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.

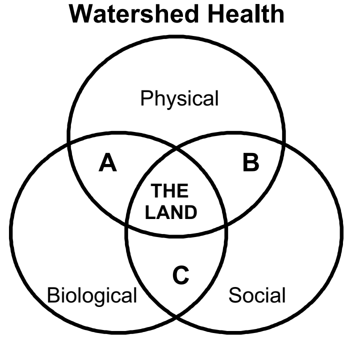
SFEI's Watershed Science Approach

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.

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.

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.

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.

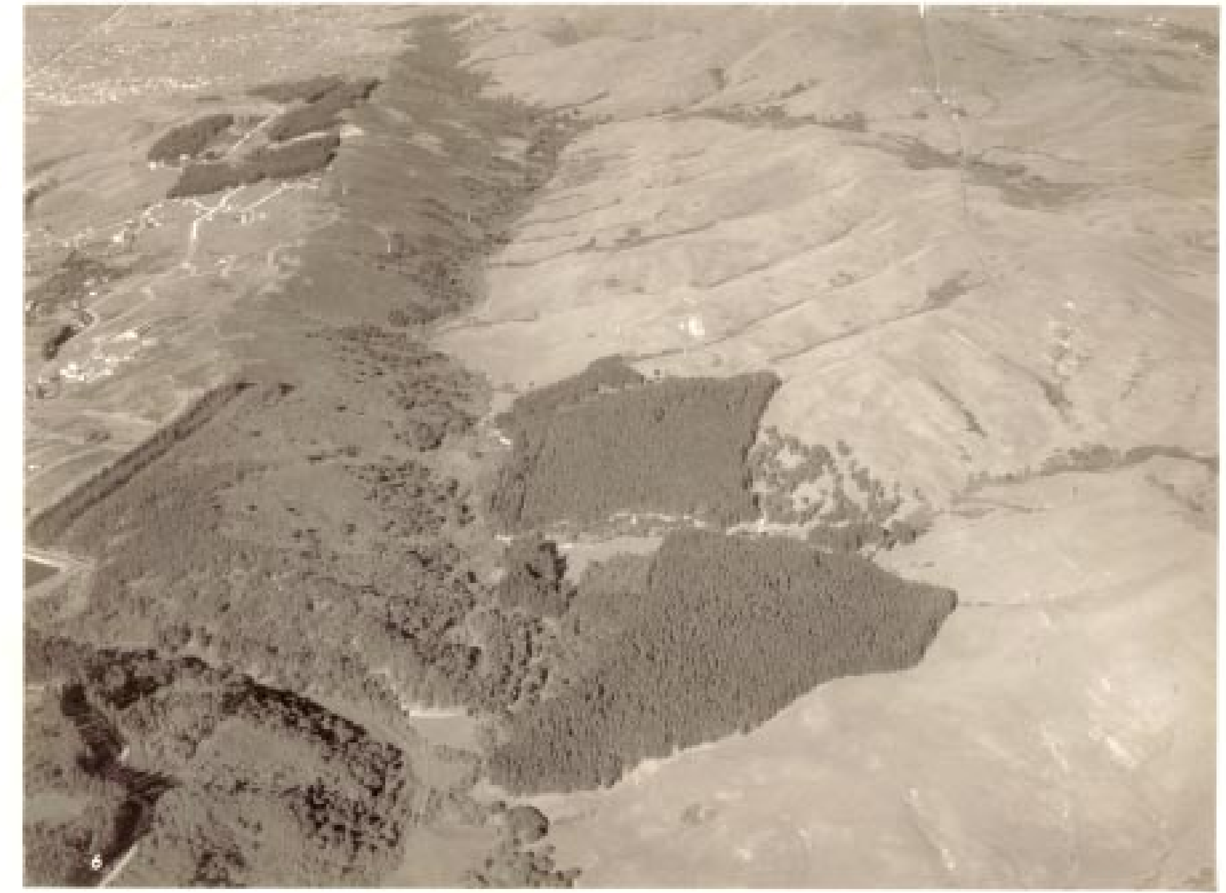
Aggradation and Degradation

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.

