CALFED Bay-Delta Program Project # 97-N07
FINAL REPORT

HYDROLOGY, GEOMORPHOLOGY, AND HISTORIC CHANNEL CHANGES OF LOWER COTTONWOOD CREEK, SHASTA AND TEHAMA COUNTIES, CALIFORNIA

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HYDROLOGY, GEOMORPHOLOGY, AND HISTORIC CHANNEL CHANGES OF THE LOWER COTTONWOOD CREEK, SHASTA AND TEHAMA COUNTIES, CALIFORNIA

1.0 INTRODUCTION

Recent and ongoing streambank erosion along lower Cottonwood Creek has damaged numerous properties along the lower 15 miles of the channel, including ranches, residences, and bridges. A proposal was submitted to CALFED in 1998 by Graham Matthews & Associates for the Bengard Ranch in order to conduct hydrologic and geomorphic analyses, and evaluate channel and riparian restoration design alternatives for a potential large-scale restoration project along lower Cottonwood Creek. The Bengard Ranch suffered substantial bank erosion in 1997 and 1998, damaging its orchards and facilities. As originally conceived, the Bengard Ranch project would provide an opportunity to implement a large-scale channel and riparian restoration project, as a pilot for other properties along the creek that have experienced significant erosion-related losses. Without the participation of CALFED and/or similar funding sources, it was acknowledged that the Bengard Ranch would likely be forced to utilize standard erosion control techniques such as riprap that would not include appreciable riparian restoration, setback levees, or other instream habitat features, due to cost constraints.

The original purpose of this project was twofold: (1) to document geomorphic change along lower Cottonwood Creek, and (2) to develop a channel and riparian restoration design for the Bengard Ranch and perhaps adjacent properties and then move towards implementation of such a project. In order to develop a complete restoration design, it was identified that a larger scale geomorphic analysis combined with localized design studies would be necessary to produce intermediate design elements and information. It was originally proposed to use a three phase approach to the project: (1) Phase 1 would involve geomorphic and hydrologic analyses and re-surveys of historic data to document trends, (2) Phase 2 would involve detailed site surveys and restoration project design development, and (3) Phase 3 would involve project construction. Funding was not sought for Phase 3 at this time due to significant uncertainties in scope of the proposed project and thus implementation costs. Task 1 would provide the geomorphic basis for the design, while Task 2 would produce construction ready plans and specifications.

The Bengard Ranch lies about 2 miles downstream from Interstate 5 along Cottonwood Creek, due east from the town of Cottonwood, and about 2 miles upstream of the confluence of the creek with the Sacramento River. Unfortunately, early in the project the property owner felt it was necessary to implement an erosion control project in the fall of 1998 to protect sensitive ranch facilities. The channel of Cottonwood Creek had eroded within about 100 feet of the southern valley hillslope. In this small remaining sliver of alluvial land was a critical road and irrigation ditch. If erosion continued, it appeared that the ranch would be severed by advancing erosion. The property owner went ahead and constructed an emergency “project” to prevent further damage to his land. The project involved construction of an armored jetty extending several hundred feet out into the flood channel of Cottonwood Creek and relocation of the main channel away from the eroding banks. As a result of spending about $150,000 on a levee project that has fairly effectively protected his property, the property owner was not particularly interested in contributing to additional work. Unfortunately, the work completed is not in any sense a restoration project, and the property owner is not particularly interested in modifying or removing his emergency work unless he would obtain equal or better protection. Thus, there appeared to be little reason to proceed with Task 2, since it is not likely that any project would ultimately get built.

In 2002, in contrast to the situation at the Bengard Property, it was found that there was substantial local interest in implementing, as soon as possible, restoration work along at least a 2-mile reach of Cottonwood Creek upstream of the South Fork Cottonwood Creek confluence. Substantial erosion has occurred in the last few years on a number of properties. These property owners have requested technical assistance from the Cottonwood Creek Watershed Group (CCWG) and its Technical Advisory Committee (TAC) in the development and implementation of an overall plan for that reach of the creek, including construction of near-term pilot or demonstration projects. The TAC is concerned that geomorphic data and analyses are necessary to develop a sound plan, but at the present such information is lacking. In particular, the TAC is concerned that the effects of instream aggregate extraction between I-5 and the South Fork confluence may be propagating upstream into this reach and causing or contributing to the recent instability. Unfortunately, CCWG does not have funding currently available to conduct such studies, and is concerned that without the ability to move forward in a coordinated manner in the near-term, the property owners will feel necessary to obtain individual permits and proceed in a piecemeal fashion.

This reach (South Fork to Dry Creek) is immediately upstream of the reach for which the present grant has conducted a geomorphic evaluation (Mouth to South Fork), thus, GMA was ideally situated to expand its present study upstream, already having the USGS 1982 cross section data, a number of the aerial photographs, survey control at the South Fork confluence, etc. In March 2002, the scope of the project was revised to include two tasks: Tasks 1 and 1A. Task 1 was the original geomorphic analysis from the mouth to the confluence of the SF Cottonwood Creek. Task 1A added a similar geomorphic analysis for the next reach 5 mile upstream of the SF Cottonwood Creek confluence. Task 2 of the original scope of work which involved preparation of the restoration design and project permitting was deleted in the amendment process.

2.0 SCOPE AND OBJECTIVES

Collection and analysis of geomorphic data provide the basis for science-based decision making regarding project design, evaluation, implementation, and monitoring. It is particularly important to evaluate the current conditions and any proposed restoration scheme within the context of historic channel and watershed changes (Kondolf and Micheli 1995). Developing a comprehensive geomorphic data set on Cottonwood Creek provides insight into the historical and active processes along the creek and evaluates the long-term effects of activities such as instream aggregate extraction. Historical analysis provides documentation of the sequence of channel changes, allowing assessment of the role of individual events or activities in this process of change, and to evaluate the present channel in the context of its temporal dynamics.

The expected benefit from this project involves the development of a geomorphic dataset that will allow for an improved understanding of geomorphic processes and long-term trends within the lower alluvial reaches of Cottonwood Creek, a large Westside tributary of the Sacramento River.

The project scope is to develop an updated understanding of geomorphic changes that have occurred along the lower 15 miles of Cottonwood Creek through a field-based investigation.

Project objectives include:

1. Provide geomorphic and hydrologic analyses and re-surveys of historic data to document trends, including review of existing information and analyses, including historic aerial photographs, streamflow data and sediment records from USGS records, historic survey data, as available, and other relevant information sources.
2. Implement an extensive field data collection program in the lower reaches of Cottonwood Creek (15 miles). This field effort will provide information on channel geometry, through cross sections and profiles, and bed material composition. USGS cross sections established in the early 1980s will be resurveyed (17 sites) and streambed sediment re-sampled throughout the study reach.
3. Analyze field data and compare to historic datasets, developing conclusions on the nature and rate of geomorphic change in the study reach.
4. Make recommendations regarding implementation of existing and proposed erosion control projects along this reach of Cottonwood Creek.

3.0 METHODS

3.1 HYDROLOGIC METHODS

The purpose of this section is to provide a succinct overview of office methodologies employed for collection and analysis of precipitation and streamflow data.

3.1.1 Precipitation Data

Long-term precipitation data for the project vicinity were obtained and annual totals and cumulative departure were plotted to evaluate trends over time.

3.1.2 Streamflow Data

Presently, one streamflow gaging station is operated in the Cottonwood Creek watershed (Figure 1): the USGS gage near Cottonwood (no. 11372000). Historically, a number of USGS gages have been maintained in the basin (Table 1) on the mainstem and on the North, Middle, and South Forks. Only the Cottonwood Creek near Cottonwood gage is still in operation (period of record 1941-present), and all other gages were discontinued by 1986. With much shorter periods of record compared to the lower mainstem gage, these other stations proved of little use for the present analysis.

A variety of streamflow data were obtained from the USGS for this station, including station descriptions, the 9-207 listing of all discharge measurements since operation of the gage began, mean daily flows for the period of record, annual runoff for the period of record, and instantaneous peak discharges. These data were analyzed for magnitude, duration, and frequency and were used to compute mean bed elevation for each discharge measurement.

3.1.3 Flood Frequency

Flood frequency analysis is a statistical examination of the hydrologic record. Using annual peak discharges, the likelihood that a peak flow (equaling or exceeding a certain magnitude) will occur in a given year as the annual peak, can be computed. The method assigns probabilities to flood magnitudes, expressed as recurrence interval (the average period in years between peaks of a given size or larger), or exceedance probability (the percent chance a peak will be equaled or exceeded in any year). A variety of plotting position formulas and probability distributions can be applied to flood peak data: the Weibull plotting position formula and the log-Pearson Type III distribution have been selected as the standards by federal agencies (Gordon et al, 1993).

Annual maximum peaks were obtained from the USGS for the near Cottonwood gage for WY 1941 to WY 2003 (WY 2002 and 2003 data are provisional). Standard techniques (USGS 1982) were applied to generate the log-Pearson III flood frequency curve.

3.1.4 Flow Duration

Flow Duration analysis relates mean daily discharge to its frequency of occurrence based on the complete historic record of daily flows. All mean daily flows are ranked by magnitude and the exceedance probability of each discharge is computed.

3.2 GEOMORPHIC METHODS

3.2.1 Control Surveys

An accurate survey control network is necessary for any detailed surveys in a river system. The establishment of such a network was an important component of this project. Such a network was established using survey-grade GPS and total station surveys along the lower 15 miles of Cottonwood Creek. This network was used throughout the field data collection portion of the study, particularly during long profile and cross sections surveying. Control points consisted of either 4' long, 5/8" rebar with or without a identifying aluminum cap (intended as relatively long-term benchmarks), or 1' long, 80d spikes (intended as temporary reference marks). GPS equipment was used to establish coordinates for each of these marks using either static or kinematic GPS methods in relation to a base station located on either USGS or CalTrans benchmarks. Many benchmarks are intervisible to enable occupation with a total station for either profile or cross section surveying of the reaches between the benchmarks.

3.2.2 Field Surveys of Channel Geometry

One of the primary tasks of this geomorphic study was to re-occupy as many of the original USGS cross sections (there were 16 in the lower 15 miles of Cottonwood Creek. These cross sections were originally surveyed in 1982-83. To complement the re-occupation of the USGS cross sections, additional cross sections were added in several areas (at bulk sample locations in the vicinity of the Bengard Ranch and then in various sites above the South Fork confluence where original USGS sections were spaced quite far apart. In addition to the cross section survey data, a continuous and detailed longitudinal profile was surveyed over the lower 15 miles of the creek, and the lower reach of the South Fork to Evergreen Road.

3.2.3 Historical Channel Stability Analysis

The purpose of historical channel analysis is to determine the changes to a range of morphologic parameters as a result of human modifications to the river system. This allows quantification of historic and existing channel conditions to assess past and future trends.

Changes in channel morphology occur in response to both natural phenomena (floods, droughts, rapid geologic change) and human activity (gravel mining, dam construction, water diversion, timber harvest, etc.). Furthermore, there is considerable interaction between natural events and the modified watershed conditions. Historical analysis provides documentation of the sequence of channel changes, allowing assessment of the role of individual events or activities in this process of change, and to evaluate the present channel in the context of its temporal dynamics.

This analysis also allows the data collection for one season to be viewed in terms of the historical perspective. The random nature of climatic events is such that hydrologic data will always be plagued with uncertainty. Characterization of the historical record reduces that uncertainty. Since this study is concerned with understanding the results of natural changes and human activities on the channel in the project area, it is essential that this snapshot be placed into the longer-term perspective.

An analysis of historic channel changes along the lower 15 miles of Cottonwood Creek from the upstream extent of the study area near Dry Creek to the confluence with the Sacramento River was made using the planform, cross section and long profile analysis. Cross sections and profiles were discussed in previous sections. Historic maps from as early as 1855 and aerial photographs from 1939-present were located from a variety of sources and copies obtained. Channel centerlines were developed either by using a large CalComp digitizing tablet once the map or aerial photograph was properly registered, or the paper copy of the map or aerial was scanned and rubber sheeted to match a series of known points. In addition, sequences of six years of aerial photographs were prepared for 4 sites spread out in the study reach. The sequences show the same area for each year and channel and vegetation changes can be readily observed.

3.2.4 Substrate

Substrate were to be characterized along Cottonwood Creek following the same techniques used by the USGS, namely pebble counts and bulk samples. The standard pebble count (Wolman 1954) was used to assess framework size and was used throughout the study reach. This is a reproducible method of grid sampling, typically using a sample size of about 100 “pebbles”. There are numerous advantages to this method, including ease of data collection, lack of large samples requiring drying or laboratory analysis, it provides a more representative sampling of a given population, and it is more applicable to very coarse materials. As such, it represents the most cost-effective means of determining framework size.

To characterize the intrusion of fine sediment into the streambed, bulk sampling methods were used. Pebble counts do not adequately represent sediment sizes smaller than 8mm and so are not suitable for evaluation of fine sediment intrusion. Bulk samples were collected using a modified McNeil sampler (McNeil and Ahnell 1964, GMA 2001), consisting of a 24” stainless steel cylinder. The cylinder is worked into the streambed and the substrate removed to a depth of 12-18 inches. Two samples were collected along a surveyed cross section at each study site, which were located at geomorphically consistent features, i.e. just upstream of riffle crests in areas used for spawning by salmonids. If very fine sediment (silts and clays) is present, the water column within the drum was agitated, a sample collected of the thoroughly mixed water column, and returned to the lab for analysis. The size distribution of the bulk samples was obtained by dry sieving on-site, except that splits of the less than 8 mm size were bagged and taken to the GMA lab for analysis. Samples were placed on tarps and thoroughly air dried, then processed through rocker sieves. Very large samples (400-700 kg) were collected in order to meet accuracy standards typical for this type of work (the largest grain should not weigh more than 1% of the total sample weight).

4.0 LITERATURE REVIEW

Existing information and analyses were assembled and reviewed by the Project Team. This included historic aerial photographs, streamflow data and sediment records from USGS records, historic survey data, as available, and other relevant information sources. One of the primary goals of this study was to replicate the surveys made by the USGS along lower Cottonwood Creek in 1982-83 to assess changes in the past 20 years, and copies of the original USGS survey notes were obtained from USGS archives. Existing hydrologic analyses, principally related to proposed dams, were made by the Corps of Engineers in 1977, 1980, and 1983. Other information related to proposed gravel mining operations in the vicinity of Interstate 5 and upstream was evaluated for relevance. Geomorphic information contained in various EIRs for these projects completed in the late 1980s and early 1990s are generally considered to be of questionable validity since they were mostly based on uncalibrated computer modeling, and generally contradict observations on other similar river systems in the region. Survey data for these reports to gravel extraction operators could generally not be obtained for use in this investigation.

Brief summaries of the most relevant work are contained in the following paragraphs.

U. S. Army Corps of Engineers (1978): Flood Hazard Information Cottonwood-Bend Area, California. This study provided flood hazard delineations for the 100 and 500-year floods along the Sacramento River in the Cottonwood-Bend Area along with the lower 9 miles of Cottonwood Creek (to the SF confluence). The study developed a useful description of historic floods and flood damages. Standard engineering practices were used (HEC-2 modeling) to predict 100- and 500-year flood channel velocities and water surface elevations.

U. S. Army Corps of Engineers (1983): Downstream Erosion and Reservoir Sedimentation Study. This study was primarily undertaken to evaluate the potential impacts of proposed reservoirs (one of the mainstem and one on the SF) on the channel downstream, the effect of the project on the transport of spawning gravels, and to assess the relative impacts of the reservoirs compared to historic gravel mining on the channel.

Resource Management International, Inc. (1987 and 1988): Draft and Final Environmental Impact Report for the Xtra Power Project. This document included considerable sediment transport analyses as a result of various concerns expressed in the document scoping period regarding the potential impacts of the proposed gravel extraction project on the downstream supply of spawning gravel as well as potential effects on channel conditions. The EIR concluded that there would be no adverse impact from the proposed project on spawning gravels in Cottonwood Creek, nor would the gravel supply to the Sacramento River be affected for 100 years, and then only slightly. Subsequent comments on the draft EIR by DWR, CDFG, USFWS, CalTrans, and Kondolf in 1989 suggested that a number of the assumptions used in the sediment transport analysis were substantially flawed. Litigation over the document and Tehama Counties certification of the EIR ultimately resulted in the preparation of a subsequent EIR for the proposed project (see below).

U.S. Geological Survey (1988): Channel Morphology of Cottonwood Creek near Cottonwood, California from 1940 to 1985. This study established baseline data (cross sections and profiles) with which the impacts of the proposed dams on Cottonwood Creek and the SF were to be evaluated. These data have proved invaluable in evaluating the changes to the creek that have occurred in the last 20 years.

Water Engineering & Technology, Inc. (1991): Geomorphic Analysis of Cottonwood Creek near Cottonwood, California. This study quantitatively (through use of hydraulic and sediment transport models) evaluated the potential affects of existing and proposed gravel extraction on the state highway, railroad, and county bridges (referred to as the I-5 area). The conclusion reached was that additional extraction by J.F. Shea would not substantially increase potential scour at the bridges beyond what existing ACCP operations had or would have, mostly due to the presence of hardpan which would limit channel bed degradation.

