AREA I 50 SERIES COMPLEX SITE INVESTIGATION REPORT

For
Environmental Investigation at the Formerly Used Defense Site (FUDS)
at the Benicia Arsenal, Benicia, California

FUDS Site Number: J09CA075600

FINAL

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BENICIA ARSENAL, BENICIA, CALIFORNIA

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LIST OF ACRONYMS AND ABBREVIATIONS

afbm	artificial fill over Bay mud
Arsenal	former Benicia Arsenal
AST	above ground storage tank
bgs	below ground surface
BSL	Benicia Screening Level
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CD	compact disc
cis-1,2-DCE	cis-1,2-dichloroethene
cm	centimeter
COI	chemicals of interest
COPC	chemical of potential concern
CSM	conceptual site model
DCE	dichloroethene
DoD	United States Department of Defense
DQOs	data quality objectives
DTSC	Department of Toxic Substances Control
EMLL	electromagnetic line locating
EPA	Environmental Protection Agency
FA/BC	Forsgren Associates/Brown and Caldwell
FSIP	Field Site Investigation Plan
FUDS	Formerly Used Defense Site
GPR	ground penetrating radar
IDW	investigation derived waste
J&E	Johnson and Ettinger (model)
MDL	method detection limit
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mm	millimeter
msl	mean sea level
MTBE	methyl teriary-butyl ether
NFA	No Further Action
NORCAL	Norcal Geophysical Consultants, Incorporated

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
PID	photoionization detector
ppbv	parts per billion by volume
PPE	personal protective equipment
ppm	parts per million
QA/QC	quality assurance/quality control
QAPP	Quality Assurance Project Plan
QC	quality control
QCSR	Quality Control Summary Report
Qha	Quaternary historic alluvium
Qhaf	Quaternary hollocene alluvial fan
Qhbm	Quaternary historic Bay mud
RBSL	risk-based screening level
RCRA	Resource Conservation Recovery Act
RRR	Records Research Report
RWQCB	Regional Water Quality Control Board
SHM	Site Hydrogeologic Model
SI	Site Investigation (report)
SVOC	semivolatile organic compound
TCE	trichloroethene
TDS	total dissolved solids
TOC	total organic carbon
TPH	total petroleum hydrocarbons
trans-1,2-DCE	trans-1,2-dichloroethene
Tvh	Tertiary Vine Hill
µg/L	micrograms per liter
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
UST	underground storage tank
VOC	volatile organic compound

EXECUTIVE SUMMARY

This document presents the results of a site investigation at the 50 Series Complex at the former Benicia Arsenal (Arsenal), located in Benicia, California. The purpose of this study was to assess if past Department of Defense (DoD) activities at the Arsenal impacted soil or groundwater at the 50 Series Complex. This fieldwork was conducted at the request of, and with oversight, by the U.S. Army Corp of Engineers, Sacramento Region (USACE), and was performed in accordance with planning and USACE guidance documents.

Site Setting and History

The Arsenal is located about 25 miles northeast of San Francisco. The Arsenal was created in 1849 with the transfer of 345 acres of land by the founders of the City of Benicia (Jacobs, 1999). Between 1849 and 1958, the facility grew by land acquisition to a total of 2,728 acres. During its active life, this facility served the United States Army as a principal depot for ordnance and ordnance stores, as well as issuance, manufacture, cleaning and testing of small arms. The Arsenal was declared excess by the government in 1963. Deactivation and closure of the facility was completed in 1964 (Jacobs, 1999).

The southern portion of the Arsenal, the industrial area, served as the main industrial and manufacturing area throughout the 115-year history of the facility and was the center of activity at the Arsenal. Several machine shops, manufacturing shops, and cleaning and painting shops were housed here, along with a blacksmith shop, a welding shop, numerous vehicle and artillery repair shops and a small arms shop. Area I also housed the Arsenal's administrative offices, most of the permanent housing facilities, photographic laboratories, a firehouse, and hospital. Fuel storage and dispensing facilities, a locomotive house, boiler houses, storehouse and warehouse facilities, open storage facilities, landfills and quarries were also located within Area I.

The 50 Series Complex is in the central portion of Area I and was originally constructed as three separate workshop buildings (Buildings 55, 56, and 57) between 1876 and 1884. The remodeling of these buildings occurred over many phases, including the addition of eight new buildings (today commonly identified as Buildings 55A, 56A, 56B, 56C, 57A, 57B, 57C, and 65(B)) and the removal and relocation of three existing buildings (Buildings 59, 65, and 66).

Multiple historical land uses have been identified at the 50 Series Complex, and a variety of locations may have been impacted by chemical releases from former DoD operations. The following activities have been specifically identified as part of previous investigations at the Arsenal: ordnance storage (supplies, ammunition, small arms parts and accessories); small arms manufacture and testing; manufacture of mobile and seacoast artillery targets; and vehicle maintenance. Since closure in 1964, land use has been predominantly commercial/industrial, although the Arsenal and surrounding areas also currently support residential and park/open space uses as well.

Purpose and Scope

This site investigation sought to ascertain whether past DoD activities at the 50 Series Complex resulted in soil or groundwater contamination by evaluating the following:

- the presence of acids/alkalis, fuels, oils, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), foundry wastes, metals and/or explosives in soil;
- the presence of solvents and volatile organic compounds (VOCs) in soil gas beneath the 50 Series Complex and if the concentrations could impact indoor air;
- the extent of semivolatile organic compounds (SVOCs), VOCs, and metals previously identified at Building 57A in soil gas, soil, and groundwater;
- the presence and extent of solvents, VOCs, PAHS, SVOCs, and metals in groundwater;
- the impact of soil type and stratigraphy on the presence and distribution of chemicals of interest (COIs);
- the impact of groundwater depth, general chemical quality, and groundwater gradient and flow direction on the presence of COI;
- if COIs are present in soil and soil gas and if the risk screening analysis determined that the COIs are chemicals of potential concern (COPCs);
- if additional data collection, risk analysis, or remediation are required;
- the presence and extent of fuel additives in soil and groundwater that would indicate post-Army releases; and
- collect data to provide the framework for non-beneficial use of groundwater.

Geology

The Arsenal is located at the southern end of California's Northern Coast Range. The geologic history of the region is complex, with episodes of compression and the effects of lateral movement on the nearby San Andreas strike-slip fault system.

Low-lying hills of steep, southwesterly dipping beds of massive sandstone, siltstone, and shale (Vine Hill Sandstone) surround the 50 Series Complex and are present in a steeply sloped area between Buildings 56A and 53. Quaternary artificial fill and alluvial/fluvial material overlies the Vine Hill

Sandstone in most low-lying areas, and ranges from a few feet thick to more than 80 feet thick. Typically the alluvial/fluvial material is found uphill from the artificial fill. The artificial fill commonly overlies Bay Mud. This sequence is predominantly present in the low-lying areas south of the 50 Series Complex, where marshlands were filled during the development of the Arsenal.

Most soil borings in the area encountered artificial fill overlying Quaternary alluvial/fluvial material consisting of native silt and clay with minor sands. The fill material consists of gravelly silt, low to medium plasticity clay, silty sand, with some wood and brick. Depth to the sandstone bedrock in borings drilled at the 50 Series Complex ranged from 1 foot below ground surface (bgs) in the utility tunnel area, to 3 feet bgs at the ground floor, to 25 feet bgs just south of the Complex. The shallower occurrence of sandstone correlates to areas of excavation and removal of native soils to create firing ranges in the basement.

Hydrogeology

In general, groundwater is encountered at the Arsenal at levels less than 20 feet bgs. In the industrial area, groundwater is encountered at less than 8 feet bgs. To better understand the hydrogeology at the Arsenal, 17 piezometers were installed as part of the Site Hydrogeologic Model. Six piezometers were installed in the industrial area and generally located within the former marshland. At times, groundwater has been measured flowing out of three of the six piezometers.

Ultimately, groundwater flows from the surrounding hills into the Carquinez Strait, but the routes may be influenced locally. In the northern and central portion of the Arsenal, groundwater flows into the Sulphur Springs Creek Drainage from the north, west, and east and then turns south into the Carquinez Strait. In the southern portion of the Arsenal, where the 50 Series Complex is located, groundwater flows from the hills to the south and southeast into the Carquinez Strait.

Water Quality

Water quality information such as total dissolved solids (TDS) and the concentrations of specific ions were used to assess the hydrogeologic setting of the 50 Series Complex.

Concentrations of TDS were reported in samples from borings and monitoring wells at less than 1,000 milligrams per liter (mg/L) implying that the groundwater at the 50 Series Complex is mostly freshwater recharged from surface water infiltration. An influence from brackish/salt water sources such as water trapped in former marsh sediments or water from the Carquinez Strait appears to be occurring near the southeast corner of the 50 Series Complex. The concentrations of specific ions represented in graphical radial plots also imply the groundwater is mostly fresh water or mixed with seawater.

Approach

This investigation of the 50 Series Complex occurred in several stages. The Arsenal buildings were identified, including internal features where commodities were used (e.g. fuels, solvents). A list of potential chemicals that may have impacted the environment (COIs) was generated by examining past building use. Source areas were evaluated for the presence and extent of COIs.

After COIs were identified, release mechanisms were assessed. Potential release mechanisms may have included leaking underground storage tanks (USTs), overflow of chemicals from dipping tanks, the dumping of chemicals into storm drains or onto the ground surface, firing ranges where bullets may have accumulated in near surface soil, and foundry operations that may have introduced metals into the soil.

The main buildings and features of the 50 Series Complex are presented in the following table along with their potential COIs.

Building Number	Feature	Commodities	COIs
56, 56A, 56B, 57A	Parkerizing Tanks and Areas	Solvents (post-Army use) in 57A, Acids/alkalis, Preservatives, Metals	volatile organics, semi-volatile compounds, hexavalent chromium, polyaromatic hydrocarbons, metals
58, 65(A), 65(B)	Boiler Rooms	Fuels, Oils, Lead	volatile organics, petroleum and polyaromatic hydrocarbons, lead
56A and 57	Degreaser	Solvents, Acids, Preservatives	volatile organics, semi-volatiles, hexavalent chromium, polyaromatic hydrocarbons
57, 65(B)	Test Firing Rooms and Areas	Metals, Ammunition/powders	copper, lead, antimony and arsenic
56, 56A, 57, 57(B), 58	Small Arms Storage and Repair	Metals, Ammunition/powders	metals
Perimeter of complex	Cisterns	Solvents, Acids, Preservatives, Foundry Waste	volatile organics, semi-volatile, hexavalent chromium, polyaromatic hydrocarbons
55	Foundry	Foundry Waste	metals
55	Forges	Metals, Fuels	volatile organics, petroleum and polyaromatic hydrocarbons, metals
55	Hydraulic Press	Oils	volatile organics, petroleum and polyaromatic hydrocarbons, metals
53, 65(A), 65(B), 120	USTs, ASTs	Fuels	volatile organics, petroleum hydrocarbons, polyaromatic hydrocarbons, lead
Near 66A	Smoke Stack/Incinerator	Explosives, Hexavalent Chromium, Metals, Powder	explosives, hexavalent chromium, metals
56A	Transformer Room	PCBs	PCBs

Building Number	Feature	Commodities	COIs
56A	AST in Equipment Room	Fuels	volatile organics, petroleum hydrocarbons, polyaromatic hydrocarbons

A Conceptual Site Model (CSM) was developed and used during this phase of the project to help design and guide the investigation and evaluate the results. The CSM was developed after reviewing the various building histories and activities, previous investigations, numerous field surveys, and other pertinent documents. Data quality objectives (DQOs) were also developed. A field investigation program was then developed based on the DQOs and the CSM. The field investigation was performed, between September 7 and September 28, 1999, yielding information on the distribution and concentrations of COIs.

Based on the results of the field investigation, preliminary ambient metal concentrations in soil were developed using statistical methods. A human health risk screening analysis was performed that included the preliminary ambient metal concentrations in soil, organic soil concentrations, and soil gas concentrations. The analysis was used to eliminate analytes from the COI list that were not found at concentrations likely to cause a significant health concern. Based on the results of this investigation and data analysis, 14 chemicals are considered COPC.

Results and Conclusions

The results of the investigation, the preliminary ambient metals concentrations in soil, and the human health risk screening analysis are summarized below. Identified COIs are attributed mostly to historical DoD use at the complex. However, post-Arsenal use has occurred in these buildings and evidence exists that some original structures (e.g., parkerizing vats in Building 57A) were used beneficially.

A total of 188 soil samples, 12 soil gas samples, one grab groundwater, and 13 *in-situ* groundwater samples were collected. In general, solvents and fuel related hydrocarbons were identified in several of the areas investigated. Detections of metals are expected in soil because they are mostly naturally occurring but there are areas that indicate concentrations of various metals are above ambient concentrations.

The predominant COIs in soil, soil gas and groundwater is from chlorinated solvents. Fuel-related compounds and metals are also found in soil and groundwater. Some are widespread from multiple sources and others are isolated to a source.

Solvents. Based on data collected during this investigation, it appears chlorinated solvents have been released to the subsurface in the vicinity of the 50 Series Complex and beyond the complex to the southwest and northeast. VOCs were detected in Building 57A near the deepest end of the vat, south of the vat, and in isolated locations in Building 56 and 55. The extent of trichloroethene (TCE) and cis-1,2-dichloroethene (cis-1,2-DCE) in soil are similar and appear to be present under

much of the 50 Series Complex. The data indicate that the TCE is degrading, by either biotic or abiotic pathways, into cis-1,2-DCE. This is demonstrated by both the spatial relationships and relative concentrations observed in the samples.

Fuel Related Compounds. Petroleum hydrocarbons are another COI detected in soil and groundwater during this investigation. Diesel and motor oil were detected most frequently. Gasoline and diesel were also detected in groundwater.

The highest concentrations of diesel and motor oil correlate to former UST locations beneath Building 56A, Building 55 and within the utility tunnel. Gasoline concentrations are elevated in soil and groundwater in the area of the former Building 154 USTs (5,790 milligrams per kilogram [mg/kg]) and at Building 53 USTs beneath Building 56(A) (1,300 micrograms per liter [μg/L]).

Up to seven separate fuel releases have been identified at and in the vicinity of the 50 Series Complex: 1) southwest of Building 56A; 2) southeast of Building 56A; 3) south of Building 55; 4) beneath Building 57A; 5) north of the 50 Series Complex; 6) north of Building 120; and 7) at Building 103. The fuels in groundwater at the southwest and southeast of Building 56A and Building 103 are associated with former USTs. The petroleum hydrocarbons near Building 120 may be associated with suspected USTs. The sources of the other fuels in groundwater are unknown based on the available data.

Methyl Tertiary-Butyl Ether (MTBE), a fuel oxygenate used since the early 1970s, was detected in three groundwater samples at concentrations of 0.59, 0.52, and 17 μg/L. MTBE was first used as an additive in fuel in the 1970's, after Arsenal closure. Therefore, these detections of MTBE indicate a post-Army gasoline release. The locations of MTBE found in groundwater is Building 57A and southeast of Building 56A.

Metals. Typical metals associated with former activities at the 50 Series Complex include antimony, arsenic, copper, and lead. Elevated concentrations of copper and lead were found in soil samples from beneath the basement, near the former foundry in Building 55, near the parkerizing vat in Building 56 and the boiler room at former Building 65(B). Lead was also found in soil at elevated concentrations in the western portion of Building 56A, which may be associated with the former USTs at Building 154.

PAHs. Polyaromatic hydrocarbons are commonly found associated with fuels. Data from the 50 Series investigation supports this correlation. PAHs were identified in soil and groundwater in the area of the tool house at former Building 59(A), boiler house at former Building 65(A) and former Building 58, the transformer room in Building 56A, and the soil removed from the former boiler room in Building 65(B).

Details about COIs at each site feature are described below.