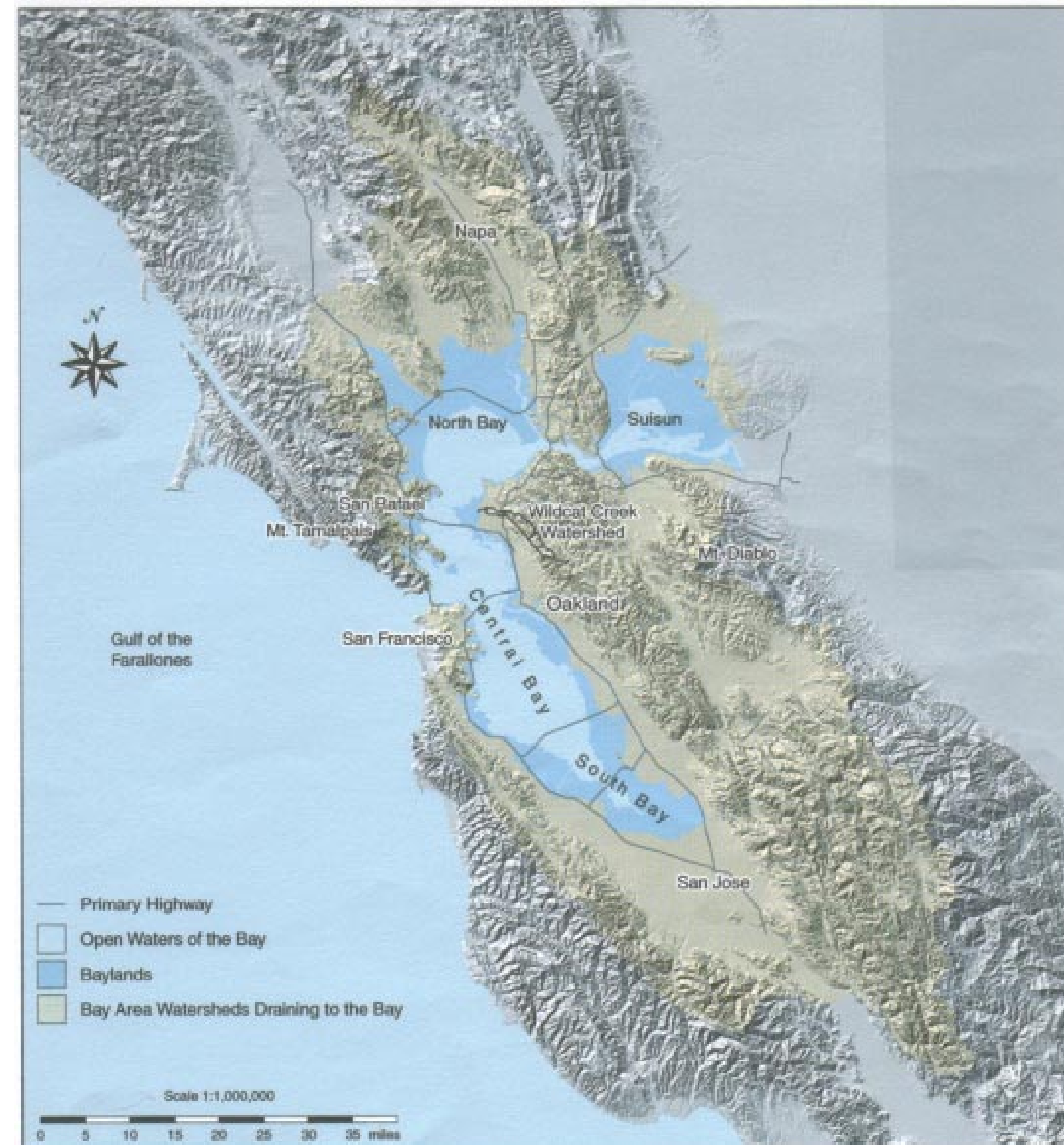
The Bay Area is the most urbanized region of the Golden Gate Watershed. Great amounts of fuel, power, water, and goods move daily through the Bay Area. It provides critical support for a unique natural community, including salmon and waterfowl that migrate along the Pacific coast. Vital flows of materials 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 3. Golden Gate Watershed

