An Assessment of Trails, Watercourses, Soils, and Redwood Forest Health in Joaquin Miller Park, Oakland, California, with Recommendations for Management

Submitted to:

City of Oakland
Office of Parks and Recreation
1520 Lakeside Drive
Oakland, California 94612

Prepared by:

Richard D. Koehler and Janet M. Sowers
William Lettis & Associates, Inc.
1777 Botelho Dr., Suite 262
Walnut Creek, CA 94596

and

Frank Mileham and Clare Tipple Golec
Natural Resources Management Corporation
1434 Third St.
Eureka, CA 95502

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INTRODUCTION

This report summarizes the methodology and results of an assessment of the current condition of trails, watercourses, soils, and redwood forest within Joaquin Miller Park, Oakland, California. This assessment was performed by William Lettis & Associates Inc. (WLA) of Walnut Creek, California and Natural Resources Management Corporation (NRM) of Eureka, California under contract with the City of Oakland, Office of Parks and Recreation. The purpose of the investigation was to provide baseline data on sediment sources and erosion associated with the trail network and watercourses and to determine the health of the redwood forest within the park. The investigation was focused on 11 specific areas of concern identified by the City of Oakland. An assessment of additional problem areas identified during field reconnaissance is also included. The motivation for this study arises from concerns over the perceived negative impact of increased recreational use in the park. The baseline data produced in this report will provide a framework for understanding the impacts of erosion and sedimentation on park resources and help land use planners evaluate watershed management plans.

TRAIL EROSION PROCESSES

Several factors contribute to the erosion of forest trails. Fluvial erosion is a major natural process that acts on the landscape in the presence or absence of trails. It results from the concentration of surface water runoff and is often enhanced by groundwater seepage. Sheetwash, rilling, gullying, streambank erosion, and bed scour are all examples of fluvial erosion processes. When trails are constructed without adequate provision for surface and groundwater water drainage, trails become subject to fluvial erosion.

Mass wasting is another natural process that can contribute to the erosion of trails. Landslides and streambank failures are examples that can be found in Joaquin Miller Park. Although natural, these processes can be exacerbated by human activities.

Recreational use results in two types of human induced processes which can cause or exacerbate trail erosion. Abrasion, in which soil is physically loosened and moved downhill or to the side by feet, tires, or hooves, can move significant amounts of soil. Evidence of such movement can be seen in the form of steps, grooves, troughs, and skids on hillslopes or on trails. These features can then enhance fluvial erosion by providing pathways for concentrated water flow. On some trails the cumulative effects of trail use can lower the trail surface and create an outside berm. Outside berms prevent surface water from exiting the trail and encourage fluvial erosion by forcing surface flow downhill.

Trampling is a second process caused by recreational use. Trampling by itself does not erode the soil; rather it destroys the vegetation and compacts the soil. Soil compaction, in turn, makes the soil less permeable resulting in greater runoff and subsequent fluvial erosion, and it prevents the penetration of roots and reestablishment of vegetation.

Other studies have documented the effects of recreational land use on trail erosion (eg. Seney and Wilson, 1989; Barbera et al., 1986; Kuss, 1983; Summer, 1980; Weaver and Dale, 1978). These studies all agree that recreational land use tends to increase erosion rates on trails due to destruction of vegetation, compaction of soil, and loosening of the surface layer of soil. The amount of erosion is dependent on the type of use, intensity, and the length of time of use.

The effectiveness of the above processes in degrading the trails is governed in large part by the trail conditions. Trail grade, alinement, drainage, tread material characteristics (specifically infiltration properties and erodibility), trailside vegetation, and local geomorphology all make the trail more or less susceptible to erosion. For example, trails that have gentle gradients and hard trail tread materials (i.e. bedrock) are relatively resistant to erosion. In contrast, fluvial or recreational erosion can cause large volumes of erosion on trails that have steep gradients and soft trail tread materials (i.e. forest soil). Thick soil cover and vegetation in close proximity to a trail can absorb surface water and limit fluvial erosion. Properly located drainage structures can also limit fluvial erosion by diverting surface water off the trail. Decayed or plugged culverts can increase fluvial erosion by causing streams to overtop their banks and flow on the trail surface.

LOCATION AND BEDROCK GEOLOGY

Joaquin Miller Park is located in Alameda County on the southwestern slope of the East Bay Hills between Highway 13 and Skyline Boulevard. The City of Oakland owns and operates the park. Numerous small creeks drain the upper reaches of the park into Palo Seco Creek, a major tributary to Sausal Creek (Figure 1). The park consists of a rugged upper section located east of Sunset Trail and a gently sloping lower section located west of Sunset Trail (Figure 1).

The rugged upper section of Joaquin Miller Park is underlain by Upper Cretaceous Oakland Conglomerate and Joaquin Miller Formation bedrock (Radbruch, 1969). The Oakland Conglomerate underlies the flat ridgetops located on the northern edge of the park and is composed of pebble and cobble (up to 8 inches in diameter) conglomerate in a yellowish-brown, weathered sandstone matrix. The Joaquin Miller Formation underlies the steep sided ridges and canyons in the middle of the park and is composed of thinly bedded to massive (up to 10 feet thick) beds of yellowish-brown sandstone, shale, and minor conglomerate. The rocks in the upper section of the park have a northwesterly strike, a moderately steep northeasterly dip, and comprise one limb of a large anticlinal fold.

The lower section of the park is characterized by gentle topography and is separated from the steep upper section of the park by the northwest-trending Chabot fault located in the vicinity of the park visitor center and Palo Seco Creek. The lower section of the park is underlain by Upper Jurassic massive shale and interbedded sandstone of the Knoxville Formation, Upper Jurassic to Cretaceous greenstone and serpentine of the Franciscan Formation, and Pliocene Leona Rhyolite bedrock (Radbruch, 1969). The southwestern border of the park is less than a quarter mile from the active, northwest-trending Hayward fault. The rock formations in the lower section of the park also strike to the northwest.

