ENVIRONMENTAL CONDITIONS

GEOLOGY

Folsom Lake State Recreation Area

April 2003

by

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Introduction

This summary documents the geologic and subsurface conditions at the Folsom Lake State Recreational Area (the Unit). Fieldwork consisted of a brief site reconnaissance. Literature reviewed included published scientific articles, maps, files, and previous studies pertaining to the Unit. No subsurface investigations were performed as part of this Resource Inventory. The purpose of this summary is to:

- Describe the geology, mineral resources, and geologic hazards of the Unit,
- Identify the types and locations of geologic and geotechnical concerns for inclusion in the General Plan.

The primary sources for the background research were the California Division of Mines and Geology (now the State Geological Survey) Regional Geologic Map 1A (Figure G-1), Mineral Resources maps, and various other publications available from the United States Geological Survey (USGS) or University of California at Berkeley Earth Sciences libraries. We also reviewed documents provided by LSA and WRT. A list of source documents is included in the reference subsection.

Topography

The Unit lies within the American River watershed. Folsom Lake occupies the deep, narrow, V-shaped canyons of the North and South Forks of the American River and the valley at the confluence of the two forks. At the spillway elevation of 466 feet, Folsom Lake extends upstream on the North Fork to just south of Auburn, and about a mile east of where Salmon Falls Road crosses the South Fork. Lake Natoma lies in the wide gulch of the American River cut into Tertiary sedimentary rocks below Folsom Dam.

Elevations in the upper Folsom Lake area range from around 1,500 feet along the ridge tops between the North and South Forks of the American River, though this ridge does not lie within the Unit boundary. The highest elevation within the Unit is just over 800 feet and occurs in the hills surrounding the Peninsula Campground. The rolling hills above the canyon of the North Fork range from 800 to 900 feet, but the highest elevation in the Unit in the upper reaches of the North Fork is between 600 to 800 feet. The low terraces surrounding lower Lake Natoma are about 100 feet in elevation. Slopes are generally steep to moderately steep along the margins of Folsom Lake, the exceptions are at the Peninsula Campground area, Goose Flat, and the Granite Bay area.

Figure G-1: Regional Geologic Map

Regional Geology

The Folsom Lake State Recreation Area is situated within the westernmost extent of the Sierra Nevada Foothills, between the Central Sierra Nevada and the Central Valley Geomorphic Provinces. The Sierra Nevada is a geomorphic region in California characterized by a north-northwest trending mountain belt with a broad region of foothills along the western slope (Harden, 1997). The Folsom Lake Region is dominated by rolling hills and upland plateaus located between major river canyons. Folsom Lake is impounded above Folsom Dam; it occupies the lower reaches of the canyons of the North and South Forks of the American River, with a peninsula extending between the two arms of the lake. Lake Natoma, downstream of Folsom Dam and behind Nimbus Dam, occupies a broad river valley that is incised into sedimentary rocks.

The margin of Folsom Lake has considerable topographic relief as shown by the hill slopes depicted in the slope map of Figures G-2 and G-3. Steep bluffs occur on a portion of the north side of Lake Natoma; elsewhere, the topography is subdued.

One major fault zone traverses the Unit; it is the west trace of the Bear Mountains Fault Zone. In the Unit area, the fault trends nearly north-south from Auburn to El Dorado Hills, crossing Folsom Lake in the upper reaches of the North Fork arm near Manhattan Bar Road, and crossing the South Fork arm at about New York Creek. This portion of the fault zone is characterized as not active (Jennings, 1994).

Three major geologic divisions occur in the Unit area. From oldest to youngest, these are: 1) a north-northwest trending belt of metamorphic rocks with included ultramafic (dense, and rich in iron and magnesium) rocks, 2) younger granitic intrusive plutons that intruded and obliterated some of the metamorphic belt, and 3) nearly flat-lying deposits of volcanic ash, debris flows, and alluvial fan deposits that overlie the older rocks. These divisions have created a varied and interesting geology within the boundaries of the Unit.