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

Figure 4. Bay Subregions

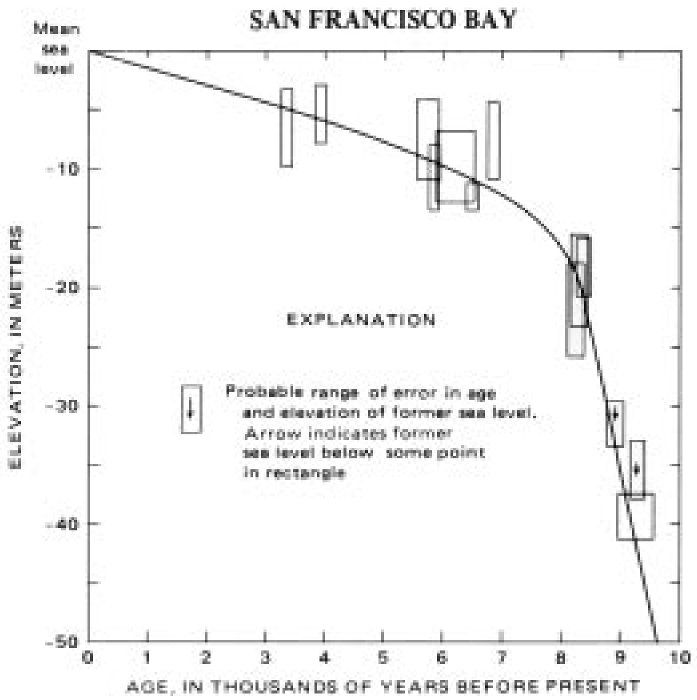


Source: SFEI EcoAtlas 2000

Tides and Sea Level

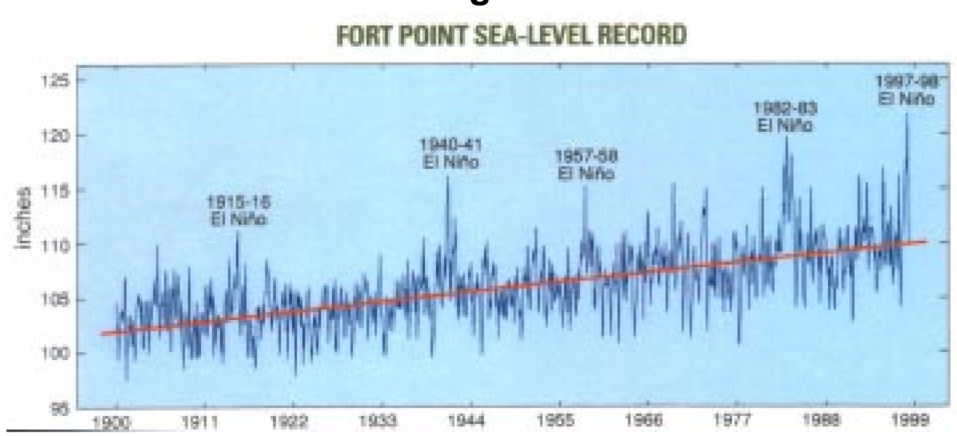
Figure 5

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.

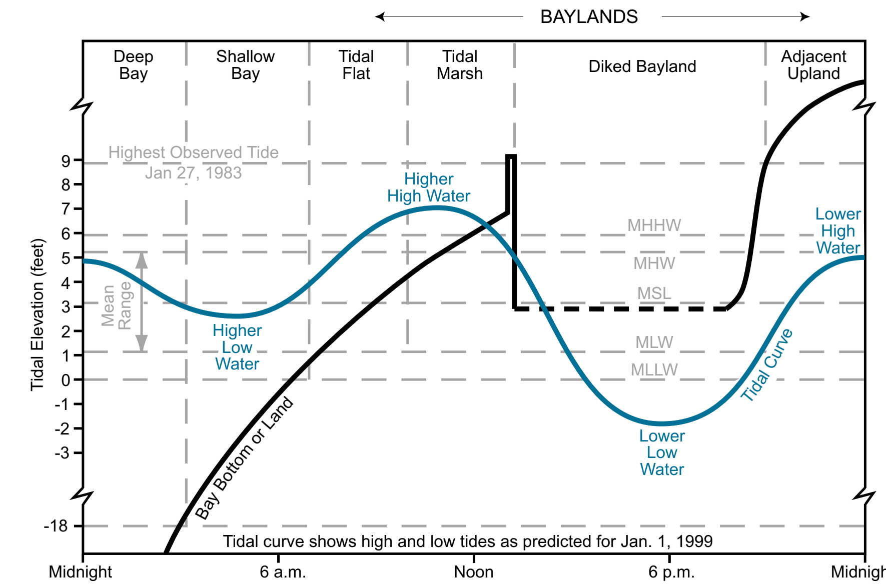
The National Ocean Survey maintains a network of benchmarks in the Estuary that are referenced to local tidal datums. The tidal elevations of the benchmarks are updated once each tidal epoch to account for sea level rise. The tidal benchmarks nearest Wildcat Creek are at Point Pinole. The tidal statistics 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.

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.

