released from the dams during winter. Streamflow from May through September is typically maintained by flow releases at the upstream dams. The streamflow in Cache Creek drops to very low levels as flow releases terminate at the end of the water delivery season (typically in September) until the arrival of winter storm systems brings additional runoff from the watershed.

Streamflow in Cache Creek has ranged from near zero to greater than 50,000 cfs. The variability of streamflow in the continuous record from 1943-2007 was evaluated by flow duration analysis. The frequency of flows within a given range is illustrated by the flow duration curve in Fig 3-3. The duration curve can be utilized to find the percentage of time that streamflow can be expected to exceed a design flow of a given value, or to find the streamflow that is expected to occur at some design frequency. The median daily flow, equaled or exceeded during 50 percent of the daily record, is about 330 cfs. Mean daily values between 200 and 1,000 cfs account for approximately half of the 65 year record. Mean daily values greater than 8,000 cfs are rare; occurring less than 1 percent of the time (about 4 days per year on average). The ranges of daily values greater than 1,350 cfs or less than 20 cfs each occur about 10 percent of the time (an average of 37 days per year).

Year-to-year variability of both precipitation and streamflow is large. Annual rainfall totals in the upper watershed reveal considerable scatter, ranging between 35- and 200-percent of the long term average, and suggest an increase in variability for the period since 1975 (Fig. 3-4). Annual mean streamflows in Cache Creek at Rumsey display a similar variability. During the period 1943-2007 annual streamflow averaged 746 cfs and ranged from a minimum of 2 cfs in water year (WY) 1977 to a maximum of 2,864 cfs in WY 1983 (Fig. 3-4).

3.3 Flood Frequency Analysis

Flooding occurs in Capay Valley during large winter storm events that deliver water from the upper basin at a faster rate than the stream channel can transport it downstream. Flooding from typical winter storms may inundate low-lying portions of the floodplain and is not a great hazard to the local community. Less frequently, major flood events have the potential to inundate much greater areas including terrace surfaces elevated above the floodplain. Table 3-2 summarizes the ten largest peak flows recorded since 1940.

Annual peak streamflow data were compiled from USGS stream gaging records for stations above Rumsey, near Capay, near Brooks, and downstream of the study area at Yolo (Table 3-1). The gaging station at Yolo has the longest continuous record (1903-present). Peak streamflow data from the period prior to 1940, however, were omitted from the record at Yolo because these data are thought to underestimate peak flow magnitudes as a result of bypass flows that were not accounted for at the gaging station (NHC, 1995). The long term record of peak annual flows at Yolo is presented in Figure 3-4.

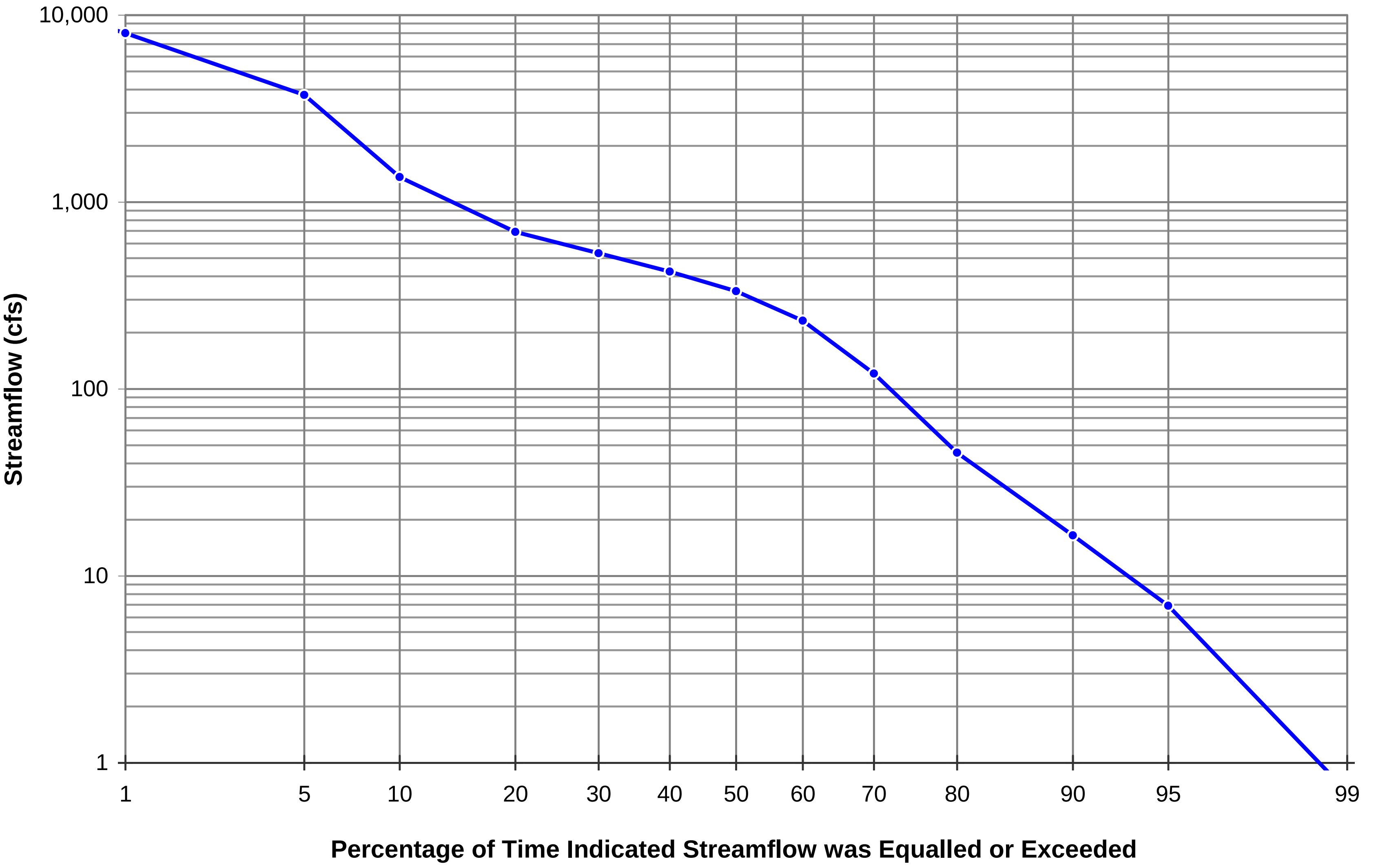


Figure 3-3. Flow duration curve for Cache Creek at Rumsey during the period 1943-2007. The plot displays the percentage of time, or the duration, that a given mean daily streamflow was equaled or exceeded during the historical record.

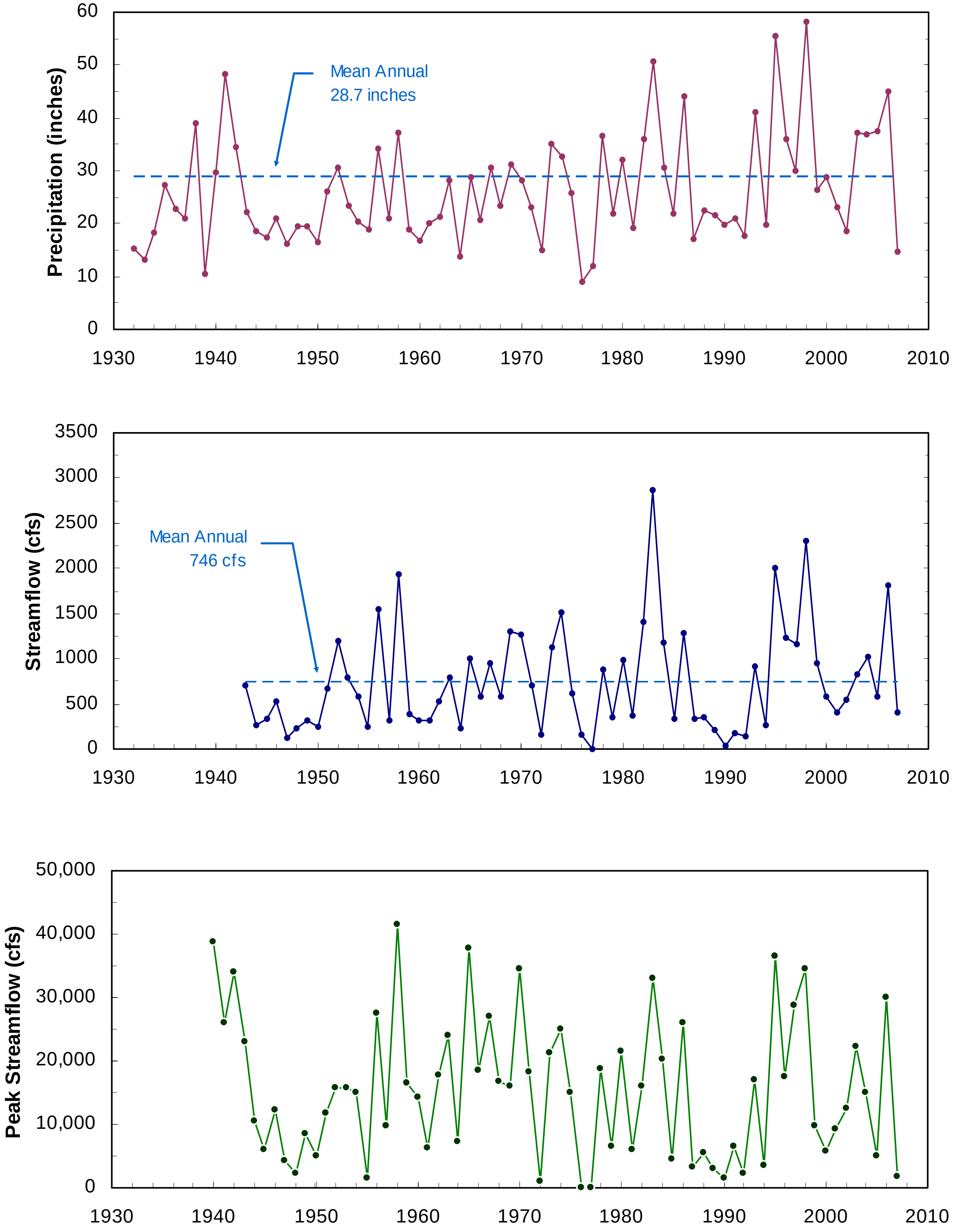


Figure 3-4. Annual time series data for precipitation at Clearlake (top), mean annual flow at Rumsey (middle), and peak annual flow at Yolo (bottom).

Table 3-2. Ranked summary of peak discharge magnitudes since 1940.

Rank	Date	Discharge (cfs)	Measured at
1	January 26, 1983	53,500	Rumsey
2	March 9, 1995	52,000	Rumsey
3	February 24, 1958	51,600	Capay
4	January 5, 1965	44,500	Capay
5	February 28, 1940	38,700	Yolo
6	February 17, 1986	37,000	Brooks
7	January 24, 1970	36,200	Capay
8	December 31, 2005	35,200	Rumsey
9	January 21, 1943	35,000	Capay
10	February 3, 1998	34,600	Yolo

Observations of peak streamflow reveal similar flood histories for the gaging stations at Rumsey, near Capay, and at Yolo. Flood hydrographs for lower Cache Creek tend to show a rising limb that spans a time period between about 12- and 24-hours, a peak flow that is maintained for a short duration (approximately 1- to 2-hours), and a falling limb that recedes to a winter baseflow level over a span of 12- to 24-hours (Fig. 3-5). Graphical comparison of flood hydrographs between the DWR station at Rumsey and the USGS station at Yolo reveal additional information about the flood characteristics of Cache Creek. The lag time between the flood peak at Rumsey and the corresponding peak at the Yolo gaging station is about 12 hours. As the downstream extent of Capay Valley is just less than halfway between the two stations, the lag to peak within Capay Valley can be expected to occur within a span of about six hours. The plot of concurrent flood hydrographs also suggests a tendency for the flood peak to attenuate in the downstream direction (Fig. 3-5).

Periods of overlapping data were evaluated to assess the relation between peak flows at gaging stations in Capay Valley and at the station with the long-term record at Yolo. Graphical review of the data suggests some flood peak attenuation between stations above Rumsey and near Capay. Despite the fact that an additional 89 square miles contribute drainage to Cache Creek between the two stations, peak flows tend to be slightly higher at the upstream station above Rumsey when compared to the peak flow near Capay from the corresponding flood event (Fig 3-6A). The degree of flood peak attenuation is likely dependant on the ability of the floodplain areas in Capay Valley to slow down and retain floodwater and the timing and spatial distribution of rainfall. An additional area of 95 square miles contributes drainage between the gaging station near Capay and the station at Yolo, yet again comparison between gage sites shows a tendency for flood peak attenuation in the downstream direction (Fig. 3-6B). The degree of attenuation appears to be greater for the higher-magnitude peak flows in the historic record and is likely attributed to the retention of floodwaters by overbank floodplain areas.

Data from the USGS gaging station near Capay (see Fig. 2-1 for site location) during the period 1943-76 were analyzed using the Bulletin 17-B guidelines for determining flood frequency (U.S. Interagency Committee on Water Data, 1982). The resulting flood frequency curve is shown in Figure 3-7. Note that the period of observation is limited to the historical period prior to construction of Indian Valley Dam and are therefore likely to overestimate the peak flow magnitude for a given frequency. More recent observations at USGS gaging stations in Capay Valley are limited to the three year period 1984-86.

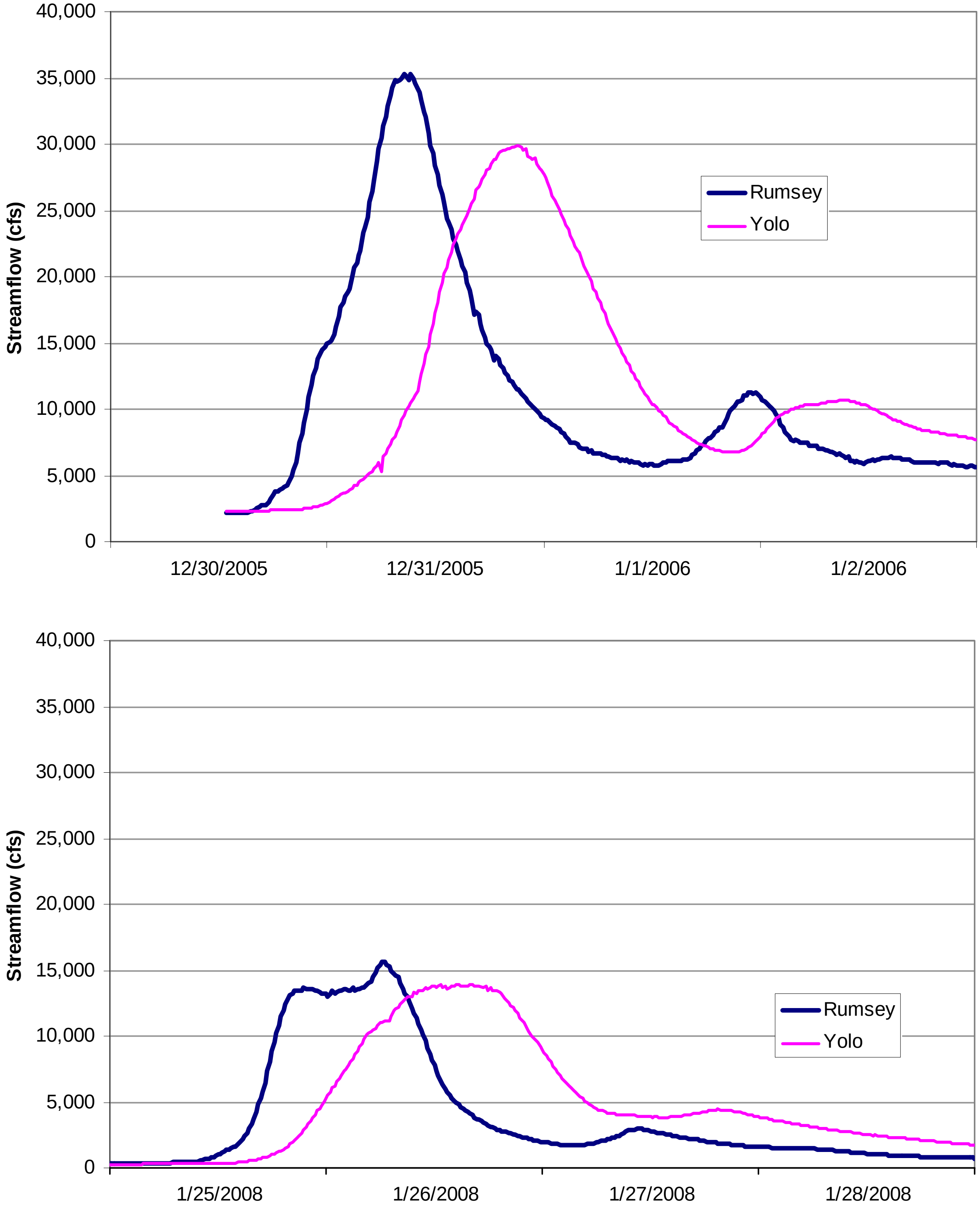


Figure 3-5. Concurrent flood hydrographs for Cache Creek at Rumsey (DWR gage) and at Yolo. The upper panel shows the flood event of New Year's Eve 2005/06 and illustrates a downstream attenuation of the flood peak. The lower panel shows a more moderate flood event from 2008.

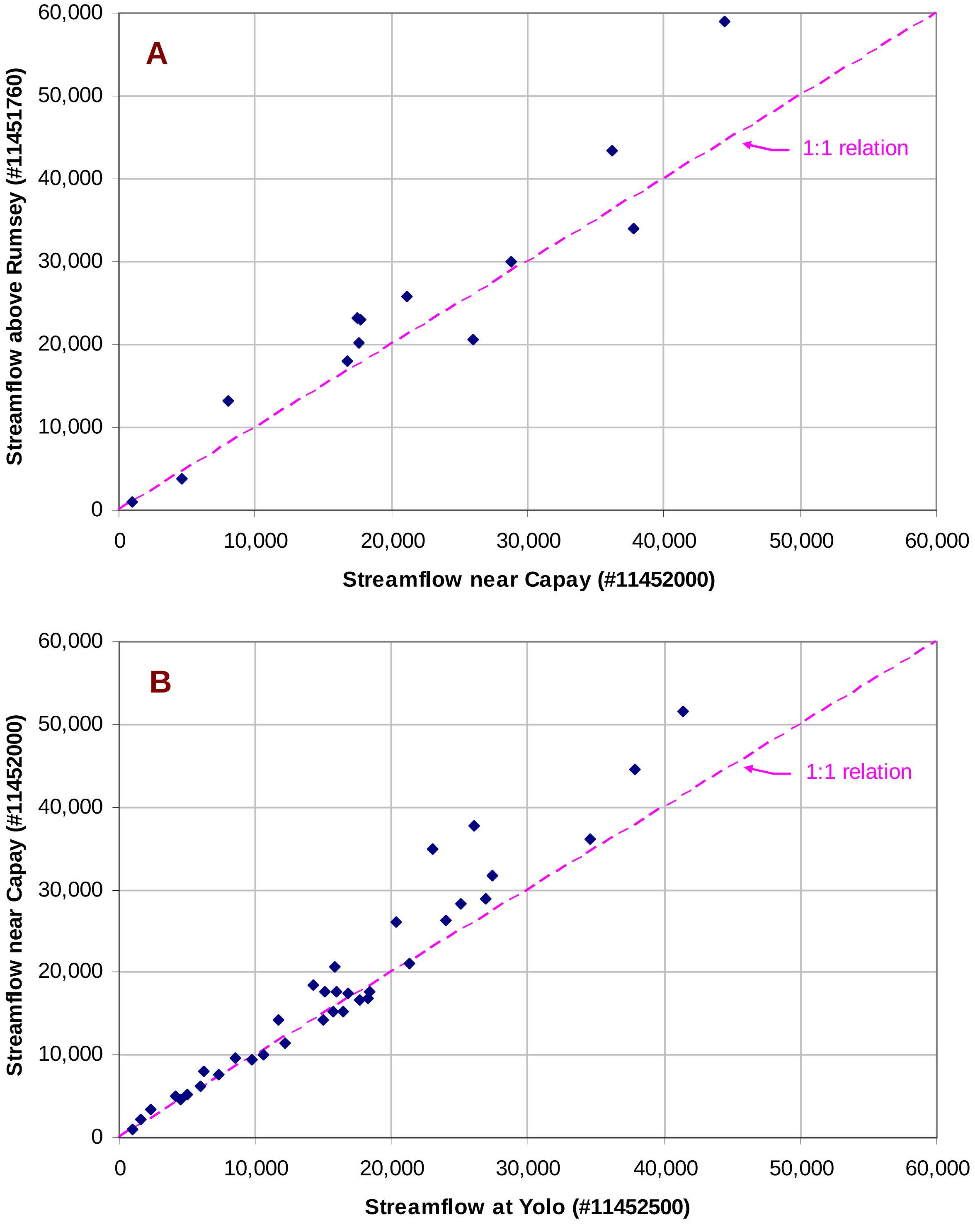


Figure 3-6. Matched-pairs of peak streamflow for periods of overlapping data. Panel A (top) plots the peak streamflow above Rumsey and the corresponding peak flow near Capay (n = 20 years). Panel B (bottom) plots the peak streamflow near Capay and the corresponding peak flow at Yolo (n = 35 years). The dashed line indicating a 1:1 relation is the theoretical position that would indicate that concurrent flood peaks were equal between the two sites in a given year.

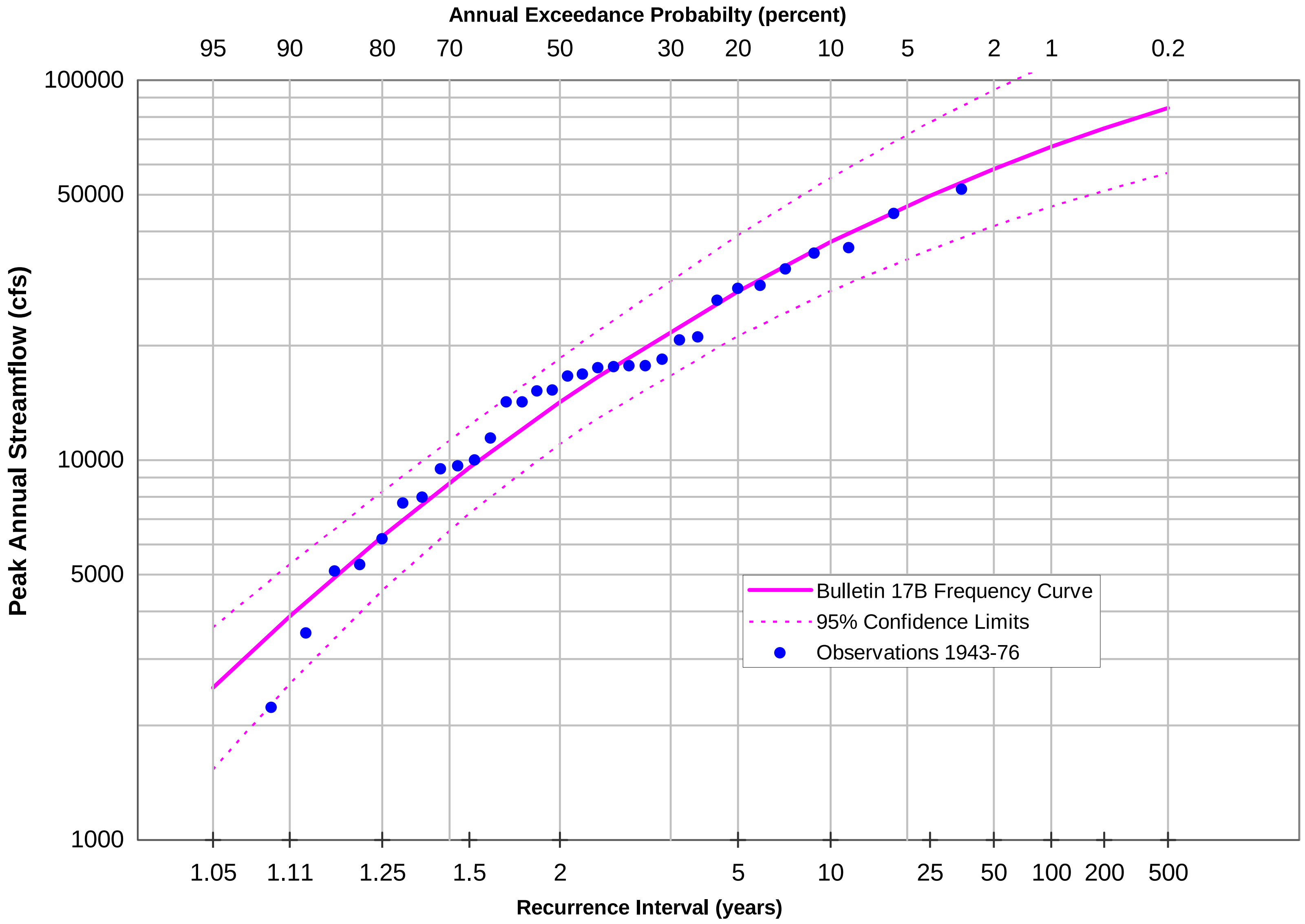


Figure 3-7. Flood frequency curve for USGS gaging station Cache Creek near Capay (#11452000) for data 1943-76. Note that streamflow measurements represent the condition prior to construction of Indian Valley Dam and are therefore likely to overestimate flow at a given recurrence interval under existing (more regulated) conditions.

3.4 Historical Changes in Streamflow

Changes a watershed's hydrologic conditions are typically attributed to: (1) climatic variability or climate change; (2) changes in environmental conditions of the watershed, such as land use changes, that affect hydrologic processes; or (3) flow regulation or other water resource management actions. Previous discussion described the impact of flow regulation on streamflow characteristics in Cache Creek (section 3.2). The impact of flow regulation is further discussed here and expanded to assess the hydrologic changes associated with construction of Indian Valley Dam which was completed in 1975.

The hydrologic regime of the Clear Lake basin was partially regulated by the lake under natural conditions. Cache Creek Dam, completed in 1914, enhanced the ability to store winter runoff in the lake and deliver it to water users downstream during periods of peak demand (summer). Indian Valley Dam, completed in 1975, stores runoff from an area draining approximately 120 square miles and supplements water deliveries to the service area downstream. The area regulated by Indian Valley Dam accounts for about 22 percent of the watershed area that was unregulated prior to 1975 (the watershed area excluding the Clear Lake basin).

Data from the observed flow record for Cache Creek at Rumsey were compared to a dataset of unimpaired flow estimates by DWR (2007) to assess the hydrologic changes due to flow regulation. The comparison shows the expected moderation of seasonal variability whereby winter flows have generally been lower and summer flows have generally been higher than those expected under unimpaired conditions (Fig. 3-8). Regulation has also affected the inter-annual variability of flows in Cache Creek. During the wet season, between December and March, the range of flows representing the difference between wet and dry water year types has increased. The opposite effect has occurred during the dry season as flows are maintained at an unnaturally high level due to the flow releases from the upstream dams. Estimates of unimpaired runoff suggest that a natural streamflow pattern would frequently include streamflows less than 100 cfs between August and November (DWR, 2007). Under existing conditions, dam releases for irrigation sustain streamflows within a range between 300 and 700 cfs for much of the summer and natural baseflows aren't observed until October.

The hydrologic changes due to flow regulation are significant to the physical characteristics of the stream corridor through Capay Valley. The increased magnitude and decreased variability of streamflow during the summer affects the shallow groundwater conditions along the creek and may influence the characteristics of riparian vegetation. The decreased magnitude of streamflow during the winter affects the channel downstream because the high flows are most important to sediment transport processes.

The historic record of streamflow data for Cache Creek has been affected by regulation at Cache Creek Dam (below Clear Lake) for the entire period. Flow regulation at Indian Valley Dam, however, began more recently. Streamflow data from the historic period were analyzed to evaluate the hydrologic changes between the periods pre- and post-construction of Indian Valley Dam. Data analysis represented the pre-Indian Valley Dam period by data for 1943-1974. The post-Indian Valley Dam period was represented by data for 1975-2007. The two periods were assessed qualitatively to evaluate potential differences due to climatic variability. Mean annual

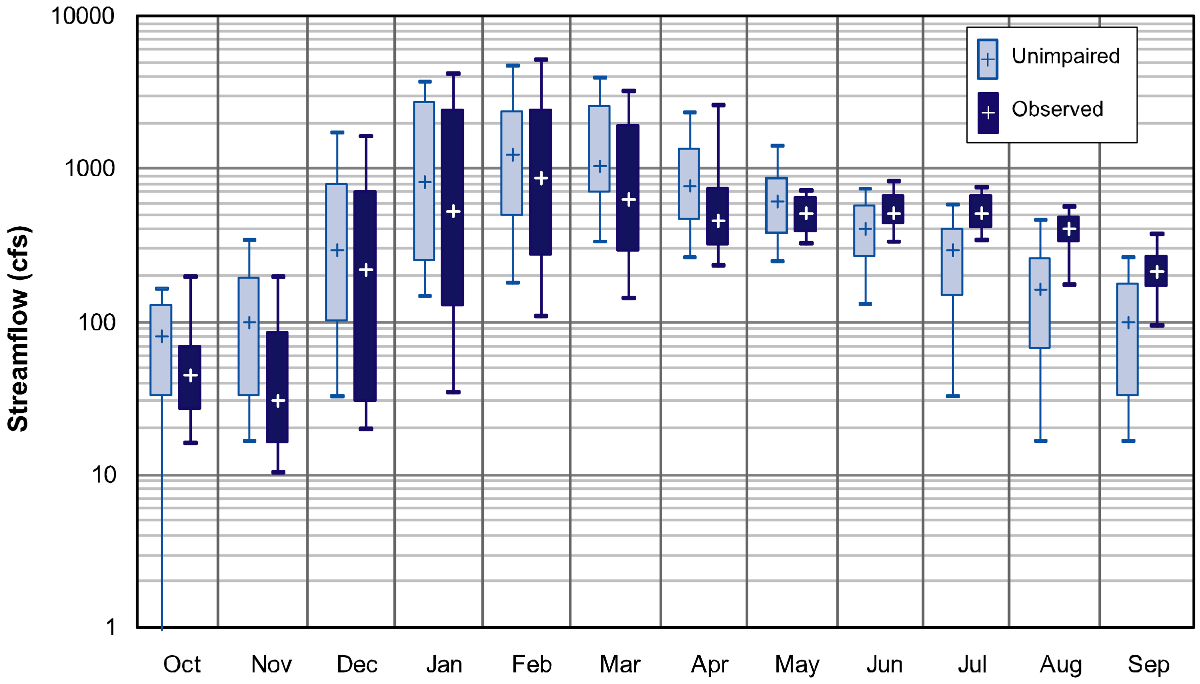


Figure 3-8. Monthly streamflow percentiles under existing (observed) and pre-dam (unimpaired) conditions, Cache Creek at Rumsey, 1943-2003. Monthly streamflow statistics are shown for the 10- (bottom whisker), 25- (bottom of box), 50- (cross), 75- (top of box), and 90-percentile streamflows. Unimpaired runoff estimates from DWR (2007).

precipitation at Clearlake was 23.5 inches during the period 1943-1974 and increased to 29.5 inches for the period 1975-2007. Similarly, mean annual flow increased from 682 cfs to 808 cfs between the two periods. Graphical evaluation of the time series plots in Figure 3-4 suggests that the mean values are skewed by a few extremely wet years in the recent period such as WY 1983, 1986, 1995, 1998, and 2005. The median annual flow, which is equaled or exceeded by half of the years in the annual time series, is perhaps a better measure of central tendency as it is less affected by extreme values. Comparison of the median annual flow for the pre- and post-Indian Valley Dam periods reveals nearly identical values of 579 and 584 cfs, respectively.

Streamflow data from the pre- and post-Indian Valley Dam periods were assessed to evaluate changes within the historic record. In general, the addition of Indian Valley Reservoir in the upper watershed has increased the effect of flow regulation on the seasonal variability of streamflow in Cache Creek. Comparison of annual hydrographs showing the median monthly flow for the pre- and post-Indian Valley Dam periods reveals a general decrease in flow during the wet season and an increase in flow during the summer period when flows are released from the dams upstream (Fig. 3-9).

Further analysis of the historical record evaluated the effect of additional regulation from Indian Valley Reservoir on the magnitude/frequency relations of floods in Cache Creek. The magnitude of a flood which can be expected at a given recurrence interval should decrease with the additional reservoir storage created by construction of Indian Valley Dam. Flood modeling by the USACE (1995) simulated storm events from 1983 and 1995 and suggests that reservoir storage behind Indian Valley Dam reduces the expected peak flow magnitudes of large floods by approximately 20 percent. The change to the flood frequency relation in Cache Creek was further assessed by analysis of the annual maximum flow record at Yolo. The station at Yolo was selected for analysis because of its long-term record; stations in Capay Valley do not have an adequate record of peak flows for the period since 1975. Comparison between the flood records at Rumsey, near Capay, and at Yolo suggest that the Yolo record may differ slightly in magnitude, due to the downstream attenuation of peaks, but is suitable for assessing relative changes in the historic record for Capay Valley. The annual maximum series of peak streamflow at Yolo (Fig. 3-4) was divided into the pre- and post-Indian Valley Dam periods and analyzed separately using the Bulletin 17-B guidelines for determining flood frequency (U.S. Interagency Committee on Water Data, 1982). Results of the flood frequency analysis are presented in Figure 3-10. Comparison of the flood frequency data for the pre- and post-Indian Valley Dam periods shows a general decrease in the magnitude and frequency floods at Yolo. The decrease is most notable at the lower end of the frequency curve for floods less than about 15,000 cfs.