LAND USE HISTORY

Much of the Oakland Hills, including the area of Joaquin Miller Park was extensively logged of its old growth redwood forest between the years of approximately 1850 and 1860. In 1886, the writer and poet Joaquin Miller built a cabin (named "The Hights") in the location of the present day park. Joaquin Miller was dedicated to preserving the acres surrounding his home and planted more than 75,000 Monterey pine, Monterey cypress, sequoia, olive, and eucalyptus trees. After his death, the City of Oakland purchased 68 acres from the estate of Joaquin Miller. In 1928 the Save the Redwoods League purchased additional acreage, bringing the park total to approximately 425 acres.

Today the park offers scenic trails and a wealth of recreational (e.g., hiking, horseback riding, mountain biking), educational, and cultural opportunities. Recreational use of the park has increased steadily over the past few decades, and recently there has been public concern over the health of the redwood forest, erosion of the trail network, and downstream sedimentation in Palo Seco Creek and Sausal Creek (Tony Acosta, personal communication, 2000).

METHODOLOGY

William Lettis & Associates conducted field assessments of the 11 areas of concern identified by the City of Oakland (Areas A through K on Figure 1) in order to characterize soils and document the nature and extent of erosion on the trails and watercourses in Joaquin Miller Park. Natural Resources Management Corporation conducted field surveys to assess the general health of the redwood forest and understory vegetation. In particular, their surveys were designed to assess whether the existing trail use is having a detrimental effect on tree health and growth.

The general characteristics of soils in the redwood forest in Joaquin Miller Park were determined by describing soils from four hand-auger holes. A 1.5 meter long hand auger was used to obtain samples of the soils for inspection. In order to document the variability of soils existing in different topographic locations, we described one soil in a valley bottom, two on a ridgetop, and one on the flank of the ridge. Soils were described according to the methods of the Soil Survey Division Staff (1993) and Birkeland et al. (1991) and include horizon thickness, nature of horizon boundaries, color, percent gravel, estimated clay content, texture, structure, wet and moist consistence, and the abundance of roots and pores.

Sources of erosion and sediment production from trails were identified by walking the trail network. At each significant erosion feature observed on the trail system (features numbered 1-27 on Figure 1 and Table 1), qualitative and quantitative baseline erosion data were recorded on field data sheets (located in Appendix 1). Erosion data collected included location of feature, nature of feature, volume of past erosion, potential for future erosion (low, moderate, high), and priority for repair (low, moderate, high). Individual erosion features were photographed and their locations plotted on the Joaquin Miller Park trail map. These data are attached to the corresponding field data sheet. The volume of erosion that has occurred at each site was calculated by measuring the length, width, and depth of the feature with a tape measure. Observations bearing on possible causes of each erosion feature were recorded in a field notebook and summarized on the field data sheet.

The current condition of the watercourses within Joaquin Miller Park was evaluated by walking selected streams and making observations and measurements at trail/stream crossings and along stream banks. The watercourses targeted in this study included; (1) the main channel of Palo Seco Creek; (2) the major tributary of Palo Seco Creek along Cinderella Trail; and (3) the four prominent tributaries that cross the Sequoia Bayview Trail and drain the steep redwood forest in the southern portion of the park. The types of baseline erosion data collected on these watercourses are similar to the baseline erosion data collected at trail erosion sites. The baseline erosion data was used to prioritize individual erosion features for mitigation and future study.

The general health of the redwood forest overstory and understory was assessed by field surveys around the trail areas within the areas of concern. The overstory surveys consisted of two types of survey methods. First, a general random ocular survey was conducted to assess the overall health of the trees and to identify areas that may warrant additional investigation. Observations were made for tree vigor, mechanical damage, and tree pathogens. Second, specific trees were selected to sample for age, growth rates, and defect observations. Selected redwood trees were sampled for growth rates by taking sample cores with an increment borer and measuring radial growth. Understory surveys were performed to identify native and non-native plant species and to assess traffic impacts on the health of the vegetation.

RESULTS

Trails

Sediment sources and erosion problems were documented along the trail network and watercourses in Joaquin Miller Park, specifically in 11 areas of concern identified by the City of Oakland, labeled A through K on Figure 1. Trails in these areas of concern are cut into a variety of different soil and rock conditions, and they range from flat to steep. Additionally, the trails traverse several different ecosystems, mainly redwood forest, oak woodland forest, and grassland. Trails in the more popular areas of the park have experienced more use than trails in less popular areas. "Bootleg trails" (trails created by users and not maintained by the park) and trails not included in the City of Oakland's specific areas of concern also were observed.

The majority of the specified trails have experienced a considerable amount of use over the years, and as a consequence are well compacted. Many of these trails were constructed with adequate grade, alinement, and width characteristics. Because of tight compaction and good construction techniques, trails that have gentle gradients, and/or bedrock tread material were observed to be relatively resistant to erosion and have few erosion problems. Some trails, however, were constructed with poor grade and alinement characteristics on areas with soft soils. Rill and gully networks were observed on steeper trails with the same degree of compaction as shallow gradient trails.

Rills are common on steep trails throughout the park and are usually associated with improper drainage or drainage structures that have not been maintained. Rills form in places where surface runoff cannot exit off the trail, forcing the water to concentrate in low spots and flow down the trail. After the water erodes through the compacted surface layer, rill development accelerates. Rills that are left untreated for many years develop into rill networks, and in extreme cases become gullies. Local shallow bedrock conditions on steep and flat trails can contribute to their relative stability and resistance to rill development.

The erosional impacts identified during the field inventory were related to natural processes including slope instability, rainfall, and surface runoff, as well as recreational trail use including running and hiking, horseback riding, and bicycle riding. Individual erosion features documented in the specific areas of concern are presented in Appendix A, which includes descriptions of the physical parameters measured, field sketches and photographs. The total volume of past erosion that has occurred at each feature observed on the trails and watercourses is presented in Table 1. Approximately 59% of the total past erosion is attributed to naturally occurring bank failures and landslides observed along watercourses. This volume is considered a minimum because the volume of older healed bank failures and inner gorge landslides is difficult to calculate. The most common erosion feature in Joaquin Miller Park is rills created by surface runoff. This erosion, however represents only 7% of the total past volume of erosion.

