MATILIJA DAM
Ecosystem Restoration Feasibility Study

Appendix C
GEOTECHNICAL REPORT

September 2004

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1. General

Matilija Dam is located on the Matilija Creek, approximately 15 miles north of the City of Ventura (see Figure 1). The thin arch concrete dam was built in 1947 by Ventura County and has undergone significant degradation of the concrete due to an alkali-aggregate reaction. The dam, originally 190 feet high, has been notched twice; the crest is currently 160 feet above streambed. The thickness of the arch structure varies from 8 feet at the crest to about 35 feet at the base. The original capacity of the reservoir, 7000 acre-feet, has been reduced to less than 400 acre feet due to sedimentation and the notching. The dam is owned by the Ventura County Flood Control District and operated by Casitas Municipal Water District.

2. Purpose

The purpose of this report is to summarize the existing geotechnical conditions at Matilija Dam, including an assessment of the proposed uses of the impounded sediments. The report summarizes the pertinent literature review, field and laboratory investigations, geotechnical site conditions and evaluations of dam and sediment removal alternatives.

3. Coordination

This geotechnical report is the result of a team effort between the Geotechnical Branch of the Los Angeles District (USACE – Geotechnical), and the local sponsor, the Ventura County Flood Control District. Acting as the sponsor's geotechnical representative was the Bureau of Reclamation, Mid-Pacific Region Office, hereafter referred to as "Reclamation". Tasks between the agencies were negotiated and are identified in the Project Study Plan (PSP). The following is a brief summary.

3.1. Reclamation

Reclamation was responsible to conduct all the drilling, coring, and sample collection to obtain subsurface data and sample material. This responsibility included all regulatory coordination, access road development and addressing issues associated with placing and operating the barge in the reservoir and drill rigs on land. Reclamation provided field geologists, prepared logs, and documented the exploration and sampling.

3.2. USACE – Geotechnical

USACE-Geotechnical was responsible for (1) establishing sampling protocols, and for the processing and testing of samples at both Corps and contract labs to determine engineering and environmental characteristics of the sediments, (2) site characterization, including grain-size distribution and contamination of the sediments, and to assess the uses of the sediment with respect to the various proposed alternatives, and (3) summarizing existing literature on the nature and condition of the concrete in the dam. During Plan Formulation, USACE-Geotech was responsible for addressing geotechnical issues such as dewatering, slope stability, constructibility and participated in the actual formulation and assessment of various alternatives.

4. Geotechnical Site Characterization for Matilija Dam

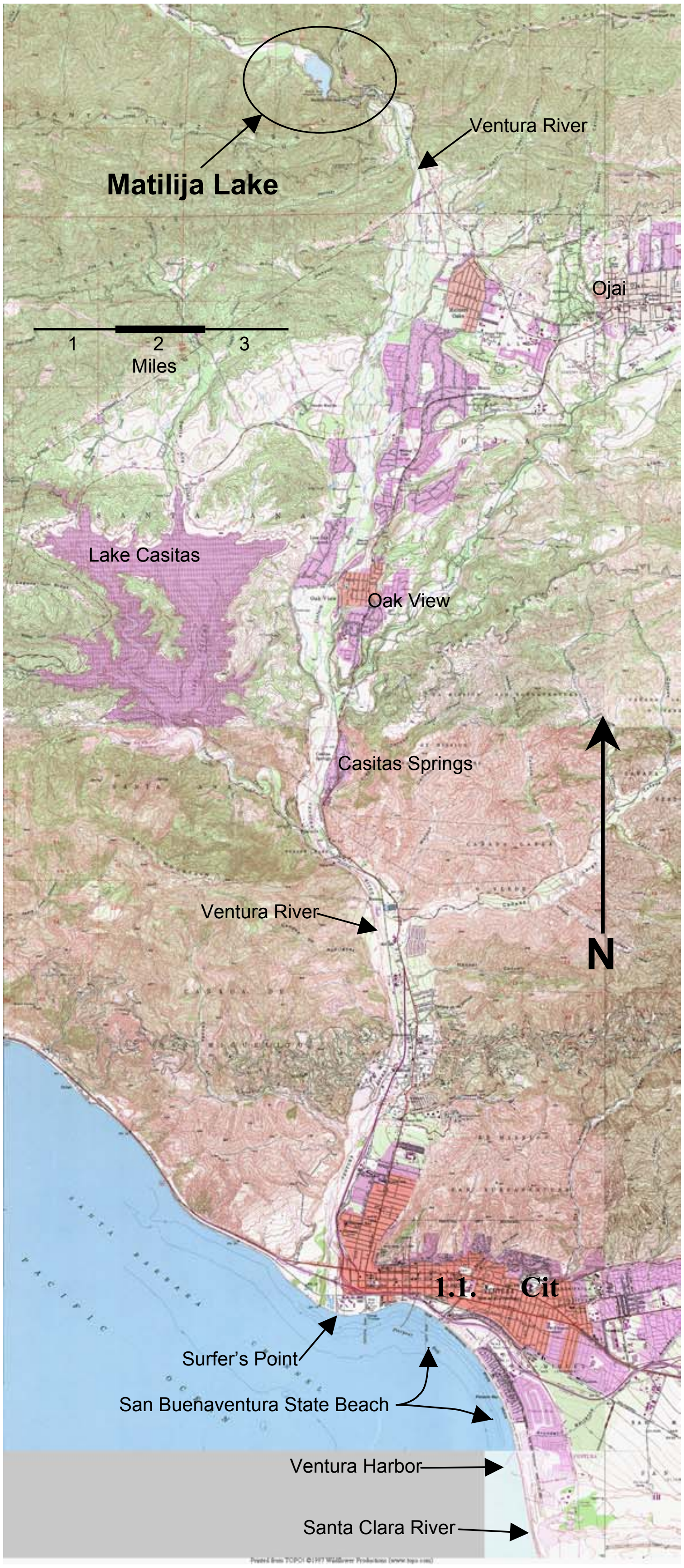
4.1. Regional Geologic and Physiographic Setting

Matilija Dam lies near the eastern end of the Santa Ynez mountains, within the Transverse Range geologic province of Southern California. Geologic structures within this province trend mainly east, in contrast to the predominant northwest trend in surrounding terrains. The range is composed almost entirely of highly folded and faulted, unmetamorphosed, mostly marine sedimentary rocks of Cenozoic and late Mesozoic age, elevated out of the ocean primarily on the Santa Ynez fault along the northern base of the range. In the Matilija reservoir vicinity, the steep southern slopes of the Santa Ynez range are underlain by folded and overturned, north dipping beds that form the Matilija overturn, part of the southern limb of a 40 mile long, intricately faulted, east-west trending anticlinal fold.

The Santa Ynez Mountains uplift is a very young, late Cenozoic mountain range (Dibblee, 1982). Uplift started in late Miocene as an anticlinal warp within the 60-75 million year old Ventura Basin which contained more than 40,000 feet of mostly marine sediments. The anticlinal structure was broken and uplifted by north to northeast directed compression along the Santa Ynez fault as stress continued. Predominant movement on the steeply south-dipping, east-west-trending Santa Ynez fault has been interpreted as left-slip, up on the south, with a maximum vertical displacement of several miles. This active fault passes about two miles north of Matilija Dam, and is continuous for 90 miles, the largest transverse fault west of the San Andreas fault.

The south side of the Santa Ynez Range possesses several east-trending faults, up on the south, with small left-slip components. The Mission Ridge-Arroyo Parida-Santa Ana fault which passes about 3.4 miles south of Matilija Dam is one of these faults. The recent movement along this fault is displayed by offset and rotation of Quaternary fan gravels and Pleistocene terrace deposits.

Although the San Andreas fault lies approximately 25 miles northeast of the dam, local seismicity and faulting are dominated by the right-slip tectonics of the San Andreas fault system, the boundary of the North American and Pacific plates.


