STREAM MIGRATION AND SEDIMENT MOVEMENT ON LOWER CACHE CREEK FROM CAPAY DAM TO INTERSTATE 5 AT YOLO, CA

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STREAM MIGRATION AND SEDIMENT MOVEMENT ON LOWER CACHE CREEK FROM CAPAY DAM TO INTERSTATE 5 AT YOLO, CA

A Thesis

by

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Abstract

of

STREAM MIGRATION AND SEDIMENT MOVEMENT ON LOWER CACHE CREEK FROM CAPAY DAM TO INTERSTATE 5 AT YOLO, CA

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The geomorphology of waterways like Cache Creek has been modified not only by natural flooding events, but also by human activity. Aggregate mining, agriculture and infrastructure have been linked to changes in geomorphology on Cache Creek. Erosion issues were recognized on Cache Creek during the 1970's and mining practices on Cache Creek were subject to intense scrutiny. This study analyzes the historical datasets to determine trends in aggradation and degradation of sediment on Lower Cache Creek, and lateral and vertical channel movements related to high flow events and projects performed on the creek.

The Technical Studies and Recommendations of the Lower Cache Creek Resources Management Plan (CCRMP) is a guide for managing the natural resources on Lower Cache Creek and requires regular geologic, hydrologic, and biologic analysis. Previous studies, aerial images, maps, digital data (AutoCAD, ArcGIS), and historical information were acquired from Yolo County Department of Parks and Resources (DPR), Yolo County Archives, Yolo County Flood Control and Water Conservation District

(YCFCWCD), University of California at Davis Map Library, consulting firms, and private personal book collections to map changes in Cache Creek.

Results show that since the 1995 Technical Studies and Recommendations of the Lower Cache Creek Resources Management Plan was completed, the longitudinal profile of the streambed has risen significantly in two distinct areas within the Cache Creek channel, and six of the seven reaches of the channel have narrowed. These trends are decreasing the flood conveyance capacity of Lower Cache Creek. A comprehensive hydraulic analysis is critical to determine the current flood conveyance capacity of Cache Creek.

_______________________, Committee Chair
Timothy Horner

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Date

Dedication

This thesis is dedicated to my wonderful husband, Craig Leathers, and in loving memory of my father, Dale Carson Ansley.

Acknowledgements

I would like to thank Kent Reeves and Yolo County's Department of Parks and Resources for employing me to work on this thesis. Without that financial support, this thesis may not have been possible to complete. Advising from Dr. Timothy Horner, Dr. Kevin Cornwell, and Dr. David Evans was critical in guiding me through this endeavor. I am grateful to Marcus Neuvert for his GIS expertise and never ending patience. A special thanks goes out to Laura Liddicoet who acted as editor-in-chief during my writing process. My irreplaceable friendships with Lisa and Kenny Calhoun, Emily Anderson, Lisa McClish, and Anne Abele are what kept me going through the long days of research and writing. I would like to thank my family, especially my husband, Craig Leathers for their boundless encouragement and support during graduate school.

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INTRODUCTION

1.1 - The Study

For over one hundred years, Cache Creek has provided water to farms and residents of Yolo County. The creek has also provided a large source of high quality aggregate used for construction in Northern California. The need for these precious natural resources has given rise to a long and turbulent political history in Yolo County.

Cache Creek can be a gentle, serene stream at one moment and a wild torrent the next. This intermittent surge in stream power is the reason high quality agricultural lands, high quality construction aggregate, and diverse riparian habitat exists in Yolo County. Geomorphologic changes on all creeks, streams and rivers occur naturally over geologic time. However in the case of Lower Cache Creek, has this natural process been altered due to human influences? And if so, what are the effects of that interference?

Geological and structural landforms of the Coast Ranges control the orientation of streams and rivers in Northern California. Sediments in the Sacramento Valley are derived from weathering of the Coast Ranges (Harden, 2004). Water and aggregates found in and along the streams and rivers of the Coast Ranges are important resources to all residing in the area. Water is used to produce agricultural crops and high quality aggregate is used for construction of roads and buildings.

The geomorphology of waterways like Cache Creek has been modified not only by natural flooding events, but also by human activity. Dams and irrigation canals were constructed on Cache Creek in the late 1800's to deliver water to farms (Gilbert, 1879 and Russell, 1940). Aggregate from the creek was extracted as early as 1906 to aid in the reconstruction of San Francisco after the great earthquake and fire (NHC, 1995). In-channel aggregate mining continued on Cache Creek until 1996, while only off-channel mining continues today.

Aggregate mining has been linked to changes in geomorphology on the Russian River and may have similarly impacted geomorphology on Cache Creek. A study conducted in the late 1970's determined that in-channel aggregate mining was causing the Russian River to undergo significant incision and knick-point migration along the channel profile. River migration also resulted in the erosion of approximately seventy acres of prime farmland along the Russian River (Shuirman and Slossen, 1992).

Erosion issues were also recognized on Cache Creek during the 1970's and mining practices were subject to intense scrutiny. Nearly twenty years of heated political debate regarding mining on Cache Creek followed. On August 20, 1996, the Yolo County Board of Supervisors adopted the Cache Creek Resources Management Plan (CCRMP), a document that essentially ended the "gravel wars", although debate still occurs. This resources management plan recognizes that Cache Creek is a dynamic stream system that naturally undergoes gradual and sometimes sudden changes during high flow events (CCRMP - Goal 2.2-1). Elements compiled in the CCRMP include floodway and channel stability, water resources, biological resources, open space and recreation, aggregate resources, and agricultural elements.

1.2 – Purpose

The purpose of this thesis project is to evaluate channel position and gravel mobility on Cache Creek. This study is located is in the lower section of Cache Creek from the Capay Dam to Interstate 5 (Figure 1.1).

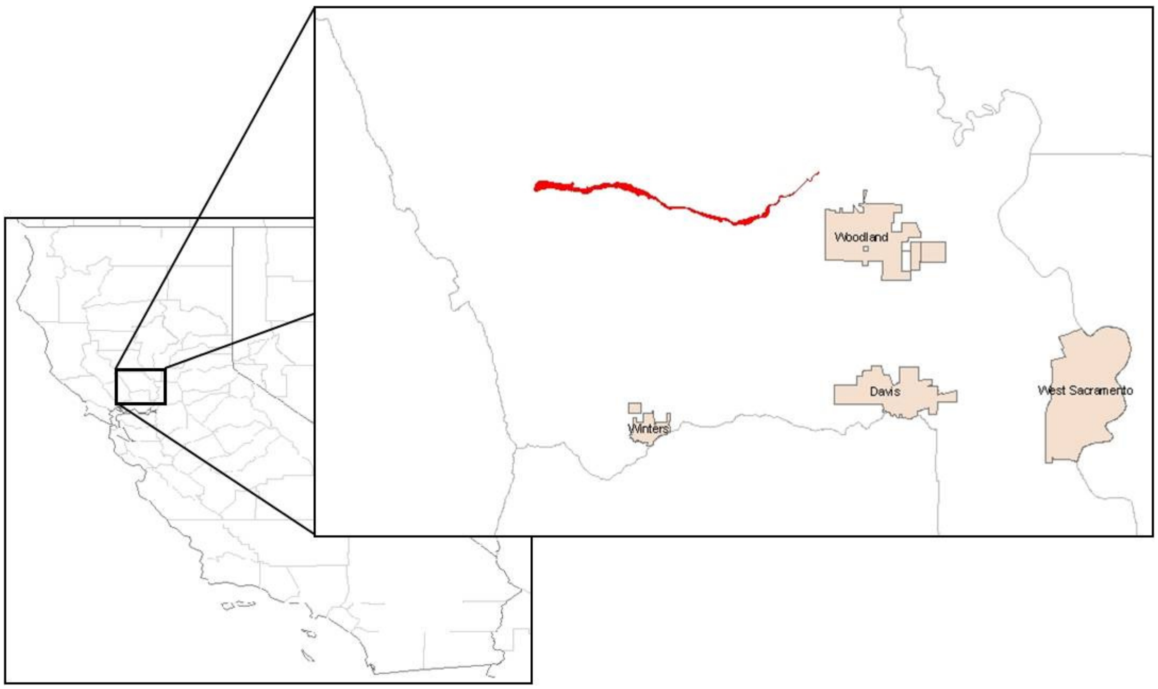

Figure 1.1 Study Area Cache Creek CA Capay Dam to Interstate 5 Overcrossing

This thesis will evaluate the floodway, channel stability, and aggregate resources of Cache Creek from 1937 to present, using a variety of Geographic Information System (GIS) and mapping tools. The information obtained from this study will be available for the Yolo County Department of Parks and Resources for adaptive management decisions on Cache Creek pertaining to the Cache Creek Resources Management Plan (CCRMP). This project will provide information outlined in the CCRMP as noted below.

- Acknowledge the streamway influence boundary described in the Technical Studies as the general area of the creek which has historically been subject to meandering. The streamway influence boundary also defines the area where in-stream and off-channel issues overlap and are address in both plans (CCRMP - Floodway and Channel Stability Element Action 2.4).
- The County shall manage collection of the information necessary to make informed decisions about the management of Cache Creek, including: regular water and sediment discharge data at Capay and Yolo gauge sites, water and sediment discharge data at other sites during high flow events, and topographic data showing the erosion, aggradation, and the alignment of the low-flow channel within the creek. This data should be maintained in the County Geographic Information System so that staff can the Technical Advisory Committee can coordinate this information with the results of other monitoring programs to develop a comprehensive and integrated approach to resource management. Monitoring may, at the discretion of the County, be conducted by either consultants or trained volunteers, including landowners, public interest groups, the aggregate industry, and students, as a part of future public education programs associated with Cache Creek. However, the County shall maintain responsibility for the collection of high quality data (CCRMP - Floodway and Channel Stability Element Action 2.4-10).

Maps and other data compiled in this study may be posted electronically by Yolo County for public use and education purposes. The CCRMP, the 1995 Technical Studies and Recommendations for the Lower Cache Creek Resources Management Plan, and on-going work have outlined areas where updated knowledge of channel dynamics and sedimentation patterns on Cache Creek are needed.

This project will analyze temporal and spatial changes in the channel system using modern and historical datasets, and will address the Floodway and Channel Stability Element of the CCRMP. Analyses will include channel incision patterns, temporal changes in channel position, identifying and quantifying areas of sediment aggradation and degradation.

The following questions pertaining to channel mobility will be the main focus of this research.

- Has there been a net aggradation of sediment on Lower Cache Creek since in-channel aggregate mining was stopped in 1996?
- How has aggradation and degradation affected lateral and vertical creek movement?
- How have creek projects (bridge construction and bank stabilization) and high flow events affected incision and migration of the creek channel?
- Have there been interactions between projects performed on the creek and aggradation and degradation?

1.3 - Previous Work

Several documents have been produced to manage natural resources on Cache Creek. The Cache Creek Area Plan (CCAP) is a document that encompasses the Cache Creek Resources Management Plan (CCRMP) and the Off-Channel Mining Plan (OCMP). The CCRMP is based on the Technical Studies and Recommendations of the Lower Cache Creek Resources Management Plan conducted by Northwest Hydraulic Consultants (NHC), David Keith Todd, Consulting Engineers, and EIP Associates in 1995.

The Technical Studies and Recommendations of the Lower Cache Creek Resources Management Plan is a comprehensive study on Cache Creek and was conducted to evaluate, review, and understand the following:

- All existing relevant data on Cache Creek;
- Historic conditions on and adjacent to the creek;
- Changes in the nature of the creek and its resources over time and why those changes occurred, and;
- Interrelationships between the streamway morphology, and riparian habitat characteristics of Cache Creek and how conditions are likely to change in the future under various approaches to resource management.

The CCAP was completed in 1996 and the Yolo County Board of Supervisors adopted the CCRMP and OCMP in the same year. The CCRMP furnishes the management structure for restoration on Cache Creek between the Capay Dam and I-5 Bridge. It includes definitive implementation requirements and the Cache Creek

Improvement Program (CCIP). The CCIP is the implementation policy for the CCRMP that identifies areas of distinct restoration and conservation projects along an explicitly defined stretch of Cache Creek. Two ordinances fall under the OCMP, which regulates current mining along Cache Creek. These two ordinances regulate off-channel mining and reclamation of previously mined areas on the creek.

The research performed in 1995 was the foundation for the policies developed to manage the lower Cache Creek area defined in the CCRMP. With these documents and ordinances, significant amounts of data were collected for analysis. Work in this study will be the first analysis of geomorphology on the lower Cache Creek area since 1995 and will build on the Technical Studies and Recommendations of the Lower Cache Creek Resources Management Plan by using modern GIS and landform analysis techniques.

1.4 - Settlement in Yolo County

Anthropologists as far back as 3000 years ago have recorded human activity in Yolo County. Remains of these ancient humans were separated into three distinct categories based on age and physical description of the remains. The three pre-history categories were described as Early Culture, Transitional Culture, and Late Culture (Russell, 1940).

Modern history of Yolo County and Cache Creek begins with the Spanish Conquistador exploration of California in the early 19th Century. The first expedition north of San Francisco was recorded as “Arguello’s expedition to the Columbia” which began on October 18th 1821. From translations of the original diary kept of this exploration, Rancheria's were discovered and established October 23rd and 24th, 1821 in the area near the present day town of Winters and along Cache Creek (Russell, 1940).

An enormous amount of change occurred in the western part of North America in the period spanning from 1820 to 1848. The Spanish abdicated control of the area known as California to Mexico (Russell, 1940), the first white settlers began to arrive, and the Mexican Government sold Rancheros in Yolo County. Also, the first irrigation of agricultural lands began on Cache Creek (Russell, 1940), the Mexican-American War began and ended with the acquisition of Texas, California, and New Mexico by the United States (http://www.lone-star.net/mall/texasinfo/mexicow.htm), and gold was discovered by James W. Marshall on January 19th, 1848 (Russell, 1940).

Following the discovery of gold in California in 1849, the population of California increased dramatically and by 1864, the Gold Rush had ended (http://ceres.ca.gov/ceres/calweb/geology/goldrush.html). On September 9, 1850, California was admitted as the 31st state in the Union. The organization of Yolo County took approximately three years spanning 1850-1853 (Russell, 1940).

1.5 - Human Impact on Cache Creek

1.5.1 - Agriculture and Water

Even before California was admitted into the Union, settlers along Cache Creek realized water was the key to successful agriculture. Russell wrote, "all realized that unless it (water) was made to serve the whole people at the lowest possible cost, grazing was the only use to which the land could profitably be put and that not for long" (Russell,

Figure 1.2 Row Crop in Yolo County c. 1910 (http://www.sacramentohistory.org)

Figure 1.3 Irrigation Canal c. 1910 (http://www.sacramentohistory.org)

1940, p. 71). This realization sparked farmers like James Moore to develop ways to transport water to lands for irrigating crops such as alfalfa, sugar beets, and clover (Figure 1.2). Moore, in 1855 "began negotiations to secure riparian rights to the water of Cache Creek" (Russell, 1940, p. 72), and in 1856 the construction of the Moore Ditch was started. Many other claims for water soon followed. Ditches were extended and paid for by private landowners (Figure 1.3). Because competition for water was fierce, lawsuits were filed. Heated legal disputes continued for nearly 30 years, until the Wright Act was passed in 1887. This legislation granted the formation of publicly owned irrigation districts (http://www.usbr.gov/history/cvpintro.html). Prior to the passage of the Wright Act, R.B. Blowers developed the first well in Yolo County. The invention of the submersible centrifugal pump by Byron Jackson in Woodland CA (http://www.bjservices.com/website/index.nsf/WebPages/History-Origins?OpenDocument) made extracting ground water from wells easy (NHC, 1995) (Figure 1.4). This new development produced reliable high quality water for irrigation without relying on the sporadic availability of surface water in Cache Creek (Russell, 1940).

Agriculture became more lucrative and consistent than gold mining in the mid 1800's. As this trend continued, more and more people flocked to the Yolo County region. It was during this time when reclamation of swamplands began. As early as 1852, Josiah Greene built the first levee to protect his farmland from floodwaters (Russell, 1940). With the passage of the Wright Act, swamplands (tule marshes) were divided into reclamation districts, the water was drained, and levees were built to open up more land for farming (Figure 1.5).

Figure 1.4 Byron Jackson's Centrifugal Deep Water Pump c. 1901 (Yolo County Archives)

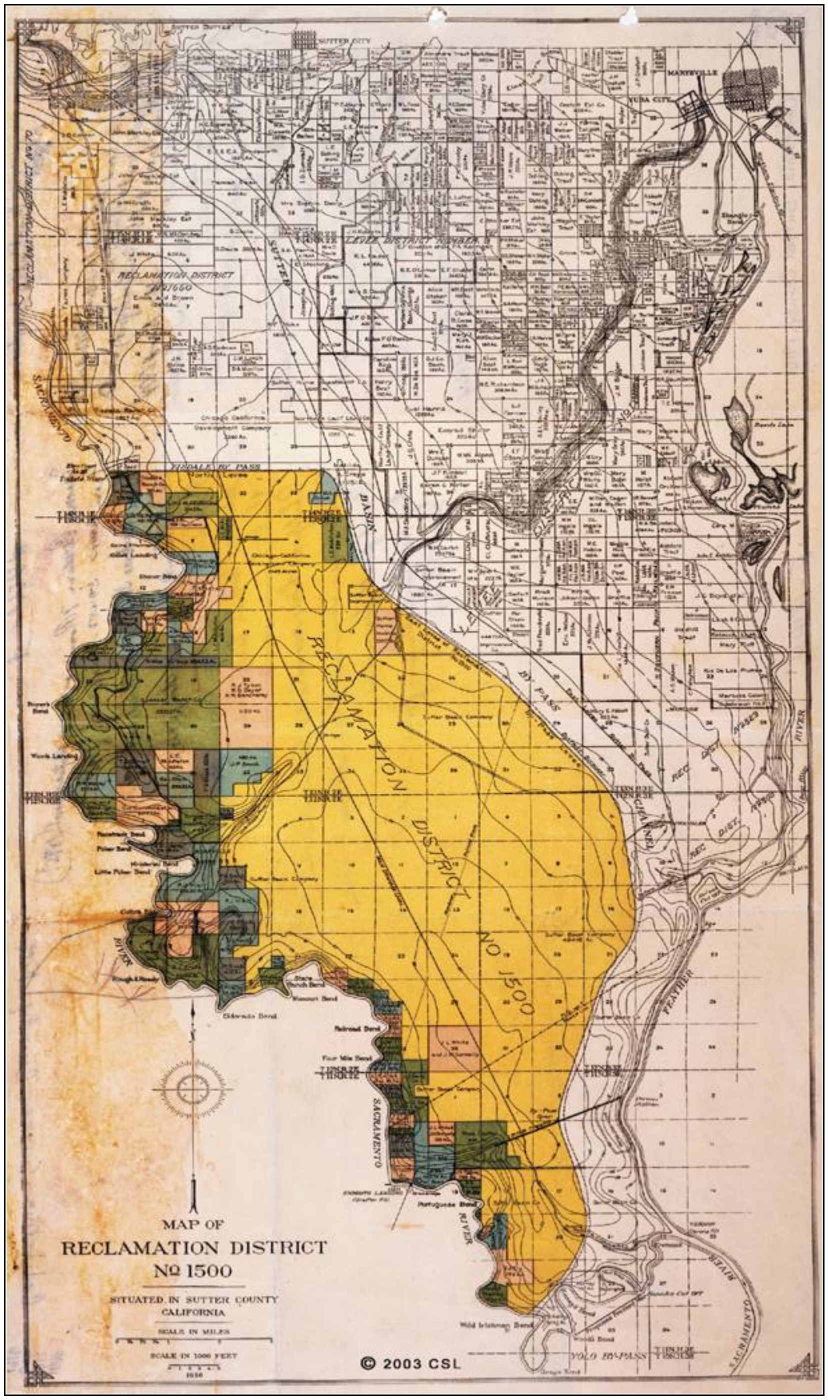

Figure 1.5 Example of Reclamation District Map (District 1500)
(http://www.sacramentohistory.org)

This practice continued well into the early 1900's and in 1911, the California Legislature formed the Sacramento and San Joaquin Drainage Districts overseen by the Reclamation Board. It was deemed necessary to create a bypass system along the Sacramento River to convey naturally occurring floodwaters adjacent the river (Figure 1.6).

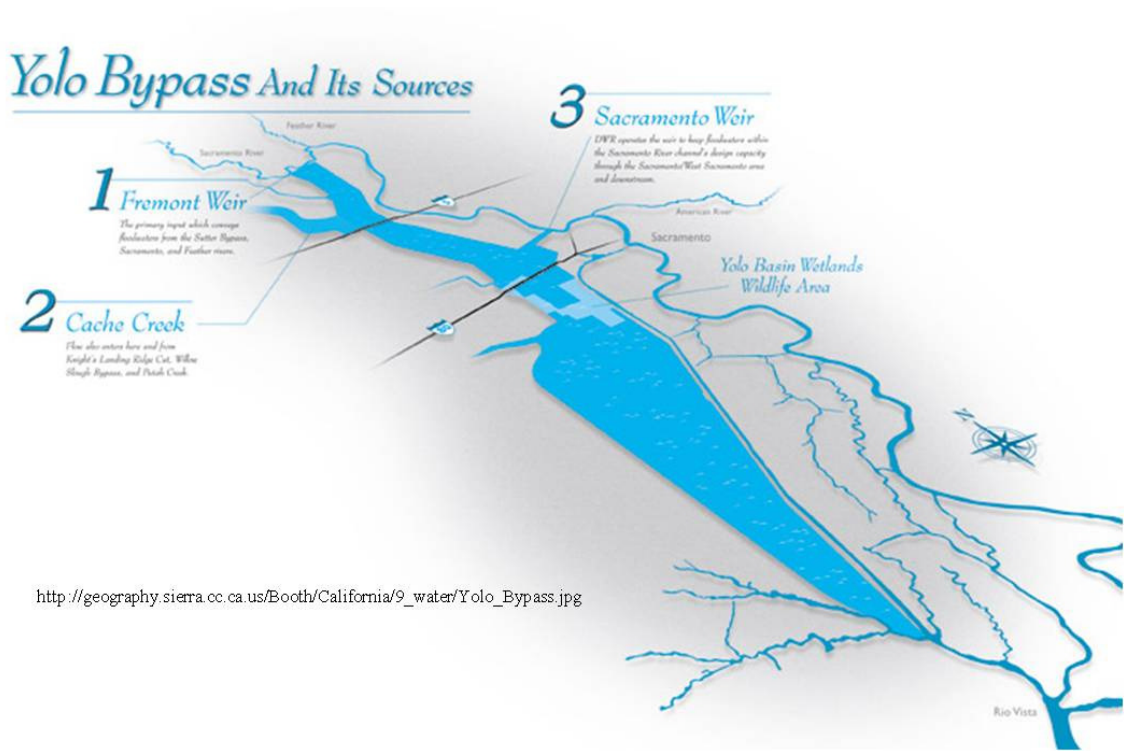

Figure 1.6 Yolo Bypass System

This provided flood safety to local communities and maintained the reclaimed farmland. Of the four weirs constructed to alleviate pressure on the levees, two were placed in Yolo County (Russell, 1940). By 1940, the Yolo By-Pass had been completed from the Fremont Weir to the Southern Pacific Railroad Lines.

With settlement in Yolo County came a great deal of change regarding land and water use. Land adjacent to Cache Creek was quickly converted from riparian corridors and livestock grazing to farming crops requiring more water than nature could provide.

This need for water spurred the development of irrigation diversion ditches and establishment of ground water wells. The landscape of the Cache Creek area was forever changed.

Agriculture continued to flourish in Yolo County after the turn of the century and provided food and fodder for the war effort during World War I (NHC, 1995). This profitable industry continued to be quite successful until the stock market crash and subsequent depression hit the nation. To make matters worse, Yolo County and surrounding areas experienced drought conditions in the early 1930's (NHC, 1995), and the agriculture industry was severely affected economically.

As the nation pulled itself out of the depression and World War II geared up, Yolo County farmers and ranchers began to turn a significant profit (NHC, 1995). Increased production also occurred just after the war ended due to the development of large machinery capable of working large pieces of land previously too difficult to farm (NHC, 1995).

Figure 1.7 Photos Agricultural Machinery c. 1910 (top) and 1926 (bottom)
(http://www.sacramentohistory.org)

The value of agricultural commodities produced in Yolo County has steadily increased since the county started keeping records in the 1930's.

In 1937, Yolo County reported agriculture values at approximately $19 million. The 2008 agriculture crop report listed Yolo County commodities valued at $505,588,750 (http://www.yolocounty.org/Index.aspx?page=486). Some years have seen marked decreases in the value of agricultural commodities, but many of these decreases can be attributed to weather conditions (drought or flood years) and times of war.

1.5.2 - Aggregate Mining

Concrete is an intimate mixture of an aggregate, water, and Portland cement (http://www.webref.org/geology/c/concrete.htm). Sixty to seventy-five percent (60-75%) of concrete (http://www.cement.org/basics/concretebasics_aggregate.asp) is aggregate. This mineral resource is extracted from surface mines, commonly surrounding modern and ancient stream channels. Mineral resources were found and mapped along Cache Creek by the California Department of Conservation Division of Mines and Geology (Figure 1.8).

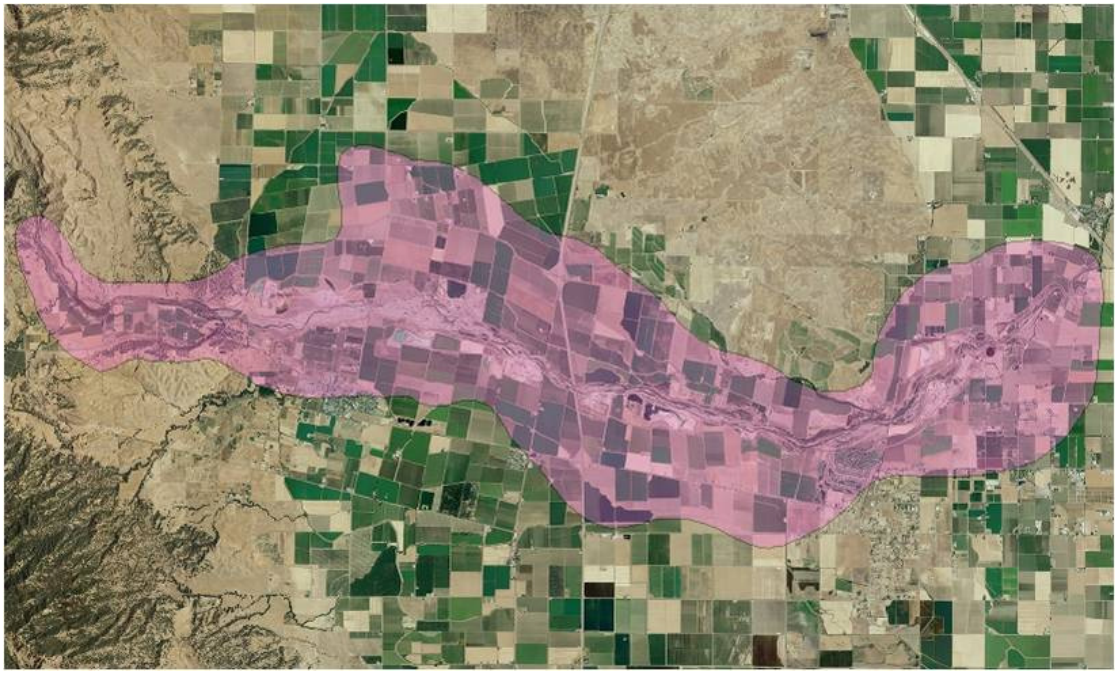

Figure 1.8 Cache Creek Mineral Resource Map

Aggregate mining on Cache Creek can be traced back to the turn of the 20th century. A minimal amount of aggregate was extracted from the creek as early as 1906 to aid in the reconstruction of San Francisco after the great earthquake and fire (NHC, 1995).

Limited aggregate mining continued on Cache Creek until the 1940's and 1950's. Following WWII, the Federal Highway Act of 1944 was passed designating a 40,000-mile (65,000-km) "National System of Interstate Highways", however little progress was made (http://www.tfhrc.gov/pubrds/06jan/01.htm). In 1956, President Dwight D. Eisenhower signed the Federal-Aid Highway Act of 1956, which authorized $25 billion to be spent creating the Interstate Highway System from 1957 to 1969 (http://www.ourdocuments.gov/doc.php?flash=true&doc=88). With the passage of this federal act, the need for aggregates soared, thus aggregate companies began extracting the high quality aggregates found in Cache Creek. At the time the easiest and most cost effective way to obtain the aggregate material was to mine the gravel directly from the creeks channel. Millions of tons of aggregate were mined within the channel from the early 1900's to 1996.

1.5.3 - Bridges

Bridges were built early in the history of Yolo County. Prior to 1937, five bridges were constructed across Cache Creek. These bridges include County Road (CR) 85, CR 87, CR 89, CR 94B, and CR 99W (Figure 1.9).