Unit Geology and Mineral Resources

The overall trend of the regional structure is defined by the predominantly northwest-southeast-trending belt of metamorphic rocks and the strike-slip faults that bound them. The structural trend influences the orientation of the feeder canyons into the main canyons of the North and South Forks of the American River. This trend is interrupted where the granodiorite plutons outcrop (north and west of Folsom Lake) and where the metamorphic rocks are blanketed by younger sedimentary layers (west of Folsom Dam) (Wagner *et al*., 1981).

The four primary rock divisions found in the Unit area are: 1) ultramafic intrusives, 2) metamorphics, 3) granodiorite intrusives, and 4) volcanic mud flows. Each is associated with a particular part of the tectonic history; each has distinct mineral resources. These are described below.

Ultramafic intrusive rocks: Ultramafic rocks are not commonly found at the surface of the

Figure G-2A: Slope Map of the Unit (Folsom Lake)

Figure G-2B: Slope Map of the Unit (Lake Natoma)

Earth. The ultramafic rocks found in the Unit represent the lowest part of the Earth's crust. These rocks have been lifted as much as 20 miles vertically by the faulting and underthrusting of other pieces of crust, which probably occurred when crust was added to North America by accretion. The term "ultramafic" indicates enrichment of magnesium, manganese, and iron in the minerals that form the rock. The rock names of these units are dunite, pyroxenite, and peridotite. Outcrops of ultramafic rocks tend to be resistant to erosion and often form topographic highs. Outcrops are gray or green in color if fresh, tan if weathered. They are identified easily in the field by the extraordinary density of the rock. The largest exposure of ultramafic rocks occurs on Flagstaff Mountain on Folsom Lake Peninsula, with a small outcrop found south of the lake on the hill known as "Iron Mountain". Some geologists assert the Pillikin ore deposit may be part of a larger ultramafic intrusive body known as the Pine Hill Complex that intruded the pre-existing rocks about 157 to 175 million years ago (Jurassic). The main body of the Pine Hill Complex occurs south of the South Fork of the American River east and south of Salmon Falls.

Ultramafic rocks occur as the base of a sequence of oceanic sediments that include volcanically derived materials such as pillow basalts and andesite breccia. Oceanic sediments generally occur above the volcanics, examples of which include deepwater limestone, chert, shale, and greywacke sandstone.

Mineral resources for the area are described in Loyd (1984) and Kohler (1984); both of their works are publications of the California Division of Mines and Geology (now known as the State Geological Survey). Minerals associated with ultramafic rocks include chromite, minor nickel, talc, and asbestos. The richest chromite mining area in the western foothill region occurs on Flagstaff Hill (just northeast of the Peninsula Campground), where chromite (Cr_2O_3) occurs in pod-shaped deposits within the ultramafic unit. Mining occurred sporadically from numerous sites on and around Flagstaff Hill between 1894 and 1955 (El Dorado County Library website). Presently, the mines are idle or abandoned. Several mine or prospect workings occur in the Unit: Zantgraf mine, about a mile south of Goose Flat; an unnamed adit about ½ mile south of Goose Flat; a mineshaft in Granite Ravine and another about ¼ mile south of Anderson Creek in the Peninsula Campground area. One of the more well-known old mines is the Pilliken Chrome Mine, accessed from Rattlesnake Bar Road, the access road to the Peninsula Campground. Some of the abandoned mines are still open and may pose a hazard to Unit users. The locations and status of these mines may become important in the future if future acquisitions are made on the Peninsula.

The entire belt of ultramafic rock is designated MRZ-2b for chromite and MRZ-3a for asbestos and talc. MRZ-2b is defined as "areas containing deposits where geologic information indicates significant inferred resources are present". MRZ-3a is defined as "areas in which undiscovered mineral deposits similar to known deposits in the same producing district or region may be reasonably expected to exist (hypothetical resources). Such areas may include prospects of undetermined significance".