Areas "A, B, C, F", and "G" (Figure 1) have minor evidence of erosion. Bishops Walk and Sinawik Trail within areas "B" and "C", respectively, have shallow bedrock conditions that are resistant to natural and recreational erosion. These two trails do not have erosion problems associated with drainage or recreation. The Sunset Trail within area "A" is relatively flat, well compacted, and relatively resistant to erosion. North of Sinawik Cabin the Sunset Trail traverses the southeasterly facing slope of Palo Seco Creek canyon. This portion of the trail is cut into a steep hillside and is vulnerable to landslides. Presently, there is a small pile of rocks and debris that has been deposited on the trail from a cut slope landslide. This material can easily be removed by a shovel crew and is not considered a major problem. The Sinawik Trail and Lower Palos Colorados Trail parallel each other on opposite banks of Palo Seco Creek in the vicinity of area "G". In places where these trails are next to the creek, high flows have caused bank erosion (erosion features 2, 3, and 3A). Area "F" includes the upper portion of the Wild Rose Trail and its junction with the Sequoia Bayview Trail. The upper Wild Rose Trail traverses a redwood grove and is relatively flat. This portion of the trail had no signs of significant rill, gully, landslide, or recreation-related erosion.

Area "D" encompasses the Cinderella Trail and the creek that parallels Cinderella Trail. This area includes erosion features 5, 7, 8, 9, 10, 11, and 12. The trail is cut into the valley wall approximately 75 feet upslope of the creek. It is well compacted and extremely steep in places. Efforts have been made in the past to divert surface runoff away from the trail. Unfortunately, the water bars have not been maintained and have been either filled with sediment or overtopped and eroded away. A high outside berm exists along the trail between erosion features 10 and 12. This berm prevents water from escaping the trail and routes runoff down the trail. Small rills have formed in many places along the trail in response to these drainage problems. Shallow bedrock conditions in the vicinity of erosion feature 10 are limiting the development of rills. Erosion feature 7 has contributed a considerable amount of sediment to the creek channel and is considered a major problem. The combined effects of culvert plugging, streamflow across the trail, and past fill prism failures has resulted in a major sediment contribution to the creek and a recreation safety hazard.

Erosion features 13, 14, and 15 were documented in Area E (Figure 1). These features were located between Sequoia Arena and the junction of the Chaparral Trail and Sequoia Bayview Trail. Drainage problems associated with a high outside berm has contributed to the development of rills and gullies at each of these features. Troughs in the trail exist in a few places along Area "E". These troughs are approximately 1.5 to 2 feet wide and resemble troughs the authors have observed that were created by horse pack trains on trails in the Sierra Nevada mountains. Based on the close proximity of these features to the horse arena, we infer that the troughs were originally created by horse traffic. Surface water runoff funneled down the trail by the high outside berms has caused these troughs to increase in size.

Table 1. List of erosion features, type of feature, and Total past erosion volume

Erosion feature (See figure 1)	Type of feature	Total Past Volume in cubic yards*
01	Rill	0.6
	Bank Failure	0.9
02	Fill erosion	7.4
03	Bank failure	0.9
03A	Bank failure	0.4
04	landslide	39
04A	landslide	69.4
05	Landslide	89
	stream erosion of slide debris	22 (transported downstream)
06	Bank failure	16
07	Fill failure	88.9
08	Rill	1.6
09	Fill failure at culvert	Unknown, repaired
10	Rill	1.1
11	Rill	0.2
12	Rill	1.3
13	Rill	2.3
14	Rill	0.2
	Gully	0.6
15	Rill	10
16	Rill	0.6
17	Potential culvert failure	0
18	Rill	0.2
19	Rill	0.37
20A	Tire groove	0.2
20B	Tire groove	0.07
21	Rill	0.17
22	Rill	0.3
23	Rill	0.07
24	Rill	0.24
	Gully	1.4
25	Gully	3.5
26	Rill	0.1
27	Rill	0.1
		Total past erosion = 337.12 cu. yds.

* Past erosion volume estimates represent the last approximately 20 years.

Area "H" encompasses the northern portion of the Harold Ireland Trail and a section of the Sunset Loop Trail. Erosion features 23 and 26 are related to the lack of water bars and non-maintained water bars, respectively. Erosion features 24 and 25 are related to stream water flowing across the trail. The Harold Ireland Trail was constructed across two small stream channels with no provision made for stream water to safely cross the trail. In the winter during high stream flows, the trail fill prevents the stream from flowing down the channel and diverts the water onto the trail. The result of this process has been the formation of large rills and gullies. One of these rills transports water from erosion feature 24, off the Harold Ireland Trail, through the brush, onto the Sunset Loop Trail, ultimately causing the rill erosion at feature 22.

Areas "I" and "J" (Figure 1) are located in the redwood forest in the southern portion of the park. The Big Trees Trail traverses through Areas "I" and "J" and is less compacted than other trails in the park. The trail is cut into extremely soft soils and has redwood tree roots exposed on many sections. There are numerous "bootleg" trails between the Sequoia Bayview and Big Trees Trails. Based on trampled vegetation and step holds many of these trails have been created by hikers walking off the trail (see understory vegetation below), although in other places narrow grooves and skids indicate that some of these trails have been created by bicyclists riding off the trail. Erosion features 20A and 20B, in the vicinity of Area "J", are two grooves that appear to be related to bicyclists slowing down or braking on a sharp corner.

Area "K" encompasses the Upper Palos Colorados Trail located between the Sequoia Bayview Trail and Sunset Trail. The Upper Palos Colorados Trail traverses a steep northeast facing hillslope that drains into Palo Seco Creek. The trail has similar soil, width, and compaction characteristics to the Big Trees Trail. Surface water flowing down the trail in Area "K" has eroded soil in between the exposed roots. Erosion feature 21, located at the upper entrance to the trail, is the result of surface water flowing down the trail. Recreational land use may be causing the two rills to expand.