North State Resources, Inc. (1991): Subsequent EIR for the Xtra Power Gravel Extraction Project. This document was prepared to address three areas of inadequacy identified by the Court of Appeals, of which one, the cumulative impacts of the Xtra Power project combined with other "reasonably foreseeable" gravel extraction projects on the mainstem of Cottonwood Creek is, in large part, geomorphically based. Conclusions were only slightly different than the original EIR essentially that the proposed project would have no impacts on gravel supply downstream or local bank erosion.

California Department of Water Resources (1992): Sacramento Valley Westside Tributary Watersheds Erosion Study. This study collected additional baseline data sets (profiles) for lower Cottonwood Creek and performed a variety of geomorphic analyses, which generally showed that existing gravel operations were having an impact of channel morphology.

5.0 RESULTS

5.1 HYDROLOGY

5.1.1 Hydrologic Setting:

Cottonwood Creek drains a basin of about 927 square miles (mi^2) upstream from the USGS gaging station near Cottonwood, located at river mile 2.8 only a short distance (and virtually no change in drainage area) above the confluence with the Sacramento River. The watershed rises to over 8,000 feet at the crest of the Coast Ranges, which separates Shasta and Tehama Counties from Trinity County. The entire watershed is essentially unregulated, although a small reservoir, Rainbow Lake (capacity 4,800 acre-feet), is located on the NF Cottonwood Creek. Normal annual precipitation for the entire Cottonwood Creek watershed has been estimated by the U.S. Army Corps of Engineers at 36.3 inches.

5.1.2 Previous Work

Previous hydrologic analyses of various types have been conducted by U.S. Army Corps of Engineers (1977), the USGS (McCaffrey et al., 1988), and Water Engineering & Technology, Inc. (1991).

5.1.3 Precipitation

Precipitation in the Cottonwood Creek Watershed, as is typical of California, is highly seasonal, with about 90 percent falling between October and April. A small portion of the annual precipitation falls as snow at the higher elevations in the upper watershed, and snowmelt runoff is not a major component of the streamflow in the Cottonwood Creek Watershed. Occasionally though, rain-on-snow events can contribute significantly to the production of large floods. Annual precipitation rates in the watershed range from about 25 inches at the confluence with the Sacramento River to over 50 inches in the headwaters of the watershed along the crest of the Yolly Bolly Mountains. Normal annual precipitation for the watershed is about 36 inches (U.S Army Corps of Engineers 1977). The isohyetal maps for the watershed for the 1911-1960 period indicate that annual precipitation generally increases as one moves towards the higher elevations along the western portion of the watershed, increasing from about 25 inches per year in the lower reaches to over 70 inches in the high elevations along the watershed divide.

There are relatively few long-term precipitation stations near the basin and none located high in the watershed. The longest is that of Red Bluff roughly ten miles to the south, with a period of record of 1905-present, and this gage was used in this analysis. Figure 3 shows the annual precipitation at Red Bluff along with the computed cumulative departure. For Red Bluff, as is common in northern California, the wettest year contained in its record is 1983, when precipitation totals reached 51.03 inches, somewhat wetter than 1941, 1995 or 1998, the next three highest, when 43.19, 44.41, and 45.23 inches, respectively, were recorded. The driest year at Red Bluff was 1976, when only 7.20 inches of precipitation were recorded. The mean for the 96-year record is 22.83 inches.

Cumulative departure from the mean is a measure of the consecutive and cumulative relationship of each year's rainfall to the long-term mean. When the cumulative departure line is descending (left to right), there is a dryer than normal period, while an ascending line denotes wetter then normal. In reviewing the record at Red Bluff, we see a slightly wetter than normal wet period extending from 1906 through 1915, followed by a prolonged drought period from 1916-1936. 1928-1934 was the worst multi-year drought in the 96-year record, with 7 consecutive years below the long-term average. 1937-1945 was a wet period, followed by a prolonged dry period that lasted essentially between 1946 and 1977. 1968-1970 was the only wetter than normal stretch that lasted more than a year or two. The 1976 drought was intense, but short-lived. 1978 through 1983 was a wet period. 1992 through 1998 was the wettest period on record (i.e. has the steepest rise). Annual precipitation is not a very good indicator of flood magnitude, as substantial flood peaks often occur in years with only normal or slightly higher precipitation.

5.1.4 Streamflow

5.1.4.1 Annual Flows

Annual runoff has been measured in the Cottonwood Creek watershed at the USGS streamflow gage since Oct 1940 (WY1941). The mean annual runoff for the 1941-2000 period is 645,000 acre-feet for Cottonwood Creek. The annual runoff data are shown in Figure 4. The range of annual runoff totals is large, with only 68,000 acre-feet in 1977, while 1983 had almost 2 million acre-feet. Large volumes of runoff are often associated with both large flood years and years with high annual precipitation. The two largest annual runoff years were 1983 and 1998, followed by 1941, 1958, and 1995. Interestingly, only one of the five largest volumes of runoff is associated with a large flood year (1983). The other years had very high annual precipitation, but it was spread out enough that no unusually large flows were generated. Three particular dry periods stand out in a cumulative departure analysis of annual runoff, 1943-1951, 1959-1968, and 1987-1994.

5.1.4.2 Monthly Flows

As Figure 5 shows, the distribution of streamflow for Cottonwood Creek is dominated by rain runoff during the months of January through March. Significantly lower monthly amounts are found in December and April. Although significant rainstorms have occurred in Nov-Dec or April-May, they are infrequent enough not to have much effect on the mean monthly flows for the period of record.

5.1.4.3 Peak Flows and Flood Hydrology

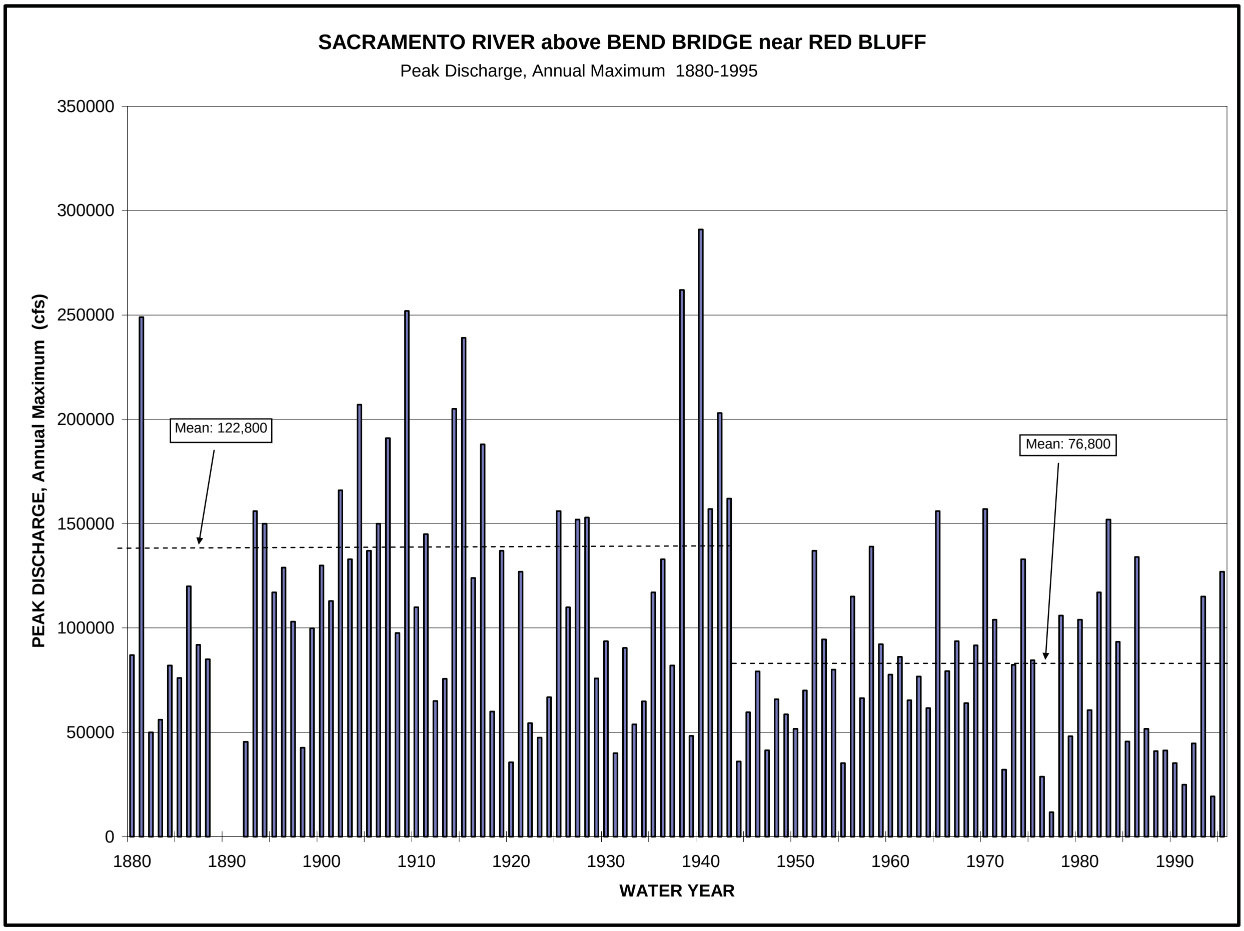
Peak Discharge

Long-term records of annual maximum peak discharges in the study area are available from the USGS gage Cottonwood Creek near Cottonwood gage. .

The largest flood in the watershed, during the 63 years of record, occurred in January 1983, when discharge reached 86,000 cfs. This was probably the largest flood event in the watershed this century, although December 1937 and February 1940 were also very large events and were larger on some streams in the area (Battle Creek [December 1937], Sacramento River above Bend Bridge [February 1940], for example) than 1983. The 1937, 1940 or 1983 events were probably the largest since 1862. January 1974, January 1982, December 1964 (WY1965), and January 1970 round out the top five peak flows in the period of record. January 1997, although very significant in areas with substantial snow, was only about a 5-year event in Cottonwood Creek. Interestingly, the five largest floods during the 63-year period of record occurred in an 18 year period from 1964-1983. Storms in the past decade have all been between 3 and 10-year events.

Historic Floods

The geomorphic significance of the various historic storm events prior to the earliest peak discharge records on Cottonwood Creek can be evaluated through historical accounts and other regional streamflow records. The extensive period of streamflow records for the Sacramento River provides considerable insight into for the 1880-1943 period, which was prior to the construction of Shasta Dam and also the first streamflow gage on Cottonwood Creek.



There have been a number of significant floods in the historic streamflow record in the Sacramento basin. Accounts from early settlers describe particularly unusual floods in January 1862, which is well-known to have been a very large, basically state-wide flood. USGS records at Sacramento River near Bend Bridge near Red Bluff gage for the period 1880 to 1943 indicate February 1881, January 1890 (missing), February 1909, February 1915, December 1937, and February 1940 were all large flood years.

When the two sources of gaging records (Cottonwood Creek and the Sacramento River) are combined with other regional and historic data, a reasonable evaluation of significant floods from 1862 to present can be developed. Known large flood events in the region, many or most of which would also have occurred in the Cottonwood Creek watershed, are known to have taken place in Water Years 1862, 1890, 1937, 1940, and 1983. The available evidence suggests that the events in 1862, 1940, and 1983 were the largest floods in the historic record. The largest of these is likely to have been the 1862 event, followed by the 1983, 1940, 1937 and 1890 events.

Flood Frequency Analysis

Flood frequency analysis is a method used to predict the magnitude of a flood that would be expected to occur, on average, in a given number of years (recurrence interval) or to have a specific probability of occurrence in any one year (1% chance event, for example). Typically, the observed annual maximum peak discharges are fitted to the distribution using a generalized or station skew coefficient, although numerous other distributions may also used. When long records are available, the station skew is generally used exclusively. The results of a Log-

Pearson Type III flood frequency analysis for the Cottonwood Creek annual maximum peak discharges for the 1941-2000 are shown below and in Figure 7. This analysis indicates that the 1983 flood would be about a 45-year event, while flows similar to January 1974 would be about a 25-year event. The 2-year event is about 21,500 cfs, while the 1.5-year event is about 15,000 cfs.

COTTONWOOD CREEK NR. COTTONWOOD
FLOOD FREQUENCY ANALYSIS

Return Period (years)	Computed Annual Maximum Peak Discharge (cfs)
2	**21,500**
5	**40,200**
10	**53,500**
25	**70,300**
50	**82,600**
100	**94,400**

-- Log-Pearson Type III Distribution

Flow Duration Analysis

A flow duration analysis was performed using the historic mean daily discharge records for the USGS gage Cottonwood Creek near Cottonwood. The results are presented in Figure 8. The analysis indicates that Cottonwood Creek only exceeds 2,000 cfs 10% of the time, or 36 days per year on average, while 50% of the time flows are below 230 cfs. Relatively little sediment transport probably occurs below 10,000 cfs, thus all of the geomorphic work accomplished by the river occurs in less than 5% of the time, with most concentrated in the top 1% of the flows.

5.2 GEOMORPHOLOGY AND HISTORIC CHANNEL CHANGES

5.2.1 Introduction to Historic Channel Analysis

A geomorphic analysis of a stream channel encompasses a variety of techniques in an effort to at least qualitatively describe the change in channel form and pattern over time (Kondolf and Sale 1985, Kondolf and Larson 1995), which provides the context to evaluate the current conditions. Channel geometry will vary depending upon the flow characteristics and sediment transport at a given location. In addition, vegetation may influence channel shape. In alluvial systems, with erodible bed and banks, the geometry will change over time primarily when the shear stress of the flowing water exceeds the strength of the sediment forming the bed and banks of the channel, as is often the case during flood events. In humid areas, research has shown that the geometry of the active channel is often adjusted to a run-off event having a recurrence interval of only a few years, typically between 1 and 3 years, while in arid regions the recurrence interval may be on the order of 30-100 years. However, the sequence of events, i.e. the number of years between significant events, is often as important as the peak magnitudes (Richards 1982) in determining geomorphic significance.

Alluvial channels have the ability to adjust their channel boundaries to reflect the forces being applied by a given flow or pattern of flows. In the absence of floods, it is common for a channel geometry to develop that contains the 1.5- to 2-year, or "bankfull", event on an annual flood frequency analysis (Dunne and Leopold 1978). However, during large floods, forces are typically applied to the channel boundaries that are substantially in excess of the resisting forces. This leads to bank erosion, lateral migration of the channel, and scour of the streambed. Depending upon the location within the drainage basin, a large flood may be degradational (downcutting the streambed) or aggradational (depositing sediment to raise bed elevations) or a combination thereof during the passage of the flood wave. Many large floods on alluvial channels result in channel widening. Then, in the intervening years between floods, the channel is gradually encroached by vegetation and sediment deposition and slowly returns to the pre-flood condition.

Techniques used in historical channel stability analysis include: evaluation of planform characteristics, such as channel location, channel response to flood events, channel length, channel pattern, and sinuosity; evaluation of cross section characteristics, such as channel width, depth, and area (often computed at a consistent elevation termed “bankfull” or approximately the elevation reached by a flood with a recurrence interval of 1.5 years); evaluation of profile characteristics such as channel slope, pool riffle sequence; evaluation of riparian vegetation characteristics; evaluation of soils and geologic conditions that may influence channel pattern, location, profile, or cross sectional characteristics; and evaluation of anthropogenic activities that may influence stream channels, such as dam construction, water diversion, channelization, instream aggregate mining, changes in vegetation types, etc.

For the historic channel stability analysis of lower Cottonwood Creek contained in this study, most of the techniques listed above were used and are described in the following sections.

5.2.2 Historic Maps and Aerial Photographs for Planform Analysis

A variety of sources were examined in order to compile a relatively complete set of documents (maps and aerial photographs) with which to perform a planform analysis of lower Cottonwood Creek. Sources for historic maps included the USGS, BLM, State Lands Commission, local museums, and Shasta and Tehama County Planning Departments, Recorders Offices, and Public Works Departments. Relatively few useful maps were found, other than an 1855 General Land Office (GLO) survey in the BLM archives and early topographic maps which did not show channel alignments that were different from the earliest aerial photographs.

Aerial photographs were the primary medium used in the planform analysis. Aerial photographs were located from 1939 to 2002. Two sets of aerials were flown of the study area during the course of this study effort: one in 1998 at 1:12000 to provide general coverage of the entire study area and one in 1999 at 1:6000 to locate targets sets during GPS surveys to assist in rubbersheeting the images to form a mosaic. Numerous sets of aerial photographs at various scales were located in the National Archives, ASCS, USGS, USACE, and private companies including Cartwright, Hedges, and WAC. Generally 3-4 sets per decade of a useable scale (1:40000 scale or larger) were located and copies, prints, or digital images obtained. Most of the photos were then scanned and rectified using AutoCAD software. Some of the photos only had the channel centerline digitized. Table 3 lists the maps and aerial photographs used in the planform analysis and includes type, year, date (if available), scale, photograph format (black & white or color), and source.

The centerline of the low-flow stream channel mapped from each year is shown in Figures 10a, 10b, and 10c, with the entire study area broken up into three segments: one (Figure 10a) from the confluence with the Sacramento to about one mile downstream of Interstate 5, the second (Figure 10b) from one mile downstream of Interstate 5 to just above the South Fork Cottonwood Creek confluence, and the third (Figure 10c) from the SF confluence upstream to Dry Creek. The alignments are shown overlaid on either 1999 aerial photographs (Figures 10a and 10b) or 2002 aerial photographs (Figure 10c) in order to provide general cartographic features for reference.