Metamorphics: A north-northwest trending band of metamorphosed sediments and slightly metamorphosed igneous rocks occurs east of Rattlesnake Bar, through most of the peninsula between the two arms of the lake, and all along the southern margin of the Unit. These metamorphic rocks, known as the Copper Hill Volcanics, make up the western part of a long belt of metamorphic rocks that occurs generally west of the main batholith (granitic body) of the Sierra Nevada and east of the more flat-lying sedimentary rocks of the Central Valley. The metamorphic rocks represent ancient chains of volcanic islands (island arcs) and the associated seafloor sediments; these have since been buried, squeezed, and heated to form metasedimentary and metavolcanic (metamorphosed volcanic) rocks. The island arcs were added (accreted) to the western margin of North America during a long time period (Jurassic and Cretaceous) when a vast ocean plate was being subducted beneath the continent. Each related set of accreted rocks is known as a "terrane"; terranes are separated by faults. The Melones Fault and Bear Mountains Fault are examples of major faults that separate adjacent terranes. The metamorphic rocks exhibit nearly vertically dipping foliation in most areas, creating tombstone-like outcrops where thin soil covers the bedrock around the bases of tablet-shaped protuberances.

The age of the volcanic rocks has been measured as 160 ±5 million years (Clark, 1964; Saleeby, 1982; Day *et al*., 1985). The timing of the metamorphic deformation ranges from about 153 ±2 to 139 million years ago (Schweickert *et al*., 1984; Paterson *et al*., 1987).

Mineral resources associated with the metamorphic rocks include disseminated gold, lode gold, copper, and zinc. A small limestone body that occurs within the metamorphics is also mined; it is located on the north side of the peninsula opposite Rattlesnake Bar. Mines and small pits are found away from the lake margins. The entire metamorphic belt is designated MRZ-3a, defined as "areas in which undiscovered mineral deposits similar to known deposits in the same producing district or region may be reasonably expected to exist (hypothetical resources). Such areas may include prospects of undetermined significance".

Granodiorite intrusive rocks have slightly more iron and magnesium-bearing minerals and less quartz than granite. Crystal sizes range from less than a millimeter to several millimeters; overall, the rock is fairly coarse-grained. Two bodies of granodiorite have intruded the older metamorphic rocks along the north and west side of Folsom Lake; they are named the Rocklin and Penryn Plutons. The Penryn Pluton occurs upstream from the Rocklin Pluton, though there is some interfingering of the two rock masses near the boundary (at about Granite Bay). The Rocklin Pluton is present on both sides of Folsom Dam, extending to the upper reaches of Lake Natoma.

Dark-colored mafic dikes (containing magnesium and iron-rich minerals) occur near the edges of the granodiorite plutons. Some of the dikes consist almost completely of the mineral hornblende. Some good examples of these are found at low water along the peninsula near the contact between the Rocklin Pluton and the metamorphics. Additional rock types found in the mafic dikes include amphibolite and gabbro. Also associated with the plutons are light-colored aplite (granite with very small crystal sizes) and pegmatite dikes. These are most common at the contact between the two plutons.

Ages of the plutons and dikes are summarized in Table G-1**,** Ages of the Intrusions. An interesting point is that these small plutons are younger than the usual age of intrusions in the high Sierra; and that the typical gold-bearing quartz veins associated with other Sierran granitic intrusions do not occur in association with these plutons.

Table G-1: Ages of the Intrusions

Unit	Age	Reference
Rocklin	128 to 131 ± 3.3 my*	Wagner and others, 1981
Penryn	139.5 ± 0.2 my	Wagner and others, 1981
Other mafic intrusions (hornblende and aplite dikes)	≤128 my	Swanson, 1978
Sierra Nevada	96 to 143 my (highly variable)	Wagner and others, 1981

*my = million years

No indications of identified mineral resources associated with the granodiorite plutons are noted on the mineral resource maps of Loyd (1984) or Kohler (1984).