Surface water runoff was determined to be the dominant erosion mechanism acting on the park trails. Erosion generated by horses, bicycles, and hikers was determined to be a minor erosion mechanism on established park trails. However, recreational use was determined to be major source of soil erosion on "bootleg" trails. We noted many off trail hiking and biking tracks throughout the park. Hiking tracks were identified based on trampled plants, footprints, and the presence of step holds. Bicycle tracks were identified based on skid tracks through soft soils and narrow grooves. We observed that these "bootleg" trails often break through the soil O horizons exposing the erodible A horizons. With continued use, bicycle tracks begin to remove A horizon material, forming a groove that becomes progressively deeper. Hiking tracks expose and compact the A horizons and trample vegetation, making it difficult or impossible for the trail tread to naturally recover. Because the most fertile layer has been stripped, roots may have difficulty penetrating the compacted soil, and the trail may be eroding too rapidly for new plants to become established. Many of these trails, both hiking and bicycle, are oriented directly downhill, facilitating the rapid flow of water that deepens the tracks. One particularly bad "bootleg" trail begins near the DAR monument on the Big Trees Trail and ends near the junction of Fern Trail and the Sequoia Bayview Trail. Bicycle traffic on this trail has eroded a deep rill in the soft redwood soil.

Watercourses

The watercourses in Joaquin Miller park were found to be in excellent condition. The four main creeks that drain the redwood forest in the southern portion of the park have steep channel gradients, deep v-shaped canyons, and often flow on bedrock. These channels have occasional bank failures related to saturated slopes and high stream flow. The stream that parallels the Cinderella Trail upstream of the junction with Sunset Trail has steep valley walls and has had natural bank failures caused by high flows. Upstream of erosion feature 10, the creek has a shallower gradient, thick brush, and no landslide or bank failure problems. We noted no major effect of recreational land use on these channels.

Palo Seco Creek itself has a relatively shallow channel gradient through the Upper Meadow and Lower Meadow areas. The channel gradient of this creek is steeper north of the Sinawik Cabin. This portion of the creek has experienced a few stream bank landslides that have contributed large volumes of sediment to the creek in the past. One of these landslides, erosion feature 4, occurred within the past few winters and the majority of the sediment is still present in the stream channel.

Soils

Soils were described by WLA geologists in four locations within the redwood forest in the general vicinity of the Daughters of the American Revolution (DAR) historical marker and the Big Trees Trail. Soil-profiles SP-1 and SP-2 were located on the ridgecrest, soil-profile SP-3 was located on the west flank of the ridge, and soil profile SP-4 was located in the adjacent valley bottom (Figure 1). Care was taken to avoid the centers of obvious “fairy rings” (rings of second-growth redwood trees that sprouted from the base of a logged old-growth tree) and areas of bedrock outcrop. All four profiles were similar in the degree of development and character of horizons, but differed slightly in the depth and thickness of horizons and to a minor extent in clay content and structure. All are residual soils developed on sandstone bedrock. They are characterized by an organic horizon of leaf litter and humus, underlain by a very friable dark gray, loamy A-horizon that grades downward into either a weak B horizon or C horizon of weathered sandstone bedrock or sandstone-derived colluvium.

The O horizon (organic horizon) consists of two subhorizons (O1 and O2) both of which are relatively thin. The O1 horizon consists of redwood leaf litter, including twigs, needles, and cones. This leaf litter is about 3 cm deep and has an abrupt smooth boundary with the underlying O2 horizon. The O2 horizon is porous, light humus and decomposed leaf litter in which some individual needles and twig fragments can still be recognized but all are matted together in a soft spongy mass with abundant fine to medium roots. The roots are presumed to belong to the redwood trees as there are no other tree species in the vicinity and we have noted similar root mats in other redwood forests. The O2 horizon is 7 to 10 cm thick and has an abrupt boundary with the underlying A horizon.

The A horizon extends from about 10 to 80 cm in depth and is black to dark brown very friable loam with common medium roots and a weak subangular blocky structure. In two of the four profiles, we noted moderate granular structure in the upper 10 cm of the A horizon. The color the upper A horizon is black (10YR 2/1), grading toward dark brown (10YR 3/3) with depth. Wet consistence is non-sticky to slightly sticky and non-plastic to slightly plastic, with clay estimated to be about 10%. Gravel comprises 0 to 10%.

A Bw horizon is present in SP-1 only. This was recognized by a slightly greater clay content (15%) compared to the A horizon (10%), and a dark yellowish brown color (10YR 4/4). Wet consistence is sticky and plastic. No clay films or accumulations of other pedogenic minerals were observed.

In profiles 2, 3, and 4 the A horizon gradually transitions to a C horizon composed of yellowish brown to light yellowish brown (10YR 5/4 to 6/4) very friable loam. Fragments of weathered sandstone comprise 10% to 50% of the horizon and typically increase with depth. Wet consistence is slightly sticky and slightly plastic and the structure is massive to single grained.

The depth to bedrock varies greatly on the ridge. Bedrock outcrops are present intermittently through the forest; we deliberately selected augering sites that were likely to have deeper soil. We were surprised to note the great depth of the soil in profile JMP-3 on the hillside. The soil was as deep or deeper than the other sites, suggesting that the hillside has been stable with very low erosion rates, for a long period of time. We expected the hillslopes to have relatively shallow soil due to typically greater erosion rates on steeper slopes. In many other places, the hillsides have very shallow soils. A good example is the bedrock tread of the Big Trees Trail near its junction with the Sequoia Bayview Trail.

