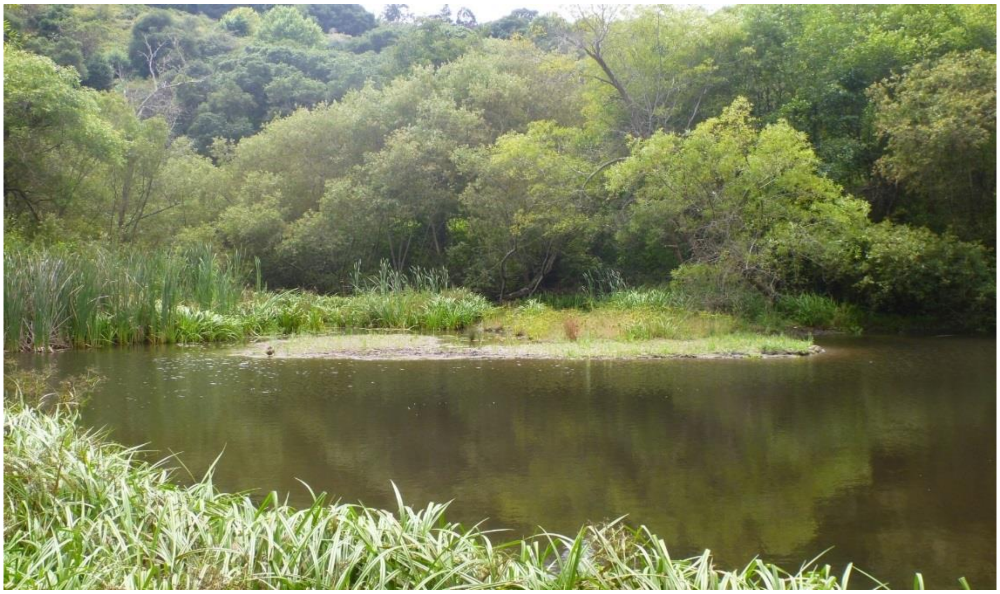
Wildcat Creek Watershed Erosion and Sediment Control Project



Prepared for:

East Bay Regional Park District

Prepared by:

FlowWest

February 11th, 2016

Contents

List of Figures

List of Tables

Executive Summary

Background and Purpose

The Wildcat Creek Erosion and Sediment Control Project (Project) has been undertaken by East Bay Regional Park District (EBRPD) to address long-standing sedimentation and erosion impacts to Jewel Lake and Wildcat Creek. Natural geologic conditions in the Berkeley Hills combined with legacy and modern land use impacts to Tilden Regional Park cause Wildcat Creek to have high sediment supply rates to Jewel Lake, which is an open water and interpretive amenity of the EBRPD. Formerly, the Lake was a drinking water reservoir operated by the People's Water District from 1921 to 1933. To maintain open water in Jewel Lake, dredging is required. In addition, creek incision downstream of the concrete spillway poses a collapse hazard. Tilden Regional Park occupies the majority of the watershed upstream of Jewel Lake and much of the sediment and erosion related problems involve slope instability and stream incision along Wildcat Creek and its tributaries within the Park. Jewel Lake is 1.5 miles downstream of Lake Anza, which is a larger and deeper recreational reservoir constructed in 1938. As of 2013, Jewel Lake has almost re-filled with sediment after having been dredged in 1967 and 1991. Prior to the recent filling of Jewel Lake with sediment, Jewel Lake maintained a population of Sacramento perch, which EBRPD relocated during late summer 2014.

Project Description

EBRPD engaged FlowWest to help manage the sediment supply to Jewel Lake by locating and classifying sources of sediment, including sites of significant erosion, and proposing sediment management and erosion control alternatives for those sites. For the Project, FlowWest performed the following activities:

- Reviewed existing data sources on erosion and sedimentation rates in Wildcat Canyon and summarized the current watershed condition (Section 1)
- Developed a project Geographic Information System (GIS) to help identify source points and sediment yields for Wildcat Creek and its tributaries (Section 2)
- Facilitated stakeholder meetings to guide development of conceptual erosion control and sediment management alternatives (Section 3)
- Conducted and analyzed bathymetric surveys of Jewel Lake and Lake Anza(Section 4)
- incorporated the field results from the sediment source analysis from Watershed Sciences (WS) into a GIS sediment database, analyzed field-measured data provided by WS for determining watershed sediment supply rates (Section 5)
- Developed alternatives to control erosion and sediment deposition, estimated costs for the alternatives, and identified permitting and environmental compliance requirements for each alternative (Section 6)
- recommended alternatives for implementation (Section 7)

Historical Sedimentation Analysis

FlowWest identified the recent (last 31 years from 1982-2013) sediment supply and storage volume for channel segments of Wildcat Creek and its tributaries. This time period was chosen because the 1982 Water Year was an extreme event that created identifiable sediment deposition and erosion features. Erosional features were measured in the field and summed for each reach and erosion in reaches that were not directly observed were extrapolated. FlowWest summarized sediment supply rates for the channel network and adjacent hillsides by subwatershed to prioritize proposed sediment management actions. The highest sediment supply rates in Wildcat Creek occurred in the reach above Jewel Lake and in Upper Wildcat Creek reach. The highest sediment supply rates from tributaries occurred in the Meadow, Laurel Canyon, Central Park, and Big Springs subwatersheds. Table 1 summarizes the overall sediment supply rate from several different types of erosional features in the watershed for the 31-year period of analysis. The highest sediment supply comes from the channel processes. The supply from landslides has been substantially diminishing since the 1980s but could become elevated again over a relatively short time if rainfall conditions reinitiate their movement.

The long-term sedimentation rates provided by bathymetry surveys are also shown in Table 1 for a 93-year period for Jewel Lake (1921-2013) and a 75-year period for Lake Anza (1938-2013). The long-term sedimentation rate for Jewel Lake includes the sediment removed during dredging and the Lake Anza long-term sediment rate includes sand added to the swimming beach (further described in the Section 4).

Table 1: Sediment rates developed for this study for short-term rates from 1982 to 2013 and long-term rates from construction of Jewel Lake (1921) and Lake Anza (1938) to 2013.

Units	1982 to 2013 Sediment Supply Rate by Source						Long-term Sedimentation Supply Rate	
	Cubic Yards/Year (yds^3/yr)						(yds^3/yr)	
Watershed	**Channel Processes**	**Slides**	**Gully**	**Over-land**	**Roads and Trails**	**Total**	**Period**	**Bathymetry Survey**
Jewel Lake Dam to Lake Anza	597	85	61	5	40	788	1921 – 2013	653
Upstream of Lake Anza	357	2	4	4	14	381	1938 – 2013	1,626
Total	971	87	65	9	54	1185		

Collins et al. (2001) estimated sediment supply rates and yields for the reaches downstream and upstream of Jewel Lake and Lake Anza. Downstream of the two reservoirs, they attributed high rates of sediment supply from channel incision and bank erosion in part to the loss of bedload due to capture behind the dams (Figure 1). The current short-term sediment supply rate to Jewel Lake from this study generally matches the rate reported by Collins et al. (2001) for the downstream segment of Wildcat Canyon (downstream of Jewel Lake to exit of the canyon at Alvarado Park), as illustrated in Figure 1. The similar rates indicate that restoration of sediment continuity will reduce channel incision and bank erosion in the reach downstream of Jewel Lake.

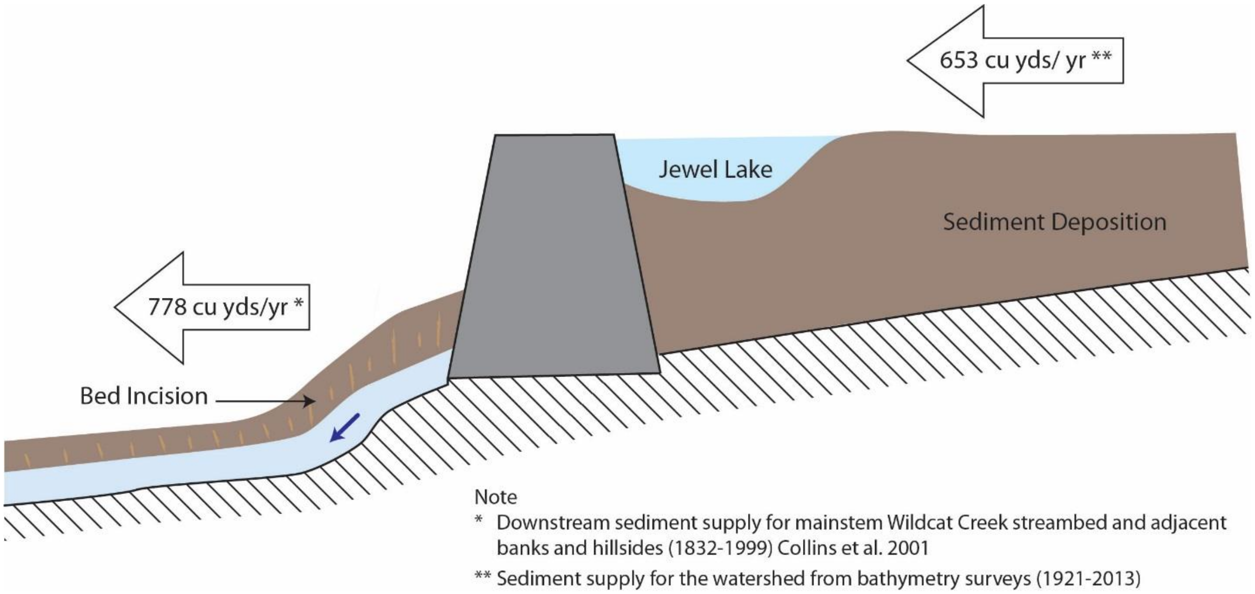


Figure 1: Sediment supply rate into Jewel Lake from the watershed that is trapped behind the dam was determined by using the long-term rate (1921-2013) developed from bathymetric surveys of Jewel Lake, while the reach downstream of Jewel Lake sediment supply rate (1832-1999) was developed from Wildcat Creek bed and adjacent bank sources (Collins et al. 2001).

Alternatives

FlowWest used the results of the sediment analysis and initial conceptual ideas developed with WS to guide development of alternatives for erosion control and sediment management. The sediment management and erosion control alternatives included:

- Dredge Jewel Lake
- Reconnect Wildcat Creek (bypass Jewel Lake)
- Stabilize gullies initiated at stormwater outfalls
- Construct additional sediment detention basins
- Re-grade dirt roads
- Install permeable parking areas and implement Low Impact Development (LID) treatments
- Excavate multi-stage channels for sediment deposition and floodplain restoration
- Install check dams to stabilize tributaries to Wildcat Creek

FlowWest conducted planning-scale assessments of hydrology, hydraulics, and sediment transport dynamics for each alternatives to determine associated sediment reduction and anticipated ecological improvement.

Recommendations

We ranked each erosion control and sediment management alternative, using criteria developed with EBRPD. The criteria included the amount of sediment managed, construction costs, permitting requirements and additional studies, sediment management efficiency, impacts to habitat, and stakeholder feedback. Based on our ranking of the different alternatives, we recommended the following alternatives: reconnect Wildcat Creek (Jewel Lake bypass), stabilize stormwater outfalls, construct additional sediment detention basins, and re-grade dirt roads. We selected the reconnection of Wildcat Creek (Jewel Lake bypass) as the preferred project because this alternative restores physical processes and improves habitat. Key components of this alternative are illustrated in Figure 2. Lastly, if future sediment transport modeling shows that reconnection of Wildcat Creek and bypassing Jewel Lake will contribute excess sediment to the downstream reaches, we recommend stabilization of stormwater outfalls, re-grading of dirt roads, and annual maintenance of existing sediment detention basins.

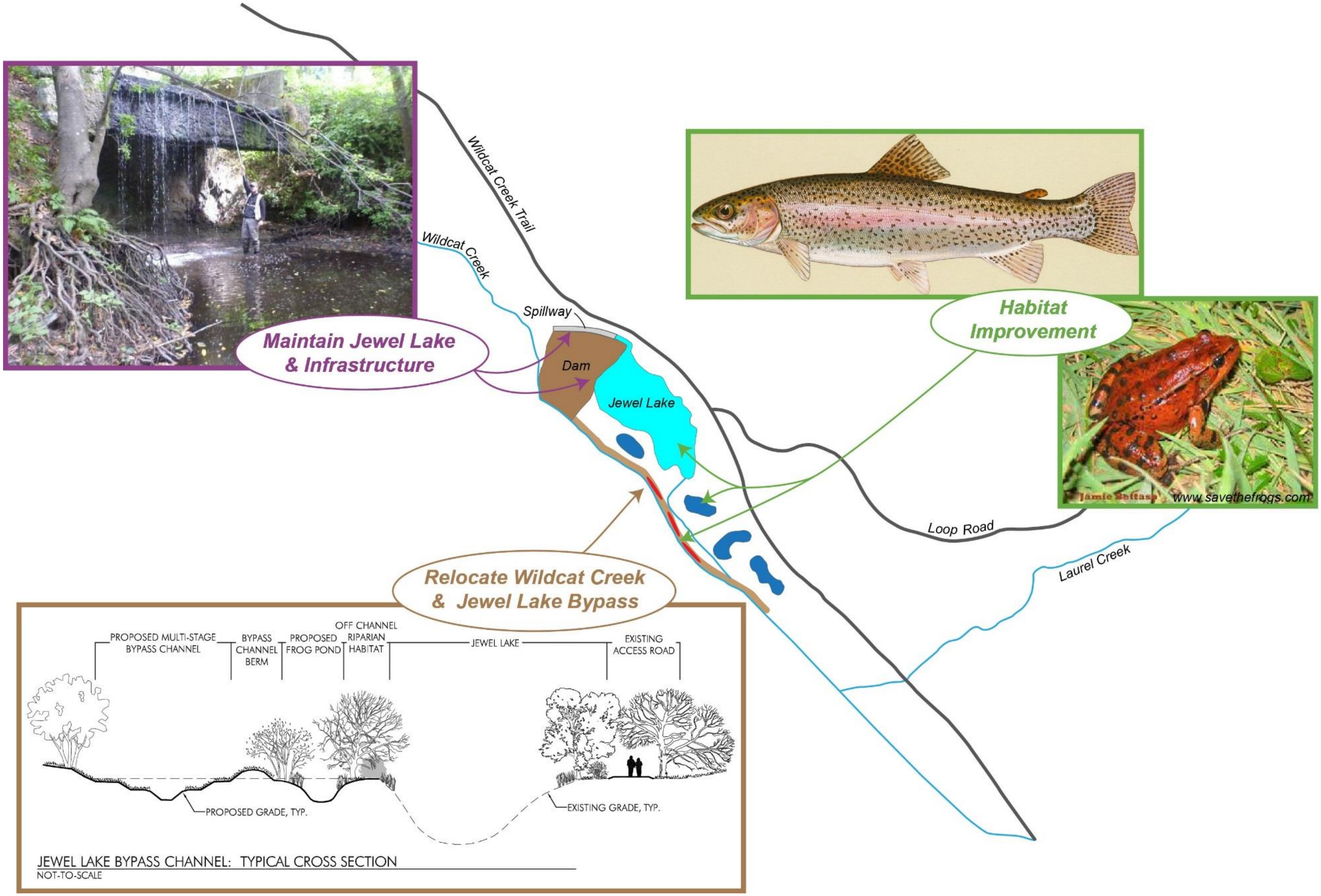


Figure 2: Components of the preferred alternative highlighting structure improvements, habitat enhancement, and restoration of sediment continuity.

1. Introduction and Project Setting

Introduction

High rates of erosion in the Wildcat Creek watershed upstream of Jewel Lake have led to numerous problems for the East Bay Regional Park District (EBRPD), including instability in the mainstem and tributary channels of Wildcat Creek, especially downstream of Jewel Lake Dam, and sediment accumulation in Jewel Lake and Lake Anza Reservoirs. Management concerns related to current sediment supply and transport conditions include: ongoing and future impacts to resident fish (including native rainbow trout, three-spine stickleback, and Sacramento perch) and other species such as western pond turtle and red-legged frog, degradation of infrastructure and recreational facilities, and expenses associated with maintenance of those facilities. Sedimentation of Jewel Lake combined with the fourth year of drought required EBRPD staff to relocate Sacramento perch from Jewel Lake in late summer 2014. Additionally, EBRPD was concerned with maintaining healthy, sustainable ecosystems throughout the upper watershed.

The primary goal of Wildcat Creek Erosion and Sediment Control Project (Project) was locating and classifying sites of significant erosion that function as sources of sediment to the project area (Wildcat Creek watershed upstream of Jewel Lake Dam). To satisfy this goal, the following project objectives were developed in collaboration with EBRPD:

1. Assess the stability, rate of down-cutting and deposition of sediment for Wildcat Creek, throughout the project area.
2. Locate and map significant sediment sources supplied to Wildcat Creek watershed.
3. Locate and assess the effectiveness of existing sediment impoundments along the creek, and recommend sediment reduction and removal strategies needed to restore capacity and function.
4. Provide conceptual design solutions and recommend methodologies for erosion control at identified source points:
    a. Utilize analysis and modeling to assess technical feasibility and effectiveness of each proposed alternatives.
    b. Assess each alternative for constructability.
    c. Estimate costs for each alternative.
5. Develop recommendations for the long-term, programmatic maintenance of the water courses within the study area.

The Project required both specific alternatives and recommendations on methodologies for erosion control at identified source points and for the long-term, programmatic maintenance of the water courses in the upper watershed. As such, FlowWest produced conceptual level alternatives to control erosion and sediment deposition, developed cost estimates, developed permitting and environmental compliance strategies, and performed stakeholder outreach to evaluate the effectiveness and potential to implement each alternative. Next, we performed constraint and opportunity analyses, and produced a set of recommendations for project implementation and long-term maintenance.

FlowWest and Watershed Sciences (WS) identified unique sediment sources (of both human and natural origin) upstream of Jewel Lake and Lake Anza in Tilden Regional Park and presented alternatives for sediment supply and transport mitigation projects. Additionally, FlowWest proposed changes in management to reduce high sedimentation supply rates to Jewel Lake and the need for frequent dredging of Jewel Lake, as well as improve the conditions of degraded natural resources. Our team identified key drivers and processes causing accelerated rates of sediment supply in the watershed and ways to increase mechanisms that moderate sediment transport and increase sediment storage throughout the upper watershed. This project has improved the understanding of sediment sources and transport, and presented alternatives that will improve sediment management in the Wildcat Creek watershed upstream of Jewel Lake Dam.

This project refined the understanding of key influences of land use impacts in the project area that have caused pervasive channel adjustments through much of the channel network. These influences include: increased runoff from roads and residential and recreational structures, legacy impacts from grazing, retention of water and sediment in reservoirs, bedload-starved and incising reaches downstream of dams, increased drainage network from road ditches and headward eroding steep first-order channels, landsliding associated with changes in runoff, the influence of dirt and paved roads and drainage structures such as ditches and culverts. These changes are largely linked to sediment supply which can become abundant or limited depending upon climatic variability and land use impacts. In channels that become incised and entrenched, natural sediment storage often becomes a diminishing function. For example, gravel bars become depleted in what are now becoming predominately bedrock reaches, and fine sediment deposition on floodplains now stays in the channel because floodplains now become abandoned as terraces above the floodprone elevation. In some areas where the channel has become deeply incised, summer base flow has diminished because the groundwater is drawn down and more rapidly depleted along the incised channel banks, and off-channel habitat and natural depression storage that once provided diverse habitat has virtually disappeared.

Report Format

This document summarizes drivers (processes), sediment sources, and ecological functions in Section 1-5, and then provide a series of alternatives (Section 6) and recommendations (Section 7) that not only reduce sedimentation in Jewel Lake and Lake Anza but also enhance habitat conditions and a wide range of beneficial uses in ways that are consistent with the Tilden Regional Park Land Use-Development Plan (EBRPD 1988). FlowWest reviewed existing documents on erosion and sedimentation rates in Wildcat Canyon (Section 1) and developed a project GIS (Section 2) to help identify source points and sediment yields for tributaries and Wildcat Creek in the project watershed. Section 3 summarizes the three stakeholder meetings we facilitated to guide development of conceptual erosion control and sediment management alternatives. Section 4 summarizes the bathymetric surveys of Jewel Lake and Lake Anza and Section 5 summarizes the reconnaissance level sediment source analysis. In Section 6, we developed alternatives to control erosion and sediment deposition as well as cost estimates for the designs, and identified permitting and environmental compliance requirements for each alternative. Lastly, we recommended alternatives for implementation (Section 7).

FlowWest turned to WS to collect field data on sediment sources and to provide quality assurance and quality control of the transfer of the field data to FlowWest. Once the field data was transferred and quality control assessed between WS and FlowWest, FlowWest assumed responsibility for all data analysis, interpretation, and report writing. In addition, WS provided initial conceptual ideas for reconnection of Wildcat Creek and the bypass of Jewel Lake and aquatic habitat restoration in the Jewel Lake delta and attended the three stakeholder meetings. Lastly, WS provided a limited review of the Sediment Source Analysis segment of FlowWest's Draft Report. WS did not contribute to any other analyses, estimates, recommendations or review of this project or report.

Project Location

Wildcat Creek is located in the Berkeley Hills of Contra Costa County in the East Bay Area of California (Figure 3). The Wildcat Creek watershed drains to San Pablo Bay and the watershed includes portions of the cities of Oakland, Berkeley, El Cerrito, San Pablo, and Richmond. The lower portion of the watershed is characterized by the Wildcat Creek alluvial fan and is highly urbanized. The alluvial fan extends upstream to the Alvarado Park and the transition between the canyon and alluvia fan is shown in Figure 3. The canyon portion of the watershed and project area is mostly within EBRPD ownership. The project area is located in the upper canyon portion of the Wildcat Creek watershed is mostly contained within EBRPD property. Although the EBRPD is the primary land manager in the study area, Tilden Regional Park is a resource for the entire Bay Area and Wildcat Creek flows through many different jurisdictions downstream of Tilden Regional Park.

The project area for this study covers the Wildcat Creek watershed upstream of the Jewel Lake Dam in Tilden Regional Park to the headwaters of Wildcat Creek on the slopes of Vollmer Peak (Figure 3). The majority of project area is owned by EBRPD and encompasses the majority of Tilden Regional Park. The total project area watershed area is 1,998 acres (3.12 square miles) and EBRPD is the largest single landowner with 1,783 acres (2.78 sq mi).

Figure 3: Wildcat Creek watershed and the study area for this project located in the San Francisco Bay Area, California.

Although EBRPD manages the majority of the land in the project area, there are constraints and limitations to potential sediment management or restoration actions in the upper watershed, including our ability to access and propose sediment management measures on property not owned by EBRPD, the Tilden Park Golf Course (leased by the EBRPD to a private concessionaire), and the portion of the channel through the Botanical Gardens. EBRPD facilities in Tilden Regional Park are also constraints from recreational and historical perspectives. In addition, FlowWest recommended sediment management alternatives were limited to natural and bioengineered strategies compatible with sensitive habitat and the existing land use plan for Tilden Regional Park (EBRPD 1988).

Geology

The Project area is comprised mainly of sedimentary and volcanic rocks as illustrated in Figure 4. The watershed upstream of Jewel Lake and downstream of Lake Anza is composed primarily of rocks from the Orinda Formation, Moraga Formation, and unnamed sedimentary and volcanic rocks. The Moraga Formation is located on the west side of Wildcat Canyon downstream of Lake Anza, while the east side of the canyon is composed of The Orinda Formation and unnamed sedimentary and volcanic rocks. The Orinda Formation is composed of bedded, nonmarine, pebble to boulder conglomerate, conglomeratic sandstone, coarse to medium-grained lithic sandstone, siltstone, and mudstone (Graymer 2000). The

Laurel Canyon and Meadow subwatersheds are composed of mostly unnamed sedimentary and volcanic rocks, which includes conglomerate, sandstone, and siltstone (Graymer 2000). The valley bottom is filled with stream channel deposits that include poorly-sorted to well-sorted sand, silt, silty sand, or sandy gravel with minor cobbles (Graymer, 2000). Also, alluvial fan fluvial deposits are mapped at the confluence with Meadow, Little Farm, Laurel Canyon drainages, suggesting high sediment loads from the unnamed sedimentary and volcanic rocks unit. Upstream of Lake Anza the watershed is predominately composed of the Moraga Formation with intrusions of Bald Peak Basalt and Sierra Formation in the headwaters of Wildcat Creek and along the subwatershed divide with the Big Springs Watershed. The Moraga Formation includes basalt and andesite flows and minor rhyolite tuff (Graymer 2000). The Bald Peak Basalt unit was formed by massive basalt flows (Graymer 2000). In general, the geology units in the study area can be characterized as both sedimentary and volcanic rocks between Jewel Lake and Lake Anza, and volcanic rocks upstream of Lake Anza.