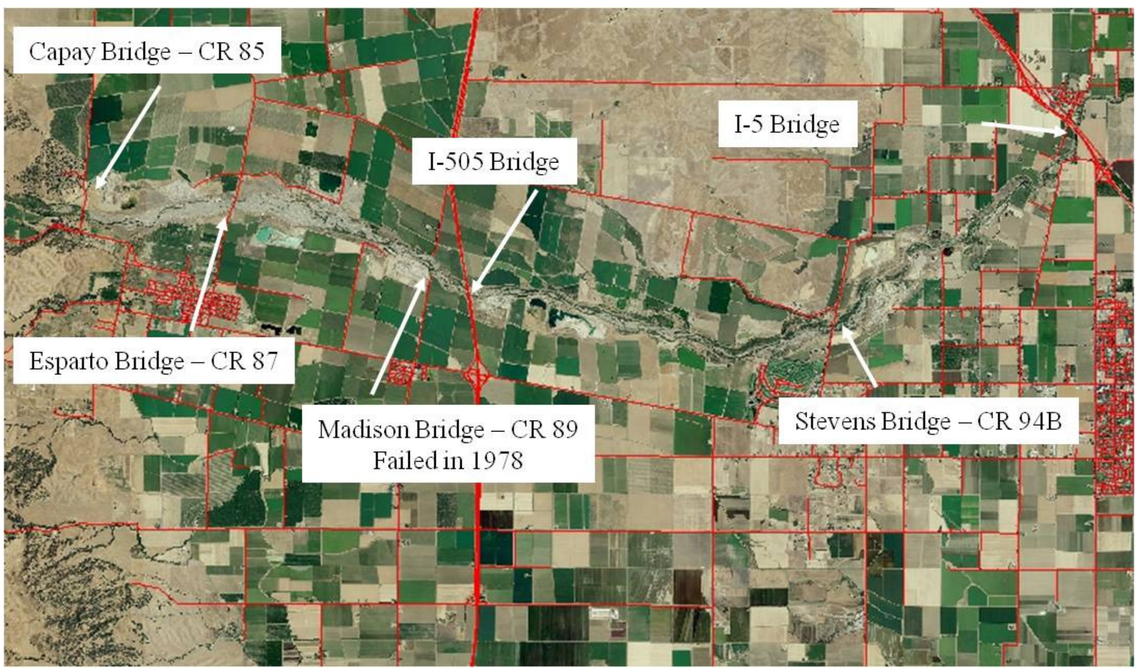

Figure 1.9 Bridges Crossing Cache Creek

These bridges were built to transport agricultural commodities easily across Yolo County. Bridges over Cache Creek were constructed along the narrowest sections of the channel and the natural creek channel was often narrowed significantly. All bridges listed above with the exception of CR 99W, effectively narrowed the Cache Creek Channel. With the construction of the Federal Highway System came a need to build additional bridges over Cache Creek. The new bridges were the I-505 Bridge near the town of Madison and the I-5 Bridge near the town of Yolo (Figure 1.9). More care was taken in the construction of these bridges; however, the I-505 Bridge design has a vane structure that redirects flow of water in Cache Creek. Due to the constriction of the channel, several bridges have been damage or destroyed over time. In 1940 and 1941, the CR 94B Bridge (Stevens Bridge) and the CR 85 Bridge (Capay Bridge) respectively were washed out by large flood events. Both bridges were reconstructed in 1947 (NHC, 1995). The CR 89 Bridge (Madison Bridge) collapsed in 1978 and was never replaced (NHC, 1995). Bridge abutments can still be seen today at this site (Figure 1.10).

Figure 1.10 Bridge Abutments CR 89 – 2006

Finally in 1995, the CR 85 Bridge was severely damaged (again) during a high flow event, and was repaired immediately following.

1.6 - Cache Creek Resources Management Plan (CCRMP)

In the early 1970's residents became increasingly concerned with channel incision and loss of riparian habitat occurring in and along Cache Creek. As time moved forward these concerns escalated into heated political battles between residents, aggregate companies, and local government officials. Many studies were conducted on Cache Creek attempting to determine the best course to take to protect the health of the creek as well as protecting the local economy.

In June of 1994, the Yolo County Board of Supervisors adopted the Off-Channel Mining Plan (OCMP) and Cache Creek Resources Management Plan (CCRMP) (http://www.yolocounty.org/Index.aspx?page=1598). Implementation of the goals and objectives in the CCRMP is the main purpose of the Cache Creek Improvement Plan (CCIP), also adopted by the Board of Supervisors in 1994 (http://www.yolocounty.org/Index.aspx?page=1602). In 1996, resolution 96-132 amending the general plan to include the CCRMP was passed by the Board of Supervisors. This document in conjunction with the OCMP instituted goals to aid in the management of Cache Creek and its natural resources (Tschudin, 1996). These plans eliminated in-channel mining and increased levels of environmental protection and monitoring on approximately 2,324 acres of land from the Capay Dam to the I-5 overcrossing. The goals in the CCRMP relate primarily to six elements for management and enhancement of the Lower Cache Creek Area. These elements include floodway and channel stability, water resources, biological resources, open space and recreation, aggregate resources, and agricultural resources.

The CCRMP is a management tool used by Yolo County Parks and Resources that enables the Natural Resources Division to manage and maintain a healthy balance between economic and environmental issues related to natural resources located in and along the Lower Cache Creek area.

Chapter 2

GEOLOGIC BACKGROUND

2.1 - General and Regional Geology

Cache Creek's headwaters originate at the southern most portion of Clearlake and flow primarily southeast through southern Lake County into northern Yolo County. The creek meanders eastward through steep canyons into the Capay Valley where the stream direction turns south. Cache Creek flows along the eastern side of the Capay Valley for approximately 15 miles (24 km) before it turns easterly flowing across the Sacramento Valley to the Cache Creek Settling Basin (Figure 2.1).

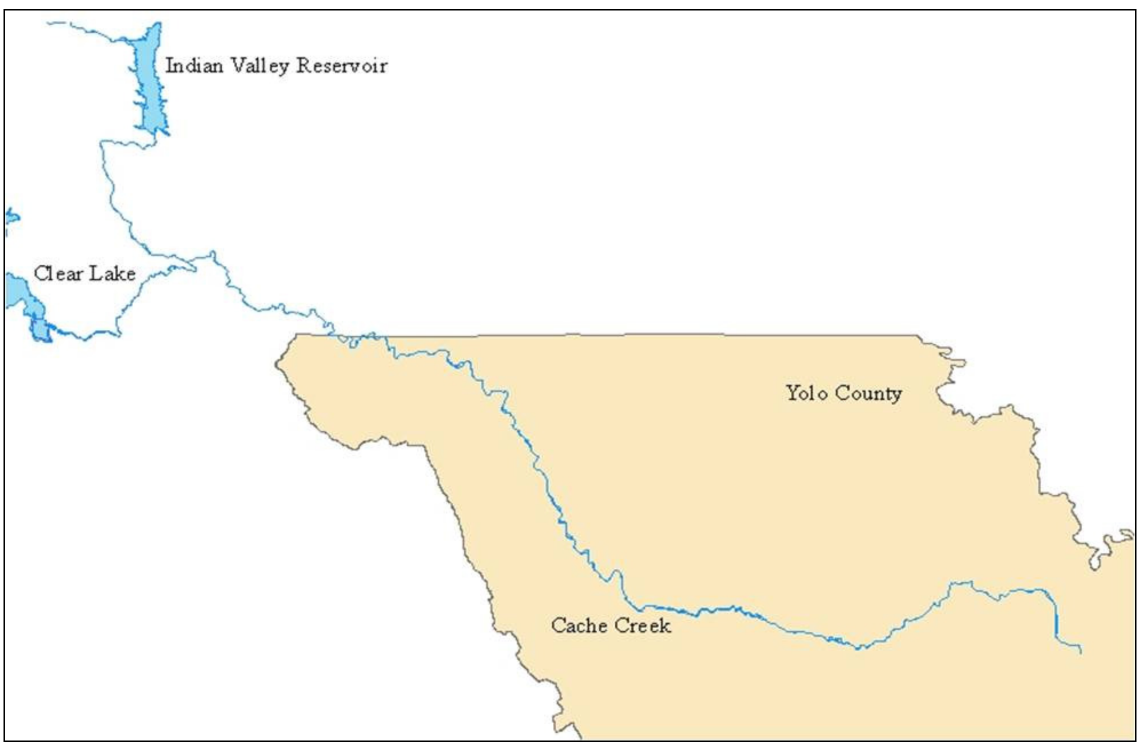

Figure 2.1 Aerial Image Cache Creek - Clearlake to Settling Basin

Cache Creek flows through two general geologic sequences. The bedrock geology in the upper reaches of the creek is primarily the Franciscan Assemblage, and in the lower reaches (within the study area), the creek cuts into the Great Valley Sequence and recent alluvial sediment from the Sacramento River. The Coast Ranges are primarily composed of the Franciscan Assemblage, which is a sequence of Late Jurassic to Late Cretaceous (Figure 2.2) rocks consisting of shale, greywacke sandstone, chert, altered volcanic rocks, limestone, and atypical metamorphic rocks (CDMG Bulletin 183, 1964).

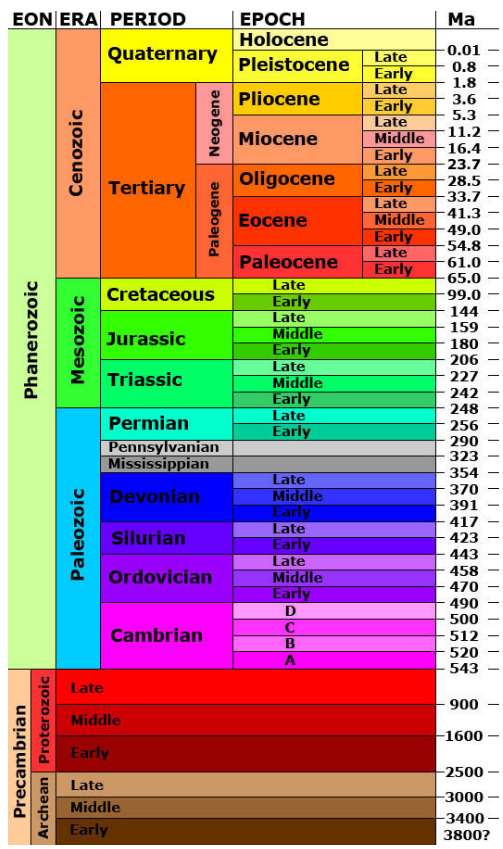

Figure 2.2 Geological Timescale (http://3dparks.wr.usgs.gov/haywardfault/images/timescale_small.jpg)

Adjacent to the Franciscan Assemblage lies the Great Valley Sequence. The Great Valley Sequence is exposed along the eastern side of the Coast Range and the edge of the Sacramento, San Joaquin, and Central Valleys of California. The age of the Great Valley Sequence is similar to the Franciscan Assemblage (Late Jurassic to Late Cretaceous), but is composed of sandstone, shale, and conglomerate, is highly fossiliferous, has fairly regular bedding, and clearly lacks the volcanic rocks and deformation found in the Franciscan Assemblage (CDMG Bulletin 183,

1964) (Figure 2.3). The study is conducted primarily in the Great Valley Sequence and several younger formations; although many rocks from the Franciscan Assemblage can be found in the channel due to sediment transport from the Capay Valley Reach.

Figure 2.3 Deformed Strata - Cache Creek Regional Park (Tami Leathers, 2010)

Much of Cache Creek within the study area cuts through the Great Valley Sequence and overlies the Tehama Formation, the Red Bluff Formation, the Modesto and Riverbank Formation, and natural channel and levee deposits.

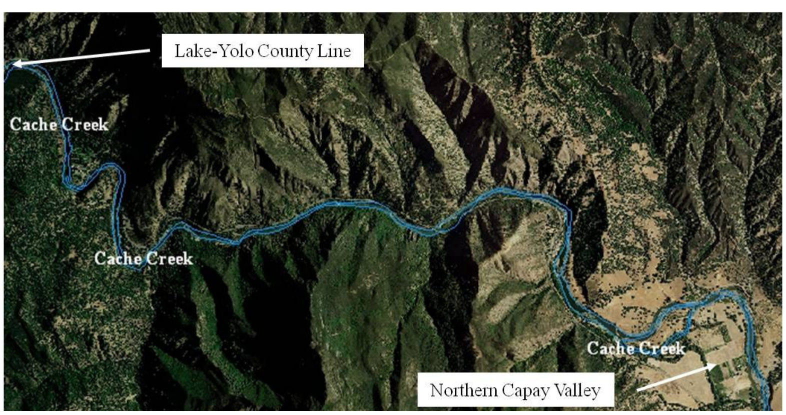

Figure 2.4 Cache Creek Aerial Photo – Lake-Yolo County Line to Northern Capay Valley

The Capay Valley Reach is upstream of the study area (above Capay Dam). The Capay Valley Reach consists of bedrock-bounded steep canyons from the county line until it enters the northern tip of the Capay Valley near the town of Rumsey (Figure 2.4).

Figure 2.5 Photograph of Deformed Strata near Camp Haswell (Tami Leathers, 2010)

Canyon walls of the upper portion of the Capay Valley Reach consist of moderately erodible sandstone, shale, and conglomerate of the Cretaceous Great Valley Sequence (Figure 2.5). Much of the aggregate mined from the lower reaches originated from these rocks. At the downstream end of the Capay Valley Reach, Cache Creek turns toward the east where the Capay Diversion Dam is located (Figure 2.6).

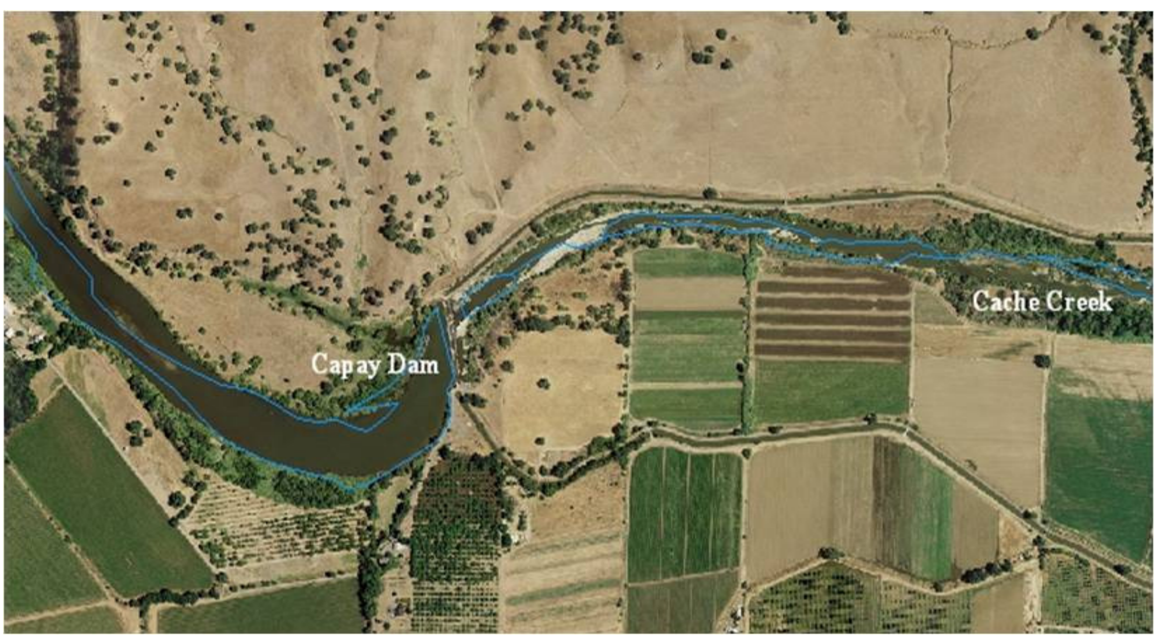

Figure 2.6 Aerial Photograph of Capay Diversion Dam on Cache Creek

At this location, the creek widens as the dam holds back water that is diverted into irrigation canals during peak agricultural growing season. Maximum diversion occurs from March through October of each year.

2.2 - Geology of Study Area

This study is focused on the lower reaches of Cache Creek from the Capay Dam to the Interstate 5 Bridge Overcrossing near the town of Yolo (Figure 1.1). In this area, Cache Creek flows through the Tehama Formation, the Red Bluff Formation, the Modesto and Riverbank Formations, and Natural Channel and Levee Deposits (Figure 2.7).

Figure 2.7 Geologic Map of Study Area

The Tehama Formation is Pliocene in age, lies unconformably above Eocene or Cretaceous rocks, and is composed of sand, silt, gravels, and some clay deposited on floodplains in the Great Valley (Olmsted and Davis, 1961). This formation is extremely thick; measuring over 2000-feet (~610-m) thick in most areas and typically has a massive, poorly sorted sandy-silt fabric (California Department of Natural Resources Division of Mines, 1939). Within the study area, the Tehama Formation is composed of fairly coarse, uncemented and poorly consolidated crossbedded sandy-silt material. This sandy-silt material is pale yellowish to greenish gray and changes from pale buff to yellow brown when weathered (California Department of Natural Resources Division of Mines, 1939). Olmstead and Davis state that “the Tehama Formation is one of the most important sources of ground-water for irrigation in the Sacramento Valley.” Volcanic deposits are also associated with the Tehama Formation. Interfingering of the Tuscan Formation (containing volcaniclasics) and the Tehama Formation is evidence that both formations were deposited at the same time (California Department of Natural Resources Division of Mines, 1939). Beds of the distinctive Nomlaki Tuff and Putah Tuff lie within the Tehama and Tuscan Formations. The presence of these components within the Tehama Formation explains the volcaniclastic sediments found in the levee and channel deposits in the study area.

Atop the Tehama Formation lie the Red Bluff, Modesto and Riverbank Formations, and the Natural Levee and Channel Deposits. Each has been dated to the Pleistocene and decrease in age respectively. The Red Bluff Formation consists of poorly sorted, pebble to small cobble sized gravel in an unmistakable reddish silty or sandy matrix (Olmsted and Davis, 1961). The Red Bluff Formation is unconformably in contact with the Tehama Formation below, and the Riverbank and Modesto Formations (previously called the Victor Formation) above (Olmsted and Davis, 1961). In the study area along Cache Creek only remnant gravels from the Red Bluff Formation can be found (Helley and Harwood, 1985).

The Riverbank and Modesto Formations are undifferentiated alluvial deposits. In 1967, Shlemon named the Riverbank and Modesto Formations out of the originally named formation called Victor. The Riverbank and Modesto Formations are associated with the lower Victor (middle Pleistocene) and upper Victor (late Pleistocene) respectively (Shlemon, 1967). The thickness of the Riverbank Formation ranges from zero to 90-feet, and is composed of granitic sand and silt interbedded with metamorphic channel gravel (Shlemon, 1967). Commonly, cross bedding and channeling can be found in the lithologically heterogeneous and laterally discontinuous beds. The Modesto Formation is nearly identical in lithology and stratigraphy. The Modesto Formation differs by geomorphic position in terraces and the degree of post-depositional soil profile development (Helley and Harwood, 1985).

Natural levee and river deposits are recent sediments moved by moderate to large flow events and deposited in and along the channel and its banks, which are constantly shifting. Levee and river deposits are composed of highly permeable, homogeneous, usually unconsolidated sediment ranging in size from cobble and boulder gravel down to fine silt and clay (Olmsted and Davis, 1961).

Nearly all of the surficial geology within the study area is made up of natural levee and river deposits. Sediments contained in this defined geologic unit are composed of remnants of the Franciscan Assemblage, the Great Valley Sequence, and all of the formations listed above.

2.3 - Stream Morphology

Cache Creek has very different morphologies from its headwaters to its terminus and is separated into nine reaches based on the geomorphology of the stream. The upstream region of the Capay Valley Reach consists of steep canyons while the downstream region is mildly sinuous and generally flowing as a single channel; however, there are areas where the stream exhibits braided form. Capay Dam holds water for irrigation diversion and is located within the Capay Valley Reach. There are nine reaches from the Yolo-Lake County Line to the Settling Basin in Woodland, and they are referred to as Capay Valley, Capay, Hungry Hollow, Madison, Guesisosi, Dunnigan Hills, Hoppin, Rio Jesus Maria, and the Settling Basin reaches.

The Capay Reach begins approximately 650-feet (198-meters) downstream from the Capay Dam. This reach begins at river mile 28.3. For reference, river mile zero begins at the USGS water monitoring station #11453000 named Yolo Bypass NR Woodland. River miles are measured every tenth of a mile upstream to the Capay Dam. The Capay Reach has a relatively straight, steep, confined single channel. The channel is incised into bedrock, has an average bed slope of 9.0 feet/mile (1.70-m/km) [10.8 ft/mi in 1995] and an average width of 301-feet (91.74-m) as determined in this project using the Geographic Information System (GIS) ArcMap (Tables 2.1, 2.2, Appendices A, B).

Table 2.1 2006 Average Width, Slope, Vegetation and Channel Type

	Average Width		Slope		Vegetation*	Channel Type
Reach	feet	meters	ft/mile	m/km	* Qualitative Analysis	
Rio Jesus Maria	98	29.79	5.88	1.11	Dense	Meandering, Incised
Hoppin	500	152.55	8.00	1.52	Moderately Dense	Braided to Meandering
Dunnigan Hills	562	171.43	8.15	1.54	Moderate - Dense	Braided
Guesisosi	375	114.41	7.62	1.44	Moderate	Braided
Madison	802	244.50	12.17	2.31	Sparse - Moderate	Braided
Hungry Hollow	1061	323.34	11.85	2.24	Very Sparse	Braided
Capay	301	91.83	9.00	1.70	Dense	Fairly Straight
Conversions: 1 feet = 0.304 8 meter; 1 mile = 1.609 344 kilometer						

Table 2.2 1995 Average Channel Widths

Reach	Length (mi)	Stationing	Slope[1] (ft/mi)	Width[1] (ft)	Depth[1] (ft)	Comments
Capay	2.1	1500+00 - 1390+00	10.8	1759	19.7	steep, confined and incised with bedrock controls
Hungry Hollow	2.8	1390+00 - 1240+00	11.3	1548	11.5	channel widens; braided planform; active gravel mining
Madison	2.5	1240+00 - 1110+00	12.4	692	19.3	downstream portion if reach narrows and not actively mined
Guesisosi	2.3	1110+00 - 990+00	6.2	614	18.6	channel initially confined be levee, reasonable straight but meanders further down stream; some in-channel mining
Dunnigan Hills	2.8	990+00 - 840+00	9.9	879	16.1	well-developed low flow meanders; significant riparian vegetation; site of former Moore diversion dam; bedrock controls along Dunnigan Hills; some in-channel levees; West Adams Canal drain and Goodenow Slough enter upstream from road 94B
Hoppin	3.3	840+00 - 665+00	7.4	1584	32.6	some meander development; bedrock controls upstream from Stevens Bridge; some in-channel levees
Rio Jesus Maria	7.5	665+00 - 590+00	7	384	41.6	upper 1.4 mi included in stidy area; channel considerable narrower and constricted with steep banks; some riparian vegetation; contains COE flood control levees; four bridge crossings near station 60000, at Yolo

[1] Reach-averaged values

Source: NHC 1995 Technical Studies

Moderately dense riparian vegetation is present along both banks (Figure 2.8). Within the Capay Reach, the channel narrows by a factor of 2.6 at the County Road 85 Bridge. Immediately downstream of the bridge the channel widens dramatically and an active, braided section forms.

Figure 2.8 Aerial Photograph of Capay Reach

Figure 2.9 Aerial Photograph of Hungry Hollow Reach

The Hungry Hollow Reach begins at river mile 26.3 and the creek morphology changes significantly (Figure 2.9). This reach has an average slope of 11.9 feet/mile (2.24 m/km) [11.3 ft/mi in 1995], width of 1061-feet (323.39-m), and lacks the dense riparian vegetation found in the Capay Reach, although some vegetation is still present (Tables 2.1, 2.2, Appendices A, B). This part of the channel has been rigorously mined for aggregate, thus significant degradation or channel lowering (incision) has occurred along the entire length of the study area (Figure 2.10). The Granite Capay Aggregate mine and the eastern part of the Teichert Esparto mine site are located along the north bank of the Hungry Hollow Reach. Downstream within this reach, County Road 87 Bridge transects Cache Creek and narrows the channel significantly by a factor of 1.5.

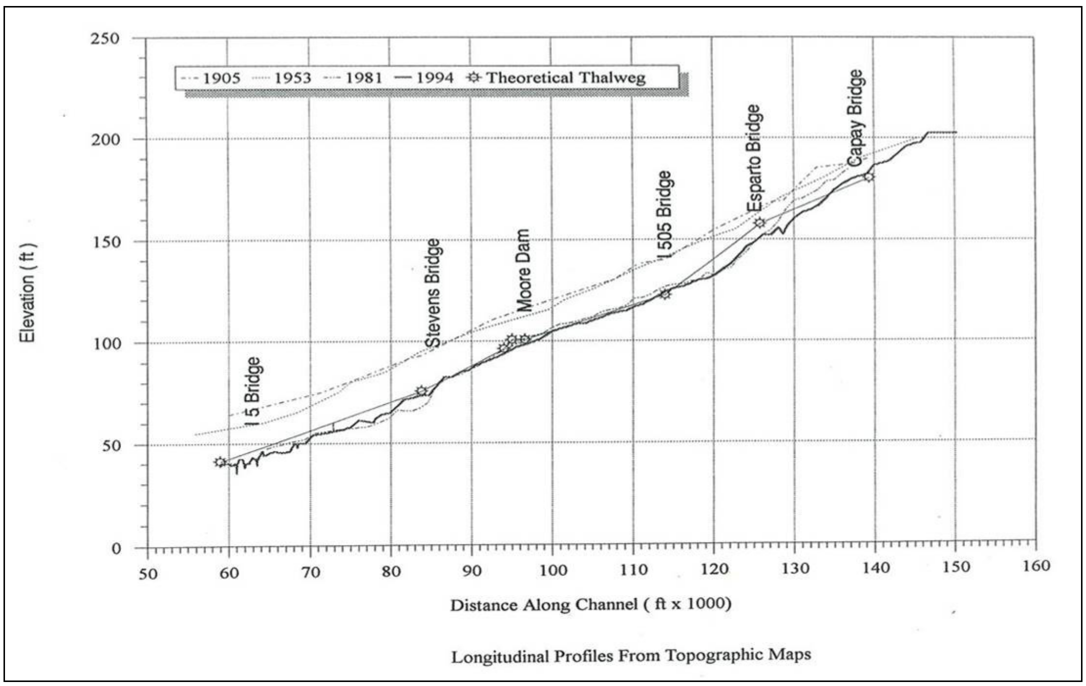

Figure 2.10 Longitudinal Profiles from Topographic Map (NHC 1995 Technical Studies)

The Madison Reach starts at river mile 23.4. This reach is characterized as braided. Bank-full margins narrow considerably and the slope increases to 12.2 feet/mile (2.30 m/km) [12.4 ft/mi in 1995], with an average width of 802-feet (Figure 2.11).

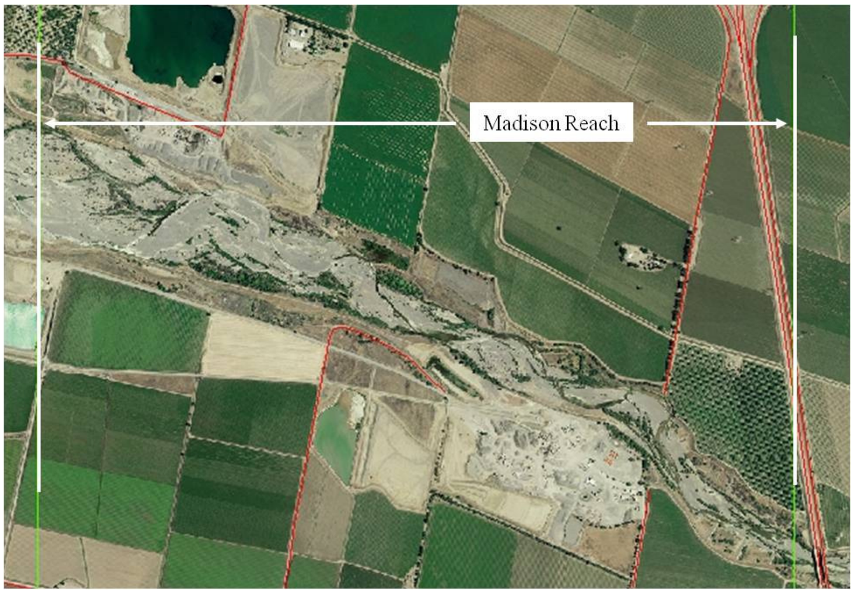

Figure 2.11 Aerial Photograph of Madison Reach

Moderately dense riparian vegetation occurs in disconnected stands throughout the reach (Tables 2.1, 2.2, Appendices A, B). Historically, little in-channel mining occurred within this reach, although presently a significant amount of off-channel aggregate mining does occur along the north bank and the south bank.

Figure 2.12 Aerial Photograph of Guesisosi Reach

The average slope decreases to approximately 7.6 feet/mile (1.44 m/km) [6.2 ft/mi in 1995] in the Guesisosi Reach, which begins at river mile 21.1 and has an average width of 375-feet (Figure 2.12, Tables 2.1, 2.2, Appendices A, B). Within this reach, the water table rises and allows some riparian vegetation to flourish (NHC, 1995). The Guesisosi Reach is fairly straight and is bordered on the south bank by artificial levees and the CEMEX aggregate operation.

The Dunnigan Hill Reach starts at approximately river mile 18.9 and has just one active mine sites along its banks (Figure 2.13) (NHC, 1995).

Figure 2.13 Aerial Photograph of Dunnigan Hills Reach

Teichert Aggregates mined aggregate extensively along the north edge of the Dunnigan Hills Reach. High quality aggregate was extracted east of present day operations in this reach. After mineral reserves were exhausted in the 1990's, Teichert helped to reclaim the abandoned pit mine and donated the property to Yolo County. Today this piece of property is known as and managed by the Cache Creek Nature Preserve. The average slope within this reach is approximately 8.1 feet/mile (1.54 m/km) [9.9 ft/mi in 1995], and the reach is approximately 562-feet (171.3-m) in width (Tables 2.1, 2.2, Appendices A, B). This reach has a high water table year round (NHC, 1995). Due to the consistently high water table, the riparian vegetation is thick and can be found up to 1000-feet (~305-m) outside the bank-full margins.

The Hoppin Reach begins just downstream of river mile 16.1, (Figure 2.14) (NHC, 1995).

Figure 2.14 Aerial Photograph of Hoppin Reach

The Teichert Woodland mine operation borders both the north and south banks within this reach. Areas of reclaimed riparian vegetation and naturally occurring vegetation can also be found along the channel. The average gradient here is approximately 8.0 feet/mile (1.52 m/km) [7.4 ft/mi in 1995] and has an average width of 500-feet (Tables 2.1, 2.2, Appendices A, B). The channel is initially sinuous, but straightens and narrows considerably downstream.

The Rio Jesus Maria Reach has an extremely narrow, incised, meandering channel with levees. It begins at approximately river mile 12.9 and terminates at the I-5 Bridge (Figure 2.15).