TABLE 2. DEPTHS OF SOIL HORIZONS

Soil Profile:		**SP-1**	**SP-2**	**SP-3**	**SP-4**
Location:		Ridgecrest	Ridgecrest	Hillside (20°)	Valley bottom
	O	0-10	0-9	0-7	0-13
Depth of	**A**	10-62	9-50	7-76	13-88
Horizon:	**Bw**	62-84	--		
(cm)	**C**		50 +	76-150	88-108
Bottom of hole at (cm) :		84	60	150	108

The fine texture and friable nature of these soils suggests they will be highly susceptible to erosion if exposed. At present, the O horizon with its dense root mat provides a protective skin for the soft soil underneath. Providing additional protection are the permeable nature of the surface, which promotes infiltration rather than runoff, and the presence of the redwood canopy, which may diffuse the impact of raindrops. However, if the O horizon were removed, soil loss could be rapid and extensive. The O horizons are also important in themselves. They hold a significant percentage of the rootmass of the redwood trees and they cycle nutrients from the decomposition of the leaf litter back into the redwood roots. Every precaution should be taken to preserve the O horizons of these soils.

Redwood Forest Overstory.

No extraordinary conditions were observed with regard to tree vigor, mechanical damage, and tree pathogens. No areas showed signs of declining vigor. One area was noted, however, that was observed to be a poorer growing site than other areas of the Park. This area is located on a ridge along the Big Trees Trail and is identified as Area "I" on Figure 1. The redwood trees in this area are of much smaller diameters than in other areas of the Park, and they exhibit a shaggy bark condition that is more pronounced than seen on other trees of the Park (see Figure 2).

Figure 2: Area"I" of the Big Trees Trail, Harsh Growing Site

Although these trees are smaller on average than other trees of the Park, they are the same age as the other larger redwood trees. This area shows a lower overall tree vigor because it is a harsher growing site, probably due in part to shallower soils, not due to any Park use.

Very little mechanical damage was observed in the Park. Even broken tree tops, occurring from wind stress, were found to be less common than expected. The one exception that was observed, albeit not a serious condition, was that some trees have experienced some animal rub damage. A few redwood trees along the Big Trees Trail between Areas "I" and "J" lying just west of Skyline Boulevard have scuffed bark at two to six feet above ground level. This condition is not uncommon in forests where bear and often elk will return to a favorite tree to scratch themselves. The result is often that most of the bark gets rubbed off, and damage occurs to the underlying cambium layer. Trees do not usually die from this; however, their growth is often retarded. The trees observed in the Park had very light damage that was likely caused by horses hobbled in this area by equestrian users. This situation should be monitored in the future to insure significant damage does not occur.

Pathogens, rots and insect infestations, are less common in redwood than in other tree species occurring in this region. However they do occur. Often rot causing fungus will be introduced through a mechanical wound on a tree. The redwood trees in Joaquin Miller Park appear more resistant than average to effects of rot. Even where the base of a tree was observed to have damage that may expose the tree to a fungal infection, very little to no rot was observed. No problems with pathogens were observed.

No specific areas were observed that could be identified as significantly different from overall conditions observed in the Park trees relative to tree vigor, mechanical damage, or pathogens.

A total of twenty trees were bored to determine age and growth rate. Table 3 shows tree bore data including sample location, diameter at breast height (DBH), total height, and radial growth increments for five year time periods. Trees were sampled in areas "F, H, I, J", and "K" (Figure 1). Areas "D" and "E" were found to have very few redwood trees, those located were small saplings which were in good health and growth status. Area "G" exhibited significantly lighter trail use than other areas surveyed and was not sampled. Sample trees were selected from the heavier use trail areas. Trees were selected for growth measurement that were immediately adjacent to trails and had exposed roots on the trail (see Figures 3 and 4); and also trees located approximately 30 feet off the trail where the tree base was unaffected by trail use compaction and disturbance, but the tree crowns essentially occupy the same space as the trail adjacent trees.

Table 3. Redwood Radial Growth Increments for Five Year Periods in 20ths of an Inch

Sample Tree Number	Sample Area	Increment by Five Year Period (in Years Past)						Diameter At breast Height (DBH)	Tota Heig
		0-5	6-10	11-15	16-20	21-25	26-30		
1	F	3	2	2	2			16.7	
2	H	26	34					49.8	[illegible]
3	F	14	10	14	14	6	10	31.3	[illegible]
4	F	7	5	7	7	8	11	22.2	[illegible]
5	F-I	7	3	4	7	6	5	14.3	
6	F-I	8	7	10	10	5	6	29.2	[illegible]
7	I	11	8	10	6	8	5	32.2	[illegible]
8	I	3	3	2	2	4	3	13.5	
9	I-J	8	6	5	6	6	8	34.1	[illegible]
10	I-J	4	4	3	5	4	4	26.0	
11	I-J	9	5	7	8	3	2	24.5	[illegible]
12	J	5	4	3	3	5	5	27.8	[illegible]
13	J	2	2	3	3	6	4	26.0	[illegible]
14	J-K	6	5	5	4	7	6	18.7	
15	K	3	3	3	2	2	2	18.5	
16	K	3	4	5	6	7	3	20.5	[illegible]
17	K	1	2	2	5	9	7	16.3	[illegible]
18	K	8	7	10	8	7	6	37.6	[illegible]
19	K	6	3	4	5	5	4	24.3	[illegible]
20*	F							25.6	
21**	H							33.9	[illegible]

* Observations on a freshly cut redwood tree stump, no boring data.
** Observation before the boring program began, no boring data.
*** Age assessed from tree borings taken at breast height. Only borings that resulted in reliable age assessment are reported.
Paired Tree Samples are as follows: 3 & 4, 7 & 8, 10 & 11, 12 & 13, 15 & 16.

Figure 3: Area “K” of the Big Trees Trail west of Sequoia Point

Figure 4: Area "K" of the Big Trees Trail at Junction of Sunset Trail

The sample trees ranged in size from 14 inches to 50 inches diameter at breast height (DBH). Six of the trees were also bored for age at breast height (4.5 feet above ground level). Ages ranged from 90 years to 140 years with an average of 121 years. Growth was gauged by measuring six 5-year radial growth increments over the past 30 years. Radial growth of the trees was compared within each tree to determine if a significant deceleration or acceleration of growth was occurring. Radial growth was also compared between trees to determine if a discernable difference was occurring between trees adjacent to trail surfaces and trees off trails. Particular attention was given to paired sample trees, or sample trees located close to one another, one tree immediately adjacent to the trail and the other tree about 30 feet from the trail.