Matilija Lake
Ventura River
Ojai
1
2
3
Miles
Lake Casitas
Oak View
Casitas Springs
Ventura River
N
1.1. Cit
Surfer's Point
San Buenaventura State Beach
Ventura Harbor
Santa Clara River

4.2. Local Geologic and Physiographic Setting

4.2.1. Physiography and Topography

The approximately 55 mi^2 contributory watershed of the Matilija Reservoir is drained by Matilija Creek and the North Fork, Matilija Creek, as well as relatively short streams that flow northward off the north slope of the Santa Ynez Mountains, and south-east draining Rattlesnake Canyon, which is about 1.5 miles long. Topographic relief is high in this mountainous area, ranging from 6,525 feet at Old Man Mountain and 6,003 feet at Monte Arrido on the southwest boundary of the Matilija watershed, 5,378 feet at Three Sisters at the northwest corner of the watershed, 4,707 feet at Divide Peak on the southwest corner of the area, about 5,400 feet near Ortega Hill on the northeast, and about 3,300 feet on the ridges at the southeast end of the area immediately above the dam on the north side, to about 950 feet at the toe of the dam.

Matilija Creek drainage is characterized by steep slopes mantled by loose, erodible colluvium (USBR, 2000). Topography on both sides of the reservoir is very steep, and pre-dam topography shows steep canyon walls continue below the reservoir sediment package. The steep canyon walls along both sides of the reservoir host a moderately dense growth of trees and brush.

The Matilija Reservoir area is covered by the following topographic map sheets: Los Angeles, California 1:250,000 sheet; and Matilija and Wheeler Springs 1:24,000 sheets.

4.2.2. Geologic Units

Matilija reservoir is underlain by the Matilija sandstone of Middle Eocene age and the Juncal Formation of Mid-Lower Eocene age (Fig.1, Table 1). Bedrock is generally exposed or covered by a thin veneer of soil. An alluvial terrace deposit composed chiefly of sand, gravel, and scattered boulders occurs along the south side of the reservoir.

Matilija Dam is founded on the Matilija Formation in a narrow canyon where Matilija Creek is confined by steeply dipping and overturned sandstone beds. Bailey (*in* Bechtel, 1965) attributed the change in strike of the beds across the canyon to a fault, with offset of perhaps 100 feet, developed in a tight fold of an overturned anticline. The anticline is part of the Matilija Overturn. The top of the anticline has been eroded in the vicinity of the dam.

The Matilija Formation at the dam site is composed of resistant, massive, sandstone beds interbedded with thin, closely fractured sandstone beds and minor siltstone, mudstone and weak shale layers. The sandstone is silica-cemented and fine- to medium-grained. The thick resistant sandstone beds are slightly weathered, gray to gray brown, hard, and only moderately fractured with joints generally spaced greater than one foot. The thin sandstone beds are weathered brown, locally leached light gray, soft to moderately hard and closely fractured. The joints are spaced less than 6 inches and many are clay coated. Locally the weathered and leached sandstone is friable. The shale layers are weathered, brown and black, soft, closely fractured and locally crushed, and are subject to air slaking. The shale beds range in thickness from 0.1 to 4.0 feet (Bechtel, 1965).

The Matilija Formation is very resistant, and forms steep slopes, strike ridges, and craggy topography. Local relief can be up to many hundreds of feet. Rockslides and landslides occur on very steep slopes. Bedding plane failure can occur where shale partings are present and dip out of natural slopes and artificial cuts. Rockfalls, boulder rolls, and landsliding can be triggered by moderate to strong earthquakes (Weber, et al., 1973).

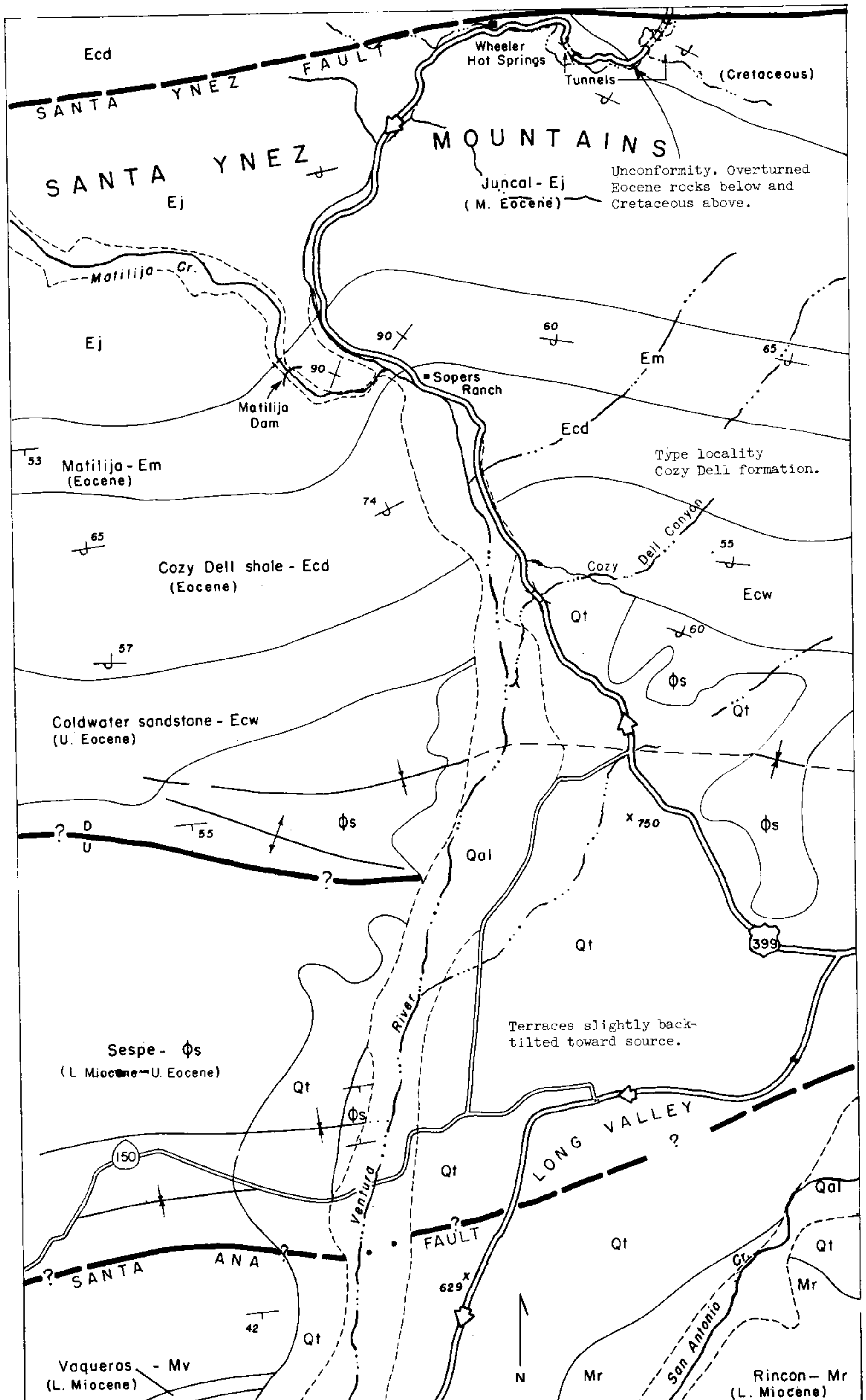


Figure 2. General geologic map of the upper Ventura River-Matilija Creek area, Ventura County, California, from Jennings and Troxel (1954).

Series	Formation	Lithology
Oligocene	Sespe	Pink sandstone and conglomerate.
Eocene	Coldwater sandstone	Light-colored hard sandstone; fossiliferous; green and red shale.
	Cozy Dell shale	Gray shale with some sandstone.
	Matilija sandstone	Gray hard sandstone.
	Juncal formation Sierra Blanca limestone member.	Gray shale with minor sandstone layers.
Upper Cretaceous	Undifferentiated	Hard shale and sandstone, thin beds, with conglomerate layers.

Table 1. Rocks exposed in the Ojai-Wheeler Hot Springs area, from Jennings and Troxel (1954).

Thin, sparse, sandy soil is locally developed on the Matilija Formation, and the unit is generally non-water-bearing (Weber, et al., 1973), however, Matilija Hot Springs emanate from fractured Matilija Formation rocks immediately downstream from the dam.

The Juncal Formation consists mainly of dark gray thin-bedded shale, siltstone, and mudstone, with occasional thin layers of hard dark gray sandstone and thin black limestone. The unit forms generally gentle slopes, saddles, and topographic lows (Weber, et al., 1973). It weathers to thin, locally expansive soils.

