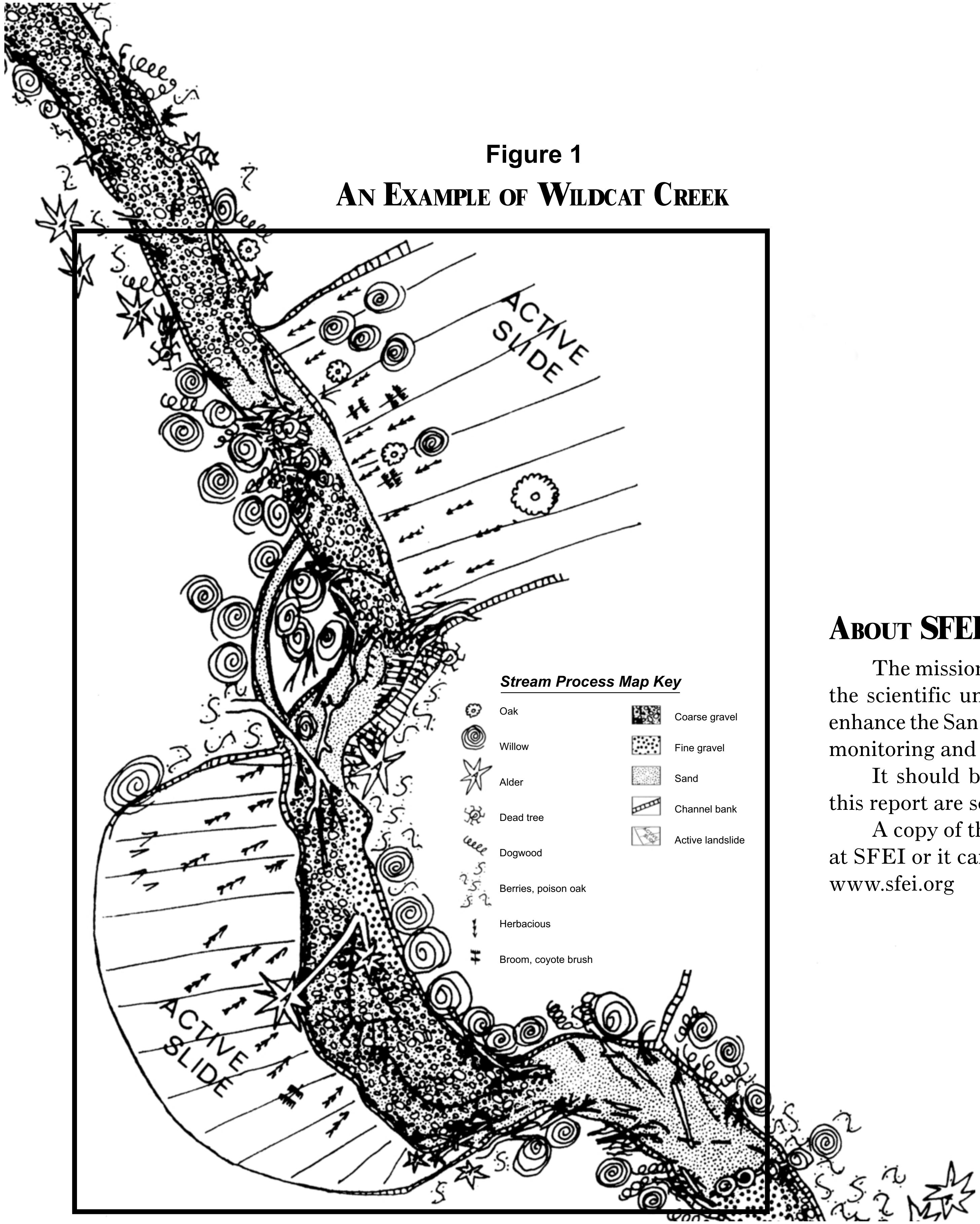
WILDCAT CREEK WATERSHED

A Scientific Study of Physical Processes and Land Use Effects

June 2001

Figure 1

AN EXAMPLE OF WILDCAT CREEK



ABOUT SFEI

The mission of SFEI is to foster development of the scientific understanding needed to protect and enhance the San Francisco Estuary through research, monitoring and communication.

It should be acknowledged that all aspects of this report are scientific and not political.

A copy of this report is available as a CD ROM at SFEI or it can be viewed on the SFEI website at www.sfei.org

Table 1

WILDCAT CREEK FACT SHEET

Mainstem	Total
Length of mainstem channel (mi) from upstream extent of tidal influence to headwater	13.8
Drainage area to tidal influence (sq mi)	8.8
Drainage area to flood control project	8.7
Mainstem flow regime - Alluvial Plain	Intermittent
Flow regime - Canyon	Intermittent/ perennial
Mean annual precipitation (in)	23
Average annual maximum temperature (F)	64.7
Average annual minimum temperature (F)	49.6
Highest point in watershed *(Volmer Peak)* (ft)	1,905
Impoundments in Canyon	Jewel Lake, Lake Anza
Sediment basins in Alluvial Plain and Canyon	Flood Conrol Project, Tilden Golf Course
USGS gage station # (Richmond)	11181400
Drainage area (sq mi)	8.7
Years of record	1965-1975
Elevation at gage (ft)	20.6
USGS gage station # (Vale Rd)	11181390
Drainage area (sq mi)	7.8
Years of record	1976-1997
Elevation at gage (ft)	65.6
Record high flow year	1982
Record high flow (cfs) (Vale gage)	2050
Record low flow year	1976
Record low flow (cfs) (Vale gage)	26
Bankfull discharge (1.5 recurrence interval) from combined records for Vale site (cfs)	300
Bankfull discharge from Regional Curves (cfs)**	380
Effective discharge for sediment basin at Flood Control Project (cfs)*	500
Mean annual discharge (2.3 recurrence interval) from combined records for Vale site (cfs)	530

** WES USACE 1999*

*** Leopold 2000*

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Acknowledgments

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Preamble

THE NEED FOR WATERSHED SCIENCE

Large amounts of private and public money are spent each year in the Bay Area to implement numerous state and federal policies and programs relating to watershed management. Through these policies and programs government agencies manage various watershed factors, including land use activities, water supply, flooding, pollution, erosion, fire, and natural resources.

The individual and cumulative impacts of these various efforts have been unclear. Overall, watershed health has not been assessed to determine response to past watershed activities or future trends. Local watersheds cannot be compared to each other or compared to themselves over time because there has not been a standard approach to watershed assessment. The work done to date is variable in content and methodology. A standard approach to assess watershed health would be useful.

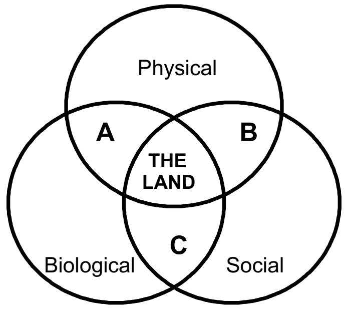
Various approaches to watershed health assessment have been devised and tested for other regions. The nature of watersheds can differ enough among regions that a variety of approaches can be justified. In the San Francisco Bay Area, where no standard approach exists at this time, it may be useful to try a number of different approaches, making adjustments as necessary to create an assessment methodology that is tailored for this region, especially for urbanized watersheds.

SFEI'S WATERSHED SCIENCE APPROACH

In 1996, SFEI met with key federal and state agencies to discuss the need for a regional program of science support for local watershed management. SFEI thereafter proposed to develop a watershed science approach to assess Bay Area watersheds, based on approaches developed for other regions of the world.

Figure 2

Three Aspects of Watershed Health



Multiple views can be useful in watershed science. For example, physical and biological views (A) are needed to describe habitat. Physical and social views (B) are needed to define flooding and landslide hazards. Biological and social views (C) are needed to define water quality and sediment toxicity. The land might be regarded as everything viewed from all three perspectives.

SFEI has been approaching watershed assessment from regional and local perspectives. The regional view has a Geographic Information System (GIS) with a digital elevation model, aerial imagery, and a standard file structure for spatial data that can be used throughout government and the private sector to help organize and visualize local information. There needs to be a regional view of local conditions. All the information must be accessible to watershed managers, scientists, and the public.

This regional perspective is developed by detailed empirical studies of local watersheds. These studies can explain the form and function of local watersheds in the context of major management concerns, such as flooding, erosion, pollution, and natural resource protection.

SFEI has chosen Wildcat Watershed to test field methodologies for measuring sediment sources. Wildcat was chosen for several prime reasons. Managers at Contra Costa County were interested in learning more about Wildcat Creek, especially in relation to its high sediment supply that affects natural resources and requires management at the Flood Control Project. Wildcat has much of its lands accessible as open space. There is pre-existing data from surveys and stream gages that allow us to assess change. There has also been keen interest in restoring the steelhead fishery that once existed in the Canyon.

The methodology that we chose to test requires intensive field measurement of sediment sources by measuring "voids," which are essentially holes left behind by erosional processes. We decided to measure all sediment sources along the mainstem creek up to the first major impoundment, Jewel Lake Reservoir. We sampled as much of the tributary streams and hillslope sources as possible within the constraints of time and field conditions that inhibited data collection. Above Jewel Lake, we performed bathymetric surveys to compare volumes of sediment deposited in reservoirs to volumes of individual sediment sources. XÖ attempted to identify processes associated with sediment input as well as establish whether the sediment supply was natural or related to land use activities. Much of the field methodology was developed for this project to determine whether we could develop a picture of how the landscape has responded to land use activities since the time of non-native settlement. The methodology also provides basic data for monitoring future change.

Watersheds that have intensive documentation and quantification of their attributes could become "Observation Watersheds." Such Observation Watersheds might be used to learn how watersheds work, to assess trends in stability or responses to changing land practices, to further develop and test diagnostic tools for assessing watershed health, and to train assessment personnel. SFEI is striving to develop a regional scheme for classifying local watersheds and selecting Observation Watersheds.

Since 1997, SFEI has used aspects of our Watershed Science Approach to learn more about landscape change in other Bay Area watersheds. By using similar methodologies, we hope to make regional comparisons of change and condition. SFEI has developed state and federal funding to advance the regional GIS, and local funding to perform pilot projects in the field to test methods of data collection, management, and presentation. To the extent possible, SFEI has worked with local sponsors to share experience and build common understanding.

The lack of a clear set of watershed management objectives or a practical definition of watershed health has retarded development of a regional program of watershed science. Without direction from mangers, watershed science can fail to meet their needs. We hope to provide this report as a tool that can be used by all managers, scientists and residents that have an interest in this watershed.

SFEI has developed a conceptual model of watershed health as a framework for planning a program of science support (Figure 2). The model suggests that the health of a watershed should be measured relative to shared goals for physical, biological, and social benefits that the watershed can provide. Good health is achieved when the goals are reached. Once watershed goals are set, then policies, programs, and projects can be adjusted to achieve the goals. Examples of existing goals for watershed management include limits on pollutant concentrations, mapped boundaries for urban growth, safety margins for water supplies, and viable populations of endangered species. Scientists can help define what is possible, what are the risks of not reaching the goals, and how to measure progress or regress relative to the goals.

According to SFEI's watershed science approach, the physical sciences provide the most fundamental view of watershed health. It is for this reason that we have started by focusing on the physical processes first. It is presumed that physical processes largely control the natural form and functions of local watersheds. An understanding of these processes is therefore necessary to protect local watersheds.

There is much to be learned about how to conduct watershed science in the Bay Area. Local goals for watershed health have not been clearly defined for all interests. There is no long-term institutional arrangement for financial support of watershed science, and not all aspects of the science are equally well supported by experience. Watershed managers and scientists will need to help each other define the need for science support. Every application of a watershed science approach is a learning opportunity that will help develop a regional picture of local watershed health.

Executive Summary

STUDY APPROACH

Watershed management should be based upon knowledge of processes operating on the basin, including those that are natural and man-induced. This needed knowledge comes from facts derived from observation, experience, and theory. Yet, because the intensity and location of these processes change with time, retrospective historical data are needed. This reports presents for one basin the details of history, location, and intensity of physical, not chemical aspects. It uses modern tools of GIS and photographic coverage to convey geomorphic information about watershed conditions. New and innovative methods of measurement, summarization, and presentation are provided. The result is a detailed and documented accounting of the sources, distribution, and mechanisms of sediment supply that cannot be obtained from sediment transport measurements alone.

The San Francisco Estuary Institute (SFEI) has conducted a study in Wildcat Creek, Contra Costa County, California for the Contra Costa Clean Water Program. Our principal objective was to determine the changes and effects of land use and nature on the distribution and supply of sediment and water. Sediment supply was analyzed by a combination of field methods, stereo photo analysis, and estimations based upon existing literature and published methods. Stream gage data from the US Geological Survey (USGS) were used to analyze water discharge. Extensive historical research was conducted to determine past conditions. The results of our estimates of historical and modern long-term rates of sediment supply are compared to other Northern California watersheds. We developed conceptual word models of watershed processes pertinent to Wildcat Creek and provided future trend scenarios.

Wildcat Watersheds consists of two distinct Sections, a gently sloping Alluvial Plain and a steeper Canyon. The Alluvial Pain was viewed in three Segments: the Tidal , the Flood Control Channel, and the Upper Alluvial Plain. The Canyon Section was also treated in three Segments: the areas above, between, and below the two reservoirs, Anza and Jewel Lakes. The Segments are called Lower, Middle and Upper Canyon. Intensive field measurements of sediment sources were conducted by measuring voids left by erosion of channel beds, banks, terraces, and landslides. This approach was used in the Upper Alluvial Plain and the Lower Canyon. For the Upper and Middle Canyon Segments, sediment supply was assessed by performing bathymetric surveys of sediment deposition and comparing change in capacity to original as-built surveys. The Upper Alluvial Plain is the most highly developed Segment that supports the most people and receives the most management.

The Upper Alluvial Plain and Lower Canyon Segments were viewed in detail among 17 Reaches. Bed and bank conditions of the mainstem Wildcat Creek were thoroughly evaluated along these Reaches. For the areas draining into these Reaches, tributary and hillslope conditions were evaluated. Landslides, drainage density, and impervious area were quantified for the Segments above the flood control channel. All field methods are supported by a comprehensive Quality Control and Assurance Plan available from SFEI.

LOCAL SETTING

The 8.8 sq mi watershed ranges in elevation from sea level to about 1900 ft. The Canyon is bordered by the Berkeley hills to the South and San Pablo Ridge to the North. The watershed ends at the tidal marshlands northeast of the Richmond Protrero. The tides run upstream into the Alluvial Plain through the lower Reaches of the creek. Sea level is rising at about 0.008 ft/yr and the tidal range is about 5.90 ft. Average rainfall is 23 in/yr with slightly less falling on the Alluvial Plain and slightly more in the Canyon. The dominant onshore winds are occasionally interrupted during the dry season by warm Diablo winds that blow offshore and increase the risk of wildfire. A pattern of short deluges interspersed with periods of average rainfall has persisted for at least 400 years.

HISTORICAL LAND USE

The land use history of Wildcat Watershed is marked by sudden changes in culture, numbers of people, and land practices. The native Huchiun prospered from the Watershed for at least 3,000 yr. Beginning in the late 1700s native people were replaced by Europeans in less than three decades. Dramatic changes in vegetation followed the arrival of cattle and horses. Deep-rooted perennial grasses that protected the soil from chronic erosion were replaced by shallow-rooted annual grasses grazed down to the ground surface. The rapid conversion may have been aided by general drought conditions occurring around the 1850s and early 1900s.

Cattle first entered Wildcat Watershed in 1817. By the 1830s, runoff increased greatly, causing tributaries to incise and erode headward. The mainstem channel began to incise in the Canyon and Upper Alluvial Plain, while extending its fan onto the tidal marsh. Cattle herds and sediment loads continued to increase. By 1850, Wildcat and San Pablo Creeks joined at the edge of the Bay, behind their extended fan. Farms then spread across the Plain. By 1900, the large sediment load forced the creeks apart again. The Protrero was developed for maritime shipping, railroading, and oil refinement, which rapidly increased landscape change. Between 1900 and 1930, most of the tidal marsh was reclaimed. Wells were drilled and the Creek in the Middle Canyon was dammed to meet the water supply needs of the City of Berkeley. The number of people living on the Alluvial Plain increased by a factor of 500. Residential development extended upslope from the Plain to the top of the Berkeley Hills. The need for water out grew the supplies from local sources. Local wells and water diversions from Wildcat Creek were soon abandoned. By 1936, a new public district for regional parks purchased the Upper and Middle Canyon and grazing was discontinued in these segments. Between 1950 and the present, the Plain was almost completely urbanized. More of the Lower Canyon was purchased for parks. Wildcat Creek was variously revetted, culverted, channelized, and dredged.

HYDROLOGY

Wildcat Creek is a fifth-order mainstem channel that is 13.5 mi in length to its headwater end. With the addition of artificial channels, such as storm drains and inboard ditches (not including paved gutters), drainage density is 9.1 mi/sq mi of watershed. Drainage density has increased 26% since the time of non-native settlement. Such an increase helps explain increased frequency and magnitude of flooding. There are 217 pipe culverts and 15 bridges or box culverts on the Alluvial Plain. Runoff coefficients for the watershed range from 0.18 to 0.74, depending upon antecedent soil moisture. Bankfull flow at the USGS gage (in the middle of the Alluvial Plain) is estimated to be about 300 cfs. Annual peak flows range from as little as 26 cfs (1976) to 2050 cfs (1982). Flows greater than 1000 cfs have been associated with local flood problems on the Alluvial Plain. Culverts, bridges, and the railroad trestle have contributed to local backwater flooding. Perennial flow varies annually. Its extent and magnitude has decreased in the Canyon from slow infiltration and groundwater flow that maintained summer base flows through the Canyon to more rapid overland flow. The watershed is dominated now by more overland flow that causes flashy winter runoff and minimal summer base flow. Creek flow on the Alluvial Plain has always been intermittent.

GEOLOGY

Wildcat Watershed is geologically complex and seismically active. The Alluvial Plain consists almost entirely of alluvial fan deposits from Wildcat Creek. There are Holocene-aged deposits along the ancient creek courses that radiate outward from the head of the fan. The Lower Canyon is mostly clay-rich non-marine sediments of the Orinda Formation. The Upper Canyon is largely volcanic bedrock of the Moraga and Bald Peak Formations. The Middle Canyon is a combination of both sedimentary and volcanic rocks. The Hayward Fault crosses the Wildcat Creek near the Canyon mouth and accounts for the abrupt transition from Canyon to Plain. The fault is laterally creeping at a rate of about 0.4 in/yr. Vertical offset is occurring at a rate of about 0.04 in/yr with uplift to the east. The Pleistocene deposits at the fan head have been offset northward by right-lateral movement of the Hayward Fault. Displacement of about 0.5 mi may have started 80,000 yr ago. Wildcat and other faults nearly parallel Wildcat Creek within the Hayward Fault zone. Seismic activity is clustered on the Hayward Fault in Kensington and the Lower Canyon. Additional faults that splay from the Hayward Fault and cross through Wildcat Watershed were mapped during this study. Some appear to have active seismicity.

DISTRIBUTION OF LANDSLIDES

Maps were made showing active and inactive landslides. The Canyon is an earthflow-dominated landscape. Earthflow features involve about 69% of the area of the Canyon. About 25% of the landslide area has been active in the past 52 years. Aspect and slope are less predictive of landslide activity than geology, rainfall, and land use. Almost all the earthflows occur in the Orinda Formation in the Middle and Lower Canyon Segments. The volcanic rocks of the steep Upper Canyon generate few earthflows and more debris flows. Active earthflows in the Orinda Formation are more abundant on the actively grazed grasslands of the Lower Canyon than grasslands of the Middle Canyon (not grazed since 1936). Active earthflows are most abundant in the Middle Canyon along the western urbanized ridge that supplies urban runoff into earthflow deposits and has frequent vegetation management. Active down-cutting of gullies, tributary channels, and mainstem Wildcat Creek from increased runoff has removed lateral support from earthflow toes. This often initiates and can maintain landslide activity. Major increases in activity have been associated with ENSO events that can increase annual rainfall by 200% as per 1998 for example.

TRIBUTARY AND HILLSLOPE EROSION

Field measurements of sediment supply were conducted on about 50% of the total length of the tributaries in the Lower Canyon. This was performed by either continuous measurement of channel incision or by extrapolation between field inspected sites. Sediment supply from the other 50%, which were mostly west side tributaries in impenetrable brush, was estimated from stereo photo analysis. Sediment volumes were assigned to natural, land use-related, or uncertain causes. They were differentiated by geomorphic process. Different time periods were used to calculate erosion rates for different kinds of sediment sources. Landslide rates were based upon comparisons of 1947 and 1998 aerial photography. Unless otherwise indicated by dendrochronology or field conditions, we assumed that land use-related incision and headward extension began around 1832 after the introduction of cattle. Methods for calculating erosion rates from roads, soil creep and landslide creep were taken from published values, interviews, and field observations. In the Lower Canyon, the total long-term sediment supply from void measurements of tributaries and landslides was 507 cu yd/yr and 1,217 cu yd/yr, respectively. Road erosion (188 cu yd/yr), soil creep (546 cu yd/yr), and soil lowering (1,174 cu yd/yr) were calculated. Total estimated sediment supply for the Lower Canyon hills and tributaries was initially estimated at 3,613 cu yd/yr. A subwatershed analysis for the grassland tributaries in the eastern side of the Lower Canyon showed that at least 26% of the incision of tributaries was caused by grazing practices and 4% from ranch roads and culverts. Roads and culverts were minimal in these sub-basins.

RESERVOIRS

Jewel Lake and Lake Anza were constructed in 1922 and 1938, respectively. The Upper Canyon with volcanic bedrock and few earthflows drains into Lake Anza. The Middle Canyon has both volcanic and sedimentary bedrock. It has abundant earthflows and drains into Jewel Lake. Both reservoirs trap bedload, but a portion of the suspended load flows over the dam. A trickle of water flows over both spillways during summer drought. Re-surveys of the bathymetry of these two reservoirs plus all records of dredging and artificial fill indicate long-term sediment capture rates of 1,345 cu yd/yr for Jewel Lake and 378 cu yd/yr for Lake Anza. This rate does not account for the total load that includes suspended sediment supply transported over dams. Suspended load over the dams was estimated to provide another 6, 616 cu yd/yr of very fine sediment to the downstream channel. Much of the recent sedimentation at Jewel Lake has occurred on a large deltaic fan that extends upstream of the Lake. Jewel Lake has been dredged several times to maintain its open water.

MAINSTEM CONDITIONS

Sediment supply from mainstem channel incision upstream of Havey tributary is influenced by the effects of sediment retention at Jewel Lake. Excessive incision, caused by the capture of bedload, has caused 233 cu yd/yr of measured sediment supply directly related to land use. Pervasive fluvial erosion is also associated with ongoing grazing impacts, storm drains, and intensive urbanization during the 1940s. For the banks along the mainstem channel in the Upper Alluvial Plain and Lower Canyon, landslides (987 cu yd/yr), fluvial erosion (1,315 cu yd/yr), and soil creep (112 cu yd/yr) account for a total of 2,414 cu yd/yr of sediment supply. About 61% of the banks in the Canyon are eroding, versus 28% in the Upper Alluvial Plain. However, the Upper Alluvial Plain has 40% of its bank length covered by artificial revetment, as opposed to the 5% in the Canyon.

Volume of sediment supply from bank erosion on the Alluvial Plain dramatically increases toward the head of the fan where terrace banks extend 26 ft above the channel bed. Our analysis of particle size distribution for the bed surface shows that sand and finer bed materials increase upstream from 24% on the Upper Alluvial Plain to 32% in the Lower Canyon. The range of sizes also increases upstream. There are few pools greater than 1 ft deep on the Alluvial Plain. Pool spacing is poor, averaging one pool per 245 ft. Most of this segment is dry during summer and fall. Many pools exist in the Lower Canyon. Their average spacing is 80 ft and 32% are formed by the effects of large woody debris. Most of the woody debris is supplied by willow, alder and bay trees. It is predominantly recruited by bank erosion and landsliding.

AGGRADATION AND DEGRADATION

Chronic incision began throughout the Lower Canyon and Upper Alluvial Plain after the advent of cattle grazing in the early 1800s. This caused rapid aggradation at the toe of the alluvial fan and the backshore of the tidal marsh. The flood control catchment basin is in this area of historical aggradation. The upstream extent of the tidal slough has been pushed 4,000 ft bayward by sediment deposition. Localized aggradation is occurring upstream of undersized and misaligned engineered crossings, such as trestles, bridges, and culverts. In the Canyon and the upper Reaches of the Alluvial Plain, the general long-term trend for Wildcat Creek has been down cutting. The amount varies depending upon position in the watershed. Localized sites of aggradation in the Canyon are associated with debris jams and landslides.

WATERSHED SUMMARIES

Of the 13.5 mi of mainstem channel below Jewel Lake that includes the tidal slough, only 14% is available for upstream fish migration. The first migrational barrier is at the Flood Control Project. About 6% of this length is tidal slough. Slightly less than half a mile of the creek is covered by bridges or enclosed in culverts. The south bank of the Alluvial Plain is eroding about 7% more than its north bank, indicating a possible direction of long-term migration.

We compared the total sediment yield for Jewel Lake to the measured yield for the Lower Canyon. This provided a way to normalize the data for drainage areas of different size. After assessing the difference between Middle and Lower Canyons, we considered that there was still a portion of sediment supply that could not be accounted for by measurements of voids. Much of the missing supply was from historical soil disturbance from construction activities and from pervasive accelerated rates of surface erosion from bare or sparsely vegetated soils. We used several assumptions to back-calculate the supply that could not be field measured. This amount accounted for 32% of the final estimated long-term sediment supply to the channel network, which was determined to be 18,146 cu yd/yr. About 20% of the total long-term supply comes from natural sources, another 20% from direct and indirect land use impacts, and 60% may be either natural or man-induced. However, of this 60%, we hypothesize that perhaps 40% also represents indirect land use effects. So, perhaps a total of 60% of the long-term supply is land use-related. Compared to other north coast watersheds of larger size, Wildcat Creek has a very large sediment supply.

View of Wildcat Canyon looking northward, 1934.

EXPECTED TRENDS

If management practices and development conditions remain the same, sediment supply rates in the Upper Canyon should show a decreasing future trend. This may be true for grassland sections in the Middle Canyon as well, since grazing was halted over 63 years ago. However, sediment supply rates from urban impacts on the west side of the Middle Canyon may not substantially diminish for some time. Sediment supply rates through the Lower Canyon and Upper Alluvial Plain are not expected to show significant decrease under status quo conditions. Dredging of the sediment detention basin will continue to be required if its design capacity is to be maintained.

FINAL NOTE

This study quantifies the relative effects of natural processes and land use on long-term trends in watershed condition based on intensive field studies that document landscape response to land use. The key diagnostics are rates of erosion and deposition of sediments on hillsides, terraces, and in channels, as indicated by the volumes of sediment voids and deposits. The rates are estimated for periods of time demarcated by major historical land uses changes, as indicated by historical records of land management. Unlike a sediment budget, this approach does not depend on expensive measures of sediment transport and storage, the cost of which usually prohibits long-term records required to assess trends. This is not an alternative to sediment budgets. It is a different approach to watershed assessment that, despite uncertainties caused by assumptions needed to fill data gaps, provides a rigorous basis to hypothesize future landscape responses to management actions, to compare one watershed to another, and to monitor changes over time. These diagnostic tools are transferable from Wildcat Watershed to other watersheds. A regional program to study and monitor sediment and water supplies in local watersheds could significantly help meet the needs of watershed managers for fundamental scientific support.

Wildcat Study Approach

PURPOSE

This study of Wildcat Watershed was initiated in mid 1998 by SFEI to develop empirical methods of investigation and ways to present the findings that could be used in future environmental assessments of watersheds in Contra Costa County and elsewhere in the San Francisco Bay Area. Our intent was to learn how the distribution and supply of water and sediment has changed because of land use activities since the time of non-native settlement. An ancillary objective was to develop a team of scientists at SFEI that could help local watershed interests compile existing information and conduct field studies.

There was no intent in this study to assess the overall health of Wildcat Watershed or to measure the impacts or performance of any particular project or management practice. There also was no attempt to address any particular management objectives or concerns for Wildcat Watershed, nor have we attempted to develop any management recommendations. SFEI has no political interests in the results of this study.

A glossary is included on page 84.

FOCUS

Numerous social factors and interactions among physical and biological processes affect the character of a watershed. We directed our measurements to answering the questions of what have people done in the watershed and how have the physical landscape processes been influenced? The initial challenge of this study was to focus on the most fundamental aspects of watershed form and function that influence the broadest array of management interests.

We decided to focus on the relative effects of natural processes and people on historical changes in water and sediment supplies. The distribution and abundance of water and sediment strongly influence the risk of flooding and landsliding, the fate and transport of pollutants, aesthetics and recreation, and the species composition of plant and animal communities. Expensive efforts to protect and conserve human life, property, and natural resources in a watershed will tend to fail unless they follow from an understanding of water and sediment supplies.

METHODS

Another challenge was to identify what to measure in our assessment of water and sediment supplies. The selection criteria included the need to estimate long-term trends with a short-term study. A program to estimate sediment supply and flux from sediment transport sampling would take longer than the study we conducted, and not would not reveal the sediment sources.

The value of short-term measurement of rainfall, sediment load, and flow is greatly reduced by their annual variability. Rather than develop a short record of rainfall and flow, we employed the historical records from established gages in and near the Watershed, and applicable longer-term reconstructions from tree-ring analyses. We also made intensive measurements of erosional voids downstream of Jewel Lake, and used bathymetric surveys upstream of the Lake to understand sediment supply.

Changes in average channel form integrate among short-term changes in water and sediment supply. We used historical aerial photos, maps, explorers' accounts, ages of trees relative to their elevations, as-built drawings for engineered creek crossings, and various other kinds of evidence to reconstruct a history of channel change in plan view, cross section, and longitudinal profile. We developed a picture of existing creek conditions based upon new aerial photos and our field surveys.

Sediment supplies also vary greatly. Yet, long-term records can be constructed from short-term studies of sedimentation in catchment basins. The catchment basins in Wildcat Watershed are large enough to trap coarse bedload but too small to trap wash load and some of the suspended bedload of large storms. To estimate supplies of suspended sediment we relied upon published relationships between suspended load and bed load.

To assess the relative effects of natural processes and people on sediment supplies, we needed to classify and quantify the sources of sediment. We distinguished between fluvial sources and mass wasting. Of the fluvial sources we quantified bed degradation, erosion below bankfull height, terrace erosion, gullying, and headward channel extension. Of the mass wasting sources, we quantified inner gorge slumps, earthflows, debris flows, landslide creep, and soil creep. Erosion and mass wasting were quantified as the voids left by the material lost. Creep was assessed using published rates for the region. Landslides were mapped from stereo aerial photography (1:12,000 scale) and classified as active or inactive based upon field inspections and review of historical aerial photos from 1947. We used published rates of tectonic uplift as proxies for overall rates of landscape erosion. To test the accuracy of our estimated erosion rates we compared them to measured rates of sedimentation in the catchment for the Flood Control Project.

We developed detailed descriptions of perennial pools, revetments, large woody debris, and bedload particle size to help assess the habitats of aquatic and amphibious wildlife, and to assess geomorphic processes.

A history of land use change was developed for 50-year intervals. It was based upon extensive reviews of archeological studies, historical maps and photos, city and county records, published local histories, and environmental impact reports. Historical changes in land use were plotted on a timeline and referenced to major changes in channel condition.

DATA ORGANIZATION

Field notebooks and data templates were developed specifically for this methodology. Data pertaining to the mainstem channel were referenced to station distances (in feet) measured along a centerline tape puled upstream from the point of maximum tidal extent. Data for tributaries were referenced to unique tributary codes. All measured data were referenced to their source locations on a rectified photographic base map (scale 1:1800) in a GIS. The GIS includes separate coverages for subwatershed boundaries, baylands, drainage network, headward extension of channels, culverts and storm drains, dirt roads and trails, topography, and landslides. A separate database houses lists of historical information sources.

The data for channel condition are graphed for the entire length of mainstem channel, summarized for individual stream reaches, larger watershed segments, and for the Watershed as a whole. By knowing from which reach and distance station the data were collected, a field scientist can return to the exact place to validate the data or see if conditions have changed.

DATA QUALITY ASSURANCE AND CONTROL

Quality Assurance and Protection Plans were written for each kind of field measurement, and are available from SFEI. All coverages in the GIS are supported by geospatial metadata consistent with the specifications of the Federal Geographic Data Committee.

PRESENTATION OF FINDINGS

The findings have been summarized as a set of conceptual models from which can be generated many testable hypotheses about the relationships among climate, geology, land use, and water and sediment supplies. We briefly discuss potential future trends and recommend topics of future research. The base map and selected GIS coverages exist at SFEI and include applications for panning, zooming, and exporting the maps from a personal computer to a standard printer. A CD ROM version of the report is available as a PDF file from SFEI. A copy of this report is also provided on our web site at www.sfei.org

Regional Setting

Wildcat Creek is one of many streams of the greater Golden Gate Watershed (Figure 3), which includes all the lands that drain through the San Francisco Estuary and the Golden Gate and into the Gulf of the Farallones.

The San Francisco Estuary and the Gulf of the Farallones are where freshwater from the Golden Gate Watershed meets salt water from the Pacific Ocean. The Estuary extends upstream through the Delta and surrounding streams to the maximum extent of the tides.

The Bay Area is one region of the Golden Gate Watershed (Figure 4). It includes the Estuary and attending watersheds between the Golden Gate and the Delta. Important subregions are South Bay, the Peninsula, the East Bay, Central Bay, North Bay (San Pablo Bay), and Suisun. Some of the distinguishing landmarks are Mt. Diablo, Mt. Hamilton, Mt. Tamalpais, Livermore Valley, Santa Clara Valley, Napa Valley, Suisun Slough, the Napa River, the Petaluma River, the Guadalupe River, Suisun Marsh, Carquinez Strait, San Pablo Bay, San Francisco Bay, the Golden Gate, Yerba Buena, Alcatraz, and Angel Islands, and the San Andreas and Hayward Faults.

The basic physical structure of the Bay Area is complex. Tectonic pressures between the Pacific and North American plates have folded and faulted the region into valleys and ridges of marine sedimentary and metamorphic rocks that roughly parallel the coast. Volcanic rocks have extruded into the basic structure and rivers have cut through it, depositing upland sediments in the lowlands. As sea level rises, the Estuary moves further upstream and inland through the region, covering valleys and hillsides with estuarine sediments.

The regional climatic pattern has a cool wet season from November through March followed by a warm dry season. Shifts of the mid Pacific high pressure zone mean the difference between cold or warm winter storms and whether they hit mainly North Bay or South Bay. El Nino-Southern Oscillation (ENSO) tends to produce warm winter storms throughout the region, whereas La Nina tends to produce less rain. The regional climate is greatly modified by local topography. Average rainfall can vary by a factor of two among locales.

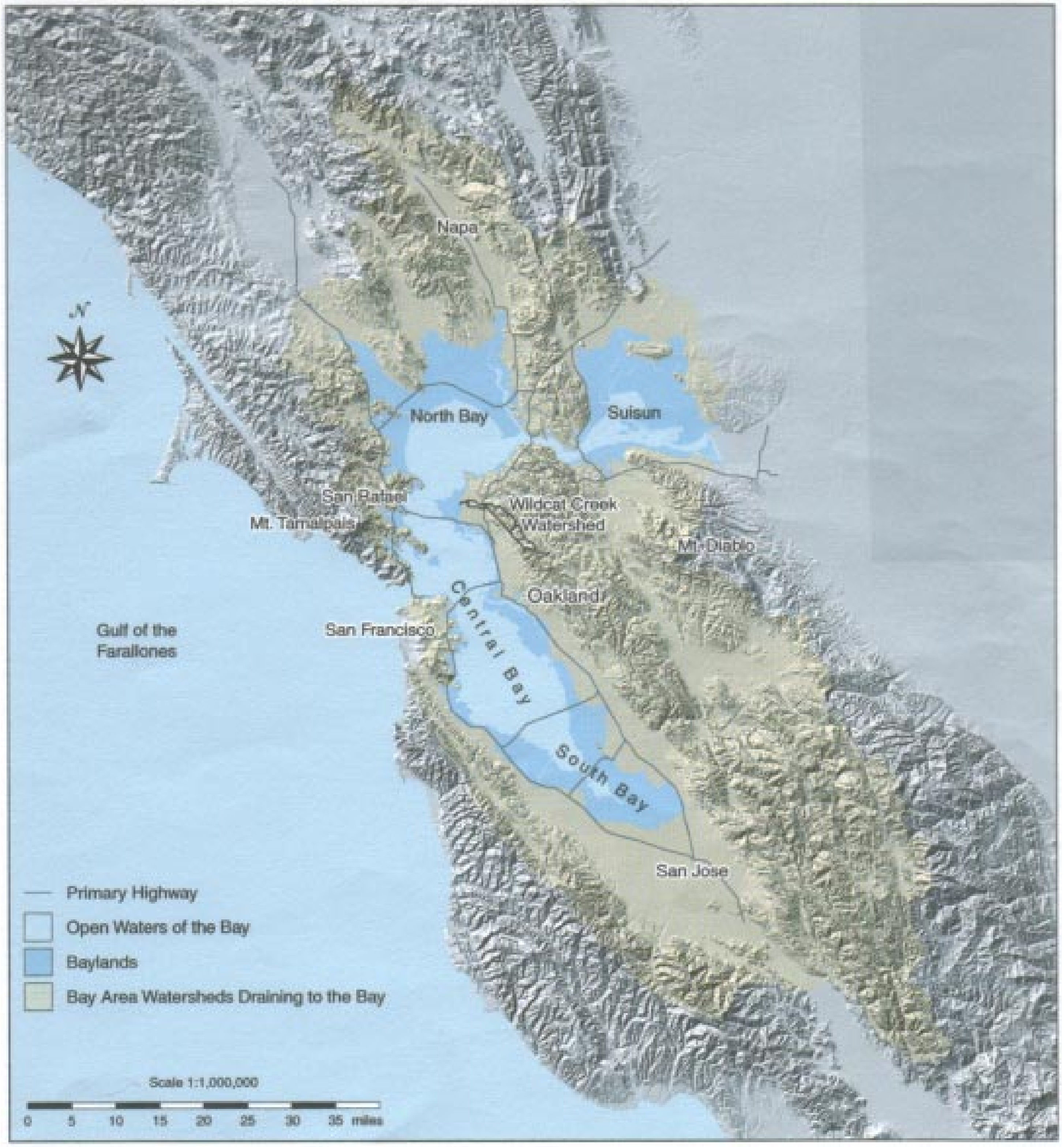
Figure 3. Golden Gate Watershed

Bay Area watersheds are part of the greater Golden Gate Watershed that drains much of California.

The Bay Area is the most urbanized region of the Golden Gate Watershed. Great amounts of fuel, power, water, and goods move daily through the Bay Area. It provides critical support for a unique natural community, including salmon and waterfowl that migrate along the Pacific coast. Vital flows of materials and energy sustain life in the Bay Area and connect it to the rest of the world.

Wildcat watershed is located at the north end of the East Bay Area. It flows northward through its canyon where it turns westward on its alluvial fan as it flows to the San Pablo baylands.

Figure 4. Bay Subregions

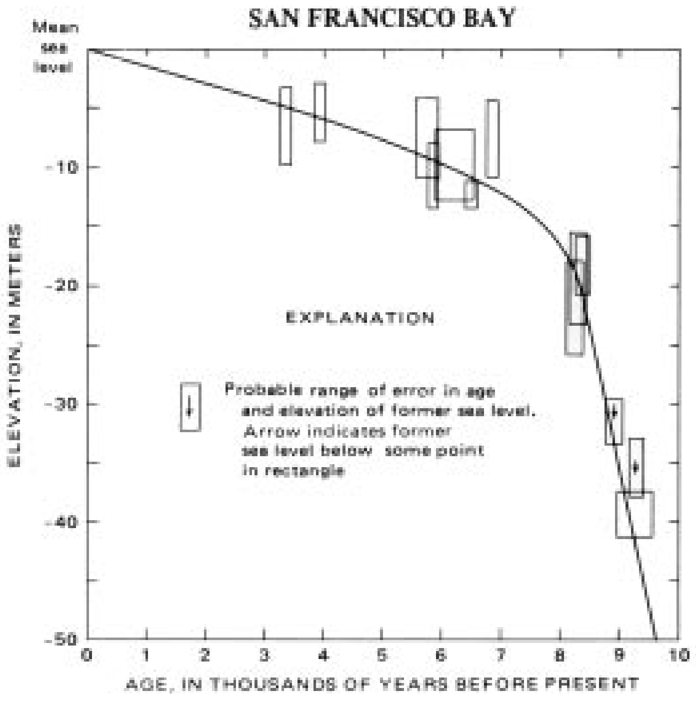


Source: SFEI EcoAtlas 2000

Tides and Sea Level

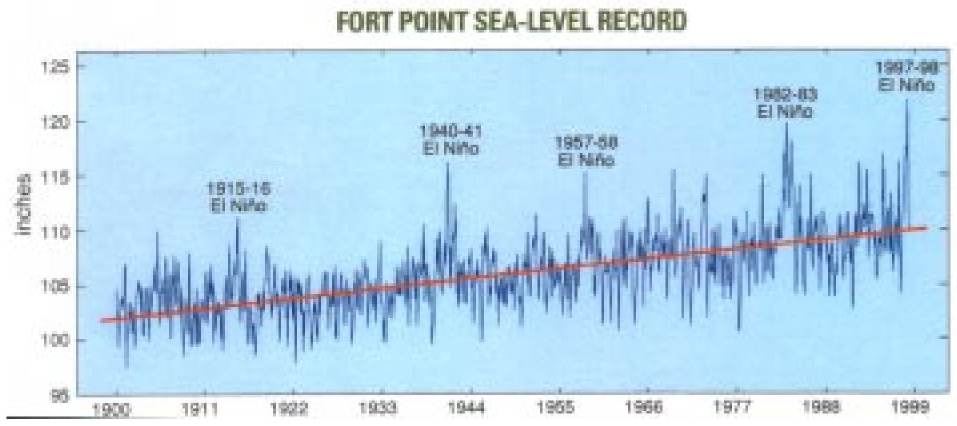
Figure 5

Daily Tide Pattern Relative to Bayland Surfaces



Based on Figure 5, p.40, Atwater (1979).

Figure 6



From USGS Fact Sheet 175-99 (2001). http://marine.usgs.gov

Sea-level measurements collected at Fort Point in San Francisco since before 1900 form the longest continuous sea-level record for any site on the west coast of North America. This record was recently analyzed by U.S. Geological Survey scientists, who found that four major factors influence sea level at Fort Point—daily tides, annual sea-level cycles, a long-term trend of slowly rising sea level (red line), and the occurrence of atmospheric events such as El Niños and La Niñas.

Baylands comprise the most downstream portion of Wildcat Watershed. The baylands include tidal flats, tidal salt marsh, and diked historical marshlands.

The rate of sea level rise has varied significantly since the tides began to enter the Golden Gate about 10,000 years BP (Figure 5). Until about 7,000 years BP, the rate of sea level rise was too rapid for tidal flats and marshes to persist anywhere in the Estuary. Based upon coring the tidal marsh and applying average sedimentation rates, the tidal marsh at Wildcat Creek is less than 3,000 years old (Josh Collins, unpublished data). During the last three millennia, the rate of sea level rise has averaged about ten inches per century.

The annual rate of sea level rise varies much more than the long-term rate. Sea level can vary by more than six inches from one year to the next (Figure 6), due to variations in winter storm patterns and large-scale variations in ocean temperature.

The tidal flats and marshes of the San Francisco Estuary are subject to a mixed type of tide having two high tides and two low tides each lunar day (Figure 7). The average heights of the tides for the 19-year tidal epoch are called tidal datums. The datum for the higher of the two high tides is called local mean higher high water. The datum for all the high tides is called mean high water. There are many other datums, including mean lower low water, mean low water, and mean tide level, which is mid way between mean high water and mean low water. Tidal datums vary throughout the Estuary and over time, due to variations in bathymetry, freshwater input, wind, barometric pressure, and sea level rise.

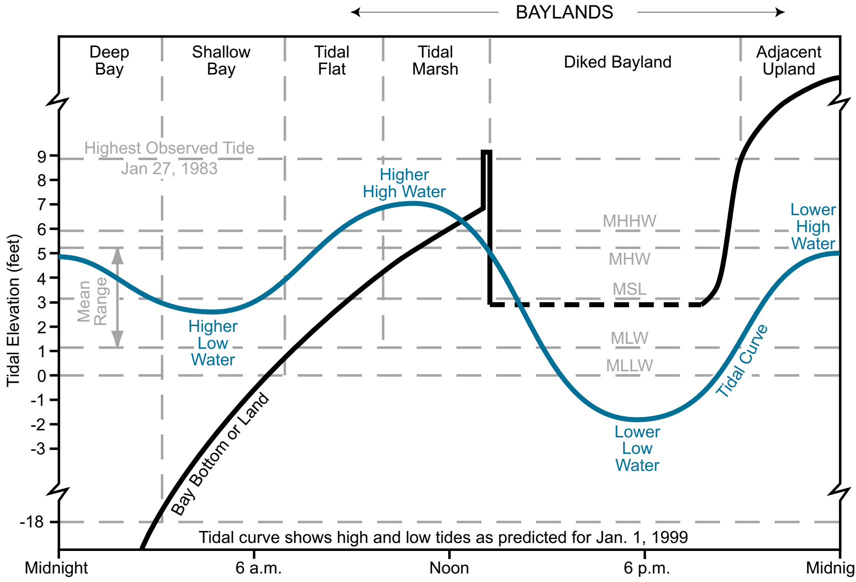
The National Ocean Survey maintains a network of benchmarks in the Estuary that are referenced to local tidal datums. The tidal elevations of the benchmarks are updated once each tidal epoch to account for sea level rise. The tidal benchmarks nearest Wildcat Creek are at Point Pinole. The tidal statistics for these benchmarks indicate a local tidal range of 5.90 ft, for the tidal epoch ending in 1978 (Figure 8).

Local deviations from predicted tide heights can be important. The highest observed tide in the Estuary was more than 3 ft above the predicted height. Since tide heights vary daily, the shoreline and upstream extent of the tides also vary. The exact edge of the Estuary can therefore be difficult to find.

Tide height can influence the conveyance of floodwaters coming from Wildcat Creek because base level, and therefore backwater influences, can vary by more than 6ft during storm conditions.

Figure 7

Tidal Statistics for Wildcat Marsh



This schematic diagram shows tidal datums for a mixed tide for the major baylands and adjacent habitats. The tidal curve and datums represent the Golden Gate. Bay bottom and land elevations are much more variable than shown. The mean range of the tide also varies around the Estuary.

Based on Figure 2.3, p.14, the Goals Project (1999).

Figure 8

Long-term Rates of Sea Level Change

CALIFORNIA III - 941 5056

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SURVEY

Tidal Bench Marks

Point Pinole, San Pablo Bay
Lat. 38°00.9í   Long. 122°21.8í

	Feet
Mean higher high water	5.90
Mean high water	5.30
Mean tide level	3.15
Mean low water	1.00
Mean lower low water	0.00

Tidal Benchmark Sheet California III-941-5056 (1979). U.S. National Ocean Survey, Rockville, MD.

Wind

On calm days in the dry season, warm air in the Central Valley east of the Bay Area rises above the Diablo Range and is replaced by cooler air from the Pacific coast. These westerly, onshore winds blow across San Francisco Bay and San Pablo Bay, keeping west-facing watersheds of the East Bay hills, such as Wildcat, cooler than many other parts of the Bay Area. The onshore winds of the dry season are usually strongest at the Golden Gate (Figure 9).

During the middle of the dry season, upwelling of deep ocean waters chills the outer coast, helping to create advective fog that can persist for days. The daily onshore winds bring the fog into the Bay Area. The fog tends to dissipate over the warmer bay waters, but can reform where moist marine air rises and cools over the East Bay hills. Fog drip helps to keep the ground in the oak/bay woodlands moist along the northeast-facing hills of Wildcat Watershed.

Near the end of the dry season, warm ocean waters come close to the Central California coast and inhibit the formation of advective fog. This initiates a warming trend along the coast, and onshore winds subside. Southwest-facing hillsides become parched. In Wildcat most of the hills with such an aspect are grasslands.

During the transition from the dry season to the wet season, a combination of high pressure over Eastern California and Nevada, plus low pressure along the Central California coast can generate strong offshore winds. Relatively warm, dry air from the east flows bayward through the East Bay hills. These easterly “Diablo Winds” (Figure 10) seldom occur for more than a few consecutive days and average about 15 days per year. When these winds coincide with the end of the dry season, they greatly increase the risk of wildfire. Most of the major fires that have occurred in the East Bay hills, including the 1923 conflagration that charred the western headwaters in Wildcat (Impact Map, page 24), were fanned by Diablo Winds.

Figure 9

Calm Day Wind Pattern

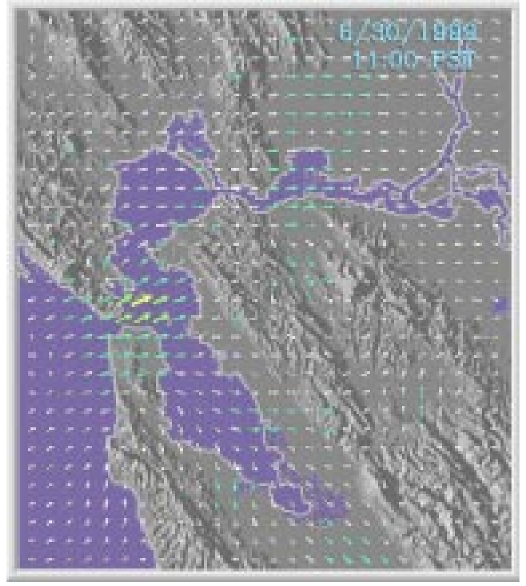


Figure 10

Diablo Wind Pattern

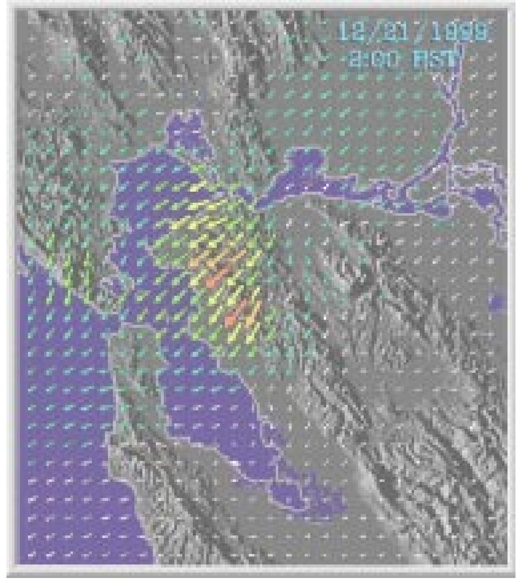
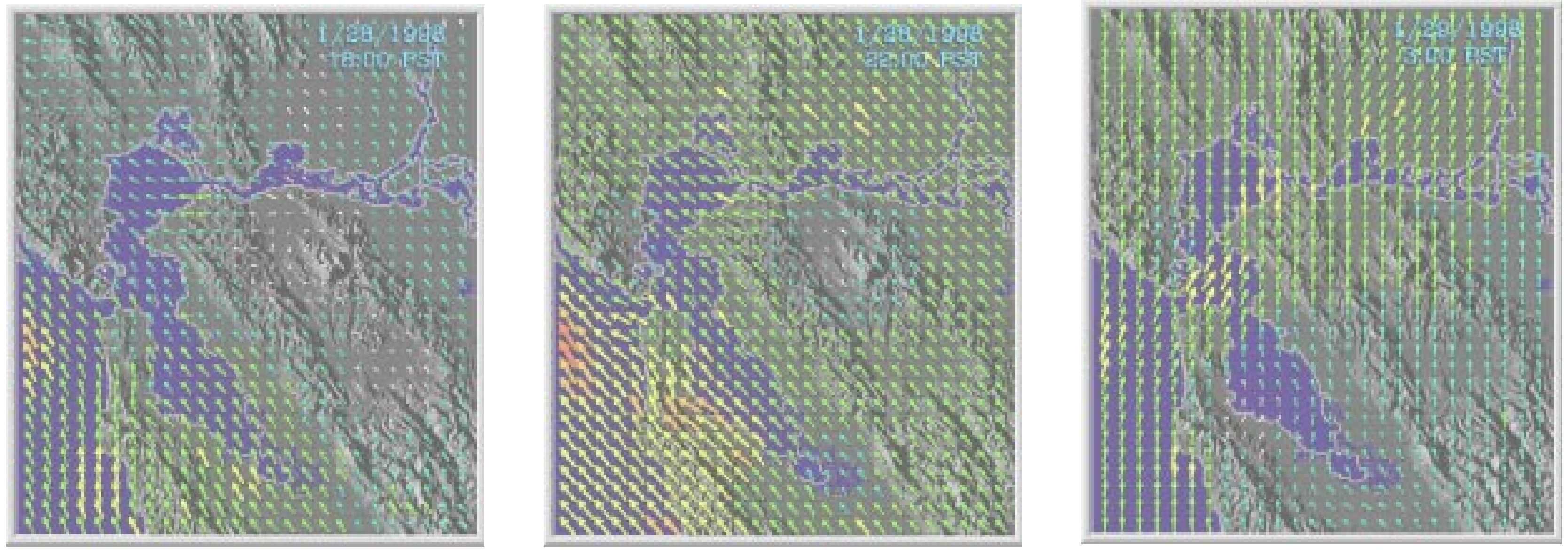


Figure 11

Passing Winter Storm Wind Pattern



Wind Speed (knots)

0 - 4.9	5 - 9.9	10 - 14.9	15 - 19.9	20 - 24.9	+25

Real-Time San Francisco Bay Wind Patterns @, www.wc.com/~paulg/weather.html

During the wet season, cyclonic storms that form over the Pacific Ocean (Figure 11) typically begin with strong southerly and southeasterly winds. As the storms pass through the Bay Area, the winds become westerly. West-facing slopes such as Wildcat can be subjected to very strong southerly and westerly winds for relatively short periods during major storms. These winds are most likely to damage buildings, and topple overhead utilities and forest trees. On rare occasions snow has fallen in the upper Canyon and stayed on the ground for usually no more than a day or two.

Rain

In the Bay Area, rain occurs mainly during a five month wet season from November through March. Most of the rain is associated with low-pressure systems that form over the Pacific Ocean. Northern and Southern storm tracks are largely controlled by latitudinal shifts of the Pacific high-pressure zone (NOAA, 1974), although local topography can strongly influence local rainfall amounts (Figure 12).

During the wet season, the Pacific high tends to move south, allowing cold rainstorms from the Gulf of Alaska to reach the Bay Area. Rainfall from these storms generally decreases from north to south. Variations in the Pacific high can allow warm air from the Subtropical Pacific to meet cold air from the north causing intense rainstorms with high quantities of rainfall to occur in Central California and the Bay Area. If the Pacific high fails to shift far enough south during the wet season, it can block the northern storm track and cause drought.

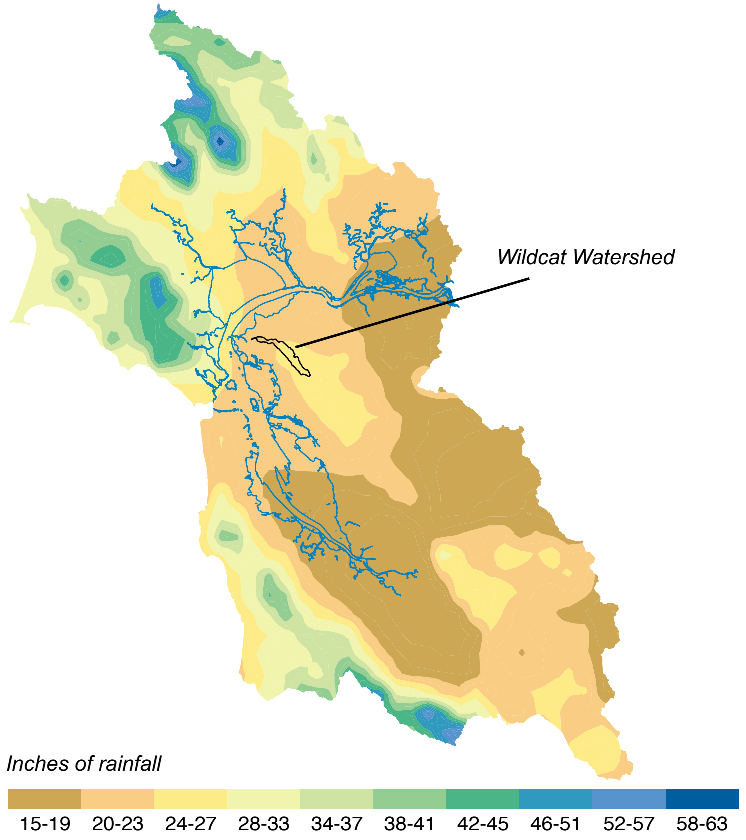
The long-term history of rainfall specific to Wildcat Watershed before the 1850s is unclear. Applicable tree-ring data date back to about 1600 (Figure 13). It indicates long cycles of wet and dry periods in the western United States (Fritts and Gordon, 1980), with general dryness from about 1760 to about 1830. There is much local and regional variation within this general pattern (e.g., Michaelson *et al.*, 1987; Graumlich 1987; Brown, 1988). A reconstruction of low flow events for the American River, which is almost due east of Wildcat and influenced by snow melt from the Sierra Nevada Mountains, (Figure 14) shows droughts of varying duration since 1560. There are notably some very wet years between the droughts (Earle and Fritts, 1986). Local rain gage data (Figure 15) indicates that the major drought of the dust bowl era ended earlier for Wildcat Creek (about 1933) than for the American River (about 1937). All of these records show much year-to-year variability in rainfall.

Tree ring records for the American River (Earle and Fritts, 1986) and the Pacific North Coasts (Graumlich, 1987) are perhaps most applicable to Wildcat Watershed. They indicate that at least seven major droughts have occurred in the Watershed during the past 250 years: 1776-96, 1843-48, 1927-33, 1947-49, 1959-61, 1977-78, and 1986-88. The 1861-62 wet season was the wettest for the modern record. The 1955-56 season was the wettest in the 20th century (Brown, 1988).

Based upon the data from local rain gages, mean annual rainfall in Wildcat Creek ranges from 4.7 to 49.3 in, and averages about 23 in. This is slightly higher than the Bay Area average of 22 inches. Fog drip is an important form of precipitation in the upper reaches of Wildcat Canyon, but it is not included in local precipitation records.

Figure 12

Spatial Pattern of Average Annual Rainfall in the Bay Area



Source: Prism Climate Mapping Program, Oregon Climate Service, oregon State University, Corvalis, Oregon.

Figure 13

Historical Precipitation Record based on Tree-Ring Data

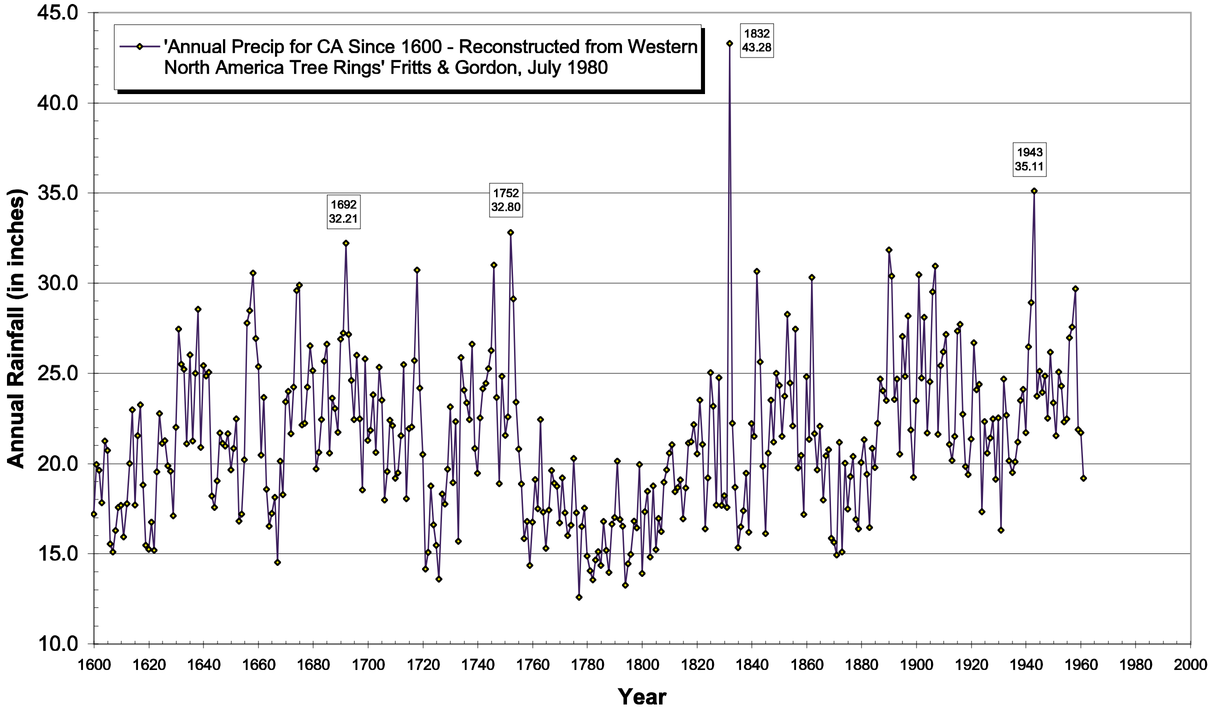
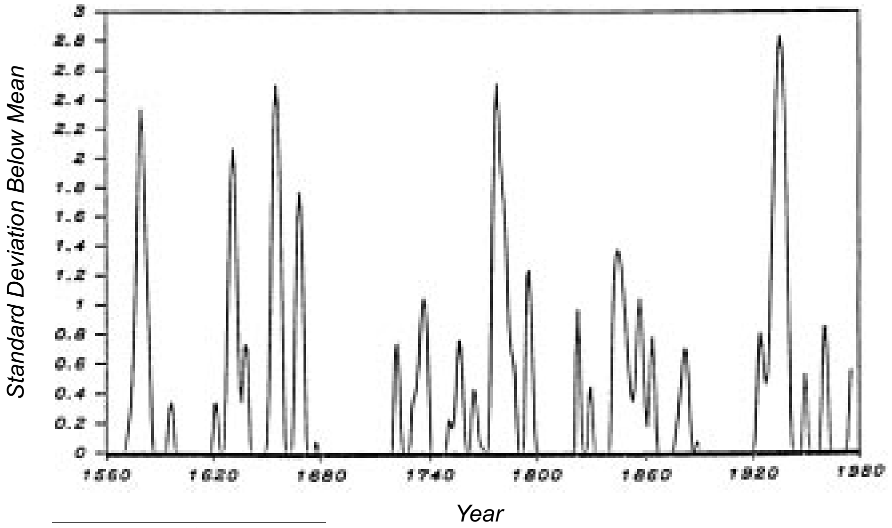


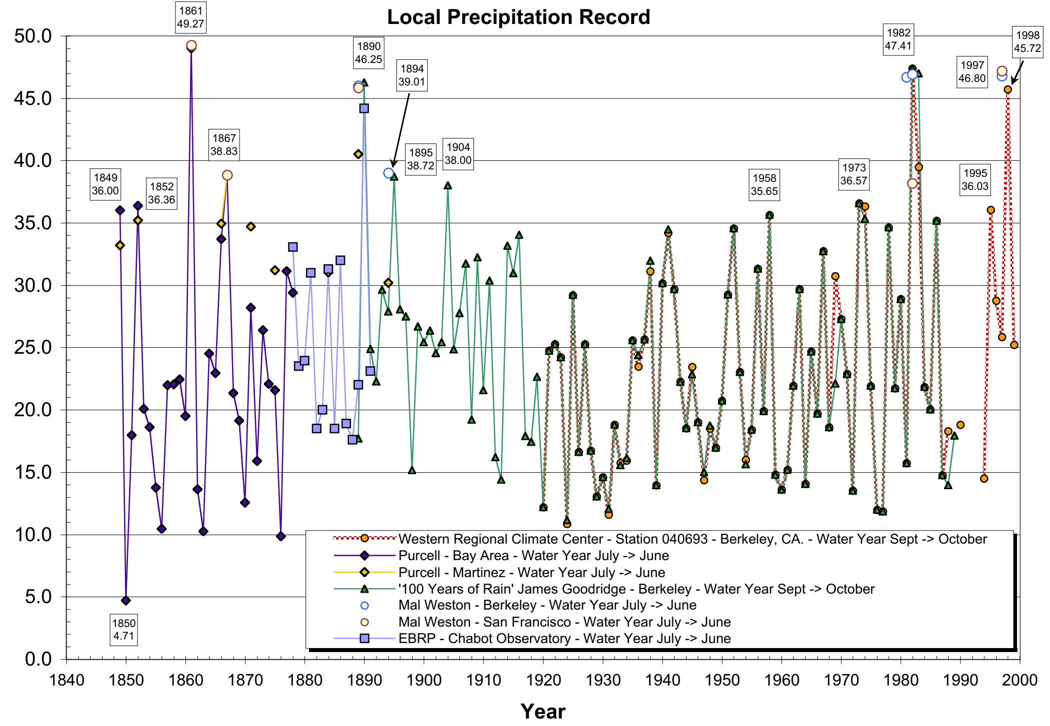
Figure 14

Long-term Record of Droughts for the American River Watershed



Source: Earle & Fritts, 1986.

Figure 15



Local Setting

Panoramic View

(Photo 1) Wildcat Watershed Looking East from the Richmond Potrero

Wildcat Creek begins on the western slopes of Volmer Peak near the northern end of the Berkeley Hills in Contra Costa County (Figure 16). The physical setting for Wildcat Watershed includes the neighboring watershed of San Pablo Creek, the western slopes of the Berkeley Hills, the Richmond plain, the baylands and bay fill along the eastern edge of the Estuary and the Richmond Potrero. The Hayward Fault runs near the top northwestern extent of the Berkeley Hills.

San Pablo Creek drains the watershed northeast of Wildcat Creek. San Pablo Reservoir on San Pablo Creek stores water that is diverted from the Mokelumne River of the central Sierra Nevada Mountains.

Above the Richmond plain, Wildcat Watershed is almost completely contained within Wildcat Canyon Regional Park and Charles Lee Tilden Regional Park. The East Bay Regional Park District (EBRPD) manages these parks as open space for natural resource conservation, public recreation, and environmental education. The eastern grasslands in Wildcat Regional Park are leased for cattle grazing. Wildcat Canyon supports many wildlife species of special concern, including rainbow trout and mountain lions. Steelhead and Grizzly bears were still present near the turn of the 20th century. Steelhead were expurgated from the Watershed sometime after World War II. Native rainbow trout have since been re-introduced into the Canyon in 1983 from Redwood Creek in Oakland (verbal communication Ken Burger, EBRPD). Steelhead migration has not been observed upstream of the Flood Control channel since the time of its construction in 1988. Box culverts beneath San Pablo Ave and Davis Park playfield also inhibit migration during various flow conditions.

Wildcat Marsh and the adjoining tidal mudflat comprise the tidal baylands near Wildcat Creek, in the natural embayment northeast of the Potrero (Photo 1). This is the largest patch of tidal salt marsh in the East Bay north of Fremont in southern Alameda County. Among other endemic wildlife, Wildcat Marsh supports endangered California clapper rail and salt marsh harvest mouse. Duck hunting occurs along the foreshore of the marsh, next to the tidal mudflat.

Wildcat Marsh is bordered to the north and south by diked baylands and bay fill. The Chevron Oil Refinery is located partly on diked baylands south of the marsh. There is a large sanitary landfill north of the marsh. It has added significant fill to the local topography. It defines the embayment occupied by tidal flats and Wildcat Marsh.

The Richmond Potrero is a ridge of low hills that is separated from the Berkeley Hills by the Richmond plain. The Potrero provides the plain with a modest amount of protection from the dominant onshore westerly winds. Brooks Island represents the top of a southern extension of the Potrero that existed when sea level was lower. Dredged tidal channels provide access to recreational boating marinas on the points of the Potrero. The southern lee contains Richmond's industrial harbor. The windward side of the Potrero provides access by land to the deepwater shipping lanes that connect San Francisco Bay and San Pablo Bay.

Access by land to deepwater shipping channels is a unique feature of this East Bay setting. It has caused a variety of industries to be located at the Potrero, including railroading, commercial whaling, shrimp fishing, military fuel storage, and oil refinement.

The broad Richmond plain that extends between the Potrero and the Berkeley Hills consists almost entirely of an alluvial fan created by Wildcat Creek. Its fan merges with San Pablo Creek's fan to the north. A similar landscape has been created by Alameda Creek between Niles Canyon and the Coyote Hills in Fremont. There are no other significant ridges of hills separating plains and baylands in the Bay Area.

Major transportation lines and utility corridors span the Richmond plain. There are railroads, interstate freeways, and large arterial avenues, in addition to smaller municipal streets. High-tension power lines cross the middle of Wildcat Marsh. Heavy industry and commercial agriculture exist in the lowermost portions of the alluvial fan. The major lines of transportation are generally parallel to the shore and perpendicular to Wildcat Creek. A major, box culvert structure exists where rail lines cross Wildcat Creek near the upper extent of the Flood Control Project. Although a fish ladder was constructed in the box culvert, it still functions as a barrier. Modifications are presently under consideration by the US Army Corps of Engineers (USACE).

The human population near Wildcat Creek is most concentrated on the upper and middle portions of the Richmond plain, in the cities of Richmond and San Pablo. More than 100,000 people reside on the plain. A map of city and county jurisdictions is located in the Appendix.

Figure 16. WILDCAT WATERSHED MAP

Photo Source: NASA, 1996

Watershed Topography: Alluvial Plain & Canyon

The 8.8 sq mi Wildcat Watershed consists of two main sections, Wildcat Canyon between Volmer Peak and Alvarado Park, and the portion of the Richmond plain that drains into Wildcat Creek between the Canyon and San Pablo Bay. Wildcat Creek has a large, usually perennial tributary, Havey Creek, and two small impoundments, Lake Anza and Jewel Lake.

The Watershed has topography and shape similar to its neighboring watersheds of comparable size that drain to San Pablo Bay. For example, like Wildcat Creek, the watersheds of San Pablo Creek and Pinole Creek are divided into a Canyon section and an Alluvial Plain section. Like these other creeks, Wildcat trends northwest-southeast between parallel ranges of nearly equal height and grade. It then flows west to San Pablo Bay.

Wildcat Canyon is bounded by San Pablo Ridge to the North and by the Berkeley Hills to the South. The ridgelines that delimit the Canyon range in elevation from about 120 ft in the northwest to about 1900 ft where they meet at Volmer Peak in the southeast. The ridgeline of the Berkeley Hills is straight and lacks prominent spurs except in its upper third extent. San Pablo Ridge is complexly dissected for most of its length. The largest spur that extends into Wildcat Canyon from San Pablo Ridge delimits the southern boundary of the Havey Creek subwatershed.

The Canyon is much longer than it is wide. A straight line drawn from Volmer Peak to the mouth of the Canyon is about 7.5 mi long. The average width of the Canyon is only about 1.1 mi.

The northeastern aspects of San Pablo Ridge and the Berkeley Hills are generally steeper than their southwestern aspects. The southwestern aspects have an average slope of about 15%. The average slope of the northeastern aspects is about 25%. Tributaries on the northeastern aspects have a shorter distance to the mainstem channel of Wildcat Creek. The southwestern aspects have dryer soils than the northeastern aspects that support vegetation requiring more moisture.