The earliest channel alignment from the 1855 GLO surveys did not define a low flow channel and only showed a wide "flood channel". The centerline of this flood channel was used as that was all that was available, but undoubtedly there was somewhat higher sinuosity at that time than the alignment indicates. In addition, the 1855 alignment shows channel locations that are clearly not possible, i.e. on higher terrace surfaces that are far too old to have had a channel alignment there in the last 150 years.

The most evident feature of Figure 10 is the wide historic meander belt that the stream channel has occupied over the past 150 years and the rapid change in channel alignments that have occurred in some areas. In some locations, the width of the historic low-flow channel meander belt is between 2400 and 3000 feet (a reach near river mile 2 towards the downstream end of the Bengard property, and a reach just upstream of Interstate 5, are good examples). This width does not cover the entire active (100-year) floodplain width, which is considerably greater in many places. In addition, it is apparent from channel scars and vegetation lineations along historic channel alignments that in some areas the active meander width is even greater than shown from the available historic record. Either these alignments occurred between 1855 and 1939 or were from even earlier periods. It is unlikely that these alignments occurred in the post 1939 period, as the frequency of aerial photographs available would likely have shown that course. In contrast to the reaches with very wide meander belts, there are also reaches that have remained quite narrow, whether from confinement by geologic features or stabilization from anthropogenic activities (rip rap placement and bridge construction, for example). Good examples of narrow reaches include the USGS Cottonwood Creek near Cottonwood gage, where the meander belt width is only about 400 feet, the reach just downstream of Interstate 5, and a reach just upstream of the SF confluence.

In some areas, such as the reach towards the downstream end of the Bengard Ranch, the channel alignments show a progressive migration of the channel, typically with decreasing radii of curvature, over periods of time up to two decades, until the channel could not support such a tight meander pattern and the sharp bend was cut-off with a resulting dramatic change in the channel course.

Review of these historic channel alignments leads to the following conclusions:

1. Channel alignments were quite stable in the 1939-1966 period despite a number of fairly large flood events (1940, 1941, 1956, 1958, and 1964 all in the 50,000-60,000 cfs flood peak range (8-15 year recurrence interval events).

2. Beginning in 1972, more frequent and rapid shifts in the channel alignments occurred. Some of the larger shifts occurred during large floods, such as those in 1970, 1974, 1982, and 1983, while other substantial shifts occurred in relatively small years, such as between 1977 and 1981 when no floods larger than a 5-year event took place. It appears that some event, sequence of events, or human activity initiated a series of changes that resulted in greater channel instability.

3. Since the end of the 1987-1992 drought, substantial channel change and bank erosion have occurred at many sites along the river despite no storm flows exceeding an 8-year event.

4. The amount of channel migration generally diminishes with distance upstream of the SF confluence, as geologic controls (higher, older terraces) confine the channel.

5. Several of the alignment changes appear to have been initiated by activities associated with instream aggregate extraction (either pit capture or bar skimming which allowed the channel to cut-off a bend due to removal of the gravel bar on the inside of the bend). These occurrences were also described in the WET (1991) study.

Figures 11-14 show a series of views from 1939 to 1999 or 2002 aerial photographs at four sites randomly situated throughout the study area. Each figure shows a sequence of 6 aerial views for each site, typically 1939, 1952, 1966, 1981, 1988, and 1999.

In Figure 11, at the Bengard Ranch, a reach that includes the USGS gage location, it is evident that overall there is an increase in the amount of riparian vegetation in this reach. In the 1939 view, high flow scars (probably from the Dec 1937 flood) are visible over a wide floodplain with scattered riparian vegetation, much of which is limited to the edges of older channel alignments or the current low flow channel. In 1952, a more defined high flow flood scar indicates that the channel was braided at high flows. In 1966, grading that resulted in a long linear riprap stabilization feature, isolating historic high flow braided channels, is visible. During the 1950s and 1960s, the expansion of large orchards on floodplain areas in the reach occurred. Braided channels are evident in the 1981 view.

In Figure 12, a reach about one-two miles downstream of Interstate 5, relatively small changes occurred between 1939 and 1966. The agricultural land south of the creek was protected by a thick stand of riparian vegetation along a historic channel alignment. Evidence of instream gravel mining is visible in 1981. By 1988, channel migration to the south had just pierced the protective riparian corridor and active bank erosion was present. This meander bend continued to migrate south between 1988 and 1999, causing perhaps 300-500 feet of bank erosion. A number of off-stream gravel pits along the north side of the creek were developed between 1988 and 1999.

In Figure 13, a view that includes the vicinity of the present Interstate 5 (formerly Highway 99), a similar sequence of events occurred, complicated by the presence of the highway and railroad bridges. In 1939, the main creek channel was relatively straight in this reach and flanked by high flow channels that contained extensive stands of riparian vegetation. In 1952, only minor channel changes had occurred, except that the channel had broken through a thin riparian corridor on the north side of the river about 2000 feet upstream of the railroad bridge and eroded into some agricultural fields. In 1966, Interstate 5 had recently been built, adding two new bridges. Additional channel erosion and loss of riparian vegetation had occurred upstream of the bridges. Instream gravel mining appears to have begun at a small scale in this period. By 1981, a large meander had formed upstream of the bridges, substantially changing the alignment of the channel as it passed under the railroad bridge. As noted by WET (1991) the pier spacing (which they believe caused an extensive backwater effect at high flows) of the railroad bridge was possibly responsible for the formation of this large meander. When the pier spacing was doubled from 30 to 60 feet by bridge modifications in 1982, the large meander was immediately cut-off. Gravel mining intensified in the 1981 and 1988 views. In 1999, migration of the channel into a large block of riparian forest along the south side of the stream just upstream of the railroad is threatening to outflank the bridge abutment and is now at a highly acute angle to the railroad bridge which again creates unfavorable local hydraulics.

Figure 14 is a view of the creek in the vicinity of the Baker property, located about 3 miles upstream of the SF confluence. In 1939, the channel was braided, but without any significant meandering. A large historic meander scar to the south side of the creek is visible in 1939, and particularly visible in 1952, due to irrigation on that floodplain surface. By 1966, the channel appeared to have adopted a single thread alignment (except at high flows) with slightly greater meandering. The meander development intensified in the 1980s, with much more rapid channel migration and meander cut-offs occurred.

Determination of the length of channel represented by each channel alignment is a simple task once the alignment is defined, and tracking of trends in channel lengths (which can be easily converted into sinuosity can be a powerful tool in channel stability analysis. Table 4 summarizes the channel lengths for the study area divided into two reaches: the mouth to the SF confluence and the SF confluence upstream to the end of the surveys, while Figure 15 graphically presents the same data. Not all years had channel lengths upstream of the SF confluence due to fewer complete datasets for that reach. Substantially different trends in channel length occurred in the two reaches over the period of record. In the lower reach, channel length increased steadily after 1939 and reached a peak in 1982, then declined until the mid 1990s when channel length began increasing once again. In contrast, channel lengths in the upper reach have continued to increase and, as shown in Figure 15, the rate of increase appears to have increased since the early 1980s.

5.2.3 Gaging Station Analysis

Gaging station records used to develop a stream channel history include the station description, level notes, and discharge measurement records (Smelser and Schmidt 1989). Discharge measurements collected at the same location allow development of the most definitive record of change. Since the location of low-flow (wading) measurements depends on the selection of the best measurement site and may vary over a reach up to 1000 feet upstream or downstream from the gage, analysis is often limited to high-flow discharge measurements taken at a cableway or bridge (Hickey 1969). Data obtained include the thalweg (or minimum streambed elevation) and mean streambed elevation over the period of record of the gage. The procedure involves computing average channel depth (area/width or discharge/(width)(velocity)) and then subtracting this value and the maximum channel depth from the gage height at the time of the streamflow measurement. Any changes in gage datum during the period of record must be carefully taken into account. Care must be taken in interpreting upward (e.g. channel fill) spikes of the mean bed elevation plot, as very high discharge measurements have a greater top width, which may artificially create the appearance of fill. If the cross section has very steep banks, such as in bedrock canyon reaches, these upward spikes may in fact reflect channel aggradation. Plotting the mean and minimum bed elevations provides a check for this effect.

Selected discharge measurements can also be plotted as cross sections to compare channel shape changes over time. In addition, peak discharge for very large floods is often calculated by the Slope-Area method, which involves surveying two or more cross sections, a profile of high water marks, and then assuming channel and overbank hydraulic roughness values and computing the discharge using a conveyance form of the Manning's equation. These cross sections are usually surveyed in the vicinity of the gage, and often near the cableway and may be used to compare with cross sections plotted from discharge measurements.

Changes in hydraulic geometry relationships may also be used to define changes in channel geometry and specifically in the rate of adjustment of the various hydraulic variables.

For Cottonwood Creek, the presence of a streamflow gage with over a 60-year record presents a good opportunity to conduct such a gage analysis. Figure 16 shows the results of mean bed elevation analysis for this gage. The reach at the gage was clearly incising between 1940 and 1950, then it appears to have aggraded through about 1960. In the early 1960s the gage was relocated and the datum changed. Since about 1975, when the mean bed elevation was around 369 feet (NGVD 1929), there appears to be about 3 feet of degradation at the gage. These findings are in contrast to the analysis by the USGS in 1983, WET in 1991, and DWR in 1992. At those times, it is apparent that the mean bed elevation had not changed enough to appear to reflect anything other than random scatter as bedforms moved through the gage reach. Since about 1990, a much more pronounced decline has occurred and the trend since 1975 is much more readily apparent.

5.2.4 Cross Section and Profile Analysis

Trend monitoring of channel geometry can provide insight into changes to the river channel due to specific events (typically large floods), human activities in the watershed or channel that directly or indirectly impact the channel, and to longer-term adjustments and recovery from these flood events or impacts. Channel geometry is most often monitored through cross section and profile surveys, both of which are two-dimensional representations of channel shape, with the cross section perpendicular to the flow direction, and the longitudinal profile parallel and most often along the thalweg.

Streambed elevations generally reflect the overall balance of sediment transport at their location. If sediment delivered to the channel is greater than the transport capacity of the channel (which is a combination of flow and channel geometry), then the channel will aggrade or rise in elevation. When sediment loads are less than transport capacity, the channel will degrade or scour as long as suitably sized (i.e. capable of being mobilized) alluvial deposits are present on the channel bed. Dramatic channel adjustments have been observed to occur in watersheds with very high sediment production and delivery, particularly when delivered catastrophically, such as in the December 1964 flood in many northern California basins.

5.2.4.1 Control Surveys and Network

A detailed control network was established using survey-grade GPS along the lower 15 miles of Cottonwood Creek. This network was used throughout the field data collection portion of the study, particularly during long profile and cross sections surveying. Control points consisted of either 4' long 5/8" rebar with or without a identifying aluminum cap (intended as relatively long-term benchmarks), or 1' long 80d spikes (intended as temporary reference marks). GPS equipment was used to establish coordinates for each of these marks using either static or kinematic GPS methods in relation to a base station located on either USGS or CalTrans benchmarks with published coordinates and elevations. Individual coordinates for all reference marks may be found in the data files on the CD in the back of this report.

5.2.4.2 1983 USGS Cross Sections and 1999-2002 GMA Cross Sections
The USGS established 28 cross sections along lower Cottonwood Creek (21) and the South Fork Cottonwood Creek (7) in 1982-1983. The mainstem cross section locations are shown in Figures 9a, 9b, and 9c. In 1999-2002, GMA re-occupied, as closely as possible, 16 mainstem cross sections and also established 7 additional cross sections: 5 on the mainstem upstream of the South Fork confluence (Figure 9c) and 2 on the lower South Fork (Figure 9b).

Re-occupation of the original USGS cross sections was very challenging after almost 20 years. Even though we had obtained copies of the original field notes from USGS archives, many of the landmarks and in some cases features where end pins were located (trees, fences, etc) were no longer there. There were no coordinates to relocate, and the best location map for the cross sections was Figure 2 in McCaffrey et al (1988), which was at a scale of 1.4 miles per inch. We also talked with more than one of the field crew who surveyed the cross sections (still with the USGS), but their memories were of little value in relocating the sections. Thus, the cross sections were located at best we could, and some were right on, when old monuments were found, but many are probably only within 50-200 feet of the original location.

Figures 17a-d show the 1983 USGS cross section data overlain with the 1999-2002 GMA survey data. It is readily apparent that at most of the cross sections, the channel has incised a considerable amount since 1983. In many cases, the cross sectional area has also increased 100-200% as a result of the incision. Table 5 summarizes the thalweg elevations for both surveys. Note that there is disagreement between the thalweg elevations described in original field notes and those published Table 2 of McCaffrey et al (1988) for cross sections 2 through 7. In some cases, it appears that the survey data from the original field notes only went to the water surface, while at other sections the field notes clearly call out a thalweg shot. Given this disparity, which amounts to between 2.5 and 8 feet at the various sections, there is some doubt about the actual magnitude of channel incision in the lower 5 miles. If the field notes are correct, then the incision has ranged from 1.3 to 8.5 feet. If the published table is correct, then the incision has ranged from 1.1 to 5.3 feet, with one section aggrading two feet and another (at the USGS Gage) showing no change). Downstream of Interstate 5 (I-5), the maximum bed degradation would be 5.9 feet at cross section 1, followed by 5.3 feet at cross section 5. Upstream of I-5, closer to several areas of gravel extraction, the incision is even greater, ranging from 4.6 to 10.6 feet, and averaging 7.5 feet for cross sections 11-16 (there is no cross section 15).

5.2.4.3 Profiles: COE, USGS, XTRA POWER, GMA
Historic profiles of lower Cottonwood Creek, from the South Fork to the mouth, are available from the U.S. Army Corps of Engineers in 1977, the USGS in 1982, and the Xtra Power EIR in 1987. Unfortunately, no historic profile data could be located for the study reach above the South Fork confluence. In 1999, GMA surveyed a detailed profile from the mouth to 2000' upstream of the South Fork confluence, a total length of about 47,000 feet. The result of the

GMA surveys and the comparison to the historic surveys is shown in Figure 18a. The obvious conclusion from review of the different profiles is that substantial channel bed degradation has occurred since 1977, pretty much along the entire 9 mile reach. Both aggradation and degradation were apparent between the 1982 USGS profile and the 1987 Xtra Power profile, depending on reach. Since 1987, the lower 4 miles show only modest changes. The difference in the amount of detail between the surveys (the GMA surveys have over 1000 points while the others have 10-20 points) makes it difficult to precisely evaluate the change at a given point, though the overall trends are apparent. Substantial degradation occurred between 1987 and 1999 for a reach extending about 7,000 feet downstream of I-5 and 2,000 feet upstream. Then substantial incision also occurred in the mile below the South Fork confluence.

During the 1999 GMA profile surveys, all exposures of the Tehama Formation in the bed of the channel were identified. Figure 18b shows all of these mapped exposures from the mouth to the South Fork confluence. There are many outcrops in the lower 2.6 miles or so, to a point just upstream of the USGS gage. Then there is a large gap for over two miles in an area that the profile shows to be aggraded relatively to the rest of the profile, which would explain the absence of the exposures. More exposures occur in the vicinity of I-5 and at a number of locations upstream towards the South Fork confluence.

Figure 18c shows the 2002 GMA profile from the South Fork confluence upstream to Dry Creek, a distance of almost 35,000 feet. Again, the profile includes all of the exposures of the Tehama Formation, referred to in the figure as “hardpan”. Extensive exposures of the Tehama Formation occur in this portion of the study area, reflecting the substantial incision that has affected this reach, based on the cross section re-surveys.

The question that is immediately raised after observing the extent of channel bed degradation that is reflected in either the cross section or profile surveys involves what actions or processes could have caused so much change in a relatively short period of time. The primary causes of channel bed degradation include dam construction, urbanization, channelization, and gravel extraction. In extreme cases, vegetation conversion could possibly also trigger incision, through a substantial increase in runoff. Of these, only gravel extraction appears to be involved in Cottonwood Creek at a scale necessary to have caused the observed changes. There is a remarkable correlation in space and time between the presence of gravel mining in the vicinity of I-5 and upstream to the South Fork confluence and a substantial amount of streambed degradation. This will be discussed further in section 6.

5.2.5 Substrate Investigations

The original intent of substrate investigations was to evaluate whether changes in substrate size distribution has occurred since the 1982-1983 USGS study. Review of the original field notes and a description of the methods in McCaffrey, et al (1988), indicated that non-standard field data collection methods were used and thus there would be little likelihood of producing useful comparisons. The USGS used two methods: point counts of coarse channel material were made at one or more points along each cross section, and samples of finer materials were also collected several bank or floodplain surface locations along each cross section and then sieve analyzed. The primary problem with this dataset is that samples were collected at each cross section rather than at consistent locations on similar geomorphic features (i.e. head of point bar). Challenges in relocating the USGS cross sections has been described in previous sections, and the difficulty in attempting to accurately locate the sediment sample location quickly convinced us to take another approach.