Volcanic mud flows and consolidated alluvial deposits occur below Folsom Dam and are best exposed along the bluffs on the northwest side of Lake Natoma and at Nimbus Dam. Two units are identified on the regional geologic map – the Miocene to Pliocene-aged Mehrten Formation and the Pliocene Laguna Formation. The bulk of the bluff on the west side of Lake Natoma exposes Merhten, a complex unit of volcanically derived sediments mixed with volcanic mudflows. Above the Merhten is the Laguna Formation, a sequence of gravel, sand, and silt derived mainly from granitic and metamorphic sources. The mode of deposition of both these units was by debris flow and stream deposits.

The mineral resource associated with the Mehrten Formation is placer gold, which occurs in the bases of ancient stream deposits. The only place within the Unit where Mehrten deposits are exposed is in the bluffs northwest of upper Lake Natoma.

Dredge deposits are man-made as a result of placer gold-mining activities. The dredge deposits cover the entire southeast side of Lake Natoma as well as a large portion of the northwest side. These deposits are mainly well-washed large gravel, cobbles, and boulders that have been washed clean of finer-grained sediment and left in large, unorganized heaps along the river banks.

The deposits themselves are their only mineral resource. The well-rounded cobbles and boulders could be mined for landscape rock.

Lithology

The geologic units are described below in stratigraphic order (oldest to youngest) in Table G-2, Stratigraphic Column. Descriptions are taken largely from Wagner *et al* (1981).

Table G-2: Stratigraphic Column

Age	Geologic Unit
Pleistocene	Riverbank–Modesto Formation
Pliocene	Laguna Formation
Pliocene Miocene	Mehrten Formation
Early Cretaceous Latest Jurassic	Rocklin Granodiorite
Early Cretaceous Latest Jurassic	Penryn Granodiorite
Jurassic	Copper Hill Volcanics
Jurassic	Salt Springs Slate
Triassic	Ultramafic rocks

Ultramafic rocks – The ultramafic rocks were originally formed as intrusive bodies of peridotite, pyroxenite, and gabbro as deep as 10 miles below the surface approximately 157 to 175 million years ago (Page, *et al*., 1982). Over time, and with tremendous tectonic forces, these rocks have been uplifted and exposed by erosion of the overlying rocks. Most of the original minerals have been altered to serpentine minerals (light- to dark-green aggregates of antigorite, chrysotile, and chlorite). Where the majority of minerals are serpentine, the rock is called serpentinite. Some occurrences of talc schist and magnesite are found locally near Flagstaff Hill. Ultramafic rock is resistant and generally forms topographic highs. Soil developed over serpentinized ultramafic rocks tends to be high in nickel and cobalt, creating toxic conditions for many plants. Consequently, a limited variety of plants are found over these rocks.

Salt Springs Slate – Minor outcrops of Salt Springs Slate are mapped on either side of the river just east of the bridge over Lake Natoma along Folsom-Auburn Road. The slate is mainly dark gray with some mica schist. Salt Springs Slate was originally shale that was metamorphosed during accretion onto the continent and subsequent deformation. Slate is resistant to erosion and breaks into thin tablets.

Copper Hill Volcanics – Copper Hill volcanic-related rocks occur all along the southern margin of Folsom Lake as well as in a small patch on either side of the river just east of the bridge over Lake Natoma along Folsom-Auburn Road. These rocks are described as metamorphosed basaltic breccia and ash (mafic pyroclastic) rocks, pillow lava, and minor bodies of granitic composition (felsic porphyrite). The origin of most of these rocks is at or near an oceanic island volcanic arc that was later added (accreted) to the continent and deformed. These rocks are generally resistant to erosion and form thin, clayey soil.

Penryn and Rocklin Granodiorite – These intrusive bodies were emplaced within the existing metamorphic belt at a relatively shallow depth (2 to 5 miles). Quartz diorite and diorite make up the primary rock types of the Penryn Pluton (Wagner *et al*., 1981). Light gray silica-rich quartz diorite makes up the Rocklin Pluton (Olmsted, 1971). Crystal sizes range from several centimeters for some potassium feldspars to a millimeter or less. Weathering breaks down the feldspar and the hornblende of the granodiorite causing the more resistant quartz crystals and remaining feldspars to separate from the main rock and form “decomposed granite”. This coarse, sandy material is easily weathered and moved by water. The areas of worst erosion in the Unit are those underlain by granodiorite.