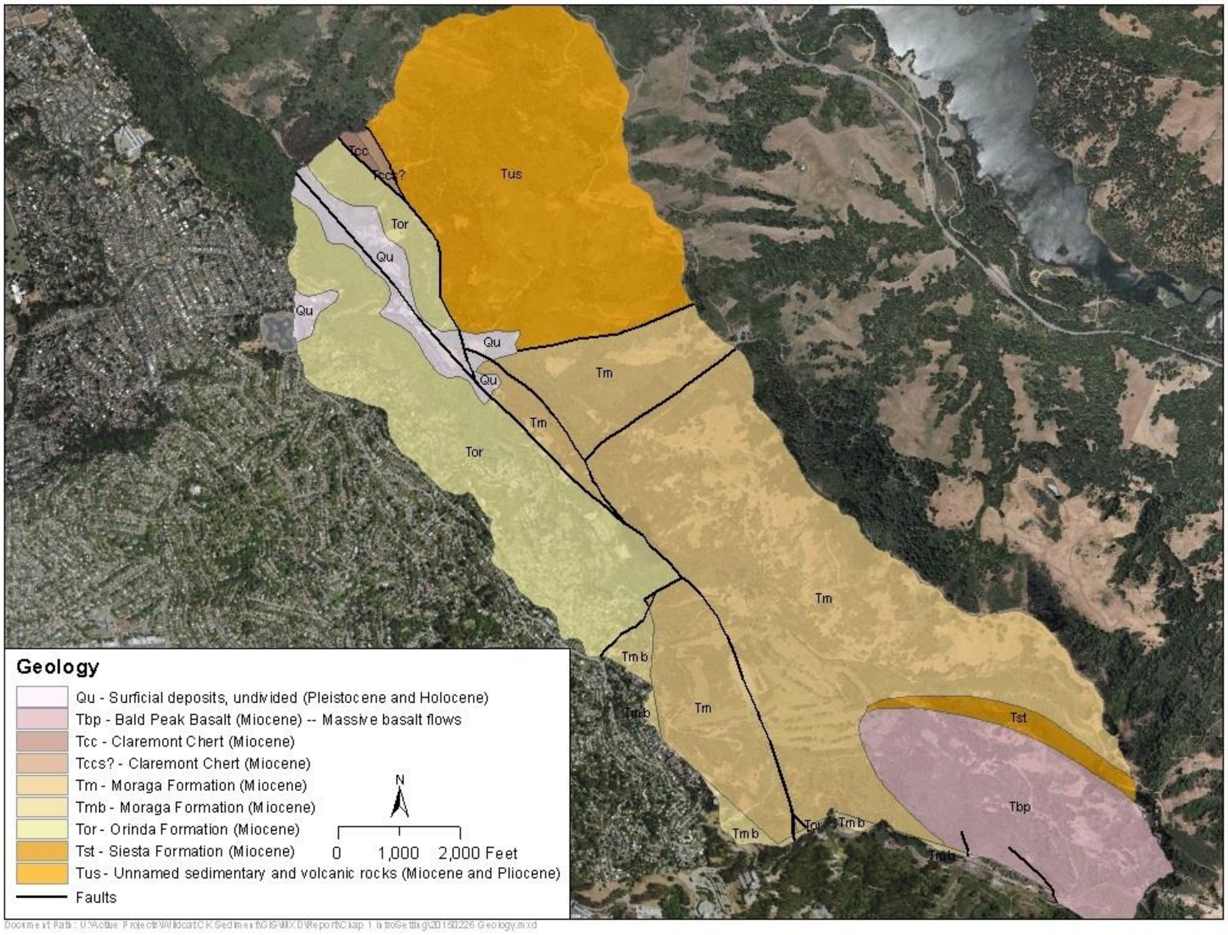


Figure 4: Geologic units in the project area (from Graymer 2000).

Climate and Hydrology

The San Francisco Bay Area is characterized by a Mediterranean climate with warm, dry summers and cool, wet winters. During most years, portions of Wildcat Creek go dry during the late summer and early fall months. The annual average rainfall in the study area ranges from 26 inches/year (in/yr) near Jewel Lake to the 29 in/yr near Grizzly Peak (PRISM 2010). Although precipitation has natural fluctuations often associated with extremes of drought and deluge, historical land uses have increased the amount of runoff associated with precipitation due to introduction of cattle grazing by European settlers, timber harvesting, ranch roads, water impoundments, and conversion of annual grasses to perennials. In addition, urbanization on the western edge of the canyon has increased the amount of runoff from impervious surfaces and has decreased the lag time between peak precipitation events and peak discharge events in Wildcat Creek. The increase in runoff creates larger peak floods which result in greater erosion force in the channel that causes channel adjustment and increase sediment supply.

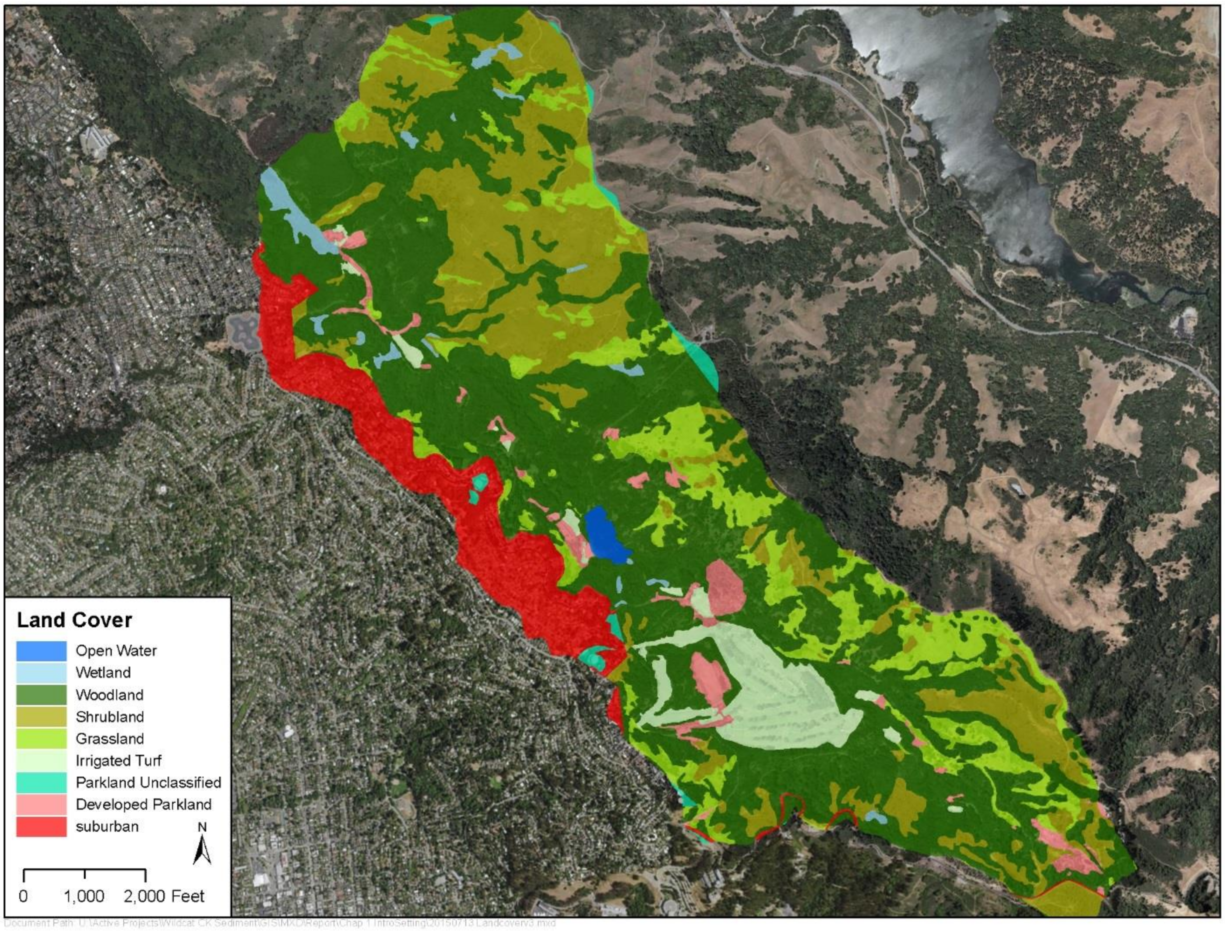
There is no active United State Geological Survey (USGS) streamflow gage on Wildcat Creek in the project area. However, the USGS operated two gages on Wildcat at two different locations. The Wildcat Creek at Richmond, California (USGS Gage 11181400) was in operation from 1964 to 1975, and the Wildcat Creek at Vale Rd at Richmond, California (USGS Gage 11181390) was in operation from 1975 to 1998. The drainage area for the two gages was 8.69 sq mi and 7.79 sq mi respectively. The largest peak annual discharge for the period of record for both gages occurred on January 4, 1982 with a discharge of 2,050 cubic feet per second (cfs). Collins et al. (2001) conducted a flood frequency analysis using the USGS gage data and determined that recurrence interval flows for the 1.5, 5, 10, 25, and 50-year events were 300, 948, 1,322, 1,825, 2,188 cfs respectively. We conducted a flood frequency analysis based on regional regression equations (Waananen & Crippen 1977; Hjalmarson & Waltemeyer 1997) for the study area (3.12 sq mi) and calculated the recurrence interval flows reported in Table 2 at the Jewel Lake Dam.

Table 2: Recurrence interval flows calculated at Jewel Lake Dam.

Recurrence Interval (yrs)	Peak Discharge (cfs)
2	99
5	251
10	385
25	578
50	745
100	927
500	1,370

Land Cover and Ownership

As mentioned previously, the majority of the project watershed is within EBRPD property and is mostly undeveloped parkland. To understand the spatial distribution of areas that likely produce higher runoff due to increased impermeable area in the study area, we used vegetation GIS data from EBRPD merged with parcel data from Alameda County and Contra Costa County to identify land cover types (Figure 5). We classified residential properties as suburban.



Document Path: U:\Active Projects\Wildcat CK Sediment\GIS\MXD\Report\Chap 1 IntroSetting\20150713 Landcoverv3.mxd

Figure 5: Land cover showing suburban development on the west slope of the project area watershed.

Land cover in the study area is further summarized in Table 3. Woodland is the largest land cover category (49%) in the project area followed by shrubland (20.6%), and grassland (11.4%). Adding wetland (1.3%) and parkland unclassified (0.8%) totals 1,661 acres or 83% of the project area that contains natural land cover types. Managed land cover types include suburban (8%), irrigated turf (4.8%), developed parkland (2.9%), and open water (0.5%). The developed parkland category includes park facilities (parking lots, Environmental Education Center, Little Farm, Tilden Golf Course parking lot and structures, Tilden Botanic Garden, and other park facility structures). Irrigated turf includes the golf course and large lawns within Tilden Regional Park. Together managed land cover types total 17% (337 acres) of the total project area. Although the project area is generally considered parkland and undeveloped, residential development and developed park facilities impact a significant portion of the project watershed through increased stormwater runoff from an increase in impervious area. The suburban area also impacts the heads of steep tributaries and has a larger influence on the stream network.

Table 3: Land cover categories in the project area upstream of Jewel Lake Dam.

Land Cover	Acres	Percentage
Developed	57.5	2.9%
Grassland	227.9	11.4%
Irrigated Turf	96.6	4.8%
Open Water	9.3	0.5%
Parkland Unclassified	16.1	0.8%
Shrubland	411.8	20.6%
Suburban	173.3	8.7%
Wetland	25.8	1.3%
Woodland	979.1	49.0%

Table 4 summarizes land ownership in the project area. The majority of the land in the project area is owned by EBRPD (90%). Residential properties were added together and classified as private. Private property owners represent the second largest landowner category (9%). East Bay Municipal Utility District (EBMUD), UC Berkeley, and municipal account for less than 2% of the remaining land ownership in the project area.

Table 4: Land ownership in the project area upstream of Jewel Lake Dam.

Ownership	Acres	Percentage
EBRPD	1,794	89.8%
Private	170	8.5%
EBMUD	13	0.7%
UC Berkeley	17	0.8%
Municipal	4	0.2%

Geomorphology

Understanding the natural geomorphic processes acting in the Wildcat Creek watershed is important for determining the background sediment supply, while understanding impacts of people and land use is essential for determining future landscape response and sediment supply rates. This understanding puts landscape changes in perspective. The core of fluvial geomorphology is the group of processes by which rivers move sediment and shape the landscape.

Rivers shape the landscape by transporting sediment from areas of uplift (mountains) to lowlands, lakes, or oceans. Watersheds can be classified into three zones regarding sediment: production, transport, and deposition (Schumm 1977). The sediment production zone includes steep, rapidly eroding headwaters. Rivers move sediment in the transport zone and deposit sediment in the depositional zone. Sediment in the transport reach under natural conditions establishes an equilibrium where sediment transport is balance by sediment supply from tectonic uplift. Rivers can be thought of as a conveyor belt that transports sediment production areas to depositional areas (Kondolf 1997). Rivers actively migrate, scour and deposit sediment creating complex forms and patterns that create important habitat features.

A multi-stage channel contains a low flow channel with at least one bench before the floodplain. Along the gradient of the watershed the size class of sediment transported decreases with the decrease in the river slope. Under natural geomorphic conditions, channels form different surfaces where sediment is stored and scoured in the bed, on bars, on the channel banks, or on the floodplain.

In the steeper portion Wildcat Creek watershed, the channel is characterized by bedrock or steeps consisting of cascades of boulders and cobles or steps and pools. Channel features found in the transport reach include point bars, pools, and riffles. Depositional reaches are found where tributaries join Wildcat Creek and in the backwater formed by upstream extents of Jewel Lake and Lake Anza. These depositional reaches occur at alluvial fans or delta where sediment is deposited as the channel gradient rapidly decreases. The channel bed material in the flatter gradient alluvial fans consists of finer material that is predominately sand and gravel.

Post-European settlement-induced changes to the Wildcat Creek watershed have significantly altered natural geomorphic processes. The increased overland flow and drainage density (length per unit area) from legacy land use (grazing and logging), urban development, and road construction has increased runoff and peak discharge in the project area. Channels in the Wildcat Creek watershed have responded by headward erosion (extension of the channel uphill) and by adjustment of their cross sectional area through channel incision (downcutting) and bank erosion in tributary channels and the mainstem Wildcat Creek. In addition to these changes in physical processes, dams constructed to create Jewel Lake in 1922 and Lake Anza in 1938 have trapped bedload and reduced sediment continuity between the project watershed and the lower watershed. Only fine suspended sediment is transported over the Lake Anza Dam and bedload is completely trapped. The stream energy that was used to transport bedload downstream now causes the Wildcat Creek channel to incise its bed and erode its banks. Hence, Wildcat Creek's adjustments to increased flow, lead to incised and entrenched channel conditions (downcut channel with steep banks) that become self-perpetuating as Wildcat Creek disconnects from the floodplain. Accelerated rates of sediment supply through this mechanism will continue until enough channel width is created to establish a new inset floodplain within the former channel banks creating a multi-stage channel. Much of Wildcat Creek mainstem channel is presently in this entrenched condition. It has minimal floodplain width and evidence of ongoing bank erosion and channel incision is apparent throughout most of the channel length.

In terms of future trends, the historical impacts from grazing and vegetation removal from logging and oak cutting for fire wood in the 1880's should decrease in the Wildcat Creek watershed, but the impacts from urban development and dam construction will continue until steps are taken to mitigate stormwater discharge from the suburban areas to Tilden Regional Park and Wildcat Creek and restore sediment continuity upstream and downstream of Jewel Lake and Lake Anza. If Jewel Lake is to be maintained as a recreational amenity, it will need to be dredged at least every 20 years based on the past dredging frequency and volume removed (9,450 yds^3 in 1967 and 10,404 yds^3 in 1991). We calculated the 2013 capacity of Jewel Lake of 4,322 yds^3 with a maximum depth of 6.7 feet (ft) (Section 4), which is similar to the capacity the last time Jewel Lake was dredged. Climate change will also impact future short-term sediment supply to Jewel Lake If climate change results in increased runoff from less frequent, but more intense precipitation events may also increase the frequency of dredging to maintain

Jewel Lake as a recreation amenity. Storage of bedload material in both Jewel Lake and Lake Anza will continue to induce channel incision and bank erosion downstream of the dams.

2. Project GIS Development

FlowWest collected GIS data to guide and organize a systematic evaluation of sediment sources in the project area and provide the foundation for the development and screening of alternatives in the project area. We obtained detailed topographic datasets to serve as basemaps for field mapping and alternatives developed for this project. We used the GIS layers from the following sources:

- East Bay Regional Park District
- San Francisco Estuary Institute (SFEI)
- Alameda County
- Contra Costa County
- US Geological Survey
- National Geodetic Survey (NGS)
- University of California Earth Sciences Library (UCB)

First we obtained geospatial data that was collected and used to develop the sediment budget described in the Wildcat Creek watershed: A Study of Physical Processes and Land Use Effects (Collins et al 2001) report and integrated it into the project GIS. This data provided by SFEI was an enormous asset to this project, as it contains mapping based upon hundreds of hours of aerial photo analysis and field surveys that are directly relevant to the identification and quantification of sediment sources and transport in the Upper Wildcat Creek watershed. This data was coupled with relevant data from the EBRPD catalog of GIS data to further support the sediment source analysis and development of erosion control alternatives. We reviewed additional data next, including publicly available GIS data (e.g. road network information, aerial photography, county assessor and parcel data, etc.). After all useful existing data resources were identified and integrated into the project GIS, we performed a data gap analysis to determine the locations and types of data that were lacking and required to complete the project. The data gap analysis informed and prioritized the field data collection effort for the sediment analysis, described in Section 5. The complete project GIS was utilized to determine the feasibility of hydrologic improvements and inform development of project alternatives. Data layers incorporated into the project GIS are listed in Appendix A.

3. Stakeholder Involvement

To build consensus for the selected erosion control alternatives, FlowWest facilitated three stakeholder meetings for both internal and external stakeholders. Internal stakeholders included EBRPD staff and external stakeholders included representatives from municipalities and agencies with jurisdiction or interest in the Wildcat Creek watershed. As the funder of this project and primary land manager of the watershed, EBRPD staff were the largest stakeholder group at each of the meetings. To engage stakeholders in the project, we developed a list of potential stakeholders and held three public meetings to explain the purpose of the project, present results, and obtain feedback for the sediment and erosion control alternatives. This section summarizes the three stakeholder meetings.

In collaboration with EBRPD, FlowWest identified local agencies and municipalities that either had jurisdiction over Wildcat Creek or would be affected by proposed sediment management or habitat restoration / enhancement projects. Representatives from the following agencies, municipalities, and stakeholders were invited to the stakeholder meetings:

- East Bay Regional Park District
- Contra Costa County Flood Control and Water Conservation District (CCCFC&WCD)
- San Francisco Bay Regional Water Quality Control Board (SFBRWQCB)
- Urban Creeks Council
- City of Richmond
- California Department of Fish and Wildlife (CDFW)
- City of Berkeley
- Kensington (Contra Costa Board of Supervisors)
- US Fish and Wildlife Service
- US Army Corps of Engineers (USACE)
- Wildcat-San Pablo Creeks Watershed Council

Table 6 lists attendees and agencies represented at the stakeholder meetings. EBRPD and outside stakeholders provided many different perspectives on erosion sources and erosion control alternatives.

Table 5: Attendees representing a broad range of the stakeholders for erosion and sediment control in the study area.

Name	Agency	Title/Position	1/15/13 Meeting	11/7/2013 Meeting	6/11/2014 Meeting
Larry Leong	CCCFC&WCD	Staff Engineer	X		
Carl Roner	CCCFC&WCD	Associate Civil Engineer		X	
Brain Louis	CCCFC&WCD	Civil Engineer			X
Anne Riley	SFBRWQCB	Watershed and River Restoration Advisor	X	X	X
Katie Hart	SFBRWQCB	WRCE			X
Daria Mazey	HydroPlan for USACE	Planner		X	
Michelle Leicester	CDFW	Environmental Scientist	X		
Lynne Scarpa	City of Richmond	Stormwater Program Manager		X	
Danny Akagi	City of Berkeley	Engineer		X	
Sergio Huerta	EBRPD	Tilden Park Manager	X	X	X
Mark Ragatz	EBRPD	Parklands Unit Manager	X	X	X
Diane Althoff	EBRPD	Chief of Design and Construction			X
Steve Edwards	EBRPD	Botanical Garden Supervisor	X		
Dan Cunning	EBRPD	Regional Trails			X
Jeff Rasmussen	EBRPD	Grants Manager			X
Dave Zuckerman	EBRPD	Tilden Environmental Education Center Supervisor	X	X	X
Matt Graul	EBRPD	Chief of Stewardship	X	X	X
Joe Dahl	EBRPD	Park Supervisor at the Botanic Garden	X	X	X
Joe Sullivan	EBRPD	Fisheries Program Manager	X	X	X
Pete Alexander	EBRPD	Fisheries Program Manager	X	X	X
Laurel Collins	WS	Geomorphologist	X	X	X
Anthony Falzone	FlowWest	Geomorphologist	X	X	X
Mark Tompkins	FlowWest	Engineering Geomorphologist	X	X	X
Andrea Schmid	FlowWest	Planning and Permitting	X		

The three stakeholder meetings were held on January 15, 2013, November 7, 2013, and June 11, 2014 at the EBRPD Trudeau Training Center and Headquarters Board Room in Oakland. The first meeting introduced stakeholders to the project, the second meeting presented preliminary results from the sediment budget and solicited feedback on sediment and erosion control alternatives, and the last meeting presented the results of our analysis and the preferred alternatives for erosion control actions (Table 7).

Table 6: Date and purpose of the of the three stakeholders meetings for this project.

Date	Purpose
January 15, 2013	Project overview and stakeholder input to help guide sediment source identification and erosion control actions
November 7, 2013	Stakeholder input on conceptual sediment erosion control actions
June 11, 2014	Stakeholder input on the selected erosion control actions and funding opportunities for these actions

First Stakeholder Meeting

At the first stakeholder meeting the project purpose and scope of work was presented to the group. Participants in the meeting discussed many of the historical land use changes and alteration of the watershed and the history of Jewel Lake with its first use as a water supply reservoir for Berkeley and its current recreation use. Red-legged frog presence was listed as a concern and potential impediment to future maintenance of erosion control actions. The importance of educational and recreational attributes of the park and Jewel Lake were expressed. Maintenance actions in the study area related to roads and trails were summarized by EBRPD staff. Many trails and roads were poorly designed or constructed and are now burdened by heavy use. EBRPD rarely grades dirt roads, but their current practice is to grade roads towards the outside slope instead of sloping the road towards an inboard ditch that concentrates runoff and increases erosion. EBRPD actively repairs eroding trails, but there is a long backload of trails that need maintenance. Potential erosion control actions discussed during the first stakeholder meeting included a bypass around Jewel Lake, utilization of the sediment deltas from tributaries to store sediment, gully repair on the side of Jewel Lake Dam, and the outward sloping existing roads.

Action items from the first stakeholder meeting included: inviting additional stakeholders from the City of Berkeley, the Regional Water Quality Control Board, Urban Creeks Council, and East Bay Municipal Utility District, continuing analysis of the a bypass around Jewel Lake, utilizing of sediment deltas from tributaries as sediment sinks, completing sediment analysis fieldwork, and identifying potential site specific designs. The comments from stakeholders helped us refine our field analysis and conceptual designs and added additional criteria to evaluate erosion control alternatives. Key criteria suggested for erosion control actions included long-term and self-sustaining design, restoration of geomorphic processes, improvement of habitat quality, recreational use, cost, reduction of sediment load to Jewel Lake, and downstream sediment impacts.

Second Stakeholder Meeting

The agenda for the second stakeholder meeting included a summary of geomorphic processes in the study area, preliminary results of the sediment source analysis and bathymetry survey, and erosion control alternatives. Increased discharge and erosion in Wildcat creek were discussed and increased incision was attributed to increase discharge in the watershed from land use changes and capture of the sediment load behind dams at Jewel Lake and Lake Anza. Incision downstream of the Jewel Lake spillway was measured over 14 ft since construction of the spillway. FlowWest presented preliminary bathymetry results which showed that Jewel Lake is almost completely filled with sediment and that the deepest point in the lake is less than 6 ft deep (Section 4). Lastly, we presented conceptual erosion and sediment control alternatives that included: sediment detention basins, multi-stage channel, stormwater management including Lowe Impact Development (LID) methods, reconnecting Wildcat Creek and bypassing Jewel Lake, tributary stabilization, and road and trail design.

Stakeholders at the meeting provided feedback that guided the selection of erosion control alternatives for further analysis. Stakeholders suggested including outfall stabilization to the list of erosion control alternatives and suggested that EBRPD should coordinate with the City of Berkeley on future repairs to stormwater outfalls along Wildcat Drive. An agency stakeholder stated that multi-stage channels are not applicable for the majority of the study area because the steep canyon walls limit the space for establish a floodplain except in limited areas. Another agency stakeholder related his experience implementing a permeable pavement project that proved to be ineffective because of the high clay content in soils in the East Bay that limit infiltration. The Contra Costa County Flood Control and Water Conservation District representative was concerned that the bypass around Jewel Lake could increase the sediment load to their sediment basin near San Pablo Bay. Tributary stabilization methods that rely on check dams were criticized because check dam structures have high rates of failure form being undermined. Stakeholders from EBRPD expressed their concern that detention basins would only work if long-term maintenance was included in the permitting of the project. Stakeholders also pointed out that the presence of red-legged frogs could prevent maintenance from being completed. The group preferred sediment control and erosion reduction alternatives that require only limited or infrequent maintenance over alternatives that require frequent or annual maintenance due to the cost of maintenance. EBRPD staff commented that the current maintenance budgets do not cover the existing facilities and trails and that additional maintenance requirements would further tax existing maintenance budgets.

Third Stakeholder Meeting

At the final stakeholder meeting we presented the results of the sediment analysis, prioritization of the erosion control and habitat enhancement designs, and made recommendations for the top three concepts. Results from the sediment budget are presented in Section 5 of this report and prioritization of erosion control actions is covered in Section 6. We recommended that EBRPD continue to explore the bypass of Jewel Lake, sediment detention basins, and outfall stabilization.

Of the three recommended erosion control actions, the Jewel Lake bypass generated the most interest and discussion. The representative from Contra Costa County Flood Control and Water Conservation District was concerned about increase sediment deposition in the reach of Wildcat Creek near San Pablo

Bay, where flood conveyance is limited. To address these concerns, Contra Costa County Flood Control and Water Conservation District recommended sediment transport modeling of any proposed changes to Jewel Lake. The group agreed that sediment transport modeling should be conducted as part of a future feasibility study for this alternative. The bypass action was favored by the group because the bypass restores geomorphic processes, is a long-term solution, and restores habitat and passage for native fish species. Stakeholders felt that the sediment detention basins were the weakest of the three proposed actions because of uncertainty related to permitting for removal of sediment from basins if the basins become habitat for special status species. Some of the detention basins were proposed in areas that are currently used for recreation, and the group thought that would be unpopular with park users. Stakeholders agreed that outfall stabilization should be conducted at outfalls along Wildcat Drive that are currently eroding and suggested exploring joint funding with the City of Berkeley. FlowWest is grateful for the participation of both EBRPD staff and outside stakeholders in the three meetings. Stakeholder involvement helped identify criteria for different erosion and sediment control actions, identified issues or problems to be addressed for erosion control alternatives, and contributed invaluable regional and on the ground knowledge.