Two methods were employed using standard techniques of substrate investigation: bulk sampling and pebble counts. Bulk samples were collected fairly early on in the project all in the vicinity of the Bengard Ranch in order to characterize riffle substrate to evaluate size distribution and spawning habitat quality. Large bulk samples were collected at 7 sites located along pool tail-riffle crest features (Figure 9a). Each site consisted of two bulk samples with combined dry weights of 600-900kg. The coarse fraction of all samples was processed on-site using rocker sieves while splits of the fine fraction were taken to the lab for sieve analysis. Table 6 lists the size distribution of the surface and sub-surface samples at each site, while Table 7 provides various particle size indices for each site. At all sites, the surface layer was coarser than the sub-surface. D_{50} of the surface samples were typically between 25 and 50mm, while D_{50} of the subsurface samples ranged from 1.7 to 17.7mm. The one sample at 1.7mm was an substantial outlier, while the remainder were in the 10-18mm range. The percent fines less than 2mm were all in the 14-25% range with the one exception which was very sandy with 52% less than 2mm. Percent less than 0.85mm, often used to evaluate the quality of spawning substrate for salmonids, ranged from 4.5 to 10.4%, with the one outlier at 42%. These figures indicate fair quality spawning substrate. Figure 19 shows size distributions of the sub-surface portion of bulk samples, which clearly shows the one outlier at Site 7. Figure 20 compares the size distribution of a pebble count taken of the surface framework prior to the collection of the bulk sample with the size distribution of the surface layer of the bulk sample. For many of the samples, these two types of surface substrate measurement result in very different values, while a few of the samples (Site 4 for example) had similar values from the two methods. Figure 21 plots the particle size index of the bulk sample against the size index from the pebble count and shows the scatter in these relationships.

The second type of substrate investigation involved pebble counts to evaluate framework size through the entire study reach. 42 pebble counts were collected at consistent geomorphic features (pool tails) were salmonids were likely to spawn over 74,000 feet of channel. Table 8 compares the size distribution parameters for these 42 samples, while Figure 22 plots the D_{50} and D_{84} versus distance along the long profile. In general, considerable variability in size distributions were found, most likely due to local variations in channel hydraulics. A slight trend of increasing grain size as one moved upstream was found. D_{50} of the substrate ranged from 18 to 50mm.

5.2.6 Sediment Transport

Although no sediment transport data were collected as part of this study, an evaluation of existing information was conducted as an element of the geomorphic analysis.

5.2.6.1 USGS Data

Several datasets collected by the USGS are available with which to evaluate historic suspended sediment discharge, bedload discharge, and total annual loads. However, no sediment transport data have been collected on Cottonwood Creek since 1980.

<u>USGS Suspended Sediment Data</u>

USGS collected suspended sediment data records at the Cottonwood Creek near Cottonwood gage during the 1964-1967 and 1978-1980 periods. Figure 23 is a plot of all of the daily values with best-fit power equations for each of the obvious subdivisions of the dataset. This analysis resulted in 4 curves with considerably different slopes, which when combined provide a long-term suspended sediment rating curve.

<u>USGS Bedload Data</u>

Very limited bedload measurements have been collected by the USGS at the Cottonwood Creek near Cottonwood Gage. Between 1977 and 1979, 10 bedload measurements were collected at flows up to about 7000 cfs, or only about 50% of bankfull. Unfortunately, 5 of the measurements did not have streamflow values associated with them and the 15-minute data were not available at the time of this report to assign such values. Figure 24 shows the bedload rating curve for the available bedload data. The limited number of data points do define a linear relationship ($r^2 = 0.97$) when plotted on log-log paper.

<u>Load Computation</u>

As a computational exercise, total sediment load was computed for the 1941-2000 period using the suspended load and bedload rating curves developed in this study and the mean daily discharge records from the USGS gage. Over the 60 year period, some 52,245,000 tons of suspended sediment and 482,000 tons of bedload were computed to have been transported by the creek at the lower USGS gage. This equates to annual averages of 870,700 tons for suspended load and 8,040 for bedload. Based on these calculations, bedload is approximately 1% of the suspended sediment load. The bedload transport values seem quite low, as the literature typically predicts bedload as 5-10% of suspended sediment load.

To evaluate the accuracy of this approach, the annual suspended sediment totals computed by this method were compared to the USGS values for the periods when the Cottonwood Creek near Cottonwood gage was operated as a daily suspended sediment station (WY1963-1967 and 1978-1980). In wetter years, the much simpler computational method used in this study was within 10-15% of the USGS values, while in drier years the differences were typically greater. However, the relative closeness of the computed values to the USGS values for suspended sediment indicates that the approach is reasonable. A much larger issue would involve whether the suspended sediment rating curves are really applicable to the much longer time period used in the computations compared to the time periods when the samples were collected. There is no way to answer or address that question.

5.2.6.2 Comparison to Clear Creek Bedload Data

As a comparison, recent bedload data (GMA 2003) from Clear Creek, the adjacent basin to the north, are also plotted on Figure 24. There is a substantial difference in the slope of the power fit equations between the two bedload rating curves, with Clear Creek being much steeper, indicating much higher bedload transport rates at the same discharge, except for very low rates in the 1,000 to 2,000 cfs range. Since the drainage areas of the gages where the two bedload datasets were collected are substantially different (Cottonwood Creek near Cottonwood is 927 mi^2, while the unregulated drainage area of Clear Creek is only 29mi^2), Figure 25 compares the unit discharge (i.e. discharge divided by drainage area to get cfs/mi^2) bedload transport rates of the two datasets. Although the slope of the lines remains unchanged, the relative position of the data along the x-axis is shifted. Unit discharge at bankfull (1.5-year event) for both gages is 15-20 cfs/mi^2, which would indicate that by extrapolation of the Cottonwood data above 7 cfs/mi^2, the bedload transport rate would be about 500 tons/day. This transport value seems quite low, being about 25% of that of the Clear Creek data for a 1.5-year event. Unfortunately, without additional data, little more can be said regarding bedload transport.

5.3 SITE MAPPING ON BENGARD RANCH

Although there was a substantial change in the scope of the project that resulted in additional geomorphic investigations rather than specific project development on the Bengard Ranch, a considerable amount of mapping on the ranch was conducted prior to the change in study direction. Figure 26 shows a 1999 aerial view of the Bengard Ranch vicinity. The USGS Cottonwood Creek near Cottonwood gage is located at the very constricted channel location at the center of the image, where the low-flow channel meanders to the south against the levee road along the outside of the orchards. Just downstream is the large riprap protected levee or jetty constructed by the Bengards in 1998 to protect their property from continuing erosion damage. The jetty completely blocked the existing channel and a new channel was excavated to the north, east of the downstream tip of the levee. The jetty has served its function and protected that portion of the property from further erosion. Upstream from the USGS gage along the Bengard property is a straight riprap bank, apparently constructed by the Corps of Engineers after the 1955 and 1958 floods, which created the erosion scar in that area (no orchards are planted in the crescent shaped area, since the erosion removed most of the prime soil.

The original concept was to breach the riprap levee, grade an overflow channel along the edge of the orchard, and construct a setback levee. This concept would have tied the erosion scar into an existing riparian area downstream of the USGS gage and reduced the constriction at high flows that occurs at the USGS gage. Figure 27 is a 1-foot contour interval map of the site was developed in preparation for design. Considerable changes have occurred in the channel since the mapping was completed in 1999. Re-surveys of the channel portion of this area, via conventional methods or LIDAR, could evaluate the change in stored sediment volume in this reach over the intervening period, which could be used to estimate minimum sediment transport rates and track gravel bar volume.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The following sections present the conclusions reached over the course of this study, as well as selected recommendations.

6.1 GEOMORPHIC CHANGES TO LOWER COTTONWOOD CREEK, 1939-2002

Substantial geomorphic changes have occurred along the lower 15 miles of Cottonwood Creek over the past 63 years. The channel is far less braided than it was historically, having adopted a single-thread channel throughout the study area. Most of this change appears to have occurred since the mid 1960s. Channel lengths and sinuosity have increased by 20-25% over the period of study. Bank erosion has occurred at a variety of locations as a result of channel changes, and with intensification in land use on the adjacent floodplains during this period, has resulted in greater loss of valuable agricultural land.

Relatively little quantitative data describing channel geometry could be found prior to 1982, with the exception of a profile surveyed by the US Army Corps of Engineers in 1977 as part of a flood hazard study of Cottonwood Creek downstream of the SF. Thus, most conclusions are based on planform changes and inferences from sequential aerial photography.

1. Channel alignments were quite stable in the 1939-1966 period despite a number of fairly large flood events (1940, 1941, 1956, 1958, and 1964 all in the 50,000-60,000 cfs flood peak range (8-15 year recurrence interval events).

2. Beginning in 1972, more frequent and rapid shifts in the channel alignments occurred. Some of the larger shifts occurred during large floods, such as those in 1970, 1974, 1982, and 1983, while other substantial shifts occurred in relatively small years, such as between 1977 and 1981 when no floods larger than a 5-year event took place. It appears that some event, sequence of events, or human activity initiated a series of changes that resulted in greater channel instability.

3. Since the end of the 1987-1992 drought, substantial channel change and bank erosion have occurred at many sites along the river despite no storm flows exceeding an 8-year event.

4. The amount of channel migration generally diminishes with distance upstream of the SF confluence, as geologic controls (higher, older terraces) confine the channel.

5. Several of the alignment changes appear to have been initiated by activities associated with instream aggregate extraction (either pit capture or bar skimming which allowed the channel to cut-off a bend due to removal of the gravel bar on the inside of the bend). These occurrences were also described in the WET (1991) study.

6.2 CHANGES SINCE 1983 USGS STUDY

With the quantitative dataset provided by the USGS study, more rigorous evaluation of geomorphic changes in the past 20 years has been undertaken in this study. All types of analyses used in this study (planform analysis, cross section and profile analysis) point to substantial geomorphic changes over the past two decades that are generally deleterious to stream health (i.e. significant channel incision, bank erosion, loss of floodplain function, etc.). The available evidence strongly suggests that the proximate cause for most of this change is related to instream aggregate extraction far in excess of annual replenishment rates. Disagreement between experts over the cause of geomorphic change has occurred in the past on Cottonwood Creek, but with the present dataset which quantifies the magnitude and extent of these changes, there is much less opportunity for such disagreement.

6.3 EFFECTS OF INSTREAM GRAVEL MINING

The effects of instream gravel mining on alluvial rivers have been thoroughly evaluated and described in the literature (e.g. Bull and Scott 1974, Sandecki 1989, Collins and Dunne 1990) and are primarily based on published field studies. A thorough summary of these effects is contained in Collins and Dunne (1990) and consists of up to 12 potential effects:

1. Extraction of bed material in excess of replenishment from upstream causes bed degradation. Degradation can extend in both upstream and downstream directions from the extraction site, and can occur whether the extraction is from above or below the elevation of the low-water channel.
2. As a result of bed degradation, bridge piers or abutments can be undermined, and pipelines or siphons previously buried can become exposed.
3. Bed degradation may change the morphology of the river channel, which could affect aquatic habitat and salmonid spawning sites.
4. Degradation can deplete the entire depth of gravel on a channel bed either continuously or in specific locations, thereby exposing other substrates that may underlie the gravel. If these other substrates have lower habitat value than alluvium, then aquatic habitat may be deleteriously affected.
5. Groundwater levels can be lowered as a result of channel degradation, as most alluvial rivers have floodplain aquifers that discharge to the channel. Lowering of the water table would reduce aquifer storage capacity, increase depth to groundwater, and drain wetlands.
6. Lowering of the groundwater can weaken or kill riparian vegetation due to chronic dewatering. Eventually vegetation can colonize lower elevation banks as they are exposed. Destruction of riparian vegetation can in turn adversely affect fish and wildlife habitat. In streams where vegetation acts to stabilize the banks, bank erosion may be increased as a result of vegetation destruction.
7. The frequency and magnitude of overbank flooding are lessened as bed elevations and flood heights decrease, reducing hazard for human occupancy of floodplains. However, with additional energy contained in the channel and a lack of floodplain connectivity, bank erosion can be accelerated.
8. Rivers migrate across the floodplain by eroding the outside bank of a bend and depositing material on a point bar on the inside bank. With time the gravel bar on the inside of the bend is covered with fine sediments and organic materials from overbank flooding, eventually making the soil suitable for vegetation. However, if the accretion occurs while the riverbed is rapidly lowering, the accreted land will be stranded above the active floodplain as a terrace. Newly arrested or existing floodplains may no longer be supplied during floods with water and fine, organic-rich sediments, which are important for some agricultural land uses.
9. Rapid bed degradation may induce lateral bank erosion by increasing the height of banks, which are then more prone to undercutting and failure.
10. The reduction in size or height of gravel bars can cause either the erosion or the stabilization of upstream and downstream banks. The existence of the point bar tends to force the current toward the opposite bank, undermining it. Removal of the point bar may therefore stabilize the opposite bank. However, lowering of the point bar may also have a destabilizing effect on banks as a greater portion of the flow follows a more direct path downstream, increasing the erosivity of the river on the outside bank of the next bend downstream.
11. Removal of gravel from bars may cause erosion of downstream bars by interrupting the supply of gravel to them while the river maintains its capacity for transporting gravel from them.
12. Some dredging operations result in the preferential removal of gravel from mixed sand and gravel beds. Lagasse and others (1980) suggest that a reduction in the gravel supply

in such a river can affect channel stability, because bars, which are armored by gravel, could be destabilized as a result of the decrease in gravel supply.

Of these 12 potential effects, this study concludes that there is considerable field evidence that effects 1, 2, 4, 7, 9, and 10 have occurred and can be demonstrated on lower Cottonwood Creek. Other effects (i.e. #3, involving effects on fish habitat, and numbers 5 and 6 involving effects of groundwater levels and riparian vegetation) may well have occurred but data to evaluate them were not collected as part of this study.

1. <u>Bed Degradation</u>: Both the long profile and cross section surveys conducted for this study, when compared to previous surveys, clearly demonstrate that significant bed degradation has occurred since 1977 over long reaches of lower Cottonwood Creek.
2. <u>Bridges Affected or Pipelines Exposed</u>: Although there is disagreement between various experts on the effect of extraction on the I-5 bridge, the bridge was recently replaced and CalTrans has maintained that gravel extraction was responsible. Upstream, the ACID siphon, formerly buried well below the streambed, has become exposed, as well as other pipelines.
4. <u>Exposure of Other Substrates</u>: The profile surveys conducted for this study have demonstrated that extensive exposures of Tehama Formation are now present at many locations along much of the channel.
7. <u>Reduction in Overbank Flooding</u>: Cross section surveys conducted for this study show that the cross sectional area of the channel has increased substantially since the 1982-83 USGS surveys which results in a reduction in the frequency of overbank flooding.
9. <u>Bank Erosion increase due to Bank Height Increase</u>: According to observations of bank erosion made during channel surveys, analysis of aerial photographs, and conversations with landowners, the rate and extent of bank erosion has increased substantially in the last 20 years. In particular, more erosion seems to be occurring at smaller flood magnitudes (i.e not more than a 8-year storm since 1986, but much larger and more frequent erosion episodes).
10. <u>Reduction in Height of Gravel Bars may lead to Bank Erosion</u>: Channel incision and bank erosion are closely linked

Based on the detailed surveys conducted in this investigation there is little doubt that many of these effects have occurred. The effects were noticeable in data collected between 1977 and 1989, and have become more so in the last 20 years, indicating that ongoing gravel extraction in the 1980s and 1990s have continued and perhaps even accelerated this trend. These changes are spatially and temporally correlated with the extent and intensity of aggregate extraction activities. While it is possible that other human activities, operating at a watershed scale (such as vegetation conversion and road construction) were causing changes in the channel due to increased run-off (we did not analyze the flow records for any evidence of such hydrologic changes), the effects of instream gravel mining certainly appear to have dramatically accelerated any such trends.

6.4 RECOMMENDATIONS

6.4.1 Future Monitoring

This study has provided a detailed baseline geomorphic dataset against which future changes along the lower 15 miles of Cottonwood Creek can be evaluated. As described in the previous sections, lack of historic data at the same level of detail as the present study has prevented precise determination of the extent and magnitude of the various types of geomorphic changes. With the accurate coordinate data (both vertical and horizontal) developed in this study, it will be possible to very closely re-occupy both cross sections and the longitudinal profile, enabling a careful assessment of future trends in channel geometry. At a minimum, future monitoring should include the re-occupation of the cross sections and portions of the profile established in this study. Optimally, additional cross sections would be established in the various reaches to provide improved resolution of changes in channel geometry.

Re-establishment of former USGS streamflow gaging stations on the South Fork and mainstem near Olinda would be useful in assessing streamflow and sediment transport relationships in the lower portions of the watershed and assisting in the development of a sediment management program.

6.4.2 Restoration Approaches

Application of channel restoration or even simply bank stabilization approaches to protect property along a large alluvial river that is undergoing substantial geomorphic adjustment, particularly base level adjustment through channel bed degradation, is a challenging proposition. There are three general approaches differing substantially in philosophy: (1) Limited Action, (2) Moderate Stabilization using Bioengineering, and (3) Extensive Stabilization. These possible attributes of these three potential approached are outlined below.

<u>Limited Action</u>: This approach would be generally passive, allowing the geomorphic changes underway along the river to continue while a new equilibrium channel develops at some lower elevation. Over time, continued bank erosion will result in the establishment of a new floodplain over much of the valley floor. Limited actions would be used only to protect valuable structural development (i.e. houses) where it was infeasible to relocate the structure to a more stable location. The probable ultimate meander belt of the channel could be defined and actions taken to restrict development in these areas and attempt to obtain (most likely by purchase) easements to allow river migration.