Figure 2.15 Aerial Photograph of Rio Jesus Maria Reach

The slope and width averages approximately 5.9 feet/mile (1.11 m/km) [7.0 ft/mi in 1995] and 98-feet (~30-m) respectively, and riparian vegetation is fairly thick with sporadic areas of little vegetation (Tables 2.1, 2.2, Appendices A, B).

Of the nine reaches of Cache Creek in Yolo County, seven fall within the study area. The terrain of the study area is quite diverse, ranging from an incised single channel with dense riparian vegetation to barren, gravelly braided channels.

Chapter 3

METHODS

3.1 - Data Acquisition

Available data pertaining to Cache Creek was compiled over several months. Previous studies, aerial images, maps, digital data (AutoCAD, ArcGIS), and historical information were acquired from Yolo County Department of Parks and Resources (DPR), Yolo County Archives, Yolo County Flood Control and Water Conservation District (YCFCWCD), University of California at Davis Map Library, consulting firms, and private personal book collections.

3.2 - Geographic Information System (GIS) Software

Two versions of Geographic Information System (GIS) Software were used in this study. ArcMap Version 9.2 and 9.3 by ESRI were used to georeference and digitize the position of stream banks and the active channel of Cache Creek. Both versions were used due to a software upgrade mid-way through the digitizing process.

3.2.1 - Scanning

The UC Davis Map/GIS Collection Library has an extensive collection of aerial photos of Yolo County and Cache Creek. Complete aerial photographs of Yolo County were collected from flights that occurred in 1937, 1953, 1957, 1964, 1971, and 1984. Aerials from these datasets are black and white orthophotographs and were obtained and scanned at the UC Davis Map Library using an Espon Expression 10000 XL Scanner. All photographs were scanned at 600-dpi in grey scale as a TIFF file to retain as much quality of the original photo and to limit the size of digital files created.

3.2.2 - Georeferencing

Yolo County Parks and Resource has acquired digitally georeferenced aerial photos from 2004 through 2007. One recent aerial dataset (2006) was selected as a base-map for control points to georeference historical images from 1937, 1953, 1957, 1964, 1971, and 1984. At this time, Yolo County has not received the 2008 aerial photos and the 2007 dataset is not spatially referenced, therefore the 2006 dataset was chosen as the most recent reference image.

Aerial photo sets from 1937, 1953, 1957, 1964, 1971, and 1984 were scanned and georeferenced. With each photo set, the farthest upstream photograph including the Capay Dam was georeferenced first. A minimum of three control points were used to georeference each photo. Older photos had fewer control points that could be matched with the 2006 reference images. Permanent structures such as houses, barns, power poles, and irrigation canal gates were the most common objects used for georeferencing. Because the older photo datasets had limited number of control points available for georeferencing, first order polynomial transformations were also performed. Second order polynomial transformations were performed on photos where more than six control points were determined to be acceptable.

3.3 - Criteria for Digitizing Channel Boundaries

Datasets were digitized and analyzed in ESRI ArcMap v. 9.2 and 9.3 from years 1937, 1953, 1957, 1964, 1971, 1984, 1998, 2002, 2006. Digitized shape files were produced using Lambert Conformal Conic projection in the NAD1983 California State Plane (feet) coordinate system. This projection and coordinate system were used because this is the standard used by the Yolo County Information Technology (GIS) group.

For this project, the first step was to digitize “bank full” margins. Bank full is defined by Leet (1982) in Physical Geology, 6th Edition as the stage of flow at which a stream fills its channel up to level of its bank with recurrence interval averages from 1.5 to 2 years. Under this definition, Cache Creek has 2-year flood interval discharge of 13,500 cubic feet per second (cfs) (NHC, 1995). Left and right bank full delineations were marked using a combination of georeferenced aerial photos, AutoCAD elevation data, and mean daily flows when available. When AutoCAD digital elevation model contours were not available for older photo sets, delineations were based on georeferenced aerial photos alone.

A standard process was developed to maintain a consistent method of determining bank full lines. Datasets were digitized and analyzed in the order of most recent to the oldest available datasets. Aerial photos were overlain by AutoCAD digital elevation model contour lines in ArcMap v. 9.3 and visually compared with mean daily flows from Cache Creek at Yolo collected from the USGS website http://waterdata.usgs.gov/ca/nwis/sw. The 2006 aerial photos (baseline dataset) were taken on April 18, 2006. The mean daily flow on that day at the Yolo Gage was 5090 cfs. The “bank full” discharge at the Yolo Gage is 13,500 cfs and this flow covers the main gravel channel bottom to the level where the banks began to steepen. Bank full lines included small shrubs, grasses, and areas of recent sediment deposition. Visually mature (large) vegetation was not included within the bank full channel in most cases. At narrow areas, with steep banks, bank full margins were drawn approximately mid-way up the sloped banks to account for decreased area for water to flow.

The majority of datasets were digitized using aerial images alone. This made digitizing difficult because no other information except black and white images was available. In these cases, bank full lines were drawn primarily following what appeared to be mature or large riparian vegetation versus areas of light colored sediment.

Due to the lack of data associated with progressively older aerial images and their diminishing quality, the accuracy of bank full lines is lower with older photos than that of the most recent datasets. These data do, however show general channel form.

3.4 - Criteria for Determining Areas of Channel Movement and Change

The polylines for each dataset (1937, 1953, 1957, 1964, 1971, 1984, 1998, 2002, and 2006) were converted into polygons so channel position and area of channel migration could be determined. Polygons from two successive photosets were overlapped and compared to document channel migration

Polygons were generated from the digitized polylines in ArcMap by utilizing the *Feature to Polygon* data management tool for each of the nine datasets. For each comparison, the polygon from the earliest dataset was overlain by the following polygon dataset. Using the *Symmetrical Difference* analysis tool, an output file was created which calculated two areas of difference or changes within the channel. The areas were separated into two attribute records: ID 0 and ID -1. Resulting polygons associated with an attribute ID value of "0", are areas of channel migration out of that locale (areas of deposition). Polygons in datasets having an ID value of "-1" were areas where the channel moved into that locale (areas of erosion).

The symmetrical difference output files were converted to a new file separating the single erosion and single deposition polygons into individual polygons using the "multipart to singlepart" data management tool (Figure 3.1a-d).

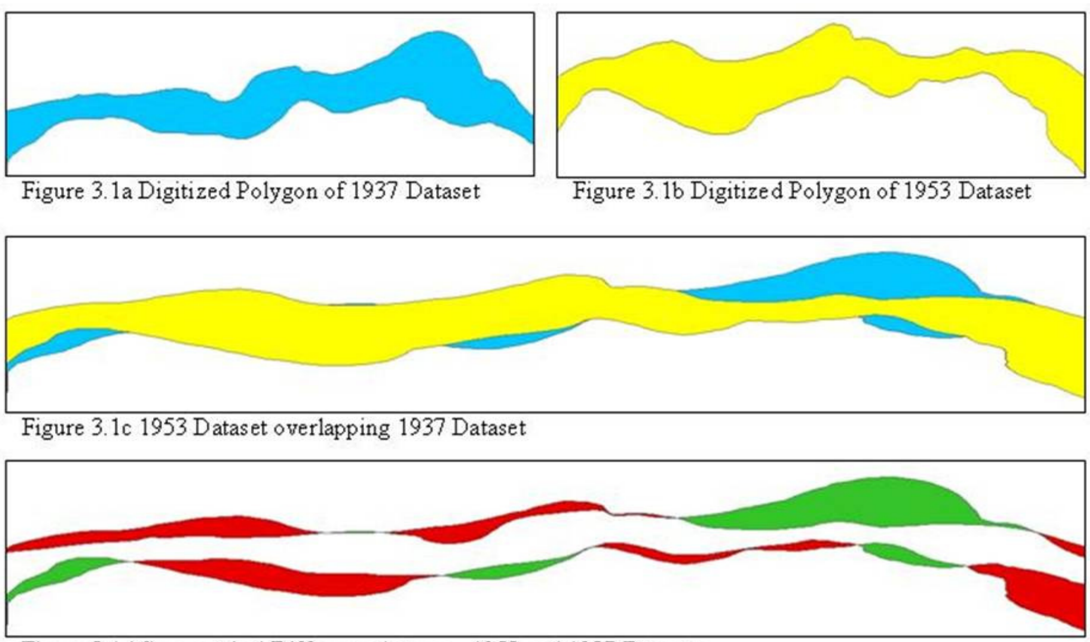

Figure 3.1a Digitized Polygon of 1937 Dataset

Figure 3.1b Digitized Polygon of 1953 Dataset

Figure 3.1c 1953 Dataset overlapping 1937 Dataset

Figure 3.1d Symmetrical Difference between 1953 and 1937 Datasets

Figure 3.1a-d Example of GIS Symmetrical Differences

This final step was taken to pinpoint large areas of erosion possibly creating damage to infrastructure or farmland. Two new fields (acres, square feet) were added to the attribute tables in the multipart to singlepart shape files. Using the field calculator, acreage and square footage was calculated for each of the records in the attribute table. Eight visual images were created showing temporal changes of erosion and deposition.

Average channel width was measures in each photoset to identify trends. For each dataset, average widths of each reach in the study area were measured at approximately every tenth mile along the channel. The bank full polygon was used in conjunction with the "river mile" shape file to measure channel widths at each tenth mile using the *measure* tool in ArcMap. Lines measuring the widths were drawn as near perpendicular to the channel edges as possible. All measurements were recorded and averages were calculated for each reach within the study area.

Average widths were calculated by measuring and recording widths at one-tenth mile increments on the digitized polygon from datasets 1937, 1953, 1971, 1998, 2002, and 2006 and separated by reach. Points on the river mile shape file were used to as reference to measure the width of the channel as close to perpendicular to flow as possible. All widths within each reach were averaged to determine possible trends over time.

Digital elevation models and channel incision was analyzed using data from the 1995 Technical Report and new orthophotographs. The Technical Studies and Recommendations for the Lower Cache Creek Resources Management Plan graphed the longitudinal profile of Cache Creek from topographic maps from 1905, 1953, 1981, and 1994. This information was used in conjunction with a longitudinal profile created in this study from the 2006 aerial photographs and Digital Elevation Model (DEM). The DEM and river mile shape file were draped over the 2006 aerial photograph in ArcMap 9.3. The contour interval of the DEM was 2-feet, accurate to within two sigma or two standard deviations. The lowest DEM contour found within the channel was recorded at each tenth mile river mile marker. The river mile marker was converted to feet (distance along channel) to correspond with the 1995 Technical Study longitudinal profiles. All profiles were graphed in Microsoft Excel and plotted as distance along channel (X-Axis) versus elevation (Y-Axis) and compared.

3.5 - Stream Flow and Affected Area

Peak annual stream flow was examined as a factor on channel migration for the eight photosets. Stream flow data were collected on Cache Creek at the USGS stream

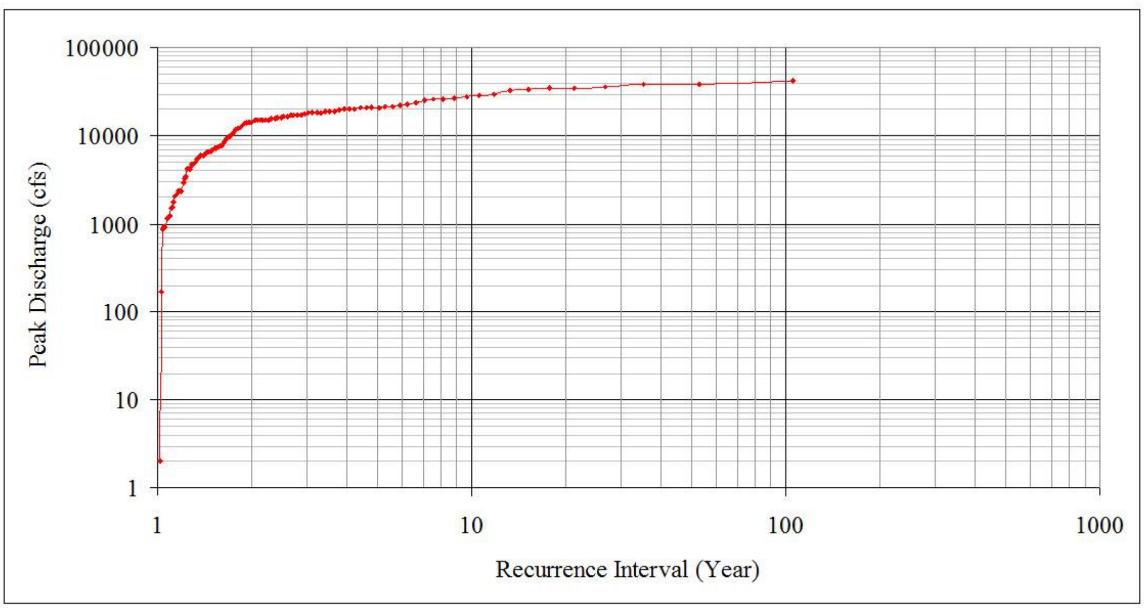

Figure 3.2 Recurrence Interval Curve for Yolo Gage #11452500

gage at Yolo (site #11452500), and downloaded from the USGS Surface-Water Data from California website (http://waterdata.usgs.gov/ca/nwis/sw). The recurrence interval curve was generated by plotting annual peak discharge against the inverse of percent probability (recurrence interval). Based on this graph (Figure 3.2) the 2-year, 5-year, 10-year, 50-year, and 100-year flood frequency intervals correspond to flows of 14,200 cfs, 21,100 cfs, 28,000 cfs, 38,700 cfs, and 41,400 cfs respectively. These estimates are comparable to the 1990 Army Corps of Engineers flood frequency (2, 5, 10, 50, and 100-year events) flows of 13,500 cfs, 23,500 cfs, 29,000 cfs, 41,500 cfs, and 46,000 cfs. Thus the published Army Corps of Engineer flood frequency recurrence interval flows (Table 3.1) were used as the benchmark in the analysis of flows potentially affecting stream migration and sediment movement on Cache Creek. An additional low flow event of 5,000 cfs was also used in this analysis to determine effects of small, frequent flows.

Table 3.1 Cache Creek Stream Flow Frequencies

	Peak Discharge (cfs)				
Location	2 Year	5 Year	10 Year	50 Year	100 Year
Cache Creek above Rumsey[1]	15,000	27,000	35,000	52,000	60,000
Cache Creek near Capay[1]	15,000	27,000	34,000	50,000	58,000
Cache Creek at Capay[1]	(14,500)[2]	(28,000)[2]	(37,000)[2]	(57,000)[2]	(63,500)[2]
Cache Creek at Yolo	13,000	23,500	29,000	41,500	46,000

[1] Stream gage recorder discontinued.

[2] Values in parentheses from COE, Aug 1994 Westside Tributaries Study, Cache Creek at Capay Peak Flow Frequency Curve

SOURCE: Flood frequency data for Rumsey, Capay, and Yolo from COE, 1990, General Design Memorandum for Cache Creek Basin Outlet channel. Taken from NHC 1995 Technical Studies

Mean daily discharge data were used in the flow analysis and is defined by the USGS as, “daily values are summarized from time-series data for each day for the period of record and may represent the daily mean, median, maximum, minimum, and/or other derived value. Daily values include approved, quality-assured data that may be published, and more recent provisional data, whose accuracy has not been verified." Mean daily discharge (cfs) was plotted on a hydrograph for the same period of time channel migration data were analyzed. These data were analyzed to identify links between stream flood events and stream migration.

Several parameters were evaluated to determine how flow magnitude and flow duration affects the channel migration along Cache Creek. The factors assessed were recurrence intervals, total area affected, average number of flow events equal to or greater than 5,000 cfs, 13,500 cfs, and 23,500 cfs (magnitude), as well as average number of flow event intervals occurring two days or longer at flows ≥5,000 cfs, ≥13,500 cfs, and ≥23,500 cfs (duration).

Chapter 4

RESULTS AND DISCUSSION

Chapter 4.1 - Hydrograph and Flood Recurrence Interval Curve

Results

Annual peak flows measured at the USGS surface water monitoring gage #11452500 at Yolo have been recorded from 1903 to 2007 and are shown in Figure 4.1.

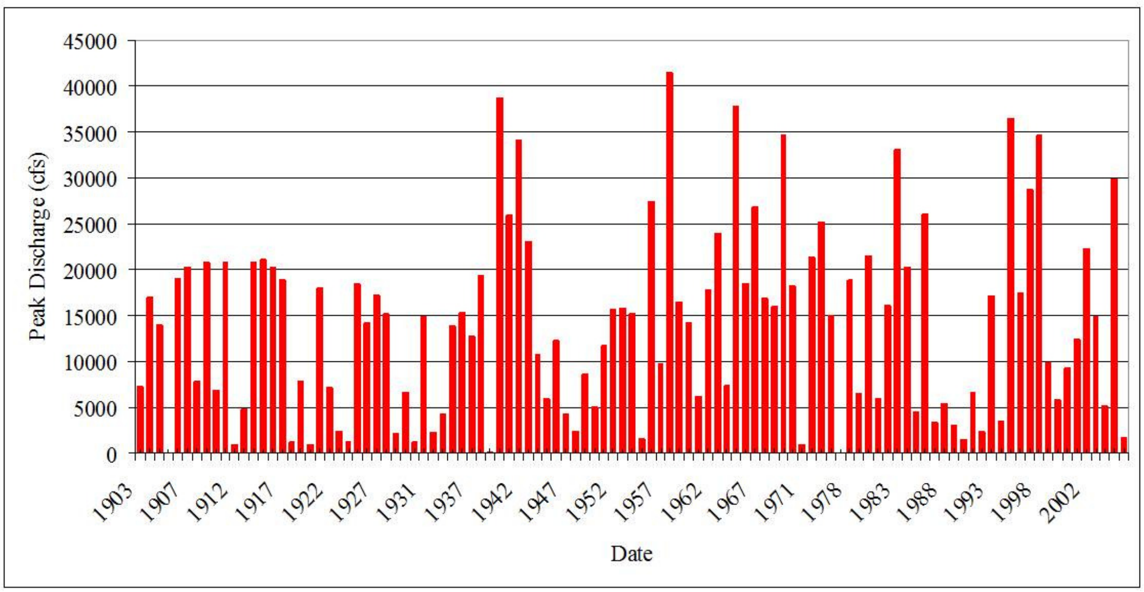

Figure 4.1 Hydrograph of Annual Peak Discharge for Yolo Gage #11452500

Peak discharges range from 41,400 cfs recorded on February 25, 1958 to zero flow recorded in 1977. From 1903 to 2007 mean annual peak discharge was calculated at 13,954.4 cfs. It does not appear there are any trends with this dataset. However, there may be a tendency toward lower peak flows prior to 1940.

The recurrence interval was generated (Figure 3.2) from the annual peak flow data discussed above. As stated in chapter 3.5, the recurrence interval values estimated in this study are comparable to published data from the Army Corps of Engineers (Table 3.1). Table 4.1 shows that the percent difference between the results estimated in this study and the Army Corp of Engineer's results (3-10% difference).

Table 4.1 Flood Frequency Comparisons

Recurrence Interval	1990 ACOE	STUDY 2010	Difference	% diff
2-year flood	13,500	14,200	-700	-5
5-year flood	23,500	21,100	2400	10
10-year flood	29,000	28,000	1000	3
50-year flood	41,500	38,700	2800	7
100-year flood	46,000	41,400	4600	10
Source: Army Corps of Engineers				

Discussion

Annual peak discharge on Cache Creek is unpredictable. Prior to 1940, annual peak discharges did not exceed 21,100 cfs, which is less than a 5-year flood event. The second highest flow event recorded at Yolo Gage #11452500 occurred in 1940. Larger flood events may be more common after 1940.

Flood recurrence interval curves can change with every year of new data collected. The Army Corps of Engineer's flood recurrence flows were calculated and published in 1990, therefore a current flood recurrence interval curve was created in this study to determine any significant changes in estimated flows. The percent difference between Army Corps of Engineer and this study's recurrence flow values (3-10%) were not significantly different, thus the flow values published by Army Corps of Engineers are used in this study.

4.2 – Bank Erosion and Deposition

Nine sets of aerial photographs were used to create polygons of the bank-full channel on Cache Creek from the Capay Dam to the I-5 overcrossing bridge. Eight comparison datasets were generated from the aerial photographs to determine the total area affected by erosion and deposition between each dataset.

It is important to convey that flood frequency intervals are normally generated from annual peak discharge events, which may last minutes or hours in time. In the following sections, mean daily flow data is used in the analysis to determine any relationship between flow duration, magnitude, and affected channel area. The mean daily flow is a calculated average over a 24-hour period, and it is critical for the reader to understand these data represent an underestimate of peak flow magnitude during each large storm event. It is also important for the reader to recognize that flood frequency recurrences (measured by annual peak discharge) are used as a benchmark when analyzing the mean daily flows.

Amplified stream power increases the ability of the stream to transport sediments. Stream power (w) is equal to the product of specific weight (γ) of stream water, discharge (Q), and slope (S) (Ritter, Kotchel, and Miller, 2002).

$$w = \gamma * Q * S$$

As specific weight, slope and discharge increase, so does stream power. High flows, and steeper slopes along reaches of Cache Creek increase the probability of erosion. Table 4.2 compares the average slope in each reach from 1995 to 2006. This table shows the slopes are alternately decreasing, then increasing between each ensuing reach. This fluctuation in slopes between reaches may indicate an attempt by the creek bed to reach equilibrium with each flood event.

Table 4.2 Slope Comparisons 1995-2006

	Slope (1995)		Slope (2006)	
Reach	ft/mile	m/km	ft/mile	m/km
Capay	10.80	2.05	9.00	1.70
Hungry Hollow	11.30	2.14	11.85	2.24
Madison	12.40	2.35	12.17	2.31
Guesisosi	6.20	1.17	7.62	1.44
Dunnigan Hills	9.90	1.88	8.15	1.54
Hoppin	7.40	1.40	8.00	1.52
Rio Jesus Maria	7.00	1.33	5.88	1.11

Conversions: 1 feet = 0.304 8 meter; 1 mile = 1.609344 kilometer

The following sections describe areas of migration on the channel, the longitudinal profile, channel widths, and analysis of mean daily flows and affected area, and in several cases the annual peak flow and affected land area.

4.2.1 - Bank Erosion and Deposition - 1937 to 1953

Results

The 1937 to 1953 dataset comparison shows areas of significant channel migration. Lateral migration of the channel is significant along most of the channel (Figure 4.2).

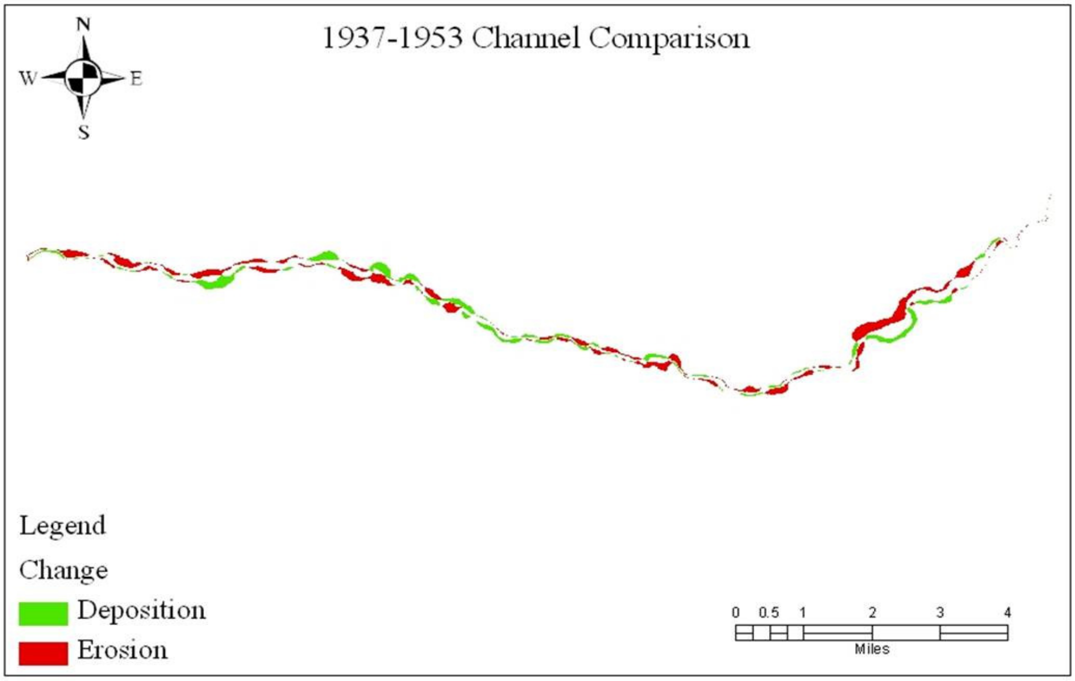

Figure 4.2 Channel Comparison Map 1937-1953

Total area affected by migration totals 886.7 acres, which averages of 52.2 acres of affected area per year. GIS estimates of the land area affected by erosion and deposition shows total areas of 536.6 acres and 350.1 acres respectively. The overall net change in land area is 186.5 acres of erosion (Table 4.3a).

Table 4.3a-h Calculated Areas Affected and Water Volumes

Table	Dataset	# Total Years	Total Affected Area (Acres)	Total Deposition	Total Erosion	Difference	# Acres Affected per Year (Ac/Year)
4.3a	1937-53	17	886.7	350.1	536.6	-186.5	52.2
4.3b	1953-57	5	517.3	270.2	247.2	23.0	103.5
4.3c	1957-64	8	624.0	355.1	268.9	86.3	78.0
4.3d	1964-71	8	692.1	278.0	414.0	-136.0	86.5
4.3e	1971-84	14	672.7	314.1	358.7	-44.6	48.1
4.3f	1984-98	15	359.1	162.6	196.6	-34.0	23.9
4.3g	1998-02	5	217.5	143.7	73.8	69.9	43.5
4.3h	2002-06	5	222.1	72.1	149.9	-77.8	44.4

Hydrographs created from USGS mean daily flow data show five events from 1937 to 1953 where the mean daily flow measured above 13,500 cubic feet per second (cfs) and two events measured above 23,500 cfs. All five larger flood events were short in duration (Figure 4.3a). A logarithmic plot of the same data (Figure 4.3b) shows that smaller flows (higher frequency events) were also short in duration from 1937 to 1953.

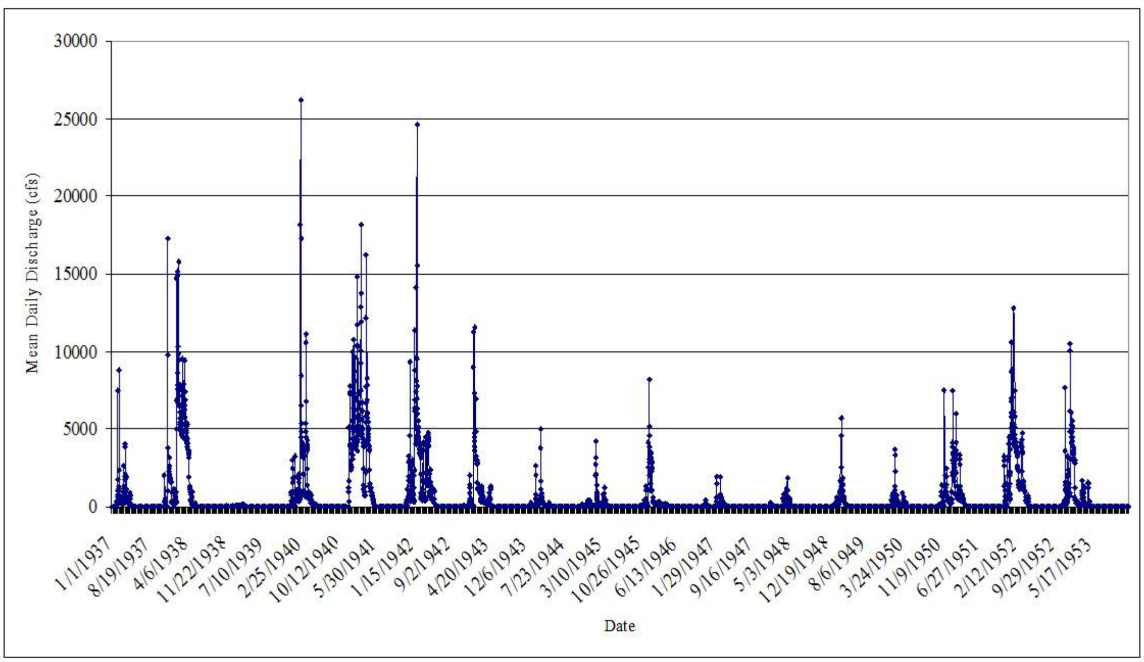

Figure 4.3a Hydrograph of Average Daily Flow - Cache Creek at Yolo 1937-1953 (Linear Scale)

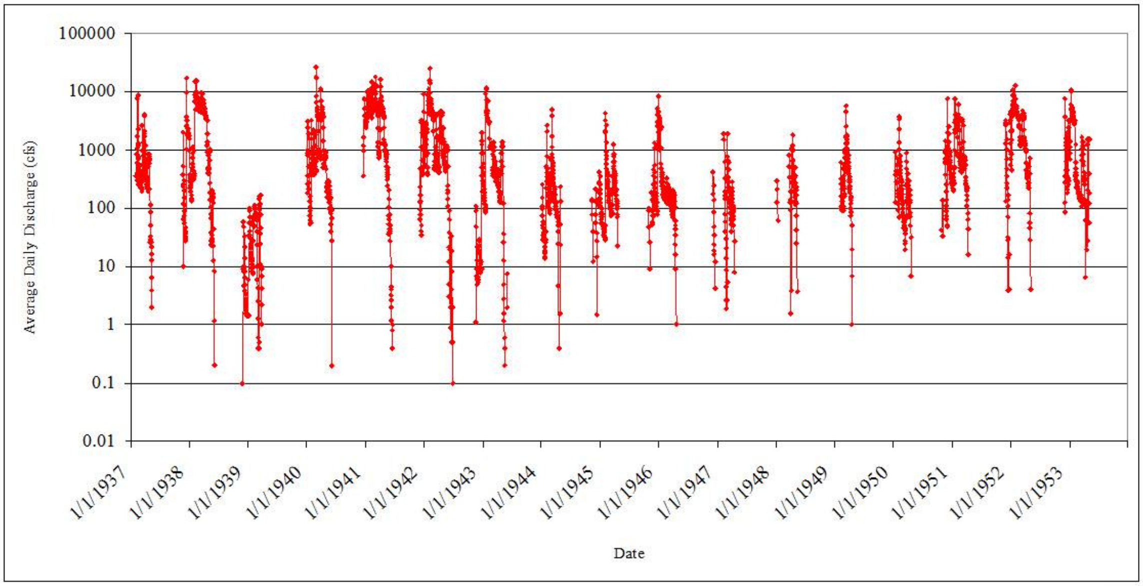

Figure 4.3b Hydrograph of Average Daily Flow - Cache Creek at Yolo 1937-1953 (Logarithmic Scale)

Discussion

Seventeen years elapsed between aerial photograph datasets (1937 to 1953) available for evaluation. Little commercial aggregate mining occurred during this time and the Capay Dam was already in operation. There is no aerial photography data prior to the construction of the 1914 Capay Dam, thus it cannot be determined what effect unaltered stream flow would have on stream migration. For this early time period (1937 - 1953), changes in channel migration are correlated primarily to natural flood events moderated by the Capay Dam and not significantly related to mining.