Figure 9

Calm Day Wind Pattern

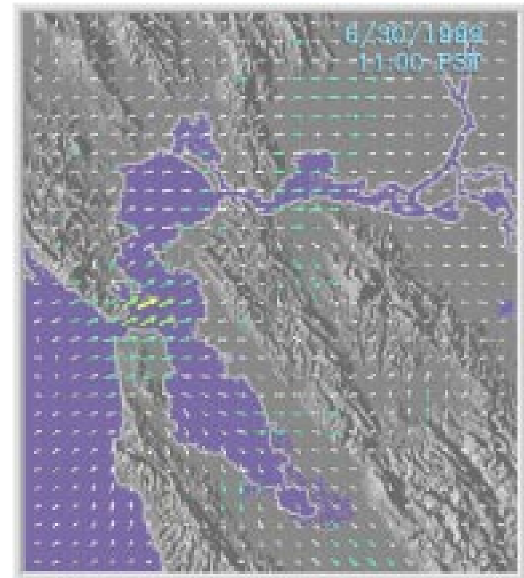


Figure 10

Diablo Wind Pattern

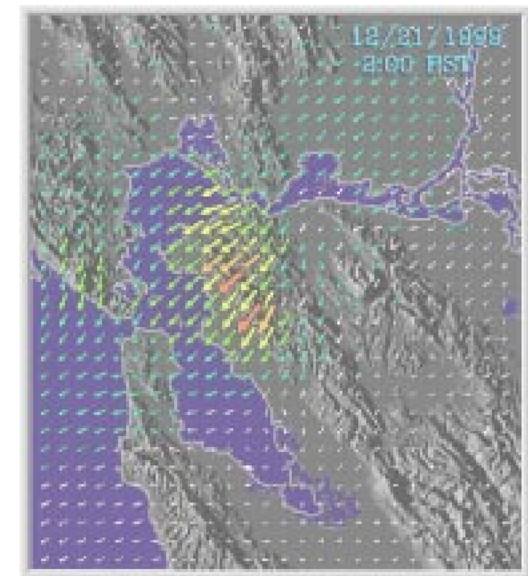
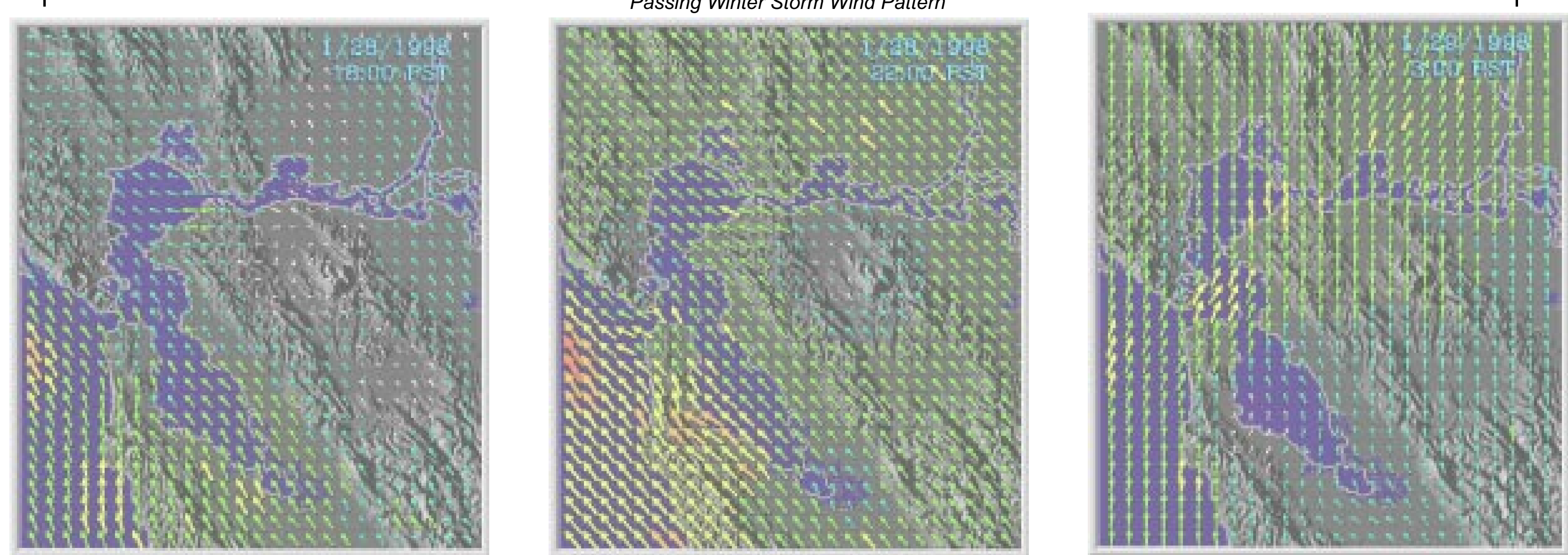


Figure 11

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

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).

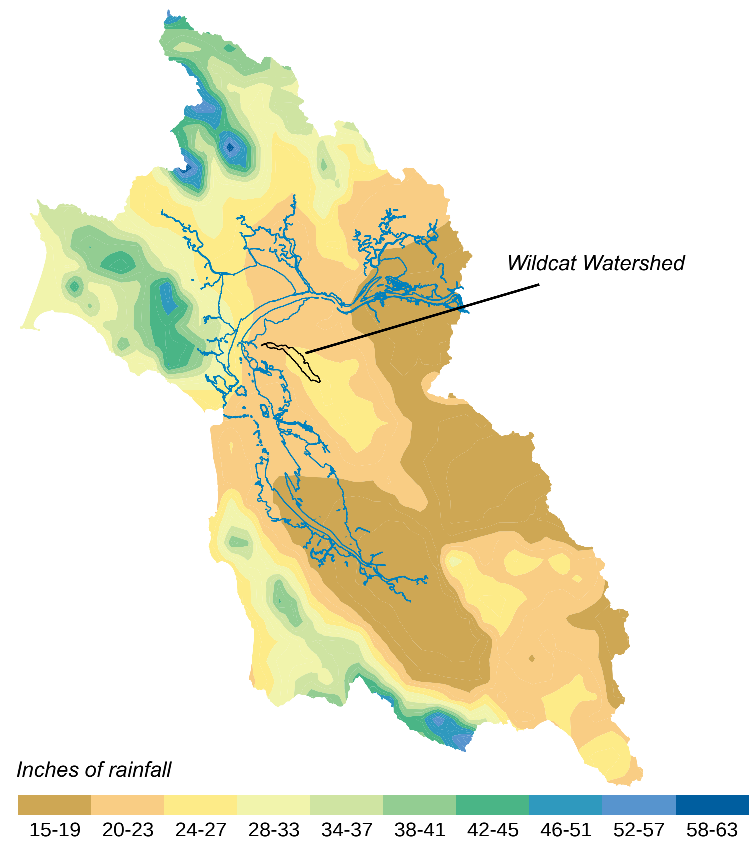
During the wet season, the Pacific high tends to move south, allowing cold rainstorms from the Gulf of Alaska to reach the Bay Area. Rainfall from these storms generally decreases from north to south. Variations in the Pacific high can allow warm air from the Subtropical Pacific to meet cold air from 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, Corvallis, Oregon.