Most of the alluvial fan of Wildcat Watershed is outside the drainage divide of Wildcat Creek. Small channels, some of them remnants that do not drain back into Wildcat Creek, have dissected the alluvial fan. The watershed boundary for the Alluvial Plain as shown in this report includes the parts of the alluvial fan that most obviously drain to Wildcat Creek (Figure 17). All the lands that drain to the Creek through storm drains and inboard ditches upstream of the Flood Control Project are included within the delineated boundary. Storm drain maps along the Flood Control Channel were not made available at the time of this study. Thus, the functional extent of the boundary along this segment has not been determined. We have shown the watershed boundary to coincide with the man-made levees along the Flood Control Project.

The alluvial fan for Wildcat Creek ranges in elevation from sea level to about 120 ft. From its base near the baylands to its apex at the mouth of Wildcat Canyon, the fan gradually steepens and then levels off. San Pablo Creek and Wildcat Creek nearly converge near the middle of the fan. There is a broad, round plateau at the head of the fan. Its slope is less than 1%. The plateau steepens downstream to greater than 1% and then substantially decreases at the Flood Control Project. Fill has been used to flatten the grade of the fan for major roadways. The most obvious example is represented on the topographic map (Figure 17) as sharp projections of contour lines that, when viewed together, resemble a straight dashed line trending due east from the most western edge of the alluvial fan. Wildcat Creek consists of approximately 70 mi of channels. This measure includes the lengths of recent headward erosion of tributaries, but excludes the tidal sloughs, storm drains, and inboard ditches along roads that are connected to the creek. The average slope of the mainstem channel is about 0.5% for the alluvial plain, 1.6% for the Lower Canyon, 3.9% for the Middle Canyon between the reservoirs, and about 8.1% for the Upper Canyon above Lake Anza. The slope changes suddenly at the mouth of the Canyon.

(Photo 2) View from the east side of Wildcat Canyon, looking west.

The amount and distribution of perennial flow varies from year to year, due to variations in rainfall amounts that control base flow. The creek along the Alluvial Plain is usually dry at the surface during the latter part of the dry season. Perennial flow in the Canyon usually occurs from the mainstem channel from the Tilden golf course to a short distance below Jewel Lake, and from just above the confluence of Havey Creek to about a mile downstream. Havey Creek usually flows year-round near its confluence with Wildcat Creek. A few small tributaries on northeastern aspects of the Berkeley Hills also flow year-round. Persistent pools of water are scattered among the intermittent reaches in the Canyon. Few exist on the plain. The upstream excursion of the tides is artificially restricted in the creek by a sewer line that elevates the creek bed above mean higher high tide.

Aspect, soil moisture, tidal excursion, and land use affect the distribution and composition of major plant communities in Wildcat Watershed. Brushland and grassland dominate the southeastern aspects above the canyon bottom. Mixed hardwood forest and north coastal scrub dominates the northeastern aspects in the Canyon. A narrow zone of riparian forest attends the natural channels throughout the Canyon and becomes sparse along portions of the Alluvial Plain. There are plantations of Monterey Pine and Eucalyptus in the Canyon, and most of the plain supports an urban forest of cultivated trees. The tidal marsh is densely covered by native salt marsh vegetation, which is predominantly pickleweed.

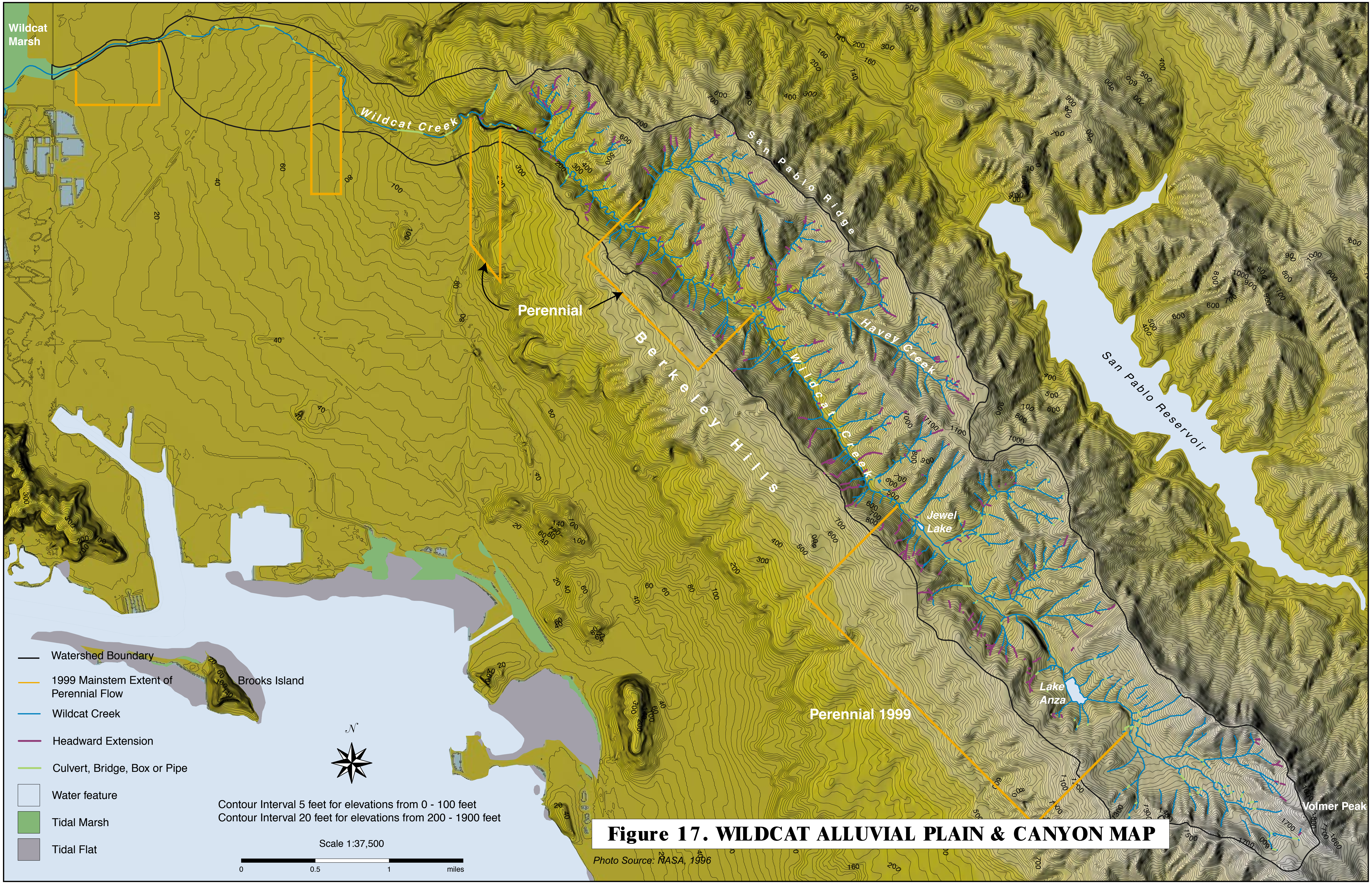


Figure 17. WILDCAT ALLUVIAL PLAIN & CANYON MAP

Photo Source: NASA, 1996

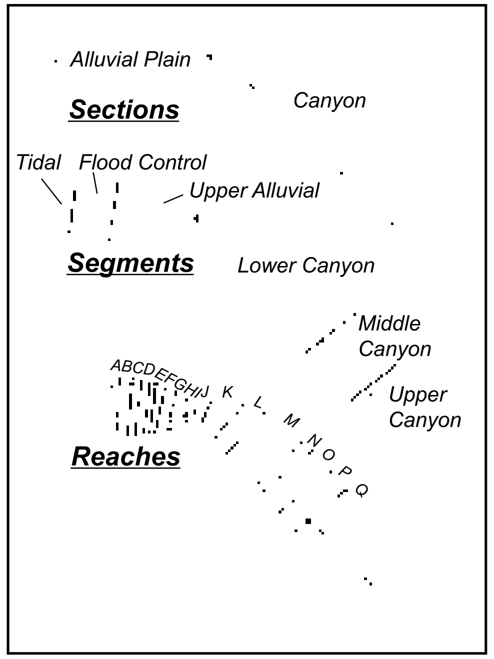
Sections, Segments, and Reaches

For the purposes of this study, we partitioned the Wildcat Watershed into a set of hierarchical parts that we call Sections, Segments, and Reaches. These are shown schematically (Figure 18) and in detail in the Sections, Segments, and Reaches Map (Figure 20). The watershed is comprised of two large sections that we call Canyon and the Alluvial Plain. These sections have significant geomorphic differences as well as differences in abundance of people and infrastructure. The Hayward Fault nearly defines the boundary between the two Sections in Alvarado Park. The Canyon is the ravine in the hills that has been cut by Wildcat Creek flowing over bedrock. The Alluvial Plain is the highly urbanized, cone-shaped deposit of alluvium formed by Wildcat Creek as it exits the Canyon. Names of the reaches are listed in the map legend of Figure 20.

Each section has been divided into three segments. These are based upon different parameters for the Canyon than the Alluvial Plain. The Canyon is partitioned into the Upper, Middle and Lower Canyon Segments. The Upper and Middle Canyon Segments have their downstream boundaries ending at the reservoir spillways of Lake Anza and Jewel Lake, respectively. The Lower Canyon ends at the apex of the alluvial fan in Alvarado Park. The Alluvial Plain Section, from upstream to downstream, is divided into Upper Alluvial Plain, Flood Control Channel, and Tidal Segment. The Upper Alluvial Plain defines its downstream boundary at the upstream end of the concrete box culvert at the Union Pacific Railroad, which is within the Flood Control Project. At the downstream end of the box culvert is a sediment catchment basin as part of the Flood Control Project. The boundary between the Flood Control and Tidal Segments is at the upstream maximum extent of tidal flow, which is 750 ft downstream of the intersection of the Wildcat Creek and Richmond Parkway. Note that the Flood Control channel actually includes 1,350 ft of tidal zone and extends about 400 ft inside the Upper Alluvial Plain Segment. Also, note that the watershed boundary corresponds to the flood control levees.

Figure 18

Schematic for Sections, Segments, and Reaches



(Photo 3) A deteriorated 15 ft diameter culvert fails along with its overlying fill in the Upper Alluvial Plain Segment, January 1997.

The area and length of each Segment is shown in Table 2. The Tidal Segment does not have a computed drainage area because it is part of San Pablo Bay, as well as Wildcat Watershed. The Lower Canyon Segment has the largest drainage area, 4.38 sq mi, and it has the longest length of channel, 5.33 mi. The Upper Alluvial Plain Segment has the fourth largest drainage area, but second longest length of channel. These are the two mainstem channel Segments that were intensively studied.

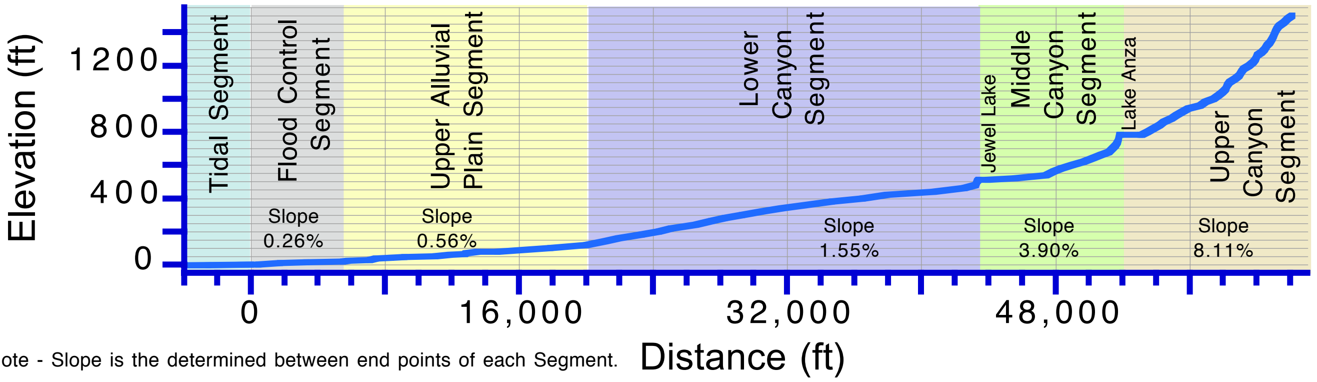
(Photo 4) A 3 ft diameter culvert fails along the Havey Creek Trail in the Lower Canyon Segment, January 1997.

The Upper Alluvial Plain and Lower Canyon Segments were subdivided into reaches. For the Upper Alluvial Plain, the reach boundaries correspond to concrete box culverts at road crossings. For the Lower Canon Segment, some reach boundaries were based on box culverts, and others were based on geomorphic characteristics, such as the occurrence of perennial flow, amount of bedrock exposed in the channel, and stream gradient.

The data from the USGS 7.5' Quadrangle is plotted to exemplify the general gradient of Wildcat Creek (Figure 19). Average slopes for the six Segments are also shown. These reported slopes are simply the gradient between the ends of each segment. These slopes are typically steeper than actual channel gradients as measured in the field. Details of channel gradient are discussed further on pages 69 and 71.

Figure 19

Longitudinal Profile from USGS 7.5" Quadrangle



Note - Slope is the determined between end points of each Segment.

Table 2

Area & Length of Wildcat Creek by Segment		
	Area (sq mi)	**Length (mi)**
Tidal		0.76
Flood Control	0.11	1.04
Upper Alluvial Plain	1.13	2.55
Lower Canyon	4.38	5.33
Middle Canyon	1.71	1.75
Upper Canyon	1.46	2.13
Total Watershed	***8.79***	***13.59***

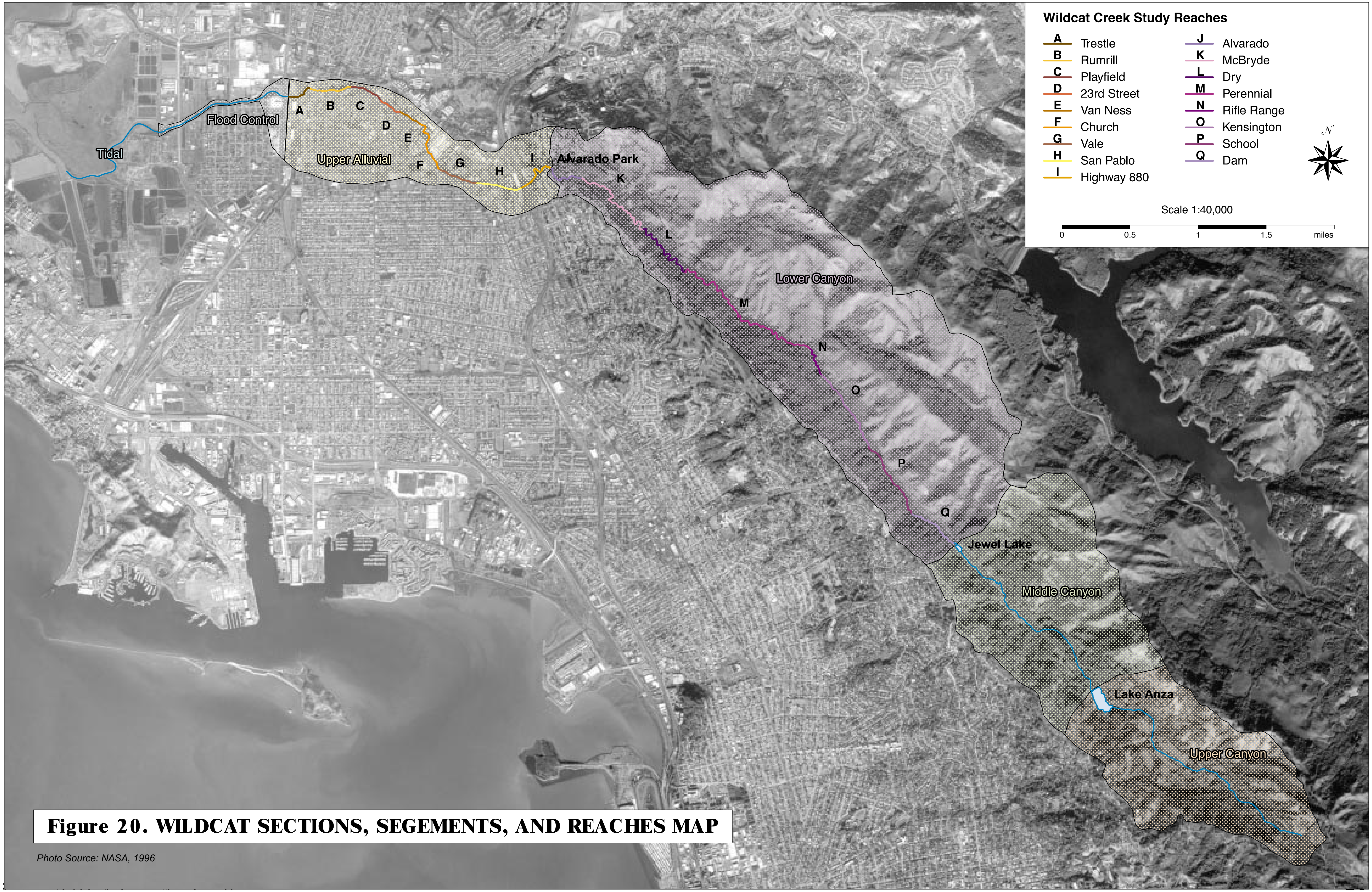


Figure 20. WILDCAT SECTIONS, SEGEMENTS, AND REACHES MAP

Photo Source: NASA, 1996

Land Use History

OVERVIEW

People have lived along Wildcat Creek since at least 3-4 thousand years before present. Sea level rise had slowed and the Bay's size stabilized, allowing broad mudflats and tidal marshes to develop, and significant local settlement to commence (Banks and Orlins 1985, Fentress 1994). Along lower Wildcat and San Pablo Creeks, villages began to grow as new resources were utilized along the edge of the bay. Clam, mussel, and other shells soon covered areas of dense cultural activity. Several thousand years later the shellmounds, containing burials, ceremonial and household artifacts, fish, birds, and other animals had been built up to as high as thirty feet and acres in size (Luby and Gruber 1999).

At the time of European contact, the people living in Wildcat Watershed were known as the Huchiun, or Jutchiun, or Cuchiyun (Milliken 1979). Of the shoreline inhabited by the Huchiun, which probably extended from about Temescal Creek to Rodeo Creek, the area around lower Wildcat Creek and the Potrero was the most densely populated, presumably because of food resources from the extensive marshes behind the Potrero (Banks and Orlins 1979).

The first recorded Spanish expedition to cross Wildcat Creek took place in 1772, although it is possible that Spaniards may have traveled this far north as early as 1769 (Milliken 1979). The 1772 Fages and 1776 DeAnza expeditions received festive greetings at two villages along Wildcat Creek, one of which was estimated at 100 – 200 people in size. Within three decades, nearly all the native Huchiun had been forced to move to Mission Dolores and convert to Christianity (Milliken 1979). The Huchiun homeland would remain essentially unpopulated for over a decade. The Huchiun did not disappear, though; at least one account documents native people coming down from the hills annually, perhaps a century later to harvest shellfish at the Ellis Landing marshes (Fridell 1954).

In 1817, San Francisco's Mission Dolores needed more food to support the growing population of the Mission, so they established a ranch in the East Bay. Wildcat Creek was chosen as the headquarters because of the broad plains and grassy hills of Wildcat Watershed and adjacent lands. While we do not know how many cattle were grazed during this period, the ranch was operated by as many as 49 Christianized Indians (Milliken 1979), suggesting that significant grazing effects were initiated at this time. In 1823, the Mission shifted its ranching operations to the newly created Sonoma Mission. Subsequently, Francisco Castro took possession of the area, becoming the first white man to settle on the Contra Costa ("opposite coast"; Fridell 1954).

By 1830, Castro had developed Rancho San Pablo, which boasted fourteen hundred cattle, six hundred sheep, and five hundred horses (Williams 1952). With the expansion of the cattle trade to the international market, especially the eastern United States in the 1830s, Castro and other landowners became barons of a major industry that flourished throughout the 19th century (Purcell 1940).

After the United States took control of California in 1846, many squatters settled on the huge Castro landholdings. The onerous court proceedings lasted nearly 50 years, causing the family to lose much of its property by the time the case was settled (Richmond Chamber of Commerce 1944). During this period, farming expanded from family gardens limited to the immediate vicinity of the adobes to commercial market gardens developed especially by Portuguese, Italian and Irish immigrants. The bottomlands along Wildcat and San Pablo Creeks, with fertile alluvial soils and available water, supported a wide range of fruits and vegetables. Away from the creeks, hay and grain were the dominant crops, while intensive stock and dairy ranching continued to dominate the Potrero and the Canyon. On the Bay edge of the Potrero, Chinese immigrants used the deepwater access to establish a regional center of fishing and shrimp harvesting.

Because of the uncertainty over land ownership, the length of time required to adjudicate the San Pablo Rancho Land Grant case – infamous nationally – had the effect of preventing more intensive development (Richmond Chamber of Commerce 1944, McGinty 1921). Ranching of the Alluvial Plain and Canyon, with rodeos and horseracing on the weekends at San Pablo Road (Banks and Orlins 1979), continued as agriculture expanded. Urban development was scant (compared to the towns to the south) until MacDonald's fateful duck hunt in 1895.

Taking a break from an unsuccessful afternoon of hunting ducks in the marshes at the mouth of Wildcat Creek, A.S. MacDonald climbed the Potrero. He noted how its unusual location provided the only local intersection of dry land with deep water. Along the rest of the East Bay, wide marshes and mudflats created a shallow water barrier for ships, necessitating long wharves like the Oakland Mole (Richmond Chamber of Commerce 1944, Rego 1997). Within five years of MacDonald's entrepreneurial insight, Point Richmond had become the Western continental terminus of the massive Santa Fe railroad system, which catalyzed the subsequent industrial and urban development of Wildcat Creek's alluvial fan. The proximity of undeveloped flatlands to both the deepwater port and the urban central bay almost instantly transformed Richmond into an industrial center of international significance, celebrated as "The Wonder City" and "The Pittsburgh of the West" (Cutting 1917).

In 1901, Standard Oil selected the Potrero and the marshes along Wildcat Creek (apparently ideal because of their immunity to wildfire) as the site of their West Coast refinery. A number of other major corporations followed within the next 15 years (Richmond Chamber of Commerce 1944, Cole 1980). The population of the Wildcat area, which at the turn of the 20th century only consisted of several hundred people from the earlier Huchiun villages, now began to increase rapidly. The population of Richmond increased approximately tenfold during 1901–1903 (200 to 2,500), and again during 1903-1923 (2,500 to 23,000), (Cutting 1917, Richmond Chamber of Commerce 1944). Residents tapped into groundwater supplies by drilling over three hundred wells (Dockweiler 1912) and several intensive commercial well fields by 1911. By the 1930s, however, local demand overwhelmed groundwater supplies and Sierran water deliveries soon rendered the local wells obsolete (Figuers 1998). In 1936, most of the upper canyon was protected from residential development by the formation of Tilden Regional Park (National Park Service 1936).

Population expansion slowed in the 1920s and 1930s, such that about 23,000 people were again reported in Richmond in 1940 (Purcell 1940). However, World War II led to the placement of another major industrial corporation on the Wildcat Creek alluvial fan. Creation of the Kaiser Shipyard and rapid production for the war effort necessitated an even more dramatic pulse of development than that of four decades earlier. Between 1941 and 1945, 90,000 employees, particularly white and African-American families from the South and Southwest settled in the East Bay to work at Kaiser. In these five years, Richmond's population quadrupled to nearly 100,000 people (Richmond Public Library, no date).

The shipyard boom transformed the lower watershed but did not last long. The shipyards closed immediately after World War II, leaving Richmond with the problems of poorly developed infrastructure and housing, and reduced employment (Cole 1980). The population of Richmond declined to about 72,000 people by 1960 (City of Richmond 1999), while in the upper watershed, housing expanded into the Canyon along the edges of El Cerrito, Kensington, and Berkeley. In the 1960s, a major development planned for the northern grasslands in Wildcat Canyon was abandoned, enabling the formation of Wildcat Canyon Regional Preserve in 1976. In the last two decades of the 20th century, the area's population has increased again, particularly among the Asian American and Latino communities, to an estimated 93,000 people in the city of Richmond (Banks and Orlins 1985), over 20,000 in San Pablo, and an unspecified number in the upper watershed (Richmond Chamber of Commerce 1996, City of Richmond 1999).

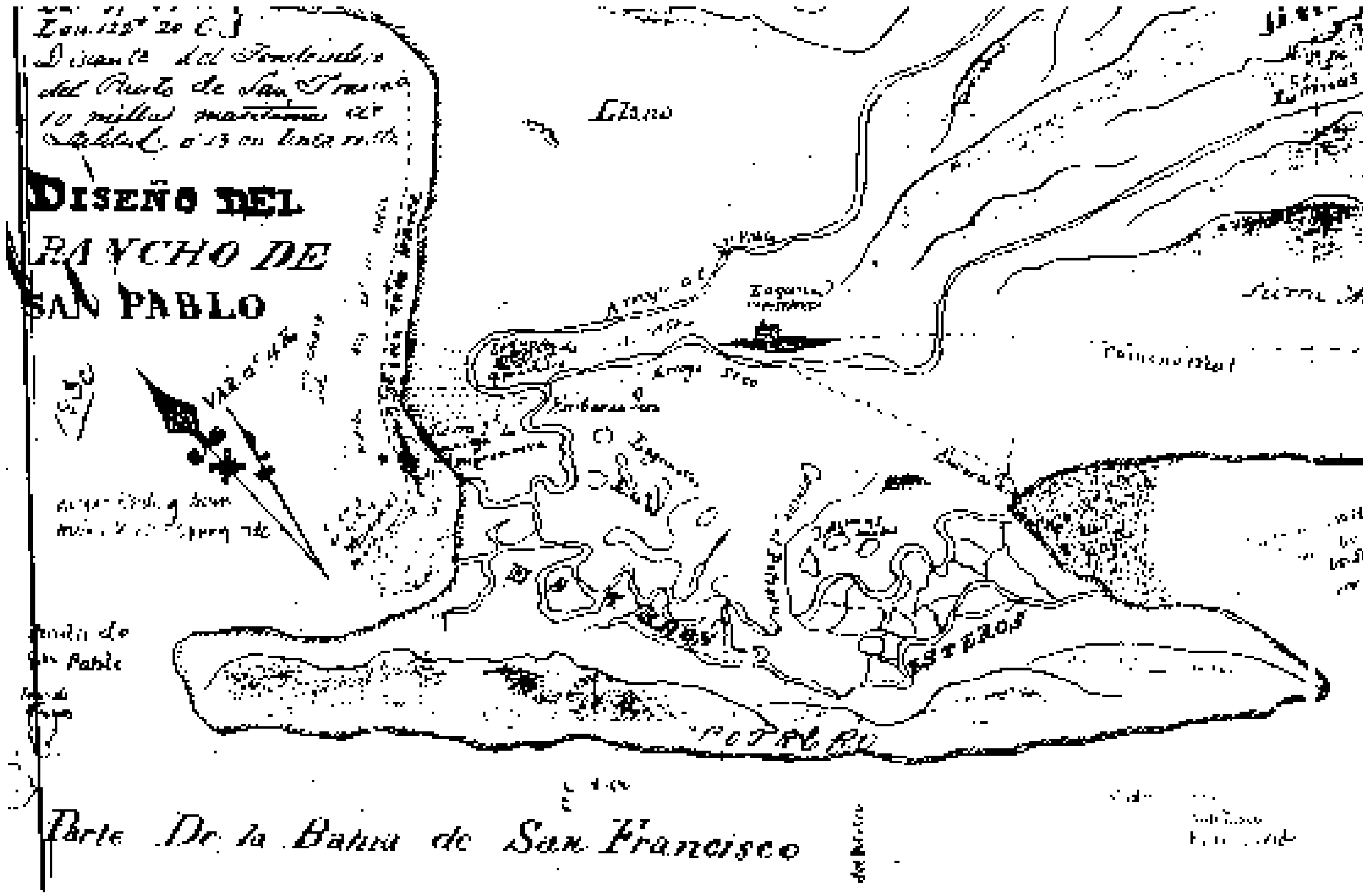
Format of Landscape History Section

To illustrate how the Wildcat Creek Watershed has changed in response to human activities and natural processes, we divided the recent history of Wildcat Creek Watershed into five periods. Maps were made for each interval: Native Landscape (1750–1800), Ranchero Landscape (1800–1850), Agricultural Landscape (1850–1900), Urban Landscape (1900–1950), and Modern Landscape (1950–2000). These intervals correspond fairly well to major events in human history that mark transition points between major types of settlement and land use in the watershed, i.e., depopulation of the Huchiun by 1805; the Treaty of Guadalupe Hidalgo (1846); the establishment of the Santa Fe railroad terminus (1899); and the end of World War II (1944).

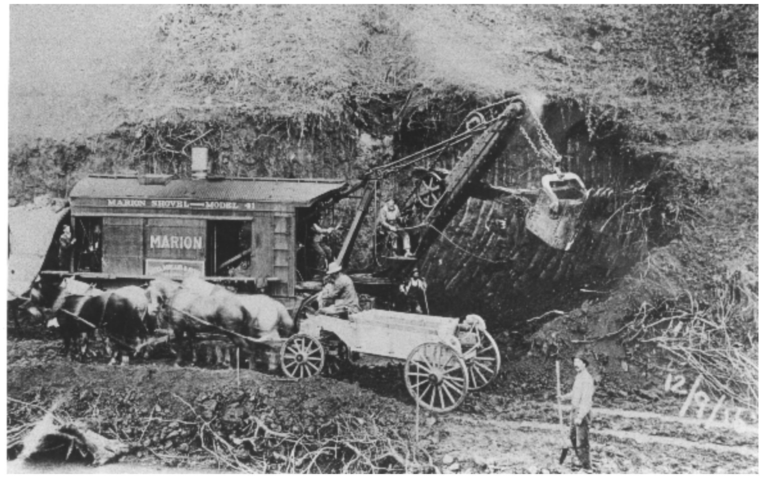
Three types of graphics illustrate each time period. The Eventline (Figure 22) at the top of the following pages tracks the dates of specific events that affected the watershed. Impact Maps (Figures 23, 25, 27, 29, 31) show the general or specific locations of potentially important impacts to the watershed. As a composite map of the approximate distribution of cultural features, hydrological features, and major vegetation types, the Watershed View Maps (Figures 24, 26, 28, 30, 32) illustrate the changing landscape as influenced by non-native land use practices.

Fully documented records are available of all historical references at SFEI's Historical Ecology Department.

Figure 21. 1830 Diseño



Circa 1830 Spanish Diseño (land grant) of San Pablo Rancho showing Wildcat Creek as a Arroyo Seco (which means dry creek), esteros (marsh), and lagunas (fresh water pond or lagoon). Courtesy of University of California at Berkeley Map Room.



(Photo 5) Stripping the banks in preparation for construction of Wildcat Dam, 1919 (see #24 pg. 24.) Source: East Bay Municipal Utility District.

(Photo 6) Curran Homestead (see #16 on pg. 22) near current site of Brazil Building, circa 1900. Source: Louis Stein collection from East Bay Regional Park District.

Land Use History 1750-1800: Native Landscape

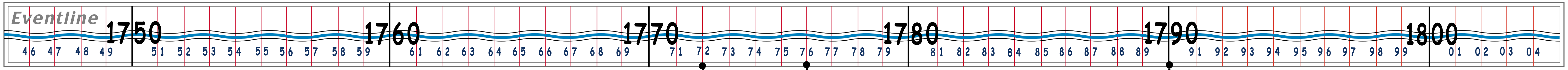


Figure 22

1772
First documented European crossing of Wildcat Creek; Huchiuns invite Spanish to villages between San Pablo Creek and Wildcat Creek.

1776
Second Spanish expedition crosses Wildcat Creek.

Mission Dolores is established in future city of San Francisco.

1790s
Most of Huchiuns were removed from vicinity of Wildcat Watershed to Mission Dolores.

(Photo 7) Stone mortar found at the base of a tributary confluence in the Lower Canyon (given to East Bay Regional Park District).

To observe Wildcat Creek in this era, we might follow the deepwater channel along the northeast end of the Potrero toward the mouth of the creek, as the Huchiun, returning from the Bay in tule balsas, would have. The channel curves to the north through the mudflats, passing several small islands indicative of recent erosion of the marsh. It shows a pattern of *spartina sp.* (cordgrass) and *salicornea sp.* (pickleweed) transitioning to *scirpus sp.* (tules) as the influence of freshwater increases.

Crossing the native grasslands of the alluvial plain, Wildcat Creek passes numerous shellmounds, particularly around the large laguna between the two creeks. Fish caught both in the Bay and the creeks are processed here for local consumption and trade. Near the first shellmound along Wildcat Creek, we reach the upper extent of the tides and the beginning of the narrow riparian forest, the sole trees of the alluvial plain. Continuing upstream, the creek splits with the older overflow channel to the south. The split marks the boundary of present-day Davis Park. Trails lead along the Creek to the Potrero, to marsh ponds (for salt harvest and waterfowl hunting) and channels, and to the shellmounds at Ellis Landing and Stege.

Where the creek turns south, it passes the large shellmound and ceremonial center of the area, located at a lagoon in a “sink” at the end of a remnant channel of Wildcat Creek. The creek then intersects the main road of the East Bay plain (now San Pablo Avenue), which the Spanish explorers followed into the Huchiun lands, passes the shellmounds and village at Alvarado Park, and enters the canyon. The Canyon, like the Alluvial Plain, is much more open than in years to come. Regular burning by the Huchiun prevents encroachment of brush and woodland, except in the more sheltered ravines and north-facing slopes. Woodland is densest in the narrow Lower Canyon, giving way to more brushland where the Canyon widens, and open grasslands at the top of the western ridge. Several trails cross the Canyon, and springs are common.

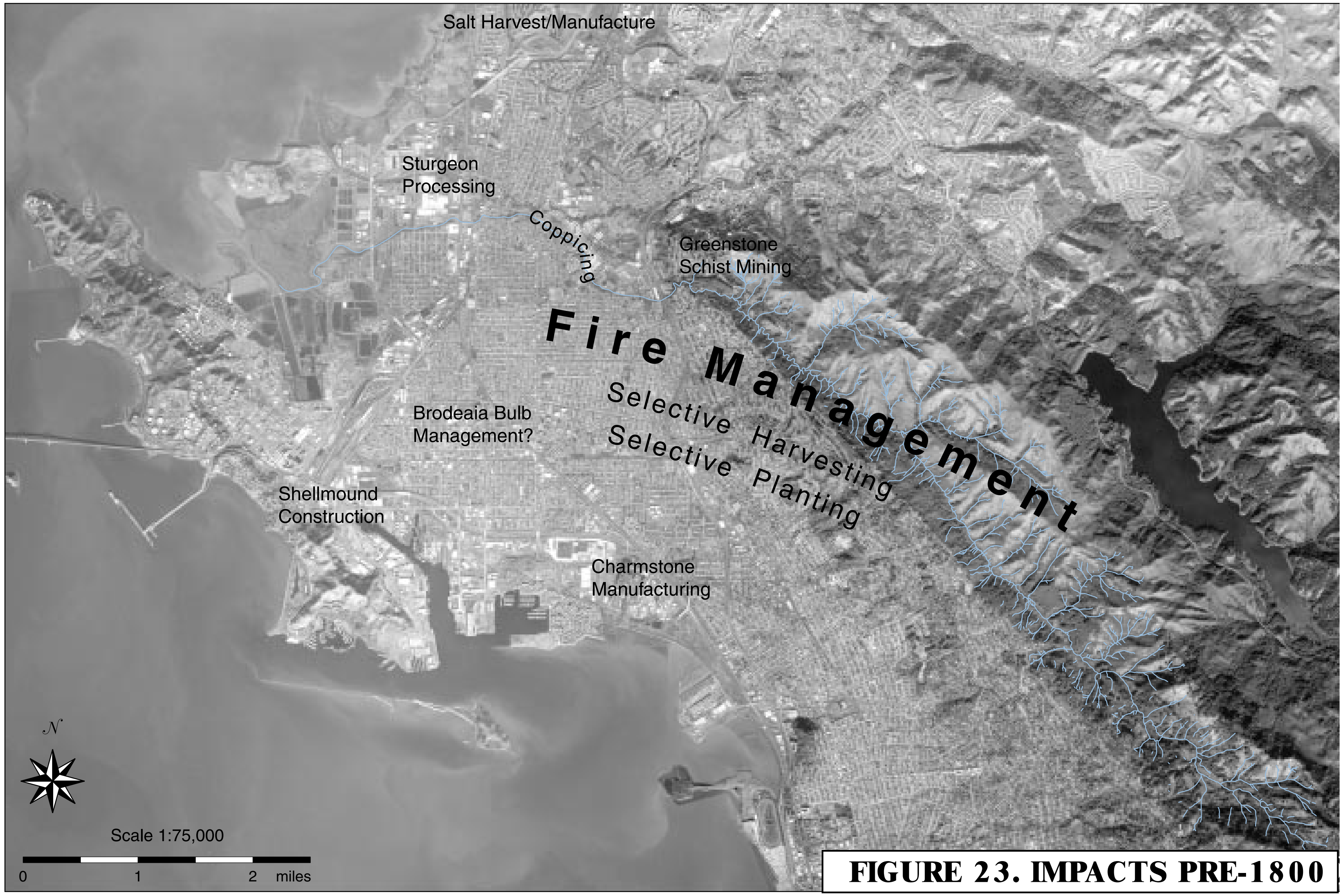


FIGURE 23. IMPACTS PRE-1800

Photo Source: NASA, 1996

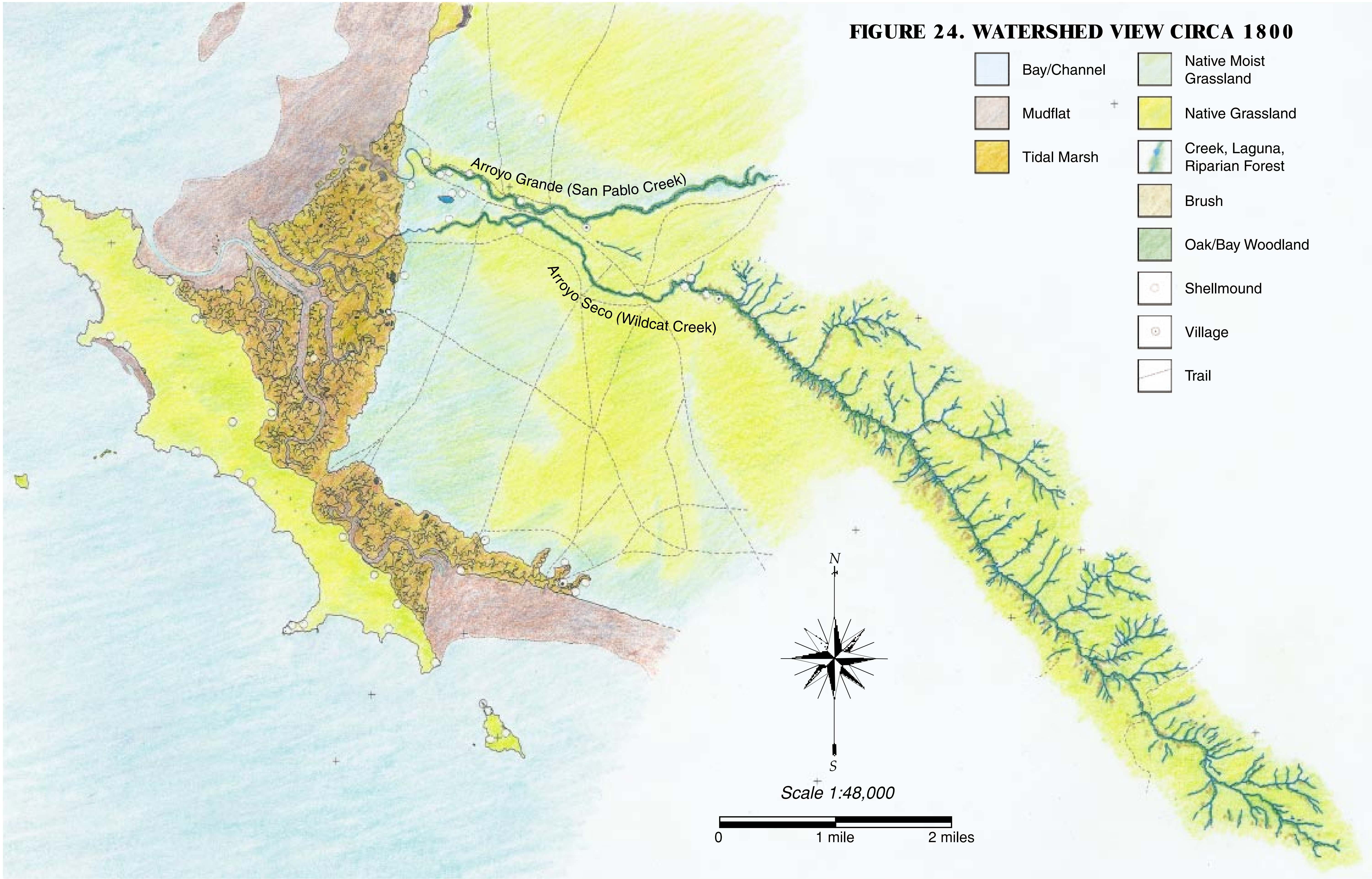
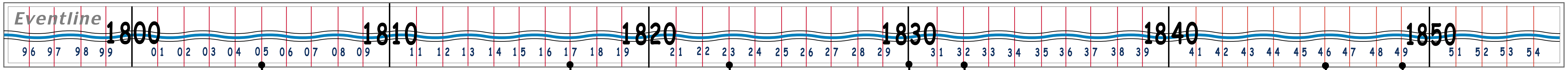


FIGURE 24. WATERSHED VIEW CIRCA 1800

Land Use History 1800-1850: Ranchero Landscape



1805
Last unindentured Huchiuns were removed to Mission Dolores, but 350 kept tending herds in Wildcat

1817
Mission Dolores ranching Headquarter were established on Wildcat Creek; cattle grazing initiated in Wildcat Watershed.

1823
Francisco Castro takes possession of Rancho San Pablo.

1830s
Cattle production has already exceeded regional consumption; international export of cattle products starts.

~1832
Wildcat Watershed has significantly responded to grazing.

1846
California comes under control of the United States Government in the Treaty of Guadalupe.

1849
Ellis Landing becomes shipping point for grain from Contra Costa County to San Francisco.

Approaching the mouth of Arroyo Chiquito (Wildcat Creek) from La Bahia de San Pablo in 1850, one would observe several changes. Sediment from recent erosion of San Pablo and Wildcat Creek has buried over 100 acres of marsh with a lobe of alluvial sediment. San Pablo Creek has filled its old bed that independently connected it to the bay. It captured and widened a small slough that connects to Wildcat Creek. Note the change in the boundary between the uplands and the marsh in Figures 24 and 26.

At the convenient juncture of Arroyo Chiquito, Arroyo Grande (San Pablo Creek), and the receiving marsh slough, an Embarcadero has been built, enabling transfer of cattle products to San Francisco and markets that are more distant. As we follow Wildcat Creek upstream across the flatlands, it passes just north of Juan Jose Castro's adobe, built with an unusual cellar which elevated the house 3.5 feet above ground, presumably to avoid flooding. Continuing upstream, we pass the original adobe, placed near the perennial laguna and built onto the earlier Mission Dolores ranch headquarters. Small gaps in the riparian forest are noted near the adobe, probably the first removal of riparian timber or signs of vegetation loss due to bank erosion.

The grasslands of the Alluvial Plain and Canyon - now grazed by cattle, sheep and horses - have undergone major changes in species composition and ecology, with deep-rooted perennials replaced by shallow-rooted annuals. The drought, which seemed to start at the time of the Spanish contact, has broken with the floods of 1832 (see page 9). Wildcat Creek is no longer referred to as Arroyo Seco.

After more than a decade during which the landscape was essentially abandoned, Rancho San Pablo is in full swing. Several thousand cattle graze the Alluvial Plain and the grassy hillsides of the Canyon. Despite the cattle, the area of brush and woodland has expanded in response to increased moisture conditions, greatly reduced fire frequency from lack of Indian burning practices and the fact that the cattle did not enter the watershed until 1817. We suggest that brush expansion on the western slope is most notable in areas of active or recent landslides.

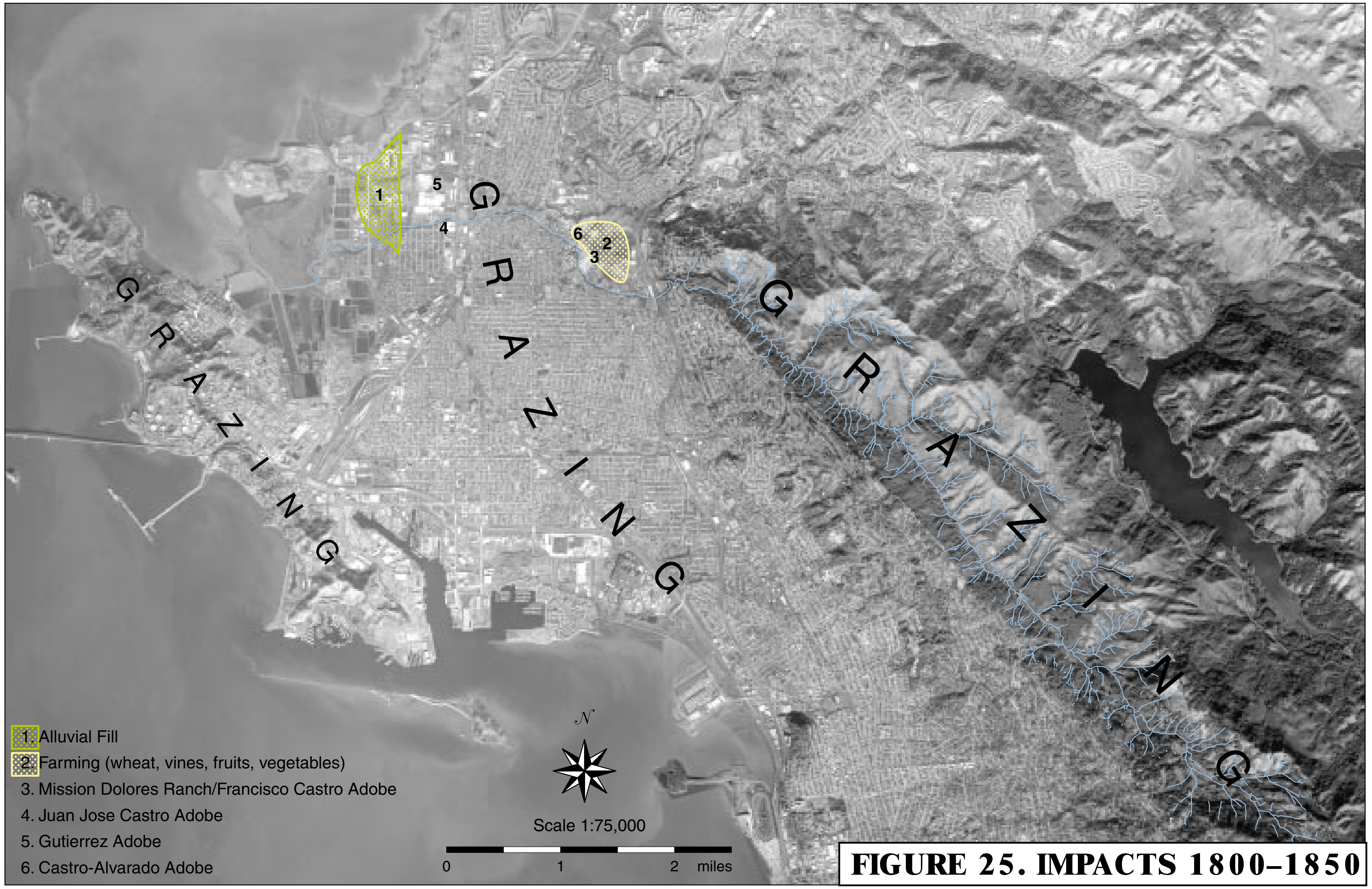


FIGURE 25. IMPACTS 1800–1850

Photo Source: NASA, 1996

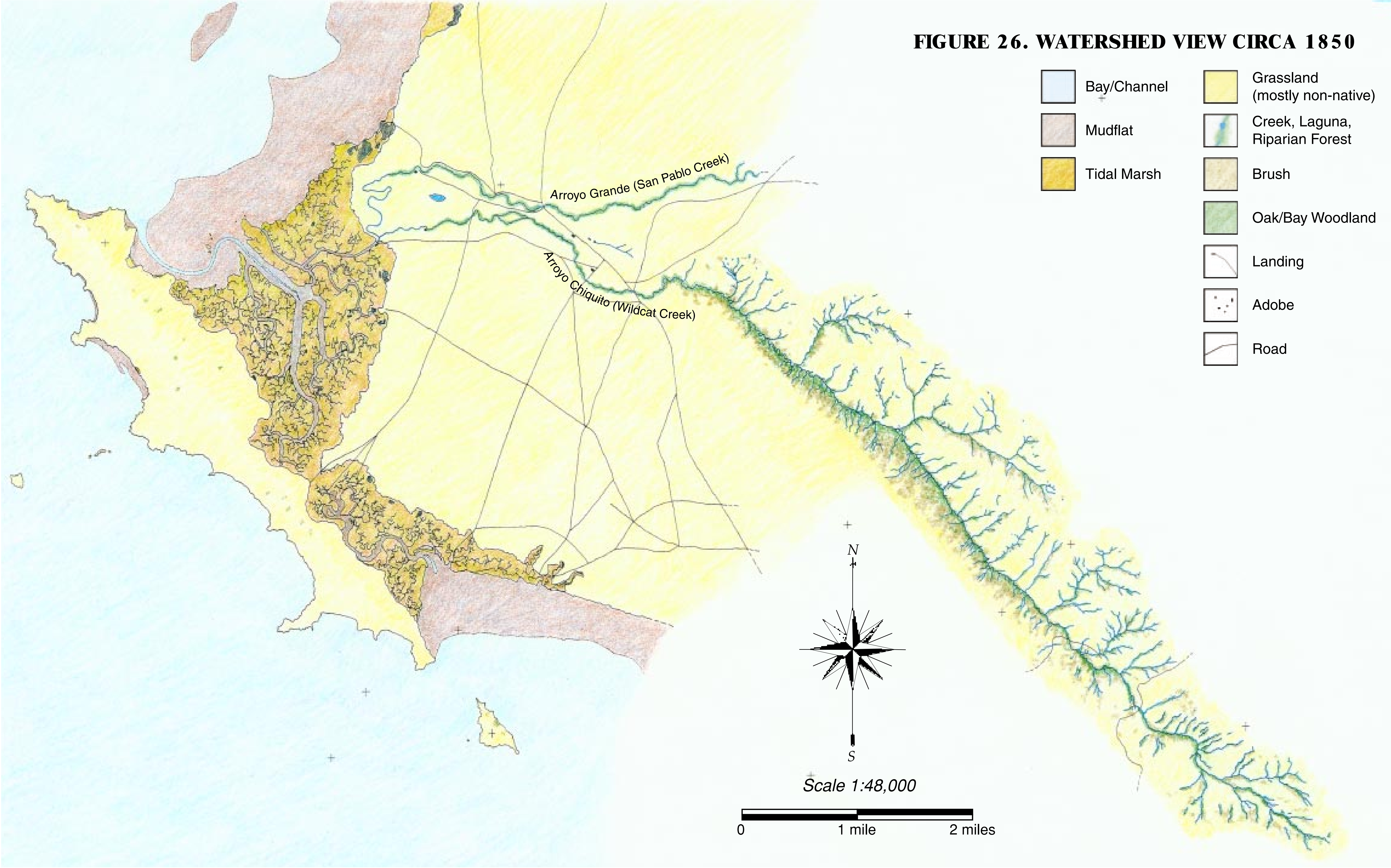
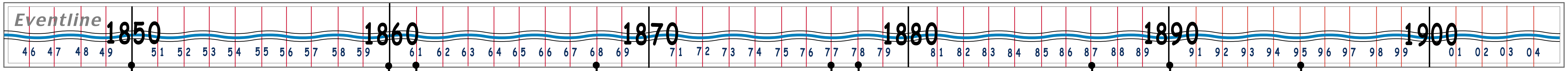


FIGURE 26. WATERSHED VIEW CIRCA 1850

Land Use History 1850-1900: Agricultural Landscape



1850s
American settlers begin farming fruits and vegetables along lower reaches of Wildcat Creek and San Pablo Creek.

1860s
Dikes were constructed around marshland bordering Wildcat Creek to the south.

1861
49" of annual rain falls; a steamship passes east of Potrero in the Bay Area.

1868
Large Hayward earthquake ocurs on Hayward Fault.

1877
Sportsman's Gazetteer reports "good catches" from trout fishing on Wildcat Creek.

1878
Southern Pacific Railroad crosses Wildcat Creek.

1887
California and Nevada Railroad was constructed across Wildcat Creek on upper Alluvial Plain.

1890
46" of annual rain falls in East Bay.

1890s
Lower reach of Wildcat Creek erodes its banks and the channel loses sinuosity.

~1895
San Pablo Creek abandons its connection to Wildcat Creek.

1895
MacDonald observes Potrero and adjacent plain and realizes its value as a deepwater port.

By 1900, further changes in the watershed are evident. Beginning at the Bay outlet of Wildcat Creek, we see a sequence of adjustments. The deepwater channel through the mudflats has shifted. It is now directed between an expanded marsh island and the accreting front edge of the small remnant marsh, away from the Potrero. In a successful attempt to extend his title from the Alluvial Plain to the Potrero, a local resident has constructed levees around the perimeter of the marshland. The levees significantly reduce tidal flow to the marsh, drying up the narrow point between the Potrero and the mainland.

Most of the wider sloughs in the remaining marsh have filled in, indicating the effects of reduced tidal prism and increased sediment load from the watershed. The creek's route through the marsh has been diverted to a more direct connection to Castro Slough near the landing, perhaps to help keep it open. The lower reach of the creek has new avulsion channels, probably as a result of increased sediment supply, and a mainstem channel that is less sinuous. The lobe of sediment at the bottom of the alluvial fan continues to expand onto the marsh. Most dramatically by 1895, San Pablo Creek has abandoned the meanders connecting it to Wildcat Creek and now flows directly into San Pablo Bay; 50 acres of willow have rapidly colonized the vicinity of the former channel. With the reduction of tidal prism, the riparian corridor along Wildcat Creek rapidly extends nearly a mile downstream.

On the Alluvial Plain, farming replaces grazing in many areas, especially along the creek. San Pablo City Hall is located near the original adobe, and the first two railroad bridges across the creek have been built.

In the Canyon, brush and woodland have slowly continued to expand, with a rapid increase on the west side due to removal of dairy cattle and increased landslide activity. More roads lead to the Canyon and along parts of the creek, but there are still substantial gaps with no roads. Good trout fishing on Wildcat Creek is noted in the national 1877 Sportsman's Gazetteer.

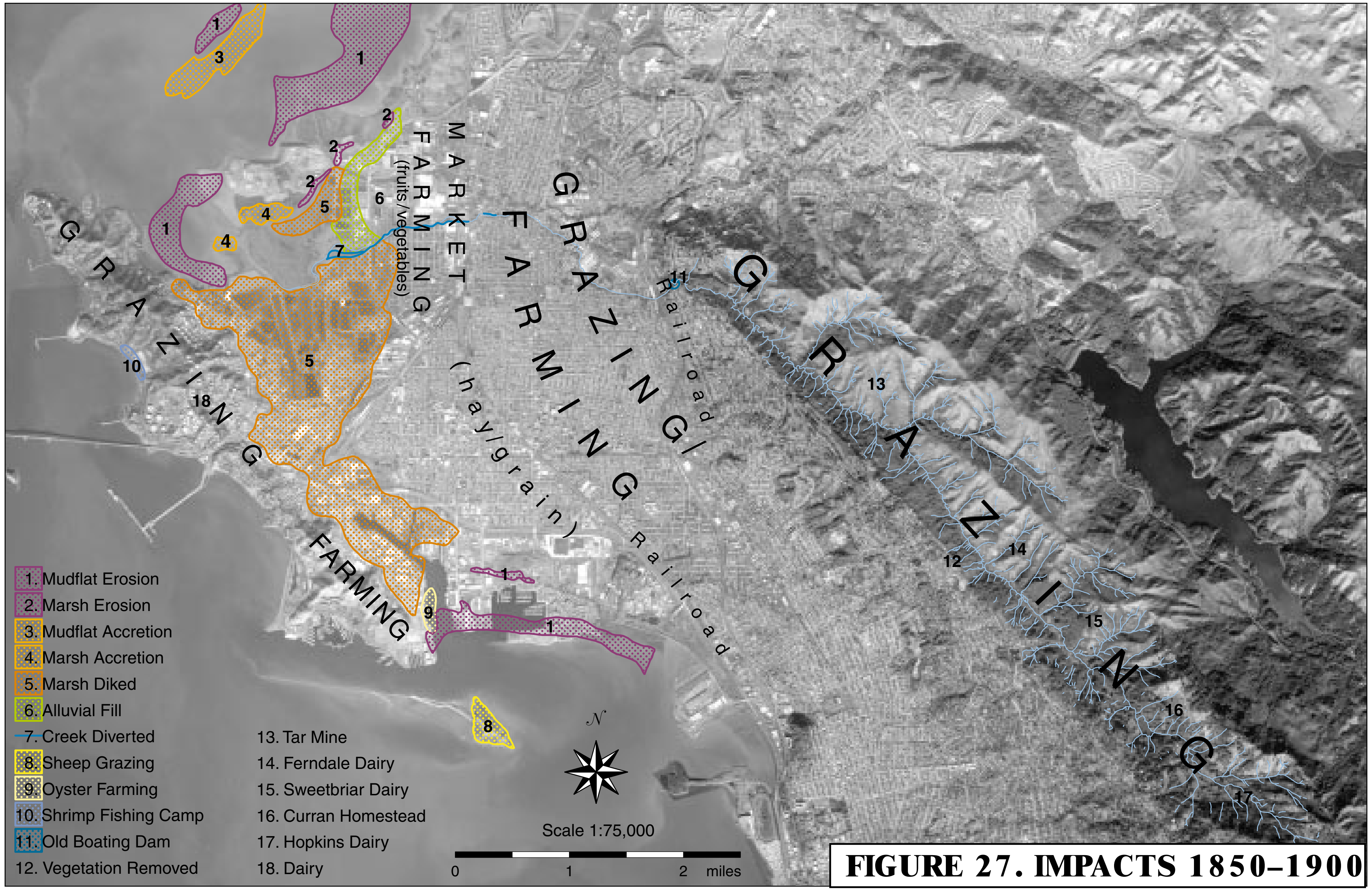
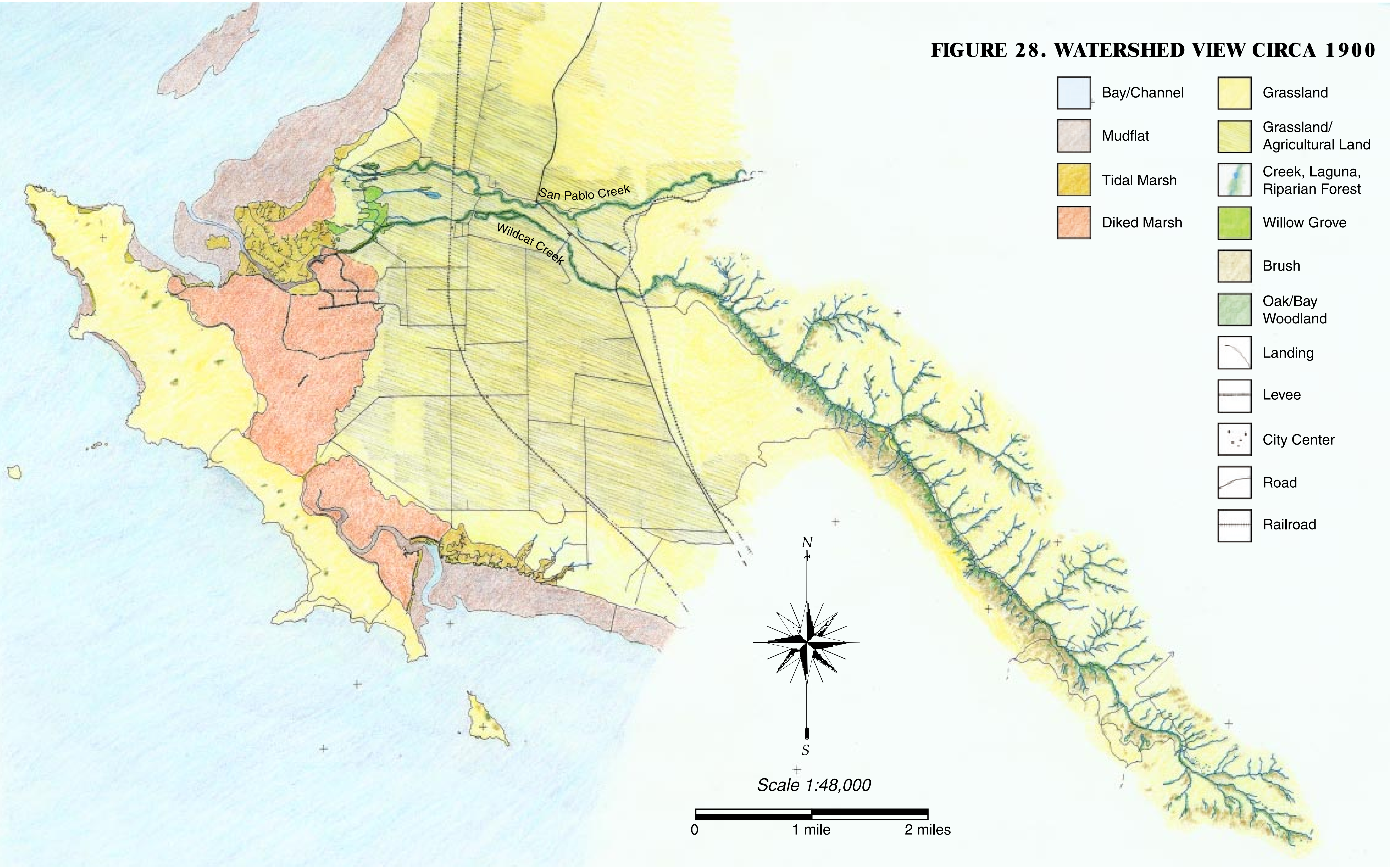


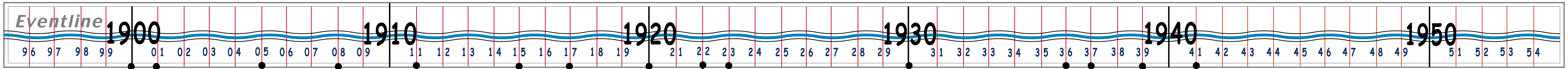
FIGURE 27. IMPACTS 1850–1900

Photo Source: NASA, 1996

FIGURE 28. WATERSHED VIEW CIRCA 1900



Land Use History 1900-1950: Urban Landscape



1900
Santa Fe Railroad crosses Wildcat Creek, establishing western continental terminus on Potrero.

1900-1920s
Hundreds of wells were drilled in alluvial fan.

1901
Standard Oil purchases 150 acres of marshland to establish west-coast refinery. First electricity and telephone come to area.

1905
City of Richmond incorporated.

1908
First paved roads were constructed in the area.

1911
Eucalyptus plantations and Monterey Pines were started in Wildcat Canyon.

1915
Hutchinson describes "speckled trout" in Wildcat Creek.

1917-21
San Pablo Dam and Wildcat tunnel shaft constructed.

1920s
Flower nurseries were developed on lower Wildcat Creek .

1919-1922
Wildcat Dam (Jewel Lake) was constructed and its flow was diverted for drinking water.

1923
Wildfire burns ~300 acres of upper watershed.

1930s
Historic WPA Stone Walls were constructed in Alvarado Park.

1936
Tilden Regional Park was created; most of Upper Watershed was protected from residential development, fire suppression policy was initiated, and cattle removed from Tilden.

1937-38
Lake Anza Dam was completed.

1939
Golf Course was constructed along Wildcat Creek in Upper Wildcat Canyon.

1941-45
90,000 workers build 727 Liberty Ships at Kaiser Shipyards for World War II.

Viewing Wildcat Creek from San Pablo Bay on a low tide in 1950, one would see vastly expanded mudflats that cover nearly twice their 1900 aerial extent. Most of the diked baylands of the previous period have been filled; yet, ironically, the area of fully-tidal marshlands has increased. Where there is no fill, the tides have washed away nearly all traces of the earlier levees, and over 100 acres of new marsh has aggraded at the mouth of San Pablo Creek. The entry to Wildcat Creek now follows a deepwater shipping channel dredged through the marsh to serve the oil refinery located on the Potrero and former marshland. Turning east towards Wildcat Creek from the shipping channel, the slough passes a remnant levee and row of fishing shacks.

On the Alluvial Plain, agriculture has expanded bayward to use the new alluvial sediment deposited over the salt marsh, and the Creek channel is now straightened below the railroad tracks. A large gap in riparian forest has appeared between 23rd and Church Streets. Except for along the lowest reaches of Wildcat and San Pablo Creeks, urban development has replaced nearly all of the earlier farms and ranches. Most of this change has taken place during a short period; about two-thirds of the development occurred during 1940-1945. Along with the housing, an urban forest has begun to grow.

Activity in the Canyon has also been intense, leading to numerous new trails and roads. Large plantations of eucalyptus or Monterey pine have been planted, and the dams for Jewel Lake and Lake Anza have been constructed. With the creation of Tilden Regional Park, grazing practices have been discontinued in the Upper Canyon. Fires, which may have been common along the ridge of the Canyon, are now actively suppressed. While most of the Upper Canyon is now protected from urban development, some housing, and associated urban trees, have entered the southwestern edge of the Canyon.

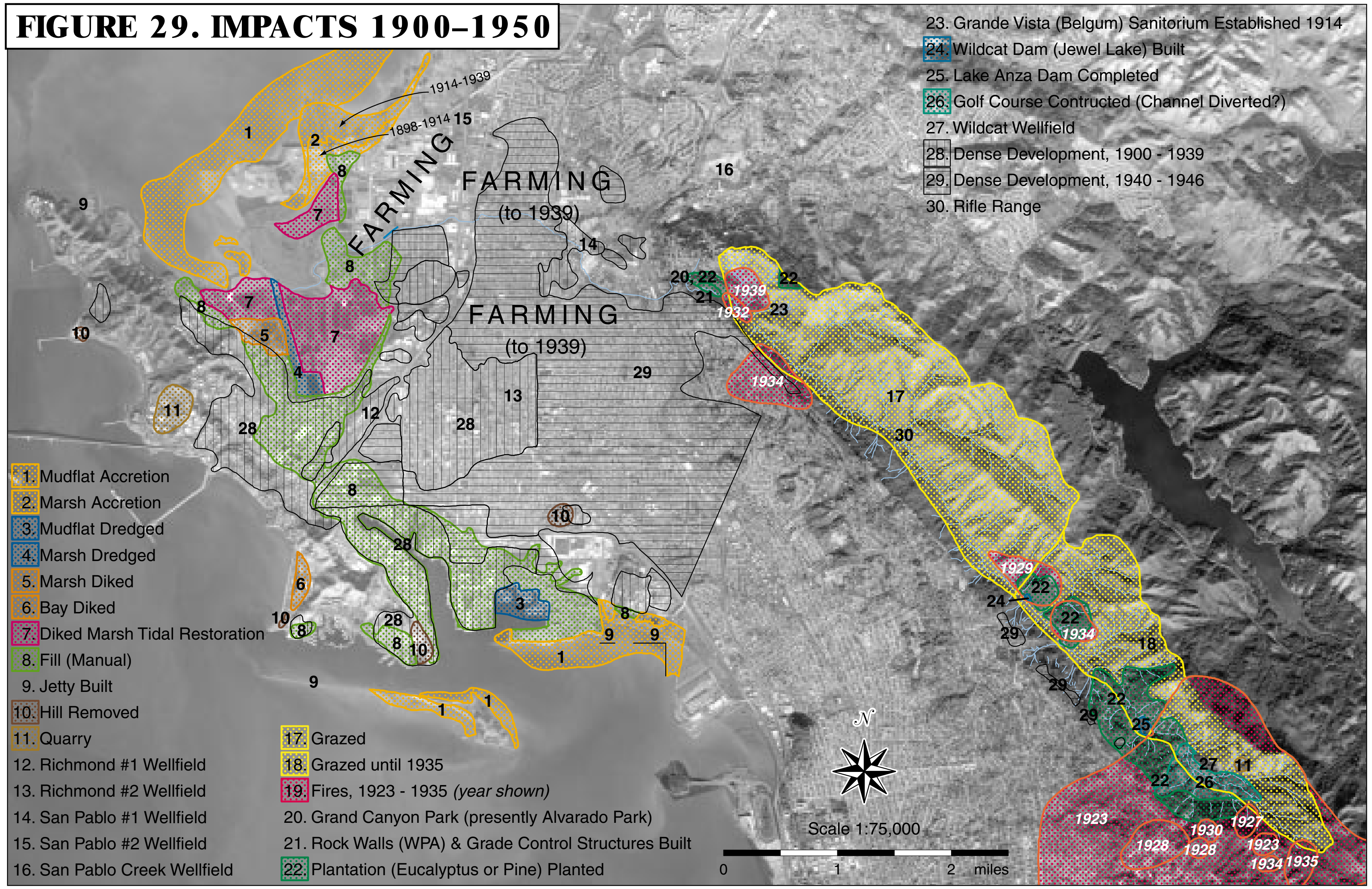
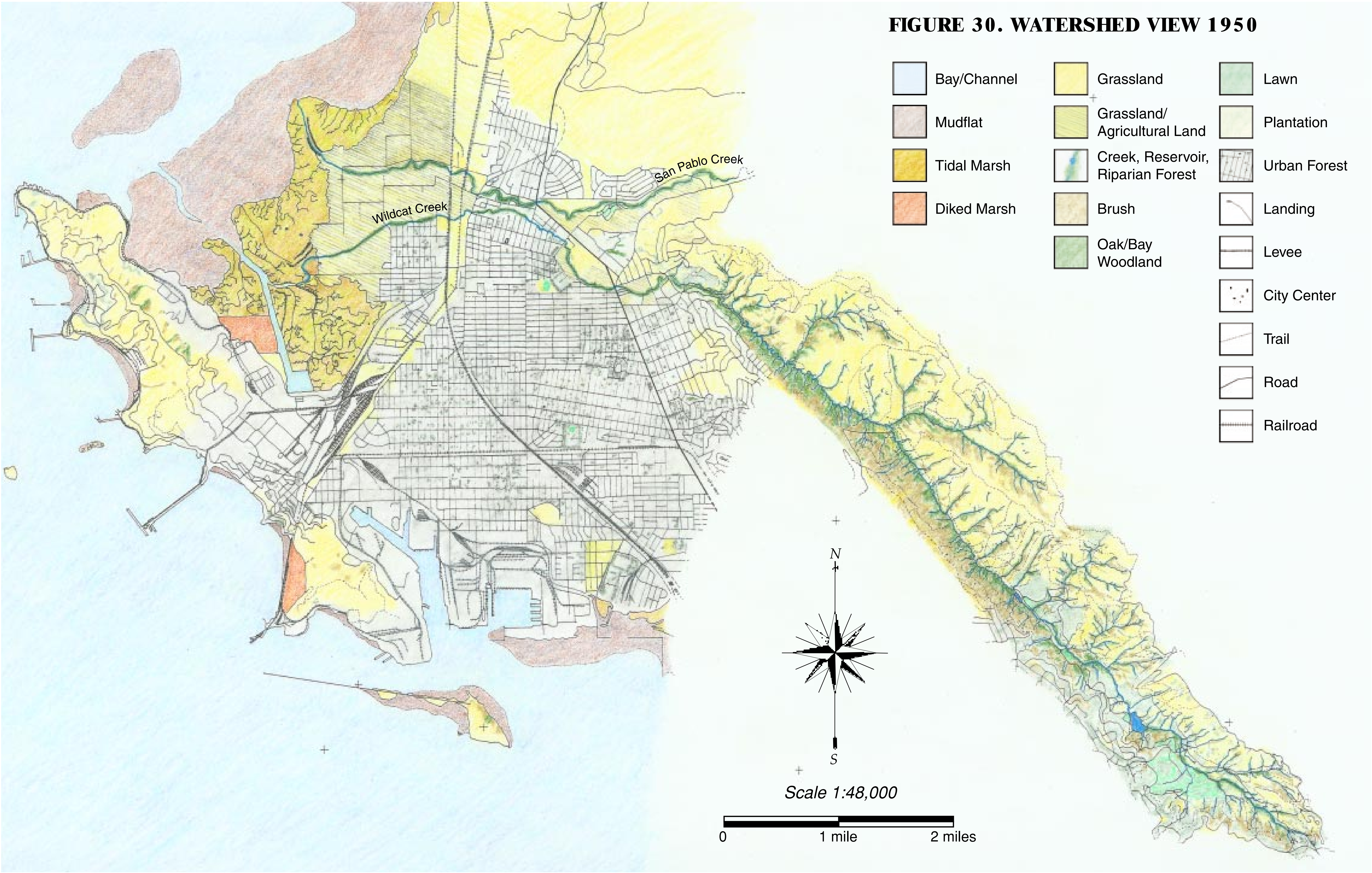


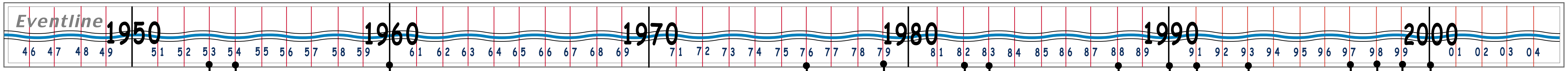
FIGURE 29. IMPACTS 1900–1950

Photo Source: NASA, 1996

FIGURE 30. WATERSHED VIEW 1950



Land Use History 1950–2000: Modern Landscape



1953
West Contra Costa County Landfill was constructed in baylands between Wildcat Creek and San Pablo Creek.

1954-57
Interstate Highway 80 is constructed across Wildcat Creek.