4. Jewel Lake and Lake Anza Capacity Analysis

Purpose

To estimate the amount of sediment captured by Jewel Lake and Lake Anza, FlowWest compared the current capacities of Jewel Lake and Lake Anza with historical capacities. The sedimentation rates of these two reservoirs will inform future management or erosion control actions, and ensure that future actions are properly sized, configured, and located.

Methods

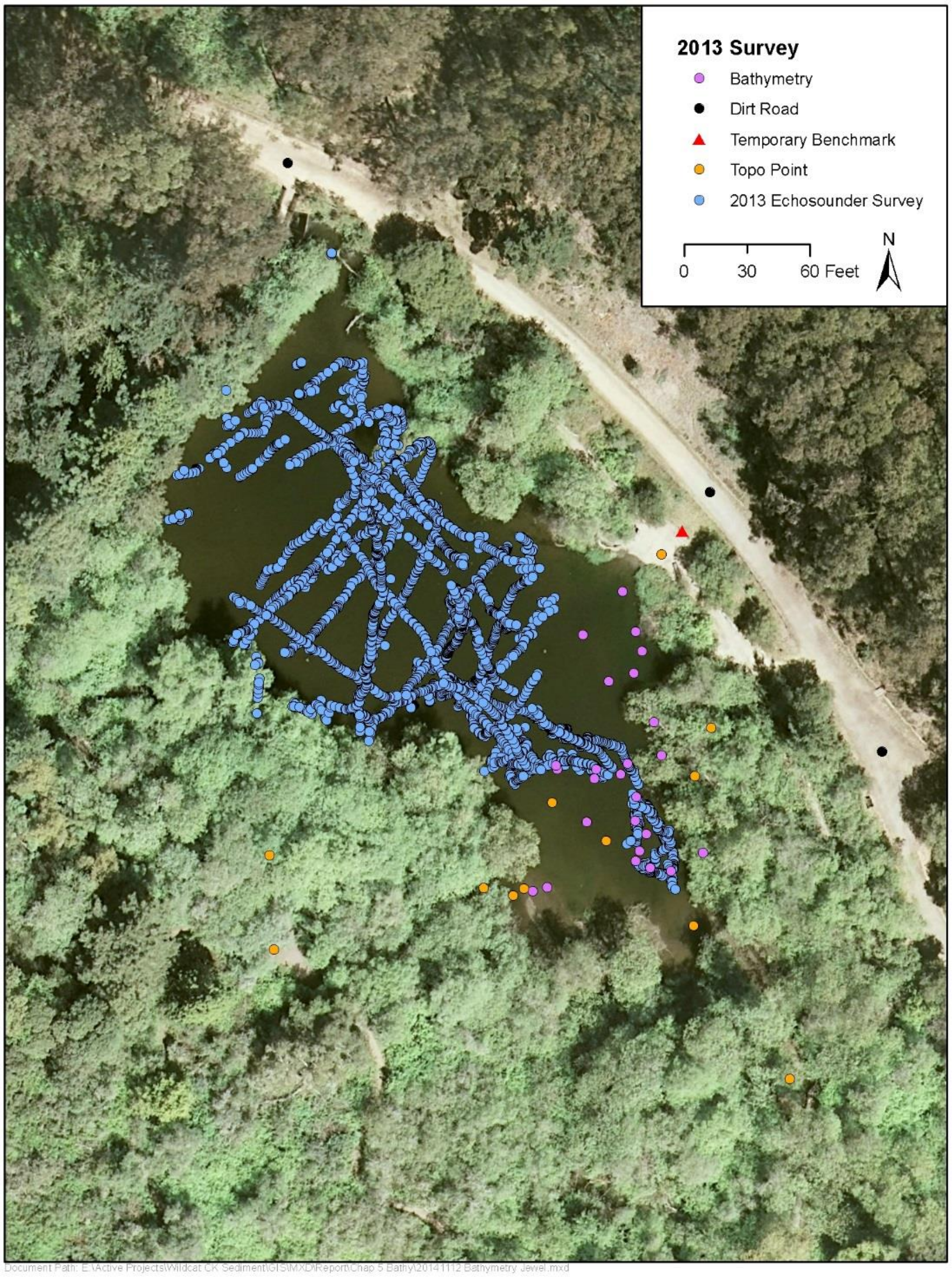
FlowWest used historical bathymetric measurements and a bathymetric survey performed for this study to assess sediment loading rates into Lake Anza and Jewel Lake. We incorporated both the historical data and the 1999 surveys reported by Collins et al. (2001). The 1999 surveys of Lake Anza and Jewel Lake were accomplished using frequent soundings using a weighted tape at numerous transects (Collins et al. 2001).

FlowWest surveyed Jewel Lake and Lake Anza in the spring of 2013 to determine capacity. We used a single beam echosounder to capture the depth, and used a survey quality GPS (Global Positioning System) tied to a local benchmark to obtain the water surface elevation. We used the Contra Costa County topography data to determine the extent of each lake at the spillway elevation. Next we used the survey data to determine the capacity of each lake. The methods we used to survey the bathymetry of each lake is described in further detail below.

FlowWest conducted bathymetric surveys of the lakes using a HydroLite-TM™ single beam echosounder to measure depth and Trimble GeoXT GPS to record the horizontal location of each depth sounding on February 19, 2013. The echosounder has a minimum depth reading requirement of 2 ft, and we mounted the echosounder to an inflatable kayak (Figure 6) a few inches under the water surface. The distance from the water surface to the bottom of the echosounder was recorded in a field book.

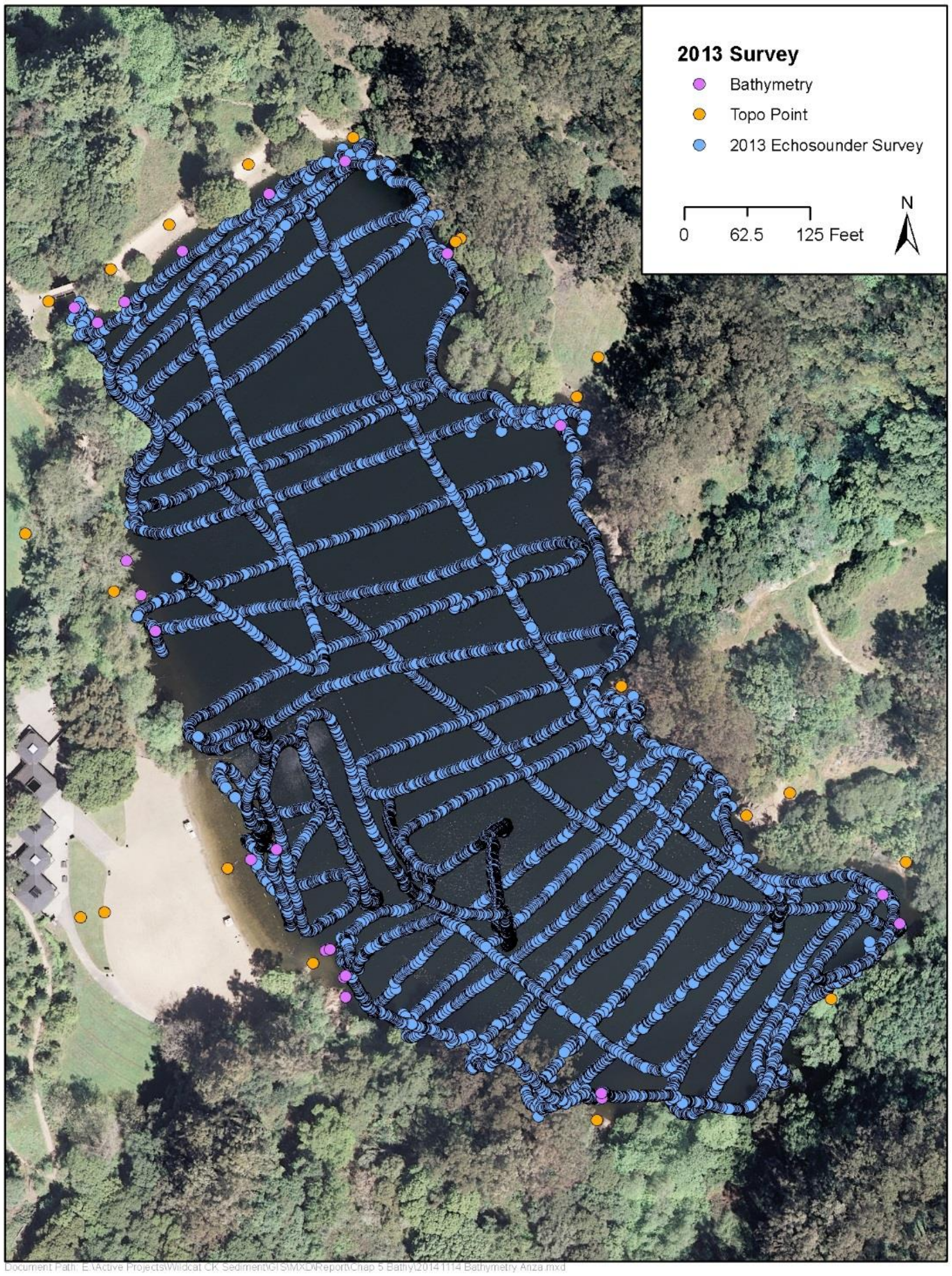
Figure 6: Single beam echosounder and GPS mounted on inflatable kayak for the bathymetry survey of Jewel Lake and Lake Anza.

We paddled transects across the lakes where the depth was greater than 2 ft and collected over 5,000 points in Jewel Lake and over 18,000 points in Lake Anza. Using post-processing software, we removed outlier soundings from the dataset. Echosounder measurements were spot checked in the field with a weighted tape. All echosounder measurements were made relative to the water surface of each reservoir, which we assumed to be constant around each reservoir during each survey. To determine the water surface elevation of each reservoir, we established temporary benchmarks on inundated structures or objects. We measured the vertical distance from the water surface elevation of each reservoir to the temporary benchmark and recorded our measurements in a field book. To convert the depth data from the echosounder to a ground surface elevation, we surveyed the water surface elevation and temporary benchmarks at both reservoirs using a survey quality Trimble R8 RTK GPS tied to a NGS registered survey benchmark on March 22, 2013. In addition to the benchmarks, we also surveyed nearshore points or the spillway for each reservoir (Figure 7 and 8). We used the spillway elevation as the maximum elevation for the capacity of each reservoir. The HydroLite echosounder data points were augmented with the FlowWest surveyed nearshore elevation points and the Contra Costa County 2-foot contour data to create a bathymetric surface using the Spatial Analyst Extension in ArcMap 10.1. We used the spline geoprocessing function to generate the bathymetry Digital Elevation Model (DEM) for both reservoirs. We clipped the new raster to the outline of each lake we delineated using survey data and the Contra Costa County topography. Next, we converted the raster to a polygon shapefile with 1 foot depth intervals and calculated the area of each polygon. By multiplying the area of each polygon by the depth we obtained the volume of each lake.



Document Path: E:\Active Projects\Wildcat CK Sediment\GIS\MXD\Report\Chap 5 Bathy\20141112 Bathymetry Jewel.mxd

Figure 7: FlowWest 2013 bathymetry and survey points collected at Jewel Lake.



Document Path: E:\Active Projects\Wildcat CK Sediment\GIS\MXD\Report\Chap 5 Bathy\20141114 Bathymetry Anza.mxd

Figure 8: FlowWest 2013 bathymetry and survey points collected at Lake Anza.

Results

The FlowWest 2013 survey for Jewel Lake shows that the deepest part of the lake is 6.7 ft deep and field observations show that a sediment delta extended into Jewel Lake. Figure 9 shows the FlowWest 2013 bathymetry contours map for Jewel Lake based on the echosounder survey points.

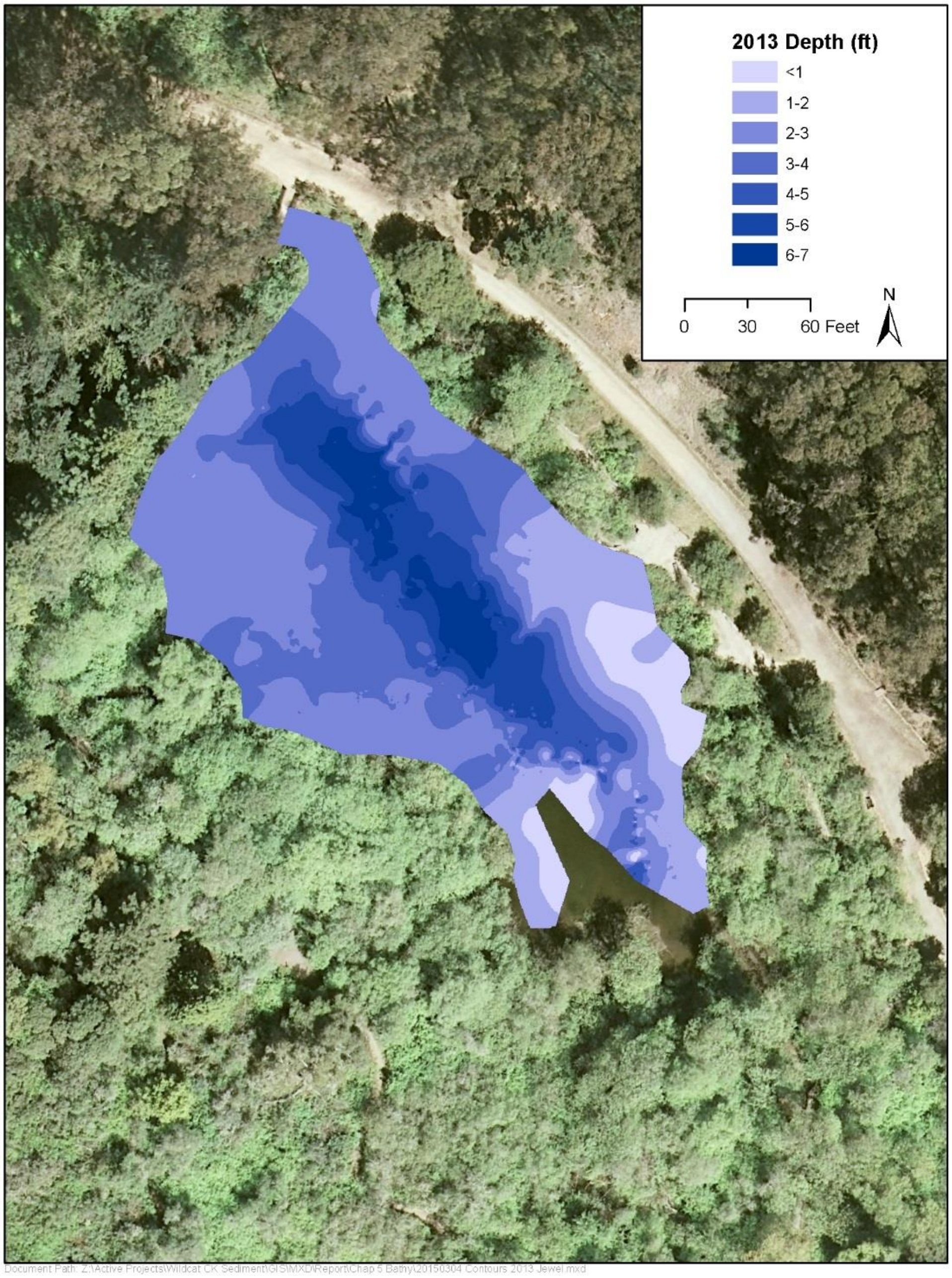
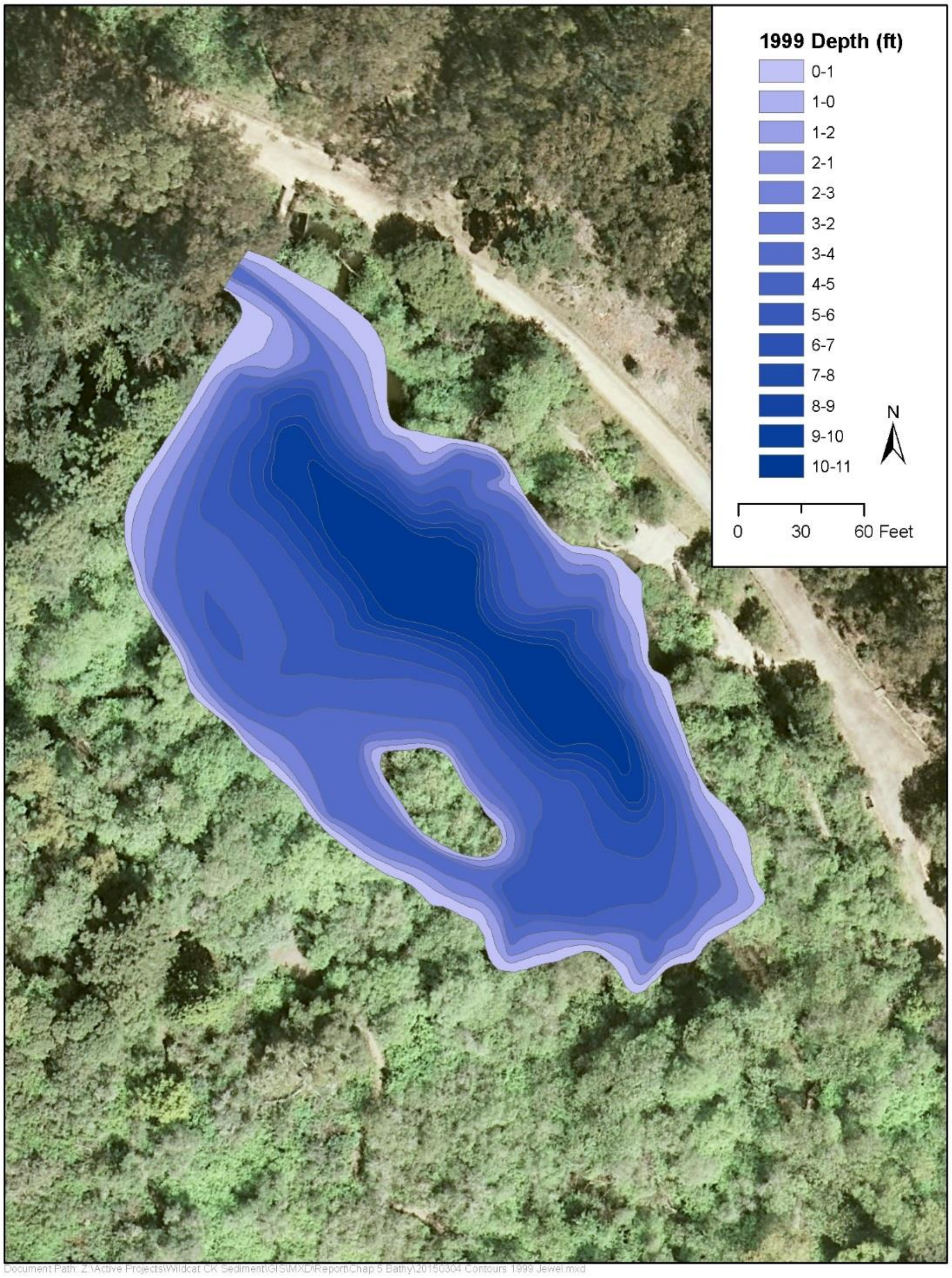


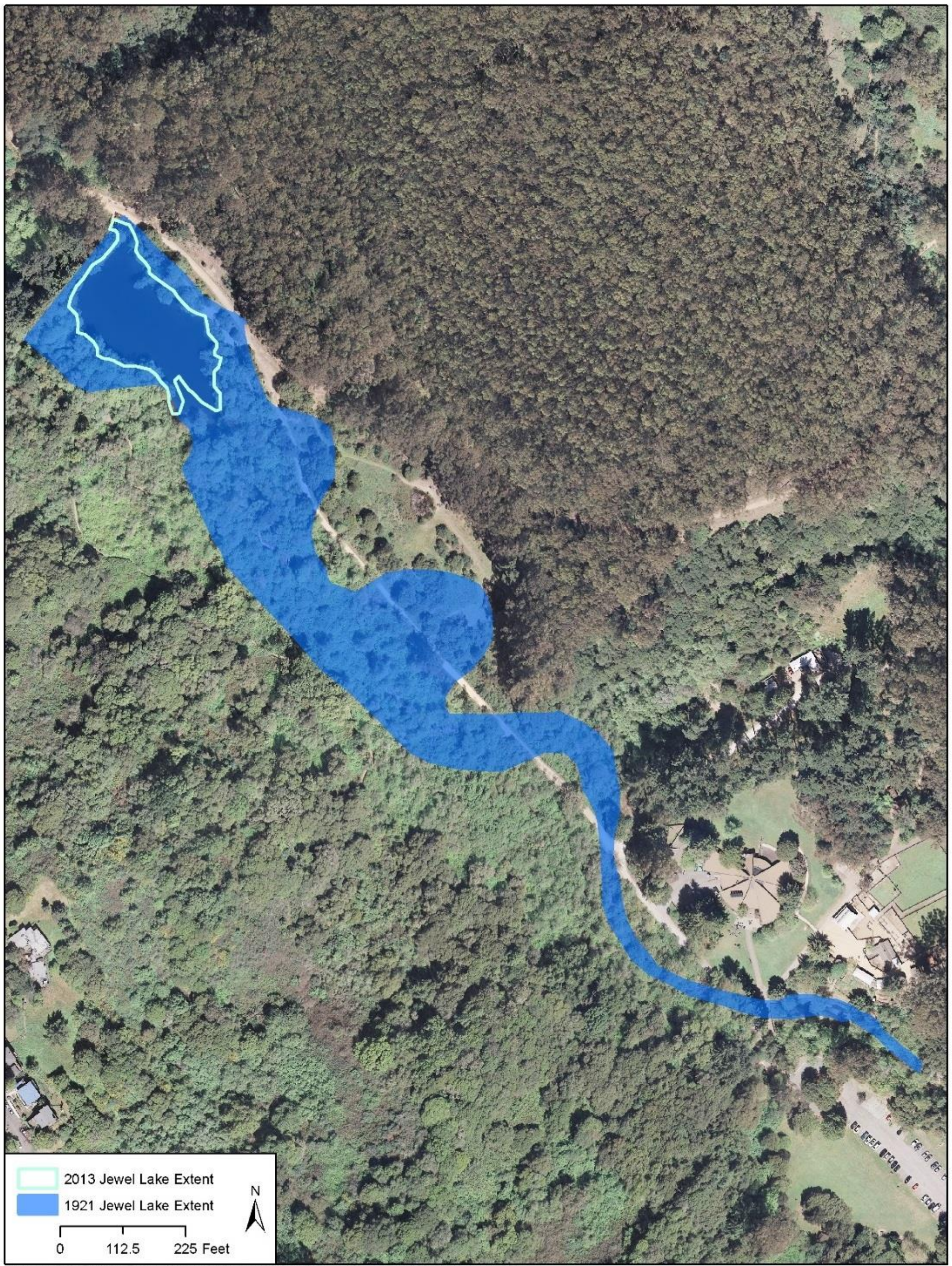
Figure 9: Contours generated from the FlowWest 2013 bathymetry survey of Jewel Lake.



Document Path: Z:\Active Projects\Wildcat CK Sediment\GIS\MXD\Report\Chap 5 Bathy\20150304 Contours 1999 Jewel.mxd

Figure 10: Contours generated from the 1999 bathymetry survey of Jewel Lake Collins et al. (2001).

By comparing FlowWest 2013 survey (Figure 9) and Collins et al. (2001) 1999 survey (Figure 10), we observed that the capacity of the lake has been significantly reduced. The extent of the lake has decreased and the deepest part of the lake after dredging in 1991 was 13 ft deep compared to the current 6.7 ft. Wetted areas in 1991 around the edge of the lake and in particular near the mouth have filled in with sediment. Figure 11 also shows the long-term decrease in the extent of Jewel Lake from 1921 to 2013.



Document Path: E:\Active Projects\Wildcat CK Sediment\GIS\MXD\Report\Chap 5 Bathy\20150719 Jewel 1921.mxd

Figure 11: Decrease in Jewel Lake extent from 1921 to 2013.