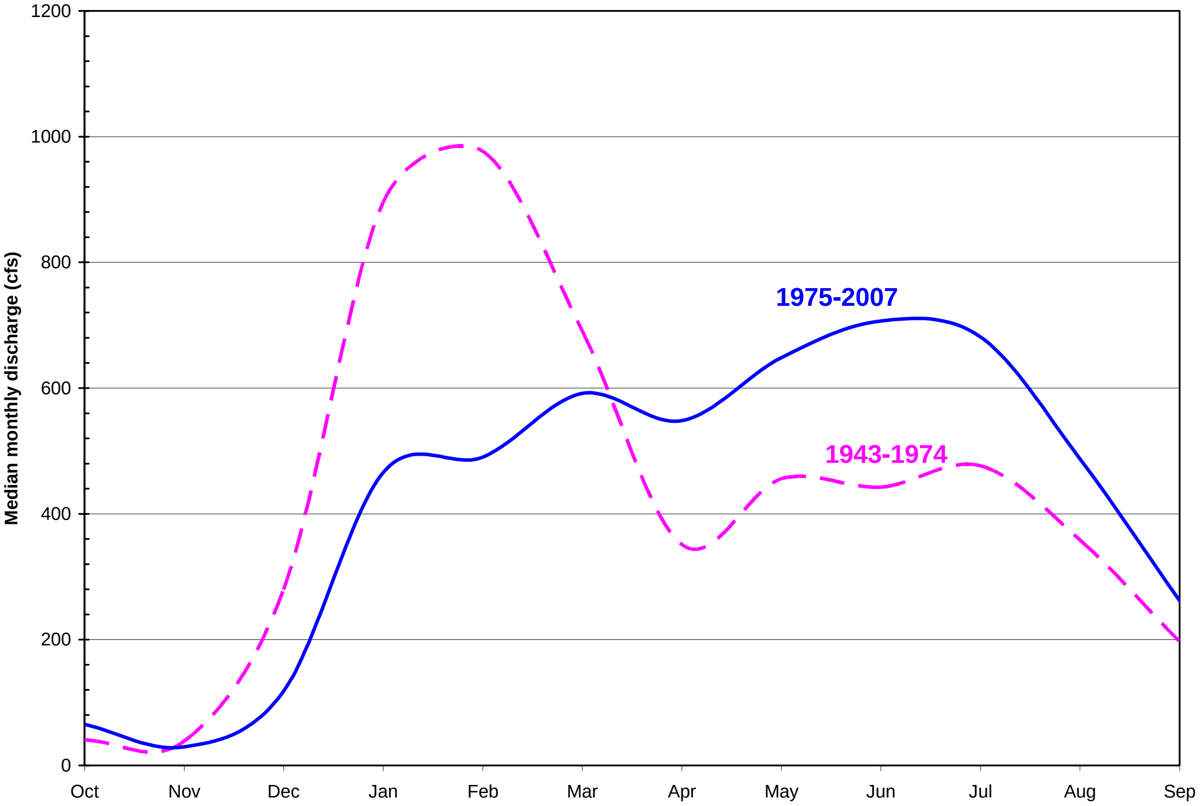


Figure 3-9. Comparison of annual hydrographs for the median monthly flow during the periods 1943-1974 (pre-Indian Valley Dam; flow regulation from Cache Creek Dam only) and 1975-2007 (post-Indian Valley Dam).

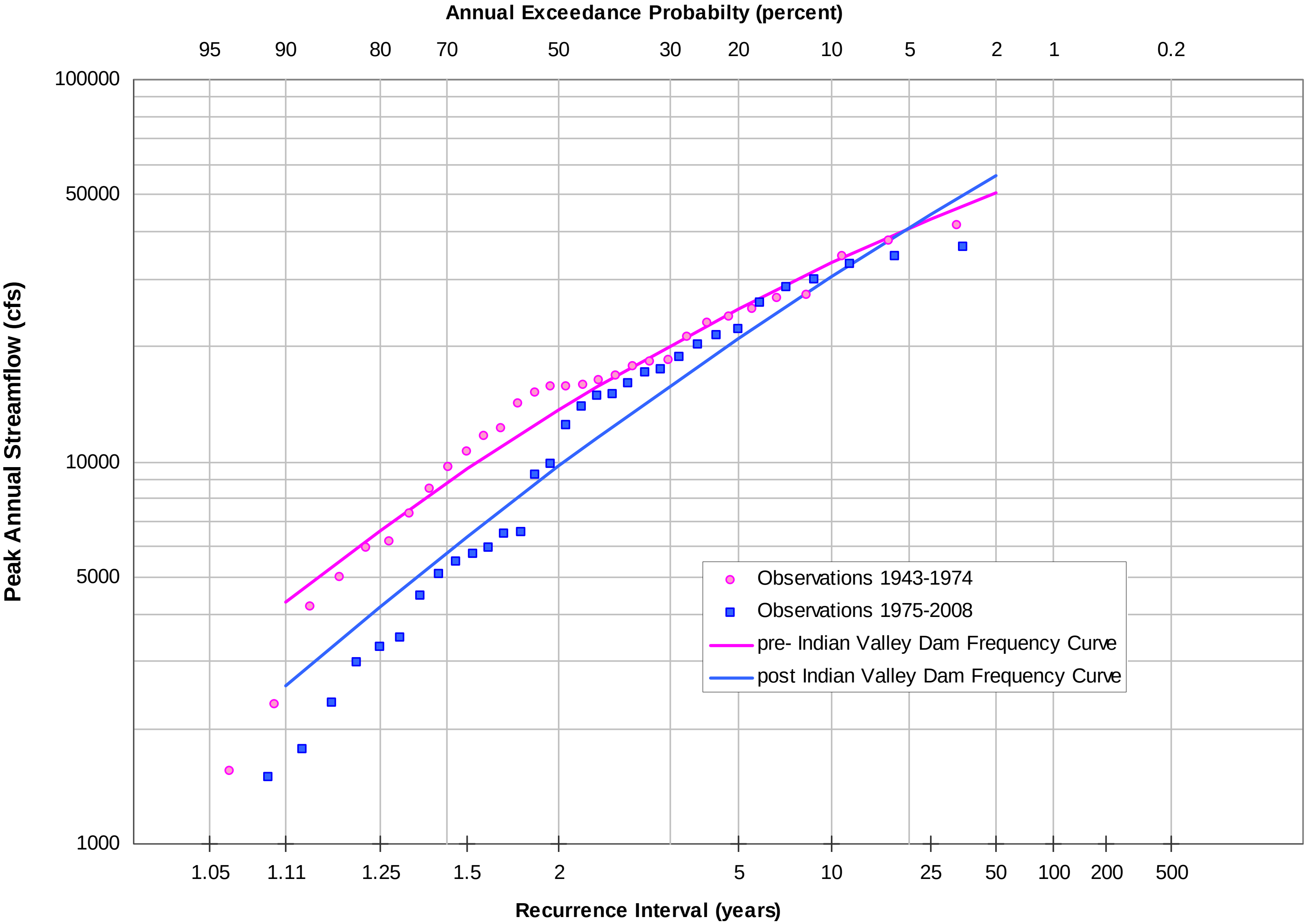


Figure 3-10. Comparison between flood frequency curves for the periods 1943-1974 (pre-Indian Valley Dam; flow regulation from Cache Creek Dam only) and 1975-2007 (post-Indian Valley Dam).

3.5 Groundwater Hydrology

The primary water bearing deposits within the Capay Valley include relatively young stream channel alluvium (unconsolidated silt, fine- to medium-grained sand, gravel and cobbles deposited in and adjacent to Cache Creek and its tributaries) and the underlying Tehama Formation. Creek alluvium deposits are moderately to highly permeable and range in thickness from approximately 0 to 150 feet. The Tehama Formation consists of moderately compacted silt, clay, and fine sand enclosing lenses of sand and gravel, silt and gravel, and cemented conglomerate. This formation outcrops along the edges of the Capay Valley and is generally less than a few hundred feet thick in the Valley. The permeability of the Tehama Formation is variable, but generally less than the overlying recent stream channel and floodplain alluvium. Bedrock underlying the Tehama Formation consists of older Cretaceous Marine Rocks consisting of sandstone and shale of marine origin. The basement rocks generally contain saline connate water and are not considered viable water bearing formations.

Analysis of Department of Water Resources long-term (>50 years) groundwater monitoring data for wells within Capay Valley (see Figure 3-11) indicate that groundwater levels in Capay Valley vary from approximately 10 to 40 feet below ground surface with depth to groundwater mimicking the surface topography. As such, the groundwater flow direction perpendicular to the creek alignment is towards the creek (see Figure 3-12), while groundwater flow parallel to the creek is down gradient to the south, following the surface and creek channel slope (see Figure 3-13). Groundwater levels are remarkably stable, especially in wells close to the creek. Wells located in the higher locations along the edge of the valley show a greater seasonal variability, and appear to be more impacted by dry years, especially the 1976-77 drought (see Figure 3-14). Recharge to groundwater in Capay Valley comes primarily from Cache Creek, with lesser amounts coming from surrounding tributaries and runoff from the surrounding hills.

Groundwater within Capay Valley is derived almost exclusively from Cache Creek and its tributaries. Consequently, water quality samples taken from Cache Creek within the Capay Valley reflect the quality of the water within the groundwater basin (DWR, 2003). Water samples taken from a diversion dam near the lower end of the Capay Valley indicate principally good quality calcium-sodium bicarbonate-type with moderate to very high hardness. Total dissolved solids measured in water taken from 6 wells in the Capay Valley ranged from approximately 300 to 500 parts per million (ppm), and are comparable to concentrations found in Cache Creek (DWR, 2003).

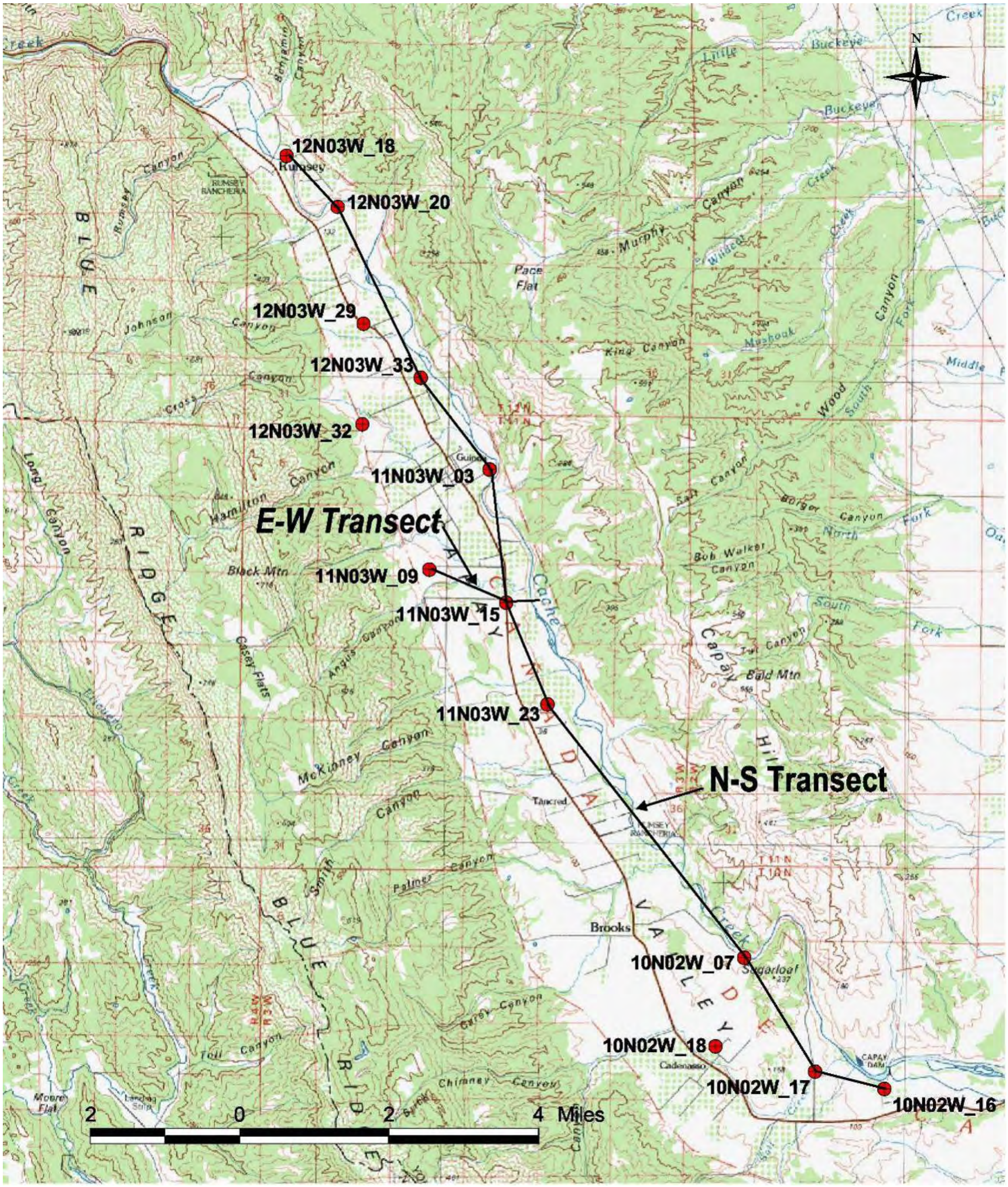


Figure 3-11. Groundwater wells located in Capay Valley and monitored as part of the California Department of Water Resources (DWR) Water Data Library. Profiles for E-W and N-S transect lines provided in Figures 3-12 and 3-13, respectively.

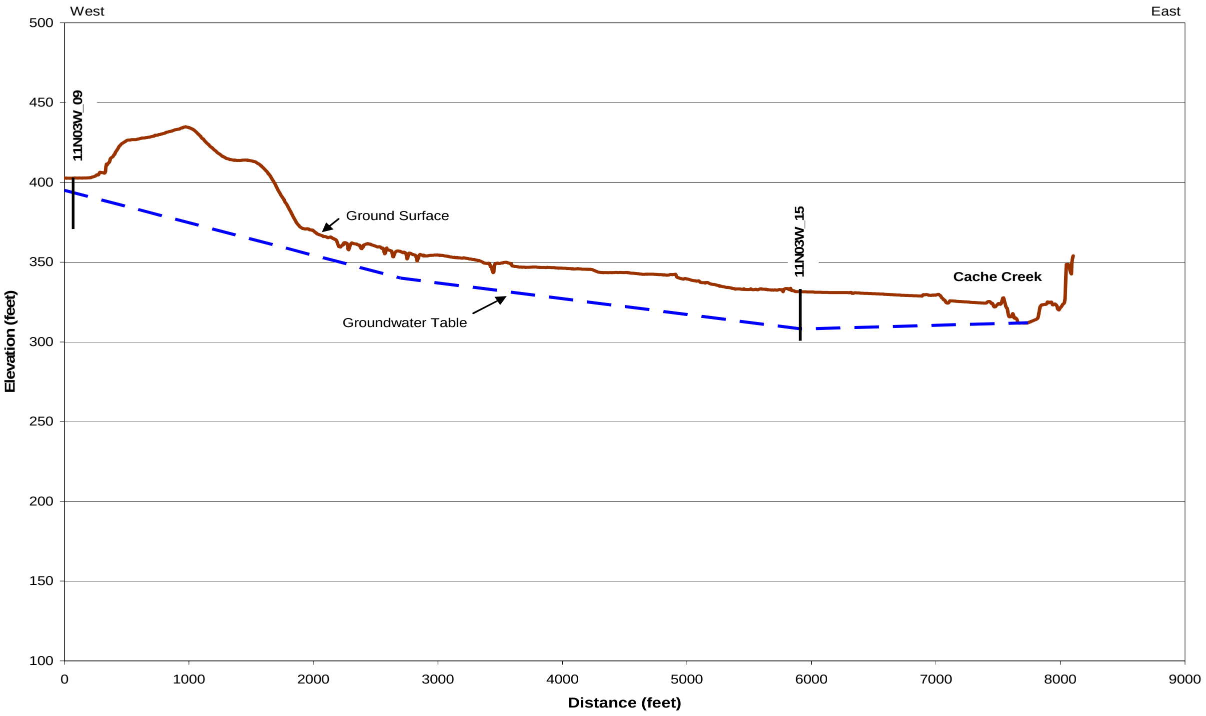


Figure 3-12. Profile along E-W Transect of long-term average groundwater levels relative to ground surface and Cache Creek channel.

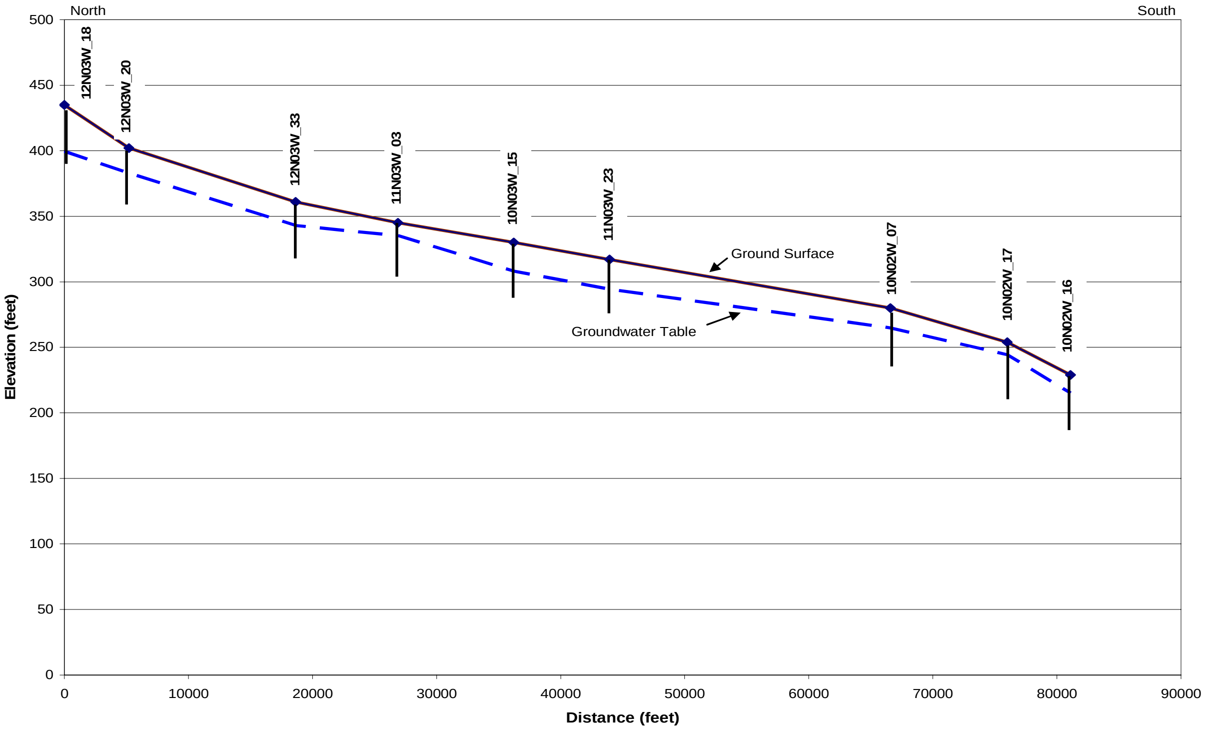


Figure 3-13. Profile along N-S Transect of long-term average groundwater levels relative to ground surface and Cache Creek channel.

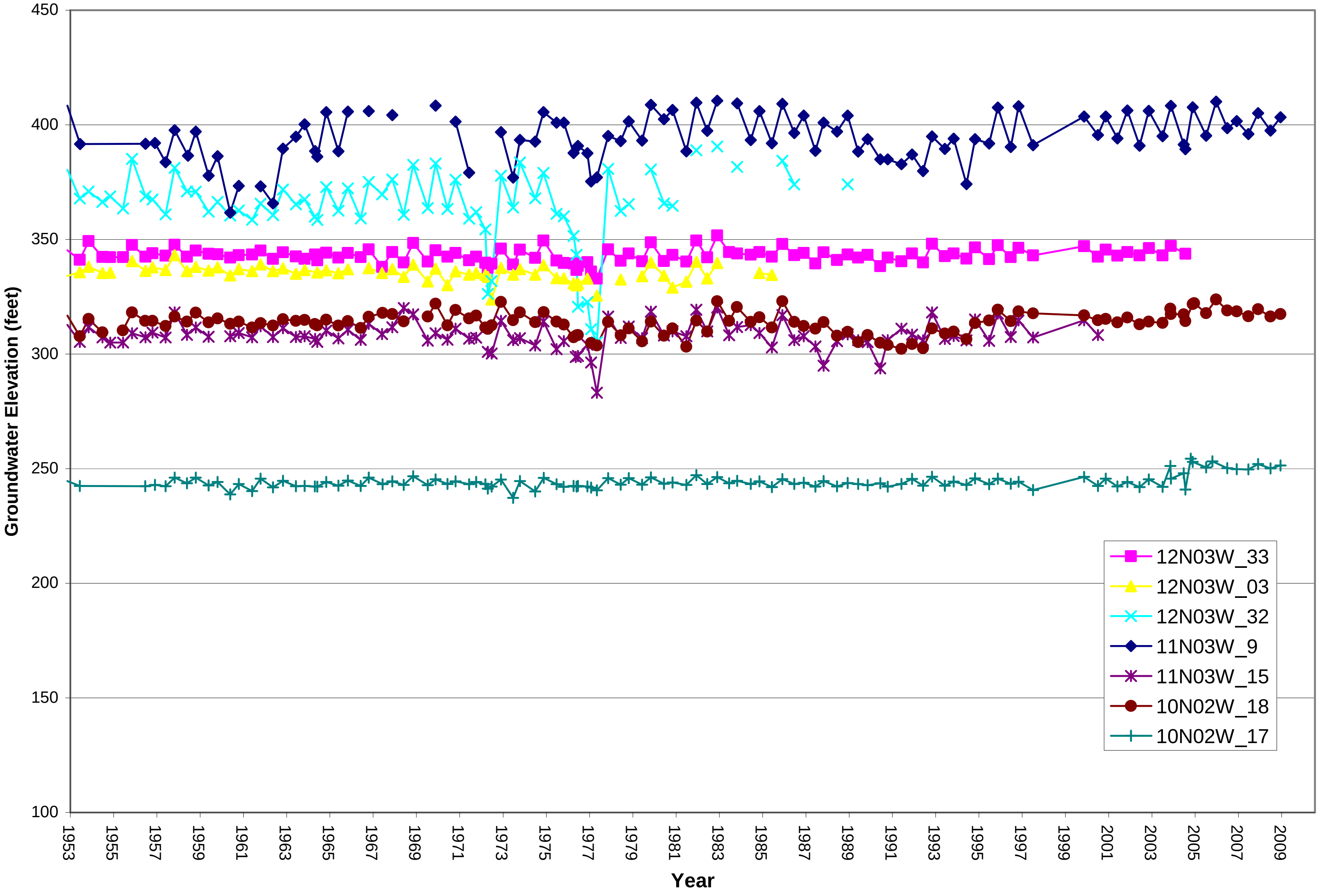


Figure 3-14. Groundwater well hydrographs for the period 1953 through 2008 for selected Capay Valley wells.

4.0 Stream Corridor Characteristics

The present study is primarily concerned with the river channel morphology along the Capay Valley segment of Cache Creek. Over time, the channel geometry of alluvial rivers adjusts to external controls, primarily the discharge of water and sediment, imposed by the drainage basin. The stream corridor is a landscape feature that encompasses the stream channel and the adjacent areas that are directly shaped or influenced by hydrologic and geomorphic processes (Fig. 4-1). Key components of the stream corridor include:

- the channel **thalweg**: the main channel alignment that follows the path of minimum elevation and carries water during low-flow conditions.
- the **active channel**: includes the low flow channel and adjacent bar surfaces that are mostly unvegetated and inundated at times of moderately high discharge.
- the **floodplain**: the relatively flat area adjacent to the stream channel created by depositional processes associated with lateral migration of the stream channel.
- **terrace** surfaces: an abandoned floodplain created under an earlier set of hydrologic conditions. Terraces are typically perched at a higher elevation than the active floodplain.

The purpose of this section is to describe the prevailing physical characteristics of the stream corridor through Capay Valley. Questions addressed in this discussion include:

- What is the prevailing channel pattern?
- What is the topographic relation between the active channel, the floodplain, and terrace surfaces within the stream corridor?
- What are the typical bankfull channel characteristics (i.e., width, depth, discharge)?
- What are the characteristics of the stream-bed material?
- What are the dominant processes of floodplain formation and gravel bar development
- What are the characteristics of the riparian vegetation and how do they relate to the characteristics of stream channel morphology?

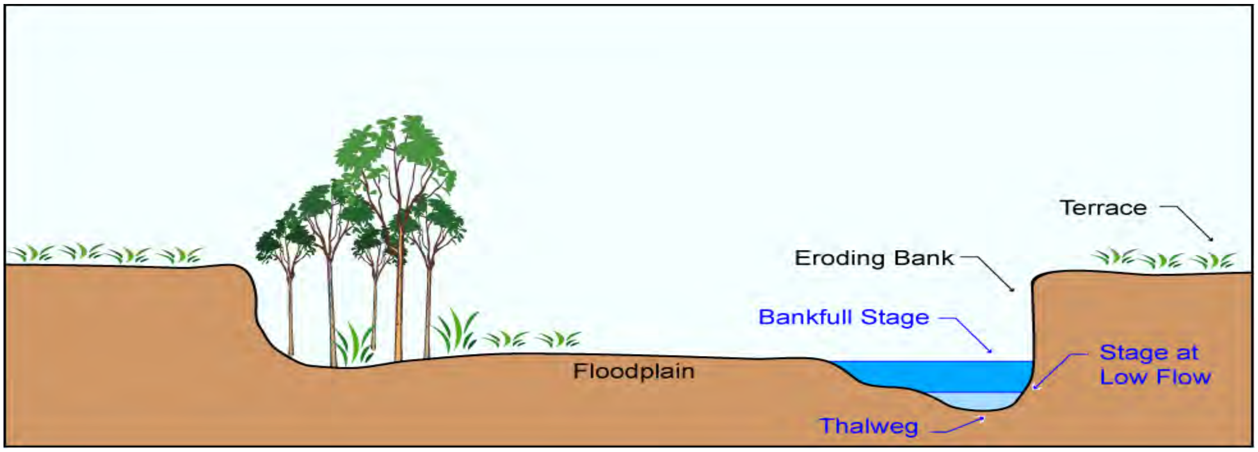


Figure 4-1. Schematic illustrating the primary components of the stream corridor in cross-sectional profile.

4.1 Terrain Analysis and Topographic Mapping

KHE's assessment of morphologic characteristics combined site observations from field visits, a review of aerial photographs, and analysis of topographic data. The USGS 7.5 minute (1:24,000) topographic map series is useful for describing the larger geomorphic features of the landscape, however, the level of detail on these maps (20 foot contour interval) is not sufficient to describe the more subtle features within the stream corridor. A key component of the current study has been the development of a high-resolution topographic dataset for the Capay Valley region.

KHE developed a high-resolution digital terrain model of Capay Valley that allows for rapid assessment of geomorphic features in a geographic information system (GIS). The Yolo County Flood Control and Water Conservation District (YCFCWCD) provided a LIDAR[1] dataset collected in March 2008. The LIDAR data list geographic coordinates as x,y,z (easting, northing, and elevation) values for discrete points spaced at roughly one meter intervals on the landscape. KHE processed the x,y,z data files to generate a grid surface, or digital elevation model (DEM), with a horizontal resolution (grid spacing) of five feet.

The map series in Appendix A depicts geomorphic features and historic channel alignments in the Capay Valley segment of Cache Creek. KHE used GIS tools to illustrate the topographic and geomorphic characteristics of the stream corridor. Graphical review of the DEM surface in conjunction with recent aerial imagery and cross-sectional profiles yield information that is utilized to describe the morphologic characteristics of the stream corridor. Characteristics of the stream corridor visible on the aerial image, such as gravel bar or vegetated floodplain surfaces, can be can be evaluated on the DEM to compare relative elevations and streambank configuration.

Cross-sectional profile alignments are indicated on the map series in Appendix A and correspond to the graphical plots of cross-sectional profiles in Appendix B. The cross-sectional profiles were derived from the DEM surface and are based on the LIDAR data collected in 2008. Profile alignments were drawn perpendicular to the stream channel alignment and extended beyond the stream bank areas to depict the topographic relations between channel, floodplain, and terrace features. By convention, the left and right banks of the creek are defined as viewed from a perspective looking downstream. Note that due to the channel configuration in Capay Valley where the creek generally flows in a southeasterly direction, many of the cross-sectional profiles are reversed from the way that the alignment appears on a map view (i.e., where the left side of the channel corresponds to the eastern bank, the cross-sectional profile will plot from east to west).

The LIDAR terrain data collected in the 2008 omits the subaqueous portions of the stream channel because the LIDAR pulses do not penetrate the water surface. As such, the cross-sectional profiles are truncated at the elevation of the water surface on the day data were collected. Most of the Capay Valley data was collected on March 27, 2009. The streamflow reported by the DWR gage at the Rumsey Bridge was less than 150 cfs. The water surface is shaded light blue in the cross-sectional profiles to indicate that it is not the ground surface. The

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[1] Light Detection and Ranging (LIDAR) is a technology that employs an aircraft-mounted scanning laser rangefinder to produce accurate topographic survey data at a high spatial resolution.

active channel of Cache Creek is wide and shallow and riffle bars are likely to have a residual water depth of less than 1 foot at the time data were collected. Although the low flow channel characteristics are not fully described, the profiles provide a useful illustration of the topographic relations between gravel bar, floodplain, and terrace surfaces.

Cross section ID's are based on a numbering scheme for cross-sectional profiles surveyed by USGS in 1984 (Harmon, 1989). The exact endpoints of the USGS cross sections remain unknown; however, the general locations are indicated by a map in Harmon's (1989) open-file report and by a series of maps presented with the SLA (1987) report. The 2008 cross-sections were drawn in the same general location as the earlier surveys, however, the alignment was altered in places to remain perpendicular to the stream channel and the profile lines were extended a greater distance from the stream bank to include more information about the overbank areas. A few of the profiles from the 2008 data set are positioned in locations that the earlier USGS data did not survey. In such instances the profile was given a new ID by adding the suffix "B" (e.g., XS-14B) to the nearest cross-section profile ID.

4.2 Stream Channel Morphology

Channel geometry refers to the three-dimensional form of the stream channel and includes three main components: (1) channel gradient – the slope of the streambed through the study reach (longitudinal profile); (2) channel pattern – the channel form as viewed from an aerial perspective (planform geometry); and (3) cross-sectional form – the size and shape of the channel along a profile that is perpendicular to the direction of flow. Although the prevailing streamflow characteristics and sediment load are the dominant controls on channel morphology, other factors can influence geomorphic characteristics such as the size of materials which compose the streambed and banks and the characteristics of riparian vegetation.

The longitudinal gradient, or slope, of Cache Creek undergoes a transition as the channel exits the bedrock-controlled canyon reach and emerges into Capay Valley (Fig. 4-2A). The prevailing gradient in the canyon downstream of the junction with Bear Creek is about 0.005 (slope = 0.5%). A bedrock outcrop spans the channel in the vicinity of Camp Haswell and controls the grade at the headward extent of Capay Valley (labeled "bedrock control" on Fig. 4-2B). The streambed elevation drops steeply below this bedrock control over a horizontal distance of about 500 feet, flattens to a gradient of about 0.003 for the segment downstream to the Rumsey Bridge, then maintains a relatively consistent gradient of about 0.002 downstream through Capay Valley (Fig. 4-2B). Local variations to the prevailing channel gradient are produced by grade controls such as an isolated bedrock outcrop north of the Guinda Bridge and a landslide depositing large boulders in the channel within the confined reach upstream of Capay Dam.

Channel pattern describes the general characteristics of the stream in planimetric, or map, view. The wide variety of channel patterns observed in nature form a continuum between straight, meandering, and braided forms (Leopold and Wolman, 1957). The Capay Valley segment of Cache Creek displays characteristics of a channel pattern that is transitional between meandering and braided channel types. Streams of this type of pattern are characterized by large sediment loads, with a significant portion composed of gravel-sized particles or larger, and a high width-depth ratio. These types of channels are relatively unstable in form as chute cutoffs, meander shifts, and streambank erosion are typically common (Schumm, 1985). The alignment and configuration of the stream channel and adjacent bar features changes over time as episodic cycles of sediment erosion, transport, and deposition alter the morphology of the stream corridor in response to natural variations in streamflow and sediment supply. Development of gravel bar features is a key process controlling the channel pattern and shaping the geomorphic features of the stream corridor in Capay Valley.