In the reservoir area, pre-dam alluvium is composed primarily of coarse-grained gravel, cobbles, and boulders of Quaternary age. These deposits form two types, “older gravel”, or dissected boulder gravel overlapping Tertiary bedrock on the south side of the reservoir, and “younger gravels” within the active river bed. Reservoir sediment overlying this alluvium is predominately fine grained, non-plastic sediment deposited in the slack water environment behind the dam and for about 1,400- to 1,800-feet upstream (USBR, 2002).

4.2.3. Geologic Structure

The sandstone and shale strata have been complexly folded and faulted. The weak shales are highly contorted and frequently badly sheared. A prominent structural feature on the north side of the reservoir is a series of recumbent folds produced by thrust faulting. No major thrusts are mapped in the reservoir area (Dibblee, 1982), and none were observed during Bechtel's site study (Bechtel, 1965). Bechtel noted contorted shales and minor faults with up to 10 feet of visible displacement that were interpreted to have formed in response to folding.

The right abutment is excavated into sandstone with interbeds of relatively weak shale with a low modulus of deformation (Bechtel, 1965). The channel section ranges from a completely decomposed sheared material, with strength characteristics of soil, to a fractured sandstone. The left abutment is composed of sheared and shattered sandstone and shale crossed by numerous, deeply-weathered, high and low angle faults.

4.2.4. Dam Foundation Geology

In their report to Ventura County, Bechtel (1965) described the foundation geology of Matilija Dam. The following is a summary of this report.

Right Abutment. The right abutment is composed of resistant sandstone with interbedded weaker sandstone and shale layers. The general strike is N55°E and the dip is very steeply upstream. The thrust of the dam is very nearly normal to the attitude of these strata. During construction a three-foot shale layer was excavated and backfilled with concrete to strengthen the foundation.

Talus accumulations of up to 25 feet deep (in 1965) occur on the steep slopes of this abutment. Minor slumping has occurred. No major faults were found on the right abutment but there was a bedding plane slippage during folding.

Channel Section. During construction of the dam 20-40 feet of river gravels were removed to expose bedrock. The bedrock beneath was composed of shattered sandstone and some shale. A 150 foot wide fault zone was exposed near the base of the right abutment. Fault gouge and contorted clay lenses were reported within shattered and crushed sandstone beds. Most of the rock in this zone was leached to a soft and friable condition probably by the action of warm springs in the area. The sulfur springs, which are presumably related to faulting, were found on the east side of the channel section. The Matilija hot spring occurs a few hundred feet downstream of the dam, also on the east side of the creek.

Left Abutment. The left abutment is comprised of fractured beds of sandstone and shale. The general strike of the overturned beds is N40°E and they dip 75 to 80 degrees upstream. The thrust of the dam is at an acute angle with the strike of these strata.

Intense faulting has produced numerous zones of shattered rock and well defined crushed zones. During core drilling fault gouge and numerous planes of weakness were encountered. Several significant faults occur in the abutment area, including high angle faults both normal and parallel to the bedding, and low angle faults crossing the bedding and dipping downstream.

Talus and slope wash accumulations estimated to be as much as 20 feet deep (in 1965) occur on this abutment. Slumping was not readily apparent but loose blocks of sandstone were observed to be gradually moving downslope (note: since this 1965 report, several large boulders of sandstone have fallen down onto the left abutment concrete structures causing significant damage to access stairs, etc.).

Drilling. Bechtel (1965) drilled eight 3-inch core holes totaling 338 feet in 1964-5. This drill program was designed to gather foundation information and to install joint meters. Four core samples from the thick, resistant sandstone were analyzed to determine modulus of elasticity (ave. 2.3 x 10^6 psi, range 1.151-2.8 x 10^6 psi), unconfined compressive strength (ave. 14,800 psi, range 9,270-20,800 psi), specific gravity (ave. 2.55), porosity (ave. 2.22%), and absorption(<1%). Large enough samples of the weaker shale material could not be obtained.

4.2.5. Groundwater

Ground water in the Matilija Dam area occurs predominantly within Tertiary-Quaternary river sediments and terrace deposits. These sediments are bounded below by relatively impermeable Tertiary bedrock. These formations are inclined nearly vertical at the dam site, but dip beneath the Ventura Basin to the south, where they are present at great depth. Although the bedrock formations are poor aquifers, movement of groundwater within faults and fractures in bedrock is evidenced by several local, cool-water, sulfurous, non-metalliferous springs.

A search of the California Department of Water Resources web site located only one water well within 2 miles of Matilija Reservoir. The well is located 1.25 miles downstream from Matilija Dam near the center of the Ventura River bed. Data for this well from 1972-1999 shows fluctuation in groundwater depths ranging from 14.3 feet (815 feet elevation) in February 1973 and March 1975 to 40.8 feet (788 feet elevation) in August 1990. The average depth to groundwater over this time was 22.4 feet (807 feet elevation).

Historic groundwater levels (pre-dam) for the Ventura and Ojai Valleys (California Department of Public Works, 1932) for the area immediately downstream from the Matilija dam site indicate that the groundwater table in this area has remained at nearly the same level before and after dam construction. The nearest well, at the confluence of the Ventura River and Cozy Dell Creek, 1.0 miles downstream from the modern well referred to above, recorded a groundwater level of about 740 feet (depth approximately 20 feet) in 1931-2.

Upon removal of the Matilija Dam, the groundwater table would be lowered, along with the reservoir and creek lowering, for several miles upstream of the reservoir as a result of the steepening of the gradient and subsequent downcutting of the creek bed. Downstream effects of dam removal on groundwater levels are expected to be minimal.

4.3. Geologic Hazards

4.3.1. Faulting and Seismicity

Faults. Matilija Dam lies in a seismically active area. While no major faults have been mapped within the reservoir and dam area (Dibblee, 1982) there are many faults close to the site. See Figure 3 (Draft EIS/EIR).

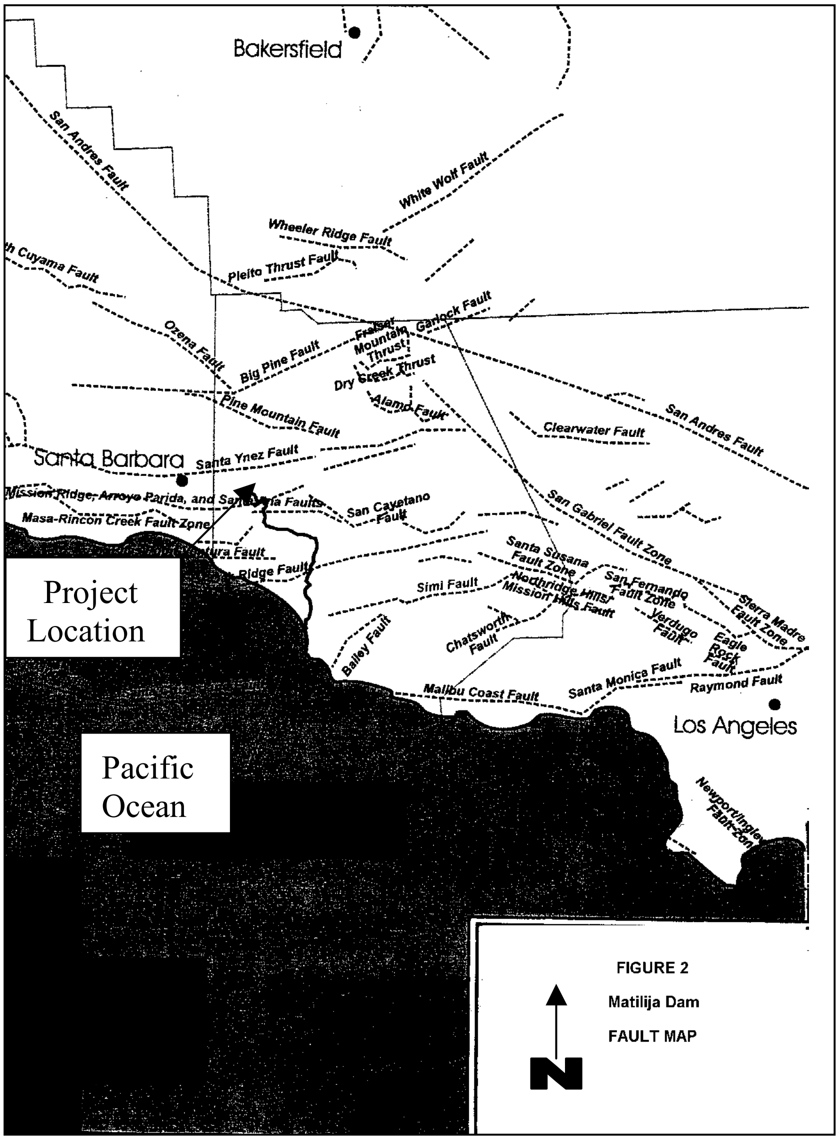


Figure 3. Fault Map from May 2000 Draft EIS/EIR.