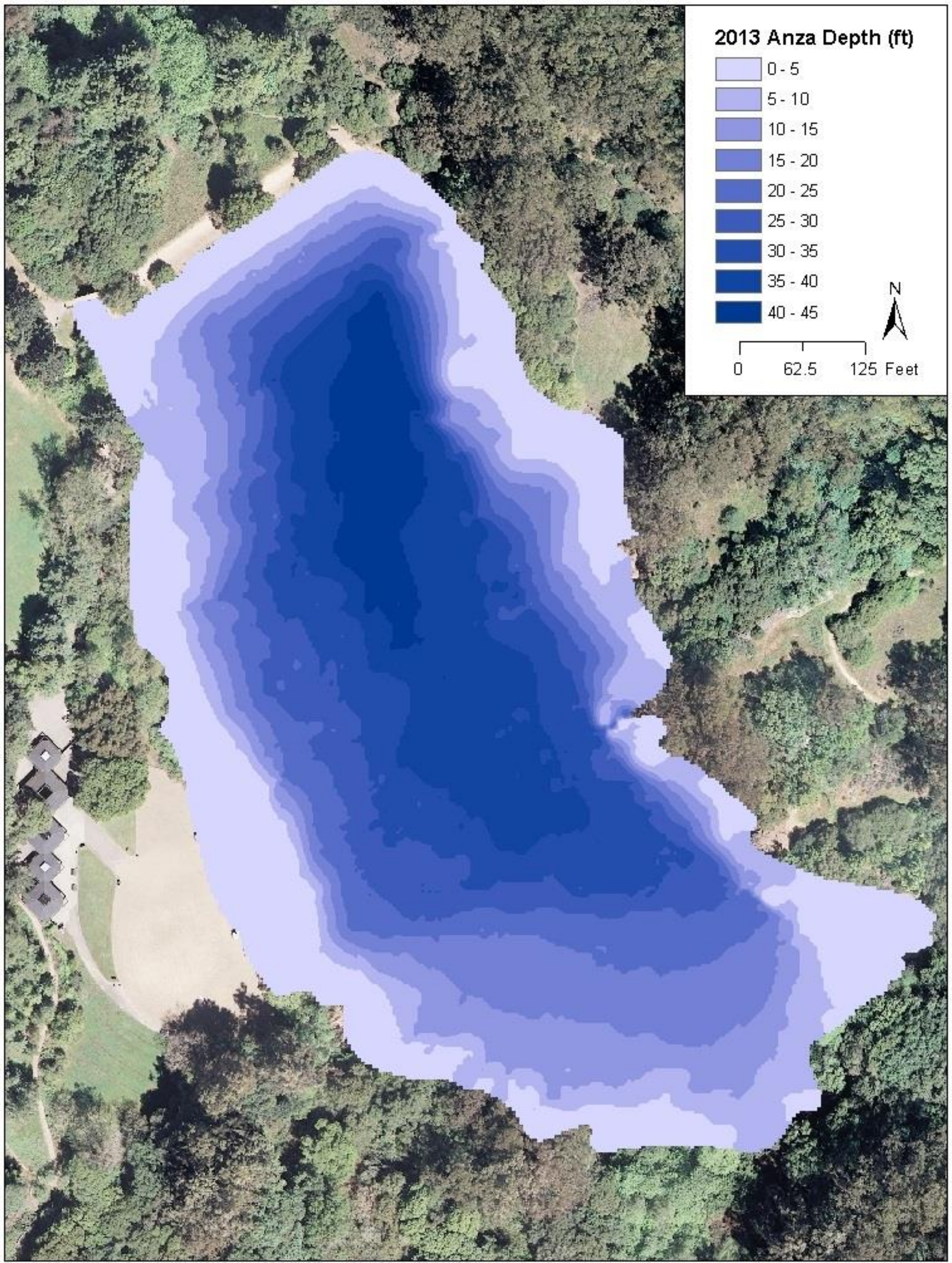
The historical records for capacity and dredging of Jewel Lake were compiled by Collins et al. (2001) and updated by FlowWest with the latest data (Table 8). The as-built capacity of Jewel Lake was 44,560 yds^3 in 1921. By 1949, the long upstream finger of Jewel Lake filled in, decreasing the size of the lake to close to its current extent. By 1967 the capacity of the lake was 9,450 yds^3, and the same amount of material was dredged from the lake later that year. The capacity of the lake decreased to 4,599 yds^3 by 1984, and 10,404 yds^3 of material was removed in 1991. Between 1991 and 1999 the capacity had decreased by 1,093 yds^3 and continued to decrease by another 5,505 yds^3 between 1999 and 2013. Using the capacity data, we calculated a long-term (1921-2013) sedimentation rate of 653 yds^3/yr, and a short-term term (1999-2013) sedimentation rate of 393 yds^3/yr.

Table 7: Summary of Jewel Lake capacity from construction in 1921 to the FlowWest 2013 survey

Date of Survey	Capacity (yds^3)	Notes
1921	44,560	Jewel Lake completed
1933		Jewel Lake diversion discontinued
1938		Lake Anza completed
1967	9,450	Estimate by DWR 1977
1967		Dredging 9,450 yds^3 by EBRPD
1979	8,202	Bathymetric survey by EBRPD
1982	5,494	Bathymetric survey by EBRPD
1984	4,599	Bathymetric survey by EBRPD
1991		Dredging 10,404 yds^3 by EBRPD
1991	10,920	Bathymetric survey by EBRPD
1999	9,827	Bathymetric survey by Collins et al. (2001)
2013	4,322	Bathymetric survey this study

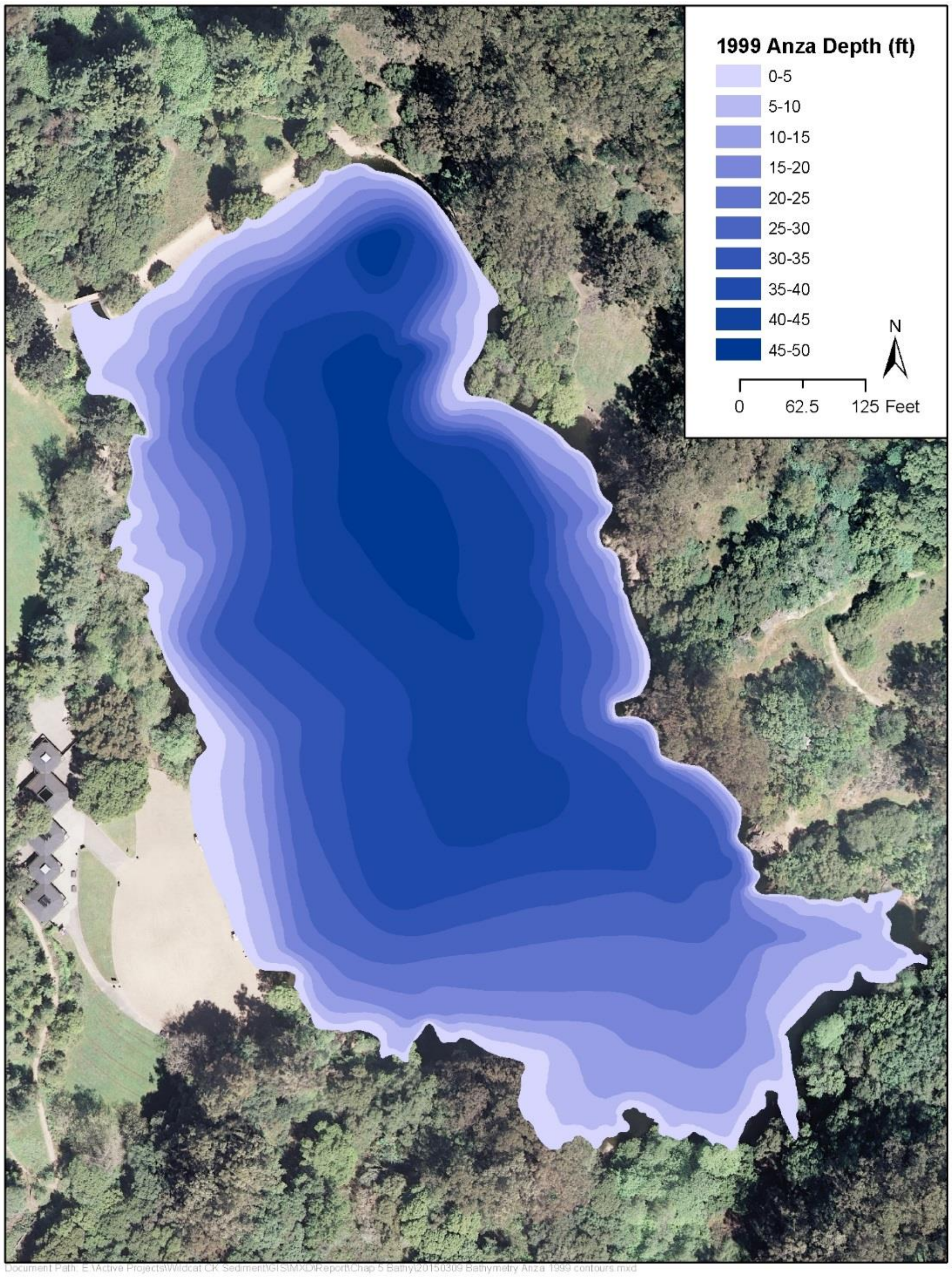
Table adopted from Collins et al. (2001)

Similar to the change in Jewel Lake, the FlowWest 2013 survey of Lake Anza shows that the depth of the lake has decreased to 44.2 ft. Two small sediment deltas were observed at the mouth of Wildcat Creek and from a tributary near the beach, but there was not an obvious decrease in the extent of Lake Anza. Figure 12 shows the FlowWest 2013 bathymetry contours map for Lake Anza based on the echosounder survey points. Records searches as part of this study did not turn up any additional bathymetric data of Lake Anza that were not already included in the Collins et al. (2001) study. Figure 13 shows the contours from the 1999 survey of Lake Anza (Collins et al. 2001).



Document Path: U:\Active Projects\Wildcat CK Sediment\GIS\MXD\Report\Chap 5 Bathy\20141118 Bathymetry Anza Contours.mxd

Figure 12: Contours generated from the FlowWest 2013 bathymetry survey of Lake Anza.



Document Path: E:\Active Projects\Wildcat CK Sediment\GIS\MXD\Report\Chap 5 Bathy\20150309 Bathymetry Anza 1999 contours.mxd

Figure 13: Contours generated from the 1999 SFEI bathymetry (Collins et al, 2001) survey of Lake Anza.

The capacity of the Lake Anza decreased between the two surveys. The deepest part of the lake was between 45 - 50 ft below the spillway elevation in the 1999 Collins et al. (2001) survey compared to the FlowWest 2013 maximum depth of 44.2 ft. Differences in the survey method and the number of soundings may account for much of the difference in the calculated capacity of the lake between the two surveys. Additional beach sand may have been added to Lake Anza by EBRPD that was not captured in our analysis. In general, the two surveys show that the lake has shallowed near the mouth of Wildcat Creek and at the north eastern corner of the lake. We added the 2013 survey to the historical records for capacity of Lake Anza compiled by Collins et al. (2001) and present the changes in capacity in Table 9.

The as-built capacity of Lake Anza was 432,008 yds^3 in 1938. Our review of historical aerial photographs shows that the extent of the lake has remained consistent over time compared to the significant decrease in the extent of Jewel Lake. By 1999, the capacity of the lake decreased to 409, 084 yds^3, which includes landslide deposition of 7,404 yds^3 and 9,976 yds^3 of imported beach sand (Collins et al. 2001). The results of our 2013 survey showed a capacity of 320,002 yds^3. Using the capacity data we calculated a long-term (1938-2013) sedimentation rate of 1,262 yds^3/yr, accounting for the landslide and imported sand, and the short-term term (1999-2013) sedimentation rate of 6,363 yds^3/yr.

Table 8: Lake Anza capacity from construction in 1938 to the FlowWest 2013 survey

Date of Survey	Capacity (yds^3)	Notes
1938	432,008	Lake Anza completed
1962		Landslide deposition, 7,404 yds^3
1965		Imported beach sand , 9,976 yds^3
1984		Golf course sediment basin completed
1999	409,084	Bathymetric survey by Collins et al. 2001
2013	320,002	Bathymetric survey this study

Table adapted from Collins et al. (2001)

Lake Anza captures more sediment than Jewel Lake although the contributing watersheds are relatively similar in size. The long-term sedimentation rate is nearly 2 times that of Jewel Lake, and the short-term term rate is 16 times greater. The contributing watershed area upstream of the Lake Anza Dam is 948 acres compared to 1,050 acres for the watershed between the Jewel Lake Dam and the Lake Anza Spillway. The large difference in the short-term term sediment rates may be explained by the difference in the methods of the Lake Anza surveys between this study and the Collin et al. study (2001), leading to a possible overestimate of the capacity of Lake Anza in 1999. The higher sediment rates in Lake Anza partially explains the rapid increase in the sedimentation of the Jewel Lake after construction in 1921, and the significant decrease in the extent of Jewel Lake shown in aerial photographs from 1939 and the 1949 map. After construction of Lake Anza the sedimentation rates for the Jewel Lake likely decreased because upstream sediment after 1938 was captured by Lake Anza. Another possibility for increase in the short-term rate between 1999 and 2013 is that there may have been imports of sand for the Lake Anza Beach that are being reworked by wave action and deposited into the lake. This warrants further investigation with EBRPD. Given that there have been only three surveys of Lake Anza we recommend using the long-term sediment rate for Lake Anza for future planning and analysis.

5. Sediment Analysis

Purpose

To establish whether land management actions or restoration activities can be conducted to reduce resource damages and the need for frequent dredging of Jewel Lake, a watershed sediment analysis was conducted to identify different sediment sources upstream of Jewel Lake and Lake Anza. The sediment analysis will help determine the sediment sources upstream of the two reservoirs and guide management practices to reduce sedimentation of the reservoirs.

Background

In 2001, Collins et al. reported that the total long-term (1832-1999), watershed sediment supply was approximately 18,146 yd^3/yr. They also determined that approximately 46 % of the total supply was generated upstream of Jewel Lake (8,347 yd^3/yr). About 39 % of the amount from upstream of Jewel Lake was from the middle canyon segment (Jewel Lake to Lake Anza), while only 7 % was from the upper canyon segment (upstream of Lake Anza). They determined that the middle canyon segment, which had the smallest drainage area of the upper, lower, and alluvial plain segments, had the highest sediment yield for the entire watershed, about 4,140 yd^3/yr/sq mi. In the 2001 study, sediment sources downstream of Jewel Lake were uniquely identified by generation process (e.g. landslides, streambank erosion, etc.), while upstream sediment sources were not uniquely identified. Instead, sediment supply rates to both Jewel Lake and Lake Anza were determined by bathymetric analyses of reservoir deposition and trap efficiency to establish the amount of suspended sediment transported over the spillways. The Collins et al. study identified the long-term rates of sediment supply but noted that short-term rates could be quite variable depending upon the occurrence of significant storms and landslide activity.

Since discrete sediment sources have not been identified upstream of Jewel Lake and since only long-term rates were established in the 2001 study, the approach for this current project differs. Data collection methodology for this project was designed to be collected in a similar fashion to the 2001 study downstream of Jewel Lake, but to use only measure short-term rates relative to landscape adjustments since the largest modern storm event in the watershed (WY 1982) and to develop new bathymetric data of the reservoirs to contrast and compare short-term rates of sedimentation.

Methods

The methodology for the sediment source analysis involved field measurement of sediment supply rates from the different sources along the stream network and adjacent hillsides along all of the mainstem of Wildcat Creek and in a sampling of tributary reaches in different topographic and geomorphic settings. For reaches not measured, rates of supply were extrapolated from nearby measured rates. Field measurements also included measuring sediment sources along road cuts and inboard ditches that drain to the stream network. WS walked dirt roads and trails in the watershed and measured sediment supply from the road treads, such as rills and gullies. The same method of modeling dirt road sediment supply that was used by Collins et al. (2001) was used for this project. FlowWest applied the Washington Road Surface Erosion Model (WARSEM) (Washington Forest Practices Board 2011) so that rates could be compared to the previous analysis. Erosional features that did not supply sediment to the stream network were not measured.

As best possible, the channel network and all storm drains were mapped using GIS and on-the-ground visual verification and GPS coordinates. FlowWest developed a geomorphic unit map for the watershed using topographic and geologic datasets, and the volumetric supply of sediment along measured channel reaches from each geomorphic unit was assessed using available datasets. The sediment sources that were measured were chosen to represent the short-term inputs that have occurred since 1982 to 2013. This 31-year period was selected because 1982 was the largest recent flow event that caused significant sediment mobilization and channel change. WS estimated the year of occurrence of each erosional feature so that an annual rate could be associated with all inputs. This eliminated the problem associated with road grading that was assumed to occur on annual basis for all the fire trails. The age of the erosional features and voids could usually be assessed by age of vegetation and associated with certain flow events or landslide producing storms during this period. Most erosion features were attributed with the following recent, peak flows:

- 2013 (peak flow occurred in November)
- 2011
- 2005 (highest flow of the last decade)
- 1998
- 1982 (highest peak flow for the USGS Gage # 11181390 period of record from 1976-1997)

WS categorized the geomorphic processes supplying the sediment as bank erosion, bed incision, landslide input, and dry raveling, gullying, and whether they were naturally caused or associated with a land use feature, such as culvert outfalls or roads. WS visually estimated the percentage of fine sediment (particle sizes less than 2 millimeter (mm) including sand, silt and clay) for each source and noted potential supplies of bedload deposited as deltas and suspended and wash load delivered to the more interior parts of the reservoirs. The trap efficiency of Jewel Lake is so diminished that most of its wash load is probably transported over the spillway.

During the field surveys, WS measured areas of significant sediment storage that exceeded the natural veneer of sediment along the active channel bed and below the bankfull elevation. Most of these sediment storage sites were behind debris jams and are most likely, temporary storage sites because the sediment will likely be remobilized after the debris jams become dislodged. The resulting sediment budget was organized by “natural” vs. “human-induced” drivers, sources, and storage of sediment.

Field Assessment

WS documented observations of sediment sources and field conditions on hardcopy field maps, field data sheets, and by digital photography. Notes, pictures, and data were attributed with an identification number that was either mapped on a hardcopy map or associated with a GPS point to develop a relational database in GIS for review and further analysis. Figure 14 provides an example of the detailed mapping completed in the field. In Figure 14, the yellow lines represent paved roads, orange lines represent dirt roads and trails, black dotted lines represent inboard ditches, arrows show the flow direction in ditches, boxes represent inlets, double hatched lines represent storm drains and culverts, green lines show flow paths, blue lines represent streams, the pink line is the watershed boundary, red lines delineate landslide scarps, and black lettering near colored brackets is the station ID.

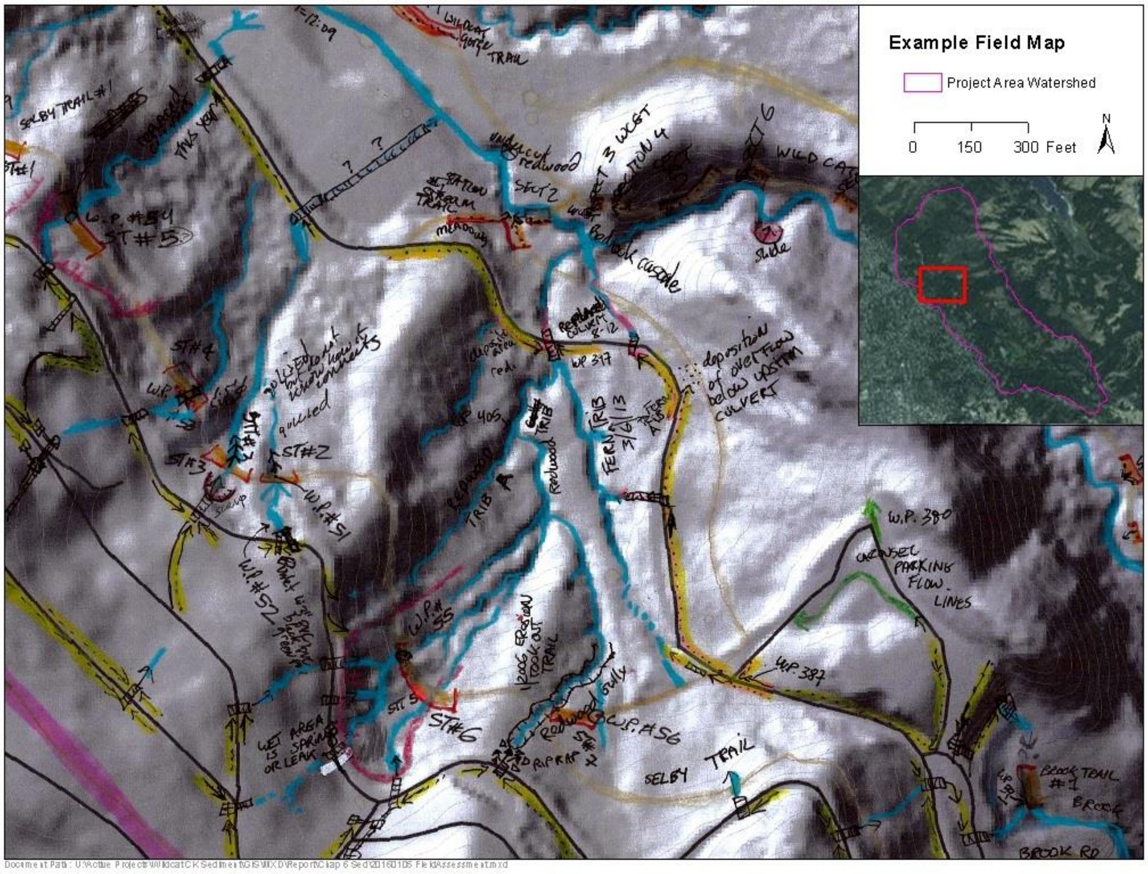


Figure 14: Example mapping and notes from the reconnaissance level sediment investigation by WS. The base hillshade was developed from the Contra Costa County and Alameda County Digital Elevation Models.

WS measured the length, width, and depth of the erosional voids and the percent fines (sand and smaller) were visually estimated and noted for each feature. Erosional voids along the bank or channel bed that were less than 0.25 ft in depth were not measured. Therefore all estimates should be considered conservative. WS also noted both the cause and types of erosion observed at each erosional void or contributing feature. WS classified the causes of erosion as one of the following:

- Landslides, bank slumps, or earthflows
- Raindrop impact erosion
- Ravel erosion
- High flow or flood-related
- Gullies
- Large Woody Debris (LWD)-related
- Structure-related, such as bridges or culverts

Types of erosion were classified as one of the following:

- Streambed incision
- Stream bank lateral erosion
- Canyon slope ravelling
- Landslide
- Dirt or paved road tread
- Road cut
- Road fill
- Inboard ditch

The mapped landslides for this analysis only include the ones contributing sediment to Wildcat Creek. Collins et al. (2001) showed that significant landsliding occurs within the Orinda Formation on the west side of the Wildcat Creek and that much of the renewed earthflow activity is associated with suburban runoff along the developed western ridge. However, these large landslides are predominately contained on the valley slope and are not directly connected to Wildcat Creek.

WS recorded areas with significant sediment storage on the field maps, along with the GPS coordinates, and timeframe since presumed deposition. The same method was also used to record locations of instream structures such as culverts, bedrock outcrops, and bridges. Sediment erosion rates were calculated and reported in cubic yards per year (cu yd/yr), and sediment storage was reported as a measured volume in cubic yards (cu yd). WS measured sediment voids caused by erosional processes in the field and were attributed to a discharge event, ultimately to calculate an erosion rate, whereas sites of storage volume were identified and measured. Storage sites were not converted to a rate because once the storage volume is filled, any additional suspended sediment is transported downstream. To establish actual sediment supply rates the total volumes of stored sediment was subtracted from the total annual volume of supplied sediment for the 31 year period.

Integration of Field Data into the Project GIS

FlowWest incorporated WS' field notes, recommendations for remediation, data spreadsheets, digital photographs, mapped features and attributes, and GPS data into the project GIS. These data sets were integrated into the project GIS to spatially analyze and visualize sediment contribution rates in the watershed. FlowWest digitized features on the field maps as sediment point features (culverts, bridges, LWD, etc.), sediment line features (inboard ditches, creeks, trails), and any other notes pertinent to the sediment analysis. FlowWest applied the sediment line features delineating inboard ditches and contributing dirt trails or roads in the road and trails analysis below to determine runoff contribution from these features.

Channel Segments

FlowWest calculated short-term sediment supply rates for the different measured segments by summing the various annual input rates of each feature. The supply rate of the total annual load and fine sediment load was calculated. FlowWest divided both the fine and total sediment supply rates by the linear length of the segment to calculate a standardized segment supply rate per linear foot of channel.

FlowWest transferred data from field maps to the Project GIS, delineating segments of stream length measured in the field as well as noting segments as null if sediment supply was determined to be negligible. Sediment supply rates were assigned to unmapped segments (segments that could not be verified in the field due to dense vegetation cover and/or not enough time to walk all the streams in the watershed) by extrapolating from the upstream and downstream sediment supply rates from adjacent measured creek segments. Professional judgment, observation of watershed-averaged rates, geologic bedrock, and stream order were all considered throughout the extrapolation process. Measured and extrapolated creek segments were digitized in GIS such that all creek lengths in the subwatersheds were designated to have a sediment supply rate that was measured, null, or extrapolated. A quality assurance and quality control check was conducted between WS and FlowWest for transfer and mapping of data into the FlowWest GIS to ensure that the accurate representation of subwatershed sediment contribution to mainstem Wildcat Creek. FlowWest summed all sediment segments (measured, null, or extrapolated) to determine subwatershed fine and total sediment supply rates (yd^3/yr). The volume of storage capacity was determined from the field notes, datasheets, or field maps, and incorporated into the project GIS to identify areas of sediment storage.

Roads and Trails

FlowWest calculated sediment contributions from roads and trails by combining field observations with a road surface erosion model. Field observations by WS determined which roads and trails were connected to Wildcat Creek by walking along relevant dirt and paved roads, taking GPS points at the start and end of segments that provide sediment to the channel network and noting the delivery method. The extent of the connected road and trail system that provides sediment was measured and plotted on watershed maps. Rill and gully erosion was measured on the road tread, road cut, and fill. The extent of the inboard ditch system, roads, and trails that were connected to channel network were mapped and FlowWest incorporated the data into the project GIS. Using WARSEM (Washington Forest Practices Board 2011) FlowWest, calculated the annual road tread erosion and sediment delivery to channels. The width and length of the relevant segments were either measured in the field or estimated in the office. The model output is reported as average annual tons of sediment per year. It allows identification of road segments that are most likely to producing large amounts of sediment and determination of the relative sediment savings from a variety of management practices. FlowWest used WARSEM values to determine erosion rates for the road type, traffic, and geology. FlowWest assumed that the contribution of sediment from cut and fill slopes was minimal based on field observations. For example many of the road cuts were at a stable angle, are greater than 50 years in age, and covered by vegetation. The hiking trail network is extensive in Tilden Regional Part and FlowWest modeled trails as narrow dirt roads with minimal traffic.

Roads and impervious areas in the suburbanized portion of the watershed increase runoff to Wildcat Creek tributaries. At some outfalls, gullies have formed and contributed large amounts of sediment to Wildcat Creek. Sediment from these gullies was included in our analysis as an independent source attributed to road construction or urbanization.

Subwatersheds

FlowWest summarized sediment supply rates by subwatershed for display purposes as we calculated the sediment supply rates just for the channel and near bank areas and not for the entire subwatershed. We delineated the subwatersheds in GIS using a combination of the Contra Costa County 2-ft contours and 2-ft contours generated from the Alameda County DEM. We delineated subwatersheds for the major tributaries to Wildcat Creek and grouped minor tributaries and the remaining areas together into subwatersheds that contribute sediment and runoff directly to Wildcat Creek.