This comparison dataset is the longest in duration, shows the most total area affected, and the most net difference in acreage affected by stream migration. When this is averaged over the 17-year time span, a moderate amount of land area (52.2 acres) is affected each year (Table 4.3a). The large amount of area affected in this dataset appears only to be related to the number of years between the two datasets.

4.2.2 – Bank Erosion and Deposition – 1953 to 1957

Results

The channel comparison from 1953 to 1957 is much shorter in duration than the previous comparison, and less migration occurred on Cache Creek (Figure 4.4).

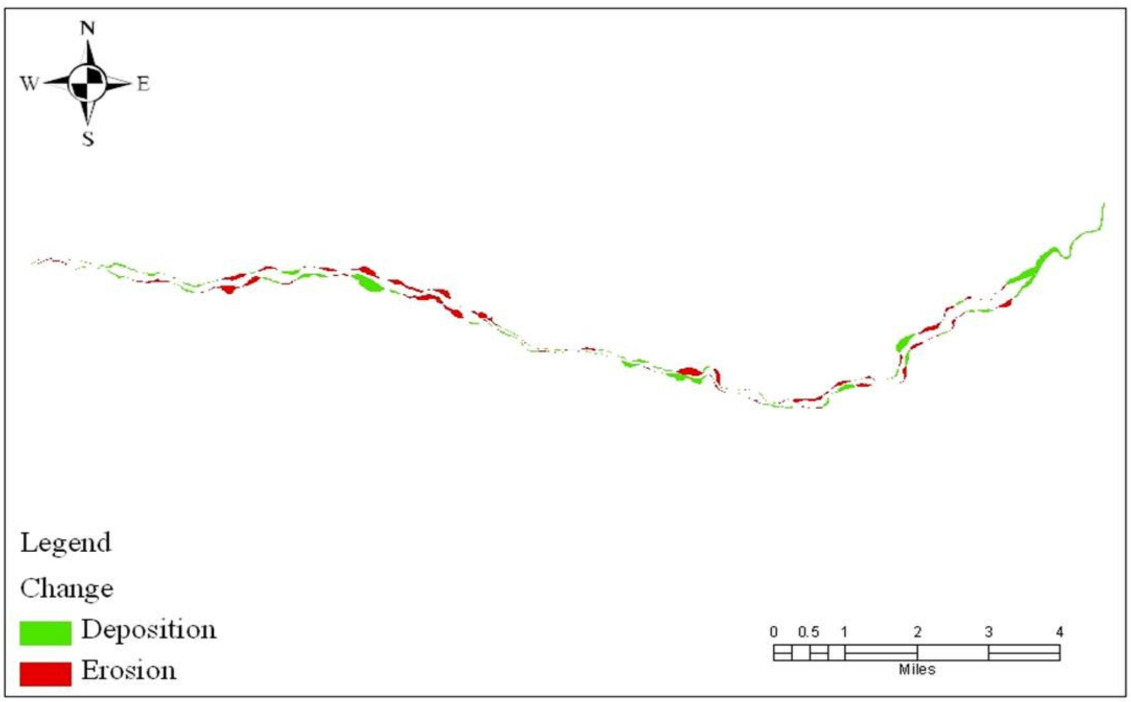

Figure 4.4 Channel Comparison Map 1953-1957

The total affected area in this comparison is 517.3 acres with an average of 103.5 acres affected per year. Two hundred forty seven (247) acres were eroded, 270 acres deposited for a net change of 23.0 acres deposition (Table 4.3b).

Mean daily flow data shows only two flood events measuring above 13,500 cfs (2-year flood frequency), with no other events recorded above a 23,500 cfs (5-year flood frequency) (Figure 4.5a-b). One long duration event was recorded between 1955 and 1956 with mean daily flows recorded above 2500 cfs for nearly two months.

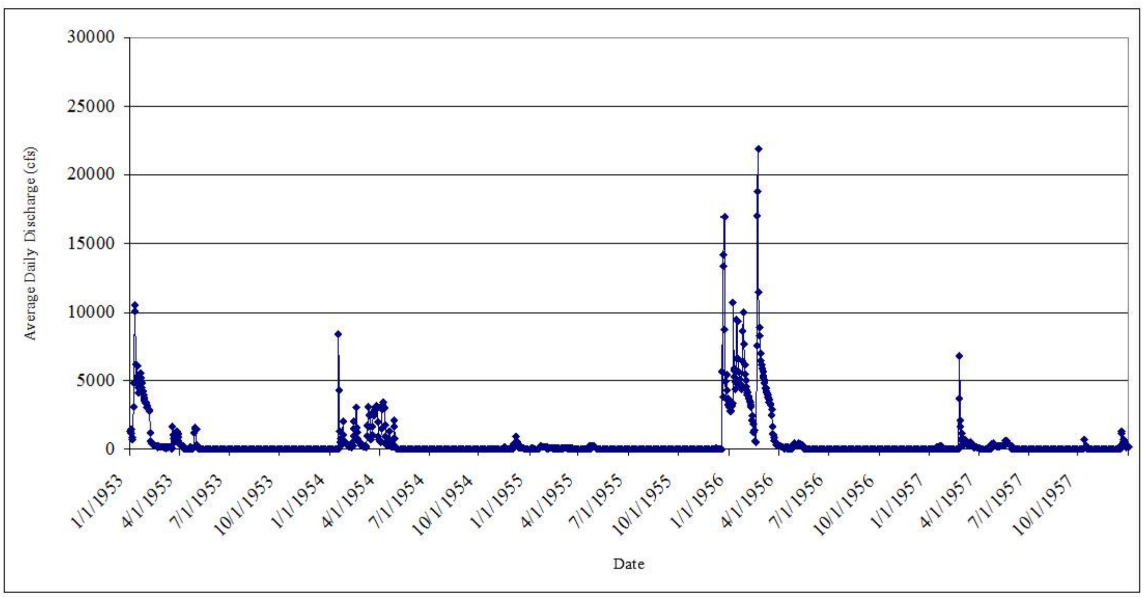

Figure 4.5a Hydrograph of Average Daily Flow - Cache Creek at Yolo 1953-1957 (Linear Scale)

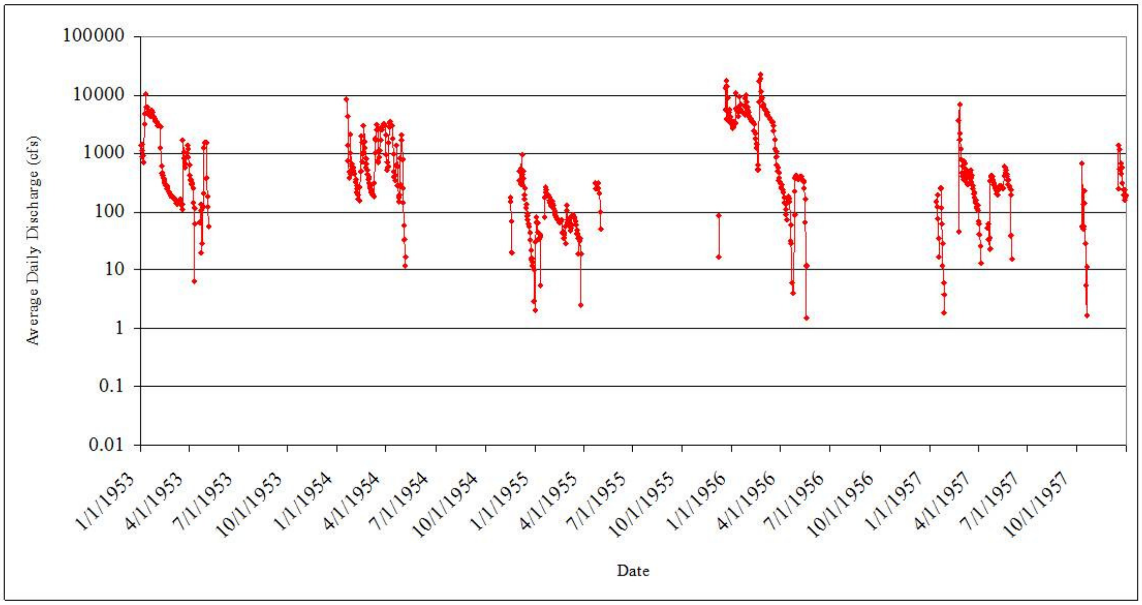

Figure 4.5b Hydrograph of Average Daily Flow - Cache Creek at Yolo 1953-1957 (Logarithmic Scale)

Discussion

This dataset spans only 5-years; however, the analysis shows that 103.5 acres/year were affected during this short period of time (Table 4.3b). There is no correlation between the number of mean daily flow events and sediment moved. An elevated flow continuing over an extended period of time may be the link to effective channel migration. In this time span, it is difficult to separate the natural stream migration from the effect of mining, because this is a period of time where aggregate mining was beginning to significantly increase. The migration of the channel may have been affected most by the excavation of aggregates from the channel.

4.2.3 – Bank Erosion and Deposition – 1957 to 1964

Results

There is a moderate amount of channel migration in the 1957 to 1964 comparison dataset (Figure 4.6). There were 355.1 acres of deposition and 268.9 acres of erosion, with a difference of 86.3 acres of net deposition. Total affected area measured 624.0 acres, averaging 78.0 affected acres per year (Table 4.3c). There are four events that average between or above the 2 to 5-year flood frequency and one very large event in 1958 where the mean daily flow measured 29,300 cfs.

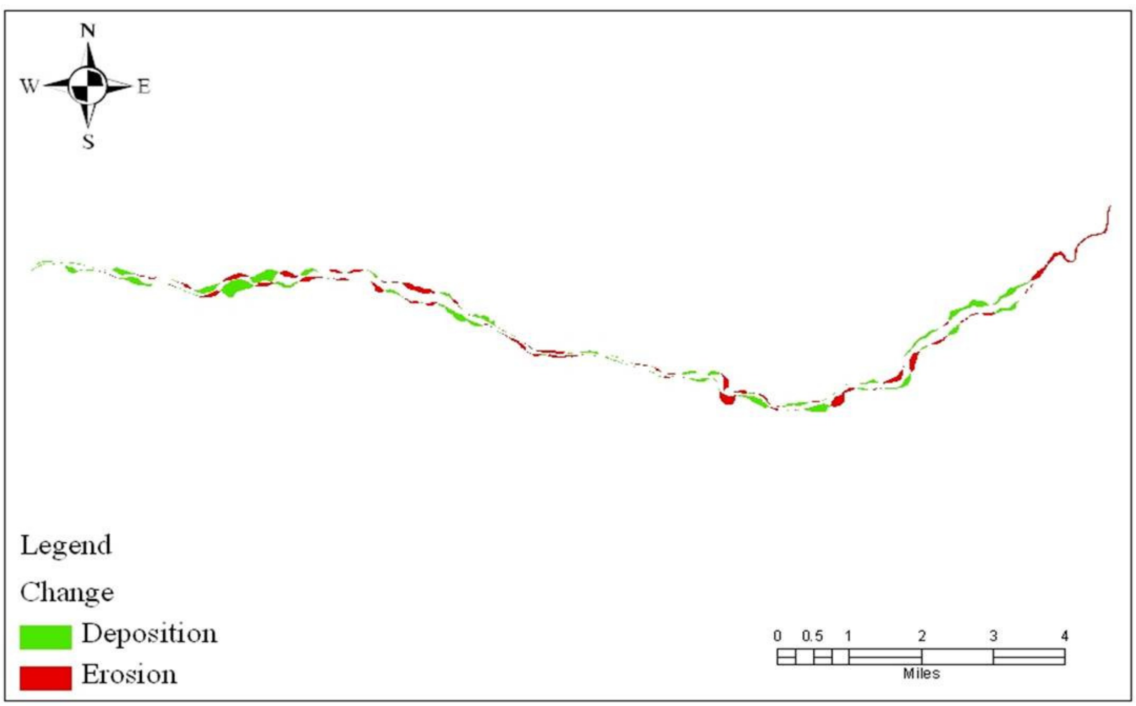

Figure 4.6 Channel Comparison Map 1957-1964

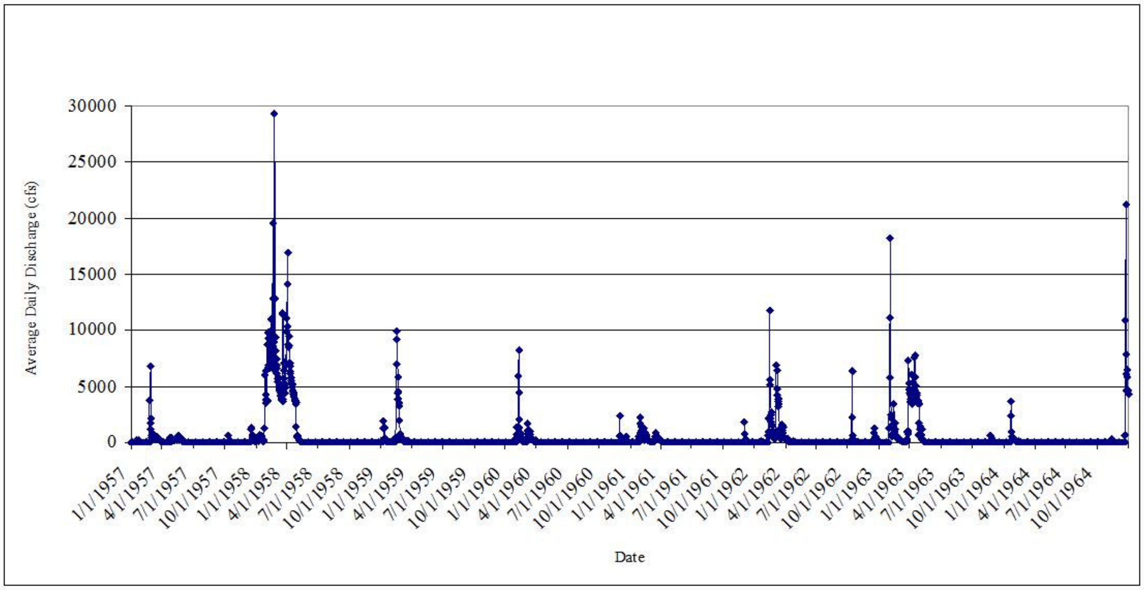

Figure 4.7a Hydrograph of Average Daily Flow - Cache Creek at Yolo 1957-1964 (Linear Scale)

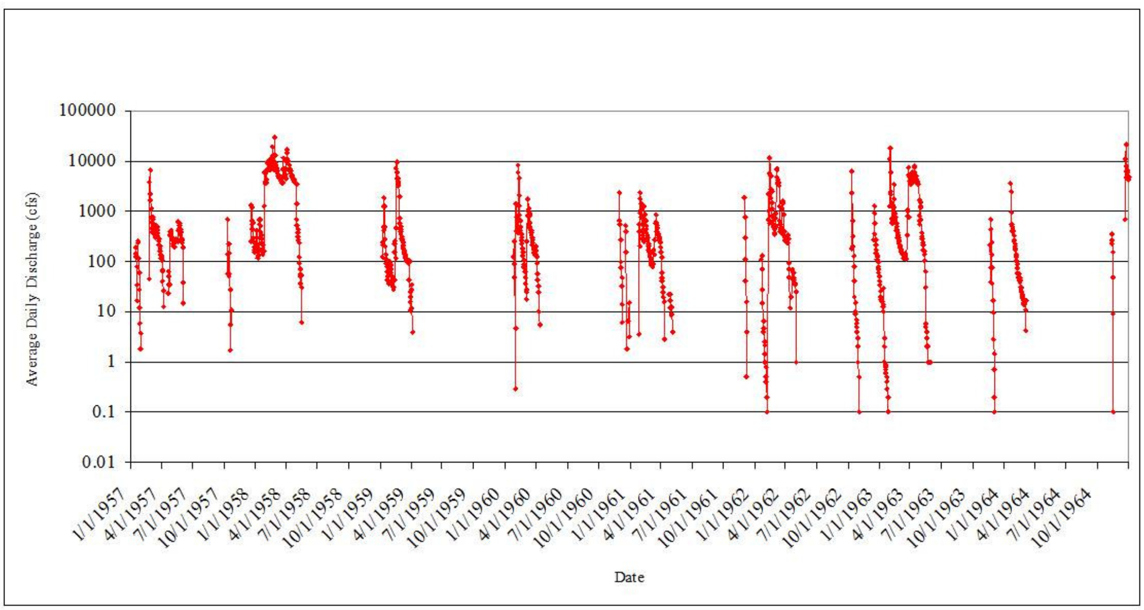

Figure 4.7b Hydrograph of Average Daily Flow - Cache Creek at Yolo 1957-1964 (Logarithmic Scale)

This falls in the 10 to 50-year flow frequency category (Figure 4.7a-b). Mean daily flows greater than 2500 cfs was recorded from January 26 to April 29, 1958 (94 days). The largest recorded annual peak flow (41,400 cfs) at the Yolo gage was recorded on February 25, 1958 (Figure 4.1).

Discussion

There are distinct stream reaches in the 1957 to 1964 comparison that show large amounts of migration (Figure 4.6). These areas of migration are located in and around aggregate production facilities. One mean daily flow event with flows greater than 2,500 cfs was recorded for 94 days in early 1958. In those days there are 3 separate long duration average daily flows ≥ 5000 cfs. These prolonged events lasted 35-days, 6-days, and 18-days. The single largest annual peak flow event was recorded at 41,400 cfs during this same period in 1958. This peak flow event ranks just below the 50-year flood frequency recurrence interval (Figure 4.1). Mining, flood duration, and flood intensity are factors having contributed to the high number of acres affected per year (78.0 acres/year).

4.2.4 – Bank Erosion and Deposition – 1964 to 1971

Results

There is a large amount of channel migration between 1964 and 1971. There are areas with significant shifts in the channel and other areas where very little shift has occurred (Figure 4.8).

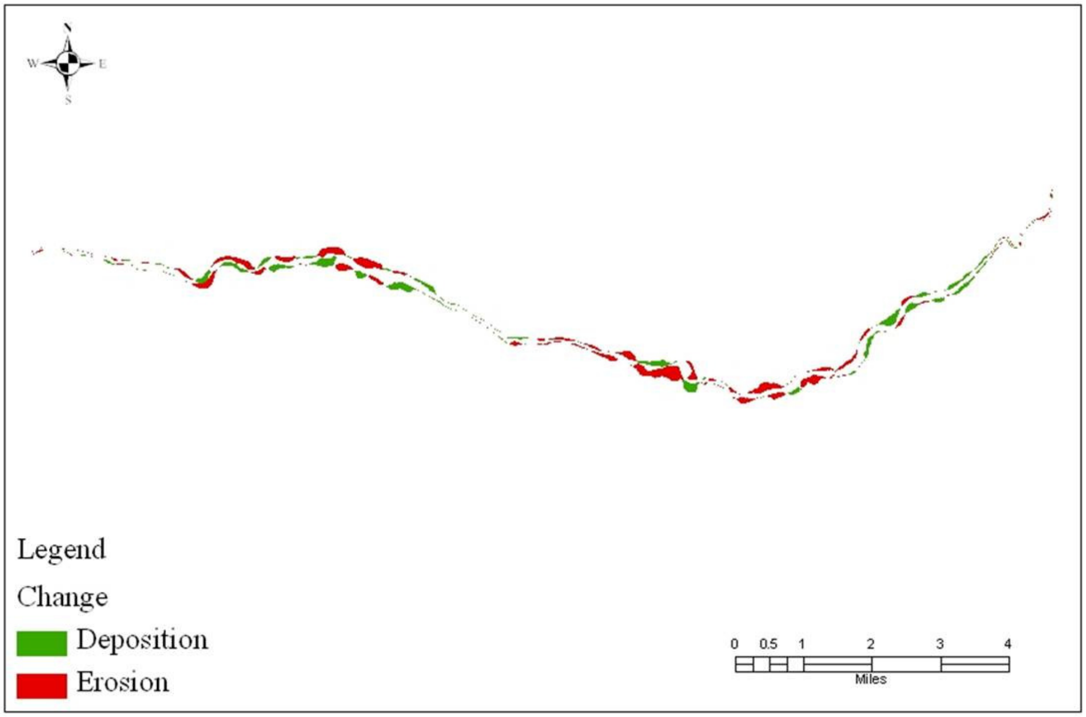

Figure 4.8 Channel Comparison Map 1964-1971

Areas of erosion totaled 414.0 acres where deposition occurred on 278.0 acres, thus leaving a net 136.0 acres of eroded area. The total affected area equaled 692.1 acres and averaged 86.5 acres/year of affected land (Table 4.3d).

The hydrographs illustrate five mean daily flow events occurring at or above the 2-year flood frequency and two events occurring above the 5-year flood frequency (Figure 4.9a-b). There are seven mean daily flow events with flows $\geq$ 5,000 cfs lasting for five or more days.

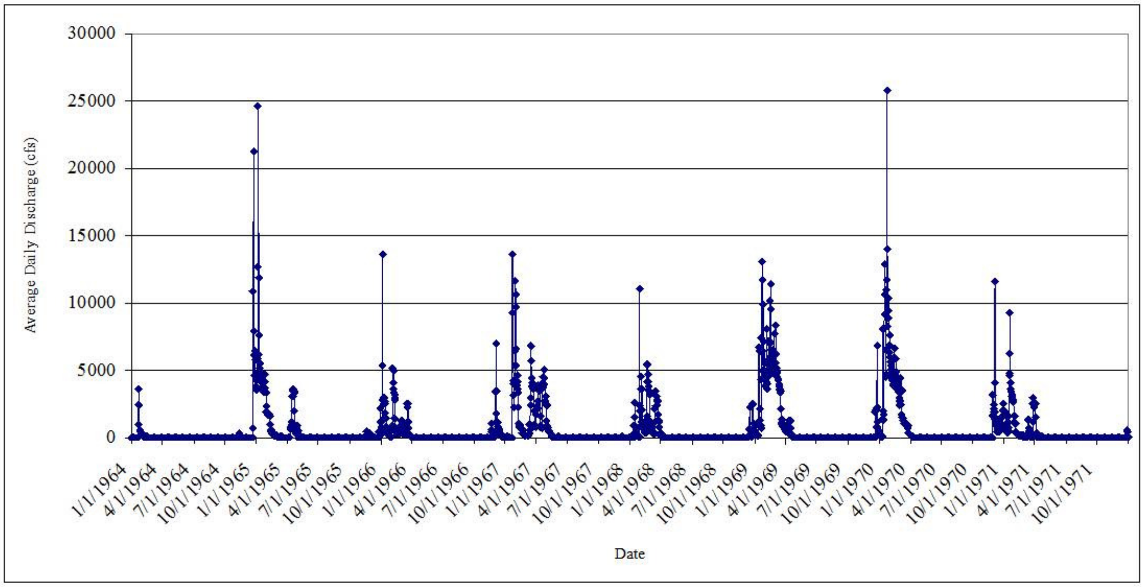

Figure 4.9a Hydrograph of Average Daily Flow - Cache Creek at Yolo 1964-1971 (Linear Scale)

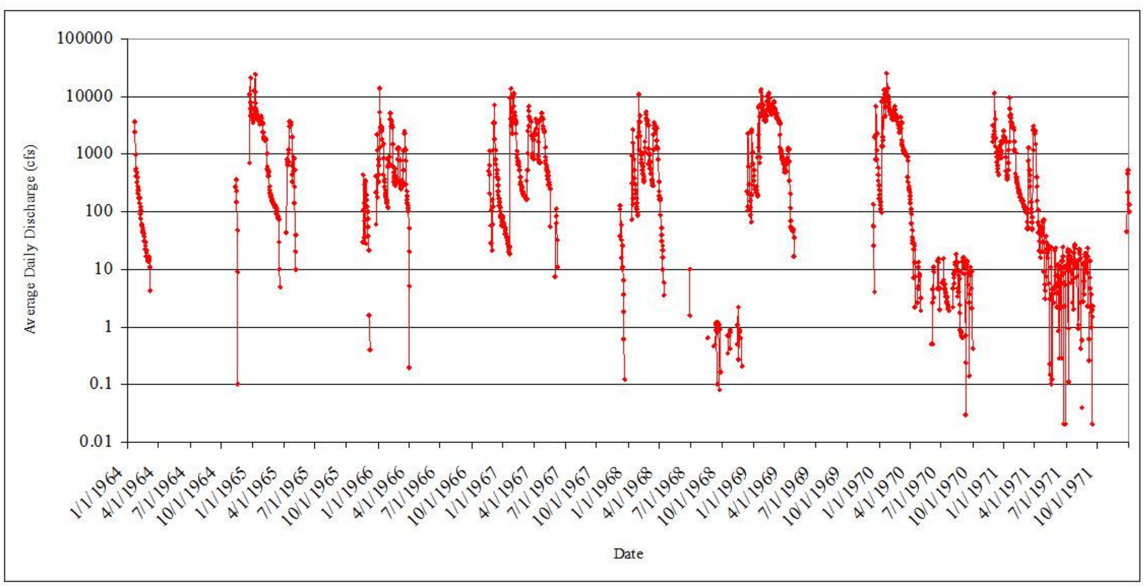

Figure 4.9b Hydrograph of Average Daily Flow - Cache Creek at Yolo 1964-1971 (Logarithmic Scale)

Discussion

The 1964 to 1971 dataset has a large amount of affected land area (692.1 acres) and a high number of acres affected per year (86.5 acres/year) (Table 4.3d). The number three and number five highest ranked annual peak flows were recorded during this time (1964-1971). Similarly, there were a considerable number of moderate flow events lasting long periods of time. Aggregate excavation quantities ranged from 1.5 million tons to 2.5 million tons per year within the study area during this period (Figure 4.10). It is reasonable to conclude that long duration moderate mean daily flows, annual peak events, and mining contributed to the high amount of channel migration.

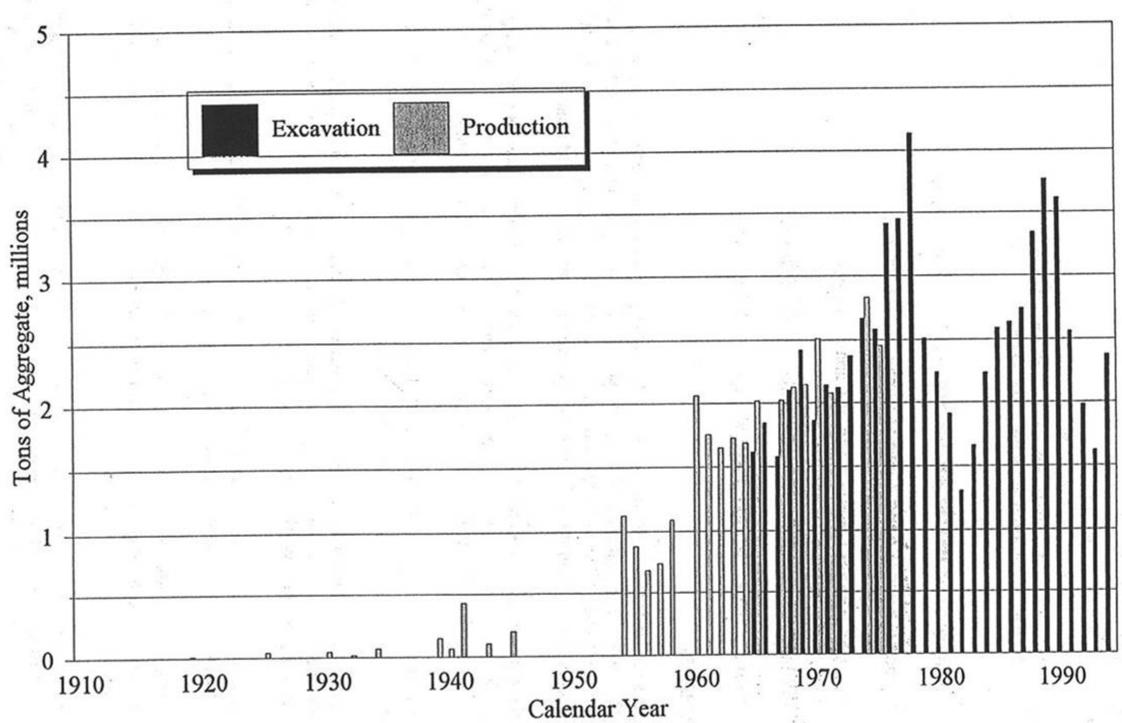

Figure 4.10 Cache Creek Aggregate Extraction/Production from 1919-1995 (NHC 1995 Technical Studies)

4.2.5 – Bank Erosion and Deposition – 1971 to 1984

Results

From 1971 to 1984, the upstream one-third of the study area shows large channel changes, mostly erosion, where the downstream two-thirds portion of the Cache Creek has smaller areas of migration (Figure 4.11).