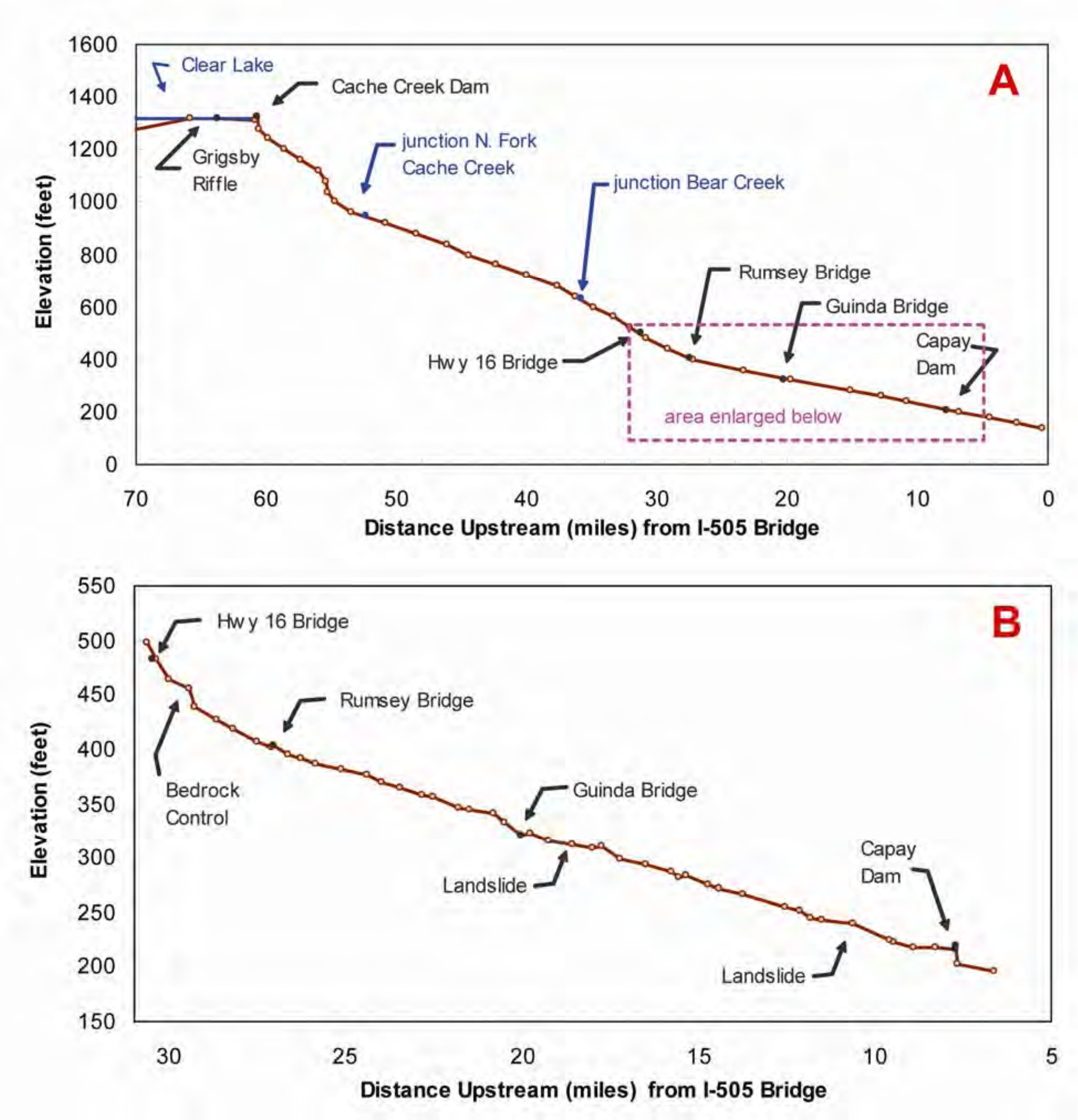

Figure 4-2. Longitudinal profiles of Cache Creek. Panel A shows the channel profile for a length that extends to the origin of Cache Creek at the Clear Lake outlet and is digitized from USGS 7.5' topographic maps. Panel B shows a more detailed profile of the Capay Valley segment that was digitized from the 1983 channel survey presented by data in SLA (1987) and by Harmon (1989).

The channel pattern and configuration varies with changes in streamflow. At low to moderate flows, the main channel is directed around gravel bar surfaces. The prevailing pattern is characterized by a single-thread, primary channel that is directed around gravel bar surfaces at low to moderate flows (Fig. 4-3). In localized areas the flow in the main channel is split into two or more flow paths by incipient bars developing in the active channel. At higher stages of flow, water begins to overtop the channel banks and inundate the bar surfaces. The upper surfaces of gravel bars are commonly traversed by depressional swales that become side channels when hydraulically connected at flows near bankfull stage. At extremely high flows the bar surfaces are completely inundated creating a broad, continuous floodway.

Meandering of the channel is irregular and does not deviate far from the primary axis which generally parallels the axis of the valley. Sinuosity, the ratio between channel length and valley length, varies within a range between 1.1 and 1.5 through most of the study area. Sinuosity is greatest in the upper reaches of Capay Valley (about 1.5), decreases to an intermediate range of values between 1.2 and 1.3 through most of the study area, and decreases to less than 1.1 within the confined segment of the channel that loops around Sugarloaf Hill.

Stream channels typically migrate laterally by erosion of one bank and concurrent deposition along the opposite bank. Sediment deposition occurring opposite of an eroding streambank leads to the formation and extension of gravel bar surfaces within the floodplain. Over time, the channel maintains a relatively consistent morphology even though the position is shifted laterally. This morphology is best conceptualized and described by the channel's cross-sectional

Figure 4-3. The channel pattern is characterized by a primary channel directed around gravel bar surfaces at low to moderate flow. Flow is split around incipient bar surfaces in localized areas. Source: USDA (2005).

profile. The cross-sectional form of the stream channel is influenced by the streamflow characteristics, sediment load, composition of bed- and bank-materials, and riparian vegetation.

A series of cross-sectional profiles were extracted from the DEM surface at a longitudinal spacing of approximately half-mile intervals through the study area. Graphical plots of the profiles area presented in Appendix B and the alignments of individual cross-sections are indicated on the maps in Appendix A. The profiles display local variations in stream channel characteristics but also reveal some general characteristics that can be used to describe the prevailing geomorphic conditions in Cache Creek. Examination of the profile data assisted in an assessment of the topographic relation between the channel, the active floodplain, and terrace surfaces in the stream corridor. An example is given by the cross-sectional profile at site 37 (Fig. 4-4). From left to right the profile shows a drop from a high bluff surface to an undulating surface with an average elevation of about 420 feet. This lower surface represents a gravel bar on the active floodplain. The channel shifted its alignment in the 1990's from a flow path that concentrated erosion on the left side of the channel, at the toe of the bluff, to an alternate path which concentrates erosion on the right side of the channel. Erosion along the right bank since the late 1990's has coincided with development of the gravel bar surface which extended laterally over 250 feet by deposition of recent floodplain sediment (mostly gravel- and sand-sized particles). Note that the slightly higher, flat surface extending to the right of the eroding bank has not been actively reworked by erosion or deposition dating back to the earliest source of historical channel information (1935). The upper surface appears to be a terrace and represents an abandoned floodplain. In contrast, the active floodplain is characterized at a lower elevation and is defined by the level of the gravel bar to the left of the channel.

Cross-sectional channel morphology is often specified in terms of its bankfull channel characteristics. Bankfull discharge is identified when flow in the channel has risen to the stage at which water overflows the bank and begins to inundate the floodplain. The bankfull discharge of a river is significant to the morphologic characteristics at any given location. Although large floods have the capacity to transport large volumes of sediment, the frequency of such events is relatively rare. It has been observed that, over time, flood discharges of more a moderate magnitude and frequency, those that approximate the bankfull discharge, cumulatively transport the most sediment and are most influential on the cross-sectional morphology of a river (Wolman and Miller, 1960). Investigations of the frequency of bankfull flow show similar relationships among various channel types and different environmental conditions. Data from observations at stream gaging stations indicate that the recurrence interval of bankfull discharge typically varies within the range of one to two years and that an average value of 1.5 years[2] is a good approximation (Leopold et. al, 1964). Bankfull discharge is often linked with related concepts known as the dominant or channel-forming discharge and the effective discharge.

Cross sectional profiles were graphically assessed to identify bankfull stage. Bankfull stage is defined as the water level at which flow has risen to the top of the bank and is beginning to inundate the floodplain (Fig. 4-4). Bankfull width is defined as the channel top width at bankfull stage. Field observations at selected locations guided delineation of bankfull stage. Most gravel bars within the stream corridor have developed a relatively consistent bar top elevation that is

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[2] A recurrence interval of 1.5 years corresponds to an annual exceedance probability of 0.67 and is expected to be equaled or exceeded during two out of every three years on average.

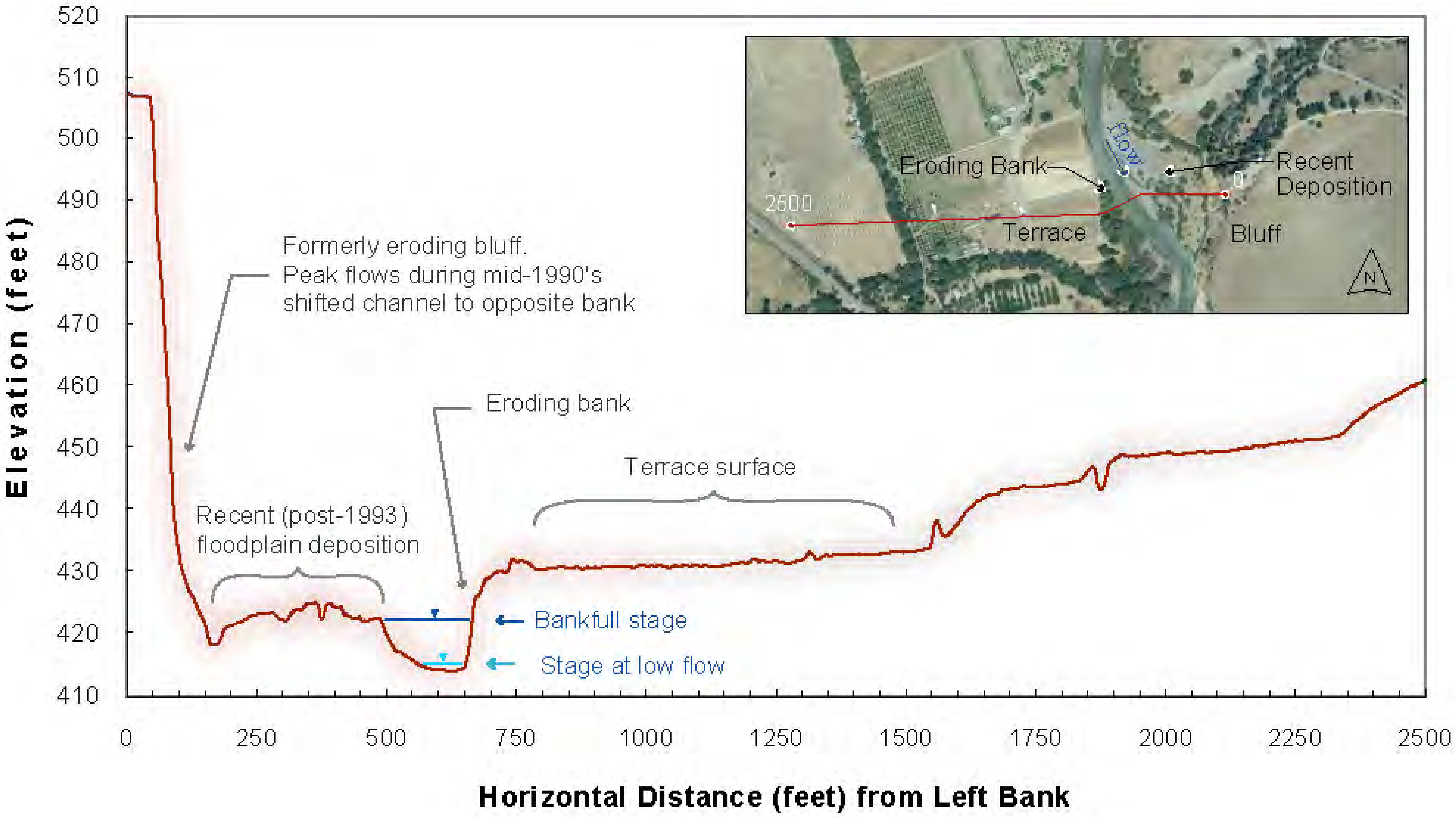

Figure 4-4. Cross-sectional profile of the stream corridor at XS-37.

representative of the elevation for the active floodplain. Field observations noted a clear scarp on the face of many gravel bars that could be identified on the cross-sectional profiles to delineate bankfull stage and width (Fig. 4-5). A selection of representative cross-sections was further analyzed to determine the bankfull discharge. Hydraulic parameters were evaluated with use of the Win XSPRO computer program (Hardy, Panja, and Mathias, 2005). Channel slope referenced reach average values derived from Harmon's (1989) survey of high water marks for the Dec. 25, 1983 peak flow. Channel roughness was evaluated by assessment of additional cross-sections from Harmon's survey. Manning's roughness coefficient (*n*) was iteratively adjusted to best match the stage of the high water mark to the measured discharge for the 1983 event (Peak flow of 20,700 cfs measured at Rumsey). Results yielded estimates of *n* = 0.035 for the active channel area and *n* = 0.07 for the vegetated overbank areas. Some deviation from these estimates was made based on variations of vegetation density at select locations but the listed values are considered a good approximation.

Results of the cross-section analysis yielded a range of estimates for bankfull discharge between about 6,000 and 10,000 cfs. Such flows correspond to an annual exceedance frequency between one and two years (Fig. 3-7) and correspond closely to the discharge at which incipient motion of the bed-material begins (section 4.3). Bankfull width was observed to vary between 150 and 400 feet, however, the width measured at most sites was in the range between 150 and 250 feet and 200 feet is a good approximation of bankfull width in the study area. Bankfull depth (averaged for the cross-section by dividing the cross-sectional area at bankfull stage by the bankfull width) was observed to vary between 4 and 8 feet with depth at most sites in the range between 5 and 7 feet and 6 feet being a good approximation for bankfull depth. These characteristics are consistent with the observation that stream channels characterized by a high sediment load, with a large percentage of that load composed of coarse (gravel-sized or larger) sediment, typically develop a form that is wide and shallow. The width-to-depth ratio of the bankfull channel in Cache Creek is typically greater than 30:1.

Figure 4-5. Photograph of the gravel bar surface at XS-37 (view is looking downstream). The upper surface in the foreground and left side of the image is used to morphologically define the height of the floodplain. The break in slope at the edge of the upper surface delineates bankfull stage and defines the bankfull channel.

4.3 Streambed Composition and Sediment Transport

The sediment load of a river is split into two components characterized by the source of the sediment. The wash load is primarily composed of finer grained particles (sand, silt, and clay) derived from erosional processes in the watershed (sheet, rill, and gully erosion) and by streambank erosion. The wash load is transported downstream in suspension by turbulent fluctuations of the streamflow. The bed-material load is that portion of the sediment load composed of particles that are similar in size to the sediment that forms the bed of the channel. Bed-material load is transported downstream by rolling, sliding, and jumping (saltation) along the bed of the stream. An important distinction between the two components is that wash load is normally a function of sediment supply whereas bed-material load is limited by the hydraulic characteristics and sediment transport capacity of the stream channel in a given reach.

The supply of sediment to the Capay Valley segment of Cache Creek is strongly affected by the environmental conditions and watershed characteristics of the upper basin. Despite the large area covered by the Clear Lake subbasin (525 square miles), the tributary areas draining into Clear Lake contribute very little to the sediment supply downstream as the lake acts as an effective sediment trap. Indian Valley Reservoir, created by construction of Indian Valley Dam in 1975, similarly traps sediment from a subbasin of 120 square miles. Sediment availability and sediment discharge to Cache Creek increase progressively downstream in the remaining (undammed) areas of the upper basin. Greater amounts of precipitation at higher elevations support a denser vegetation cover and limit sediment erosion from the vegetated hillslopes. At lower elevations, a decrease in precipitation is accompanied by a general decrease in the density of vegetation on the landscape, particularly in the riparian areas. The decrease in vegetation cover overlaps with outcrops of highly erodible sedimentary deposits in the lower reaches of North Fork Cache Creek. This area, along with a portion of the mainstem Cache Creek upstream of the North Fork, has developed a badland-type topography characterized by steep bluffs and deep gullies that contribute a large amount of sediment to Cache Creek.

Additional contributions of sediment are added within the Capay Valley segment of Cache Creek. Large areas of highly erodible sedimentary deposits are exposed along the valley wall. Vegetation is sparse, due to the low precipitation, and zones of badland-type topography illustrate the potential for high sediment yields (Fig. 4-6). Several tributary streams enter Cache Creek within the valley, however, the tributaries are primarily ephemeral and the sediment contributions have not been quantified. Agricultural activities in the valley date back to the 19th century and likely accelerate the sediment inputs from the valley floor

Streambed material in the Capay Valley segment of Cache Creek is primarily composed of coarse gravel and small cobbles (fig. 4-7). Samples of the channel substrate in the Capay Valley segment of Cache Creek were described by Simons, Lee, and Associates (SLA, 1987) and Harmon (1989). Of the samples taken from 45 locations along Cache Creek during the period 1984-1986, 12 percent of the bed-material analyzed was sand, 63 percent was gravel, and 23 percent was coarser than gravel (Fig. 4-8). The median grain size for the samples included in Harmon's (1989) investigation ranged between 5 and 86 mm. The longitudinal variation in grain-size from these samples reveals considerable scatter in the downstream direction, however, a slight trend towards a downstream decrease in grain size is evident. A distinct change to finer-grained bed materialoccurs in the pool upstream of the Capay Diversion Dam.

Figure 4-6. Photo of highly erodible surficial deposits creating a badland-type topography that contributes large volumes of sediment to Cache Creek.

Figure 4-7. Photo of a point bar surface showing the streambed composed primarily of gravel- and cobble-sized sediments.

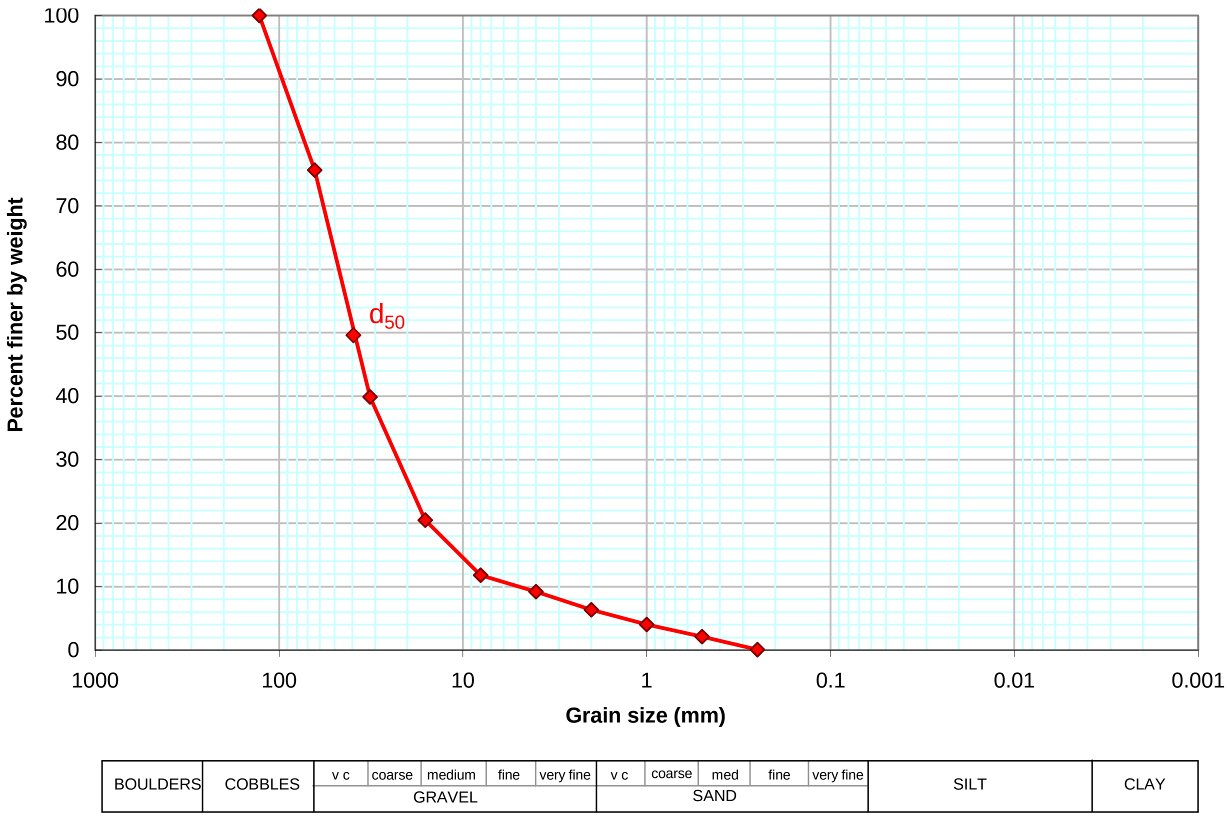

Figure 4-8. Grain size distribution for streambed sediments at cross section 19A. Source: Harmon (1989)

Active transport of the bed-material load in gravel bed rivers is a relatively infrequent event over the course of a typical year. In order for a river to move the larger grains of sediment that compose the streambed, the flow strength must exceed a critical threshold known as the threshold of entrainment. Initial movement of bed-material load is commonly estimated by the critical shear stress (τ_c) for sediment grains of a given diameter. KHE analyzed the incipient motion of bed materials in Cache Creek by: (1) calculating critical shear stress for the median grain size (d_{50}) of the streambed at a selection of representative cross sections; (2) assessing the boundary shear stress (τ_o) at the cross section for a range of streamflows; and (3) identifying the streamflow magnitude at which sufficient shear is generated to exceed the critical threshold of entrainment ($\tau_o \geq \tau_c$).

The critical shear stress necessary to entrain the median grain size is estimated by:

$$\tau_c = \tau^*_c \, (\gamma_s - \gamma) \, d_{50} \qquad \text{Equation-1}$$

where τ_c is the critical shear stress, in Pascals; τ^*_c is the Shields parameter, or dimensionless critical shear stress (estimated as 0.045); γ_s is the specific weight of sediment, approximated by the specific weight of quartz (26 kN/m^3); γ is the specific weight of water (9.8 kN/m^3); and d_{50} is the median grain size, in millimeters. Some variability of τ_c can be expected as the grain size distribution of the streambed material varies spatially, both laterally and longitudinally. Data from cross section 19A, for example, revealed a median grain size of 40 mm (Fig. 4-8). Calculation of critical shear stress at cross section 19A by means of equation 1 yielded the result τ_c = 29.2 Pa.

Representative cross sections derived from the 2008 LIDAR data were then analyzed in WinXSPRO to compute hydraulic characteristics of the stream channel over a range of flow depths specified at regular (half foot) increments. Boundary shear stress (τ_o) was calculated for each increment by:

$$\tau_o = \gamma R s \qquad \text{Equation-2}$$

where τ_o is the shear stress, in Pascals; R is the hydraulic radius and s is slope.

Reach averaged slope was given by Harmon (1989) as 0.0019 for the segment between Rumsey and Guinda and 0.0018 for the segment downstream of Guinda. The actual shear generated by a specific magnitude of flow at a given site varies with slope and the cross-sectional morphology. A representative calculation, utilizing data for cross-section 19A ($s = 0.0018$, $d_{50} = 40$ mm) yielded a critical shear stress of 29.2 Pa and an equivalent boundary shear stress is generated by a streamflow of approximately 9,000 cfs. Similar calculations at other cross section locations yielded results suggesting that the threshold of incipient motion for the bed-material load at most locations ranges between 6,000 and 10,000 cfs. Note that this range of flows is similar to the estimated range of bankfull discharge in the study area (section 5.2).

The sediment transport characteristics in the Cache Creek basin have been previously studied by two USGS investigations. Lustig and Busch (1967) maintained a network of five suspended sediment monitoring stations during the period 1960-63. Stations located on the North Fork Cache Creek and on Bear Creek were used to describe sediment transport characteristics of the upper basin. Stations along Cache Creek at Rumsey and near Capay described conditions at the upstream and downstream ends of Capay Valley. A fifth station described conditions in the lower basin at the stream gaging station near Yolo. Data analysis revealed a marked increase in the suspended sediment yield per unit area between stations in the upper basin and stations in the Capay Valley segment of Cache Creek (Fig 4-9). The increase is attributed primarily to the environmental conditions that favor an increase in erodibility within the middle part of the basin.

Harmon’s (1989) USGS study presented data from an investigation during the period 1984-86. Two stations were operated as streamflow and sediment monitoring sites for the study: Cache Creek at Rumsey and Cache Creek near Brooks. The suspended sediment transport rate computed from sampling during 1984-86 was lower than that presented for 1960-63 by Lustig and Busch (1967). Harmon (1989) attributes the decrease to the effect of Indian Valley Reservoir, created by construction of Indian Valley Dam in 1975, which reduced the effective drainage area contributing sediment to the Capay Valley reach.

Knowledge of the sediment transport rate for the bed-material load remains a large data gap in the assessment of sediment transport characteristics. Harmon (1989) estimated bedload discharge with a limited number of bedload transport measurements collected with a Helley-Smith bedload sampler. Harmon’s data was limited to six sample measurements made within a range of relatively low flows. Additional estimates of sediment transport were calculated from the Meyer-Peter and Muller (MPM) sediment transport equation. The MPM equation calculates sediment transport as a function of the size distribution of bed material and hydraulic data at a representative cross section of the stream channel (streamflow, velocity, width, hydraulic radius,

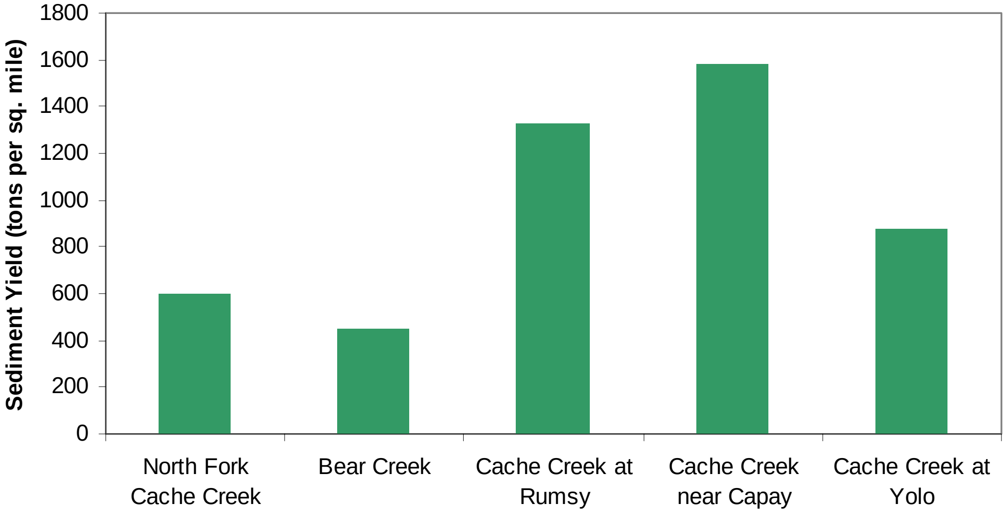

Figure 4-9. Mean annual suspended sediment yield, 1960-64. Data from Lustig and Busch (1967).

and slope). Harmon (1989) presents relations between bedload discharge and streamflow. Regression analysis of the data points in Harmon's (1989) relation (both bedload samples and estimates derived from the MPM equation) yielded the bedload transport rate:

$$Q_{sb} = 0.0003\ Q^{1.665}$$

Where, Q_{sb} is the transport rate of bedload sediment, in tons per day; and Q is streamflow, in cfs. The relation should be used with caution, however, because of the limited number of samples and the large amount of uncertainty that is typical of sediment transport equations due to the non-linear form of the relation between streamflow and sediment load.

A previous investigation by Northwest Hydraulic Consultants (NHC, 1995) assessed the sediment transport characteristics of the Cache Creek near Capay (just upstream of Capay Diversion Dam) to estimate sediment supply of the reach downstream of Capay Valley. The study noted the paucity of bedload measurements and chose instead to quantify bedload as a fixed percentage (6 percent) of the suspended sediment load. Based on these data, NHC (1995) estimate the mean annual sediment yield for Cache Creek near Capay as 927,600 tons, of which about five percent is gravel, about 12 percent is sand-sized particles, and the remaining 83 percent is finer than sand.

4.4 Floodplain Characteristics and Riparian Vegetation

The active floodplain along the Capay Valley segment of Cache Creek is primarily composed of gravel bar surfaces formed through depositional processes. Gravel bars typically develop by lateral accretion triggered by a change in stream channel alignment that favors sediment erosion on one bank of the channel and sediment deposition on the opposite bank. The concurrent processes of streambank erosion and deposition continually build gravel bar features and extend the bar surface laterally over time. Gravel bar surfaces are subjected to episodic disturbance by high flows during large winter storm events. Floodplain areas subjected to flows of relatively high velocity during flood stage have surfaces composed primarily of course sediment. Areas of the floodplain that are positioned away from the primary flow paths at flood stage receive contributions of finer-grained sediment deposited by vertical accretion from overbank flow. Soil development in floodplain areas is extremely limited because of the dynamic nature of shifting channels that rework floodplain deposits faster than soil forming process can occur. Limited areas of riparian forest have developed in areas protected from fluvial disturbance and thin soils have developed in these areas.

Alluvial soils and floodplain sediments in the Capay Valley segment of Cache Creek contain elevated levels of mercury, a legacy of historic mining activities in the upper watershed. Water quality conditions of Cache Creek and two of its tributaries, Bear Creek and Harley Gulch, are impaired by elevated concentrations of mercury and are subject to numeric targets set by the Regional Water Quality Control Board (Cooke et al., 2004). Sources of mercury include natural geothermal springs, historic mining sites that are abandoned or inactive, and remobilization of mercury stored in streambed sediments along Cache Creek (Domagalski et al., 2004). The watershed above Rumsey is the greatest source of mercury to the total mercury budget of Cache Creek (Cooke et al., 2004). Holloway et al.'s (2009) recent study of mercury mobilization in the Cache Creek watershed confirms that mercury is stored in alluvial soils and floodplain sediments far from the original sources of mercury in the upper watershed. Analysis of a floodplain soil sample collected in Capay Valley near Guinda showed elevated mercury concentrations that range between 0.1 and 1.6 mg Hg kg^{-1} (Holloway et al., 2009). Although elevated above natural levels, the observed concentration in the floodplain soil was significantly less than the mercury concentrations observed in samples near the historic mining sites (mercury concentrations in a floodplain soil along Sulphur Creek ranged between 4.3 and 9.6 mg Hg kg^{-1}). The vertical profile of the floodplain soil in Capay Valley showed that mercury concentration decreased with depth suggesting that the Hg inputs at the sample location were greater in the past (Holloway et al., 2009).

The characteristics of riparian vegetation in the stream corridor reveal successional stages of vegetation with a distribution that is determined by fluvial processes (erosion, deposition and lateral channel migration), seasonal hydrology, flood frequency, and landform characteristics. Although no description of historic riparian conditions in Capay Valley was obtained as part of this investigation, the likely conditions can be reasonably inferred from descriptions of adjacent and receiving watersheds such as Putah Creek and the Sacramento River. The pre-European settlement riparian corridor of Cache Creek within Capay Valley was likely much wider and more developed than occurs today. Katibah (1984) indicates that the natural conditions of the Sacramento River floodplain supported riparian vegetation to about the 100-year flood line. By analogy, the overall pre-settlement riparian vegetation pattern along Cache Creek likely extended much wider than exists today and was more diverse. We estimate the historic riparian corridor to have spanned from one-third to two-thirds of a mile in width through Capay Valley, roughly two- to three-times greater than the current riparian corridor width.

Based on site observations, available vegetation maps (Yolo Natural Heritage Program, 2008) and the findings of studies of local area riparian systems (Katibah, 1984; Strahan, 1984; McBride and Strahan, 1984; and Shanfield, 1984), the distribution of riparian vegetation along Cache Creek appears to be dominated by early successional stages of riparian corridor development, dominated by initial seedling establishment on disturbed gravel bars by the native pioneer species of cottonwood and willow. There is a notable lack of later successional stage species and rarity or thinning of more mature riparian forest along the Capay Valley reach, than what would occur naturally. Over the last century, invasive species of tamarisk and arundo have become well established and widespread in the riparian corridor and now play an important, if not dominant, role in riparian vegetation establishment and succession.

Based on site visits and review of available information, the typical riparian vegetation pattern observed along the study reach consists of initial colonization by native willow and cottonwood species and non-native tamarisk and arundo along recently disturbed point- and mid-channel gravel bars. Typically, a vegetated bar surface has a lifespan of a few decades before subsequent realignment of the channel erodes the surface by the process of lateral migration and a new bar surface develops on the opposite bank. One notable finding from this investigation is that the distribution of invasive tamarisk and arundo are restricted to zones of historic channel migration (confirmed through review of historic aerial photographs) with little, if any of these species, being observed to have spread outside of the historic area of geomorphic disturbance. This finding indicates the dependence of tamarisk and arundo colonization on geomorphic disturbance in Cache Creek.

In general, more mature stands of early successional species of cottonwood and willow are found with distance away form the active channel and floodplain, with the largest and most mature specimens occurring within abandoned channels (swales), typically near the base of older terraces. These sites are likely closer to the groundwater table and have a better developed fine-grained, organic soil horizon that retains moisture better than the fresh gravel bar surfaces. Although not a focus of this investigation, observations indicate that later or secondary successional stages of riparian forest, consisting of more shade-tolerant species (e.g., box elder and ash) are not typical through the Capay Valley. In many instances, this mature cottonwood-willow alliance extends up the face of the adjacent terrace scarps terminating at the top of the scarp face. In many instances, terrace faces were observed to consist of much finer-grained soil material than the active channel and floodplain, providing more water holding capacity and likely serving as a better host to riparian vegetation. Available mapping and field observations indicate a notable shift in vegetation types when stepping up to the top of the higher elevation terrace that borders the active channel and floodplain. Species on these terraces consist of oaks and annual grasses with some of the oldest cottonwoods observed at the cut-bank edge of the terrace surface.