Mehrten Formation – This complex unit is comprised of mainly volcanic conglomerate and ash-rich (tuffaceous) sandstone and siltstone derived from andesitic sources (likely the ancient Sierran volcanic mountains). Coarse stream deposits are also found within the Mehrten; some of these contain placer gold in beds with the coarsest material. The most resistant beds in the Mehrten are andesite mudflow breccias that form steep cliffs where they are exposed along the Lower American River north of Lake Natoma. The age is late Miocene to early Pliocene.

Laguna Formation – This unit consists of consolidated alluvial gravel, sand, and silt composed of granitic, metamorphic, and some volcanic detritus. It was deposited mainly as debris flows and as alluvial fan and stream deposits. Some of the sediment was derived from eroded Mehrten Formation. Some of the beds of the Laguna Formation represent flood deposits and were deposited under high energy conditions. Such beds may contain placer gold that has been reworked from older placer deposits or eroded from lode gold deposits upstream. The age is Pliocene. Land vertebrate fossils have been found in other locations along the Foothills in finer-grained deposits of the Laguna Formation.

Quaternary Modesto-Riverbank Formations – These units occur nested within the lower valley of the American River downstream of Folsom Dam. Modesto and Riverbank Formations are young and largely unconsolidated. The bulk of their sediment is derived from decomposed granite and metamorphic rock of the western Sierra. The age is Pleistocene. Where fine-grained deposits occur, land vertebrate fossils may be found.

Structure

Structures of the metamorphic belt are, in general, parallel to the main through-going faults of the Bear Mountains Fault Zone. Within the metavolcanic and metasedimentary units, contacts are nearly vertical and often lie nearly parallel to the cleavage planes. Isoclinal folds have been identified along the same trend, some miles south of the Unit. The Bear Mountains Fault Zone itself is nearly vertical, with a slight east dip.

The granodiorite plutons are fairly young and undeformed, indicating that most of the deformation associated with the metamorphic belt had ceased by the time of emplacement of the plutons. The plutons cut across the northwesterly trend of the metamorphics. Small faults and shears have been described by Olmstead (1971) in both plutons. The relative sense of displacement is strike-slip with a nearly vertical fault plane. Individually, the faults show only minor displacement, but the offsets add up over hundreds or thousands of microfaults. Also, joint sets have been measured in the plutons by Olmsted (1971).

The sedimentary Mehrten Formation lies unconformably above the Rocklin Pluton and the metamorphics. These beds dip to the west at a very low angle and do not appear to be cut by any faults.

The relationships of these units and their relative positions are depicted in Figure G-4, Cross-Section of the Area Just South of the Folsom Lake State Recreation Area.

Geologic History

The following geologic history is based on that provided by Chapter 3 of Norris and Webb (1990).

During the Jurassic period, from about 160 to 140 million years ago, several volcanic island arcs were accreted as the ocean plate in which they were embedded was subducted beneath western North America. These rocks are interpreted to have originated as crystalline and volcanic oceanic crust, and deep ocean sediments. As they were attached to the continent, they were folded and metamorphosed. Near the end of the Jurassic or early in the Cretaceous, the subduction zone shifted west of the modern Great Valley. The magma generated by the subducting oceanic slab came up as isolated plutons in the western Sierra rather than coming up as part of the main Sierran Batholith. In the early Cretaceous, the Penryn and then the Rocklin plutons were emplaced within the western metamorphic belt. A long period of erosion wore away the volcanic peaks and metamorphic cover of the ancient Sierra Nevada, eventually exposing the granitic core beneath. By Eocene time (about 50 million years ago), the Sierra was a relatively subdued mountain range, much like the modern Coast Ranges, with a shallow sea flanking the western side where the Great Valley lies today. Deep canyons and incised river valleys carried eroded rock away from the mountains. Lode gold was exposed by the downcutting rivers, and bits of gold were washed into the streams.

