A Report Prepared for

U.S. Navy
Western Division Naval Facilities
Engineering Command
San Bruno, California

PROPOSED GROUND-WATER MONITORING PLAN
NAVAL SUPPLY CENTER - OAKLAND
NAVAL AIR STATION - ALAMEDA
ALAMEDA COUNTY, CALIFORNIA

HLA Job No. 7748,006.04

by

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I INTRODUCTION

This report, prepared by Harding Lawson Associates (HLA), presents the proposed ground-water monitoring plan for the Naval Supply Center in Oakland (NSC-O) and the Naval Air Station in Alameda (NAS-A). Both sites are located in Alameda County, California, on the eastern side of San Francisco Bay (Plate 1).

The U.S. Navy is planning to dredge selected areas of the Oakland Middle Harbor. An underlying fresh water aquifer that may be affected by deepening the harbor exists beneath both sites. The dredging will involve removing sediments overlying the aquifer zone, thus exposing the aquifer to sea water. Because of density differences between salt water and fresh water, salt water could move inland, under the fresh water, increasing the salinity of the ground water.

The following sections present a study to assess the effect dredging may have on the underlying aquifer. A summary of background information for NSC-O and NAS-A developed after a literature search and is presented in the Appendix. Information from the search includes site descriptions, regional geology, and hydrology. References, the result of the literature search are included in this report. The following sections present the proposed ground-water monitoring plan, an aquifer testing program, and report preparation information.

II GROUND-WATER MONITORING PLAN

A ground-water monitoring plan has been developed to assess the impact, if any, of dredging on the fresh water Merritt Sand/Posey aquifer. A discussion regarding the reasons for monitoring the Merritt Sand/Posey aquifer is described in the hydrogeology section of the Appendix. The initial study is designed to obtain background ground-water quality at each site for one year prior to deepening the harbor area. The background data will be compared to data obtained after dredging has been completed to determine if salt water intrusion is occurring and impacting the ground-water quality of the Merritt Sand/Posey aquifer. The background information obtained will only provide information on the current ground-water quality of the aquifer because the impact previous dredging operations may have had on the aquifer cannot be assessed at this time.

Dredging for both sites will involve selected areas of the Oakland Middle Harbor (Plates 2 and 3). Basically, dredging at NSC-O will change bottom depths from -35 MLLW to -39 MLLW and dredging at NAS-A will change bottom depths from -42 MLLW to -50 MLLW (plus a standard 2-foot overdredge allowance). These dredging depths and locations are approximate and may be further modified. At NSC-O, dredging will only take the sand and mud cover off of the Merritt Sand and will not penetrate it. Dredging at NAS-A will penetrate a few feet into the Merritt Sand. As discussed in the hydrogeology section in the Appendix, the Merritt Sand has been penetrated before during dredging operations. This is also confirmed by bathymetry maps provided by the Corps of Engineers for the Oakland Inner and Outer Harbor areas.

It is proposed to study the impact of dredging on the Merritt Sand/Posey aquifer by installing monitoring wells at both locations and analyzing the ground-water samples from these wells for parameters that may indicate increased salinity content.

Eight ground-water monitoring wells will be installed, four at each site (Plates 2 and 3). The proposed well locations should intercept potential salt water intrusion if it moves inland and provide good lithologic information for both sites. Depending on site lithology, the wells will be placed approximately 1000 feet apart. This distance will be modified if it is determined that the aquifer has a high transmissivity, and that the distance between monitoring wells will be too great to obtain useful information from the aquifer tests. The borings are not expected to exceed 300 feet in depth and will be terminated when one of the following is encountered: salt water, the San Antonio aquitard, or Franciscan bedrock. If salt water is encountered during drilling, the boring will be terminated and the well will monitor the upper zone of the aquifer to detect further movement of saline water. Because of density differences due to varying salinity content, salt water (high salinity) will move below fresh water (low salinity). Monitoring the lower 20 feet of the fresh water zone is therefore adequate for detecting the movement of saline waters.

The wells will be sampled on a quarterly basis for one year to provide sufficient background information on the ground-water quality of the aquifer. In addition to the eight new wells, four existing private wells will be included in the quarterly sampling. Three of the four existing wells (State identification numbers: 2S4W3E1, 2S4W10B1, and 2S4W11D1) are in proximity to NAS-A and one (1S4W34F4) is in proximity to NSC-O. Two of the existing wells (1S4W34F4 and 2S4W3E1) are completed in the Alameda Formation and will provide background information of this aquifer. The other two wells are completed in the Merritt Sand and will be used for background information of that aquifer (Table 1). Aquifer testing will be conducted by performing at least one pump test at each site.

A. Well Installation Procedures

To obtain one year's worth of ground-water chemistry data prior to the proposed dredging, the wells will be installed during February and March, 1987. The following procedures will be followed for the installation of the ground-water monitoring wells.

- The borings will be drilled using a dual tube rotary rig and reamed with mud rotary. The use of a dual tube rotary rig to drill a pilot boring is to obtain good lithologic and formation water samples. Because the dual tube rotary rig can only drill a 4-inch-diameter hole, reaming the hole to approximately 10 inches in diameter will be performed using mud rotary. The formation water will be tested for specific conductivity to determine when or if salt water is encountered. The boring will be terminated when salt water, the San Antonio aquitard, or Franciscan bedrock is encountered.

- The borings will be logged by an experienced geologist using the Unified Soil Classification System (Plate 4). All specific conductivity measurements will be recorded on the boring log sheet.

- After the boring has been reamed with mud rotary, the well will be installed. A diagram showing generalized well construction details is shown on Plate 5. The well will be constructed of 4.5-inch-diameter PVC well casing with a minimum wall thickness of Schedule 80. The bottom 20 feet of the aquifer zone will be screened; screen slot size will be determined based on the aquifer materials encountered. A 2-foot silt trap will be placed below the well screen to prevent sediments from blocking the screen. A cap will be placed over the top of the well to prevent material from entering the well. Sand graded for use with the screen slot size will be packed in the annulus between the boring wall and the well casing. The sand will be brought to 2 feet above the top of the well screen. Bentonite pellets or fine-grained sand will be placed above the top of the sand to prevent material above from entering the sand pack. To provide a good sanitary seal, a cement/bentonite grout will be pumped through a tremie pipe placed a few feet above the top of the sand or bentonite seal. The grout will be placed from the top of the sand or bentonite seal to ground surface. In general the wells will be completed below grade with a steel locking well housing placed over the well casing. A Christy box with a steel traffic cover will be placed over each well to prevent damage.