Settlement and agricultural development within Capay Valley is the primary cause for reduction and change in the riparian corridor along Cache Creek. Riparian vegetation removal to accommodate agriculture is the primary cause for change and areas of the floodplain and low terrace surfaces that are relatively protected from flood discharges have been converted to agricultural land uses including pasture, row crops, and orchards. Katibah (1984) indicates that timber harvest from riparian forest along Cache Creek and the Sacramento River supplied fuel at Knight’s Landing for steamships navigating the Sacramento River. Other contributing causes towards riparian corridor reduction and/or change come from grazing and water development (gravel mining was not a significant activity within the Capay Valley reach). The summer water delivery releases from Clear Lake and Indian Valley Reservoir over the last century undoubtedly has introduced a significant change to the riparian corridor, by maintaining near perennial flows through the Capay Valley, which maintains a very constant shallow water table. Prior to water development in the Cache Creek watershed, summer flow through the Valley may have been much lower to non-existent in drier years. In turn, the shallow water table probably would have displayed greater seasonal fluctuations with greater depths to water during the summer. This would have stressed native pioneer species on gravel bars to a greater extent, leading to higher mortality rates. Although not substantiated as part of this study, the current altered hydrology is believed to be more conducive to sustaining pioneer riparian species, which are currently dominated by the invasive tamarisk and arundo.

5.0 Channel Dynamics, Stability, and Historical Channel Changes

Previous sections of this report have documented that the Capay Valley segment of Cache Creek is characterized by: (1) a highly variable hydrologic regime; (2) a large sediment load that includes a relatively high proportion of coarse sediment (gravel-sized particle or larger); and (3) morphologic characteristics that include a high width-depth ratio, a moderately low sinuosity, and a tendency for frequent shifts of the stream channel alignment. This section presents an assessment of the stream channel dynamics, or mechanisms of geomorphic adjustment, that have prevailed in the study area during the historic period. Historical channel changes are discussed in order to assess the relative stability of Cache Creek through the study area.

Key questions to be addressed in this discussion include:

- Is the channel bed aggrading? Degrading?
- What are the dominant mechanisms of bank erosion?
- What are the prevailing rates of streambank erosion and channel migration during the historic period?

5.1 Geomorphic Equilibrium and Longitudinal Stability

A fundamental component in the assessment of channel dynamics is an evaluation of geomorphic equilibrium, or channel stability. The concept of geomorphic equilibrium describes a general condition whereby the stream channel is adjusted to a state in which the sediment transport capacity is in balance with the sediment supply from upstream. This stable channel balance is often conceptualized as a scale on which the capacity of a stream to transport its sediment load is opposed by characteristics of the sediment supply. Changes to either side of the balance can tip the scale in such a way to trigger aggradation (accumulation of sediment) or degradation (incision produced by a net loss of sediment) of the channel bed.

Episodes of bed aggradation or degradation typically result from changes in the watershed conditions that alter the hydrologic regime and/or sediment load of a stream. Dam construction and gravel mining are examples of human activities that can significantly reduce the sediment supply of a given reach and frequently result in channel incision for a reach adjusted to a higher sediment load (Kondolf, 1997). Gravel mining in the lower reaches of Cache Creek (downstream of Capay Diversion Dam), for example, lowered the streambed elevation by 15 to 25 feet in places and created a state of geomorphic instability (NHC, 1995).

Simons, Lee, and Associates (SLA, 1987) presented an earlier assessment of bed stability in Capay Valley that compared longitudinal profiles derived from two surveys of channel cross-sections completed in 1977 and 1983. The uppermost reach of Capay Valley was not assessed because the upstream terminus of the 1977 profile falls about two miles downstream of the Rumsey Bridge. The report concludes that the comparison did not indicate a general, system-wide trend toward either bed aggradation or degradation. Limited areas of bed aggradation and degradation were noted, however, results were not deemed conclusive because data points were not repeated at the same locations and the time span between surveys was relatively short and thus unlikely to detect temporal trends. An area of localized aggradation was identified just downstream of the Guinda Bridge where sediment inputs from an active landslide at the toe of the valley had raised the bed elevation four to five feet. Areas of bed degradation were identified at the Guinda Bridge and also in the reach downstream of Guinda where streambed material was dredged from the channel during the period between surveys.

The present assessment extended the analysis of bed stability by comparing the 1983 channel thalweg (as presented in SLA, 1987) to data acquired from a USGS topographic map printed in 1939. The 1939 map was compiled from topographic survey data collected in 1934-36 (for simplicity, the survey will be herein referred to by its mid-point, 1935). The historic map is drawn with a contour interval of 10 feet on the land surface and an intermediate (5-foot interval) contour included within the stream channel. Thalweg elevations from the 1935 survey were compared to the equivalent longitudinal position on the 1983 channel profile (Fig. 5-1). Results of the longitudinal comparison augment the earlier findings by SLA (1987) with a look at historical changes over a longer time period and extended the assessment upstream to account for a greater length of the channel.

In general, the streambed elevation through the Capay Valley segment of Cache Creek appears to have maintained a stable profile during the historic period. No system-wide trends of aggradation or degradation were documented, however, observations of localized changes in bed elevation were noted. The area of most extensive bed degradation is located in the reach immediately upstream of the Rumsey Bridge. A bedrock outcrop spans the channel just downstream of Camp Haswell and functions as a grade control for a short segment. The profile data suggest that the channel bed downstream of this outcrop has lowered its elevation by six to ten feet for a reach that spans approximately two miles. Comparison of the channel profiles for the 2-mile reach below Rumsey shows a much smaller change between successive surveys and is suggests that the streambed is relatively stable. Localized incision of about eight feet is revealed at the location of the Guinda Bridge crossing. This incision is possibly attributed to a change in the flow hydraulics at the site following construction of the bridge in 1959. Further comparison of the two profiles reveals additional areas of localized channel incision in the reach below Guinda to a point about three miles downstream of the bridge where SLA (1987) had noted dredging of the channel at the time of the survey.

Comparison of longitudinal profiles from the period 1935-1983 suggests an episode of bed instability (degradation) for the reach above Rumsey but a relatively consistent profile of bed elevations for the remainder of the channel downstream of Rumsey. The terrain model generated from LIDAR data collected in 2008 was utilized to investigate potential landscape indicators that

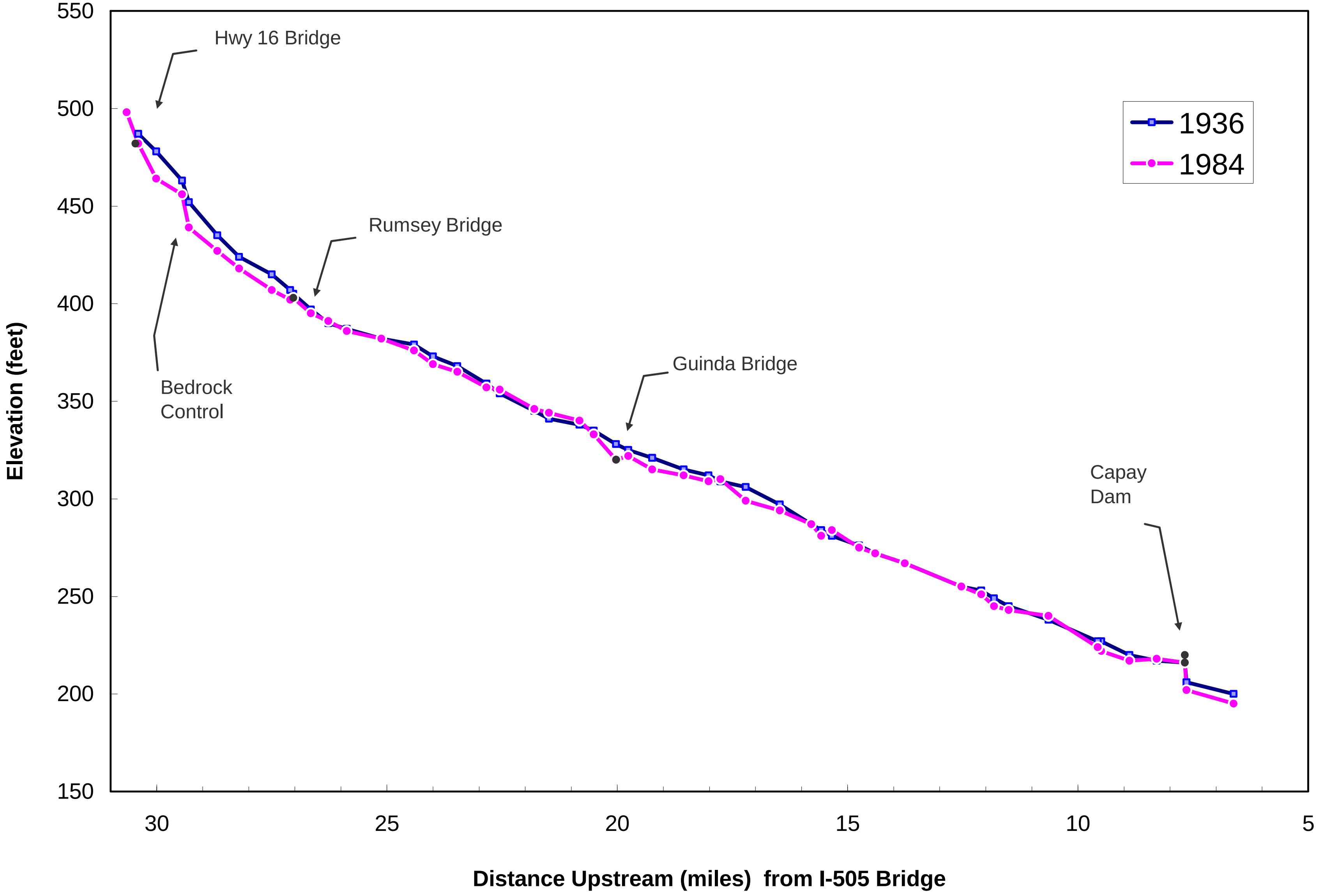

Figure 5-1. Comparison of longitudinal profiles from 1935 (USGS) and 1983 (SLA, 1987).

might reveal evidence of channel instability that predate the 1935 survey. Degrading channels typically progress through a sequence of channel adjustments that begins with down-cutting and continues with expansion of the floodplain area by bank erosion and lateral channel migration (Schumm, 1984). Deposition of sediment within the incised channel leads to the development of floodplain features such as gravel bars at a lower elevation than those formed during the pre-degraded state. In such cases, the former floodplain surface is abandoned and becomes a terrace.

Terrace surfaces are prevalent in Capay Valley and represent the level of abandoned floodplains formed by Cache Creek under different environmental conditions. Given the dynamic tectonic setting it is likely that the higher terraces have been uplifted to their present elevation by tectonic processes. Of greatest interest to the present discussion, however, is a low terrace that is positioned at an elevation that is between five and ten feet above the elevation of the present floodplain. It is possible that the low terrace has been disconnected from Cache Creek by continued tectonic uplift of the valley floor. An alternative explanation hypothesizes that the low terrace was recently abandoned and is representative of the floodplain elevation prior to an episode of bed degradation in the late 19th and early 20th centuries. This hypothesis builds on the observed incision in the reach upstream of Rumsey during the period 1935-1983 (Fig. 5-1). Channel incision often occurs episodically by migration of a nick point, or head cut, in the channel bed that progresses upstream lowering the bed elevation. It is possible that the 1935 survey captured the channel condition at a point where a head cut had migrated upstream and was positioned in the vicinity of the Rumsey Bridge. In such a case degradation of the channel bed would explain the five to ten foot vertical offset between the modern floodplain surfaces and the elevation of the low terrace through much of Capay Valley. A detailed assessment of the geomorphic processes that led to abandonment of the former floodplain and creation of the low terrace would require further study.

Field observations and review of the terrain model suggest that the present channel condition is one of relative bed stability. Floodplain deposits created by lateral migration of the channel since the mid-1980s are at a similar elevation to floodplain features observed in the 1984 cross-sections. An updated survey of the channel thalweg was not available at the time of this assessment; however, water surface elevations from the LIDAR survey align closely with the bed elevation on the 1983 channel survey. Although comparing the water surface profile to an earlier profile of the channel bed is not conclusive, the channel characteristics of Cache Creek are such that the water surface at low flow (discharge was less than 150 cfs on the days of LIDAR data collection) is typically only one to three feet above the channel bed. An updated survey of the channel thalweg would be helpful to compare with the longitudinal profiles from 1935 and 1983 to further assess bed stability of the present channel condition.

5.2 Bank Erosion and Lateral Channel Migration

Previous discussion of the stream channel morphology described the channel pattern of Cache Creek as a type that is characterized by frequent shifts in the channel position and alignment. The purpose of this section is to describe the dominant mechanisms of streambank failure in the study reach and to assess the rates of lateral channel migration.

The composition of streambank materials varies significantly through the study area. In general, the streambank materials at any given location reflect the geomorphic setting of the landscape surface that is being eroded. The geomorphic setting at bank erosion sites can be classified into four general types: (1) erosion of floodplain deposits; (2) erosion of terrace surfaces; (3) bluff erosion; and (4) erosion at the toe of hillslopes. Where the channel is migrating through a recent floodplain deposit the eroding streambank is commonly cut into a gravel bar surface composed of gravel- and sand-sized particles. Streambanks eroding into a terrace surface often show a horizonation between a lower unit, composed primarily of gravel-sized material, and an upper unit composed of finer grained material (mostly sand-sized particles with clay- and silt-sized particles making up about 10-20 percent of the material) in various stages of soil development. Bluff erosion infers erosion into a large sedimentary feature such as a sandstone bluff. Erosion at the toe of hillslopes often exposes a streambank composed of bedrock, cemented conglomerates, or colluvial deposits containing a poorly sorted mix of gravel- cobble-, and boulder-size materials.

Streambank erosion in the Capay Valley segment of Cache Creek is primarily attributed to naturally occurring geomorphic processes associated with the shear stress produced along the channel boundary by moving water at high flows. Human activities in the watershed and along the stream corridor may influence erosional processes in localized areas, however, human activities are not likely responsible for creating any system-wide impacts on streambank instability. Streambank erosion in Capay Valley occurs at a naturally high rate due a combination of factors that include: (1) high flood flow magnitudes that generate sufficient energy to entrain sediments from the channel boundary; (2) streambank materials that tend to compose a large proportion of sand-sized particles or coarser-grained sediments that have a low degree of cohesiveness; (3) a bank configuration such that the toe is often unprotected by riparian vegetation; and (4) a channel pattern and bed configuration that is characteristized by frequent shifts in the channel alignment that lead to development of new bar features within the channel and directs flow against the streambank at relatively steep angles.

The general process of streambank erosion is typically attributed to entrainment of the streambank material by the shear stress created by moving water at high flows. The potential for erosion is influenced by the cohesiveness of bank sediments, the stabilizing effect of riparian vegetation, the alignment of the channel – shear is typically greatest along the outside of a meander bend, and the magnitude of streamflow. Slumping of the streambanks is important to bank erosion in addition to the direct entrainment of streambank material. Given the flashy nature of the hydrologic regime for Cache Creek, there is a steep hydraulic gradient between the water stored within the streambank material and the level of the creek as it recedes with the passage of a flood. The gradient triggers two mechanisms that yield bank failure. First, flow out of the saturated streambank material toward the exposed bank and into the creek has the potential to loosen streambank material and trigger slumping of the channel bank that results in the accumulation of debris at the bank toe (Fig 5-2). Second, receding flows leave over-weighted saturated banks unsupported, leading to slumping. Sediment in the debris piles at the bank toe is readily available as a supply of sediment to subsequent high flow events. A winnowing of the finer-grained particles at the surface of the debris piles leaves behind a coarsened layer with many cobble-sized particles that armors the toe of the bank.

An earlier assessment by Simons, Lee, & Associates (SLA, 1987) concluded that the dominant cause of streambank erosion in Capay Valley is the entrainment of fine-grained streambank materials from the shear stress created by high flows acting on the nearly vertical face of a bank. The assessment characterized the typical streambank configuration in the study area as comprised of two layers – an upper layer that is nearly vertical and composed primarily of sand-sized particles and a lower layer that lies at an angle and is composed of eroded material from the bank that accumulates at the toe. The debris piles which make up the lower unit were described as armored by a layer of gravel- and cobble-sized particles. The SLA assessment presented a conceptual model whereby the streambank erosion occurs when flow in the channel increases such that it can overtop the debris piles and entrain sediment from the unprotected face of the bank. The threshold at which the armor layer at the toe is overtopped was estimated to be generally less than 5,000 to 6,000 cfs (SLA, 1987). Such a flow has an annual exceedance frequency in the range between one and two years and approximates the 1.5-year flood magnitude (Fig. 3-7).

Harmon (1989) discussed results of a concurrent USGS investigation which included an assessment of bank erosion and lateral migration. Harmon observed that the minimum mean daily flow related to bank erosion was about 3,000 cfs. For example, no measurable erosion of the channel banks was observed during WY 1985, a period in which the largest mean daily flow was about 2,500 cfs and the maximum instantaneous peak discharge was about 4,600 cfs. Note that Harmon’s observation referenced the mean daily flow and not the peak discharge. As such, Harmon’s observed threshold for bank erosion at a mean daily flow of 3,000 cfs agrees closely with SLA’s (1987) estimate of the threshold at which the streambank armor layer is overtopped at an instantaneous discharge of about 5,000 to 6,000 cfs. A mean daily flow of 3,000 cfs is exceeded during about five percent of the time in the composite flow record for the period 1943-2007 (Fig. 3-3). Such a flow is expected to be exceeded about 18 days in a year, on average. During wet years this threshold may be exceeded for a longer duration and during relatively dry years, such as Harmon’s observation from 1985, the threshold may not be exceeded at all.

Figure 5-2. Photograph of eroding streambank along the outside of a meander bend. The bank is nearly vertical near the top and debris piles have accumulated at the toe.

While the conceptual model of a threshold discharge at which bank erosion occurs is valid and supported by field observations, the actual rate of bank erosion varies spatially within the stream corridor. Variation in the sediment composition of streambank materials, for example, affects the rate at which the bank migrates laterally. Similarly, variation in the type and density of riparian vegetation affect rates of bank erosion. Erosion rates tend to be lower where banks are covered by riparian vegetation and greatest where the streambank is clear of vegetation.

Comparison of aerial photographs from successive years in the historical record suggests that the rate of bank erosion is strongly related to the alignment of the channel in a given reach. Flow is directed around gravel bars in an irregular meandering pattern. Bank erosion is greatest at the outside of a bend in the channel alignment because flow around a bend generates secondary currents, indicated by a three-dimensional spiral motion in the flow pattern, that increase shear stress on the channel boundary along the toe of the outer bank. Shear stress, and thus the potential for bank erosion, increases with increasing tightness of the meander bend.

In general, the Cache Creek channel is characterized by a relatively low sinuosity and most meander bends have a low angle of curvature. Thus, bank erosion progresses along the outer bends of the channel at a relatively gradual rate. In localized areas, however, shifts in the channel alignment direct flow against the bank at a steep angle. As flow is directed around a sharp bend the shear acting on the channel boundary leads to rapid rates of bank erosion and lateral channel migration. Evidence of rapid erosion that occurs subsequent to a realignment of the channel upstream, such that the flow is directed against the channel bank at a steep angle, is presented in the subsequent discussion of historical channel changes.

A previous discussion of the riparian vegetation characteristics alluded to the potential impacts of invasive species, such as arundo and tamarisk, on the geomorphic characteristics of the stream channel. In general, riparian vegetation tends to stabilize streambanks and floodplain surfaces. This is true for both the native and non-native species in the Cache Creek corridor. Both tamarisk and arundo, however, have a tendency to grow in dense stands. Aside from the obvious negative impact on wildlife habitat and ecological conditions, the dense colonies of tamarisk and arundo have the potential to create localized impacts on stream channel processes. Development of dense thickets on gravel bar surfaces creates favorable conditions for accelerated sediment deposition. The resistance to flow created by dense thickets tends to increase the hydraulic roughness at the channel boundary, reduce the velocity of flow, and lead to the vertical accretion on the floodplain. Studies of tamarisk invasions in rivers in the southwestern U.S. suggest a general model whereby the spread of tamarisk triggers accelerated sedimentation in the channel and leads to a net effect that narrows the channel cross-section (Graf, 1980; Graf, 1982; Dudley et al., 2000; Tickner et al., 2001). Review of historical channel information for Cache Creek suggests that the geomorphic impact of invasive species does not follow the model presented above. With limited exceptions, channel narrowing has not been observed within the Capay Valley segment of Cache Creek. In localized areas, however, channel changes were observed where riparian plant invasions colonized bar surfaces and altered the flow path and channel alignment. Such an impact is likely a control on the location and rate of streambank erosion in localized areas but is not responsible for any system-wide trends toward bank instability.

5.3 Analysis of Historical Channel Changes

Successive sets of aerial imagery spanning the historical period (Table 5-1) were reviewed to assess the historical channel changes in the Capay Valley segment of Cache Creek. Recent imagery dating back to 1993 is available in digital format and is georeferenced for use in a geographic information system (GIS). Imagery scanned from photographs (applies to data acquired for period pre-1993) were georeferenced in GIS through the identification of common landmarks visible in both the historical and modern images. Landmark features used to define the spatial reference information include road intersections or the corner of buildings. The accuracy of the resulting georeferenced datasets is adequate for observing large changes (measured in tens of feet) in channel alignment or configuration but has limited utility in measuring small changes.

Harmon (1989) presented results from an analysis of aerial photographs over the period 1953-84. Total measured erosion between 1953 and 1984 was estimated to be about 300 acres or a rate of about 10 acres per year, on average. This value refers only to areas lost to bank erosion and does not account for new floodplain deposition during this period. Furthermore, it is not clear what criteria were used to define what constitutes bank erosion. Harmon (1989) tabulated eroded area between photo sets for three distinct segments of Capay Valley. Although variation between the three segments was observed for individual periods, the total eroded area was nearly identical for the three segments over the long term.

Initial work for the present study focused on updating the analysis of aerial photograph comparison by extending it with analysis of changes since 1984, the latest set in the Harmon's study, and imagery from a more recent set representative of the present channel condition. Quantifying channel changes from aerial photography, however, is complicated and difficult to do at a high level of precision. Before proceeding with the assessment of recent channel changes an attempt was made to duplicate the values presented by Harmon for the periods studied in the previous investigation. Initial results were discouraging as the estimates of bank erosion generated from the present study deviated greatly from those presented by Harmon. Deviations did not indicate a bias in any one direction as estimates for one reach may have overestimated erosion, relative to the estimate presented by Harmon, while estimates for another reach may have significantly underestimated erosion.

Table 5-1. Inventory of aerial imagery utilized in evaluation of historical channel changes.

Year of Imagery	Source
1937	Scanned from collection of the Shields Library at UC-Davis
1953	Scanned from collection of the Shields Library at UC-Davis
1957	Scanned from collection of the Shields Library at UC-Davis
1964	Scanned from collection of the Shields Library at UC-Davis
1971	Scanned from collection of the Shields Library at UC-Davis
1985	Scanned from collection of the NRCS office in Woodland, CA
1993	Obtained digitally from USGS (B/W DOQQ 1m resolution)
2005	Obtained digitally from USDA NAIP (Color, 1m resolution)
2007	Obtained digitally from Yolo County (Color, 0.5 ft resolution)
2009	Obtained digitally from USDA NAIP (Color, 1m resolution)

The preliminary exercise illustrated that a clear set of criteria is needed to make a comparison between successive sets of photography. For example, is bank erosion measured at all locations or only at locations affecting upland areas that are valuable to agricultural production? It was decided that in order to be useful, estimates of bank erosion would have to be categorized into groups such as erosion of terrace surfaces and erosion of gravel bar surfaces. Identifying the difference between terrace and a vegetated gravel bar is difficult, especially in the older aerial photographs. Due to the large degree of uncertainty in generating reach-scale estimates of bank erosion, it was decided to proceed with a more qualitative approach evaluating bank erosion and lateral channel migration. Emphasis is placed on understanding the physical changes in the channel affecting the rate of channel migration and not solely estimating an area of land affected.

The geomorphic features of the stream corridor, shown by a shaded relief image of the topography and by aerial photography, are mapped alongside a time series of the historic channel alignments in Appendix A. Cross-section alignments are indicated on the maps in Appendix A and can be used to relate the historical channel movement to the existing cross-sectional morphology depicted by the topographic profiles in Appendix B. The sequence of changes between successive photo sets in the historic period was assessed to evaluate the mechanisms of stream channel adjustment and to measure rates of streambank erosion and lateral channel migration. Significant horizontal movement of the channel was observed throughout the stream corridor. The collective area occupied by the channel in the historical record was delineated as the historic migration zone (HMZ) and is overlaid with recent aerial photography of the stream corridor in Appendix A. Additional effort was made to delineate a broader area to define the channel migration zone (CMZ). Delineation of the CMZ identifies areas along the stream corridor that are susceptible to hazards associated with streambank erosion and provides a useful tool to guide development and land management actions along river systems (Rapp and Abbe, 2003). The CMZ is typically delineated as the cumulative area occupied by the historic migration zone and an erosion hazard area. Calculation of the erosion hazard area can be accomplished by (1) measurement of the erosion rate over the historic period, (2) extrapolation of the erosion rate for some defined period into the future (e.g., 100 years), and addition of a geotechnical setback to account for slumping along the channel margin (Rapp and Abbe, 2003). The erosion rate varies systematically and is strongly influenced by the composition of the streambank materisls. Extrapolation to a future timeframe could not be undertaken within the limits of the present assessment. A preliminary CMZ was delineated based on professional judgment that defined the boundary using evidence of previous disturbance due to fluvial processes derived from field observations, terrain analysis of the DEM surface, and from indicators presented in historical aerial photography. The preliminary CMZ is overlaid with recent aerial imagery on the map series in Appendix A. Delineation of the CMZ was completed independent of reference to the Federal Emergency Management Agency (FEMA) 100-year flood boundary. However, when compared, there is close agreement between the aerial extents of these two zones (FEMA, 1980).

Another analysis of historical channel changes complete by KHE included an inventory of agricultural land encroachments and losses within the CMZ as observed from aerial photograph review for the period between 1937 and 2009. The results of this analysis are depicted in Figure 5-3 and indicate that since 1937 there have been approximately 334-acres of agricultural lands that have been created within the historic channel migration zone and approximately 142-acres destroyed due to channel migration, in some cases the same agricultural lands that were established since 1937. The main purpose of this analysis is to demonstrate that the creek is migrating in a natural manner within a predictable zone and encroachments of agricultural lands into this zone are susceptible to being eroded through channel migration, likely within the time-frame of tens to one-hundred years.

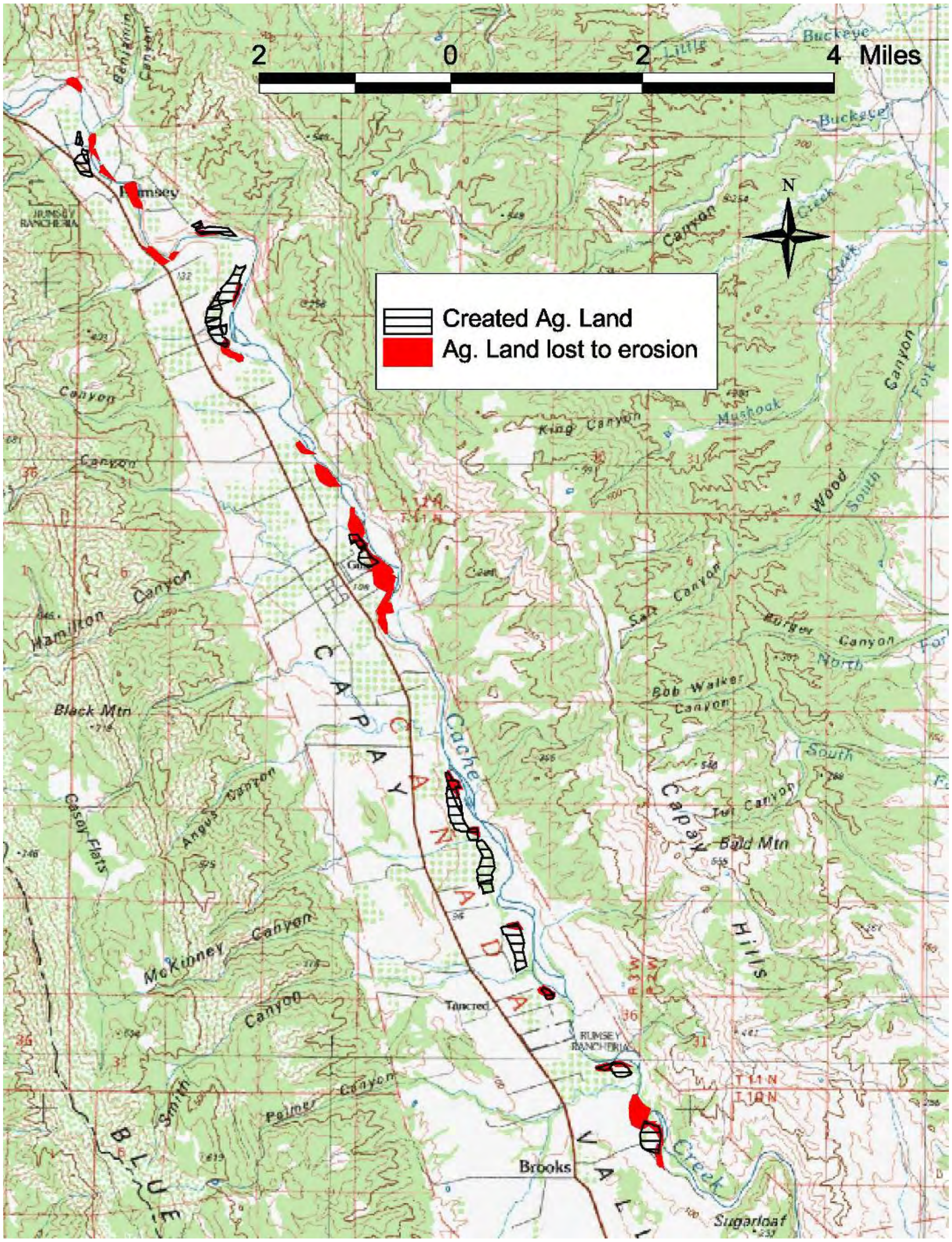

Figure 5-3. **Areas of agricultural lands that were established and destroyed within the Cache Creek CMZ for the period 1937-2007.**

5.4 Site-Specific Examples of Historical Channel Changes

The discussion below presents observations at selected locations that illustrate a variety of channel changes in the study area. The discussion proceeds through a series of field sites and generally follows a downstream direction. Sites are referenced by a combination of cross-section ID and river mile. The reference point was defined to maintain consistency with a system of measurement previously established by Yolo County Parks and Resources (the point of reference for the measurement of river miles is the USGS stream gaging station at Yolo).

Site 38 (River Mile 50.4). The present channel alignment at XS-38 shows a steep bluff that is about 40 feet high along the left bank (Fig. 5-4). The channel has been migrating laterally and has streambank erosion has required the road position to be moved back. Approximately 1,000 linear feet of the left bank has eroded since 1937. At the apex of the meander bend bank erosion has exceeded 250 feet during the historical period. On average, this relates to a rate of three to feet per year, however, the actual rate in any given year is expected to vary greatly from the average with years of high flows experiencing more rapid rates of erosion. The 1937 imagery shows that upstream of this location the channel formerly followed a different alignment that included split flow around a relatively stable island. Shifting the main channel towards the northern alignment has shortened the overall flow path of the channel in this location. This shift may be related to the incision of the channel bed noted for this reach (section 5.1). It appears that the channel shift has created a state in which the creek maintains an excess of energy and is eroding the bank at XS-38 in effort to increase its sinuosity and dissipate energy. Erosion at this location is likely to continue at approximately the same rate as the historical period.

Figure 5-4. Photograph of eroding bluff along the left bank at XS-38.

Site 36 (River Mile 49.2) - Rumsey Bridge

The comparison of historical aerial photographs at the site upstream of the Rumsey Bridge (Fig. 5-5) illustrates the sequence of channel changes that has led to the present alignment and configuration. The image from 1937 shows a broad depositional floodplain, greater than 1,000 feet in width, transitioning to a zone of constriction as the channel passes beneath the bridge. The bridge was constructed in 1929 and replaced an earlier bridge at the site that had been damaged by flooding.

Channel changes between the 1937 and 1953 images are shown by a realignment of the main channel towards the right bank that eroded a new channel through the floodplain deposits and led to the development of a new gravel bar along the left bank. The gravel bar has persisted since that time and has an average elevation that is about five feet lower than the overbank area on the opposite (west) side of the creek (see cross-section 36B in Appendix B). Recall from the discussion of bed stability that comparison of topographic survey data from 1935 and 1983 suggested incision of the channel bed by five to ten feet for a two-mile segment of channel that progressed upstream from Rumsey Bridge. The changes shown between the 1937 and 1953 images in Figure 5-5 appear to illustrate this incision process which has cut a new channel alignment, developed a new gravel bar surface, and abandoned the former floodplain.

The post-1953 channel alignment follows a relatively straight course until it makes a slight bend to the left at a point just over 500 feet upstream of the bridge crossing. Hydraulic properties of the channel at this location led to an episode of bank erosion that progressively cut into the terrace surface exposed along the right bank. The configuration led to failure of the right bank during a flood event in March of 1995 that washed out the western approach to the bridge. Emergency bank repairs utilizing boulders and riprap protection helped to realign the creek and a subsequent effort was coordinated to construct a series of four rock groins that redirect flow away from the streambank and align the channel beneath the bridge crossing. Streambank protection appears to have been adequate during the New Year’s 2005 flood and is likely to maintain a fixed channel position in the near future.