The Santa Ynez fault is 2 miles north of the dam. It is a south dipping high angle reverse fault capable of producing a Magnitude 7.0 earthquake. The Mission Ridge-Arroyo Parida-Santa Ana fault is 3.4 miles south of the site. It is a north dipping low angle thrust fault capable of producing a Magnitude 7.0 earthquake. The dam is within 25 miles of the San Andreas fault. The San Andreas fault is a right lateral strike slip fault capable of producing a Magnitude 8.3 earthquake along some segments of the fault. However the portion of the fault near the site, known as the 1857 rupture, is capable of producing a Magnitude 7.8 earthquake. The reoccurrence interval for the San Andreas fault varies from 20 to 300 years depending on the segment.

Keller, et al. (1981) listed two faults along the north flank of the central Ventura Basin, the San Cayetano and Red Mountain thrust faults, as having both ground rupture and seismic shaking hazard. The western end of the San Cayetano fault is located approximately 10 miles east of the dam, and stretches eastward 35-40 miles from this point. This fault is a north-dipping thrust fault with up to 5 miles of apparent vertical up on the north stratigraphic offset. The fault is capable of producing a San Fernando (1971) type earthquake of Magnitude 6.0 to 7.0 The Red Mountain fault passes south of Oak View, about 10 miles south of Matilija Dam. The Red Mountain fault is a north-dipping thrust that has produced nearly 4mm/year differential movement from 1934-1968

(Buchanan, et al., 1975 *in* Keller, et al., 1981), and is also capable of producing a San Fernando (1971) type earthquake of Magnitude 6.0 to 7.0.

Previous Seismicity Studies. There have been numerous studies of the site seismicity. These have been summarized in the Draft Report of Stress Analysis-Matilija Dam by Harza. The information in this section is from page 3-1 to 3-3 of that report.

In 1972 a IECO study reported that "...no earthquake epicenters have been reported in the immediate vicinity of the dam, and none with a Richter Magnitude greater than 4 had been reported within 8 km (5 miles) of the dam." For the slope stability analysis the 1972 study used a 8+ event on the San Andreas fault with a resulting peak ground acceleration (PHGA) of 0.35g and a magnitude 7 event on the Santa Ynez fault resulting in a PHGA of 0.45 g at the site.

The 1979 report by the California Division of Safety of Dams (DSOD) reported that the Santa Ynez fault was capable of producing a Maximum Credible Earthquake (MCE) of Richter Magnitude 7.5, 1.2 to 1.9 miles from the site which would result in a PHGA at the site of 0.7 g.

The 1999 report by Harza also studied the seismicity of the site. It reports the MCE ground motion for Matilija Dam is 0.7 g, based on a earthquake on the Santa Ynez fault located 1.9 miles from the site. The report also notes that "...the PHGA calculated for this fault ...was modified in accordance with discussions held with staff of DSOD on December 4, 1998 to account for the fact that the Santa Ynez fault is a south-dipping, high angle, reverse fault."

Historical Seismicity. A search of earthquake records for a 50 mi radius around the project was conducted with EQSEARCH version 3.00 using the Boore et al. 1997 Horizontal - Rock attenuation relationship to derive mean plus one standard deviation peak acceleration values. Records were examined for the period between the years 1800 and 2000 and the magnitudes of 5.0 and greater. This search found 49 earthquakes occurring within the search parameters. The magnitude information is shown in Table 2.

Table 2: Magnitude and Exceedences

Earthquake Magnitude	Number of Times Exceeded
5.0	49
5.5	21
6.0	10
6.5	5
7.0	4
7.5	1

A separate search for magnitude 4.0 and greater earthquakes within a 20 mile radius, was also conducted. The closest earthquake to the site was a magnitude 4.2 event 2.5 miles away resulting in a calculated peak ground acceleration of 0.17 g at the site. The largest earthquake site acceleration from this search was a 0.20 g resulting from a 7.7 magnitude earthquake 39 miles from the site.

Table 3 shows the earthquakes of magnitudes

7.0 and greater that have occurred within 100 miles of the site. The largest magnitude earthquake was in January of 1857 and was a magnitude 7.9 which resulted in a calculated acceleration of 0.15 at the site.

Table 3:
Magnitude 7 and Greater Earthquakes Within a 100 Mile Radius

Earthquake Date	Magnitude	Site Acceleration (g)	Distance (miles)	Modified Mercalli Intensity[1]
12/08/1812	7.0	.07	94.8	VI
12/21/1812	7.0	.15	34.2	VIII
09/24/1827	7.0	.14	37.8	VIII
11/27/1852	7.0	.13	39.7	VIII
11/04/1927	7.5	.10	84.1	VII
07/21/1952	7.7	.20	39.3	VIII
01/09/1857	7.9	.15	62.9	VIII

[1] The effect of an earthquake on the Earth's surface is called the intensity and is expressed by the Modified Mercalli (MM) Intensity Scale. This scale composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, is designated by Roman numerals. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects. Table 4 is an abbreviated description of the applicable levels of Modified Mercalli intensity.

TABLE 4: Modified Mercalli Intensity Scale

Intensity	Observed Effects
VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Damage slight in specially designed structures; considerable damage in ordinary structures. Substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, and walls. Heavy furniture overturned.
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.
XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

From *The Severity of an Earthquake*, a U. S. Geological Survey General Interest Publication. U.S. GOVERNMENT PRINTING OFFICE: 1989-288-913

Deterministic Seismic Study. Table 5 shows peak site acceleration data obtained from the April 2000 addition of the computer program EQFAULT by Thomas Blake. This calculation used the 1997 Boore et al. attenuation relationship for rock to calculate mean plus one standard deviation PHGA at the site for the various fault magnitudes and distances. The highest PHGAs at the site come from the Mission Ridge-Arroyo Parida-Santa Ana and the Santa Ynez faults .77 g and .72 g respectively. This data is consistent with the 1999 report by Harza which reported the MCE ground motion for Matilija Dam as 0.7 g, based on a earthquake on the Santa Ynez fault located 3 km (1.9 miles) from the site.

Table 5: Faults

Name	Dist. to Fault Plane (mi)	Max EQ	Peak Site Acc (g)	MM	Last Known Fault Rupture	Slip Rate mm /yr	Interval Between Major Ruptures	Type of Faulting
Santa Ynez	2.7	7.0	.72	XI	Late Quaternary and Holocene	.1 to .7	Uncertain	Reverse, high angle south dip
Mission Ridge-Arroyo Parida-Santa Ana	3.4	6.7	.77	XI	30,000 Probably ruptured in Holocene	0.37	8000	Thrust, low angle, north dip
Red Mountain	5.4	6.8	.61	X	Holocene to Late Quaternary	.4 to1.5	Uncertain	Thrust
San Cayetano	8.5	6.8	.40	X	Less than 5,000	1.3 to 9	Uncertain	Thrust, low angle, north dip
Ventura - Pitas Point	12.4	6.8	.33	IX	Holocene 1,500	.5 to 1.5	Uncertain	Left, reverse North dip
Big Pine	13.3	6.7	.22	VIII	Pre-quaternary to Late Quaternary	1.0 to 4.0	Uncertain	Strike slip, left lateral
Oak Ridge (on shore)	17.3	6.9	.25	IX	Holocene Late Quaternary	3.5 to 6.0	Uncertain	Thrust, low angle, south dip
San Andreas (1857 Rupture)	26.8	7.8	.23	IX	9 Jan 1857	20 to 35	20 to 300	Strike Slip, right lateral

Probabilistic Seismic Study. The probabilistic seismic hazard analysis adds an assessment of the likelihood that ground motions will occur during a specified time period. To calculate the EPGA for various periods of exceedence, the USGS Seismic Hazard Mapping Project Earthquake Hazards Program, http://eqint.cr.usgs.gov/eq/html/lookup.shtml, is used to get spectral accelerations at various probabilities of exceedence. This data is put into a spreadsheet that calculates Estimated Peak Ground Acceleration (EPGA) for various periods of exceedence based on ER 1110-2-1806, 17 November 1995 CECW-ED memorandum, 30 October 1996 CECW-ED memorandum and NEHERP 1994.