- The wells will be developed using the air lift method. Compressed air will be pumped down the well, forcing the water in the well to move up and out of the well. Development will continue until several well volumes have been removed from the well and the development water is reasonably clear. The development water will be pumped to the closest storm sewer.

- After the wells have been installed, they will be surveyed to a known datum. Top of casing elevation as well as ground surface elevation will be recorded. A mark will be put on the casing where it was surveyed, and will be used as a reference point when taking water levels or depth soundings of the well.

B. Ground-Water Sampling

The following procedures will be followed for sampling ground water in the new and existing wells.

- Prior to sampling each well, all sampling equipment will be decontaminated using an anionic detergent (Alconox) and water solution and rinsed with tap water.

- Before purging each well, depth to water and bottom of casing measurements will be taken using a steel tape or an electronic well sounder and referenced to a surveyed point on the well casing. The measurements will be recorded on a field record sheet (Plate 6).

- A submersible pump will be placed down the well and the well evacuated of at least three well volumes. If the well pumps dry, it will be allowed to recover and then pumped again until three volumes are removed.

- During purging, the evacuated water will be tested for pH, temperature, and specific conductance. These measurements will be recorded on the field record sheet.

- After three volumes have been removed, a water sample will be obtained using a stainless steel bailer or a polyurethane bottle. The water sample will be poured into clean containers provided by the analytical laboratory. Each sample bottle will have an attached sample tag with the following information: job name and number, date sample collected, sampler's name, and analyses requested. The sample bottles will be placed on ice and delivered to the analytical laboratory.

- Each sample will be accompanied to the laboratory by a chain of custody form with the following information: job name and number, sample numbers, date samples collected, sampler's name, analyses requested, and the signature of person(s) handling the samples (Plate 7).

- The water samples will be analyzed by the analytical laboratory for total dissolved solids (TDS), nitrate, and chloride. Table 2 provides the testing method and preservation and holding times for these parameters.

III AQUIFER TESTING

At least one pump test will be conducted at each site to calculate the hydraulic conductivity and storage coefficient of the Merritt Sand/Posey aquifer. Ground-water flow velocities will be determined from the pump test data and values generated from the pump tests will provide parameters for numerical modeling of the sites should this be required. Only the new ground-water monitoring wells will be pumped and monitored because the existing wells are located too far away from the new wells to be respond to pumping. The pump tests are scheduled to be conducted during March and April, 1987, after the wells have been installed and developed.

IV REPORT PREPARATION

It is estimated that it will take 6 to 8 weeks to complete installation of the wells at both sites. The first round of ground-water sampling will begin immediately after the wells have been installed and properly developed.

Ground-water sampling results will be reported on a quarterly basis. The reports will include the ground-water chemical results, water elevation measurements, and water level contour maps for each site. The quarterly reports should be available within three weeks after receiving the water chemistry reports from the analytical laboratory. Findings from well installation and aquifer testing activities will be reported separately.

V REFERENCES

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SOIL BORING LOGS

Many foundation studies have been performed at both study areas. Soil borings drilled for these studies range in depth from 5 to approximately 100+ feet. These reports noted below are on file at U.S. Navy, Western Division, Naval Facilities Engineering Command in San Bruno, California.

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TABLES

Table 1. Well Inventory
(From: U.S. Army Corps of Engineers July 1983
Oakland Inner Harbor Feasibility Report and Environmental Impact Statement, Appendix G)

Well Location (State Well Number)	Dissolved Chloride (mg/l)	Specific Conductance at 25° (Microhms/cm)	Date Sampled	Completed Depth of Well Meters (feet)		Approximate Producing Depth Interval Meters (feet)		Probable Producing Formation
*1S4W34F4	180	1030	7/27/82	122	(400)	61-116	(200-380)	Alameda
1S4W35A2	155	1080	8/3/82	29	(95)	23-30	(75-100)	Alameda
1S4W35Ea	28	426	8/11/82	27.7	(91)	Insufficient Information 82-88	(270-290)	Insufficient Information
*2S4W3E1	88	749	7/27/82	108	(353)	104-107	(340-350)	Alameda
2S4W10B	11	281	8/3/82	4	(12)	1.5-3.7	(5-12)	Surface Soils
*2S4W10B1	39	856	8/5/82	11	(35)	3-9	(10-30)	Merritt
*2S4W11D1	6	287	7/27/82	9	(29)	4.6-9	(15-30)	Merritt
2S4W11E1	25	422	8/5/82	7	(23)	4.6-9	(15-30)	Merritt

*Wells to be included in quarterly sampling.

Table 2. Sampling and Preservation Procedures

Parameter	Test Method[1]	Recommended Container[2]	Preservative	Maximum Holding Time	Minimum Volume Required for Analysis[3]
Chloride	EPA 300.0	P, G	Cool 4°C	28 days	50 ml
Nitrate	EPA 300.0	P, G	Cool 4°C H_2SO_4 to pH<2	48 hours	100 ml
Total Dissolved Solids (TDS)	EPA 160.1	P, G	Cool 4°C	7 days	100 ml
pH	Field Measurement	T, P, G	None	None	100 ml
Conductivity	Field Measurement	T, P, G	None	None	25 ml
Temperature	Field Measurement	T, P, G	None	None	25 ml