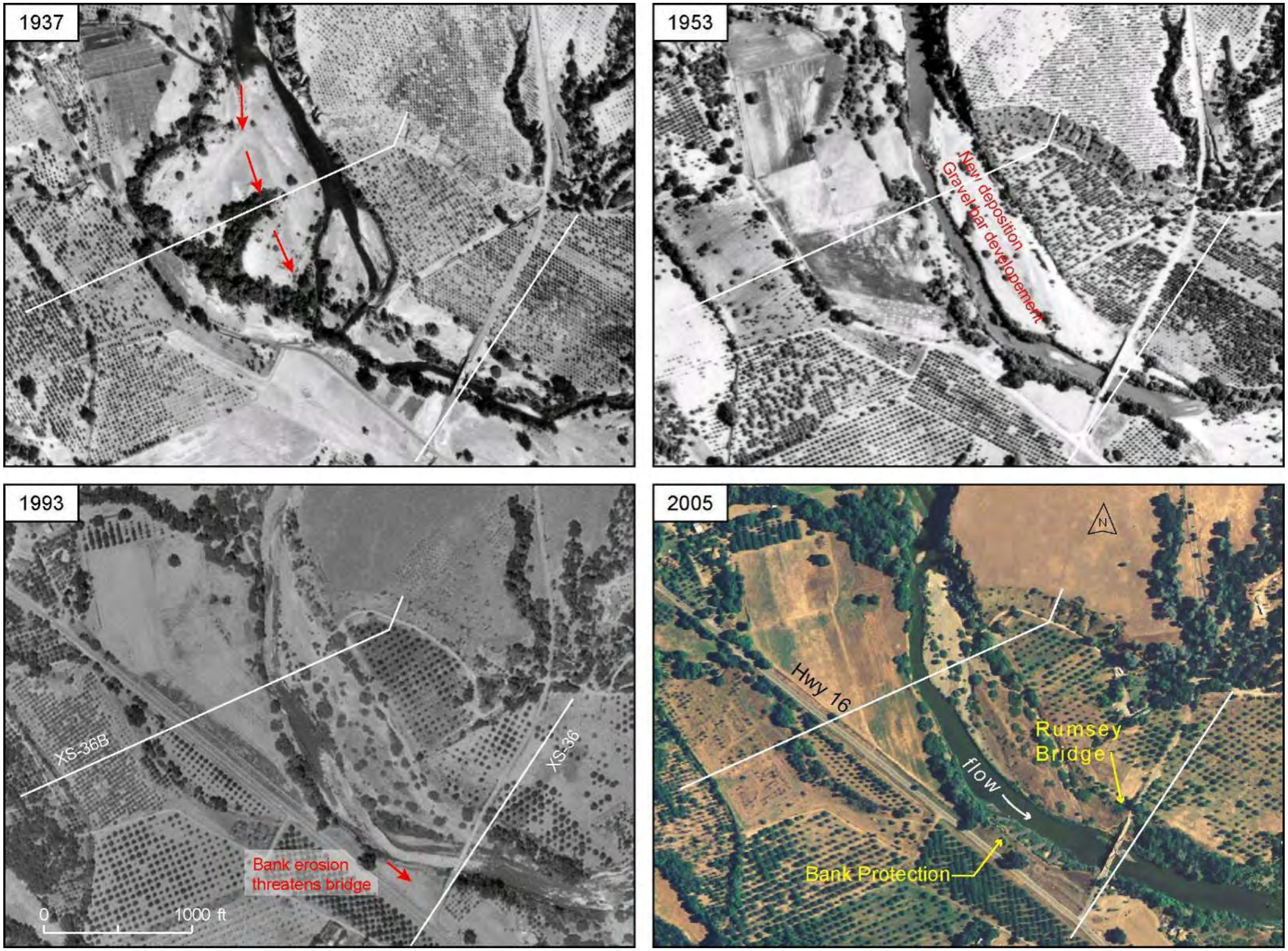

Figure 5-5. Comparison of historical imagery for the channel segment near Rumsey Bridge. Note that red arrows indicate the direction of channel migration.

Site 30 (River Mile 45.5)

Historic channel changes in the stream segment downstream from the Blue Cliffs illustrate a dynamic setting where lateral channel migration has shifted the channel position approximately 1,500 feet since 1937 (Fig. 5-6). The 1937 channel alignment is relatively straight through this segment, however, a wide floodplain in the right (western) overbank area is especially broad (greater than 2,000 feet across) and displays a crescent shape that is incised below the adjacent slope. Landowners in the reach began utilizing this floodplain area for agricultural activities in the 1950's and the area used for agriculture has expanded to include an orchard as well as pasture areas. During the 1980's, a barn was constructed in the floodplain area immediately adjacent to the right bank of the creek and the streambank has been hardened at this location to limit erosion.

Erosion along the right bank has triggered migration of the channel into these floodplain sediments and deposition on the opposite (left) bank has accreted laterally to form a large gravel bar surface. Cross-sectional profile 30B traverses the bar surface approximately perpendicular to the direction of flow and shows that the average elevation of the new gravel bar deposits is equivalent to the elevation of the stable floodplain deposits beyond the right bank.

It is of interest to note that the planform geometry of the channel and gravel bar, formed by recent lateral migration, closely mimics the crescent shape of the floodplain area to the right (west) of the present channel alignment. It is likely that a similar process has repeated episodically at this location whereby the channel alignment lengthens by the migration and extension of a meander bend over the course of decades until some change in the physical conditions shifts the direction of erosion and continued channel migration. Such a shift in the channel position, and the area of bank erosion, could arise by either (1) an avulsion of the channel across the recently deposited alluvium on the gravel bar or (2) a change in the alignment at the upstream end of the reach where the channel emerges from the toe of the large bluffs (Blue Cliffs). At some former time the channel was aligned in a more southwesterly direction and was positioned within the floodplain area currently utilized for agricultural activities. A shift in alignment at the upstream end of this segment is likely to trigger changes where the channel reoccupies this part of the floodplain at some point in the future.

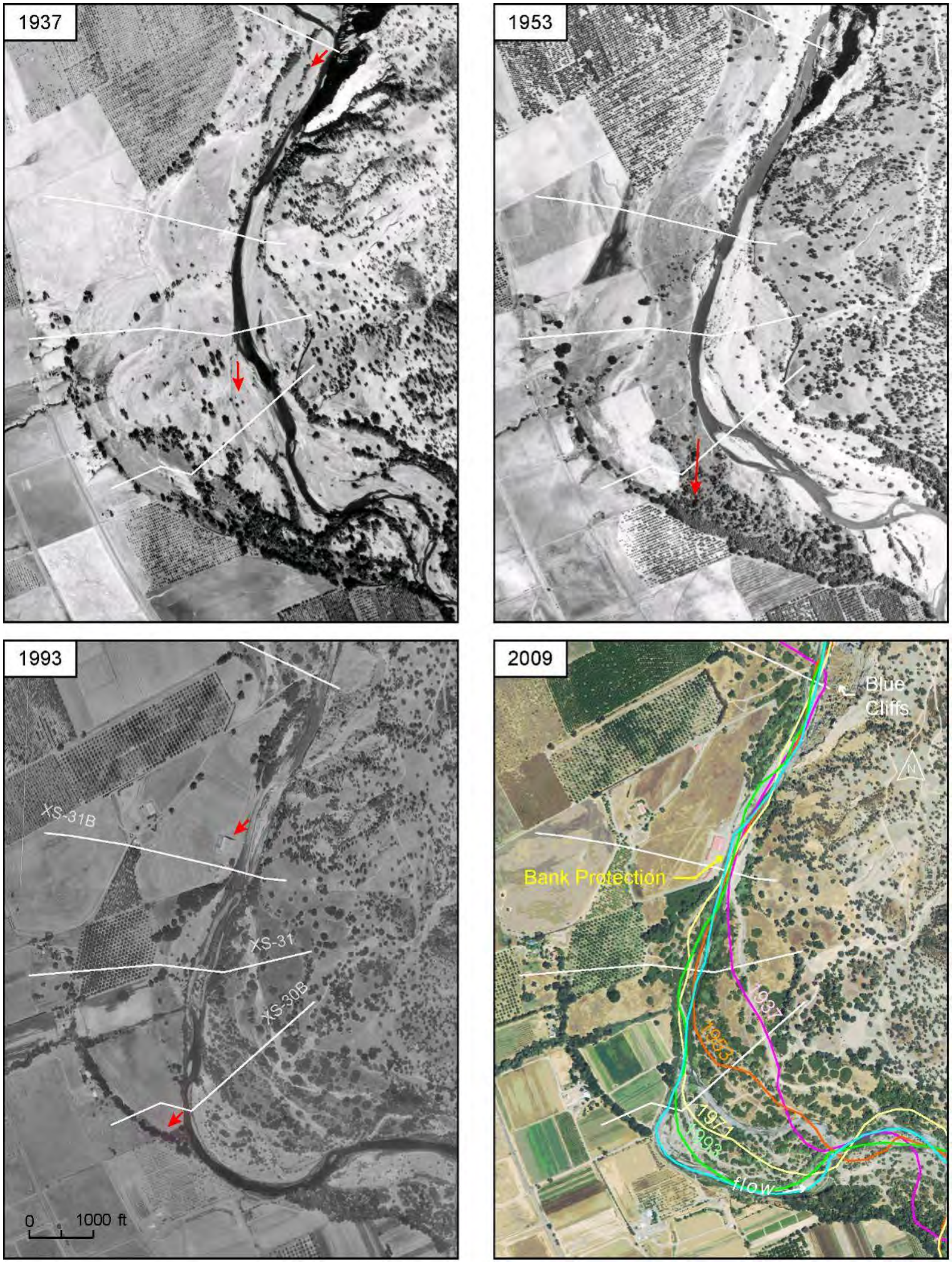

Figure 5-6. Comparison of historical imagery for the channel segment downstream of the Blue Cliffs. Note that red arrows indicate the direction of channel migration.

Site 23 (River Mile 41.7) – Guinda Bridge

Historic channel changes near the town of Guinda are depicted by the comparison of aerial photographs in Figure 5-7. The 1937 image shows a relatively straight channel alignment that turns to the left (heads to the east) at the former location of a wooden bridge. The wooden bridge is still visible in imagery from 1953 but is no longer present in a subsequent image from 1964. Large floods occurred in December, 1955 (31,800 cfs at Capay) and February, 1958 (51,600 cfs at Capay) that may be responsible for damaging the bridge. The present bridge crossing (County Road 57) was built in 1959 at a new site almost a mile downstream from the former crossing.

Continued realignment of the channel position has altered the flow characteristics at the site. The 1971 image shows a channel alignment directed in a southeasterly direction that abuts the valley wall about 2,000 feet north of the present crossing and is deflected to the south where it crosses beneath Guinda Bridge. Lateral migration of the channel approximately one mile upstream triggered a series of adjustments that subsequently threatened to outflank the bridge crossing by erosion of the terrace surface on which its western approach is constructed. Figure 5-6 shows erosion of the right bank at the location of XS-25 between the 1971 and 1985 images. Migration of the meander bend in the downstream direction triggered deposition and the development of a new gravel bar along the opposite (left) bank. Subsequent imagery shows continued erosion along the right bank, additional migration of the meander bend in the downstream direction, and continued growth of the bar surface on the opposite bank by lateral accretion. Adjustment to the channel alignment in this section well upstream of the bridge altered the flow path of the next meander bend downstream such that the flow was directed at a relatively steep angle into the right bank above the bridge crossing. Rapid erosion of the right bank resulted in the migration of the meander bend that nearly wiped out the bridge. The lateral migration and associated channel changes above the bridge crossing has led to the development of large gravel bar surfaces both upstream and downstream of the bridge (Fig. 5-7). Subsequent efforts to stabilize the right bank in the segment above the bridge crossing has utilized large rock riprap to armor the bank and constructed a series of rock groins that extend into the channel to re-direct the flow.

Current trends at the site near Guinda show that the bank protection structures have fixed the channel in place at the bridge crossing. Continued evidence of channel migration is evident at both upstream and downstream locations. Just upstream of the upstream of the bank protection near the bridge the channel is migrating towards the left bank through recent floodplain deposits. Further upstream, between XS-24 and XS-25 (see location of the word “flow” the lower right panel of Fig. 5-7) the channel is migrating toward the right bank and eroding agricultural land. Realignment of the channel in recent years has triggered erosion of the bank which had formerly been relatively stable. Erosion since 1993 has totaled 300 feet at the maximum. This agricultural area is utilizing a portion of the floodplain that is within the channel migration zone but has been a stable floodplain surface in recent decades. The elevation of the agricultural fields is equivalent to the floodplain deposits of the bar surfaces along the active channel. The site in the present example shows how the channel tends to shift the location of bank erosion over a span of decades. Bank erosion will continue until some threshold is exceeded that triggers a realignment of the channel upstream and then the erosive energy of the channel is directed in a new location.

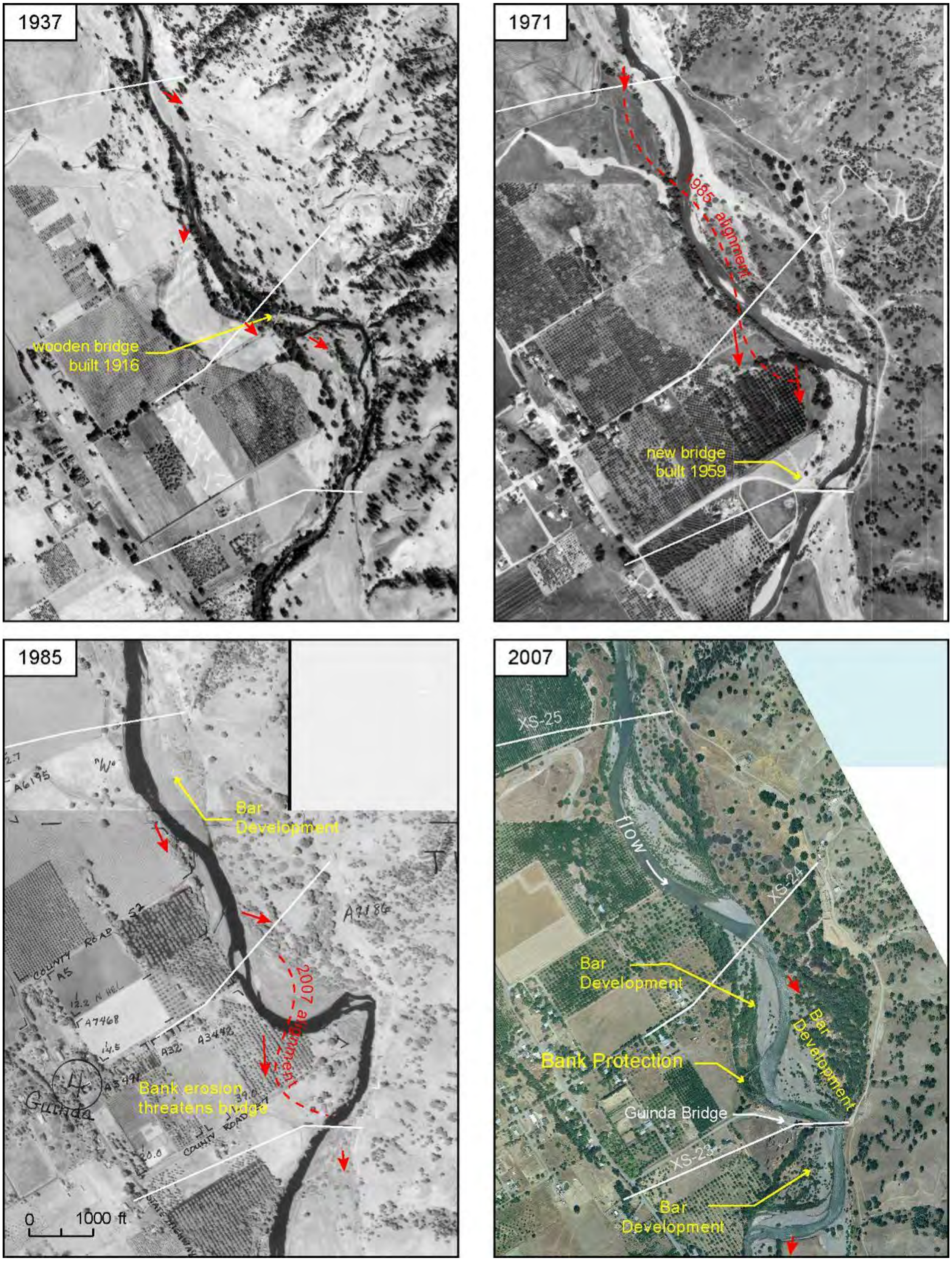

Figure 5-7. Comparison of historical imagery for the channel segment near the town of Guinda. Note that red arrows indicate the direction of channel migration.

6.0 Findings and Recommendations

Alluvial rivers are dynamic systems in a nearly continuous state of adjustment driven by fluctuations of streamflow and sediment load in the river channel. Observations over time reveal morphologic changes within the stream corridor that occur through episodes of streambank erosion and concurrent sediment deposition. This continuous adjustment in channel form is the primary mechanism for energy dissipation in the system and is critical to the stability of the stream corridor. Although naturally occurring, streambank erosion along the Capay Valley segment of Cache Creek poses resource management issues due to: (1) encroachment of agricultural land into the floodplain; (2) potential threats to infrastructure such as roads, bridges, or structures located within the stream corridor; and (3) the remobilization of sediments characterized by elevated mercury concentrations. Erosion of the channel banks is a natural process and essential to the maintenance of ecological health for aquatic and riparian habitats (Florsheim el al., 2008). Land management approaches in recent decades have increasingly integrated strategies that protect property and infrastructure from bank erosion while maintaining natural processes characteristic of dynamic river systems (Piegay 1997, 2005; Florsheim et al., 2008).

6.1 Hydrologic and Geomorphic Conditions

The hydrologic regime in the watershed is characterized by large seasonal and inter-annual fluctuations of streamflow and a large sediment load that includes a high proportion of gravel- to cobble-sized sediments. The seasonal pattern of streamflow includes peak flows in response to winter storm runoff, a varied winter/spring baseflow, an unnaturally high summer flow maintained by flow releases from the upstream dams, and an extremely low baseflow period that prevails as flow releases are terminated in the fall.

Sediment yield is greatest for watershed areas in the middle part of the watershed (the lower reaches of tributary streams in the upper basin and Capay Valley) where rainfall totals tend to be low, vegetation coverage sparse, and outcrops of highly erodible surficial deposits create a badland-type topography in places.

Dam construction in the upper watershed has moderated the seasonal variability of streamflow and reduced the magnitude and frequency of peak flows in Cache Creek. The hydrologic regime of the Clear Lake basin was partially regulated by the lake under natural conditions. Cache Creek Dam, completed in 1914, enhanced the ability to store winter runoff in the lake and deliver it to water users downstream during periods of peak demand (summer). Indian Valley Dam, completed in 1975, stores runoff from an area draining approximately 120 square miles and supplements water deliveries to the service area downstream. The area regulated by Indian Valley Dam accounts for about 22 percent of the watershed area that was unregulated prior to 1975 (the watershed area excluding the Clear Lake basin). Flood modeling from the Army Corps of Engineers (1995) suggests that reservoir storage behind Indian Valley Dam reduces the magnitude of peak flows during large floods by approximately 20 percent.

The previous three decades (1980-2010) have been characterized by greater hydrologic variability than the 50 years which preceded them (1930-1980). The peak flow of record (53,500 cfs) occurred during WY 1983, an extremely wet year. Additional wet years characterized by high flows in the recent period include: 1986, 1995, 1998, and 2006. Mean annual streamflow exceeded 1,800 cfs four times since 1983. An annual flow of such magnitude was exceeded only once (1958) during the preceding 50 years.

Groundwater levels monitored from wells in Capay Valley display little seasonal or long-term variability. Groundwater levels are also relatively shallow and maintained by recharge from the Creek. Summer deliveries to agricultural users have essentially created perennial flow conditions in Cache Creek through Capay Valley. The increased and year-round recharge from the creek explains the steady, shallow water levels observed over the last 60-years.

The longitudinal profile of Cache Creek undergoes a transition as the channel exits the bedrock-controlled canyon reach and emerges into Capay Valley. The prevailing gradient in the canyon above Capay Valley is about 0.005. A bedrock outcrop spans the channel in the vicinity of Camp Haswell and maintains the grade at the headward extent of Capay Valley. The streambed elevation drops steeply below this bedrock control and then maintains a relatively consistent gradient that ranges between 0.0020 and 0.0018 downstream through Capay Valley.

The channel characteristics through the Capay Valley segment of Cache Creek are transitional between meandering and braided channel forms. Streams of this type of pattern are characterized by a high width-depth ratio and lateral instability. The lateral instability, evident in the frequent changes in channel alignment, episodes of rapid bank erosion, and reworking of gravel bar deposits, is a critical component in maintaining the overall channel stability of the river system. The continual adjustment in channel form is the process by which the creek dissipates energy during high flows.

Bankfull discharge, the flow at which water overflows the bank and begins to inundate the floodplain, varies between about 6,000 and 10,000 cfs at cross sections assessed in Capay Valley. Such a flow has an annual exceedance frequency of approximately 1.5 years and is exceeded for prolonged durations during relatively wet water year types. The width of the bankfull channel averages about 200 feet across and the bankfull depth is about 6 feet. These characteristics yield a width-depth ratio greater than 30:1.

The streambed is primarily composed of gravel- (intermediate diameter between 2 and 64 mm) and cobble-sized sediments (intermediate diameter between 64 and 256 mm). The distribution of grain-sizes in the streambed material varies downstream, however the variation does not constitute a significant trend within the Capay Valley segment until the reach just upstream of the Capay Diversion Dam where the distribution of streambed-material displays a significant trend toward finer-grained sediments. The median grain size of the streambed material varies from site-to-site; however, 40 mm is a good approximation at most locations. The threshold of entrainment for the streambed material is estimated to occur within the range of 6,000 to 10,000 cfs. Cross-sectional analysis of hydraulic characteristics showed that this threshold of incipient motion occurs at or near the bankfull discharge.

Floodplain areas in Capay Valley form primarily through lateral channel migration and concurrent sediment deposition that develops gravel bar surfaces. Riparian vegetation in floodplain areas includes a mix of native (Fremont Cottonwood and several varieties of willow, for example) and non-native species. Tamarisk and arundo, two non-native species have spread along the riparian corridor and are believed to have increased in aerial extent and density over recent decades. These invasive plants colonize within zones of channel disturbance and delineate those areas in Capay Valley since being introduced into the watershed. It is hypothesized that the change to near perennial flows through Capay Valley have improved conditions for riparian plant establishment and development. Unfortunately, the invasive riparian species appear to be out-competing the natives.

6.2 Summary of Channel Dynamics and Historical Channel Changes

The Capay Valley segment of Cache Creek is a dynamic alluvial river subject to large fluctuations in streamflow, episodes of rapid streambank erosion, and frequent adjustments of the channel alignment. The map series in Appendix A and cross-sectional profiles in Appendix B illustrate the existing topography of the stream corridor in relation to the sequence of historical channel changes in Capay Valley. The stream channel morphology appears to be adjusted to the range of flows under present hydrologic conditions. This form allows for effective sediment transport through the reach without aggrading or degrading the streambed. In order to maintain a form that balances the sediment transport capacity with the sediment supplied from the watershed, the channel is continually adjusting its morphology as a mechanism to dissipate energy during high flows.

KHE’s assessment of the geomorphic equilibrium, or longitudinal stability, did not find evidence of widespread channel incision such as the bed degradation observed for the segment of Cache Creek downstream of Capay Dam where commercial gravel mining and other impacts have triggered a state of geomorphic disequilibrium (NHC, 1995). Comparison of topographic survey data from 1935, 1983, and 2007 show a generally stable longitudinal profile through Capay Valley. Localized exceptions were noted at two locations. Comparison of longitudinal profiles from 1935 and 1983 suggest significant channel incision of six to ten feet for the reach upstream of the Rumsey Bridge. Data also show a more limited area of incision downstream of the Guinda Bridge.

Bed degradation leads to an abandonment of the former floodplain surface (which becomes, by definition, a terrace surface) and the formation of a new floodplain area by deposition of sediment on bar surfaces at a lower elevation than the pre-disturbance floodplain. Incising channels tend to widen and create new floodplains, inset into the pre-existing floodplain terrace. Terrace surfaces were observed at many locations along the Cache Creek channel in Capay Valley. Some of these are well above the present floodplain elevation and obviously not related to recent channel changes. A low terrace, positioned about five to ten feet above the present floodplain, is present at many locations, however, the available data are not sufficient to conclude whether this terrace was produced by incision that occurred before the 1935 survey or by some other process such as tectonic uplift of the valley floor. A sequence of multiple terraces at elevations up to sixty feet above the present floodplain is indicative of active tectonism in Capay Valley.

Historic channel changes observed in Capay Valley include areas of relatively rapid channel migration in which the streambank along the outside of a bend in the channel thalweg erodes and concurrent deposition on the opposite bank develops gravel bar surfaces. Streambank erosion is primarily attributed to these naturally occurring geomorphic processes associated with the shear stress produced along the channel boundary by moving water at high flows. Streambank erosion in Capay Valley occurs at a naturally high rate due a combination of factors that include: (1) high peak flow magnitudes that generate sufficient energy to entrain sediments from the channel boundary; (2) streambank materials that tend to compose a large proportion of sand-sized particles or coarser-grained sediments that have a low degree of cohesiveness; (3) a bank configuration such that the toe is often unprotected by riparian vegetation; and (4) a channel pattern and bed configuration that is characterized by frequent shifts in the channel alignment and development of bar features that periodically directs flow against the streambank at relatively steep angles.

Streambank erosion primarily occurs at streamflow magnitudes greater than 5,000 cfs, the flow rate at which debris piles at the channel toe are typically overtopped (SLA, 1987). Lateral migration of the channel proceeds over a time span of years or decades until a shift in the channel alignment upstream redirects flow such that bank erosion is concentrated in a new location. The episodic nature of such shifts in the channel alignment is highly variable in time and space and makes detailed predictions of the future locations of bank erosion highly uncertain. The rapid shifts in channel alignment are likely driven by development of mid-channel bars that form during peak flow conditions due to the naturally high sediment transport rate of course-grained sediment in this active alluvial system.

KHE analyzed former stream channel alignments from historical aerial imagery to delineate the historic migration zone (HMZ) shown on the map series in Appendix A. The HMZ depicts the cumulative area occupied by the channel during the period since 1937. Field indicators, terrain analysis, and graphical review of historical aerial photography guided further delineation of a preliminary channel migration zone (CMZ), also shown on the map series in Appendix A. The CMZ depicts areas that appear to have been occupied by the channel in the recent past under the current set of environmental conditions and corresponds closely to the area in which the channel can be expected to migrate in the future.

6.3 Recent Impacts on Geomorphic Conditions in the Stream Corridor

Human impacts in the watershed and along the stream corridor in Capay Valley have had localized impacts on channel morphology, but are not likely responsible for any system-wide trends toward geomorphic instability. The hydraulic connectivity between the channel and floodplain areas remains relatively undisturbed as no major levees or impediments are present in the study area.

Extraction of gravel occurred at a select number of localized area in the 1970’s and 1980’s, however, the extractions were not a part of any commercial mining operations and the scope of the impact from mining does not appear to have had a significant lasting impact on the overall geomorphic conditions in the reach.

Flow regulation has moderated the magnitude of peak flows and reduced the sediment supply to Cache Creek, however, the scale of these impacts appear to be small and have not triggered any significant changes in channel morphology or geomorphic processes.

Probably the largest impact of human activities on the physical condition of Cache Creek is associated with encroachment into the riparian corridor. Land clearance and grazing in the early settlement period is likely to have reduced the extent of the natural riparian woodland areas. Relatively protected areas of the floodplain have been utilized for agricultural production such as pasture, row crops, and orchards. Construction of bridges, roads, and additional infrastructure within the channel migration zone has prompted the need for emergency streambank protection. The erosion threats at these sites, however, are primarily attributed to natural geomorphic processes. The stabilization measures have primarily utilized protection structures which contain large rock. Such measures may provide limited protection in the short term, however, they do little to dissipate the energy of the creek and primarily transfer the erosive energy towards an adjacent bank downstream.

The spread of invasive plants such as tamarisk, arundo, and ravenna grass has altered the ecological conditions of the riparian areas. These non-native plants are ubiquitous within the Capay Valley segment of Cache Creek. KHE’s assessment of historical channel changes did not identify any system-wide changes in response to the spread of invasive plants, however, localized impacts of bar stabilization were noted that redirect flow into adjacent areas of the floodplain. The typical geomorphic response to riparian plant invasions is characterized by a general narrowing of the channel cross-section. Cache Creek appears to have maintained a relatively consistent cross-sectional profile and channel pattern due to its dynamic nature which frequently reworks gravel bar and floodplain surfaces. Continued spread of the invasive plants and development of denser thickets of riparian shrubs may eventually cross some threshold at which the channel can no longer maintain its natural profile.

6.4 Recommendations for Management Strategies

The assessment of hydrologic and geomorphic conditions in the Capay Valley segment of Cache Creek yielded the following recommendations:

1. Continue vegetation management efforts that aim to eradicate invasive species in the stream corridor. To date, our studies do not indicate that the spread of tamarisk and arundo is a major cause of streambank erosion in the study area; however, dense stands of these species (especially arundo) have been observed to redirect flow in localized areas and accelerate bank erosion where it may not have occurred otherwise. More importantly, tamarisk and arundo are now dominating the pioneer stage of riparian vegetation establishment. A review of current literature suggests that these particular invasive species degrade overall ecological health of the riparian corridor. Continued encroachment in the Cache Creek corridor could create a more regionally significant impact.

2. Educate the public that Cache Creek within Capay Valley is behaving within the bounds of a naturally occurring system. The perception of an altered, uncontrolled or destructive system arises due to human activities such as historic removal of riparian corridor and encroachment into the active floodplain.

3. Promote the use of the Historic Migration Zone (HMZ) and Channel Migration Zone (CMZ) boundaries (see Appendix A) to assist landowners and resource agencies in identifying

erosion prone areas to assist in the planning and management of lands within Capay Valley. This may require people to adapt land and management practices to acknowledge future shifts in channel alignment and associated erosion and deposition. One logical policy would be to limit future development within the channel migration zone.

4. Limit the use of structural bank protection measures, such as riprap or flow directing groins, only where necessary to protect infrastructure that cannot be feasibly relocated out of the channel migration zone. Inventory and analysis of existing structures suggest short-term relief, but eventual failure during high magnitude, low frequency floods. If required, integrate a component of woody plantings with structural techniques to maintain some ecological functions of the riparian area.

5. Minimize the use of rock riprap to stabilize eroding streambanks to protect property. Riprap hardens the bank and does not allow for the natural processes that are essential to the formation and maintenance of aquatic and riparian habitats. Rock structures tend to redirect creek flow, introducing changes in stream energy (and erosion) to reaches adjacent to the treatment area.

6. If structural bank protection is deemed necessary, utilize deformable bank protection measures where necessary to protect property. Bank reshaping techniques, in conjunction with other biotechnical techniques may be well suited to areas where the channel alignment is intersects the streambank at a sharp angle. The design guidelines of such techniques are illustrated in the Integrated Streambank Protection Guidelines published by the Washington State Aquatic Habitat Guidelines Program (2003)

7. Promote expansion of riparian forest as a natural bank stabilization measure. This would require transitioning some agriculture lands adjacent to the creek and within the active floodplain back to riparian forest in order to better protect farms on adjacent low terraces that still experience flooding. Expanding the riparian corridor will promote improved ecological diversity and health by supporting later stage successional species, currently rare or missing within Capay Valley. A larger and self-maintaining mature riparian forest will also provide more large wood to the active channel zone, promoting increased geomorphic diversity and improved aquatic habitat.

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Appendix A.

Map Series Depicting the Geomorphic Features and Historical Channel Alignments within the Capay Valley Segment of Cache Creek.

KHE developed a high-resolution digital terrain model of Capay Valley that allows for rapid assessment of geomorphic features in a geographic information system (GIS). The Yolo County Flood Control and Water Conservation District (YCFCWCD) provided a LIDAR[1] dataset collected in March 2008. The LIDAR data list geographic coordinates as x,y,z (easting, northing, and elevation) values for discrete points spaced at roughly one meter intervals on the landscape. KHE processed the x,y,z data files to generate a grid surface, or digital elevation model (DEM), with a horizontal resolution (grid spacing) of five feet.

The map series in Appendix A depicts geomorphic features and historic channel alignments in the Capay Valley segment of Cache Creek. The left panel in each map is a shaded relief image of the DEM surface. Elevations along the stream corridor are shaded in 5-foot increments. Portions of the DEM that are above the range of the color ramp, such as adjacent hillslopes, are depicted by a grayscale image to show terrain features.

Areas of streambank protection, such as rock riprap or flow directing groins, are indicated over the shaded relief map for general reference. The bank protection features depicted on the map include those installed as part of the NRCS Emergency Watershed Program, structures inventoried in an earlier assessment by Simons, Lee, and Associates (1987), and additional features identified by field reconnaissance. The inventory of bank protection features on the maps in Appendix A is not comprehensive as additional areas of rock riprap have not been mapped.

The middle panel in each map shows a recent aerial photograph from 2007. The 2007 images were provided by the Yolo County Parks and Resources Department. The Historic Migration Zone (HMZ) and Channel Migration Zone (CMZ) boundaries are overlaid with the 2007 images. The HMZ is the collective area occupied by the channel in the historical record. Additional explanation of the HMZ and CMZ is presented in the analysis of historical channel changes (section 5.3). The panel to the right side of each map shows a background image created from aerial photography taken in 1937. A series of historical channel alignments are overlaid on the 1937 image. The alignments shown are a subset of the historical channel alignments studied to delineate the HMZ.