Tree growth from 30 years ago to 10 years ago had been fairly constant, changing little from period to period and both increasing and decreasing. However, from 10 years ago to 5 years ago there was a significant decrease in growth. Trees adjacent to trails decreased growth by 20% from the previous period, and trees not adjacent to trails decreased 22% from the previous 5 year period. Then, from 5 years ago to current both sets of sample trees exhibited accelerated growth from the previous period, increasing 26% and 34% for trail adjacent trees and non-adjacent trees respectively. These changes are likely in response to climatological influences rather than trail use trends, and in any case both adjacent and non-adjacent trees responded similarly.

Looking only at the current growth rates, the trees sampled immediately adjacent to the trails had a growth rate that was about 4% greater than trees sampled that were not adjacent to trails. In looking at the paired samples, in 40% of the pairs, trees adjacent to trails were growing at a faster rate than trees not adjacent to trails, in 40% of the pairs the situation was reversed, and in 20% of the pairs the growth rates were identical.

One sample tree stood out from the others in that it had a growth rate more than 400% greater than the average and almost 200% greater than the next highest growth tree. Ironically, this tree was located in the picnic area of the lower meadow, one of the highest use impact areas. However, the tree was also growing in a filled riparian area providing higher than normal available moisture. Overall, no significant differences were observed in growth rates between redwood trees growing immediately adjacent to trails and with exposed roots in the trails, and trees not adjacent to trails and not affected by trail use compaction and disturbance.

Redwood Forest Understory Vegetation

The redwood forest understory was assessed by NRM's botanist. In particular, traffic impacts (pedestrian, equestrian, and bicycle) and the general health of the understory were noted along and adjacent to the trail system through the redwood (*Sequoia sempervirens*) forested portions of the park. The redwood forest supports a moist (mesic), shady, and sheltered environment for the understory vegetation, which is a unique and important environmental resource for this commonly dry (xeric) woodland to grassland and urban-developed region (East Bay hills).

The understory vascular plants encountered in the redwood forest during the field survey are presented in a species list (Table 4), and the taxonomic nomenclature used was based on *The Jepson Manual* (Hickman 1996). The native plants, which are in bold type in the list, comprise 71% of the total species. The greatest diversity of native plants is in the forest understory: 87% are shrubs or herbaceous species. The understory also has the greatest percentage of non-native plants (31%).

The understory impacts and health problems identified during the field survey were trampling of the vegetation, soil compaction, invasive weed infestation, and a loss of species diversity and native plant components. The vegetation trampling results from all types of off-trail traffic (pedestrian, equestrian, and bicycle) with no distinct difference in degree of impact between the types of off-trail traffic. The off-trail traffic causes direct physical impact to the plants as well as soil compaction, which can be a limiting factor for plants (especially the liliaceous species). Off-trail use was noted throughout the trail system. In particular, the flat and gentle slope areas, such as the ridgeline and spur ridges associated with the Ravine and Big Trees trail areas, were heavily impacted (see Figure 5).

Table 4: Joaquin Miller Park Redwood Forest Vascular Plant Species List. Bolded species are native to California.

Tree Layer:

***Acer macrophyllum* bigleaf maple**
***Alnus rubra* red alder**
***Cupressus lawsoniana* Port Orford-cedar** (planted)
***Pseudotsuga menziesii* var. *menziesii* Douglas-fir**
***Quercus chrysolepis* canyon live oak**
***Sequoia sempervirens* coast redwood**
***Sequoiadendron giganeum* giant sequoia** (planted)
Ulmus sp. elm (planted and escaped)
***Umbellularia californica* California bay**

Shrub Layer:

***Baccharis pilularis* coyote brush**
***Corylus cornuta* var. *californica* California hazelnut**
Cytisus scoparius scotch broom (invasive)
***Gaultheria shallon* salal**
Genista monspessulana French broom (invasive)
***Mimulus aurantiacus* orange bush monkeyflower**
***Physocarpus capitatus* Pacific ninebark**
Pyracantha sp. firethorn
***Rhamnus californica* coffeeberry**
***Ribes menziesii* canyon gooseberry**
***Ribes sanguineum* var. *glutinosum* red flowering currant**
***Rosa gymnocarpa* wood rose**
***Rubus parviflorus* thimbleberry**
***Sambucus racemosa* var. *racemosa* red elderberry**
***Symphoricarpos albus* var. *laevigatus* common snowberry**
***Toxicodendron diversilobum* poison-oak**
***Vaccinium parvifolium* red huckleberry**
***Vaccinium ovatum* evergreen huckleberry**

Herbaceous Layer:

***Actaea rubra* baneberry**
***Agrostis exarata* western bent-grass**
***Asarum caudatum* wild ginger**
***Athyrium filix-femina* lady fern**
Briza maxima large rattlesnake grass
Bromus sp. brome
Carduus pycnocephalus Italian thistle (invasive)
***Carex subfusca* rusty sedge**
Cirsium vulgare bull thistle (invasive)
Conium maculatum poison hemlock (invasive)
Cynosurus echinatus hedgehog dogtail grass
***Cyperus eragrostis* nut-grass**
***Disporum smithii* Smith's fairy bells**
***Dryopteris arguta* coastal wood fern**

Table 4. (Cont.)