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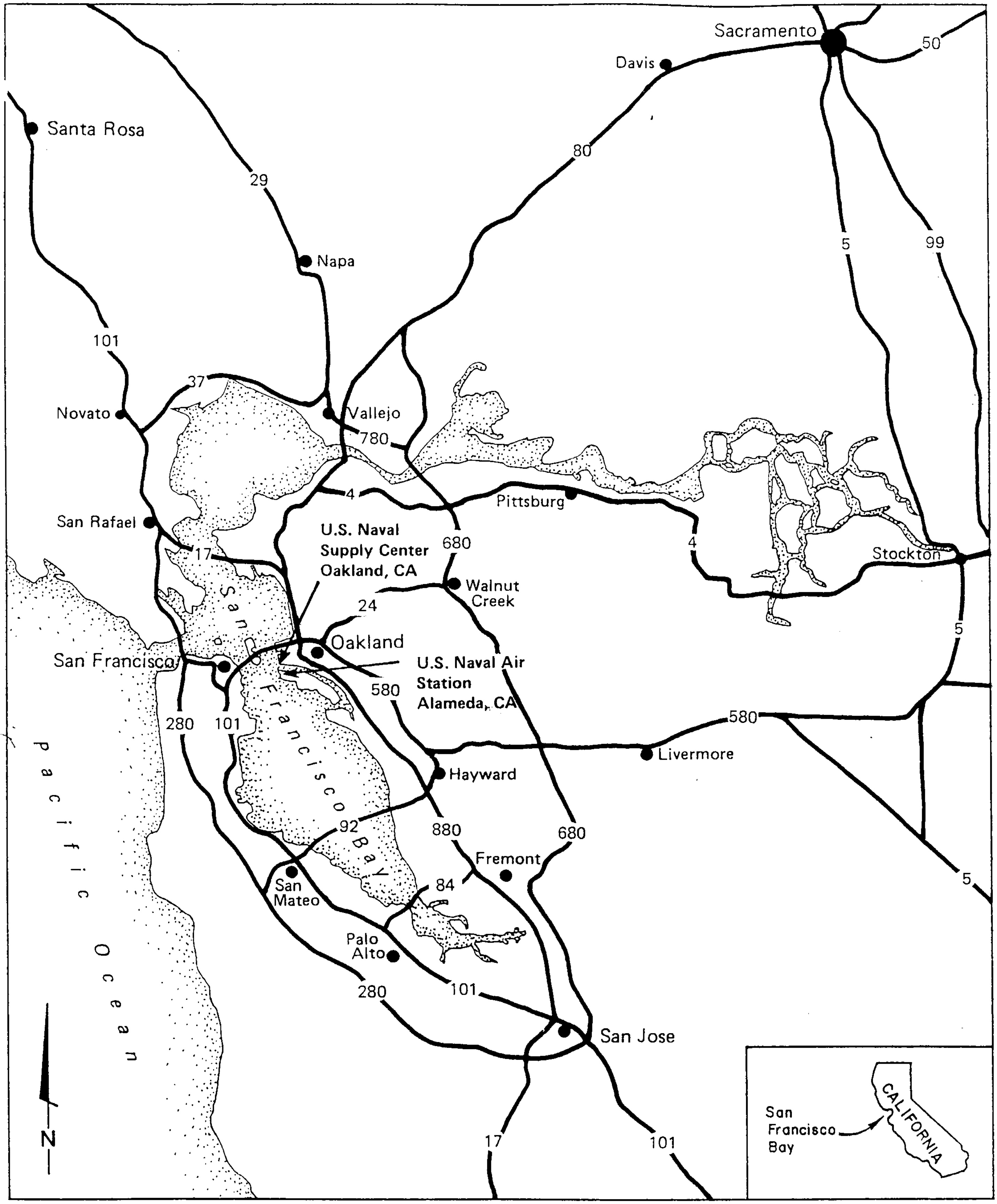
1 Procedures according to Methods for Chemical Analysis of Water and WAstes, EPA-600/4-79-020.

2 Container types:
P=Plastic (Polyethylene)
G-Glass
T-Teflon

3 ml=milliliters

ILLUSTRATIONS



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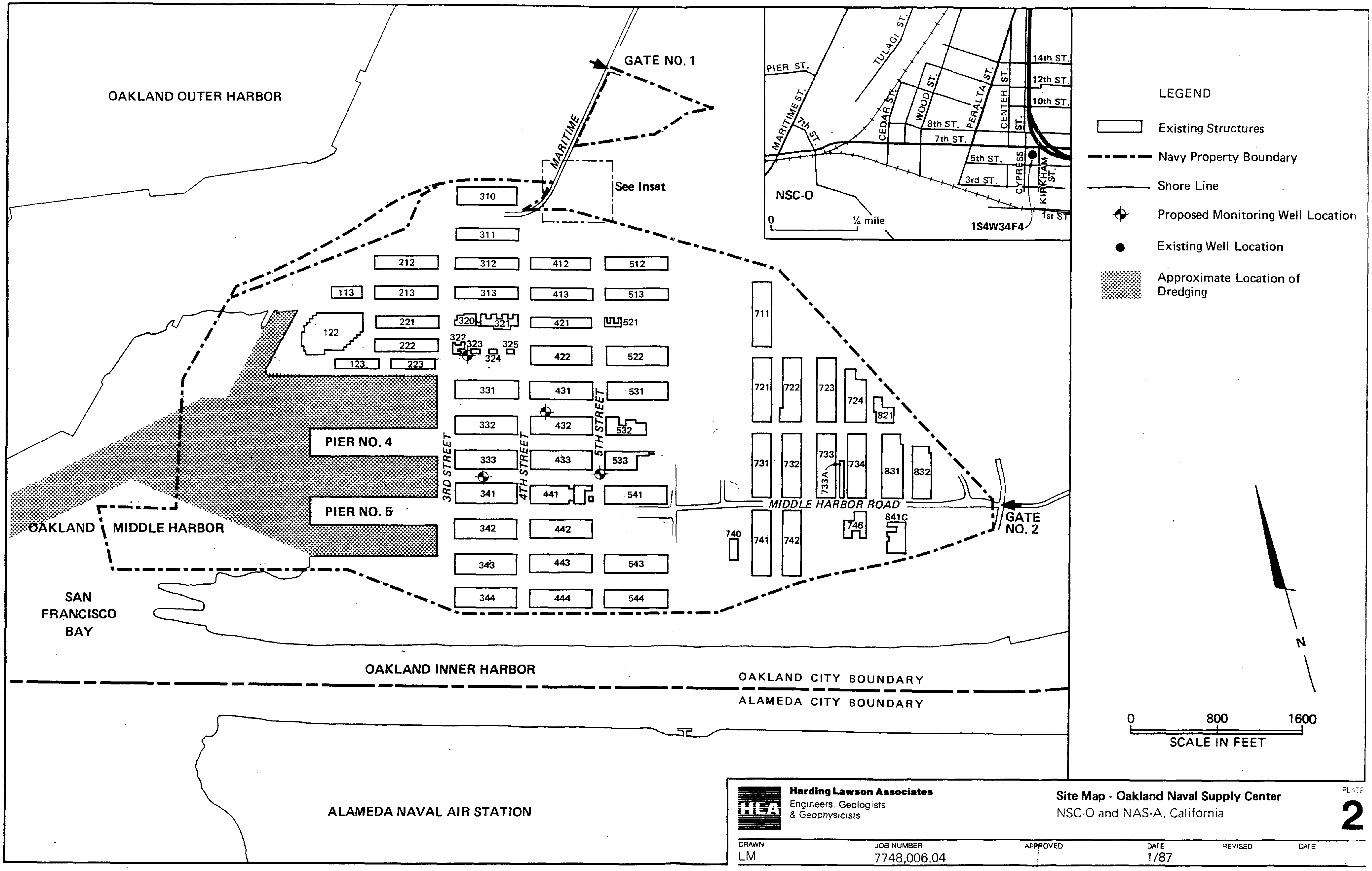
General Location Map
NSC-O and NAS-A, California