Cross-sectional profile alignments are indicated on the map series in Appendix A and correspond to the graphical plots of cross-sectional profiles in Appendix B. Graphical review of the DEM surface in conjunction with recent aerial imagery and cross-sectional profiles yield information that describes the morphologic characteristics of the stream corridor. Characteristics of the stream corridor visible on the aerial image, such as gravel bar or vegetated floodplain surfaces, can be can be evaluated on the DEM to compare relative elevations with the historical series of stream channel alignments.

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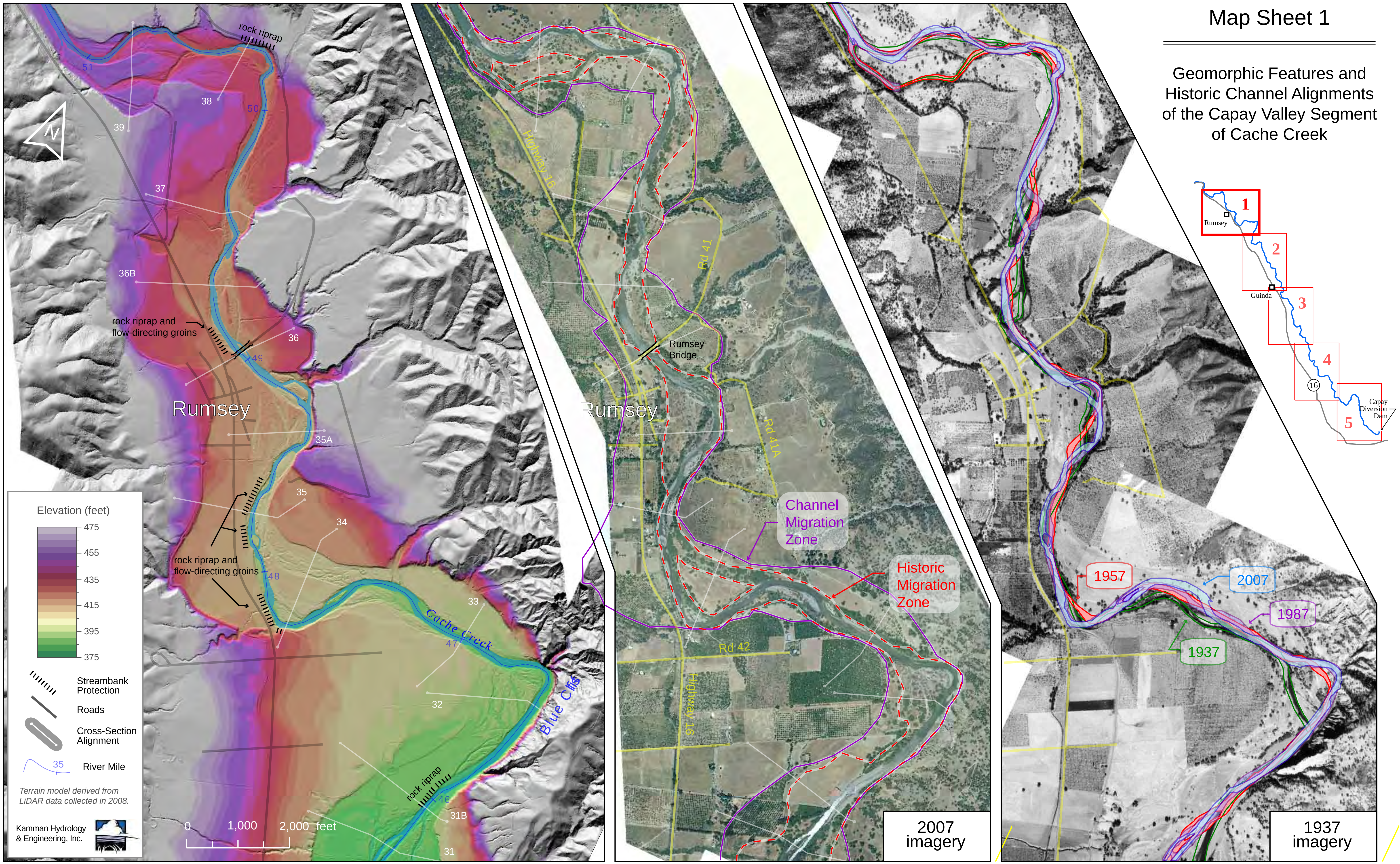
[1] Light Detection and Ranging (LIDAR) is a technology that employs an aircraft-mounted scanning laser rangefinder to produce accurate topographic survey data at a high spatial resolution.

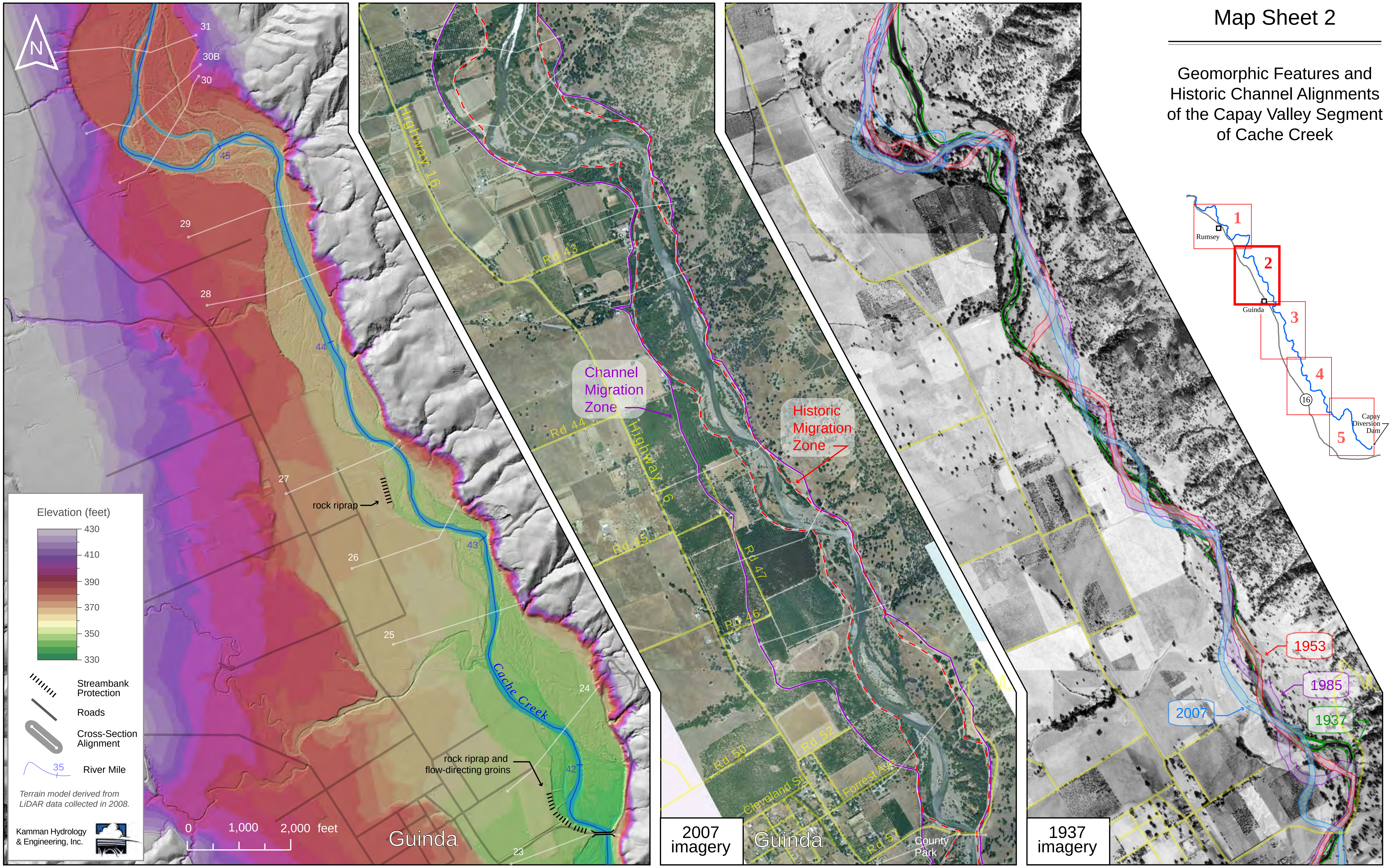
Map Sheet 1

Geomorphic Features and Historic Channel Alignments of the Capay Valley Segment of Cache Creek



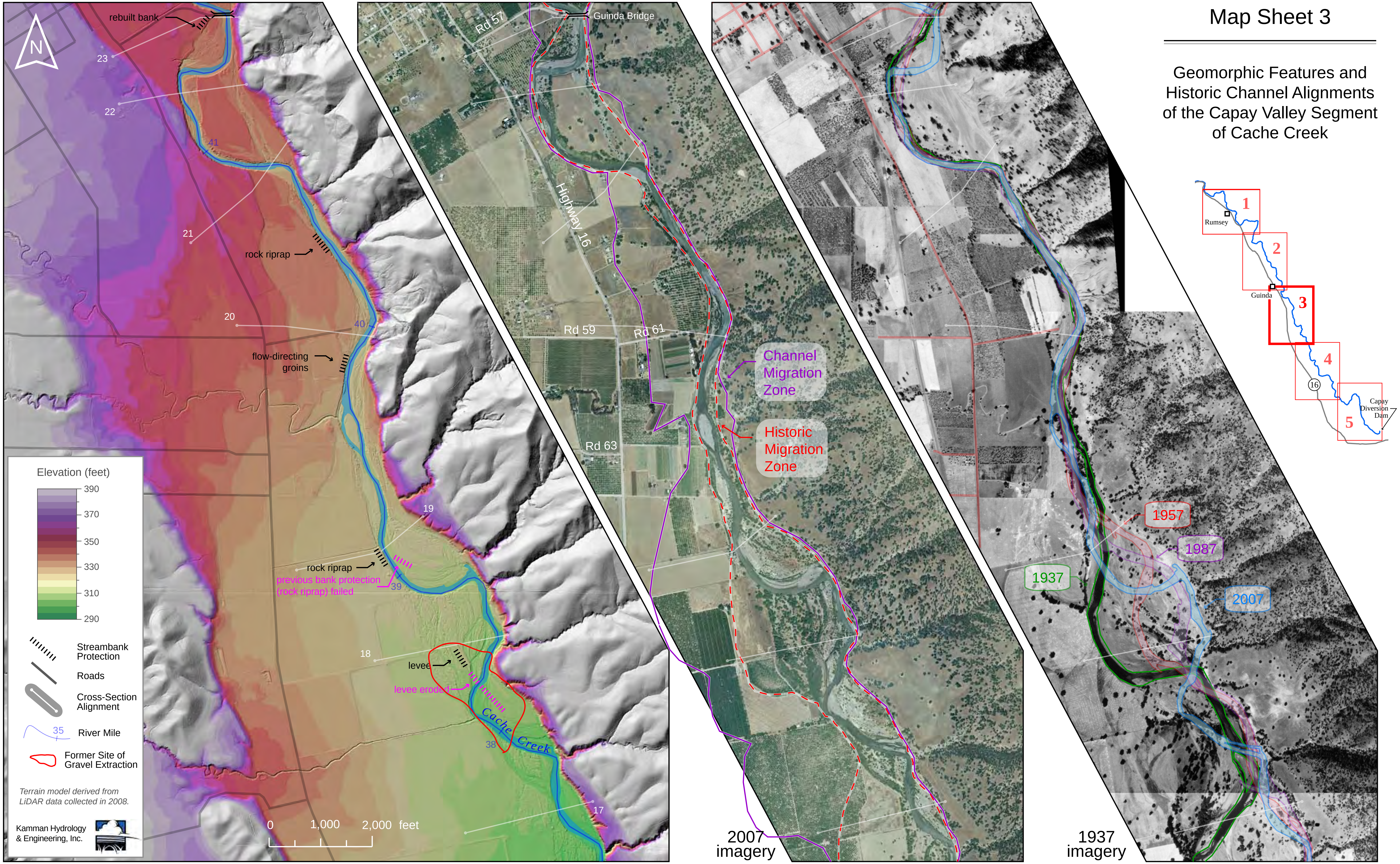
Map Sheet 2

Geomorphic Features and Historic Channel Alignments of the Capay Valley Segment of Cache Creek



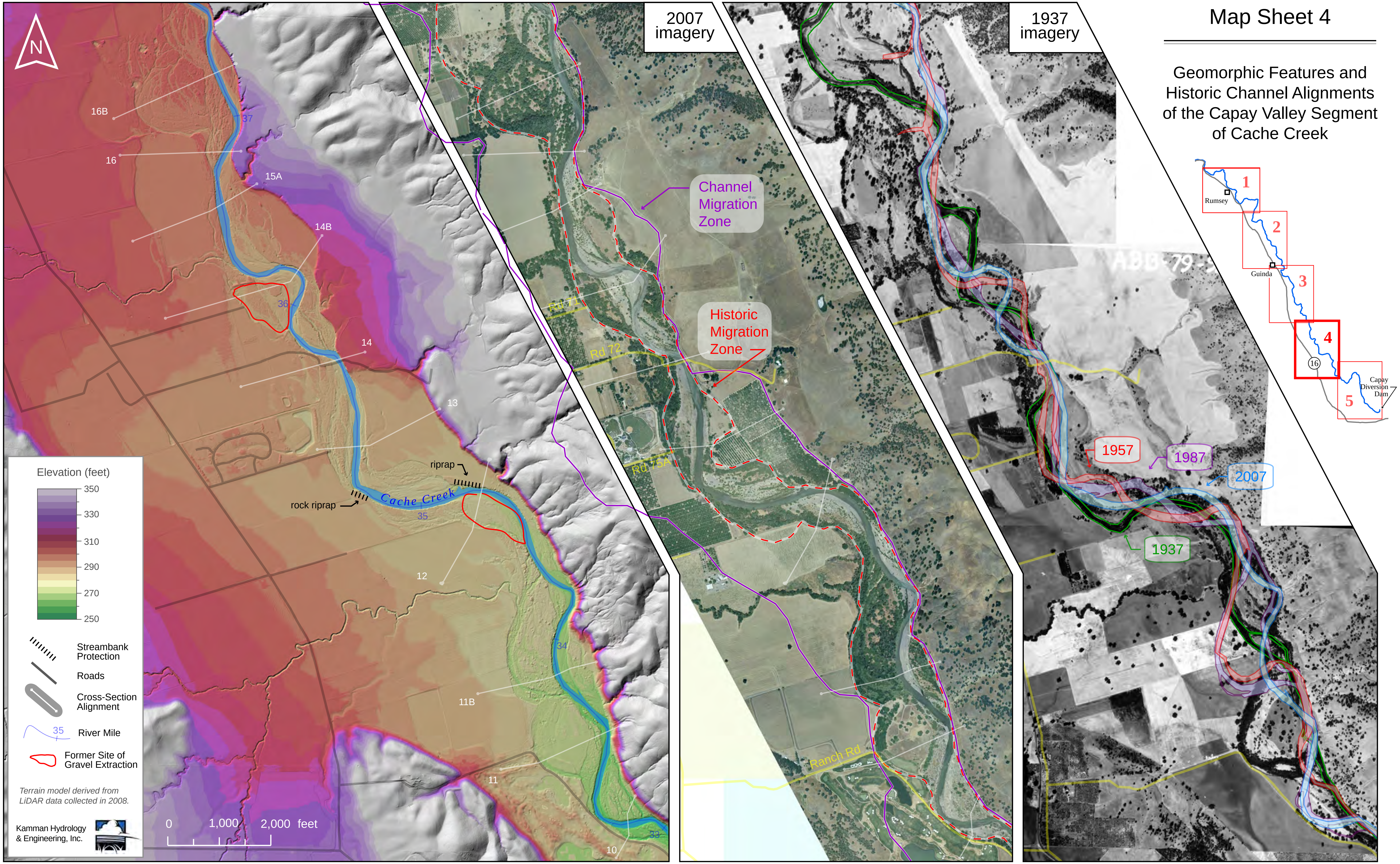
Map Sheet 3

Geomorphic Features and Historic Channel Alignments of the Capay Valley Segment of Cache Creek



Map Sheet 4

Geomorphic Features and Historic Channel Alignments of the Capay Valley Segment of Cache Creek

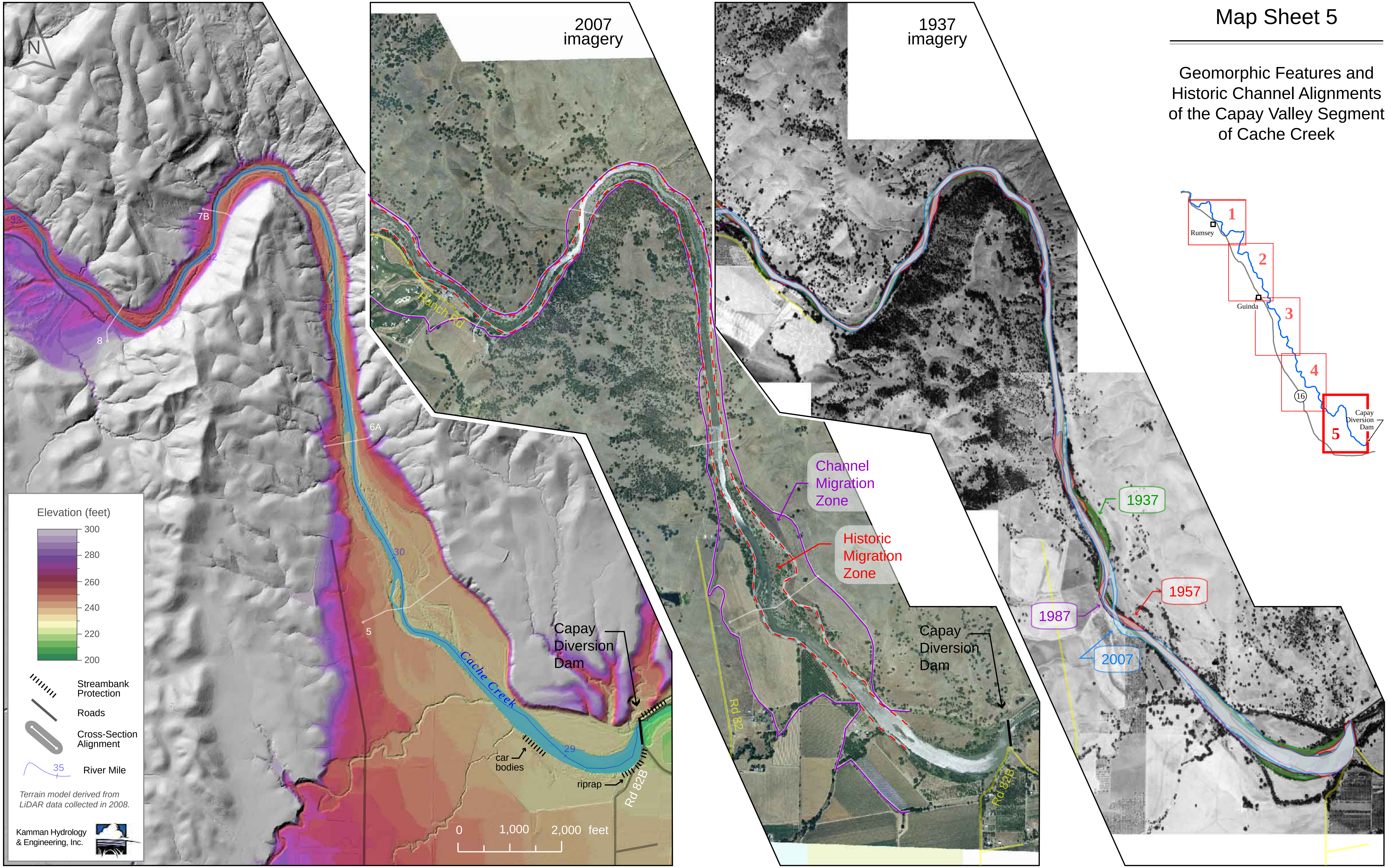


Terrain model derived from LiDAR data collected in 2008.

Kamman Hydrology
& Engineering, Inc.

Map Sheet 5

Geomorphic Features and Historic Channel Alignments of the Capay Valley Segment of Cache Creek



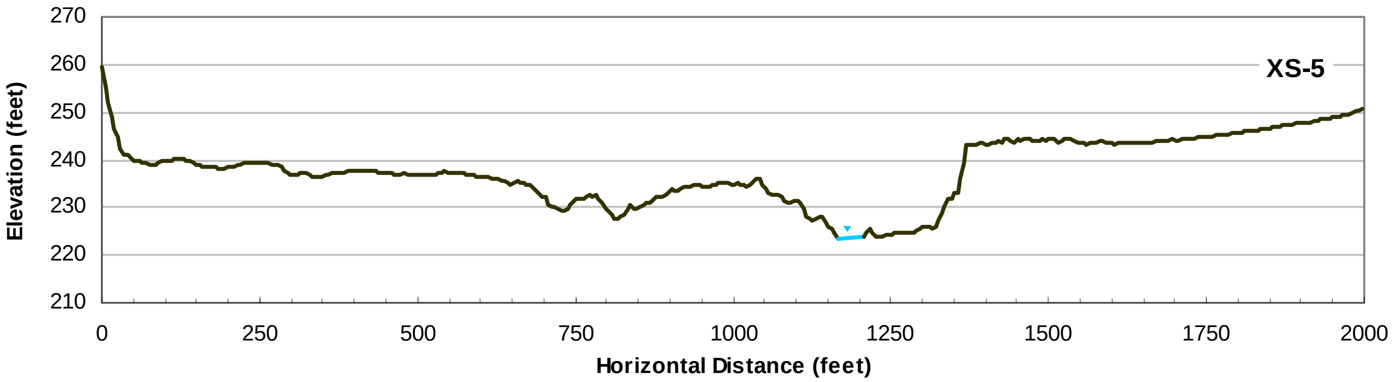
Appendix B.

Cross-Sectional Profiles at Select Locations along Cache Creek through Capay Valley.

Topographic profiles were extracted from a digital elevation model derived from a LIDAR dataset collected in 2008. Profile alignments were drawn perpendicular to the stream channel alignment and extended beyond the stream bank areas to depict the topographic relations between channel, floodplain, and terrace features. Horizontal distances are measured from the left overbank area as viewed from a perspective looking downstream. At most locations the profile direction (and distance measurement) is from east to west.

The LIDAR terrain data collected in the 2008 omits the subaqueous portions of the stream channel because the LIDAR pulses do not penetrate the water surface. As such, the cross-sectional profiles are truncated at the elevation of the water surface on the day data were collected. Most of the Capay Valley data was collected on March 27, 2009. The streamflow reported by the DWR gage at the Rumsey Bridge was less than 150 cfs. The water surface is shaded light blue in the cross-sectional profiles to indicate that it is not the ground surface. The active channel of Cache Creek is wide and shallow and riffle bars are likely to have a residual water depth of less than 1 foot at the time data were collected. Although the low flow channel characteristics are not fully described, the profiles provide a useful illustration of the topographic relations between gravel bar, floodplain, and terrace surfaces.

Cross section ID's are based on a numbering scheme for cross-sectional profiles surveyed by USGS in 1984 (Harmon, 1989). The exact endpoints of the USGS cross sections remain unknown; however, the general locations are indicated by a map in Harmon's (1989) open-file report and by a series of maps presented with the SLA report (1987). The 2008 cross-sections were drawn in the same general location as the earlier surveys, however, the alignment was altered in places to remain perpendicular to the stream channel and the profile lines were extended a greater distance from the stream bank to include more information about the overbank areas. A few of the profiles from the 2008 data set are positioned in locations that the earlier USGS data did not survey. In such instances the profile was given a new ID by adding the suffix "B" (e.g. XS-14B) to the nearest cross-section profile ID.


XS-5
Elevation (feet)
270
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240
230
220
210
Horizontal Distance (feet)
0
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500
750
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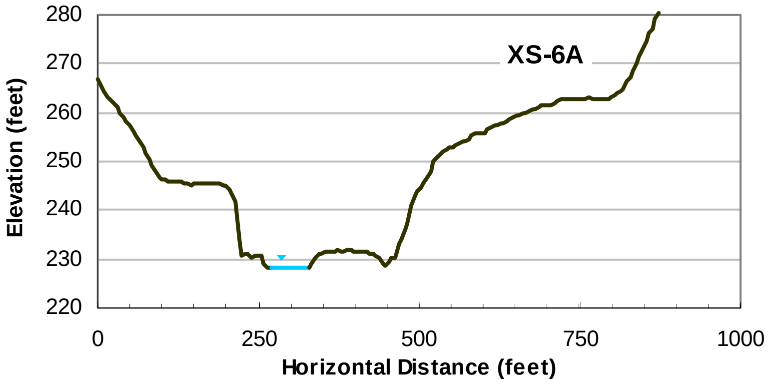
1250
1500
1750
2000


XS-6A
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240
230
220
Horizontal Distance (feet)
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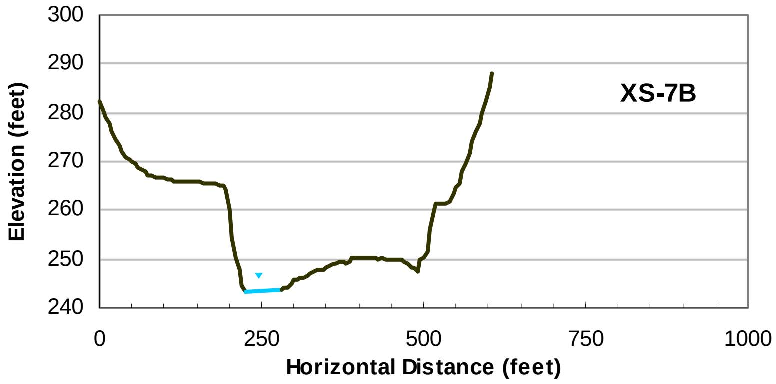
500
750
1000


XS-7B
Elevation (feet)
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240
Horizontal Distance (feet)
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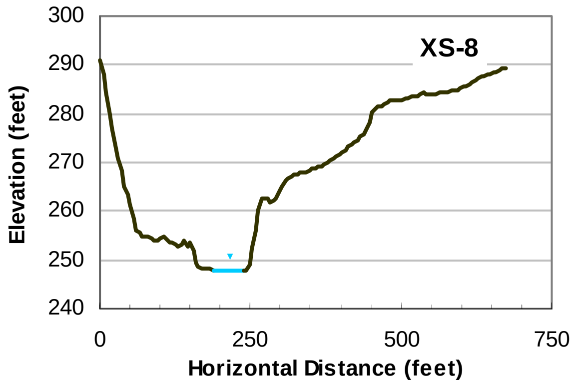
500
750
1000


XS-8
Elevation (feet)
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270
260
250
240
Horizontal Distance (feet)
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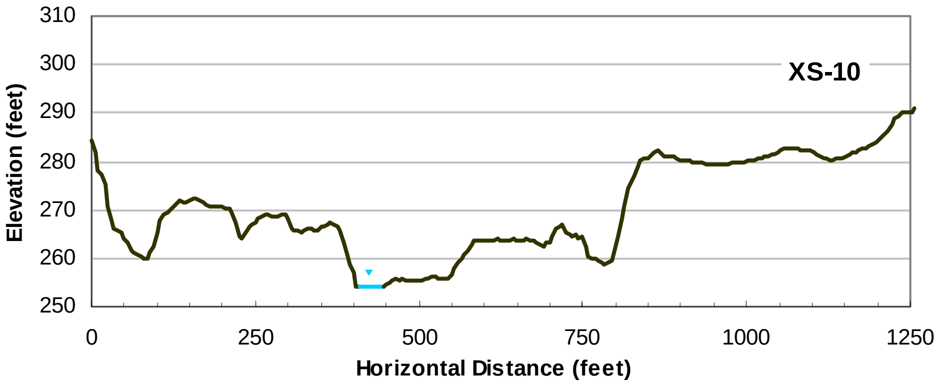
250
500
750


XS-10
Elevation (feet)
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280
270
260
250
Horizontal Distance (feet)
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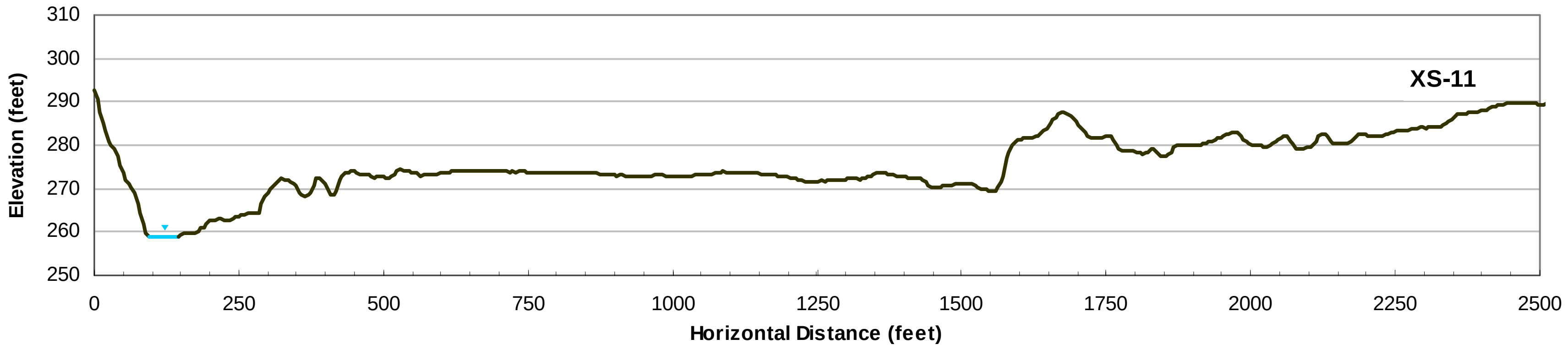
250
500
750
1000
1250


XS-11
Elevation (feet)
310
300
290
280
270
260
250
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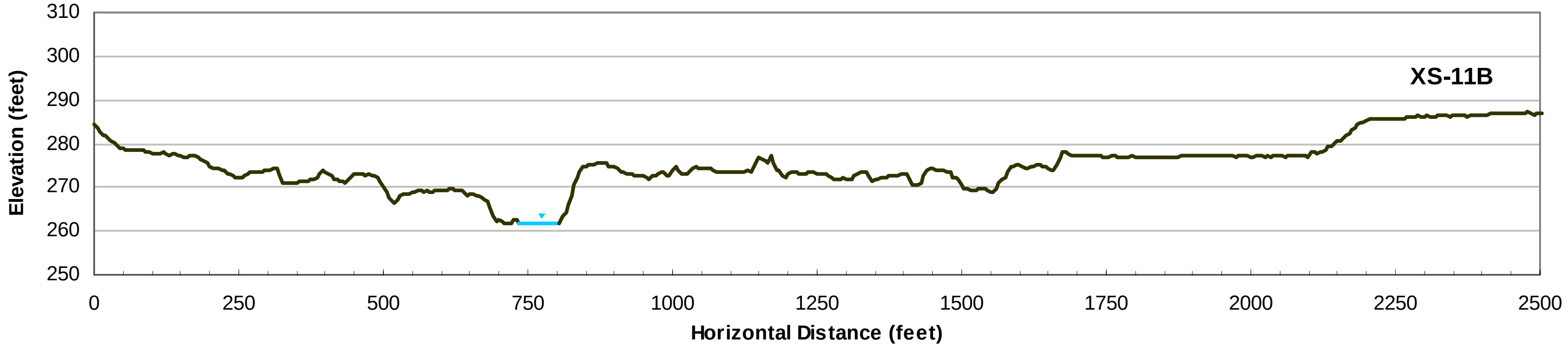
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-11B
Elevation (feet)
310
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290
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260
250
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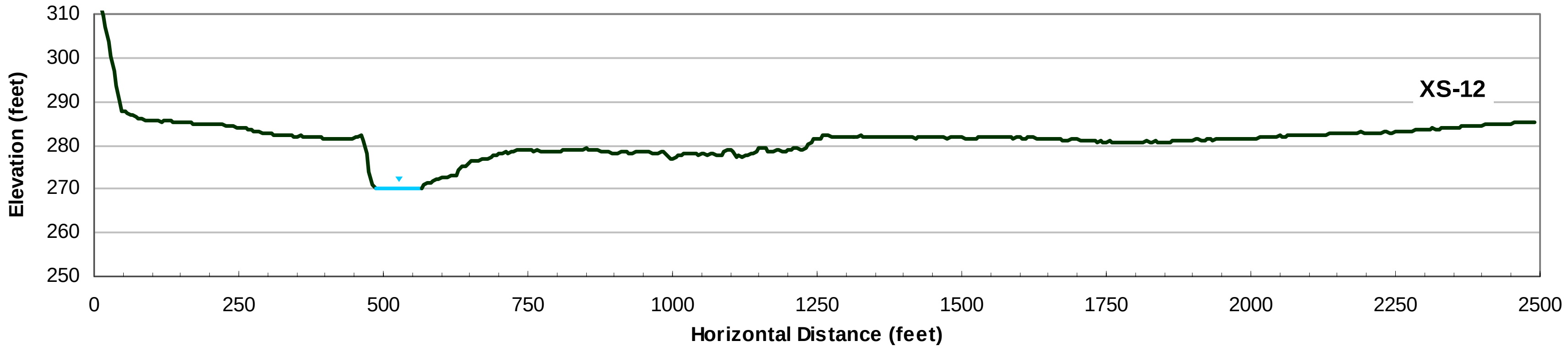
1750
2000
2250
2500
Horizontal Distance (feet)