Figure 13
Historical Precipitation Record based on Tree-Ring Data

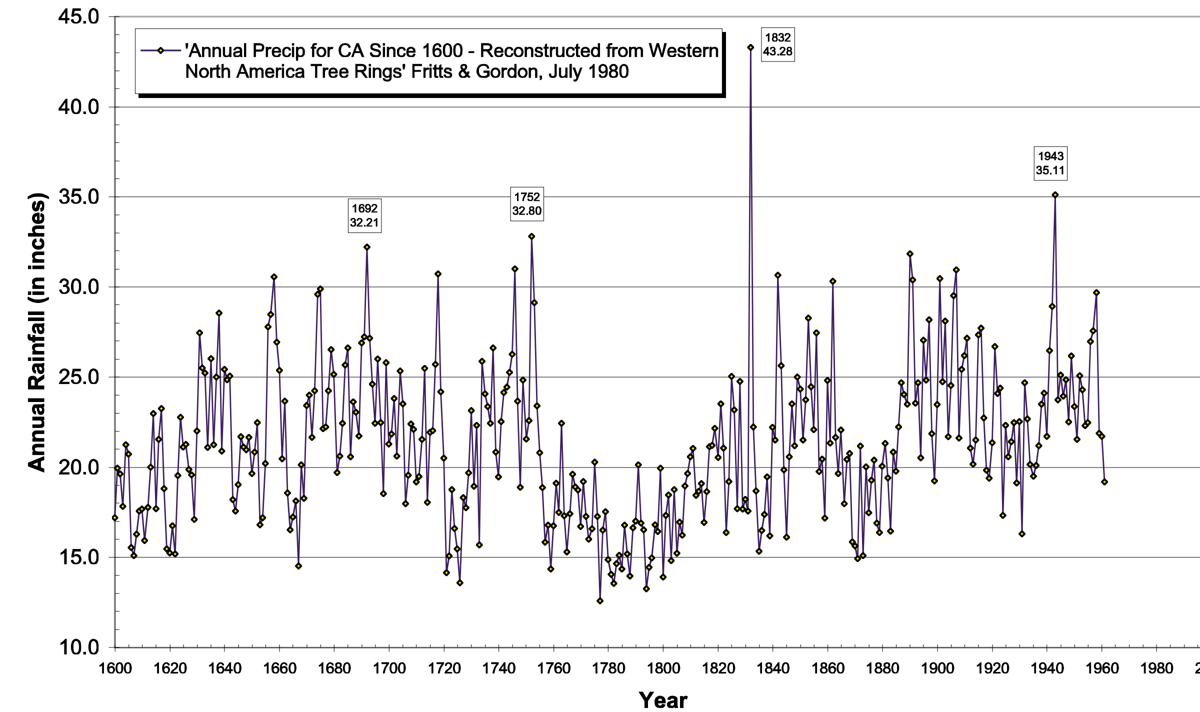
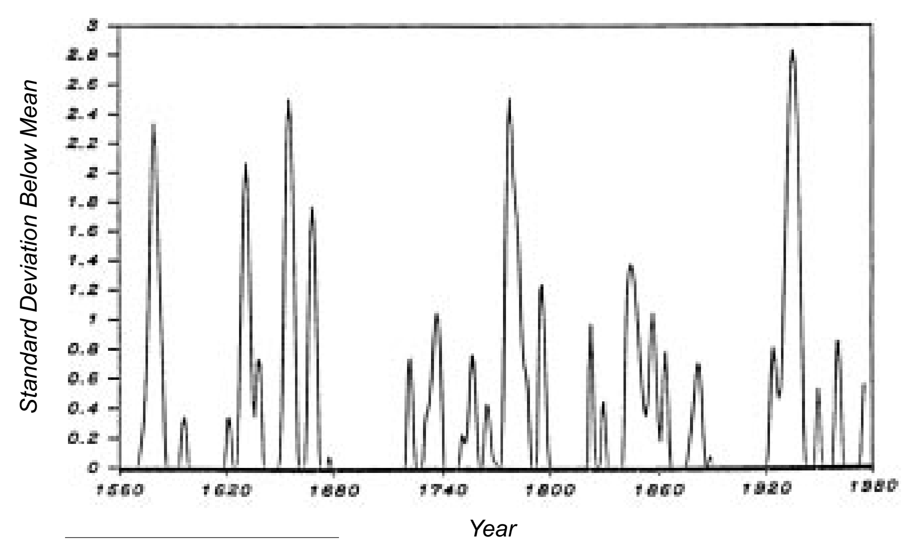