Shrub Layer:

***Dryopteris expansa* spreading wood fern**
Duchesnea indica mock-strawberry
***Epilobium ciliatum* northern willowherb**
***Equisetum telmateia* ssp. *braunii* giant horsetail**
***Fragaria vesca* wood strawberry**
***Galium triflorum* sweet-scented bedstraw**
Hedera helix English ivy (invasive)
Holcus lanatus common velvet grass
Hypochaeris radicata hairy cat's-ear
Ilex aquifolium English holly (invasive)
***Iris douglasiana* Douglas iris**
***Juncus effusus* common rush**
***Juncus patens* spreading rush**
Lactuca virosa wild lettuce
***Lathyrus* sp. pea**
***Lonicera hispidula* var. *vacillans* hairy honeysuckle**
***Marah fabaceus* California man-root**
Myosotis latifolia forget-me-not
***Osmorhiza chilensis* mountain sweet-cicely**
***Oxalis oregana* redwood sorrel**
Oxalis pes-caprae Bermuda buttercup
Panicum dichotomiflorum fall panicum
***Pentagramma triangularis* goldenback fern**
***Polystichum munitum* sword fern**
***Pteridium aquilinum* var. *pubescens* western bracken fern**
***Rubus ursinus* Pacific bramble**
Rumex crispus curly dock
***Satureja douglasii* yerba buena**
***Scrophularia californica* coast figwort**
Senecio mikanioides German-ivy (invasive)
***Smilacina racemosa* branched Solomon's seal**
***Smilacina stellata* star Solomon's seal**
***Solanum americanum* small-flowered nightshade**
Sonchus oleraceus common sow thistle

Herbaceous Layer:

***Stachys ajugoides* hedge-nettle**
***Stachys stricta* Sonoma hedge-nettle**
Taraxacum officianale common dandelion
***Tellima grandiflora* fringe cups**
***Tolmiea menziesii* youth-on-age**
Torilis arvensis rattlesnake weed
***Trillium ovatum* western trillium**
***Urtica dioica* ssp. *holosericea* stinging nettle**
***Veronica serpyllifolia* thyme-leaved speedwell**
***Vicia gigantea* giant vetch**
Vinca major greater periwinkle (invasive)
***Viola sempervirens* evergreen violet**

Figure 5: Off-Trail Vegetation Trampling Impacts in the Redwood Forest (Ravine trail area).

There are several internal and external factors contributing to invasive weed infestations, which threaten the diversity and existence of the native plants. The external factors are the surrounding urban development and disturbance, which introduce and spread exotic plants. The internal factors are traffic impacts (trail and off-trail) that destroy the native plants and disturb and compact the soil. These traffic impacts allow an opportunity for the invasive and exotic plants to colonize the edges of these exposed trail corridors, as well as provide a method of seed dispersal for these plants via shoes, hooves, or tires. The majority of exotic and garden plants coexist with native species and are not ecologically harmful. However a small number of exotic plants are ecologically devastating. These exotic plants are highly invasive and their presence can have numerous negative consequences and effects, such as the following (Pickart and Eicher 2000):

- Invasive plants displace native plants, alter habitat (for flora and fauna) and soils, and frequently form monocultures.
- Invasive plants are the second most important reason for loss of biological diversity after habitat destruction.
- Invasive plants in agricultural and natural areas cost our country 13 billion dollars per year.
- The Bureau of Land Management, the nation's largest public landowner, estimates that 2,300 acres per day of its land are being lost to invasive plants.

The following 13 invasive plants were noted during the field survey in or nearby the redwood forest:

1. *Acacia* sp. acacia (outside redwood forest)
2. *Carduus pycnocephalus* Italian thistle
3. *Cirsium vulgare* bull thistle
4. *Conium maculatum* poison hemlock
5. *Cortaderia jubata* weedy pampas grass
6. *Cotoneaster pannosa* cotoneaster
7. *Cytisus scoparius* scotch broom
8. *Eucalyptus globulus* Tasmanian blue gum (outside redwood forest)
9. *Genista monspessulana* French broom
10. *Hedera helix* English ivy
11. *Ilex aquifolium* English holly
12. *Senecio mikanioides* German-ivy
13. *Vinca major* greater periwinkle

The majority of these invasive plants are associated with roadsides, trailsides, and openings in the redwood forest, except Tasmanian blue gum and acacia which form monoculture stands nearby or adjacent to the redwood forest. Two of the invasive plants, English ivy and English holly, are shade-tolerant species that aggressively displace native plants in the closed-canopied portions of the redwood forest. In particular, English ivy has a distinct impact in the riparian corridor associated with Palo Seco Creek downstream of the Lower Meadow in Area “G” (Figure 1), where it has begun to smother the herbs, shrubs, and trees (see Figures 6 and 7). There are several other areas where English ivy is just getting established and will potentially spread rapidly. One area of concern is just below Area “K” (Figure 1), where the slope supports the most diverse and intact native vegetation observed along the trail system during the field survey. This slope supports a large patch of wild ginger (*Asarum caudatum*) and scattered baneberry (*Actaea rubra*), Smith’s fairy bells (*Disporum smithii*), spreading wood fern (*Dryopteris expansa*), star Solomon's seal (*Smilacina stellata*), fringe cups (*Tellima grandiflora*) and western trillium (*Trillium ovatum*).

There are other invasive plant infestations associated with the redwood forest that were observed during the field survey. There is a large periwinkle patch just down slope of the Big Trees trail near Area “J” (Figure 1). There is a moderate-sized patch of German-ivy along the Sunset trail just west of an unidentified trail that connects to the Sequoia Bayview trail. These species also displace native plants and greatly reduce the diversity of an area in both flora and fauna.

Figure 6: English ivy climbing redwood trees (along Palo Seco Creek).

Figure 7: English ivy carpeting and smothering the herbaceous layer (along Palo Seco Creek).

CONCLUSIONS AND RECOMMENDATIONS

Trail reccommendations

General recommendations are presented below to reduce the impact of fluvial and recreation-related erosion on the trail system in Joaquin Miller Park. Specific recommendations for mitigating each erosion feature are presented in Appendix A. Possible mitigation measures to reduce fluvial erosion include:

- Install water bars or repair existing water bars to redirect runoff off trails.
- Redirect ephemeral streams to natural channels.
- Install in board ditches and ditch relief culverts to help drain trails.
- Clean or replace old culverts.
- Replace fill crossings with bridge or rolling dip crossings.
- Regrade trails where deep gullying has taken place.