<u>Moderate Stabilization</u>: This approach would attempt to respond to individual erosion problems, which would be addressed primarily with bioengineering solutions involving channel shaping, rootwad placement, soil encapsulation techniques, and extensive revegetation. No extensive riprap would be used. Use of this approach would require a long-term view, as failures would undoubtedly occur. This approach would be best coupled with a sediment management approach that attempts to reestablish an equilibrium grade through implementation of a sediment management program, which would likely involve addition of sediment throughout the reach affected by gravel extraction.

<u>Extensive Stabilization</u>: This approach would follow a more traditional engineering path, involving extensive stabilization, primarily based on riprap combined with vegetation. This

approach would be the most expensive and it could be difficult to obtain permits, but there would be the least loss of land and have the lowest risk. It is doubtful whether funding could be secured to allow an approach of this type, and it would almost certainly be beyond the resources of the affected property owners.

Other Recommendations:

In-channel gravel extraction should be ended immediately, if that has not already occurred. The consequences of allowing extraction far beyond replenishment rates have been documented by this study and a host of other studies in the literature. It is unfortunate that the opinions and analyses by a number of well-known geomorphologists were ignored in the mid 1980s through early 1990s, and extensive in-channel extraction was allowed to continue. The stream will continue to evolve and attempt to adjust to a new base level for many years, most likely to the detriment of local property owners.

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USGS GAGES IN COTTOWNWOOD CREEK WATERSHED

Station No.	Station Name	Drainage Area (sq. miles)	Period of Record
11374400	Middle Fork Cottonwood Creek near Ono	244	1957-75
11375500	North Fork Cottonwood Creek at Ono	58.8	1908-13
11375700	North Fork Cottonwood Creek near Igo	88.7	1957-80
11375810	Cottonwood Creek near Olinda	395	1971-86
11375815	Cottonwood Creek above South Fork, near Cottonwood	478	1982-85
11375820	South Fork Cottonwood Creek near Cottonwood	217	1963-78
11375870	South Fork Cottonwood Creek near Olinda	371	1977-86
11375900	South Fork Cottonwood Creek at Evergreen Rd near Cottonwood	397	1982-85
11376000	Cottonwood Creek near Cottonwood	927	1941-present

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COTTONWOOD CREEK near COTTONWOOD CALIFORNIA

Annual Maximum Peak Discharges, USGS Gage #11376000, WY 1941 - 2003

Water Year	Peak Gage Height, Annual Maximum (feet)	Peak Discharge, Annual Maximum (cfs)	Unit Peak Discharge (cfs/mi^2)
1941	15.4	52,300	56
1942	14.1	42,600	46
1943	13.42	32,000	35
1944	6.7	5,800	6
1945	9.88	16,100	17
1946	12.06	22,000	24
1947	9.84	13,200	14
1948	8.4	9,870	11
1949	12.04	21,900	24
1950	8.63	10,700	12
1951	10.31	14,800	16
1952	14.15	32,600	35
1953	12.03	20,300	22
1954	11.82	19,500	21
1955	7.59	7,020	8
1956	15.23	49,000	53
1957	10.8	15,900	17
1958	15.2	48,600	52
1959	11.4	18,900	20
1960	12.78	26,100	28
1961	10.8	16,700	18
1962	11.26	18,300	20
1963	12.28	23,100	25
1964	13.25	13,000	14
1965	19.64	60,000	65
1966	13.88	14,700	16
1967	14.7	22,800	25
1968	14.14	19,400	21
1969	15.48	23,500	25
1970	19.46	58,500	63
1971	15.57	31,300	34
1972	9.39	4,670	5
1973	15.43	27,400	30
1974	20.15	70,000	76
1975	15.88	30,600	33
1976	8.99	3,220	3
1977	8.52	2,210	2
1978	17.92	39,100	42
1979	12.94	13,200	14
1980	17.27	36,300	39
1981	15.97	27,500	30
1982	19.7	64,400	69
1983	21.59	86,000	93
1984	16.39	32,800	35
1985	11.22	8,660	9
1986	17.64	52,400	57
1987	11.01	9,310	10
1988	11.37	10,500	11
1989	10.88	8,620	9
1990	9.48	4,050	4
1991	12.03	13,000	14
1992	13.8	18,000	19
1993	18.03	42,200	46
1994	7.98	3,820	4
1995	18.54	48,600	52
1996	11.86	14,400	16
1997	16.76	40,600	44
1998	17.43	46,500	50
1999	10.96	12,900	14
2000	11.72	16,700	18
2001	14.83	30,900	33
2002		30,900	33
2003		39,800	43
Max		**86,000**	**93**
Min		**2,210**	**2**

COTTONWOOD CREEK GEOMORPHIC STUDY

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TABLE

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COTTONWOOD CREEK GEOMORPHIC STUDY
LIST OF MAPS AND AERIAL PHOTOGRAPHY

TYPE	YEAR	DATE	SCALE	B&W or Color	SOURCE
Map	1855				GLO Surveys, BLM
Aerial	1939		1:20000	B & W	National Archives
Aerial	1952	14-Jul	1:20000	B & W	ASCS Salt Lake City
Aerial	1962	June	1:20000	B & W	Cartwright Aerial Surveys
Aerial	1963	14-Jul	1:20000	B & W	ASCS
Aerial	1966		1:20000	B & W	ASCS
Aerial	1969	16-May	1:20000	B & W	ASCS
Aerial	1972	10-Jul	1:40000	B & W	ASCS
Aerial	1977		1:40000	B & W	USACE
Aerial	1979		1:40000	B & W	ASCS
Aerial	1981		1:12000	B & W	Hedges Aerial Surveys
Aerial	1982		1:12000	B & W	Hedges Aerial Surveys
Aerial	1984		1:24000	B & W	WAC
Aerial	1988		1:24000	B & W	WAC
Aerial	1994		1:40000	B & W	ASCS
Aerial	1996		1:24000	B & W	WAC
Aerial	1998	8-Nov	1:12000	B & W	GMA, Cartwright Aerial Surveys
Aerial	1999		1:6000	Color	GMA, Hedges Aerial Surveys
Aerial	2002		1:12000	B & W	Cottonwood Creek Watershed Group

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CENTERLINE CHANNEL LENGTH BY YEAR

MAP OR PHOTO YEAR	MOUTH TO SF CONFLUENCE (ft)	SF CONFLUENCE TO UPSTREAM END OF SURVEYS (ft)	TOTAL (ft)
1855	38106	27364	65470
1939	40681	28683	69364
1952	43004		
1966	44226	27940	72166
1972	45273	29650	74923
1977	45370		
1981	45162	29853	75015
1982	46205		
1984	43609	32537	76146
1988	42840	32850	75690
1993	41358		
1996	42635		
1998	42704	32405	75109
1999	44210		
2002	44065	33781	77846

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TABLE
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COMPARISON OF THALWEG ELEVATIONS, USGS DATA (1982) AND GMA DATA (1999 AND 2002)

		USGS DATA			GMA DATA	
CROSS SECTION NUMBER	DISTANCE UPSTREAM FROM MOUTH (1982) (feet)	1982 THALWEG ELEVATION*1 (feet, NGVD 1929)	1982 THALWEG ELEVATION*2 (feet, NGVD 1929)	DIFFERENCE BETWEEN USGS DATA	1999 OR 2002 THALWEG ELEVATION*3 (feet, NGVD 1929)	ELEVATION DIFFERENCE (1999 or 2002 minus 1982)*4
1	1,640	348.7	348.7	0	342.8	-5.9
2	2,900	351.4	348.9	-2.5	348.2	-3.2
3	9,930	363.1	358.9	-4.2	360.9	-2.2
4	13,500	372.3	364.3	-8.0	364.4	-7.9
5	15,700	374.6	371.4	-3.2	366.1	-8.5
6	20,300	385.9	380.9	-5.0	379.8	-6.1
7	22,800	386.1	383.1	-3.0	382.0	-4.1
8	27,600	387.8	387.8	0	386.5	-1.3
9	27,900	391.1	391.1	0	387.9	-3.2
10	28,300	390.9	390.9	0	388.2	-2.7
11	32,700	404.4	404.4	0	395.7	-8.7
12	38,900	413.9	413.9	0	406.6	-7.3
13	45,500	423.8	421.2	-2.6	417.6	-6.2
14	50,200	428.6	428.6	0	424.0	-4.6
15	Not surveyed	Not surveyed		-na-		-na-
16	60,600	449.3	449.3	0	438.7	-10.6
17	66,300	458.4	458.4	0	454.5	-3.9

Notes:
*1From Original USGS Survey Field Notes
*2From McCaffrey et al (1988) Table 2
*3GMA surveys from the mouth to the SF Confluence were conducted in 1999 (XS 1-12)
*3GMA Surveys from the SF Confluence to Little Dry Creek were conducted in 2002 (XS 13-17)
*4GMA data subtracted from Original Field Notes

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TABLE
5

COTTONWOOD BULK SAMPLES
SIZE DISTRIBUTION OF MEAN SURFACE AND SUB-SURFACE SAMPLES BY SITE

SITE	2	2	3	3	4	4	5	5	6	6	7	7	8	8
SAMPLE #	1&2 SURF	1&2 SUBSURF	1&2 SURF	1&2 SUBSURF	1&2 SURF	1&2 SUBSURF	1&2 SURF	1&2 SUBSURF	2 SURF	1&2 SUBSURF	1&2 SURF	1&2 SUBSURF	1&2 SURF	1&2 SUBSURF
DRY WEIGHT (KG)	107.04	829.19	118.41	653.22	87.84	761.92	102.11	527.53	75.89	636.57	99.47	576.47	115.75	566.29
FRACTION'S % OF TOTAL														
128	9.6%	4.4%	2.4%	0.4%	0.0%	0.0%	2.1%	0.7%	2.7%	1.6%	4.1%	2.2%	8.8%	0.3%
90.5	14.1%	4.6%	7.7%	6.0%	0.0%	0.0%	0.0%	0.0%	9.2%	5.2%	25.8%	2.5%	18.7%	4.7%
64	10.8%	4.0%	9.4%	4.6%	26.6%	14.4%	24.6%	11.1%	14.0%	6.3%	11.6%	3.1%	10.8%	3.8%
45.3	10.7%	5.9%	10.8%	7.6%	14.1%	6.1%	15.5%	9.1%	16.6%	8.7%	11.3%	3.8%	11.0%	5.9%
32	10.6%	8.5%	11.5%	10.1%	9.0%	8.5%	12.9%	10.8%	10.6%	9.5%	10.6%	4.8%	10.2%	8.7%
22.6	7.7%	7.5%	11.5%	11.0%	8.0%	9.3%	9.6%	10.8%	7.4%	8.4%	8.9%	4.8%	8.1%	10.1%
16	6.1%	6.8%	9.5%	9.7%	7.4%	9.9%	8.8%	10.4%	6.1%	7.7%	6.9%	4.7%	5.6%	11.3%
11.2	5.3%	6.2%	7.6%	8.1%	6.1%	9.3%	6.9%	9.7%	4.3%	7.4%	4.6%	4.9%	5.0%	11.2%
8	3.8%	4.7%	5.3%	6.1%	4.4%	7.1%	4.9%	7.1%	3.4%	5.7%	3.1%	3.9%	3.7%	8.1%
6.3	2.2%	2.8%	2.6%	3.4%	2.3%	4.2%	2.8%	4.2%	1.9%	3.4%	1.3%	2.2%	1.8%	4.2%
5.6	0.7%	1.4%	0.9%	0.9%	1.0%	1.0%	0.5%	0.9%	0.6%	0.8%	0.4%	0.6%	0.7%	1.0%
4.75	1.1%	2.6%	1.5%	2.0%	1.2%	1.8%	0.9%	1.9%	1.1%	1.9%	0.6%	1.2%	1.1%	1.8%
4	1.0%	2.5%	1.3%	1.8%	1.1%	1.8%	0.8%	1.8%	1.1%	1.9%	0.5%	1.3%	1.0%	1.7%
3.55	1.1%	2.8%	1.4%	2.2%	1.2%	2.0%	1.0%	2.0%	1.2%	2.1%	0.6%	1.6%	1.1%	1.9%
2	3.4%	8.7%	3.7%	6.3%	3.3%	6.3%	2.8%	5.7%	4.6%	6.9%	2.2%	5.6%	2.9%	5.6%
1	5.5%	13.0%	5.2%	8.2%	5.9%	8.7%	3.2%	7.6%	7.3%	11.1%	3.4%	8.6%	4.0%	8.4%
0.85	1.4%	3.1%	1.4%	1.9%	1.8%	2.1%	0.7%	1.8%	1.5%	2.4%	0.7%	2.4%	1.0%	2.2%
0.5	2.8%	6.5%	3.5%	4.8%	3.9%	4.6%	1.2%	3.1%	3.5%	4.2%	1.6%	9.3%	2.5%	5.2%
0.25	1.6%	3.3%	2.3%	3.9%	2.2%	2.2%	0.6%	1.0%	2.5%	3.4%	1.1%	19.9%	1.4%	3.0%
0.125	0.3%	0.5%	0.4%	0.7%	0.5%	0.5%	0.2%	0.3%	0.5%	1.1%	0.5%	9.3%	0.3%	0.7%
Pan	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%	0.2%	0.2%	3.3%	0.1%	0.3%
SIEVE SIZE						CUMULATIVE PERCENT FINER THAN								
180	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
128	90.4%	95.6%	97.6%	99.6%	100.0%	100.0%	97.9%	99.3%	97.3%	98.4%	95.9%	97.8%	91.2%	99.7%
90.5	76.2%	90.9%	89.9%	93.6%	100.0%	100.0%	97.9%	99.3%	88.1%	93.2%	70.2%	95.3%	72.5%	95.0%
64	65.4%	86.9%	80.6%	89.0%	73.4%	85.6%	73.3%	88.2%	74.1%	86.9%	58.6%	92.1%	61.7%	91.2%
45.3	54.8%	81.0%	69.7%	81.3%	59.3%	79.5%	57.8%	79.2%	57.6%	78.2%	47.2%	88.4%	50.6%	85.2%
32	44.1%	72.5%	58.2%	71.2%	50.3%	71.0%	44.9%	68.4%	46.9%	68.7%	36.6%	83.6%	40.4%	76.5%
22.6	36.4%	65.0%	46.7%	60.2%	42.4%	61.6%	35.3%	57.6%	39.6%	60.4%	27.7%	78.7%	32.3%	66.4%
16	30.3%	58.2%	37.2%	50.4%	34.9%	51.7%	26.6%	47.3%	33.5%	52.6%	20.8%	74.0%	26.7%	55.1%
11.2	25.0%	52.0%	29.6%	42.4%	28.9%	42.4%	19.6%	37.6%	29.2%	45.2%	16.2%	69.1%	21.7%	44.0%
8	21.2%	47.3%	24.3%	36.2%	24.4%	35.4%	14.7%	30.4%	25.9%	39.5%	13.1%	65.2%	18.0%	35.9%
6.3	19.0%	44.5%	21.7%	32.8%	22.2%	31.2%	11.9%	26.2%	24.0%	36.1%	11.8%	63.0%	16.2%	31.7%
5.6	18.3%	43.1%	20.8%	31.9%	21.2%	30.1%	11.4%	25.3%	23.4%	35.4%	11.4%	62.4%	15.5%	30.7%
4.75	17.2%	40.5%	19.3%	30.0%	20.0%	28.4%	10.5%	23.4%	22.3%	33.5%	10.8%	61.2%	14.3%	28.9%
4	16.2%	38.0%	18.0%	28.1%	18.8%	26.6%	9.7%	21.6%	21.2%	31.5%	10.3%	59.9%	13.4%	27.2%
3.55	15.1%	35.2%	16.6%	25.9%	17.6%	24.6%	8.7%	19.6%	20.0%	29.4%	9.7%	58.3%	12.3%	25.3%
2	11.7%	26.5%	12.9%	19.6%	14.3%	18.3%	5.9%	13.9%	15.4%	22.5%	7.6%	52.7%	9.4%	19.7%
1	6.2%	13.5%	7.6%	11.4%	8.4%	9.6%	2.7%	6.3%	8.0%	11.4%	4.1%	44.1%	5.4%	11.3%
0.85	4.8%	10.4%	6.2%	9.6%	6.6%	7.4%	2.0%	4.5%	6.6%	9.0%	3.4%	41.7%	4.4%	9.2%
0.5	2.0%	3.9%	2.7%	4.7%	2.8%	2.8%	0.8%	1.4%	3.1%	4.8%	1.8%	32.4%	1.8%	3.9%
0.25	0.4%	0.6%	0.5%	0.8%	0.6%	0.6%	0.2%	0.4%	0.6%	1.3%	0.7%	12.6%	0.4%	1.0%
0.125	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.1%	0.1%	0.2%	0.2%	3.3%	0.1%	0.3%
0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

COTTONWOOD CREEK GEOMORPHIC STUDY
CALFED PROJECT#: 97-N07

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TABLE
6

COTTONWOOD CREEK SUBSTRATE
INDEXES OF COMBINED SUBSURFACE BULK SAMPLES

	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
D84	54.77	51.81	59.20	55.27	57.75	33.14	43.47
D75	35.88	36.98	38.31	40.15	40.78	17.39	30.62
D50	9.82	15.75	15.12	17.74	14.31	1.69	13.79
D25	1.88	3.32	3.64	5.48	2.56	0.44	3.46
D16	1.19	1.56	1.74	2.56	1.42	0.29	1.56
dg	8.08	8.99	10.14	11.90	9.05	3.10	8.22
FREDLE	1.85	2.69	3.13	4.40	2.27	0.49	2.77
% FINES<2mm	26.5%	19.6%	18.3%	13.9%	22.5%	52.7%	19.7%
% FINES <1mm	13.5%	11.4%	9.6%	6.3%	11.4%	44.1%	11.3%
% FINES <0.85mm	10.4%	9.6%	7.4%	4.5%	9.0%	41.7%	9.2%