Results

Results from the sediment analysis include the summary and figures below, Appendix A, GIS shapefiles, and an Excel spreadsheet. This section summarizes the results using a series of maps generated from the shapefiles and figures and tables generated from the Excel spreadsheet. Appendix A describes the GIS shapefiles and Excel spreadsheet included on a DVD with this report that, which contains the data from the sediment analysis. The shapefiles and spreadsheet in Appendix A were designed to be used by EBRPD for future sediment and erosion control management.

Field Analysis

FlowWest compiled field data and observations into the project GIS from field maps, data sheets, GPS waypoints, and digital photographs collected by WS.

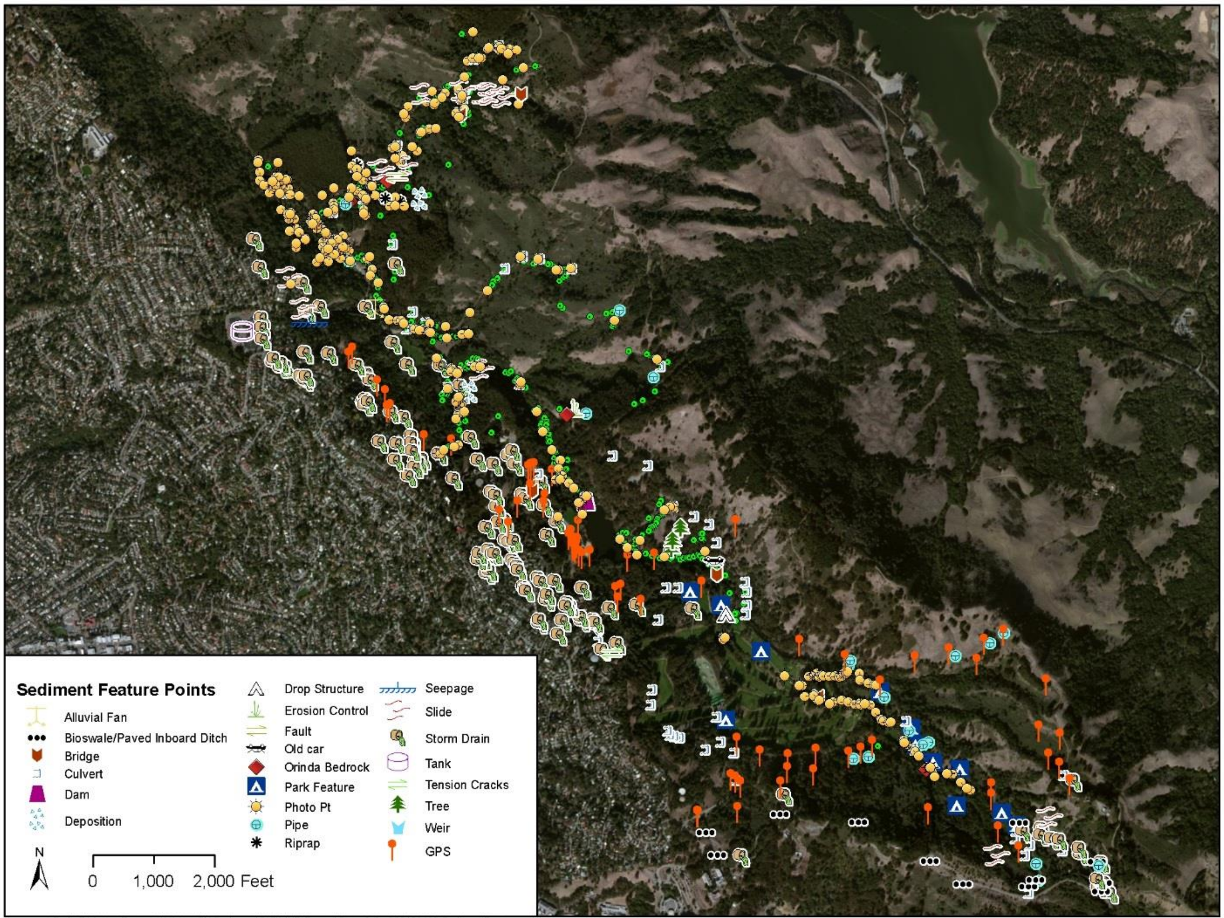
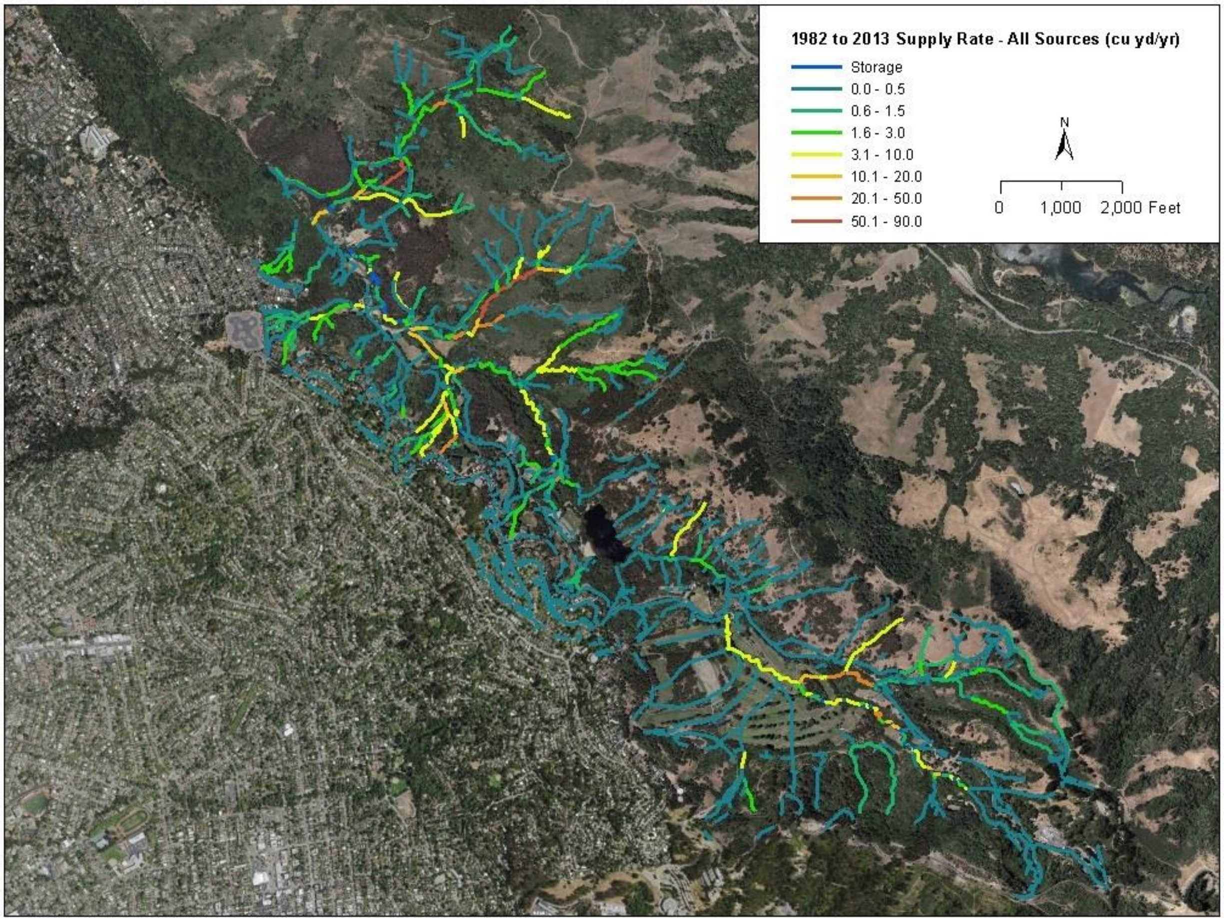


Figure 15: Sediment point features mapped in the field by WS and incorporated into the project GIS by FlowWest.

The features transferred from the field maps and data sheets to the point file primarily show the location of channel and sediment related features such culverts, erosion features, and the location of photo points from the field effort. Mapped features were used to determine lengths of sediment contribution segments and integrated into the sediment analysis spreadsheet.

Sediment Contribution Segments

Using the point features, data sheets, and field maps, FlowWest created a sediment segment shapefile which shows the short-term sediment supply rate for each creek segment and contributing road and trail. Channel short-term sediment supply rates include both measured and extrapolated rates. An Excel spreadsheet was also used to document field observations for measured erosion features or extrapolated segments. The relationship between the shapefile and the Excel spreadsheet are further described in Appendix A. Figure 16 shows the short-term sediment supply rate in yd^3/yr for each segment, and Figure 17 shows the linear Short-term sediment supply rate in ft^3/yr/ft. These units are reported to show both the short-term supply rate of sediment generated by a segment (yd^3/yr) and the amount of sediment normalized by linear length of each segment (ft^3/yr/ft). This helps identify large point sources of sediment as the segment length varies from very short to hundreds of feet. Figure 17 shows the largest short-term sediment supply rates in the following tributaries Laurel Canyon, Meadow, Central Park, Big Springs, and the mainstem through the Quarry, Golf Course, and Upper Wildcat reaches.



Document Path: U:\Active Projects\WildcatCK Sediment\GIS\MXD\Report\Chap 6 Sed\20160108 SedimentRates_All.mxd

Figure 16: Short-term sediment supply rates (yd^3/yr) from channel and landscape processes and roads and trails.

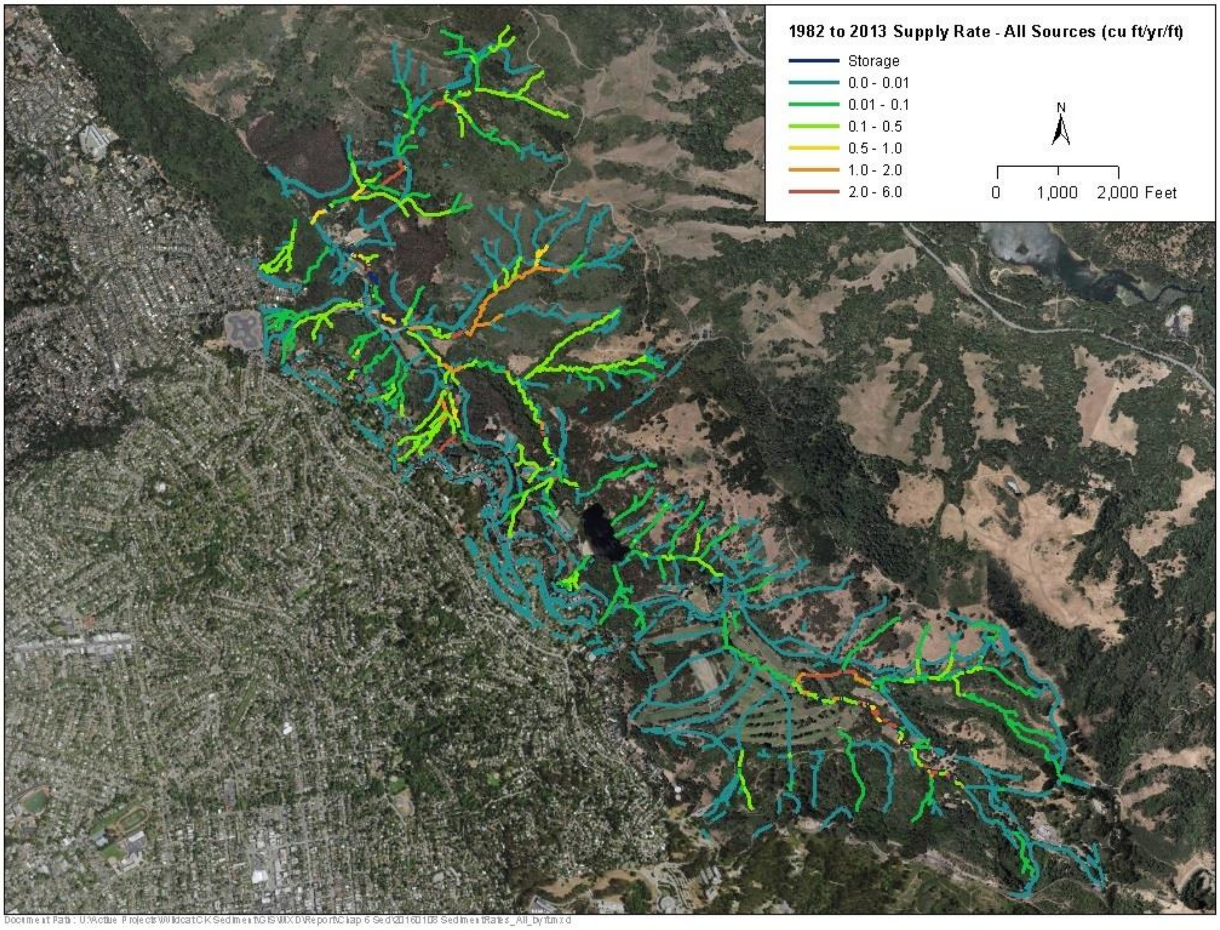


Figure 17: Short-term sediment supply rates normalized by linear foot (yd^3/yr/ft) for each segment.

Subwatershed Sediment Totals

FlowWest summed the sediment analysis GIS data by subwatershed to identify which subwatersheds contained channels and adjacent hillsides with the highest short-term sediment supply rates to target future erosion control actions. Figure 18 shows the total short-term sediment supply (yd^3/yr) from channels and adjacent hillsides as well as roads and trails. The subwatersheds with the highest short-term sediment supply rates (highlighted in red) include Meadow, followed by Laurel Canyon, Central Park, Wildcat Creek Upstream of Anza, and Upper Wildcat. Of these subwatersheds, Big Springs and Upper Wildcat are located upstream of Lake Anza. The subwatersheds containing channels and adjacent hillsides with the lowest short-term sediment supply rates are shown in blue and green. One important finding of this analysis was that localized erosion features, such as a large gully associated with suburban point source runoff downstream of a culvert, can contribute the majority of sediment for the channel network in a subwatershed. For example, the large gully that formed downstream of a stormwater outfall along Wildcat Canyon Road in the Central Park Subwatershed (this feature is described further in Section 6) was a large source of sediment for the entire channel network in that subwatershed. Considering this finding, it is important to note that there are numerous large landslides on the west side of Wildcat Canyon that are not presently directly connected to Wildcat Creek or tributaries. For these slides, sediment is stored on the valley slope. If these large landslides are mobilized during a wet winter, the amount of sediment contributed by landslides could be much higher than estimated for the past 31 years.

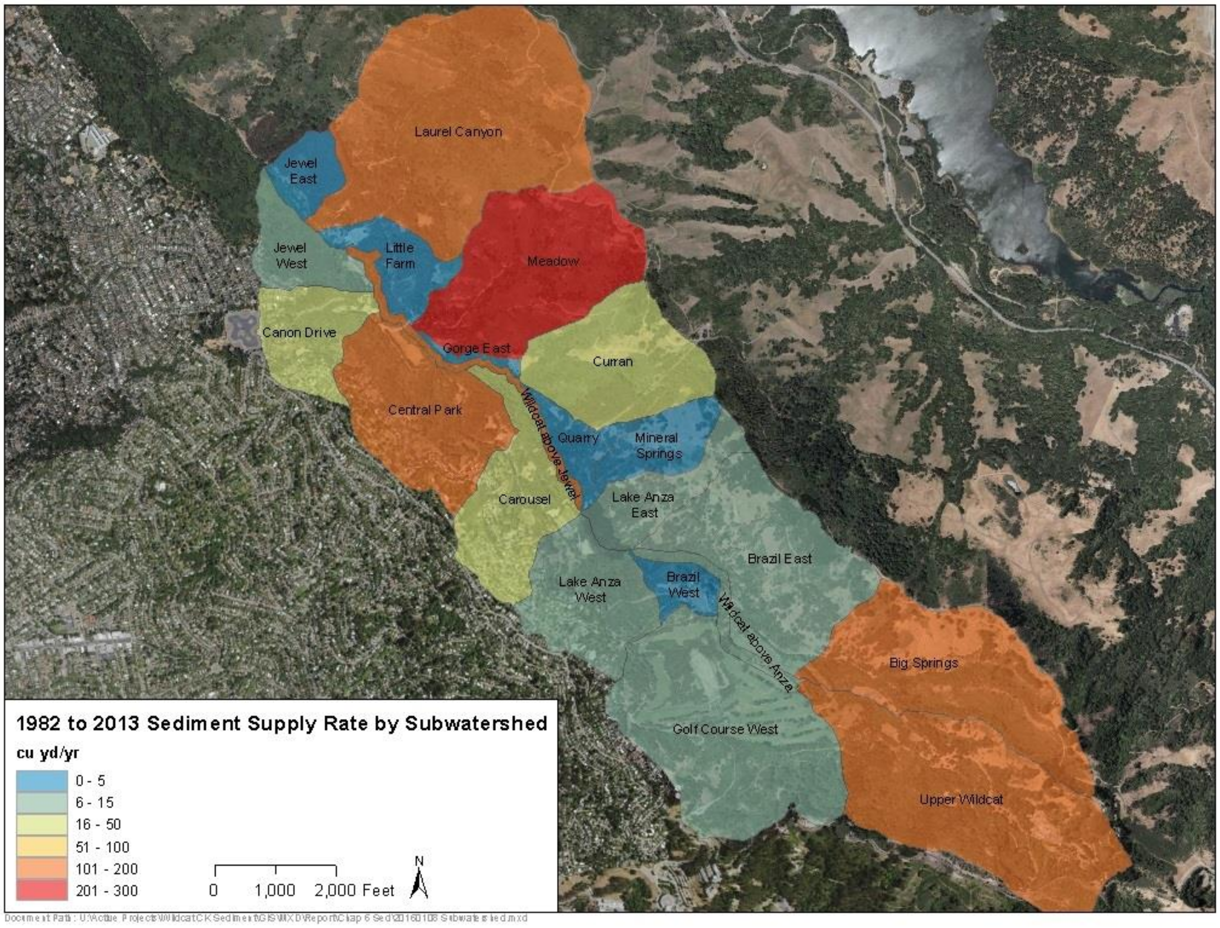


Figure 18: Short-term sediment supply rates (yd^3/yr) for channels and adjacent hillsides in each subwatershed.

Sediment Storage Sites

Sediment storage sites in the channels of the study area occur as sites of streambed aggradation that shift the bankfull elevation above its usual level. WS observed such areas in the streambed upstream of obstructions including LWD, boulders, and instream structures such as culverts and bridges. Storage sites were mostly observed in the mainstem of Wildcat Creek. WS reported storage as a volume instead of a rate because once the storage site is filled with sediment, additional sediment is transported downstream. Storage was measured to subtract out from supply rates of sediment potentially making it to the reservoirs. FlowWest adjusted the short-term channel sediment supply rates by summing the short-term channel sediment supply rates per subwatershed and multiplying by 31 years, subtracting the storage volumes, and then divided the remaining volume by 31 years to get annual short-term sediment supply rate per subwatershed.

Sediment Source Categorization

Using the sediment supply processes identified in the field, FlowWest categorized short-term sediment supply sources as channel, gully, overland, slides, and roads and trails. Channel processes included incision and bank erosion. The overland category included rills, ravel, sheet wash, and rain drop impact estimated during field data collection. Road and trail short-term sediment supply sources included field measurements of sediment from roads, trails, and inboard ditches and modeling of roads and trails. Gullies mapped in the field included deeply incised channels at outfalls, channel where natural channels do not occur, and eroded road drainage outfalls. The majority of the gullies mapped in the field were related to stormwater outfalls, but some pre-existing, deeply incised channels may have also been classified as a gully instead of an incised existing channel. The short-term sediment supply rates from channels and adjacent hillsides and roads and trails were then summarized by subwatershed (Figure 20, Table 10). The results of this analysis showed that the overall sediment contribution from erosion of road and trail surfaces in the watershed was smaller than other sources. However, increased runoff from impervious, suburbanized areas has been largely routed through ditches and stormwater drains along paved roads in the western portion of the watershed leading to erosion identified as gullies. Short-term sediment supply rates are highest for channel processes such as incision and bank erosion. Table 10 shows that the short-term sediment rate for channel processes the project area is 970.6 yd^3/yr, while the rate for road and trails is 53.9 yd^3/yr. The channel processes short-term sediment supply rate is 82% of the total, and slides, gullies, roads, and overland respectively accounting for 7%, 5%, 5%, and 1% (Table 10 and Figure 21). Considering the amount of landslides near the western watershed divide, slide processes are a relatively small component of the total short-term sediment supply rate, less than 87.3 yd^3/yr. The amount of sediment supplied by gullies was dominated by one large gully in the Central Park Subwatershed at the end of a stormwater outfall. Although the contributions from this one gully were significant to the Central Park Subwatershed (further described in Section 6), the total contribution of gullies in the project area were less than 65 yd^3/yr. We were unable to observe all channels in the field and other large gullies may exist that were obscured by dense vegetation or missed during the field reconnaissance. FlowWest may have underestimated the short-term sediment supply for subwatersheds like Central Park because tributaries emanating from numerous active landslides could not be field sampled.

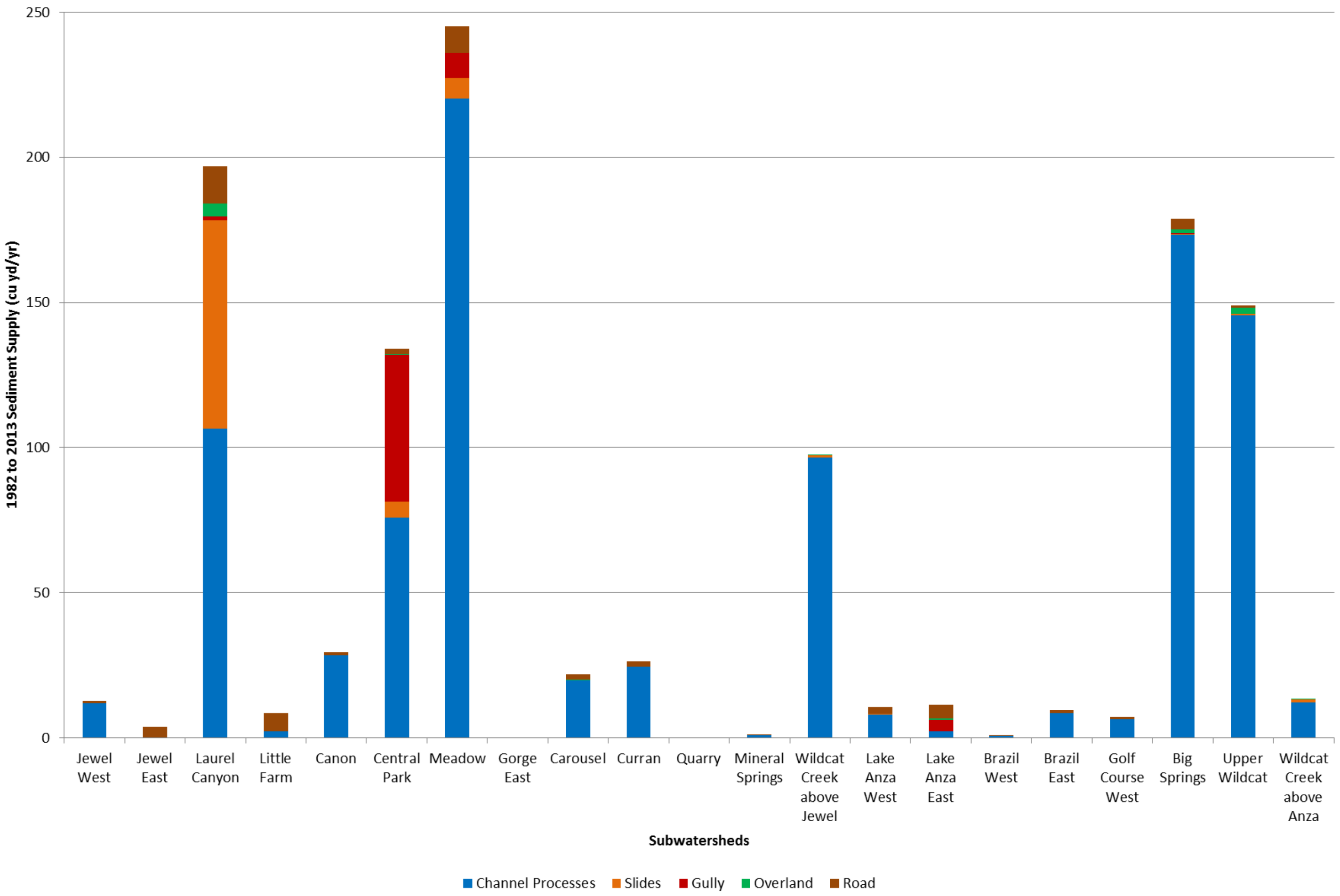


Figure 19: Short-term sediment supply rates by category for each subwatershed in the study area.

Table 9: Sediment supply rates for each subwatershed by categories for each subwatershed.