Parkerizing and Degreasing Locations. There is evidence of spills associated with parkerizing and degreasing activities from site visits and interviews of former employees, which were used to determine parkerizing and degreasing locations. The investigation of COIs associated with parkerizing and degreasing activities was conducted primarily in Buildings 56 (degreasing), 56A (degreasing), and 57A (parkerizing). Solvents or acids were used as degreasers. Parkerizing is a phosphate finish coated on the metal. There are significant concentrations of VOCs detected in groundwater extending beneath the 50 Series Complex and in groundwater outside the perimeter of the 50 Series Complex near the former parkerizing vat in Building 57A, beneath Building 56 and north of the vat in Building 56.

Boilers and the Breezeway. Boilers were present in three locations of the 50 Series Complex, Buildings 58, 65(A), and 65(B). Petroleum hydrocarbons and PAHs were detected in soil at Building 56A, near the location of former Buildings 58 and 65(A), and may indicate a surface release of fuels from the former boiler. In addition to the fuel-related compounds, lead was detected at the same location.

Diesel, motor oil, lead, and PAHs were also detected in soil in the breezeway between Buildings 56A and 55. The soil was removed from the former boiler room in Building 65(B) and spread out in the breezeway. Lead was detected at 550 and 164 mg/kg at 1 and 3 feet bgs, and motor oil concentrations are 970 and 450 mg/kg at the same depths. Diesel is less than 120 mg/kg. A variety of PAHs were detected at concentrations less than 1.4 mg/kg. These results indicate the soil is impacted with residuals that are likely from the boiler house. Groundwater was not encountered in any of these borings.

Degreaser and Oil/Water Separator. A boring was drilled along the western side of Building 57 to assess the potential impact to soil and groundwater from possible leakage of solvents from a degreaser. Drilling could not continue through hard quartzite encountered at 26.5 feet bgs, so the boring terminated at 27 feet without encountering groundwater. There was no visual evidence of staining, discoloration, or elevated PID readings that would indicate an impact to soil or groundwater at this location.

Firing Ranges and Small Arms Storage and Repair. There are three firing ranges in the basement of Building 57. Groundwater was encountered in one boring outside the firing ranges; lead was detected in the groundwater sample at a concentration of 0.023 mg/L. The surface in this area is exposed soil and because the water is near the surface (approximately 0.5 feet bgs), there is potential that the lead from the nearby firing ranges was introduced directly into the water. Gunite target material was sampled from the end of each firing range. Arsenic, antimony, copper, and lead were detected in these materials.

At a suspected machine gun test firing area, one hand auger boring was advanced. This boring was located inside the courtyard area just north of Building 56A. Petroleum hydrocarbons and lead were detected. The lead may indicate an impact to soil at this location from the suspected machine gun test firing area.

Cisterns. The geophysical survey did not identify any of the suspected cisterns believed to be located around the perimeter.

Foundry Facilities. Building 56B was the location of the former foundry. Arsenic, chromium, copper, and lead were reported in soil.

Forges and Hydraulic Press. In Building 55, lead was detected at an elevated concentration in shallow soil (1,640 mg/kg) and at lower concentrations in the deeper soil, 7.01 mg/kg. Petroleum hydrocarbons were reported in all three borings drilled at the locations of the former forges and hydraulic press. Low concentrations of TCE (less than 2.1 mg/kg) was reported in shallow soil. These results indicate possible surface releases of metals (in particular lead), TCE, and fuels to soil in the area of the two suspected forges.

Underground Storage Tanks. Previous investigations indicate fuels in soil and groundwater at the former UST locations at Building 53, 154, and 103. USTs were suspected at other locations within and in the vicinity of the 50 Series Complex. These locations include the southeast corner of Building 56A, Building 65(B) and the north side of Building 120.

During the investigation for the boiler houses at the former Building 65(A) and Building 58, results for soil samples collected reported high concentrations of diesel, gasoline, and motor oil hydrocarbons. The highest concentration of fuel detected was motor oil with a concentration of 11,000 mg/kg. Groundwater data is lacking beneath Building 56A. Former USTs at Building 154 are located approximately 80 feet southeast of these former buildings. Based on the high soil and groundwater concentrations, the Building 154 USTs are the likely source of the petroleum hydrocarbon contamination in this area.

Similarly, data from the two borings near the southeast portion of Building 56A indicate fuel impacted soil and groundwater. The source of the fuel is likely the nearby former UST located at Building 53, but also could indicate a release from the suspected USTs beneath the southeast corner of Building 56A.

Diesel fuel and motor oil were also detected in soil beneath the blacksmith shop at Building 55 and approximately 20 feet south of the building at B057HP002. The extent of the diesel fuel and motor oil in soil extends beneath most of Building 55 with the highest concentrations beneath the southern half in the utility tunnel and extending south of the building. Gasoline and diesel fuel were detected in groundwater in B057AHP002. The source of the fuel in groundwater at this location is unknown. Diesel fuel and gasoline have also impacted the groundwater at B057AHP003 located approximately 60 feet north of Building 55. There are no other groundwater samples between B057AHP002 and B057AHP003 to confirm if these two detections are related.

A former UST was located at Building 120. During drilling a hydrocarbon-like odor and an elevated PID reading of 200 ppm was observed from the saturated clay-like soil. Above the water table (5.0 feet bgs), the soil (sandy clay-like gravel) was not visually stained and had no odor. The data

indicates that petroleum hydrocarbons may have impacted the capillary fringe, but the soil above the water table does not appear to be impacted suggesting the petroleum hydrocarbons in the groundwater have migrated to this area.

Utility Tunnel. Data was collected from 4 hand auger borings (B055HA001, B056BHA001, B056HA002, and B057BHA001) along the utility tunnel. There is no direct evidence of releases from the ground floor into the basement soil. Lead concentrations are elevated throughout the surface soil. Arsenic and lead concentrations are elevated in the left-over materials from former sandblasting operations.

Paint Shed/Smoke Stack/Incinerator. There is no evidence of impact to soil from explosives or metals from the former smoke stack/incinerator or metals and oils stored in the former paint shed/shop at former Building 66(A).

Transformer Room. PCBs were reported at concentrations less than method detection limits (MDLs) in soil. Based on this evidence there appears to be no creditable release of PCBs to subsurface soil in the transformer room.

Equipment Room. Petroleum hydrocarbons were detected in soil immediately beneath the equipment room. Based on this evidence there appears to be a release to subsurface soil from the former equipment or the former above ground storage tank (AST) that was located in this room.

Human Health Risk Screening Evaluation

The objective of this human health risk screening evaluation is to analyze and to identify COIs that can be eliminated from further consideration based on a comparison of the maximum concentration of the chemical in soil to the applicable Benicia Screening Levels (BSLs). Given that BSLs represent COI concentrations in soil that are unlikely to pose a significant risk of adverse health effects, they may be used to decide if additional site investigation is needed or if a No Further Action (NFA) decision is warranted. Conversely, maximum concentrations that exceed BSLs indicate that that COI may be a COPC for a particular exposure scenario.

A total of 14 analytes were detected at concentrations that exceeded at least one of the associated BSLs. Of these, eight COPCs were metals, three were PAHs, one was a VOC, and two were petroleum hydrocarbons. The COPCs are listed below. No organic COPCs were associated with any of the open space visitor exposure scenarios.

Summary of COPCs in Soil for the 50 Series Complex

Inorganic Analytes	Organic Analytes
Antimony	Benzo(a)pyrene
Arsenic	Benzo(b)flouranthene
Cadmium	Dibenz(a,h)anthracene
Chromium, total	Trichloroethyene
Copper	Diesel Fuel
Iron	Motor Oil
Lead	
Manganese	

Inhalation of vapors released from subsurface soil to enclosed indoor spaces may be a potentially complete exposure pathway for commercial/industrial workers and residents. To evaluate the potential risk posed by volatilized chemicals intruding into indoor air spaces, maximum concentrations reported in soil gas samples were input into the J&E model. For the slab-on-grade scenario, one VOC (TCE) was associated with an incremental risk above 1×10^{-6}, and no VOCs were associated with a hazard quotient above 1.0. For the below-grade basement scenario, TCE was the only VOC associated with an incremental risk above 1×10^{-6}, and no VOCs were associated with a hazard quotient above 1.0.

Recommendations

Recommendations are summarized below.

- Conduct a geologic investigation to determine the surface topography of the bedrock and the relationship of the bedrock topography on contaminant distribution in soil and groundwater.
- Conduct additional soil and groundwater sampling to assess the vertical and lateral extent of VOCs and TPHs southeast of the 50 Series Complex.
- Conduct groundwater sampling and additional soil sampling to assess the lateral and vertical extent of metals, TPHs, and PAHs in the area of the former forges at Building 55.
- Conduct additional soil and groundwater sampling to assess the vertical and lateral extent of VOCs and TPHs in soil and groundwater in the area of Building 56 and north of the 50 Series Complex.
- Conduct removal and off-site disposal of the waste materials from the former sandblasting operations located in the Building 56 basement.
- Conduct additional investigation to determine the lateral and vertical extent of petroleum hydrocarbons in soil at the equipment room in Building 56A.

- Conduct an additional soil investigation or risk analysis per the soil removed from the former foundry at Building 56(B).
- Conduct removal and offsite disposal of firing range target material from the basement of Building 57.
- Conduct patching of exposed soil at B057HA004 in the basement of Building 57 to eliminate potential exposure to constituents in shallow groundwater. Some soil excavation may be necessary.
- Conduct further soil, soil gas, and groundwater assessment at Building 57A to determine vertical distribution of VOCs in soil and vertical and lateral extent of VOCs in groundwater related to Building 57A vat.
- Conduct an additional soil and groundwater investigation to determine the lateral and vertical extent of TPHs and PAHs for the suspected USTs beneath the southeast corner of Building 56A and the tool house at former Building 59(A).
- Conduct a groundwater investigation and additional soil assessment to determine the lateral and vertical extent of TPHs, lead, and PAHs at former Building 65(A) and former Building 58.
- Conduct additional soil and groundwater sampling in the vicinity of reported detections of diesel and motor oil near Building 120.
- Conduct additional perimeter groundwater sampling to determine vertical and lateral extent of VOCs and hydrocarbons.
- Conduct an additional soil investigation and/or risk analysis to determine the extent or risk of lead in soil at the former machine gun test firing range at Building 65(B).
- Conduct an additional soil investigation or risk analysis for the soil removed from the former boiler house and the suspected USTs at Building 65(B).
- Conduct a risk analysis for lead, PAHs, and TPH in soil in the utility tunnel.
- No further action under FUDS is recommended to address the Building 56A transformer room.
- No further action under FUDS recommended at the former Building 66(A) and the smoke stack/incinerator.

1.0 INTRODUCTION AND BACKGROUND

The Arsenal is located in Benicia, California, about 25 miles northeast of San Francisco (Figure 1-1). The Arsenal was created in 1849 with the transfer of 345 acres of land by the founders of the City of Benicia (Jacobs, 1999). Between 1849 and 1958, the facility grew by land acquisition to a total of 2,728 acres, of which 190 acres were located in Carquinez Strait to the south and Suisun Bay to the northwest. During its active life, this facility served the United States Army as a principal depot for ordnance and ordnance stores, issuance, manufacture and testing of small arms. The Arsenal was declared excess by the government in 1963. Deactivation and closure of the facility were completed in 1964 (Jacobs, 1999).

The 50 Series Complex is a collection of buildings within the central portion of Area I of the Arsenal property (Figure 1-2). The complex was originally constructed as three separate workshop buildings between 1876 and 1884. The remodeling of these buildings occurred over many phases and included the addition of eight buildings and the removal and relocation of three buildings (Figure 1-3). Low-lying marshland areas to the west of the complex were filled in during site development (Figure 1-2). Currently, the 50 Series Complex consists of 11 interconnected buildings (Figure 1-4).

This Site Investigation (SI) Report presents data from an environmental investigation conducted at the 50 Series Complex between September 7 and September 28, 1999. Forsgren Associates/Brown and Caldwell (FA/BC) conducted the investigation in accordance with the Field Site Investigation Plan (FSIP) for the 50 Series Complex, the Arsenal-Wide Quality Assurance Project Plan (QAPP), and the Arsenal-Wide Site Investigation Workplan for the Benicia Arsenal (FA/BC, 1999a, b, and c) on behalf of and with oversight by the USACE, Sacramento District.

In accordance with the Formerly Used Defense Sites (FUDS) program and USACE guidance documents, this SI report documents investigation activities in the 50 Series Complex area within the Arsenal. Under the FUDS program, land that was previously utilized by the United States Department of Defense (DoD) that has no "beneficial use history" from subsequent landowners or lessors will be characterized and if necessary remediated appropriately. Beneficial use of former DoD land is defined as use by subsequent landowners or lessors in manners that would either mask contamination caused by DoD or continue contamination in the same way.

This document also complies with both Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) requirements, as appropriate, for hazardous and toxic waste cleanup actions.

This SI report is organized into ten sections. Section 1.0 presents background information, including the historical use of each building and a summary of previous investigations. Section 2.0 describes the investigative approach used at the site. Section 3.0 presents a summary of field methods and sampling rationale. It also summarizes disposal of Investigation Derived Waste (IDW). Section 4.0 describes the regional, localized, and site-specific geology and hydrogeology. After the discussions about geology and hydrogeology, water quality data is presented.

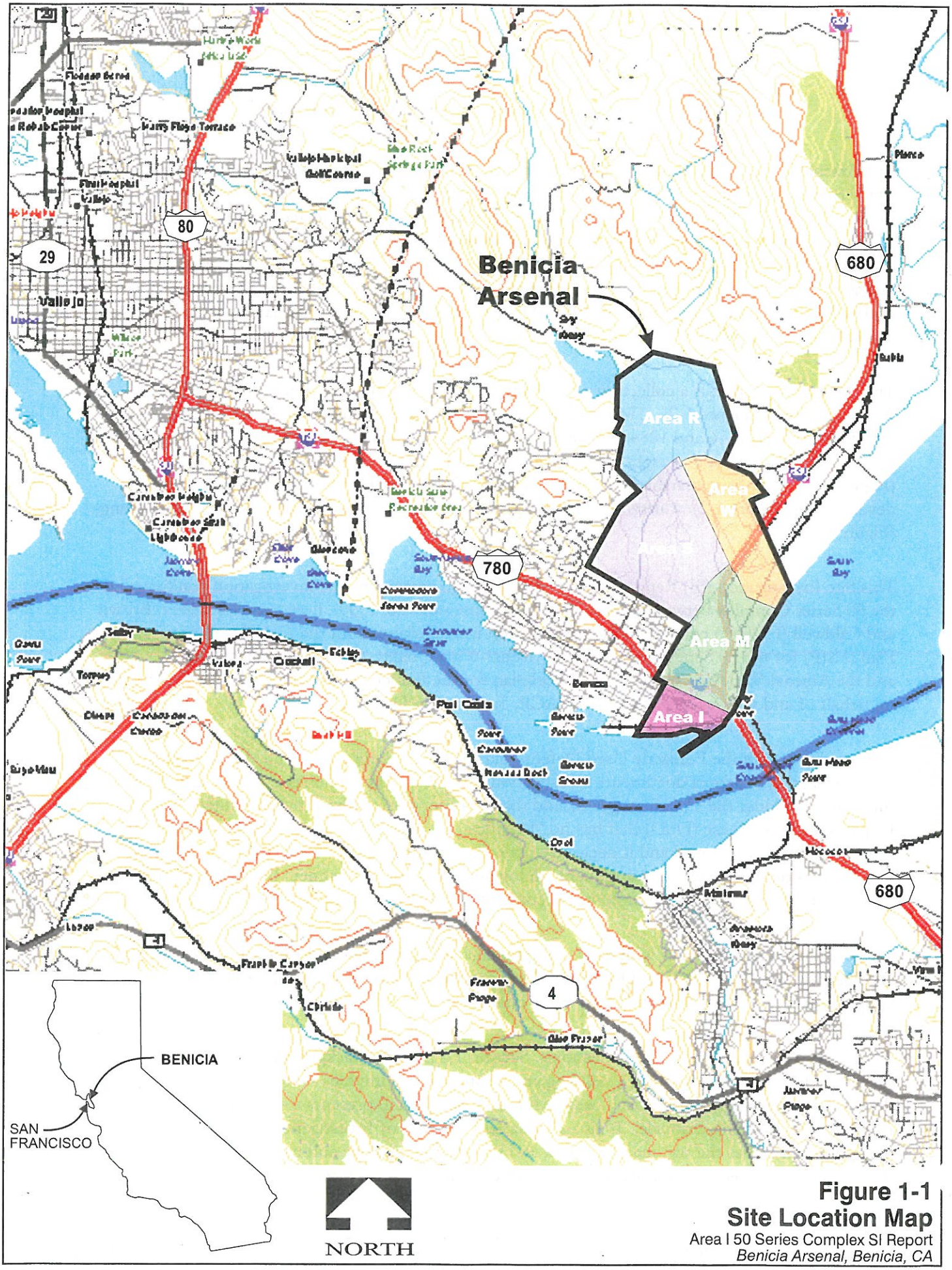


Figure 1-1
Site Location Map
Area I 50 Series Complex SI Report
Benicia Arsenal, Benicia, CA