One of the periods of exceedence calculated is the Operating Basis Earthquake (OBE), which is the earthquake that can reasonably be expected to occur during the service life of the project. The other period of exceedence calculated is the Maximum Design Earthquake (MDE), which is the maximum level of ground motion for which a structure is designed or evaluated with the performance requirement of no catastrophic failure. The OBE and the MDE are shown in Table 6.

Table 6:
Operating Basis Earthquake and Maximum Design Earthquake

	Return Period	Probability of Exceedence	EPGA
OBE	144	50% in 10 Years	.34
MDE	1000	10% in 100 Years	.67

Summary. During the life of Matilija Dam, the site has experienced calculated peak earthquake accelerations in the range from 0.15 g to 0.20 g as the result of relatively small local events to larger, more distant earthquakes. There are numerous potential sources of earthquake generated ground motions (faults) in close proximity to the dam, and the site can be expected to experience peak horizontal ground accelerations up to approximately 0.7 g.

4.3.2. Landslides

The steep slopes and fractured nature of sedimentary bedrock in the Matilija Dam area, as well as the proximity of active earthquake faults, make the area prone to landslides, slumps, and rockfalls. Rockslides and landslides may occur on the very steep slopes which characterize the Matilija Formation. The large boulders of Matilija sandstone which have fallen on the concrete steps leading to the top of the left abutment area of the dam are evidence of this. Rockfalls, boulder rolls, and landsliding can also be triggered by moderate to strong earthquakes.

The Juncal Formation forms most of the bedrock beneath the Matilija reservoir. This formation is composed primarily of soft, erodible shale and siltstone. This type of material is often prone to slumping and landslides, especially as bedding plane failure along shale partings where these form dip slopes.

Removal of accumulated reservoir sediments behind the dam should be expected to create oversteepened slopes and banks within the unstable talus accumulations and loose colluvial soil covering bedrock. Some slumping of this material will undoubtedly occur.

Study of aerial photographs and field reconnaissance of selected areas should be undertaken before sediment removal to evaluate potential hazard zones.

5. Investigations

5.1. Field Investigations

The primary source of geotechnical data for the feasibility study is the field investigation conducted between July 30 and September 15, 2001 by the U.S. Bureau of Reclamation, Mid-Pacific Regional Office. These investigations consisted of 15 drill holes, eight of which were drilled from a barge while the remaining seven were drilled on land using a truck mounted drill rig. The barge-based holes were drilled using an Ingersoll-Rand, Model A200 drill. A 3-3/4 inch interior diameter hollow stem flight auger continuous dry core (FADC) system with a 5-foot long 3-inch interior diameter split tube sample collection barrel was used to collect continuous core samples of the reservoir sediment. The land holes were drilled utilizing a CME 750 rig mobilized from Reclamation's Boise, Idaho office. Hollow stem flight augers with interior diameters of 6-5/8 and 4-1/4 inch were used. Samples were collected with five foot long core barrels with interior diameters of 5-3/4 and 3-1/2 inches. Where refusal occurred, drilling proceeded using a rotary diamond coring system. Following extraction of the sample, the field geologist visually logged and photographed the cores, and packaged and labeled the samples for testing. Field logs are included in Attachment A. Details of the investigation, including photographs are included in Attachment D.

In addition to the investigations described above, the USBR conducted a surface study of the upstream channel sediments in June 2002. 4,100 linear feet of cobble/gravel/boulder bars in the braided stream deposit were mapped, comprising 332,000 square feet, or about 22% of the upstream channel area (78% of the upstream channel area was covered by dense vegetation, and was inaccessible for mapping purposes). Percentages of sand, gravel, cobbles, and boulders based on visual estimates were recorded in the mapped areas. A detailed estimation of sediment size fractions was made within two 50 ft by 50 ft gridded areas which were further subdivided into 100 5-ft by 5-ft cells. These materials were classified into percent fines, sand, fine gravel, coarse gravel, 3- to 5-inch cobbles, 5- to 12-inch cobbles, 1- to 2-ft boulders, and >2-ft boulders. A geologic map (scale: 1inch = 100 feet) plotted on an aerial photo base was produced, along with 4 geologic sections, 3 diagrammatic sketches, and numerous photographs. This study is included in USBR, July 2002 as Appendix E.

5.2. Laboratory Investigations

A total of 83 samples were sent to the Los Angeles District, El Monte laboratory for gradation, Atterberg limits, and moisture content testing. Similar testing was done on 15 samples sent to Reclamation's laboratory in Willows, California. Sediment toxicity analyses were done on 39 samples through four laboratories under contract with the Navy Regional Environmental Laboratory (NREL) of San Diego, California. Analyses were conducted on two methane gas samples by Zymax Forensics and Envirotechnology, San Luis Obispo, California. Results of the material testing are presented in Attachment B. Toxicity testing is summarized below and presented in Attachment C. Methane testing results are presented in Attachment D.

Reclamation's Technical Services Center in Denver, Colorado (contact: Joe Brummer, soil scientist) is currently conducting an assessment of the silty soils for use is agricultural applications.

6. Site Characterization

Based primarily on gradation data, Reclamation (2002) identified three primary areas behind the dam. These areas have been identified as Reservoir, Delta, and Upstream Channel and are presented in plan in Figure 4. Figure 5 shows the average gradation of the samples collected in each area. Each curve is weighted to account for the length which that sample represented in the core. For example, a one-foot long sample has 1/10 the influence as a 10-foot sample. The samples tested represent the minus 3-inch fraction of the material. Due to the large quantity of +3-inch material in the Upstream Channel, significant interpretation is required. The estimated curves below reflect an integration of laboratory data based on the drilling and the estimate of the project geologist who conducted the investigation summarized in Reclamation, July 2002, Appendix E.