Units	1982 to 2013 Total Short-term Sediment Supply Rate by Source Yd^3 / yr					
Subwatershed	**Channel Processes**	**Slides**	**Gully**	**Overland**	**Roads and Trails**	**Subtotal**
Jewel West	11.9	0.0	0.0	0.0	0.8	12.7
Jewel East	0.0	0.0	0.0	0.0	3.9	3.9
Laurel Canyon	106.5	71.9	1.3	4.5	12.8	197.0
Little Farm	2.1	0.0	0.0	0.0	6.5	8.7
Canon	28.4	0.0	0.0	0.0	1.1	29.5
Central Park	75.9	5.6	50.6	0.1	2.0	134.1
Meadow	220.3	7.0	8.6	0.0	9.0	245.2
Gorge East	0.0	0.0	0.0	0.0	0.2	0.2
Carousel	19.9	0.0	0.0	0.0	2.0	22.0
Curran	24.6	0.0	0.0	0.0	1.8	26.4
Quarry	0.0	0.0	0.0	0.0	0.0	0.0
Mineral Springs	0.9	0.0	0.0	0.0	0.0	0.9
Wildcat Creek above Jewel	106.3	0.7	0.0	0.3	0.0	107.3
Lower Watershed (Jewel to Anza)	597.0	85.2	60.5	4.9	40.2	787.8
Percent	75.8%	10.8%	7.7%	0.6%	5.1%	100.0%
Lake Anza West	7.9	0.4	0.0	0.0	2.3	10.5
Lake Anza East	2.2	0.0	3.9	0.5	4.8	11.5
Brazil West	0.7	0.0	0.0	0.0	0.1	0.8
Brazil East	8.6	0.0	0.0	0.0	0.9	9.6
Gold Course	6.6	0.0	0.0	0.0	0.7	7.4
Big Springs	174.0	0.2	0.4	1.2	3.8	179.5
Upper Wildcat	153.8	0.7	0.0	1.9	0.9	157.5
Wildcat Creek above Anza	12.3	0.9	0.0	0.1	0.0	13.2
Upper Watershed (Upstream of Anza)	366.2	2.1	4.3	3.7	13.6	390.0
Percent	93.8%	0.6%	1.1%	1.0%	3.6%	100.0%
Study Area Total	970.6	87.3	64.8	8.6	53.9	1185.2
Study Area Total Percent	81.9%	7.4%	5.5%	0.7%	4.5%	100.0%

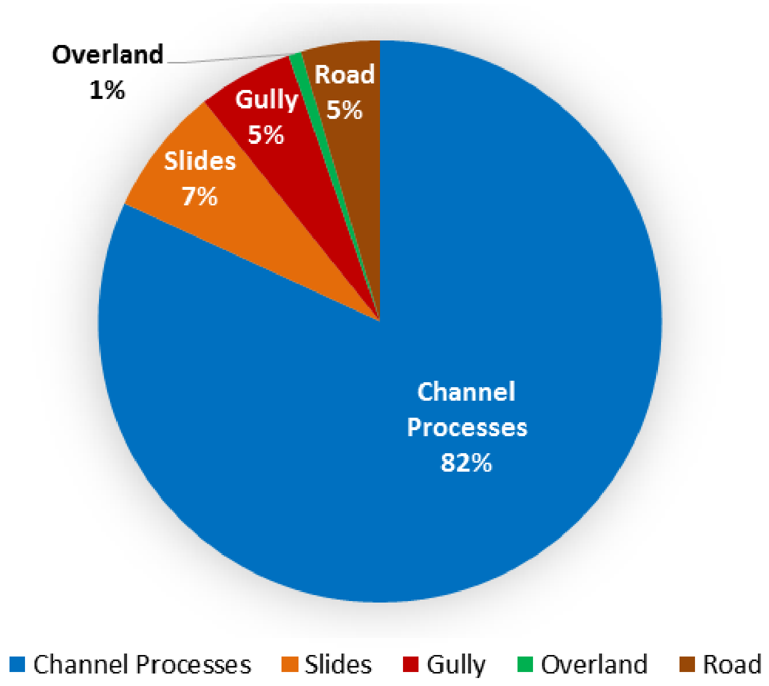


Figure 20: Percentage of short-term sediment supply rates by category for the study area for the period 1982 to 2013.

Watershed Scale Management

From a management perspective, targeted maintenance can reduce the amount of sediment contributed from a small number of erosion sites that have a large impact on individual subwatersheds. However, the largest contributors of sediment are channel processes that require a watershed scale approach to reduce runoff and cooperation with private landowners and municipalities outside of the East Bay Regional Park District's jurisdiction.

Jewel Lake Sedimentation

Jewel Lake and Lake Anza are sediment traps that capture the bedload and likely a high percentage of the suspended sediment load. Since Lake Anza captures the majority of the total upstream sediment load and has a much larger storage capacity than Jewel Lake, deposition rates in Jewel Lake can be estimated from sediment erosion rates for the subwatersheds upstream of Jewel Lake Dam to Lake Anza Dam. Short-term sediment supply rates from channels and adjacent hillsides and roads and trails are presented for each subwatershed (Figure 22) along with percentage of short-term sediment supply contributed by each process for the entire watershed from Jewel Lake Dam to the Lake Anza Dam (Figure 23). Channel processes account for 76% of the Short-term sediment supply, with slides, gullies, roads, and overland respectively accounting for 11%, 8%, 5%, and less than 0.5%. Compared to the entire study area, the lower watershed shows an increased contribution from slides and gullies and decreased contribution from channel incision and bank erosion. This change in short-term sediment supply rates shows the increased impact from gullies downstream of stormwater outfalls and roads. Many factors may influence this change including the number of culverts and the underlying change in geology. Another contributing factor may include the steepness of the slopes that homes have been built on and road network in the urbanized portion of the lower watershed.

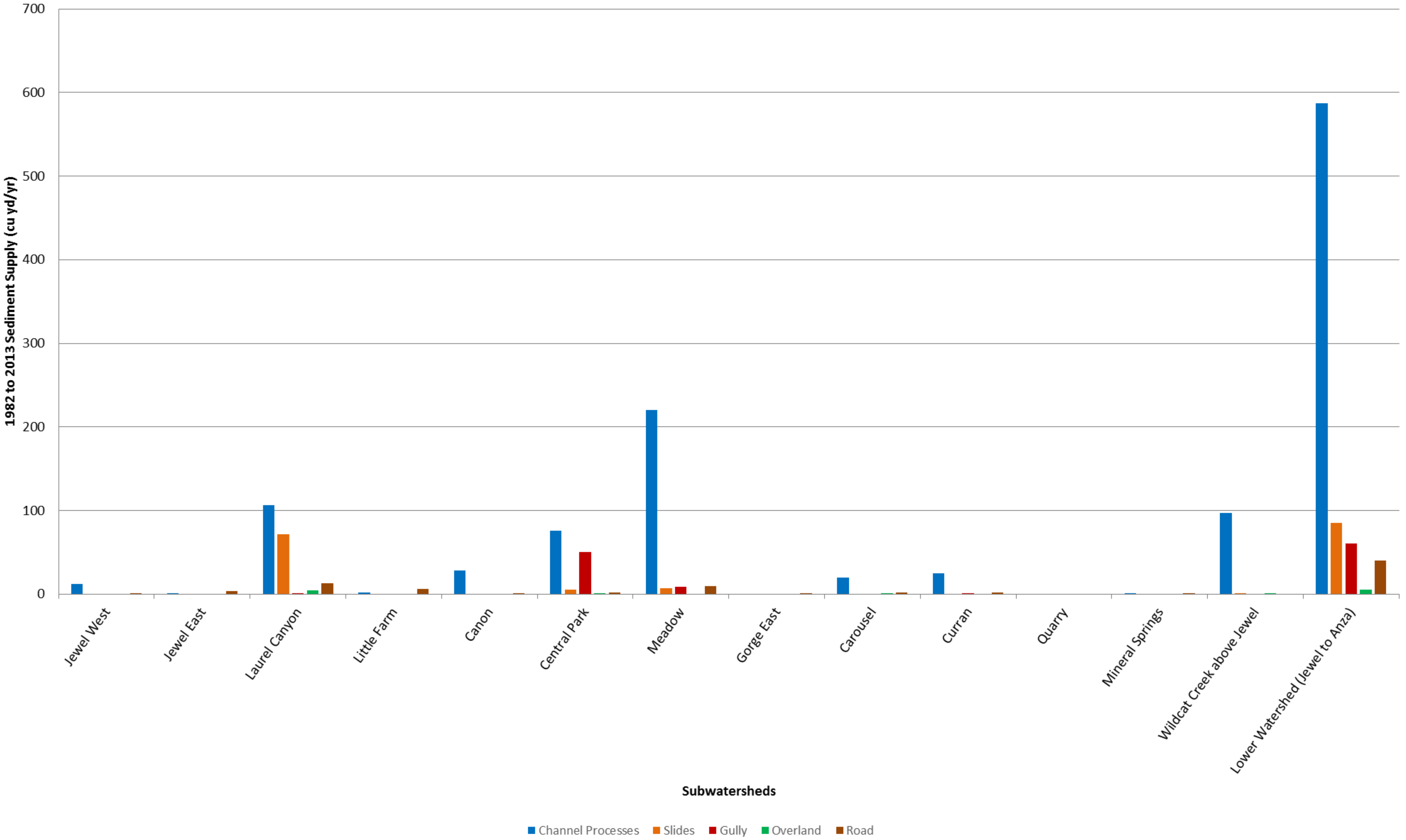


Figure 21: Short-term sediment supply rates by category for each subwatershed upstream of Jewel Lake Dam to Lake Anza Dam.

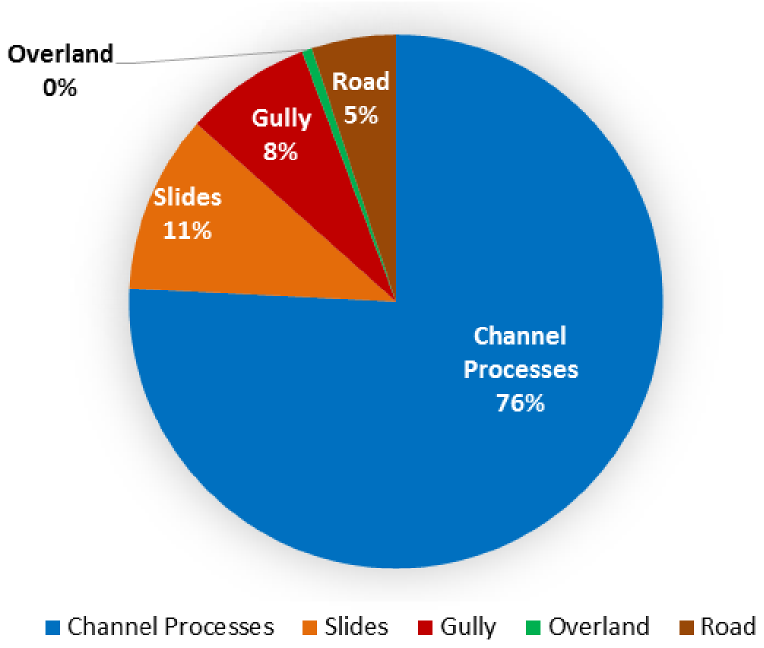


Figure 22: Percentage of short-term sediment supply rates by category for the study area for the period 1982 to 2013 from Jewel Lake Dam to Lake Anza Dam.

6. Erosion Control Alternatives

FlowWest summarized existing conditions (Sections 1, 2, and 4), conducted stakeholder outreach (Section 3), and conducted a sediment analysis (Section 5) to guide development of alternatives for erosion control and sediment management. In addition to these analyses, FlowWest reviewed EBRPD's map of potential problem areas for erosion and sedimentation in the watershed. Using the information collected, we developed the following specific sediment management and erosion control alternatives for the project area:

- Dredge Jewel Lake
- Reconnect Wildcat Creek (bypass Jewel Lake) to restore sediment continuity and fish passage
- Stabilize gullies initiated at stormwater outfalls
- Construct additional sediment detention basins
- Re-grade dirt roads
- Install permeable parking areas and Implement Low Impact Development (LID) treatments
- Excavate multi-stage channels for sediment deposition and floodplain restoration
- Install check dams to stabilize tributaries to Wildcat Creek

If implemented, these alternatives have the potential to incorporate recreational and educational components that would increase opportunities for naturalists and teachers to use sediment management actions, habitat restoration, and enhancement actions as educational resources.

The following section summarizes the development of alternatives to a sufficient degree to allow evaluation of their technical feasibility, effectiveness, and constructability. FlowWest conducted planning-scale assessments of hydrology, hydraulics, and sediment transport dynamics for each alternative to determine associated sediment reduction and anticipated ecological improvement. FlowWest also estimated the permitting level of effort and construction cost of each alternative. These analyses allowed us to assess potential opportunities and constraints as a basis for recommending preferred alternatives (Section 7).

FlowWest estimated costs to construct each alternative based on the cost for excavation, hauling, and revegetation. These costs do not include the cost of design or contingencies, but were systematically developed for each alternative as a means of comparison. As we developed each alternative, we made the following assumptions:

- No presence of species requiring Endangered Species Act (ESA) or California Endangered Species Act (CESA) protection
- No affects to historic properties
- No National Environmental Policy Act (NEPA) requirements due to lack of federal nexus (funding)
- No significant impacts under the California Environmental Quality Act (CEQA) and all alternatives will be justified under an existing Environmental Impact Report (EIR) or will be covered under a Categorical Exemption or Initial Study/Negative Declaration

At the end of this section we summarized the key attributes of each alternative into a matrix that we used in Section 7 to prioritize and recommend alternatives for implementation.

The descriptions of each alternative include:

- Descriptions of the erosion control or sediment management alternative
- Conceptual renderings, example graphics, diagrams, and location maps
- Estimated construction and permitting costs
- Estimated reductions in the amount of sediment for each alternative
- Assessments of habitat improvements or impacts

Dredge Jewel Lake

Jewel Lake's original capacity was 44,560 yds^3 after construction in 1921, and historical maps show that a significant portion of the lake filled in before construction of Lake Anza in 1938. Jewel Lake was dredged in 1967 and 1991, removing 9,450 yds^3 and 10,404 yds^3 of material, respectively. The survey we conducted for this study showed a capacity of 4,322 yds^3 (Section 4). At this capacity, the lake can no longer support Sacramento Perch, leading EBRPD to rescue the remaining perch during the late summer 2014. This proposed sediment management action will restore the capacity of Jewel Lake to its 1991 capacity by dredging 10,000 yds^3 of material. This will require an 8-12 inch suction dredge and temporary storage of material onsite for dewatering before hauling to Livermore or Fairfield for offsite disposal. Re-use of dredge material onsite will provide a significant cost savings. Based on past dredging volumes and the estimated sedimentation supply rate (653 yds^3/yr, Section 5), Jewel Lake will need to be again in approximately 20 years.

Figure 23: 1991 dredging of Jewel Lake (photograph from Collins et al. 2001).

In terms of existing habitat in Jewel Lake, dredging will significantly disturb habitat and alter the existing ecosystem in Jewel Lake. Resident fish will need to be captured and relocated during the dredging operation. A settling pond will be required to remove suspended sediment from the hydraulic dredge slurry, and vegetation will need to be replanted in disturbed areas.

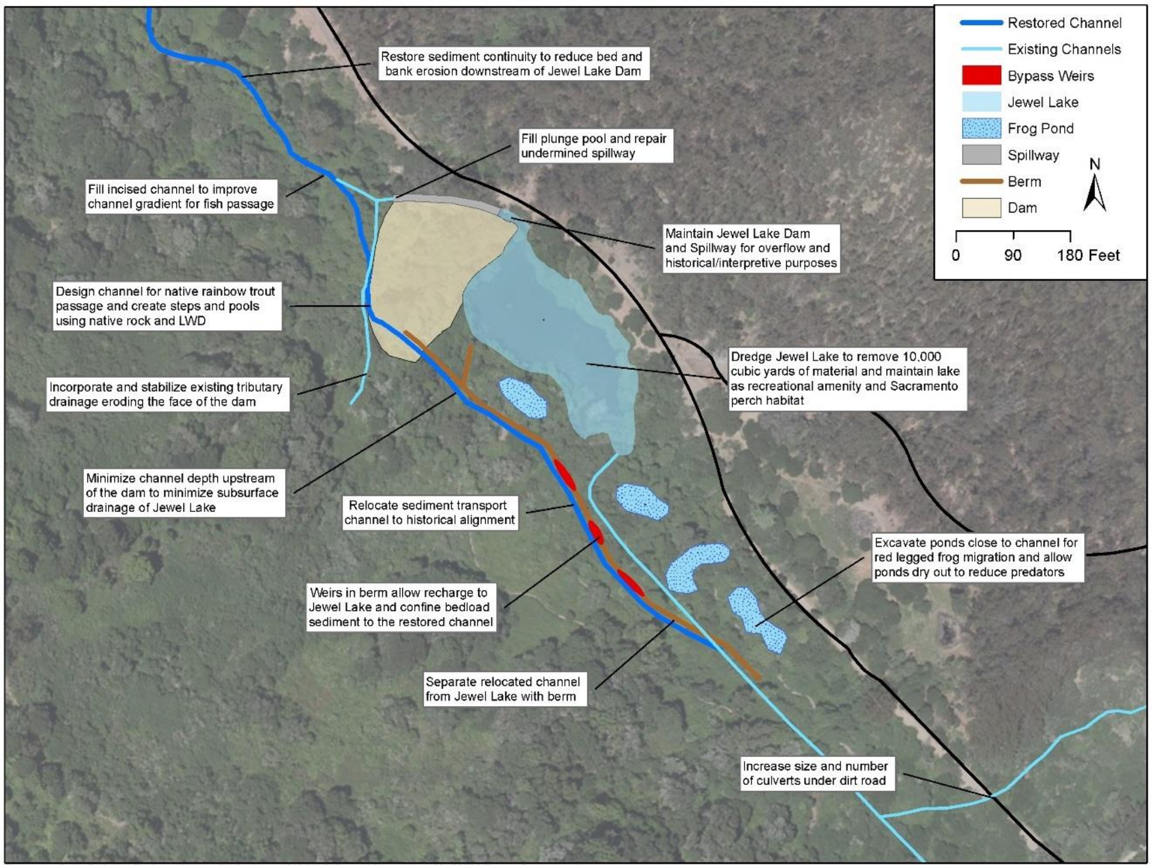
FlowWest estimated that the cost of dredging and offsite disposal of dredge material in Fairfield or Livermore at $312,000 and $520,000, respectively. Obtaining permits for dredging has become more difficult as agencies look for other methods to manage sediment that reduce the impact on aquatic environments. FlowWest estimates that this project will require a Clean Water Act (CWA) Section 404 general permit for dredging and a California Department of Fish and Wildlife (CDFW) Lake or Streambed Alteration Agreement, Section 1600 at a total cost of about $150,000, including studies.

With respect to long-term maintenance, repeat dredging will be required every 20 years to maintain Jewel Lake's depth and capacity for Sacramento perch and as a recreational amenity. In addition, the Jewel Lake Dam and Spillway will require improvements in the future. Currently, the spillway is perched over 15 ft above the channel bed (Figure 25), and the base of the spillway is likely to collapse and possibly undermine the dam. Repair of the downstream extent of the Jewel Lake Spillway was not included the cost estimate for this alternative, but will likely need to be addressed before the lake is dredged again. In addition, a deep gully on the west face of the dam has form and will need to be repair.

Figure 24: Downstream extent of the undermined Jewel Lake Spillway.

Reconnect Wildcat Creek (Bypass Jewel Lake) to Restore Sediment Continuity and Fish Passage

The alternative to reconnect Wildcat Creek by bypassing Jewel Lake with a restored channel will restore sediment continuity upstream and downstream of Jewel Lake and provide fish passage for native rainbow trout and other species. Additional components of this alternative include creation of habitat ponds for red-legged frogs, dredging 10,400 yds^3 of material from Jewel Lake to maintain recreational uses and Sacramento perch habitat, and installation of additional culverts for Laurel Creek under the fire road to Jewel Lake. The Jewel Lake dam and spillway will be preserved for historical and educational purposes, and the undermined spillway will be repaired under this alternative. Key components of this alternative are presented in Figure 26 and Figure 27. Restoration of sediment continuity likely will reduce downstream bed incision, downstream bank erosion, sediment delivery to the lower watershed, and sediment delivery to Jewel Lake. This alternative will also restore the alignment of Wildcat Creek to its historical location on the west side of Wildcat Canyon. Excavation of the sediment transport channel will be limited adjacent to Jewel Lake to prevent subsurface drainage from Jewel Lake to the restored channel. The proposed channel will extend downstream and will fill the existing incised channel to create a channel gradient suitable for fish passage. Adjustable weirs will be used to provide flows to Jewel Lake and the newly constructed frog habitat ponds located on the Laurel Canyon and Jewel Lake sediment deltas. The ponds will be designed to go seasonally dry—a condition suitable for native red-legged frogs, but not suitable for invasive bull frog predators. The locations of ponds were chosen to allow red-legged frog migration to the restored Wildcat Creek channel during dry periods and to take advantage of shade from the existing riparian forest to limit cattail growth. Rock vanes and LWD used to create steps and pools along the restored channel will contribute to channel stability and act as grade control for the restored channel. Bioengineering techniques including willow plantings to stabilize the channel banks will be used whenever possible.



Document Path: E:\Active Projects\Wildcat CK Sediment\GIS\MXD\Report\Alternatives\20150720 BypassDesign.mxd

Figure 25: Key components of the alternative to reconnect Wildcat Creek and bypass Jewel Lake.

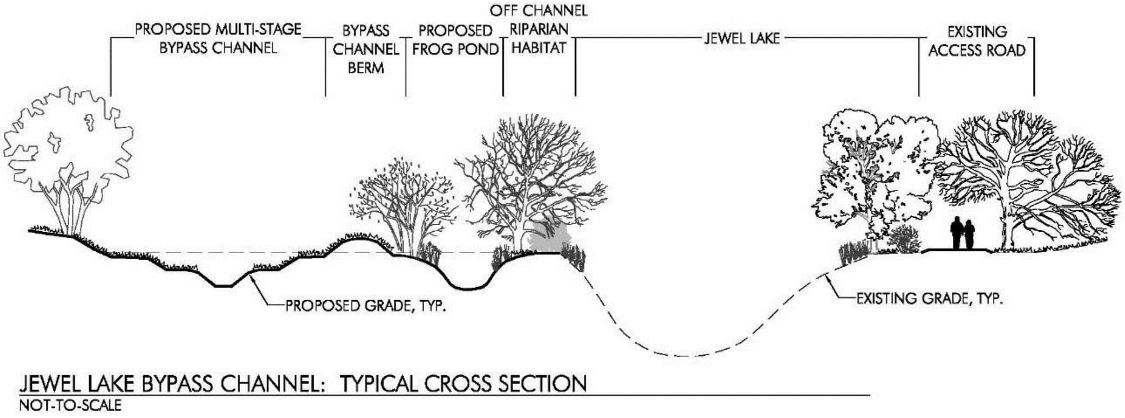


Figure 26: Cross section illustration of the reconnect Wildcat Creek and bypass Jewel Lake alternative showing the restored Wildcat Creek sediment transport channel, the separation berm, frog ponds, dredged Jewel Lake and existing access road to Jewel Lake.

Habitat impacts during construction will likely be significant; however, after project completion, there will be no impacts for the 100-year life of the project and the environmental benefits will be greater as compared to many of the other alternatives. Restoration of Wildcat Creek will remove a barrier to native fish species and increase the amount of usable habitat upstream of Jewel Lake. If the remaining downstream barriers to salmonids are removed, fish passage around Jewel Lake could restore salmonid access to Tilden Regional Park.

Under this alternative, the lake will not need to be dredged again for the 100-year life of the project because sediment delivery will be reduced by 653 yds^3/yr (Section 4). Cut material will be used on site to build up the incised downstream channel (Figure 28). FlowWest estimated the cost of this project to be $1,577,500, including $520,000 to dredge Jewel Lake. This cost estimate was based predominantly on excavation, revegetation, dredging, and fish passage structure construction. The total cost of the project may be up to two times more than this estimate once design and supporting studies are included.

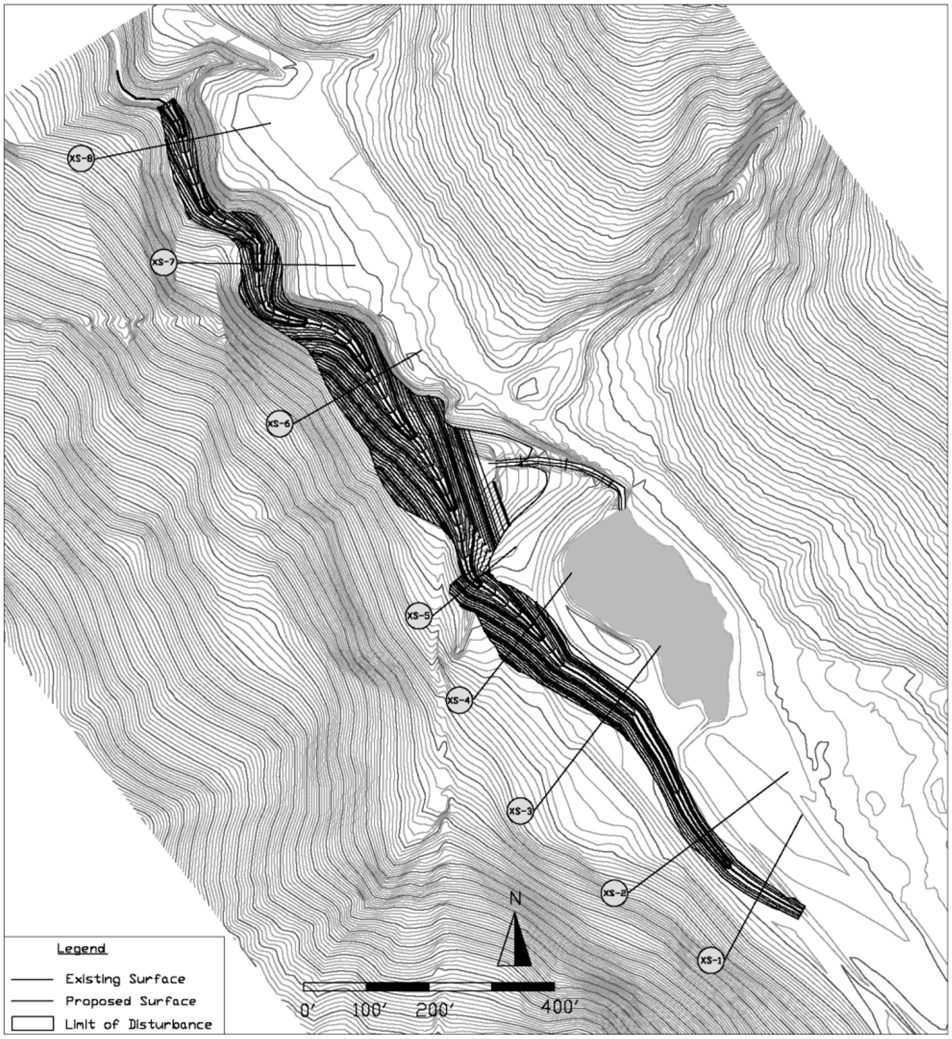


Figure 27: Conceptual grading plan for the Jewel Lake bypass alternative.