PLATE
1

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
PAS	7748,006.04		1/87		

7658



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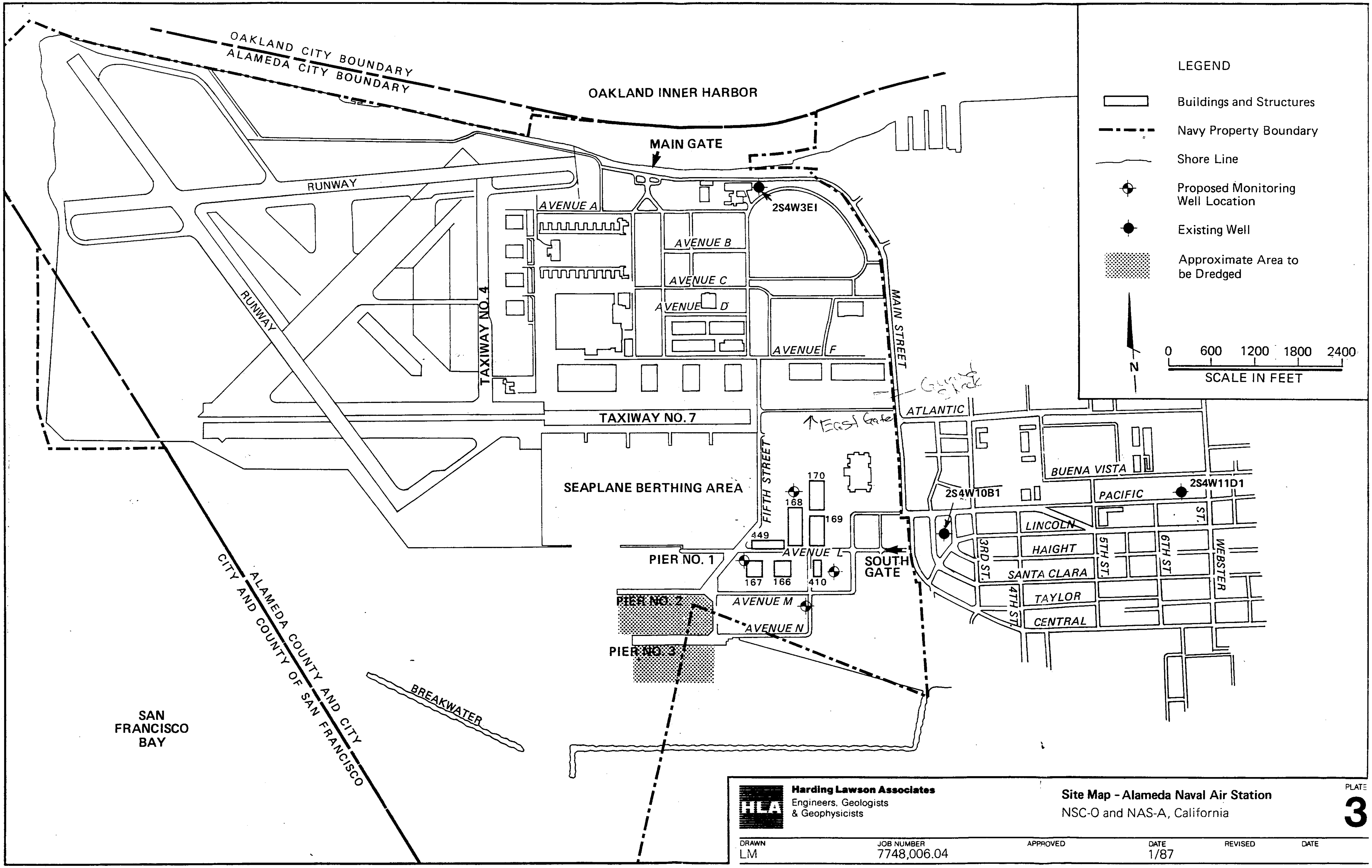
Site Map - Oakland Naval Supply Center
NSC-O and NAS-A, California

PLATE **2**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
LM	7748,006.04		1/87		

7673



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Site Map - Alameda Naval Air Station
NSC-O and NAS-A, California

PLATE **3**

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
LM	7748,006.04		1/87		

MAJOR DIVISIONS				TYPICAL NAMES
COARSE - GRAINED SOILS MORE THAN HALF IS LARGER THAN NO 200 SIEVE	GRAVELS MORE THAN HALF COARSE FRACTION IS LARGER THAN No. 4 SIEVE SIZE	CLEAN GRAVELS WITH LITTLE OR NO FINES	GW	WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES
			GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES
		GRAVELS WITH OVER 12% FINES	GM	SILTY GRAVELS, POORLY GRADED GRAVEL-SAND-SILT MIXTURES
			GC	CLAYEY GRAVELS, POORLY GRADED GRAVEL-SAND-CLAY MIXTURES
	SANDS MORE THAN HALF COARSE FRACTION IS SMALLER THAN NO. 4 SIEVE SIZE	CLEAN SANDS WITH LITTLE OR NO FINES	SW	WELL-GRADED SANDS, GRAVELLY SANDS
			SP	POORLY GRADED SANDS, GRAVELLY SANDS
		SANDS WITH OVER 12% FINES	SM	SILTY SANDS, POORLY GRADED SAND-SILT MIXTURES
			SC	CLAYEY SANDS, POORLY GRADED SAND-CLAY MIXTURES
FINE - GRAINED SOILS MORE THAN HALF IS SMALLER THAN NO 200 SIEVE	SILTS AND CLAYS LIQUID LIMIT 50% OR LESS		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS, OR CLAYEY SILTS WITH SLIGHT PLASTICITY
			CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
			OL	ORGANIC CLAYS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS LIQUID LIMIT GREATER THAN 50%		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACIOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS
			CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
			OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS			Pt	PEAT AND OTHER HIGHLY ORGANIC SOILS