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COTTONWOOD CREEK SUBSTRATE

Size Distribution Parameters for Pebble Counts throughout Study Area

SAMPLE #	LONG PROFILE STATION	Value of Size Distribution Parameter (mm)				
		Dmean	D90	D84	D65	D50
23	2428	34.3	66.7	56.6	39.8	28.4
22	3910	39.7	76.6	67.3	46.5	33.8
21	5789	36.4	65.9	59.1	45.9	32.0
20	7277	40.3	80.9	69.1	44.7	34.2
19	8164	32.5	63.2	51.2	36.3	27.9
18	9242	37.1	74.6	64.0	40.9	30.4
17	11880	33.0	71.0	59.5	37.7	26.9
16	13425	31.5	71.2	60.1	35.1	23.0
15	15607	29.5	59.0	48.9	32.0	24.9
14	17524	34.2	62.0	51.3	37.3	31.1
13	18200	31.7	65.5	52.8	34.8	26.9
12	19900	31.2	59.0	49.9	36.3	29.1
11	20600	29.2	58.6	47.9	33.9	25.2
10	22081	18.2	36.8	31.3	22.6	15.6
9	27131	32.4	74.6	64.5	36.4	24.4
8	28364	34.4	66.3	56.6	38.0	29.4
7	32300	22.5		41.0	24.8	18.5
6	33123	25.8	54.3	46.0	29.0	22.6
5	34944	40.8	74.1	61.7	47.8	37.7
4	39441	38.8	86.2	69.5	48.4	32.5
3	41140	28.7	62.9	50.0	30.0	22.6
2	44185	31.6	68.0	54.3	31.5	23.1
1	45237	40.0	82.5	68.2	46.0	33.0
1	48670	36.3	58.3	51.2	39.4	33.7
2	49110	41.6	77.7	69.0	50.0	36.1
3	50240	44.8	90.5	74.4	52.0	40.0
4	51933	43.1	108.5	90.9	46.8	30.5
5	53100	36.9	71.5	62.4	41.6	31.1
6	53709	34.0	73.8	62.3	38.6	27.2
7	55306	44.7	88.9	73.8	49.4	35.5
8	57641	44.3	76.0	66.2	48.8	39.3
9	58637	23.4	51.2	42.5	27.0	18.4
10	59213	34.4	73.0	64.0	41.1	27.9
11	62485	50.2	92.2	81.2	60.6	45.3
12	64515	31.2	59.0	49.9	36.3	29.1
13	65592	23.9	47.1	38.9	27.0	21.1
14	68710	36.6	80.6	68.8	40.8	28.2
15	69465	28.9	57.3	50.5	33.8	24.7
16	71672	36.9	75.8	64.1	39.2	29.4
17	74620	24.1	45.9	40.2	28.7	20.3
18	76767	49.1	82.8	75.3	60.5	49.6
19	77937	38.9	73.6	64.9	45.7	35.2

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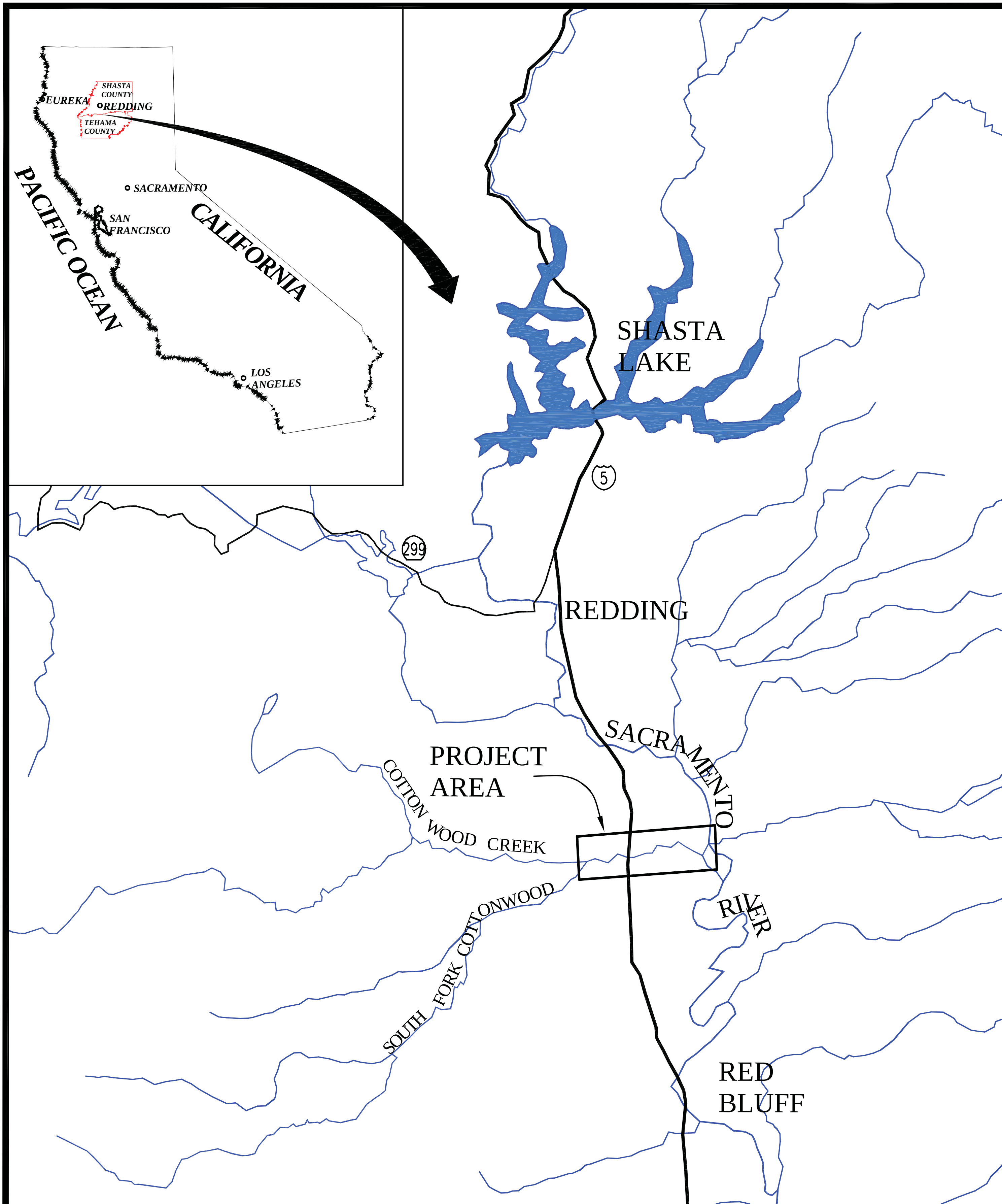
TABLE

8



LOCATION MAP

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N

SCALE
(ft)
0 20,000

FIGURE
1

View of the confluence of Cottonwood Creek with the Sacramento River. Note the turbid water from Cottonwood Creek and the pro-grading delta.

View of Levee constructed in 1998 on the Bengard Ranch, RM 3 to relocate channel and prevent further bank erosion .

View downstream of large meander migration into pasture. Property Owner has placed concrete rubble from old I-5 bridge in windrows for protection.

View of bank erosion threatening SPRR just upstream of I-5. Gravel operation is in the background.

View of the South Fork confluence with the Mainstem at the Satori Ranch.

View of Bank Erosion on the Baker Ranch, near the upper end of the study reach.

OBLIQUE AERIAL VIEWS OF COTTONWOOD CREEK IN FEB 2002

COTTONWOOD CREEK GEOMORPHIC STUDY

CALFED PROJECT #97-NO7

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FIGURE

2

RED BLUFF PRECIPITATION

Annual Precipitation and Cumulative Departure, Years 1905 - 2001

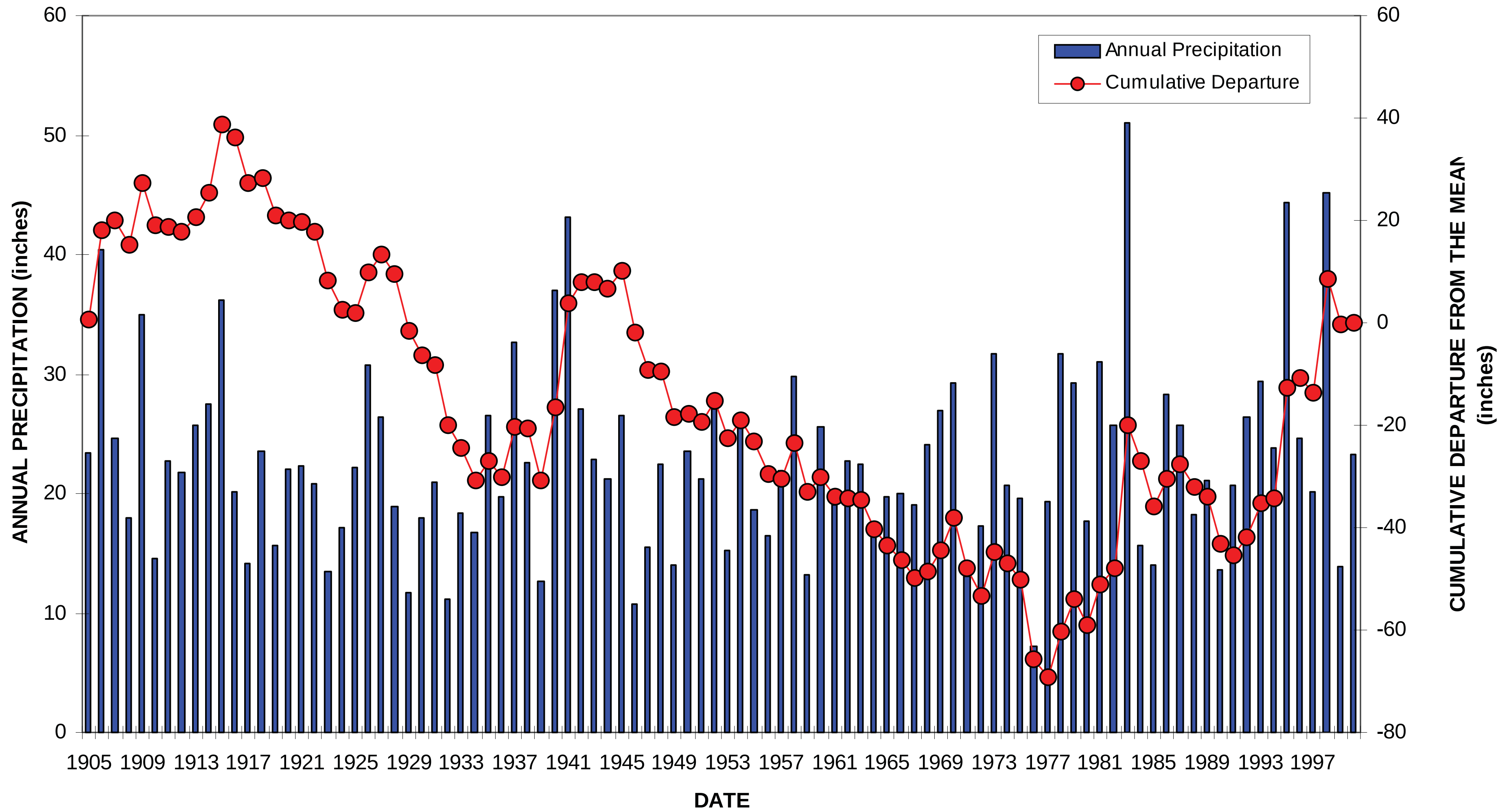

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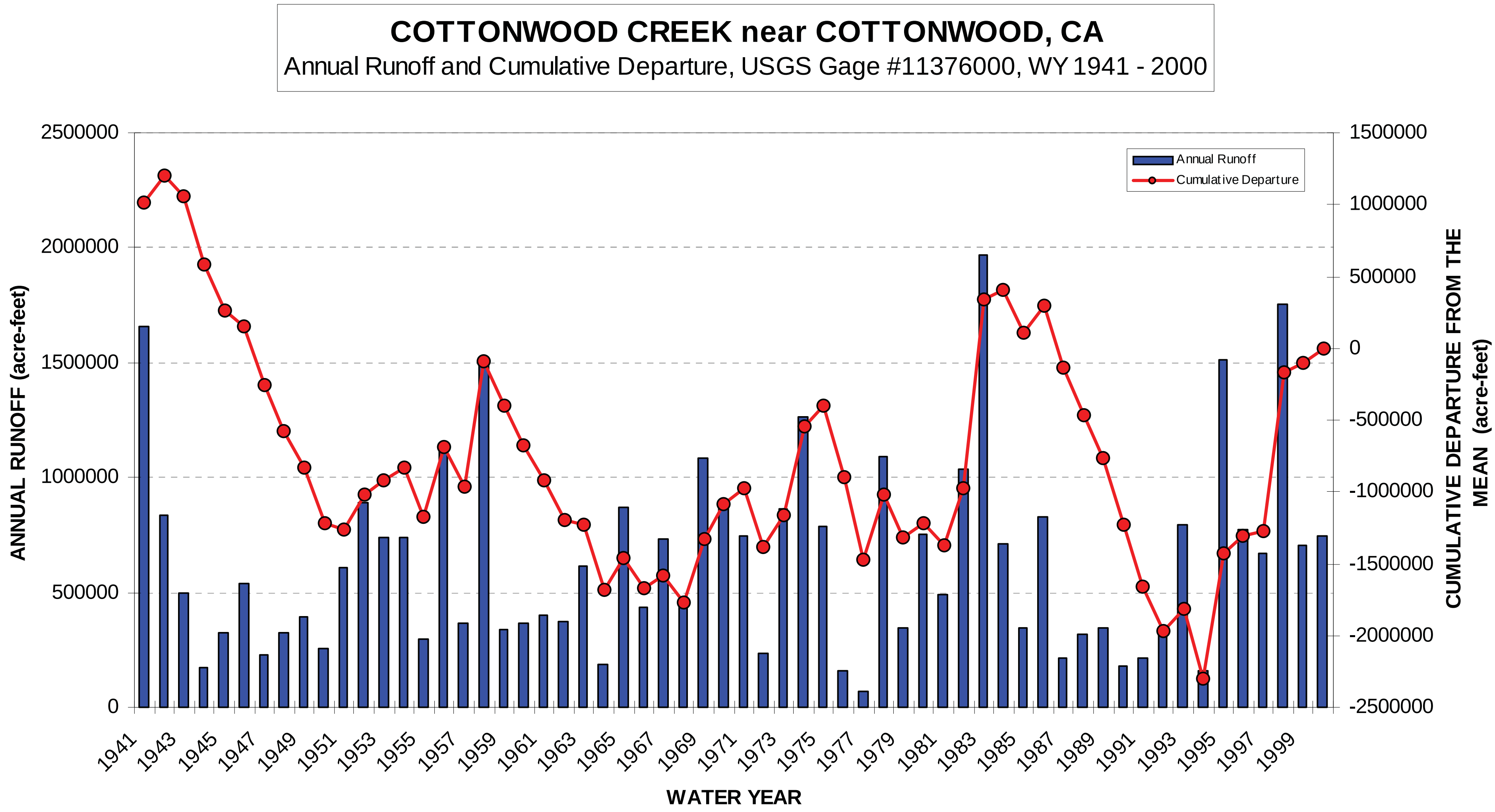
FIGURE