1960s
Townhouse development is planned in Lower Wildcat Canyon; project later abandoned.

1976
Wildcat Canyon Regional Park is created.

1979
Fuel Break Project begins in Upper Canyon and Middle Canyon

1982
47" of rain falls.

1983
Native rainbow trout are reintroduced in Wildcat Canyon.

1988
Wildcat Creek Flood Control Project completed. Project inhibits fish migration.

1990s
Wildcat Marsh Restoration Project conducted.

1991
Cattle fenced from mainstem of Wildcat Creek, in Wildcat Canyon Regional Preserve.

1993
Restoration project on Wildcat Creek at Alvarado Park.

1997
47" of rain.

1998
46" of rain.

1999
Revision of restoration project at Alvarado Park.

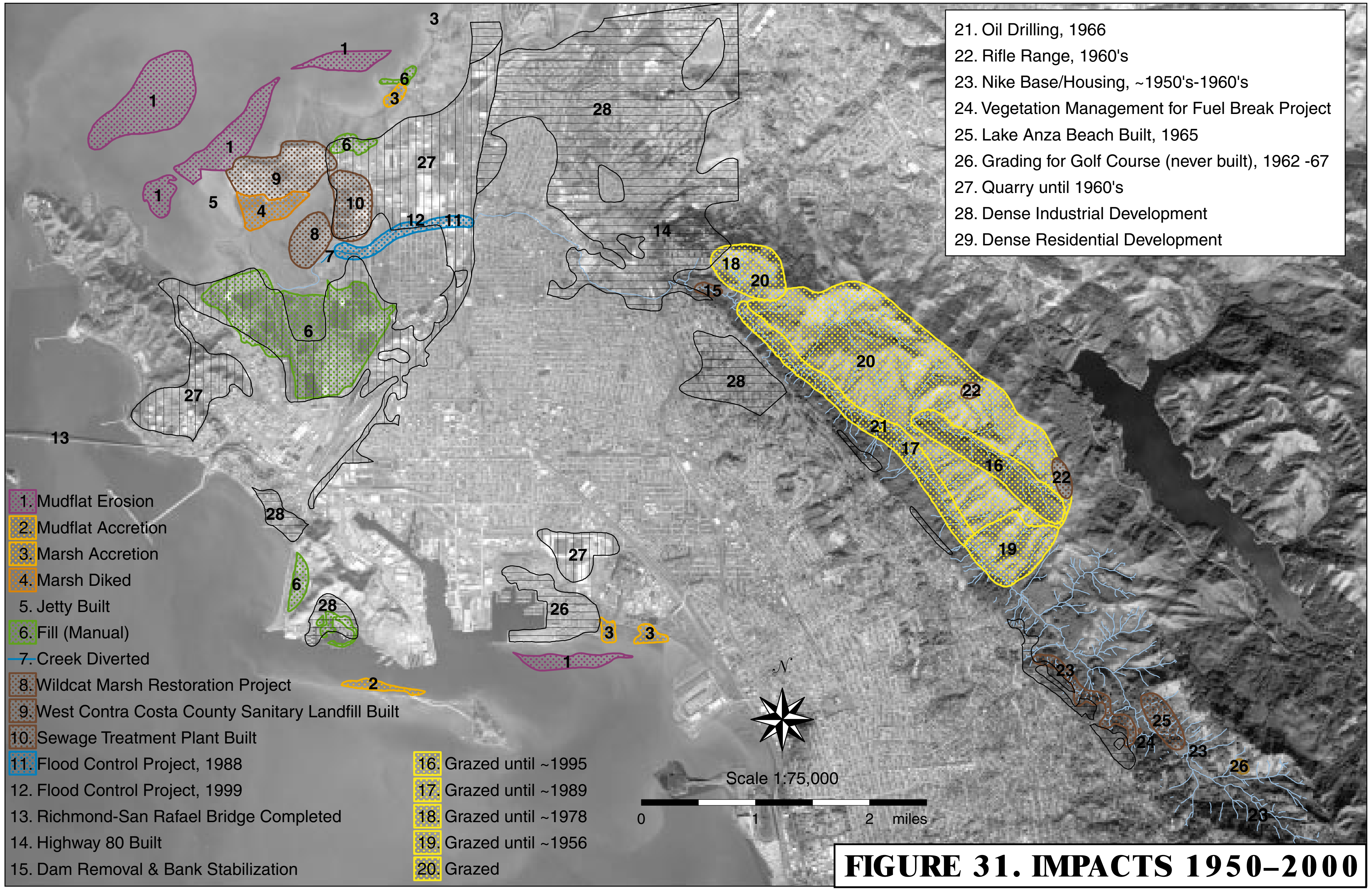
1999-2000
Army Corps proposed redesign of Wildcat Creek Flood Control Project to allow fish passage.

During the period 1950–2000, we observe a large reduction in mudflat acreage because of both erosion and filling. The shipping channel at the mouth of Wildcat Creek has been enclosed, along with much of the remaining marshland, to store oil production materials.

The route of the creek into the marsh has been changed through recent flood control projects that include a sediment catchment basin on Wildcat Creek. Immediately adjacent to Wildcat Creek lies the sole remnant of the earlier flower nurseries on the Wildcat Creek bottomlands. Industrial, residential and commercial development has covered most of the remaining flatlands to the north and northeast. The urban forest has become quite substantial in the older parts of town. A local sewage treatment plant and garbage landfill has filled portions of the marsh. Little or no accretion of marshland has occurred near Wildcat Creek or San Pablo Creek during this period.

New gaps in the riparian forest along the Alluvial Plain are evident, near Highway 80 for example, but it should be noted that some earlier gaps have filled in with new vegetation. Major changes occur along the lower sections of Wildcat Creek when the 1988 Flood Control Project realigned, straightened, and shortened the creek downstream of the Southern Pacific Railroad crossing. Sections of the riparian corridor were lost and the channel was configured into a wide trapezoid, designed to contain the assumed 100-year flood. A sediment catchment basin was constructed at the upstream end of the Project.

In the Canyon, the area of open grassland has continued to decrease as brush and woodland expands. The growth of new brushland is noticeable both in the upper, ungrazed part of the Canyon, and in some still-grazed areas, such as Havey Canyon. Similar changes can be seen in the undeveloped parts of the Potrero. With the addition of more housing in the Upper Canyon and concomitant fire concerns, areas along the western urban boundary have been set aside for intensive vegetation management.



21. Oil Drilling, 1966
22. Rifle Range, 1960's
23. Nike Base/Housing, ~1950's-1960's
24. Vegetation Management for Fuel Break Project
25. Lake Anza Beach Built, 1965
26. Grading for Golf Course (never built), 1962 -67
27. Quarry until 1960's
28. Dense Industrial Development
29. Dense Residential Development

1. Mudflat Erosion
2. Mudflat Accretion
3. Marsh Accretion
4. Marsh Diked
5. Jetty Built
6. Fill (Manual)
7. Creek Diverted
8. Wildcat Marsh Restoration Project
9. West Contra Costa County Sanitary Landfill Built
10. Sewage Treatment Plant Built
11. Flood Control Project, 1988
12. Flood Control Project, 1999
13. Richmond-San Rafael Bridge Completed
14. Highway 80 Built
15. Dam Removal & Bank Stabilization
16. Grazed until ~1995
17. Grazed until ~1989
18. Grazed until ~1978
19. Grazed until ~1956
20. Grazed

FIGURE 31. IMPACTS 1950–2000

Photo Source: NASA, 1996

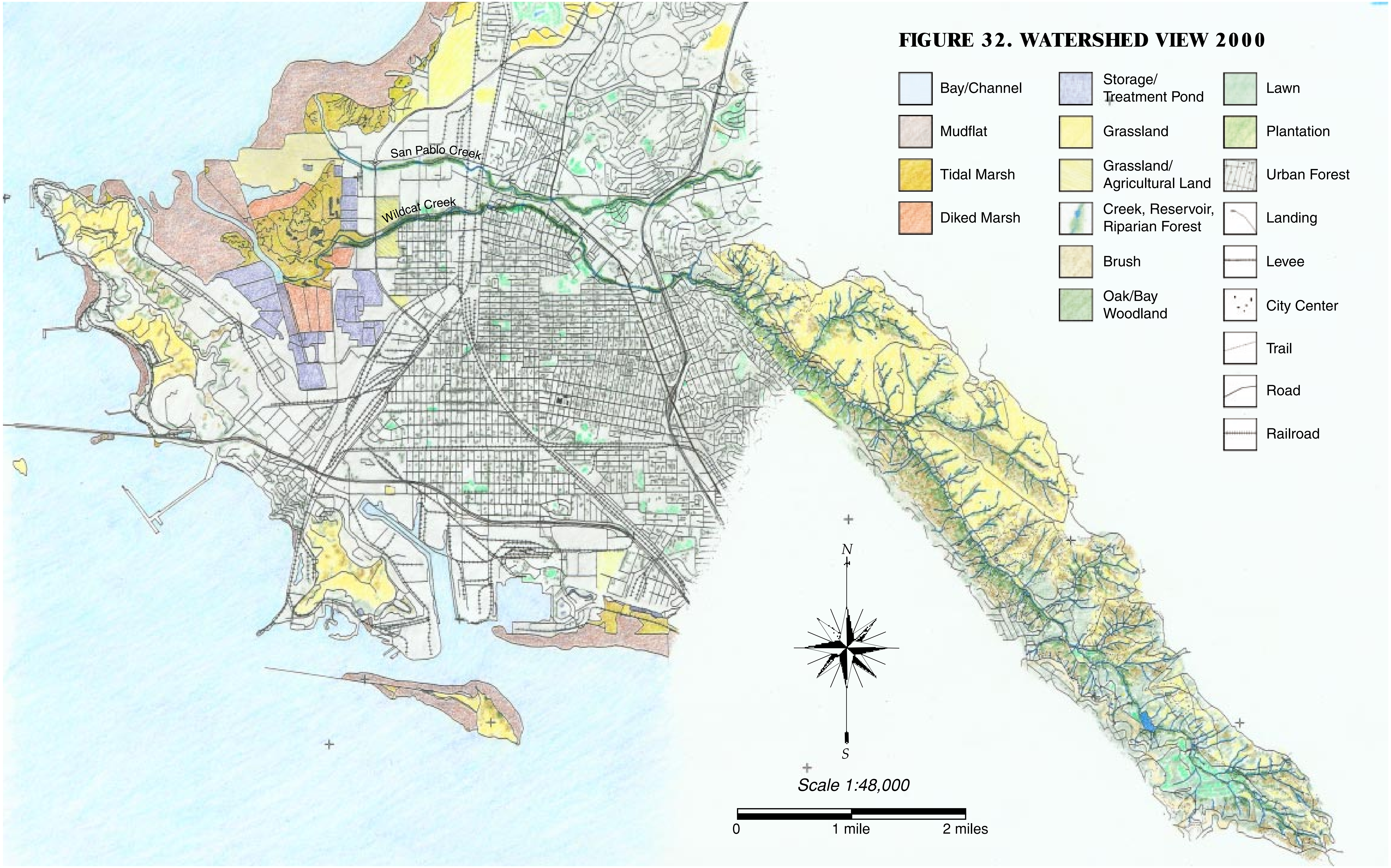


FIGURE 32. WATERSHED VIEW 2000

Figure 40

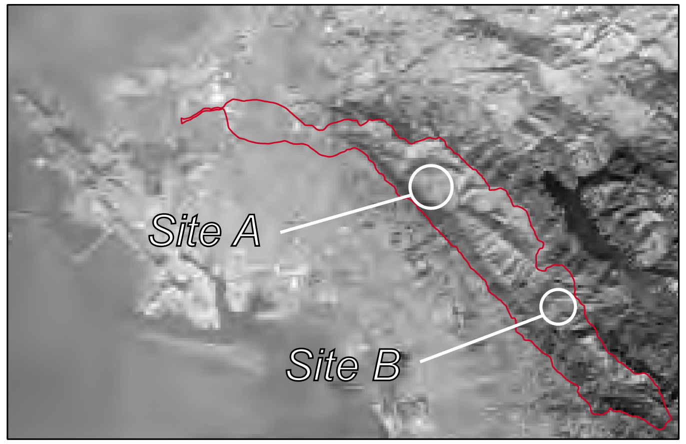


Photo Source:NASA, 1996

cattle grazing (Figure 41, A and B). Each photo pair shows landsliding at two dates, 1939 and 1999. Site A shows areas that have been grazed continuously since about 1817. Site B shows an area that was grazed from 1817 to 1939. We consider the geology of both sites to be Orinda Formation.

In both areas, there was a greater number and extent of active landslides in 1999 than in 1939. This might relate to the generally wetter conditions that have existed in the region since the late 1930s (page 9). However, the increase in landslide activity since 1939 was greater in the area that has been continuously grazed. Field inspections revealed that gullies and natural channels in this area have continued to incise and erode headward, removing the lateral hillslope support. This area also has many more slides that have merged since 1939 to form complex slides.

There has been a large increase in brush in the area of Site B following the removal of cattle. The cessation of grazing and continued fire suppression has allowed the encroachment of brush into the annual grasslands, with a concomitant increase in rainfall interception, rooting depth, root density, and rate of evapotranspiration. In the non-urbanized grass and brushlands, these changes have locally reduced shallow landslide activity and fluvial incision.

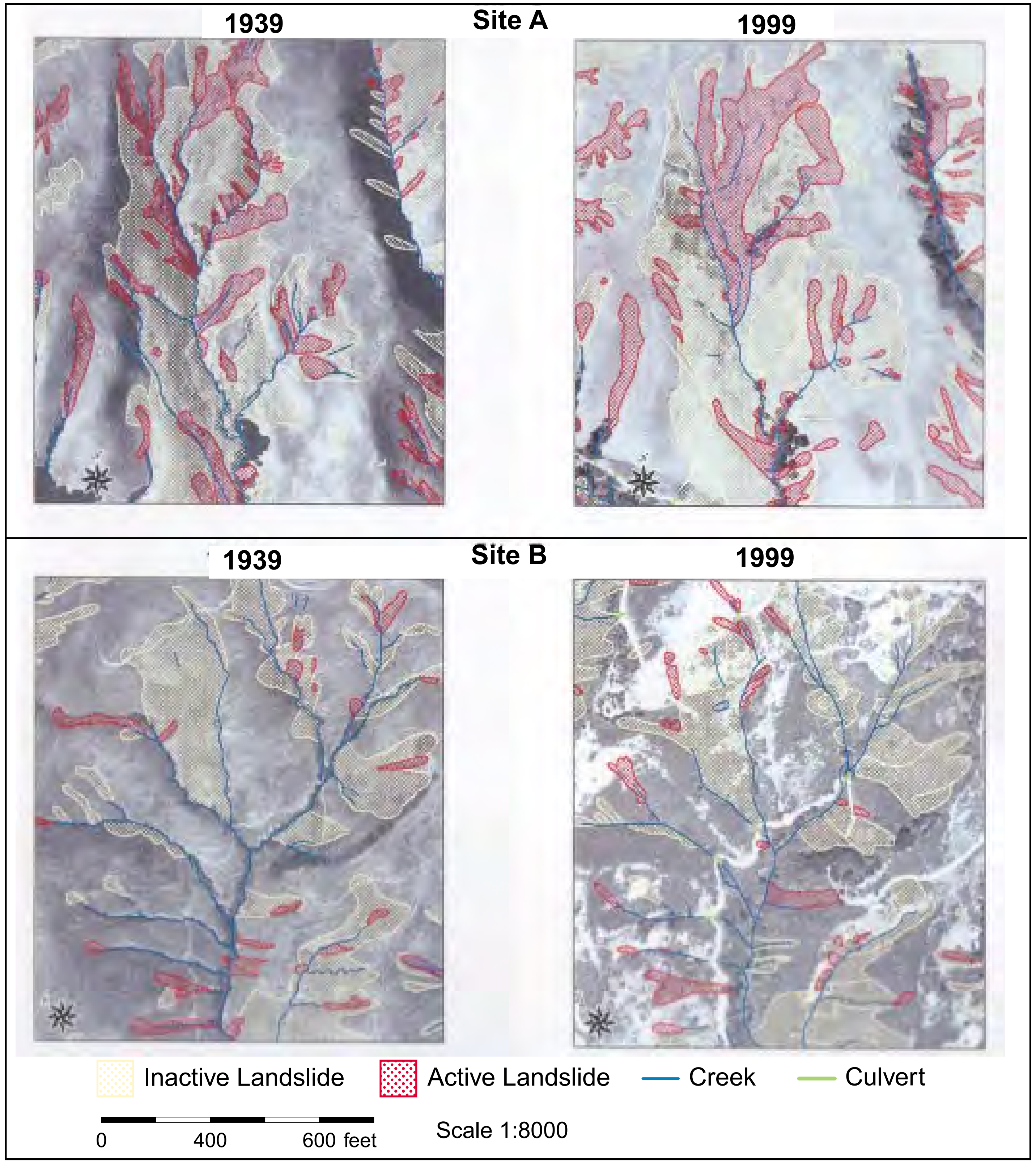
CLIMATIC EFFECTS

Examples of climatic control on earthflow activity are apparent near Point A (Figure 39). The activity of these landslides has been observed in the field by Laurel Collins (SFEI) for the last two decades. Analyses of historical aerial photos confirm the field observations.

Several very large, deep-seated earthflows have substantially increased in activity twice since the early 1980s. These slides have been most active during years of precipitation much greater than normal. Wet years of 1981-82 (150% of normal rainfall) and the 1997-98 ENSO (200% of normal rainfall) events reactivated very large deep-seated earthflows in this area. Some of the slides may not have previously moved for many centuries. One large earthflow severely damaged several homes situated at the ancient crown scarp. More landslide activity was actually associated with the earlier 1982-83 wet season than the later ENSO events of 1983 and 1998 because much of the rainfall occurred during a single storm that was very intense. Many debris slides also occurred at this time.

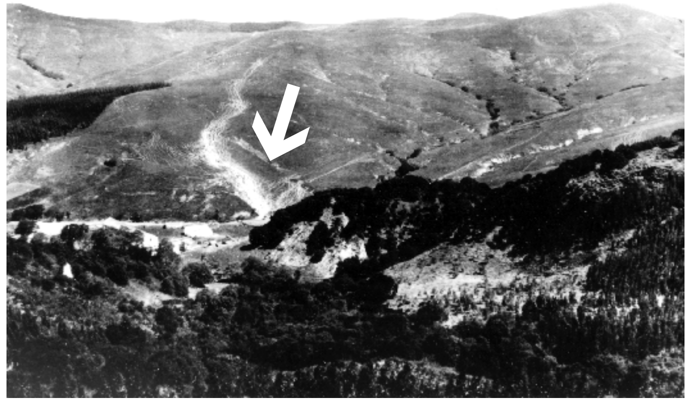
(Photo 17) February 1983, compound landsliding in the same area shown to the right, Site A.

Figure 41. Landslide Comparisons



Erosion That Could Not be Measured

A variety of historical sources of sediment could not be included in our long-term estimates of sediment supply. These are mostly localized sources relating to past land use practices. In most cases, the sources would have resulted in pulses of sediment that affected the short-term supply, more than the long-term average supply. Dairy ranches comprised an important exception becasue they were intensive operations that lasted many decades. Although not pictured, another source of sediment that we could not estimate was simply the amount that is generated by raindrop inpact and overland flow over the bare surfaces of soil with sparse thatch cover. How much sediment is entrained and whether it is delivered to the channel could not be ascertained within the scope of this project.



(Photo 18) Sweet Briar dairy in the Upper Canyon Segment, circa 1900. Consider the amount of sediment production from historic dairy ranches. The arrow indicates the extensive cattle trail network that has been gullied by surface runoff. Also observe the erosion scars occurring along the incising channels. Note the minimal riparian vegetation along the distant drainages. Source: photo from Louis Stein Collection, East Bay Regional Park District.

(Photo 19) Construction underway at Wildcat Reservoir (Jewel Lake) 1919. Consider the amount of sediment production and downstream impacts from these disturbed soils. Channel incision downstream of the dam and subsequent sediment production has been ongoing. Source: East Bay Regional Park District.

(Photo 20) Construction site erosion in disturbed soils. Soils that have been mechanically disturbed are more susceptible to erosion than soils that are bare but still have small rootlets intact. (Booker et al. 1993) Such a situation may occur after burning, grazing or application of herbicides.

(Photo 21) An example of rill erosion in soils prepared for sod in Alvarado Park. Consider the amount of sediment production during preparation of the Tilden golf course during the late 1930s.

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Local Short-Term Channel Changes

The four photos below illustrate typical changes in mainstem channel conditions within the Canyon over a 5 yr period from 1994 through 1999. Each photo is looking downstream from approximately the same left bank position. Peak annual flows had been moderately low for 7 years preceding photo 22 for 1994. Flows greater than 1000 cfs ocurred during 1995, 1996, 1997, and 1998.

(Photo 22) (a) August 1994. A tree has fallen across the channel during the dry season. The bed is mostly coarse cobble due to a reduced supply of fine sediment during the previous 7 yrs. The banks are sharp-edged. The bed has been incising since 1986.(b) April 1995. Two significant flood flows occurred during January and March. The peak flow was the second highest in 33 yrs. Heavy rains activated landslides, providing large woody debris that were mobilized by floods. A debris jam has formed at the fallen tree (see photo a). The dominant bed material changed from cobble to sand. A gravel bar 4 ft high formed behind the jam. The standing alders are freshly scarred from being rammed by floating debris (see trunk left foreground).

(Photo 23) (b) April 1995. Two significant flood flows occurred during January and March. The peak flow was the second highest in 33 yrs. Heavy rains activated landslides, providing large woody debris that was mobilized by floods. A debris jam has formed at the fallen tree (see photo 22). The dominant bed material changed from cobble to sand. A gravel bar 4 ft high formed behind the jam. The standing alders are freshly scarred from being rammed by floating debris (see trunk left foreground).

(Photo 24) (c) January 1997. The debris jam has collected more woody debris, but the channel has cut around the jam on the left, releasing the sediment that had deposited behind the jam. Much of the bar has eroded away. Sand from local landslides is beginning to cover remnants of the bar (see bar top left foreground).

(Photo 25) (d) June 1999. The debris jam has almost completely deteriorated. The gravel bar and its sandy cover have mostly washed away. The bed material is generally finer and the bed is higher than in 1994 (see photo 22). The banks are not as steep. The large alder (see left foreground photo 23) has been broken at its trunk and washed downstream.

Tributaries and Hillslopes

We developed a diagnostic tool for identifying and stratifying different sources of sediment and their causes in tributaries and hillslopes. The tool is called the Hillslope and Tributary Decision Tree (Figure 42). It defines sediment by sources and assigns it to natural, land use-related or uncertain categories of cause.

This Decision Tree was used in the hills and tributaries of the Lower Canyon Segment where we performed void measurements. A similar decision tree was used for the mainstem analysis of Wildcat Creek.

(Photo 26) An incised tributary channel in bedrock that drains the east-side grasslands.

We were conservative in attributing local erosion to land use. For example, there were situations where we could certainly relate landslide activity to a road cut or bed incision, but in the latter case we could not be certain that the flow causing the stream incision that initiated the slide was related to land use. In such situations, we did not rate the landslide as land use-related. Good use of this tool requires much discussion in the field among trained personnel.

Not all tributary erosion could be measured in the field (see page 41 and Table 6). Many channels on the western side of Wildcat Creek were covered by impenetrable vegetation. We were able to measure directly the conditions throughout 34% of the total tributary length of the Lower Canyon. For 19% of the field measured channels, we estimated conditions by extrapolating for short distances between points of access. We did not visit 47% of drainage network, so we conservatively estimated the amount of incision by viewing stereo photos and assuming similar conditions to nearby channels. The Middle and Upper Canyon Segments were not measured in this way because we decided to analyze sediment deposition in their reservoirs as an alternative for comparing yield.

The completed Decision Tree shows the long-term sediment supply rates of various sources in the Lower Canyon. The total rate of supply form field and map measurement techniques is 1,143 cu yd/yr. To estimate channel incision rates, we had to identify a time when incision started. Different starting times were used for different causes of incision. For example, incision of the channel downstream of Jewel Lake started after the dam was constructed in 1922. We decided that incision and channel extension caused by cattle began in about 1832, after the local herds were well established and the drought of the early 1800s had passed. We measured landslide activity since 1947 (the date of the earliest photographic record that was of sufficient quality to assess landsliding). This was the only way we could make reasonable estimates of long-term sediment supply rates as influenced by the settlement of non-native peoples.

The total amount of land use-related tributary incision is equal to the sum of the amounts that are directly attributed to various land uses plus the amount that is in excess of natural tectonically driven incision. We estimated the amount of downcutting that could be caused by tectonic uplift on the east side of the Hayward Fault (Figure 36). The expected incision was determined as the product of the bed surface area of the Lower Canyon tributary network and the 0.27 ft depth of incision that would occur over 167 ys assuming an uplift rate of 0.02 in/yr (0.5 mm/yr). We computed a tectonically driven sediment supply rate of about 31 cu yd/yr from tributary incision. The sums of the rates of various types of tributary incision that are not directly related to land uses are 402 cu yd/yr. If we subtract the tectonically driven rate from the total rate of measured incision, we have 372 cu yd/yr more than the natural tectonically driven supply. We suggest that this supply is also generated from land use activities, either indirectly or in a way that can no longer be measured.

Table 7 shows 11 categories of sediment sources based upon field measurements, calculations, and published studies and methods. Rates from just our field measurements are reported in the Hillslope and Tributary Decision Tree (Figure 42). The Decision Tree shows that the bulk of measured sediment comes from landslides (591 cu yd/yr) for which we cannot distinguish natural versus indirect effects of land use as a causative factor.

Table 6

Percent of Total Length of Tributaries Measured in Lower Canyon Segment

	Lower Canyon Segment	Eastern Side of Lower Canyon Segment
Field measured	34%	41%
Field extrapolated	19%	23%
Estimated from aerial photos	47%	36%

Table 7

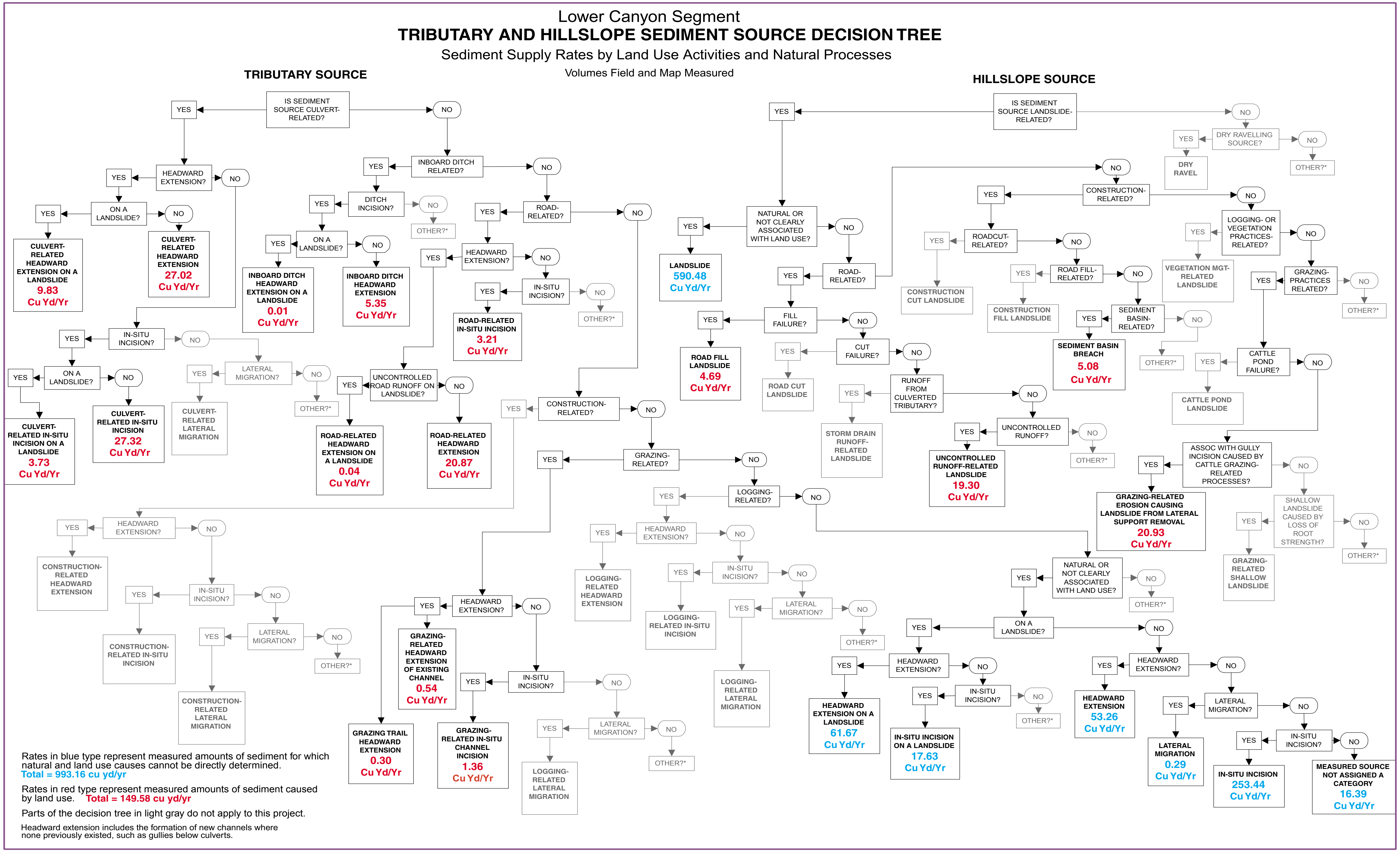
Calculated and Measured Rates of Sediment Supply from Wildcat Canyon Hillslope and Tributary Sources, Lower Canyon Segment Applicable to the Last 167 Years

Sources	cu yd/yr	Percent of Total
Field and map measured erosion directly related to land use or landslides	**149.6**	**4.1**
Grazing-related inner gorge slides and incision (from Decision Tree)	23.1	0.6
Culvert-related slides and incision (from Decision Tree)	67.9	1.9
Road-related slides and incision (from Decision Tree)	53.5	1.5
Construction-related (from Decision Tree)	5.1	0.1
Field and map measured landsliding natural and/or indirectly related to land use (from Decision Tree)	**590.5**	**16.3**
Field and map measured tributary incision, natural and/or indirectly related to land use (from Decision Tree)	**402.3**	**11.1**
Bed incision driven by tectonics (uplift rate = 0.5 mm/yr) (considered natural)	30.7	0.8
Bed incision in excess of the natural tectonic driven rate (402.3 - 30.7, natural and/or indirectly related to land use of which cattle grazing may account for at least 238.2 cu yd/yr; the remaining 133.4 cu yd/yr is from other combined indirect land use effects)	371.6	10.2
Lateral migration of tributaries (from Decision Tree)	**0.3**	**< 0.1**
Calculated	**2,488.6**	**168.5**
Dirt road tread surface erosion (WA State Forest Practices Method 1994)	187.6	5.2
Soil creep (WA State Forest Practices 1994) (soil creep rate = 5 mm/yr) (mean depth = 3 ft)	545.7	15.0
Landslide creep for active slides bordering channels (landslide creep rate = 30 mm/yr) (assume only 80% are earthflows) (mean depth = 3 ft)	581.3	16.0
Soil lowering (assume all goes to channel as suspended sediment) (0.05 mm/yr)	1,174.0	32.3
Totals	**3,631.3**	**100.0%**

When we incorporate calculations of sediment supply for erosion that we could not directly measure, the supply from landslides that includes slide creep and man-related causes exceeds 1,300 cu yd/yr. This is slightly higher than the calculated 1,174 cu yd/yr general lowering rate of the soil surface by raindrop impact and overland flow on the hillsides. We have used a conservative natural soil lowering rate of 0.05 mm/yr (verbal communication William Dietrich, Department of Geology and Geophysics, UC Berkeley) to try to account for the pervasive supply of sediment that cannot be measured in a short-term study. The proportion that actually is delivered to the channel is unclear, yet our estimate may be conservative if we consider the amount of accelerated supply from all the historical construction activities.

(Photo 27) The head of an extending channel in the east-side grasslands.

Figure 42



Lower Canyon Segment

TRIBUTARY AND HILLSLOPE SEDIMENT SOURCE DECISION TREE

Sediment Supply Rates by Land Use Activities and Natural Processes

Volumes Field and Map Measured

Rates in blue type represent measured amounts of sediment for which natural and land use causes cannot be directly determined. Total = 993.16 cu yd/yr

Rates in red type represent measured amounts of sediment caused by land use. Total = 149.58 cu yd/yr

Parts of the decision tree in light gray do not apply to this project.

Headward extension includes the formation of new channels where none previously existed, such as gullies below culverts.

Example Subwatersheds

We used our intensive surveys of tributaries and hillslopes in the Lower Canyon Segment to examine the possible effects of slope and drainage area on sediment supply. We chose to focus on the subwatersheds of the northeast side of the Lower Canyon because of similar geology, vegetation, and land use history. Cattle grazing has been the predominant land use, although the basins differ in extent of time grazed. Other than some minor ranch roads, few additional impacts were observed. Impervious surfaces did not exist.

Figure 43 shows the boundaries of 24 subwatersheds, labeled A through X. Subwatersheds H through O comprise the Havey Creek tributary. The boundaries for subwatersheds A-G, P-X, and Havey Creek stop just upstream of the culvert inlets that cross under the main dirt road that parallels Wildcat Creek that we refer to as Wildcat Trail. Cattle were introduced into the entire area in1817, but were removed from subwatersheds A, B, and C in 1978, from W and X since 1956, and from a small portion of O and J in the mid-1990s. All other subwatersheds have been grazed continuously at varying intensities At least two dairies were located in the Canyon, one in the Lower Canyon at the base of watershed V in the Subwatershed Map (Figure 43).

Figure 44 shows the distribution of hillsides among slope classes for each of the subwatersheds. Subwatersheds A, M, N, and O are distinguished by having large areas that are not steep. Much of the Havey Creek watershed is less steep than the neighboring subwatersheds.

Figure 44

Subwatershed Slope Classes

Values below watershed names represent the average percent area for the slope classes.

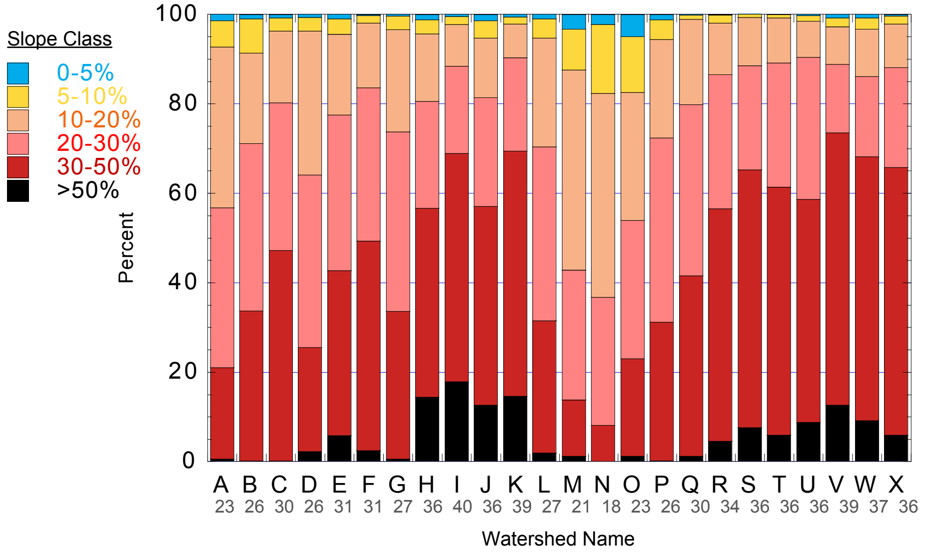



FIGURE 43. WILDCAT SUBWATERSHED MAP

Figure 45

Percent Increase in Subwatershed Drainage Density from ~1830 to 1999

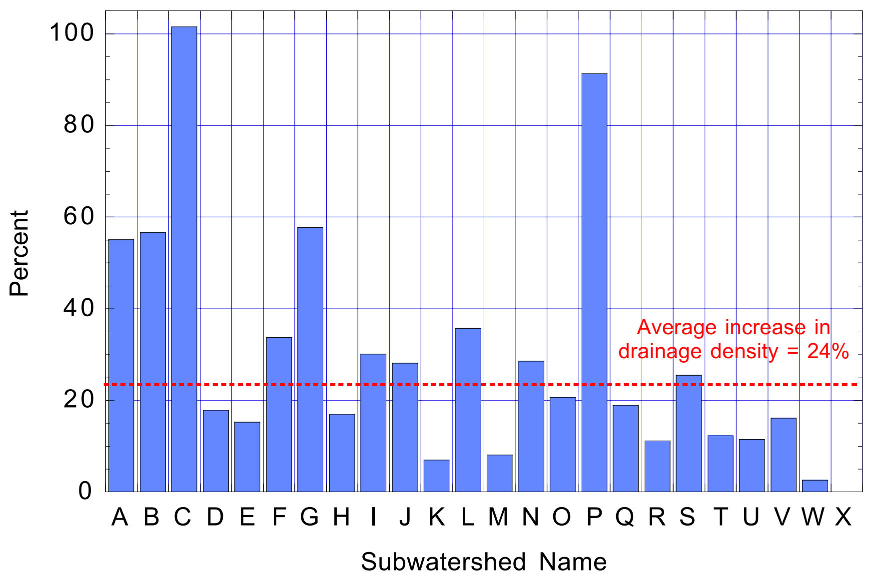


Figure 46

Percent of Field and Map Measured Sediment from Different Sources in Grassland Subwatersheds

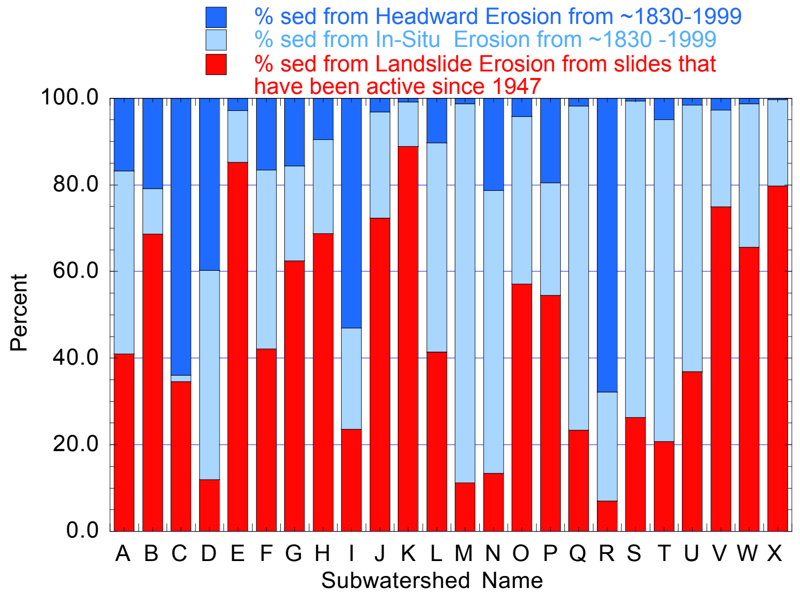
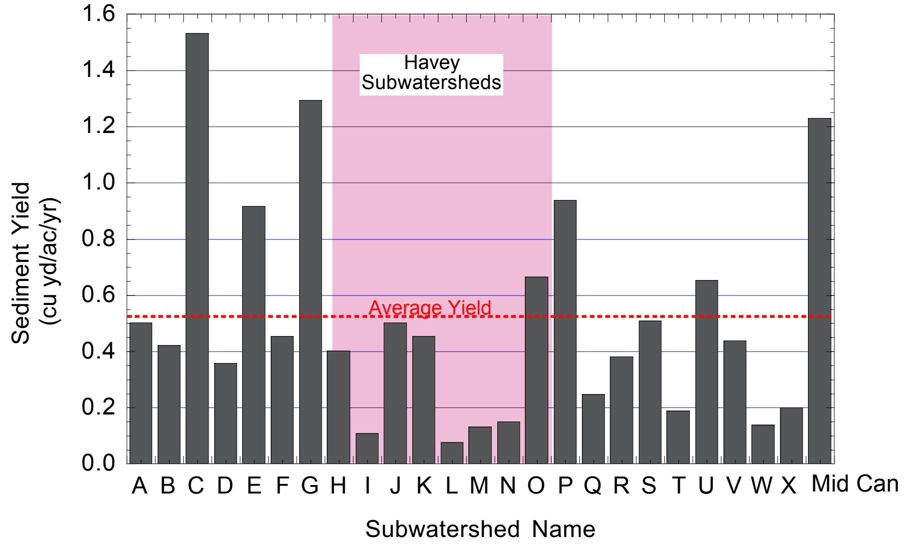


Figure 47

Long-term Sediment Yield from Subwatersheds from ~1830-1999



By comparing slope classes and landslides, we determined that steep slopes do not necessarily correlate with active earthflows. Watershed A, for example, has the third largest area of active landsliding, although it ranks 20th for area having slopes greater than 20%.

Figure 45 shows that since about 1830, average drainage density has increased by 24% within these 24 subwatersheds. Overall drainage density has increased from about 57 ft/acre to 72 ft/acre of watershed. For watersheds A, B, C, G, and P, drainage density has increased by more than 55%. These five subwatersheds are dominated by large, deep-seated complex earthflows that are particularly susceptible to gullying and headward extension from the reduced soil cohesion within the sheared slide deposits. As the landslide masses shift, they divert flow into other unconsolidated portions of the slide material that is also easily eroded. These subwatersheds were excessively grazed until cattle were removed about 21 years ago (verbal communication Neil Havlik, former EBRPD range manager). Watersheds G and P are still grazed and have large deep-seated complex earthflows. Watershed G is pictured as Photo Site A on Figure 41, and as Photo 17 on page 40.

Figure 46 shows the relative sediment contribution from landslides, in-situ channel erosion, and headward extension. Landsliding contributes about 46%, channel in-situ incision contributes 38%, and headward erosion contributes 16% of the total sediment supply from all 24 subwatersheds. For half of them, the main source of sediment is landslide erosion. In subwatersheds C, I, and R, the main source is headward extension of small channels, especially within landslide deposits. Although headward extension is not the dominant sediment source, it is a chronic form of erosion among these and other grazed subwatersheds in the Canyon.

By converting sediment rates to yields, we can compare sediment production among subwatersheds of different size. Figure 47 shows that the subwatersheds of Havey Creek have lower sediment yields than other subwatersheds. This is probably because hillsides are less steep in Havey basin (Figure 43, L-D). These subwatersheds only yield about 0.4 cu yd/ac/yr of sediment. Subwatersheds C and G have the highest yield, about 1.5 cu yd/ac/yr and 1.3 cu yd/ac/yr, respectively.

WHAT IS CAUSING ALL THE CHANNELS TO INCISE IN THE OPEN GRASSLANDS?

The analysis of sediment supply among the subwatersheds leads us to ask what drives the headward extension and incision in the open grassland channels? Theory and experience would attribute this erosion to significant increases in runoff and reduction of vegetation resistance to surface erosion. Given that rainfall patterns have not changed (page 9), increases in runoff must be due to land use. The headward extension and incision on the southwest side of the Canyon is generated by urban roads, culverts, and impervious development. Since the subwatershed grasslands on the east side of the Canyon do not have these impacts, indirect effects of cattle grazing cause accelerated rates of channel incision.

The grazing has caused runoff to exceed historical amounts that occurred before modern settlement. While urban runoff can be measured as direct effects from ditches and culverts, erosion associated with grazing must be deduced as the indirect effect of diffuse changes in vegetation and soils. By subtracting the estimated rate of tectonically driven incision (11%) for all the subwatershed channels (27.7 cu yd/yr) from their total measured rate (330 cu yd/yr), we calculate that 92% of the sediment supply exceeds that which might be driven by tectonics. If we consider the data from Table 7 where about 64% of the sediment supply is associated with soil and landslide creep, an soil lowering that cannot be separated from natural versus land use-related supply, we can conservatively estimate that 36% (109 cu yd/yr) of the sediment supply from these subwatersheds is indirectly related to grazing.

The Mainstem Channel

Our analysis of sediment sources for the mainstem channel of Wildcat Creek has focused on the reaches of the Upper Alluvial Plain and Lower Canyon Segments. In addition, we have analyzed how the two reservoirs, Lake Anza and Jewel Lake, have responded to fluvial erosion and mass wasting in their catchment basins. To quantify erosion and assess the geomorphic processes that influence the mainstem channel, we applied a more detailed methodology than that which we developed for the tributaries.

Table 8 lists a sample of cross-sections along the mainstem channel. The sections that are labeled alphabetically are also shown as cross-section sketches in Figure 49. Note that the vertical scale of the diagrams is twice the horizontal scale. The exaggerated vertical scale is needed to show fine relief of the channel banks. Locations of the sketched cross-sections are shown on the Locator Map, Figure 48.

(Photo 28) Looking downstream at the tidal reach that has old levees along its banks. This reach is represented in cross section "B" in Figure A (see facing page).

Cross-sections A and B are in the Tidal Segment, C-E are in the Flood Control Segment, F-R are in the Lower Canyon, S-X are in the Middle Canyon, and Y-Z3 are in the Upper Canyon. The cross-sections C-D show the maximum width of the trapezoidal-shaped flood control channel and the constructed berms on the banks. Starting at cross-section G, changes in the natural elevation of the valley flat (developed terrace) relative to the channel bed can be observed. As you travel up the alluvial fan to cross-sections Q and R, terrace bank height increases from 9 ft at section F to 25 ft at section Q.

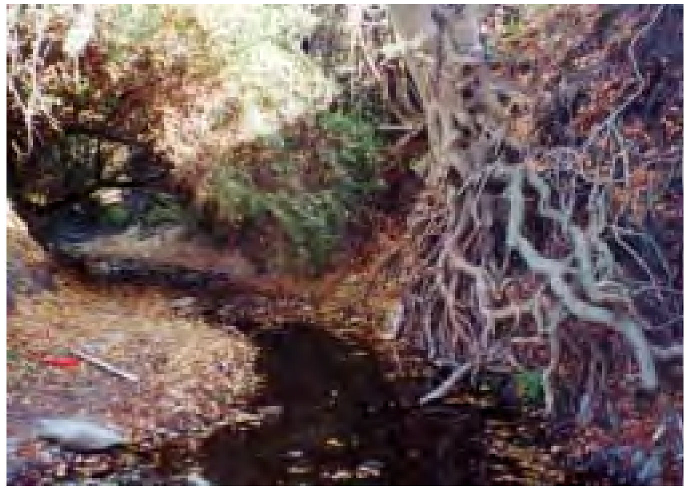
(Photo 29) Looking downstream at Santa Fe Railroad trestle and rip rapped trapezoidal banks of the flood control project, as represented in cross section "F" in Figure A (see facing page). The grouted rip rap bed corresponds to the aggradation shown in Figure 89, page 69.

A channel that has an entrenchment ratio of less than 1.4 is considered highly entrenched. If the ratio is between 1.4 and 2.2 it is moderately entrenched, and only slightly entrenched if the ratio is greater than 2.2 (Rosgen 1996). By looking at Table 1, we can see that the entrenchment ratio for Wildcat Creek changes downstream through the Upper Alluvial Plain from highly entrenched to slightly entrenched. The significance of entrenchment is discussed on page 31. We note again that entrenchment confines flood flows between terraces so less entrenched reaches downstream on the Alluvial Plain are more likely to flood, especially upstream of poorly designed culverts.

(Photo 30) Looking upstream from the Rumrill box culvert at the plain bed of the creek that lacks topography. This reach is represented in cross section "I" (which is drawn looking downstream) in Figure 49.

(Photo 31) Looking downstream at revetted channel at Davis Park, which floods with flows that have a recurrence interval of less than 10 yrs. This area is represented by cross section "K" in Figure 49 (see facing page).

Wildcat Creek tends to decrease in width downstream along the Upper Alluvial Plain Seg-



(Photo 32) Looking upstream at the exposed roots of a buckeye tree that indicates recent bank erosion, as represented by cross section "P" (which is drawn looking downstream) in Figure 49 (see facing page).

Table 8

Wildcat Creek Cross-Sections

Cross-Section Name	Adjusted Station Distance (ft)	Bankfull Width (ft)	Bankfull Depth (ft)	Entrench-ment Ratio	Width/ Depth Ratio	Rosgen Stream Class	Notes
	Tidal Segment						
A	-3836	NA	NA	NA	NA	NA	marsh
B	-3041	NA	NA	NA	NA	NA	marsh
	Flood Control Segment						
C	651	NA	NA	NA	NA	NA	channelized marsh
D	1289	NA	NA	NA	NA	NA	channelized creek
E	4239	NA	NA	NA	NA	NA	channelized creek
	Upper Alluvial Plain Segment						
	6030	28.0	3.5	1.1	8.1	E4	
	6123	31.4	3.5	2.6	9.0	E4	
	6991	24.5	3.5	2.5	7.1	E4	
	7207	29.0	3.2	2.1	9.0	E4	
	7997	24.6	3.7	2.8	6.7	E4-5	
	9037	29.5	3.6	3.3	8.1	E4-5	
F	9675	NA	NA	NA	NA	NA	trapezoidal w/ riprap
G	10026	21.0	2.7	1.3	7.8	G4	
	10103	22.0	4.7	1.4	4.7	G4-5	
H	10320	NA	NA	NA	NA	NA	box culvert
I 10398		21.5		not determined			
	10655	25.2	4.1	1.3	6.2	G4	
J	10910	22.0	2.7	1.5	8.1	G4	
	10977	26.1	3.5	1.2	7.4	G-E4	
K	11162	25.0	2.8	1.3	8.9	G4	
	11386	26.2	3.5	1.5	7.4	G4	
L	11735	19.0	2.7	1.3	7.0	G4	
M	12384	NA	NA	NA	NA	NA	box culvert
	12390	27.4	3.3	1.7	8.3	G-B4-5	
	12682	22.6	4.1	1.6	5.5	G-B4	
N	12847	18.0	2.4	1.4	7.5	G3	
	13354	20.2	4.1	1.6	5.0	B4	
O	13674	24.0	3.5	1.3	6.8	G4	
	14047	28.2	3.3	1.8	8.6	G-B5	
	16292	22.8	3.7	1.6	6.1	G-B4	
	16598	23.3	3.7	1.4	6.3	B-G4	
P	16835	17.8	2.4	1.0	7.4	G4	
	17942	31.0	2.6	2.1	11.1	B4	
	18618	22.4	3.6	1.4	6.2	G4	
Q	18733	15.0	2.7	1.3	5.5	G4	
	18913	39.2	2.1	1.4	18.6	B4	
	21275	28.0	1.8	1.2	16.0	F4	
R	21602	25.3	2.1	1.4	12.1	B4	
	Lower Canyon Segment						
S	22184	22.0	1.8	1.0	12.2	G3	
	22379	26.3	2.3	1.3	11.1	B-G4	
T	22414	27.0	1.2	1.3	22.5	B3	
	24097	26.0	2.3	1.2	11.1	F4	
U	26941	22.5	1.7	1.1	13.2	F3	
V	28854	21.7	2.0	1.2	10.8	B3-5	
	28951	25.0	2.2	1.5	11.3	B-4	
	30413	23.7	2.2	1.6	10.7	B-G3	
W	31686	19.4	1.7	1.2	11.4	B3-5	
X	35774	15.3	1.7	1.3	9.0	B1	
	36103	18.8	2.4	1.4	7.8	B-G4	
2	39291	38.5	2.2	1.4	7.9	B-G	
1	42280	20.3	2.1	1.2	9.6	G4	
	Upper Canyon Segment						
Y		16.0	1.1	1.3	14.5	F3	
Z1		6.3	1.5	1.9	4.2	A3	
Z2		6.0	1.5	1.6	4.0	A4	
Z3		3.8	2.1	4.2	1.8	A3	

*note: combination stream classes are transitional between classes

Figure 48. Cross-Sectional Locator Map

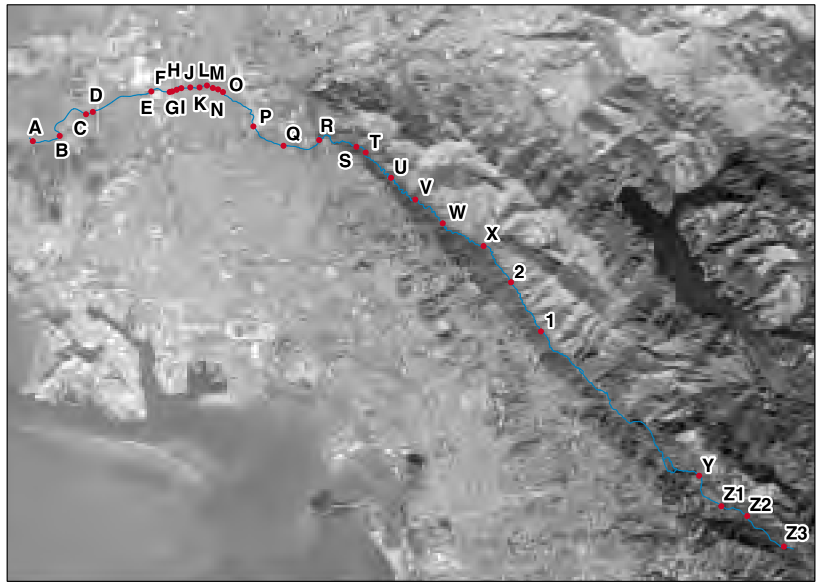
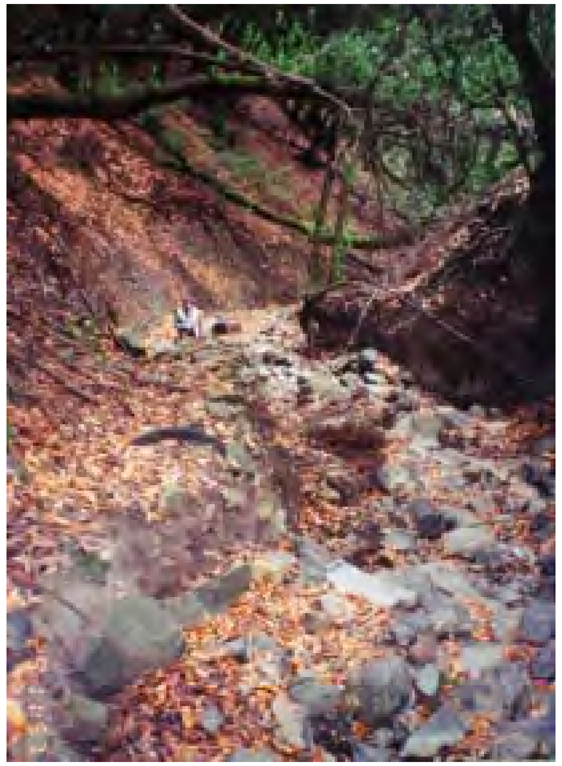
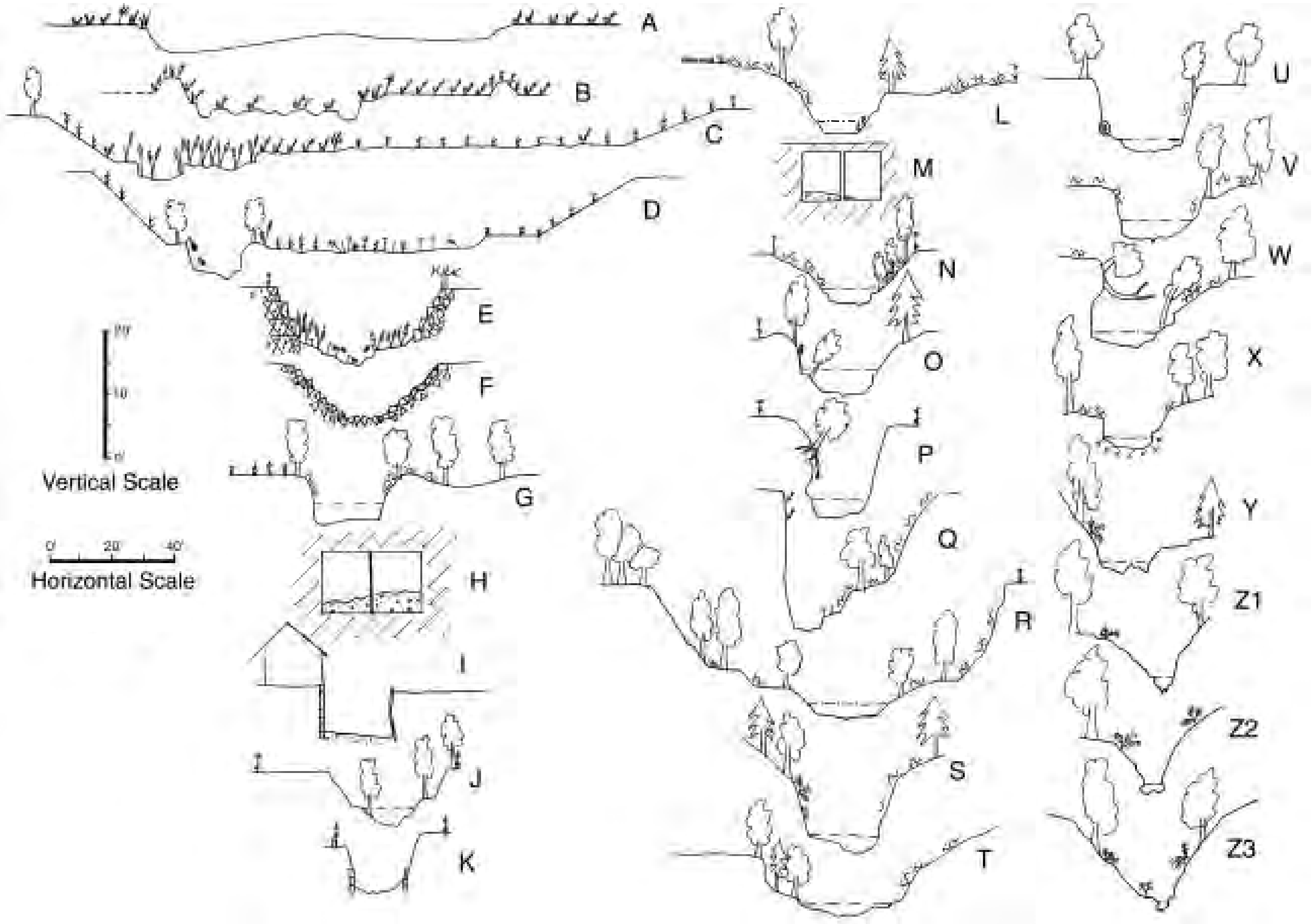


Photo Source: NASA, 1996



(Photo 33) Looking downstream at mainstem Wildcat Creek between cross sections Z1 and Z2 (Figure 49). The channel is dominated by volcanic cobble from debris flow deposits that armor the bed.

Figure 49. Wildcat Cross-Sections



ment. Table 8 shows that the width/depth ratio also decreases in the downstream direction. This differs from the typical expected pattern for most streams, which get wider as they pass through more catchment and receive more runoff. Increased amounts of urban runoff from the developed alluvial fan are added to Wildcat Creek through storm drains. However, the creek does not widen as predicted to accommodate this runoff. Table 8 shows that the mainstem channel is wider in the downstream half of the Lower Canyon Reach than the downstream reaches of the Upper Alluvial Plain. The wider Canyon reaches might be caused by the influence of large woody debris (LWD) and landslides, while the narrower downstream reaches may be associated with the increased bank cohesion from higher clay content. The historical natural channel that existed before urbanization also decreased in width downstream of the Canyon as can be seen on the 1856 Coast Survey maps.

We have used the Rosgen Stream Classification System (Rosgen, 1996) on the Upper Alluvial Plain and Lower Canyon Segments of Wildcat Creek. An example of the system is in the Appendix. We have found that the Rosgen system works better for streams in this region, if we change the threshold for width/depth ratios to 10 ± 3, rather than 12 ± 2. Reaches that could not be easily distinguished as one particular type were labeled as transitional.

Mainstem Reservoirs

Figure 50

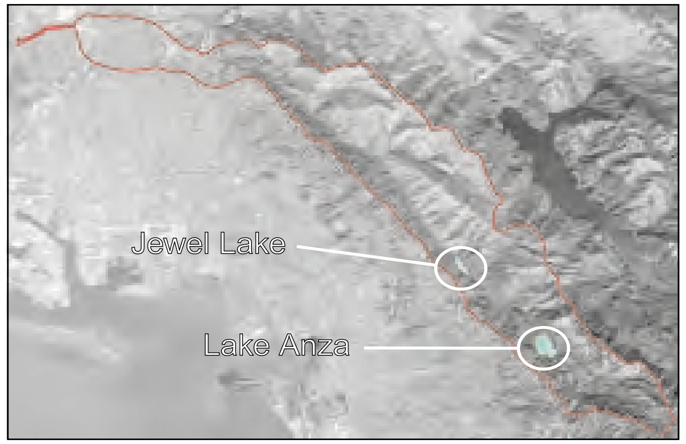


Photo Source: NASA, 1996

Two reservoirs in Wildcat Watershed, Lake Anza and Jewel Lake impound the mainstem channel in Wildcat Canyon. They capture the bed load and most of the sands that comprise the suspended portion of the bedload. They have captured varying proportions of silt and clay that comprise the wash load portion of the total load that flows over the spillways during the wet season. Lake Anza may be large enough to capture some portion of the washload from the Upper Canyon. Sedimentation in the reservoirs is mostly due to bedload input and its suspended fraction.

We have used changes in reservoir capacity, records of dredging and artificial fill to estimate the supply of bed load coming from the Middle and Upper Canyon Segments. For both reservoirs, historical bathymetric maps show filling over time. Jewel Lake has been periodically dredged by the EBRPD. They have kept good records of the amounts removed. To use Jewel Lake as a measure of bedload sediment supply from the Middle Canyon, we had to account for changes in the trap efficiency (Brune 1953) and survey the elevation of the backwater fan at the Lake's upstream end. We plotted the height and width of the fan on the original as-built profile of the Lake to estimate the volume of sediment that has accumulated in the fan since the Lake was constructed. This fan has risen above the original level of the Lake.

During the fall of 1999, we resurveyed the bathymetry of both reservoirs. Frequent soundings were taken with a weighted tape measure along numerous transects located on our photo base map. We tried to match the methods previously used by others for these reservoirs to produce new maps comparable to the older maps. Yet, we were unable to compare our maps to some of the others because shorelines were inaccurately depicted. This reduced the number of time intervals for which filling of the reservoirs could be computed.

(Photo 34) Looking toward the dam at Lake Anza.

Figure 51 shows both reservoirs as they have changed through time. Lake Anza was completed in 1938 for recreational purposes and golf course irrigation. Jewel Lake was completed in 1922. It was used for drinking water supply until 1933. Table 9 shows the major influences of sedimentation in these reservoirs.

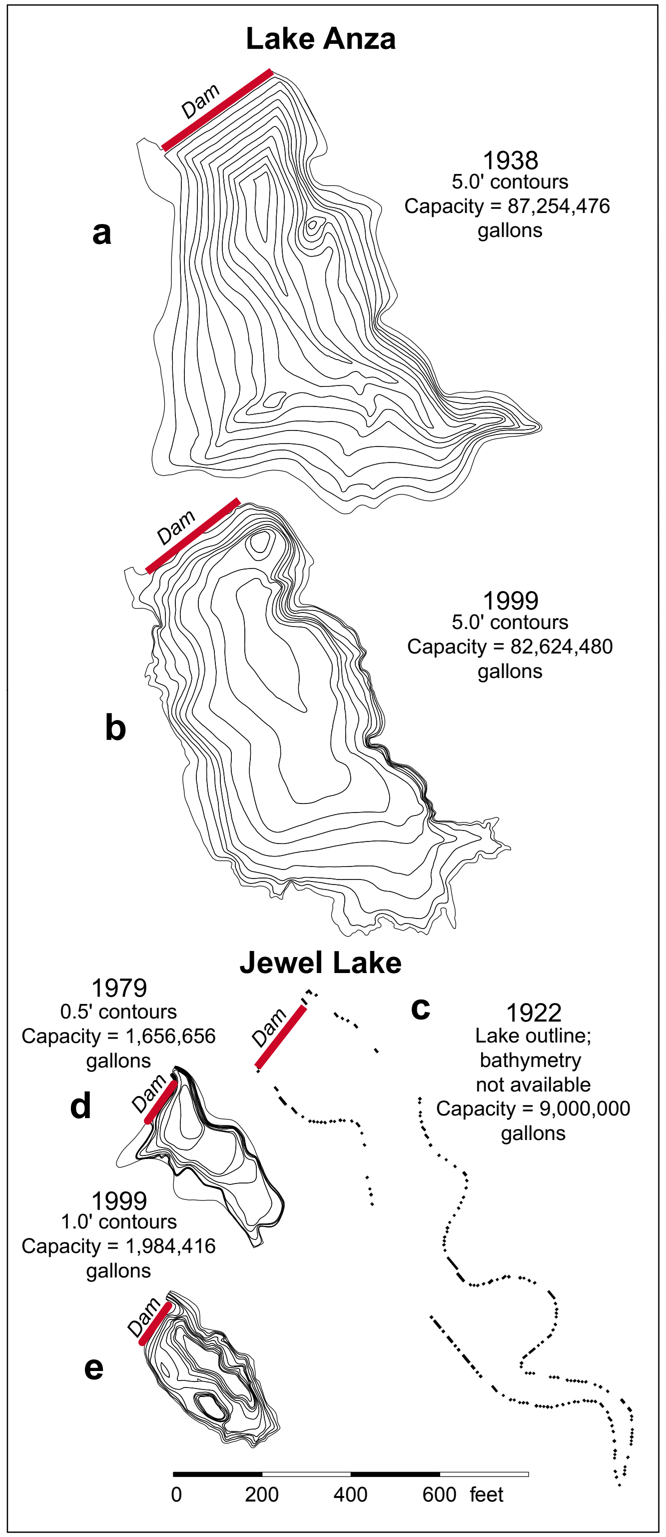
Table 9

LAKE ANZA HISTORY		
Date	**Capacity (gal)**	
1938	87,254,476	Lake Anza completed
1962		landslide deposition, 7,404 cu yd *
1965		imported beach sand, 9,976 cu yd **
1984		golf course sediment basin built ***
1999	82,624,480	bathymetric survey, SFEI

* East Bay Regional Park District
** Buffler *In* : Saffell, A.
*** Superintendent, Tilden Golf Course

The as-built survey for Lake Anza is shown as Figure 51a. This bathymetric map shows the maximum capacity of the reservoir before any filling. By 1999 (Figure 51b), only 5% of the original capacity had been lost by sedimentation. The depositional history of Lake Anza includes beach construction (verbal communication Jerry Kent, EBRPD) that had to be subtracted from the calculation of filling by bed load. The volumes of fans from small tributaries entering the reservoir were included in the calculations as well as landslides (Buffler, 1964 in Saffell, 1980). Zuckswart (1953) reported a filling rate of 13.8 cu yd/yr during the first thirteen years after Lake Anza dam was constructed. This information was combined with the data derived from the apparent changes in bathymetry. In 1984, a small settling basin was constructed upstream of Lake Anza in Tilden Golf Course. According to our interview of the Tilden Golf Course Supervisor, about 2.5 cu yd of sediment accumulate in this basin each year. The basin is occasionally dredged.

Figure 51. Historical and Modern Reservoir Contours



(Photo 35) Dredging Jewel Lake in 1991.

Jewel Lake (Figure 51c) has a more complicated history than Lake Anza (Table 10). We are not certain that all its history has been recorded. Some dewatering or dredging was observed by long-time residents in the early 1950s (verbal communication Dean Bacon). Nevertheless, by comparing Figures 51c and 51d, we can see that the aerial extent of Jewel Lake decreased by about 82% between 1921 and 1979. Dredging of Jewel Lake in 1967 achieved about 37% of its original capacity. There are accurate bathymetric surveys for 1982, 1984, 1991, and 1999 (this study). Figure 51e shows the condition for 1999.

Figure 52 and Table 11 have been prepared to show changes in sedimentation rates and the long-term average rates of sedimentation for the two reservoirs and the small settling basin in the golf course. Lake Anza has a much slower rate of sedimentation than Jewel Lake. The rates for Anza and for Jewel Lake, following the construction of Lake Anza, are 375 cu yd/yr and 1,272 cu yd/yr, respectively. Their representative bedload yields are 257 cu yd/sq mi/yr and 744 cu yd/sq mi/yr. The erosion-resistant volcanic bedrock that has few landslides in the Upper Canyon is responsible for low sedimentation rates in Lake Anza. About 87% of the Upper Canyon is comprised of volcanic rocks. Although the rate of sediment supply to Lake Anza is slow compared to other supply rates in Wildcat Canyon, it was most accelerated during times of road, home, golf course, and reservoir construction. Only about 5% of the surface area of the watershed above Lake Anza is impervious due to roads or other development (Table 17, page 73). There is a high density of dirt roads and trails; however, drainage density has increased by 19% from headward extension of channels, creation of storm drains, and inboard road ditches.