By the close of Oligocene time (about 24 million years ago), the west-flowing stream valleys and ridges became buried under thick deposits of quartz-rich volcanic ash probably derived from volcanoes to the east in Nevada. Another phase of canyon-cutting and erosion took place before a second volcanic episode blanketed the landscape with basaltic and andesitic flows, breccias, and volcanic-rich mud flows (lahars) of the Mehrten Formation.

Sometime in the Pliocene, the Sierra Nevada started to rise. The most uplift probably occurred on the east side, where huge normal faults separated the massive batholith from the faulted, broken crust of the Great Basin. With uplift came the erosion of new canyons. These canyons formed generally between the old river valleys and canyons which had been filled with volcanic flows and were slightly more protected than bare rock. These rivers were the ancestors of the modern American River.

In the Pleistocene, glaciers formed in the high elevations of the Sierra Nevada. Their movement gouged and scoured the upland valleys. The meltwater rivers carried the sediment to what was by then a shallow inland bay (the Great Valley).

Figure G-4: Cross Section of Area Just south of the Unit

Geologic Hazards, Constraints, and Sensitivities

Significant Features

Paleontological – There are no paleontological resources in the metamorphic, ultramafic, or igneous rocks. Some fossils of vertebrate land mammals have been recovered from the Laguna Formation in other areas along the western edge of the Foothills; similar fossils could be found on the north side of Lake Natoma at the outcrops of Laguna Formation. The Society of Vertebrate Paleontology has determined that such fossils are significant and important. California law protects significant fossils when found on State land.

Mineralogical – Economical mineral resources have been mined in the region in the past, and mining may become economical or feasible again in the future. Abandoned chromite mines occur on Flagstaff Mountain on the Peninsula of Folsom Lake. Abandoned or idle pit mines for talc and asbestos occur on the peninsula between the forks of the river. Placer gold occurs in the active streambeds of the American River upstream of the lake. Dredge tailings represent the past activity of dredging for placer gold; reworking of the tailings may occur in the future.

Structural and Other Features– The most interesting geologic feature of the Folsom Lake area is the contact between the younger, intruded plutons and the older, pre-existing metamorphic rocks. This boundary is well exposed near the Peninsula campground and at Rattlesnake Bar. Interpretive signs at the contact could be used to explain the relationship.

Another significant geologic and structural feature is the large exposure of ultramafic rocks on Flagstaff Mountain. Both top and bottom of this unit are fault contacts that represent the juxtaposition of rock that formed as deep as 20 miles into the crust against sediments that were deposited on the sea floor and later heated and squeezed to become the metamorphic belt.

Dredge tailings are a historical relict of the gold mining heyday of California and are well exposed in the Unit. Again, interpretive signs could tell the story of the occurrence of placer gold and the methods used to recover it.

Landslide Hazards

Factors influencing slope stability in the Unit include slope inclination, bedrock geology, geologic structure, geomorphology, weathering, vegetation, and precipitation. In studies of landslides along the Highway 50 corridor, Wagner and Spittler (1997) noted that many slides originated at the contact between metamorphic and granitic rocks. They also described landslides that occurred at the contact between Tertiary sedimentary rocks (Mehrten Formation) and the underlying metamorphic and granitic rocks. Similar conditions may be present in the Unit where the sedimentary Laguna Formation overlies metamorphic bedrock. Examples of this relationship can be found in places along the north side of Folsom Lake where granite hills are topped with Mehrten Formation (Mooney Ridge), and near the upper reaches of Lake Natoma east of the river (near Folsom) where Laguna Formation overlies metamorphics.