This alternative will require a CWA Section 404 general permit, CWA Section 401 for protection of water quality for dewatering and discharge, a Stormwater Pollution Plan (SWPP), and a California Department of Fish and Wildlife Lake or Streambed Alteration Agreement, Section 1600 permit. FlowWest estimated that the permitting cost for this project will be approximately $300,000 for analysis and preparation of the permits. With respect to long-term maintenance, the restored Wildcat channel will be designed to be self-sustaining. As with most restoration projects, some maintenance will likely be required to adaptively manage the project and a monitoring plan should be built into future project funding. Maintenance likely will be greatest immediately following construction and before riparian vegetation has been established.

Stabilize Gullies Initiated at Stormwater Runoff Outfalls

In the suburban portion of the watershed (crest of the western canyon) runoff has been concentrated into stormwater outfalls from the road network, impervious areas, and plastic drainage pipes from residences (Figure 29).

Figure 28: Plastic pipe transporting runoff from a residential gutter directly into the stormwater drainage system along Wildcat Canyon Road.

The stormwater system collects runoff from paved roads and impervious suburban areas and discharges runoff onto EBRPD property at outfalls along Wildcat Road. Concentration of flow at some outfalls has resulted in substantial erosion and, in one location, a massive gully that has undermined mature redwood trees and required re-routing of a trail (Figure 30).

Figure 29: Gully downstream of stormwater outfall along Wildcat Canyon Road that has toppled mature redwood trees and contributes 40 yds^3/yr of sediment to Wildcat Creek.

Field reconnaissance identified over 27 stormwater outfalls along Wildcat Canyon Road. The gully illustrated in Figure 30 was the largest that originated from a stormwater outfall along Wildcat Canyon Road that we observed, and shows the potential sediment contribution from unstable stormwater outfalls. FlowWest identified potential stormwater outfall stabilization techniques to disperse residential runoff downstream of stormwater outfalls shown in Figure 31. These techniques include different methods to disperse and infiltrate stormwater. Many stormwater outfalls along Wildcat Canyon Road are open pipes that discharge onto unprotected soil. The first technique installs diffusers on the end of outfall pipes to slow and spread stormwater over a large area. Diffuser pipes should discharge into a pad of rock of various sizes to slow stormwater velocity and dissipate energy. The rock bed should be placed on top of geotextile fabric with an aggregate base. Larger rocks should be supported in a gravel matrix to fill void spaces near the diffuser pipe, and rock sizes should decrease to gravel with distance from the outfall. Where suitable, a diffuser trench should be installed along the contour of the slope to infiltrate stormwater. On active slides where infiltration of stormwater could reactive a slide, coir rolls should be placed along the contour of the slope to diffuse stormwater over a larger area instead of infiltration trenches. We estimate the project life for these techniques at 20 years and potentially longer for low discharge stormwater outfalls.

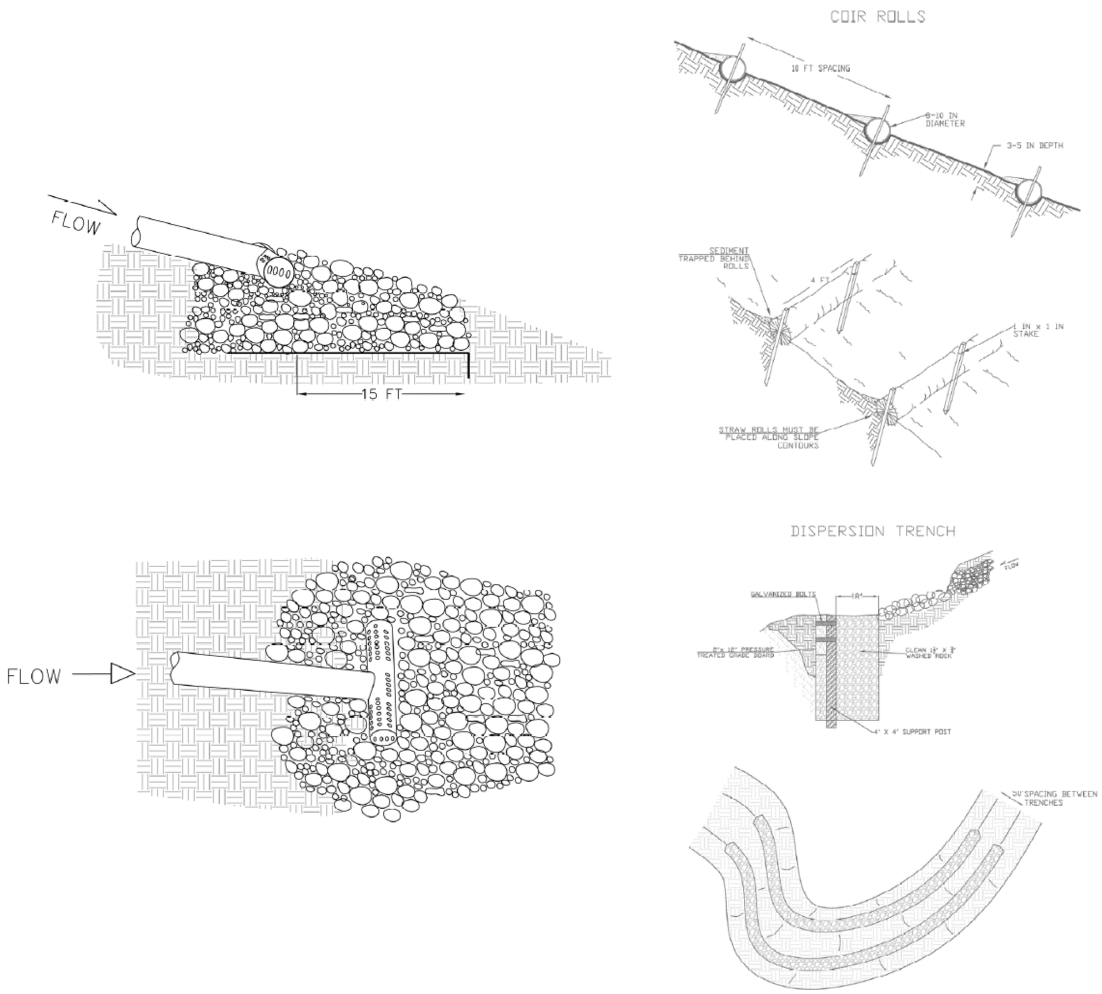


Figure 30: Stormwater outfall diffusion and infiltration methods.

FlowWest estimated the cost to stabilize one stormwater outfall at $14,500. Treatment for the 27 stormwater outfalls identified will cost $397,500 and could reduce the short-term sediment supply rate by up to 40 yds^3/yr for each outfall location. Flow dispersion structures will also require annual monitoring to identify clogged outlets, scour at the stormwater outfall, undermining, and concentration of flow. In terms of permits, the level of effort required is generally low for these types of projects. Likely, the permitting effort will consist of coordination with the City of Berkeley Department of Public Works and the Contra Costa County Flood Control and Water Conservation District. We expect coordination costs to range from $10,000 to $30,000.

Construct Additional Sediment Detention Basins

There are currently three sediment basins in Tilden Regional Park that are currently full with sediment since routine maintenance to empty the sediment basins has lapsed. EBRPD is currently working to obtain necessary permits to restart the maintenance program to remove sediment from the detention basins. This alternative will install additional sediment detention basins in the watershed on alluvial fans of tributaries to Wildcat Creek with easy road access (Figure 32).

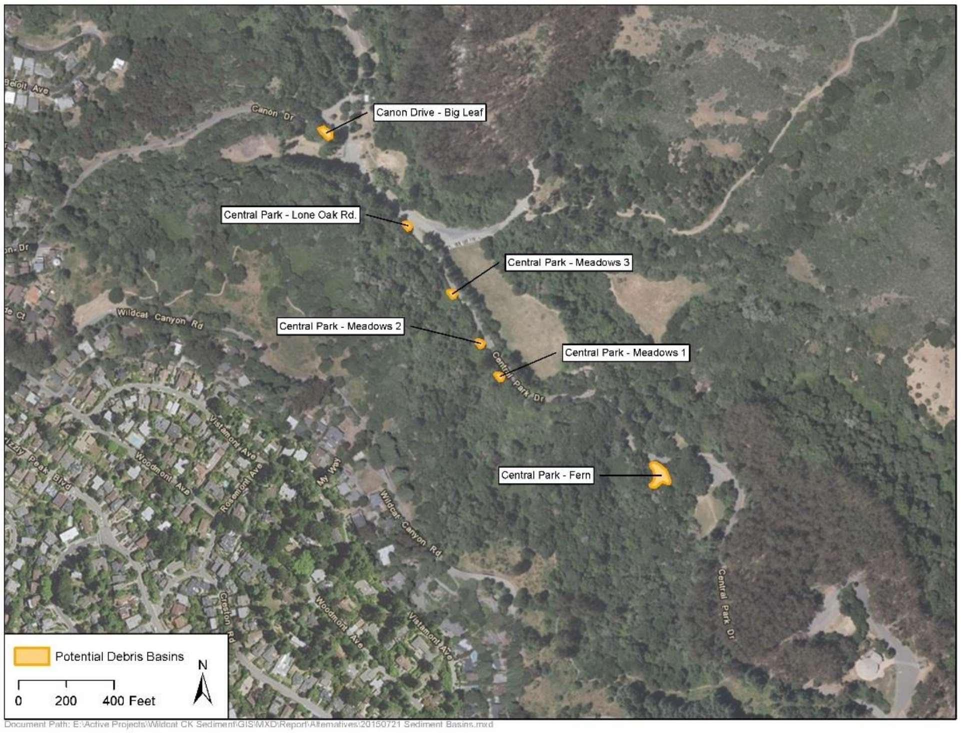


Figure 31: Potential location of six additional sediment basins with a total capacity of 761 yds^3.

FlowWest proposed sediment basin locations based on low channel gradient and ease of access for annual maintenance. Table 11 lists the upstream sediment yields and capacities of each proposed sediment basin. The Central Park – Fern sediment basin includes the large gully from the stormwater outfall in Figure 30 that has a short-term sediment supply rate of 40 yds^3/yr. The Fern sediment basin will capture sediment from two tributaries that experience high sediment loads from residential runoff. The other proposed sediment basins are much smaller, but will cumulatively capture high short-term sediment supply rates (40 yds^3/yr) from the residential area on the western canyon. Sediment basins should be designed to capture at least five times the estimated short-term sediment supply rate.

Table 10: Potential sediment basin capacities.

Subwatershed	Short-term Sediment Supply Rate Upstream of Sediment Basin (yds^3/yr)	Design Capacity (yds^3)
Central Park – Fern	112	558
Central Park – Meadows 1	5	23
Central Park – Meadows 2	3	17
Central Park – Meadows 3	3	17
Central Park – Lone Oak Rd.	3	16
Canon Drive – Big Leaf	26	131
Total	152	761

FlowWest estimated the initial construction cost at $50,500 based on the cost of excavation for the four proposed sediment basins. In addition, maintenance will require periodic excavation and hauling of the sediment trapped in the sediment basin. We estimated excavation, hauling, and disposal to cost up to $20,000 each time the sediment basins are emptied. Permitting for the new sediment basins will likely take longer and be more complicated than other alternatives. Annual maintenance should be included in the permits that authorize removal of sediment in the basins. Permits needed for construction and maintenance of additional sediment basins are expected to include CWA Section 404, CWA 401 permit for dewatering, SWPP for construction and maintenance, CDFW Streambed Alteration Agreement, Section 1600 for both construction and maintenance, and possible consultation with the California Department of Water Resources. We estimated permitting and supporting studies costs at $75,000 for construction and maintenance of the sediment basin.

Construction and maintenance of sediment basins will potentially result in significant environmental impacts. Construction of sediment basins will remove existing upland/floodplain habitat and act as barriers for migration for aquatic species between Wildcat Creek and the tributaries with the sediment basins. Additionally, mechanical excavation of sediment basins will regularly eliminate habitat that likely will establish in the sediment basins between maintenance activities. Under this alternative, we recommend empting sediment basins every year to keep the maximum capacity available in the sediment basin for large precipitation events.

Re-grade Dirt Roads

Based on field observations, dirt roads in the project watershed have been regularly maintained and were generally in good condition. However, many dirt roads in the project watershed were designed to consolidate runoff in inboard ditches and to pipe that run under the dirt road and then discharge to the outside slope. This results in erosion of the toe of the road cut and gully formation at the culvert outfall. This alternative recommends re-grading dirt roads throughout the project area, where feasible, to slope towards the outside of the road (Figure 33), installation of filter strips along outside edge of dirt roads to distribute runoff, and installation of additional culverts to reduce the length of inboard ditches in locations where road slope adjustment are not feasible. Typically filter strips are installed at the edge of an outward sloped road to capture fine sediment eroded from the road bed and slow the velocity of overland flow.

Figure 32: Example of an outside sloped road (Photo R. Harris in Kocher et al., 2007).

There are over fifteen miles of dirt roads in the watershed upstream of the Jewel Lake Dam (Figure 34). We estimated the cost of re-grading dirt roads at $22,500. In the sediment analysis (Section 5), we estimated that the short-term sediment supply rate from dirt roads was 24 yds^3/yr. We expect that only a CWA Section 401 and preparation of a Stormwater Pollution Protection Plan during construction will be required for dirt road re-grading. Permit costs are expected to be less than $10,000. Re-grading roads will not only reduce the amount of fine sediment in tributaries and the mainstem Wildcat Creek, but will also decrease annual maintenance due to the reduced number of culverts that would need sediment and debris removed.

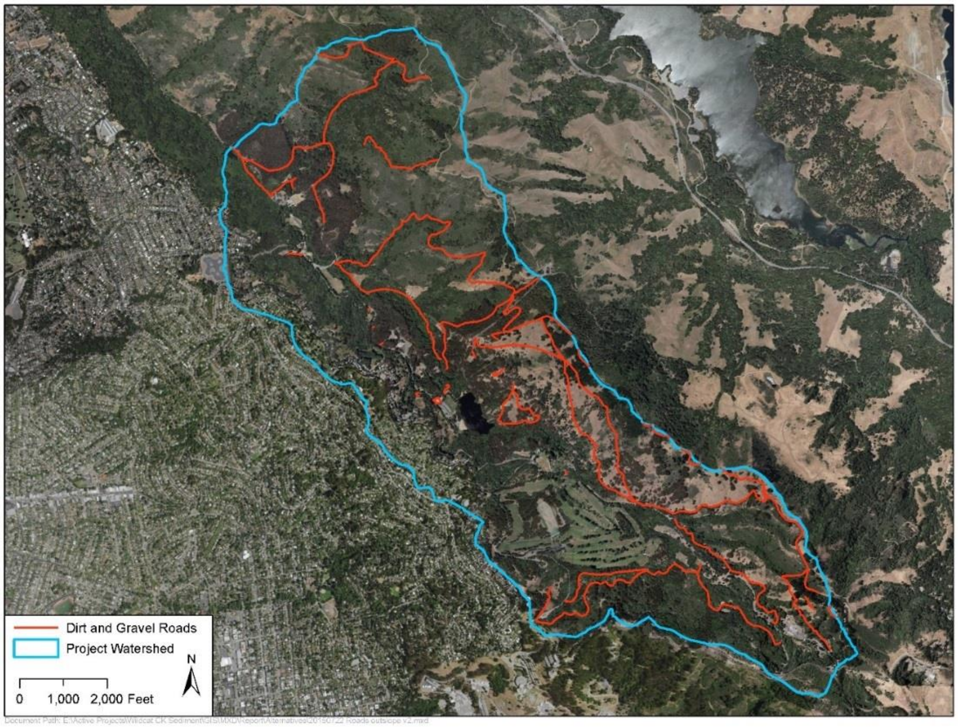
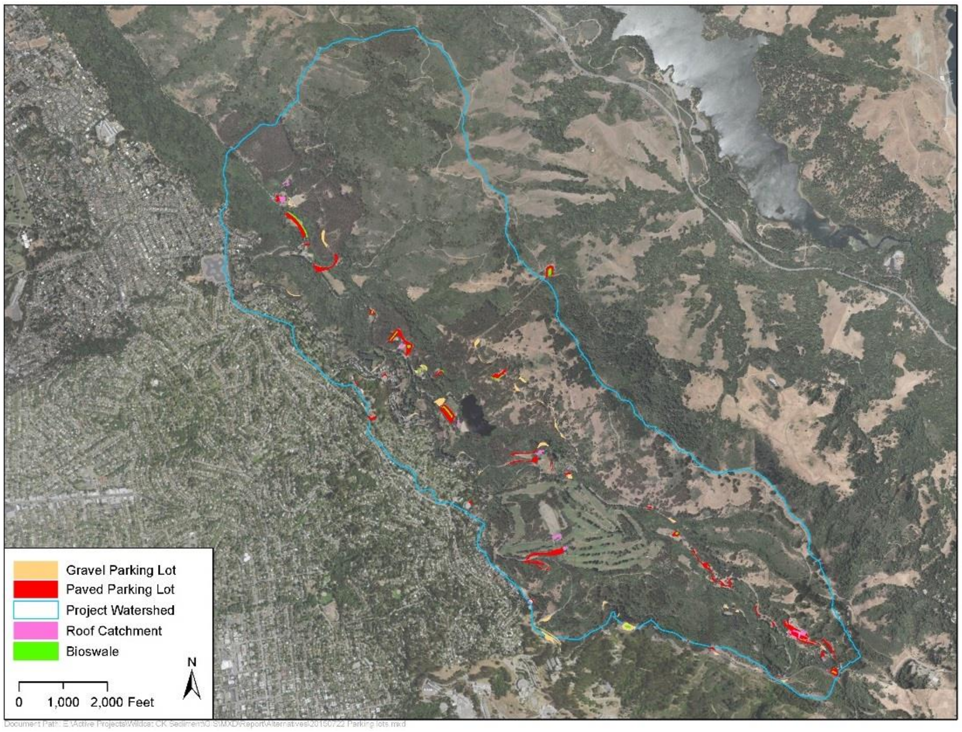


Figure 33: There are over 15 miles of dirt roads shown in red within the watershed upstream of Jewel Lake Dam.

Install Permeable Parking Areas and Implement LID Treatments

Most of Tilden Region Park is classified as undeveloped grassland and woodland (Section 1), but as a recreation destination, there are over 25 acres of parking lots in the park and 26 EBRPD buildings. These parking lots and facilities contribute runoff to Wildcat Creek and tributaries and increase the peak discharge in the creeks, contributing to channel incision and bank erosion. Many of the parking lots are located adjacent to Wildcat Creek. This alternative will replace paved parking areas with permeable pavement, install bioswales in or adjacent to parking lots, and install 2,500 gallon galvanized steel rainwater cisterns at the 26 EBRPD facilities to reduce peak runoff (Figure 35). When combined with interpretive signs, these LID actions will provide stormwater educational opportunities for park users. Permeable parking areas and bioswales will allow more precipitation to infiltrate into the ground instead of contributing to direct runoff into Wildcat Creek. In areas with heavy clay soil, the native soil will need to be excavated and replaced with more permeable soil. Runoff from parking lots will be collected in bioswales to further reduce the peak discharge and filter pollutants. Lastly, rainwater cisterns will retain runoff from roofs on EBRPD facilities for irrigation or maintenance uses. The largest area of impermeable surface in the project watershed is located in the suburban area of the watershed on private property. Although significant opportunities exist in the suburban area to reduce stormwater discharge onto EBRPD property, EBRPD doesn't have jurisdiction over these properties, and they were not included in this analysis.

Habitat improvements from this alternative include reduction of the amount of fine sediment and reduction of peak discharge in Wildcat Creek. Improving water quality by reducing fine sediment and filtering of road and parking lot related pollutants will improve habitat for aquatic species. Additionally, the decrease in peak discharge will reduce the amount of channel incision and bank erosion, which will decrease turbidity and reduce simplification of in channel habitat.



Document Path: E:\Active Projects\Wildcat CK Sediment\GIS\MXD\Report\Alternatives\20160722 Parking lots.mxd

Figure 34: Location of the parking lots, bioswales, and roof areas for stormwater cisterns.

We estimated that implementing this alternative will reduce the short-term sediment supply rate by 17 yds^3/yr. We estimated this rate by multiplying the total watershed short-term sediment supply rate by the percentage of the watershed area covered by parking lots and EBRPD buildings. We estimated the cost for rainwater cisterns will cost \$54,500, replacement of paved parking lots to permeable parking lots will cost \$4,324,500, replacement of gravel parking lots to the permeable parking lots will cost \$1,496,000, and construction of bioswales will cost \$1,863,000. In total this alternative will cost over \$7,738,000 to implement. In terms of permitting, the level of effort will be low, and the cost will be under \$20,000. Maintenance will include cleaning out sediment and garbage in swales, repair of pervious pavement areas, and annual draining of rainwater cisterns.

Excavate Multi-stage Channels for Sediment Deposition and Floodplain Restoration

Incision in Wildcat Creek has eliminated the connection to the floodplain as documented in Collins et al. (2001) and noted in field observations conducted for this study in most reaches. Channel incision is a common channel response to land use changes, and excavation of a multi-stage channel is an often-used solution to restore floodplain connection and stop channel incision. However, multi-stage channels were likely uncommon in Wildcat Creek in the project area due to the narrow confinement of the channel by steep canyon walls. Therefore, this alternative is applicable to limited reaches where the channel is not confined by steep valley slopes. FlowWest identified one suitable site for excavation of a 1,000 foot multi-stage channel in the reach between Lone Oak Road and the Stream and Nook picnic sites. Figure 36 illustrates the multi-stage channel concept showing excavation of a floodplain bench to dissipate energy from high flow events.

This alternative will likely have a significant impact to the existing riparian habitat. Initial excavation and grading of the floodplain will remove existing riparian vegetation. Channel reconnection to the floodplain will reduce channel incision and bank erosion by decreasing the forces operating on the active channel. The reconnected floodplain will also provide high flow refuge for aquatic species and capture fine sediment.

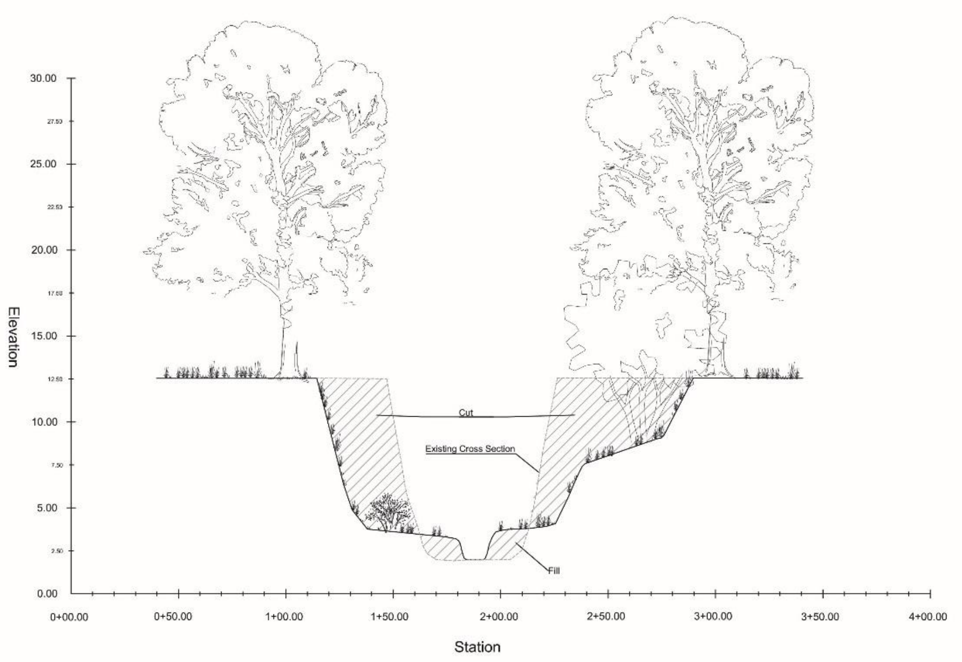


Figure 35: Excavation of the multi-stage channel to restore connection between incised channel and floodplain to reduce channel incision and bank erosion.

We estimated that excavation and revegetation of the 1,000-foot reach of incised channel will cost $382,500 and require a high level of effort to obtain permits. Permits needed will include CWA 404, CWA 401 for dewatering of the channel during construction with a SWPPP during construction, and CDFW Streambed Alteration Agreement, Section 1600. Costs to obtain these permits and the supporting studies will likely exceed $100,000. Using the results from the sediment analysis (Section 5) we estimated that channel restoration in this reach could reduce short-term sediment supply rate by 24 yds^3/yr. Maintenance of the restored channel should be minimal once the replanted riparian vegetation is established. Depending on vegetation requirements, irrigation and weeding may be required for the first five years. Post-project monitoring should be conducted to evaluate channel stability after high flow events.

Install Check Dams to Stabilize Tributaries to Wildcat Creek

Incision in Wildcat Creek has lowered the base level for tributaries in the watershed and incision has migrated up tributary channels. Proposed tributary stabilization methods will use rock and LWD steps to control the grade in the tributaries. Step height will be limited to 1.5 ft to reduce the potential for undermining the structure from scour, and steps will be keyed into the bank to prevent failure from erosion of the banks. Figure 37 illustrates typically grade control structures. To limit scour the base of the steps will be armored with rock and planted with willow stakes to dissipate energy and stabilize the bed of the tributary.

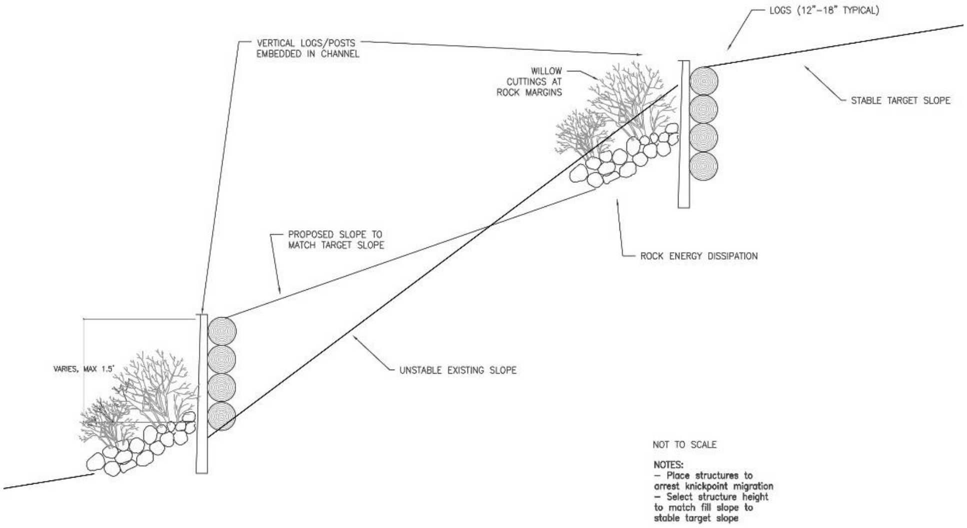


Figure 36: Conceptual design for grade control structures to stabilize tributaries that have incised in response to channel incision in Wildcat Creek.