UNIFIED SOIL CLASSIFICATION SYSTEM

Perm	—	Permeability
Consol	—	Consolidation
LL	—	Liquid Limit (%)
PI	—	Plastic Index (%)
G_s	—	Specific Gravity
MA	—	Particle Size Analysis
▀	—	"Undisturbed" Sample
☒	—	Bulk or Classification Sample

Test	Shear Strength (psf)	Confining Pressure		
TxUU (FM) or (S)	3200	(2600)	—	Unconsolidated Undrained Triaxial Shear (field moisture or saturated)
TxCU (P)	3200	(2600)	—	Consolidated Undrained Triaxial Shear (with or without pore pressure measurement)
TxCD	3200	(2600)	—	Consolidated Drained Triaxial Shear
SSCU (P)	3200	(2600)	—	Simple Shear Consolidated Undrained (with or without pore pressure measurement)
SSCD	3200	(2600)	—	Simple Shear Consolidated Drained
DSCD	2700	(2000)	—	Consolidated Drained Direct Shear
UC	470		—	Unconfined Compression
LVS	700		—	Laboratory Vane Shear

KEY TO TEST DATA

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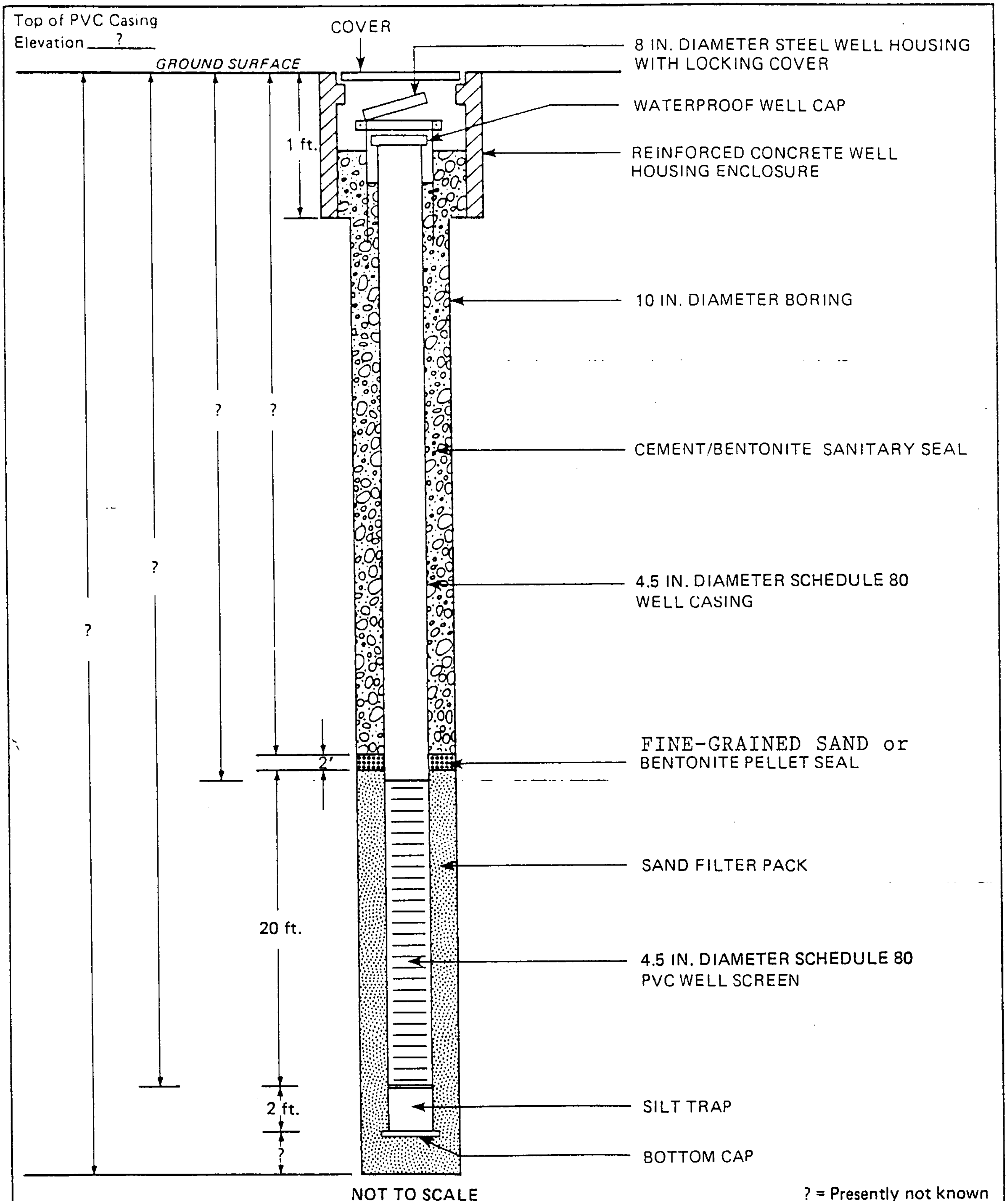
Soil Classification Chart and
Key to Test Data
NSC-O and NAS-A, California

PLATE
4

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
	7748,006.04	Cmm	1/87		



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Generalized Well Construction Diagram
NSC-O and NAS-A, California

PLATE
5

DRAWN	JOB NUMBER	APPROVED	DATE	REVISED	DATE
DM	7748,006.04	JMM	1/87		

FORM GW3

GROUND WATER SAMPLING

Well No. ____________________ Job Name and No.