XS-12
Elevation (feet)
310
300
290
280
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260
250
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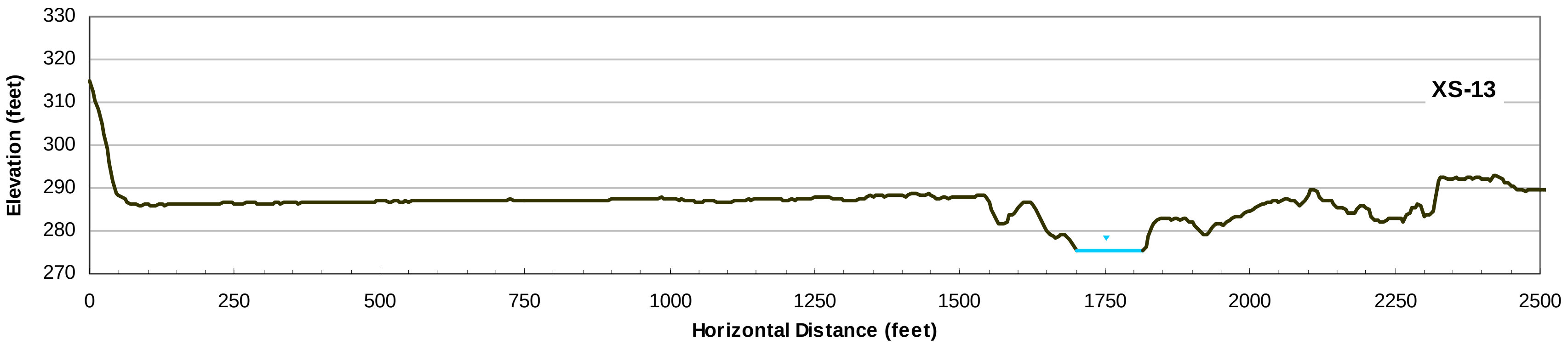
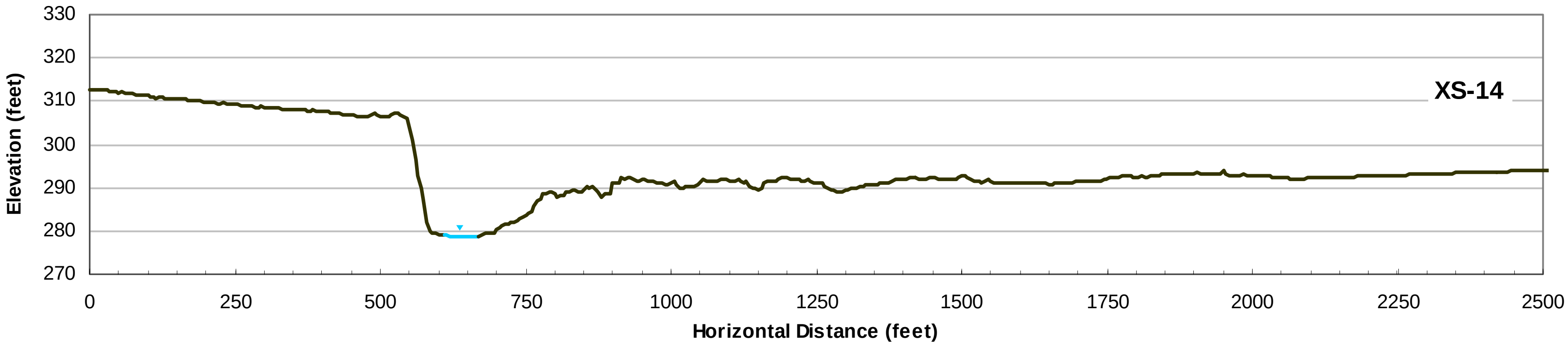
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-13
Elevation (feet)
330
320
310
300
290
280
270
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-14
Elevation (feet)
330
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270
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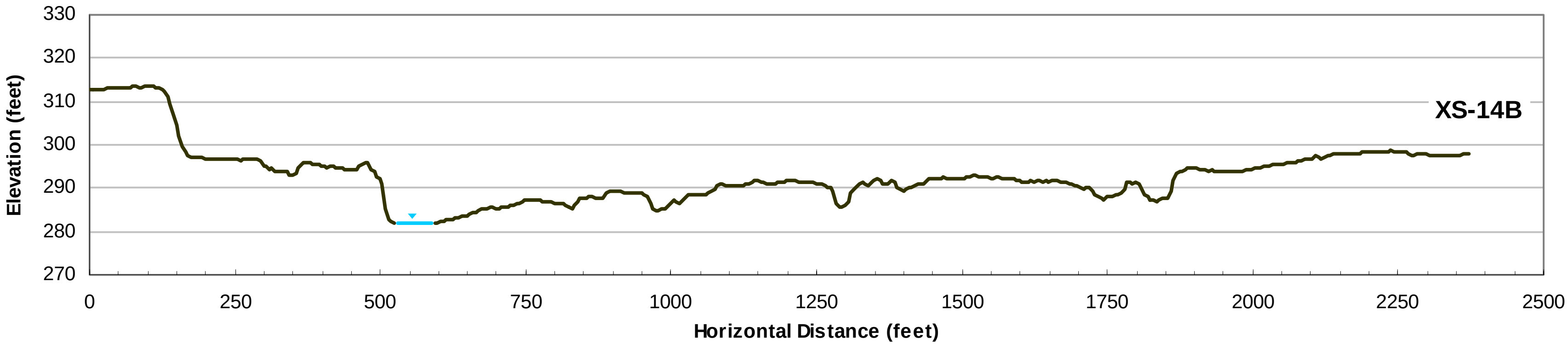
1750
2000
2250
2500
Horizontal Distance (feet)


XS-14B
Elevation (feet)
330
320
310
300
290
280
270
0
250
500
750
1000
1250
1500
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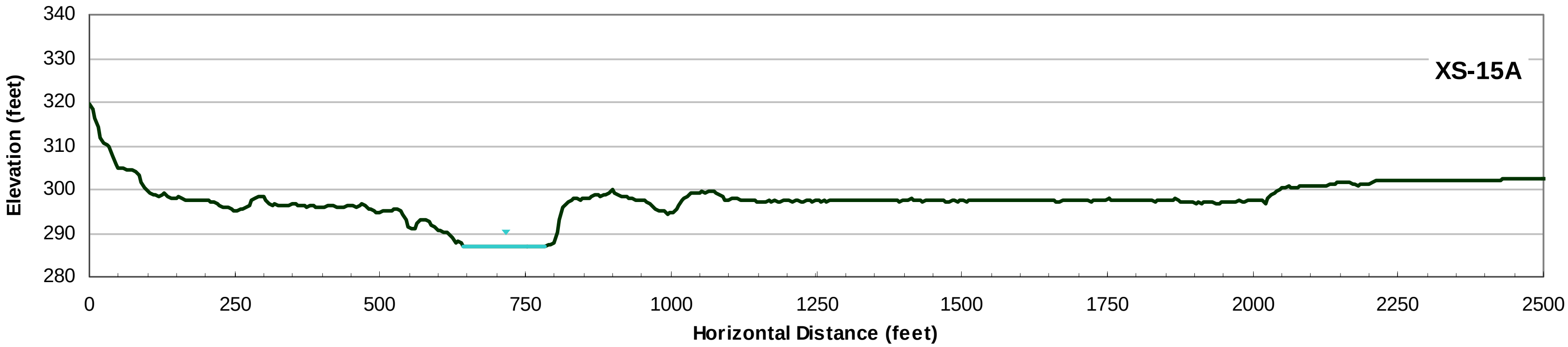
2000
2250
2500
Horizontal Distance (feet)


XS-15A
Elevation (feet)
340
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320
310
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290
280
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250
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750
1000
1250
1500
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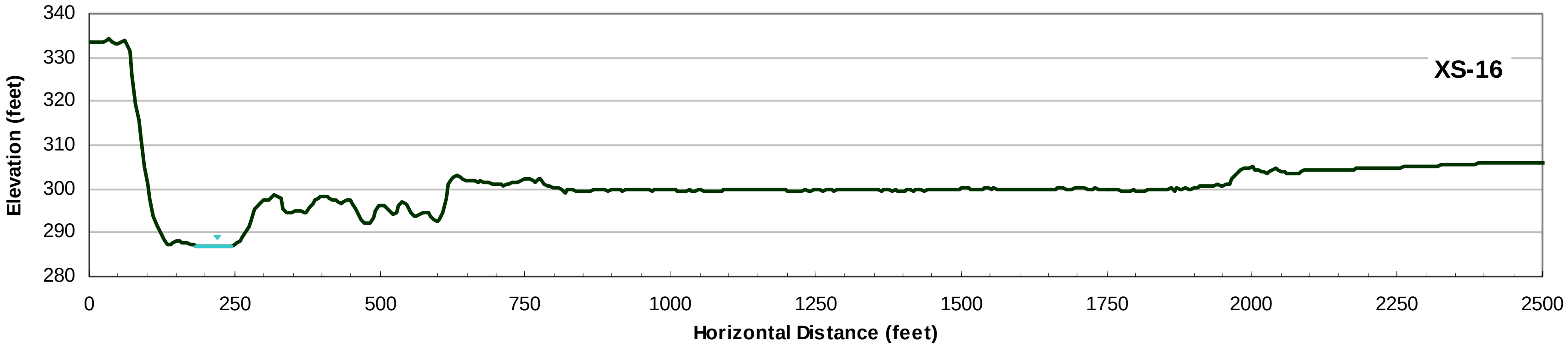
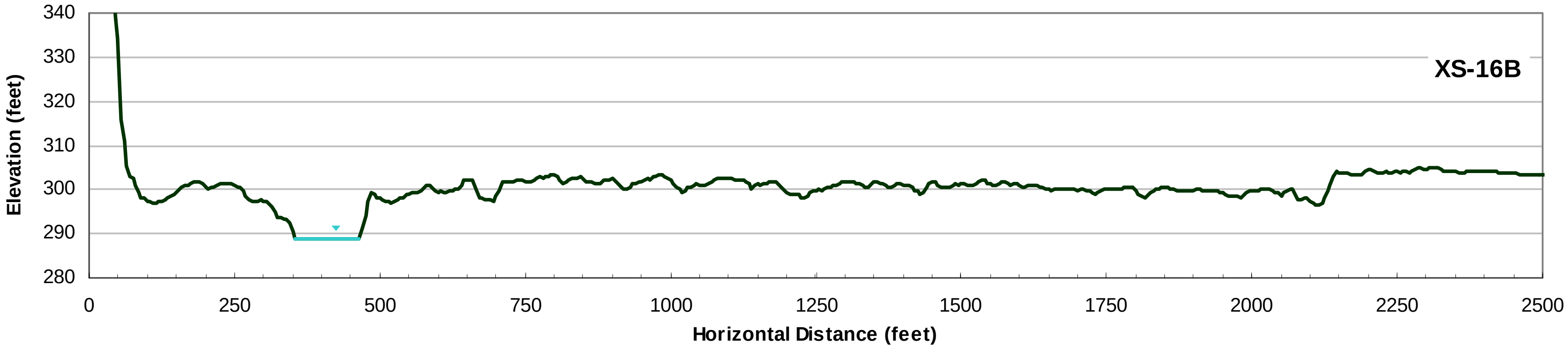
2000
2250
2500
Horizontal Distance (feet)


XS-16
Elevation (feet)
340
330
320
310
300
290
280
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-16B
Elevation (feet)
340
330
320
310
300
290
280
0
250
500
750
1000
1250
1500
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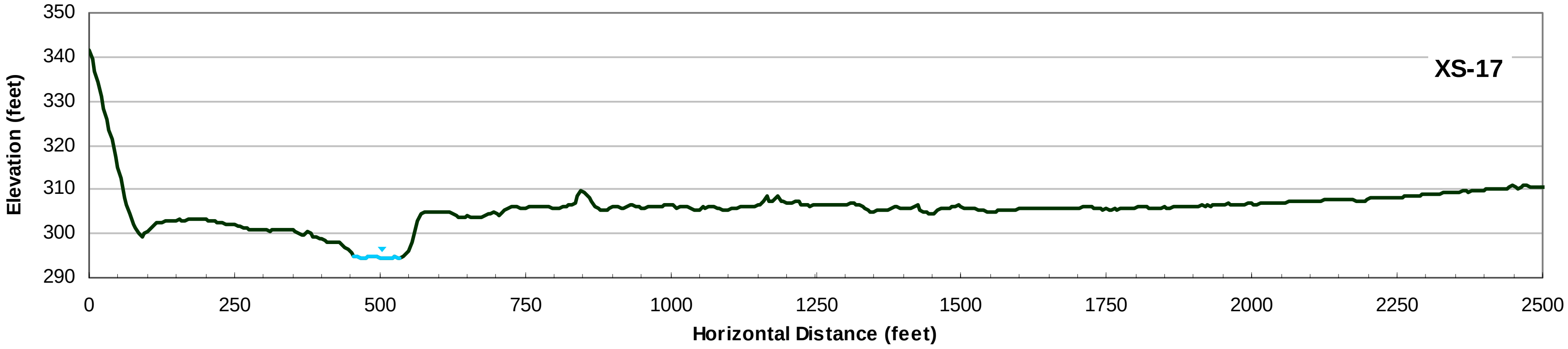
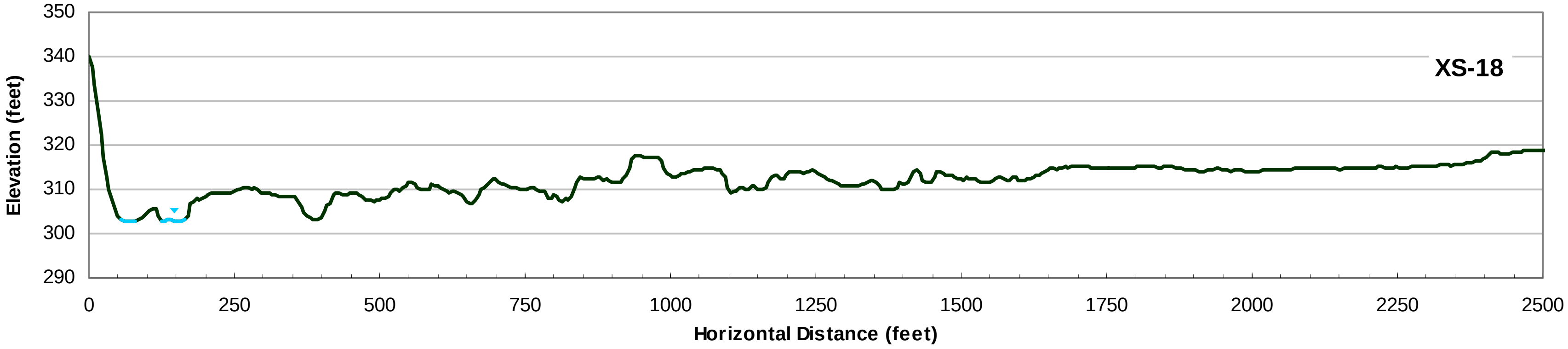
2000
2250
2500
Horizontal Distance (feet)


XS-17
Elevation (feet)
350
340
330
320
310
300
290
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-18
Elevation (feet)
350
340
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320
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300
290
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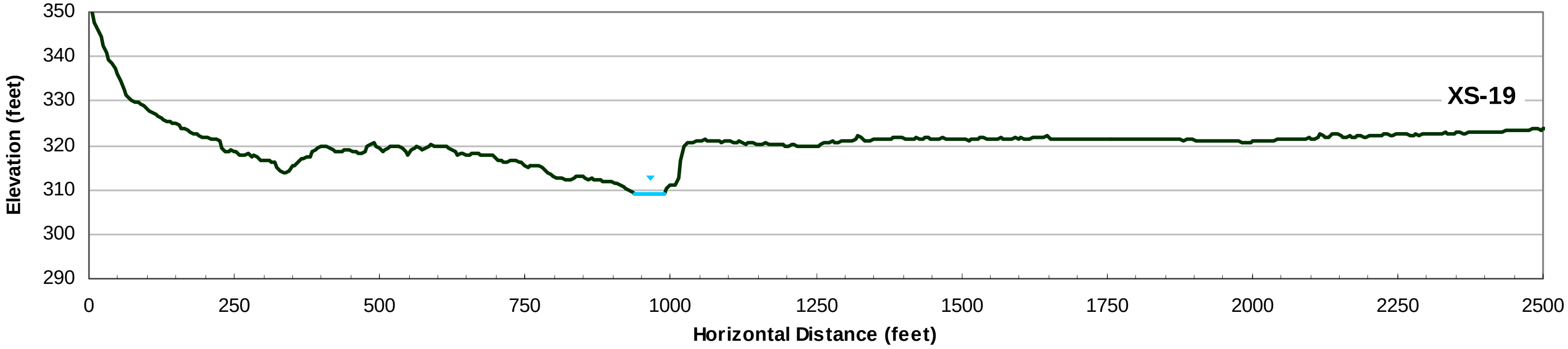
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-19
Elevation (feet)
350
340
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320
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300
290
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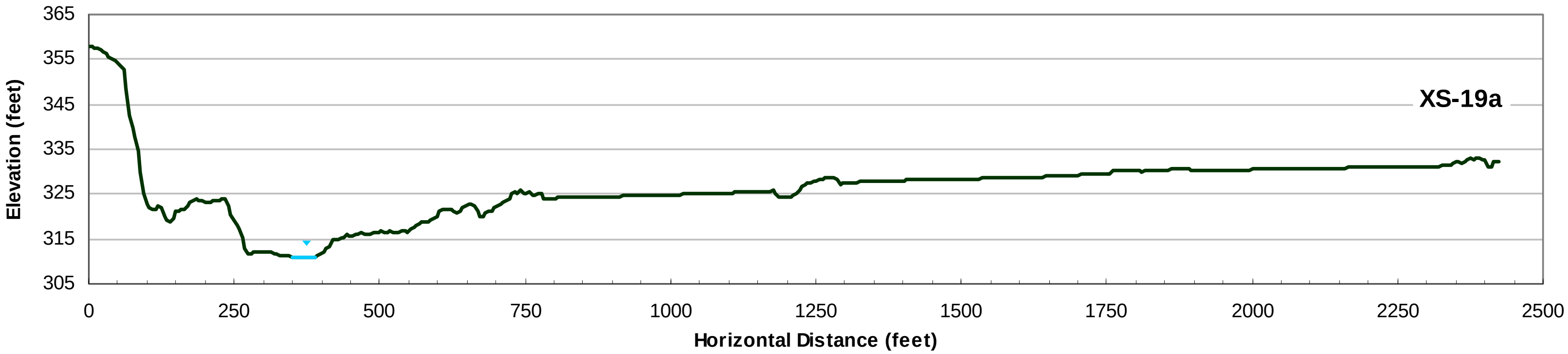
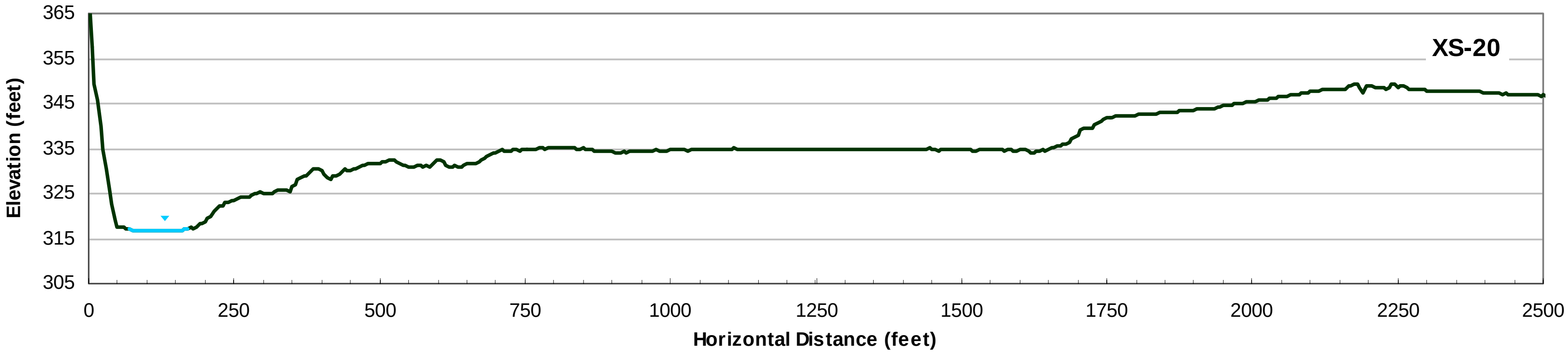
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-19a
Elevation (feet)
365
355
345
335
325
315
305
Horizontal Distance (feet)
0
250
500
750
1000
1250
1500
1750
2000
2250
2500


XS-20
Elevation (feet)
365
355
345
335
325
315
305
Horizontal Distance (feet)
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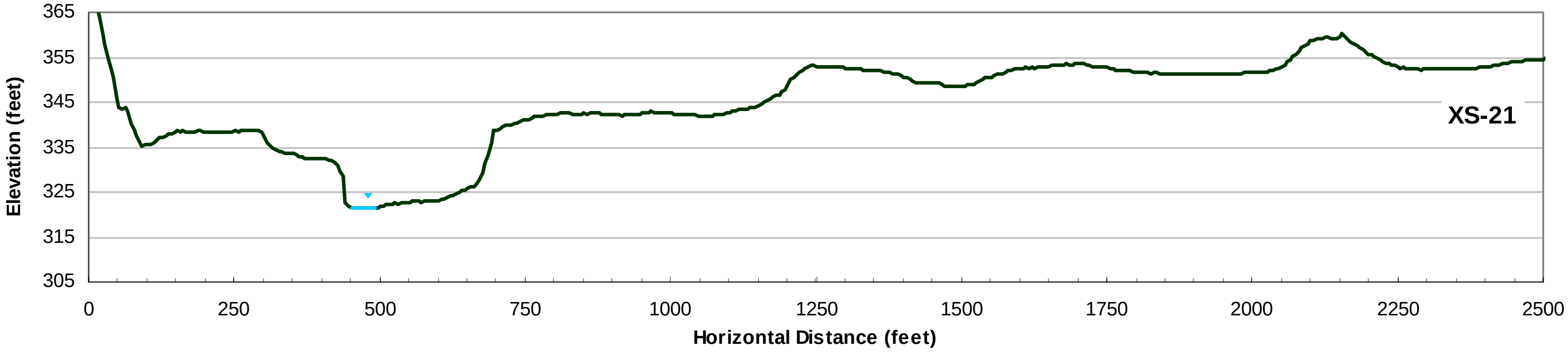
500
750
1000
1250
1500
1750
2000
2250
2500


XS-21
Elevation (feet)
365
355
345
335
325
315
305
Horizontal Distance (feet)
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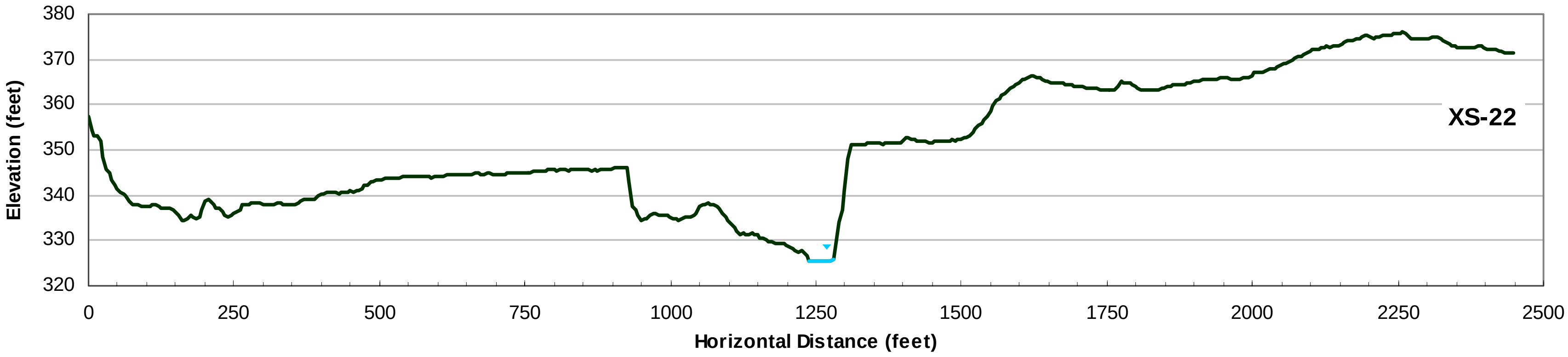
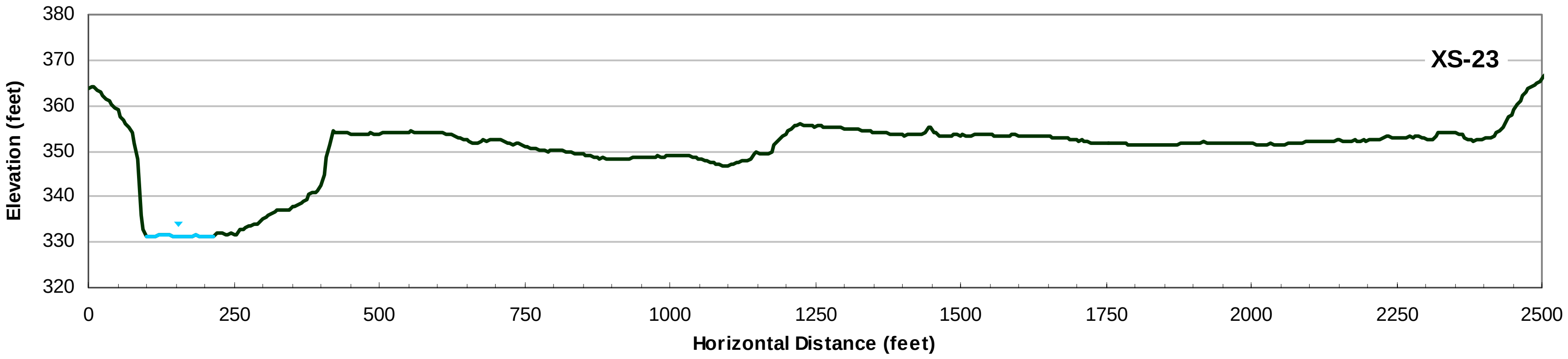
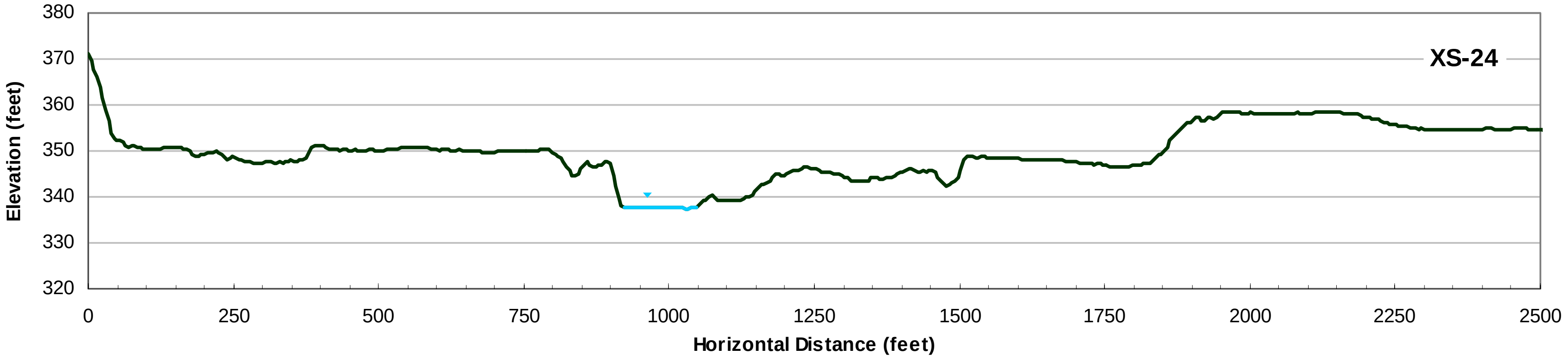
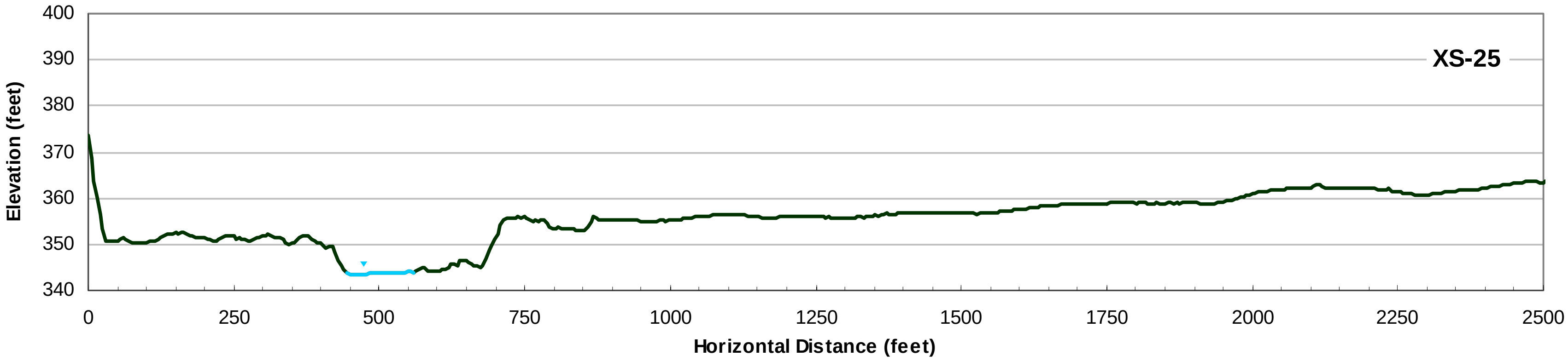
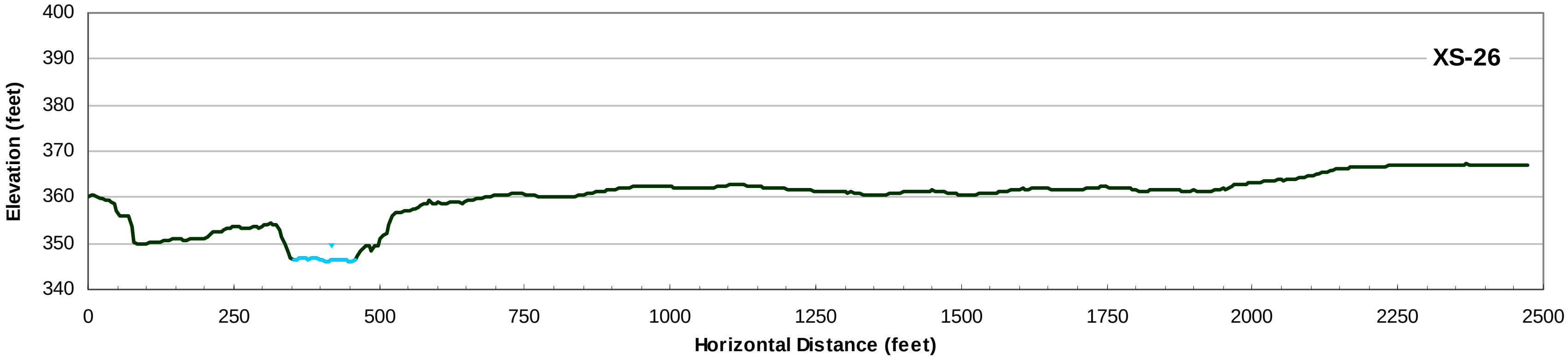
500
750
1000
1250
1500
1750
2000
2250
2500

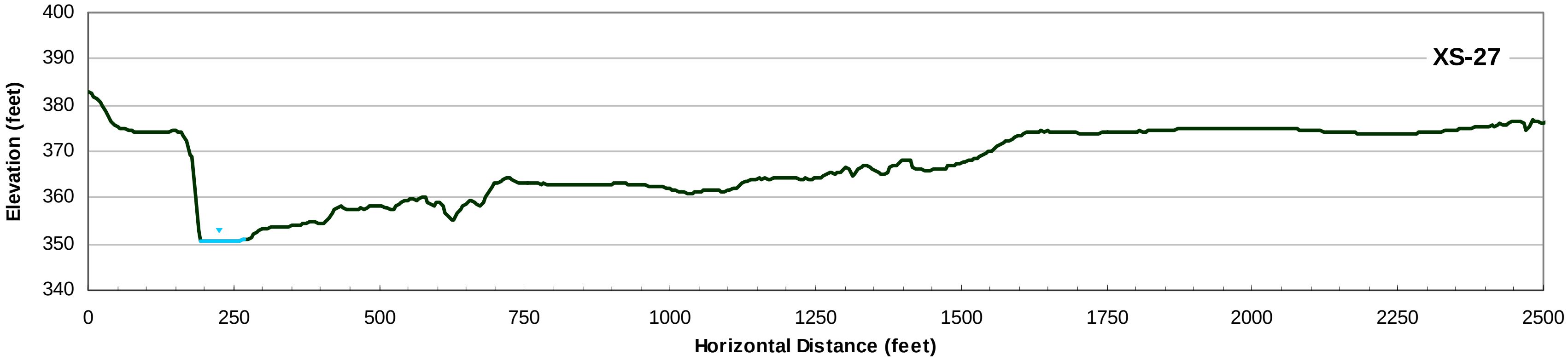

XS-22
Elevation (feet)
380
370
360
350
340
330
320
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)