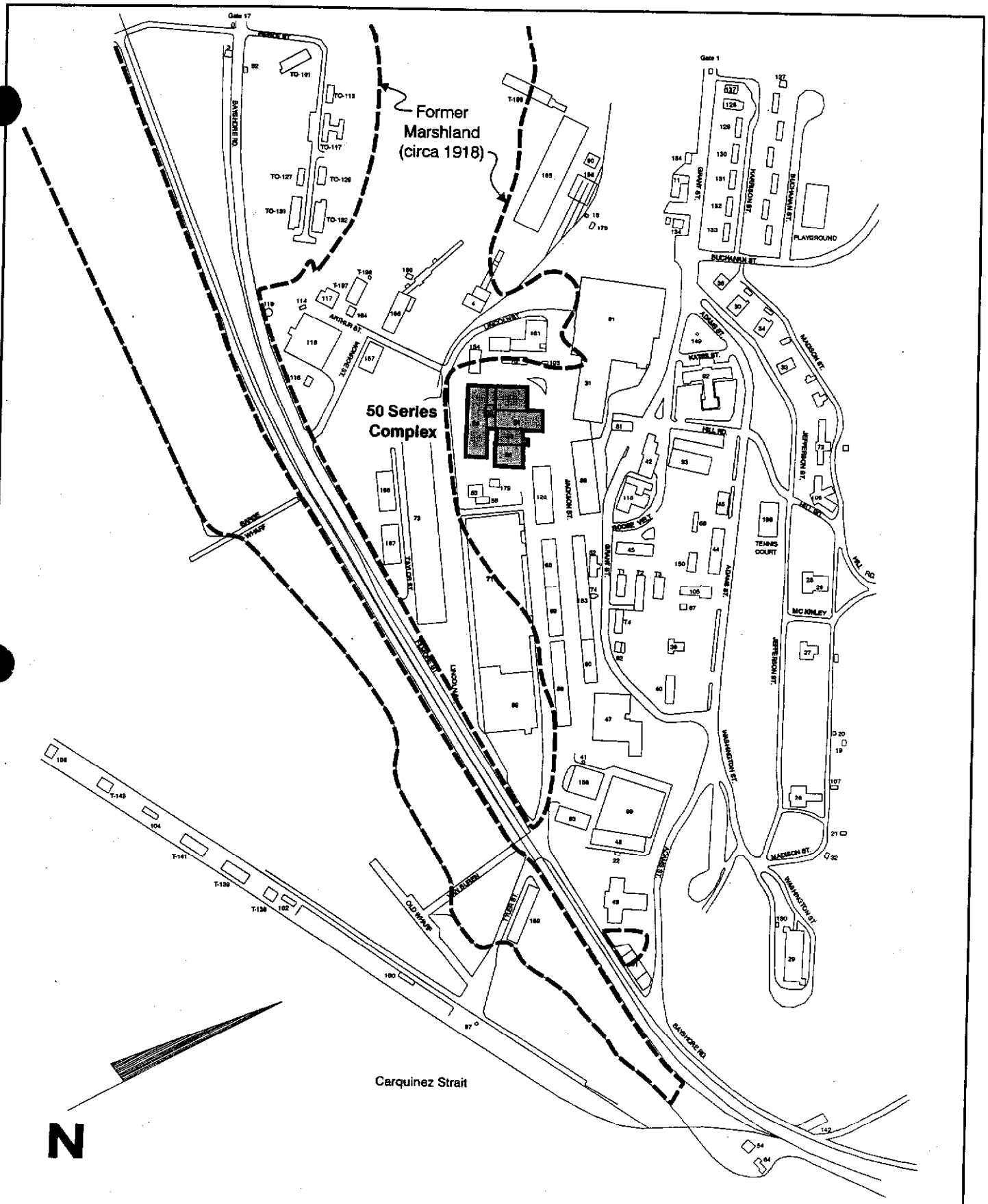
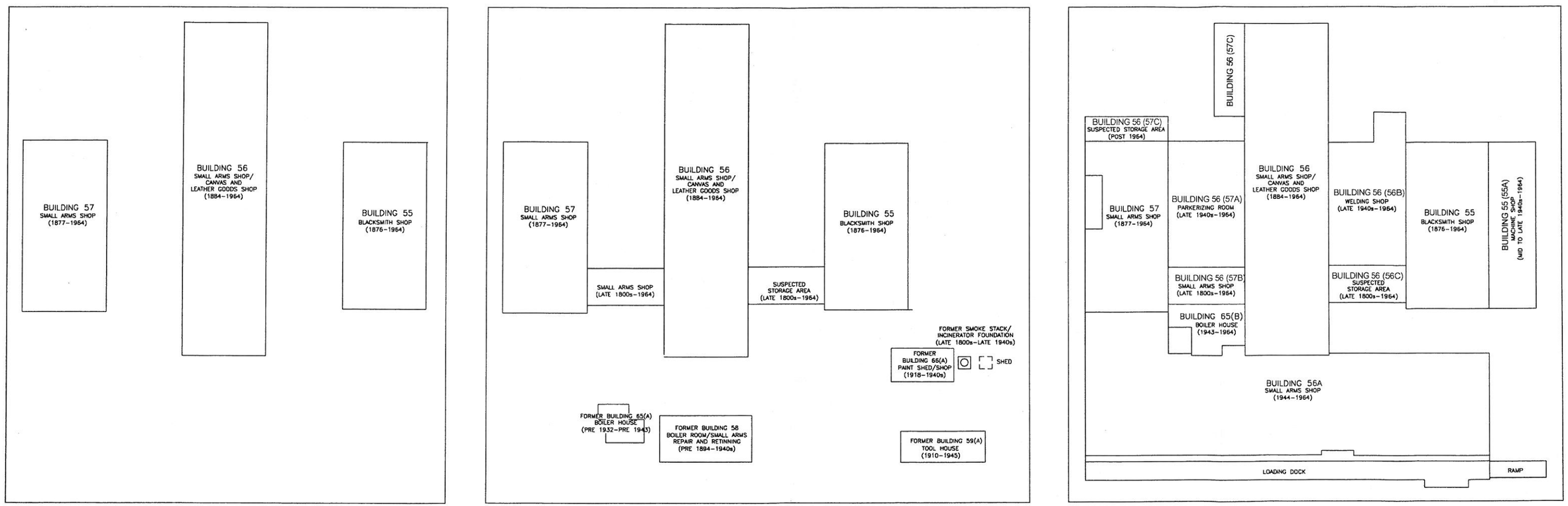
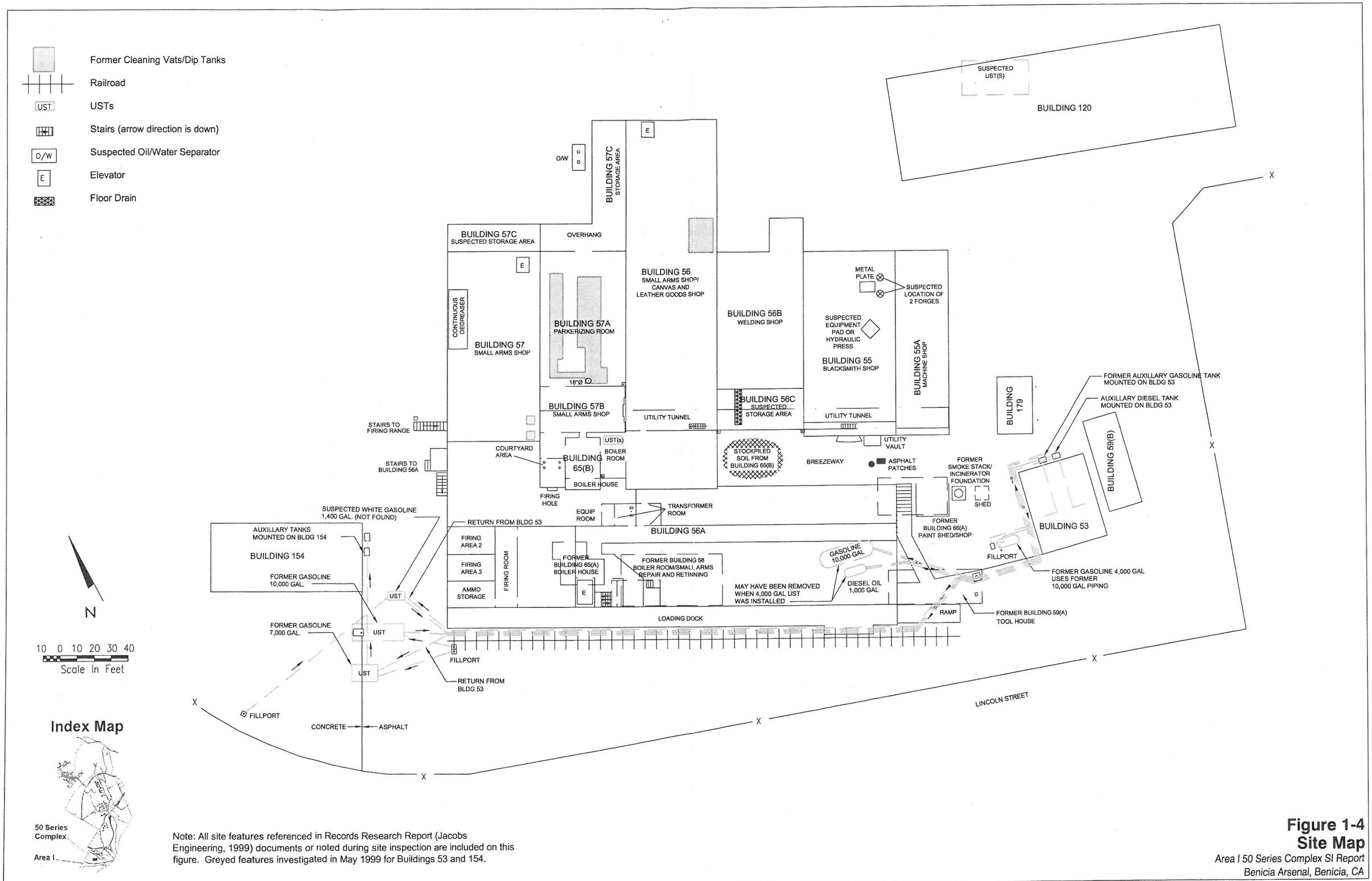


Figure 1-2
Site Vicinity Map
Area I 50 Series Complex SI Report
Benicia Arsenal, Benicia, CA



Present day building numbers are shown in parentheses( ), and are adopted in this report for consistency with other recent reports.

Figure 1-3
Historical Development
Area I 50 Series Complex SI Report
Benicia Arsenal, Benicia, CA



Note: All site features referenced in Records Research Report (Jacobs Engineering, 1999) documents or noted during site inspection are included on this figure. Greyed features investigated in May 1999 for Buildings 53 and 154.

Figure 1-4
Site Map
Area I 50 Series Complex SI Report
Benicia Arsenal, Benicia, CA

Forsgren Associates/Brown and Caldwell
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At the end of Section 4.0, there is a statistical evaluation to determine preliminary ambient metals concentrations in soil at the 50 Series Complex. Section 5.0 describes the quality and usability of the data collected during this site investigation. A summary and analysis of results is presented in Section 6.0. This section describes the site-wide aspects and focuses on specific features at the 50 Series Complex. A human health risk screening analysis for soil and air is included in Section 7.0. The preliminary ambient metals concentrations determined in Section 4.0 were included in this human health risk screening analysis. At the end of Section 7.0, an evaluation is made to compare the results of the human health risk screening analysis and the results of the 50 Series Complex investigation to determine the areas of potential risk. DQOs are presented in Section 8.0. Section 9.0 summarizes our conclusions and recommendations. References are included as Section 10.0.

This SI report contains 12 appendices. Each appendix is described briefly below:

- **Appendix A – Glossary.** Definitions of commonly used terms in this report.
- **Appendix B – Plates.** Large-size figures, in the form of plates, showing building details and analytical results.
- **Appendix C – April 2, 1999 Norcal Geophysical Consultants Survey of Buildings 53, 73, and 154.** Results of a geophysical survey conducted along the southern portion of the 50 Series Complex.
- **Appendix D – June 7, 1999 Norcal Geophysical Consultants Survey of the 50 Series Complex.** Results of a geophysical survey conducted along the west, north, and east sides of the 50 Series Complex, and for surveys within the 50 Series Complex.
- **Appendix E – Boring Logs for 50 Series Complex.** Soil borings logs from the 50 Series Complex site investigation.
- **Appendix F – IDW Manifests.** Transportation and disposal manifests for soil generated during the site investigation.
- **Appendix G - Particle Size Analysis Report.** Copies of laboratory results for particle size analysis of selected soil samples.
- **Appendix H - Tables and Figures for Ambient Metals in Soil Evaluation.** Tables and figures associated with the evaluation of ambient metal concentrations in soil.
- **Appendix I – Legend for Analytical Result Tables.** Definitions of data acronyms, quality control flags, and reason codes.

- **Appendix J - Analytical Results for All Constituents in Soil at the 50 Series Complex.** The soil results are included in Adobe® Acrobat® PDF format on the included compact disc (CD). The PDF file is bookmarked by analyte.

- **Appendix K - Analytical Results for All Constituents in Ambient Air and Soil Gas.** Ambient air and soil gas results in Adobe® Acrobat® PDF format are included on the same CD as the soil results. The PDF is bookmarked by analyte.

- **Appendix L - Analytical Results for All Constituents in Groundwater at 50 Series Complex.** Groundwater results in Adobe® Acrobat® PDF format are included on the same CD as the soil and soil gas results. The PDF file is bookmarked by analyte.

- **Appendix M – Summary of Input for Johnson & Ettinger Model Building 50 Series Risk Screening.** Input parameters for the Johnson & Ettinger Model used for risk assessment of subsurface vapor intrusion into buildings.

1.1 Problem Definition and Scope

Based on information collected for the Benicia Arsenal Records Research Report (RRR) (Jacobs, 1999), the 50 Series Complex has a long and complicated history that began in 1876 and included the construction of as many as 14 buildings (11 buildings present today and 3 buildings relocated) and features (large equipment/machinery/structures within the buildings). This site investigation sought to ascertain whether past DoD activities at the 50 Series Complex resulted in soil or groundwater contamination. Data collected from this investigation will be used to determine if additional investigation or remedial action is necessary.

This investigation of the 50 Series Complex occurred in several stages as described below.

1. The Arsenal buildings were identified, including internal features where chemicals were used. The source of most of this information came from the RRR. Additional information was attained from interviews of the current landowner and several site visits.

2. A list of potential problem chemicals (COI) was generated by examining past building use. The COI list was compared against historical activities, taking into account site geology and hydrogeology, to determine where COIs may have been released to the subsurface.

3. Field investigation was performed by FA/BC, yielding information on the distribution and possible source areas of COIs in the subsurface.

4. Based on the results of FA/BC's field investigation, preliminary ambient metal concentrations in soil were developed using statistical methods.

5. A human health risk screening analysis was performed that considered the preliminary ambient metal concentrations in soil, organic soil concentrations, and soil gas concentrations. The analysis was used to eliminate chemicals from the COI list that were not found in amounts likely to cause a significant health concern. The remaining group of chemicals are referred to as COPC.