Table 10

JEWEL LAKE HISTORY		
Date	Capacity (gal)	
1919		tunnel muck deposited in channel ***
1921	9,000,000	Jewel Lake completed
1933		Jewel Lake diversion discontinued
1938		Lake Anza completed
1967	1,466,329	estimate*
1967		dredging, 9,450 cu yd **
1979	1,656,656	bathymetric survey**
1982	1,109,658	bathymetric survey**
1984	929,075	bathymetric survey**
1991		dredging, 10,404 cu yd **
1991	2,205,669	bathymetric survey**
1999	1,984,816	bathymetric survey, SFEI

* Department of Water Resources, 1977
** East Bay Regional Park District
*** EBMUD map

Table 11

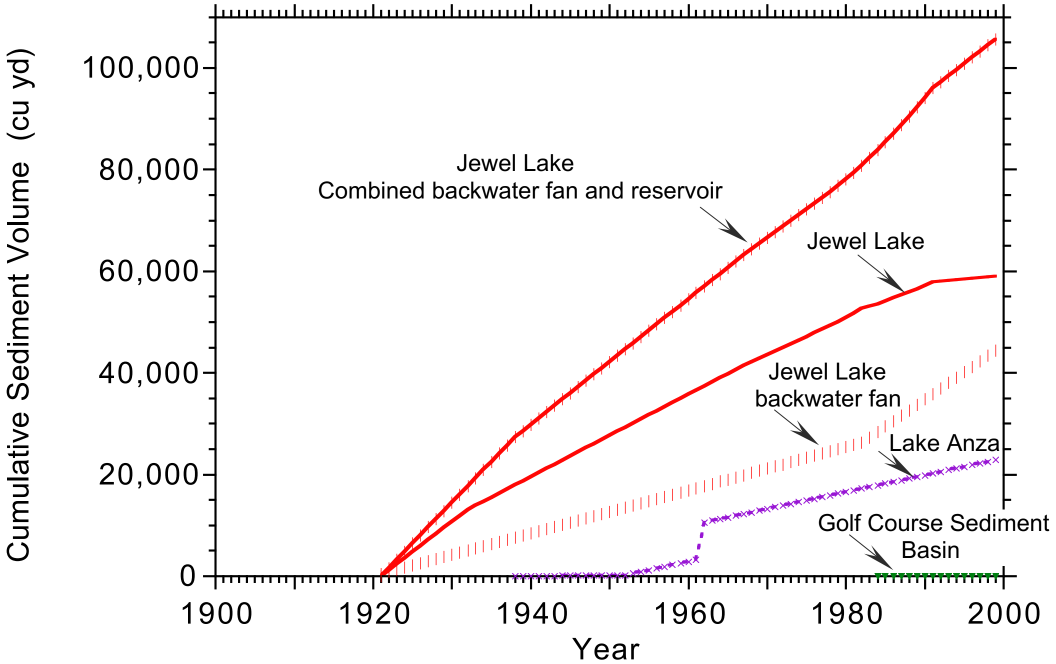
Long-Term Average Rates of Sedimentation (construction dates in parentheses)	Cu Yd/Yr
Jewel Lake Reservoir (1921)	787
Jewel Lake Backwater Fan	558
Jewel Lake Combined Reservoir and Fan	1345
Jewel Lake Combined Reservoir and Fan*	1272
Anza Reservoir (1938)	375
Golf Course Sediment Basin (1984)	2.5

* Rate of filling following construction of Anza Reservoir

Figure 52

Jewel Lake and Lake Anza Sedimentation

1921-1999



Jewel Lake sediment volumes are based upon reservoir bathymetry, and survey of the backwater fan upstream of the reservoir. Changes in trap efficiency and the effects caused by Lake Anza (1938) are taken into account.

The long-term sedimentation rate for Jewel Lake in the Middle Canyon is high because of there is a greater amount of Orinda Formation (with its associated large number of earthflows) than volcanic bedrock. The Middle Canyon also has a higher percentage of impervious surface area, vegetation maintenance for fuel breaks, and greater drainage density increase (42%) than the Upper Canyon Segment (see Table 17, page 73). Deposition rates in Jewel Lake are slowing down as trapping efficiency on the backwater fan increases, and perhaps, as construction activities have slowed. The backwater fan has developed a stand of willows as it has built upwards. As the willows have aged, they provide woody debris that helps slow water velocity and entrap sediment.

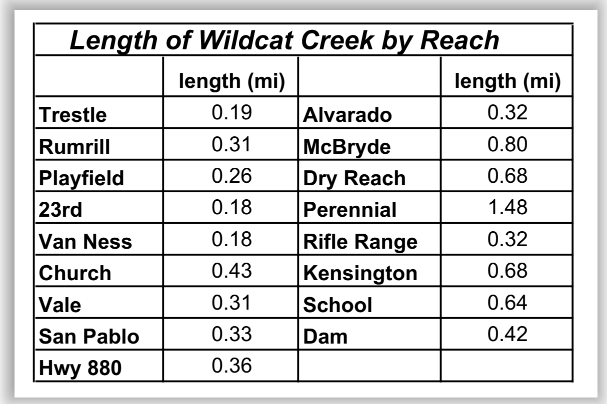
(Photo 36) Some sediment is deposited in the Tilden Golf Course upstream of the mainstem sediment basin.

Lower Canyon and Upper Alluvial Plain Segments and Reaches

The mainstem channel is subject to more kinds of stresses and management practices in the Lower Canyon and Upper Alluvial Plain than elsewhere in the watershed. Sediment sources vary significantly over short distances. To understand this variability, and to develop a comprehensive baseline assessment against which various sampling strategies could be tested in the future, we measured most sediment sources continuously throughout both segments. To maximize the relevance of the baseline survey, we collected baseline information about infrastructure and channel form that relates to flood control, pollution control, and wildlife conservation. Channel conditions are summarized by Reaches, which are shown in Figure 53. The length of each reach is listed in Table 12. The details of field conditions are documented in the streamline graphs located in the Appendix.

We show a simplified Mainstem Sediment Source Decision Tree (Figure 54) that shows our field measured sediment supplies stratified by process based locations and whether the supply was directly related to land use practices. Bank features were categorized as alluvial banks below bankful elevation, terrace banks, landslides, gullies and canyon slopes. Bed incision (1,146 cu yd/yr) and landslides (724 cu yd/yr) have contributed the greatest local supply of sediment along

Table 12



Length of Wildcat Creek by Reach

	length (mi)		length (mi)
Trestle	0.19	Alvarado	0.32
Rumrill	0.31	McBryde	0.80
Playfield	0.26	Dry Reach	0.68
23rd	0.18	Perennial	1.48
Van Ness	0.18	Rifle Range	0.32
Church	0.43	Kensington	0.68
Vale	0.31	School	0.64
San Pablo	0.33	Dam	0.42
Hwy 880	0.36		

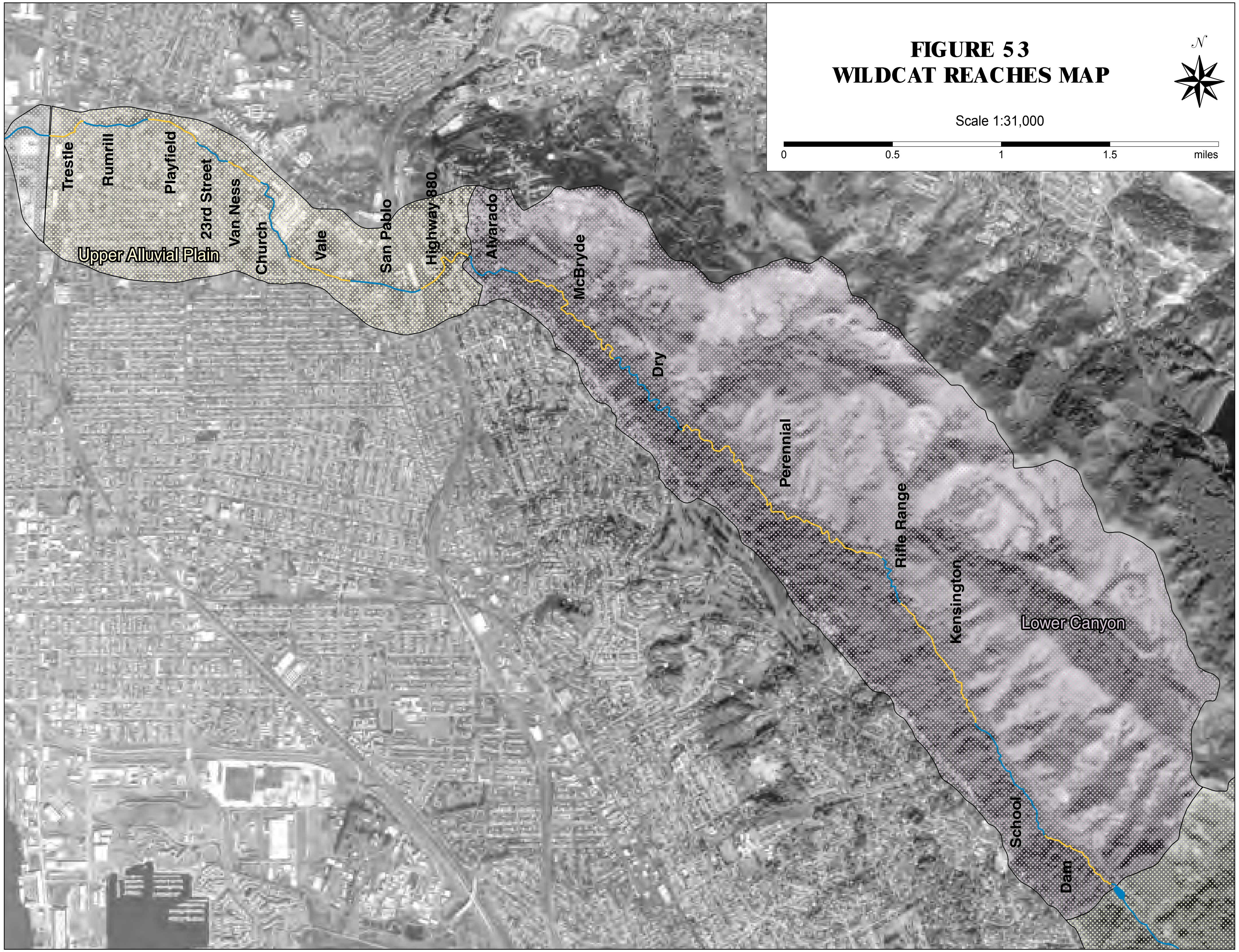


FIGURE 53
WILDCAT REACHES MAP

the mainstem since the time of non-native settlement. The amount of alluvial bank and terrace erosion from lateral migration (76 cu yd/yr) is minor compared to bed incision and slides. The total field measured sediment supply rate that is directly related to land use is 458 cu yd/yr. Another 1,580 cu yd/yr comes from sources that cannot be readily differentiated from natural and indirect land use effects.

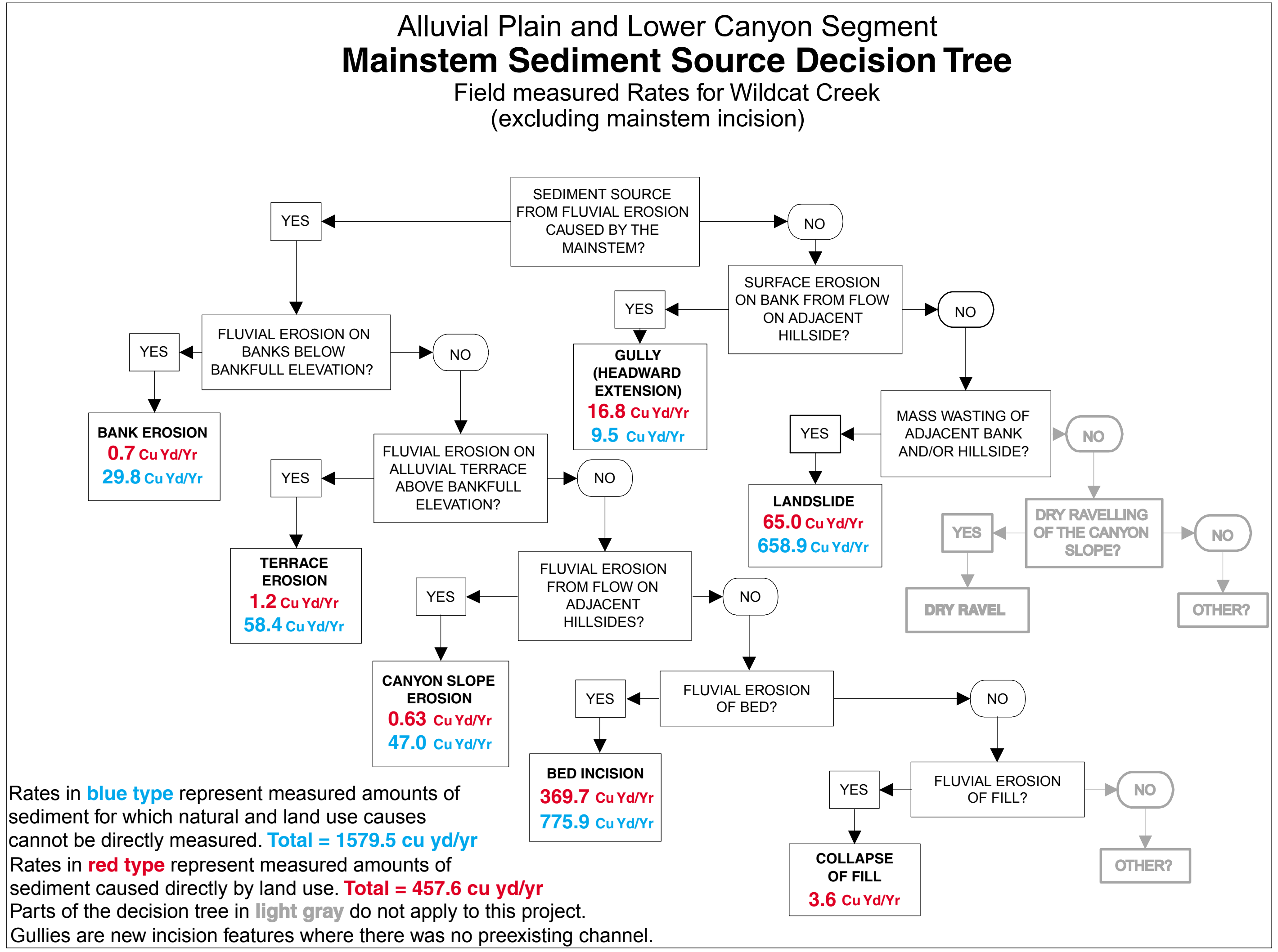
Table 13 shows categories of calculated and field measured sediment supply along the mainstem channel of both the Upper Alluvial Plain and Lower Canyon. We have further divided the sources of bed incision to exemplify our estimate of the contribution of sediment supplied by downcutting below Jewel Lake dam. This estimate may be conservative because we did not calculate its potential influence beyond Havey Creek confluence, which is the first substantial tributary that supplies significant bedload downstream of the dam. A substantial amount of incision is caused by the withholding of sediment by the reservoir. The channel below the spillway has incised 12 ft from the time it was constructed in 1922 (Photos 36 and 37). We have calculated the bed incision supply from the effects of the dam to be 233 cu yd/yr (Table 13).

Historical data and field evidence indicates that the mainstem channel has incised at least 1 ft since the 1940s when runoff increased from rapid urbanization. We considered 136 cu yd/yr a conservative estimate of direct urban influences to downcutting.

If we calculate the amount of sediment that would be generated from erosion keeping pace with the tectonic uplift (0.5 mm/yr), then the rate of supply for the mainstem in the Lower Canyon east of the Hayward Fault would only be 36 cu yd/yr. The rate of sediment supply from bed incision in the Lower Canyon that we have measured that cannot be explained by either tectonics or direct land use effects is 559 cu yd/yr, 49% of the total bed incision supply. Much of this supply may be from the adjustments that the mainstem channel has had to make to accommodate the increased runoff from the tributaries. The overall average increase in drainage density for the entire watershed upstream of the Flood Control Channel is 35%.

Soil creep and landslide creep rates are also reported in Table 13. These were calculated by the same methods discussed for Tributaries and Hillslopes (page 42), with some changes in depth and creep rates. The mainstem channel supplies 23% of the combined total for all soil and landslide creep in the Lower Canyon Segment.

Figure 54



Alluvial Plain and Lower Canyon Segment

Mainstem Sediment Source Decision Tree

Field measured Rates for Wildcat Creek
(excluding mainstem incision)

Rates in blue type represent measured amounts of sediment for which natural and land use causes cannot be directly measured. Total = 1579.5 cu yd/yr
Rates in red type represent measured amounts of sediment caused directly by land use. Total = 457.6 cu yd/yr
Parts of the decision tree in light gray do not apply to this project.
Gullies are new incision features where there was no preexisting channel.

(Photo 36a) The edge of the newly constructed dam at Jewel Lake, 1922. Note there is about 2.5 ft of fall.

(Photo 36b) The edge of the spillway in 1999 has over 14 ft of fall.

Table 13

Calculated and Measured Long-Term Rates of Sediment Supply from Wildcat Creek Mainstem Bed and Adjacent Bank Sources along the Alluvial Plain and Lower Canyon Segments Applicable to Last 167 Years		
Sources	**cu yd/yr**	**Percent of Total**
Field measured mainstem bed erosion estimated as directly related to land use	**369.7**	**15.3**
Canyon bed incision from fan to Havey Creek confluence related to effects of sediment retention at Jewel Lake Dam since 1922	233.3	9.7
Mainstem bed incision related to increased runoff from urban impacts since 1940's	136.4	5.7
Field measured mainstem bed incision (natural and/or indirectly) related to land use	**777.9**	**32.3**
Bed incision driven by tectonics for mainstem east of Hayward fault (uplift rate = 0.5 mm/yr) (considered natural)	35.5	1.5
Bed incision in excess of the natural-tectonicly driven rate (777.9 - 35.5 - 183.3)	559.1	23.2
Alluvial Plain bed incision (natural and/or indirectly related to land use)	183.3	7.6
Calculated	**374.5**	**15.5**
Soil creep at Canyon slopes (WA State Forest Practices 1994, soil creep rate = 5 mm/yr) (mean depth = 4 ft)	82.0	4.6
Soil creep at terraces (Upper Alluvial mainstem) (soil creep rate = 3 mm/yr) (soil depth = 3 ft)	29.9	1.2
Landslide creep for active slides bordering channel (landslide creep rate = 65 mm/yr) (assume 100% earthflows) (mean depth = 5 ft)	262.6	10.9
Field measured along banks (directly related to land use)	**87.9**	**3.6**
Gully erosion on mainstem banks	16.8	0.7
Landslides	65.0	2.7
Canyon slope	0.6	< 0.1
Terrace banks	1.2	< 0.1
Bankfull banks	0.7	< 0.1
Culvert fill / collapsed and washed out along mainstem	3.6	0.1
Field measured along banks (natural and/or indirectly related to land use)	**803.6**	**33.3**
Gully erosion on mainstem banks	9.5	0.4
Landslides	658.9	27.3
Canyon slope	47.0	1.9
Terrace banks	58.4	2.4
Bankfull banks	29.8	1.2
Totals	**2,413.6**	**100.0%**

Bank and Terrace Condition by Reach

Figure 55a

WILDCAT CREEK
Percent Length of Bank Condition per Reach
Upper Alluvial Plain Segment - 1998
(* Right and left banks and terraces combined)

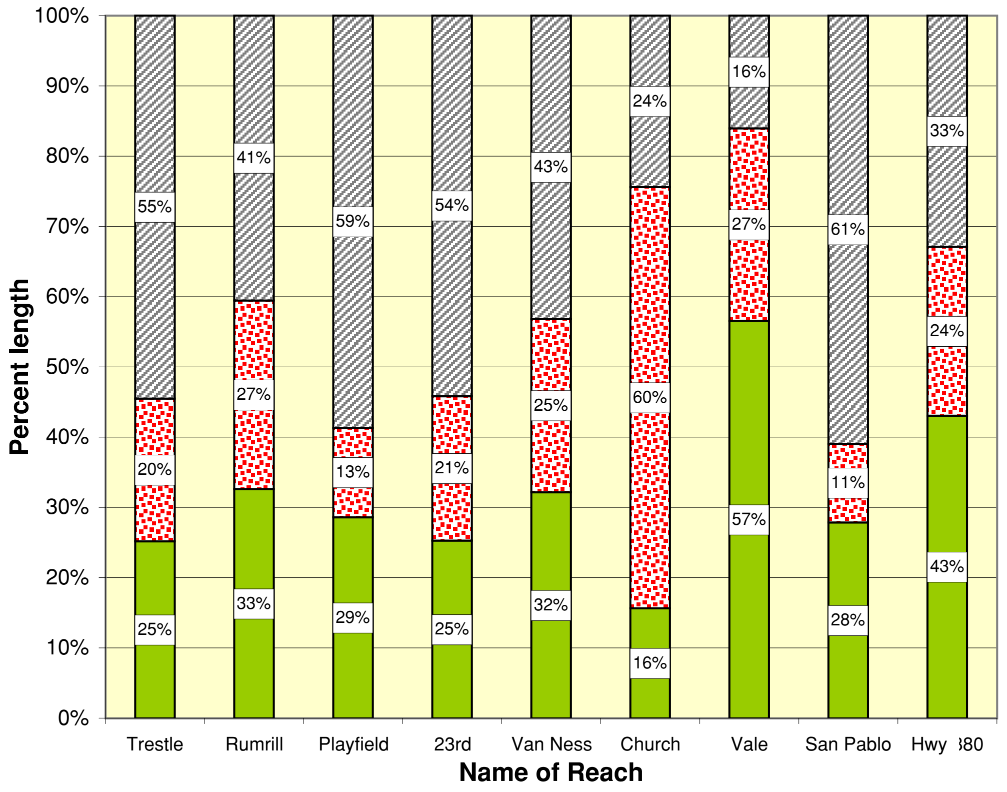
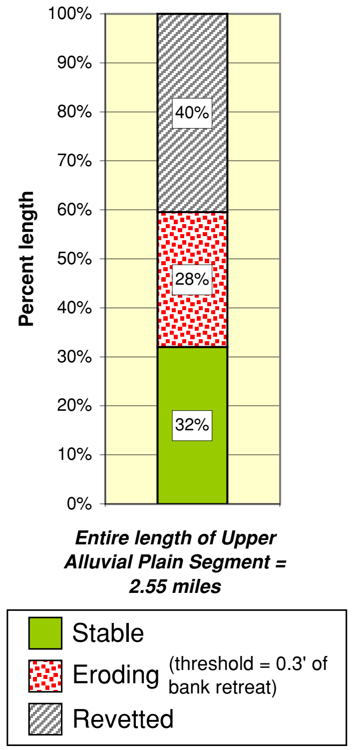


Figure 55b

Total Percent Length of Different Bank Conditions for Entire Upper Alluvial Plain Segment



Entire length of Upper Alluvial Plain Segment = 2.55 miles

🟩 Stable
🟥 Eroding (threshold = 0.3' of bank retreat)
▨ Revetted

Figure 56a

WILDCAT CREEK
Percent Length of Bank Condition per Reach
Lower Canyon Segment - 1999
(* Right and left banks and terraces combined)

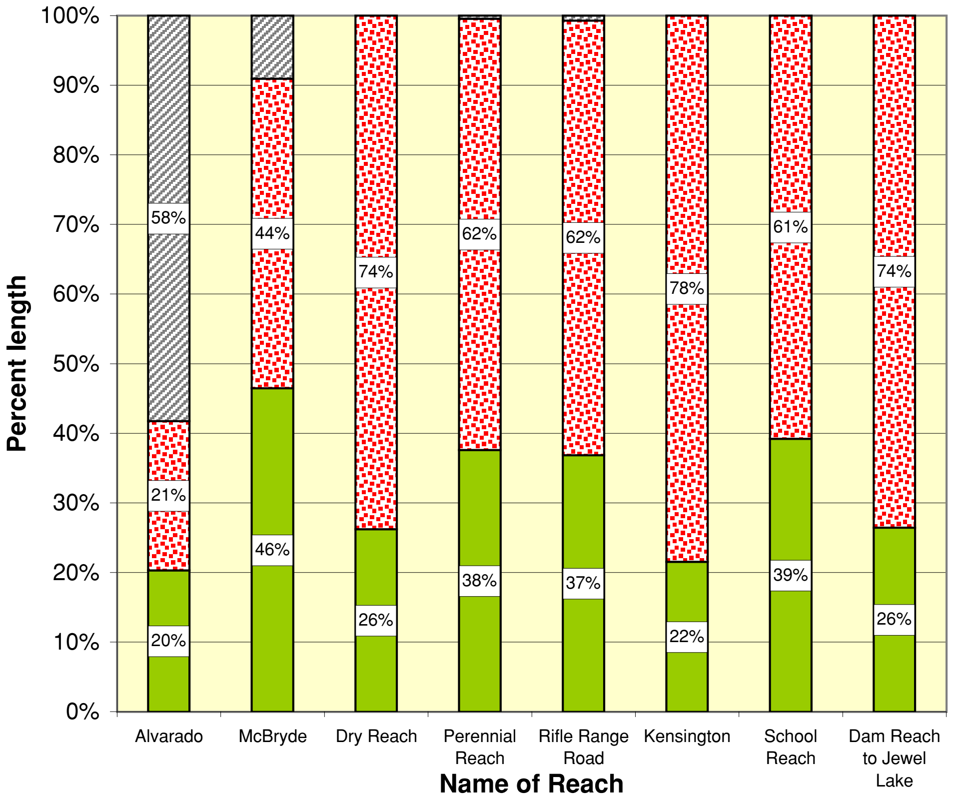
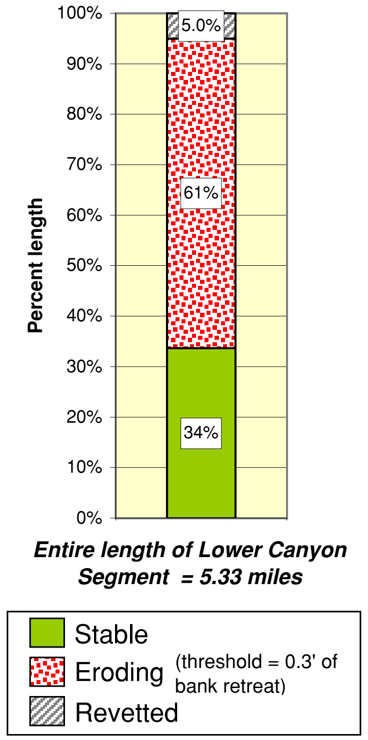


Figure 56b

Total Percent Length of Different Bank Conditions for Entire Lower Canyon Segment



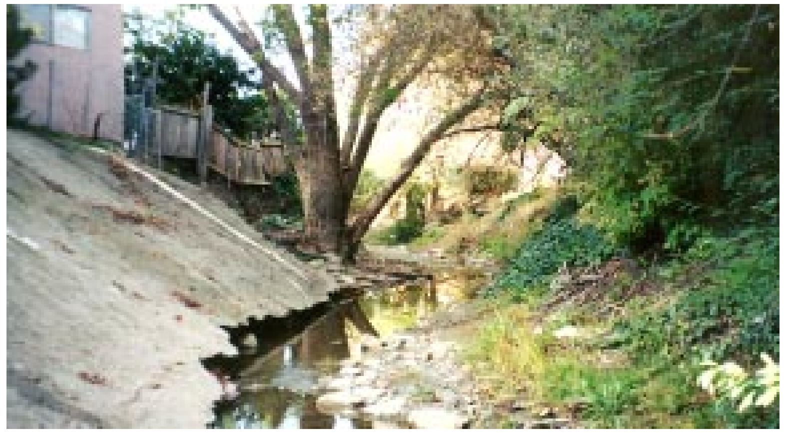
Entire length of Lower Canyon Segment = 5.33 miles

🟩 Stable
🟥 Eroding (threshold = 0.3' of bank retreat)
▨ Revetted

Amounts of eroding, revetted, and stable banks were measured and graphed for the Upper Alluvial Plain and Lower Canyon Segments. Bank erosion was measured wherever there was evidence of at least 0.25 ft of bank retreat, as indicated by exposed roots, the freshness of bank sediments, shape of the bank in plan view, and historical records. Note that even if the *banks* are shown as stable, the *channel* may be unstable if its bed is degrading or aggrading. The percents reported represent the total for four banks: right and left banks above and below bankful. Continuous bank conditions are shown in the Appendix Streamline Graphs. In Figures 55a and 56a, the data are summarized for individual reaches within each of the two respective segments. In graphs 55b and 56b, the percent length of bank erosion is totaled for each segment.

About 35% more revetments exist in the Upper Alluvial Plain than in the Lower Canyon, whereas the Canyon has 33% more length of eroding bank than the Upper Alluvial Plain. The Lower Canyon has 2% more stable banks than the Upper Alluvial Plain. If the areas that are now revetted in the Plain were assumed to be eroding in the past, then the relative amounts of stable and eroding bank are quite similar. The small percentage of stable natural bank is indicative of incising channels that are actively adjusting their hydraulic geometry.

The reach based analysis shows that Church Reach has twice the percentage of eroding banks of any other reach on the Upper Alluvial Plain and the least amount of stable natural bank. The erosion of its banks may relate to the change in gradient from Vale Reach to Church Reach (Figure 88, page 69). In the Canyon, Kensington Reach has the greatest proportion of eroding banks. The abundance of landslides along the banks in this reach might be a plausible explanation for its erosion. McBryde Reach has the greatest percentage of stable banks (46%).



(Photo 38) A revetted bank and a natural bank oppose each other along the Alluvial Plain. Bed incision within the last 50 years is apparent along the base of the concrete and at the exposed roots on the right bank.

Left and Right Bank Conditions by Segment

Figure 57

WILDCAT CREEK

Percent Length Right and Left Bank Conditions

Upper Alluvial Plain Segment - 1998

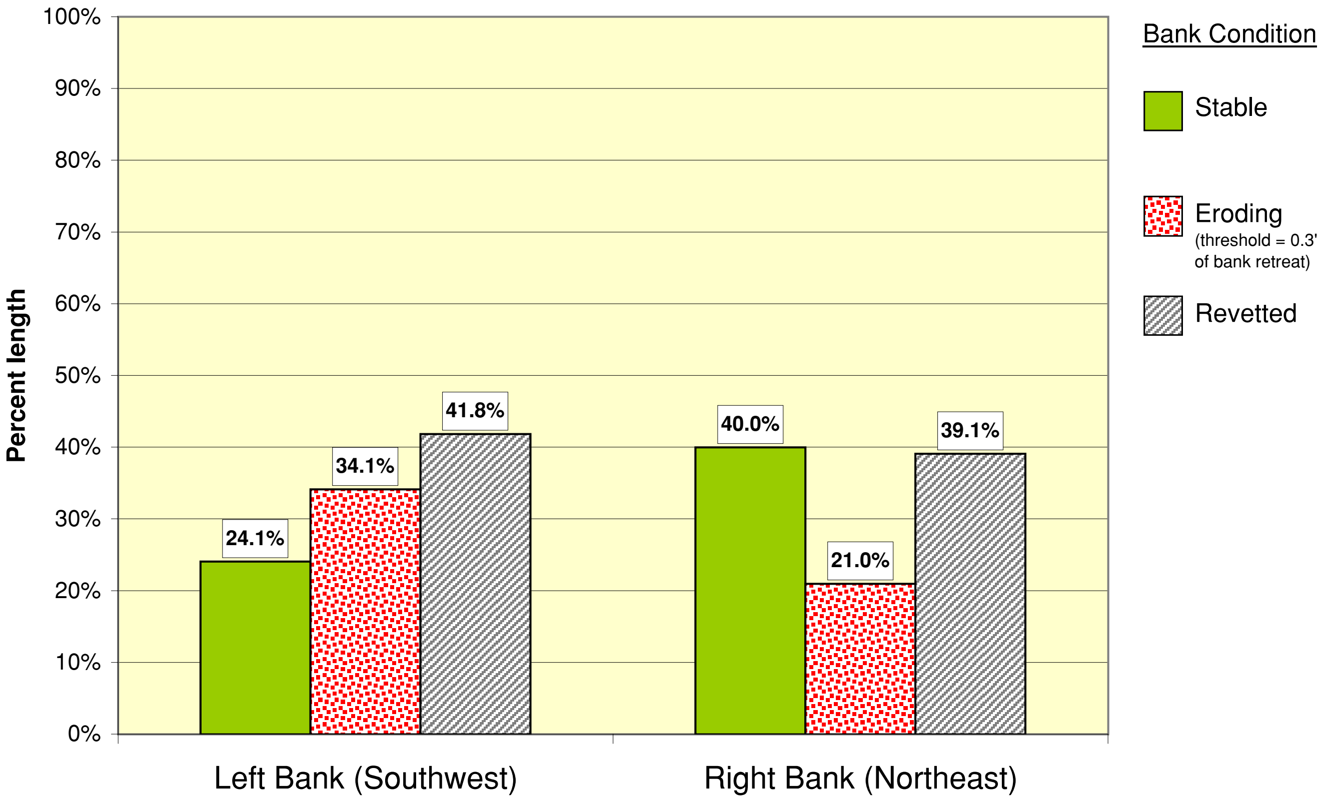
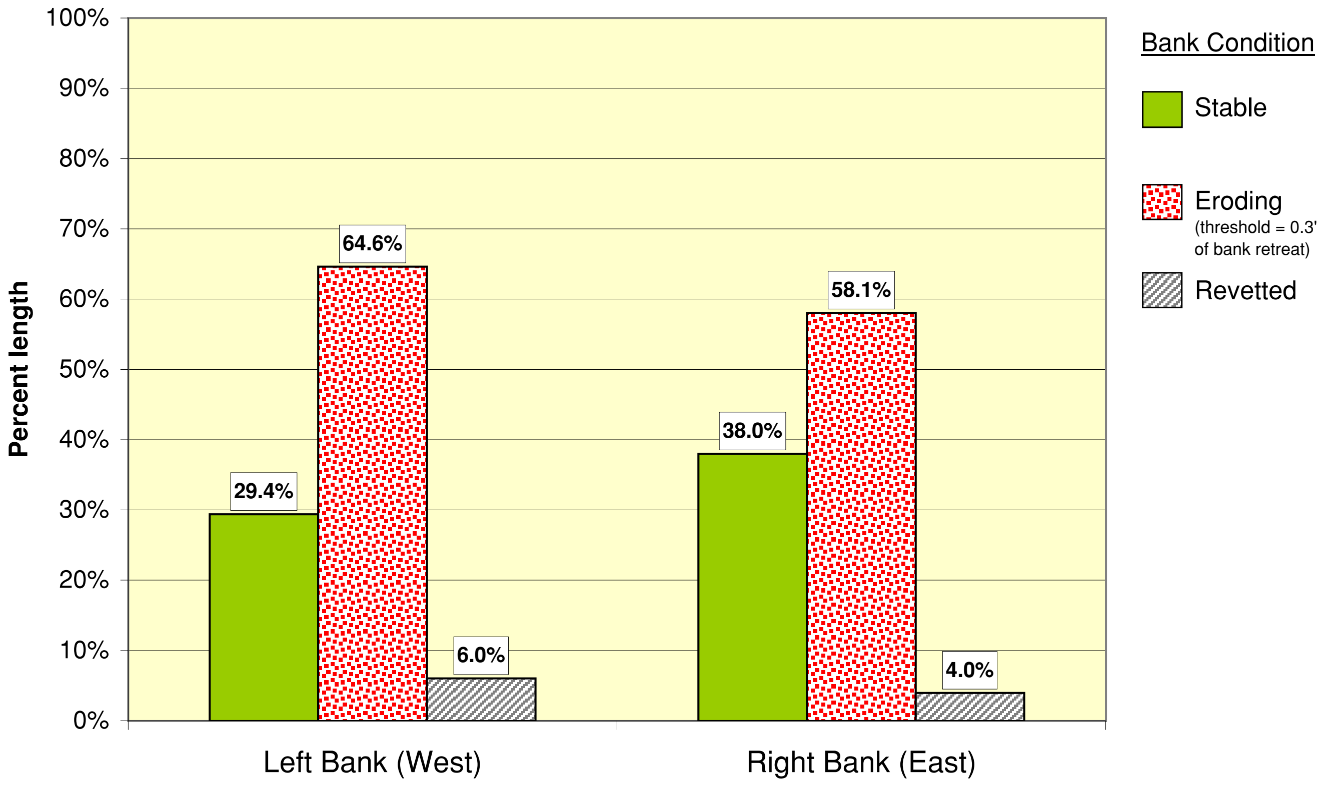


Figure 58

WILDCAT CREEK

Percent Length Right and Left Bank Conditions

Lower Canyon Segment - 1999



The percent lengths of eroding bank on the left side (south west) and right side (northeast) of the mainstem channel are plotted for the Upper Alluvial Plain and Lower Canyon Segments in Figures 57 and 58. For the Alluvial Plain Segment, the percent length of bank erosion is about 13% greater for the southwestern side than the northeastern side, even though there is a similar amount of revetment on both banks. We suggest that the greater length of eroding bank on the south side results from channel migration southward across its alluvial fan. Perhaps the northern portion of the fan is being tectonically tilted toward the south. Alternatively, right-lateral creep along the Hayward Fault could be moving the fan northward, against the westward creek flow, such that the south bank is eroding as it creeps into the creek.

In the Lower Canyon, about 6% more of the left bank (west side) is eroding than the right bank (east side). This slightly greater amount of erosion on the west side could be due to the greater abundance of large complex earthflows on the steeper Berkeley Hills.

(Photo 39) The waning flood flow of January 1997 exposes an eroding left terrace bank near Vale Road.

(Photo 40) Non-engineered revetment is failing into Wildcat Creek.

Types of Revetment by Reach

Figure 59a

WILDCAT CREEK
Length of Different Revetment Types per Reach
Upper Alluvial Plain Segment - 1998

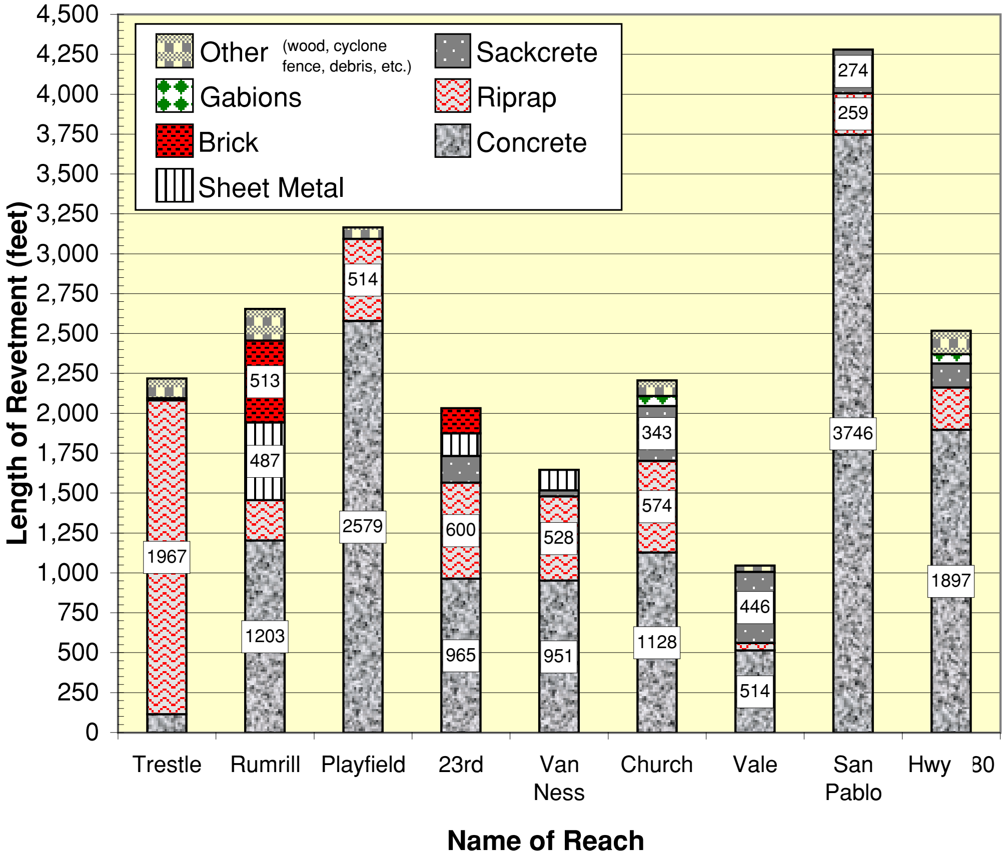
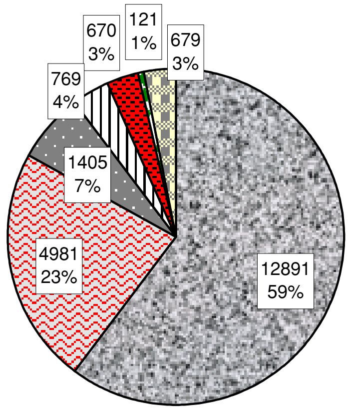


Figure 59b

Length of Different
Revetment Types and
Percent of Total Length
of All Types for Entire
Upper Alluvial Plain
Segment

(In each white box, number on top is length of revetment (feet); number on bottom is the percent of total length)



Total length of revetments = about 40% of Upper Alluvial Plain Segment which totals 2.55 miles

Figure 60a

WILDCAT CREEK
Length of Different Revetment Types per Reach
Lower Canyon Segment - 1999

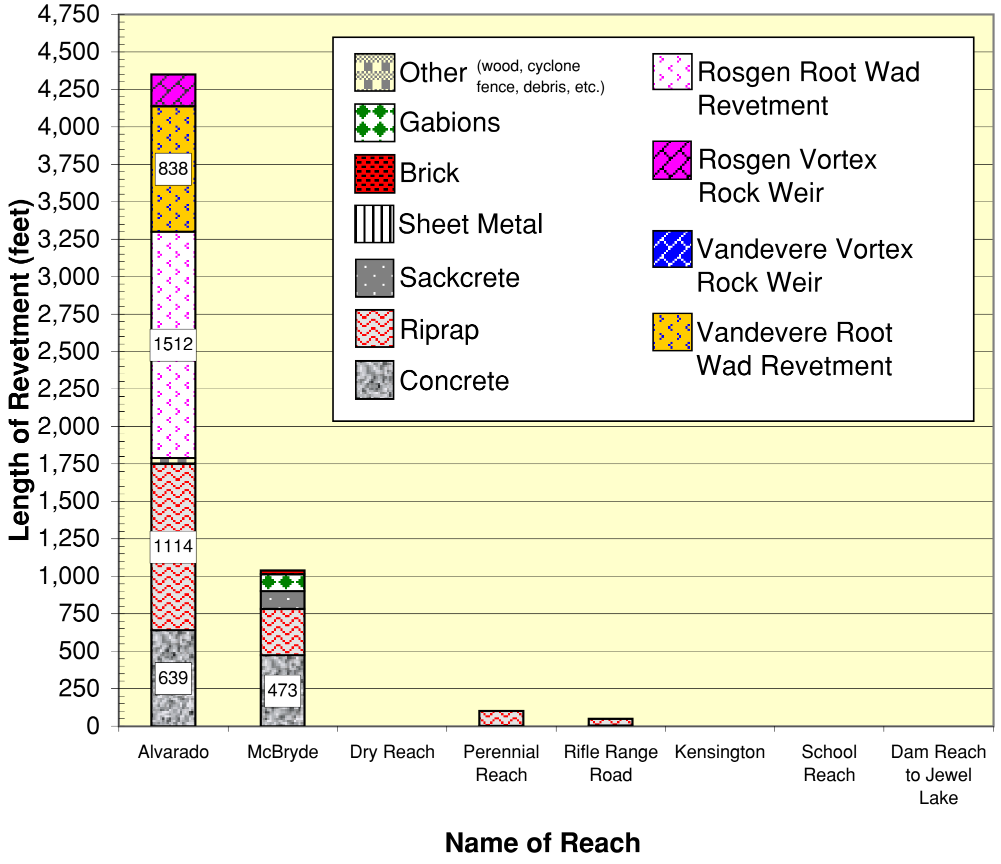
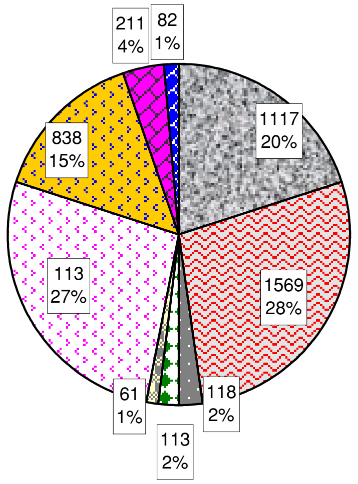


Figure 60b

Length of Different
Revetment Types and
Percent of Total Length
of All Types for Entire
Lower Canyon Segment

(In each white box, number on top is length of revetment (feet); number on bottom is the percent of total length)



Total length of revetments = 5% of Lower Canyon Segment which totals 5.33 miles

Figures 59a and 60a show the lengths of different types of revetment per reach along the Upper Alluvial Plain and the Lower Canyon. Note the difference in vertical scale of the two graphs. Figures 59b and 60b show the total length and percentage of each type of revetment per Segment. Concrete is the most common material used in Wildcat for bank revetment. Box culvert structures, poured concrete retaining walls, barriers that consisted of stacked fragments of broken concrete, and mortared banks are some of the ways that concrete is used to revet the banks of Wildcat Creek. In many cases these revetments have accelerated erosion at their downstream ends or on opposite banks.

Based upon Figure 55b on page 52,we know that 40% of the banks are revetted. From graph 59b, we can see that 59% of that revetment is concrete. From Figure 59a, we can see that nearly 3/4 of a mile (3,740 ft) of the banks in San Pablo Reach are covered with concrete. Riprap is the second most common form of revetment, as shown in Figure 59b. Trestle reach is the only reach where riprap exceeds concrete. About 1,000 ft of riprap has been applied to the banks near the railroad trestle (photo 29, page 46). Much of it is undersized and has been transported by high flows.

In the Lower Canyon, only 5% of the total length of the banks is revetted (Figure 56a, page 52). Riprap exceeds the amount of concrete by 8% (Figure 60b) in the Canyon. About 69% of this revetment is located in Alvarado Park (Figure 60a), where much was put in after a restoration project was conducted to remove two small dams. Additional amounts were constructed a few years later.

*(Photo 41)
A new wire basket gabion and apron revetment in McBryde Reach, January 1998.*

Condition of Revetment by Reach

Figure 61

WILDCAT CREEK
Revetment Conditions per Reach
Upper Alluvial Plain Segment - 1998

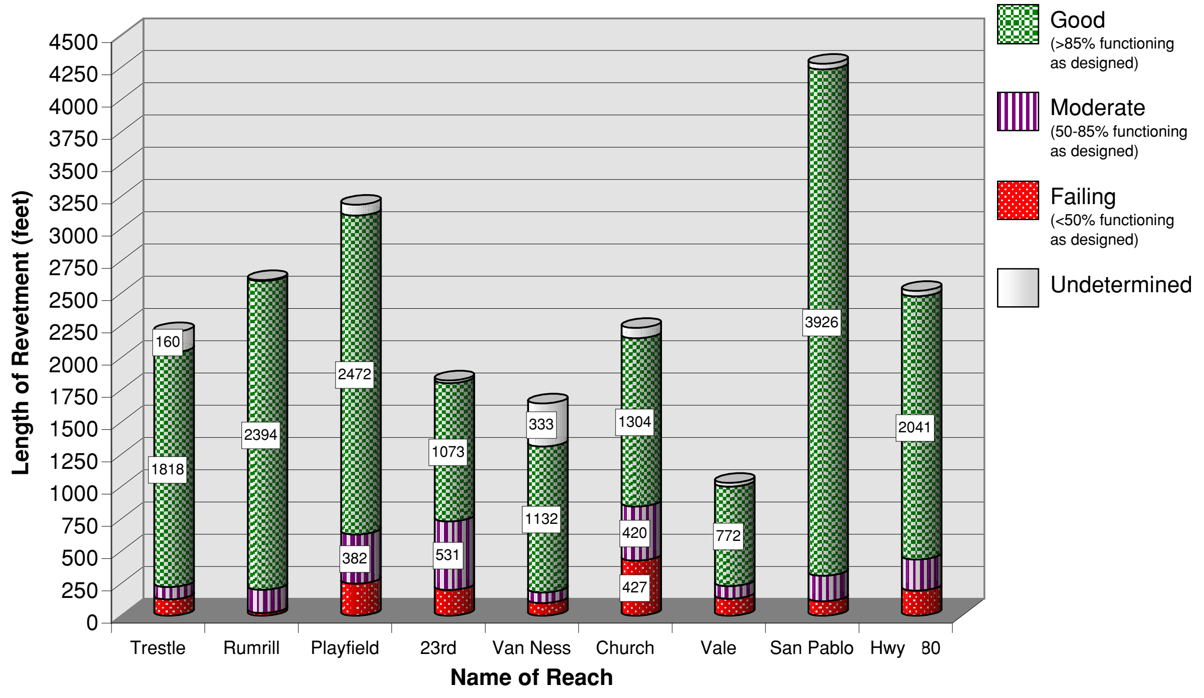
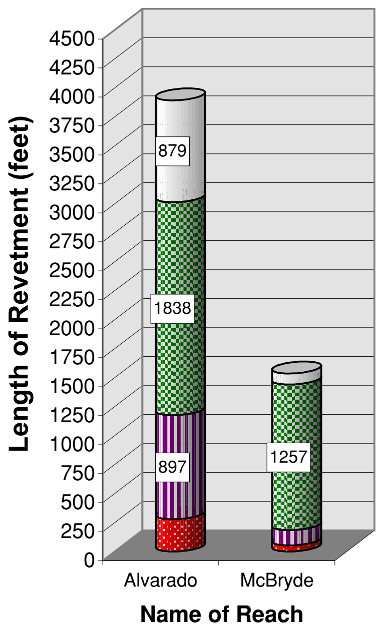


Figure 62

WILDCAT CREEK
Revetment Conditions per Reach
Lower Canyon Segment - 1999



(42)

(43)

(Photo 42) 1997, root wad and boulder revetments were used in Alvarado Park for revision of the restoration project. Note the position of the boulder on the right bank tree stump at the arrow. Photo was taken shortly after construction.

(Photo 43) 1998, same view as photo 1, but one year later. Right bank revetment has slumped about 4 ft into channel. Note the position of the boulder on the stump at the arrow.

(Photo 44) August 1998, a concrete revetment collapses along the Upper Alluvial Plain.

The condition of individual bank revetments was evaluated for the Lower Canyon and Upper Alluvial Plain reaches. If greater than 85% of a structure was functioning as designed, it was rated as good. If only 50-85% was functioning, then it was rated as moderate. If less than 50% was functioning it was rated as failing. We disregarded box culverts for this analysis so that we could better compare individual structures that were not engineered as road crossings. To evaluate the revetments, we had to determine their functions. Almost all of the structures were designed to reduce fluvial erosion of the bank. In the Canyon a few were also designed to inhibit mass wasting.

Figures 61 and 62 show the rated condition of the various revetments per reach in the Upper Alluvial Plain and the Lower Canyon. Only the lower two reaches for the Canyon Segment are shown, since there were hardly any revetments in the rest of the Lower Canyon.

Most of the revetments in the Upper Alluvial Plain were in good condition. Church Reach had the greatest combined length of revetments that were failing (427 ft). It was also the reach that had the greatest percent length of eroding banks (page 52). It had the second greatest combined length of revetment that was moderately functioning (420 ft). The 23rd Street Reach exceeded Church with moderately performing revetment (531 ft). In all reaches, the revetment type that was consistently rated as good was concrete box culverts. Overall, riprap was the type of revetment that was failing most frequently.

In the Alvarado Reach of the Canyon, about 28% of the revetment length was in moderate to failing condition. During the 1993 fish barrier removal project, root wad revetments were placed along the channel banks to preserve the integrity of some historic rock walls along the creek bank that were being severely undermined. In 1997, four years after the project was completed, a 60 ft-long portion of one of the walls failed. Just across the Creek from the failed wall, a landslide slumped into the Creek that was caused by poor drainage problems from a newly constructed playfield. Later that same year, a new 400 ft-long creek restoration project was conducted within the boundaries of the previous project. It widened and deepened the channel where the walls had failed, and along the active toe of the landslide. Root wad revetments were constructed along nearly all the banks within the 1997 project. In 1998, we noted that most of the new root wad revetments were in moderate to failing condition. They were slumping into the channel. This was due to the excessive weight of the structures on the existing landslide deposits and post project bed incision. Our data set includes a series of longitudinal profiles of this project area dating back to 1987 (Figure 88, page 71).

Forms and Lengths of Streamside Erosion

Figure 63a

WILDCAT CREEK

Length of Bank Erosion per Reach

Upper Alluvial Plain Segment - 1998

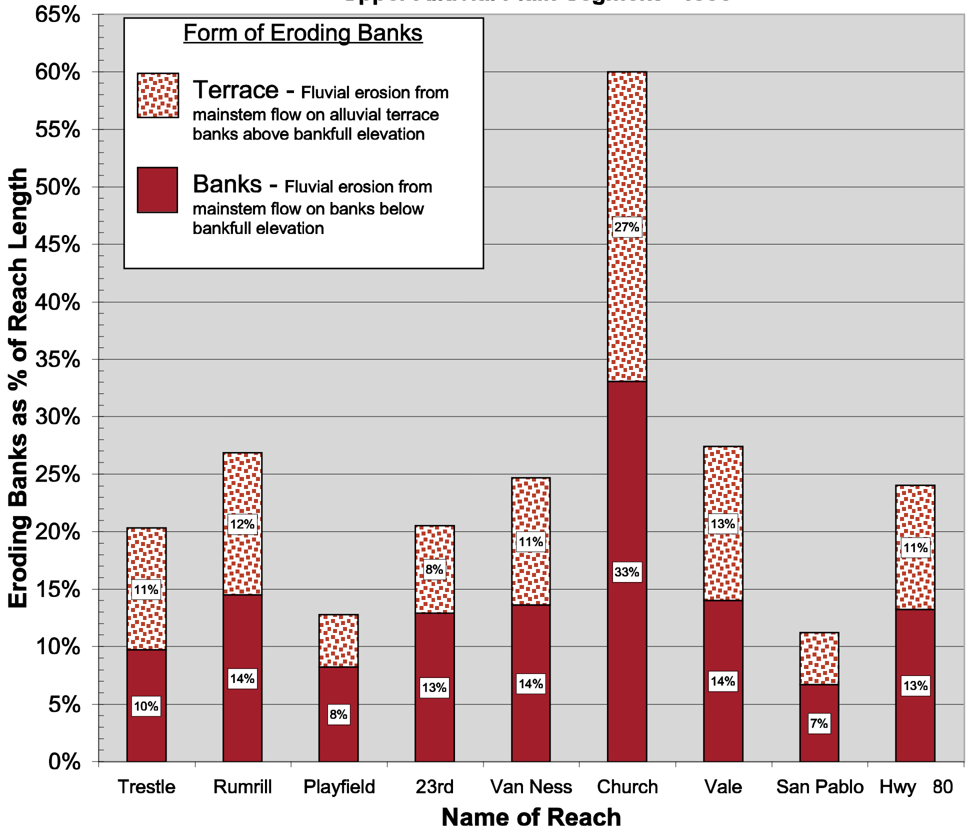
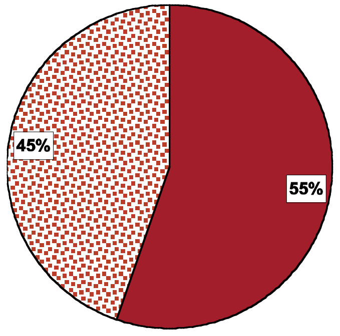


Figure 63b

Percent of Adjacent Bank and Terrace Erosion for Entire Upper Alluvial Plain Segment



Total length of Eroding Bank = 27.5 % of Upper Alluvial Plain Segment which totals 2.55 miles

Figure 64a

WILDCAT CREEK

Length of Bank Erosion per Reach

Lower Canyon Segment - 1999

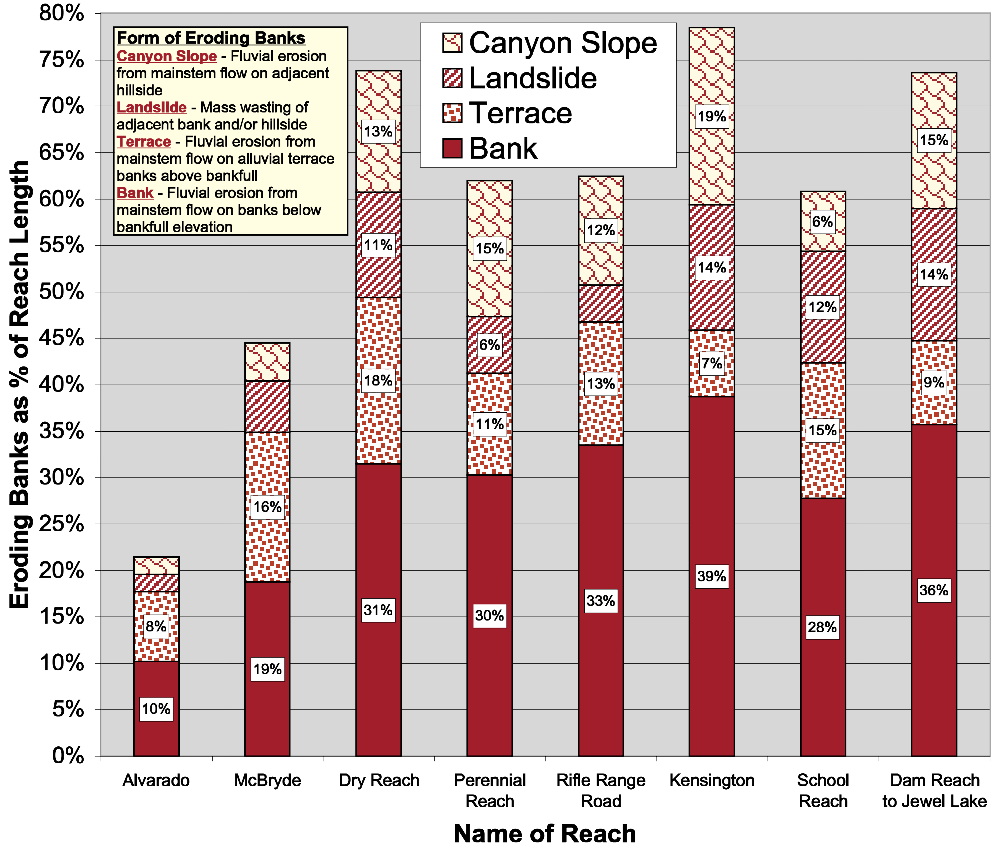
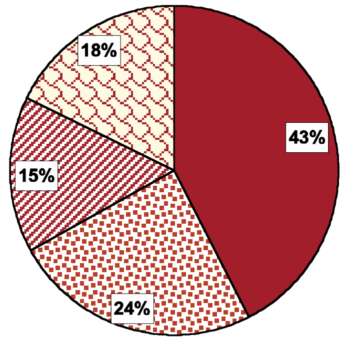


Figure 64b

Percent of Canyon Slope, Landslide, Terrace, and Adjacent Bank Erosion for Entire Lower Canyon Segment



Total Length of Eroding Bank = 61.3% of Lower Canyon Segment which totals 5.33 miles

Here we take a close look at the forms and lengths of streamside erosion for the reaches of the Alluvial Plain and Lower Canyon Segments. Figures 63 and 64 show the length of bank that is influenced by a particular process or form of erosion. For example, in Figure 63b the Upper Alluvial Plain has more length of bank below bankful elevation that is dominated by fluvial erosion (55%) than fluvial terrace erosion (45%). The Lower Canyon Segment in Figure 64b shows a similar pattern of 43% length of bank being dominated by fluvial erosion of alluvial banks below bankfull, but terrace erosion is only 24% of the length. This is because 18% of the bank length also has fluvial erosion on canyon slopes and 15% of the length is mass wasting processes from landslides.

In Figures 63a and 64a, all the reaches show the similar trend of most bank erosion being from fluvial processes below bankfull height. Length of terrace bank erosion is less important in the Lower Canyon reaches because terraces are discontinuous. This is partly due to their local destruction by landslides. All the mainstem reaches along the Lower Canyon Segment are receiving some amount of sediment from mostly earthflow-type slides. One particular exception is a large debris slide in Dry Reach that caused massive deposition of sediments and woody debris into the channel (see Figure 90, arrow at distance station 27,000, page 71).

(Photo 45) Direct sediment input to the channel from the reactivated toe of an earthflow, June 1999.

Volume of Streamside Erosion

Figure 65a

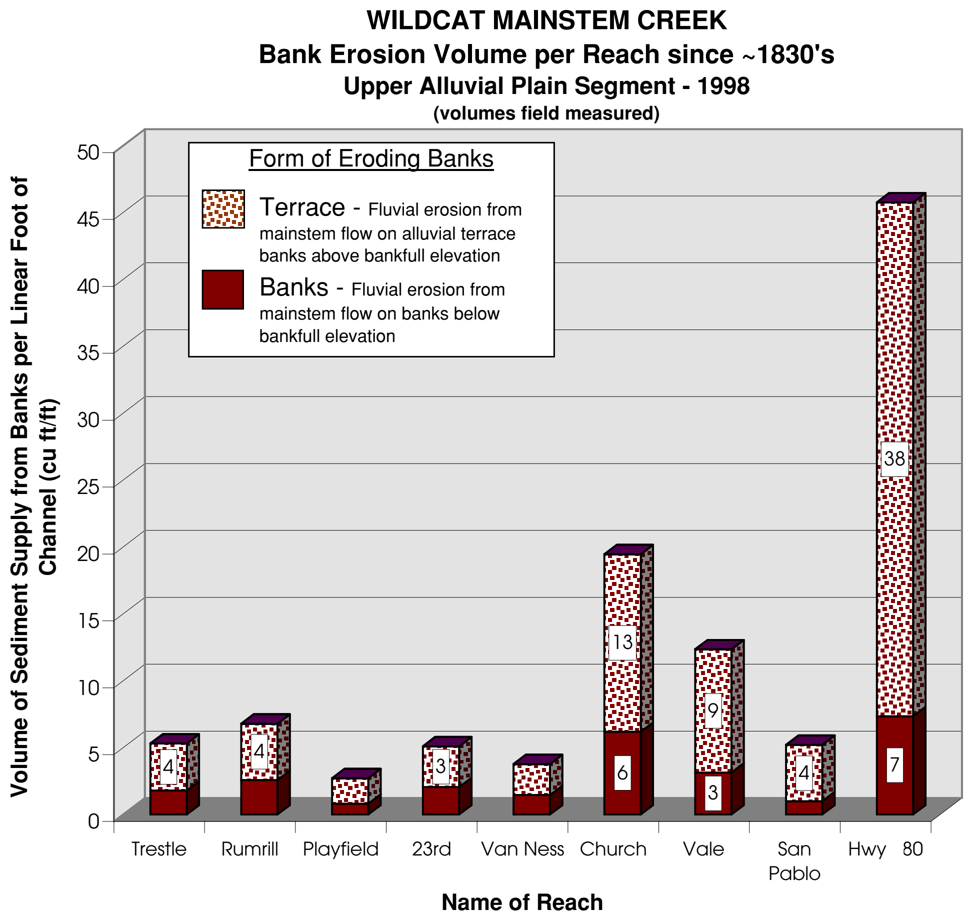
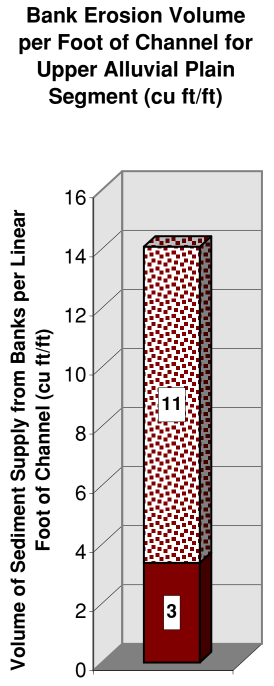


Figure 65b



For the entire Upper Alluvial Plain Segment, there is about 14 cu ft of erosion per foot of bank length

Figure 66a

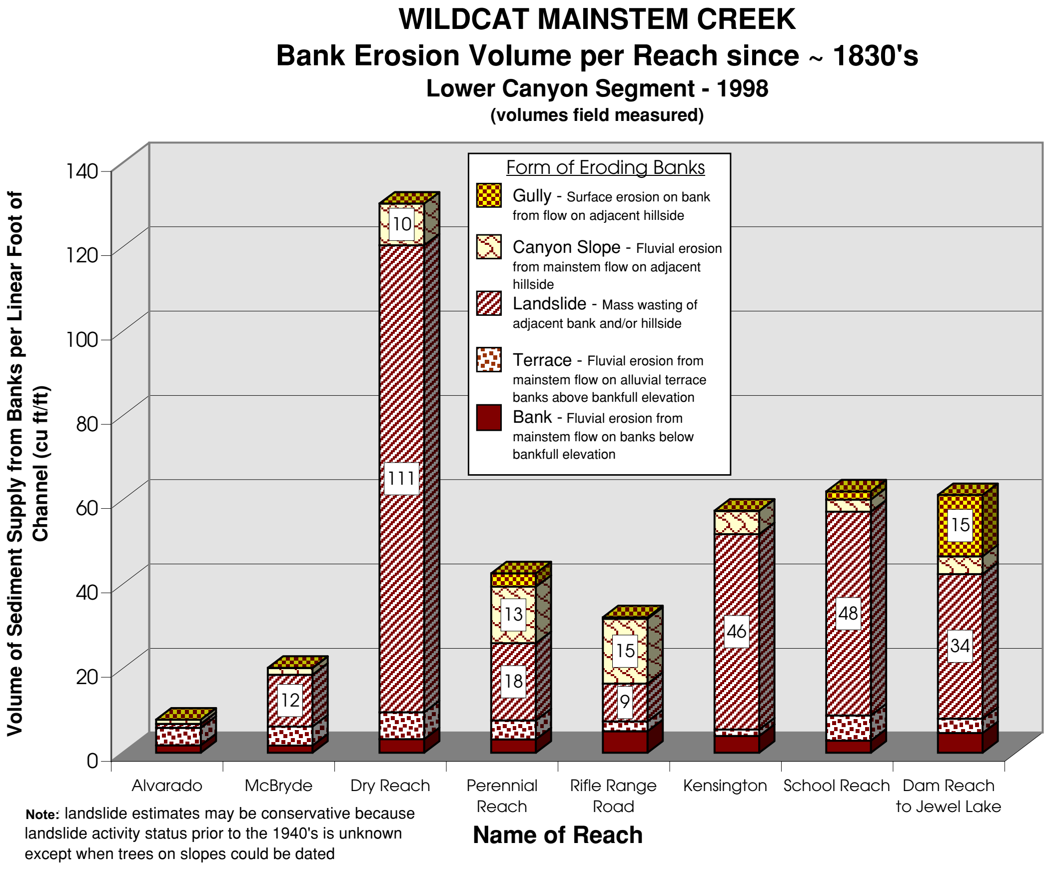
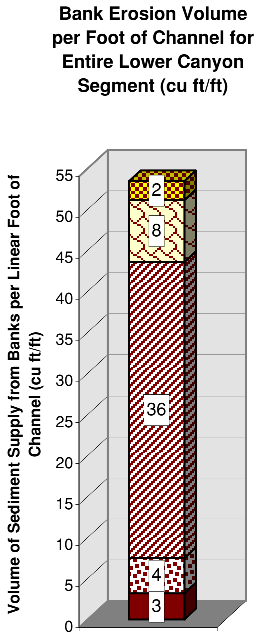


Figure 66b



For the entire Lower Canyon Segment, there is about 54 cu ft of erosion per foot of bank length

Length measurements of streamside erosion (see previous page) can be combined with measurements of height and depth of bank retreat to calculate the volume of sediment supply. The data for lengths of streamside landslides were combined with measures of their depth and height to estimate sediment supply from slides. The amount of sediment supplied by individual features is shown on the Streamline Charts in the Appendix.

Figures 65a and 66a show streamside erosion volumes for the individual reaches in the Upper Alluvial Plain and the Lower Canyon. To compare erosion volumes for reaches of different length, the total volume per reach was divided by reach length. Figures 65b and 66b show the total volumes per foot of channel for each Segment. These volumes do not include the calculated creep rates for soils or landslides, only the volumes measured in the field.

Streamside erosion near the apex of the alluvial fan involves coarse gravels at sharp meander bends occurring along traces of the Hayward Fault. It also involves the fan head, which is a geomorphic feature that can be prone to periodic natural entrenchment by over-steepening its gradient (Chorley *et al*, 1984). The Highway 880 Reach produces more than three times the volume of sediment than any other Alluvial Plain reach. It has produced about 45 cu ft/ft of streamside sediment supply. This is because the terrace banks extend more than 26 feet in height above the channel bed, such that any length of terrace erosion can supply large volumes of sediment. There has also been significant land use-related sediment supply from failure of a 15-ft diameter culvert (Photo 3, page 14). In contrast, Trestle Reach, which has a combination of artificial fill and terrace banks that are only 9 ft above the channel bed, has a supply rate of 4 ft/cu ft. Playfield Reach has the lowest supply, about 3 cu ft/ft.

The Lower Canyon has substantially less terrace erosion than the Upper Alluvial Plain, but it has very large volumes of sediment supply from landslides. This is because of their large size, and their high frequency of distribution and activity. Terraces are discontinuous in the Lower Canyon. This is partly due to their destruction by landslides. More than six terrace levels have been counted in some parts of the Lower Canyon. Such a high number may be caused by differential offsets along faults, activity of landslides, or backwater deposits from ancient debris jams when the creek was at a different elevations.

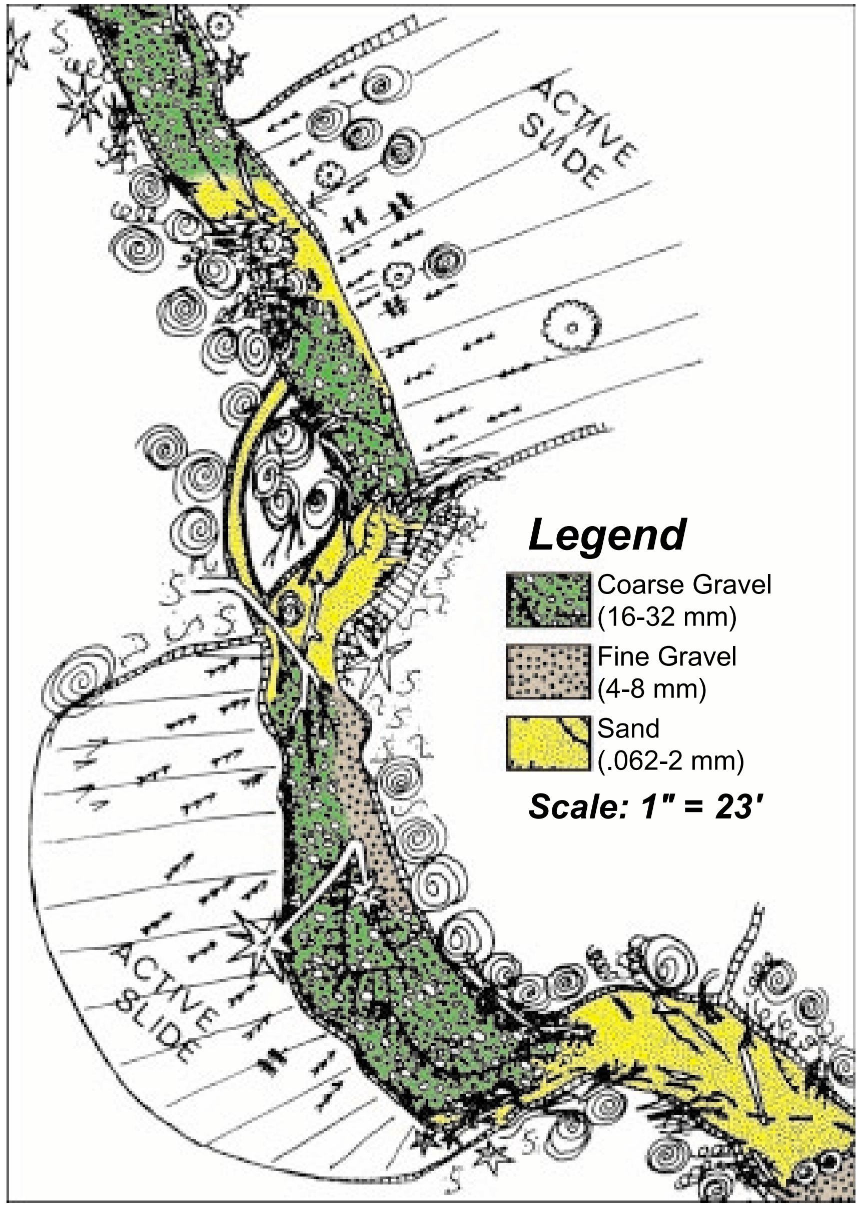
The Lower Canyon Reach with the greatest supply of bank-related sediment is Dry Reach. It has produced about 128 cu ft/ft. Fluvial erosion produces more sediment than landsliding in Perennial and Rifle Range Reaches.