Wagner and Spittler (1997) described examples of landslides caused by geologic structures. When joints in the granodiorite or foliation in the metamorphics are oriented parallel to the slope, zones of weakness tend to develop along the joints or foliation, and landslides often result. Slides often occur along roads where steep cuts have been made into rock with natural joint sets that create surfaces inclined toward the road. Specific examples of where such landslides may occur in the Unit would require site-specific studies, though it is likely that jointed and fractured rock will be encountered throughout the portion of the Unit in metamorphic rock (south and east of Folsom Lake and on the Peninsula). Prior to design of new trails or roads, the local geologic conditions should be examined to determine if the proposed cuts might trigger a landslide.

Debris flows generally form from the rapid movement of thick collections of colluvium and soil that develop in swales between ridges or hills. Further field investigation will be necessary to identify colluvium-filled swales or valleys in the Unit.

Heavy rains increase the weight of soil and colluvium by adding water. Water also reduces the amount of friction within a soil and colluvial mass, increasing the likelihood of a slide or debris flow. More shallow slides and debris flows should be expected during wet weather associated with El Niño winters.

Landslides, mudflows, and rockfalls are not considered a major hazard in the Folsom Lake portion of the Unit as most soils are too thin and slopes are too low to create conditions for mass wasting; however, the steep bluffs along the northwest side of Lake Natoma are unstable based on observations made during the Unit visit. These bluffs could spill rocks or chunks of loosely consolidated material onto the popular walking and cycling path at the base of the slope, especially after a rain storm or during groundshaking from a distant earthquake. Further studies should be performed on the Natoma bluffs to determine the best method to protect Unit users from rockfalls.

Subsidence

Land subsidence is the sudden sinking or gradual downward settling of the Earth's surface. Subsidence can be due to natural geologic processes such as cavern collapse or peat oxidation or by human activity such as mine collapse or extraction of oil, gas, or water from the subsurface. A form of subsidence called hydrocompaction can also occur when unconsolidated materials are irrigated, resulting in gradual collapse of the originally loose soil structure.

The possibility for hazard from subsidence is very low around the Unit as the conditions required for many of the subsidence processes do not exist. Local collapse of small mines around Flagstaff Mountain is unlikely as the extent of the mine shafts is limited and the surrounding rock appears to be stable (based on local field experience).

Volcanic Hazards

Volcanic hazards include ash fall and lava flows. The Unit is not in any danger of flows, but there are several dormant volcanic centers in California that could, under the right conditions, create an ash fall hazard. One example is the Clear Lake volcanic center; ages of deposits in the volcanic field range from 1.9 to 0.09 million years old (Jennings, 1994), and the geothermal gradient remains anomalously high. Clear Lake volcanism could generate an eruption that is about 80 miles upwind of the Unit. The Long Valley Caldera region

(Mammoth Lakes) could also generate an eruption with large amounts of ash, though the prevailing wind direction is more to the east and south of the study area.

The closest recent volcanic event is a lava flow mapped near Dardanelle on Highway 108, 75 miles east-southeast from the Unit. The age of the flow is 0.15 million years old (Jennings, 1994).

Seismicity

The U.S. Army Corps of Engineers (ACOE) Waterways Experiment Station conducted seismic stability analyses of all features of the Folsom project in the 1980s. Eight reports published between 1987 and 1989 indicated a seismic stability deficiency due to the liquefaction hazard at Mormon Island Auxiliary Dam. All other features of the project were declared stable considering a Maximum Earthquake (Mmax) of Magnitude 6.5, occurring at a distance of 15 kilometers on the East Branch of the Bear Mountains Fault Zone. Calculations by the ACOE estimated that the earthquake would generate 0.35 g (gravity) peak acceleration on rock outcrops, 20 centimeters/second peak velocity, and a 16-second duration of ground motion above 0.05 g. Extensive liquefaction of the dredged alluvium foundation under Mormon Island Auxiliary Dam was anticipated from this level of shaking (USACE Long Term Study, Chapter 2). This worst-case scenario earthquake for the Bear Mountains Fault Zone has a low probability of occurrence, and the State Geological Survey has not designated the Bear Mountain as an active fault. The only recorded moderate earthquake in the Foothills is the 1975 Oroville earthquake with a Richter magnitude of 5.7 (University of California at Berkeley Seismicity Catalog).