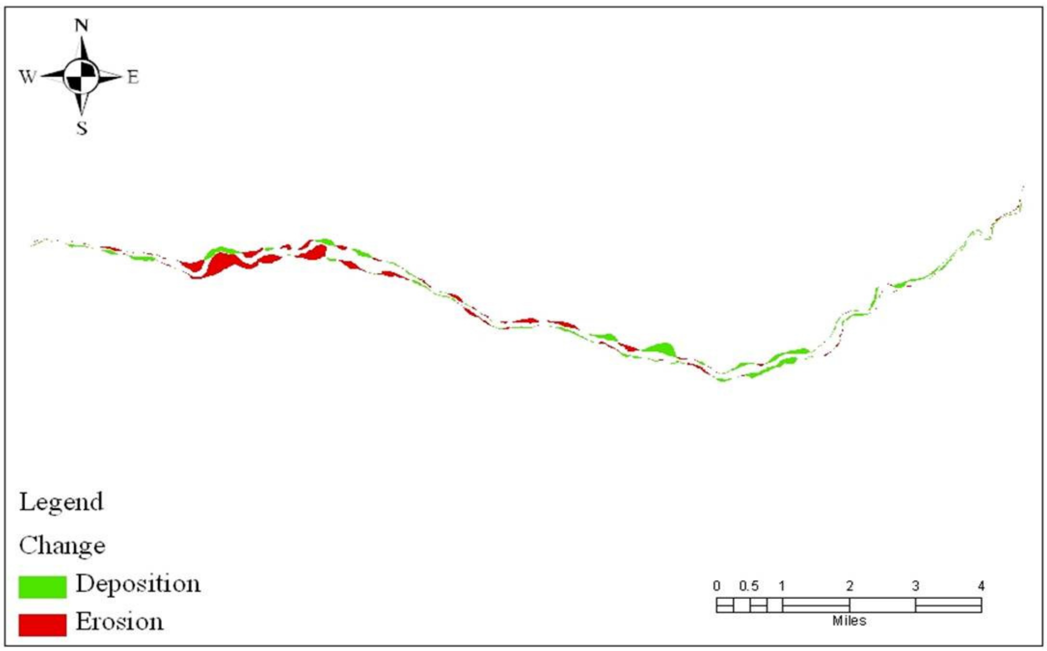

Figure 4.11 Channel Comparison Map 1971-1984

The total affected area equals 672.7 acres with 314.1 acres being that of deposition and 358.7 acres of erosion. The net difference is 44.6 acres of erosion. Average annual affected area was calculated 48.1 acre/year (Table 4.3e).

Data in Figures 4.12a-b identify ten separate times when mean daily flow events ≥ 5,000 cfs have a duration lasting six or more days. Fifteen days of mean daily flows above 13,500 cfs were recorded during this period (1971 to 1984). One average daily flow was recorded above 23,500 cfs.

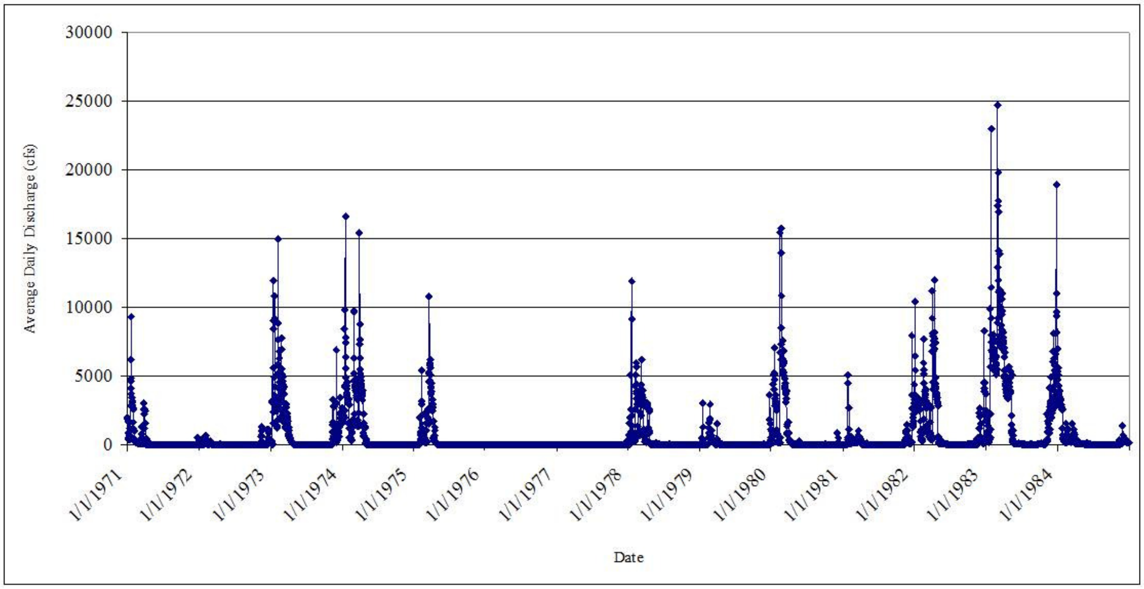

Figure 4.12a Hydrograph of Average Daily Flow - Cache Creek at Yolo 1971-1984 (Linear Scale)

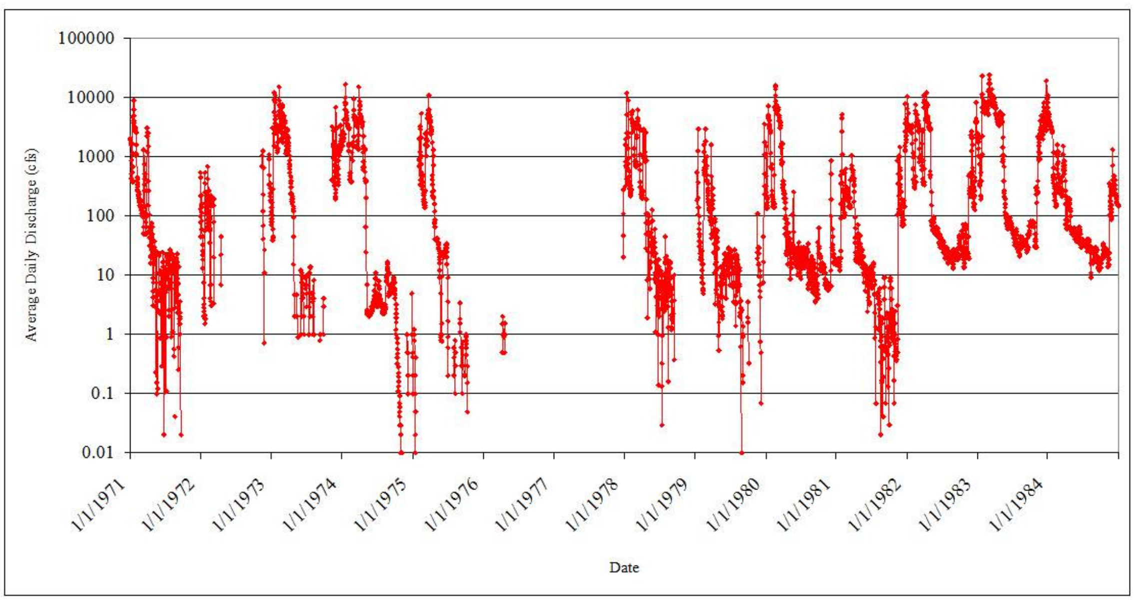

Figure 4.12b Hydrograph of Average Daily Flow - Cache Creek at Yolo 1971-1984 (Logarithmic Scale)

Discussion

The 1971 to 1984 comparison dataset spans 14-years and the overall area affected by channel migration is moderate in extent (672.7 acres), however the average affected acres per year is fairly low (48.1 acres/year) in comparison with other datasets. The upstream one-third of the study area is the most affected by stream migration with the majority being erosion. In this upstream area showing the most channel migration there are no signs of active mining seen from the aerial photographs; however Figure 4.10 shows that overall aggregate extraction within the study area was at its highest level.

Long-term low to moderate mean daily flows resulted in the majority of channel migration. Although active mining was not the direct cause of the upstream channel migration, it can be concluded that the overall extraction of aggregate and several moderate flow events may have played an indirect roll in some of the channel movement.

4.2.6 – Bank Erosion and Deposition – 1984 to 1998

Results

The comparison map illustrates little channel migration between 1984 and 1998. It was calculated that 162.6 acres of deposition and 196.6 acres of erosion occurred during this time. Slightly more change can be seen in the upstream half of the study area (Figure 4.13). Table 4.3f shows a total affected area of 359.1 acres and a mere 34.0 acres of net erosion and an average affected area of 23.9 acres/year within this period of time.

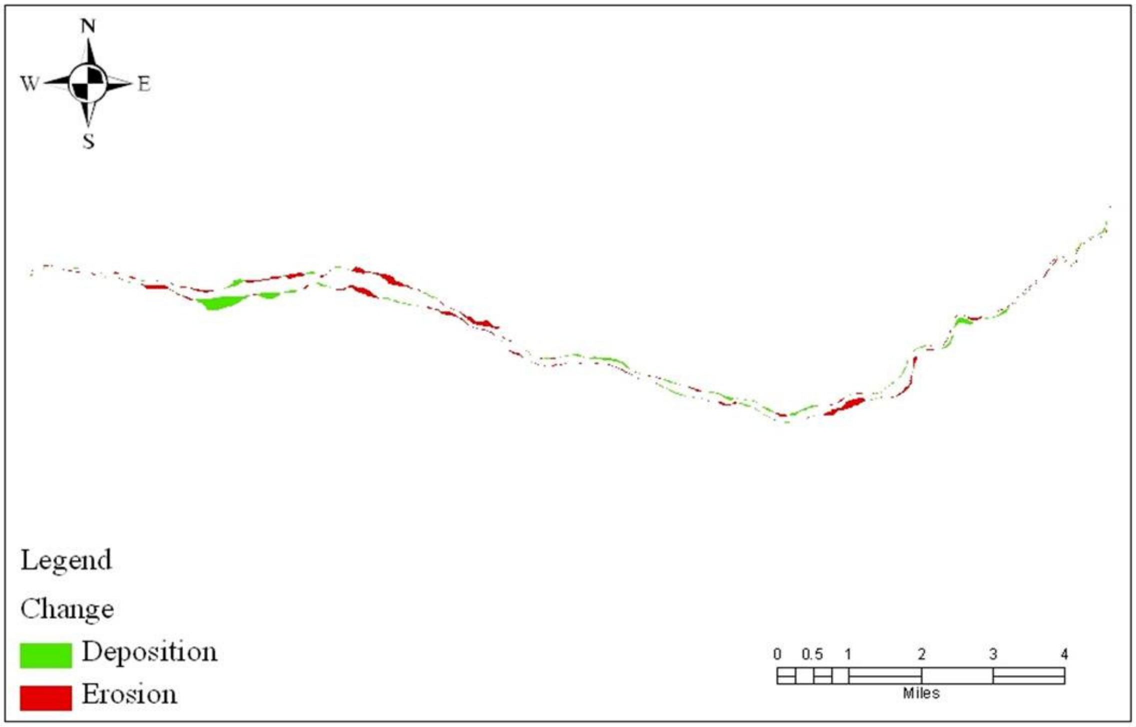

Figure 4.13 Channel Comparison Map 1984-1998

Figure 4.14a-b and show many periods of elevated mean daily flows lasting for two days or longer from 1984 to 1998. These periods of extended duration of elevated mean daily flows show that fifteen separate events had an average daily flow of more than 5,000 cfs and six events were elevated to more than 13,500 cfs (2-year frequency). Two separate days were recorded as having a mean daily flow surpassing the 5-year frequency of 23,500 cfs.

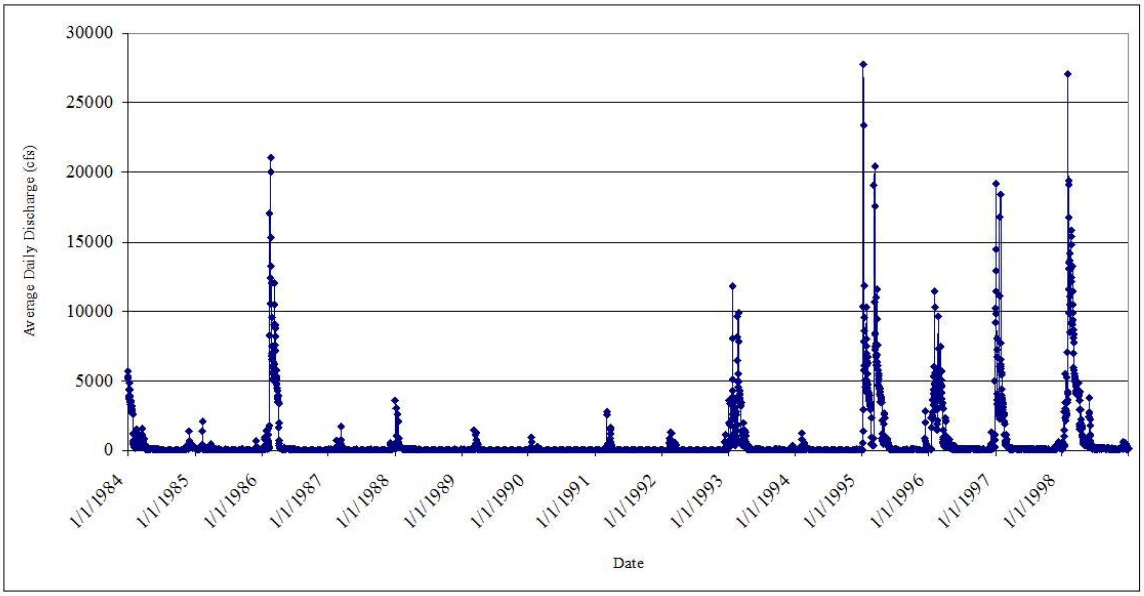

Figure 4.14a Hydrograph of Average Daily Flow - Cache Creek at Yolo 1984-1998 (Linear Scale)

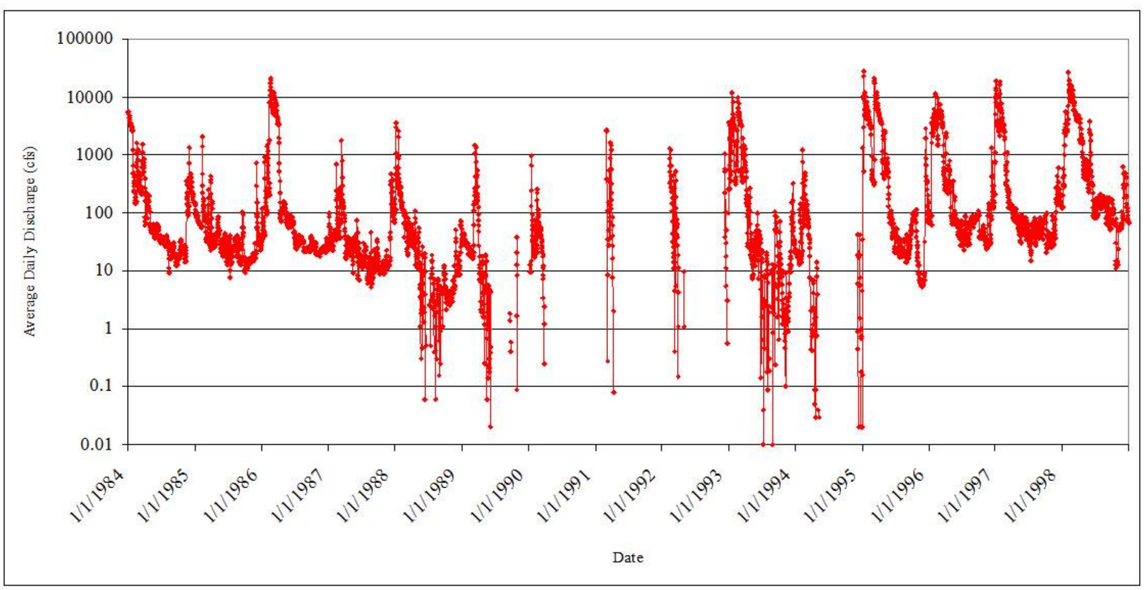

Figure 4.14b Hydrograph of Average Daily Flow - Cache Creek at Yolo 1984-1998 (Logarithmic Scale)

Discussion

The fifteen years between the 1984 to 1998 aerial images illustrates a period of time where little stream migration occurred while many long duration and high magnitude mean daily flow events were recorded. In 1996, aggregate mining shifted from in-channel to off-channel locations. This temporal dataset includes 13 years of in-channel mining and two years when no mining occurred in-channel. Between 1996 and 1998, no mining occurred in the channel and large earthen levees were constructed for flood protection.

As flow velocity increases in a stream, quantities of sediments carried as suspended load and bedload increases (Ritter, Kotchel, and Miller, 2002). There were many events of moderate to high flows from 1984 to 1998, thus it is assumed that increase sediments were transported in Cache Creek. Little channel movement occurred during this time. It can be concluded that the two years of no in-channel mining, and levee construction in the study area is probably the reason there was so little stream migration over the span of 15 years.

4.2.7 – Bank Erosion and Deposition – 1998 to 2002

Results

Very little channel migration occurred from 1998 to 2002 along the entire study area (Figure 4.15).

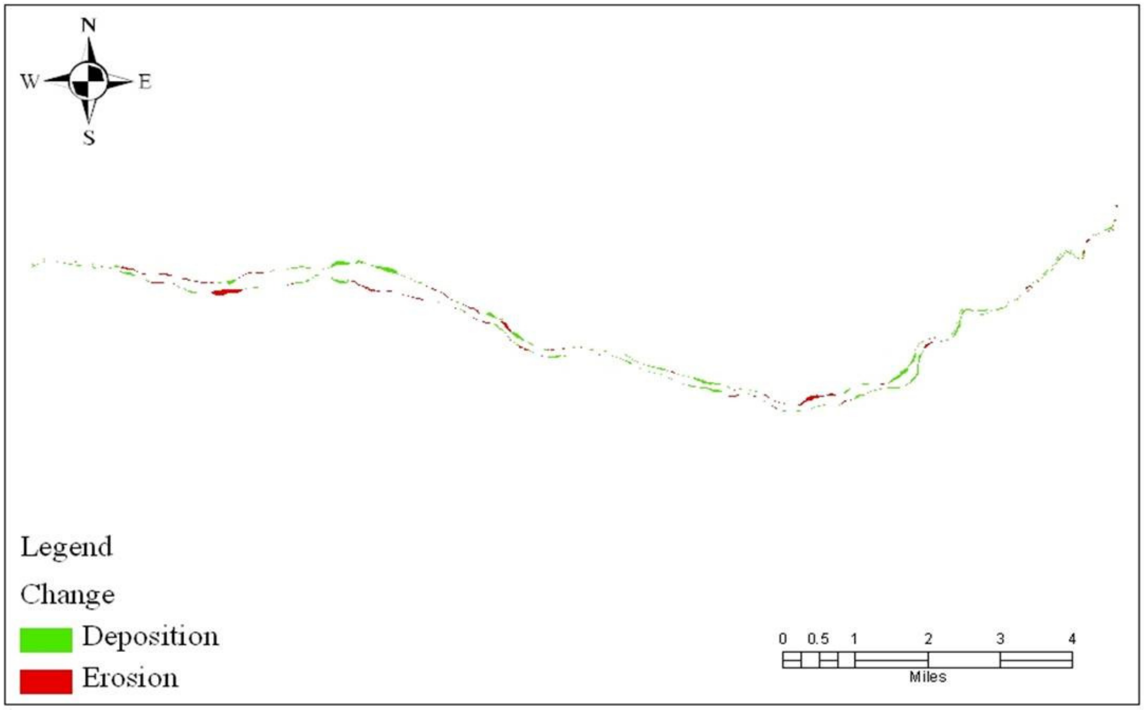

Figure 4.15 Channel Comparison Map 1998-2002

This is evident from the calculated areas of change. There were 143.7 acres of total deposition and 73.8 acres of total erosion during this period of time with a net deposition of 69.9 acres. Only 217.5 acres of land was affected for an average of 43.5 acres/year.

Although there were several periods of low mean daily flow averages (<5,000 cfs) over extended periods of time, there were only two mean daily flow events that exceeded the 2-year frequency; one was an event in 1998 that measured 27,100 cfs, well above the 5-year frequency (Figure 4.16a-b).

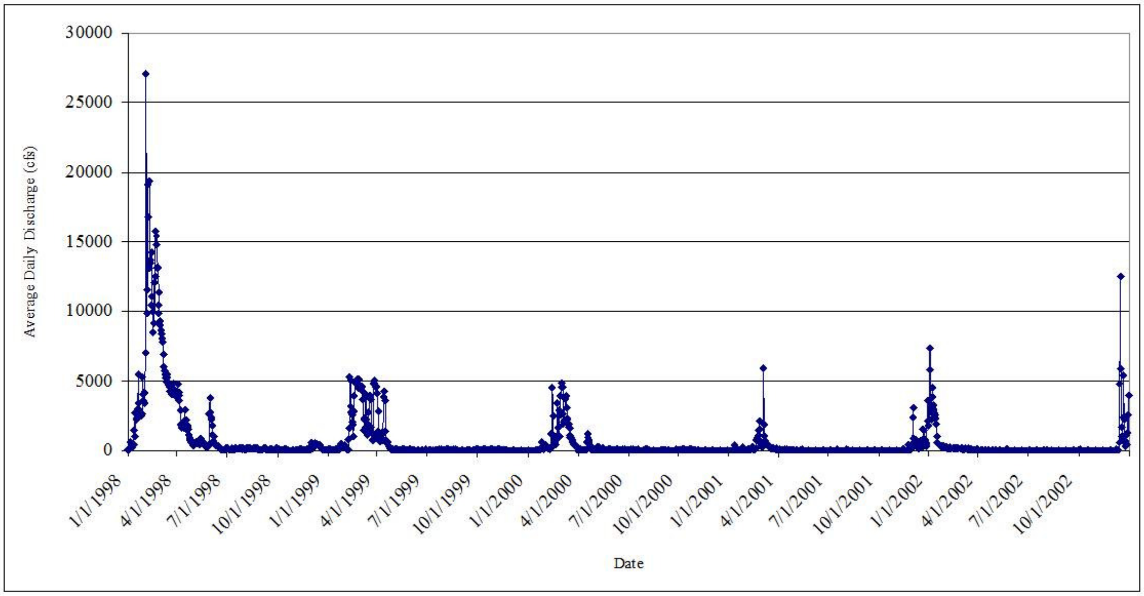

Figure 4.16a Hydrograph of Average Daily Flow - Cache Creek at Yolo 1998-2002 (Linear Scale)

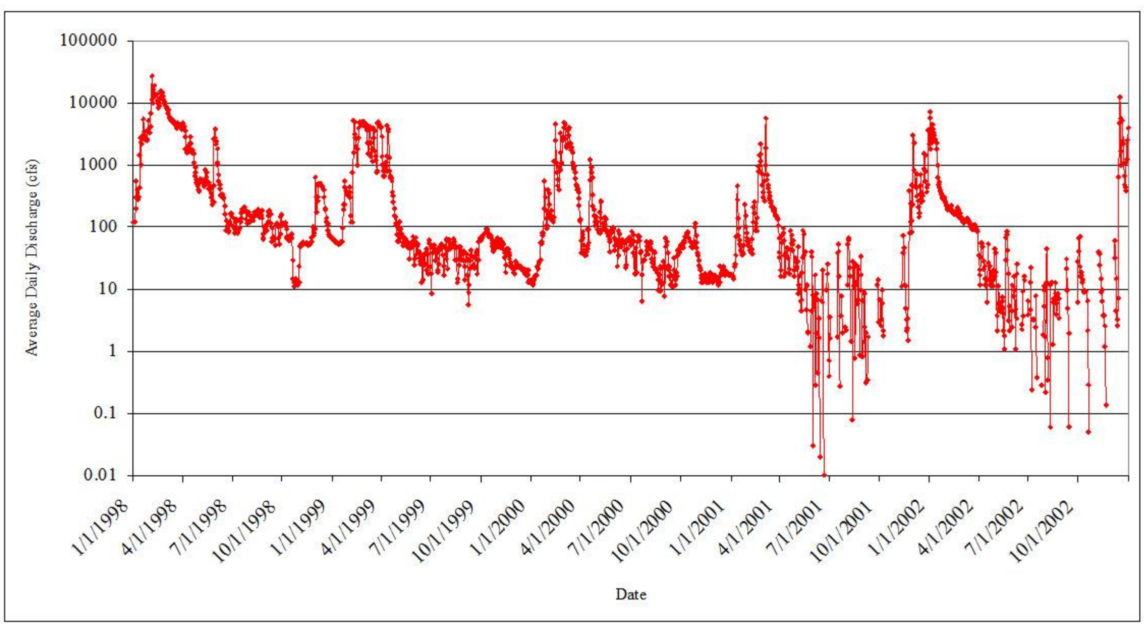

Figure 4.16b Hydrograph of Average Daily Flow - Cache Creek at Yolo 1998-2002 (Logarithmic Scale)

Discussion

Of the eight comparison datasets evaluated in this study, the 1998 to 2002 comparison had the least amount of affected land area at an average of 43.5 acres affected per year. One period of low to moderate flows which lasted 41 days in 1998 (>2-year frequency) was recorded in this five year period. Although there was a long period of moderate flow event and a moderately large flood event, little channel migration occurred. This indicates that large magnitude and long duration flood events had little effect on stream migration during this period of time.

4.2.8 – Bank Erosion and Deposition – 2002 to 2006

Results

The final dataset depicts another five-year comparison with little land being affected by channel migration (Figure 4.17). It was calculated that 79.1 acres were deposited and 149.9 were erosion, resulting in a net of 77.8 acres of erosion. The total area affected equaled 222.1 acres, averaging 44.4 acres/year (Table 4.3h).

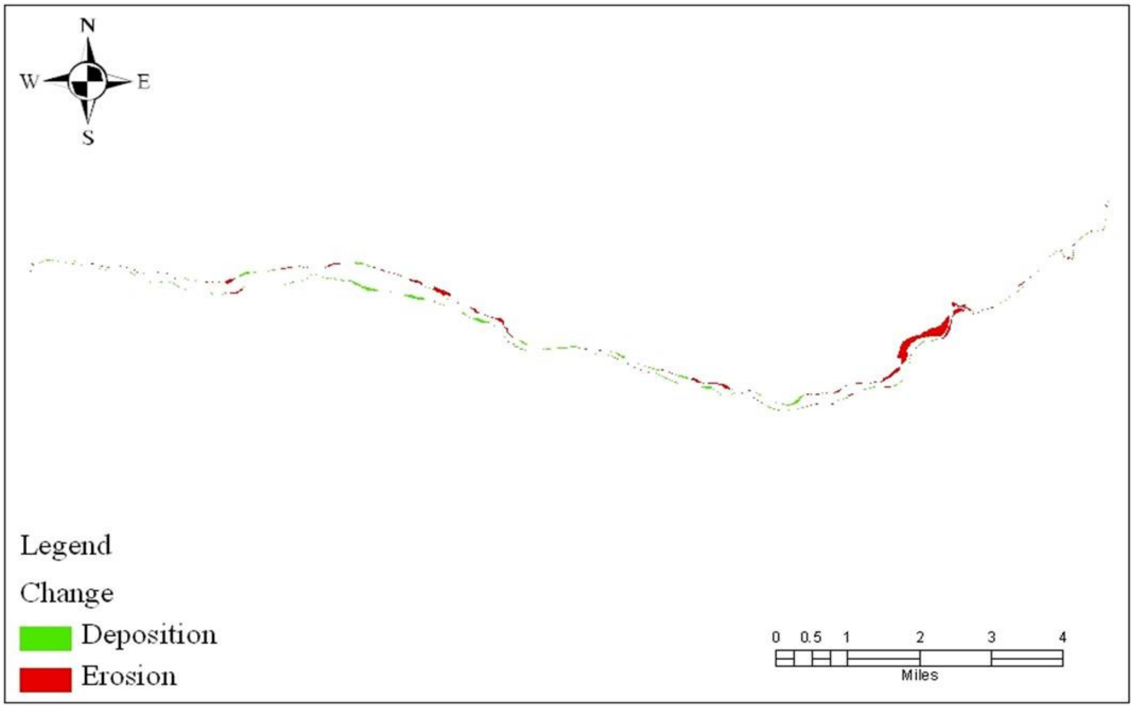

Figure 4.17 Channel Comparison Map 2002-2006

One mean daily flow event is shown in figures 4.18a-b exceeding the 2-year flood frequency and the events are short in duration. The 2002 to 2006 comparison dataset saw only one mean daily flow event exceeding the 2-year flood frequency (Figures 4.18a-b), whereas three annual peak flows surpassed the 2-year frequency and one surpassed both 5-year and 10-year frequencies (Figure 4.1).