Overall, the Lower Canyon has produced about 54 cu ft of sediment per foot of streamside, compared to 12 cu ft /ft in the Upper Alluvial Plain.

Average Size of Bed Material

This detailed Creek Map of Geomorphic Process (Figure 67) shows the anatomy of Wildcat Creek along a 215 ft-long reach of stream about one quarter mile downstream of Jewel Lake dam. The map accurately portrays the characteristics of planform, bankfull width, vegetation, and woody debris. In particular, it shows patches of sediment that have been sorted both laterally across the channel cross-section and longitudinally along the creek meanders. Patches of sediment that have been sorted into different size classes can be quantified by performing modified Wolman pebble counts (Wolman, 1954) where the average particle size (D50) is determined by statistical analysis. The method is modified by restricting the count to patches rather than averaging the entire bed. As can be seen from Figure 67, the channel bed is often characterized by different D50 size classes across its cross-section.

Figure 67. Geomorphic Map Detail of Wildcat Creek



As we walked along the channel in 1998 and 1999 measuring bank erosion, we also characterized the sorting pattern of sediment on the active channel bed. A graphical documentation of these patterns is shown in the Appendix. The average particle size (D50) on the channel bed was continuously estimated by eye for the length of the Upper Alluvial Plain and the Lower Canyon Segments. The visual estimation of D50 for sediment size classes was calibrated by occasionally performing pebble counts on different patches of sediment. The D50 estimates have an accuracy of +/- one standard size class. The range of particle size for the standard size classes is reported in the legend for Figures 68 and 69. We reported the D50 for all patches having a maximum width or length of at least a third of the bankfull width.

(Photo 46)

(Photo 46) A length of the mainstem Wildcat Creek in the Lower Canyon dominated by cobble-sized sediment.

(Photo 47) The trampled bed of a tributary channel in the east side grasslands shows a grain size of mostly silt.

Figures 68a and 69a show the percent of D50 size classes on a reach basis for the Upper Alluvial Plain and Lower Canyon. Figures 68b and 69b show the percent of different size classes for each segment. The distribution of different sized sediment may be of particular interest to fishery biologists assessing availability of spawning gravel. Abundant sediment that is of sand and finer size classes (silt and clay) adversely affects fish habitat. Pools that scour during high flows can fill with fines during lower flows, effectively reducing potential pool volume. Spawning gravels that need good aeration between the interstitial grain spaces, fill with fines that suffocate eggs and/or entrap alevins.

Wildcat Creek has a greater percentage of sand and finer sediment upstream than it has downstream (32% compared to 24%). This is likely due to the abundance of active slides in the watershed that supply fine-grained sediment. Important to note is that the bed mapping was done after the 1998 ENSO event, which had 200% of normal rainfall. These conditions reactivate earthflows. Our data may reflect the large supply of sand that occurs following storms that activate landslides.

When gravels are analyzed for fish habitat, sand, and finer particles in excess of 30% in the subsurface is considered detrimental. Estimates of average particle size on the bed surface typically underestimate the amount of subsurface fines, so the surface D50 should be considered the minimum amount of fines for the subsurface. Hence, an estimate of 30% on the surface is an indication that conditions are not ideal for salmonids.

The bed material has a greater range of size classes in the Canyon than the Upper Alluvial Plain. Fine to medium-sized gravels are less abundant on the Canyon, while cobble and boulder are nearly absent on the Alluvial Plain. Very coarse gravels and small cobbles are generally more abundant upstream of Havey Creek (above Perennial Reach). The Dam Reach has more clay-sized bed surface sediment than any other reach in the Lower Canyon.

When sediment supply is high, the bed tends to become finer in dominant grain size. When the sediment supply is low, the bed tends to coarsen. We have made these observations by comparing the 1987 maps to conditions observed during various reconnaissance surveys. Comparisons of earlier geomorphic maps of Wildcat Creek indicate that the high sediment supply from the years of 1882, 1983, and 1986 caused the bed to be patchier with more size classes and dominated by finer size classes. During the following years of low sediment supply, the bed coarsened and became less patchy. Following the wet season of 1998, the channel bed showed an increase in fines and patchiness again.

Average Size of Bed Material

Figure 68a

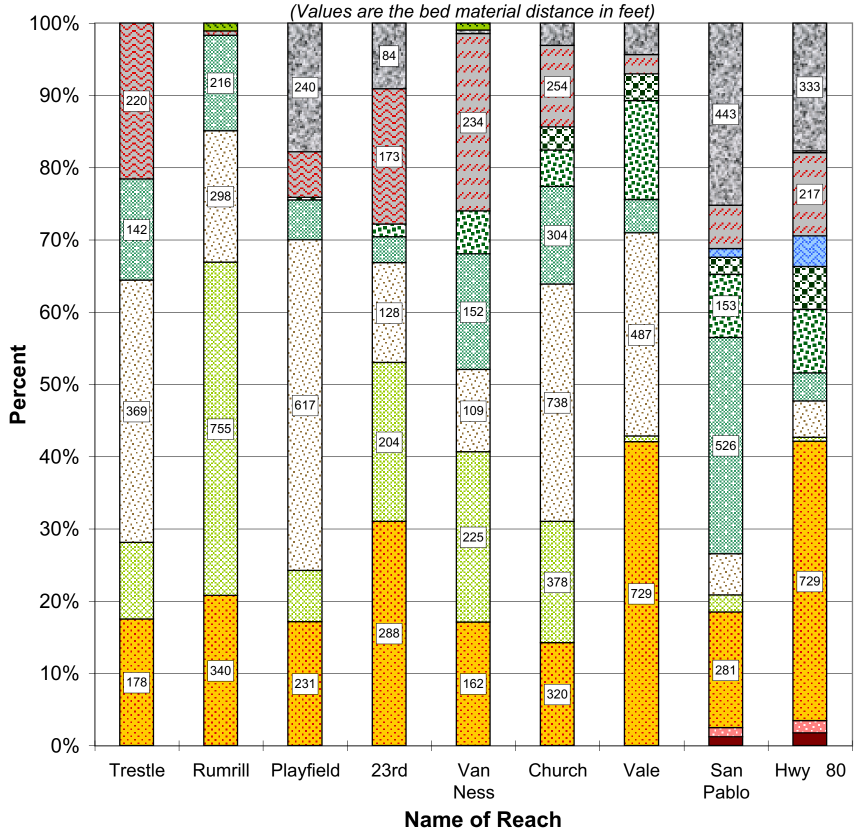

WILDCAT CREEK
Sediment D50 Size Classes and Bed Material for
Different Reaches
Upper Alluvial Plain Segment - 1998
(Values are the bed material distance in feet)

Figure 69a

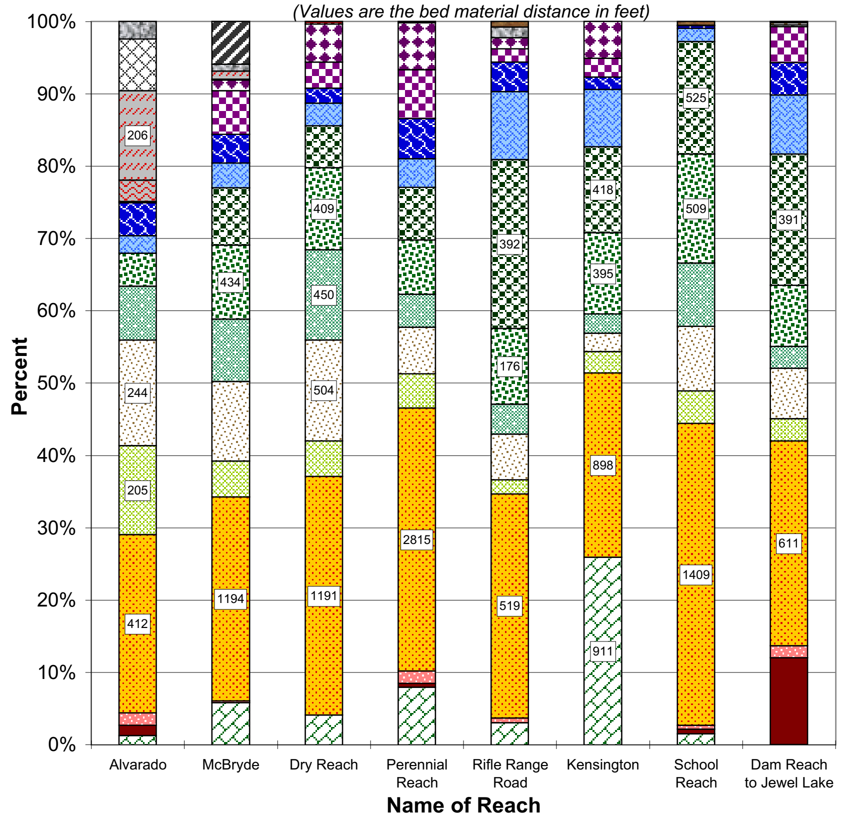

WILDCAT CREEK
Sediment D50 Size Classes and Bed Material for
Different Reaches
Lower Canyon Segment - 1999
(Values are the bed material distance in feet)

Figure 68b

Upper Alluvial Plain
Percent of Sediment D50
Size Classes
and Bed Material

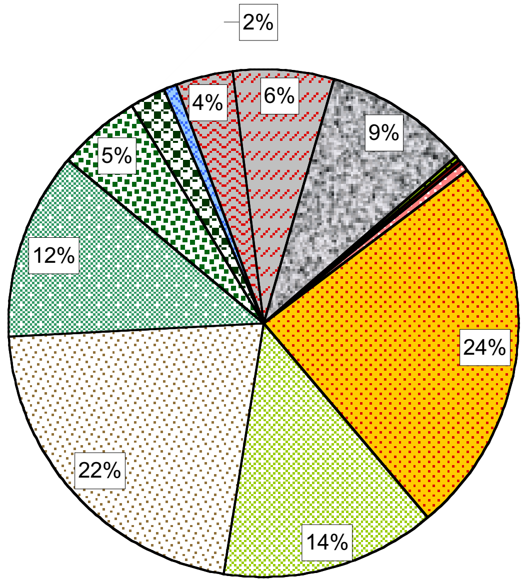
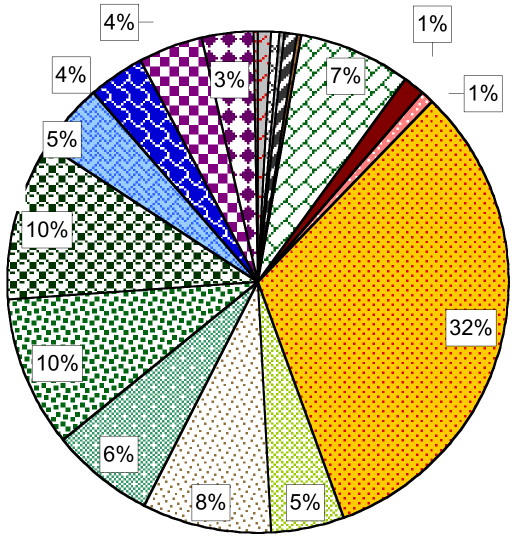


Figure 69b

Lower Canyon Segment
Percent of Sediment D50
Size Classes
and Bed Material



Sediment and Bed Material

- ▨ Grass
- ▨ Organic Matter
- ▨ Wood
- ▨ Roots
- ▨ CMP (corrugated metal pipe)
- ▨ Vortex Rock Weirs
- ▨ Concrete
- ▨ Riprap Debris (mobilized)
- ▨ Riprap (in place)
- ▨ Large Boulder (> 512 mm)
- ▨ Small Boulder (256-512 mm)
- ▨ Large Cobble (128-256 mm)
- ▨ Small Cobble (64-128 mm)
- ▨ Very Coarse Gravel (32-64 mm)
- ▨ Coarse Gravel (16-32 mm)
- ▨ Medium Gravel (8-16 mm)
- ▨ Fine Gravel (4-8 mm)
- ▨ Very Fine Gravel (2-4 mm)
- ▨ Sand (.062-2 mm)
- ▨ Silt (.004-.062 mm)
- ▨ Clay (< .004 mm)
- ▨ Bedrock

Size and Abundance of Pools by Reach

Figure 70a

WILDCAT CREEK
Number of Pools per Volume Class per Reach
Upper Alluvial Plain Segment - 1998
(Pool spacing per linear foot of channel is value shown in box at reach name)

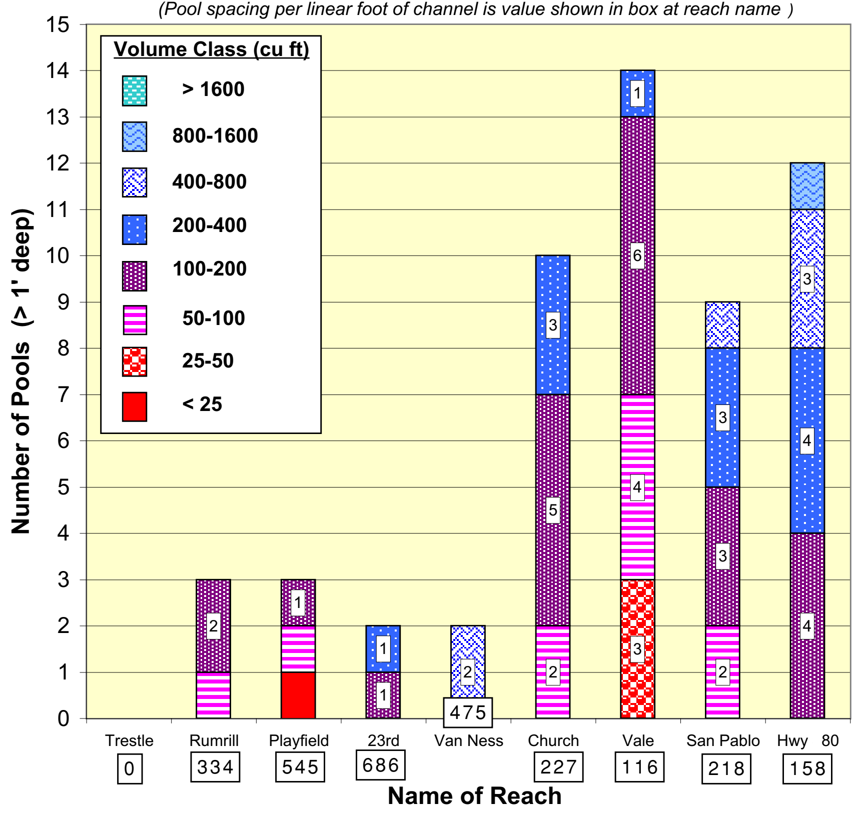
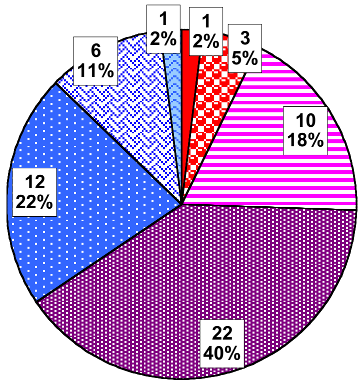


Figure 70b

Upper Alluvial Plain
Segment Number and
Percent of Different
Pool Volume Classes
(pools > 1' deep)

(In each white box, number on top is the number of pools; number on bottom is the percent of pools per size class)



Total number of pools: 55
Mean pool spacing: 245 feet
Channel length = 2.55 miles

Figure 71a

WILDCAT CREEK
Number of Pools per Volume Class per Reach
Lower Canyon Segment - 1999
(Pool spacing per linear foot of channel is value shown in box at reach name)

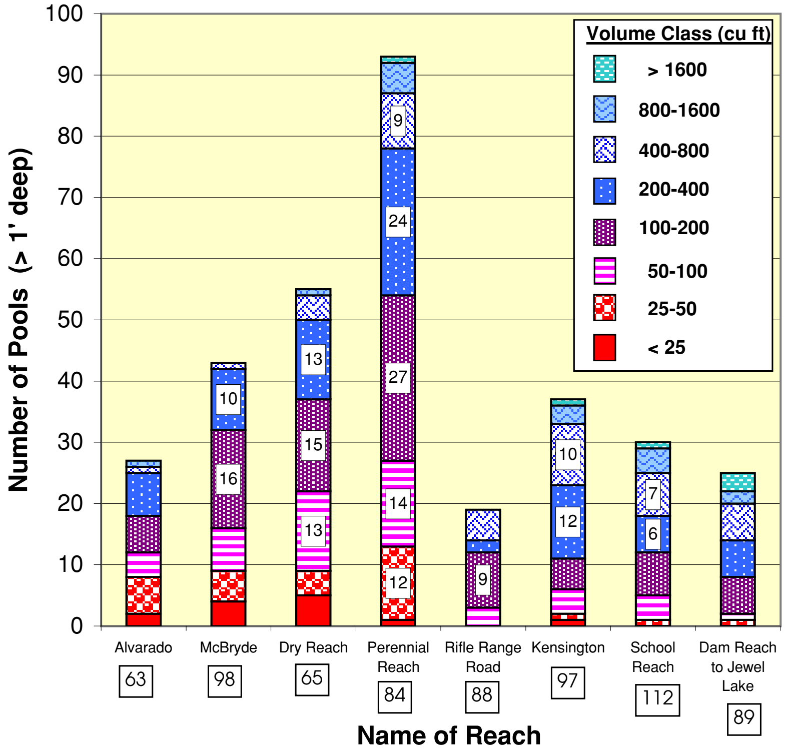
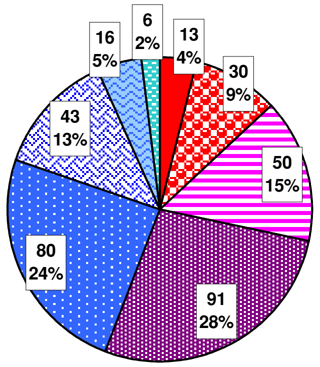


Figure 71b

Lower Canyon
Segment Number and
Percent of Different
Pool Volume Classes
(pools > 1' deep)

(In each white box, number on top is the number of pools; number on bottom is the percent of pools per size class)

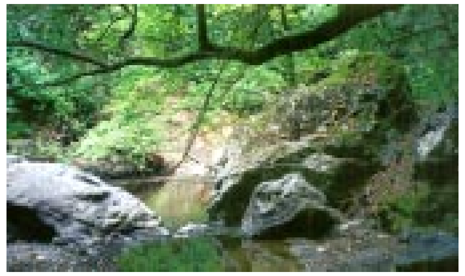


Total number of pools: 329
Mean pool spacing: 86 feet
Channel length = 5.33 miles

Alternating pool-riffle morphology is expected in natural streams with coarse sand or larger bed material (Leopold, 1994). For these types of channels with well defined meanders, the expected pool spacing is 5 to 7 bankfull widths (Dunne and Leopold, 1978). This spacing is related to the meander wavelength, where scour and pool formation is found at the outside bend of meander curves.

There are other natural stream morphologies with different pool spacing. Step-pool channels for example, have a spacing of 2-4 bankfull widths. This morphology is not present in mainstem Wildcat Creek below Jewel Lake. Channels with sandy beds can also have plain-bed morphology, which generally lacks pools or topographic relief of the bed. We observed plain-bed morphology in the aggrading Rumrill Reach, where the bed was dominated by sand and fine gravels (see Photo 30, page 46).

For pools deeper than 1.0 ft, we measured mean width, length, maximum depth, and pool tail-out depth at riffle crests. The latter parameter was measured to determine minimum depth during summer drought. Pool volume was computed by subtracting water depth at the pool tail-out from maximum pool depth. Then the adjusted maximum depth for low flow was multiplied by 0.5 to approximate average depth. This was multiplied by length and mean width to estimate volume.



(Photo 48)
A deep pool is formed by scour around boulders.

Figures 70a and 71a show the number of pools per volume class per reach in the Upper Alluvial Plain and Lower Canyon Segments. Note the large difference in vertical scales. Figures 70b and 71b summarize the data for the Segments. Individual pool locations are shown in the Streamline Graphs in the Appendix. The number of pools in the Alluvial Plain was observed to be greater than normal because of the previous El Niño winter.

Only two reaches had the expected pool spacing. Vale Reach had a spacing of 116 ft, or 5 bankfull widths, and Highway 880 Reach had a spacing of 158 ft or 7 bankfull widths. It also had the greatest number of large pools. The number of pools drops dramatically downstream of Church Reach. During years of normal rainfall some of these pools may dry completely.

The Lower Canyon has more pools and larger pools than the Alluvial Plain. Pool spacing is therefore much shorter. Average pool spacing in the Upper Alluvial Plain was 245 ft, while in the Lower Canyon it was 86 ft. Alvarado Park had the most pools.

Pool volumes tend to increase in the upstream direction, although discharge decreases significantly upstream of Havey Creek. The greater frequency and volume of pools upstream of Havey Creek is partly due to the incision caused by Jewel Lake dam, the low sediment supply, and plunge pool scouring from debris jams.

Causes, Volumes, and Depths of Pools

Figure 72

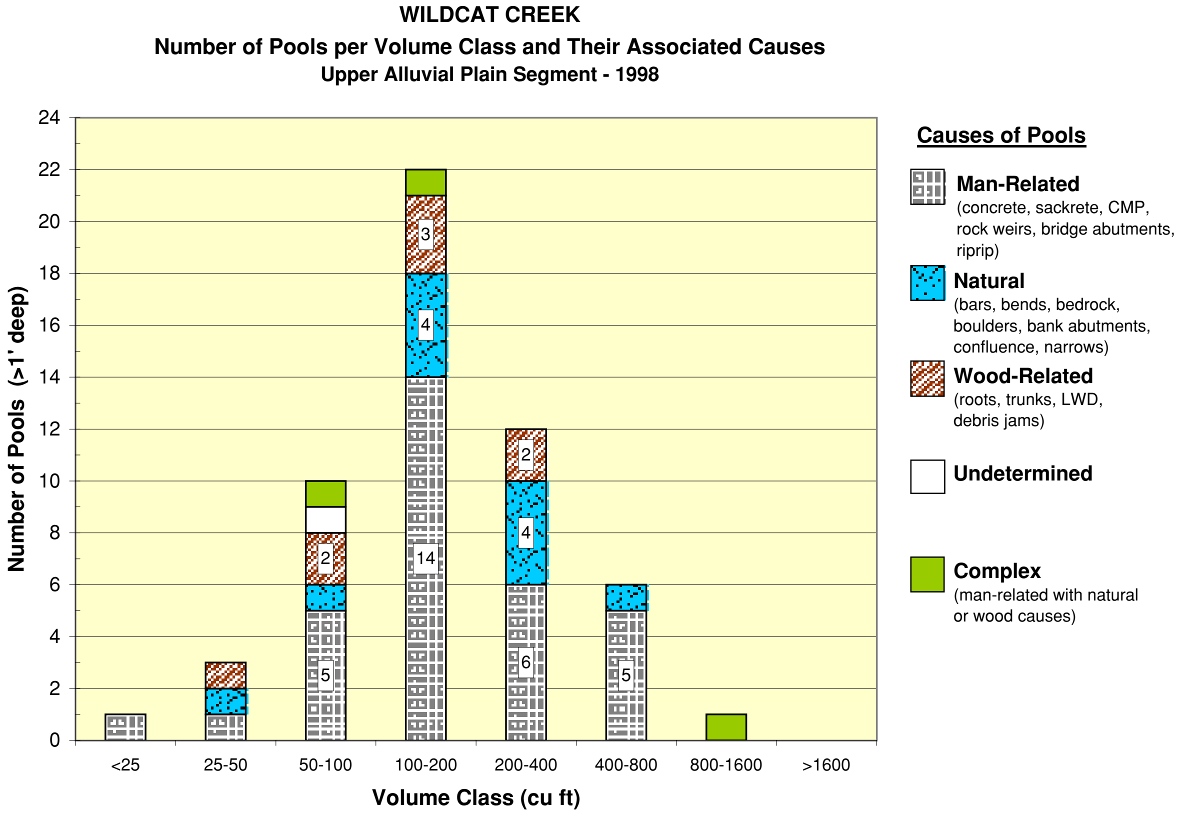
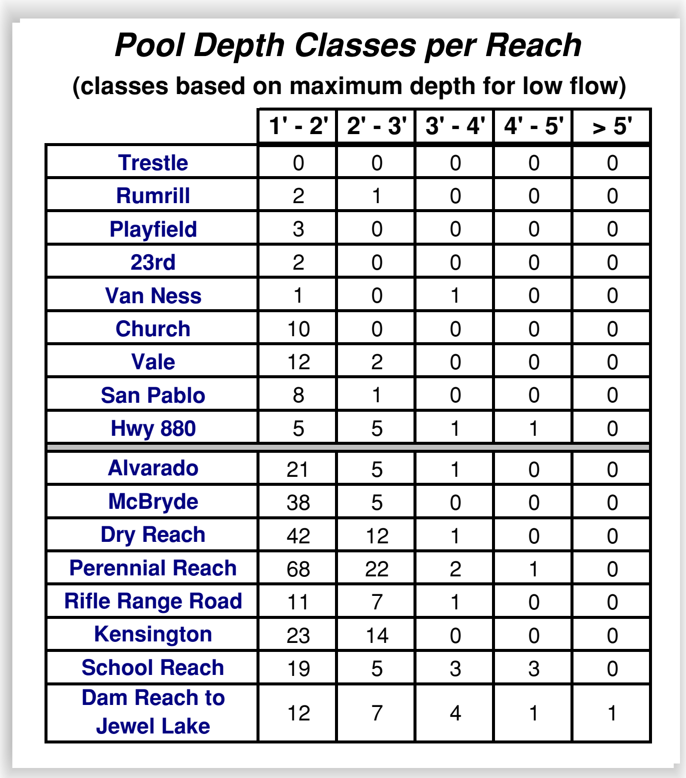


Table 14

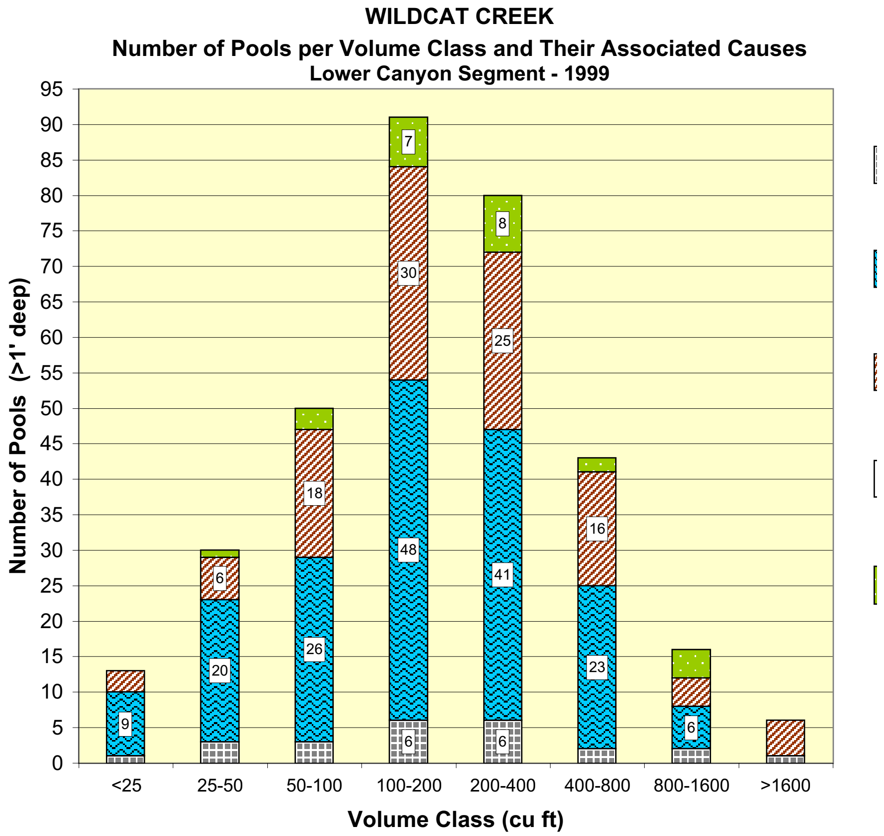


Pool Depth Classes per Reach

(classes based on maximum depth for low flow)

	1' - 2'	2' - 3'	3' - 4'	4' - 5'	> 5'
Trestle	0	0	0	0	0
Rumrill	2	1	0	0	0
Playfield	3	0	0	0	0
23rd	2	0	0	0	0
Van Ness	1	0	1	0	0
Church	10	0	0	0	0
Vale	12	2	0	0	0
San Pablo	8	1	0	0	0
Hwy 880	5	5	1	1	0
Alvarado	21	5	1	0	0
McBryde	38	5	0	0	0
Dry Reach	42	12	1	0	0
Perennial Reach	68	22	2	1	0
Rifle Range Road	11	7	1	0	0
Kensington	23	14	0	0	0
School Reach	19	5	3	3	0
Dam Reach to Jewel Lake	12	7	4	1	1

Figure 73



Pools have a natural frequency of occurrence associated with their meander bends. Surface waters forced toward the out side bend of a channel create a scour pool, while sediment is transported toward the inside bend forming a point bar. When there is an abundance of pools with spacing less than the expected 5–7 bankfull channel widths, the "extra" pools are often created by scour from flow obstructions not associated with the meander. Large woody debris, boulders, and bedrock, are common pool-forming obstructions.

Figures 72a and 73a show the causes and numbers of pools per volume class for the Upper Alluvial Plain and Lower Canyon. Note the difference in vertical scales. Although individual causes were identified for each pool in the field, we have lumped them into 4 main categories: man-related, natural, wood-related, and "complex." These are further explained in the legend for the graphs.

The number of man-related pools (65%) exceeds the number of natural pools on the Upper Alluvial Plain. In the Canyon, the number of naturally caused pools is greater than the number of man-related pools. Pool spacing for natural and "complex" pools combined is 195 ft, within 7 average bankfull widths. By having wood in the channel, pool spacing is reduced to 4 bankfull widths. Wood accounts for 33% of the pools in the Canyon and 16% in the Upper Alluvial Plain. The most common volume class for both segments is the 100-200 cu ft.

Table 14 shows the maximum pool depth determined for low flow by subtracting the tail-out of the pool from the maximum water depth. Deeper pools were more abundant in the Lower Canyon and most deep pools were formed by wood. The Upper Alluvial Plain had 22 % of its pools deeper than 2 ft, whereas the Lower Canyon had 29%. Individual pool depths are noted in the Streamline Graphs in the Appendix.

(Photo 49) A pool is formed by scour over a debris jam.

Distribution and Type of Large Woody Debris

(Photo 50) *An accumulation of different types of woody debris stores upstream sediment.*

Large woody debris (LWD) plays a major role in the form and function of channels in Wildcat Watershed. It helps establish the distribution and abundance of pools, and creates places to store large amounts of sediment that slows its downstream delivery. It increases the risk of flooding by obstructing the flow of water at constrictions such as culverts and bridges.

To begin to understand the interactions between the riparian sources of LWD and fluvial processes, data were collected on number and species of LWD elements per stream reach. Individual elements of LWD and woody debris jam locations are shown in the Streamline Graphs in the Appendix. The distance location of each LWD element having an average diameter greater than 8 in was recorded. We also noted trees or brush that leaned or hung into the flow and caused local scour. They represented about 10% of the total LWD. Willows, in particular, commonly function this way.

Figures 74a and 75a show LWD distribution and species composition per reach. Figures 74b and 75b summarize the data per Segment.

In the Upper Alluvial Plain, the total number of LWD elements was 22, with an average spacing of 612 ft (about 24 bankfull widths). We know that 8 of these pools were caused by woody debris. Willows comprise most of the LWD in the Upper Alluvial Plain. As Figure 74b shows, they represent 50% and bays represent 18% of the total LWD. On the Alluvial Plain, the abundance of woody debris corresponds more to the volume of sediment provided by streamside erosion than the form of erosion or its length. If local streamside erosion delivered most of the LWD to the channel, then spatial correlation between erosion and LWD suggests that for conditions in 1998 there has been little transport from its place of origin. Hwy 880 Reach has the shortest spacing of LWD, Trestle, 23rd, and Rumrill reaches have no LWD. Much more wood may have previously existed in the stream along the Alluvial Plain when there was more mature riparian vegetation and there was little or no effort by people to remove wood.

In the Lower Canyon, the total number of LWD elements is 1,481. This represents an average spacing of about 19 ft, which is less than one bankfull width. The species that contribute most LWD are alder (44%), willow (31%), and bay (16%). The diversity of species that contribute to LWD is greater in the Lower Canyon than the Upper Alluvial Plain. (Figure 75b). The incidence of bay trees as LWD in the channel is much greater along the mainstem channel downstream of Havey Creek than upstream. Havey Creek is located at the upstream end of Perennial Reach. Live oak is commonly a source of LWD in the Lower Canyon. There does not seem to be any relationship between the amount of LWD in the Lower Canyon and length of volume of bank erosion, or the form of erosion. This is probably because much of LWD has been transported away from its point of origin.

Figure 74a

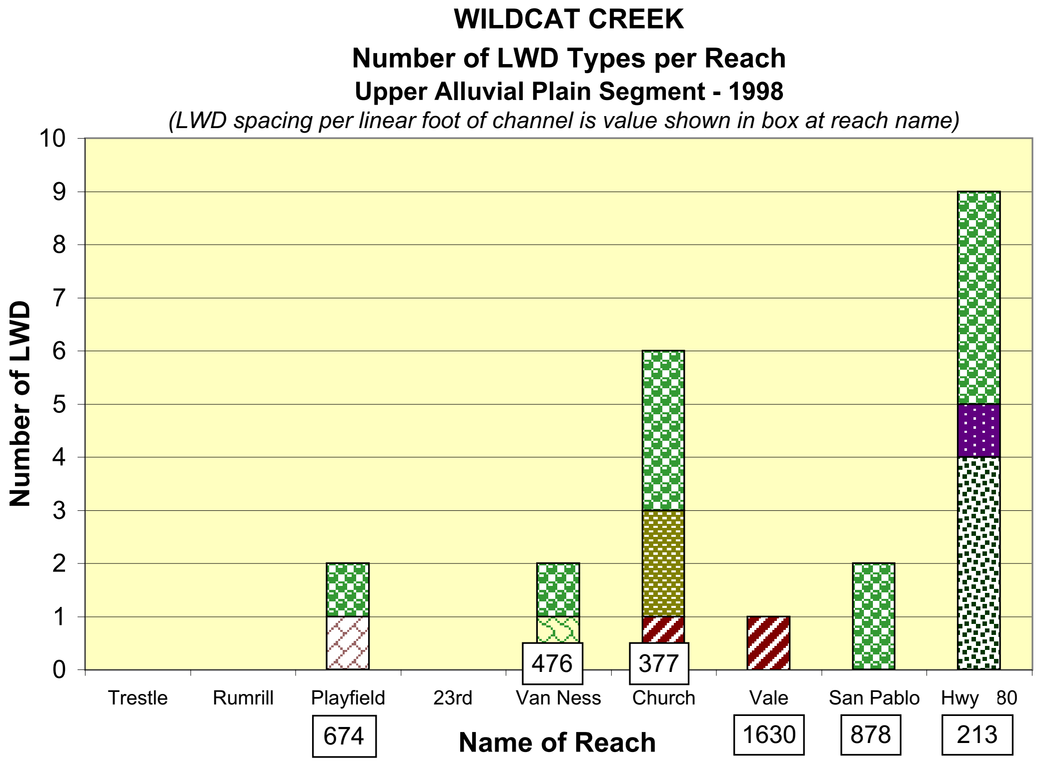
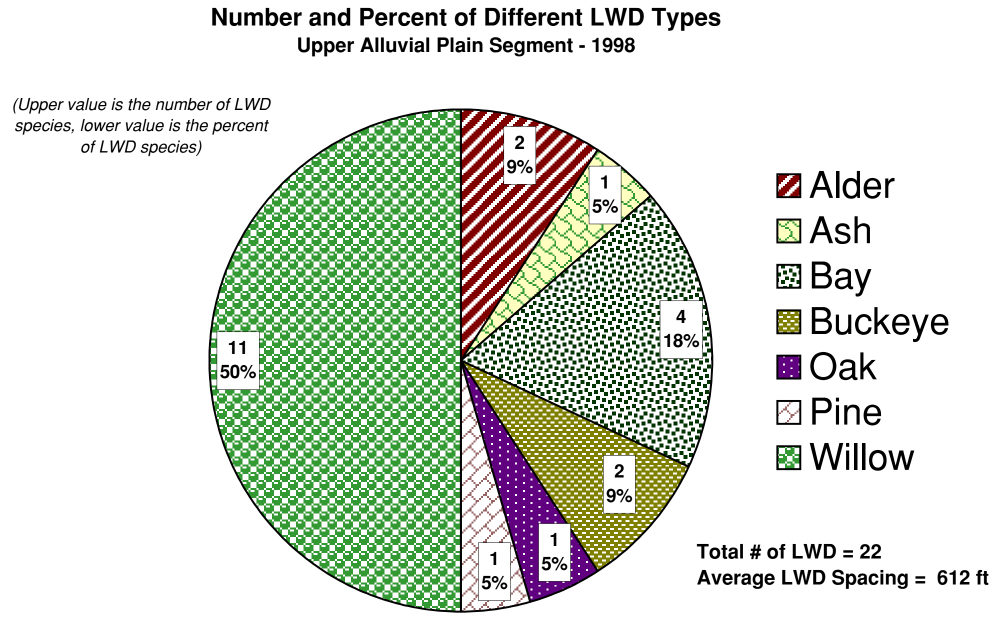


Figure 74b



Spacing of LWD is shortest in Rifle Range Reach and longest in Alvarado Reach. The difference in spacing in the Alvarado Reach is caused by two 6-ft diameter culverts at the upstream end that cause it to function as a bottleneck for LWD. Much of the wood in the Canyon is therefore not delivered to the Alluvial Plain. The next lowest spacing is in the McBryde Reach that may have occasional removal of LWD by EBRPD maintenance crews, and by private landowners along the urbanized McBryde Reach. During floods, large quantities of LWD can be transported great distances. Some standing trees in the Canyon that were tagged with distance markers during 1996 were subsequently ripped from their banks by large floating woody debris and transported more than 500 ft downstream during 1997 and 1998 floods.

Location and condition of large woody debris jams were also assessed. The deepest pools were often associated with debris jams. The debris jams were evaluated for sediment storage, flow obstruction, and management action. Figure 76 shows that a total of 47 debris jams completely spanned the creek, 33 were partly blown-out, 22 were remnants of the past, and 6 had been removed by maintenance crews. The total of 111 debris jams for 1999 represents a substantial increase from either 1987 or 1996 counts, when there were only 36 and 16 debris jams, respectively.

The LWD of debris jams can be redistributed rapidly during flood flows. The deep pools associated with debris jams may therefore be short-lived. On average, the debris jams in the Lower Canyon appeared to be storing less sediment during 1999 than after 1987, which still reflected catastrophic sediment supply from landslides associated with the record storm and flood event of 1982. These differences in sediment storage probably reflect differences in sediment supply among these years.

(Photo 51) A bay tree splits apart in 1996 summer after suffering severe rot from a fungal disease that attacked many trees. This was an important mechanism of woody debris recruitment of this species.

Figure 75a

WILDCAT CREEK
Number of LWD Types per Reach
Lower Canyon Segment - 1999
(LWD spacing per linear foot of channel is value shown in box at reach name)

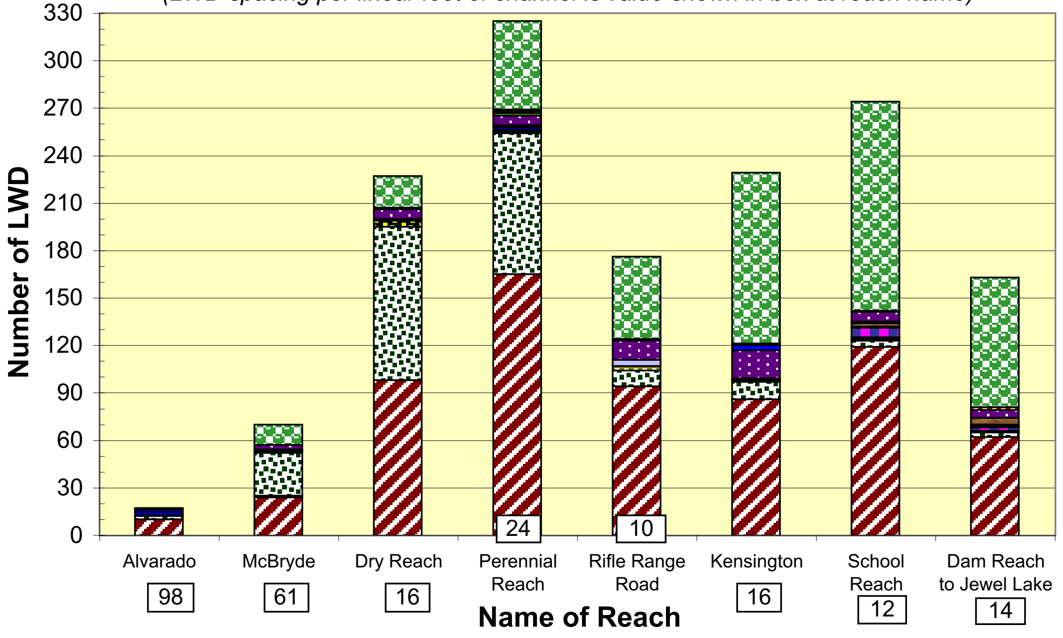
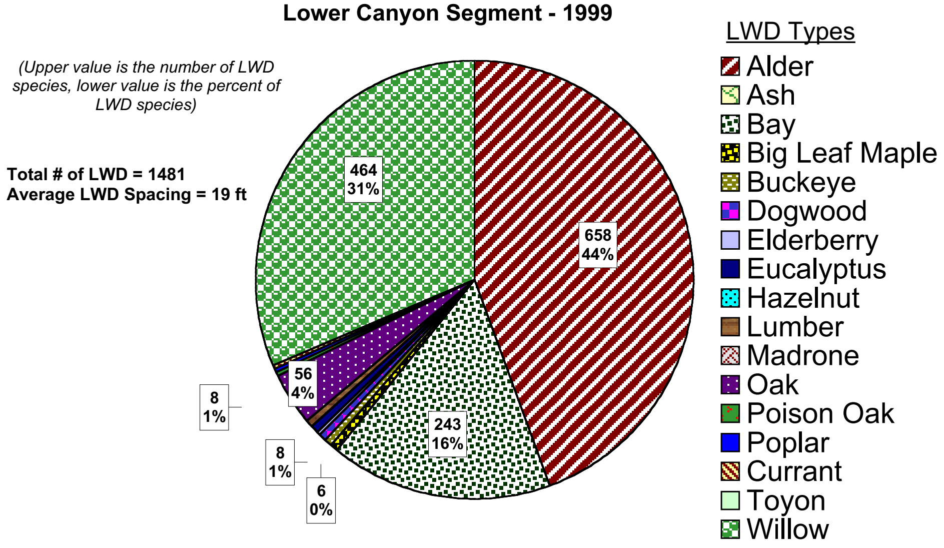


Figure 75b

WILDCAT CREEK
Number and Percent of Different LWD Types
Lower Canyon Segment - 1999

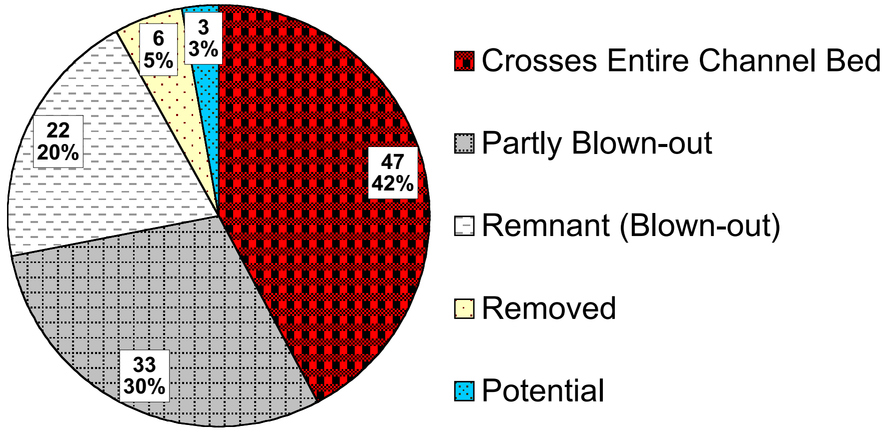


(Upper value is the number of LWD species, lower value is the percent of LWD species)

Total # of LWD = 1481
Average LWD Spacing = 19 ft

Figure 76

WILDCAT CREEK
Debris Jam Characteristics
Combined Upper Alluvial Plain and Lower Canyon Segments 1998-99



(In each white box, number on top is the number of debris jams; number on bottom is the percent of debris jams)

Total number of debris jams = 111

How Wood Enters Channels

The geomorphic and fluvial processes that supply wood to the channel need to be identified if an understanding of the recruitment and loss of wood to the system is desired. The location of LWD was recorded relative to its position along the centerline tape pulled in the field. How the wood was supplied to the channel was determined when possible. If it could not be determined, it was recorded as float, meaning that it floated to its present position. Several categories of LWD recruitment were devised that involved related processes. These include:

1. bank erosion (lateral migration and undermining);
2. landslides;
3. rammed (uprooted or ripped from the banks by large floating debris);
4. bent or leaning into the flow (functioning as large woody debris even though diameter may be less than 8 in);
5. gravity (falls from disease, windthrow, or is hit by another tree);
6. aggraded (deposited sediment fills around tree trunk incorporating it into the active bed); and
7. human-induced (for example, lumber or stumps discarded into creek bed).

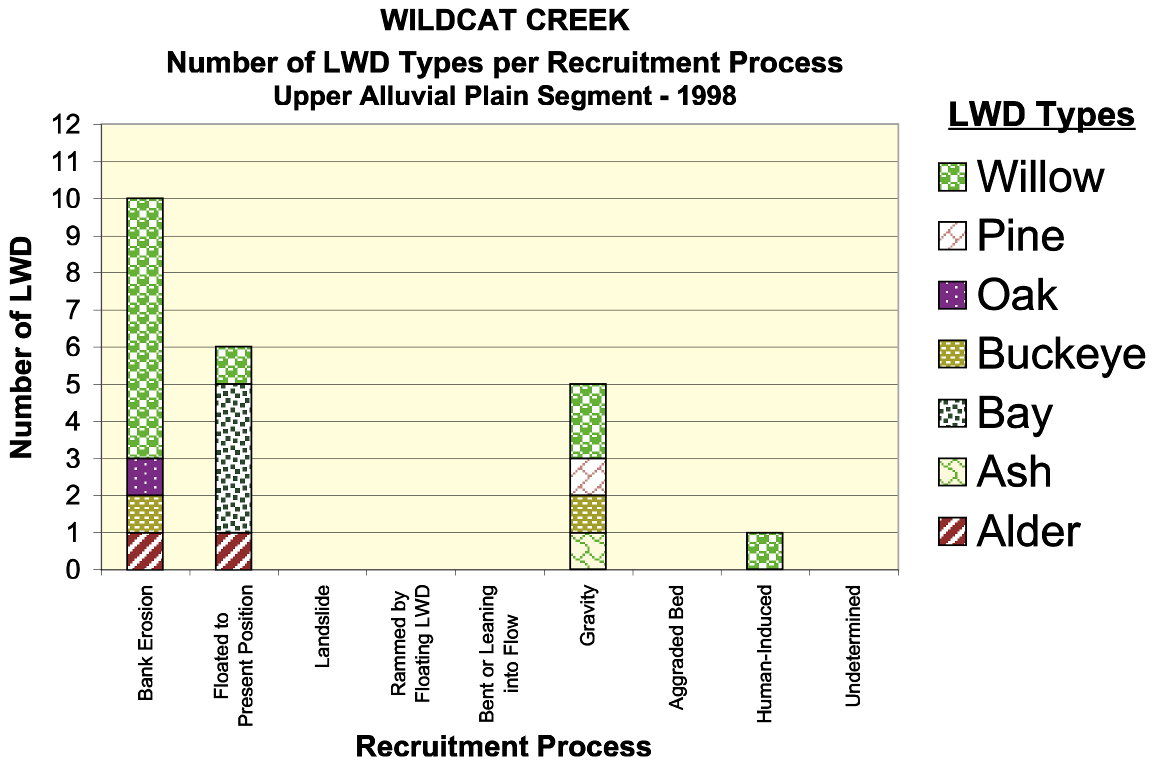
Figures 77a and 78a show the number of LWD species plotted by recruitment process per reach for the Upper Alluvial Plain and the Lower Canyon. Figures 77b and 78b summarize the data by Segment.

The Upper Alluvial Plain receives most of its woody debris form bank erosion (45%), followed by gravitational processes (23%), and by human inputs (5%) (Figure 77b). About 27% of the LWD floated to their measured location, its original source could not be ascertained. Willows dominated the different recruitment processes on the Upper Alluvial Plain, yet more bay trees had been tallied as float (Figure 77a). This is probably because many bay trees were observed to have fallen in the stream during the summer of 1996.

Figure 78a for the Lower Canyon shows that the majority of woody debris (54%) had floated to its observed position. Alder species dominated the float category. Of the processes of recruitment that we could identify, landsliding exceeded the supply from bank erosion. Input from the categories of bank erosion (12%), landslides (13%), and leaning into flow (13%), were nearly equal (Figure 78b). Gravity and ramming each account for about 3% of the input. This means that 49 LWD elements

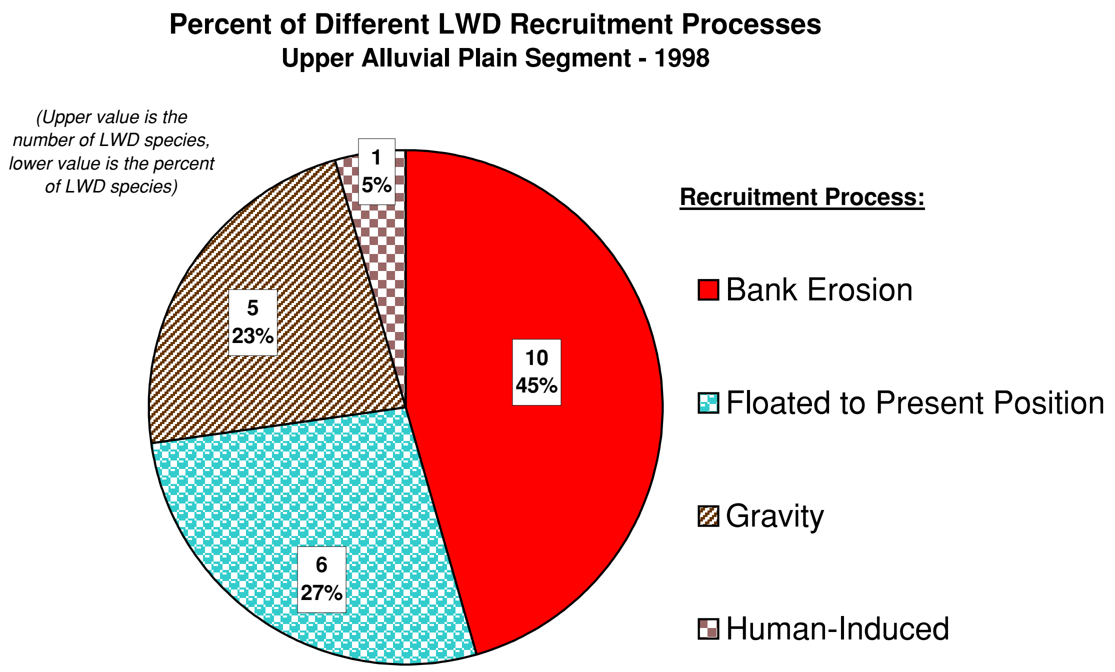
(Photo 52) Some alders are literally ripped from their beds when large floating debris rams into them during floods, May 1997.

Figure 77a



WILDCAT CREEK
Number of LWD Types per Recruitment Process
Upper Alluvial Plain Segment - 1998

Figure 77b



Percent of Different LWD Recruitment Processes
Upper Alluvial Plain Segment - 1998

(Upper value is the number of LWD species, lower value is the percent of LWD species)

were contributed to the channel by other large floating debris that literally ripped other trees from the banks. Most of the trees that were uprooted were alder that tend to grow near bankfull. Many of the oaks were supplied by landslide processes rather than by fluvial processes.

Amount of wood, its input, and spacing was quite different in the two years before 1999. Figure 79 shows the change in LWD over time. In 1996, 63 elements of LWD were counted as newly recruited to the channel in the Lower Canyon. How much wood was already in the channel in not known. Yet, if we assume that all the wood that was tallied as floated in 1997 had been in the channel in 1996, the spacing may have been about 158 ft. In 1996 the new types LWD were bay trees that had fallen during the summer and appeared to be suffering from a fungal rot, perhaps stressed from previous drought conditions of the late 1980s. Dominant recruitment processes for new LWD were landsliding (41%), followed by gravitational processes during the dry season (29%), and fluvial bank erosion (27%). In 1997 a total of 392 LWD elements were counted in the Lower Canyon that changed LWD spacing from the projected 158 ft from 1996 to 72 ft. The 1997 processes that dominated input were bank erosion (22%), followed by bent or leaning (15%), landsliding (13%), and gravity (14%). By 1999, LWD spacing changed from 72 ft to 19 ft.

These data provide a glimpse at the dynamic nature of how LWD comes into the channel, how it influences the recruitment of more wood, and how it effects sediment storage and bank erosion. The way wood is lost from the channel can also change. As entrenchment increases, the opportunity to float the wood to the high banks and remove it from frequent flow decreases. This means that the physical breaking and rotting of the wood within the channel becomes more important than its removal by floods. In addition, the removal of LWD by man increases as the number of culverts and bridges that it can obstruct increases.

(Photo 53) Large woody debris is recruited to the channel by fluvial erosion of the banks.

Figure 78a

WILDCAT CREEK
Number of LWD Types per Recruitment Process
Lower Canyon Segment - 1999

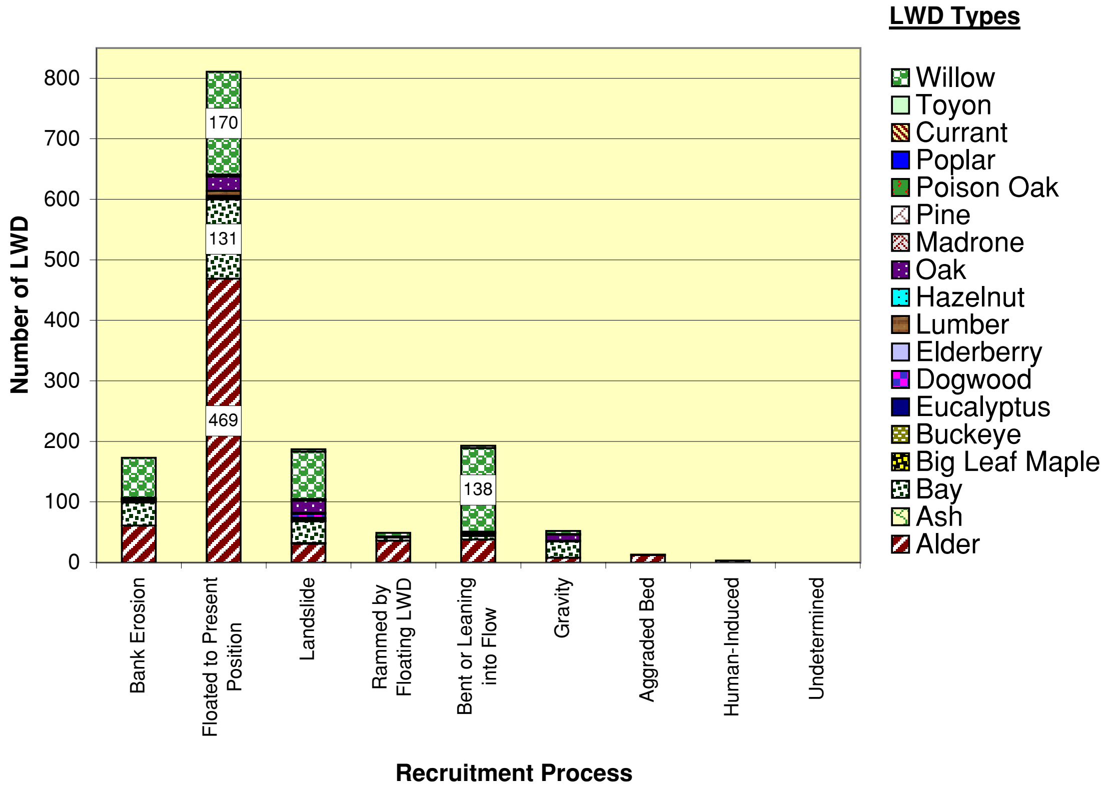


Figure 78b

Percent of Different LWD Recruitment Processes
Lower Canyon Segment - 1999

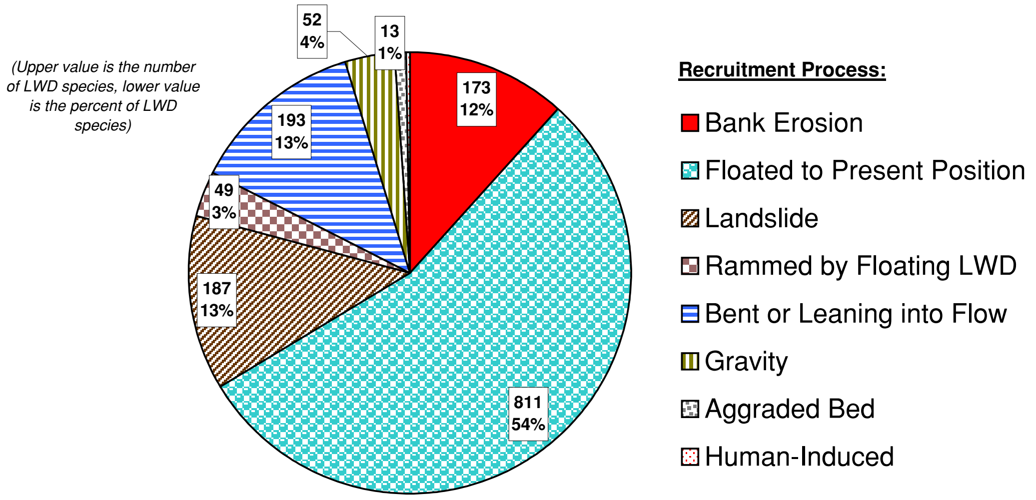
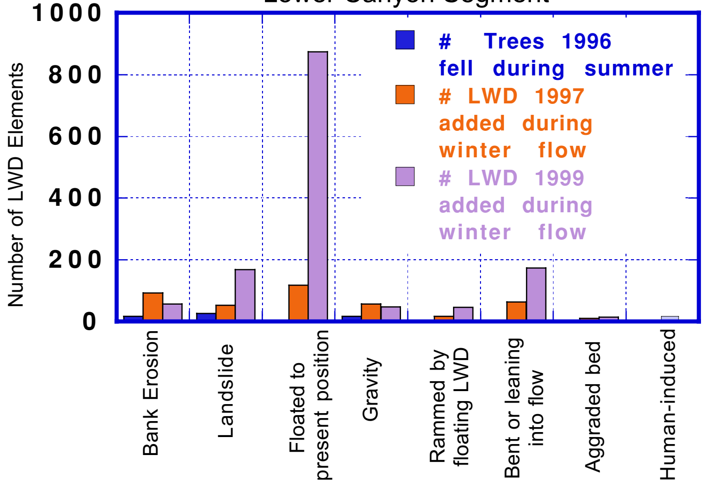


Figure 79

Change in Large Woody Debris over Time
Lower Canyon Segment



Flood Control Channel

Flood Control Project Background

Intensive modern development in the flood-prone areas of Wildcat and San Pablo Creeks began in the 1940s. Contra Costa County started planning a flood control channel as early as the 1950s. In the 1970s, the Federal Goverment started the Model Cities Program. It sponsored community-based land use plans that called for protection against the 100-year flood. It also called for enhanced environmental, aesthetic, educational and recreational opportunities.

Figure 80

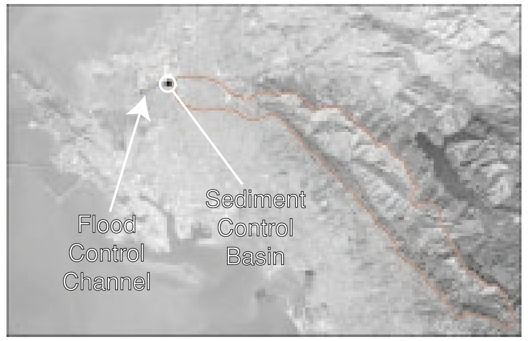


Photo Source: NASA 1996

In the 1970s, the USACE was invited through the Model cities Program to provide flood protection for both creeks. A channel modification project was proposed to extend from the tidal marshlands to Highway 880. A combination of severe channelization and environmental enhancement was proposed. The enhancements included a regional trail, a fishing pond, tree planting, and environmental facilities associated with Verde School.

In the early 1980s, when the proposed federally assisted project did not materialize, Contra Costa County Public Works (CCCPW) proposed low-cost conventional channelization for both creeks. This proposal featured a trapezoidal channel of dirt, riprap, and concrete with no environmental enhancements. Changes in environmental regulations and public protest prevented this proposal from advancing. The County then established an inter-agency, inter-disciplinary design team to develop and implement a new approach. Economic analyses by the USACE showed that extending a project upstream to Highway 880 would not be feasible (Riley, 1989). The new project boundaries extended from the tidal marshlands to the wooden Santa Fe railroad trestle. A consensus plan was completed in 1985 and construction began in both creeks in 1986. In 1996, a Federal project was authorized to modify the consensus plan to improve its environmental components.

Table 15

Records for Sediment Basin at Flood Control Channel			
	year	cu yd	cu yd/yr
Construction of Basin completed	1990		
Basin dredged	1995	6657	
Basin dredged	1996	7602	
Basin dredged	1997	14396	
Basin dredged	1998	10000	
Totals		***38655***	***4832***
Data Source: Tim Jensen, Contra Costa County Public Works *Note: drainage area = 5.4 sq mi to Jewel Lake*			

Environmental Issues Associated with the Flood Damage Reduction Project

The consensus project as devised in 1986 was the first attempt in the country to use fluvial geomorphic design concepts. An equilibrium bankfull or active channel, a riparian reserve area, and a floodplain were designed within the trapezoidal banks of the project. Set-back berms and a regional trail were designed to accompany the new channel. A fish ladder was designed to allow anadromous fish to migrate through the sediment basin and the concrete channel at the railroad crossing. The project included marsh restoration along Wildcat Creek, with a sediment catchment basin to reduce the sediment load to Wildcat Marsh. The trapezoidal banks were designed to convey a flow 2,300 cfs, the projected 100 year flood. The 'inner' bankfull channel was designed to convey the 1.5-year flow of 300 cfs.

By 1996, the bankfull channel was evidently not self-maintaining and the fish ladder actually inhibited fish passage. Additionally, the low flow channel required for fish passage through the sediment basin had never been constructed. The Wildcat-San Pablo Creeks Watershed Council is now addressing the redesign of these features through the USACE Section 1135 authority. A meeting of Federal and state agencies and environmental experts are considering a bypass channel for fish as an alternative to the fish ladder.

In 1996, the Waterways Restoration Institute excavated a new channel through the riparian reserve from the Richmond Parkway up to Verde School. The natural meander pattern established by the creek was recreated in a channel that was made as deep as possible (up to 4 ft) at a width of 10-15 ft. Monitoring after winter storms indicated that the channel was efficiently transporting sediment and not filling (Waterways Restoration Institute, 1999). Unfortunately, during maintenance operations in 1998, the County excavated the bed of the inner floodplain below the bed level of the bankfull channel. Subsequently, bankfull flows were diverted from the constructed bankfull channel to the over-excavated floodplain. The bankfull channel filled with sediment. The undisturbed downstream sections of restored bankfull channel have had sufficient flows to maintain their designed geometry to date.

(Photo 54)The waning flood of January 1997 in the trapezoidal flood control channel divides between the constructed bankfull channel on the left and the constructed flood plain on the right. Debris has collectd at the entrance of the low flow channel.

The designs for the fish ladder, channel grades, channel shape in cross-section, and sediment basin are under review for future modification. A report on alternative design modifications is expected to be provided to the Wildcat-San Pablo Creek Watershed Council by summer 20001.

Bedload Caught at the Sediment Catchment Basin

The USACE conducted a review of the project designs in 1999. Records of sediment removal from the sediment catchment basin in the Flood Control Project by the CCCPW were used to estimate sediment input. The analysis revealed that earlier estimates of sediment supply for the basin had been seriously underestimated. Table 15 shows the dredging records for the catchment basin and indicates a short-term bedload capture rate of 4832 cu yd/yr. The 8-year variability ranges from 1300-14,400 cu yd/yr. Sediment deposition has been occurring downstream of the basin as well, so the records do not account for 100% of the bedload.

The two largest floods occurring in Wildcat Creek this century occurred in 1955 and 1982. A new lobe of silt and sand was deposited across the backshore of Wildcat Marsh in 1982. Since 1988, all the flood flows have been contained within the flood control channel. However, none of the flows have been nearly as large as the 1982 flood. How the flood control channel and its sediment retention basin perform during future large floods and influence self-maintenance of the tidal marsh and its backshore remains to be seen.

Tidal Baylands

The tidal baylands are transitional environments between Wildcat Watershed and San Pablo Bay. Both estuarine processes and fluvial processes influence them, and they have important natural attributes of their own. They include the tidal salt marsh of Wildcat Creek. The relative influence of fluvial processes increases landward through the intertidal zone, but most of the tidal zone is dominated by estuarine processes. The tidal baylands are therefore not strictly regarded as part of the watershed.

Figure 81

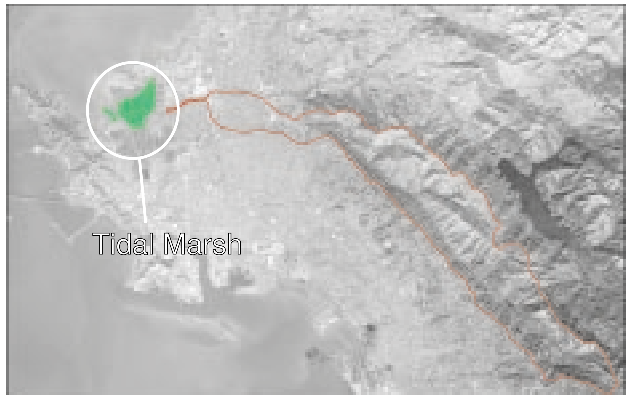


Photo Source: NASA 1996

Varieties of natural functions are attributed to tidal baylands. They trap and store sediment provided from the estuary and the uplands. They dissipate the energy of waves that cross San Pablo Bay and attack the shoreline, spread flood flows from terrestrial stream sources, provide nutrients to the bay ecosystem, and support species-rich communities of baylands plants and animals.

The baylands consist of mudflats, tidal sloughs, natural levees along the largest channels, the foreshore of the tidal marsh, the marsh plain, tidal marsh pannes, and the backshore of the marsh (Figure 82) (Goals Project, 1999). The mudflats gradually slope upwards from about mean lower low water to the vegetated foreshore. The elevation of the foreshore varies with plant species and wave height, but it generally approximates mean tide level at Wildcat Marsh. The mudflat innervates the marsh through the network of tidal channels. The largest channels have low levees. The elevation of the marsh plain varies slightly around mean high water. The plain slopes upwards at the backshore, where the marsh plain transitions into upland.

There are many kinds of tidal marsh pannes. A panne is an unvegetated area of the marsh that is poorly drained and therefore it tends to retain water on the marsh surface during low tide (Collins et al., 1984). Drainage divide pannes exist in the marsh interior, equidistant from neighboring channels. Transitional pannes exist along the backshore. Transitional pannes that form on alluvial sediments are called alluvial pannes (verbal communication Peter Baye, U.S. Fish and Wildlife Service). Drainage divide pannes tend to stay wetter longer than transitional pannes, which tend to desiccate during neap tides in the dry season.

The backshore near creeks is variable due to fluvial influences. At Wildcat Creek, floods from the uplands spread freshwater and fluvial sediments across the backshore, thus altering marsh elevations, soil texture, nutrient availability, and soil salinity. The rapid extension of the alluvial fan of Wildcat Creek over the marshland during the mid 1800s (page 68), and hence the transgression of marshland over the alluvial sediments, is a dramatic example of backshore dynamics.