We note that several established trails have excessively steep gradients and poor alinement, making them both challenging for users and susceptible to erosion. Examples of such trails are the Cinderella Trail, Upper Palos Colorados Trail and the Fern Trail. A long term goal, should funding become available, might be to rebuild these trails incorporating switchbacks to reduce gradient and wooden or stone steps where switchbacks are impractical.

To reduce recreation-related erosion on the trail system, we recommend that off trail or "bootleg" tracks be physically blocked off and signed. The split rail fences that were recently installed on the Sequoia Bayview Trail are an example of an effective barrier. These fences should be maintained regularly, and their effectiveness monitored. Other types of barriers include placement of large rocks, piles of debris, and large logs. All such barriers should be attractive and be seen to fit in with the natural environment. They should divert attention away from the tracks and onto the main trail. Tracks should be blocked off at both uphill and downhill ends. Restoration activities may help to reverse some of the impacts of these trails.

We suggest the addition of signage to the new split rail fences. The text might read:

Off-trail hiking and bicycling damages
delicate forest plants and soils
and is prohibited by law.
STAY ON THE TRAIL

The recommendations described above were determined by reviewing trail and forest road maintenance literature and represent, in the authors opinion, a viable course of action to reduce future erosion of the trails. There are many alternative methods available to treat erosion problems on forest trails. Trail construction and maintenance reference materials are available from a variety of organizations including:

- East Bay Regional Parks
- East Bay Municiple Utilities District
- Marin Municiple Water District
- United States Forest Service
- National Park Service
- International Mountain Bicycling Association

Erosion from forest roads maintained for timber harvest in the Pacific Northwest has been intensely studied in recent decades due to sedimentation problems related to fish habitat, (Elliot and Tysdal, 1999, Weaver et al., 1987, Reid and Dunne, 1984, Megahan and Kidd, 1972). Many mitigation measures have been well tested, documented, and evaluated in erosion control and prevention projects on steep forested lands, and have been shown to be effective in reducing sediment yield from managed forest roads, (Harr and Nichols, 1993, Weaver, 1998, Pacific Watershed Associates, 1994c). These proven techniques used for erosion assessment on forest roads include a field inventory of erosion and mitigation recommendations designed to minimize or eliminate the erosion. These recommendations usually entail a physical modification of the road surface (i.e. diversion ditches and/or regrading), in order to divert surface water runoff away from the road, minimizing future erosion. Many parallels exist between timber harvest roads and the trails in Joaquin Miller Park, such as compaction due to land use, loosening of surface soils, and drainage problems. Because of these similarities, techniques used to reduce erosion on forest roads may be applied to recreational trails.

We recommend that the City of Oakland, Office of Parks and Recreation review the available literature and consult related organizations in order to determine the most cost effective erosion mitigation for Joaquin Miller Park. We believe that park dollars would best be spent on the installation and maintenance of erosion control structures on the steeper trails in the park where erosion impacts are the worst.

Redwood forest recommendations

Several recommendations are presented below to reduce traffic and invasive weed impacts to the redwood forest understory. These recommended measures involve a combination of protection and restoration of the native vegetation, and weed abatement. Adoption of these recommendations can be done over a short or long time period, as logistics allow (such as funds and labor). The most important step is to initiate these recommendations at some level, because every effort can have cumulative effects and substantial results. An example is the volunteer restoration program across the San Francisco Bay at the Golden Gate National Recreation Area that has made a tremendous difference over time in several degraded open areas. The initiation of these recommendations should first involve the identification and prioritization of the problem areas and then set the objectives and goals for these areas. The recommendations are:

- Install additional barriers to divert off-trail traffic, and limit traffic impacts to the established trails.
- Initiate an invasive weed control program. Efforts in this direction will benefit not just the native plants, but birds, insects, fish, and other wildlife, as well as increase the aesthetic qualities of the park.
- Initiate revegetation and/or native plant enhancement projects for poorly vegetated areas, weed eradicated areas, and any recently disturbed areas. This effort could be coupled with the invasive weed control program.
- Daylight and restore the subsurface portion of Palo Seco Creek in the Lower Meadow area. This headwater area of the creek within the park is one of the few semi-intact natural functioning watersheds in the East Bay and is a valuable environmental resource for both flora and fauna (See Riley, 1998).

The traffic barriers are an effective method to divert and limit off trail traffic. These diversions help to protect the existing vegetation and/or promote revegetation of the understory, as well as minimize off-trail erosion and channeling of surface water run-off. Presently there are several short lengths of split rail fencing that have been installed along portions of the trails, which have successfully diverted off-trail traffic. There are several areas of intact native vegetation along the ridgeline associated with the Big Trees trail that would be good candidates for diversion structures, such as the split rail fencing. The protection of intact understory vegetation and soil in high traffic areas not only maintains native species presence, but serves as a seed source of regionally appropriate native plants that can be utilized for natural expansion or future restoration projects.

An invasive weed program is essential in maintaining the health, diversity, and esthetics of the redwood forest understory. Invasive weed infestations are indicators of a degraded habitat (disturbed and low functioning). Any effort toward invasive weed abatement is beneficial and can utilize community, park, city, state, and/or federal resources (such as California Exotic Pest Plant Council, University of California Cooperative Extension Services, California Conservation Corps, community service work groups, local chapter of the California Native Plant Society, and community/school volunteers). An example of a good initial effort would be to girdle the English ivy on the redwoods by cutting through the stems of the ivy around the base of the trees (being careful not to harm the trees). The ivy will eventually kill the trees and the aerial portions of ivy are the fertile shoots that produce the fruit, which is dispersed by birds. There has been a recent federal mandate to address weed issues (Presidential Executive Order on Invasive Weeds, February 1999) and to encourage planning and action at local, tribal, state, regional, and ecosystem levels, which is generating funds such as grant monies.

The overstory in the redwood forest appears in good health (this issue has been further addressed in this report), however the understory does appear to be the most affected by general trail traffic. One of the goals of the park users and staff should be to join together to abate the degradation of this valuable community and environmental resource through protection and restoration the of the redwood forest understory vegetation.

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APPENDIX A

Field Data sheets of individual erosion features with photographs.