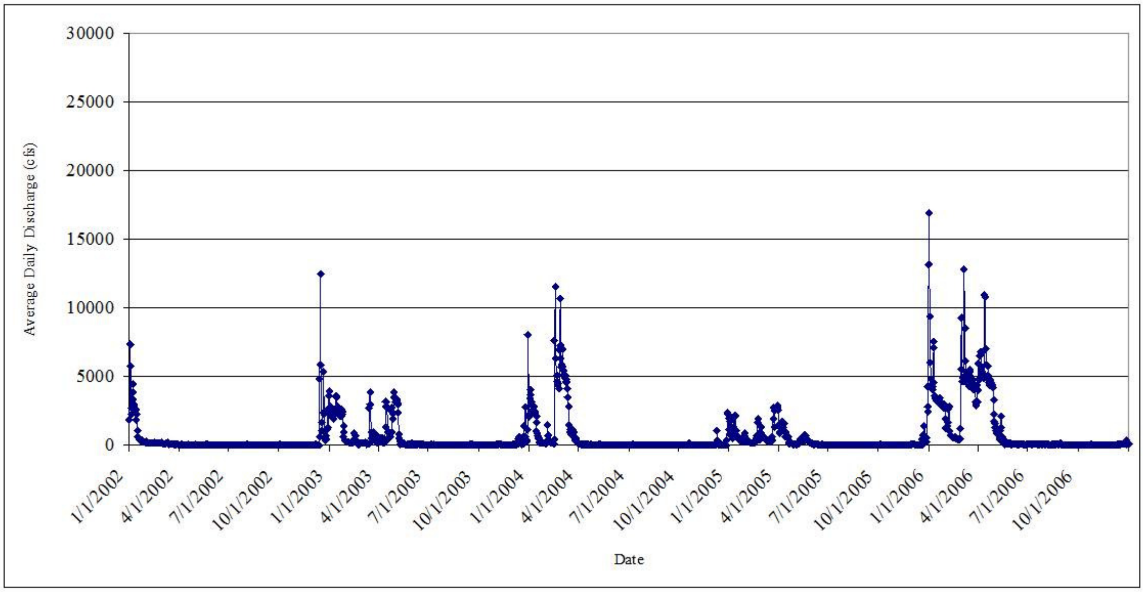

Figure 4.18a Hydrograph of Average Daily Flow - Cache Creek at Yolo 2002-2006 (Linear Scale)

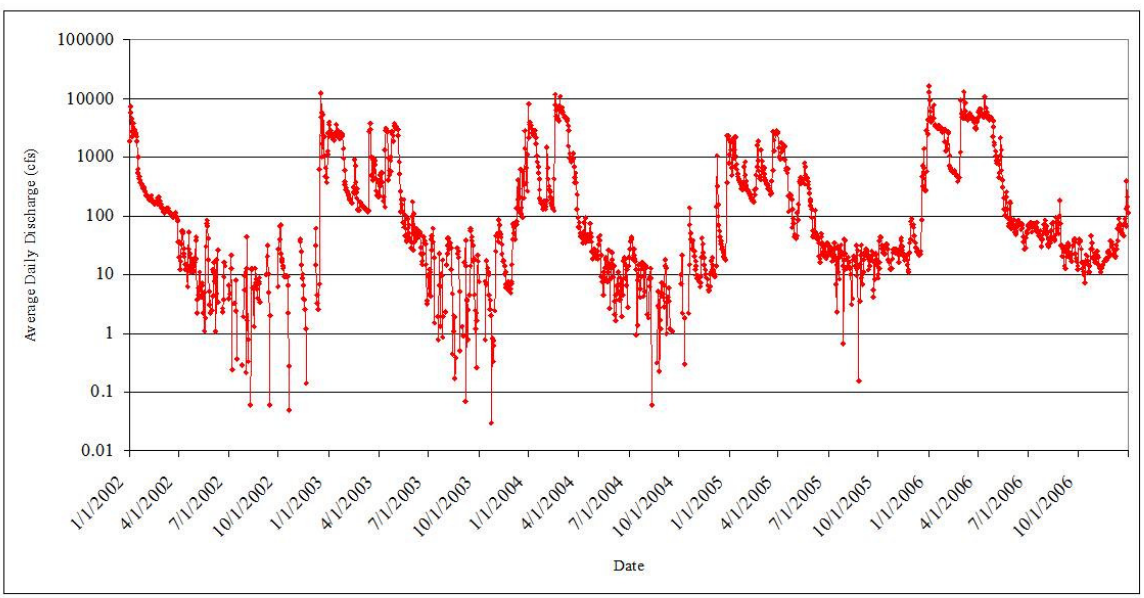

Figure 4.18b Hydrograph of Average Daily Flow - Cache Creek at Yolo 2002-2006 (Logarithmic Scale)

Discussion

No continuous long lasting flows were recorded. Few flood events and few long duration flows are responsible for a total of 222.1 acres affected, which averages 44.4 acres per year. This limited erosion occurred at a time when all mining was conducted off-channel, and levee construction continued.

4.3 - Longitudinal Profile

Results

Longitudinal profiles from 1905, 1953, 1981, 1994, and 2006 were graphed in Microsoft Excel and elevations compared (Figure 4.19).

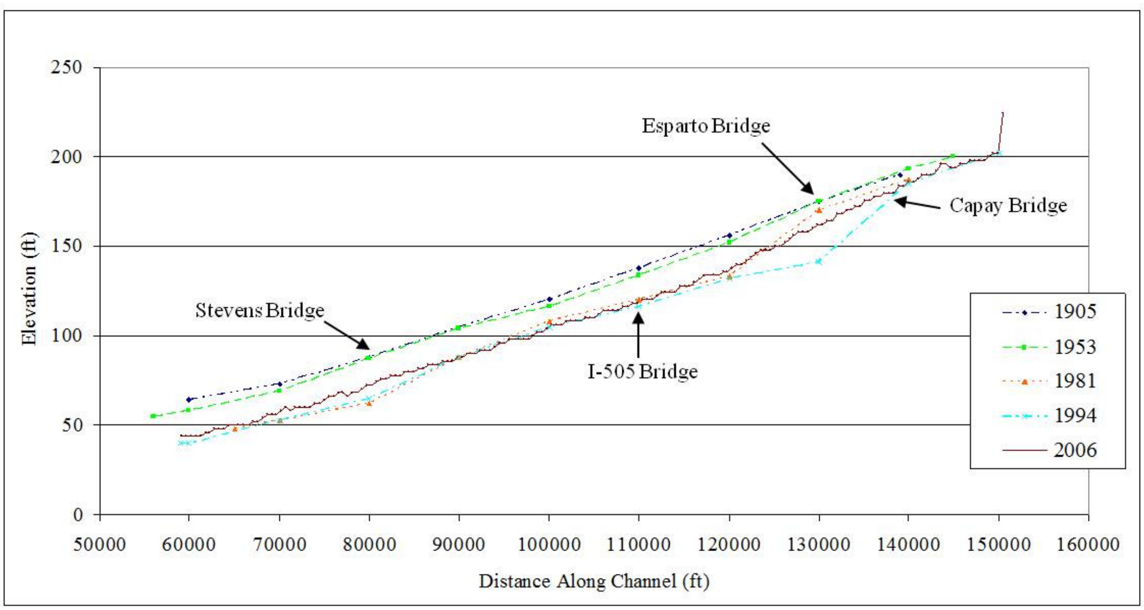

Figure 4.19 Graph of Longitudinal Profiles (Capay Dam to I-5 Overcrossing)

The elevation of the channel consistently decreases from 1905 to 1994. Significant decrease in elevation is noted between 1953 and 1981 along the entire study area. Between 1981 and 1994, the bed elevation was stable over most of the study area with the exception of the channel between river mile 22.6 and 26.4 (County Roads 88B and 85). During this period of time the greatest decrease in elevation is measured at the County Road 87 (Esparto) Bridge.

The longitudinal profiles compared between 1994 and 2006 show an increase in elevation of approximately 7-feet from river mile 12.7 to 17.2 (County Roads 18B to 93) and a 20-foot increase from river mile 22.6 to 26.4 (County Roads 88B and 85). The comparison between the 1994 and 2006 longitudinal profiles is the first analysis of sediment movement since commercial in-channel mining stopped in 1996.

Discussion

Longitudinal profiles show that in-channel aggregate mining affected the elevation of the Cache Creek channel from 1905 to 1994. The channel decreased in elevation from as little as 6-feet to as much as 34-feet along the entire study area. The most elevation change is located adjacent to four active mining operations on Cache Creek. A second area of considerable incision is located near two other active mining operations and within the channelized, engineered levees in the Rio Jesus Maria reach. With the passage of the Federal Highway Act of 1944 and other increased needs for high quality aggregate in the Sacramento Valley, commercial aggregate mining boomed in the 1950’s and continues today. Longitudinal comparisons between 1953 and 1994 indicate that in-channel aggregate mining was probably the main cause of channel incision in Cache Creek during this time (Figure 4.19).

With the inception of the Cache Creek Resources Management Plan (CCRMP) in 1996, aggregate mining was forced off-channel. Since 1996, no aggregate has been excavated from within the channel. Comparison of the longitudinal profile between 1994 and 2006 show the majority of elevations in the study area are fairly stable. However, in areas located adjacent to mining operations, the elevations have increased by as much as 21-feet. It can be concluded that aggradation is in fact occurring since aggregate mining moved off-channel. An unforeseen effect of the recent channel aggradation is that flood water conveyance is decreasing due to the aggradation of sediments in Cache Creek.

4.4 - Average Channel Widths

Results

Average widths were calculated for each reach from datasets 1937, 1953, 1971, 1998, 2002, and 2006 (Appendix A), summarized and graphed (Figure 4.20) to determine if widening or narrowing have occurred. Figure 4.20 shows that maximum widening of each reach of the channel occurred on all reaches at some point during commercial in-channel aggregate mining. Since aggregate mining moved off-channel, all reaches, with the exception of the Hoppin Reach, are showing a slight decrease in width.

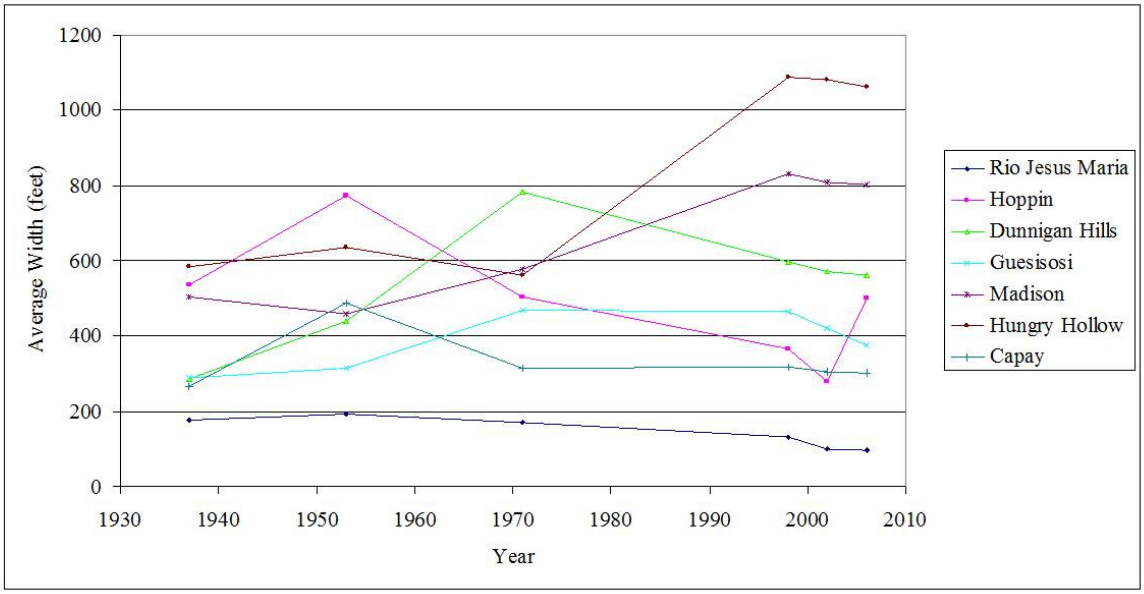

Figure 4.20 Graph of Average Reach Widths (1937, 1953, 1971, 1998, 2002, and 2006)

Discussion

As expected, the channel widths of each reach increased significantly at some point during the 43-years of in-channel aggregate mining. In the last 12-years, all but one reach (Hoppin) is showing signs of narrowing slightly. Considering the narrowing of channel and the significant increase in channel bottom elevation, it can be determined that the flood conveyance capacity of the channel has decreased since mining move off-channel in 1996. Widths in 2006 are still wider than widths in 1937 in all reaches except the Hoppin and Rio Jesus Maria reaches.

If the trend of channel narrowing and aggradation of sediments continue to occur, the 100-year flood protection to cities located along Cache Creek may be compromised.

4.5 - Stream Flow and Affected Area

Results

Affected area is defined in this study as the area where the bank full channel area (acreage) has changed over time. Areas of both deposition and erosion estimated in ArcMap were summed to determine the affected area.

The magnitude and duration of flood events were examined as a cause of channel migration. The total amount of acreage-affected area per year (erosion and deposition) was calculated and graphed for each temporal dataset (Figure 4.21).

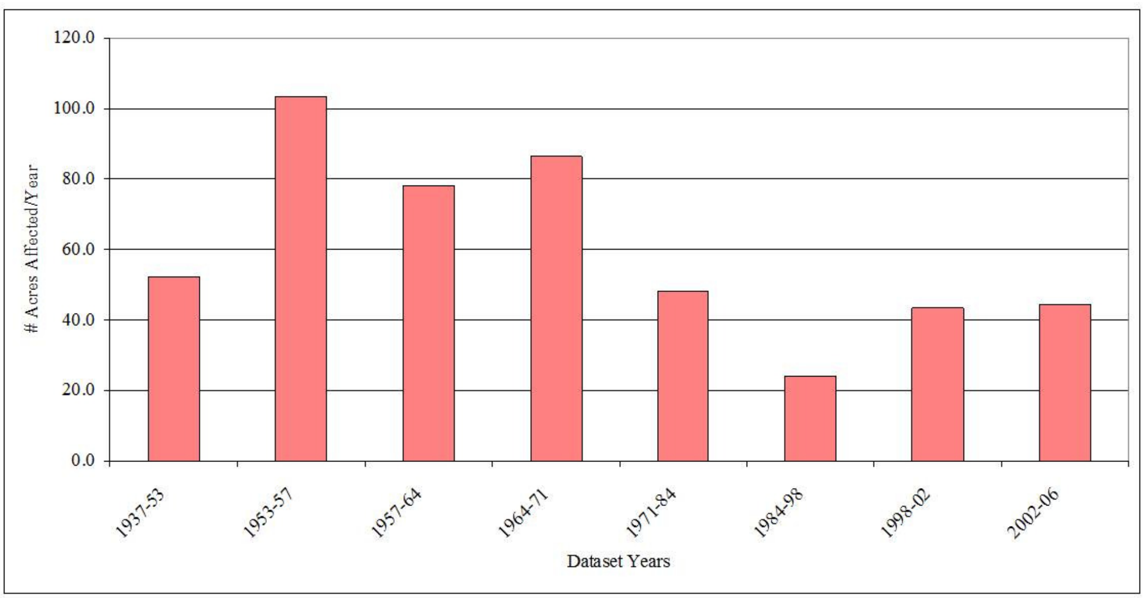

Figure 4.21 Histogram of Areas Affected (Erosion and Deposition) per Year for Each Time Interval Studied

Possible differences appeared by visual inspection in the graph between the earlier datasets (1937-1971) and more recent datasets (1971-2006). Averages and standard deviations were calculated and the datasets spanning 1937 to 1971 averaged 80.0 acres/year of affected area with one standard deviation of 21.4. The recent datasets averaged 40.0 acres/year with a standard deviation of 10.9 (Table 4.4).

Table 4.4 Average Area Affected and Standard Deviations of Temporal Datasets

Years	Avg # Acres Affected/Year	Years	Avg # Acres Affected/Year
1937-53	52.2	1971-84	48.1
1953-57	103.5	1984-98	23.9
1957-64	78.0	1998-02	43.5
1964-71	86.5	2002-06	44.4
AVG	80.0	AVG	40.0
STDEV	21.4	STDEV	10.9

To analyze flood magnitude vs. area affected, the total number of events per year was calculated and graphed for flows ≥5,000 cfs, ≥13,500 cfs, and ≥23,500 cfs. As expected, there are many average daily flow events per year ≥5,000 cfs with considerably fewer events occurring per year with flows ≥13,500 cfs, and ≥23,500 cfs (Figure 4.22). The average area affected per year was plotted against the number of events per year for flows ≥5,000 cfs, ≥13,500 cfs, and ≥23,500 cfs (Figure 4.23). No correlation between flow magnitude and acres affected were found.

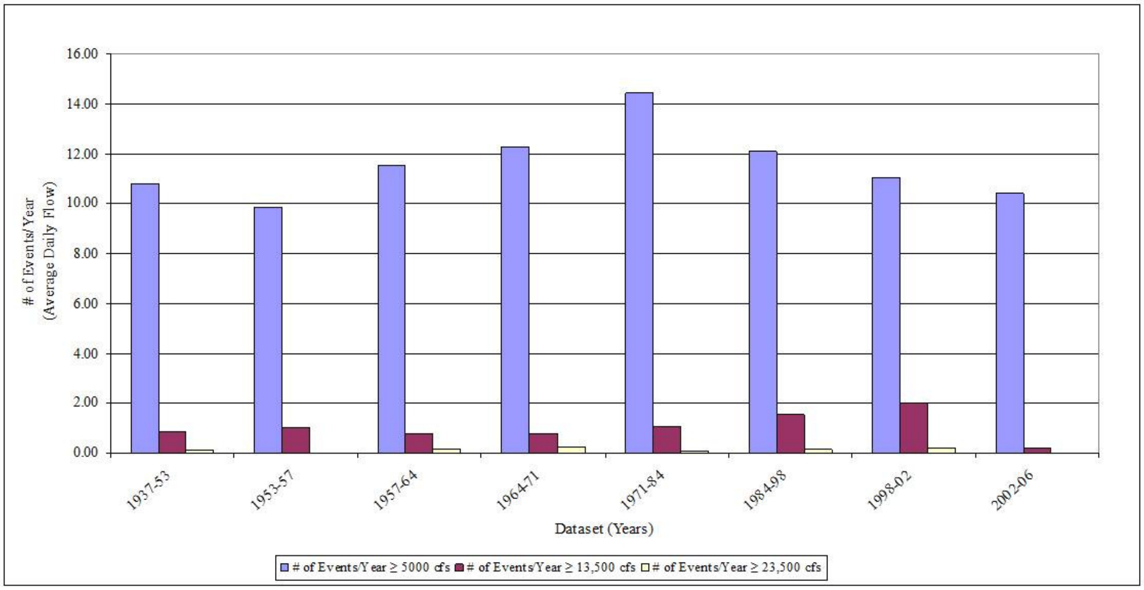

Figure 4.22 Histogram of Average Daily Flow <u>Magnitude</u> for Each Time Interval Studied

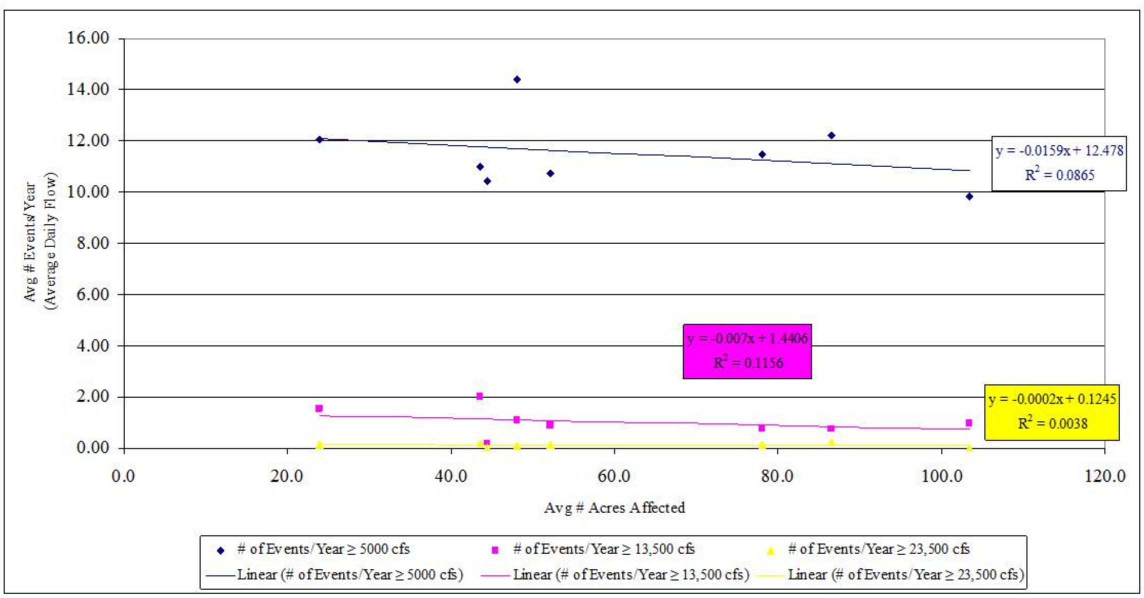

Figure 4.23 Relationship Between Average Daily Flow <u>Magnitude</u> and Land Area Affected (Erosion and Deposition)

To analyze flood duration vs. land area affected, flow events lasting two days or longer were also tabulated. For each temporal dataset, histograms of flow events/year ≥5,000 cfs and ≥13,500 cfs lasting two days or more were generated (Figure 4.24). The average number of events/year ≥2-days was plotted against average area affected per year to determine any potential correlation (Figure 4.25).

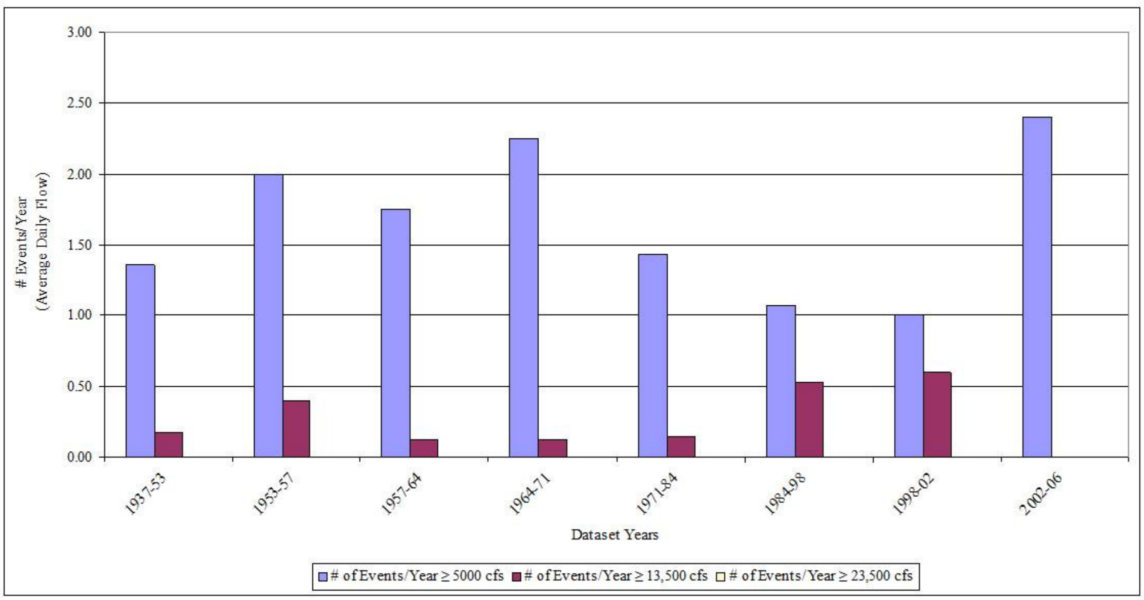

Figure 4.24 Histogram of Average Daily Flow <u>Duration</u> for Each Time Interval Studied

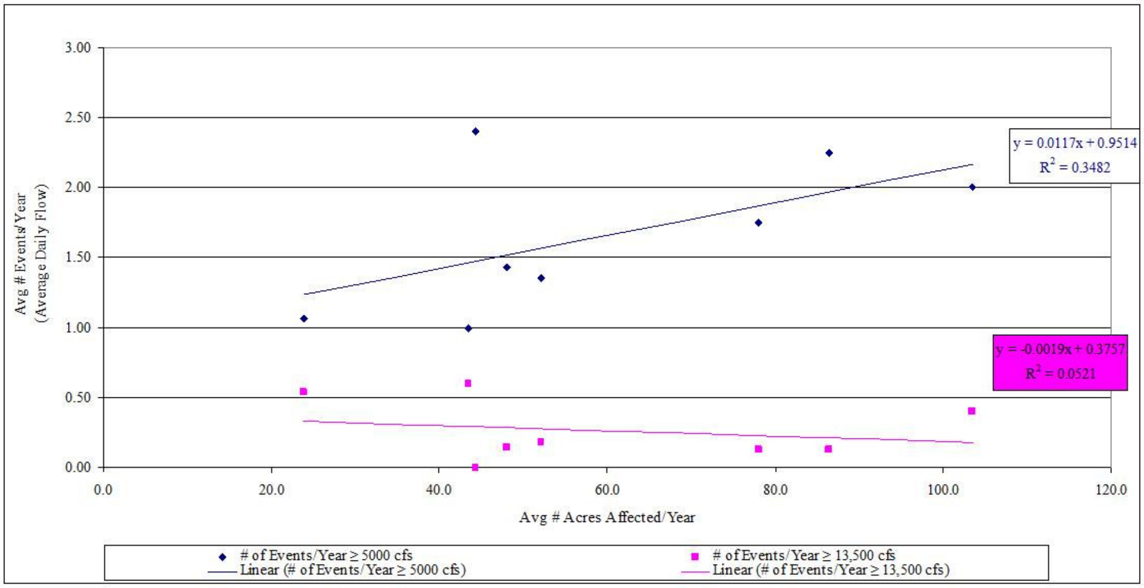

Figure 4.25 Relationship Between Average Daily Flow Duration and Land Area Affected (Erosion and Deposition)

A linear best-fit line was inserted in the graph and an R^2 value of 0.3482 was calculated for flows' occurring for two days or longer at or above 5,000 cfs. The R^2 number is used to determine the amount of variability that the average number of affected area per year (x) can be attributed to changes in the average number of flood events per year (y). In this case approximately 35% of the variability in average number of affected area per year (x) can be explained by variability in the average number of flood events per year (y), and at least 65% of the variability in (x) is due to something other than variations in (y). Thus, no connection was established for mean daily flows ≥ 13,500 cfs, but a slight correlation may exist for flows ≥ 5,000 cfs.

It is important for the reader to recognize that the following results are given for annual peak flows, which are in contrast to the results given for daily average flow in the previous paragraph. Annual peak flows ≥ 5,000 cfs, ≥ 13,500 cfs, ≥ 23,500 cfs, and ≥

9,000 cfs were plotted against the affected area for each temporal dataset. Trend lines and equations were calculated for flow magnitude (Figure 4.26) showing an R^2 value of 0.3361 for annual peak flows ≥13,500 cfs, which may exhibit a weak correlation between annual peak flow and affected area.

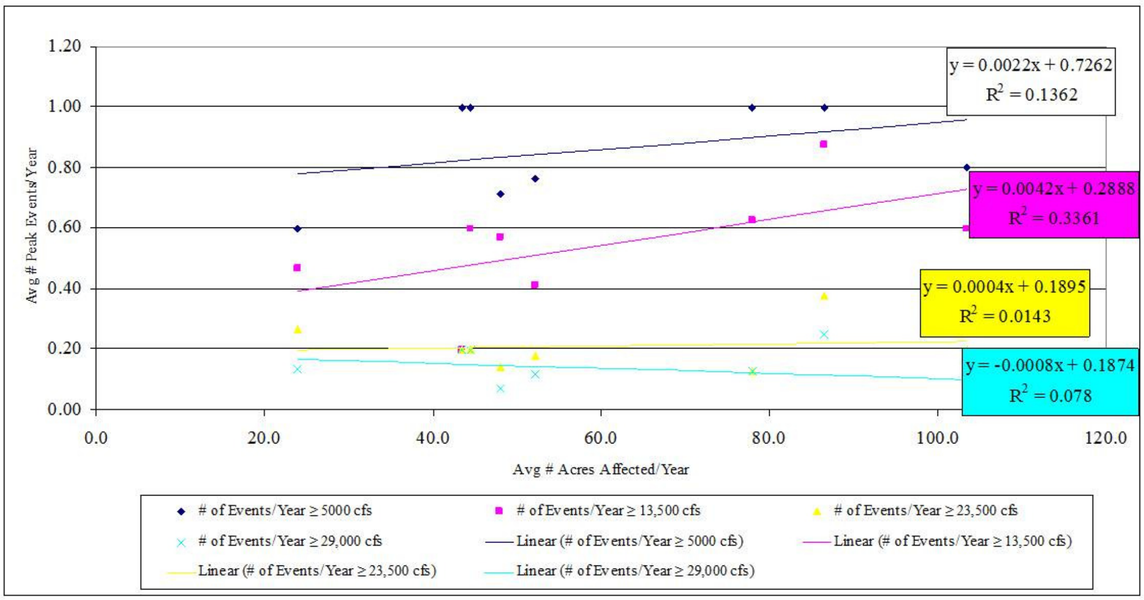

Figure 4.26 Graph of Annual Peak Flow Magnitude vs. Land Area Affected (Erosion and Deposition)

Discussion

Aggregate production and excavation totals in Figure 4.10 show dramatic increases in excavation in the mid-late 1970 and again in the late 1980's and early 1990's. Comparing this information to results in Table 4.3, the main cause of limited channel migration from 1971 to 1996 is probably in-channel aggregate mining. Little channel migration occurred since mining went off channel in 1996. Two factors may be the cause of slight migration patterns after 1996. Earthen levee construction was required bordering mining operation sites to maintain 100-year flood protection, which may have limited channel migration. It can be interpreted from the hydrographs that lack of flows of large magnitude or duration is also a major factor in channel stability on Cache Creek since 1996.

In summary, over the 70-year record, flood magnitude does not seem to be a significant factor in channel migration. The top ten highest annual peak flows were recorded between 1940 and 2005. Four of these flows were recorded during the period of least channel migration (1984-2006). There may however be a relationship between flood duration of small events (5,000 to 13,500 cfs) and channel migration. Between 1953 and 1971, there were frequent small mean daily flow events recorded over durations lasting as little as two days to as much as 35 days. This was the period of time showing the greatest amount of average land area affected per year.

Chapter 5

CASE STUDIES

5.1 – Determination of Case Studies

Several areas on Cache Creek were chosen as case studies to highlight issues affecting the management of the Cache Creek Resources Management Plan. These areas were chosen because they are areas where channel migration has resulted in damage to infrastructure (roads, bridges, utilities) and private property (agricultural crops). The following sections will describe these areas and the issues related to each locale.

5.2 – Huff's Corner

Huff's Corner is located at the downstream portion of the study area near the Interstate 5 Overcrossing (Figure 5.1).