6. The results of the human health risk screening analysis were compared with the results of the 50 Series Complex investigation to evaluate the areas of potential risk.

7. Lastly, the results of the investigation, the preliminary ambient metals concentrations in soil and the human health risk screening analysis were summarized, and recommendations made regarding the need for further investigation and/or remediation activities.

1.2 Site Location and Historical Use

Historically, the RRR (Jacobs, 1999) was the first document to divide the Arsenal into five distinct areas based on land use:

- Area W: Warehouse Area
- Area I: Industrial/Manufacturing Area
- Area R: Revetment/Explosives Holding Area
- Area M: Motor Pool and Historical Ordnance Storage Area
- Area S: Magazine Storage Expansion Area.

These areas are shown on Figure 1-1. This report presents results from the investigation performed around the 50 Series Complex located in Area I.

Area I contains several of the original Arsenal structures erected in the late 1800s. This area served as the main industrial and manufacturing area throughout the 115-year history of the facility and was the center of activity at the Arsenal. Several machine shops, manufacturing shops, and cleaning and painting shops were housed here, along with a blacksmith shop, a welding shop, numerous vehicle and artillery repair shops and a small arms shop. Area I also housed the Arsenal's administrative offices, most of the permanent housing facilities, photographic laboratories, a firehouse, and hospital. Fuel storage and dispensing facilities, a locomotive house, boiler houses, storehouse and warehouse facilities, open storage facilities, landfills and quarries were also located within Area I.

The 50 Series Complex is in the central portion of Area I and was originally constructed as three separate workshop buildings (Buildings 55, 56, and 57) between 1876 and 1884 (Figures 1-1, 1-2, 1-3, and Photographs B55-56-57). The remodeling of these buildings occurred over many phases, including the addition of eight new buildings (Buildings 55A, 56A, 56B, 56C, 57A, 57B, 57C, and 65(B)) and the removal and relocation of three existing buildings (Buildings 59, 65, and 66). The features within the 50 Series Complex (also referred to as facilities) included a smoke stack/incinerator, dip tanks, forges, firing ranges and USTs. Table 1-1 outlines the features investigated for possible source areas of contamination.

Photo B55-56-57. Looking southwest at Buildings 55, 56, and 57, from left to right. (Circa Early 1900's)

1.2.1 *50 Series Complex Construction and Historical Use*

The evolution of the 50 Series Complex is not completely understood. However, its history began in 1876 with the construction of Building 55, the Blacksmith Shop, which was the first quarried sandstone structure built at the Arsenal. A year later, Building 57 was completed as a Small Arms Shop. In 1884, Building 56 was completed as a Small Arms Shop and Canvas and Leather Goods Shop. These 3 buildings/shops comprise the main complex, which served as the primary location to clean and repair guns and carriages, make ammunition boxes and chests, repair saddles and bridles and make holsters. In the period after the Civil War, the Arsenal became the ordnance distribution point for United States Army along the West Coast.

Table 1-1. Summary of Potential Sources and Probable Chemicals Used at the 50 Series Complex

Building Number	Feature	Commodities	COIs
56, 56A, 56B, 57A	Parkerizing Tanks and Areas	Solvents (post-Army use in 57A), Acids/alkalis, Preservatives, Metals	volatile organics, semi-volatile compounds, hexavalent chromium, polyaromatic hydrocarbons, metals
58, 65(A), 65(B)	Boiler Rooms	Fuels, Oils, Lead	volatile organics, petroleum and polyaromatic hydrocarbons, lead
56A and 57	Degreaser	Solvents, Acids, Preservatives	volatile organics, semi-volatiles, hexavalent chromium, polyaromatic hydrocarbons
57, 65(B)	Test Firing Rooms and Areas	Metals, Ammunition/powders	copper, lead, antimony and arsenic
56, 56A, 57, 57(B), 58	Small Arms Storage and Repair	Metals, Ammunition/powders	metals
Perimeter of complex	Cisterns	Solvents, Acids, Preservatives, Foundry Waste	volatile organics, semi-volatile, hexavalent chromium, polyaromatic hydrocarbons

Table 1-1. Summary of Potential Sources and Probable Chemicals Used at the 50 Series Complex (continued)

Building Number	Feature	Commodities	COIs
55	Foundry	Foundry Waste	metals
55	Forges	Metals, Fuels	volatile organics, petroleum and polyaromatic hydrocarbons, metals
55	Hydraulic Press	Oils	volatile organics, petroleum and polyaromatic hydrocarbons, metals
53, 65(A), 65(B), 120	USTs, ASTs	Fuels	volatile organics, petroleum hydrocarbons, polyaromatic hydrocarbons, lead
Near 66A	Smoke Stack/Incinerator	Explosives, Hexavalent Chromium, Metals, Powder	explosives, hexavalent chromium, metals
56A	Transformer Room	PCBs	PCBs
56A	AST in Equipment Room	Fuels	volatile organics, petroleum hydrocarbons, polyaromatic hydrocarbons

This group of buildings remained the central point of the industrial area for many years through the Spanish-American War. Buildings 55, 56, and 57 were connected in the late 1800s with the construction of Buildings 56C and 57B, which were also built of sandstone. These buildings were used for storage and a small arms shop. Records indicate that Building 55 suffered a great deal of structural damage from a fire in 1883. Other buildings were built during this time period: Building 58 Boiler House, Building 59(A) Tool House, and Building 66(A) Paint Shed. These buildings supplemented the activities at the main buildings. After wartime hostilities ended, the Arsenal was still in full operation to recondition or salvage arms and supplies.

Due to the scarcity of potable water, drilling efforts were undertaken in the late 1800s to increase water supply. However, the effort to find potable groundwater was unsuccessful. To counter the problem, cisterns were brick-lined and installed to store stormwater, and reservoirs were built. It is suspected that several cisterns were located at the 50 Series Complex to collect rainwater. The locations of the cisterns are unknown.

After 1900, shops within the 50 Series Complex manufactured targets and target materials for seacoast artillery firing practice, field or mobile artillery, and small arms. With the start of World War I, the Arsenal supplied permanent Army posts on the Pacific Coast. The Blacksmith Shop (Building 55), Machine Shop (Building 49 and/or Building 56), and Carpenter Shop (Building 56) were employed in manufacturing cast iron projectiles for seacoast artillery target practice (Jacobs, 1999).

World War II dramatically changed the look of the main complex through the addition and removal of buildings (Figure 1-3). The Arsenal itself went through a major expansion of over 200 structures and the addition of 1,847 acres. The Arsenal served as a main supply point for United States

military forces throughout the Pacific. A new boiler house at Building 65(B) replaced the older boiler houses at Buildings 58 and 65(A), and Buildings 59(A) and 66(A) were demolished to make room for Building 56A. Other buildings were built during this time, including Building 57A (Parkerizing Room), Building 56B (Welding Shop), and Building 55A (Machine Shop). The transformation was completed in the 1940s into an industrial-sized small arms repair and cleaning complex.

The chlorinated solvents, TCE and tetrachloroethene (PCE), were first produced in 1923 and may have been available in the early 1920s to the Arsenal. However, chlorinated solvents were most commonly used after World War II when the manufacturing economy expanded. Solvents and cleaners were used as part of vapor degreasing techniques for small arms. Vapor degreasers were known to be used in Building 56A and 57 after World War II.

After World War II, the shops were used primarily to renovate and reclaim materiel returned from the war. Arms and vehicles were stripped, cleaned, rebuilt, and prepared for storage or for sale as salvage. The Korean Conflict in the 1950s caused more changes and expansion of the Arsenal, but not in the shop area. However, arms processing did increase. In the first half of 1950, nearly 71,000 small arms were rebuilt (Jacobs, 1999) at the Arsenal.

By 1958 operations slowed such that no new work was being accepted at the Small Arms Shop (Building 56 and/or Building 57) and the shop closed. Most of the staff was transferred to the storage division. By April 1962 all rebuilding operations were phased out.

1.2.2 *50 Series Complex Remodeling*

During the numerous remodeling phases for the workshop facilities (e.g., Blacksmith Shop and Small Arms Shop), several buildings (Buildings 59, 65, and 66) were moved (Jacobs, 1999). The first recorded locations of these buildings are shown on Figures 1-3 and 1-4 and designated by "(A)" (i.e., Building 59(A)). Buildings 59 and 65 were moved to other locations within the workshop facilities and are designated "(B)" on Figures 1-3 and 1-4. Former Building 66 was moved to a location not shown on Figure 1-4. In general, when the buildings were moved, their purpose and use also changed. Those buildings that have remained in the same location since construction also typically had multiple uses.

Building numbers 55A, 56B, 56C, 57A, 57B, and 57C, are not Army designated numbers and as such there is no historical Army references. These buildings connect the Army designated buildings 55, 56, 56A, and 57. Since the Arsenal decommission in 1964, these buildings have been given numbers by subsequent landowners. Both the Army and the present day building number is shown on Figure 1-3. The present say numbering scheme has been adopted in order to be consistent with other recent reports.

1.3 Detailed Historical Summaries

The following section describes 13 of the main buildings and features of the 50 Series Complex and briefly reviews their history. The historical records for these buildings and features were used to identify potential sources of contamination and to develop site investigation strategy. Additional detail for these buildings and features is listed in the RRR (Jacobs, 1999).

1.3.1 *Building 53 USTs beneath Building 56A*

Building 56A is approximately 85 feet west of Building 53 (Figure 1-4). A 1,000-gallon diesel fuel UST and a 10,000-gallon high octane gasoline UST were reportedly installed as part of the Building 53 fueling system. This system is described in detail in the Technical Memorandum Area I Fuel Facilities at Buildings 53, 73, 103, and 154 (FA/BC, 2000). The locations of these USTs were suspected to be beneath the southeast corner of Building 56A (Photo Disk1_13 and Figure 1-4).

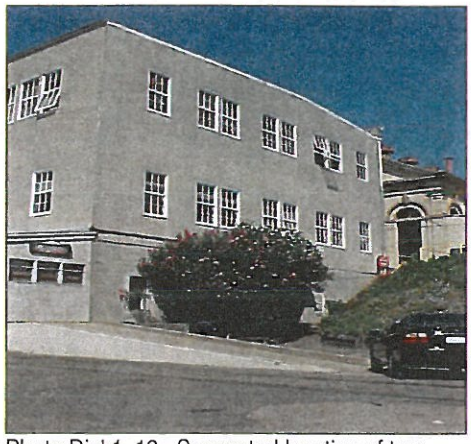


Photo Disk1_13. Suspected location of two USTs beneath the southeast corner of Building 56A. Building 53 is to the right of this photo. (September 1999)

1.3.2 *Utility Tunnel*

A utility tunnel in the basement area runs the length of the 50 Series Complex from Building 55 to Building 57 (Figure 1-4). This tunnel passes underneath the wooden floors of the Blacksmith Shop in Building 55; the Machine, Leather, Canvas, Small Arms and Welding Shops in Building 56; and the Small Arms Shop in Buildings 57 and 57B. Processes in all of these buildings used liquid chemicals. Any chemicals spilled on the wooden floors above the utility tunnel could have leaked through onto the dirt floor of the tunnel. Additionally, the section of the utility tunnel beneath Building 57B contains a tank that was constructed by turning a drum (approximately 80 gallons) on its side and cutting a hole in the area that is now the top (Photo R1#3).

1.3.3 *Buildings 55 and 55A - Blacksmith Shop*

Building 55 was constructed between 1876 and 1884 of locally quarried sandstone. Building 55 housed the Blacksmith Shop until Arsenal closure in 1964. Records indicate that the building suffered a great deal of structural damage from the 1883 fire.

Building 55 contained forges and a hydraulic stamp. At least 2 forges were housed along the east wall in Building 55 in the northern portion of the building.

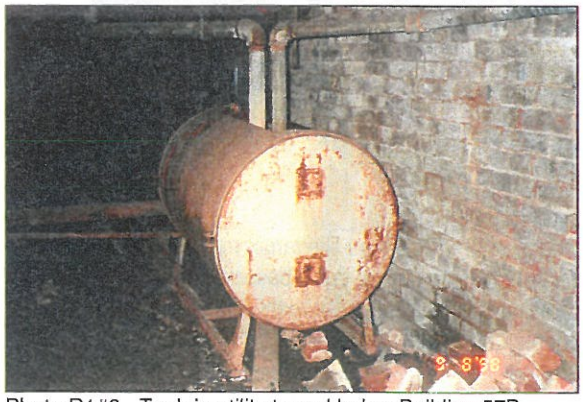


Photo R1#3. Tank in utility tunnel below Building 57B. (October 1998)

There are currently several repoured areas of concrete in Building 55A. One of the repoured concrete areas is surrounded by a metal band and may have been constructed to support large pieces of equipment used in the Blacksmith Shop. The largest repoured concrete area, near the center of the building, was the reported location for a large hydraulic metal press used to cut up rifles for salvage (Figure 1-4).

1.3.4 *Buildings 56, 56A, 56B, and 56C - Machine, Leather, Canvas, Small Arms and Welding Shops*

Building 56 was constructed in 1884 of locally quarried sandstone and originally housed the Machine and Welding Shop. Building 56A was added to the facility in 1944 as the Small Arms Shop. Historical records do not distinguish between Building 56 and Building 56A. Basement areas, the equipment room, the transformer room, and native soil were located beneath the concrete floor in Building 56A.

A parkerizing tank was located beneath the east side of Building 56, near the current intersection of the north wall of Building 56B and Building 56 (Figure 1-4). Other parkerizing areas may have been located in Buildings 56 and 56(A), but no background information is available to confirm their existence. Parkerizing fluids can contain many different types of metals such as zinc, manganese, molybdenum, and phosphate in various acids and oxides.

Building 56B served as a welding shop from the 1940s until Arsenal closure in 1964. Parkerizing may also have occurred in Building 56B. Building 56C was used for storage.

1.3.5 *Building 57 - Small Arms Shop*

Photo disk2_1. Cement-like target material at the end of the firing ranges in the basement beneath Building 57. Bullets are the rusty colored objects. (September 1999)

Constructed in 1877 of locally quarried sandstone, Building 57 originally housed the Carpenter Shop. Between 1943 and 1945, Building 57 transitioned into the Small Arms Shop, which was used for the degreasing of small arms.

The north end of the basement in Building 57 was constructed into 3 firing ranges (Figure 1-4). Each firing range was constructed with a concrete top, sides, and floor. The end of each firing range has a steel box, where a cement-like material (target material) is sloped against the back wall. The target material inside each firing range is composed of the same cement-like material, where bullets were fired into and are now imbedded (Photo disk2_1).

1.3.6 *Building 57A - Parkerizing Room*

Historically, the room was part of Building 56. An interview with Mr. Buster Byerrum, a former employee who worked at the Arsenal from the 1930s to 1962, revealed that Building 57A was used for degreasing and parkerizing of small arms. The degreasing tanks were constructed with steam-heated coils and were located on the floor of Building 57A. Mr. Byerrum's account of degreasing operations in Building 57A are not supported by Army records. According to Army records, TCE was used in a continuous degreaser in an adjacent room (Building 57). Mr. Byerrum may have been referring to the steam heated coils used to heat a phosphate solution for parkerizing guns.

During field activities, a large U-shaped, gravel-filled vat was identified in Building 57A. After the field activities at the 50 Series Complex were completed, the landowner poured a new concrete floor throughout the interior of Building 57A, thus covering the U-shaped vat. The total depth of the U-shaped vat is estimated at the troughs (west side) to be about 1 foot below surface and gradually deepened to about 6 feet (east side) with a 12-foot deep section located in the southeast corner of the vat. The vat is constructed of concrete; it is unknown if cracks exist in the vat (Telecon 9/18/02, UNICO).

Prior to UNICO, the current property owner occupying Building 57A, a transmission company operated at the building. The company is identified in the RRR as Standard Transmission (North American Wieblpfeltzer). Standard Transmission occupied the building in 1973 and used it for warehousing automotive parts and rebuilding transmissions (Telecon 9/18/02, UNICO).