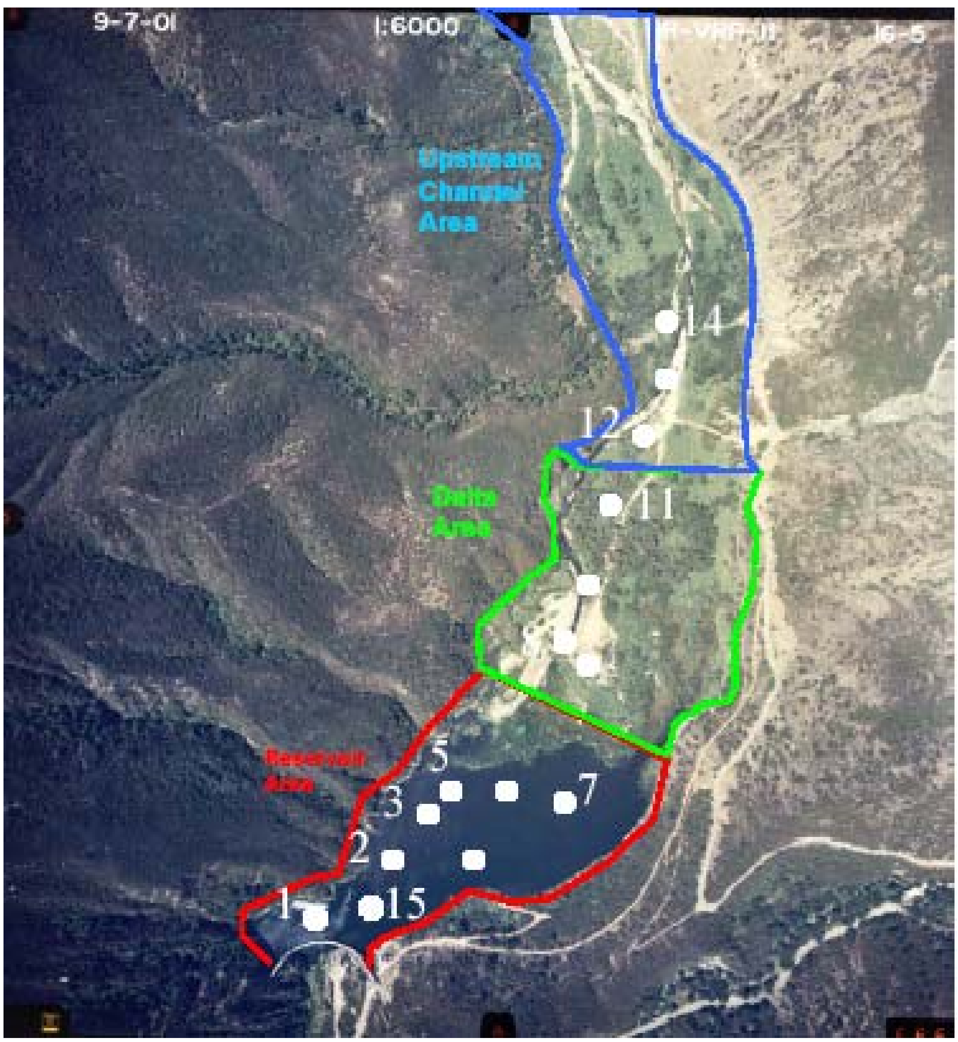


Figure 4 – Plan view of geotechnical exploration

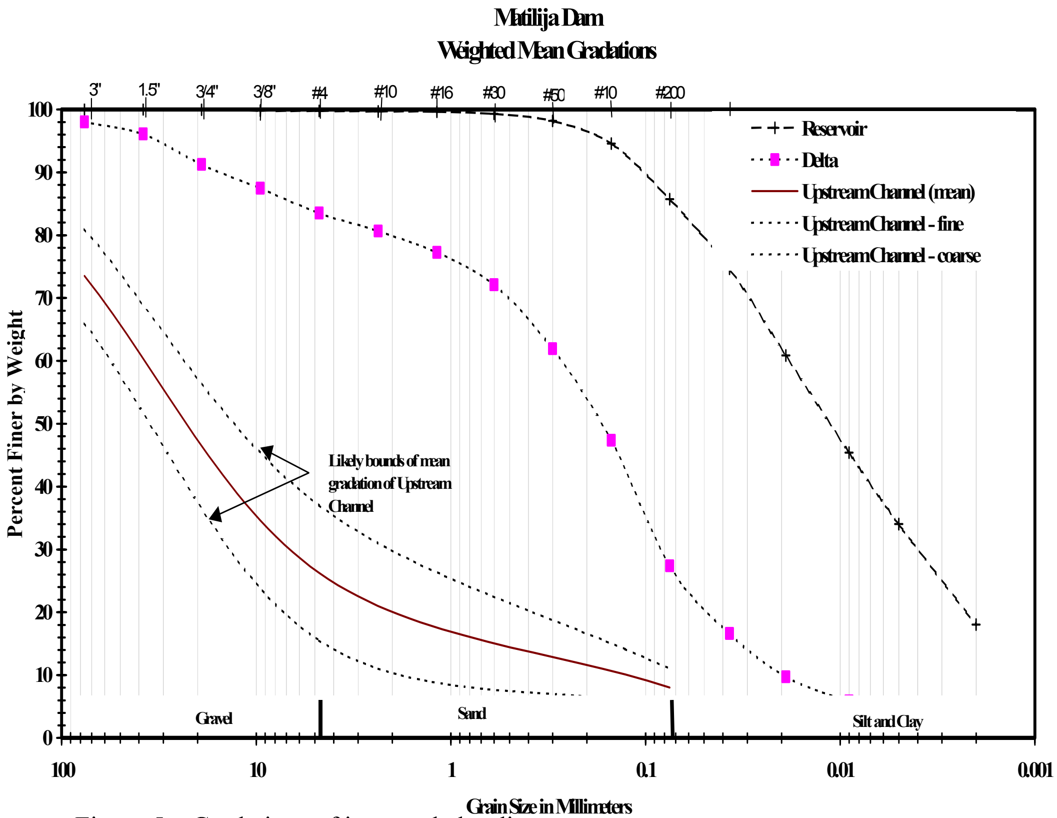


Figure 5 – Gradations of impounded sediments

6.1. Reservoir Area

The Reservoir area starts at the upstream face of the dam and continues upstream for approximately 1,400 feet. Its boundaries are approximated by the location of the pond. The total volume of sediment is estimated to be 2.1 million cubic yards.

Sediment samples were collected from eight barge mounted holes (MDH-01-01 through MDH-7-01, MDH-15-01). The total depth drilled at each location ranged from 38 to 84 feet, with the depth of the reservoir pool ranging from 8 to 13 feet. Recovery was typically very good and 37 samples were tested for gradation and Atterberg limits and 13 were collected for toxicity testing. The material typically classifies as silt, with material smaller than 0.075 mm typically composing in excess of 85 percent of the sample. Moisture contents were collected on thirteen samples from TH01-01 and TH01-02. The moisture contents of these saturated sediments ranged from 38 to 65 percent, with an average of 48.1 percent. Assuming a degree of saturation of 1.0, the dry unit weight of these sediments is 73.3 pounds per cubic foot. The average liquid limits and plasticity index are 40.3 and 11.7 percent, respectively.

Pressurized gas was encountered in holes 3, 4, 6, and 7. Due to the pressure and quantity of the gas, and reports of natural gas seeps in the region, a sample was collected from hole 7 for Carbon 14 dating. The results showed the source to be biogenic, i.e. resulting from decay of organic material. Attachment E contains the test data.

6.2. Delta Area

The Delta area extends from the upstream edge of the pond approximately 1,500 feet upstream. The total volume of sediment in this reach is estimated to be 2.5 million cubic yards.

Four holes (MDH-08-01 through MDH-11-01) were drilled in this area ranging in depth from 46 to 65 feet. Core recovery was adequate so as not to be a considered a significant factor in the sample classification. Thirty-two samples collected for gradation and Atterberg limits testing and 8 were collected for toxicity testing. The material grades predominately as silty sand and is generally coarser at the upstream holes than downstream. The average weighted values shown in the previous figure include an adjustment for the +3-inch material, as identified visually by the field geologist during the investigation.

6.3. Upstream Channel Area

The Upstream Channel area extends from the upstream edge of the Delta area (approximately 2,900 feet upstream of the dam) to the upstream limit of sedimentation behind the dam (approximately 6,000 feet upstream of the dam). The total volume of sediment in this reach is estimated to be 1.3 million cubic yards.

Three holes (MDH-12-01 through MDH-14-01) were drilled in this area ranging in depth from 25 to 41 feet. Due to the high percentages of cobbles and boulders on the surface, a flight auger pilot bit (FAPB) was frequently used in the upper 4.7 to 10 feet materials. The driller's notes describe the drilling as rough, indicating the probable existence of very coarse material below at greater depths. Fourteen samples were collected for gradation testing and four were collected for toxicity testing.

While the minus 3-inch fraction tested grades between poorly graded gravel with sand and silty sand, it was recognized that the coarse materials skewed the results. Consequently, subsequent surface mapping of the materials was conducted to compare surface estimation techniques with the drill results (USBR, 2002, Appendix E). The lack of silt mapped on the surface vs. that encountered at depth in drilling was attributed to coarser braided stream type deposits overlying finer grained sediment. The lack of boulders recovered by drilling was due to size constraints imposed by the 6-5/8 inch hollow stem flight augers used for drilling.

6.4. Summary

Based upon the field and laboratory investigations, combined with the mapping efforts, the table below presents the estimated total quantity of silt, sand, gravel, cobbles and boulders in each of the areas.