Date/Time ____________________

Sampled by ____________________

Sampling Method

__ bailed ___ other

__ discharge

Pump Type: __ submersible __ other

Pump Number: ____________

Pump Setting: __ near bottom __ other

Total depth ______________

Water level ______________

rate (gpm) ______________

Pumping time ______________

Meter Number __ ___ ___

Comments: ______________________________

Minutes since pumping began	pH	Cond.	T(°C)	Minutes since pumping began	pH	Cond.	T(°C)

Sample No.	Volume	Field Processed	Comments

Conductivity is not corrected for temperature.

PLATE
6

Ha Law ssoc
7655 Redwood Blvd.
P O Box 578
Novato, CA 94948
(415) 892-0821

CHAIN OF CUSTODY FORM

Job Number: ____________

Name/Location: ____________

Project Manager: ____________

Samplers: ____________

Recorder: ____________
(Signature Required)

SOURCE CODE	MATRIX: Water	Sediment	Soil	Oil	#CONTAINERS & PRESERV.: Unpres.	H_2SO_4	HNO_3	SAMPLE NUMBER OR LAB NUMBER: Yr	Wk	Seq	DATE: Yr	Mo	Dy	Time	STATION DESCRIPTION/ NOTES

ANALYSIS REQUESTED						
EPA 601/8010	EPA 602/8020	EPA 624/8240	EPA 625/8270	Priority Pllnt. Metals	Benzene/Toluene/Xylene	Total Petrol. Hydrocarb.

LAB NUMBER: Yr	Wk	Seq	DEPTH IN FEET	COL MTD CD	QA CODE	MISCELLANEOUS

CHAIN OF CUSTODY RECORD

RELINQUISHED BY: *(Signature)*	RECEIVED BY: *(Signature)*	DATE/TIME
RELINQUISHED BY: *(Signature)*	RECEIVED BY: *(Signature)*	DATE/TIME
RELINQUISHED BY: *(Signature)*	RECEIVED BY: *(Signature)*	DATE/TIME
RELINQUISHED BY: *(Signature)*	RECEIVED BY: *(Signature)*	DATE/TIME
DISPATCHED BY: *(Signature)* DATE/TIME	RECEIVED FOR LAB BY: *(Signature)*	DATE/TIME
METHOD OF SHIPMENT		

Laboratory Copy White | Project Office Copy Yellow | Field or Office Copy Pink

6533

PLATE

7

Appendix

SITE DESCRIPTION, REGIONAL GEOLOGY, AND HYDROGEOLOGY

APPENDIX
SITE DESCRIPTION, REGIONAL GEOLOGY, AND HYDROGEOLOGY

Site Description

Both NSC-O and NAS-A are located along the Oakland Harbor area in the East Bay portion of San Francisco Bay (Plate 1). As described by the U.S. Army Corps of Engineers, February 1977, in "Environmental Statement, Oakland Outer Harbor, California", Oakland Harbor is located on the eastern shore of central San Francisco Bay in Alameda County, California, about 8.7 miles east of the Golden Gate Bridge. The harbor occupies essentially the entire waterfront of the City of Oakland and about one-half the waterfront of the City of Alameda. The Oakland Harbor consists of five distinct areas: North Harbor, Outer Harbor, Middle Harbor, Inner Harbor, and Tidal Canal.

NAS-A is located in Alameda County, California. The station occupies the western tip of the island of Alameda, along the eastern side of San Francisco Bay. The station site includes approximately 2,479 acres owned by the U.S. Government, and an additional 155 acres leased from others. Of this acreage, about 1,526 acres is above water, and about 1,108 acres is below water. In addition, the station holds an aviation airspace easement for about 120 acres.

NAS-A has been described by Wahler Associates, May 1985, in "Draft Report, Verification Step, Confirmation Study, Naval Air Station, Alameda". A detailed description of the NSC-O site was not found, but, because of their proximity to each other, the general geographic descriptions of NAS-A are similar to NSC-O. The Wahler report provides a brief general description of NAS-A as follows.

The station is essentially flat, with typical surface elevations of 10 to 15 feet above sea level. Much of the dry land portion of the station, including all of the western portion, occupies reclaimed marshland and open water that have been filled. A substantial proportion of the fill used in this reclamation is dredge spoils from San Francisco Bay and the so-called Oakland Estuary, which separates the island from the mainland just to the north. Much of the original island is formed of comparatively fine-grained sands interlayered with clayey sands and clays. However, most of the reclaimed areas that comprise much of the station were filled over deep bay muds, which are typically silts and low plasticity clays. Available data indicate that bedrock under the station is hundreds of feet deep.

Most of the eastern half of NAS-A is heavily developed, principally with office and heavy industrial facilities. Most of the western half of the station is comprised of runways, taxiways, aprons, and undeveloped intervening acreage. There are a few shops, ordnance storage facilities, and other light developments located in the western half of the station, mainly around the perimeter.

There are no significant natural surface water drainages within the station. Precipitation is removed through infiltration, sheet runoff, and artificial storm drainage. It is believed that essentially all surface and ground waters leaving the station discharge into the surrounding bay and estuary.

Significant quantities of ground water are first encountered at a depth of only a few feet, and recur in pervious zones throughout the geologic section. Three wells are known to have been previously operated on the station. Two were both removed from service, reportedly due to high natural mercury concentrations.

Regional Geology

San Francisco Bay stratigraphy has been studied for foundation properties during the building of the San Francisco-Oakand Bay Bridge and while studying other proposed San Francisco Bay crossings. The geologic characteristics of sediments and bedrock of San Francisco Bay near the study area have been described by Trask and Rolston, 1951, in Engineering Geology of San Francisco Bay, California as follows. The description below of the stratigraphic units is structured as a geologic column, with the youngest deposits discussed first and the underlying sediments described in order of increasing age.

Bay Mud - Formation A - Thickness 0-100 feet. Soft mud, becoming firmer with depth; consists of silty clay containing grains of windblown sand. In some areas the upper part of the formation includes thin layers of fine- to medium-grained sand alternating with silty clay. In places shells and plant fragments are found. Near Webster Street in the City of Oakland, the base of the formation is dark gray, suggestive of an old soil zone. The formation generally consists of three members. An erosional unconformity may overlie Member A-3, as the upper two members are coarser in texture than Zone A-3.

Member A-1. Soft mud composed of silty clay and occasional interbedded thin sand layers; thickness 0-65 feet.