We estimated the construction cost to stabilize 20 tributaries to be $125,000. Permits needed for this alternative will include CWA 404, CWA 401 for dewatering of the channel during construction with a SWPPP during construction, and CDFW Streambed Alteration Agreement, Section 1600. Costs to obtain these permits and the supporting studies will likely exceed $75,000. Using the results from the sediment analysis (Section 5), we estimate that channel stabilization in this reach will reduce the short-term sediment supply rate by 6 yds^3/yr. Stabilization of tributaries will improve habitat by decreasing tributary incision and turbidity. Although steps at grade control structures will be limited to 1.5 ft, they will act as fish passage barriers. Grade control structures are often viewed as short-term solutions because steps often cause scour that undermines the structure. Therefore, monitoring of the structures will be required to identify scour and undermining.

Summary of Costs of Erosion Control Alternatives

To quantify the cost and short-term sediment supply benefits of each of the alternatives, we summarized key metrics from the previous discussion in Table 12. Key metrics included: effective period, costs, permitting, and the reduction in the short-term sediment supply rate. The effective period (e.g., the estimated project life) provides an estimate time period before major maintenance or replacement is expected. A 100-year project life was used as a maximum value for self-sustaining projects. Although, we expect channel restoration projects will function as designed without maintenance for more than 100 years, unforeseen watershed and climate changes could significantly alter the hydrology and sediment dynamics in the watershed leading to maintenance requirements. We estimated the raw cost based on key construction components to allow systematic comparison of all alternatives across a wide range of project types. As stated before, the raw cost was based on conceptual-level construction designs and is expected to be less than the final project cost. We estimated the permitting and resource studies cost to gage the level of effort between different erosion control alternatives. FlowWest estimated the cost per year of each alternative by dividing the total cost (raw plus permitting cost) by the effect period. Next, we summarized the reduction of the short-term sediment supply rate or amount of sediment captured by each of the different alternatives. Lastly, we divided the total cost per year by the short-term sediment supply rate to estimate the cost per cubic yard of sediment reduced or captured. This allowed for a comparison of the cost efficiency for each of the alternatives. From a cost perspective, stormwater outfall stabilization, reconnecting Wildcat Creek and bypassing Jewel Lake, and sediment basins were the three most efficient alternatives. The next tier of alternatives include dredging Jewel Lake, re-grading roads, followed by excavation of a multi-stage channel. Both the tributary stabilization and permeable parking lots with LID treatments were very expensive compared to the expected reduction in the short-term sediment supply rate. Benefits and impacts of each alternative are further discussed in Section 7.

Table 11: Summary of attributes of alternatives for erosion control and sediment management.

Erosion Control Method	Effective Period (yrs)	Raw Cost ($)	Permitting Cost ($)	Total Cost ($)	Total Cost/yr	Sediment Reduction (yds^3/yr)	Cost/yds^3
Reconnect Wildcat Creek* (bypass Jewel Lake)	100	1,577,500	300,000	1,877,500	18,775	653	29
Reconfigure/stabilize Culvert Outfalls (1 site)	20	14,500	10,000	24,500	1,225	40	31
Reconfigure/stabilize Culvert Outfalls (27 sites**)	20	397,500	30,000	427,500	21,375	1,080	20
Re-grade Roads	20	22,500	10,000	32,500	1,625	24	68
Stabilize Tributaries	10	125,000	50,000	175,000	17,500	6	2,917
Sediment Detention Basins ***	20	50,500	75,000	125,500	6,275	161	39
Dredge Jewel Lake	20	520,000	150,000	670,000	33,500	653	51
Implement LID	20	7,737,800	20,000	7,757,800	387,890	17	22,817
Multi-stage Channel	100	382,500	100,000	482,500	4,825	24	201

* includes onetime dredging of Jewel Lake. We used the long-term sedimentation rate for Jewel Lake of 653 yds^3/yr (Section 4).

** currently only one site is contributing sediment at 40 yds^3 /yr

*** includes annual maintenance cost

7. Sediment Control Alternatives, Prioritization, and Recommendations

FlowWest conducted a constraint and opportunity analyses for each of the alternatives described in Section 6. Criteria used to define constraints and opportunities included: the amount of sediment managed, construction costs, permitting requirements and additional studies, sediment management efficiency, impacts to habitat, and stakeholder feedback. FlowWest used the constraints and opportunities criteria to rank and prioritize the alternatives. Additionally, we identified compatible and incompatible actions along with actions that in combination will provide positive or negative feedbacks for project objectives. Lastly, we recommended the preferred project alternative(s). We collaborated closely with EBRPD staff to select the preferred alternatives. Additionally, we incorporated stakeholder feedback in the ranking process.

Ranking Criteria

To rank each of the erosion control and sediment management alternatives, FlowWest developed criteria in conjunction with EBRPD to optimize natural resource management. The first criteria in the ranking matrix quantifies the reduction of the short-term sediment supply rate or managed by each alternative. We grouped the sediment reduction or management rates for each of the alternatives into the following categories: over 200 yds^3/yr (high), 80-200 yds^3/yr (medium), and below 80 yds^3/yr (low). Management of sediment was given a higher priority than capture of sediment and removal from the watershed. In general, alternatives designed to restore physical processes were given a higher ranking. EBRPD has limited financial resources for management actions and expensive projects will require leveraging EBRPD resources to apply for implementation grants. Estimated construction costs were categorized as expensive if the estimated project cost exceeded $600,000, medium if the cost is between $600,000 and $100,000, and inexpensive if the project costs less than $100,000. Similarly, the permitting level of effort was categorized as high, medium, or low based on the following cost thresholds: expensive above $125,000, medium between $125,000 and $70,000, and low or inexpensive under $70,000. Next, we looked the cost of sediment management (e.g., cost per cubic yard) and categorized costs as inexpensive if the amount of sediment reduced or managed was less than \$100/yds^3, medium between \$100/yds^3 and \$1,000/yds^3, and expensive if the cost per cubic yard exceeds \$2,000/yds^3. FlowWest then filtered each of the projects by the impact or improvement to habitat. Alternatives that improve habitat conditions after the project is completed were categorized as good or improved, alternatives with limited to no change on the quality of habitat were categorized as no impact or no change, and alternatives that decreased the quality of the habitat after implementation were categorized as expensive or poor. Lastly, we incorporated stakeholder feedback from the public meetings (Section 3) to further refine our rankings based on favorable, neutral, or negative comments during stakeholder meetings. Using this criteria, we summarized each alternative in Table 12 using symbols for easy comparison between the different alternatives. A "+" symbolizes a positive outcome from implementation of an alternative, a "✓" represents a medium or unchanged outcome from implementation of the project, and a "-" represents a negative change or impact from implementation of the alternative.

Table 12: Ranking of sediment erosion control and management alternatives.

Erosion Control Method	Sediment Reduction	Construction Cost	Permitting Effort	Sediment Management Efficiency	Habitat Impact	Stakeholder Feedback
Reconnect Wildcat Creek (bypass Jewel Lake)	+	-	-	+	+	+
Reconfigure/stabilize Culvert Outfalls (1 site)	✓	+	+	+	+	+
Reconfigure/stabilize Culvert Outfalls (27 sites)	+	✓	+	+	+	✓
Re-grade Roads	-	+	+	+	+	✓
Stabilize Tributaries	-	✓	+	-	-	-
Sediment Detention Basins	✓	+	✓	+	-	-
Dredge Jewel Lake	+	✓	-	+	-	-
Implement LID	-	-	+	-	✓	✓
Multi-stage Channel	-	✓	✓	✓	+	✓

Recommended Projects

Based on the rankings in Table 12, we recommend the following projects: reconnecting Wildcat Creek (bypass Jewel Lake), stabilizing stormwater outfalls, constructing sediment detention basins, and re-grading roads. The criteria used in the ranking of the project alternatives in Table 12 were not equally weighted. Ultimately, projects we selected by balancing the criteria presented in Table 12 with management objectives for Tilden Park. Our reasoning for recommending each of these alternatives is explained in the following section.

Reconnect Wildcat Creek (bypass Jewel Lake)

From a physical processes perspective, the reconnect Wildcat Creek and bypass Jewel Lake is the preferred alternative because this project restores sediment continuity and fish passage, and includes repair of the spillway and dam stabilization. Stakeholders recommended conducting sediment transport modeling to assess the impact and benefits to the reach downstream of Jewel Lake from restoring sediment dynamics. Our initial analysis suggests that the sediment load from upstream of Jewel Lake will reduce the channel incision and bank erosion further downstream. If the sediment load from upstream of Jewel Lake exceeds the storage potential in the downstream reach, this alternative should be paired with increasing the number of sediment detention basins in Tilden Regional Park that will decrease the sediment delivered to Wildcat Creek. Funding for this project likely will require outside grants. Multi-objective projects that provide a regional benefit like the reconnection of Wildcat Creek alternative are more likely to be selected for funding than single objective projects. Stakeholder feedback suggested that this alternative is a strong candidate for grant funding through numerous state and federal programs. If matching funds are secured for implementation of this alternative, the project cost to the EBRPD may be lower than some of the other alternatives in this analysis that may not be eligible for grant funding. We strongly recommend that EBRPD continues to explore this alternative by developing a conceptual design, conducting a feasibility study that will include resources studies required for permit application, and applying for grant funding for implementation.

Stabilize Stormwater Outfalls

We recommend stabilizing the stormwater outfall at the head of the Redwood Gully downslope from Wildcat Canyon Road that has toppled mature redwood trees as soon as possible. Stabilization of the outfall will also require repair of the eroded gully, which will require additional stabilization techniques. In addition to contributing sediment to Wildcat Creek, the gully will continue to migrate upslope and eventually undermine Wildcat Canyon Road. EBRPD should explore cost sharing with the City of Berkeley to repair the gully and stabilize the stormwater outfall. For the other 27 stormwater outfalls, we recommend annual monitoring and assessment of the erosion downstream of the outfalls. At a few locations, the outfalls are perched above the current ground surface and are starting to erode. We estimated the potential amount of sediment managed based on extrapolating the short-term sediment supply rate for the Redwood Gully site to the other 27 outfalls. Our sediment rate extrapolation overestimates the potential sediment benefit of this alternative because all the outfalls along Wildcat Canyon Road do not have the same erosion potential as the Redwood Gully example (e.g., stormwater outfalls on gentler slopes).

Sediment Detention Basins

Installation of additional sediment basins ranked well in our analysis. Although EBRPD has lapsed in maintaining the existing sediment basins, the existing sediment basin captured sediment. EBRPD is in the process restarting an annual maintenance program for the three existing sediment basins. We recommend that EBRPD add a few more sediment basins that target urbanized subwatersheds with high sediment loads. The sediment basins alternative could also reduce the short-term sediment supply to Wildcat Creek downstream of Lake Anza if sediment transport modeling in the feasibility study for the reconnection of Wildcat Creek and Jewel Lake bypass alternative shows that the sediment load from upstream of Jewel Lake exceeds channel and bed erosion in the reach downstream of Jewel Lake. Additional opportunities exist for sediment basins upstream of the Lake Anza that were not included in our alternatives analysis. We also recommend that sediment basins in Tilden Regional Park be permitted as a part of a sediment management program that allows for completely cleaning out each sediment basin each year. Sediment basins ranked poorly for habitat impacts, so we selected sediment basin sites on tributaries to reduce the habitat impact on the Wildcat Creek channel. Additionally, we located some of the sediment basins upstream of culverts or roads that are currently barriers to migration for aquatic species. We sited the proposed sediment basins close to existing roads to limit the construction of any additional maintenance roads.

Re-grade Roads

We recommend re-grading dirt roads in Tilden Regional Park as regular road maintenance allows. Tilden Regional Park managers are willing to grade roads to the outside slope where access by fire trucks or other emergency vehicles is not hindered. This recommendation should be incorporated as a best management practice for Tilden Regional Park maintenance. Although the sediment contribution to Wildcat Creek from dirt roads is low, we feel that re-grading dirt roads to slope towards the outside and installation of a buffer strip of crushed rock can be incorporated into the existing maintenance budgets with little to no additional cost to EBRPD. Installation of additional culverts in road segments that can't be sloped to the outside should be implemented whenever possible.

Additional Considerations

One additional sediment management concept was discussed in the stakeholder meetings, but not included in this analysis. Future discussions of erosion control or sediment management alternatives should also consider using alluvial fans as sediment storage sites. Most major tributaries to Wildcat Creek have an alluvial fan where sediment has been deposited as the longitudinal slope of the tributary decreases on the valley floor before the confluence with Wildcat Creek. Many of these alluvial fans are currently occupied with recreational facilities that could be returned to riparian forest and wetland areas. Deposition at these sites could be encouraged by constructing structures in the tributaries that cause backwater conditions and sediment deposition on the alluvial fan. This alternative requires installation of additional culverts and rerouting of existing dirt roads and trails that cross alluvial fans.

References

Collins, L. 2007. Methods for Determining Sediment Supply in the Sonoma and Schell Creek Watersheds and Sediment Storage in Sonoma Marsh. Prepared for The San Francisco Bay Regional Water Quality Control Board. December.

Collins L.M., Grossinger R.M., McKee L.J., Riley A., Collins J.N. 2011. Wildcat Creek Watershed: A Scientific Study of Physical Processes and Land Use Effects. Richmond, CA: San Francisco Estuary Institute. Available from: http://www.sfei.org/wildcatcreeklandscapehistory

East Bay Regional Parks District. 1988. Tilden Regional Park Land Use-Development Plan and Environmental Impact Report.

Kocher, S.D., J.M. Gerstein, and R.R. Harris. 2007. Rural Roads: A construction and Maintenance Guide for California Landowners. University of California, Division of Agriculture and Natural Resources, UC Davis.

Kondolf, G.M. 1997. Hungry water: effects of dams and gravel mining on river channels. Environmental Management, Vol. 21, No. 4, pp 533-551.

PRISM Climate Group. 2010. 1981 – 2010 Annual Average Precipitation by State. Oregon State University, http://prism.oregonstate.edu, created 2010.

R.W. Graymer. 2000, Geologic map and map database of the Oakland metropolitan area, Alameda, Contra Costa, and San Francisco Counties, California: U.S. Geological Survey Miscellaneous Field Studies MF–2342, scale 1:50,000. (Available at http://pubs.usgs.gov/mf/2000/2342/.)

Schumm, S.A. 1977. The fluvial system. John Wiley & Sons, New York

Thomas, B.E., Hjalmarson, H.W., and Waltemeyer, S.D., 1997, Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States: U.S. Geological Survey Water-Supply Paper 2433, 195 p.

Waananen, A.O. and Crippen, J.R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations Report 77-21, 102p.

Washington Forest Practices Board. 2011. Washington Forest Practices, Board Manual: Standard Methodology for conducting watershed analysis, Chapter 222-22 WAC, Version 5.0, May.

Appendix A

Appendix A includes a table of the GIS layers used in this analysis (Table A1) and detailed description of the GIS shapefiles and an Excel spreadsheet that accompany this report. The shapefiles and Excel spreadsheet contain the data from the sediment analysis (Section 5). The spreadsheet and shapefiles are designed to be used by EBRPD for future management.

The four shapefiles described below and included on the DVD include:

- sediment observations points (point shapefile)
- stream segments in the watershed that can be linked to the Excel spreadsheet by unique identification numbers (line shapefile)
- road and trail segment in the watershed that can be linked to the Excel spreadsheet by unique identification numbers (line shapefile)
- summary of sediment supply rates and storage capacity for each subwatershed (polygon shapefile)

Sediment observation points were merged into the channel segment and road and trail segment shapefiles. The channel and road and trails segments are summarized in the sediment rates and storage capacities by subwatershed. These shapefiles can be utilized by EBRPD when planning sediment maintenance activities or creek restoration projects. The shapefiles are symbolized to show areas of high sediment yield to prioritize erosion control actions in the Wildcat Creek watershed upstream of Jewel Lake Dam.

GIS Layers Compiled for this Project

Table A1 summarizes the GIS layers compiled for this project and referenced Section 2.

Table A1: Data layers incorporated into the project GIS.

Source	Layer Type	Layer Name	Description
SFEI			
	Land use	Sim01	Land use digitized from 1820 maps/documents
		Lu850a	Land use digitized from 1850
		Lu1900l	Land use digitized from 1900
		Dv1900p	Land use digitized from 1900
		Lu1950l	Land use digitized from 1950
		Dv1900p	Land use digitized from 1900
	Bathymetry	anz38bthy	Lake Anza bathymetry contours from 1938
		anz99p	Lake Anza bathymetry contours from 1999
		jwl79p	Jewel Lake bathymetry contours from 1979
		jwl82p	Jewel Lake bathymetry contours from 1982
		jwl84p	Jewel Lake bathymetry contours from 1984
		jwl91p	Jewel Lake bathymetry contours from 1991
		jwl99p	Jewel Lake bathymetry contours from 1999
	Watershed	wcatbndp	Wildcat Creek watershed boundary

	Geology	Geoline	Geology units and faults in the Wildcat Creek watershed
		Geolp	Geology units and faults
	Streams	wcathyda	Streams and water bodies in the Wildcat Creek watershed
	Landslides	wcatlnds	Landslides in the Wildcat Creek watershed
	Precipitation	prism_h_sf	San Francisco Bay Area precipitation isohyetal map
	Topo Quads	quadbnds	USGS 1:24,000 scale quad map boundaries
EBRPD			
	Planning/Cadastral	Ala_prcl	Alameda County parcels
	Planning/Cadastral	Ccc_prcl	Contra Costa County Parcels
	Basemap/Public Lands	Ebrparkl	EBRPD boundaries
	Basemap/Annotation	Anno.features	EBRPD Feature Names
	Resource/Range Management	Graze	EBRPD grazing units
	Basemap/Public Lands	Ebrparkp	EBRPD lands
	Resource/Geology	Geology	Geology
	Basemap/Hydrology	Hydro	Hydrology (streams, pond and lake outlines)
	Emergency Fire	Burnarea	Large EBRPD wildland fire areas
	Planning/Land Designation	MstrPln_Trls	Master Plan Trails (existing and proposed)
	Facility	ServiceCorpYards	Service and Corp Yard locations
	Resource/Geology	Soils	Soils
	Basemap/Transportation	LandsDist_rt	Trails/roads on EBRPD
	Facility/Infrastructure	Culverts	Culverts
	Resource/Vegetation	EBRPD_vegetate	EBRPD vegetation
Contra Costa County			
	DEM		2008 4 inch DEM
	Ortho photos		2008 4 inch color
	Hydrology	CCCFCD Drains	Drainages
Alameda County			
	Ortho photos		2008 color
	Basemap	County_Boundary	County boundary
	Contours	Alco	1.5 ft contours
	DEM	Hillshade	10 ft DEM
UC Berkeley			
	Historical photos		1939 black & white
	Historical topo maps		1899 San Francisco & Concord

Sediment Point Features

The features transferred from the fields maps to the point file primarily show the location of channel and sediment related features (e.g., erosion features) not located in the channel or road ditch, the location of photo points, and culverts from the field effort (Table A2). Mapped features were used to determine lengths of sediment contribution segments and were integrated in to the line shapefile. WS took beginning and ending waypoints using a handheld GPS to measure the distance of long erosional features or road or trail segments. The point file also includes the locations of the digital photographs that WS took in the field and serves to document the existing condition of the watershed during the field period. The locations of contributing roads, inboard ditches, and trails were utilized to determine the road/trail contribution described below.

Table A2: Attributes of the point shapefile created from WS field mapping, GPS points, and digital photographs.

Attribute	Description
Id	Point Id
FeatureLab	Feature type
Date	Date data collected
Channel_ID	Stream/trail/road name
Section	Channel segment
Cause	Cause of erosional feature
GPS_Waypoi	GPS waypoint number (blank if transferred from field maps
Photo_y_n	Photo taken (yes/no)
Notes	Segment details and description of erosional features
Source	Watershed Science field maps/data sheets

Sediment Line Features

FlowWest developed separate line shapefiles for contributing channels and roads and trails. The Excel spreadsheet includes both the channel-related and road- and trail-related contributions. Both sediment sources are included in the summary polygon shapefile, and the figures and tables at the end of this section. The two shapefile have been kept separate because two different methods were utilized to estimate sediment erosion rates from roads and trails (Section 5).

Channel Related Sediment Contribution

The channel line shapefile shows the sediment yield for each creek segment (Table A3) and the corresponding segment in the Excel spreadsheet contains all of the field observations. Segments in the Excel spreadsheet and shapefile are linked by the Id and Name, which gives the subwatershed name (name field) and the segment number (id field). Field observations were summed for each segment and added to the attribute information. Sediment attribute information for the line shapefile includes: rate of fines erosion, linear rate of fines erosion, rate of total erosion, and linear rate of total erosion in both ft^3 /yr and yds^3 /yr for rates and both ft^3 /yr/ft and yd^3 /yr/ft for rates normalized by the linear distance of each segment. Table A2 lists the attribute fields for the line shapefile. Results are reported in both yd^3/yr and yd^3/yr/ft to show the amount of sediment generated by a segment (yd^3/yr) and how the amount of sediment is normalized by the different length of each segment (yd^3/yr/ft).

Table A3: Erosion and storage attributes for the channel line shapefile.

Attribute	Description	Units (GIS)	Units
Id	Stream Segment Id		
Supply	Type of stream segment supply:		
	Measured - data collected in field by WS		
	Extrapolated - data extrapolated by WS from nearby field data collected		
	Null - determined by WS to be non-contributing		
	Storage - segment supplying limited storage capacity		
Strm_order	Stream order of stream segment (1,2 or 3)		
Name	Stream segment name correlating to calculations in data spreadsheet		
Length_ft	Length of stream segment	Ft	ft
Subwatersh	Subwatershed that stream segment contributes to		
F_cuft_yr	Rate of fines erosion	cu ft/yr	ft^3/yr
F_cuyd_yr	Rate of fines erosion	cu yd/yr	yd^3/yr
Fcuft_yrft	Linear Rate of fines erosion	cu ft/yr-ft	ft^3/yr/ft
F_cuyd_yrf	Linear Rate of fines erosion	cu yd/yr-ft	yd^3/yr/ft
T_cuft_yr	Rate of total erosion	cu ft/yr	ft^3/yr
T_cuyd_yr	Rate of total erosion	cu yd/yr	yd^3/yr
Tcuft_yrft	Linear Rate of total erosion	cu ft/yr-ft	ft^3/yr/ft
T_cuyd_yrf	Linear Rate of total erosion	cu yd/yr-ft	yd^3/yr/ft

Road and Trail Sediment Contribution

The sediment contribution from roads and trails was delineated and calculated in a separate shapefile (Table A4) included on the DVD. Segments in the Excel spreadsheet are linked to the shapefiles by the following fields, subwatershed (watershed), sediment rate (cu_yds_yr), or the point identification number (Pt_ID). The sediment contribution from inboard ditches along roads and contributing trails mapped by WS was determined by a combination of field observations and the Washington Road Surface Erosion Model (WARSEM) (2011). Additionally, mapped point features of road and trail-related sediment were converted from points to lines based on the field notes and included in the road and trails line shapefile. Using field observations to indicate which roads and trails were connected to channels improved our estimate of sediment delivery. WARSEM allowed us to calculate road tread erosion rates for connected roads and trails. Additional field measurements were added to the master Excel spreadsheet included on the DVD. Table A3 describes the attributes for the road and trails summary shapefile.

Table A4: Road and trail erosion shapefile attributes.

0	Description	Units (GIS)	Units
Type	Contributing erosional feature description (paved inboard ditch, contributing dirt trails, road tread erosion, foot trail erosion, road tread rill, road tread erosion, road cut, or foot trail rill)		
Segment	Mapped segment name or description		
Name	Trail or road name		
Watershed	Subwatershed name		
Lake_Loc	Location of subwatershed in relation to Lake Anza		
Cu_yds_yr	Rate of total erosion	cu yd/yr	yd^3/yr
Pt_ID	Identification of point features digitized as lines		
GPS Waypts	GPS points associated with each feature		
Ad_Notes	Additional description of the extent or location of the erosion feature		

Subwatershed Summary

The polygon shapefile distributed on the DVD with this report contains the sediment supply rates (yd^3/yr) and volume of sediment storage for each subwatershed. The attributes for the subwatershed sediment rates and storage volumes are listed in Table A5.

Table A5: Erosion and storage attributes summed by subwatershed in the polygon shapefile.

Attribute	Description	Units (GIS)	Units
Id	Subwatershed Id		
Name	Subwatershed name		
Lake_loc	Location of subwatershed in relation to Lake Anza		
Areaft3	Area of subwatershed	Sqft	ft^2
Acres	Area of subwatershed	Acres	Acres
Watershed	Subwatershed name used Excel Spreadsheet		
F_cuyd_yr	Rate of fines erosion summed by subwatershed	cu yd/yr	yd^3/yr
T_cuyd_yr	Rate of total erosion summed by subwatershed	cu yd/yr	yd^3/yr
Fstor_cuyd	Fine sediment storage capacity summed by subwatershed	cu yd	yd^3
Tstor_cuyd	Total sediment storage capacity summed by subwatershed	cu yd	yd^3

Excel Spreadsheet

The Excel spreadsheet included on the DVD with this report contains the data for the sediment analysis. The tabs in the spreadsheet summarize the data for the study area, summarize sediment erosion, and storage features by subwatershed, and summarize sediment produced by roads and trails. The summary tabs illustrate sediment rates by subwatershed and by sediment source type.