Table – Quantities of Materials per Area

	Quantity Total (cy)	silt (cy)	sand (cy)	gravel (cy)	cobbles (cy)	boulders (cy)
Reservoir	2,120,000	1,823,200	296,800	0	0	0
Delta	2,470,000	666,900	1,407,900	345,800	49,400	0
Upstream Channel	1,300,000	104,000	234,000	676,000	240,500	45,500
Total	5,890,000	2,594,100	1,938,700	1,021,800	289,900	45,500

7. HTW Assessment

Impounded sediment of Matilija Dam is under study for a variety of disposal options, including several upland disposal options, and beach nourishment. There is no formal regulatory criteria to assess beach-suitability of sediments based on contaminants, so USACE-Geotech used the Puget Sound Dredged Disposal Analysis (PSDDA) sediment quality criteria to screen 39 samples of impounded sediments from 15 drill holes. *None of the impounded sediments exceed PSDDA limits for the 81 analytes determined and are suitable for beach nourishment with regard to contaminants* at this screening level (the analytes include 17 pesticides, 4 butyltins, 7 PCBs, 17 PAHs, 13 phenols, 11 metals, 6 pthalates, TrPH, oil and grease, ammonia, total sulfides, water soluble sulfides, calcium carbonate; in addition, total solids, total volatile solids, and pH were determined). In a few instances, the more rigorous but equally non-regulatory NOAA sediment quality assessment criteria were exceeded by some samples for some analytes; those instances are documented. Historical research and regulatory database research determined no deleterious past use of the reservoir's contributory watershed: *no* metals mining or prospecting, no industrial development or agriculture, extremely limited commercial development. Past recreational use of the reservoir occurred; in that era, DDT likely was used for mosquito control. DDT was detected in some samples.

Prior to any sampling, EPA reviewed the Sampling and Analysis plan and stated that the Plan was suitable for this phase of study but that additional sediment *quality* and *gradation* tests would have to be performed on the sediment as it is mined for transport to the beach, so as to more precisely qualify it. There are no indications through testing or research to date that any of the impounded sediments qualify as *hazardous waste* (the upland disposal criteria) but for verification, some leachate tests for 40 CRF, Part 261 analytes are warranted prior to upland disposal. Complete details are in Attachment C.

8. Geotechnical Design Issues

The various alternatives are described in Attachment I. Issues to be addressed include: dewatering, excavation of saturated fine sediments, drying of fine sediments.

8.1. Dewatering

8.1.1. Fine Sediments

Due to the very fine nature of the Reservoir area sediments, most excavation is planned to occur in the wet. No significant dewatering is anticipated.

8.1.2. Coarse Sediments

A preliminary design for dewatering the sediments was developed consistent with TM 5-818-5, Dewatering and Groundwater Control. The feasibility level analysis assumed that a line of wells would be placed at the upstream end of the Upstream Channel area to cut off subsurface flow from upstream. Dewatering of the Upstream Channel area and the Delta area themselves would be accomplished with localized sumps.

The analysis assumed that 18-inch diameter wells would be spaced on 20-foot centers through the 20-foot thick alluvial deposit and placed as deep as five feet into the bedrock. Assumptions for use in modeling include a permeability value of 1000 ft/day of the materials located up gradient of the area to be dewatered, a gravity flow system (i.e.; not artesian system), and canyon width of 300 feet. Drawdown in the wells is assumed to be approx. 19 ft. A distance of 178 ft. from wells to line source was calculated and used in the analysis.

Based on the above calculations and assumptions, required pumping rates are approximately 200 gpm per well. Assuming 15 pumps, pump efficiency of 75 percent, and motor efficiency of 85 percent, the power requirement is 17,000 Watts.

8.2. Excavatability of Sediments

Few difficulties are anticipated in the excavation of the Delta and Upstream Channel areas. Excavation of the Reservoir Area is complicated by the saturated silts. The fine-grained nature of the material will largely preclude any significant dewatering. Excavation of these soils is further complicated by the high water content.

The liquid limit (LL) is that water content at which a soil begins to act as a fluid. When actual water content of the soil exceeds the LL, disturbance of the soil causes an increase in pore pressure and has the potential to convert the deposit into a viscous fluid. The liquidity index (LI) has been proposed as a means of quantifying this problem and is defined as:

$$LI = \frac{w - PL}{LL - PL}$$

Where

w = the natural water content
PL = the plastic limit
LL = the liquid limit

Using average values for w, PL, and LL of 0.48, 0.29, and 0.40, the liquidity index is 1.7. A liquidity index greater than 1 indicates that when remolded the soil can be transformed into a viscous form like a liquid.

As a result, excavation using conventional equipment would be very difficult. Though a harder shell might form, equipment- or blasting-induced vibrations and other movements associated with construction would result in equipment getting stuck and slides. To address this issue, feasibility level estimates assume that the Reservoir area will be excavated utilizing a barge-mounted clamshell or suction head dredges.

Cut slopes are assumed to be very flat (10H:1V) as it is not possible to assure the stability of steeper slopes. Even at 10H:1V, there is a significant level of uncertainty as to the likelihood that slopes would remain stable.

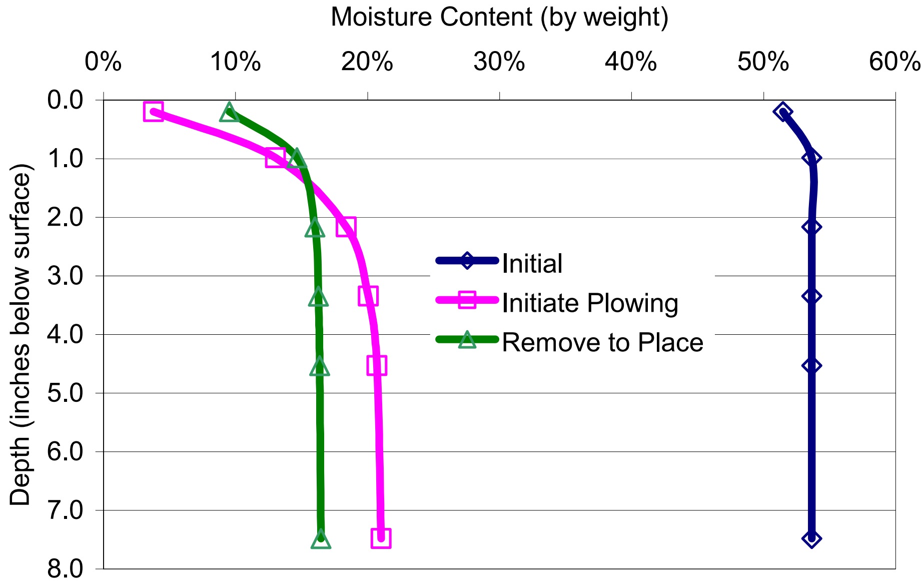
8.3. Drying of Fine Sediments

In order to place and construct upstream of the dam using the Reservoir area sediments, as proposed in Alternative 4a, significant drying would be required. While no compaction tests were conducted, optimum moisture for these soils can be anticipated to range between 14 and 19 percent, requiring approximately 30 percent loss (by weight) of moisture. The most cost-efficient method to dry the soil would be to spread it and mix it as necessary. The proposed scheme would consist of spreading the saturated sediments over approximately 25 acres upstream of the Reservoir area in multiple cycles. When an acceptable water content is attained, the fine sediment and a thin lift of the underlying coarser sediment is removed and transferred to the placement site and compacted.

To evaluate the required drying time, the Erosion-Productivity Impact Calculator (EPIC) model was used. EPIC was originally developed to assess the effect of soil erosion on soil productivity and subsequently expanded and refined to allow simulation of many processes important in agricultural management. Hydrology and tillage were the most important EPIC components used in this study. The most important hydrology components were potential evapotranspiration (PET), actual soil evaporation, and percolation. The study used Hargreaves PET method and actual soil evaporation was calculated using a function of soil moisture and depth from the surface. Percolation from a soil layer occurs when the layers soil water storage exceeds field capacity (the amount of water that remains following drainage of all free water) and the flow rate is a function of the layers saturated conductivity. The tillage component was used to mix the soil to speed drying.

The runs were conducted by Texas A&M Research Scientist Jimmy Williams and are summarized in Attachment G. The 20-year weather record for the City of Ojai (solar radiation, maximum and minimum temperature, and precipitation) was used in the analysis. Starting at the saturated in-situ water, the final moisture content was 16 percent. Based on a series of these runs, it was decided to spread the soil in 10-inch lifts, which required an average of 9 days to reach the target moisture content. Approximately two-thirds of the change occurred as a result of percolation; the other third occurred as a result of evaporation.

The following figure is an example of one drying cycle. The material is delivered to the drying site with an insitu water content of 54 percent. After a certain period of time, the moisture content was at an average water content such that plowing could begin. The green line shows the moisture variation with depth when the average target moisture content had been achieved and the soil was ready to be taken to fill.