Figure 82. A Detail of Wilcat Marsh

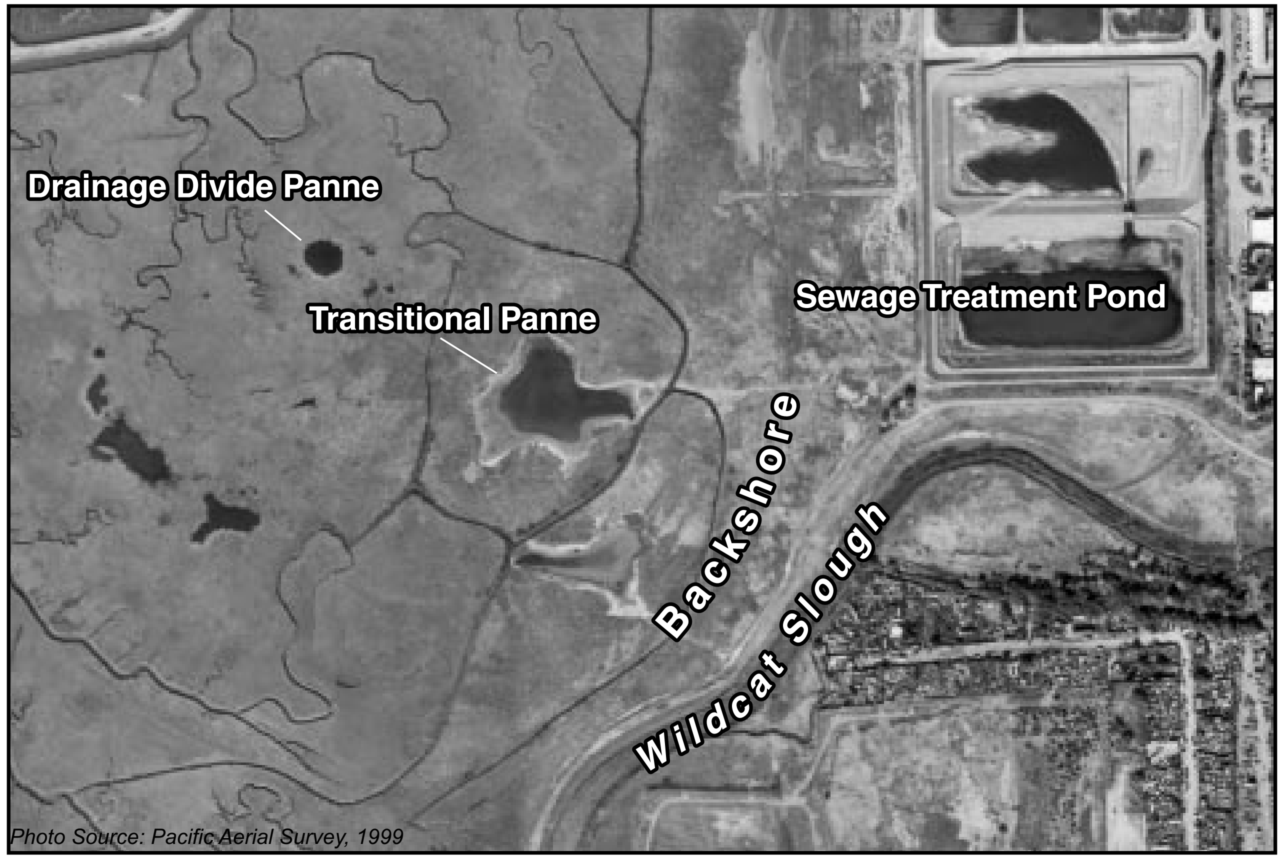


Photo Source: Pacific Aerial Survey, 1999

The evolution and natural maintenance of the tidal baylands require sediment deposition to keep pace with the average rate of sea level rise. Aggradation requires an adequate sediment supply in a depositional environment. For the Wildcat Creek baylands, the depositional environment is the quiet embayment in the northern lee of the Richmond Potrero. The needed sediment is provided in two ways. Each watershed of the Estuary contributes some sediment to the total amount that is distributed by the tides and estuarine currents. The estuarine sediments that are delivered to baylands by the tides contribute mostly to aggradation of the tidal flat, the backshore of the marsh, the tidal marsh channels, the natural levees, and the marsh plain near the tidal channels. The original source of the estuarine sediments might be any watershed of the estuary including the distant Sierra Mountains. Upward growth of the marsh surfaces in interior areas of Wildcat Marsh requires the formation of peat by marsh plants.

Our analysis of historical changes in the baylands shows that foreshore erosion has coincided with reductions in supplies of fluvial sediment from either Wildcat or San Pablo Creeks (page 22). The shape of the tidal slough in cross-section and profile are adjusted to the discharge of Wildcat Creek plus the tidal prism they convey.

For example, reclamation has reduced the flood capacity of sloughs in Wildcat Marsh by causing them to become narrower and more shallow (Haltner and Williams, 1987; Collins 1992; Siegel 1993). Castro Slough, the main channel leading from Wildcat Watershed to San Pablo Bay, is now less than half as wide and deep as it was before the surrounding marshlands were reclaimed. By diking the sloughs and containing floods flows within levees, especially at times of high tide, the backwater floods extend into areas that otherwise might not be affected.

A concrete-capped sewer line crosses Wildcat Creek downstream of the Richmond Parkway. It artificially raises the creek bed above the tides, restricting their upstream extent. The Creek has incised about 2 ft downstream of the sewer line since 1996. The concrete cap is preventing natural adjustment of the upstream gradient.

Plan View Changes of the Mainstem

Some of the most significant changes at the backshore of the Wildcat Marsh have been the result of processes that began far upstream in the Wildcat and San Pablo Watersheds. Of special interest are the dramatic aggradation of San Pablo Creek and the toe of the alluvial fan that expanded bayward onto tidal marshlands after 1817. The following scenario seems likely based upon all available evidence.

Just before European contact in the region. San Pablo Creek and Wildcat Creek were entirely separate. Each had its own way to San Pablo Bay (Figure 83). The Huchiun were most likely using fire to manage their food resources in their homeland including Wildcat Watershed. Based upon field notes from the DeAnza expedition of 1772 (Bolton 1930), Wildcat Creek at the apex of its alluvial fan was already entrenched, but not as deeply as it is today. Members of the expedition described a rather deep arroyo with a narrow riparian forest and little water near Alvarado Park.

Tree ring data from the West-Central Sierra indicates that a pronounced drought lasted in the Bay Area from about 1776-96 (Earl and Fritts, 1986). Sediment transport in Wildcat Creek would have been greatly reduced. Sediment may have started to accumulate in the upland tributary channels, while the lower mainstem channel may have started to incise because of the reduced sediment supply.

During 1798-99, severe rainstorms occurred in the Bay Area (Waananen *et al.*, 1977), whereas the early years following the 1800's were characterized by normal rainfall. Missionaries had removed almost all of the Huchiun from their homelands by this time. The major rainstorm of 1799 would have mobilized the sediment that accumulated in the upper drainage network during the previous years of drought. Aggradation of coarse sediments at the toe of the fan would have ensued while the finer load was transported through the tidal sloughs.

By the early 1800s, irreversible land use changes had begun. The missionaries had established a large herd of cattle in the watersheds in 1817. With abundant pasturage and without many predators, the cattle herd grew rapidly. An 1819 storm caused severe flooding in the north Bay Area (Montgomery, 1999) and it may have activated numerous landslides. With the introduction of cattle came shallow-rooted annual grasses from Europe. We hypothesize that the combined effects of grassland conversion to annual species and the reduced thatch cover from intensive cattle grazing greatly increased the runoff from rainstorms, and thereby initiated a cycle of channel incision and headward extension of tributaries. Channel adjustments to increased runoff increased sediment supply from fluvial sources. By the mid 1830s, cattle herds had grown too large for local consumption, so exportation of hides and tallow began (Purcell, 1944).

The changes in land use and related changes in water and sediment supplies in the Canyon and on the Alluvial Plain began to cause changes at the backshore of Wildcat Marsh. The toe of the alluvial fan began to expand across the backshore, as flows from both San Pablo and Wildcat Creeks became overwhelmed by sediment supply. New avulsion channels formed as the mainstem spread sands and fine gravels on the tidal marsh surface. Sediment cores from the toe of the fan verify the buried tidal marsh at the historical mouths of both creeks (Contra Costa Co, 1985). San Pablo and Wildcat Creeks converged through a tidal slough near the backshore of the marsh sometime between 1827 and 1830 (Figure 84).

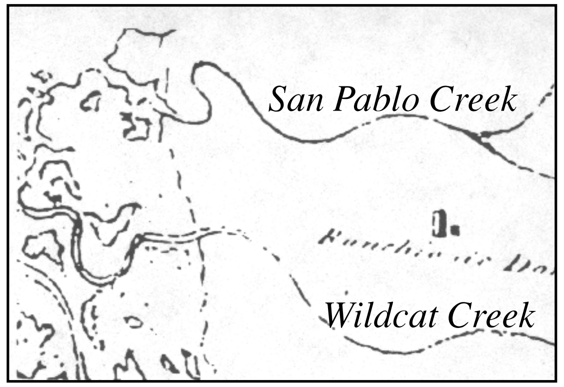
The early 1840's were marked by the onset of another drought. It probably reduced the supply of sediment supply from landslides. However, grazing continued to increase in intensity through the 1850s, until cattle were slaughtered to protect the pasturage (Paddison, 1999). With the increase in cattle, the riparian vegetation in the steep reaches of the drainage system may have also started to diminish as bank erosion and grazing pressures intensified. Until about 1856, San Pablo Creek maintained its tidal connection to Wildcat Creek through a channel along the previous backshore of the marsh. The channel was still deep enough at high tide for small boats and barges to regularly navigated the system. An embarcadero was developed on San Pablo Creek near the backshore of the tidal marsh (see Figure 85).

Creeks around San Pablo Bay flooded many times between 1850 and 1900. There must have been much landsliding and fluvial erosion in San Pablo and Wildcat Watersheds during these years. At some time in the 1860's, the tidal reaches of the creeks and their receiving sloughs began to downsize due to tidal marsh reclamation. Sediment supply from the Estuary also increased at this time from the great influx of hydraulic mining debris from the central Sierra Nevada Mountains and from land use disturbance of other local watersheds draining toward the bay. This contributed to the shoaling and loss of capacity of tidal sloughs in Wildcat Marsh, effectively increasing the base level for Wildcat Creek, and promoting aggradation near the backmarsh. The shoaling may have been particularly exacerbated by backwater effects of the 1861 flood when water from the Sacramento and San Joaquin Rivers flowed along both sides of the Potrero.

Railroads were built across both creeks. Debris jams beneath the trestles also increased backwater flooding. By 1893 (Figure 86) San Pablo and Wildcat Creeks were so choked with sediment in the tidal sloughs and backwater regions of the lower alluvial fan that numerous avulsion channels formed bayward of the channel that connected the two Creeks. Willows encroached onto the toe of the fan, where it had expanded over the salt marsh soils. Major flooding occurred again in 1895. This is about the time when San Pablo Creek abandoned its connection to Wildcat Creek. By 1898 (Figure 87), the two Creeks again flowed separately to San Pablo Bay. Local settlers placed a bulkhead across the old connecting channel to prevent its reuse by San Pablo Creek (State of California, 1893). Subsequently, a large willow grove grew through the abandoned connector channel.

Figure 83

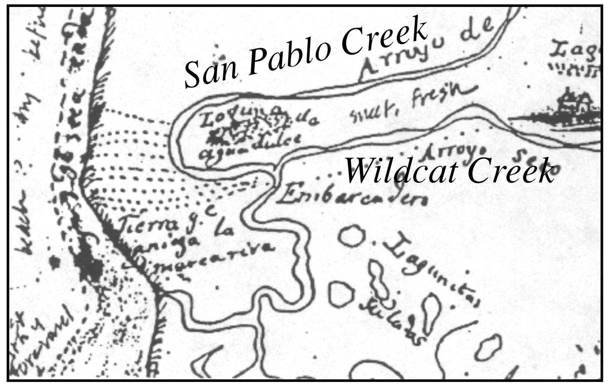
Lower Wildcat 1827-28



Source: Beechy, 1827-1828

Figure 84

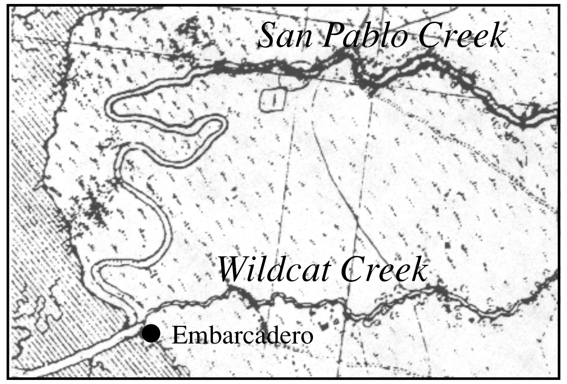
Lower Wildcat 1830



Source: Diseño del Rancho San Pablo

Figure 85

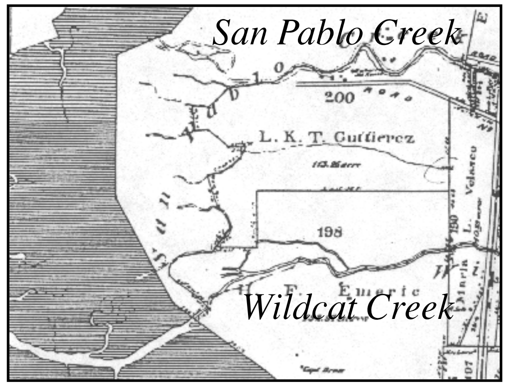
Lower Wildcat 1856



Source: United States Coast Survey

Figure 86

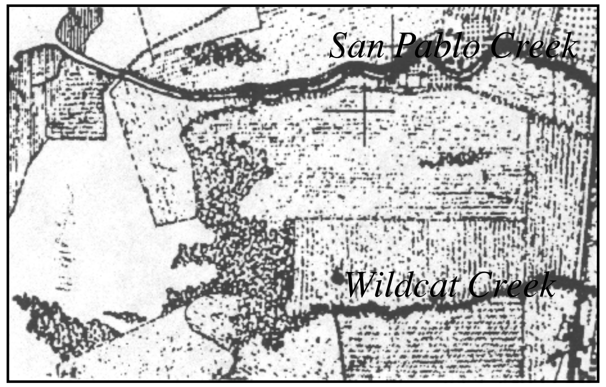
Lower Wildcat 1893



Source: Map of San Pablo Rancho

Figure 87

Lower Wildcat 1898



Source: United States Coast Survey

Channel Aggradation and Degradation

THE ALLUVIAL FAN SECTION

A longitudinal profile can be used to identify where a channel system shifts from an incision mode to an aggradational mode, and where pulses of sediment are moving through the system. A profile can also reveal sudden changes in grade that warrant investigation as headcuts or barriers to fish migration.

Figure 88 shows longitudinal bed profiles for three segments of the Alluvial Fan Section during 1817, 1830s, 1856, 1990, and 1998. The various profiles are based on numerous sources of information including field interpretation, field data, historical maps, as-built drawings for bridges, and USACE data for the flood control channel. The historical bed elevation of the early 1830s is indicated by the dashed red line, as determined from field indicators including the coring of riparian vegetation. The thin blue line is the 1998 bed profile as indicated by the elevations shown from as-builts drawings of engineered creek crossings and our recent measurements of terrace and bed heights at the locations of the as-built surveys. The thick blue line represents the as-built data for the flood control project, which has probably aggraded since the flood control channel was constructed, but recent elevation data were not available. The dashed orange line represents the average elevation of the high terrace banks that includes fill in Trestle Reach and the Flood Control Segment. The thin black line represents the probable bed elevation at Trestle and Rumrill Reaches during 1817, based on our findings that the rapid aggradation in that area began after the local introduction of cattle (page 68). The 1856 line is based upon historical evidence of tidal flow.

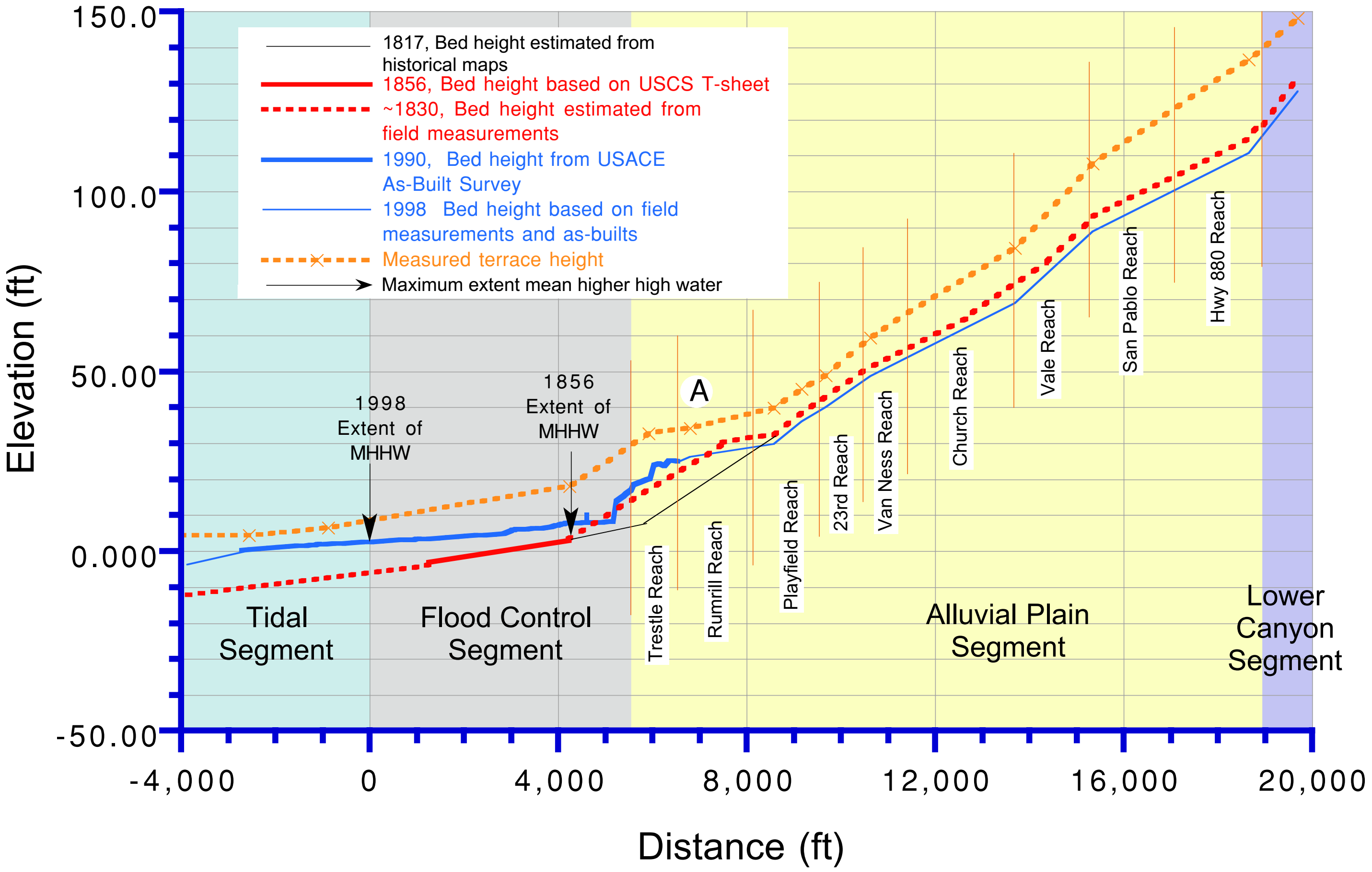
(Photo 55) *Floating woody debris collects on the railroad trestle piers. The beams and the trestle impede the passage of flood flows and contribute to the formation of backwater floods. Flows have exceeded the top of the tracks.*

The modern profile indicates that the channel is generally aggrading from about the upstream limit of Rumrill Reach through the Tidal Segment. The transition zone from aggradation to incision is near Davis Park in the Playfield Reach. This is shown at Point A in Figure 88 at the intersection of the red dashed line (1830s profile) and thin blue line (1998 profile). Although the flood control channel was excavated, its bed elevation is still above the historical bed of the early 1830s. The profile indicates considerable channel entrenchment into the terrace along the Highway 880 Reach near the fan apex. The distinct change in gradient near the apex and at the upstream end of Vale Reach approximates the position of strands of the Hayward Fault. The entrenchment of the upper fan may be driven by tectonic uplift through a series of steps east of the fault.

It seems possible that a stable channel system existed on the lower and middle alluvial fan before the 1800s. Flows at bankfull height and higher were sufficient to transport sediment through the alluvial fan and tidal sloughs that used to extend more than 4000 ft farther upstream than they do today (Figure 88). The sediment catchment basin in the flood control channel corresponds to the historical upstream extent of the tides. The transport of sediment at the historical tidal interface was complicated by the influence of the tides, storm surges, and flood flows from San Pablo and Wildcat Creeks. The rapid aggradation during the early 1800s occurred as back5water deposits upstream of the tides (see 1856 arrow, Figure 88).

Figure 88

Longitudinal Profile of Tidal, Flood Control, and Upper Alluvial Plain Segments



Channel aggradation is still occurring in the area of the historical backshore of the tidal marsh, although tidal influence has been stopped thousands of feet downstream. There are four obvious reasons for this aggradation. First, the flood control basin is much less steep than the local historical gradient of Wildcat Creek, so it lacks the power to convey as much sediment. Second, the basin of the Flood Control Project was designed

(Photo 56) *A buried reinforced concrete pipe gives evidence of an aggraded bed. It is located near station 6200 on Figure A above.*

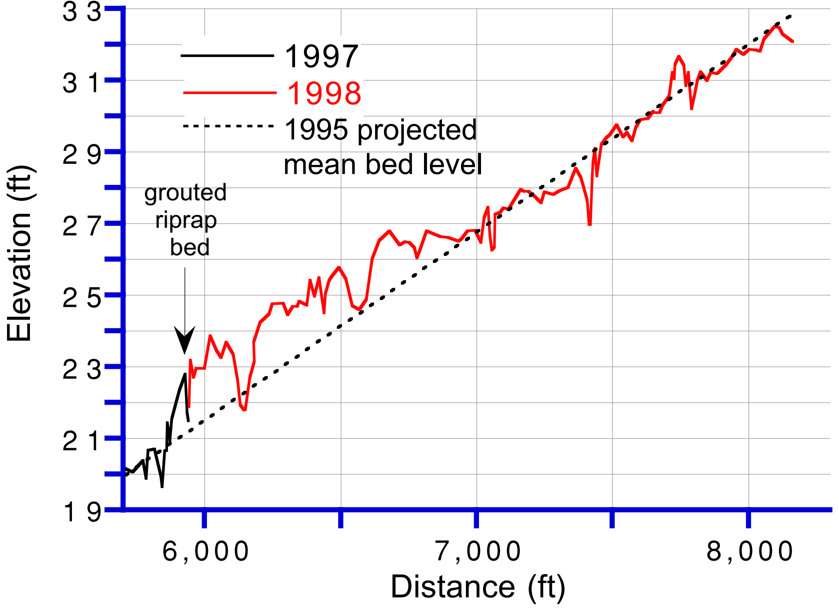
to trap sediment at its upstream end, at about station 5000 ft. Third, the Rumrill Reach is trapping bedload because of a grouted riprap structure that has artificially elevated the creek bed. Fourth, there is occasional aggradation in this reach from debris jams and flood flows that transport of water and sediment impeded by the railroad trestle.

Figure 89 shows a 1998 survey of the channel bed along Trestle and Rumrill Reaches near Point A of Figure 88. This profile extends between the box culverts of the Southern Pacific Railroad crossing and the box culvert at Davis Park. An aggradational lobe of sediment extends for more than 2000 ft upstream from approximately station 5800 ft. This aggradation began during the floods of 1995, when large amounts of woody debris accumulated under the railroad trestle, temporarily blocking downstream sediment transport. The dotted line on the graph shows the projected average bed level before the floods. Before the sediment could move downstream, grouted riprap was placed across the bed. The riprap has made permanent the aggraded bed. Aggradation now extends further upstream than the last date of survey. If the riprap were removed, the sediment would move downstream and the grade of the creek might be restored to its 1995 level. Yet occasional backwater floods and sediment deposition will still occur during future floods because of the effects of the trestle (see Photo 55, page 69). Floods have overtopped the trestle on several occasions.

Figure 89

Wildcat Thalweg Profile at Railroad Trestle

Point A from Figure 88



(Photo 57) Deposition of at least 3.5 ft has occurred behind a bay tree that slid into the channel, May 1999.

THE CANYON SECTION

The long-term mode for Wildcat Creek in the Canyon has been degradation. This is evident from the numerous abandoned terraces. Nowhere were trees older than the last 170 years found within the height of twice bankfull depth, even where the banks were stable. This was verified by our coring of trees and counting growth rings. Figure 90 shows the bed profile (solid blue line) in 1987. Black dots along the blue line are bedrock outcrops within the thalweg. The red dashed line is the projected bed elevation of the 1830s. Note how this surveyed profile differs from the USGS 7.5' quadrangle profile (Figure 19, page 14), which is too general to reveal important local detail.

Distinct steps along the profile are apparent. The most pronounced is the steep step at the intersection of the creeping trace of the Hayward Fault in Alvarado Reach. We hypothesize that other significant changes in gradient are controlled by faults. The original geologic surveys of the water tunnel under the Canyon document several of them (EBMUD, 1921). Other smaller nick points are caused by local backwater deposits of sediment behind debris dams. The largest is shown at about distance station 27,000 ft, where sediment deposited behind a landslide-related debris jam has caused sediment deposition to extend more than 1,000 ft upstream.

(Photo 58) Exposed roots in 1996 indicate the amount of bed incision that has occurred since 1987 when this reach was previously surveyed.

(Photo 59) The same set of roots in 1999 show continued bed incision by at least another foot since 1996.

Portions of some Lower Canyon Reaches have been resurveyed at points A-D of Figure 90. These are shown in Figures 91-94.

Figure 91

Wildcat Thalweg Profile at Alvarado Park
Point A from Figure 90

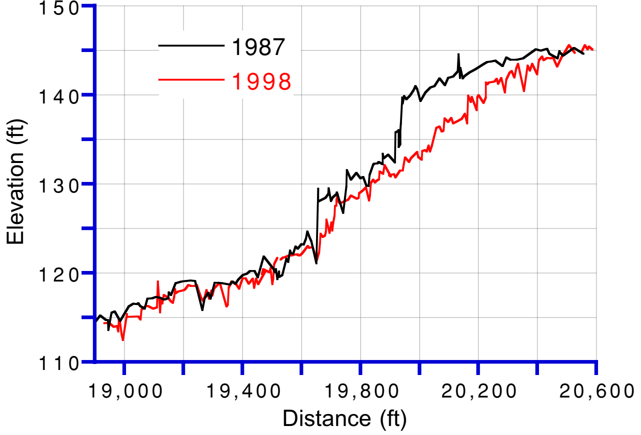


Figure 92

Wildcat Thalweg Profile at 117 Site
Point B from Figure 90

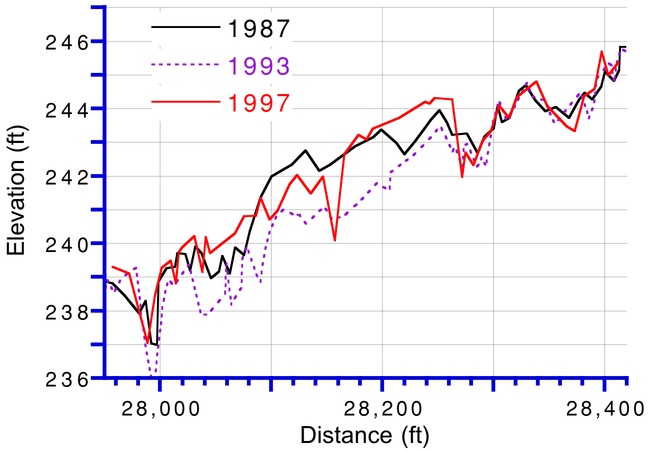


Figure 91 shows the section of Alvarado Park where the fish barrier removal project was performed to remove two small dams. There are considerable complexities of change that have evolved during this project, but the final differences between pre- and post-project profiles are shown. The net change has been incision.

Figure 92 shows surveys for 1987, 1993, and 1997 along a part of the Perennial Reach that has not been directly altered by people. Between 1987 and 1997 the channel had net erosion of about 1.0 - 1.5 ft. A small debris jam formed in 1986 at about station 28,100 ft. After it broke apart there was erosion that incised below the bed level that existed before the debris jam. In January 1997, two new debris jams formed, causing sediment deposition that is expected to last only as long as the debris jams persist. Photos 22 and 25 (page 41) show a portion of this survey reach.

Figure 90

Thalweg Profile and Reaches for Lower Canyon Segment

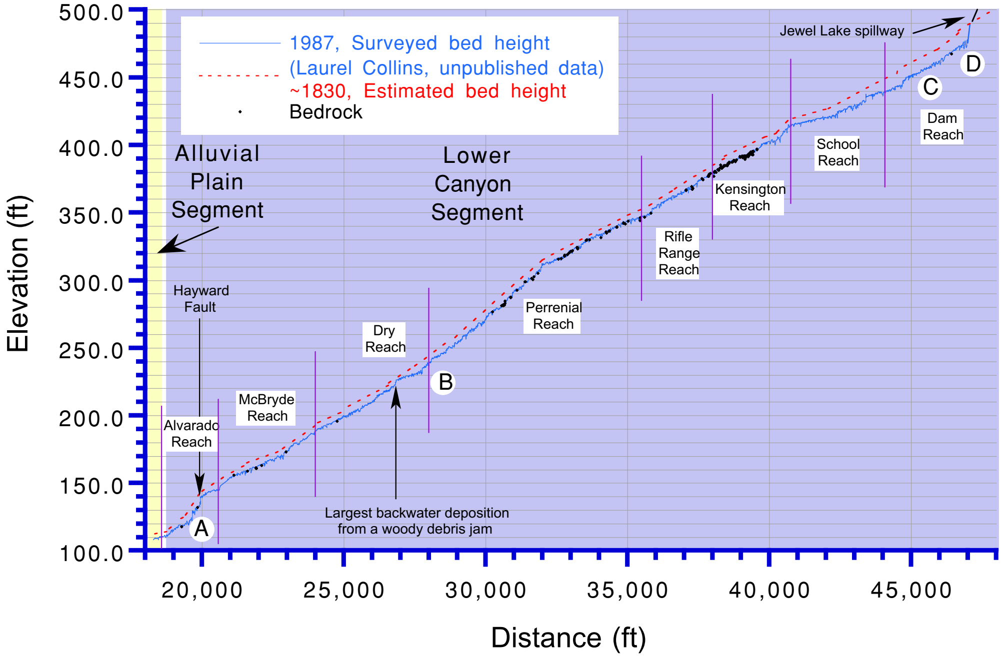


Figure 93 shows a natural reach of channel that is located about 0.3 mi downstream of the Jewel Lake dam. During the last 10 years there has been net incision of about 1.5–2.0 ft. Deposition behind debris jams has not influenced this reach during the time span of these surveys. The small floodplain that existed in 1987, with 40-year old alders growing on it, has been abandoned.

Figure 94 shows the profile for the immediate vicinity of Jewel Lake and its dam. Downstream of the dam there has been net incision of at least 12 ft (Photos 36 and 37, page 51). The incision is represented in Figure 94 by the difference in height between the top and bottom of the area colored red. The bottom profile is from a 1987 survey. A 1922 survey, which is the solid blue line along the top of the bed downstream of the dam and at the bottom of the bed, shown in red, upstream of the dam, is from an early topographic survey of the proposed dam site (East Bay Water Company, 1919). The dotted red and white area below the dam represents material excavated from the vertical shaft used to divert water to the water tunnel 300 ft below. The brown and white dotted area upstream of the dam represents the combined sediment deposited since the reservoir was built and last dredged. The light blue area on top of the fill represents the present capacity of Jewel Lake. The length of aggraded channel upstream of the dam extends at least 2,100 ft.

Figure 93

Wildcat Thalweg Profile
0.3 mi Downstream of Jewel Lake
Point C from Figure 90

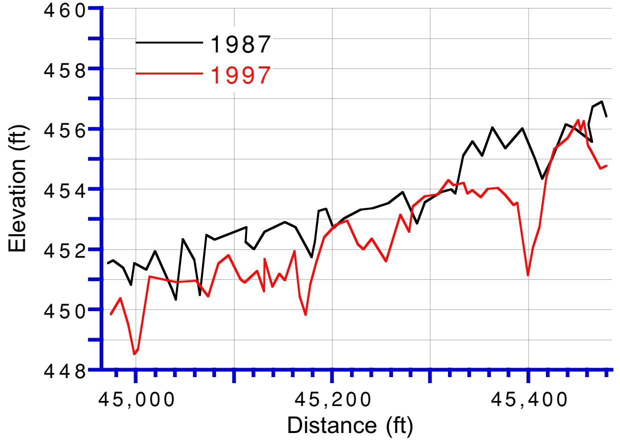
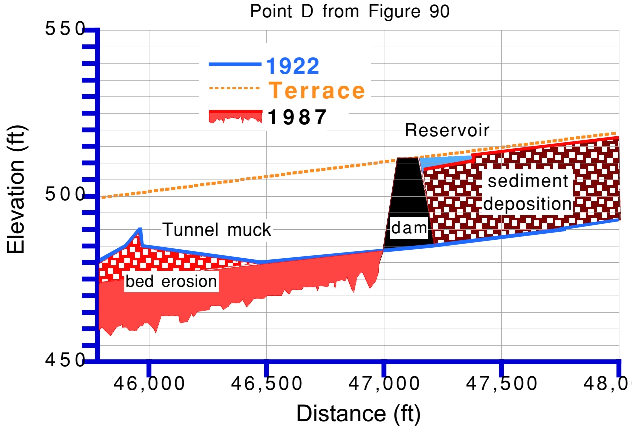


Figure 94

Wildcat Thalweg Profile at Jewel Lake
Point D from Figure 90



Tectonics, natural droughts and deluges used to control the temporal patterns of degradation and aggradation in Wildcat Watershed. The impacts of land use are now over-riding these natural controls. Sediment retention by Jewel Lake has caused extreme scour below its spillway, while urbanization and grazing have increased runoff and consequently increasing drainage density and sediment supplies.

Mainstem Channel Condition Summaries

The measured characteristics of each Reach in the Upper Alluvial Plain and the Lower Canyon Segments are summarized in Table 16.

Some reaches in the Upper Alluvial Plain and Lower Canyon have important similarities. For example, in both Segments, the Reaches with the least percent length of eroding bank (San Pablo Reach and Alvarado Reach) also have the greatest percent length of revetted bank. People obviously view erosion as a problem in these reaches, that is why we observe so many revetments. Church and Kensington Reaches have the greatest length of eroding banks for their Segments, and both have the least percentage of sand and finer-sized sediments on the channel bed. This may indicate that bank erosion in these reaches is providing coarse gravels.

There are many interesting differences among the reaches. For example, for the Upper Alluvial Plain, the predominant wood recruiting processes, are bank erosion and "gravity", (trees drop limbs or the entire tree topples into the Creek from disease or windthrow). In the Lower Canyon, most of the LWD comes from landsliding and "leaning or bent vegetation," meaning that living willows or large trees are interfering with bankfull flows.

Kensington and Dam Reaches are both exposed to large inputs of sediment from landslides, but Kensington Reach has the most length of exposed bedrock in its bed and banks while Dam Reach has the least for the Lower Canyon. Dry reach has the greatest supply of terrace erosion, which may correspond to it having the greatest amount of "F" Rosgen Stream Class in the Lower Canyon Segment. The Upper Alluvial Plain reach that has the largest sediment supply is dominated by Rosgen Stream Class B and subordinately by G conditions. This indicates that much of the channel has started to become a stable B channel after it entrenched or that much of the sediment is coming from the shorter length of unstable G channel where the terrace height is large. The Streamline Graphs indicate the latter case.

Factors that effect runoff and sediment production for all the quantified Segments are compared in Table 17. The length of roads, amount of impervious area, and historical increases in drainage density are greater for the Upper Alluvial Plain than the Canyon, due to its more extensive urbanization. Yet, overall drainage density is much greater for the Canyon than the Alluvial Plain. This is because of the topography of the Canyon and that the alluvial fan has never had many natural tributaries feeding into the mainstem. Fans, by their nature tend to have distributary systems when they are aggrading. The very large increase in drainage density in the Upper Alluvial Plain is caused by storm drains. We have not attempted to account for paved road gutters that also function as ephemeral channels.

A comparison among just the Canyon Segments reveals that the Middle Canyon has been most influenced by urbanization. It has the largest increase in drainage density and the greatest amount of impervious area (Table 17). Subsequently, our field reconnaissance indicates that upstream of the backwater influence of Jewel Lake, the mainstem channel has incised, eroded its banks, filled the reservoir with bedload, and conveyed large loads of suspended sediment downstream.

The distribution of landslides among the Canyon Segments is proportional to the distribution of volcanic bedrock (Table 17). However, the ratio of inactive slide area to total slide area correlates to the total num-

Table 16

Facts Table for Reaches

	% length eroding banks	% length of stable banks	% length of revetted channel	**Total long-term rate of field measured sediment supply since 1940's	Dominant bank sediment supply process sediment supply process	% length of reach represented by sand and smaller D50 size classes	# pools > 1' deep	Pool spacing (ft)	# wood	Wood spacing (ft)	# debris jams	Dominant wood recruitment process (excluding float)	% length of Bedrock for Right and Left Banks	% length of Bedrock in the Bed	% length of Bedrock for Combined Bed and Banks	% length of landslides adjacent to banks	Dominant Rosgen Stream Class (%)	Second Dominant Rosgen Stream Class (%)
Trestle	20	26	59	200	terrace erosion	18	0	none	0	none	0	none	0	0	0	0	46, E	43, culvert
Rumrill	27	33	40	412	terrace erosion	21	3	546	0	none	0	none	0	0	0	0	74, E	12, E-G
Playfield	13	28	59	135	terrace erosion	17	3	450	2	674	1	gravity	0	0	0	0	56, E	22, B
23rd	21	31	49	177	terrace erosion	31	2	469	0	none	0	none	0	0	0	0	51, E-F	39, E-G
Van Ness	25	32	49	133	terrace erosion	17	2	476	2	476	0	gravity	0	0	0	0	47, E-G	42, G
Church	60	15	25	1629	terrace erosion	14	10	226	6	377	0	bank erosion	0	0	0	0	72, G	24, B-G
Vale	27	57	16	745	terrace erosion	45	14	116	1	1630	1	none	0	0	0	0	41, B	31, G
San Pablo	11	28	61	339	terrace erosion	19	9	195	2	878	0	bank erosion	0	0	0	0	51, culvert	41, B-G
Hwy 880	24	43	33	3242	terrace erosion	42	12	159	9	213	2	bank erosion	1	0	0	0	41, B	35, G
Alvarado	21	22	57	488	terrace erosion	28	27	62	17	98	1	landslide	9	1	5	2	46, ND *	30, B
McBryde	45	50	5	3163	landslide	28	43	99	70	61	6	landslide	16	6	11	5	80, B-G	6, culvert
Dry Reach	74	26	0	17417	landslide	33	55	66	227	16	17	bank erosion	18	4	11	11	31, F	22, B
Perennial	62	37	1	12298	landslide	38	93	84	325	24	21	lean/bent	24	8	16	6	84, B	5, F
Rifle Range	62	36	2	1998	canyon slope	32	19	88	176	10	14	lean/bent	11	3	7	4	87, B	7, B-G
Kensington	79	22	0	7582	landslide	25	37	96	229	16	17	lean/bent	28	26	27	14	65, B	34, G
School	61	39	0	7751	landslide	43	30	112	274	12	20	landslide	5	2	3	12	64, ND	27, B
Dam	74	26	0	5037	landslide	41	25	89	163	14	11	bank erosion	1	0	1	14	ND	ND

* not determined

** does not include soil and landslide creep calculations

Note: the time frame for the Alluvial Plain is 1998, and for the Lower Canyon, 1999 ber of years actively grazed. Rates of accelerated channel incision may require tens of years to diminish after the removal of cattle, especially if channel headcuts exist that will continue to propagate upslope.

Overall, sediment and water supplies in the Upper Canyon are less sensitive to land use changes. The mainstem channel gradient is steeper in the Upper Canyon, but stream discharge is less. The channel bed tends to be armored in some areas by coarse volcanic sediment that is transported by debris flows (Photo 33, page 37). This contrasts with channel conditions on the east slope where earthflows contribute mostly fine sediments. The west slope earthflows occasionally convey coarser sediments from the Franciscan bedrock that occurs at the top of the ridge. When armoring occurs, channel repsonsiveness to increased runoff from land use is reduced, especially if the banks are bedrock. The increased runoff from urbanization in the Upper Canyon is contributing to channel changes farther downstream in the more sensitive Segments of the watershed that are underlain by Orinda bedrock.

The Lower Canyon has more landslide activity per unit area than any other segment. Most of the grasslands on the southwest aspects have been continuously grazed for about 182 years. The grasslands near the western ridge crest have also been intensively grazed, but for less time (Watershed View Map, page 23). Residential development covers only 3% of the total Lower Canyon Segment, yet it is concentrated at the top of steep tributary drainages that flow through numerous deep-seated earthflows. Runoff from these residential areas has accelerated fluvial erosion and mass wasting. Deep gullies have incised below most of the road drains. The combination of grazing, urbanization, and dam construction on the Orinda Formation accounts for much sediment production in the Lower Canyon.

Table 17

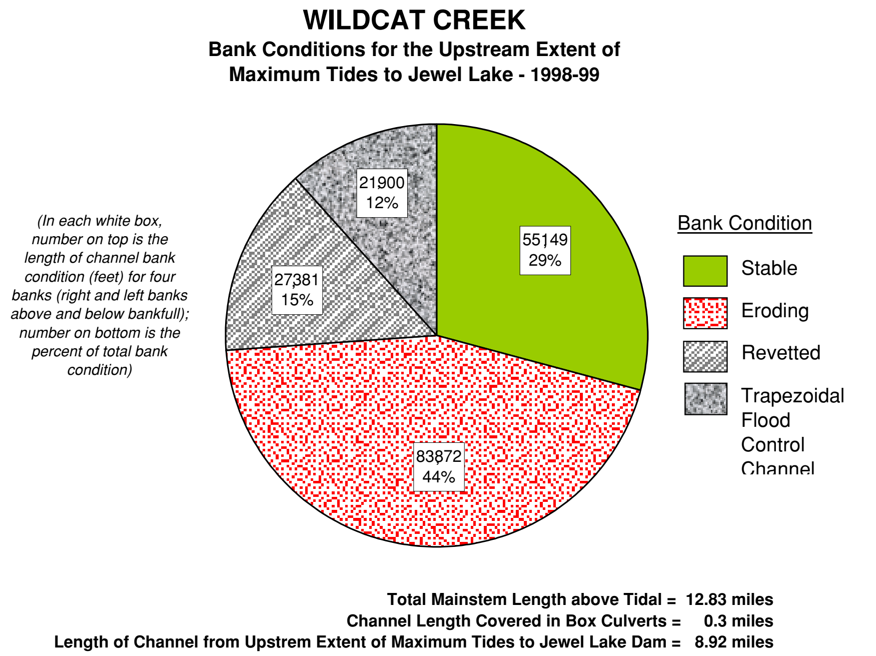
Facts Table for Segments

	Upper Alluvial Plain	Lower Canyon	Middle Canyon	Upper Canyon
Drainage area (sq mi)	1.13	4.38	1.71	1.46
1999 Drainage density since 1830's (ft/acre)*	46.9	80.0	86.9	72.4
% Increase in drainage density since 1830's	193	28	42	19
% Active slide area	0	13	4	<1
% Total slide area	1	37	22	10
% Impervious area	57	3	8	5
% Area volcanic rocks	NA	1	21	87
% Average hillslope	4	31	30	29
% Average channel gradient	0.5	1.6	3.9	8.1
Abandoned & currently used dirt road/trail density (mi/sq mi) (SFEI)	NA	9.5	14.6	13.2
Paved road and currently used dirt road density (mi/sq mi) (USGS GIS layer)	25.2	2.1	6.0	5.0
Number of years continuously grazed	~63	182**	119	119

* includes storm drains, road ditches, headward extension

** pertains mostly to grassland on east side of Wildcat Creek

Figure 95



The total percent of impervious surface for the entire watershed above the flood control channel has only increased by 11% since the time of non-native settlement. As a rule, this amount of impervious area is expected to increase peak flows by 1.1 times (Waananan, 1977). We hypothesize that there are at least four very important reasons why peak flows have likely increased much more than predicted by this general rule. First, the amount of impervious area varies among the Segments. For example, we know that the amount of impervious area in just the Upper Alluvial Plain Segment has increased by 57%, which would increase peak flows by 50% (Waananen et al., 1977). Second, we know that drainage density for the whole watershed has increased by a minimum of 35%. This means that more runoff can enter the mainstem more rapidly. Third, the replacement of perennial grasses with annual grasses, plus the concomitant reduction in thatch and perennial grasses has increased runoff in the grasslands. Runoff coefficients can be as much as 70% during large storms. Fourth, the replacement of natural banks and floodplains with concrete walls and flood control berms has decreased the lag time between rainfall and peak flow by decreasing roughness and increasing water velocity.

Figure 96

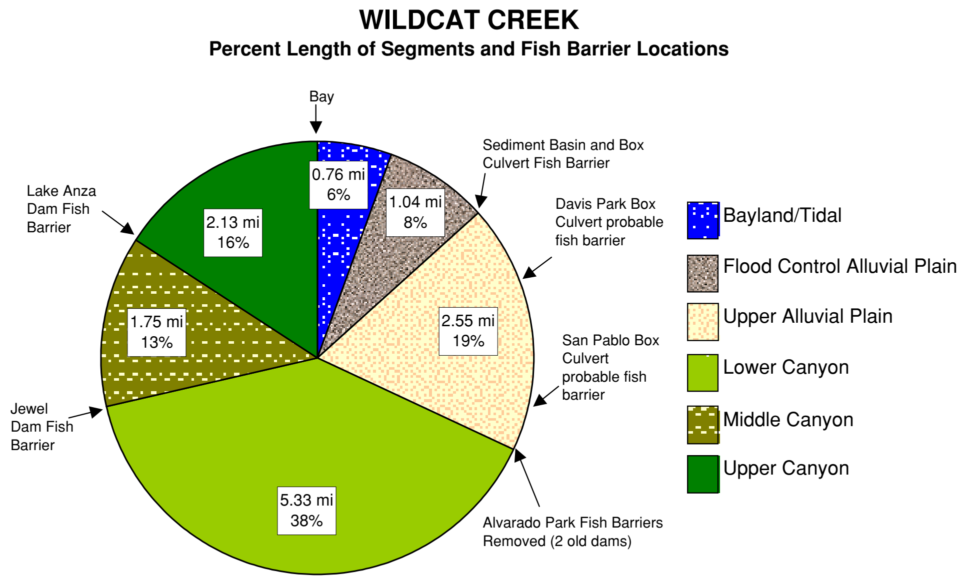


Figure 95 Summarizes bank conditions from the tides to Jewel Lake, this includes the trapezoidal channel banks. In total, 27% of the bank length has been artificially altered, and 29% remains in relatively natural, stable condition.

Figure 96 summarizes the percent length of all geomorphically distinct segments for the entire mainstem channel and the partitioning of the watershed by migration barriers for steelhead. This diagram allows us to visualize the potential increase in habitat if these barriers were removed or modified. Presently, fish can only swim up stream through 14% of the mainstem, of which no portion can be used for rearing habitat because tidal slough comprises 6% and the remaining 8% within the Flood Control Project has poor habitat. At the upstream end of the sediment basin, a nonfunctional fish ladder is under consideration for redesign by the USACE. Even if this structure is improved, two additional barriers in the Upper Alluvial Plain greatly diminish opportunities for steelhead to reach the perennial flow and viable habitat in the Lower Canyon.

Long-Term Sediment Supply Estimates

In this part of the report we make some estimates of the total amount of sediment supplied by the Watershed and then itemize the processes of input. We then provide a context for Wildcat Watershed by comparing its supply to other watersheds and by developing a picture of landscape response to land practices. We emphasize that these numbers do not constitute a sediment budget because storage and output measurements were not a component of our study. To approximate the total sediment supply to the channel, we had to make some broad assumptions by estimating proportions of suspended sediment and erosion that could not be field measured.

Figure 97 shows the measured and estimated sediment supply rates for all segments above the flood control channel. The values shown for the Upper and Middle Segments are for the bedload that was captured behind Jewel Lake and Lake Anza (Table 11, page 48).

Suspended load over the dams was not measured. It had to be estimatedusing the following guidelines. First, we used a rule of thumb that bedload usually represents about 10-20% of the total sediment load (personal communications, Bill Dietrich, University of California at Berkeley, 2000; Bill Firth, USACE, 2000). Table 18 shows that the USACE (1999) calculated the percent sand and gravel caught in sediment catchment basin of the Flood Control Project to be 19% of the total load. We applied this same percentage to the sediment caught at Jewel Lake. For Lake Anza, which is a bigger reservoir, we assumed that the captured load represented about 30% of the total.

Table 18

Army Corps of Engineers Estimate of Total Annual Load of Wildcat Creek 1989-1996
(determined for the concrete channel above the flood control basin)

Bed material	Amount (cu yd/yr)	Where it goes	Percent of Total
Clay	20,800	100% goes to the bay	48
Silt	14,150	99% goes to the bay, 1% goes to sediment basin	33
Sand and gravel	8,350	25% goes to the bay, 75% goes to the sediment basin	19
TOTAL	**43,300**		**100**

Second, to determine the relative influence of one segment to another, we needed to compute yields for each Segment per square mile (Figure 98). The combined yield of both suspended and captured bedload of the Middle Canyon Segment is compared to the sediment supplied by voids (both bedload and suspended load) in the Lower Canyon. Third, we considered that just the yield from void measurements in the Lower Canyon was too low, because a large component of existing and historical sediment sources could not be easily measured or calculated. These important sediment sources include:

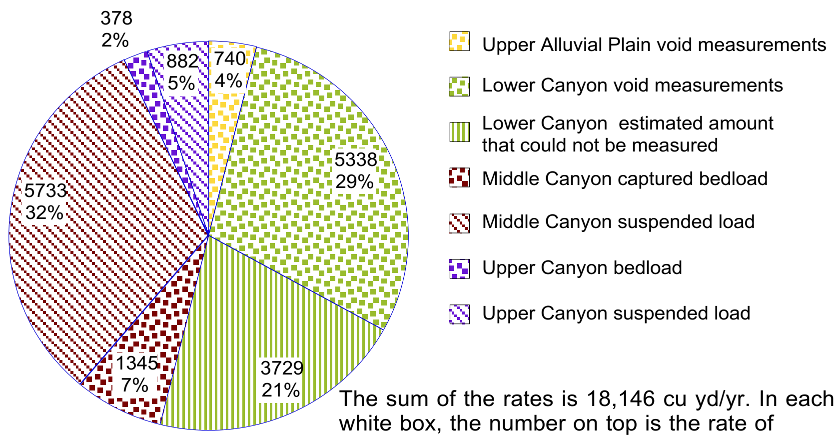
- banks that had less 0.25 ft retreat and banks that have revetment where amount of erosion could not be easily assessed;
- extensive bare, inner gorge stream banks in the grasslands that are exposed to raindrop impact and overland flow;
- bare soil from construction of road fills of Wildcat trail, some are more than 80 ft in height;.
- bare soils from construction of thousands of homes and tens of miles of paved roads;
- bare soil from construction of Jewel Lake reservoir;
- bare soil from construction of two golf courses and numerous recreational playfields;
- sparsely vegetated soils upstream of channel heads and along cattle terracettes that convey saturated overland flow;
- channel sediment that was in storage before the 1830s (in our estimates of incision we had to assume the bed was level which does not account for bars; and
- gullies that may have been obscured beneath the dense vegetative cover on the western slope where access could not be attained and features may not be visible in stereo photos.

Fourth, we considered that the yield from the Lower Canyon should not be as high as the Middle Canyon because the values of drainage density, impervious surface and road conditions (Table 17) were not as great. Based upon the latter two assumptions, we conservatively assummed that the total yield for the Lower Canyon should be about half of the yield of Jewel Lake. This assumption allowed us to back-calculate an estimated yield for the sediment sources that could not be measured. The result is a plausible picture of minimum expected long-term sediment supply rates and yields.

Given these guidelines, the Middle Canyon has the highest yield of 4,140 cu yd/sq mi/yr compared to the Lower Canyon, which has a minimum of 2,070 cu yd/sq mi/yr. The overall yield for the watershed above the flood control channel is 2085 cu yd/sq mi/yr.

Figure 97

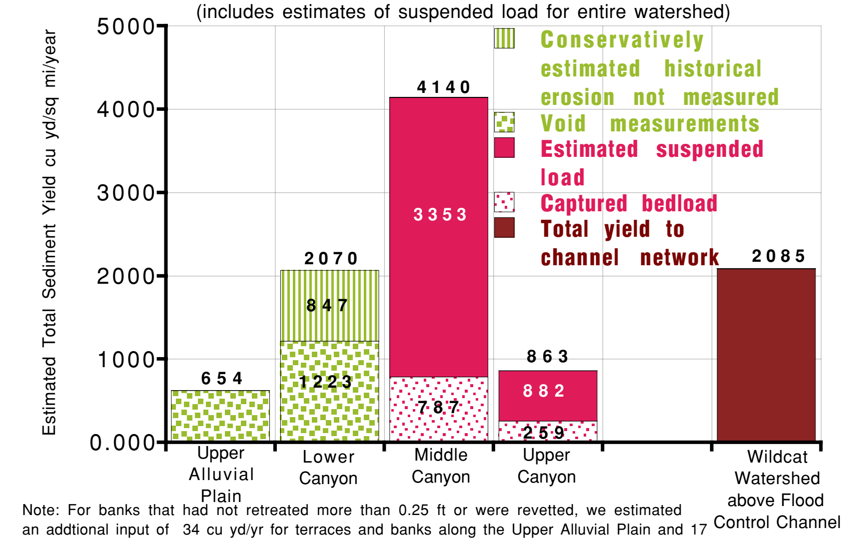
Measured Sediment Supply Rate for Each Segment
(does not include suspended load)



The sum of the rates is 18,146 cu yd/yr. In each white box, the number on top is the rate of sediment supply in cu yd/yr; number on the bottom is the percent of total estimated volume.

Figure 98

Conservative Estimate of Long-term Sediment Yield to Wildcat Channel
(includes estimates of suspended load for entire watershed)



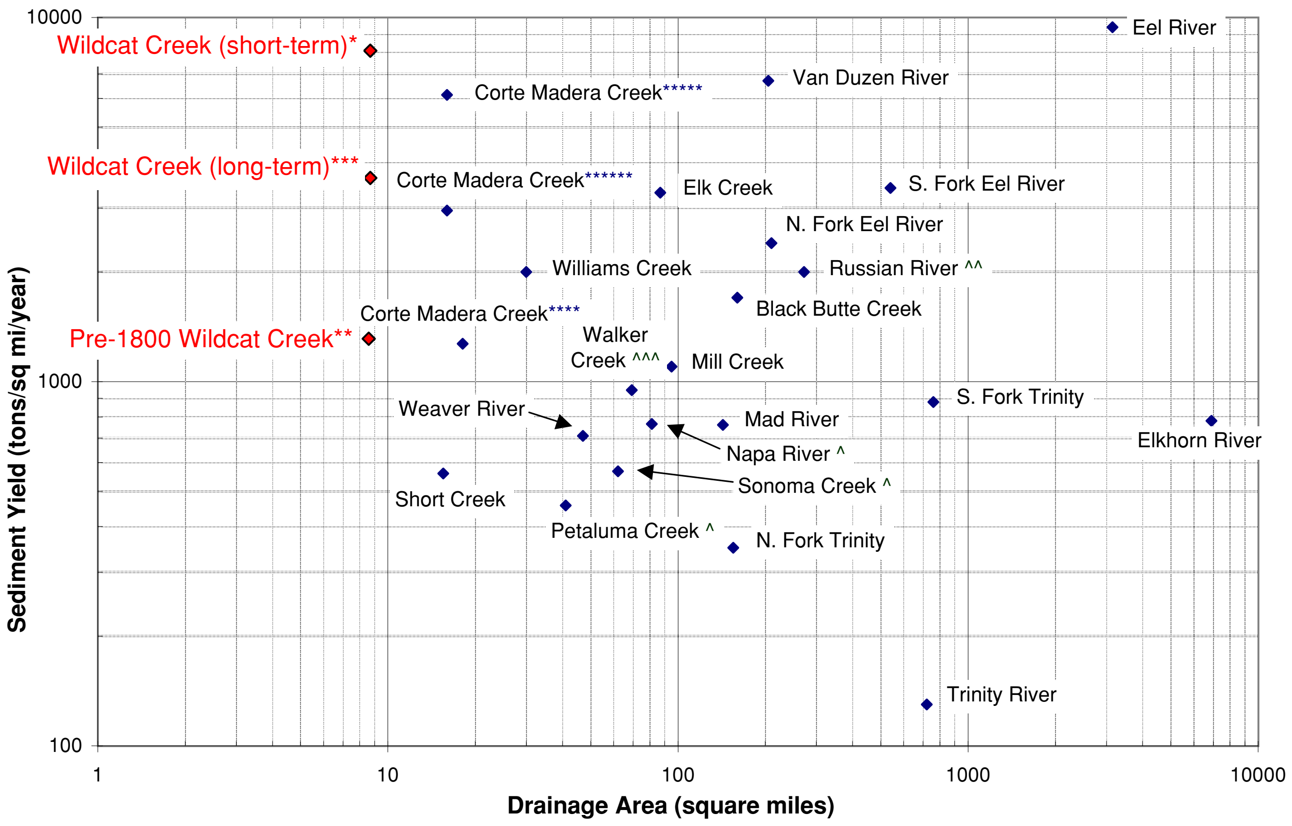
Note: For banks that had not retreated more than 0.25 ft or were revetted, we estimated an addtional input of 34 cu yd/yr for terraces and banks along the Upper Alluvial Plain and 17 cu yd/yr for the Lower Canyon. These rates were added into each segment.

If we convert the estimated yield from cubic yards to tons, we can compare the long-term yield of sediment sources in Wildcat to yield estimates determined by different methods for other Northwestern California streams (Figure 99). Some estimates are based upon sediment transport measurements or models (e.g. USACE), not sediment supply. We used a bulk density value of 1.63 tons/cu yd to convert cubic yards to tons for Wildcat Creek and Corte Madera Creek. The sediment source/transport yields from Wildcat Watershed are comparatively large for a drainage area that is so small. Some watersheds that are more than a hundred times larger than Wildcat generate lesser yields of sediment. From the perspective of watershed management, the very large sediment yield from Wildcat Watershed raises two questions: what causes the large sediment yield, and how much of it can be managed?

Figure 100 shows the rate of sediment supply stratified by the major geomorphic processes for just the Upper Alluvia Plain and the Lower Canyon. The red striped lines represent mass wasting processes, the blue striped lines represent fluvial processes. The dotted and circular patterns represent the calculated sediment supply rates from road tread erosion and soil creep. The green striped pattern shows our estimated rate from natural soil lowering. The gray color shows estimated supply from sources that could not be field measured. Fluvial erosion (18%) and landsliding (22%) account for nearly equal parts of the total measured sediment supply. However, tributaries receive most of their sediment from landslides, whereas mainstem sediment input is nearly equal for both processes. The supply of 38% (3763 cu yd/yr) of the sediment for the "gray area" may be dominated by overland flow processes on disturbed or bare soils as listed above. We expect that a large proportion of the gray area may be land use-related. Yet, a natural component would be the lateral migration of the channel.

Figure 99

Sediment Yield for Selected California Watersheds



Data points without asterisk from William Dietrich, UC Berkeley Department of Geology and Geophysics, personal communication, 1988

* *Bill Firth, USACE, personal communication, sediment transport yield above flood control basin 1989-1996 (does not include captured load at Jewel And Anza dams)*

** *This study, SFEI, estimated total sediment source yield to channel network before European contact*

*** *This study, SFEI, estimated total sediment source yield to channel network since European contact*

**** *Bill Firth, USACE, personal communication*

***** *Stetson Engineers, P-K shear values; uncalibrated estimates*

****** *Stetson Engineers, USDA FS shear values; uncalibrated estimates*

^ *USGS Water Resources Investigations 80-64*

^^ *Kondolf and Matthews*

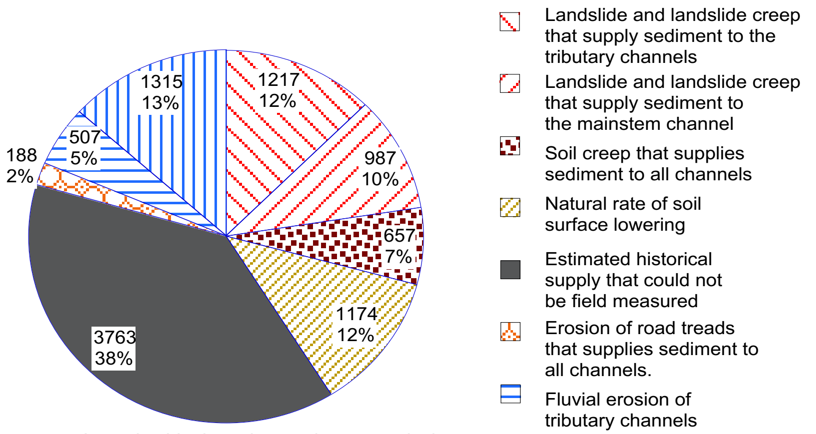
^^^ *Daetwyler (1950) as cited in Haible (1980:252)*

Figure 101 shows the sediment supply stratified by natural and land use-related causes for the Lower Canyon and Upper Alluvial Plain. We are confident that at least 20% of the supply is indirectly attributable to land use. We are also confident that least 19% is part of the natural supply. The gray area (61%) represents the same estimated amount of sediment for the "gray area" in Figure 100, plus the proportion of sediment that could not be attributed to either natural or other causes, but was measured as fluvial or landslide input. From our subwatershed analysis (page 42) we were able to deduce that at least 36% of the sediment supply was probably indirectly caused by grazing impacts (page 45). Thus, perhaps another 22% (2,160 cu yd/yr) of the overall total might be attributed to grazing. This is consistent with the findings of Cooke and Reeves (1976). They found that soil disturbance and vegetation conversion by intensive use of livestock throughout southern coastal California resulted in entrenchment of channels (arroyo formation), extension of channel networks, aggradation of low gradient valley bottoms, and increased sediment supply. We also expect that another proportion of the gray area is sediment supply that is indirectly related to recent and historical urban effects. Therefore, a conservative approximation of the total proportion of the gray area in Figure 101 that is land use-related (both urban and grazing effects) is 40%. Adding to this the 20% that is in the "red area", we hypothesize that as much as 60% of the supply in the Lower Canyon and Upper Alluvial Plain is land use-related.

In Figure 97, we reported the total natural sediment supply rate for the entire Wildcat Watershed to be 18,146 cu yd/yr. If we assume that 60% of this total rate for the entire watershed is land use-related, then the historic natural rate would have been 7,258 cu yd/yr, or 40% of the modern supply.

Figure 100

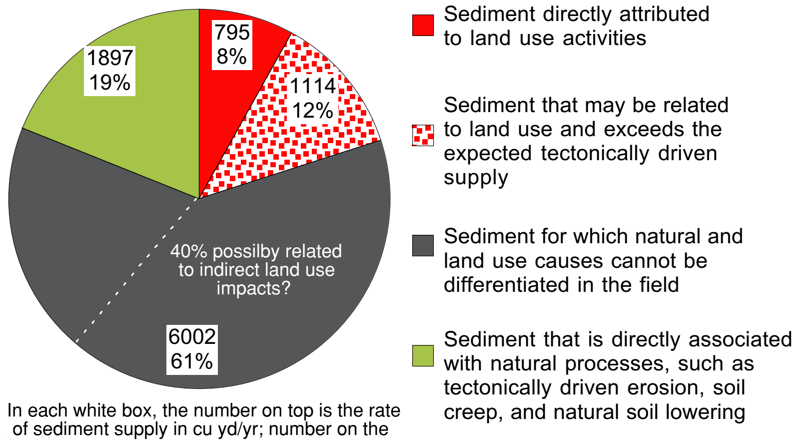
Percent of Sediment from Different Processes
Flood Control Channel to Jewel Lake



In each white box, the number on top is the rate of sediment supply in cu yd/yr; number on the bottom is the percent of total volume.

Figure 101

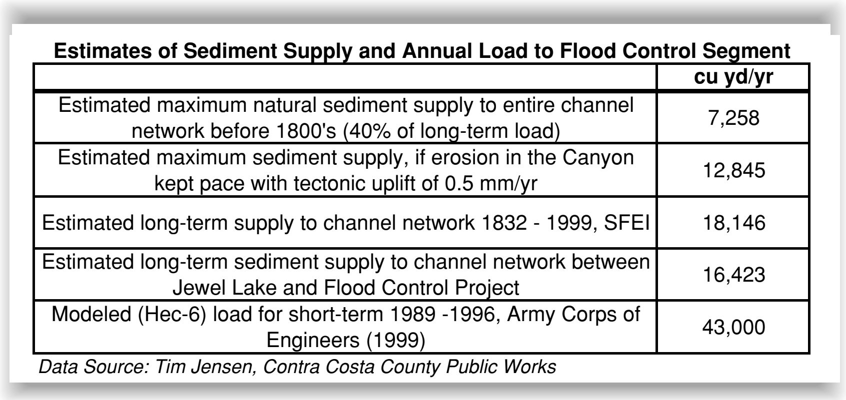
Percent of Measured Sediment Caused by Land Use
Flood Control Channel to Jewel Lake



In each white box, the number on top is the rate of sediment supply in cu yd/yr; number on the bottom is the percent of total volume . Total rate of sediment supply is 9808 cu yd/yr.

We can compare these values to the total amount of erosion that would be required to compensate for uniform uplift and erosion of the entire Canyon (Table 19). (Other estimates of erosion driven by tectonics were for the amount caused by fluvial incision of the channel bed at a similar uplift rate.) At a maximum rate of 0.02 in/yr (0.5 mm/yr), the tectoni-

Table 19



Estimates of Sediment Supply and Annual Load to Flood Control Segment

	cu yd/yr
Estimated maximum natural sediment supply to entire channel network before 1800's (40% of long-term load)	7,258
Estimated maximum sediment supply, if erosion in the Canyon kept pace with tectonic uplift of 0.5 mm/yr	12,845
Estimated long-term supply to channel network 1832 - 1999, SFEI	18,146
Estimated long-term sediment supply to channel network between Jewel Lake and Flood Control Project	16,423
Modeled (Hec-6) load for short-term 1989 -1996, Army Corps of Engineers (1999)	43,000

Data Source: Tim Jensen, Contra Costa County Public Works

cally driven supply would be 12,845 cu yd/yr. Our estimate of natural historical supply (7,258 cu yd/yr) therefore seems reasonable, given that the natural rate should be less than the maximum tectonically-driven rate, otherwise uplift would not be apparent.

The differnce between the historical and the modern long-term sediment supply rates cannot logically be attributed to causes other than changes in land use. The regional climate during the last two centuries has not had any major shifts, only short-term droughts and deluges that represent a usual pattern for the region. The lower reaches of the channel system have aggraded, not degraded, so there is no pervasive headward erosion of the mainstem due to a change in base level.

It follows that if 60% of the total sediment load from Wildcat Watershed is related to land use, some of this supply can be mitigated by improved land practices. For example, if this supply was decreased by half, sediment supply might be reduced by 5,400 cu yd/yr.

These assumptions and calculations allow some conclusions about the influence of Jewel Lake dam for modern versus historical rates of sediment supply. People generally think that dams reduce total sediment supply because they withhold bedload. If we consider the total sediment load that would have occurred at Jewel Lake before non-native settlement, we would have 504 cu yd/yr, which is 40% of the modern supply. Based upon the ratio of bedload to suspended load (from Table 1), 81% of the total load would be flowing over the dam (403 cu yd/yr) and 19% (101 cu yd/yr) would be captured bedload. The amount of long-term sediment supply from channel incision below the dam was determined to be at least 233 cu yd/yr (from Table 13), which is more than twice the amount that would have been captured historically. The yeild of sediment by bed incision downstream of the dam has more than compensated for loss of sediment trapped behind the dam.

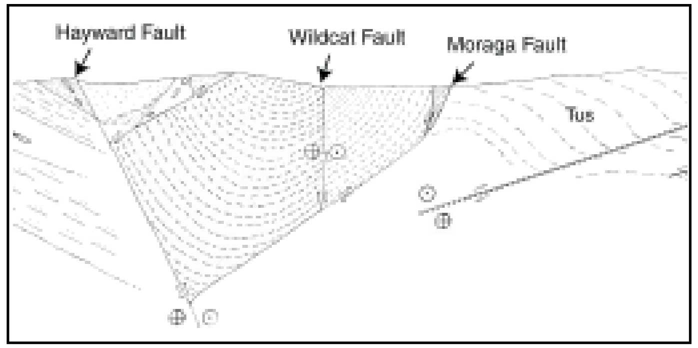
Conceptual Models

These word models integrate among qualitative and quanti tative observations of watershed form and function to produce simple statements of possible cause and effect relations that could be tested through field experiments.

TECTONICS AND SEISMICITY

Tectonic processes can be slow and incremental or punctuated by sudden seismic events. Thus watershed structure and form is influenced over very different scales of time. In practical terms, local rates of tectonic uplift and down-dropping provide a basis to calculate natural, background rates of landscape erosion and estuarine or fluvial deposition. In general, the uplift of hills around the Estuary provides a gradient for erosion, whereas the down-dropping of the basins of the Estuary and adjacent alluvial plains provides places to deposit sediments conveyed by streams and the tides. Right-lateral offset along active faults can help explain the plan form of streams and differential rates of erosion from one bank to another, whereas vertical offset can help explain breaks in stream gradient that control headward erosion. The history of seismicity can explain temporal variations in water and sediment supplies, especially as related to the productivity of springs and activation of landslides. A basic understanding of tectonic and seismic processes in relation to watershed management requires detailed investigations, including longitudinal profiles of streams, distribution of bedrock and fault traces, and compilations of all available evidence of local seismicity and tectonic motion.

Figure 102



Geologic cross-section of the Berkeley Hills. Source: Russ Graymer, USGS.

(Photo 60) Curious cattle peer over the incised channel banks.

GRAZING

Grazing practices indirectly effect sediment and water supply through direct effects on vegetation and soil that causes increased runoff. Grazing effects must be deduced from an understanding of the mechanisms relating runoff to stream flow, mass wasting, and fluvial erosion. Cattle grazing can have the following direct impacts:

1. conversion of dominant perennial grassland to dominant annual grassland;
2. trampling of banks and spring areas;
3. reduction in riparian growth of willows;
4. reduction in grass cover;
5. compaction of soils;
6. creation of extensive trail networks that function as ephemeral channels; and
7. reduction in water quality.

The combination of impacts 1-3 leads directly to increased sediment production. More sediment will aggrade the channel bed. The aggradation leads to increased bank erosion and/or flooding. The combination of impacts 4-6 leads directly to increased runoff. The following processes caused by more runoff will indirectly increase sediment production as well:

1. bed incision, which can lead to increased shallow landslides along the inner gorge, increased deep-seated landslides due to removal of lateral hillslope support, and subsequent gully formation associated with the deep-seated slides;
2. bank erosion, which can also lead to the loss of riparian vegetation leading to more bank erosion;
3. increased headward extension, which leads to increased drainage density, which increases runoff and flooding; and
4. increased frequency and magnitude of flooding.

The individual or combined effects of more sediment and runoff require an adjustment of hydraulic geometry of receiving channels. Within the grasslands and downstream, grazing has lead to destabilization of the entire channel network. The effects of entrenchment upon the long-term fluctuations in the water table in Wildcat Watershed are not immediately obvious through this study, although we can say that riparian vegetation has less probability of creating mature stands in an unstable and entrenched system.

Where grazing has been discontinued, there is more brush, more winter thatch cover, and there appears to be a greater proportion of perennial rather than annual grasses. Runoff coefficients should therefore be less in ungrazed area. The decrease in runoff reduces sediment transport capacity, thereby increasing sediment storage in tributary channels. Small woody debris dams and more overhanging vegetation help trap sediment and decrease water velocity. Sediment storage was observed to be greater and active landsliding to be less in areas removed from grazing.

(Photo 61) March 1995 Wildcat Creek near peak flood in Alvarado Park.