Quaternary faults that could affect the Unit include the following:

Fault name	**Closest distance to fault from Folsom Dam**	**Maximum expected earthquake (Richter magnitude)**
Bear Mountains Fault Zone	11 miles ENE	6.5
Concord Fault	67 miles WSW	6.9
Northern Hayward Fault	82 miles WSW	6.9
San Andreas Fault	102 miles WSW	7.9
Buried thrust fault near Vacaville	about 50 miles WSW	6.5

From Jennings, 1994; USGS, 1996.

While all of these faults have the potential to generate magnitude 6 to 7 earthquakes (the San Andreas could generate a magnitude as high as 7.9) (U.S.G.S., 1996), the risk of shaking at the Unit is very low due to the distance from major faults, the hard bedrock, and the thin soil cover. The California Division of Mines and Geology (CDMG) Seismic Shaking Hazard Map (1999) shows the Unit to lie within a zone labeled as having a 10 percent probability of exceeding 0 to 10 percent g (gravity) in 50 years. Another method of estimating the hazard from the overall seismicity is comparing rates. The rate of seismicity of the western Sierra

Nevada Foothills is about 3 percent of the seismicity rate of the Central Coast Region of California (Uhrhammer, 1983).

Shoreline Erosion

While the Unit is not on an oceanic coast, it does have a lake shoreline that is subject to similar erosion processes. Erosion appears to be caused mainly by wind-generated and boat-generated waves lapping along a margin with no sand armor. Changing lake water levels and wave action have effectively stripped the soil from most areas around the lake margin ranging from the high to low lake levels. The sediment is redeposited within the lake basin.

Areas undergoing greater than normal erosion are those where runoff from land is funneled into gullies and streams surrounding the lake basin. In places, runoff from paved surfaces (streets, driveways, and roofs) surrounding the lake has caused considerable erosion. The locations where this is occurring, as noted on the site reconnaissance, is around the new neighborhoods (area of homes on and around Francisco Drive off Green Valley Road and area of homes on and around Lakehills Drive off Salmon Falls Road).

Another cause of erosion is off-road vehicle activity. For example, at Rattlesnake Bar, numerous random roads expose bare ground. During rainstorms, no vegetation is present to slow the runoff and allow percolation into the soil. Instead, water rushes down the roads, carrying fine-grained soil along. Some of the roads are so heavily rutted, that off-roaders have created new roads to bypass the old ones, thereby exacerbating the problem.

Unlike oceanic coasts, there is no longshore current in the lake to naturally replenish sand on the beaches. When too much sand has been removed by wave action at popular beaches, artificial replenishment is the only way to re-sand the beaches; however, this is a costly undertaking that would probably be reserved only for popular bathing beaches.

Control of erosion within the Unit will be an ongoing effort. Gullying should be controlled through methods such as closing some areas to off road vehicles, redirecting natural drainages and street runoff into settling ponds, and installing devices or materials to slow water flow within drainages. In some areas, revegetation programs could help by stabilizing bare ground. Erosion control plans should be designed for each area identified by CDPR personnel as at risk from continued erosion.

Recommendations

The primary recommendations in this report are for further study of the bluffs over Lake Natoma, resolving erosion problems along Folsom Lake caused by off-road vehicle use, and resolving erosion problems caused by suburban storm water releases into the lake basin.

Changing economic conditions may cause some of the abandoned mines to once again become viable. If a larger portion of the Peninsula is added to the Unit (a portion that includes many old mines), the legal implications of the rights of mining claim owners should be reviewed so that CDPR staff are aware of potential legal and access issues.

Due to the constraints of the budget, no fieldwork was performed for this analysis. Thus, before any facilities are proposed, a geotechnical investigation should be performed to address the relevant issues associated with the Unit and the particular site.

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