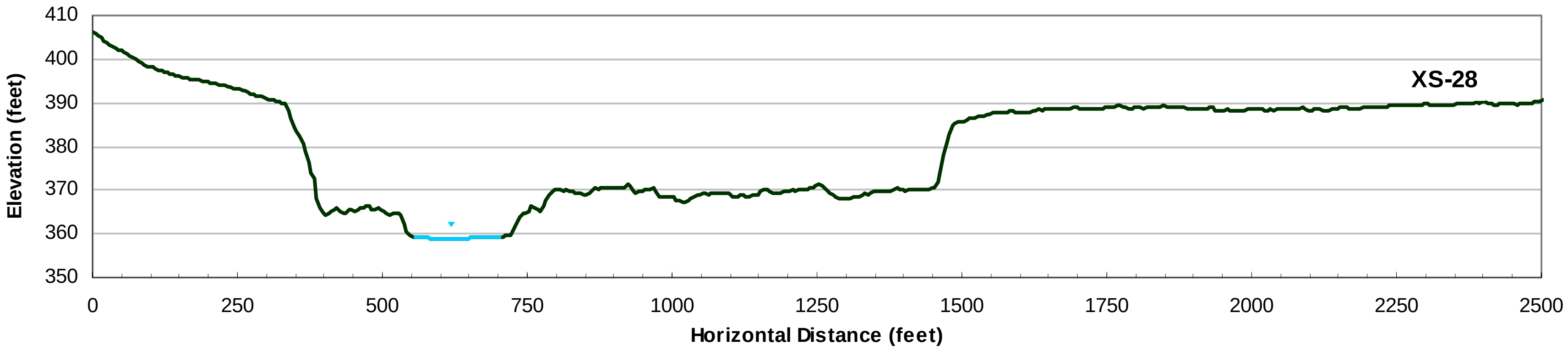

XS-23
Elevation (feet)
380
370
360
350
340
330
320
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)

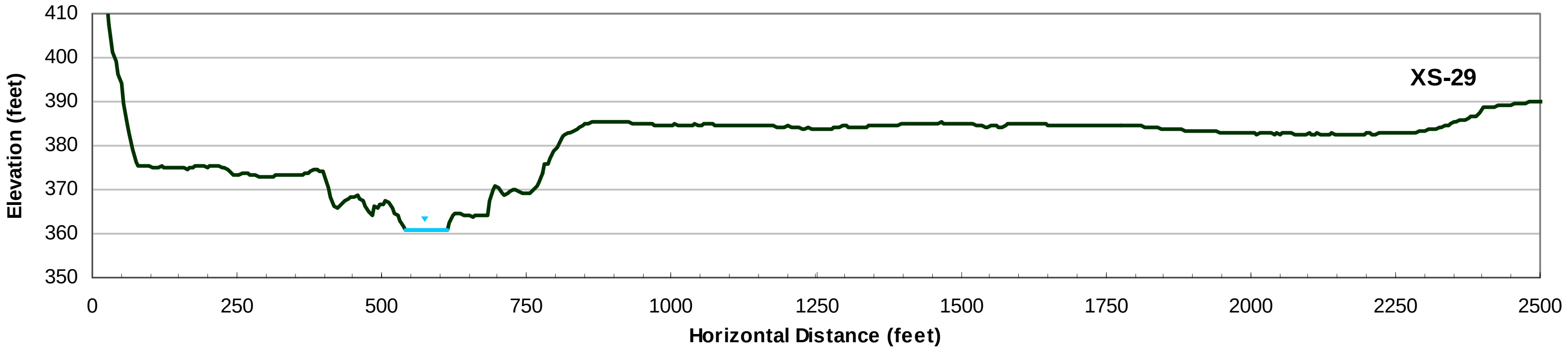

XS-24
Elevation (feet)
380
370
360
350
340
330
320
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)

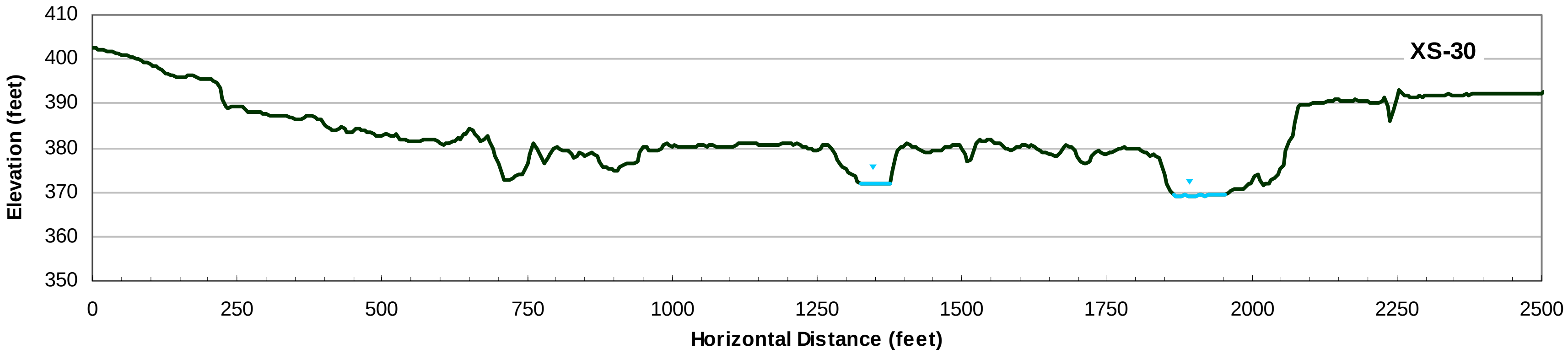

XS-25
Elevation (feet)
400
390
380
370
360
350
340
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-26
Elevation (feet)
400
390
380
370
360
350
340
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-27
Elevation (feet)
400
390
380
370
360
350
340
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-28
Elevation (feet)
410
400
390
380
370
360
350
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-29
Elevation (feet)
410
400
390
380
370
360
350
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-30
Elevation (feet)
410
400
390
380
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360
350
0
250
500
750
1000
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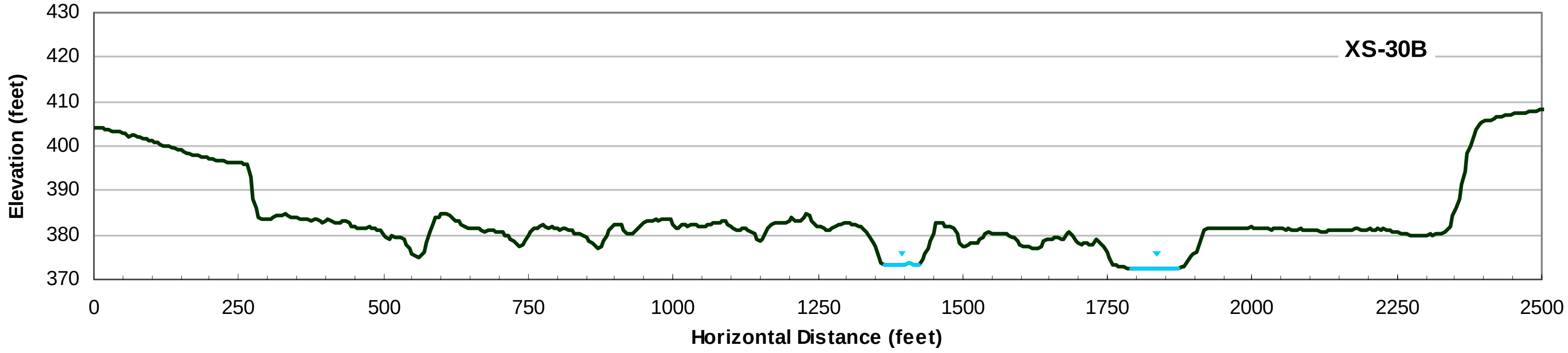
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-30B
Elevation (feet)
430
420
410
400
390
380
370
0
250
500
750
1000
1250
1500
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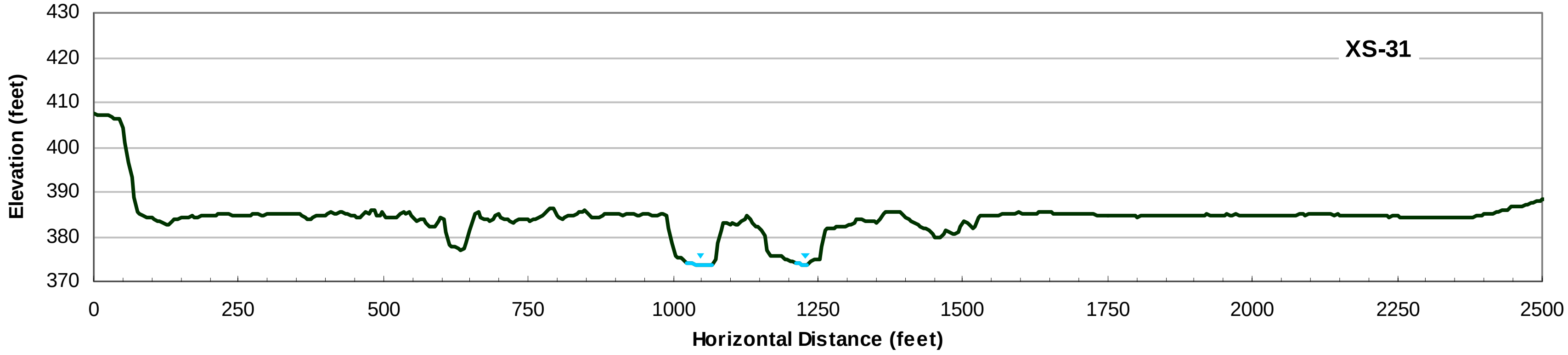
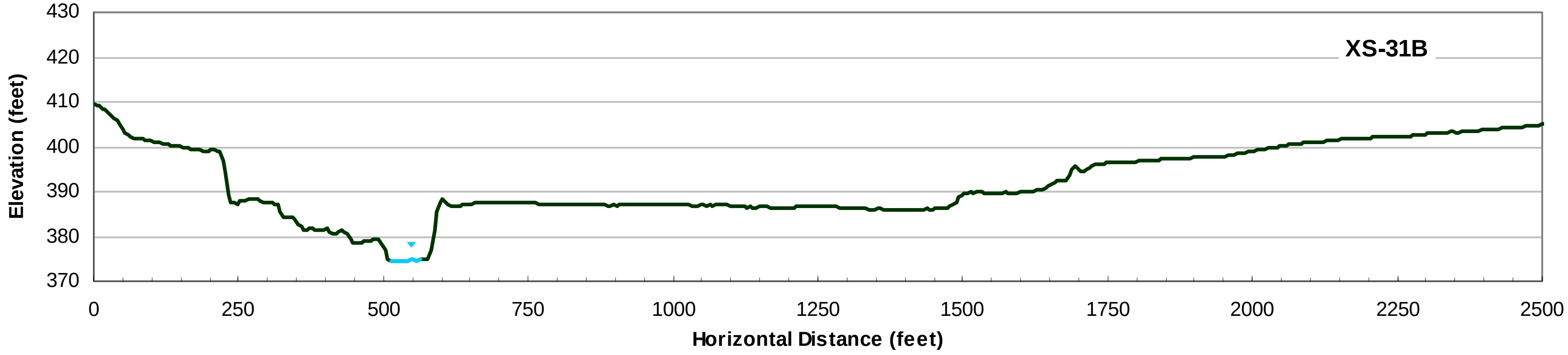
2000
2250
2500
Horizontal Distance (feet)


XS-31
Elevation (feet)
430
420
410
400
390
380
370
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-31B
Elevation (feet)
430
420
410
400
390
380
370
0
250
500
750
1000
1250
1500
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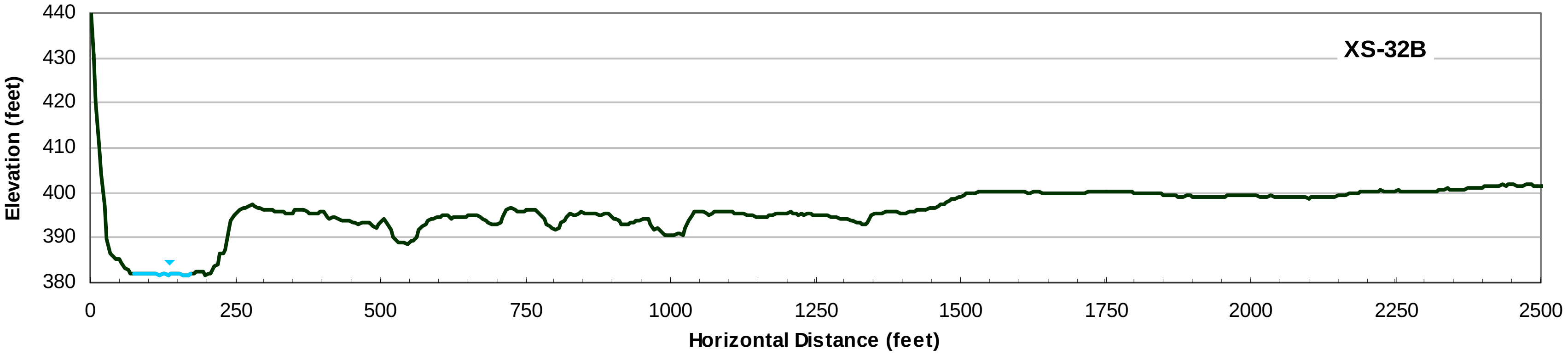
2000
2250
2500
Horizontal Distance (feet)


XS-32B
Elevation (feet)
440
430
420
410
400
390
380
0
250
500
750
1000
1250
1500
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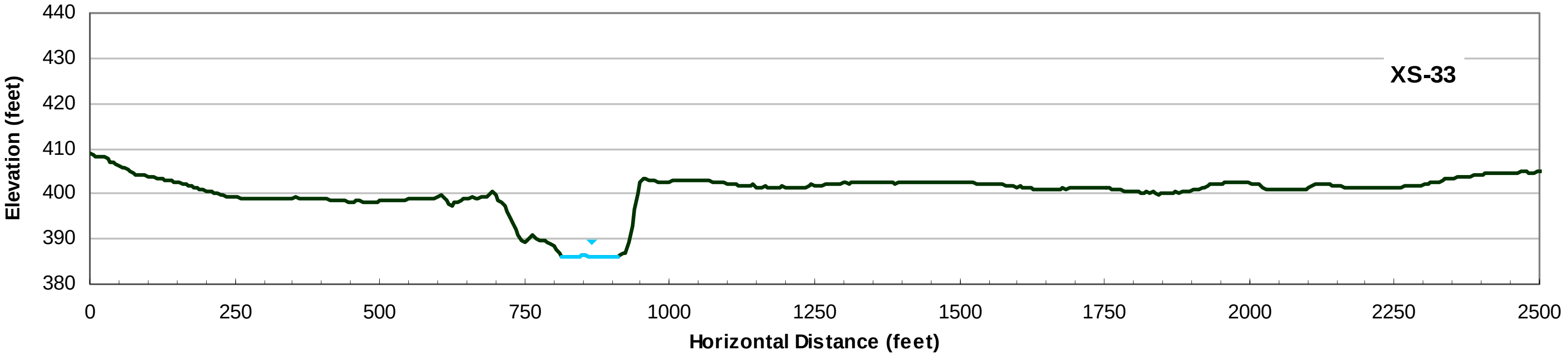
2000
2250
2500
Horizontal Distance (feet)


XS-33
Elevation (feet)
440
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380
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750
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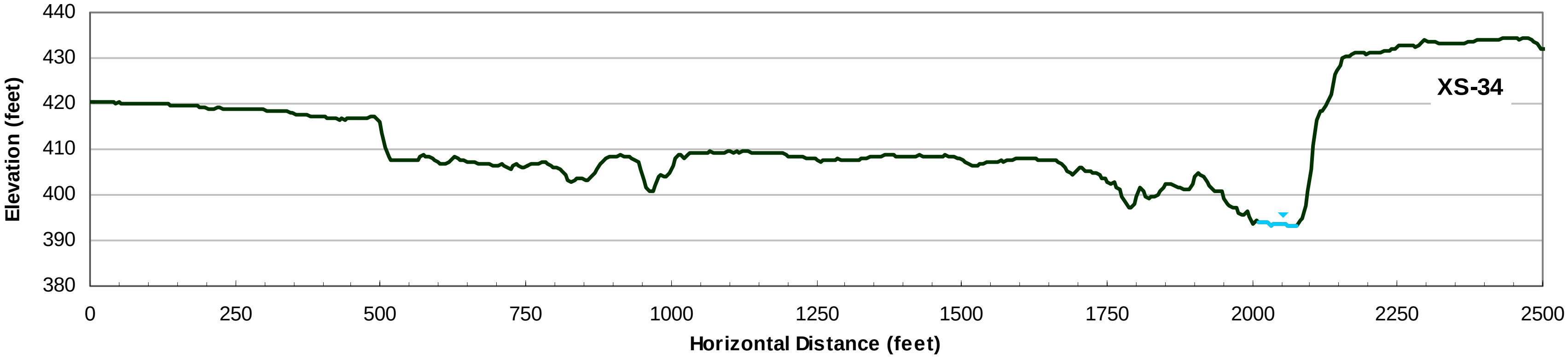
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-34
Elevation (feet)
440
430
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410
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390
380
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500
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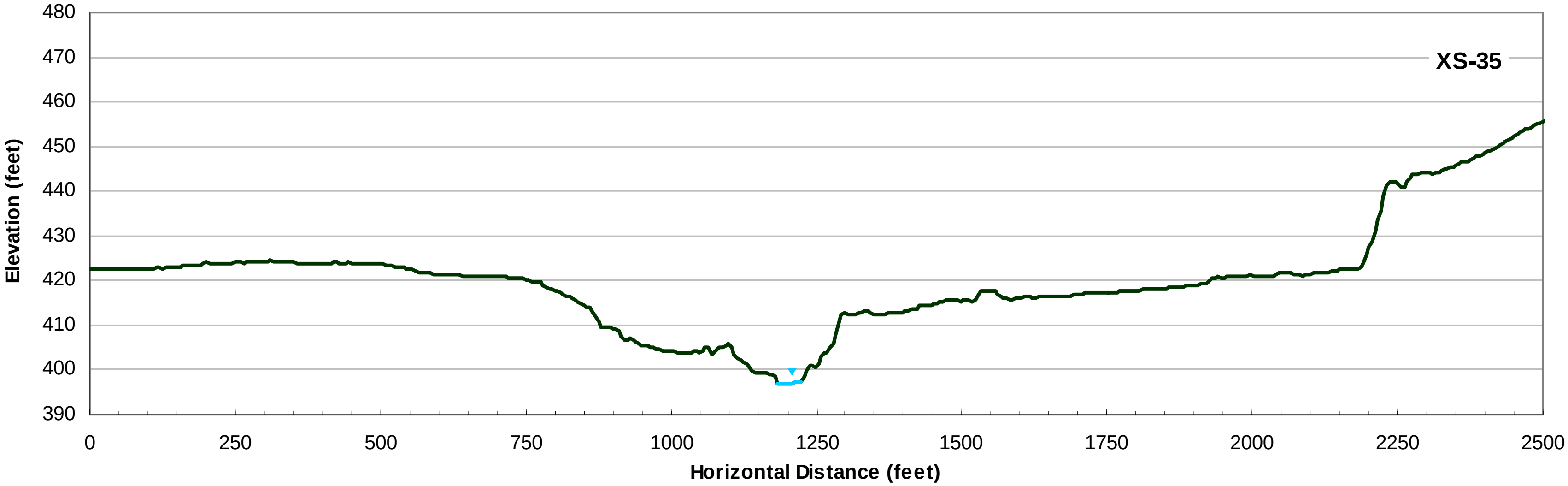
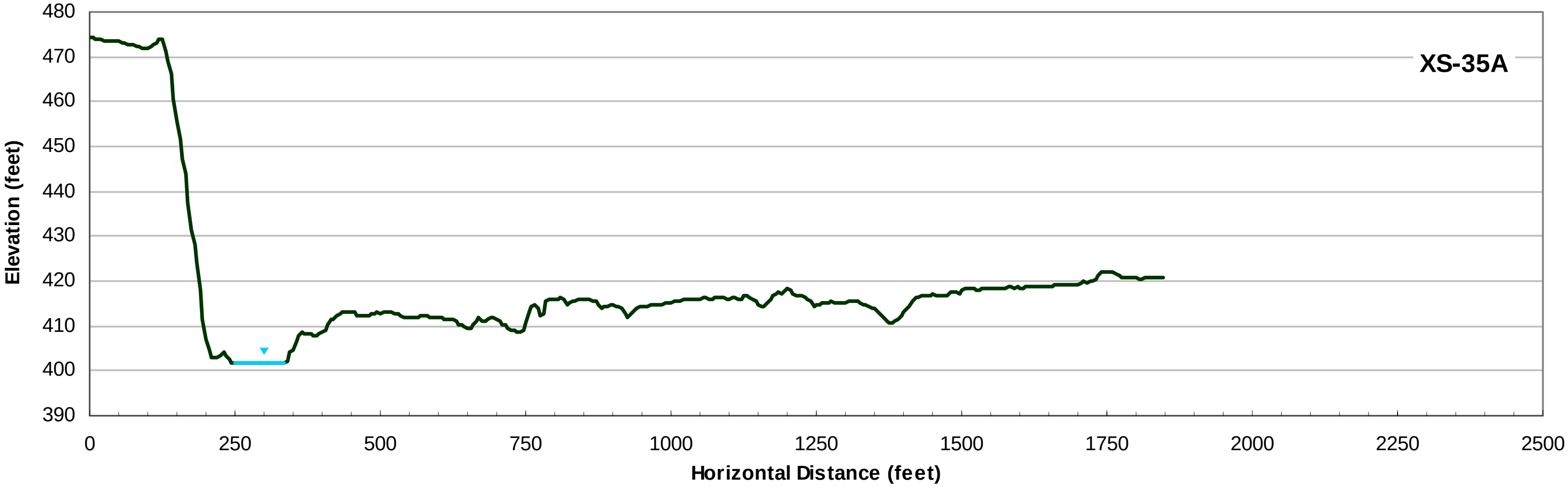
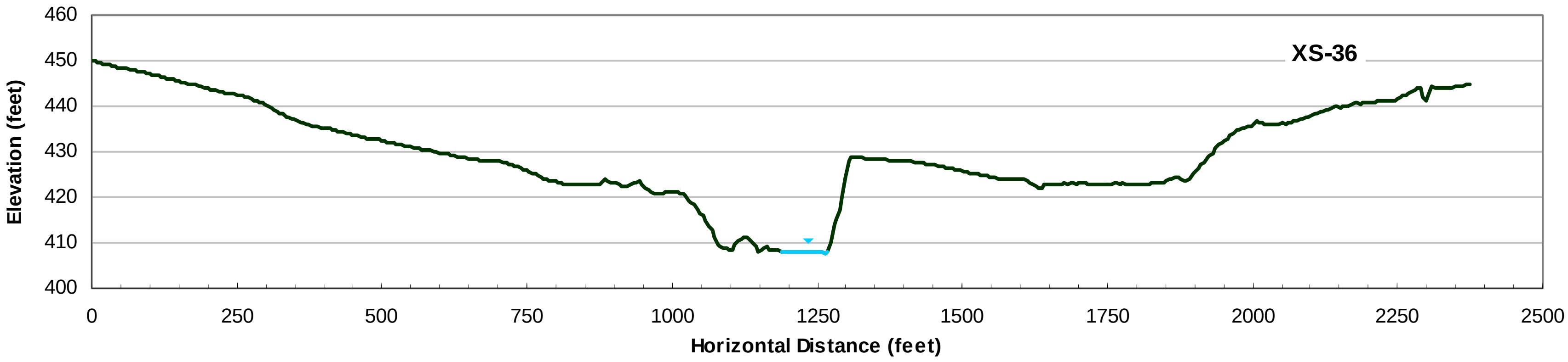
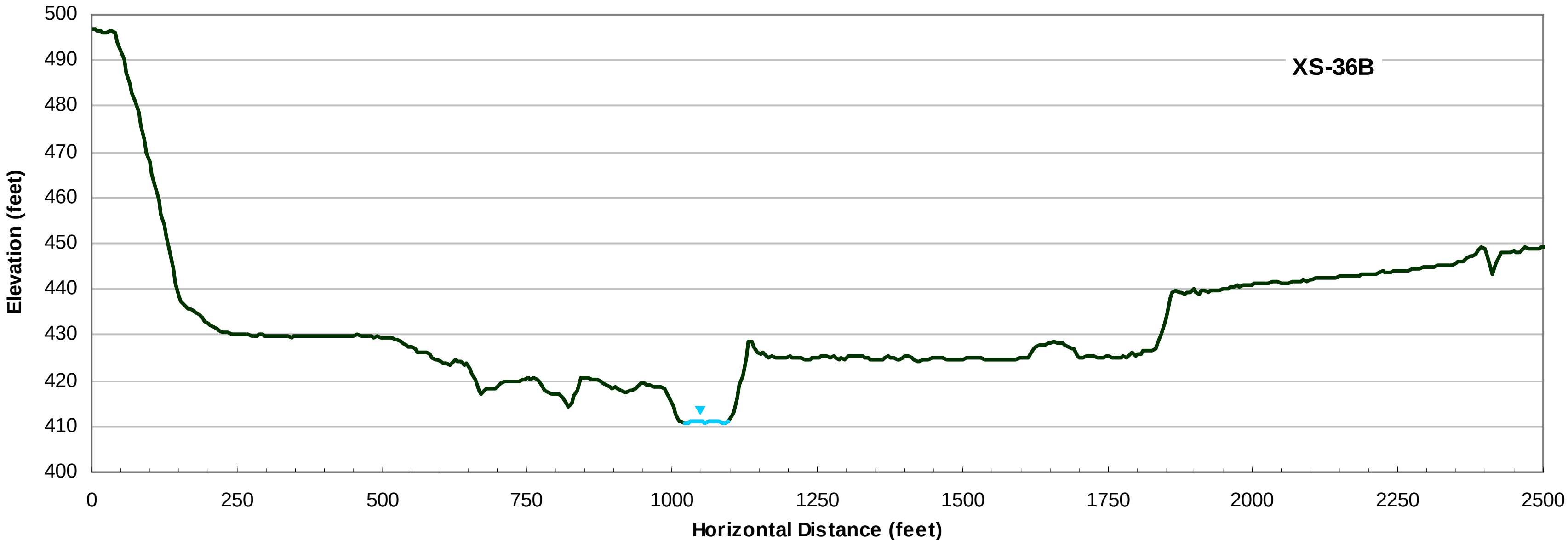
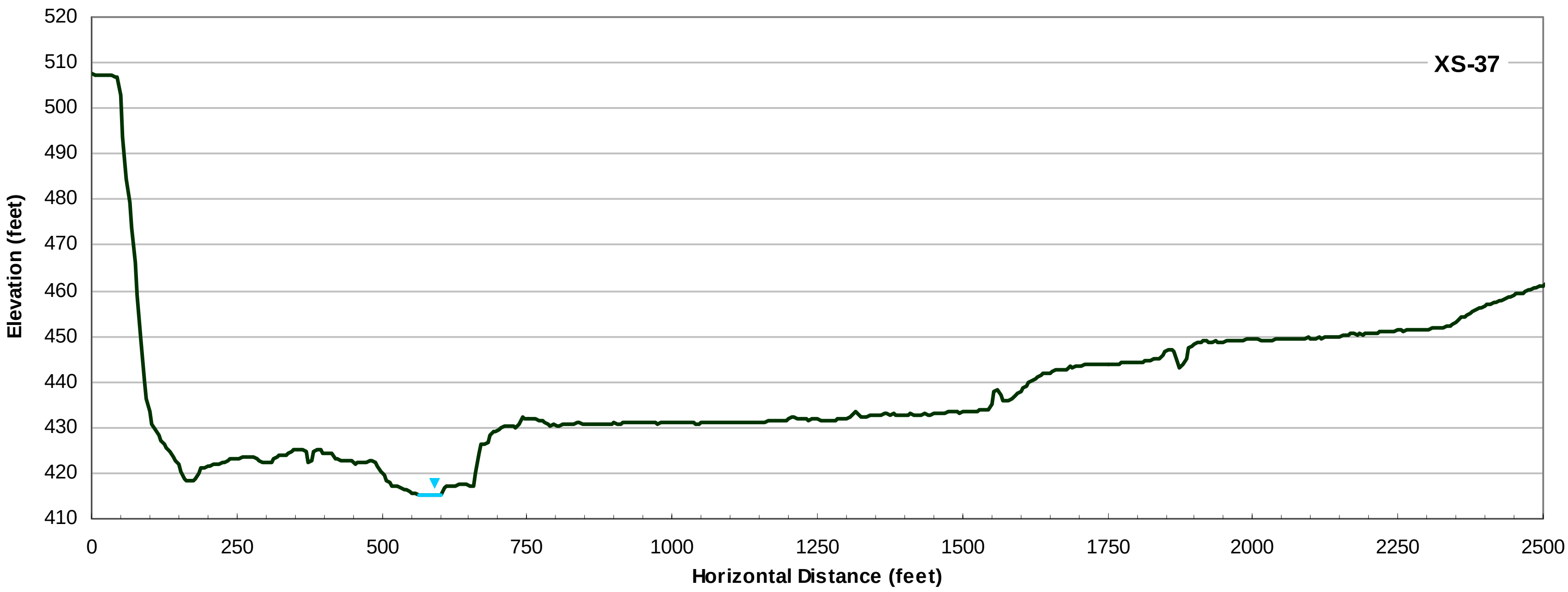
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)

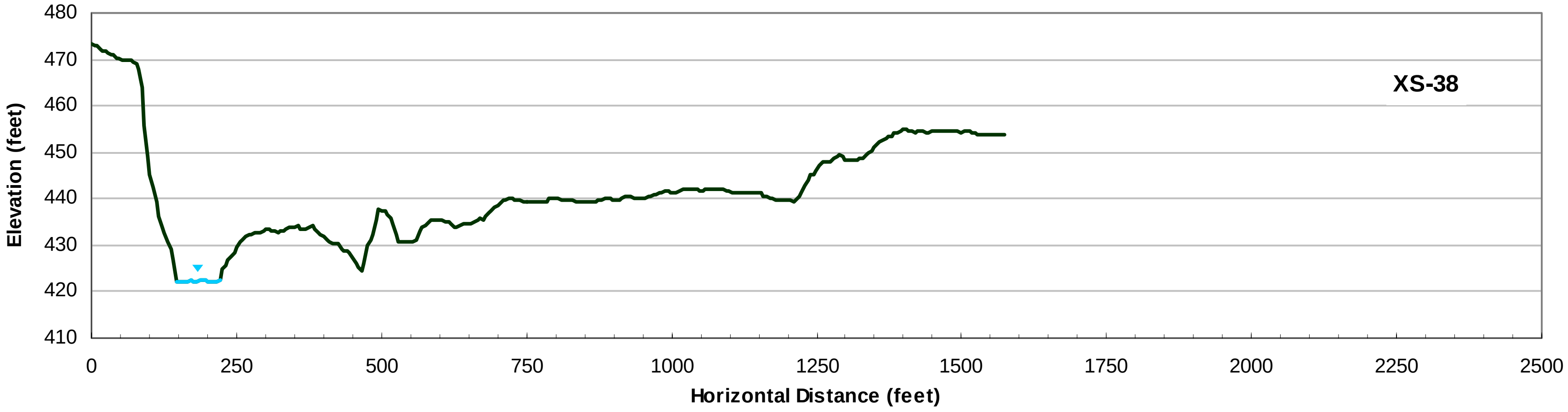

XS-35
Elevation (feet)
480
470
460
450
440
430
420
410
400
390
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)

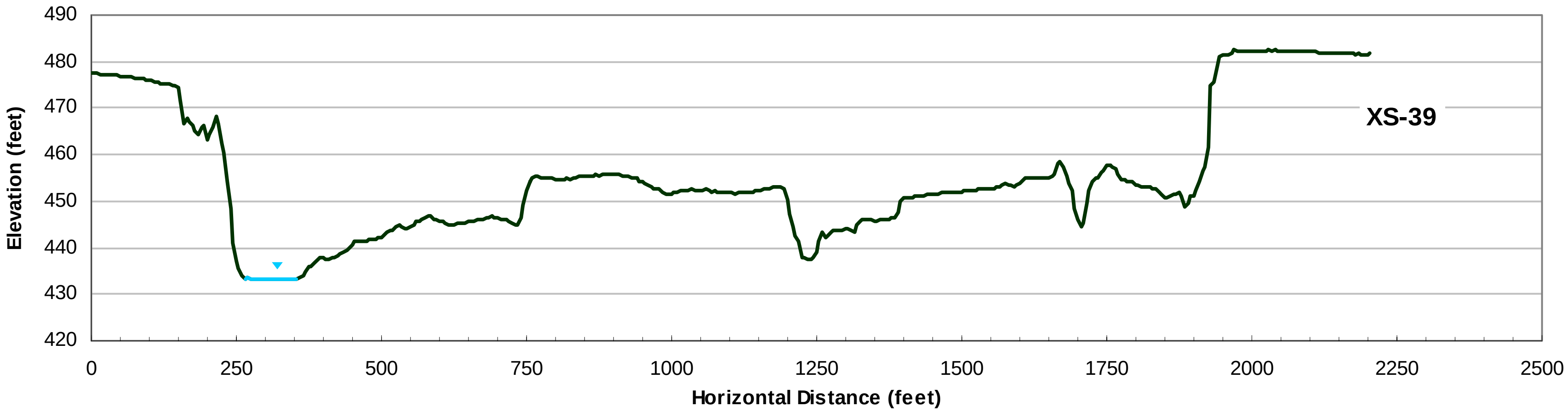

XS-35A
Elevation (feet)
480
470
460
450
440
430
420
410
400
390
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-36
Elevation (feet)
460
450
440
430
420
410
400
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-36B
Elevation (feet)
500
490
480
470
460
450
440
430
420
410
400
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-37
Elevation (feet)
520
510
500
490
480
470
460
450
440
430
420
410
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)


XS-38
Elevation (feet)
480
470
460
450
440
430
420
410
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)



490
480
470
460
450
440
430
420
Elevation (feet)
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
Horizontal Distance (feet)
XS-39