DROUGHT AND DELUGE

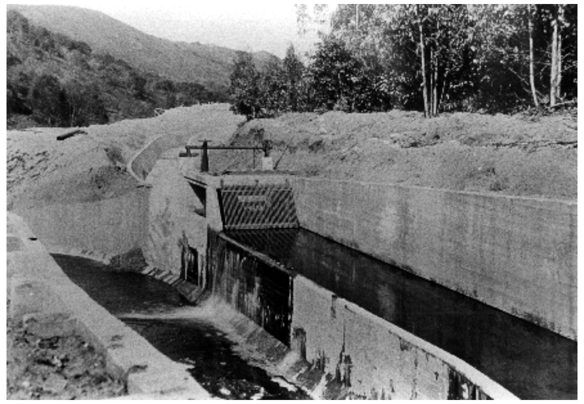
Periodic drought and deluge influence production of sediment on the hillslopes, and erosion and sediment storage in the channel. The timing of one relative to the other, their magnitude and duration all have important geomorphic consequences. If either one is extreme for an extended period of time, the hydraulic geometry of channels will change, base flow and ground water will rise or fall, riparian vegetation will respond to changes in ground water, and a scenario of aggradation or degradation may occur in either the uplands or the lowlands.

Short-term droughts might be expected to cause the following responses in an earthflow-dominated landscape:

1. a decrease in active earthflow-type landslides, which would cause a substantial overall reduction in sediment supply;
2. a decrease in flow, which would cause a reduction in sediment transport and in sediment load;
3. possibly an increase in supply of woody debris from stressed vegetation, which might lead to increased sediment storage behind debris dams;
4. coarsening of the particle sizes on the bed as the fine materials winnow from the system; and
5. aggradation in places that were previously incising, and scouring of sediments in places that were previously aggrading.

Channel response to deluge depends on whether storms produce extensive landslides and flooding, or just flooding. Floods with landslides will generate more sediment and finer-grained sediments on the bed surface than those without slides. High gradient channels will likely scour. In low gradient areas, an overall depositional mode will likely be associated with storm events that produce both floods and landslides, such as ENSO events, while scouring will be associated with floods that have limited sediment supply. High sediment loads occasionally associated with ENSO events could have cumulative downstream effects if frequency of ENSO is increasing. It took about 10 years for Wildcat Creek to rid itself of the massive amount of sediment associated with the 1982 and 1983 ENSO. The influence of accelerated rates of erosion from land use has increased ENSO impacts.

During droughts, riparian vegetation encroaches on point bars. When high flows return, the vegetated point bars push the flow against the outside banks of meander bends. The outside banks erode, releasing sediment to build more point bars.



(Photo 62) 1922 Water diversion at the old Wildcat Dam (Jewel Lake). Source: East Bay Municipal Utility District.

DAMS, BRIDGES AND CULVERTS

Engineered creek crossings, like dams, bridges, grade control structure, and culverts influence the amount and distribution of water and sediment in many ways. The dams and other grade control structures can have the following geomorphic consequences:

1. increased washload and sometimes gullying on disturbed soils at construction sites;
2. decreased flow during years of water diversion, allowing vegetation to encroach into channel bed downstream of the dam, and loss of power to convey inputs of sediment from downstream sources;
3. increased incision below dams during large floods, if flood flows are not reduced by diversions;
4. substantially increased incision and entrenchment below dams without diversions;
5. increased erosiveness of entrenched flows below dams that causes more bed incision and bank erosion that additionally increases sediment supply; and
6. increased aggradation in reservoirs resulting in loss of capacity and dredging.

Bridges and culverts mark intersections between the flow of people and the flow of water. They can have the following geomorphic consequences:

1. increased upstream flooding and bank erosion due to backwaters caused by woody debris jams in or under the crossing structure and/or by loss of its capacity due to aggradation;
2. increased deposition of sediments upstream due to backwater;
3. increased upstream bank erosion and property damages due to backwater:
4. increased downstream bed incision and bank erosion that contributes to loss of riparian vegetation due to acceleration of flow through smooth-walled structures;
5. increased bank erosion from eddies upstream and downstream of abutments;
6. in the case of culverts along dirt roads and trails, frequent clogging of the structures resulting in failure of road fills, and increased sediment supply; and
7. in the case of urban culverts, occasional failure of road fills due to structural deterioration of culvert, resulting in increased sediment supply and potential property loss.

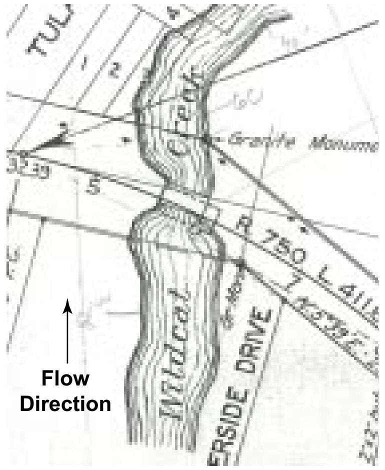
URBANIZATION

Urbanization involves hardened horizontal surfaces that prevent infiltration; hardened banks and artificial channels that inhibit riparian plant growth; and roof drains, gutters, and storm drain systems that increase drainage density. In the early days of Richmond, urbanization included extensive ground water pumping, the impacts of which may have mostly passed. The effects of urbanization in Wildcat Watershed include:

(Photo 63) 1947 Wildcat Creek and Upper Alluvial Plain. Source: Pacific Aerial Survey

1. increased urban runoff leading to increased rates of both channel incision and bank erosion from the first-order channels on the Canyon slopes, and to the mainstem channel on the Alluvial Plain; and increased sediment production due to bed and bank erosion;
2. increased runoff into landslide deposits and accelerated earthflow activity and their associated sediment production;
3. bed incision of steep tributary channels with increased inner gorge landslides along channels and gully walls;
4. increased drainage density due to storm drains and headward extension and gully formation at culvert outlets;
5. increased magnitude and frequency of flooding especially in reaches that are aggrading from the impacts of bridges and culverts.

Figure 103
Bridge Crossing on Wildcat



1927 early bridge across Wildcat Creek at San Pablo Road. Note the narrower width at bridge crossing. Source: City of San Pablo.

The following impacts are associated with channel banks that are hardened by revetments:

1. reduced lateral migration at the site of the revetment transfers erosion to opposite bank;
2. if revetments impinge on flow, erosion may be transferred to the opposite bank, and result in increased revetment on the opposite bank if erosion is initiated;
3. increased revetment upstream and downstream when erosion from erosive eddies occurs at the end points of the revetments;
4. increased flow velocities when bank roughness is decreased by smooth artificial structures;
5. increased bed incision from increased velocity; and
6. frequent undermining and failure of revetments due to bed incision.

(Photo 64) October 1991, fire in the Oakland Hills.

FIRE

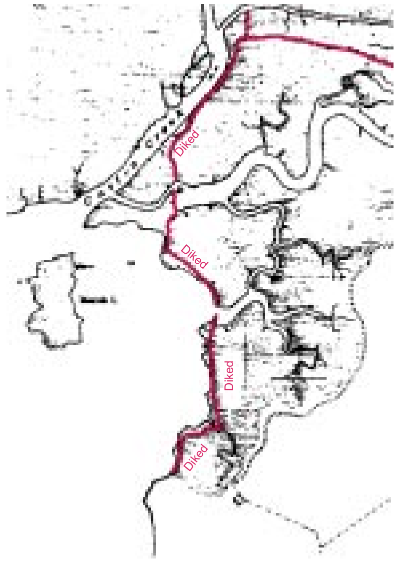
Intentional fires historically maintained vigorous grasslands and inhibited brush invasion. Even without fire, it may have been difficult for brush to successfully invade the deep-rooted perennial tussocks. In the woodlands, fires controlled the understory and maintained relatively little fuel.

Fires were not intense. Little soil erosion was associated with these cool fires. There is no evidence of ash deposits in the stratigraphy of streamside banks. Fire scars on trees are very rare. Recent monitoring of fire effects of the 1991 Tunnel Fire in the Berkeley and Oakland Hills showed that soils in this region do not develop strong water repellency or rill networks following fire, especially clay-rich soils that develop on the Orinda Formation (Collins and Johnston, 1995).

Controls on fire and fuels shifted from native fire management to cattle and fire suppression. As the population of Europeans increased, so did incidence of arson and accidental fire. With the advent of fire suppression in the 1900s and the reduction in grazing, the rate of brush invasion into the grasslands has increased. Wildfire now burns larger and hotter.

Bulldozer trails used as fire breaks mechanically disturb the soil and occasionally require culverts. Short-term pulses of sediment are associated with road construction and culvert placement. Vegetation management activities that disturb the soils also increase sediment production.

Figure 104
Detail of Wildcat Marsh



Dikes in southern Wildcat Marsh circa 1860. Source: US Coast Survey T2445 1898.

CHANNELIZATION AND RECLAMATION

Tidal marsh reclamation and channelization greatly influence the way sediment and water are conveyed through the lowermost reaches of Wildcat Creek. The impacts of diking and reclamation include:

1. reduced tidal prism causes tidal sloughs to narrow and shallow;
2. reduced cross-sectional area of the tidal sloughs causes increased flooding during terrestrial floods and reduced capacity to transport sediment;
3. increased containment of terrestrial floods between unnatural levees elevates flood waters and increases shear stress on the banks and levees and increases the potential for bank erosion and levee failure; and
4. increased flooding beyond the extent of tidal flow occurs when terrestrial flood flows, coinciding with high tides, cannot spread out over the tidal marsh.

The channelization of Wildcat Creek through a portion of the marsh and the toe of the alluvial fan was designed to reduce localized flooding. The following impacts are associated with the channelization:

1. increased water velocities convey the flood faster and increase the peak height of the flood flow to downstream points;
2. increased deposition of sediment through deepened and widened reaches due to lessened channel gradient requires dredging of sediment basin;
3. increased need to dredge beyond the boundaries of sediment control basin;
4. reduced deposition of sands on the remaining tidal marsh surface which slows the rate of marsh accretion and reduces diversity of the backshore; and
5. reduced rate of formation of new tidal mudflats and backshore pannes, and possible erosion of the foreshore of the tidal marsh.

Expected Trends

The Contra Costa County Clean Water Program has asked for a description of expected future trends in watershed conditions, assuming that there are no changes in watershed management. It must also be assumed, however, that average trends will be punctuated by extreme events, such as major landslides, large storm events, and fire, that cannot be predicted. Shifts in climate over decades or centuries will also affect the average trends. Within this framework of assumption and uncertainty, some simple pictures of future trends in hillslope and channel conditions have been developed for each of the major subregions of the watershed. These hypothesized forecasts could be tested with a program of channel and hillslope monitoring. The results of this study provide a baseline for testing these hypotheses.

Volcanic terrain above Lake Anza & Jewel Lake

The hillslopes of volcanic geology are not prone to landslides. Assuming that grazing is not reintroduced, that the extent or type of vegetation management for fuel break construction does not increase, and that there are no major increases in the amounts of trails, roads, or urban structures, then the average sediment yield from these slopes should eventually decrease as vegetation recovers from the intensive grazing of the past. Channel adjustment to the increased urban runoff should eventually diminish but the time frame is unknown. Brush may continue to encroach into annual grasslands, but the remaining grasslands may increase in relative percentage of perennial species. These ecological aspects are beyond the scope of this study, yet the ramifications of these changes on biological diversity may be important to consider. As brush increases and fire suppression practices continue, the potential for wildfire that will burn hotter will increase. Subsequently, containment may be more difficult and large fires have greater potential to generate sediment than small ones. Extreme sediment supply from water repellent soil conditions would not necessarily be expected, unless there was extensive soil disturbance by construction activities. The sediment yield to the channels from the hillsides should not increase, but the manicured turf in the golf course will maintain high rates of runoff.

Channel upstream of Lake Anza

As channels recover from past land use activities and adjust to present practices, the amount of net sediment storage in the channels may increase. Small headward channels not influenced by culverts or urban runoff should retain more sediment behind woody debris that will be provided by the recovery of riparian vegetation. The mainstem channel in its steeper reaches may continue to be armored by coarse bedload deposits from debris flows. The channel banks along the golf course that lack riparian vegetation, if they continue to be maintained in such condition, will continue to supply sediment from bank instability. Lack of riparian shade will continue to elevate water temperature. Old bridge crossings upstream of the Tilden Golf Course and culverts beneath road crossings will continue to trap debris and sediment, and this will continue to cause maintenance problems and unnaturally high rates of sediment supply.

Lake Anza

The overall rate of infilling should decline as the upper watershed recovers and as the depositional fan traps more sediment. Barring any major landslide on the lakeshore, the filling will continue to build the delta at the head of the lake, and will secondarily fill the deep areas north of the lake center. Drought and deluge will punctuate sediment supply rates. The Delta will grow above the elevation of the spillway. Fish habitat in the upstream perennial section of Wildcat Creek could improve.

Orinda hillslopes between Lake Anza & Jewel Lake

If grazing activities continue to be suppressed, runoff rates from the open grasslands should not increase above existing levels associated with the mixed native and non-native species. Runoff from road and trails will continue to maintain high drainage density and high runoff rates. Landslide activity on the eastern grasslands should not accelerate if stream incision rates are diminishing. On the western urbanized side, earthflow activity will continue to be exacerbated by urban runoff that discharges onto active and inactive slides along the ridgelands. If runoff infiltrates into the landslide deposits, it increases the potential for renewed instability. If it flows into channels that are on or along earthflows, it will continue to supply sediment from incision and potentially initiate landsliding by the removal of lateral support. Along Wildcat Canyon Drive, where vegetation management activities are expected to continue for fuel break maintenance, soil disturbance by goats, people, and equipment will continue to supply more sediment from surficial erosion processes than natural background rates. Most of the abandoned roads appear to be recovering, but yearly grading of roads used for fire fighting and maintenance purposes will continue to provide unnaturally higher rates of fine sediment supply.

Channels between Lake Anza & Jewel Lake

Small tributary channels may continue to recover from impacts associated with accelerated rates of runoff from the grazing period. They may continue to trap sediment as small woody debris accumulates and raw banks continue to stabilize from vegetation, yet natural instability within the Orinda bedrock will always persist. The mainstem channel downstream of Lake Anza flows through volcanic and then Orinda bedrock. Through the volcanic sections, there is evidence of incision associated with the capture of bedload in Lake Anza. However, the degree of incision and sediment production is not as great as the mainstem channel that flows through the Orinda Formation. Higher than natural rates of sediment supply form the hillsides will continue to be transported through most of the mainstem channel until it reaches the low gradient section that is influenced by backwater flooding from Jewel Lake (near the Tilden Educational Center parking lot). Within this low gradient and backwater zone, Laurel Creek (large eastern tributary just south of Jewel Lake) and the mainstem channel will continue to aggrade their beds during large floods and exacerbate the backwater flooding that occurs in this area. Bridge and culvert structures (at the end of the paved parking lot) contribute to the flooding.

Jewel Lake

If Jewel Lake continues as an educational resource for the EBRPD, it will require frequent dredging to offset sediment inputs from neighboring slides, road runoff, and fluvial processes. The channel will continue to aggrade around the boardwalk upstream of the open-water lake. The Dam and lake will continue to trap bedload and starve the channel downstream, at least as far as Havey Creek.

Hillslopes of the Lower Canyon

In the eastern grassland sections that continue to be grazed, landslides will continue to be exacerbated by channel incision that removes lateral support. The incision will be maintained by channels that are still adjusting to increased runoff from the grasslands. Runoff will remain higher than background rates because vegetation will remain sparse in some areas. Surface erosion of bare inner gorge banks and grasslands areas that have sparse thatch or vegetative cover will continue to supply large amounts of fine sediment from surficial erosion processes. Fire trails will continue to supply higher than background rates of runoff and sediment. Wildcat Trail will continue to have maintenance problems where it intersects active landslides. Along the western ridge, paved roads and urban structures will continue to increase runoff to channels and landslides, maintaining their instability. Structures along the western ridge will continue to be threatened by natural seismic, landslide, and fire hazards. The risk of landslides and fire will be exacerbated by the activities of people. Brush encroachment of the grasslands will be slower than in the ungrazed lands upstream of Jewel Lake.

CHANNEL OF THE LOWER CANYON

Incision downstream of the Jewel Lake spillway does not appear to be slowing during the last decade. The concrete structure at the end of the spillway is severely undermined. Its eventual failure will exacerbate downstream erosion and potentially initiate erosion at the foot of the dam. In tens of years from now, if this erosion proceeds unchecked, the results could be extremely damaging to downstream resources.

The mainstem channel is expected to continue its long-term down-cutting of unnatural rates. It will continue to have localized areas of temporary deposition and incision associated with debris jams and toes of landslides that impede flow. Sediment supply from bank erosion and loss of mature riparian forest will continue. Structures such as the Rifle Range Bridge and the two 6-ft diameter culverts at Alvarado Park will continue to require maintenance after floods deposit LWD at their inlets. Subsequently, backwater floods will create erosion and maintenance problems. Culvert structures beneath Wildcat Trail will continue to cause maintenance problems of road fills when the culverts become clogged by sediment and/or debris during storm events. Culverts will eventually require replacement as they corrode which means their condition, if left unchecked, could in tens of years lead to their complete failure. If this occurs at the eastern tributary that flows to the mainstem beneath an 80–ft high fill of Wildcat Trail (about 1 mi downstream of Havey confluence), the results could be very damaging to upstream resources. For places such as the two-6 ft culverts near Alvarado Park, damages would occur both upstream and downstream. The various revetment structures that have been placed along portions of the banks will continue to lose their functionality as they deteriorate and as the channel continues to adjust its geometry. Fish habitat is not expected to improve.

The extent of perennial flow will remain limited for two main reasons. First, land use impacts have caused the watershed to become dominated by overland flow processes because of the intersection of the water table by incised streams, reduced interception, increased drainage density, and increased impervious surfaces. Thus, base flow is limited during summer drought. Secondly, much of the natural spring flow that helped maintain perennial flow in the mainstem is now captured at Anza and Jewel Lakes. Some of this water is also lost by surface evaporation. The upstream extent of perennial flow in the Lower Canyon during summer drought will continue to depend upon flows from Havey Creek and a small western tributary north of Rifle Range Road, rather than upstream sources.

CHANNEL OF UPPER ALLUVIAL FAN

Our stream bank data indicate that the channel may be migrating toward the south. If this is true, sediment supplies from the south bank may exceed those from the north bank. Large floods within entrenched channel conditions will continue to decrease channel stability and longevity of riparian vegetation. Structures where significant erosion has already occurred will continue to be at risk. Continued deterioration of existing revetments is expected. Some structures have actually caused accelerated rates of erosion, while others have inhibited it. If artificial revetment of the 32% of eroding banks continues in the future, further loss of stream resources and further increases in velocity are likely. Increased velocity could lead to further need for grade control in the incising sections of the Creek, which depending on type of design, could lead to further loss of stream resources. Subsequent velocity increases could increase downstream flood frequency.

Many of the engineered stream crossings will continue to impede transport of water and sediment during floods. Associated backwater floods will continue to create problems for the people and infrastructure existing along the Creek. The lower reaches of the channel that currently have loss of capacity from deposition of sediments upstream of the railroad trestle will have increased flood frequency.

The fish habitat conditions and presence of perennial flow are not expected to improve along this reach. Fish migration barriers will still exist for various flow conditions in the Davis Park and San Pablo Avenue box culverts.

FLOOD CONTROL CHANNEL

Aggradation will continue, therefore maintenance dredging will always be required if the capacity of the flood control channel is to be maintained. If climatic conditions of the last ten years were to occur again, we would not expect to see a decrease in sediment deposition rates to the Flood Control Project. This is because the watershed recovery occurring upstream of Anza and Jewel Lakes will not influence deposition rates in the sediment catchment basin, because the suspended load over these dams, even if it decreases, will not settle in the sediment basin.

TIDAL REACH

The tidal marsh will continue to receive sediments from the Estuary but its upland supply of fine gravels and sand will continue to be less than natural. Higher than natural loads of suspended sediments will continue to be transported through this system during winter flows. The tidal slough may continue to narrow as it adjusts to the reduced tidal prism from former diking of the marsh. Delta building on levee shoulders during extreme floods will occur at elevations above the average tides. Gradual tidal excursion into Wildcat Creek from sea level rise is anticipated. This will result in upward migration of the null zone and sediment entrapment zone, which will increase the tendency of the Tidal Reach of the Creek to aggrade, which will, in turn, increase the risk of local flooding and increase the need for maintenance dredging.

THE ESTUARY

The downstream extent of the Tidal Reach of the Creek is strongly influenced by estuarine processes. It is difficult to project the effects of local watershed processes into the estuary. However, it can be expected that the load of fine sediments from the watershed into the Estuary will continue to be greater than natural rates. Some of these sediments will be deposited on the floor of the Estuary as a submerged delta near the mouth of the Creek. Additional development of mudflats can also be expected, mostly on the "up-estuary" side of the Creek mouth, where fine sediments from the Creek can be deposited by flood tides. Reworking of these sediments by wave action will re-distribute some of the sediments onto the nearby tidal marshes and into the tidal sloughs, including the Tidal Reach of Wildcat Creek.

Final Note

Successful watershed management requires knowing how watersheds respond to land use. The basic responses are geomorphic – changes in land use cause changes in water supply and sediment supply that in turn affect changes in stream channels. The science of geomorphology provides the tools to describe the relationships between land use and landscape.

This study of Wildcat Watershed shows that sediment sources, water sources, woody debris, and many other parameters of watershed condition can be quantified by process and causation. This quantitative analysis reveals the relative effects of natural processes and land use on landscape form and function. It therefore provides a scientific basis for restoration and/or management strategies.

Some details of the study approach are especially noteworthy.

The comparison of sediment supply estimates, based on void measurements with deposition in reservoirs, is a useful method to check the void estimates, but it requires information about suspended sediment loads that cannot be easily measured. Similarly, empirical evidence of background or natural erosion rates is seldom complete. The estimates of sediment supply are very sensitive to the assumptions required to fill these data gaps.

We have shown large differences between short-term estimates of sediment supply based on transport models or studies (i.e., the USACE study for the flood control channel) and long-term estimates based upon geomorphic analyses. Watershed managers should consider that average rates of sediment and water supply are punctuated by extreme episodes. The degree to which short-term data sets represent long-term trends should be considered when the data sets are used in engineering designs and management decisions. However, a relatively short study of the history of change in major sediment sources in the context of land use can provide estimates of long-term trends and serve to forecast future conditions. The magnitude of change can be put into context by comparing long-term supply rates other watersheds.

Bed incision is an important cause of large sediment supplies in Wildcat Watershed and probably in many other Bay Area watersheds, but most watershed studies have ignored this important parameter.

Some watershed problems can be solved on-site, and for others, the solutions are off-site. For example, if a culvert is preventing fish passage, then the onsite solution is removal or modification of the culvert. But if the culvert is failing due to chronic incision, then the solution could be modification of land use practices far upstream. Managers could benefit by maps of problems, and their on-site or off-site solutions. Managers are asking for a set of diagnostics that can be used to assess watershed conditions.

This study indicates that baseline watershed assessments might focus on parameters that inlcude: 1) drainage system extension; 2) landsliding as influenced by geology; 3) bank/terrace erosion and changes in bed elevation at the heads of alluvial fans and at engineered stream crossings (including dams); and 4) hydraulic geometry and bedload particle size distribution at references reaches of the mainstem channel. All of these diagnostics are greatly enhanced by an understanding of major historical trends in land use and landscape change. In all cases, sound study designs and the interpretation of the data require special training and much experience.

Our ability to diagnose watershed problems and recommend remedies could be greatly improved through a program of coordinated research. Much could be accomplished by conducting this kind of baseline study in other watersheds, followed by monitoring of key processes and research to fill data gaps. Some of the questions that need to be answered to improve watershed diagnostics are listed below.

How much sediment is supplied from the hillsides into the heads of first-order channels? This could be answered by developing a field sampling program in different geologic terrains with different intensities of land use.

How much do changes in drainage density from the headward extension of first-order channels and the addition of storm drains change the downstream flood frequency? This could be answered by modeling a watershed that has intensive field measurements of flood frequency, storm drain size and distribution, headward channel extension, and impervious surfaces.

What are the realistic rates of sediment supply from landslides caused by creep, and how does this vary with landslide type and position in the watershed? This could be answered by long-term monitoring of landslide-dominated hillsides.

What are the practical restoration strategies for reducing runoff into first-order channels in grazed grasslands where sediment supply from channel incision and its cumulative effects dominate the landscape? This would require field experiments and monitoring of grazed and ungrazed watersheds.

These kinds of questions point to the need for a regional watershed monitoring and research program. A regional network of watersheds like Wildcat that are used as monitoring stations and study sites could be very beneficial for developing diagnostic tools, training personnel, calibrating models, and developing best management practices. A program of watershed science is needed to meet the managers' requirements for basic information about watershed responses to management actions.

Glossary

A

Aggradation

The long-term process of building up a surface by deposition of sediment.

Alluvial fan

An outspread cone-shaped, gently sloping mass of alluvium deposited by a stream due to a rapid change in slope or valley width.

Alluvium

Stream deposits made by streams on riverbeds, flood plains, or fans that may include boulders, gravels, sands, silts, and clays.

B

Bankfull

The incipient elevation of the water surface of a stream as it begins to flow onto its floodplain. The flow may have a recurrence interval of about 1.3 to 1.7 years.

Bathymetry

The depth of water body relative to the elevation of the water surface.

C

Colluvial hollow

A bedrock depression, typically at the headward end of first-order channels that is filled with colluvium. These are commonly the source areas for debris-type slides. Sometimes referred to as a zero-order basin.

Colluvium

Deposits of soil or rock that have been transported by gravitational processes at the foot of a slope or into a bedrock hollow.

Confinement

The relationship between valley width and bankfull width.

Cross-section

The geometry of a river channel or other fluvial feature usually measured at right angles to the bankfull flow.

D

D50

Median grain sizes of sediment that can be measured by pebble count methods, sieving, or visual estimation. The particle size is measured along the intermediate axis. 50% of the grains are finer than the reported D50 value.

Debris flow

A moving mass of rock fragments, soil or mud, more than half of the particles being greater than sand size. The rate of movement can range from slow 1 ft/yr to fast 100 mi/hr.

Degradation/denudation

The long-term lowering of a surface by erosive processes, especially by flowing water.

Deposition

The short-term laying down of material previously entrained in flowing water because of a decrease in the energy needed for transport.

Dike

A fabricated levee often built along wetlands to eliminate tidal waters.

Drainage density

The ratio of the total length of all streams within a drainage basin to the area of that basin.

E

Earthflow

Downslope sliding of soil and weathered rock of low fluidity over a discrete basal shear surface with well-defined lateral boundaries. Complex earthflows may have multiple failure surfaces that involve both translational and rotational movement.

Effective discharge

The discharge which is responsible for the most sediment transport over the long-term. Effective discharge tends to be greater than bankfull discharge in entrenched channels.

Entrenchment

The down-cutting of a stream into its floodplain that causes its abandonment and results in greater containment of flood waters.

Entrenchment ratio

The floodprone width divided by the bankfull width. Highly entrenched channels have a width/depth ratio > 1.4 while moderately entrenched channels have a ratio between 1.4-2.2.

Equilibrium

A stream channel in a state of balance between erosion and deposition; with relatively stable cross-sectional geometry during a particular climatic regime.

F

Fault

A fracture along the earth's surface where there has been tectonic displacement of one side relative to another either in the vertical, horizontal, or combination of the two directions.

Flood control channel

A constructed channel designed to transmit floodwaters and sediment and reduce the chance of inundation of the floodprone areas. Banks are often trapezoidal or rectangular and may be earthen or concrete.

Flood frequency curve

Graph that describes the recurrence interval of a flooding of a given magnitude, over a period of years.

Floodplain

A flat bench or plain at the edge of the banks that floods an average of every 1.3-1.7 years.

Floodprone area

Description of an area that is likely to be inundated during flood stage above the floodplain.

Floodprone width

Floodprone width is the measured width between the banks at twice the maximum bankfull depth.

G

Grade control

Stabilization of the channel gradient with structures such as check dams or weirs.

H

Headward extension

The lengthening of a channel by erosion of its bed and banks in an upslope direction at the point of inception.

I

Incision

The short-term process of down-cutting which, if occurring at a faster rate than deposition, may eventually lead to permanent degradation of a channel bed.

L

Lateral migration

The action of a stream eroding its banks so that in time, it may move across its valley.

Longitudinal profile

The elevation of the stream bed relative to its distance along its valley.

P

Planform

The outline of a shape viewed from above.

R

Revetment

Any type of retaining structure along a bank that is intended to increase bank stability or protect it from erosion, i.e., riprap, concrete, or wire mesh.

Rosgen Stream Classification

A system of defining streams based upon their morphology.

Rosgen stream class

A system of stream classification that defines streams by their morphology. It requires measurement of width/depth ratio, entrenchment ratios, sinuosity, and stream gradient.

S

Sediment budget

The quantitative description of sources, sinks and riverine transport of sediment. Taking into account the errors associated with the definition and quantification of each of the terms, the sum of all the terms will add to zero. This represents the conservation of mass.

Sediment control basin

A basin constructed to widen and flatten a stream and thus cause the retention of sediments. The basin will usually require maintenance dredging.

Sediment rate

Transport, accumulation, or erosion of a volume or mass of sediment expressed per unit time.

Sediment yield

Transport, accumulation, or erosion of a volume or mass of sediment expressed per unit area.

Strath terrace

Remnant valley floor that has undergone dissection and may have a veneer of alluvial deposits.

Stream order

A system of ordering channels where two channels of the same order converge, they create a channel of the next higher order.

T

Tectonic uplift

The rising of a land surface because of pressure resulting from the movement of the Earth's crustal plates.

Terrace

A relatively level bench or step-like surface that was constructed by a river and represents an abandoned floodplain.

Thalweg

The deepest point of a channel at any given cross-section. A thalweg profile is a survey of the deepest point in the channel bed.

Tidal datum

The average height of a phase of the tide, such as high or low tide, during the 19-yr tidal epoch.

Trap efficiency

The relative ability of a basin or reservoir to retain sediment expressed as a percentage of the input.

W

Watershed

Area defined by a topographic drainage divide within which water from rainfall flows toward a common point.

Width/depth ratio

The relationship between the width of the channel and the depth of the channel at bankfull stage.

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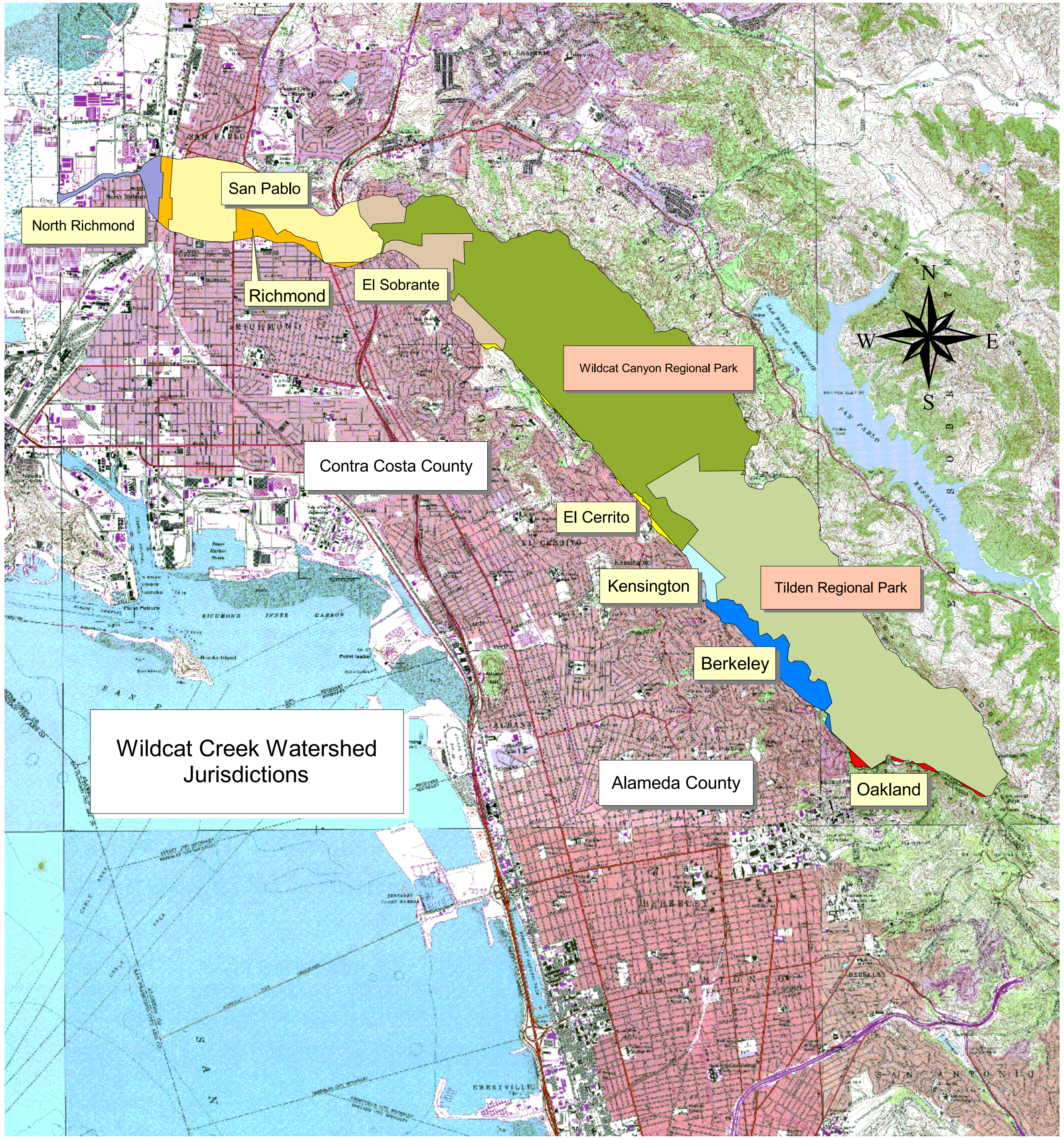
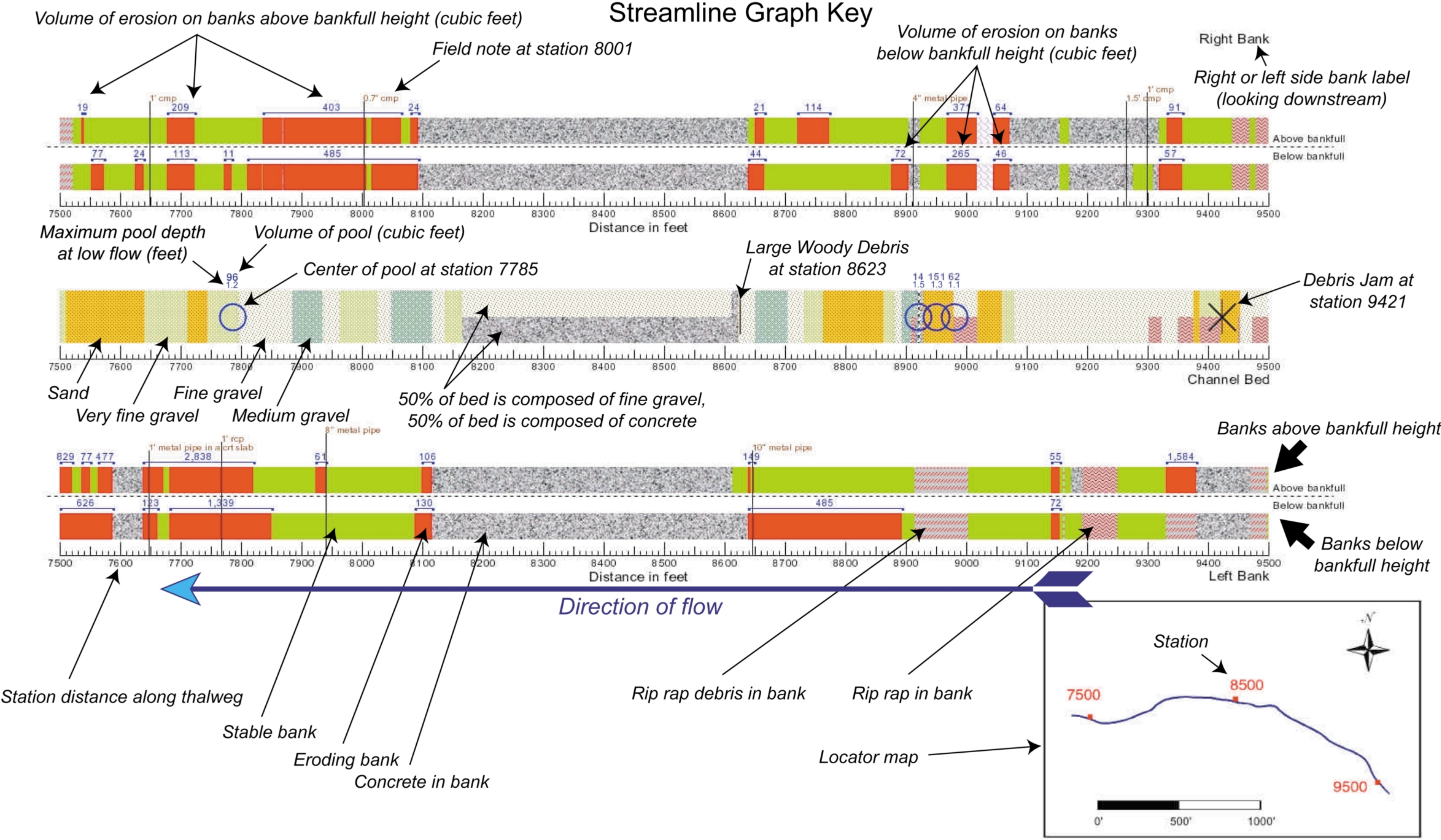
Appendix A

Jurisdictions Map
Streamline Graph Key
Station and Reach Locations Map
Streamline Graphs
Rosgen Stream Classification



Wildcat Creek Watershed Jurisdictions

Wildcat Creek
Streamline Graph Key



Wildcat Creek

Key for Bed and Bank Conditions

Bank Features

- 🟩 Stable bank
- 🟥 Actively eroding bank
- ▨ Eroding canyon slope
- ▨ Active landslide
- ▨ Stable bedrock in bank
- ▨ Eroding bedrock in bank
- ▨ Concrete
- ▨ Rip rap
- ▨ Rip rap debris
- ▨ Sackcrete
- ▨ Gabion
- ▤ Wood fence
- ▤ Brick
- ▨ Wood
- ▨ Rock wall
- ▨ Cyclone fence
- ▥ Sheet metal
- ▨ CMP (Corrugated metal pipe)
- ▨ Other

Abbreviations

cmp - Corrugated metal pipe

rcp - Reinforced concrete pipe

dbh - Diameter at breast height

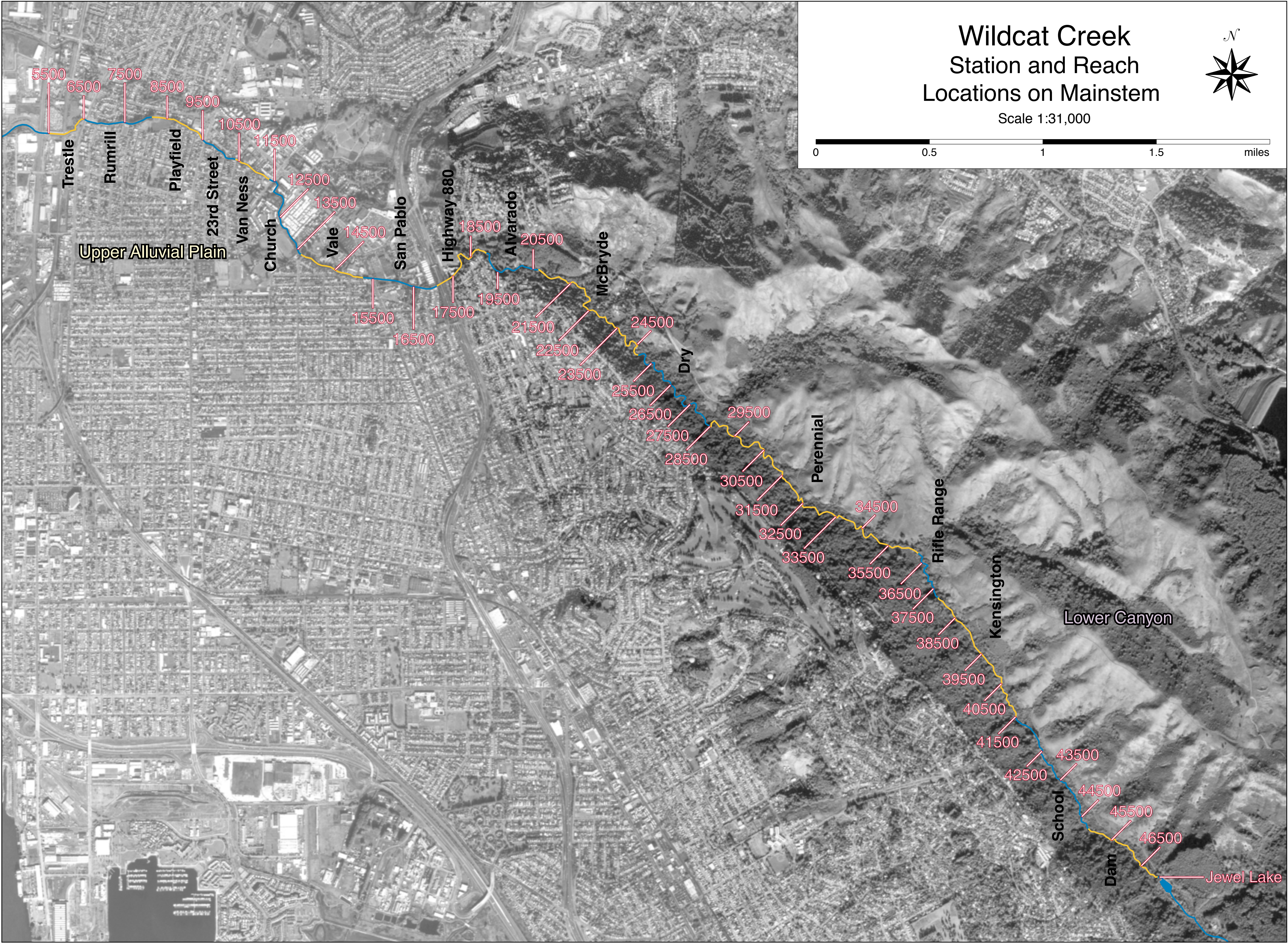
crt - Concrete

rr - Rip rap

Bed Features

- ▨ Bedrock in bed
- ■ Clay (< .004 mm)
- ▨ Silt (.004 - .062 mm)
- ▨ Sand (.062 - 2 mm)
- ▨ Very fine gravel (2 - 4 mm)
- ▨ Fine gravel (4 - 8 mm)
- ▨ Medium gravel (8 - 16 mm)
- ▨ Coarse gravel (16 - 32 mm)
- ▨ Very coarse gravel (32 - 64 mm)
- ▨ Small cobble (64 - 128 mm)
- ▨ Large cobble (128 - 256 mm)
- ▨ Small boulder (256 - 512 mm)
- ▨ Large boulder (> 512 mm)
- ▨ Rip rap
- ▨ Rip rap debris
- ▨ Vortex rock weir
- ▨ Concrete
- ▨ CMP (Corrugated metal pipe)
- ▨ Roots
- ▨ Wood
- ▨ Organic matter
- ▨ Grass

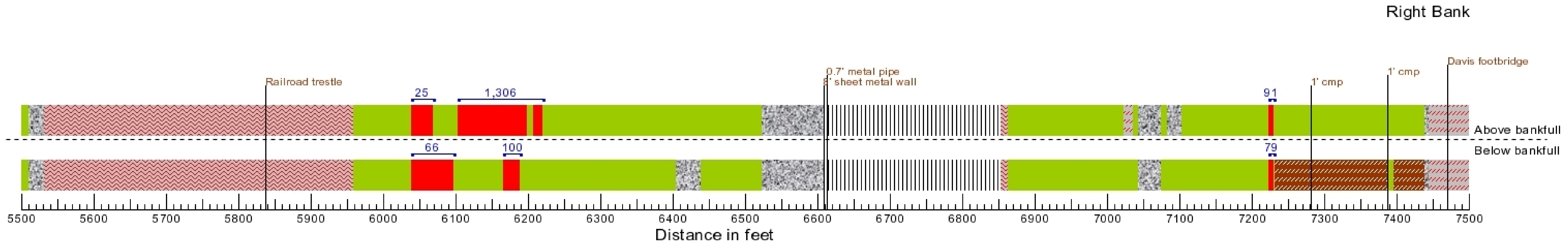
- ○ Pool greater than 1’ deep
- ✕ Debris jam
- ▮ Large woody debris

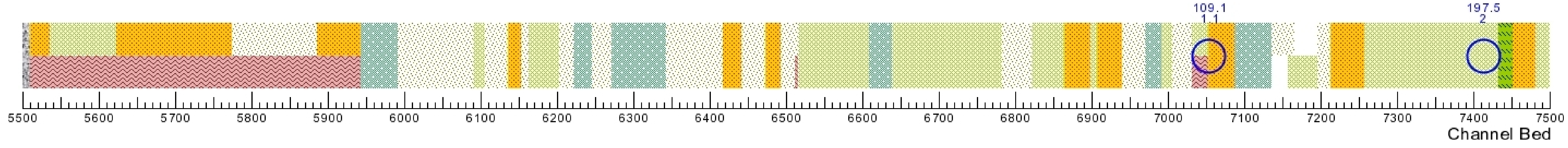


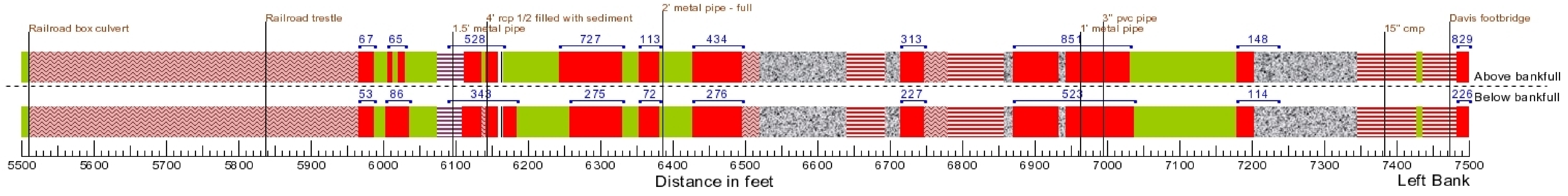
Wildcat Creek
Station and Reach Locations on Mainstem

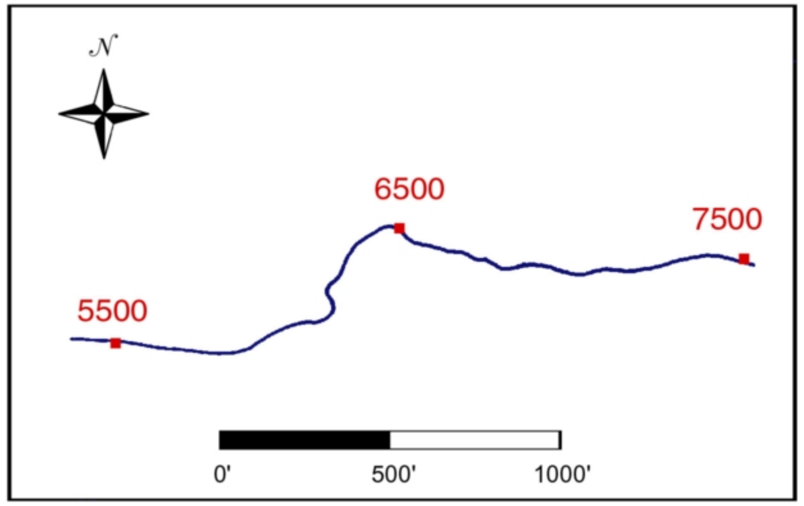
Scale 1:31,000

Wildcat Creek









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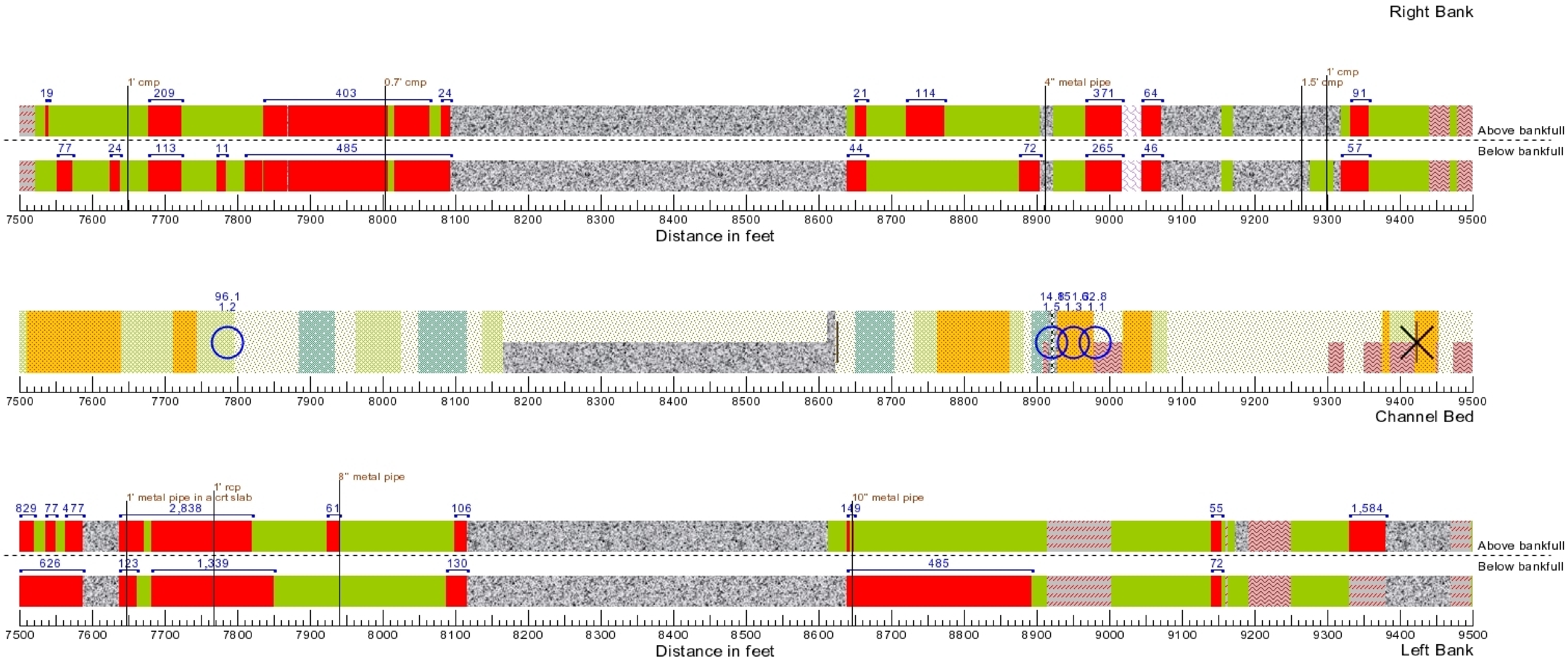

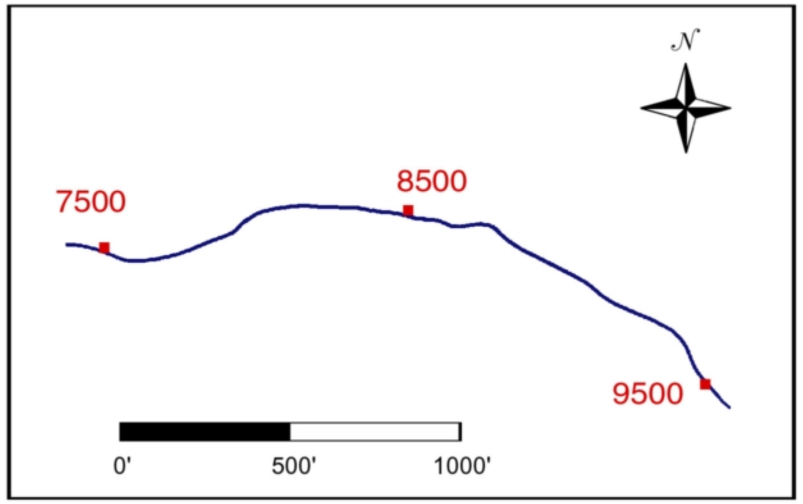

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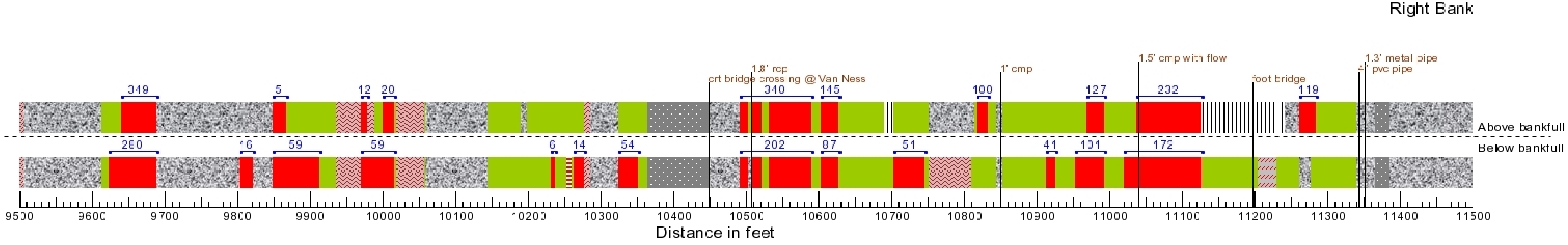

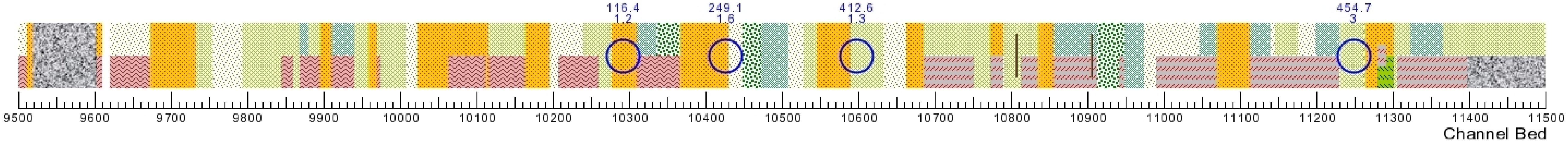

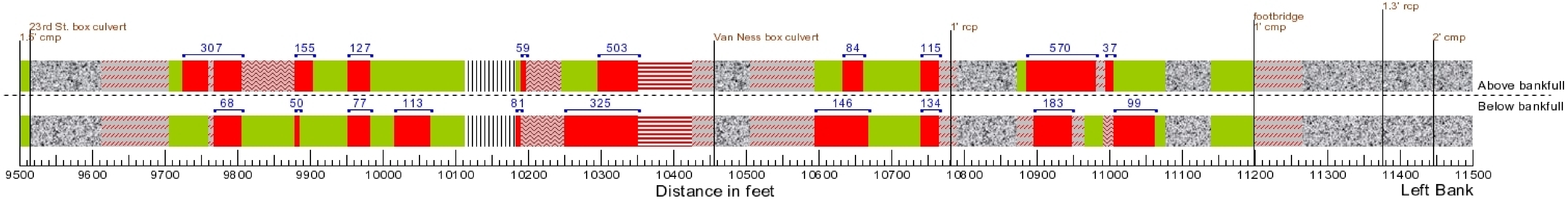

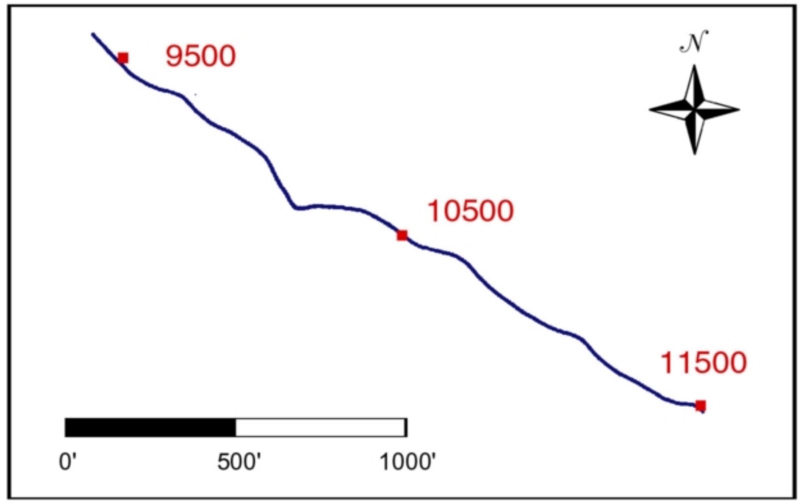

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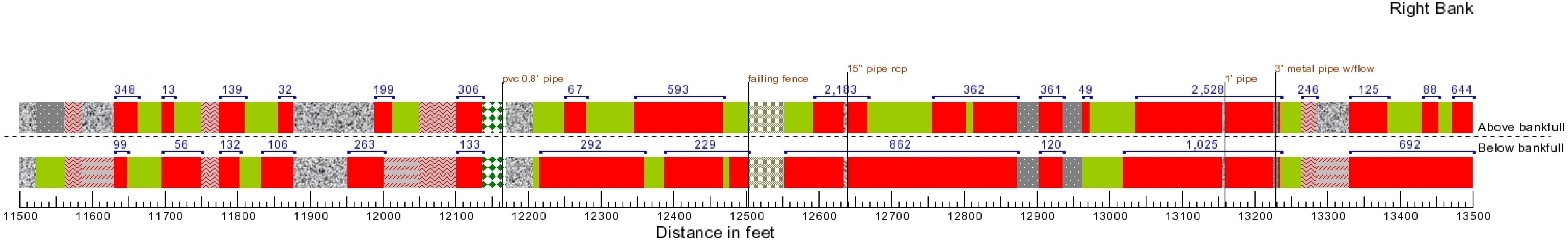

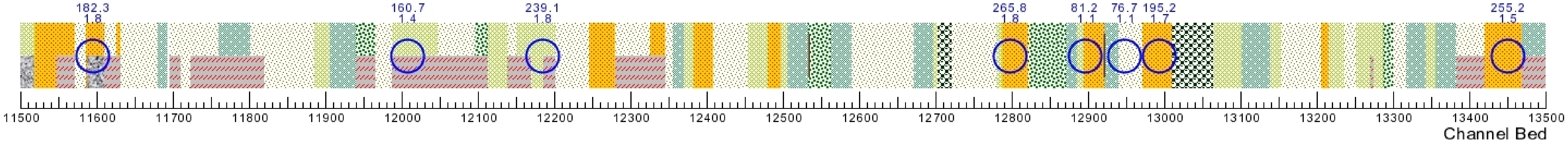

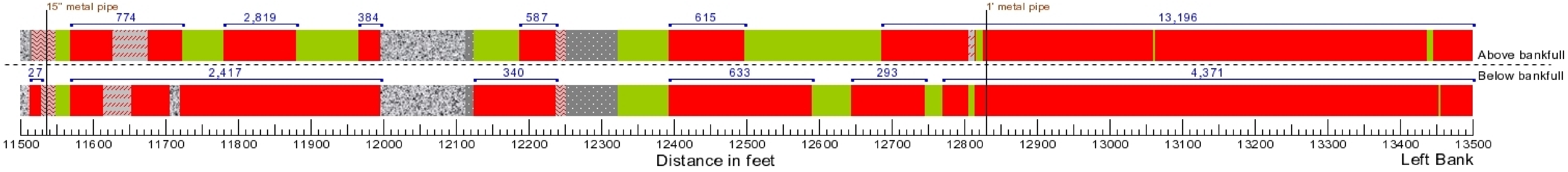

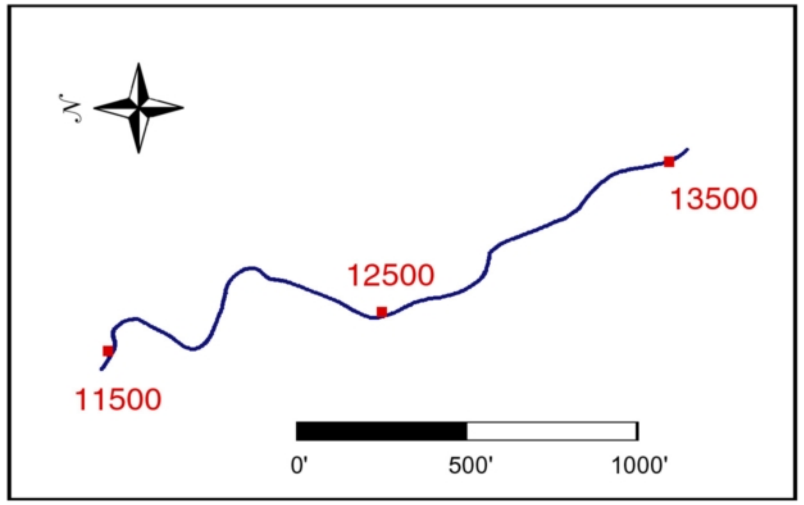

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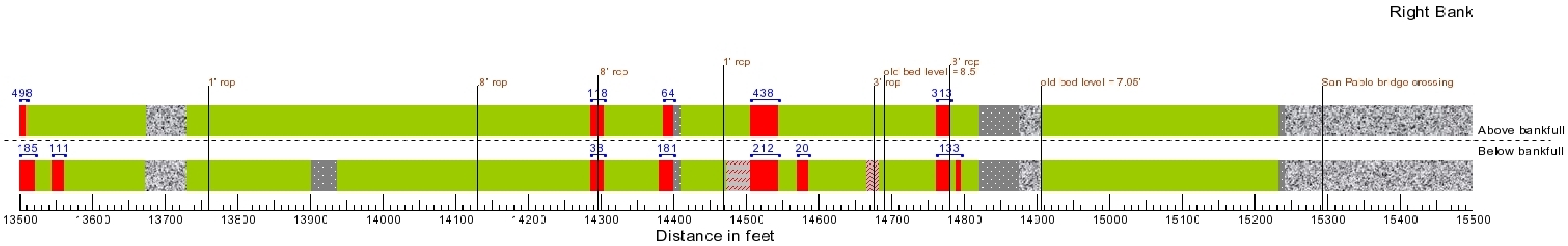

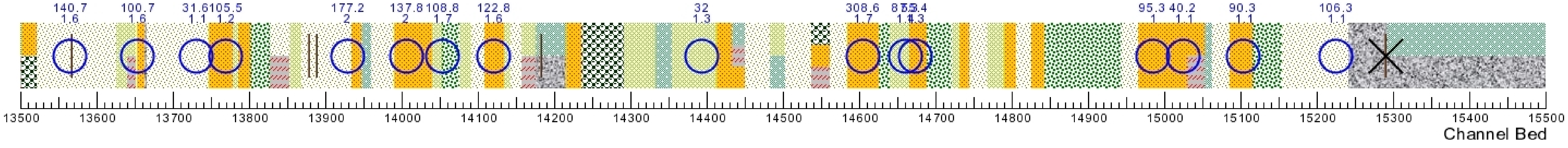

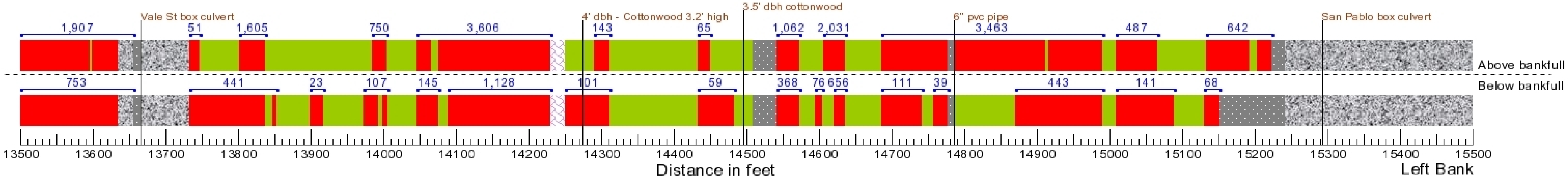

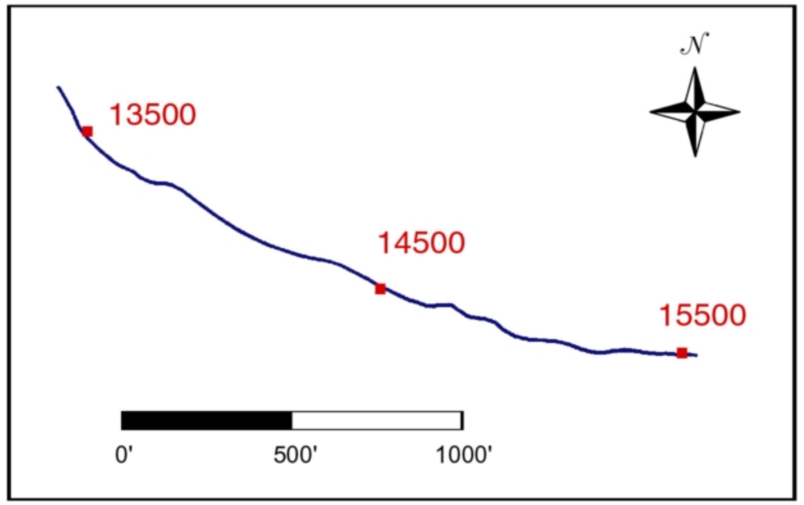

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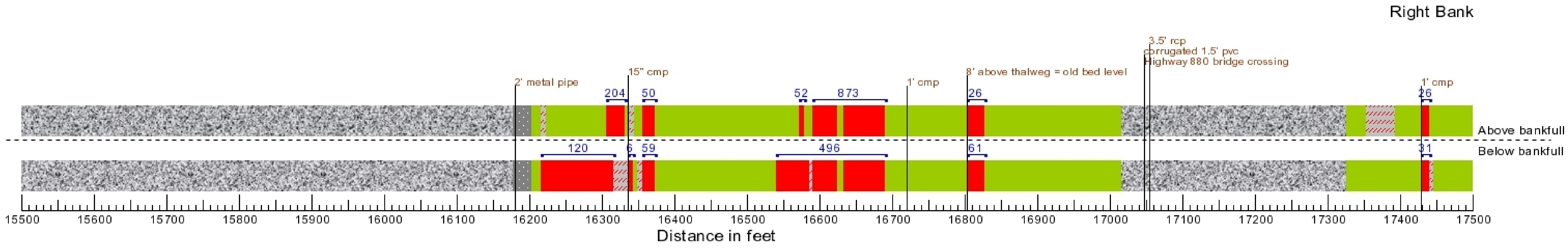

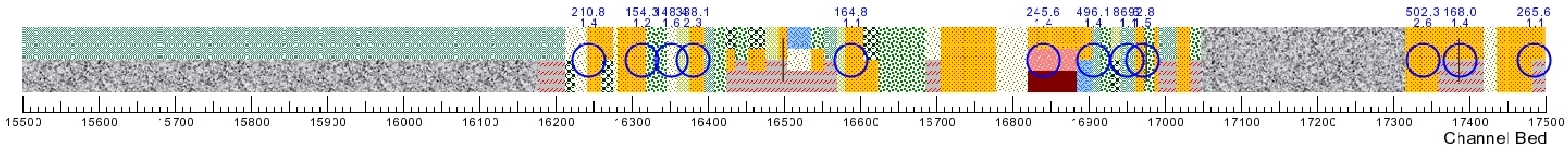

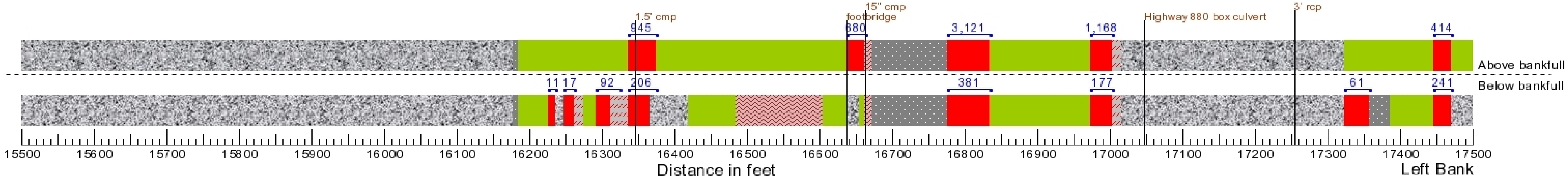

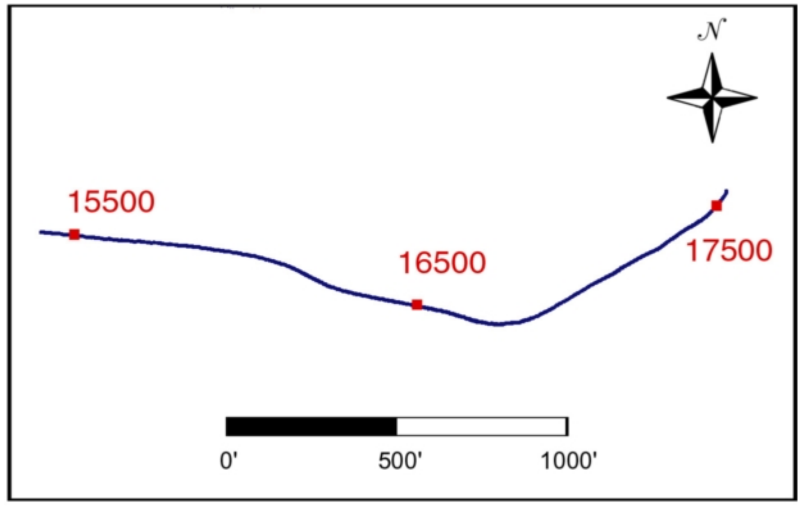

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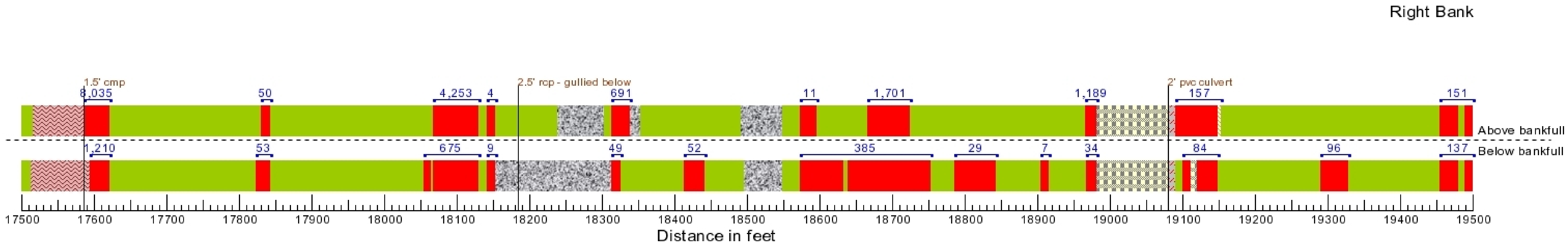