1.3.7 *Building 57B*

Historically, Building 57B has a room within Building 56. No records were found documenting the processes performed in this building.

1.3.8 *Building 57C - Storage Area*

Building 57C was built after closure of the Arsenal in 1964. Records indicate that this building has been used exclusively for storage.

1.3.9 *Former Building 58 - Boiler Room/Small Arms Repair and Retinning*

Building 58 was constructed as a boiler room, possibly during the same time period as the construction of Buildings 55, 56, and 57. In the early 1900s, Building 58 served as a facility for loading projectiles with explosive powder. After the explosives-loading operations, the building was used as a tinning plant (retinning of equipment) and for small arms repair.

It appears that the thickest part of the concrete slab from Building 56A (2 feet to more than 3 feet thick) covers the area of what was former Building 58.

1.3.10 *Former Building 59(A) - Tool House*

Built in 1910 as a tool house, Building 59 was used for storing oils and paints. The building was removed prior to the construction of Building 56A, estimated around 1945.

1.3.11 *Former Building 65(A) and Building 65(B) - Boiler House*

Building 65(A) was constructed in 1918 to serve the shop buildings, and in 1928 an oil burner was installed. Later, two gas-fired boilers were installed, the first in 1940 and the second in 1955. The boiler house still exists, although the property owner has removed the two boilers. There is no documentation that the third boiler was removed.

Based on information presented in the RRR, it appears that former Building 65(A) was located under the western portion of Building 56A (Figure 1-4).

1.3.12 *Former Building 66(A) - Paint Shed/Shop and Smoke Stack/Incinerator*

Built in 1918 to store oils and paints, former Building 66A was renovated in 1932 to house a paint shop and, in 1943, a welding shop. No information was available to document detailed activities performed at the building.

1.3.13 *Suspected Fuel Oil USTs beneath Building 120*

Built in 1943 for storage, Building 120 has also been identified as the Safety Equipment Repair Shop and electroplating shop. Documents found discuss the use of a central respirator cleaning system in the building. Paint respirators in continual use required daily cleaning and were disassembled to separate the metal and rubber parts (Jacobs, 1999).

In the 1950s, Building 120 was used as an electroplating shop. Parts were cleaned in degreasers and acid dip tanks then re-plated with chrome, nickel, copper or cadmium. The building foundation was constructed with several trench drains and a degreaser pit. A subsurface neutralizer tank was located on the north side of the building.

Fuel oil USTs are suspected of being present around Building 120 (Figure 1-4). In an interview with former employee Mr. Milburn (Jacobs, 1999), he indicated that railroad cars would deliver #5 fuel oil to USTs for the workshops. Mr. Milburn was not sure of the exact UST locations. Railroad tracks and an unidentified rectangular object are shown on May 1932 and September 1940 drawings

(Jacobs, 1999). These USTs are unlikely to still be present. They would have been removed prior to the construction of Building 120.

1.4 Previous Investigations

This section presents a summary of previous investigations at the 50 Series Complex and nearby sites pertinent to this report.

1.4.1 *Building 57A*

Mr. Gordon Potter, the present owner of Building 57A, conducted an investigation in 1994 that was required for a bank loan submittal. As part of the investigation, soil samples were collected from various depths and locations near the U-shaped gravel-filled vats for analysis. Test results from the field investigation indicated that TCE, trans-1,2-dichloroethene (trans-1,2-DCE), and methylene chloride were present in the soil beneath Building 57A (Meredith/Boli and Associates, 1994). The results of this investigation are summarized on Plate 1 (Appendix B).

Mr. Potter's investigation at Building 57A generated only limited environmental data for metals and solvents in soil. These data do not indicate the maximum concentrations or extent of solvent or metals contamination at the workshop buildings. There is no other data indicating the use of other COIs in the vicinity of Building 57A. In addition, the potential presence of underground cisterns, USTs, and associated piping was not positively determined. There is no information in the historical records regarding the disposition of the USTs and associated piping.

1.4.2 *Area I Fuel Facilities*

On behalf of and with oversight by the USACE, FA/BC conducted a site investigation for Area I Fuel Only Facilities in 2000. Area I Fuel Facilities included Buildings 53, 73, 103, and 154 where the presence of up to nine USTs was suspected. The investigation, completed in June 2000, focused on determining the existence of the USTs and associated piping, and verifying whether past DoD activities caused environmental impacts to soil or groundwater by petroleum hydrocarbons and/or lead. Both surface geophysical methods and digging of tests were used to try to identify the location of suspected USTs and associated piping. Plate 1 in Appendix B presents the results from this investigation and is summarized below.

Four of the nine suspected USTs and associated piping were identified during this investigation (one 4,000-gallon UST at Building 53, one 15,000-gallon UST at Building 103, and 7,000-and 10,000-gallon USTs at Building 154). In March 2002, the USACE removed the four USTs: one near Building 53, one near Building 103, and two near Building 154 (Montgomery Watson Harza and Geofon, 2002). Data collected during this investigation is incorporated with results obtained from the 50 Series Complex investigation and discussed in Section 6.0 of this report.

No evidence was identified during the investigations indicating the presence of the following suspected USTs:

- a 1,000-gallon and 10,000-gallon UST reported to be beneath the southeast corner of Building 56A;
- a 1,000-gallon UST at former Building 73;
- a 3,000-gallon UST at Building 103; and
- a 1,400-gallon UST at Building 154.

The suspected 1,000-gallon UST at former Building 73 was not found during the digging of the test pit. It is possible that the UST at Building 73 was removed when the building was demolished as part of the construction of Building 98.

During the June 2000 investigation, there were no geophysical anomalies or piping detected in the suspected location of the 3,000-gallon UST at Building 103. Additionally, there was no evidence of the UST or subsurface contamination in the test pit. The report summarizing the investigation (FA/BC, 2000) concluded that the 3,000-gallon UST was never installed at Building 103, and may be the UST located at Building 161.

Three test pits were dug in the area of a geophysical anomaly at Building 154. No evidence of piping or of the UST was found, but buried concrete and underground utilities were found. The geophysical anomaly in this area is probably due to subsurface concrete and interference from utility alignments.

Analytical results indicate the presence of petroleum hydrocarbons in soil at Buildings 53, 103, and 154. Petroleum hydrocarbons and chlorinated hydrocarbons were identified in groundwater at Buildings 53, 73, and 154. The lack of petroleum hydrocarbons identified in soil at Building 73 may indicate that the groundwater impacted by chlorinated VOCs is not from former fuel storage activities at Building 73, but another unidentified source. Data from the 50 Series Complex investigation will provide evidence of a source area at the 50 Series Complex that is responsible for the VOCs found in groundwater at former Building 73.

Isomers of dichloroethene (DCE) were detected in groundwater samples collected at Buildings 53, 73, and 154. These isomers are likely degradation products of the parent product of TCE. Based on the presence of these isomers and the parent compound, it is likely that TCE is undergoing natural degradation; this observation will be further substantiated by similar trends presented later in this report.

2.0 INVESTIGATIVE APPROACH

A preliminary Conceptual Site Model (CSM) was developed and used during this project to help design and guide the investigation. The CSM developed for the 50 Series Complex incorporates site-specific historical, geological, and hydrogeological information to identify COIs, potential sources of impacts to the environment, and migration pathways. The CSM is discussed in the following section.

2.1 Conceptual Site Model

Figure 2-1 illustrates the preliminary CSM developed for this site. The CSM was based on information in the RRR (Jacobs, 1999), in which the Arsenal's 115-year military history and 35 years of post closure non-military activities are described. As discussed previously, the 50 Series Complex evolved from three buildings built in the late 1800s to eleven interconnected buildings that now occupy the site. Figure 1-3 shows the evolution of the 50 Series Complex. Because of this complicated history, the CSM is a critical component in understanding subsurface conditions. The CSM was developed after reviewing the various building histories and activities, previous investigations, other pertinent reports, and numerous field surveys.

2.1.1 *Physical Setting*

The 50 Series Complex stands on the southern slope of a low-lying hill. In general, the northern portion of the 50 Series Complex was constructed on the crest of the hill, and the southern portion of the complex (mainly Building 56A) was constructed at the base of the hill. The northern and southern portions of the 50 Series Complex were constructed as concrete slab on grade. As a result of the sloping ground surface, the slabs appear to be more than 3 feet thick at the southern end. The center portion of the complex was constructed with wood flooring over an unfinished basement. The height of the basement ranges from 7 feet to less than 1 foot. The details of the 50 Series Complex, including the ground floors and basements, are distinguished in Figures 1-3 and 1-4 by shading or outlining to show the different floors and features accurately.

The low-lying hill is comprised of steeply dipping (between 45 and 55 degrees southwest) sandstone and siltstone. The oldest buildings, Buildings 55, 56 and 57, are positioned on this hill so the longest sides are perpendicular to bedding. Bedrock is exposed in the basement and on the east side of the 50 Series Complex between Building 53 and Building 56A. Portions of the complex were built into the bedrock, such as the firing ranges in the basement and the parkerizing vat in Building 57A. Alluvial, fine-grained sands to silts along with dense organic clays of the former marshland mantle the bedrock. Groundwater in the 50 Series Complex area is shallow; and research indicates that the USTs at Buildings 53 and 154 were strapped down to prevent the USTs from floating.

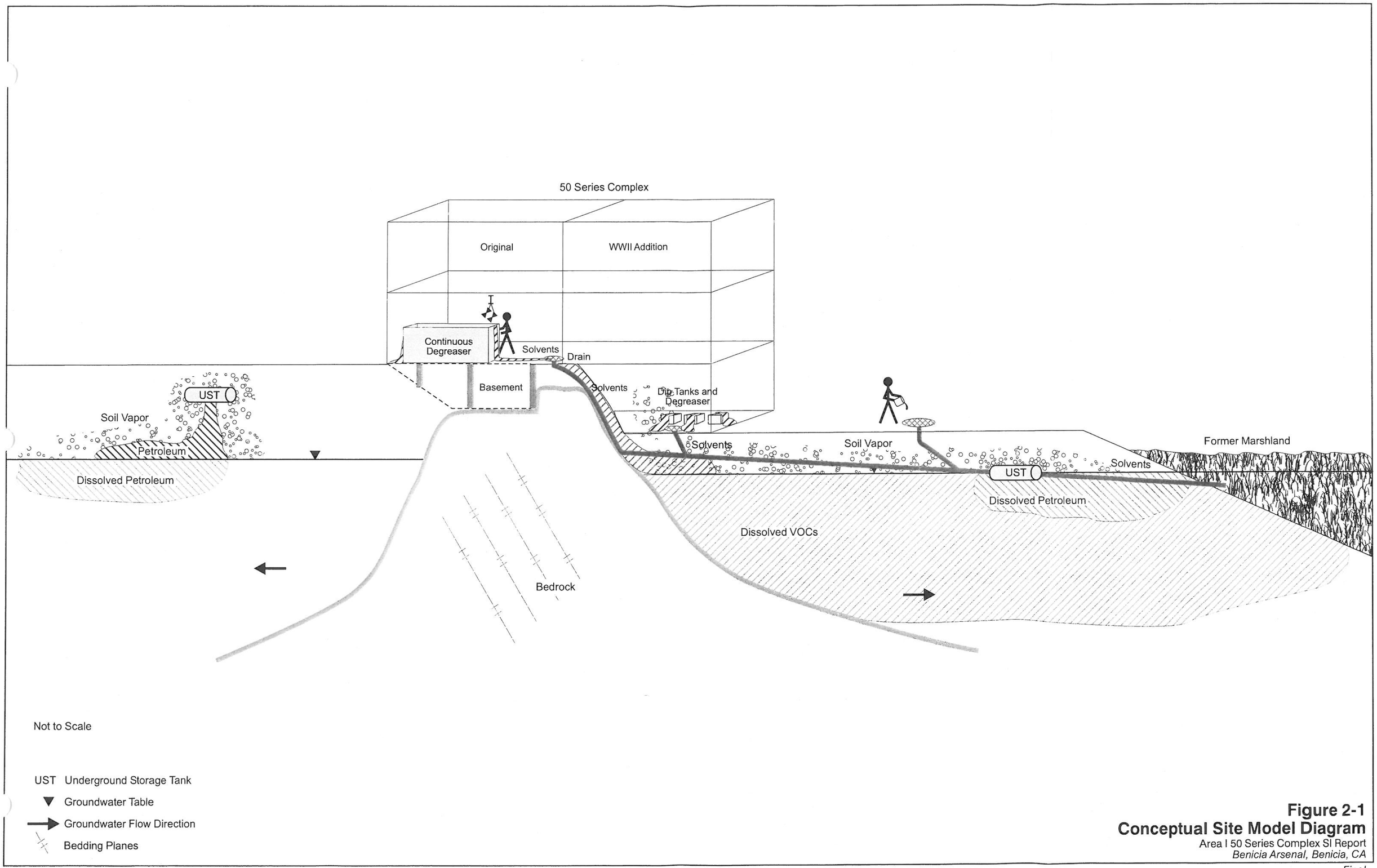


Figure 2-1
Conceptual Site Model Diagram
Area I 50 Series Complex SI Report
Benicia Arsenal, Benicia, CA

2.1.2 *Source Areas and Chemicals of Interest*

The Arsenal functioned as a site for testing gunpowder; for storing, issuing, and repairing Army ordnance; as a principal ordnance repository and distribution point for the Pacific Coast; and as a transshipment depot for holding and storing ammunition and explosives for the Port of San Francisco (Jacobs, 1999). Activities at the 50 Series Complex included industrial and manufacturing shops and fuel and waste storage.

Each of the buildings in the 50 Series Complex were evaluated to determine potential chemical source areas and chemicals used. Table 2-1 lists the activities and features identified in the 50 Series Complex area during site visits or interviews of former employees and the corresponding chemicals used. Potential sources of chemical releases include forges, a hydraulic press, test firing rooms, a foundry, an incinerator, suspected cisterns, vapor degreasers, acid tanks, and suspected USTs beneath Building 56A.

Fuel related petroleum hydrocarbons used at the 50 Series Complex included fuel oil, diesel fuel and gasoline stored in various USTs and ASTs. The shops were equipped with boilers, originally fueled by coal, but updated to use fuel oil, diesel or natural gas. Gasoline was used to fuel vehicles, machinery and other equipment at the 50 Series Complex. The type of gasoline (e.g. leaded or unleaded) used at the complex was determined from old drawings. The USTs shown on these drawings are labeled with outdated terms like "white gasoline" and "red gasoline". In today's vernacular, unleaded gasoline corresponds to "white gasoline" and leaded gasoline corresponds to "red gasoline".

In addition to fuel related petroleum hydrocarbons used at the 50 Series Complex, various chemicals were used in the different processes throughout the historical activities. The chemicals and processes of coloring, cleaning, degreasing, and preserving are described below. These processes also evolved as Army standards changed (i.e. Browning Method to Parkerizing), technology improved (i.e. hand cleaning to vapor degreasing) and as equipment was made available (i.e. single stage tanks to multiple stage degreasers). These processes are described below. Specific information that ties these activities to the 50 Series Complex from historical information is also provided.

COLORING. A procedure used by the Army in the early 1900's was developed and known as the Browning Method. Steel, iron, bronze-plated and nickel-plated pieces were colored using this methodology. Brass or nickel plated pieces were first iron plated, as the Browning mixture would only act on iron or steel surfaces. As part of the Browning process, the metal pieces were first put into boiling lime water to remove grease. The piece then received several applications of the browning mixture, was then scalded with boiling water, and oiled. A more detailed description of the Browning Method is included in the Records Research Report, Attachment 1 (Jacobs, 1999).

The recipe for the Browning Mixture contained Tincture of Steel, Blue Vitriol, Sweet Spirits of Nitre, carbonate of iron, muriatic acid, and alcohol (Jacobs, 1999).

If iron plating was needed, the recipe for the electroplating vat solution contained crystallized Sal ammoniac, water, and pure hydrogen sulfate (H_2SO_4) (Jacobs, 1999).