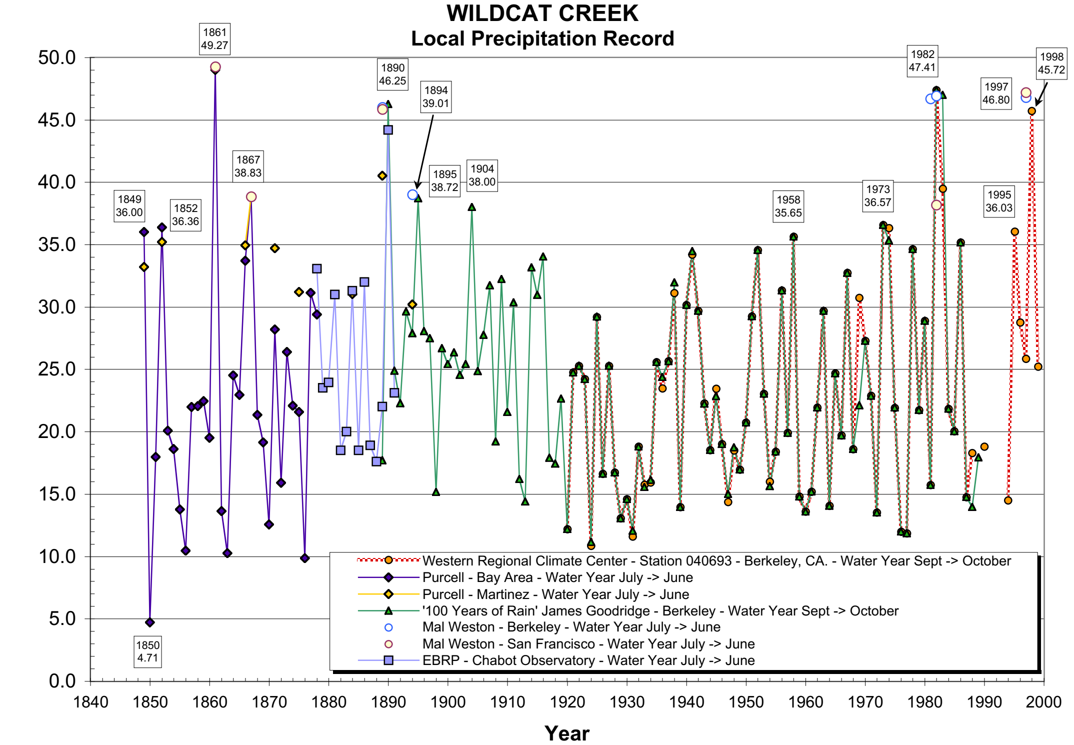
Figure 14
Long-term Record of Droughts for the American River Watershed



Source: Earle & Fritts, 1986.

Figure 15

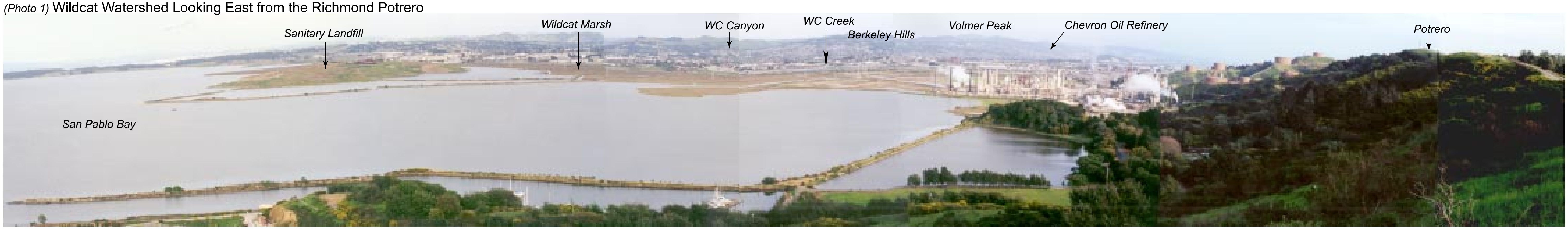
WILDCAT CREEK
Local Precipitation Record



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

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.