The drying of the material is heavily dependant upon the permeability of the base soils. The excavated material would be dried in a drying area and placed on the berm at the design water content. Since it is assumed that all construction operations will occur within the footprint of the original reservoir, the area available for drying will reduce with time. For the feasibility level design, it is assumed that the dried material will be excavated from the drying area and the placed and compacted in a narrow berm (here assumed to be approximately 25 feet wide) adjacent to the left canyon slope. Sediments will be compacted to 90 percent of maximum density. This process would continue until the design grade is attained at which point the next berm be placed adjacent to the first. Assuming 1.4 million cubic yards from the Reservoir area are excavated, dried, and placed, the total time required would be approximately two years.

8.4. Drainage of Fill

For the feasibility level design of Alternative 4a, which requires upstream storage of the sediment, it is assumed that a drainage system will be provided between the left natural slope and the fill. Following clearing, a two-foot wide sand layer will be placed adjacent to the slope. At 10-foot vertical increments, 4-inch perforated PVC pipes wrapped in a geotextile will be set in the sand. Laterals, spaced on 500-foot centers will drain to the face of the fill.

8.5. Design of Riprap

Riprap would be necessary upstream of the dam in Alternative 4a to prevent erosion of the slopes by hydraulic forces. Assuming a trapezoidal x-section with a bottom width of 60 feet, 3H:1V side slopes and the 100-year of design discharge of 21,600 ft^3/s with flows impinging on the riprap due to the curvature of the channel, 4.5 to 5 ton derrick stone would be required. The County confirmed with the nearby Schmidt Quarry that they would be able to produce that size stone. Test data at the Los Angeles District office confirms that the stone is of adequate quality.

8.6. Use of the Sediment as Aggregate/Road Base

Interest has been expressed by local aggregate producers in using the coarse sediments located in the Upstream Channel area as road base or aggregate for concrete. Should this become a recommended alternative, additional testing, including tests for ASR, would be recommended.

8.7. Use of the Sediment in Soil Cement Construction

For the recommended plan (Alternative 4b), the use of soil cement revetment as protection for a limited portion of an excavated channel through the reservoir basin has been identified. Based on mechanical analyses performed on soil samples obtained from the 2001 geotechnical field investigations, a sufficient quantity of material (primarily from the Upstream Channel area, and to a lessor extent, the Delta area) will be available for soil cement. A detailed assessment of the quantity of available material will be conducted during the design phase.

8.8. Reuse of Disposal Area

The quality of the soil for agricultural applications has been evaluated. Soil scientists at Reclamation's Technical Service Center (TSC) in Denver, Colorado performed an initial evaluation of the feasibility of the using the sediment from the Reservoir area for agricultural applications. The TSC report is presented as Attachment F. Based on the USDA classification, soil textures of sediment in the Reservoir area range from light loam to light silty clay loam, with the most common texture of the samples being light silt loam with about 15- 20% clay. While noting practical restrictions and concerns with the use of sediments, and recommending further investigations, the TSC concluded that the sediment has physical and chemical characteristics favorable for use as agricultural soils.

9. Evaluation of Alternatives

Summary descriptions are provided in this report in Attachment I but may not be sufficient in detail or accuracy for all purposes. The purpose of this section is to evaluate the feasibility of the alternatives, especially with regard to constructability issues, and to identify, where possible, further study needs.

9.1. Alternative 1: Full Dam Removal/Mechanical Sediment Transport: Dispose Fines, Sell Aggregate

1. Risk associated with proposed dredging operation. The occurrence of a large storm prior to completion of the Reservoir area excavation would result in the capping of the fine sediment with coarse sediment, potentially changing construction duration, water requirements, excavation quantities and nature of excavated sediment.

2. Water requirements for dredging. Due to the lack of water at Matilija Dam, approximately 4,500 acre-feet would be required from Lake Casitas. Other sources, including pumping of groundwater were investigated and found to be inadequate. As of May 2003, it is assumed that the water would be purchased from Lake Casitas utilizing

the excess capacity of the City of Ventura. Depending upon the design of the containment dike, it is anticipated that approximately 50 percent of the water used from Casitas could be returned directly to the reservoir or to the river. At this phase, design cost estimates assume no water is being reclaimed. An additional conservative assumption is that the water will need to be brought in directly from the lake. If possible, use of existing infrastructure may result in significant cost savings.

3. Arsenic. The Casitas Municipal Water District (CMWD) has expressed concerns over arsenic found in the sediment (results of 39 samples ranged from 3.2 to 8.7 parts per million) and the impact to water quality at Lake Casitas and the Mira Monte well. Consultations with another water agency indicated that these are background levels and that, barring very unusual conditions, are well below those anticipated to negatively influence the water quality.

4. **Reuse of disposal area. The quality of the soil for agricultural applications have been discussed previously. Another issue may be** time required for consolidation of the sediment. Due to the fine nature of the soils and their proposed method of placement, a significant amount of time would be required for consolidation prior to development. This duration, likely to be measured in years, would be dependent upon placement and drainage measures, desired use and site preparation prior to development.

5. Quantity of aggregate. It is estimated that 47 percent and 16 percent of the material in the Delta and Upstream Channel areas, respectively, are finer than the number 100 sieve. ASTM C 33 allows 2 to 10 of fine aggregate to be finer than the number 100 sieve. Accordingly, approximately 1.2 million cubic yards of material from the Upstream Channel area would not be marketable and would need to be disposed of.

9.2. Alternative 2a: Full Dam Removal/Natural Sediment Transport: Slurry "Reservoir Area" Fines Offsite

1. The issues identified in items 1 through 5 in Alternative 1 would be relevant here.

2. Impacts of sediment quality to the coastline. As discussed in Attachment C, the sampling/testing program revealed no contaminant levels that would preclude the material from being transported to the beach. The remaining materials would be mechanically compatible with the existing beach material.

9.3. Alternative 2b: Full Dam Removal/Natural Sediment Transport: Natural Transport of "Reservoir Fines"

1. The impacts of sediment quality to the coastline are as discussed in item 2 in Alternative 2a.

2. Risk associated with upstream placement of fine materials. The proposed construction method contains very significant risk in that it calls for the dredged sediments to be placed upstream of the dam. Unlike Alternatives 1 and 2a, this

alternative requires excavation and placement of the sediments upstream, unwatering of the reservoir, and complete removal of the dam prior to the occurrence of a significant storm. Failure to accomplish all phases would result in redeposition of the excavated sediment behind the dam.

9.4. Alternative 3a: Incremental Dam Removal/Natural Sediment Transport: Slurry "Reservoir Area" Fines Offsite

1. The issues identified in items 1 through 5 in Alternative 1 and in item 2 in Alternative 2a would be relevant here.

2. Constructability. This alternative is more constructable than Alternatives 1 and 2a in that it less restrictive for the contractor with reduced impacts in the case of either an untimely storm or schedule bust.

9.5. Alternative 3b: Incremental Dam Removal/Natural Sediment Transport: Natural Transport of "Reservoir Fines"

1. The impacts of sediment quality to the coastline are as discussed in item 2 in Alternative 2a.

2. Constructability. This alternative has risk similar to Alternative 2b except that, while the risk is reduced in that the quantity of material excavated and placed upstream is less, this operation must occur twice.

9.6. Alternative 4a: Full Dam Removal/Permanent Sediment Stabilization on Site

1. Impact of schedule on constructability. As in 2b and 3b, the material from the Reservoir area is to be placed upstream. In this case however, the material is to be dried and stabilized, the result being that much more time is required to complete this operation. Due to the saturated nature of the fine materials, it has been assumed that this material would be dredged using a barge-mounted clamshell, thus requiring that at least a portion of the dam remain in place until the excavation has been completed (estimated duration of three years). While pipes can be used to divert lower flows, events that exceed that capacity will deposit sediment in the reservoir. Increased deposition would increase the required duration, and would thus increase the risk of another significant storm bringing in more sediment.

2. Drying of the Sediments. There is some unknown related to the drying of the sediments. The rate of drying was modeled mathematically; while the results appear reasonable, further studies would be required to calibrate the model and verify the results. An increased drying time would result in increased costs due to direct impacts on the contractor’s schedule and increase the risk of sediment deposition as a result of a significant storm.

9.7. Alternative 4b: Full Dam Removal/Temporary Sediment Stabilization on Site

The issues identified in items 1 through 6 in Alternative 1 and in item 2 in Alternative 2a are relevant.

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