CLEANING. By the 1940's, many new chemicals were used in the cleaning and maintenance of small arms at the Arsenal. A detailed process describing the cleaning and preservation methods for ordnance material (e.g. small arms) used in 1943 was described by the Packaging Section of the General Supply Branch. The choice of the cleaning method was based on the composition of the part to be cleaned, the nature of the part surface, the complexity of the construction, the nature of the contaminants to be removed, the degree of cleanliness required, the availability of the cleaning material and cleaning equipment, and when the part was to be cleaned.

At the 50 Series Complex, small arms parts, that were made of iron or steel were the predominate materials cleaned and preserved. If the nature of the contamination on the part was oil or grease, or other contaminants that were readily soluble in organic solvents, then a cleaning solvent or alkaline cleaner was used. If the contamination was oil and/or grease and the part was highly finished, then either a petroleum solvent cleaning followed by rinsing with methanol, or petroleum solvents alone, were applied. If the contamination was inorganic (e.g. fluxes) and not soluble in organic solvents, then alkaline cleaning was used. If the contamination could not be removed by any of these means, then mechanical forms (e.g. buffing, sanding) were employed (Jacobs, 1999).

Different cleaning methods included solvent cleaning by immersion, spray and vapor degreasing and alkaline cleaning by immersion, spray and electro-cleaning. Preservatives were applied by immersion, spraying, brushing and slow coating.

Available information about the 50 Series Complex indicates that the majority of the cleaning of small arms and parts was performed using phosphoric acid dip tanks. The acid was used to clean the metal in order to prepare the metal for preservation. A total of twelve 1000-gallon phosphoric acid dipping tanks were identified within the industrial buildings during Brown and Caldwell's 1952 investigation. These tanks were emptied every two to three weeks. It is not clear where the contents of the tanks were disposed of; however, it is presumed to be storm drains and the sanitary sewer system (Jacobs, 1999).

Other dip tanks used in Building 56A included caustic baths which were used for degreasing, paint, rust, and tar removal. In caustic dipping, a paint stripping compound was used in combination with a resin added to remove grease (Brown and Caldwell, 1952). When the spent material was dumped, it had a concentration of 5 to 10 percent caustic soda (Brown and Caldwell, 1952). There were about 12 caustic tanks located throughout the industrial buildings, each with a capacity of 1000 gallons, which were dumped about once every three weeks. The tanks were emptied into floor drains connected to storm drains and the sanitary system (Brown and Caldwell, 1952). The storm drain and sewer system drained into the Carquinez Strait.

Some degreasing was performed using solvents in a vapor degreasing process. Vapor degreasers were located in Building 56A and Building 57 (Jacobs, 1999). Immersion may have occurred by scrubbing or wiping with a saturated cloth of petroleum solvent. This method was intended for localized application to bare metal areas. Solvent immersion generally was not performed on any parts that contained fabric, rubber and other organic materials (Jacobs, 1999).

Solvent Vapor Degreasing. Solvent vapor degreasing was performed on parts or simple assemblies just prior to preservation, and only when the surface contamination consisted of oils, grease, or other materials which were soluble in or readily removed by degreasing fluids (Trichloroethylene [TCE] or Perchloroethylene [PCE]). The procedures for vapor degreasing included;

- The part was passed through or suspended in the vapor phase until no further solvent condensation occured on the lighter part, or until all contamination was removed from heavy parts.
- Parts were then flushed with a stream of liquid degreaser solvent and passed through an impact spray chamber or dipped and agitated in a tank of condensed solvent. This process removed the light, loose, insoluble contamination (Jacobs, 1999).

Degreasing units were constructed in two sizes. The larger units had continuous distillation tanks that separated grease from TCE (Brown and Caldwell, 1952). Residue from this operation was collected in drums and hauled to the dump (Brown and Caldwell, 1952). The smaller degreasing units did not have stills to purify the solvent and had to be drained periodically (approximately 100 gallon per month per unit) (Brown and Caldwell, 1952). It is not clear where the contents from the smaller degreasing units were disposed of; however, it is presumed to be storm drains and the sanitary sewer system.

PRESERVATION. Similar to cleaning, the choice of preservative was carefully evaluated. The choice of preservative was based on the composition of the part to be preserved, the nature and function of the part surfaces, the complexity of the construction, the type of exposure and degree of preservation required, other functions expected of the preservative, the nature of packing to be used over the preservative, the ease of, or necessity for removal of preservative from parts prior to use, availability of preservative material and difficulties of application (Jacobs, 1999).

Based on the materials cleaned at the 50 Series Complex, preservation was required for metallic small parts that were placed in storage or shipped out for use in wartime.

Usually, preservatives were not applied on non-metallic parts such as rubber, leather, cork, paper, fabric, or plastics (Jacobs, 1999).

An example of a preservative suitable for gun parts and small gun tubes was USA 2-84, a light, rust preventative preservative. This preservative may have been applied by dipping, spraying or brushing after heating to the proper consistency. It would not be diluted with solvents and would be applied from a cold dip (Jacobs, 1999).

Many other preservatives were available based on the type of item to be preserved. Other preservatives used included USA 2-82 (a heavy rust preventive), AXS-673 (a thin film rust preventive), AXS- 674 (a medium oil lubricating preservative), AXS- 702 (a light oil lubricating preservative) and AXS- 777 (a special oil lubricating preservative) (Jacobs, 1999). In 1952, the preservatives used at the 50 Series Complex and other areas included AXS-1347, AXS-1719, AXS-673, AXS-674 and US Army 2-121. Only AXS-673 and AXS-674 coincide with the preservatives

used in 1943 (Brown and Caldwell, 1952). A web search was conducted to determine the chemical make-up of all of these preservatives, but no information was found about any of them.

The applications of the preservatives included dipping, spraying, brushing, and "flow coating" based on the preservative. "Flow coating" is the process of pouring the preservative onto the parts. Based on the known processes at the 50 Series Complex, the types of preservation methods were likely dipping, brushing or "flow coating".

In summary, the process of coloring, cleaning, and preserving metal parts at the 50 Series Complex evolved from the Browning Process of the early 1900s to the Parkerizing process since the 1940s. The overall approach to these processes included the removal of oils and grease from the metal by using boiling water, caustics or phosphoric acid. Some vapor degreasing was also performed. A vapor degreasing unit was located in Building 56A and Building 57. The location and use of Stoddard solvent is not well understood but was prescribed as a cleaner in the 1940s. Acid and caustic dip tanks were located in Buildings 56, 56A and 57 for the degreasing of small arms. Preservation and coloring was performed in Building 56 and 57. During the World War II era, Building 57A was built and was named the "Parkerizing Room". Parkerizing or Phosphating is a metal finish that gained in popularity during World War II (WWII) when the Army was looking to replace the typical blued finish on most small arms with a rust resistant and anti-reflective coating that would be both durable and abrasion resistant and hold up in all weather extremes. The Parkerizing technique is a phosphate etching process that produces a hard matte or dull finish. There are no solvents associated with the Parkerizing process and therefore not associated with Building 57A. The primary cleaner based on records research included the use of acids and caustics. The use of Stoddard solvent and TCE were used at the Complex but use was limited.

After the closure of Arsenal, subsurface structures remained (e.g. the Parkerizing vat in Building 57A, the caustic tank in Building 56 and the storm/sewer system). Tenants and landowners used these structures for a variety of manufacturing, maintenance and repair activities. It was customary to discharge untreated waste into the sewer and/or storm drain system. Regulations were later enacted and enforced to prohibit this activity. The discharge of untreated wastes into the sewer system continued for another 5 years after the Army left until 1969 when an upgrade to the sewer system was completed and untreated wastes were diverted from the Carquinez Strait into the City of Benicia Wastewater Treatment Plant. The storm drain system has discharged directly into the Carquinez Strait for over a century.

2.1.3 *Release Mechanisms*

The historical activities at the 50 Series Complex used a variety of chemicals for the servicing of arms and a variety of storage containers for fuels, acids, and wastes. Chemicals may have leaked, spilled, or been dumped to the surrounding soil and groundwater. Spills or leaks out of storage containers (USTs, vats, cisterns, drums) and dumping of unwanted or used materials are referred to as release mechanisms.

Table 2-1. Site History and Historical Use

Feature	Facility ID	Function	Potential COIs	Evidence	Corresponding Investigation Activity and Sampling Location
Ammunition storage room	Building 56A (ground floor only)	Ammunition storage	Lead, Antimony, Arsenic, Ammunition/powders, Copper	Historical drawings	None. No COI sources identified during site visit and concrete floor is several feet thick.
Asphalt patches	Breezeway between Building 55 and 56A	Unknown, possible cistern	Unknown	Site visit	Geophysical survey and B057AHP002
Boiler house	Former Building 65(A) (1918 to 1940s)	May have housed boiler(s) for industrial operations	Unknown	Historical figures, located west of Building 58	B056AHA001, B057AHP005
Boiler room	Former Building 58	Housed a boiler to heat the building	Unknown, suspected fuels	Historical figures	B056AHA002, B057AHP005, B057AHP006
Boiler room	Building 56A (ground floor only)	Housed one boiler to heat building and produce steam for industrial operations	Natural gas	Historical drawings and site visit	B056AHA002
Boiler room	Building 65(B) (1940s to present)	Housed two boilers to heat shop buildings and produce steam for industrial operations	Fuels, Oils, Lead	Historical figures, Mr. Marv Kaufman interview	B065BHA001
Cistern (suspected near Building 56)	Building 56	Water storage and industrial waste disposal	Solvents, Acids, Preservatives (oils), Foundry waste	Mr. Buster Byerrum interviews	Geophysical survey and B057AHP003
Cistern (suspected southwest corner of Building 57)	Building 57	Water storage and industrial waste disposal	Solvents, Acids, Preservatives (oils)	Mr. Buster Byerrum interviews	Geophysical survey and B057AHP004
Cistern (suspected between Building 55 and Building 56A)	Building 55	Water storage and industrial waste disposal	Solvents, Acids, Preservatives (oils)	Mr. Buster Byerrum interviews	Geophysical survey and B057AHP002
Cistern (Suspected)	Building 57A	Water storage and industrial waste disposal	Solvents, Acids, Preservatives (oils)	Mr. Buster Byerrum interviews	Geophysical survey and B057AHP001

Table 2-1. Site History and Historical Use (continued)

Feature	Facility ID	Function	Potential COIs	Evidence	Corresponding Investigation Activity and Sampling Location
Degreaser (location unknown)	Building 56A (ground floor only)	Clean small arms	Solvents, Acids	10 foot x 39 inch x 7 foot tank listed on July 1957 Equipment List, powered by electricity	B056AHA001 – B056AHA003
Degreaser - Continuous (ground floor)	Building 57	Clean small arms	Solvents, Acids	Historical text, Mr. Buster Byerrum interviews, and site visit	B057AHP007
Drainage in basement	Building 57	Unknown	Unknown, potentially all industrial wastes from Building 57	Site visit	B057HA004 and B057HA005
Elevator	Building 56 (ground floor only)	Probable hydraulic sump	Hydraulic oil	Site visit	None. No COI sources identified during site visit.
Elevator	Building 56A (ground floor only)	Probable hydraulic sump	Hydraulic oil	Site visit and historical maps	None. No COI sources identified during site visit.
Elevator - suspected (South)	Building 57 (ground floor)	Freight elevator – did not service the basement	Hydraulic oil	Mr. Buster Byerrum interviews	None. No COI sources identified during site visit.
Elevator (North) (basement to all floors)	Building 57	Freight elevator - serviced all floors (including basement)	Hydraulic oil	Site visit	None. No COI sources identified during site visit.
Equipment room – adjacent to and east of firing room with floor drain	Building 56A (ground floor only)	Unknown, potential tank or boiler stand in place on concrete floor	Fuels (unspecified)	Site visit	B056AHA004
Firing area 1 and Firing room with open floor drain	Building 56A (ground floor only)	Small arms weapons testing	Lead, Antimony, Arsenic, Ammunition/powders, Copper	Site visit and RRR	B056AHA004, B056AGR001
Firing area 2 and open drainage	Building 56A (ground floor only)	Small arms weapons testing. Drainage may have led to sewer and/or cistern	Lead, Antimony, Arsenic, Ammunition/powders, Copper	Site visit and historical drawing	None. No COI sources identified during site visit and concrete floor is several feet thick.
Firing area 3	Building 56A (ground floor only)	Small arms weapons testing	Lead, Antimony, Arsenic, Ammunition/powders, Copper	Site visit and historical drawing	None. No COI sources identified during site visit and concrete floor is several feet thick.

Table 2-1. Site History and Historical Use (continued)

Feature	Facility ID	Function	Potential COIs	Evidence	Corresponding Investigation Activity and Sampling Location
Firing ranges - small arms (basement)	Building 57	Small arms weapons testing	Lead, Antimony, Arsenic, Ammunition/powders, Copper	Site visit	B057HA001 - B057HA005
Floor drain	Building 56 (ground floor only)	Potential industrial waste disposal to sewer and/or cistern	Solvents, Acids	Site visit	None. Investigation of these features will be part of a separate FSIP.
Floor drain	Building 56C (ground floor only	Suspected drain for industrial waste to sewer and/or cistern	Unknown, potential wastes from Buildings 56 and 56B	Site visit	None. Investigation of these features will be part of a separate FSIP.
Forges (two)	Building 55	Heat metals	Metals, Fuels (unspecified)	Mr. Buster Byerrum interviews, July 1957 Equipment List, powered by "gas"	B055HA002
Foundry facilities	Building 56B (ground floor only)	Melt and mold metals	Foundry sands and other unknown industrial wastes	Mr. Buster Byerrum interviews	B056BHA002 - B056BHA004
Hydraulic press or equipment pad	Building 55	Press metals	Hydraulic oil	July 1957 Equipment List, powered by electricity (200 ton)	B055HA003
Machine shop	Building 55A	Unknown	Metals unknown	Site visit	None. Beneficial use.
Marshlands (former)	Not applicable	Potential location of industrial waste disposal	Prior to the 1940s wastes from dipping tanks (acids and caustics)	Records Research Report	None.
Metal plate	Building 55	Unknown	Unknown	Site visit	None. No COI sources associated with metal plate.
No known features	Building 57C	Storage	Unknown	Access not allowed on site visit	None. Constructed after DoD use.
Oil/water separator (ground floor)	Building 57A	Unknown	Unknown	Site visit, however may not be DoD	B057AHP001
Paint shop/shed	Former Building 66(A) (1918 to pre 1945)	Stored oils and paints	Oils, Metals	Historical figures, located north of former Building 59(A)	B066ASB001, B057AHP002

Table 2-1. Site History and Historical Use (continued)

Feature	Facility ID	Function	Potential COIs	Evidence	Corresponding Investigation Activity and Sampling Location
Parkerizing and oakite tanks (unknown location)	Building 56 (ground floor only)	Parkerize small arms	Preservatives (oils)	Historical records, site visit	B056HA001 - B056HA003 and B056SB001 – B056SB004
Parkerizing and oakite tanks (unknown location)	Building 56A (ground floor only)	Parkerize small arms	Preservatives (oils)	Mr. Buster Byerrum interviews, 9 tanks listed on July 1957 Equipment List (4 foot x 8 foot x 4 foot) powered by steam	B056AHA001 – B056AHA003
Parkerizing and oakite tanks (unknown location)	Building 56B (ground floor only)	Parkerize small arms	Preservatives (oils)	Mr. Buster Byerrum interviews	B056BHA001 – B056BHA004
Parkerizing vat (ground floor)	Building 57A	Parkerize and bluing of small arms	Solvents (post-Army use), Preservatives (oils)	Mr. Buster Byerrum interviews, and site visit	Geophysical survey, B057ASB001, B057BHA001 and B057AHP001 – B057AHP008
Pipe - 18-inch (ground floor)	Building 57A	Unknown, potential pathway for all industrial wastes to storm/sewer and/or cisterns	Solvents (post-Army use), Preservatives (oils)	Site visit – removed in 2000	Geophysical survey and B057AGR001
Pipe - Open (ground floor)	Building 57A	Unknown, potential pathway for all industrial wastes to storm/sewer and/or cisterns	Solvents (post-Army use), Preservatives (oils)	Site visit	None. No COI sources identified during site visit.
Pipe - Open (ground floor)	Building 57A	Unknown, potential pathway for all industrial wastes to storm/sewer and/or cisterns	Solvents (post-Army use), Preservatives (oils)	Site visit	None. No COI sources identified during site visit.
Pipe trench (ground floor)	Building 57A	Unknown, potential pathway for all industrial wastes to storm/sewer and/or cisterns	Solvents (post-Army use), Preservatives (oils)	Site visit	None. No COI sources identified during site visit.
Roof drain	Building 65(B) (1940s to present)	Drainage	None, only used as possible identifier for cistern location. However, may have been a pathway for industrial wastes	Site visit	None. Investigation of these features will be part of a separate FSIP.
Roof drain (ground floor)	Building 57A	Unknown, potential pathway for all industrial wastes to storm/sewer and/or cisterns	Solvents (post-Army use), Preservatives (oils)	Site visit	None. Investigation of these features will be part of a separate FSIP.