3



COTTONWOOD CREEK GEOMORPHIC STUDY

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FIGURE

4

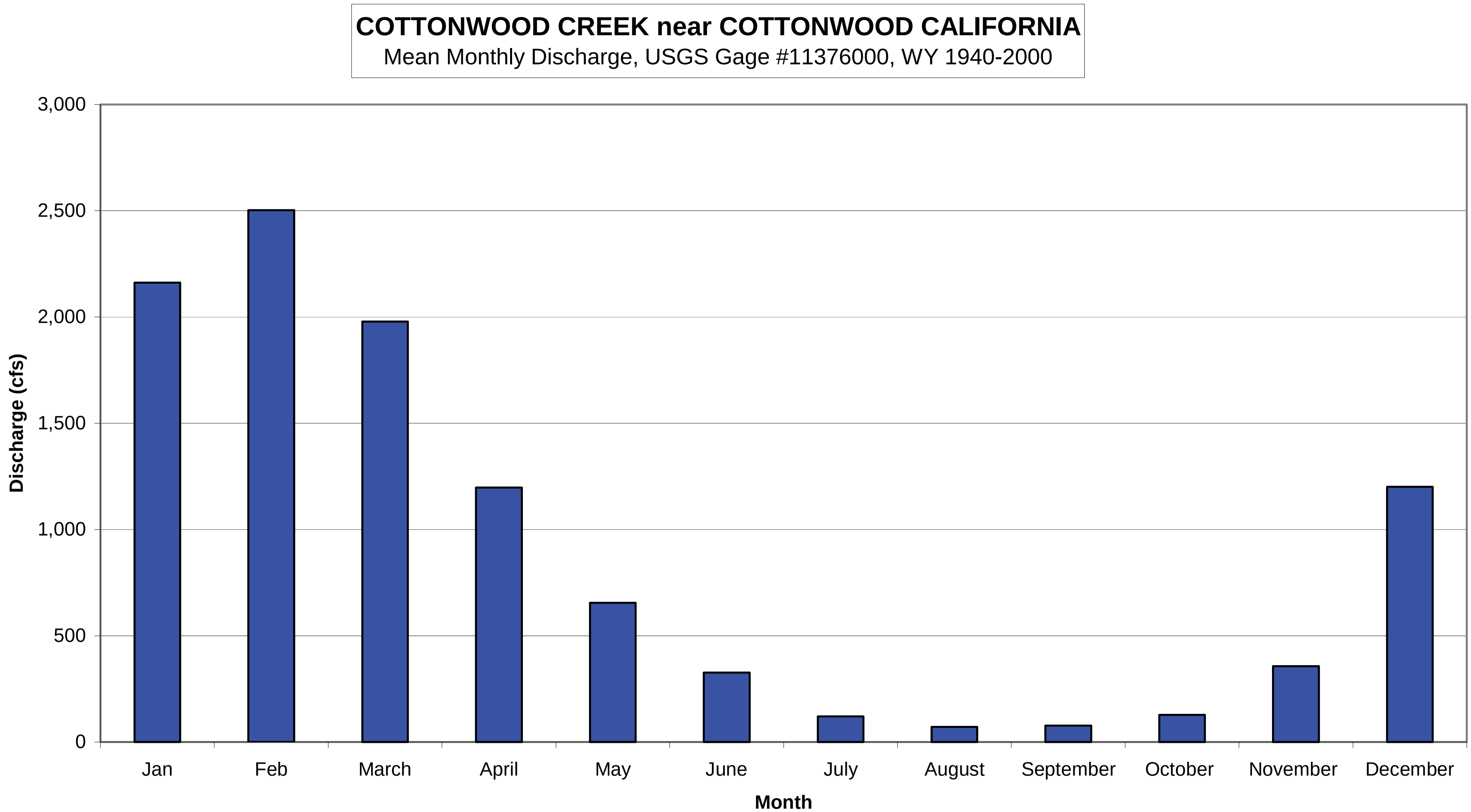

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FIGURE
5

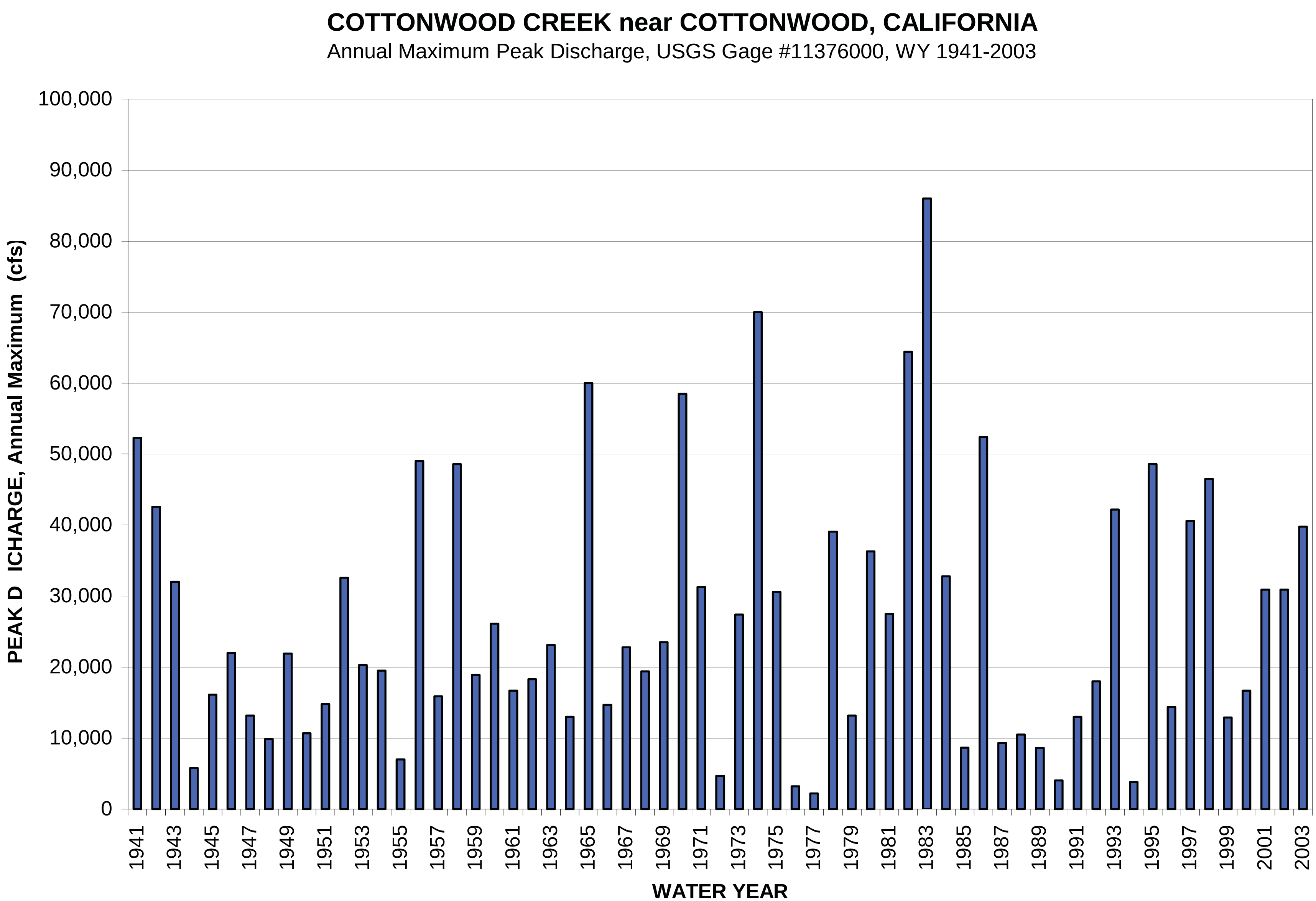

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FIGURE

6

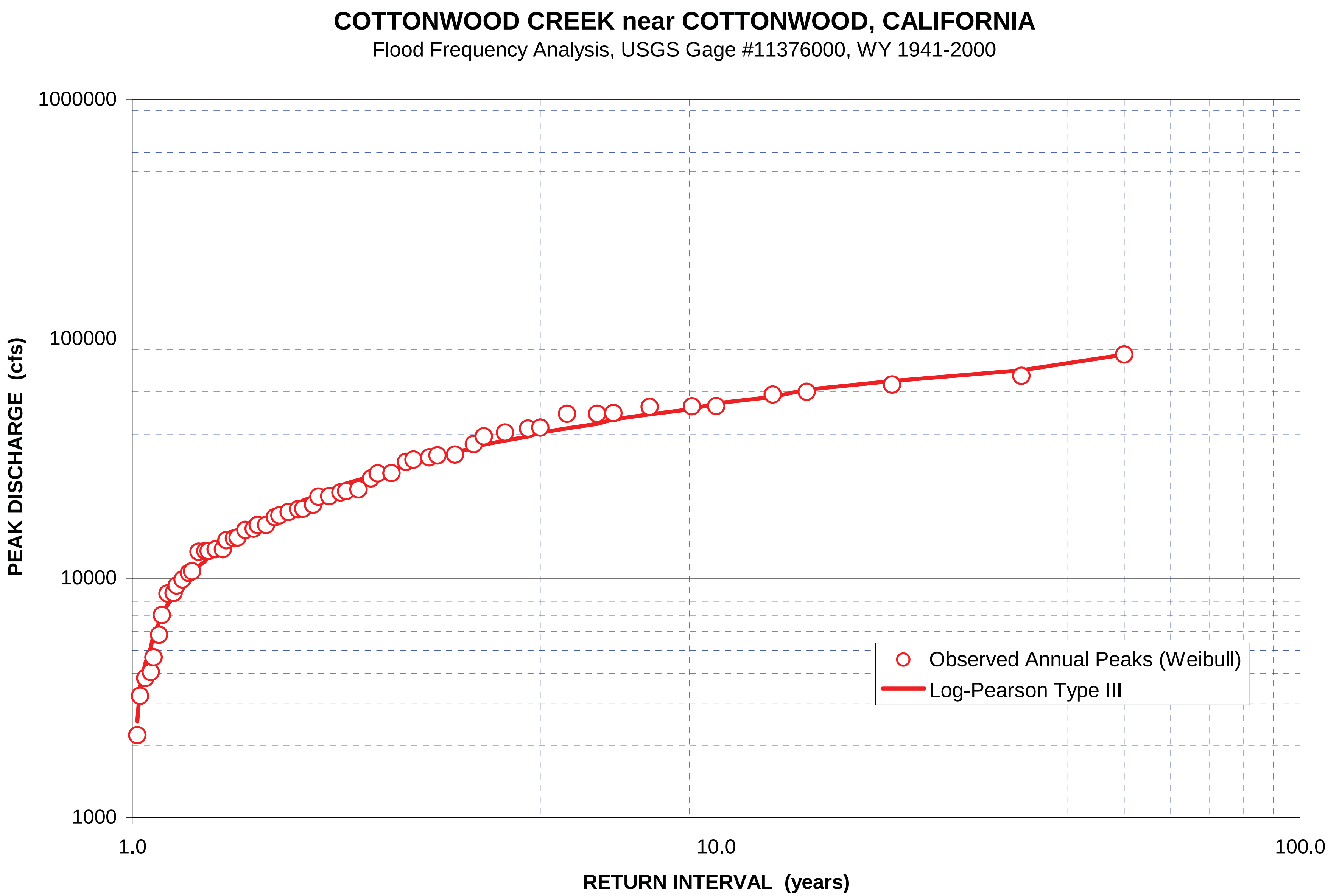

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FIGURE

7

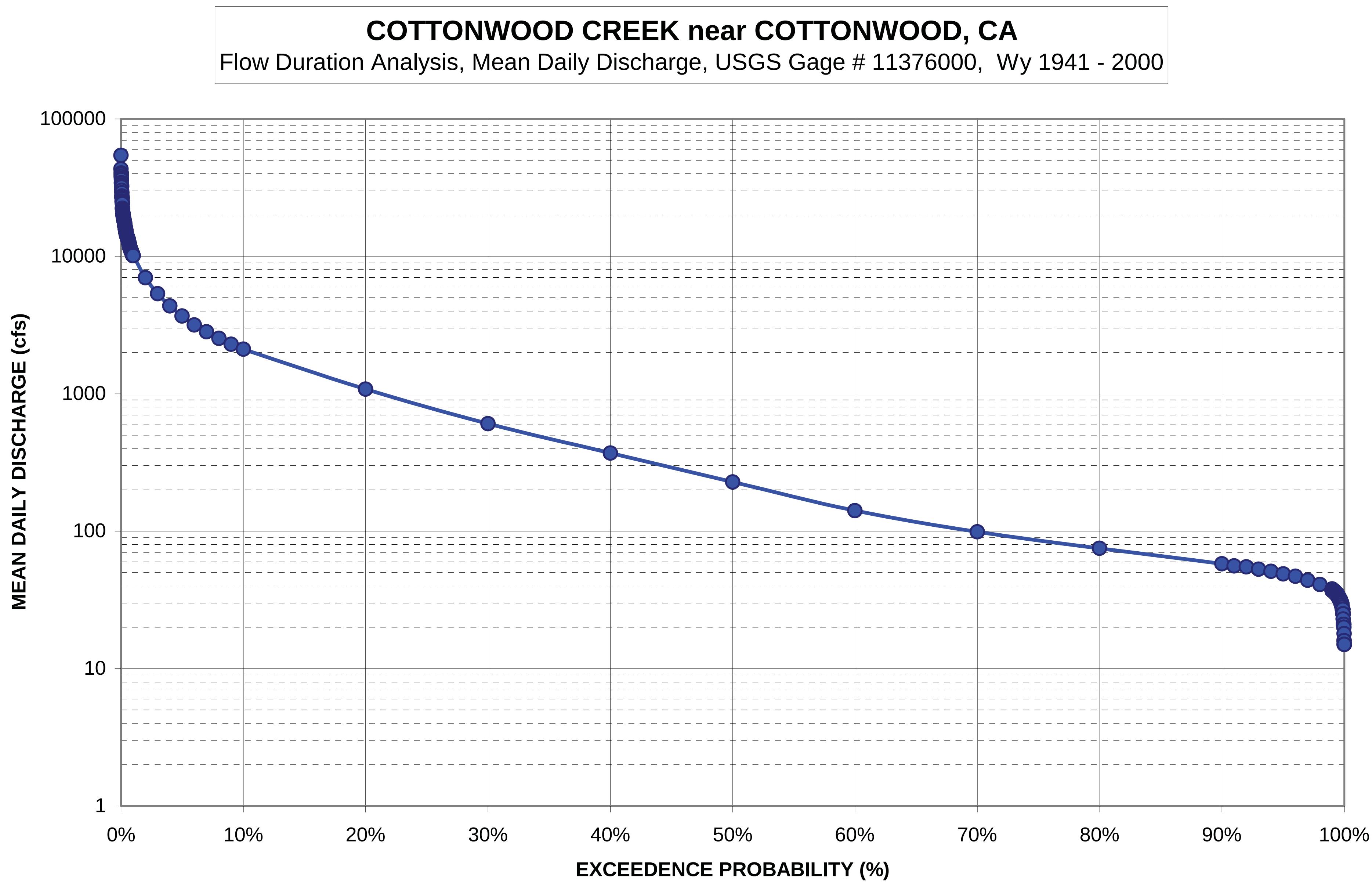

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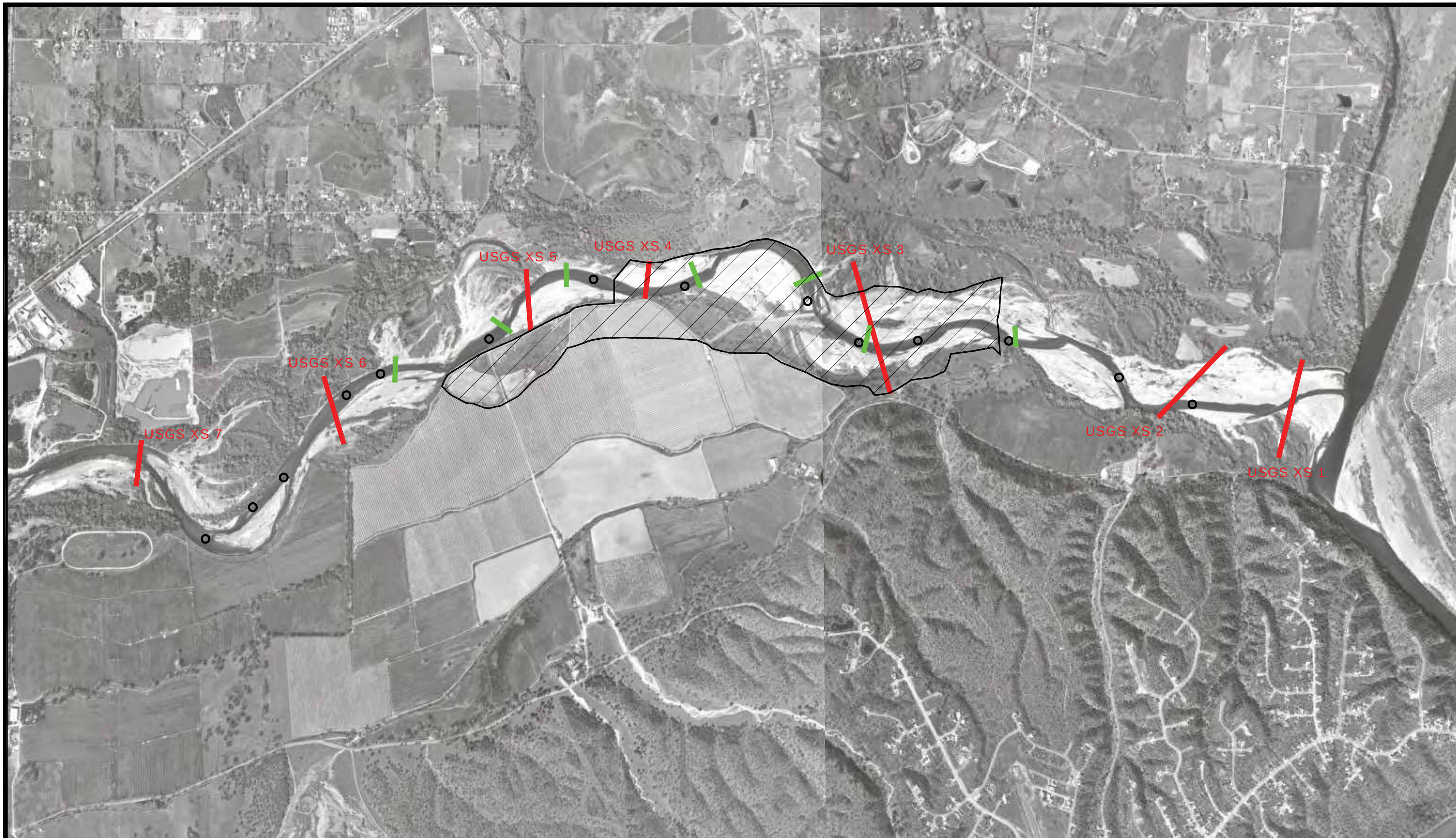
FIGURE