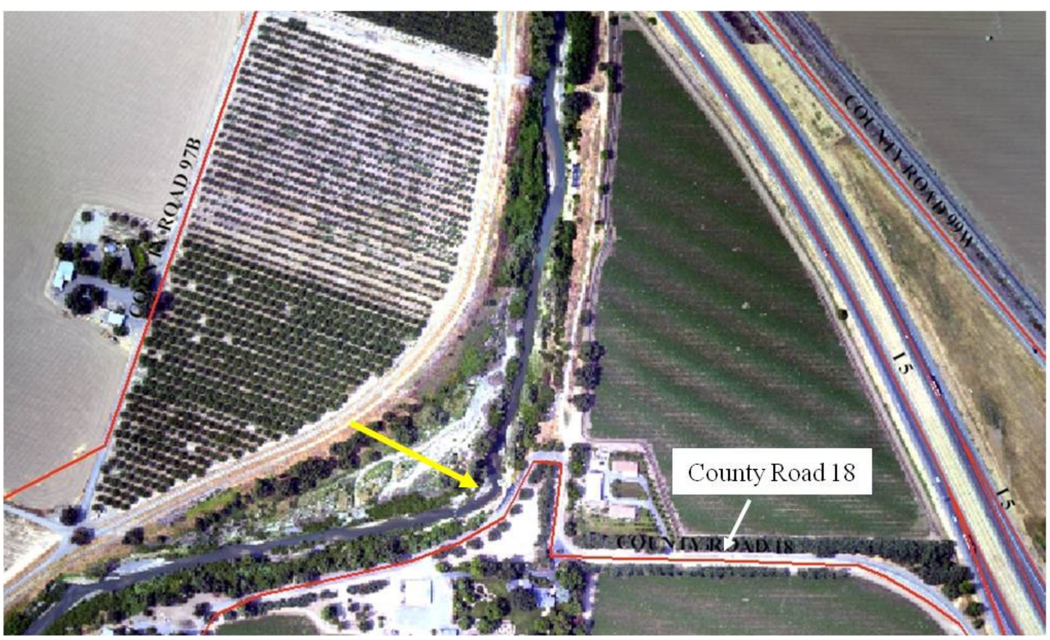

Figure 5.1 Aerial Photograph of Huff's Corner Location

This area is of importance because County Road 18 was damaged in 2005 during a high flow event and emergency repair work was done, costing Yolo County millions of dollars. This area of the creek has migrated toward the southeast over the last twelve years. Lines were drawn representing bank full water levels for 1998, 2002, and 2006 to illustrate the migration of the creek (Figures 5.2a-e).

The *measure* tool in ArcMap was used to measure the distance between the south bank margins. From 1998 to 2002, the creek migrated approximately 25-feet (~7.6-m) toward County Road 18. An additional 22-feet (~6.7-m) of migration occurred between 2002 and 2006 at the same location on the channel. High flow events have historically been a main cause of channel migration on Cache Creek. It is a reasonable assumption that Cache Creek will continue to migrate in this direction in the future. It is obvious that infrastructure along the creek has been affected and it is important that officials in Yolo County develop management plans to protect its infrastructure.

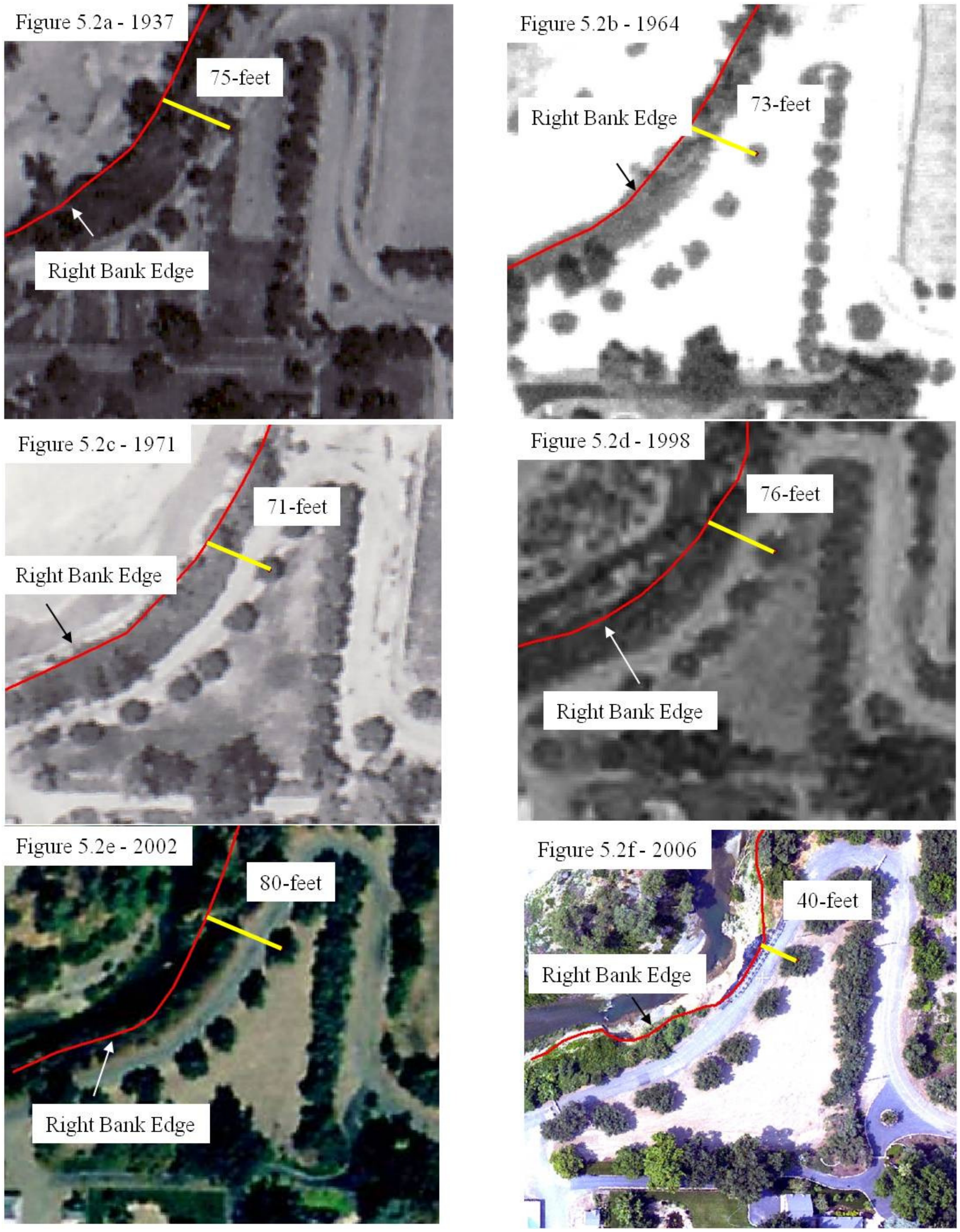

Figure 5.2a-f Aerial Photographs of Huff's Corner in 1937, 1964, 1971, 1998, 2002, and 2006

5.3 - Scheuring/SYAR Properties

In 1978, the Madison Bridge that spanned Cache Creek on County Road 89 (CR89) collapsed. Although this bridge failure was not directly related to stream migration, it is speculated that stream migration was an indirect cause to its failure. Figures 5.3a-f are snapshots through time of the area surrounding the Madison Bridge from 1937 to 2006. All the photos are equal in size, scale, and position. The arrow in each photo points to the same reference position on the ground. A thick line was drawn from the reference point to the edge of the channel. There appears to be little change in the length of this line for the majority of the early photo sets. Figures 5.3b and 5.3c are images taken in 1952 and 1971 respectively. Large amounts of native vegetation were removed during this time along the north side of Cache Creek. The images in figures 5.3c (1971) and 5.3d (1985) show land originally classified as riparian converted to agricultural use. It is clear that in 1985 (Figure 5.3d) (7-years after bridge failure) the channel migrated to the north. Little change occurred between 1985 and 1998. From 1998 to 2006 the channel migrated significantly to the north, destroying private farm land and Pacific Gas and Electric (PG&E) power poles. Spur dikes were constructed sometime between 1998 and 2006 and are visible in the 2006 aerial photograph. This set of spur dikes is anchoring the downstream end of the meander.

Stream migration was not the direct cause of the bridge failure and no Yolo County tax payer money was used to reconstruct this bridge. PG&E has replaced power poles that were destroyed by stream migration two times. The cost of replacing these poles was probably passed on in the form of local rate increases.

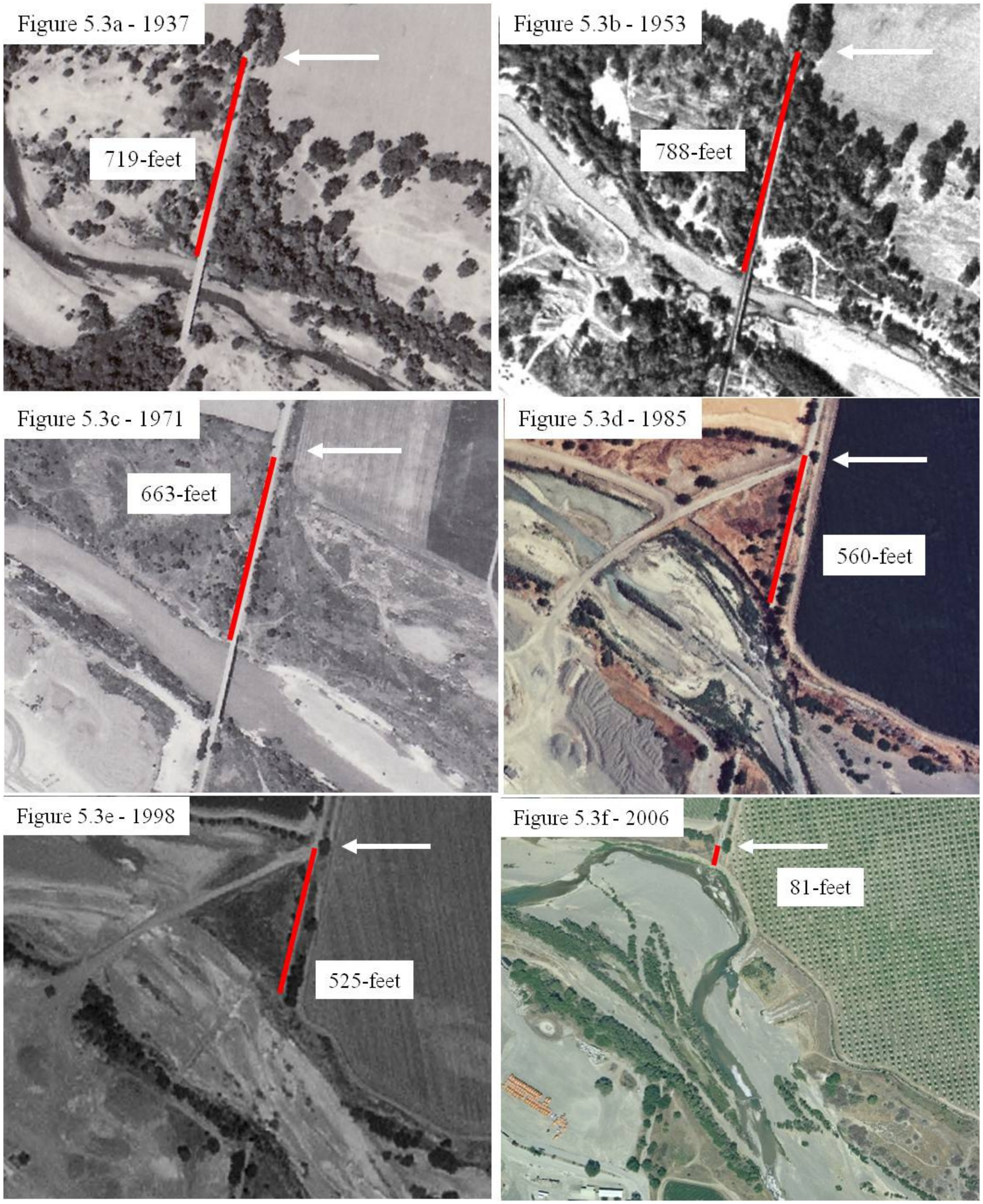

Figure 5.3a-f Aerial Photographs of County Road 89 in 1937, 1953, 1971, 1985, 1998, 2006

If this meander bend continues to migrate to the north, there will be a continued loss of agricultural land (walnut orchard), and existing PG&E power poles will again be impacted.

Loss of land at this site may be limited by increasing native vegetation populations. The increase in vegetation may provide enough bank stabilization to prevent further loss of agricultural property. Reconfiguration or removal of one or more spur dikes could also remove the stress at the downstream end of the meanders, allowing for a more natural channel configuration. Other options may include the creation of conservation easements or classification of “flood plains” along banks that show evidence of historical meander bends and riparian corridors.

5.4 – County Road 87 - Esparto Bridge

Five bridges span Cache Creek within the study area. The County Road 87 (Esparto) Bridge crosses Cache Creek to the north of the town of Esparto. It was built prior to 1937. The active channel in 1937 (Figure 5.4) was approximately 3,400 feet (~1,036-m) wide where the bridge structure spanned 600-feet (~183-m) over the existing low flow channel.

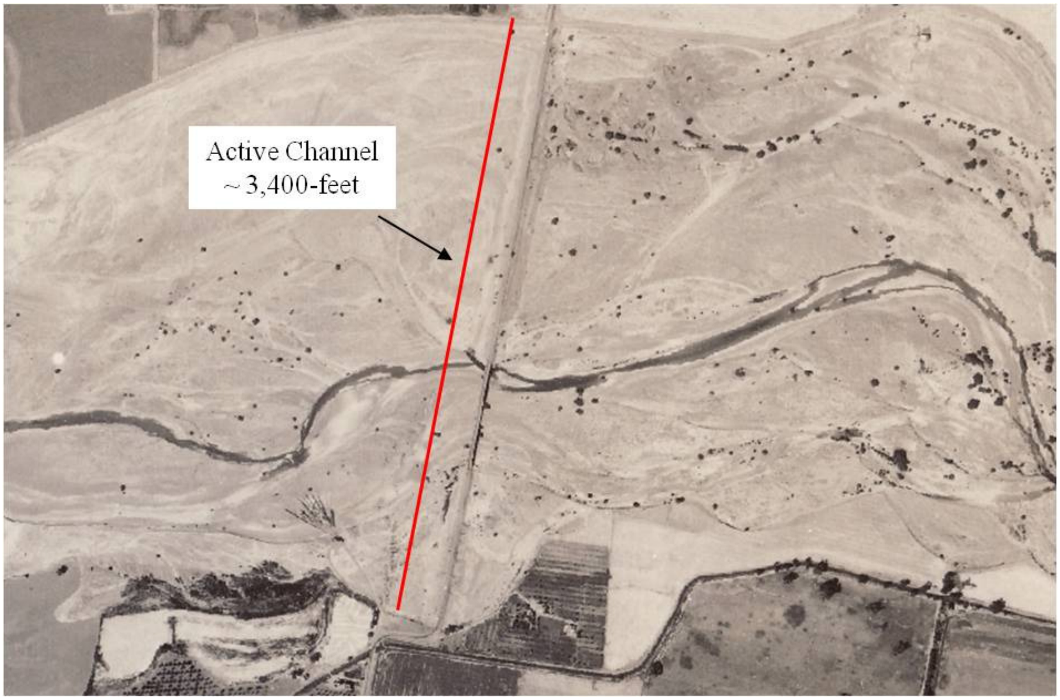

Figure 5.4 Aerial Photograph of County Road 87 (Esparto Bridge) in 1937

Raised burms were built across the Cache Creek linking the north and south sides of County Road 87. High creek flows were allowed to overtop the raised roadway, but ultimately the channel was narrowed significantly. Figure 5.5 shows the creek channel in 2006. Land along both banks was converted to agricultural uses and active aggregate mining sites. Spur dikes were constructed upstream and downstream of the bridge to limit erosion and protect county infrastructure (Figure 5.5). The significant narrowing of the channel has reduced flood conveyance and created potential flood hazards for property owners along the creek.

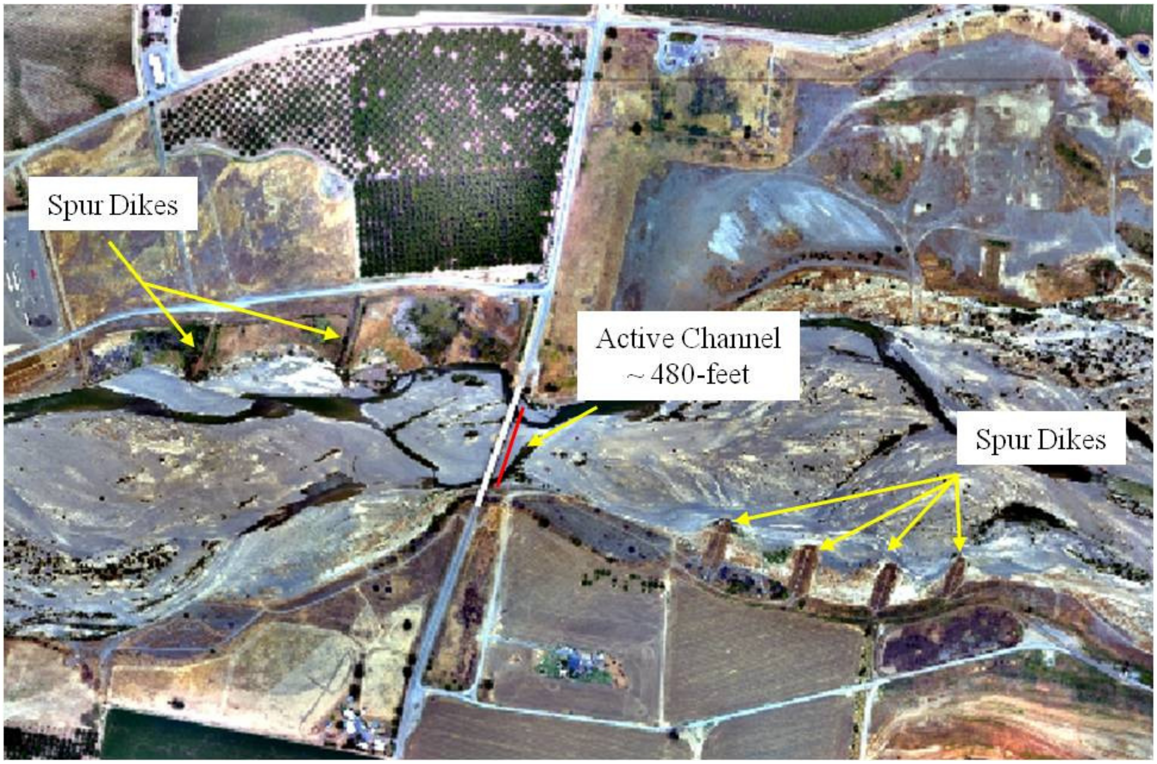

Figure 5.5 Aerial Photograph of County Road 87 (Esparto Bridge) in 2006

5.5 – Pacific Palisades

Pacific Palisades is located in the Capay Reach at river mile 26.9 (Figure 5.6). Pacific Gas and Electric (PG&E) installed a natural gas pipeline which runs below Cache Creek at this site. Since the completion of this project, channel incision occurred exposing the Pacific Palisades pipeline. Repairs to protect the pipeline ensued. PG&E installed a mass of concrete "pillow" structures to prevent further incision of the channel at that site. Figures 5.7a-b show significant damage to the concrete pillow structure where scouring occurred, exposing the pipeline a second time. No repair work has occurred to date. PG&E has spent large amounts of money to install and protect the Pacific Palisades pipeline and more will be spent to protect this infrastructure.

Figure 5.6 Aerial Photograph of Pacific Palisades – Concrete "Pillow" Structure Protecting PG&E Gas Pipeline (2006)

Figure 5.7a-b Photographs of Pacific Palisades Concrete "Pillow" Structure Protecting PG&E Gas Pipeline (Tim Horner, 2008)

Chapter 6

CONCLUSIONS

6.1 - Summary of Results

Changes on Cache Creek, as with all streams and rivers, have occurred as long as the creek has been flowing. This is the nature of all landforms, whether it is tectonic, eolian, or fluvial processes that cause the change. The natural geomorphic changes on Cache Creek were further exaggerated by human influences as early as the 1850's. The first significant human alterations of the creek were with the construction of bridges over the creek and construction of the Moore's Dam and Ditches to divert and convey water from Cache Creek to irrigate farmland.

Bridges have been built and rebuilt over the last century and the channel has narrowed significantly at locations along each creek overcrossing (Figure 6.1a-b). Channel narrowing can cause scouring at bridge supports that may contribute to bridge weaknesses or failure.

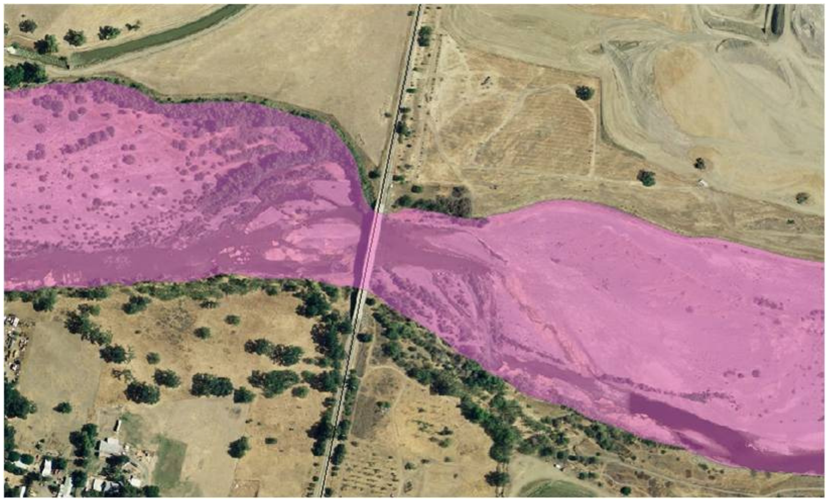

Figure 6.1a Narrow Channel at CR 85 Bridge (2006)

Figure 6.1b Narrow Channel at CR 87 Bridge (2006)

Open riparian land has been converted to agricultural use closer and closer to the creek channel. This newly converted farm ground encroached on the natural flood plain of Cache Creek. This is evident in the aerial photographs in Figures 5.3a-f. Farmland bordering on Cache Creek and in the natural flood plain was and still is at risk for annual crop damage or possible permanent loss of farmable ground.

The Federal Highway Act of 1944 created a huge demand for high quality aggregate for the construction of the system concrete highways in the Sacramento Valley. Cache Creek was a great source of aggregate and mining companies began to establish along Cache Creek. These companies began excavating within the creek bed, physically changing flows to harvest the aggregate resource. From the 1950's to 1996 banks of the channel were straightened in many areas and channel incision occurred along the entire study area. In 1996 the Cache Creek Resources Management Plan (CCRMP) was adopted which moved the mining to off-channel locations.

The CCRMP also required flood protection levees to be built bordering mining operations to ensure Cache Creek maintained 100-year flood conveyance. These flood protection levees further inhibited natural stream migration. Five longitudinal profiles were measured on Cache Creek from historic elevation datasets beginning in 1905 through 2006. Figure 4.19 illustrates continuous incision of the channel from 1905 to 1994, during the majority of in-channel mining. In-channel mining had a major effect on channel incision during this time. This figure also shows aggradation that occurred between 1994 and 2006, after aggregate mining moved to off-channel locations. During this time, the longitudinal profile is stable in most areas in the study area; however, there are two areas of significant aggradation. There is an increase in elevation at the Esparto Bridge and the Stevens Bridge of approximately 20-feet and 7-feet respectively. This aggradation can be attributed to lack of in-channel mining activities in the creek. Natural sediment transport will continue this trend.

Figure 4.20 shows the changes in channel widths over the 70-year record. During times of in-channel mining, reach widths increased and decrease periodically. Each reach generally increased width from 1937 to 1998. Since mining moved out of the channel, all reach widths with the exception of one have decrease slightly. After 1998 (2-years after mining moved off-channel) all reaches except Hoppin have consistently narrowed from as little as 17-feet (~5.2-m) to as much as 89-feet (~27-m) . Figures 6.2, 6.3, and 6.4 illustrate and compare channel migration during the early days of aggregate mining, periods of significant in-channel mining, and time spans of off-channel aggregate mining. In-channel mining was

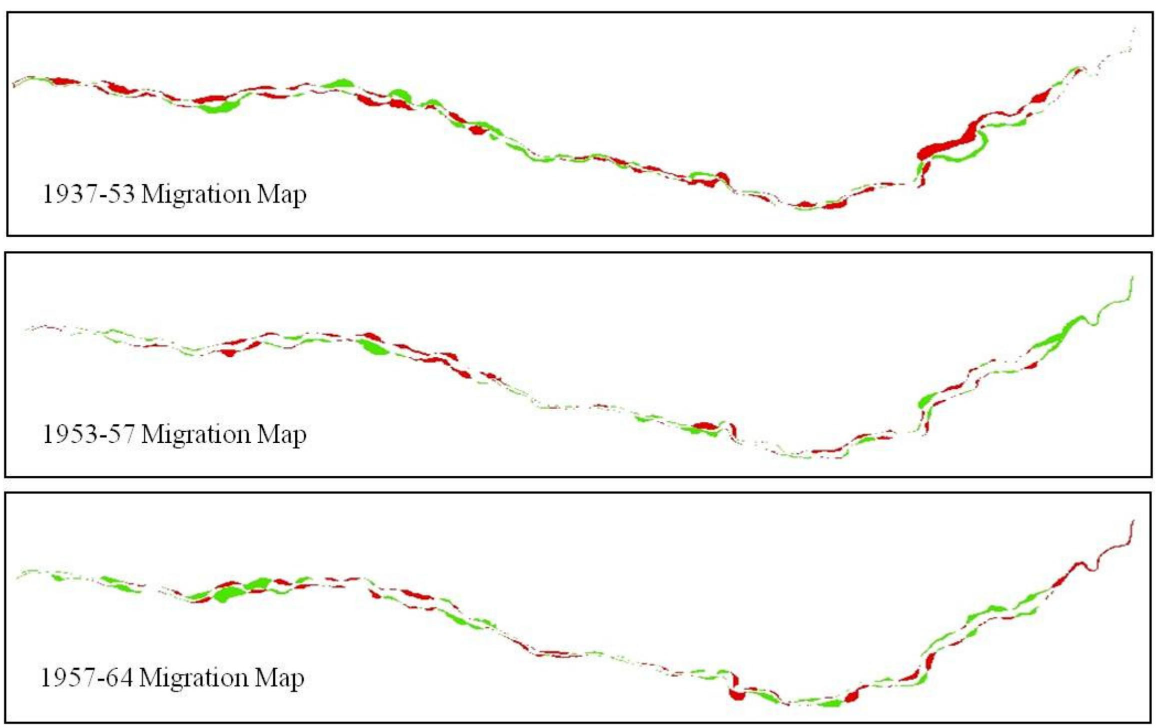

Figure 6.2 Pre to Early In-Channel Aggregate Mining on Cache Creek

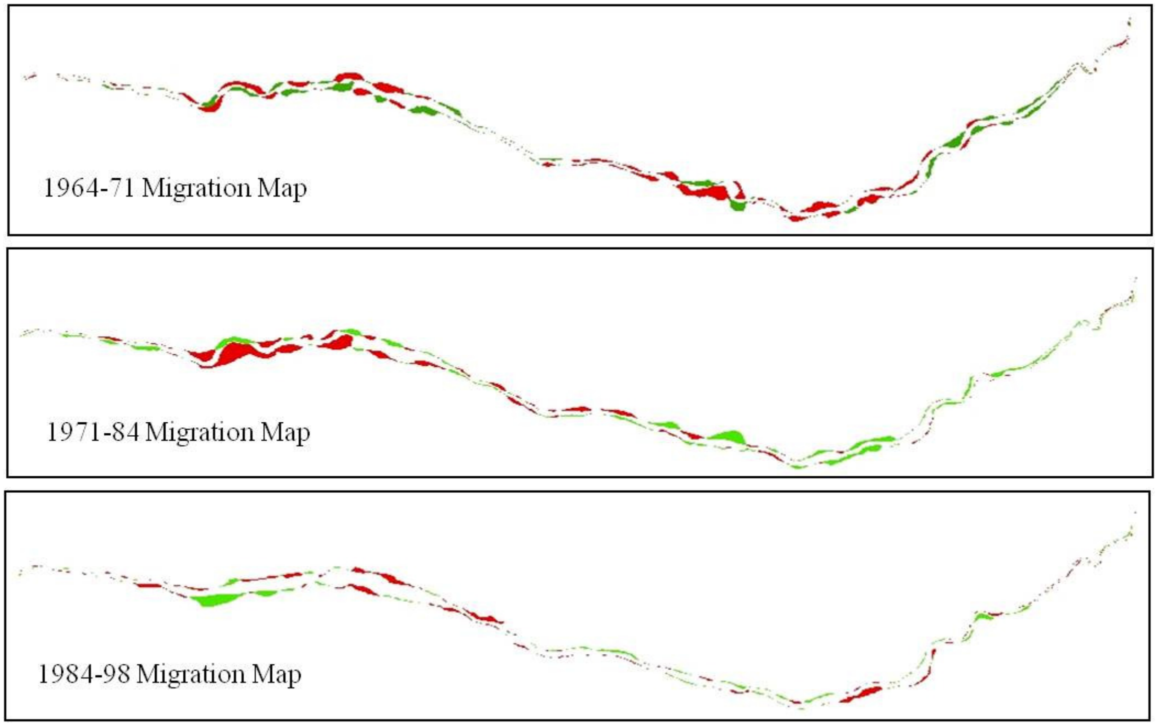

Figure 6.3 Periods of In-Channel Aggregate Mining on Cache Creek

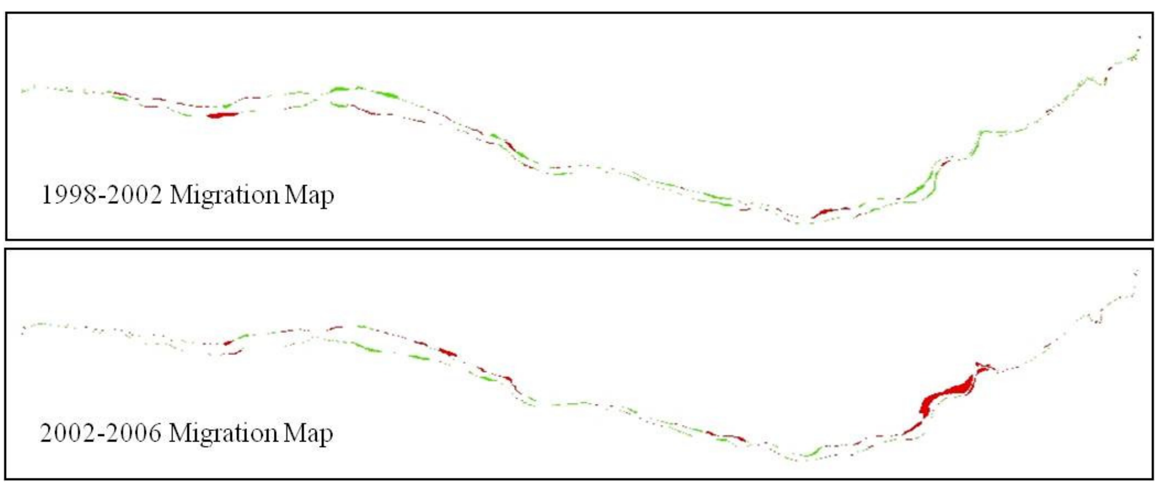

Figure 6.4 Periods of <u>No</u> In-Channel Aggregate Mining on Cache Creek

at least one cause of channel migration, incision and increased widths, while stream discharge added to the amount of stream migration.