Member A-2. Fine- to medium-grained silty sand; thickness 0-40 feet.

Member A-3. Silty clay, firmer and less sandy than Zone A-1. Locally contains layer of peat near base; thickness 0-45 feet.

Erosional Uncomformity. Valleys attaining a depth of at least 150 feet below sea level carve into the underlying formations. Most of the valleys occupy valleys previously cut during post-Posey and pre-Merritt time.

Merritt Sand - Formation B - Thickness 0-60 feet. Mostly well-sorted medium-grained sand, in part of windblown origin. The sand partially fills valleys carved in underlying Posey and older formations. The sand also lies as a blanket upon the Posey Formation, and in places rises above sea level. In some areas the upper part of the formation contains admixtures of clay. In other places, part of the formation is well-sorted silt, suggestive of loess. Merritt Sand consists of two members, which locally are discontinuous.

Member B-1. Medium-grained sand containing varying amounts of silt and clay; thickness 0-20 feet.

Member B-2. Well-sorted, fine- to medium-grained sand, in places forming a permeable aquifer; 0-60 feet thick.

Erosional unconformity. Valleys cut in underlying formations to depth of more than 150 feet below sea level and 1000 feet in width.

Posey Formation - Formation C - Thickness 0-50 feet. Firm sandy clay and sand. In places contains rounded Franciscan pebbles up to an inch in diameter. The formation is firm and has been preconsolidated from 1.5 to 3 tons per square foot, presumably because of some process of desiccation. In some places, the Posey sediments are separable with difficulty from Merritt Sand, particularly east of Yerba Buena Island. The formation consists of two members:

Member C-1. Firm sandy clay and clay; thickness 0-30 feet

Member C-2. Fine- to medium-grained sand fairly free of fines, in part seemingly of windblown origin; thickness 0-15 feet.

Erosional unconformity. Erosion interval during which member D-1 and parts of member D-2 (San Antonio Formation) were removed in areas west of San Francisco Bay.

San Antonio Formation - Formation D - Thickness 15-120 feet. Moderately firm silty clay, in places containing thin lenses of fine gravel of Franciscan pebbles up to 1 inch in diameter. A persistent zone containing shells and sand is found near the top of the formation in the east part of the bay. The lower part of the formation in many places is greenish gray, suggestive of glauconite. A black zone which seemingly is an ancient soil is found at the base of the formation near the Webster Street Tube. A more or less continuous layer of plant fragments lies a few feet above the base of the formation. The firmness of the sediments varies. In the vicinity of the Webster Street Tube, the deposits are relatively stiff, but east of Yerba Buena Island, where the formation is thickest, the sediments are soft. The formation can be separated into at least three members. The upper two members are not well developed in the west part of San Francisco Bay.

Member D-1. Silty Clay. Thickness 0-40 feet.

Member D-2. Persistent layer of shells associated with fine- to medium-grained sand and with silty clay. Not found on west side of San Francisco Bay. Thickness 0-40 feet.

Member D-3. Gray and greenish-gray clay. In places contains zones of sand or sandy gravel containing Franciscan pebbles. Persistent layer of plant fragments lies at base. Organic remains are found at other levels as well. Alternating layers of fine sand and clay are present. The clay in this formation is more fine-grained than clay in other formations. With additional boreholes this member probably could be subdivided further. Thickness 0-50 feet. This formation forms a competent aquitard between the Merritt Sand/Posey aquifer and the underlying Alameda Formation aquifer.

Erosional unconformity. Moderate erosion interval, during which perhaps as much as 50 feet of sediment was eroded from underlying formations.

Alameda Formation - Formation E - Thickness 0 to more than 200 feet. Thickness varies with distance to bedrock. Sand, sandy clay, clay, and fine gravel; commonly gray, but in places is greenish gray or brownish gray. Most of the gravel pebbles are less than 1 inch in diameter, well-rounded, and are derived from the Franciscan Formation. Plant fragments are found at several horizons, particularly in the upper part of the formation.

The Alameda Formation contains at least five members of alternating sandy clay and sand. The sand commonly contains fine gravel. The lower part of the formation perhaps is equivalent to the Santa Clara or Merced Formations. This formation is a water bearing unit and will be referred to as the Alameda Formation aquifer.

Erosional unconformity. Prior to deposition of the Alameda Formation, the bedrock was deformed and eroded to a mature topography of considerable relief.

Bedrock - Franciscan Formation (Jurassic?) - Thickness several thousand feet. The Franciscan Formation is composed of feldspathic sandstone, graywacke, siltstone, shale, interbedded chert and shale, and various types of basic and ultrabasic igneous rocks, now altered to greenstone and serpentine. The Franciscan has been broken by numerous small faults, which are no longer active. This formation is susceptible to landslides.

Depth to bedrock at the site in not known. A map published by the United States Geological Survey (1957) indicates that exploration borings made in the vicinity penetrated to depths of up to 354 feet without encountering bedrock. A boring approximately one mile northwest of NAS Alameda encountered bedrock at an elevation of -433 feet Mean Lower Low Water Datum (MLLW). Bedrock at this location was described as yellow shale. In borings that did not reach bedrock, the soils consisted primarily of clays with interbedded sandy and gravelly layers.

Additional sources describing geologic and engineering aspects of the study area are included in the References section of the main text.

Regional Hydrogeology

The two fresh-water-bearing units located beneath NSC-O and NAS-A are Merritt Sand and the Alameda Formation. These two units are separated by the San Antonio aquitard, which appears to be competent, allowing little or no communication between the two aquifers. Because it is difficult to distinguish between the Merritt Sand and the underlying Posey Formation, they will be considered one hydrologic unit (Merritt Sand/Posey aquifer).

The aquifer that will be monitored during the ground-water study at NSC-O and NAS-A is the Merritt Sand/Posey. The underlying Alameda Formation aquifer should remain relatively unaffected by the dredging operations.

Based on foundation borings from both sites, the bay mud unit appears to increase in thickness to the east, being only 0 to 10 feet thick near the shoreline. Depending on the thickness of the bay mud, the ground water in the Merritt Sand/Posey aquifer is generally within a few feet of ground surface. The hydrologic properties of the Merritt Sand/Posey aquifer are not well understood, and little published information on this topic is available.

The following presents the results of an earlier well survey and information regarding sea water intrusion.