Table 2-1. Site History and Historical Use (continued)

Feature	Facility ID	Function	Potential COIs	Evidence	Corresponding Investigation Activity and Sampling Location
Roof drains (outside)	Building 56C (ground floor only	Potential drainage to cistern	None, only used as possible identifier for cistern location	Site visit	None. Investigation of these features will be part of a separate FSIP.
Slack tub(s) (unknown location)	Building 55	Cool metals	Metals	Mr. Buster Byerrum interviews, 3 listed on a July 1957 Equipment List as "quench tanks"(size unknown)	B055HA002 and B055HA003
Small arms repair and retinning	Former Building 58	Temporary loading of projectiles with explosives	Lead, Antimony, Arsenic, Ammunition/powders, Copper	Historical figures and letter	B056AHA002
Smoke stack	Smoke Stack/ Incinerator	Incinerator	Unspecified explosives, Hexavalent Chromium/metals, Black powder	Historical photographs, maps, and Mr. Buster Byerrum interviews	B066ASB001, B057AHP002
Soil from Building 65 (B) Boiler Room	Building 65(B) Boiler Room	Stained soil from boiler(s) in Building 65(B)	Unknown, potentially diesel fuels from boiler room. Oils, lead	Site visit	B065BHA003
Small arms weapons testing	Courtyard area	Small arms weapons testing	Lead, Antimony, Arsenic, Ammunition/powders	Mr. Buster Byerrum interviews and site visit	B065BHA002
Storm/sewer drains and catch basins	Building 57	Industrial waste disposal to Carquinez Strait	All industrial wastes	Site visit	None.
Storm/sewer drains and catch basins	Building 55	Industrial waste disposal to Carquinez Strait	All industrial wastes	Site visit	None.
Storm/sewer drains and catch basins	Building 56 (ground floor only)	Industrial waste disposal to Carquinez Strait	All industrial wastes	Site visit	None.
Tool house	Former Building 59(A) (1910 to pre 1945)	Stored oils, paints, and tools	Oils	Historical figures, located south of Building 55	B053SB001 and B053SB002 associated with Building 53 FSIP and B057AHP006
Transformer room with floor drain	Building 56A (ground floor only)	Housed transformer(s)	PCBs	Site visit	B056AHA005
UST (suspected and unknown location)	Former Building 58	Fuel oil used by boiler	Fuels	Historical association of boiler with a UST	Geophysical survey and B056AHA002

Table 2-1. Site History and Historical Use (continued)

Feature	Facility ID	Function	Potential COIs	Evidence	Corresponding Investigation Activity and Sampling Location
UST (suspected and unknown location)	Building 65(B) (1940s to present)	Fuel oil used by boiler	Fuels	Historical association of boiler with a UST	B056AHA001
USTs	Fuel Oil USTs (beneath Building 120)	Suspected fuel oil storage tanks to service boilers in Building 65(B)	#5 Fuel oil, Oils, Fuels, Lead	Historical figures and Mr. Jim Milburn interview	Geophysical survey, B120SB001, B120SB002and B057AHP003
USTs	Fuel USTs Building 53	Suspected fuel storage tanks	Fuels, Lead	Historical maps and interviews	Geophysical survey (June 2000 investigation [FA/BC, 2000]), B057AHP002, B057AHP006
USTs (suspected and unknown location)	Fuel Oil Tank(s)/ Boiler House [Pre-Bldg 65(B)]	Fuel oil used by boilers suspected to be delivered by railroad tank car	#5 Fuel Oil	Mr. Jim Milburn recalled #5 oil being delivered by Railroad tank car to USTs. Railroad tracks lead to building on 1911 historical figure.	Geophysical survey and B065BHA001
USTs	Fuel USTs Building 154	Suspected fuel storage tanks	Fuels, Lead	Historical maps	Geophysical survey (June 2000 investigation [FA/BC, 2000]), B057AHP004, B057AHP005
Utility Tunnel - AST beneath Parkerizing Room (Building 57A)	Building 57B	Unknown, potential pathway for all industrial wastes to storm/sewer and/or cisterns	Solvents, Acids/alkalis, Preservatives (oils)	Site visit	B057BHA001
Utility tunnel (basement)	Building 55	House utilities	Fuels, Metals	Maps and site visit	B055HA001
Utility vault	Breezeway between Building 55 and 56A	Utility vault		Site visit	B057AHP002
Vats for cleaning (ground floor)	Building 57	Clean small arms	Acids, Kerosene	Drawing 2994	B057HA004 and B057HA005
Welding shop	Building 56B (ground floor only)	Welding	Metals (unspecified)	RRR	B056BHA002 - B056BHA004

AST = aboveground storage tank
COIs = chemicals of interest
DoD = Department of Defense
FSIP = Field Site Investigation Plan
PCBs = polychlorinated biphenyl
RRR = Records Research Report
UST = underground storage tank

Activities at the 50 Series Complex allowed for numerous potential release mechanisms including leaking USTs, overflow of chemicals from dipping tanks, the dumping of chemicals into storm drains, firing ranges where bullets may contaminate soil and/or groundwater, and foundry operations that may have introduced metals into the soil. USTs corroded and developed cracks, allowing diesel fuel, gasoline and/or fuel oil to leak into the subsurface soil or directly into groundwater. Chemicals from dipping tanks boiled over, spilled on the floor, and flowed into the drains (Jacobs, 1999). The large dipping tanks used for degreasing, paint stripping, and tar removal were usually emptied every two to three weeks (Jacobs, 1999). It is not clear where the contents of the tanks were disposed of; however, it is presumed to be storm drains and the sanitary sewer system (Jacobs, 1999). Chemicals spilled on the wooden floors from the shops above the utility tunnel may have leaked through to the dirt floor of the tunnel (Jacobs, 1999). When two USTs were removed in March 2002 near Building 154, they were found to be partially submerged in groundwater (Photo MVC-755F) with numerous holes (Photo MVC-765F) (Telecon 9/26/02, USACE) indicating that petroleum products stored in those tanks (diesel, leaded gasoline, or motor oil) may have leaked into the groundwater.

Photo MVC-765F. UST with holes. (March 2002)

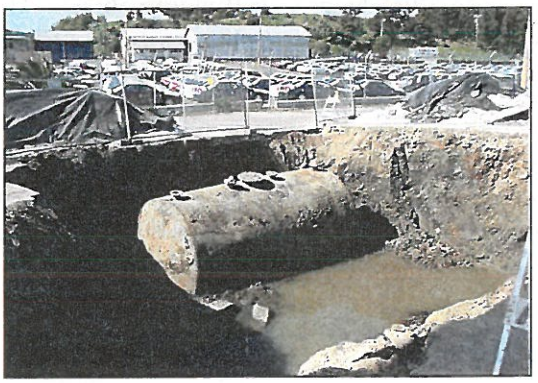


Photo MVC-755F. Building 154 UST found to be partially submerged in groundwater. (March 2002)

Firing ranges were used to test guns and the ammunition was fired into bedrock in the basement of Buildings 56A and 57. The metal bullets may still remain in the bedrock, potentially impacting the soil and possibly groundwater. Metal shavings such as lead and copper were also a by-product in the Arsenal's foundry operations and were possibly spilled or dumped into the nearby utility tunnel or onto exposed soil.

2.1.4 *Pathways and Mobility*

Once released into the environment at the 50 Series Complex, several mechanisms could transport the chemicals. Potential pathways include air, surface water, soil, and groundwater.

Air. Chemicals or COIs can be transported in the air via dust or volatilization. Examples of airborne transport of chemicals in dust include nonvolatile dusts formed during the discharge of weapons in the firing ranges or the burning of wastes in an incinerator. Large ventilation systems were installed to divert dust from the basement firing ranges to the outside atmosphere. Nonvolatile chemicals can also be transported by air when wind brings dust into suspension in the air and

distributes the chemicals throughout the area. The fine particles of dust could contain COIs like lead from ammunitions or chromium from the incinerator. In addition to dust, airborne COIs can be in the form of volitization. For example volatile chemicals can be released to the air occur during the refilling of USTs or ASTs or when fuels or solvents are spilled. Another possible pathway for volatiles to contaminate air is the volitization of contaminated soil. Volatile chemicals in soil and groundwater may also eventually reach the surface and the atmosphere.

Surface Water. Released chemicals may have been transported by surface water either by dissolving or physically mixing with the fine sediment in surface water. PCBs may have adhered to soil particles in the Transformer Room or metals from the foundry facilities may have been carried by surface water to the former marshland area and deposited. After the storm water entered the storm drains, dissolved contaminants could have flowed and discharged into the former marshland area immediately west of Building 56(A). Also, cracks in the storm drain lines or insufficiently sealed joints throughout the storm system downstream from industrial areas may also have served as points of discharge for contaminants.

Soil. Potential mobility associated with contaminated soil is volatilization and percolation/infiltration. The volatilization of chemicals in soil occurs when they are present in the shallow soil. The shallow soil at the 50 Series Complex include artificial fill overlying alluvial/fluvial material consisting of native silt and clay with poorly graded sands and gravels. Leaking USTs contain volatile chemicals that can volatilize in the silts and poorly graded gravels creating soil vapor gases.

Another possible transport mechanism is infiltration. Infiltration of surface water through surface soil can carry contaminants downward into subsurface soil and groundwater. For example, TCE spilled from the vats or metals from ammunition may have infiltrated into the subsurface soil or more deeper into groundwater.

Groundwater. Pathways to contaminate groundwater include migration of chemicals from the soil to groundwater and direct contact. After contaminants infiltrate soil, they can migrate further downward into groundwater. Once in groundwater, the contaminants spread in the direction of groundwater flow. Additionally, contamination may be introduced directly into groundwater. As shown in the previous subsection, leaking USTs located near Building 154 were found to be in direct contact with groundwater allowing petroleum contaminants to be dispersed directly into groundwater.

2.2 Project Objectives

The objective of this investigation was to ascertain whether soil or groundwater contamination resulted from past DoD use of the facilities at the 50 Series Complex and surrounding structures. Developed from the CSM, project objectives are outlined in DQO's. The DQO process is used as a strategic planning approach to optimize the data collection activities and guide the investigation. It uses a systematic procedure for defining the criteria that data collection should satisfy and is

described in Environmental Protection Agency (EPA) guidance (EPA, 1994). The site-wide project objectives were to determine:

- the presence of acids/alkalis, TPH related fuels, oils, PAHs, PCBs, foundry wastes, metals and/or explosives in soil;
- the presence of VOCs in soil gas beneath the 50 Series Complex and if the concentrations could impact indoor air;
- the extent of SVOCs, VOCs, TPH, and metals previously identified at Building 57A;
- the presence and extent of VOCs, PAHS, SVOCs, and metals in groundwater;
- how soil type and stratigraphy affect the presence and distribution of COIs;
- the impact of groundwater depth, general chemical quality, and groundwater gradient and flow direction on the presence of COIs;
- recommend additional data collection, risk analysis, or remediation if COIs are present in soil, groundwater, or soil gas, and if the risk screening analysis determined any COIs are COPCs;
- the presence and extent of fuel additives in soil and groundwater that would indicate post-Army releases; and
- collect data to provide the framework for non-beneficial use of groundwater.

Detailed DQOs by building are presented in Section 8.0, which were outlined in the FSIP (FA/BC, 1999a) with an explanation as to whether or not they were satisfied.

3.0 FIELD METHODS AND SAMPLING RATIONALE

This section describes the field methods used, the rationale for selecting the number and location of samples, analytical parameters, and IDW management procedures for the 50 Series Complex investigation.

3.1 Field Methods

Field activities were conducted in a sequence that enabled project personnel to progressively refine sampling locations. A geophysical survey was conducted as an initial step to better define target areas and clear drilling locations. After the geophysical survey, drilling and sampling activities were focused in areas identified by the survey and locations proposed in the FSIP. Field techniques used are described in the FSIP and QAPP (FA/BC, 1999a and b).

3.1.1 *Geophysical Survey*

Ground penetrating radar (GPR) and electromagnetic line locating (EMLL) methods were used for the geophysical investigation. GPR was used to attempt to identify USTs, cisterns, and other buried debris and objects inside and outside the 50 Series Complex. EMLL was used to further characterize the source of any detected GPR anomalies, as well as to scan each site for magnetic interference caused by the metal rebar in the concrete floor of the building interiors. These methods were also used to clear boring locations for subsurface obstructions and utilities.

NORCAL Geophysical Consultants, Incorporated (NORCAL) of Petaluma, California performed the geophysical investigations on March 15 and 16, 1999 and May 24 through 27, 1999. Reports prepared by NORCAL are included as Appendices C and D.

3.1.2 *Hand Auger Soil Borings*

The purpose of the soil borings was to collect soil samples for stratigraphic data and chemical analyses. Twenty hand-augered soil borings were advanced in areas of limited access, where a mechanically driven rig could not be used (e.g., basement areas), and for sample locations less than 5 feet bgs. Soil samples were collected for stratigraphic interpretation and chemical analyses. The auger was bored to the desired sampling depth and then withdrawn. To collect the soil sample, a manual slide impact sampler with a sample sleeve was pounded into the soil to a depth of 6 inches (the length of the sample sleeve). If additional soil samples were needed, the boring was advanced to the next interval and the drive sampling process was repeated. Soil borings advanced using hand auger are designated in the sample identification with "HA," for example, B057HA001.

3.1.3 *Hollow Stem Auger and Direct Push Soil Borings*

For soil borings that were to be advanced to a depth of greater than 5 feet bgs, a combination of direct push technology and hollow stem augering was employed. In general, direct push was preferred to reduce the amount of IDW generated compared to hollow stem auger drilling. For this investigation, a drill rig was used that could easily convert from direct push to hollow stem auger and back. This approach was effective in allowing for conversion to hollow stem augering once the direct push method met with refusal. Only a few borings near the northeast corner of the 50 Series Complex contained moderate to high density sandy soil that limited the direct push method to approximately 12 feet bgs. Direct push was utilized to advance thirteen borings where shallow soil conditions were favorable for its use.

The hollow stem auger drilling was used in areas outside of buildings, where the deeper borings were generally located. Ten soil borings were advanced by drilling with hollow stem augers.

Soil samples were collected in clear acetate liners while employing direct push, or in stainless-steel-lined split spoon samplers during the hollow stem auger drilling. Soil borings advanced with the hollow stem auger or by direct push are designated with "SB" in the sample identification; for example, B053SB001.

3.1.4 *Hydropunch™ Sampling*

The purpose of hydropunch™ sampling was to collect discrete groundwater samples in areas where impacts to groundwater have been previously documented (Building 57A) and in selected perimeter locations. Soil borings with hydropunch™ groundwater samples were designated with "HP" in the sample identification, for example, B057AHP001. Thirteen groundwater samples were collected using the hydropunch™.

3.1.5 *Soil Gas and Ambient Air Sampling*

The purpose of the soil gas sampling was to collect *in-situ* soil gas samples from shallow soil (from approximately 4 feet bgs) to evaluate the potential of chemicals in indoor air. Soil gas samples were collected beneath the concrete floor in Buildings 56, 56A, 56B, 57A, and the basement beneath Buildings 56 and 57.