8



LEGEND
TOPOGRAPHICALLY MAPPED AREA
USGS CROSS SECTIONS
GMA CROSS SECTIONS
BULK SAMPLE LOCATIONS
PEBBLE COUNT LOCATIONS

COTTONWOOD CREEK
LOCATION OF CROSS SECTIONS, PEBBLE COUNTS, BULK SAMPLES, AND TOPOGRAPHIC MAPPING ON 2002 AERIAL PHOTOS

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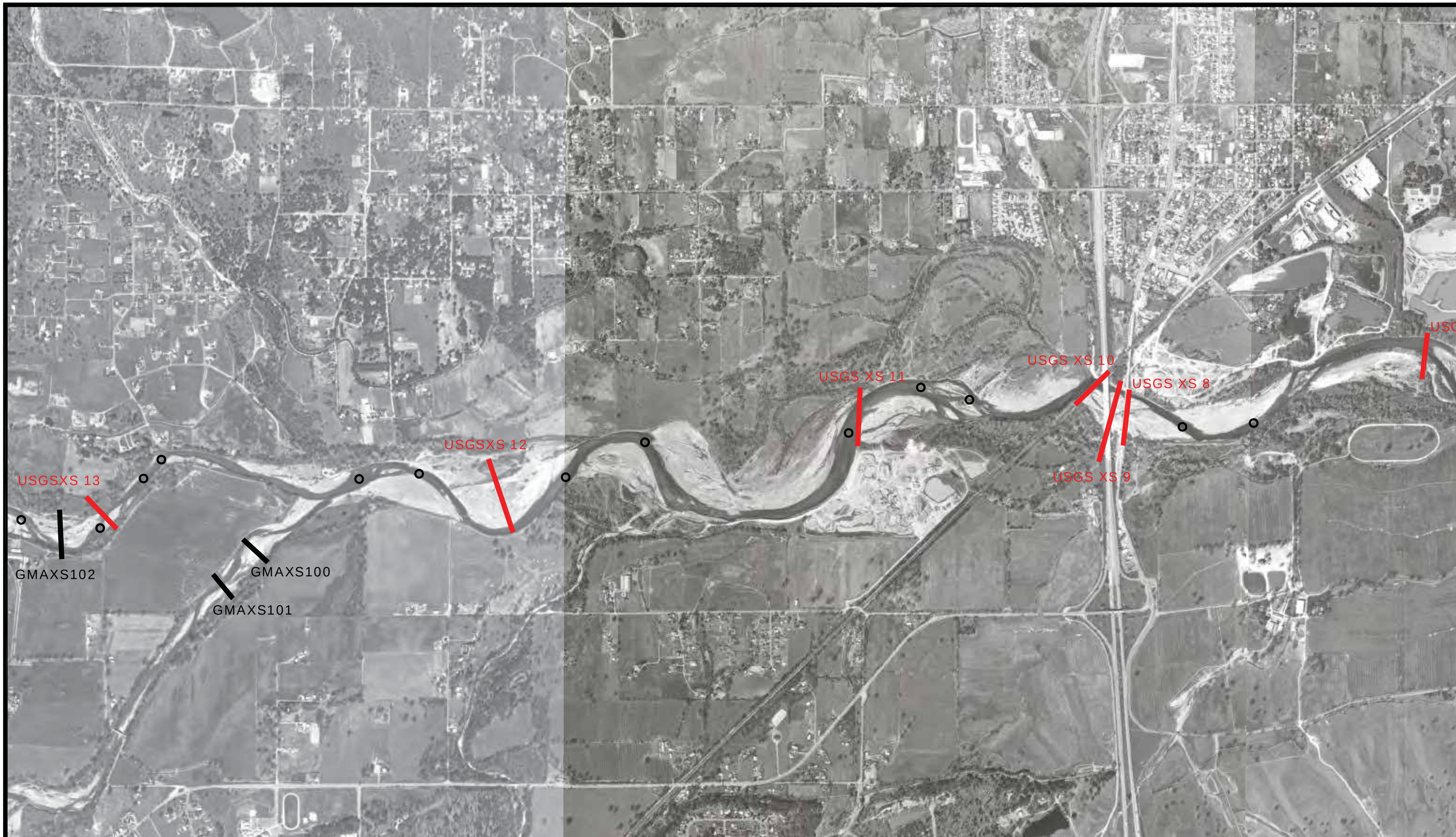
N

SCALE
0 700

FIGURE
9a



LEGEND

- TOPOGRAPHICALLY MAPPED AREA
- USGS CROSS SECTIONS
- GMA CROSS SECTIONS
- BULK SAMPLE LOCATIONS
- PEBBLE COUNT LOCATIONS

COTTONWOOD CREEK
LOCATION OF CROSS SECTIONS, PEBBLE COUNTS, BULK SAMPLES, AND TOPOGRAPHIC MAPPING ON 2002 AERIAL PHOTOS

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N

SCALE
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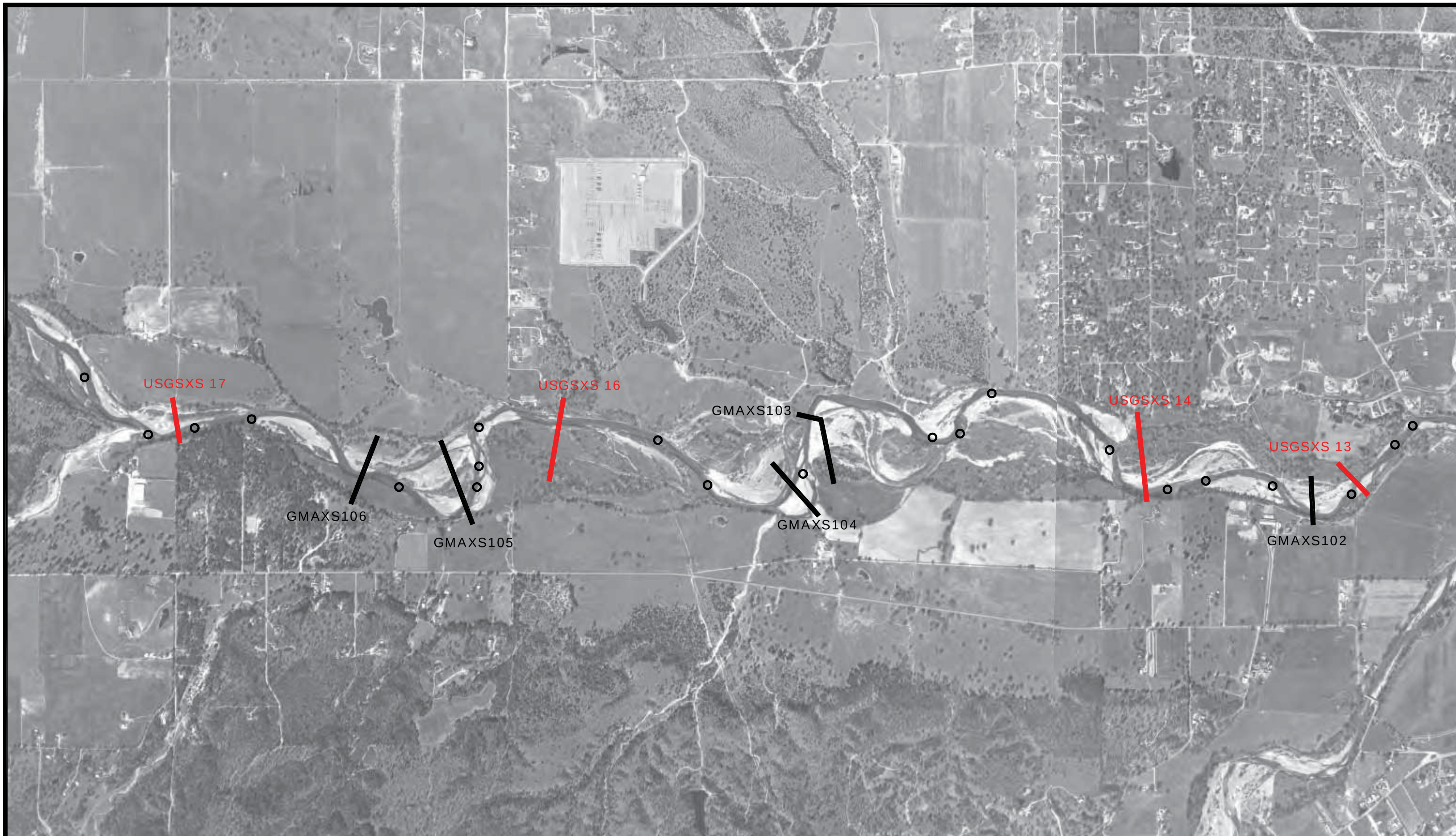
FIGURE
9b



LEGEND
- TOPOGRAPHICALLY MAPPED AREA
- USGS CROSS SECTIONS
- GMA CROSS SECTIONS
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COTTONWOOD CREEK
LOCATION OF CROSS SECTIONS, PEBBLE COUNTS, BULK SAMPLES, AND TOPOGRAPHIC MAPPING ON 2002 AERIAL PHOTOS

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N

SCALE
0 700

FIGURE
9c

COTTONWOOD CREEK CHANNEL ALIGNMENTS, 1855-1999, DOWNSTREAM SECTION

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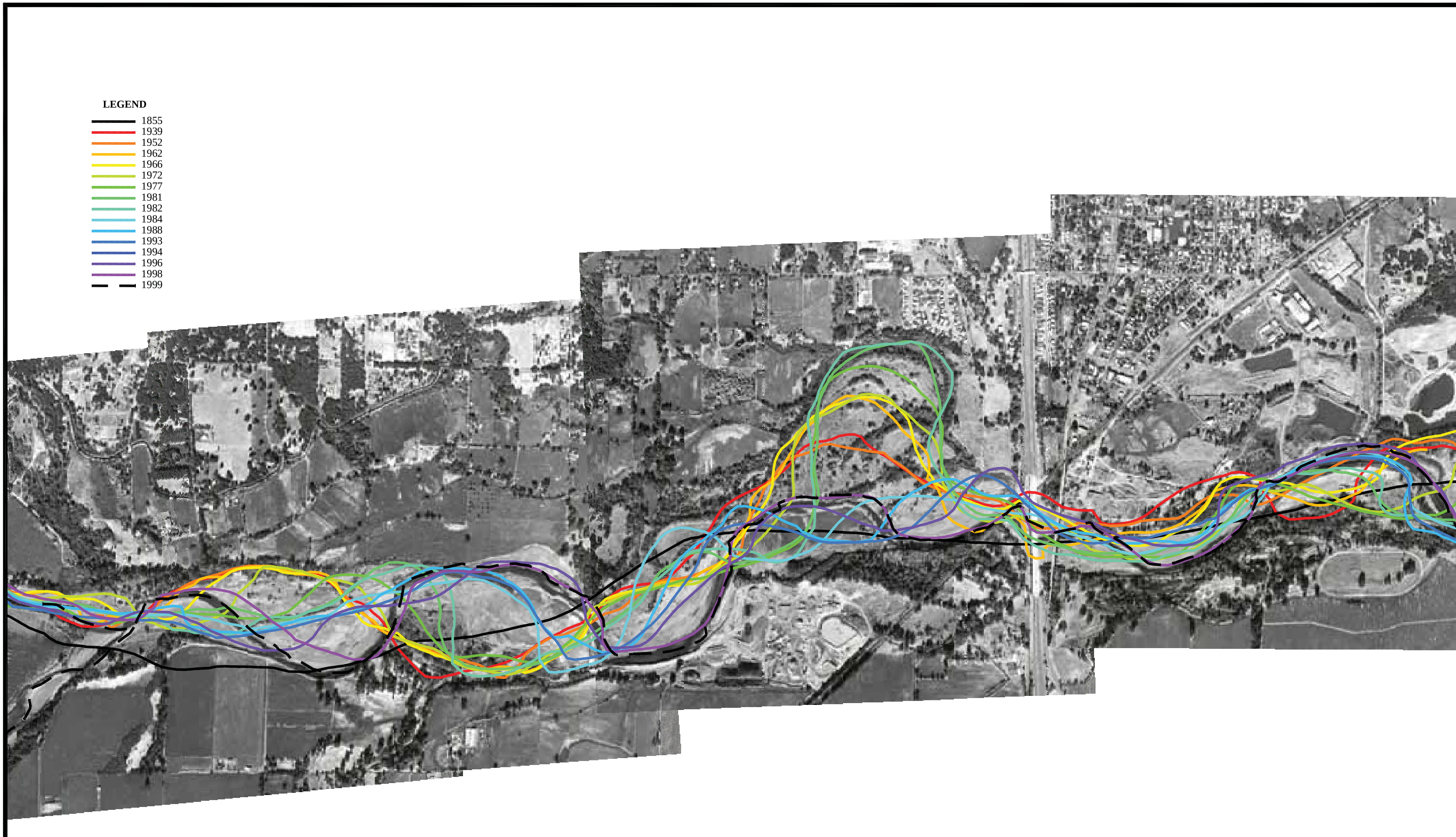
FIGURE 10a



COTTONWOOD CREEK CHANNEL ALIGNMENTS, 1855-1999, MIDDLE SECTION

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N

SCALE
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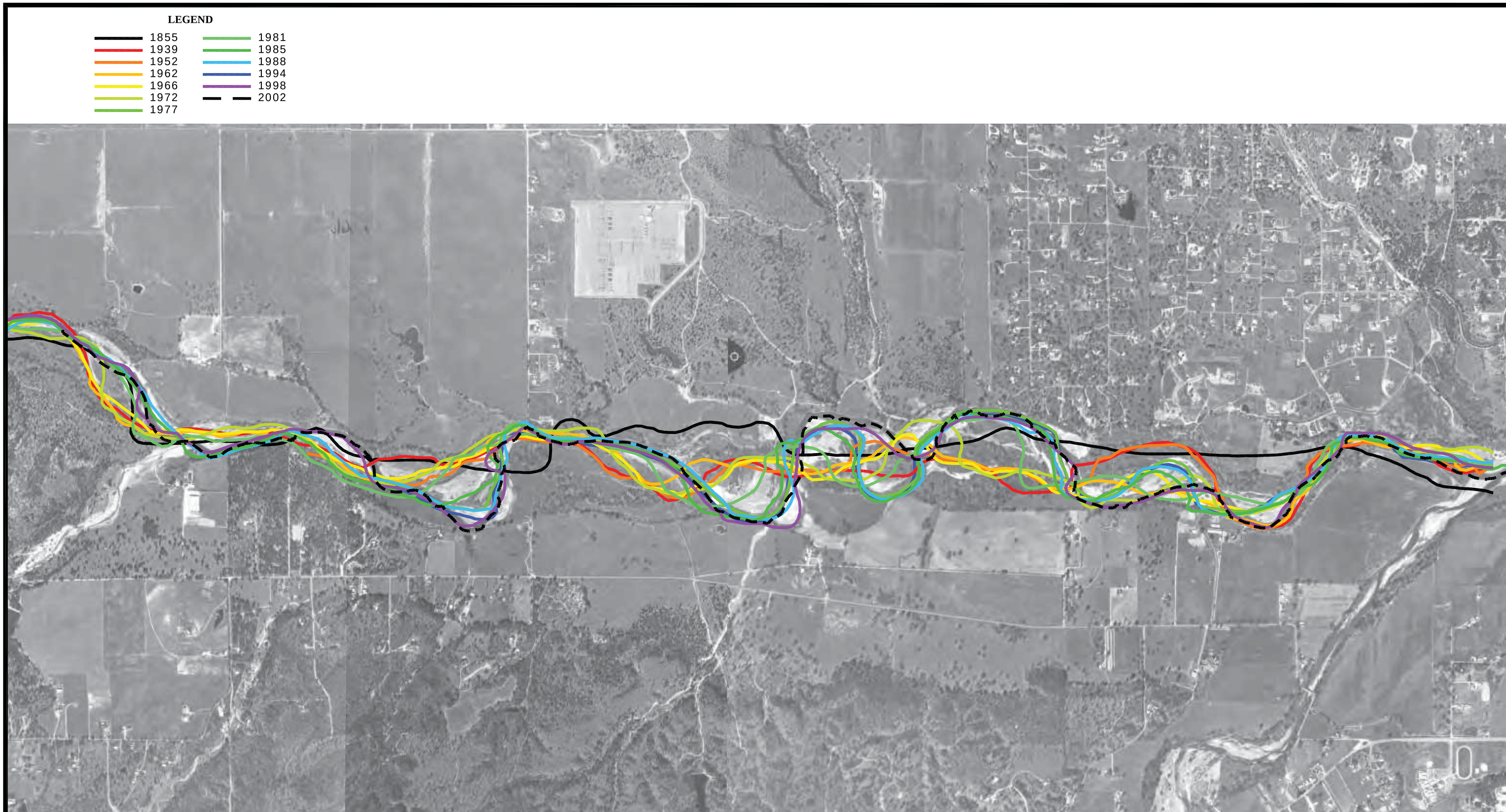
FIGURE
10b



COTTONWOOD CREEK CHANNEL ALIGNMENTS, 1855-2002, UPPER SECTION, ABOVE SOUTH FORK COTTONWOOD

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N

SCALE
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FIGURE
10c