Well Survey

In 1981 the California Department of Water Resources conducted a field inventory of all active and inactive wells within one mile of the then proposed Oakland Inner Harbor Deepening Project. Available boring logs and well construction details for the wells were obtained from the Alameda County Water District. The field inventory included a one-time water quality sampling and determination of depth to water where possible (see Table 1 in text). Based on sampling the eight wells, the wells screened in the Alameda Formation have a higher dissolved chloride content than wells screened in the Merritt Sand. The wells in this survey are not used as a drinking water source but mainly for irrigation purposes.

The water supply for NSC-Oakland does not come from private wells, but from municipal sources.

The water supply for NAS-Alameda comes both from private wells and the East Bay Municipal Utilities District (EBMUD). Well water supplements the EBMUD supply. One of the three wells located near the Married Officer Quarters (MOQ) supplies water to irrigate the lawns, trees and shrubs within the area. Water utilized for irrigation from the well may have detrimental effects on the vegetation due to excess salts. The other two wells have been shut down due to natural mercury contamination.

Sea Water Instrusion

The California Department of Water Resources in its October 1975 publication, "Sea-Water Intrusion in California, Inventory of Coastal Ground Water Basins," states that for the East Bay Plain area, the location and extent of ground water degraded by sea-water intrusion through 1971 has not been well documented. Intrusion along San Leandro Creek extending about 1.5 miles inland had been occurring at an estimated rate of 250 feet per year. From 1962 through 1965, sea water moved inland about 0.15 mile. Intrusion along the Oakland Estuary dates from the 1870s, when the depth of San Antonio Creek was increased from 8 feet to 30 feet to accommodate ocean-going vessels. This work cut into the ground-water aquifer, allowing sea water to intrude. High chloride water contained in a group of wells along upper San Pablo Creek is probably derived from connate water.

The U.S. Army Corps of Engineers in its June 1983 publication, "Oakland Outer Harbor General Design Memorandum for Deep Draft Navigation Improvement," indicated that a concern over the possibility of local contamination of ground-water aquifers by salt water intrusion in the project area had been previously expressed by the Department of Water Resources in 1981 in relation to the Oakland Inner Harbor Project. To determine the possibility of contamination of local aquifers by salt water intrusion caused by increasing the size of the Oakland Outer Harbor Project, a review was made of exploration borings conducted for the Oakland Outer Harbor area by the Corps of Engineers from December 1964 through May 1982 and exploration borings performed for the Bay Area Rapid Transit's Trans-Bay Tube in 1964. The review indicates that correlation of the deposits encountered by the Corps' borings is very difficult due to the deposits being very complex in their relationship with each other.

The complexity of the bottom deposits is due to several causes. These include surface runoff; deposits of sand and silt in the channel; influx of bay sediments with tidal action; removal of material from the channel sides; and the probable reworking of bottom sediments by propwash and surge from ships. Differences in bottom elevations and in types of sediments deposited within the same depth interval below -37 feet MLLW are encountered in holes drilled fairly close together but in different years. The sudden change from sand to silty clay within the same depth interval of close-by holes indicates probable reworking of sandy to silty clay by propwash. Propwash would winnow out the clay and fine silt size particles and redeposit coarser sediments of sand and coarse silt in the depressions left behind. The Corps' borings rarely penetrate below -48 to -52.8 MLLW in the turning basin and in the entrance to the turning basin, as shown in an October 1974 bottom survey. Comparing the October 1974 survey of the turning basin with the May 1982 survey indicates that the deep areas are not fixed but change position.

The channel and turning basin were excavated to -35 feet MLLW in the mid-1940s and subsequently maintained at -35 feet MLLW with allowances to -37 feet MLLW for overdredging. The propwash of deeper-drafted ships and local areas of possible dredging that may have exceeded -37 feet MLLW have created an erratic depositional environment. Either the Corps' exploration borings do not fully penetrate the zone of erratic deposition or they have not been drilled to depths deep enough to accurately delineate the bottom of the zone of erratic deposition. The deposits of the erratic zone are not considered to have any significant aquifer potential.

The exploration performed along the center line of the Trans-Bay BART Tube indicates that the local significant aquifer most susceptible to salt water contamination by deepening the outer harbor is the Merritt Sand. The Merritt Sand is described as a non-cemented, unconsolidated, fine-grained, very well sorted beach and windblown sand generally yellowish brown to brown in color. The Merritt Sand has been exposed by the excavation of the Oakland Outer Harbor channel. Exploration borings for the Trans-Bay Tube indicate that the bottom of the Merritt Sand on the southern side of the channel under the 7th street terminal extends to depths of approximately -64 to -60 feet MLLW and has a bottom depth of approximately -55 feet MLLW at the south edge of the channel. The bottom of the Merritt Sand under the channel is approximately -54 feet MLLW and then deepens to -86 feet MLLW just outside the north edge of the channel and thins out towards the middle of the bay. Excavation for the Trans-bay Tube cut through the bottom of the Merritt Sand and left a trough lying askew across the harbor channel. The trough has a bottom depth as deep as -56 feet MLLW per the October 1974 bottom survey. The bottom surveys of May 1982 indicate that the bottom of the channel over the top of the tube is at or very near the bottom of the Merritt Sand. The upper limit of the Merritt Sand ranges from the bottom of the Oakland Outer Harbor channel on either side of the Trans-bay BART Tube, crossing to -19 MLLW in the side slope of the channel near the pierhead line, and finally reaches the surface at approximately +13 feet MLLW in the interior of the peninsula between the Outer and Inner Harbors.

In conclusion, the movement of ships in and out of the harbor, especially the deeper-drafted ships, has kept the bottom sediments in erratic disarray. Correlation of sediments between shallow borings is extremely difficult to nearly impossible if the borings are several years apart. The borings of the Corps of Engineers do not penetrate the probable zone of erratic deposition deep enough to confidently draw a lower limit to it. The harbor channel excavation in the mid-1940s, its maintenance at -35 feet MLLW, continuing bottom disturbance by propwash and dredging, the fact that large areas of the turning basin are already at or below -42 feet MLLW, and the depth of the channel bottom directly over the Trans-Bay Tube, indicate that the full thickness of The Merritt Sand has been intersected and subjected to maximum exposure for salt water intrusion since 1974.

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