Many large mean daily flow events, as well as long duration annual daily flow events were recorded from 1937 to 2006. Damage to bridges, levees, and bank edges have occurred during some of these events. Analysis in this study show no significant correlation between the magnitude and numbers of average daily flows and affected land area (Figure 4.23). Magnitude of average daily flow has little effect on channel movement. However, there may be a slight correlation between the duration of mean daily flows lasting two days or longer and affected land area (Figure 4.25). Duration of mean daily flows may have a minor effect on channel movement. Since 1937 there have been nearly forty annual peak flows recorded above 13,500 cfs. There may be a very weak correlation between annual peak flows ≥13,500 cfs and affected area.

Many areas on Cache Creek have experienced damage during past flood events. County Road 18 has been damage and repaired. Other bridges in the study area have been damaged and repaired several times since 1937. PG&E has replaced several power poles at the Scheuring and SYAR properties and tried to fix the scour problems at Pacific Palisades. It is apparent from case study results that private and public property as well as county infrastructure has been affected by stream migration. Millions of dollars have been spent to control erosion along the banks of Cache Creek and it appears that much more will be spent in the future.

6.2 - Recommendations

There is great work occurring on Cache Creek by private landowners, Yolo County, and the aggregate mining industry. Reclaimed aggregate mines have been developed and constructed by aggregate companies and donated to Yolo County. Reclamation projects on Cache Creek should continue with an emphasis on maintenance after projects are complete.

A serious area of concern is the aggradation and narrowing of Cache Creek. Overall, the flow conveyance capacity of Cache Creek has been reduced. A detailed hydraulic analysis needs to be conducted immediately across the entire Lower Cache Creek area to determine if the channel can convey a 100-year flood event calculated by the Army Corps of Engineers (46,000 cfs). Depending on the outcome of the hydraulic analysis, Yolo County should consider several options. These include in-channel maintenance mining to deepen the channel, raising channel banks and levees, or construction of setback levees (widen the channel) to protect infrastructure and towns and cities located near Cache Creek (Yolo, Woodland, Madison, Esparto, and Capay). These potential projects can be allowed under Yolo County's In-Channel Maintenance Mining Ordinance.

Restoration of riparian vegetation and recreation of natural flood plains may also help to minimize bank erosion. The use of bioengineering techniques should be the first option when considering bank stabilization projects. Bioengineering could be enhanced with structural engineering techniques when biological forms of bank stabilization alone do not work in limiting erosion and improving flood protection.

The Cache Creek Resources Management Plan (CCRMP) requires annual monitoring and analysis of morphology, hydrology, and biology along the creek channel. In reviewing all data collected and analyzed, it has been found that data collection has occurred from 1996 to present, but little analysis has been completed. This study is the first analysis of stream morphology since the Technical Studies and Recommendations for the Lower Cache Creek Resources Management Plan was performed in 1995. The author recommends immediate channel position analysis and year-to-year comparisons of affected area vs. flow magnitude and duration for datasets from 2002 to 2010. This analysis may provide critical information regarding stream migration and average daily flows.

APPENDICES

APPENDIX A

Bank-Full Widths

Rio Jesus Maria Reach

1937

River Mile	Width (Ft)
11.2	116
11.3	102
11.4	121
11.5	106
11.6	162
11.7	91
11.8	85
11.9	70
12.0	97
12.1	102
12.2	84
12.3	116
12.4	120
12.5	221
12.6	240
12.7	441
12.8	436
12.9	490
AVG	178

1953

River Mile	Width (Ft)
11.2	90
11.3	111
11.4	110
11.5	108
11.6	142
11.7	97
11.8	111
11.9	100
12.0	103
12.1	142
12.2	144
12.3	165
12.4	120
12.5	270
12.6	356
12.7	363
12.8	475
12.9	452
AVG	192

1971

River Mile	Width (Ft)
11.2	95
11.3	104
11.4	127
11.5	175
11.6	330
11.7	281
11.8	138
11.9	99
12.0	116
12.1	121
12.2	109
12.3	145
12.4	139
12.5	260
12.6	230
12.7	225
12.8	159
12.9	184
AVG	169

Rio Jesus Maria Reach

1998

River Mile	Width (Ft)
11.2	73
11.3	97
11.4	85
11.5	101
11.6	263
11.7	154
11.8	107
11.9	100

2002

River Mile	Width (Ft)
11.2	94
11.3	82
11.4	90
11.5	78
11.6	112
11.7	119
11.8	101
11.9	94

2006

River Mile	Width (Ft)
11.2	115
11.3	75
11.4	68
11.5	69
11.6	126
11.7	98
11.8	91
11.9	92

Rio Jesus Maria Reach

1998

River Mile	Width (Ft)
12.0	71
12.1	109
12.2	102
12.3	129
12.4	91
12.5	194
12.6	176
12.7	205
12.8	165
12.9	159
AVG	132

2002

River Mile	Width (Ft)
12.0	83
12.1	117
12.2	100
12.3	105
12.4	93
12.5	135
12.6	88
12.7	100
12.8	102
12.9	104
AVG	100

2006

River Mile	Width (Ft)
12.0	101
12.1	120
12.2	132
12.3	138
12.4	85
12.5	112
12.6	68
12.7	89
12.8	80
12.9	100
AVG	98

Hoppin Reach

1937

River Mile	Width (Ft)
13.0	794
13.1	852
13.2	736
13.3	526
13.4	492
13.5	979
13.6	863
13.7	956
13.8	858
13.9	911
14.0	1208
14.1	1011
14.2	271
14.3	351
14.4	391
14.5	257
14.6	363
14.7	244
14.8	358

1953

River Mile	Width (Ft)
13.0	505
13.1	847
13.2	1067
13.3	1152
13.4	1246
13.5	1188
13.6	997
13.7	911
13.8	748
13.9	881
14.0	783
14.1	1106
14.2	901
14.3	865
14.4	726
14.5	954
14.6	732
14.7	522
14.8	629

1971

River Mile	Width (Ft)
13.0	210
13.1	191
13.2	211
13.3	302
13.4	342
13.5	286
13.6	298
13.7	394
13.8	460
13.9	528
14.0	453
14.1	539
14.2	502
14.3	548
14.4	420
14.5	522
14.6	452
14.7	356
14.8	386

Hoppin Reach

1937

River Mile	Width (Ft)
14.9	350
15.0	304
15.1	272
15.2	309
15.3	368
15.4	339
15.5	369
15.6	458
15.7	530
15.8	444
15.9	203
16.0	266
AVG	537

1953

River Mile	Width (Ft)
14.9	662
15.0	799
15.1	923
15.2	956
15.3	539
15.4	477
15.5	346
15.6	713
15.7	537
15.8	420
15.9	445
16.0	440
AVG	775

1971

River Mile	Width (Ft)
14.9	428
15.0	447
15.1	544
15.2	552
15.3	684
15.4	624
15.5	834
15.6	951
15.7	897
15.8	627
15.9	717
16.0	901
AVG	503

Hoppin Reach

1998

River Mile	Width (Ft)
13.0	184
13.1	156
13.2	147
13.3	177
13.4	214
13.5	127
13.6	131
13.7	158
13.8	320
13.9	347
14.0	266
14.1	284
14.2	318
14.3	232
14.4	217
14.5	168
14.6	220
14.7	182

2002

River Mile	Width (Ft)
13.0	109
13.1	86
13.2	195
13.3	167
13.4	257
13.5	89
13.6	104
13.7	113
13.8	267
13.9	263
14.0	241
14.1	219
14.2	236
14.3	139
14.4	160
14.5	93
14.6	112
14.7	122

2006

River Mile	Width (Ft)
13.0	107
13.1	118
13.2	194
13.3	200
13.4	201
13.5	98
13.6	107
13.7	104
13.8	287
13.9	289
14.0	253
14.1	183
14.2	274
14.3	375
14.4	470
14.5	712
14.6	864
14.7	1021

Hoppin Reach

1998

River Mile	Width (Ft)
14.8	302
14.9	331
15.0	334
15.1	498
15.2	573
15.3	506
15.4	667
15.5	1033
15.6	1054
15.7	932
15.8	540
15.9	281
16.0	439
AVG	366

2002

River Mile	Width (Ft)
14.8	250
14.9	325
15.0	428
15.1	502
15.2	391
15.3	238
15.4	442
15.5	673
15.6	798
15.7	647
15.8	340
15.9	278
16.0	406
AVG	280

2006

River Mile	Width (Ft)
14.8	903
14.9	757
15.0	640
15.1	1011
15.2	961
15.3	922
15.4	613
15.5	865
15.6	972
15.7	873
15.8	418
15.9	375
16.0	348
AVG	500

Dunnigan Hills Reach

1937

River Mile	Width (Ft)
16.1	333
16.2	234
16.3	325
16.4	457
16.5	228
16.6	276
16.7	185
16.8	296
16.9	410
17.0	259
17.1	224
17.2	295
17.3	227
17.4	259
17.5	379
17.6	551

1953

River Mile	Width (Ft)
16.1	367
16.2	537
16.3	495
16.4	504
16.5	303
16.6	451
16.7	625
16.8	561
16.9	600
17.0	350
17.1	591
17.2	557
17.3	283
17.4	280
17.5	440
17.6	581

1971

River Mile	Width (Ft)
16.1	816
16.2	1116
16.3	853
16.4	1060
16.5	675
16.6	689
16.7	869
16.8	1262
16.9	1091
17.0	773
17.1	728
17.2	704
17.3	612
17.4	466
17.5	442
17.6	335

Dunnigan Hills Reach

1937

River Mile	Width (Ft)
17.7	362
17.8	274
17.9	288
18.0	237
18.1	257
18.2	198
18.3	157
18.4	198
18.5	159
18.6	198
18.7	285
18.8	417
AVG	285

1953

River Mile	Width (Ft)
17.7	656
17.8	442
17.9	305
18.0	173
18.1	323
18.2	187
18.3	260
18.4	592
18.5	508
18.6	563
18.7	277
18.8	526
AVG	441

1971

River Mile	Width (Ft)
17.7	326
17.8	401
17.9	398
18.0	338
18.1	914
18.2	1406
18.3	1435
18.4	1376
18.5	1113
18.6	697
18.7	668
18.8	384
AVG	784

Dunnigan Hills Reach

1998

River Mile	Width (Ft)
16.1	611
16.2	860
16.3	865
16.4	869
16.5	636
16.6	807
16.7	809
16.8	729
16.9	650
17.0	640
17.1	463
17.2	514
17.3	570
17.4	476
17.5	409
17.6	439
17.7	419
17.8	358

2002

River Mile	Width (Ft)
16.1	579
16.2	810
16.3	730
16.4	744
16.5	585
16.6	892
16.7	900
16.8	751
16.9	936
17.0	713
17.1	558
17.2	484
17.3	538
17.4	523
17.5	450
17.6	433
17.7	421
17.8	364

2006

River Mile	Width (Ft)
16.1	556
16.2	815
16.3	842
16.4	763
16.5	624
16.6	980
16.7	900
16.8	773
16.9	874
17.0	528
17.1	370
17.2	357
17.3	482
17.4	441
17.5	413
17.6	402
17.7	400
17.8	445

Dunnigan Hills Reach

1998

River Mile	Width (Ft)
17.9	335
18.0	392
18.1	417
18.2	595
18.3	669
18.4	647
18.5	525
18.6	652
18.7	712
18.8	674
AVG	598

2002

River Mile	Width (Ft)
17.9	244
18.0	349
18.1	593
18.2	588
18.3	456
18.4	400
18.5	366
18.6	374
18.7	568
18.8	668
AVG	572

2006

River Mile	Width (Ft)
17.9	275
18.0	317
18.1	777
18.2	766
18.3	534
18.4	311
18.5	202
18.6	559
18.7	560
18.8	482
AVG	562

Guesisosi Reach

1937

River Mile	Width (Ft)
18.9	305
19.0	192
19.1	362
19.2	221
19.3	232
19.4	166
19.5	152
19.6	408
19.7	277
19.8	294
19.9	143
20.0	166
20.1	185
20.2	246
20.3	195
20.4	191
20.5	361
20.6	375
20.7	373

1953

River Mile	Width (Ft)
18.9	500
19.0	375
19.1	489
19.2	343
19.3	463
19.4	395
19.5	475
19.6	504
19.7	296
19.8	335
19.9	434
20.0	296
20.1	231
20.2	176
20.3	163
20.4	189
20.5	136
20.6	223
20.7	147

1971

River Mile	Width (Ft)
18.9	527
19.0	532
19.1	866
19.2	816
19.3	525
19.4	631
19.5	449
19.6	441
19.7	461
19.8	360
19.9	350
20.0	358
20.1	368
20.2	379
20.3	278
20.4	380
20.5	463
20.6	480
20.7	434

Guesisosi Reach

1937

River Mile	Width (Ft)
20.8	427
20.9	500
21.0	571
AVG	288

1953

River Mile	Width (Ft)
20.8	165
20.9	221
21.0	393
AVG	316

1971

River Mile	Width (Ft)
20.8	404
20.9	506
21.0	307
AVG	469

Guesisosi Reach

1998

River Mile	Width (Ft)
18.9	619
19.0	530
19.1	501
19.2	467
19.3	519
19.4	427
19.5	351
19.6	313
19.7	358
19.8	425
19.9	386
20.0	329
20.1	379
20.2	319
20.3	432
20.4	632
20.5	632
20.6	598
20.7	546
20.8	615
20.9	494
21.0	345
AVG	464

2002

River Mile	Width (Ft)
18.9	562
19.0	516
19.1	449
19.2	346
19.3	404
19.4	365
19.5	303
19.6	270
19.7	274
19.8	389
19.9	332
20.0	336
20.1	338
20.2	296
20.3	433
20.4	624
20.5	637
20.6	576
20.7	490
20.8	508
20.9	482
21.0	341
AVG	421

2006

River Mile	Width (Ft)
18.9	495
19.0	502
19.1	453
19.2	272
19.3	342
19.4	362
19.5	313
19.6	314
19.7	220
19.8	256
19.9	299
20.0	277
20.1	335
20.2	288
20.3	418
20.4	514
20.5	501
20.6	421
20.7	479
20.8	420
20.9	458
21.0	319
AVG	375

Madison Reach

1937

River Mile	Width (Ft)
21.1	421
21.2	406
21.3	663
21.4	673
21.5	417
21.6	883
21.7	902
21.8	374
21.9	460
22.0	388
22.1	513
22.2	506
22.3	355
22.4	325
22.5	478
22.6	539
22.7	419
22.8	486
22.9	273
23.0	493
23.1	668
23.2	473
23.3	394
23.4	556
AVG	503

1953

River Mile	Width (Ft)
21.1	38
21.2	150
21.3	249
21.4	432
21.5	354
21.6	218
21.7	242
21.8	150
21.9	780
22.0	632
22.1	344
22.2	385
22.3	707
22.4	572
22.5	334
22.6	344
22.7	294
22.8	367
22.9	640
23.0	551
23.1	711
23.2	601
23.3	805
23.4	1110
AVG	459

1971

River Mile	Width (Ft)
21.1	324
21.2	281
21.3	329
21.4	288
21.5	321
21.6	188
21.7	180
21.8	274
21.9	377
22.0	289
22.1	221
22.2	283
22.3	361
22.4	466
22.5	511
22.6	588
22.7	694
22.8	850
22.9	984
23.0	1194
23.1	1207
23.2	1316
23.3	1181
23.4	1118
AVG	576

Madison Reach

1998

River Mile	Width (Ft)
21.1	521
21.2	563
21.3	658
21.4	602
21.5	307
21.6	439

2002

River Mile	Width (Ft)
21.1	384
21.2	615
21.3	490
21.4	389
21.5	430
21.6	555

2006

River Mile	Width (Ft)
21.1	342
21.2	404
21.3	467
21.4	424
21.5	542
21.6	732

Madison Reach

1998

River Mile	Width (Ft)
21.7	581
21.8	683
21.9	569
22.0	489
22.1	568
22.2	436
22.3	505
22.4	574
22.5	618
22.6	863
22.7	932
22.8	1026
22.9	1223
23.0	1285
23.1	1344
23.2	1446
23.3	1761
23.4	1914
AVG	829

2002

River Mile	Width (Ft)
21.7	446
21.8	576
21.9	567
22.0	575
22.1	590
22.2	454
22.3	524
22.4	607
22.5	667
22.6	873
22.7	1022
22.8	1143
22.9	1229
23.0	1249
23.1	1341
23.2	1452
23.3	1486
23.4	1732
AVG	808

2006

River Mile	Width (Ft)
21.7	472
21.8	458
21.9	405
22.0	752
22.1	558
22.2	460
22.3	524
22.4	548
22.5	742
22.6	1126
22.7	914
22.8	948
22.9	1174
23.0	1301
23.1	1354
23.2	1450
23.3	1522
23.4	1633
AVG	802

Hungry Hollow Reach

1937

River Mile	Width (Ft)
23.5	352
23.6	422
23.7	629
23.8	1073
23.9	1096
24.0	689
24.1	580
24.2	546
24.3	423
24.4	686
24.5	705

1953

River Mile	Width (Ft)
23.5	1127
23.6	831
23.7	711
23.8	510
23.9	265
24.0	350
24.1	311
24.2	631
24.3	551
24.4	780
24.5	718

1971

River Mile	Width (Ft)
23.5	936
23.6	968
23.7	1208
23.8	982
23.9	454
24.0	429
24.1	333
24.2	375
24.3	566
24.4	729
24.5	649

Hungry Hollow Reach

1937

River Mile	Width (Ft)
24.6	503
24.7	632
24.8	575
24.9	348
25.0	346
25.1	328
25.2	533
25.3	588
25.4	843
25.5	971
25.6	779
25.7	650
25.8	387
25.9	519
26.0	549
26.1	384
26.2	258
AVG	586

1953

River Mile	Width (Ft)
24.6	731
24.7	913
24.8	950
24.9	994
25.0	850
25.1	493
25.2	477
25.3	617
25.4	677
25.5	439
25.6	556
25.7	491
25.8	522
25.9	614
26.0	632
26.1	600
26.2	449
AVG	635

1971

River Mile	Width (Ft)
24.6	572
24.7	571
24.8	449
24.9	413
25.0	453
25.1	444
25.2	390
25.3	448
25.4	468
25.5	527
25.6	382
25.7	435
25.8	386
25.9	404
26.0	601
26.1	660
26.2	476
AVG	561

Hungry Hollow Reach

1998

River Mile	Width (Ft)
23.5	1851
23.6	1721
23.7	1637
23.8	1609
23.9	1473
24.0	1706
24.1	1362
24.2	757
24.3	527
24.4	806
24.5	1148
24.6	1243
24.7	1203

2002

River Mile	Width (Ft)
23.5	1772
23.6	1801
23.7	1798
23.8	1504
23.9	1216
24.0	1306
24.1	1051
24.2	706
24.3	425
24.4	669
24.5	1091
24.6	1128
24.7	1172

2006

River Mile	Width (Ft)
23.5	1641
23.6	1655
23.7	1469
23.8	1361
23.9	1175
24.0	1265
24.1	1078
24.2	723
24.3	430
24.4	690
24.5	1074
24.6	1122
24.7	1243

Hungry Hollow Reach

1998

River Mile	Width (Ft)
24.8	1126
24.9	1280
25.0	1132
25.1	977
25.2	1097
25.3	1136
25.4	983
25.5	791
25.6	630
25.7	615
25.8	631
25.9	668
26.0	777
26.1	896
26.2	668
AVG	1088

2002

River Mile	Width (Ft)
24.8	1241
24.9	1299
25.0	1117
25.1	1105
25.2	1113
25.3	1168
25.4	969
25.5	847
25.6	842
25.7	977
25.8	808
25.9	759
26.0	762
26.1	798
26.2	799
AVG	1080

2006

River Mile	Width (Ft)
24.8	1186
24.9	1194
25.0	1099
25.1	1071
25.2	1086
25.3	1005
25.4	1044
25.5	1200
25.6	929
25.7	1031
25.8	828
25.9	744
26.0	804
26.1	804
26.2	752
AVG	1061

Capay Reach

1937

River Mile	Width (Ft)
26.3	308
26.4	422
26.5	262
26.6	288
26.7	336
26.8	316
26.9	270
27.0	296
27.1	449
27.2	414
27.3	216
27.4	228
27.5	195
27.6	129

1953

River Mile	Width (Ft)
26.3	438
26.4	515
26.5	549
26.6	474
26.7	720
26.8	641
26.9	830
27.0	851
27.1	1007
27.2	830
27.3	262
27.4	242
27.5	300
27.6	456

1971

River Mile	Width (Ft)
26.3	344
26.4	490
26.5	529
26.6	639
26.7	606
26.8	300
26.9	187
27.0	309
27.1	355
27.2	254
27.3	200
27.4	199
27.5	217
27.6	345

Capay Reach

1937

River Mile	Width (Ft)
27.7	147
27.8	185
27.9	230
28.0	260
28.1	184
28.2	217
28.3	253
AVG	267

1953

River Mile	Width (Ft)
27.7	701
27.8	667
27.9	120
28.0	111
28.1	97
28.2	198
28.3	246
AVG	488

1971

River Mile	Width (Ft)
27.7	468
27.8	220
27.9	167
28.0	151
28.1	153
28.2	232
28.3	258
AVG	315

Capay Reach

1998

River Mile	Width (Ft)
26.3	463
26.4	519
26.5	562
26.6	687
26.7	559
26.8	262
26.9	373
27.0	373
27.1	311
27.2	290
27.3	206
27.4	200
27.5	207
27.6	257
27.7	301
27.8	208
27.9	181
28.0	157
28.1	146
28.2	225
28.3	205
AVG	319

2002

River Mile	Width (Ft)
26.3	415
26.4	580
26.5	676
26.6	741
26.7	563
26.8	257
26.9	321
27.0	288
27.1	323
27.2	261
27.3	195
27.4	209
27.5	182
27.6	258
27.7	236
27.8	183
27.9	147
28.0	125
28.1	110
28.2	154
28.3	172
AVG	305

2006

River Mile	Width (Ft)
26.3	402
26.4	618
26.5	682
26.6	758
26.7	558
26.8	261
26.9	307
27.0	364
27.1	345
27.2	229
27.3	193
27.4	175
27.5	191
27.6	222
27.7	198
27.8	193
27.9	134
28.0	103
28.1	104
28.2	140
28.3	150
AVG	301

APPENDIX B

Longitudinal Profiles

Estimated from Figure 3.5-10 (1995 Streamway Study pp. 3.5-24)

Year	Distance Along Channel	Estimated Elevation	Year	Distance Along Channel	Estimated Elevation
1905	50000		1953	50000	
1905	60000	64	1953	56000	55
1905	70000	73	1953	60000	58
1905	80000	88	1953	70000	69
1905	90000	105	1953	80000	87
1905	100000	120	1953	90000	104
1905	110000	138	1953	100000	116
1905	120000	156	1953	110000	134
1905	130000	175	1953	120000	152
1905	139000	190	1953	130000	175
1905	150000		1953	140000	193
1905	160000		1953	145000	200
			1953	150000	
			1953	160000	

Year	Distance Along Channel	Estimated Elevation	Year	Distance Along Channel	Estimated Elevation
1981	50000		1994	50000	
1981	60000		1994	59000	40
1981	65000	48	1994	60000	40
1981	70000	53	1994	70000	53
1981	80000	62	1994	80000	65
1981	90000	88	1994	90000	88
1981	100000	108	1994	100000	105
1981	110000	120	1994	110000	116
1981	120000	133	1994	120000	132
1981	130000	170	1994	130000	141
1981	140000	187	1994	140000	185
1981	150000		1994	150000	202
1981	160000		1994	160000	

Longitudinal Profiles from 2006 DEM

Year	Distance Along Channel Feet Converted from RM	Estimated Elevation	River Mile	Year	Distance Along Channel Feet Converted from RM	Estimated Elevation	River Mile
2006	150480	224	28.5	2006	132000	168	25
2006	149952	202	28.4	2006	131472	164	24.9
2006	149424	202	28.3	2006	130944	164	24.8
2006	148896	200	28.2	2006	130416	162	24.7
2006	148368	198	28.1	2006	129888	162	24.6
2006	147840	198	28	2006	129360	160	24.5
2006	147312	198	27.9	2006	128832	158	24.4
2006	146784	198	27.8	2006	128304	158	24.3
2006	146256	196	27.7	2006	127776	158	24.2
2006	145728	196	27.6	2006	127248	156	24.1
2006	145200	194	27.5	2006	126720	154	24
2006	144672	194	27.4	2006	126192	152	23.9
2006	144144	196	27.3	2006	125664	150	23.8
2006	143616	196	27.2	2006	125136	150	23.7
2006	143088	192	27.1	2006	124608	148	23.6
2006	142560	190	27	2006	124080	148	23.5
2006	142032	190	26.9	2006	123552	148	23.4
2006	141504	190	26.8	2006	123024	146	23.3
2006	140976	188	26.7	2006	122496	144	23.2
2006	140448	186	26.6	2006	121968	142	23.1
2006	139920	186	26.5	2006	121440	140	23
2006	139392	184	26.4	2006	120912	140	22.9
2006	138864	184	26.3	2006	120384	138	22.8
2006	138336	180	26.2	2006	119856	136	22.7
2006	137808	180	26.1	2006	119328	136	22.6
2006	137280	180	26	2006	118800	134	22.5
2006	136752	178	25.9	2006	118272	134	22.4
2006	136224	178	25.8	2006	117744	134	22.3
2006	135696	176	25.7	2006	117216	134	22.2
2006	135168	176	25.6	2006	116688	132	22.1
2006	134640	172	25.5	2006	116160	130	22
2006	134112	172	25.4	2006	115632	128	21.9
2006	133584	170	25.3	2006	115104	128	21.8
2006	133056	170	25.2	2006	114576	128	21.7
2006	132528	168	25.1	2006	114048	124	21.6

Longitudinal Profiles from 2006 DEM

Year	Distance Along Channel Feet Converted from RM	Estimated Elevation	River Mile	Year	Distance Along Channel Feet Converted from RM	Estimated Elevation	River Mile
2006	113520	124	21.5	2006	95040	96	18
2006	112992	124	21.4	2006	94512	96	17.9
2006	112464	124	21.3	2006	93984	94	17.8
2006	111936	122	21.2	2006	93456	92	17.7
2006	111408	120	21.1	2006	92928	92	17.6
2006	110880	120	21	2006	92400	92	17.5
2006	110352	120	20.9	2006	91872	90	17.4
2006	109824	118	20.8	2006	91344	90	17.3
2006	109296	118	20.7	2006	90816	90	17.2
2006	108768	116	20.6	2006	90288	88	17.1
2006	108240	116	20.5	2006	89760	88	17
2006	107712	114	20.4	2006	89232	86	16.9
2006	107184	114	20.3	2006	88704	86	16.8
2006	106656	114	20.2	2006	88176	86	16.7
2006	106128	114	20.1	2006	87648	84	16.6
2006	105600	112	20	2006	87120	84	16.5
2006	105072	110	19.9	2006	86592	84	16.4
2006	104544	110	19.8	2006	86064	82	16.3
2006	104016	110	19.7	2006	85536	82	16.2
2006	103488	108	19.6	2006	85008	80	16.1
2006	102960	108	19.5	2006	84480	80	16
2006	102432	108	19.4	2006	83952	80	15.9
2006	101904	108	19.3	2006	83424	78	15.8
2006	101376	106	19.2	2006	82896	78	15.7
2006	100848	106	19.1	2006	82368	78	15.6
2006	100320	106	19	2006	81840	76	15.5
2006	99792	104	18.9	2006	81312	76	15.4
2006	99264	102	18.8	2006	80784	74	15.3
2006	98736	102	18.7	2006	80256	72	15.2
2006	98208	100	18.6	2006	79728	72	15.1
2006	97680	98	18.5	2006	79200	70	15
2006	97152	98	18.4	2006	78672	68	14.9
2006	96624	98	18.3	2006	78144	68	14.8
2006	96096	98	18.2	2006	77616	66	14.7
2006	95568	98	18.1	2006	77088	68	14.6

Longitudinal Profiles from 2006 DEM

Year	Distance Along Channel Feet Converted from RM	Estimated Elevation	River Mile
2006	76560	68	14.5
2006	76032	66	14.4
2006	75504	66	14.3
2006	74976	64	14.2
2006	74448	62	14.1
2006	73920	62	14
2006	73392	60	13.9
2006	72864	60	13.8
2006	72336	60	13.7
2006	71808	60	13.6
2006	71280	58	13.5
2006	70752	60	13.4
2006	70224	58	13.3
2006	69696	56	13.2
2006	69168	56	13.1
2006	68640	56	13
2006	68112	54	12.9
2006	67584	52	12.8
2006	67056	52	12.7
2006	66528	50	12.6
2006	66000	50	12.5
2006	65472	50	12.4
2006	64944	50	12.3
2006	64416	50	12.2
2006	63888	48	12.1
2006	63360	48	12
2006	62832	48	11.9
2006	62304	46	11.8
2006	61776	46	11.7
2006	61248	44	11.6
2006	60720	44	11.5
2006	60192	44	11.4
2006	59664	44	11.3
2006	59136	44	11.2

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