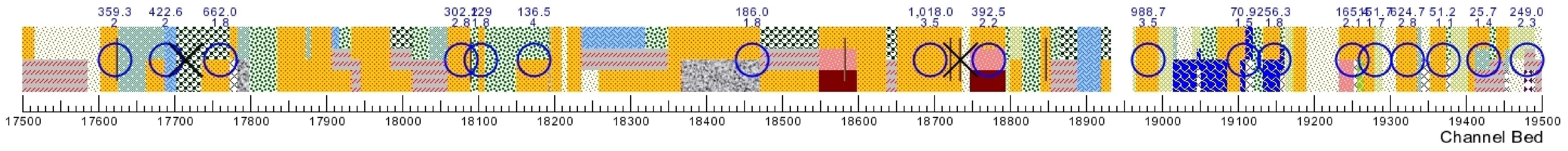

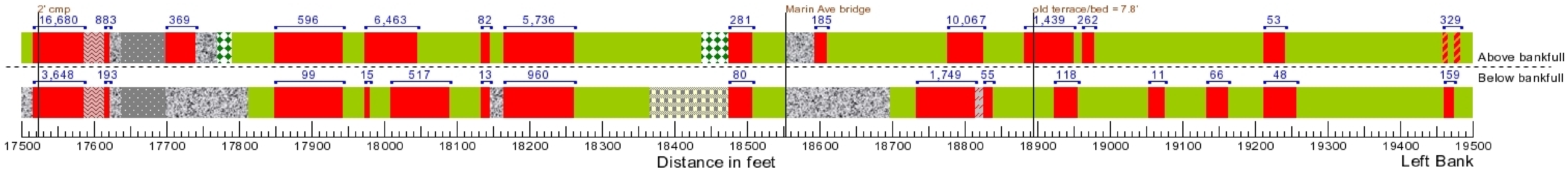

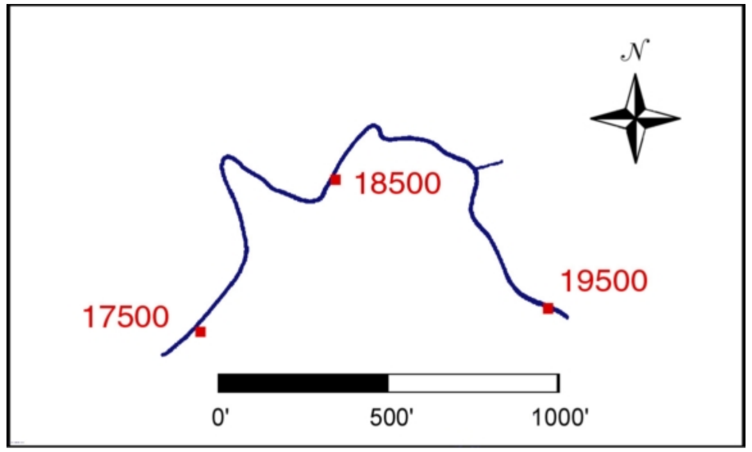

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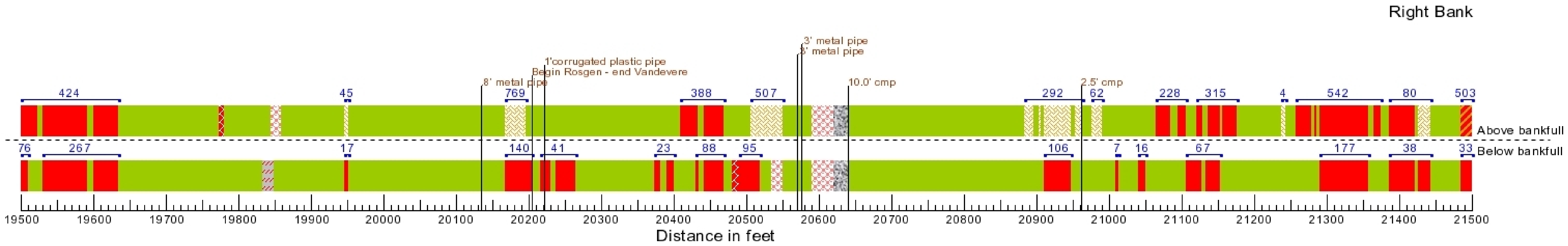

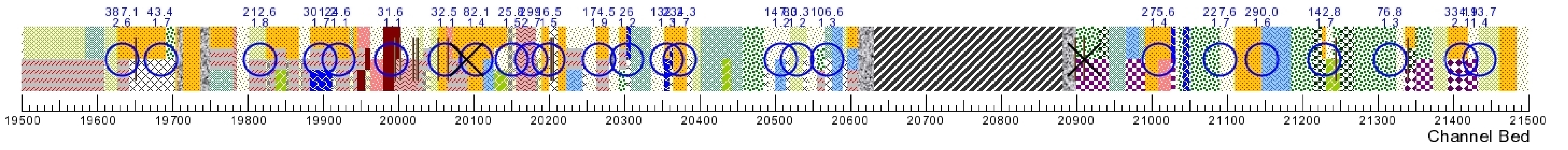

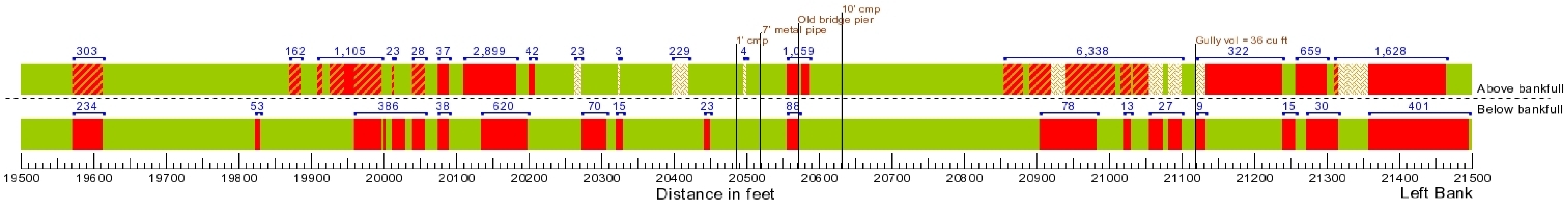

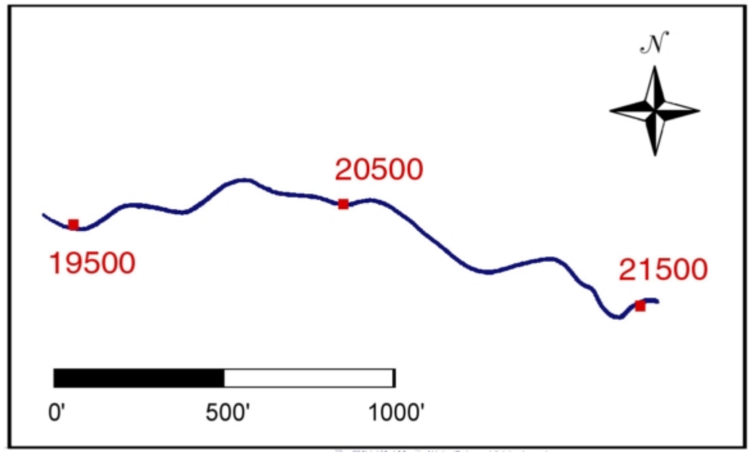

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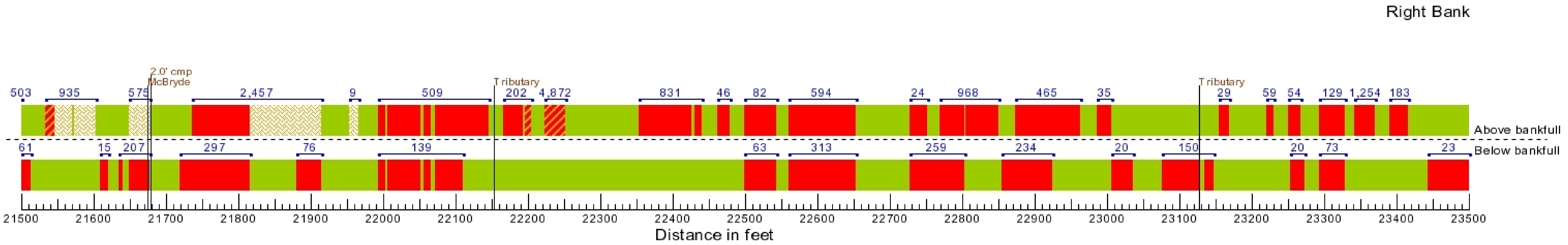

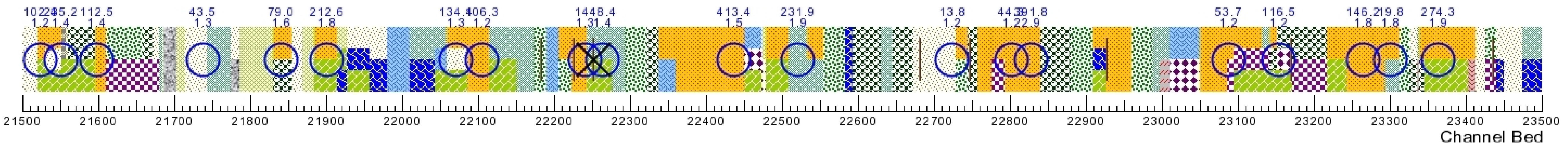

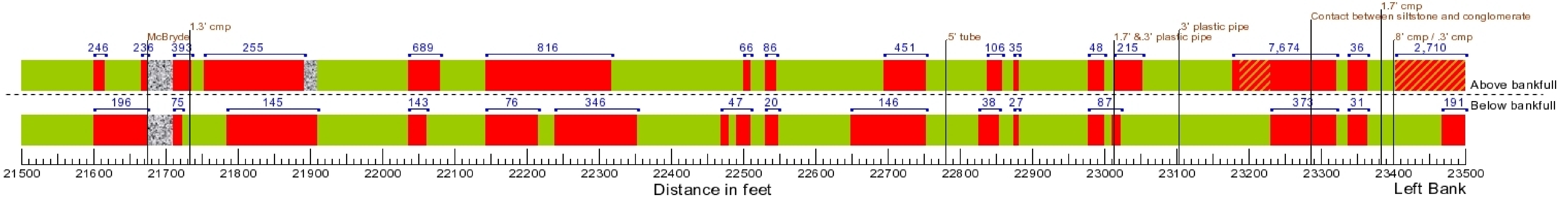

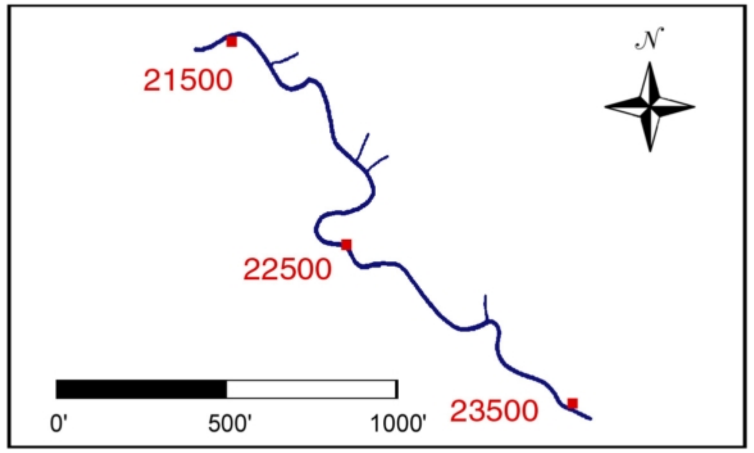

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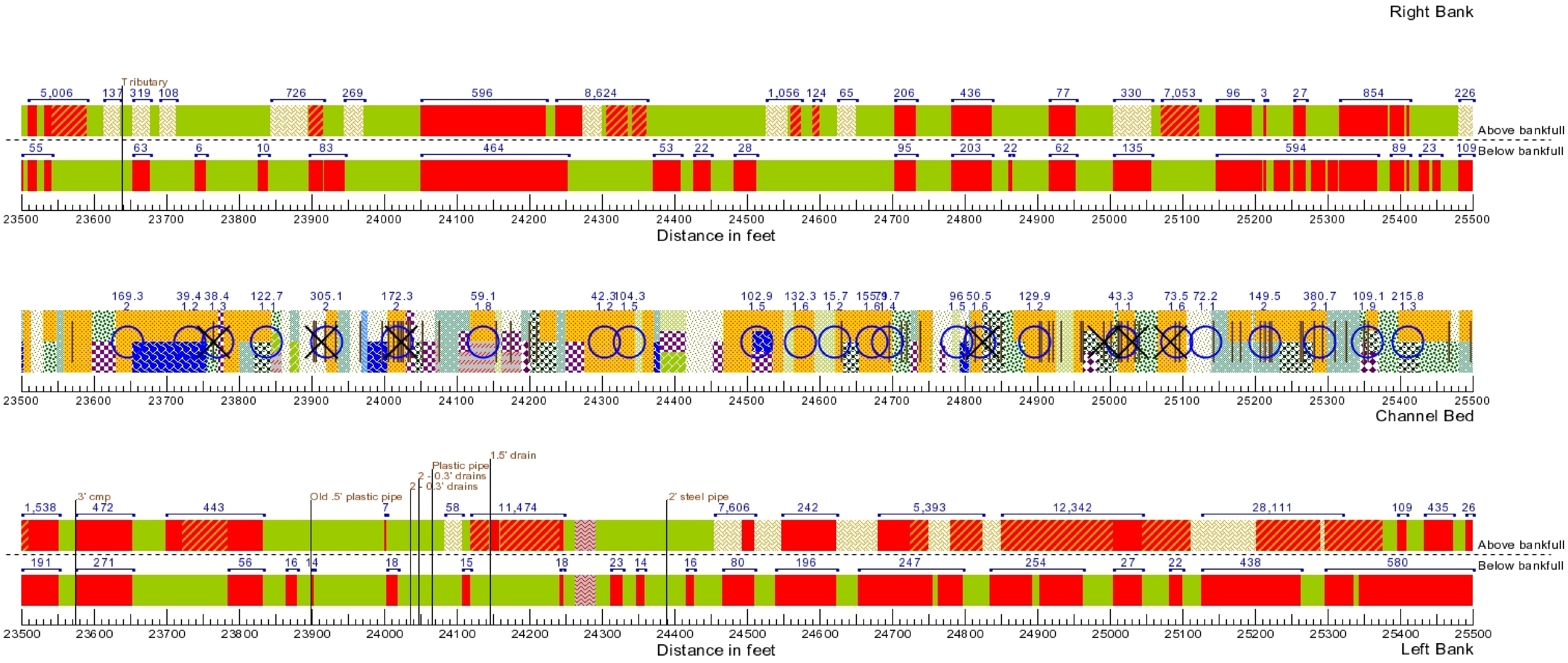

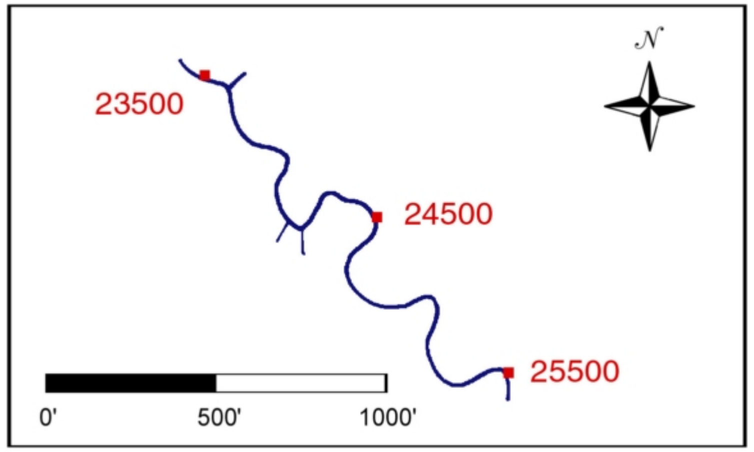

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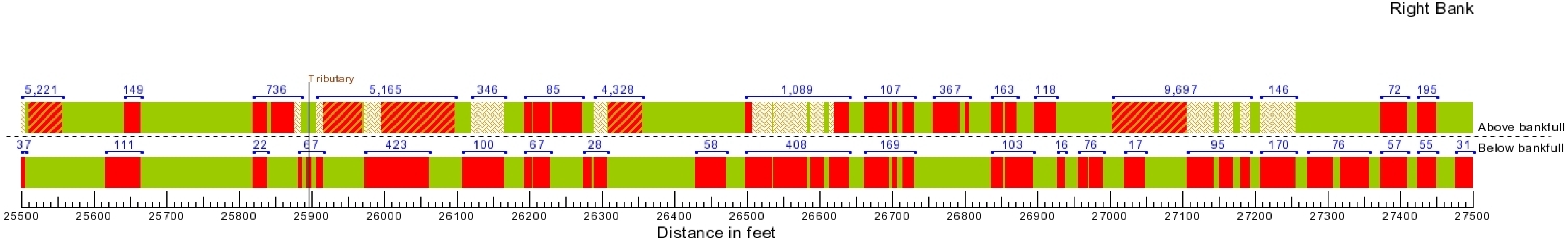

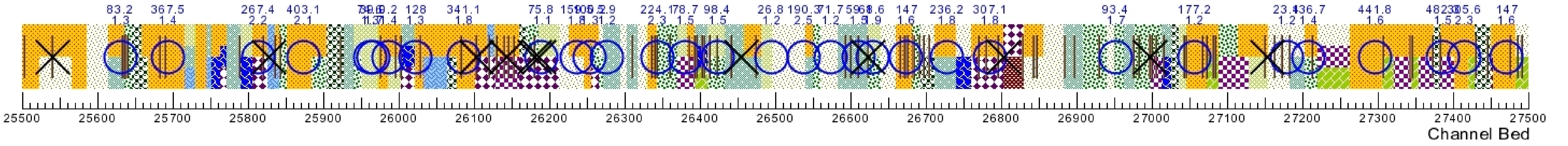

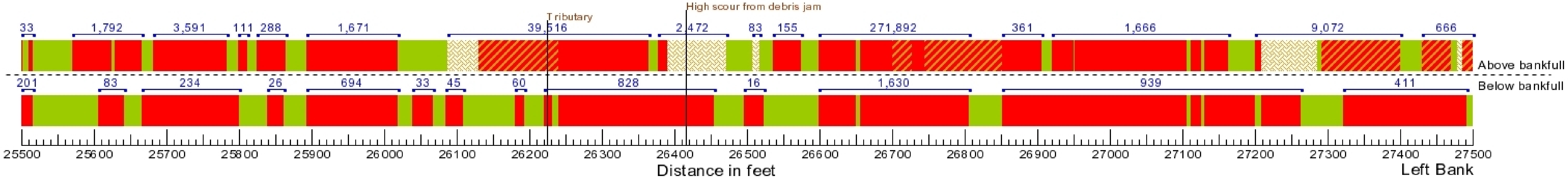

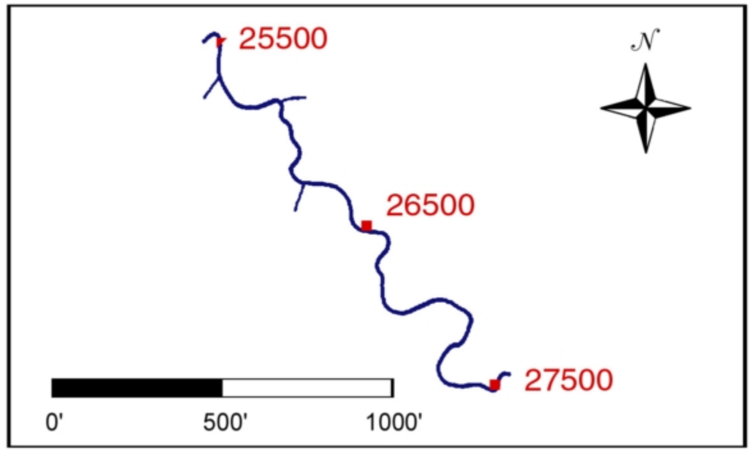

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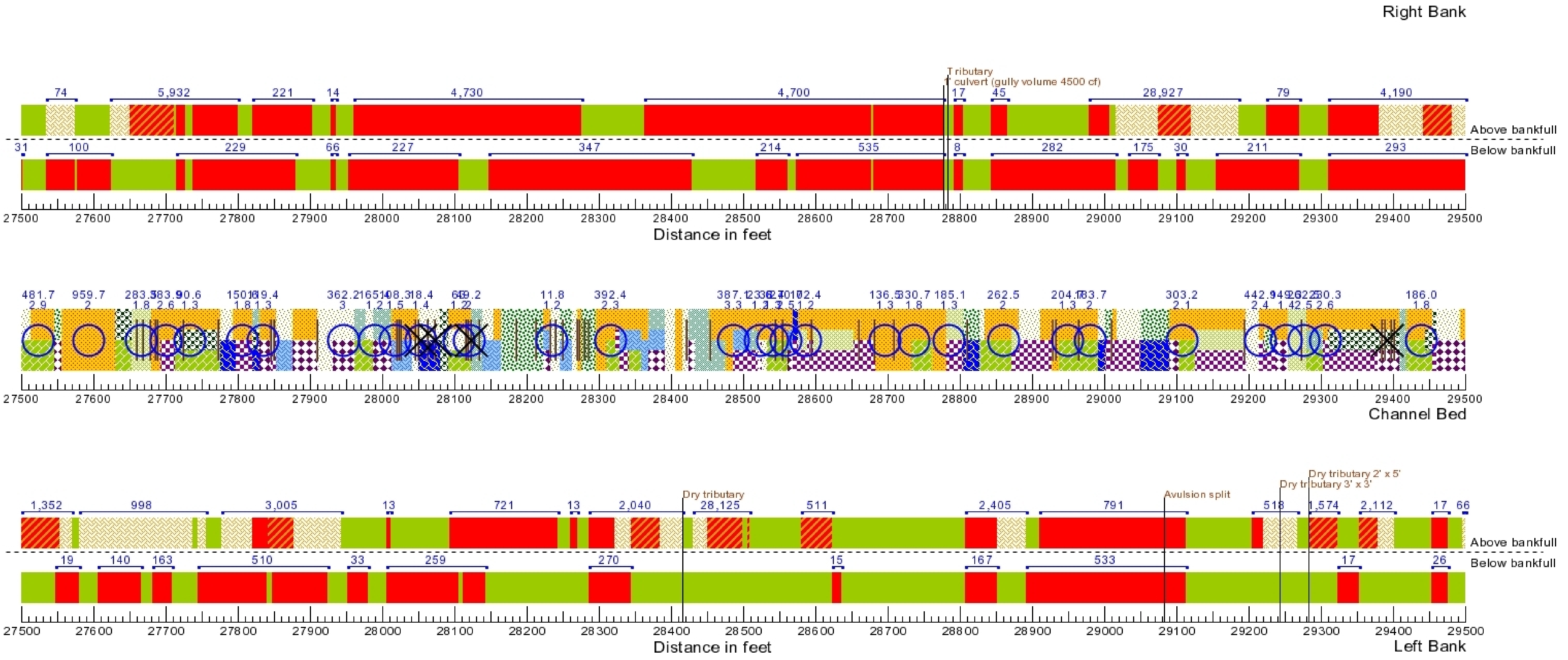
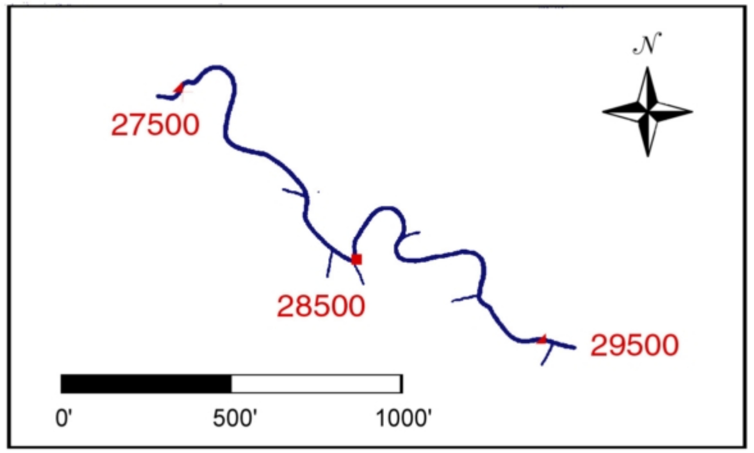
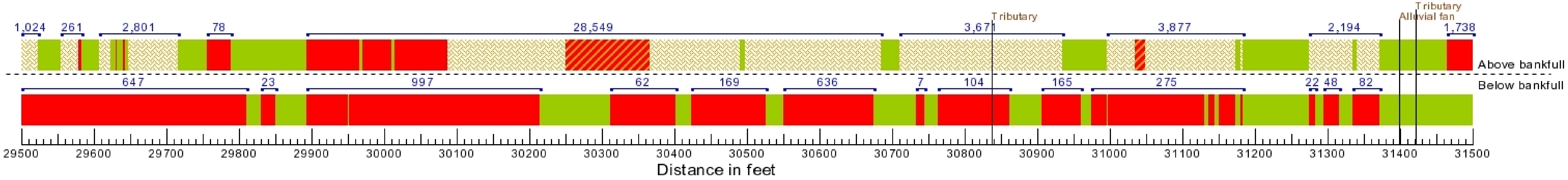
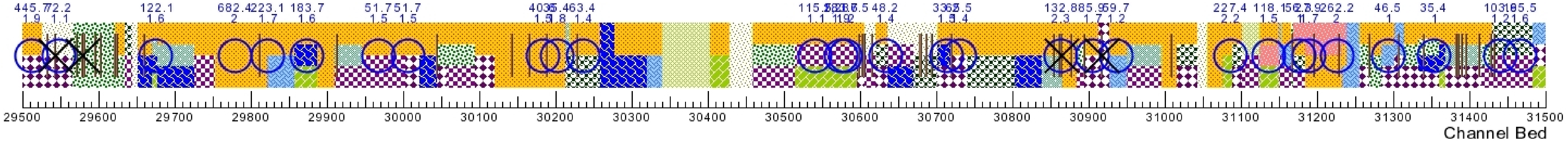


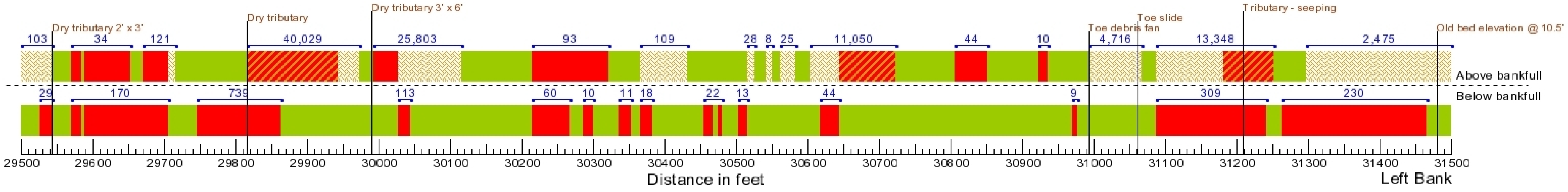


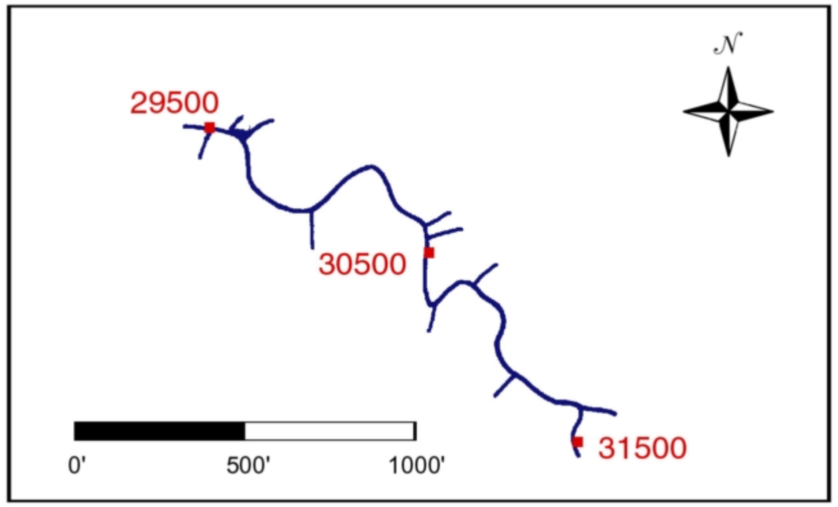
Wildcat Creek

Right Bank

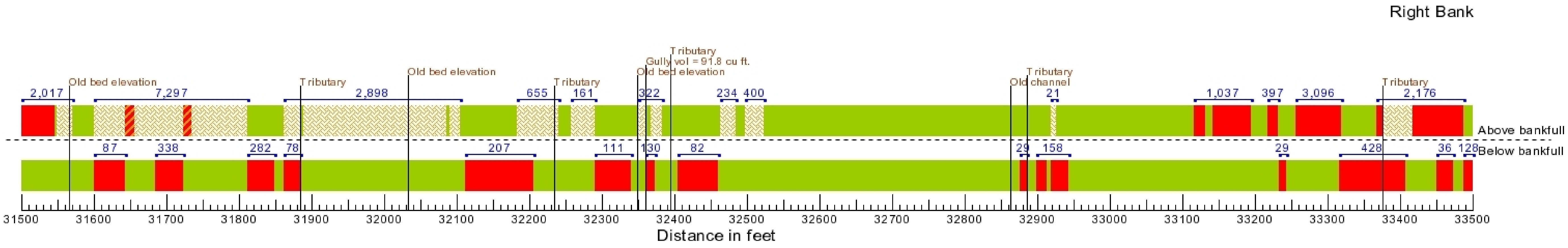


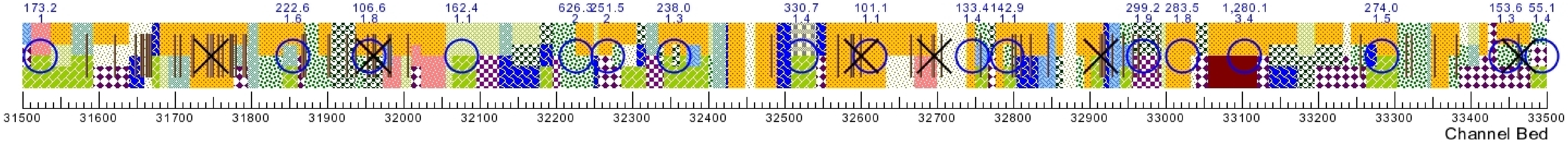


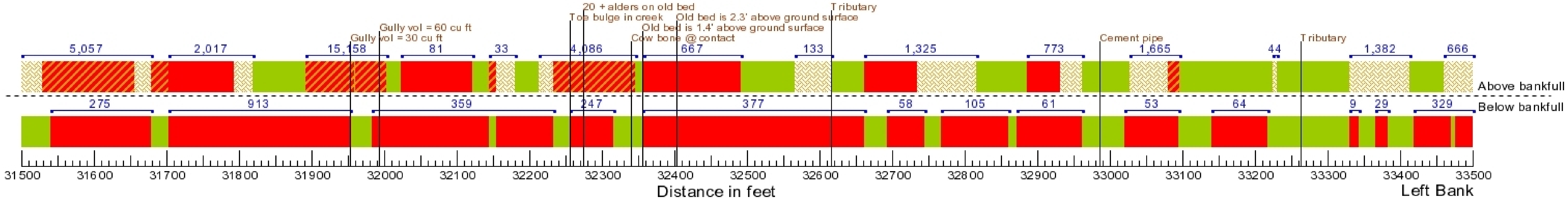


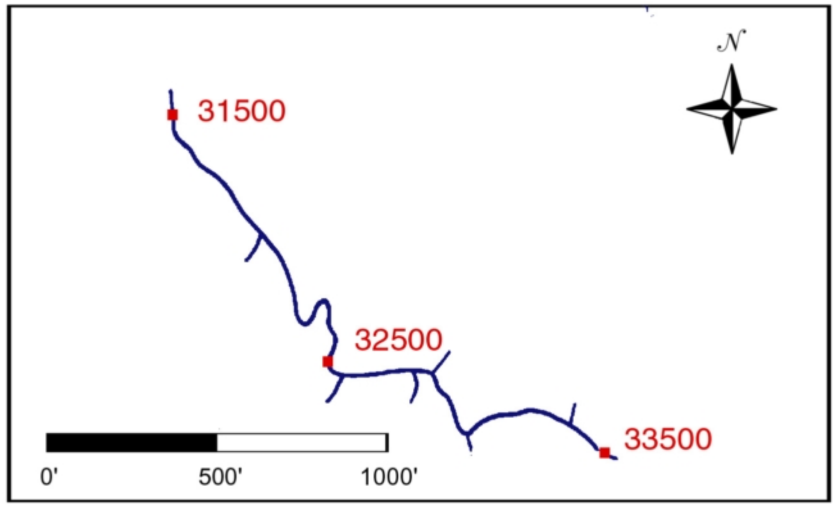


Wildcat Creek









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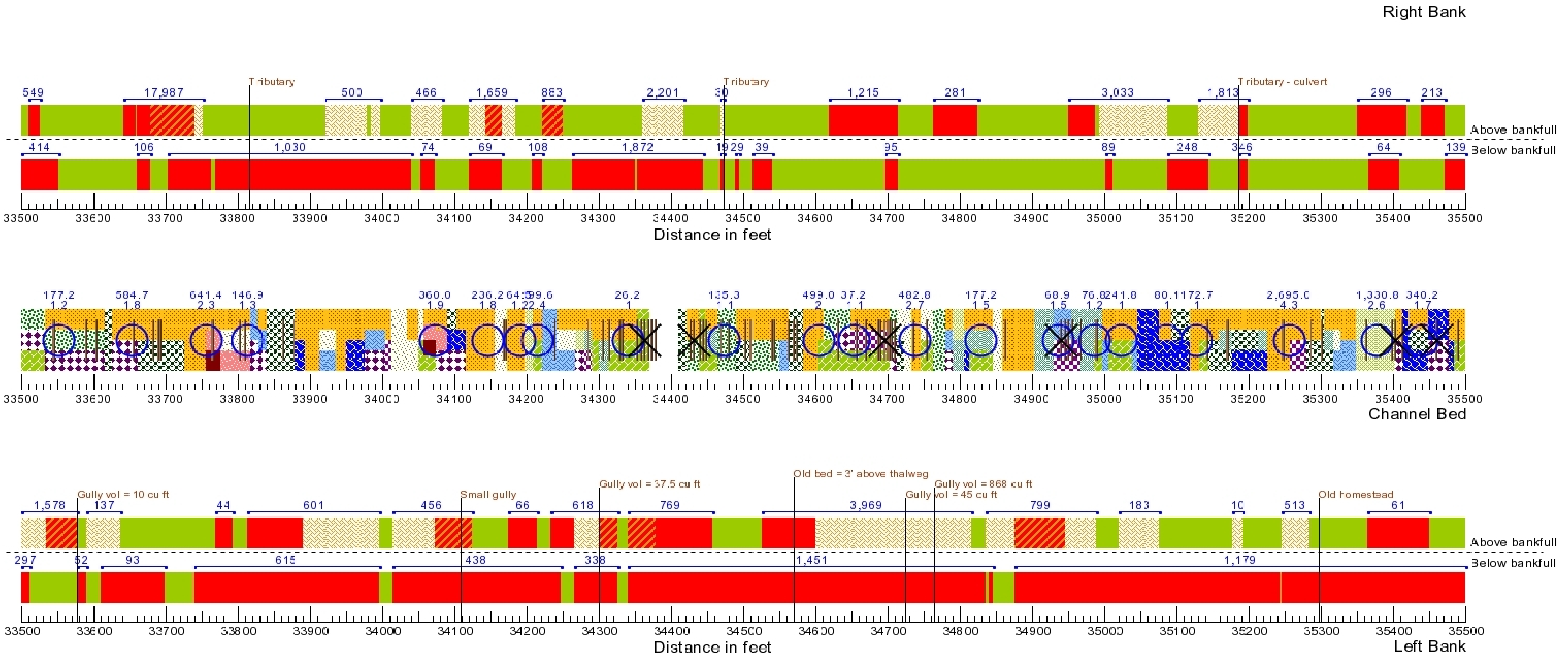

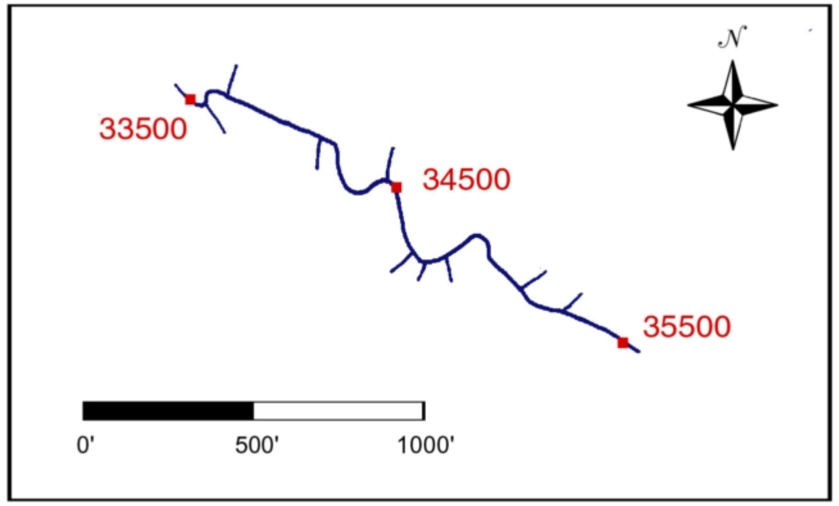

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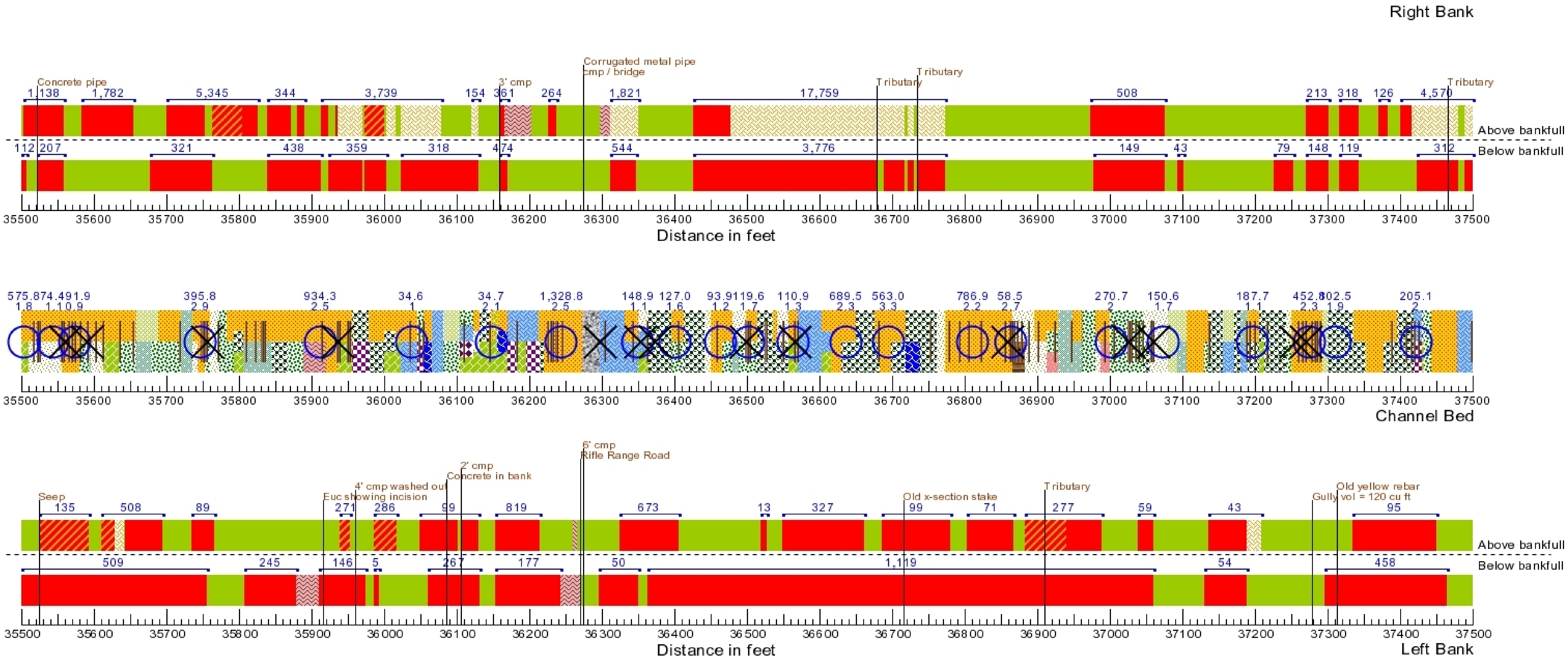
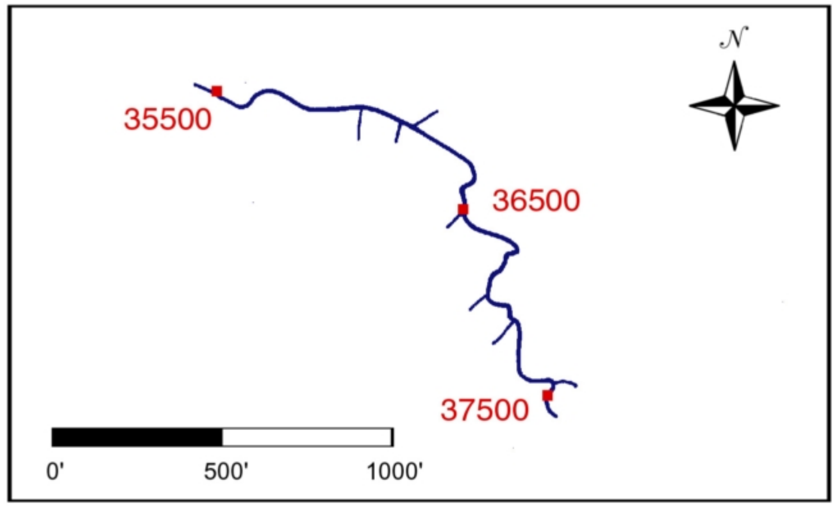
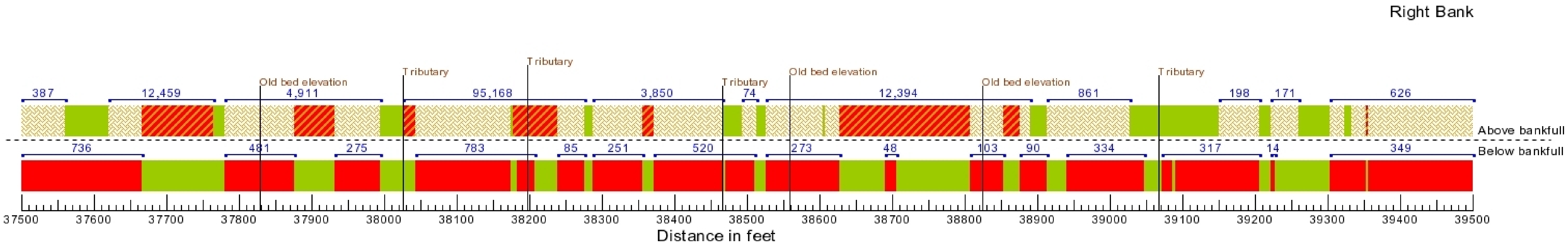
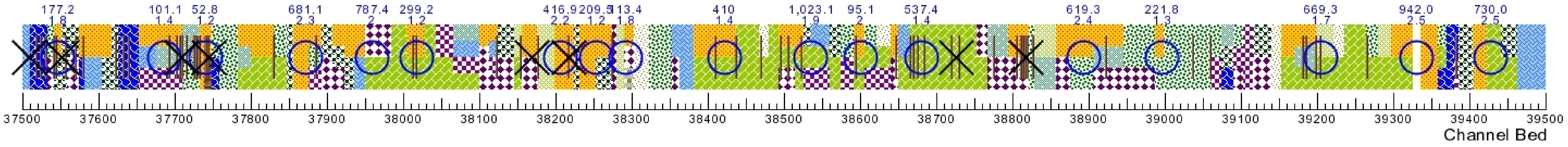
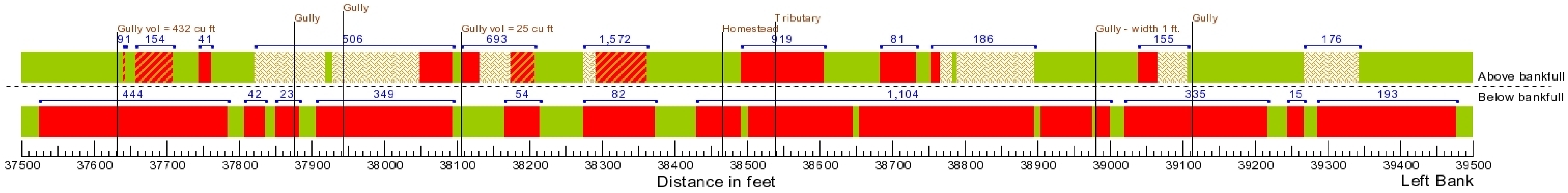


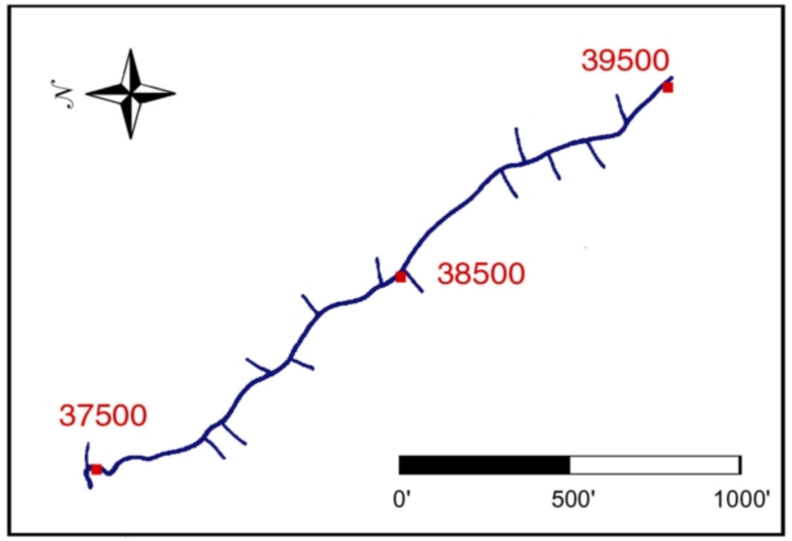


Wildcat Creek









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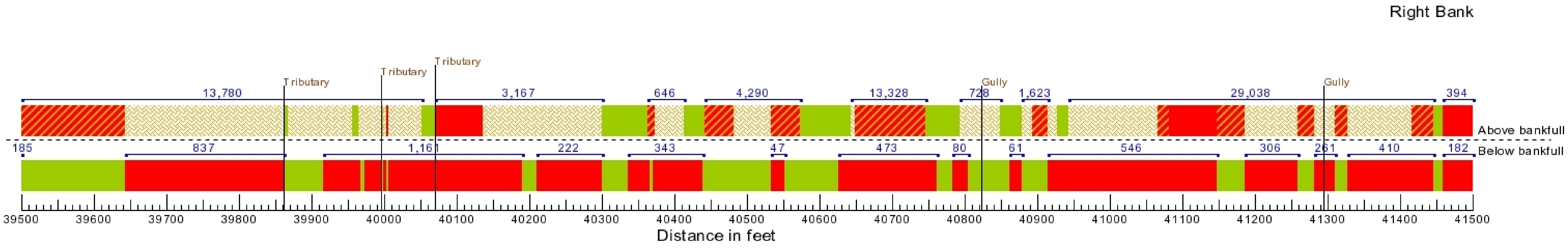

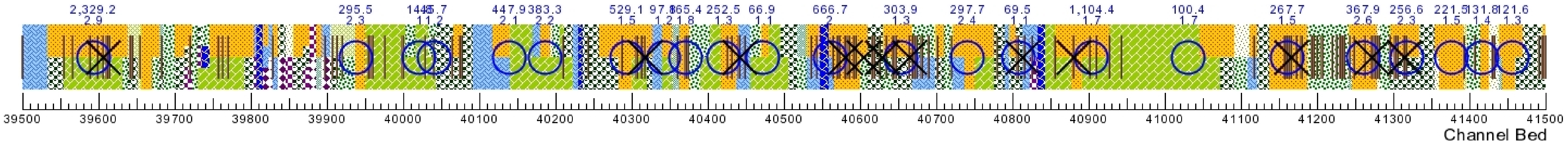

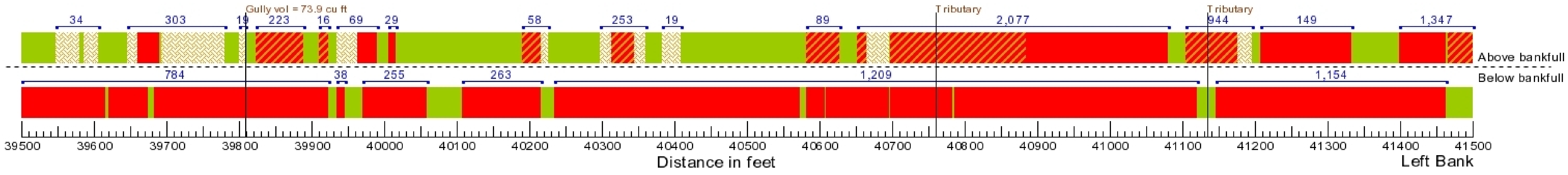

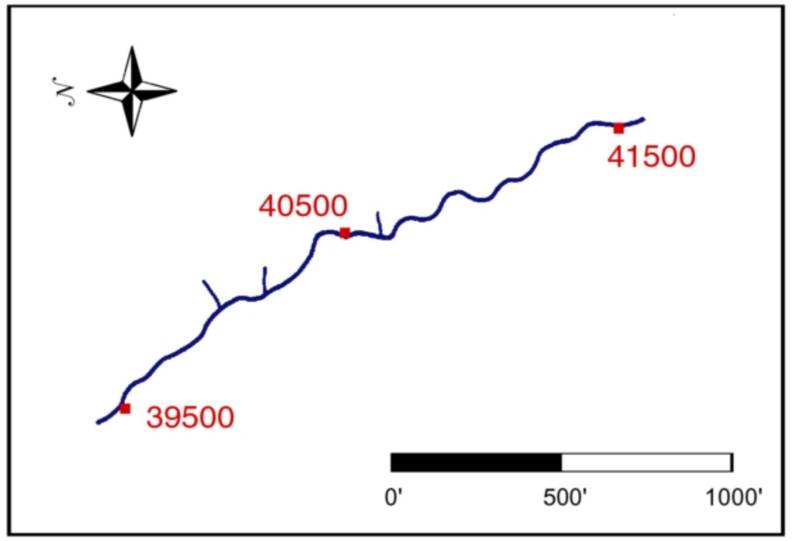

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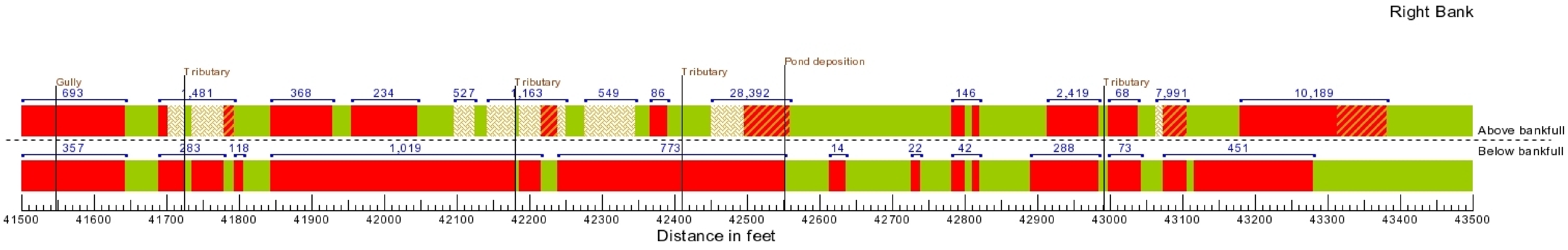

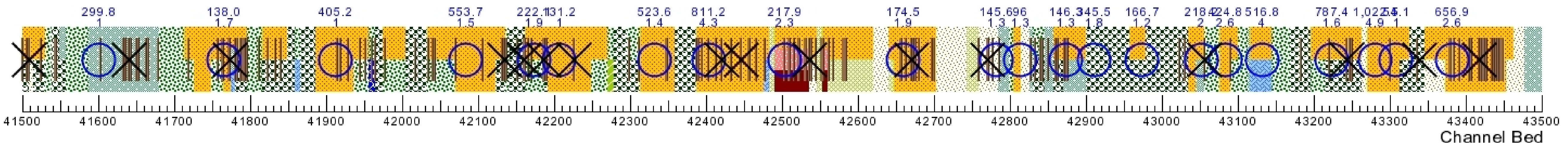

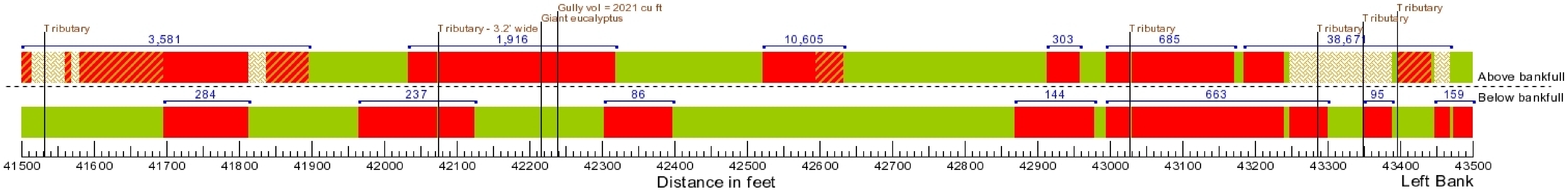

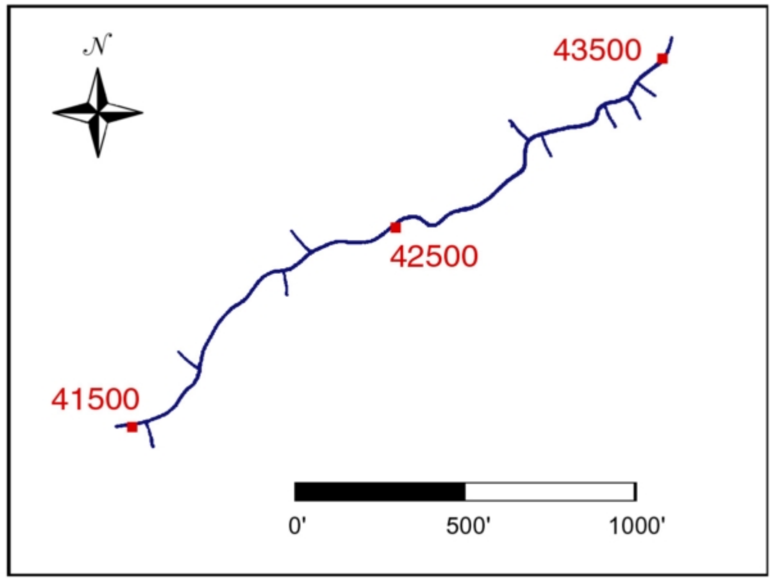

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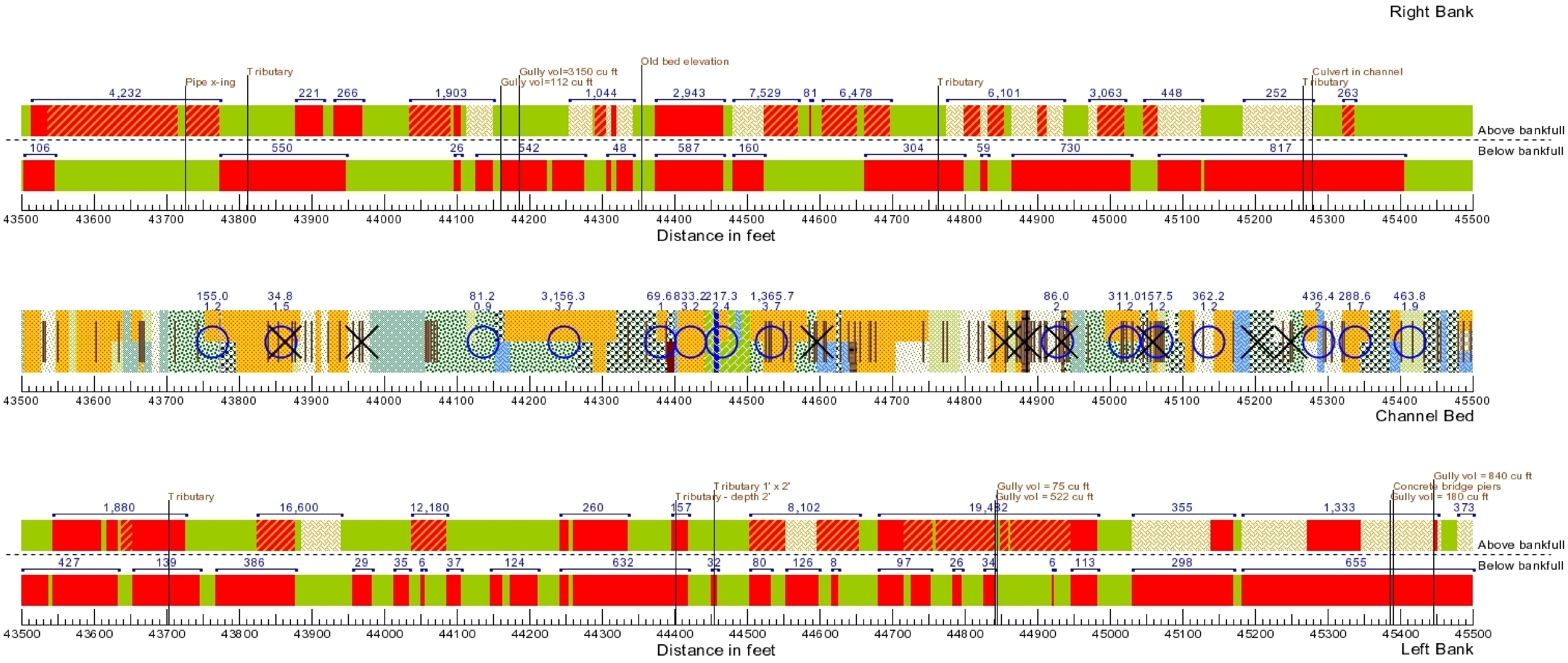

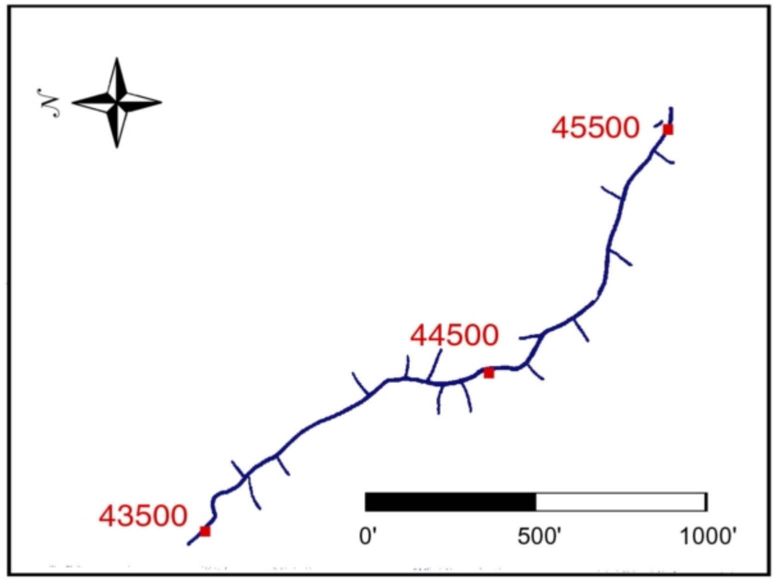

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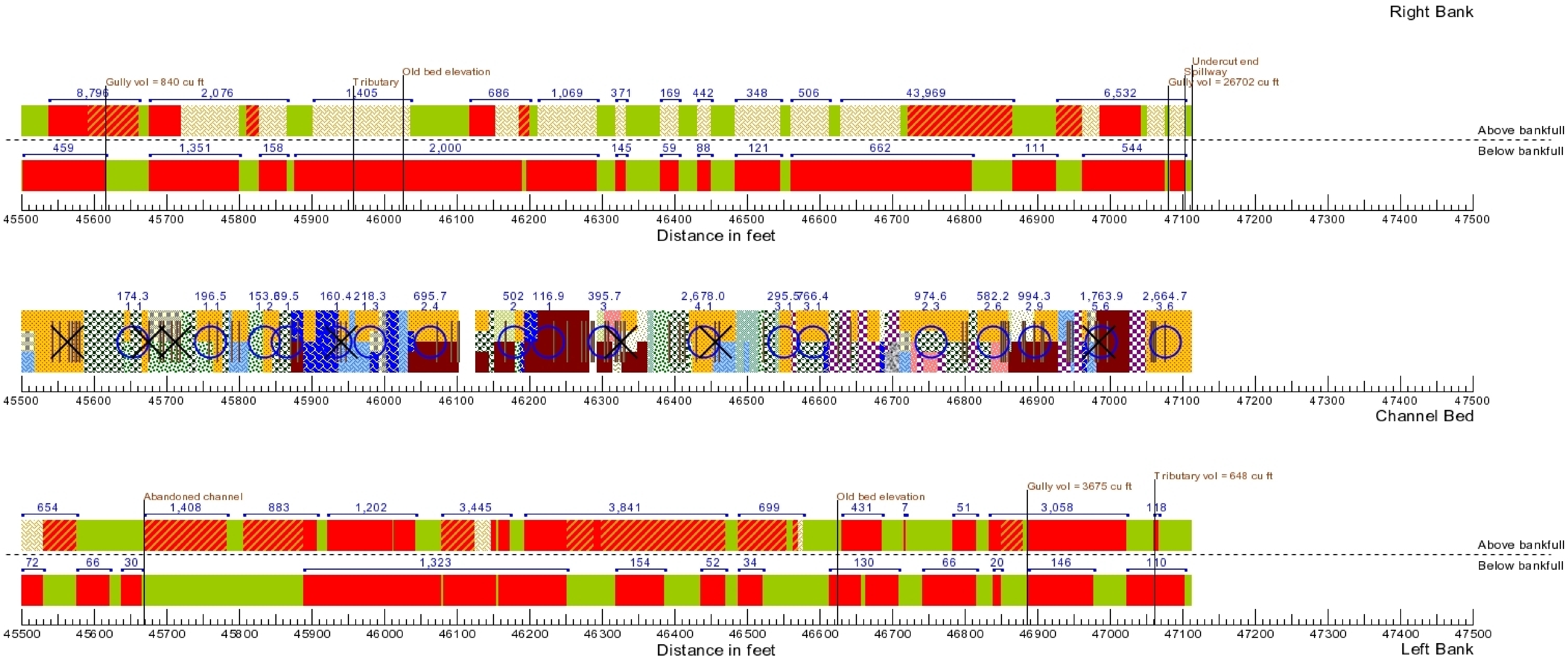
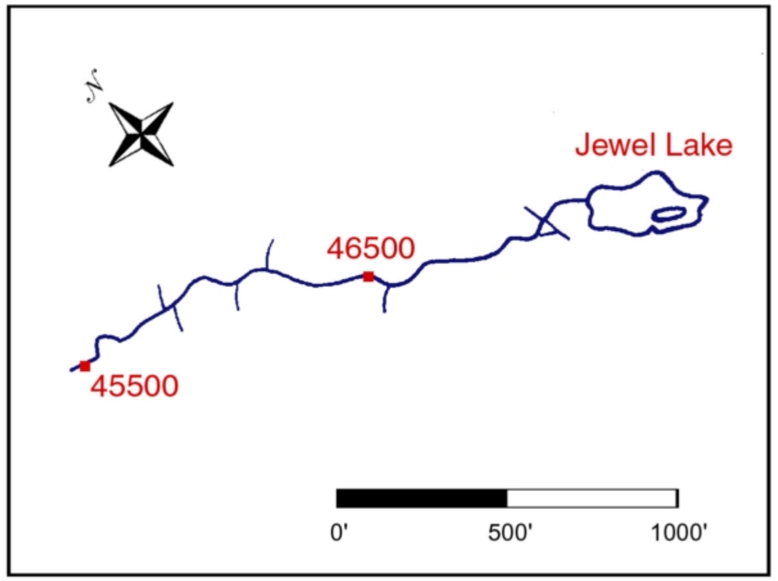
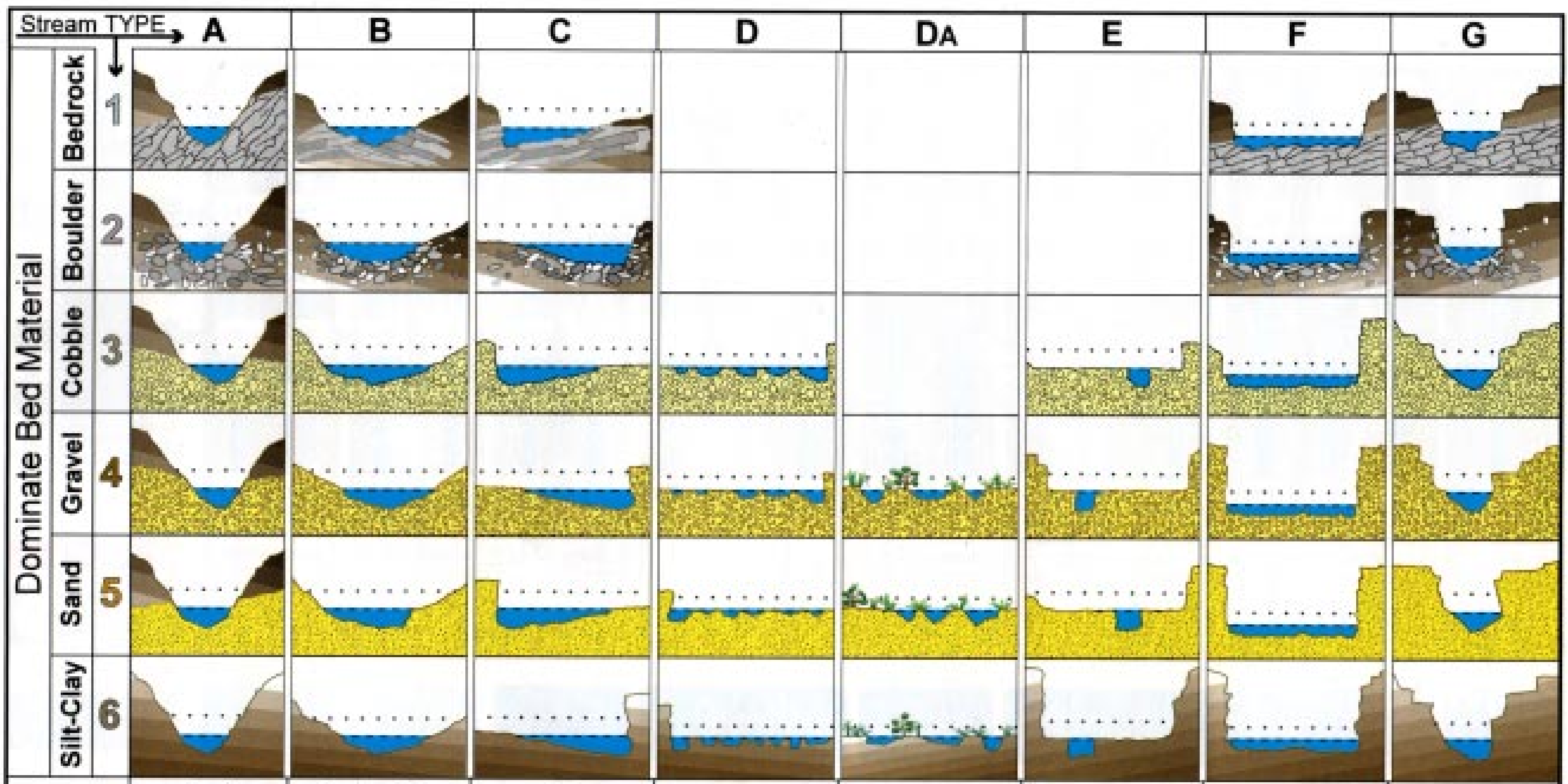
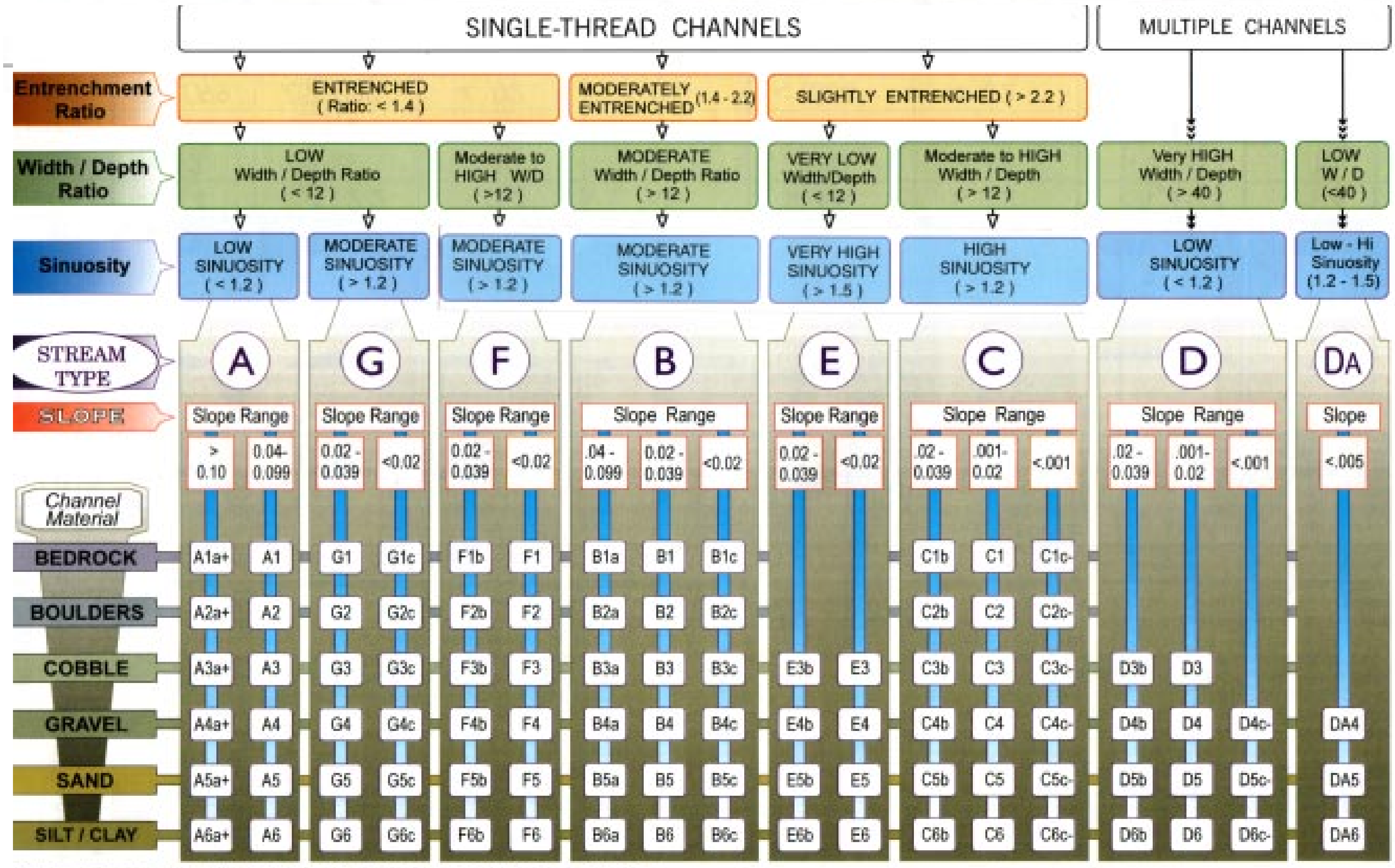




Rosgen Stream Classification



Stream TYPE	A	B	C	D	DA	E	F	G
Entrchmnt.	< 1.4	1.4 - 2.2	> 2.2	n/a	> 4.0	> 2.2	< 1.4	< 1.4
W/D Ratio	< 12	> 12	> 12	> 40	< 40	< 12	> 12	< 12
Sinuosity	1 - 1.2	> 1.2	> 1.2	n/a	variable	>1.5	> 1.2	>1.2
Slope	.04-.099	.02-.039	< .02	< .04	< .005	< .02	< .02	.02-.039



EY to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the *"continuum of physical variables"* within stream eaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

From Rosgen 1996