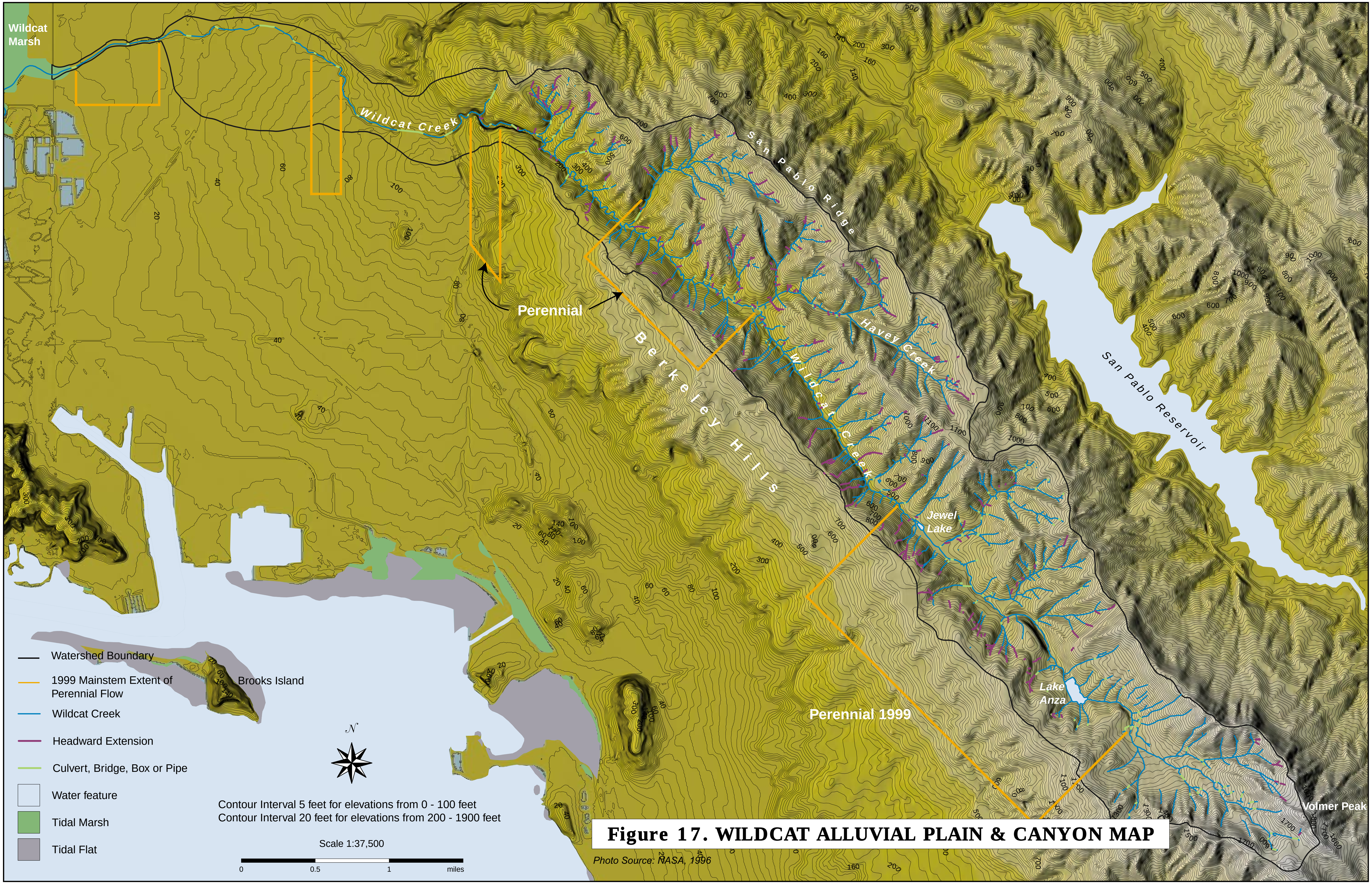


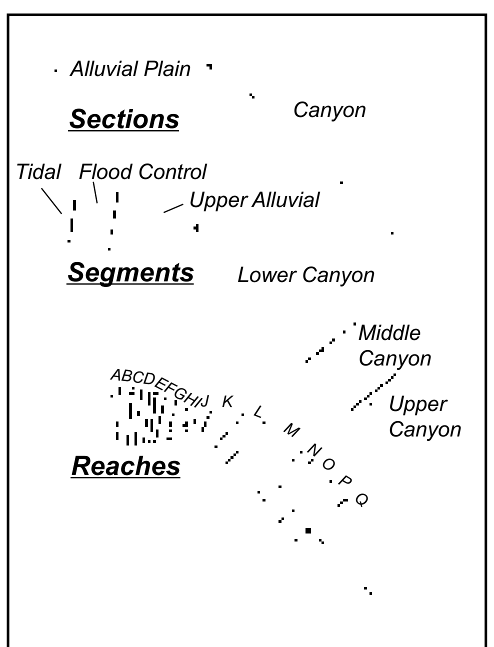
Figure 17. WILDCAT ALLUVIAL PLAIN & CANYON MAP

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.

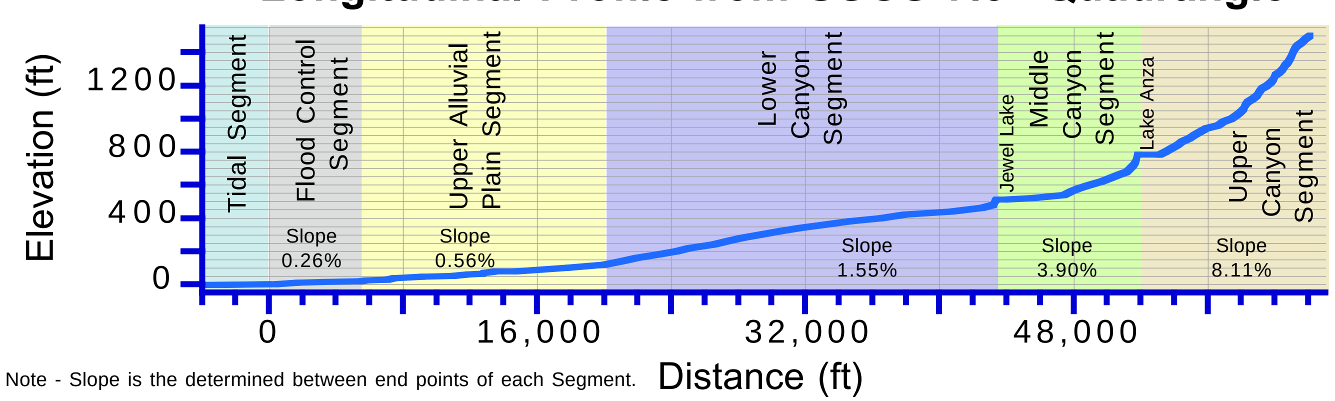
The area and length of each Segment is shown in Table 2. The Tidal Segment does not have a computed drainage area because it is part of San Pablo Bay, as well as Wildcat Watershed. The Lower Canyon Segment has the largest drainage area, 4.38 sq mi, and it has the longest length of channel, 5.33 mi. The 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***

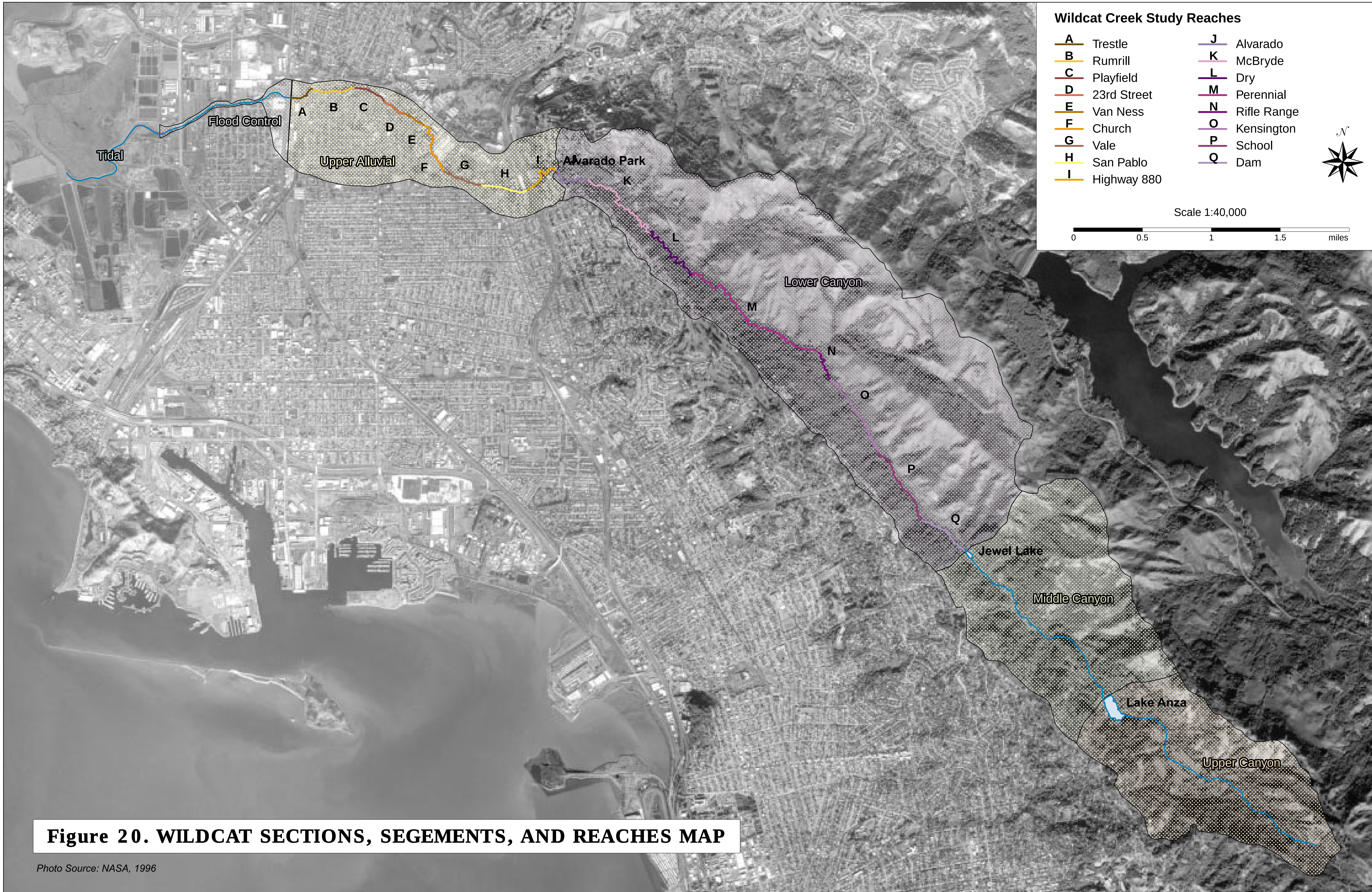


Figure 20. WILDCAT SECTIONS, SEGEMENTS, AND REACHES MAP