To collect soil gas samples at the 50 Series Complex, direct push rods were driven to the desired depth, and retracted enough to expose the perforated tip, allowing soil gas to enter. Disposable Teflon® tubing was attached to the tip and connected to a Summa® Canister at the surface. At locations where the surface was hard and direct push was unable to advance, a hollow stem auger rig was used. The auger drilled down to within two feet of the desired depth, and the soil gas probe was driven past the end of the auger.

Once the soil gas probe was in place, a pump was attached at the surface to pull the soil gases through the tube. The gases were purged for five minutes per 5 feet of depth then the sample was collected in Summa® Canisters. To collect the soil gas sample, the canister was attached to the tube from the probe, a valve was opened, and the vacuum within the canister pulled the soil gas sample in. After the sample was collected, a photoionization detector (PID) was connected to the tubing and a reading was recorded. The laboratory used the PID reading to assist in setting up their instrument. Eight soil gas samples were collected during this field investigation.

Ambient air samples were collected by the same procedures as the soil gas samples, except the probe was not driven into the ground. The purpose of the ambient air samples was to determine the ambient air concentrations in selected buildings at the 50 Series Complex. A total of four ambient air samples were collected in Building 55, Building 56B (2 samples of different days) and Building 57A.

Soil gas and ambient air samples were designated with "G" in the sample identification, for example, B057HA005-G01.

3.2 Sample Locations and Analytical Parameters

A total of 188 soil samples, 8 soil gas samples, 4 ambient air samples, 13 *in-situ* groundwater samples, and 1 grab groundwater sample were collected during this investigation. Boring locations were chosen based on the locations of historical activities, information from the RRR (Jacobs, 1999), and features identified during site visits. Plate 2 (Appendix B) depicts the boring locations drilled during this field investigation at the 50 Series Complex. As presented in Section 2.0, Table 2-1 lists all the features investigated with suspected chemicals associated with each feature and the name of the boring or field activity (e.g., geophysical survey) performed to investigate each feature. The soil and groundwater samples collected were analyzed according to the chemicals used at each feature.

Boring locations and sampling were targeted at or around the nine principal features at the 50 Series Complex, which are listed below:

- Parkerizing tanks (Buildings 56, 56A, 57A)
- Cisterns
- Forges and Hydraulic Press (Building 55)
- Test Firing Rooms and Small Arms Storage and Repair (Buildings 56, 56A, 57, 57B, 58, 65(B))
- Boiler Rooms (Buildings 58, 65(A), 65(B))
- Continuous Degreaser (Building 56A and 57) Oil Water Separator (Building 57C)
- Foundry (Building 55)
- USTs (Buildings 53, 56A, 65(A), 65(B), 120)
- Miscellaneous features such as the utility tunnel, paint shop, and smoke stack/incinerator (Buildings 56A, 59, 65(B), 66(A)).

Table 3-1 lists the boring locations, boring numbers, depths sampled, and analyses performed to investigate potential COIs at each of the principal features.

Table 3-1. Borings and Analyses

Location	Boring	Sample Depths (feet bgs)	Analyses
Building 53	B053SB001[b]	3.5, GW	Lead, TPH, VOCs, PAHs
Building 53	B053SB002[b]	3, GW	Lead, TPH, VOCs, PAHs
Utility Tunnel	B055HA001[e]	0	Metals, TPH, VOCs, PAHs
Building 55	B055HA002[h]	0, 4	Metals, TPH, VOCs, PAHs, pH
Building 55	B055HA003[h]	0	Metals, TPH, VOCs, PAHs, pH
Building 55	B055SB001[h]	0, 6.5, 10, SG	Metals, TPH, VOCs, SVOCs, PAHs, PCBs, pH, TO-14
Building 56A Basement	B056AHA001[bcdg]	0, 5, SG	Metals, TPH, VOCs, SVOCs, PAHs, pH, TO-14
Building 56A Basement	B056AHA002[abcdg]	0, 5, SG	Metals, TPH, VOCs, SVOCs, PAHs, pH, TO-14
Building 56A Basement	B056AHA003[cdg]	0, 5, SG	Metals, TPH, VOCs, SVOCs, PAHs, pH, TO-14
Building 56A	B056AHA004[ab]	0, 4	Metals, TPH, VOCs, PAHs, anions
Building 56A	B056AHA005[e]	0, 4.5	Lead, TPH, PCBs, VOCs, PAHs
Utility Tunnel	B056BHA001[g]	0, 5	Metals, TPH, VOCs, SVOCs, PAHs, pH
Utility Tunnel	B056BHA002[gi]	0, 5	Metals, TPH, VOCs, SVOCs, PAHs, pH
Utility Tunnel	B056BHA003[gi]	0, 5, SG	Metals, TPH, VOCs, SVOCs, PAHs, pH, TO-14
Utility Tunnel	B056BHA004[gi]	0, 4.5	Metals, TPH, VOCs, SVOCs, PAHs, pH
Utility Tunnel	B056GR001[e]	0	Metals, anions
Inside Utility Tunnel	B056HA001[g]	0, 3	Metals, TPH, VOCs, SVOCs, PAHs, pH
Inside Utility Tunnel	B056HA002[g]	0, 3	Metals, TPH, VOCs, SVOCs, PAHs, pH
Inside Utility Tunnel	B056HA003[g]	0, 4, SG	Metals, TPH, VOCs, SVOCs, PAHs, pH, TO-14
Building 56 Dip Tank	B056SB001[g]	0, 5	Metals, TPH, VOCs, SVOCs, PAHs, pH
Building 56 Dip Tank	B056SB002[g]	3, 9.5, GW	Metals, TPH, VOCs, SVOCs, PAHs, pH, TDS (GW), cations (GW), anions (GW), alkalinity (GW)
Building 56 Dip Tank	B056SB003[g]	0, 5, GW	Metals, TPH, VOCs (soil + GW), SVOCs, PAHs, pH
Building 56 Dip Tank	B056SB004[g]	0, 5.5, 8.5	Metals, TPH, VOCs, SVOCs, PAHs, pH
Vertical standpipe along south wall of Building 57A	B057AGR001[g]	GW	Metals, VOCs, TDS (GW), cations (GW), anions (GW), alkalinity (GW)
North of Building 57A	B057AHP001[defg]	3, 10, 20	Metals, TPH, VOCs, PAHs, pH
Courtyard between Buildings 55 and 56A	B057AHP002[efg]	0, 5, 10, 20, GW	Metals, TPH, VOCs, PAHs, pH, alkalinity, nitroaromatics, nitroamines, TDS
South of Building 56	B057AHP003[fg]	5, 10, 20, GW	Metals, TPH, VOCs, PAHs, pH, TDS (GW), cations (GW), anions (GW), alkalinity (GW)
North of Building 56A	B057AHP004[bdfg]	2, GW	Metals, TPH, VOCs, PAHs, pH, TDS (GW), cations (GW), anions (GW), alkalinity (GW)
West of Building 56A	B057AHP005[bcg]	3, GW	Metals, TPH, VOCs, SVOCs (GW), PAHs, pH, TOC, TDS (GW), cations (GW), anions (GW), alkalinity (GW)
West of Building 56A	B057AHP006[bcg]	2, GW	Metals, TPH, VOCs, SVOCs (GW), PAHs, pH, TOC, TDS (GW), cations (GW), anions (GW), alkalinity (GW)
West of Building 57	B057AHP007[d]	3, 9, 19	Metals, TPH, VOCs, PAHs, pH

Table 3-1. Borings and Analyses (continued)

Location	Boring	Sample Depths (feet bgs)	Analyses
Building 57A Dip Tank	B057AHP008[g]	3.5, GW	Metals, TPH, VOCs, SVOCs (GW), PAHs, pH, TOC, TDS (GW), cations (GW), anions (GW), alkalinity (GW)
Building 57A Dip Tank	B057ASB001[g]	3.5, 11.5, 19.5, SG	Metals, TPH, VOCs, SVOCs, PAHs, pH, TO-14
Building 57 Basement	B057BHA001[bg]	0, 5	Metals, TPH, VOCs, SVOCs, PAHs, pH
Building 57 Basement	B057HA001[a]	0	Metals, anions
Building 57 Basement	B057HA002[a]	0	Metals, anions
Building 57 Basement	B057HA003[a]	0	Metals, anions
Basement Building 57 – Exposed Soil	B057HA004 [ag]	0, GW	Metals, VOCs, pH, anions, SVOCs (GW), PAHs (GW), TDS (GW), cations (GW), anions (GW), alkalinity (GW)
Basement Building 57 – Exposed Soil	B057HA005 [ag]	0, 5, SG	Metals, VOCs, pH, anions, TO-14
Building 56A	B065BHA002[ac]	0, 5, 9.5	Lead, TPH, VOCs, PAHs, anions, Metals, anions
Building 56A	B065BHA003[cg]	1, 3	Lead, TPH, VOCs, PAHs
East of Building 56A	B066ASB001[efg]	0, 5, 10	Metals, TPH, nitrates, anions
Building 120	B120SB001[b]	4.5, GW	Lead, TPH, VOCs, PAHs
Building 120	B120SB002[b]	4, GW	Lead, TPH, VOCs, PAHs

[a] used to determine potential impacts from small arms processes.
[b] used to determine potential impacts from USTs.
[c] used to determine potential impacts from activities in boiler rooms.
[d] used to determine potential impacts from degreaser/oil water separator activities.
[e] used to determine potential impacts from the utility tunnel, former paint shed/shop, transformer room and smoke stack.
[f] used to determine potential impacts from the cisterns.
[g] used to determine potential impacts from Parkerizing activities.
[h] used to determine potential impacts from forges/hydraulic press.
[i] used to determine potential impact from foundry.

GW = groundwater
VOCs = volatile organic compounds
SVOCs = semi-volatile organics
TPH = total petroleum hydrocarbons
PAHs = polyaromatic hydrocarbons
TDS = total dissolved solids
SG = soil gas

3.2.1 *Parkerizing Activities*

Parkerizing activities were conducted at Buildings 56, 56A, and 57A. Parkerizing is the process of coating small arms with a phosphate solution to produce a hard matte finish that is both durable and anti-reflective. The small arms are dipped in the heated solution (190 to 210 degrees Fahrenheit) for 5 to 45 minutes, depending on the hardness of the metal and the desired thickness of the coating.

Photo PIC00026. Looking at a portion of the U-shaped vat filled with gravel in Building 57A. The 18-inch standpipe is shown in the background. (October 1998)

A former employee, Mr. Buster Byerrum stated that occasionally the chemicals would boil over from parkerization activities, spill on the floor, and then flow into the drains. No information is available to determine the exact parkerizing locations, except for the locations of the vats that were used to contain parkerizing fluids. The vats are shown on Plate 2 (Appendix B). at Buildings 56,

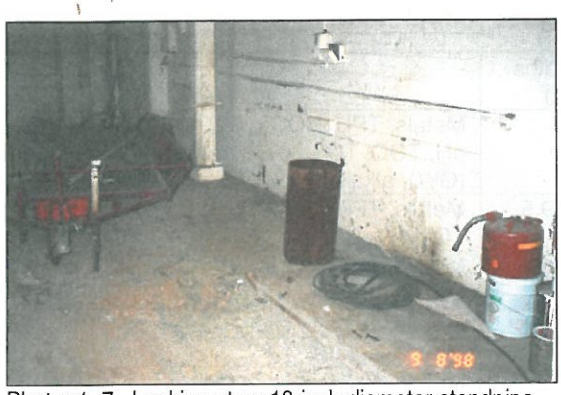


Photo r1_7. Looking at an 18-inch-diameter standpipe within the U-shaped vat in Building 57A. (October 1998)

56A, and 57A. Borings were advanced in the basement of Building 56 and the utility tunnel because chemicals from parkerizing activities may have leaked beneath the wooden floors. There were no visual signs of chemicals in either the basement or the utility tunnel; therefore the sampling locations were based on a systematic grid. Investigation locations at Building 57A focused on a U-shaped, gravel-filled vat (Photo PIC00026).

Another feature of concern at Building 57A was an 18-inch-diameter standpipe, installed after the Army left, that protruded from the vat (Photo r1_7) and was used to drain water.

Photo PIC00022. Northern edge of flooring constructed over a former parkerizing tank in Building 56. (October 1998)

Plate 2 (Appendix B) illustrates the boring locations. Parkerizing investigation activities are summarized below.

Building 56. One parkerizing tank was located beneath the east side of Building 56 near the current intersection of the north wall of Building 56B with Building 56 (Plate 2 and Photo PIC00022). Other parkerizing areas may have been located in Building 56, but no background information is available to determine the location of these possible activities. Four borings (B056SB001 through B056SB004) were advanced and samples collected beneath the concrete floor. Samples were also collected in the basement beneath the wooden floors of Building 56 to assess the potential of leakage from the other parkerizing areas. These borings were hand augers B056HA001, B056HA002, and B056HA003.

Building 56A. A survey conducted by Brown and Caldwell in 1952 indicated that Building 56A was used for degreasing and parkerizing (Jacobs, 1999). Due to the limited access inside Building 56A, 3 soil borings (B056AHA001 through B056AHA003) were advanced through the concrete slab floor in the entryway to assess possible parkerizing activities in Building 56A.

Building 56B. Parkerizing may have occurred in Building 56B. However, due to the lack of observed features and the lack of background chemical data for Building 56B, sample locations (B056BHA001 through B056BHA004) in Building 56B were placed in areas that did not conflict with the existing tenant and his woodworking operations.

Building 57A. As discussed above, a large U-shaped, gravel-filled vat existed in Building 57A. Two borings were drilled (B057AHP008 and B057ASB001) and one water grab sample (B057AGR001) was collected from a vertical standpipe located along the south wall of Building 57A to assess possible impacts at this parkerizing location. The standpipe was installed to drain water from the vat. The vat reportedly flooded with water during times of heavy rains. Hand augered borings B057HA004 and B057HA005 were advanced in the basement to assess the potential of leakage from the overlying wooden floors. Hydropunch borings B057AHP001 through B057AHP007 were located around the perimeter of the complex to assess the presence and lateral extent of COIs in groundwater due to possible release from this vat.

3.2.2 *Cisterns*

The RRR stated that cisterns (locations unknown) were used originally to collect rainwater from roof gutters and drain pipes. After a water supply system was installed, the cisterns may have been used to store solvents and other wastes. When the cisterns became full, the wastes were pumped directly into the nearby Carquinez Strait. Industrial waste from Building 57 was dumped daily into the marshland west of the building (Jacobs, 1999). Table 3-1 lists the borings advanced, depths sampled, and the analyses used to investigate potential COIs at the suspected locations of the cisterns and the analyses. Plate 2 (Appendix B) illustrates the boring locations.

3.2.3 *Forges and Hydraulic Press*

At least 2 forges were housed along the east wall in the northern portion of Building 55. Also, Building 55 contains several recently re-poured areas of concrete. The re-poured concrete is surrounded by a metal band and may have been constructed to support large pieces of equipment that were housed in the Blacksmith Shop. The largest re-poured concrete area, near the center of the building, was the reported location of a large hydraulic metal press used to cut up rifles for salvage (Jacobs, 1999). Table 3-1 lists the borings, depths sampled, and analyses that were used to address the potential COI associated with the forges and hydraulic press. Plate 2 (Appendix B) illustrates the boring locations.

3.2.4 *Test Firing Rooms and Small Arms Storage and Repair*

The courtyard area, south of Building 56 and north of Building 56A, is a suspected location of a machine gun test firing area (Photo R1_13) (Jacobs, 1999). Sampling activities were focused in the middle of the courtyard area, where the highest impact is suspected.

Three additional firing ranges are located in the basement of Building 57, and a fourth firing range is located on the ground floor of Building 56A. Borings were hand augered at the north end of each firing range. One boring was hand augered in exposed soil in the basement (B057HA004).

Small arms were stored at Buildings 56A, 57, and 58 (Jacobs, 1999). Table 3-1 lists the borings, depths sampled, and analyses that were used to evaluate the potential COI associated with the test firing rooms and small arm storage and repair. Plate 2 (Appendix B) illustrates the boring locations.

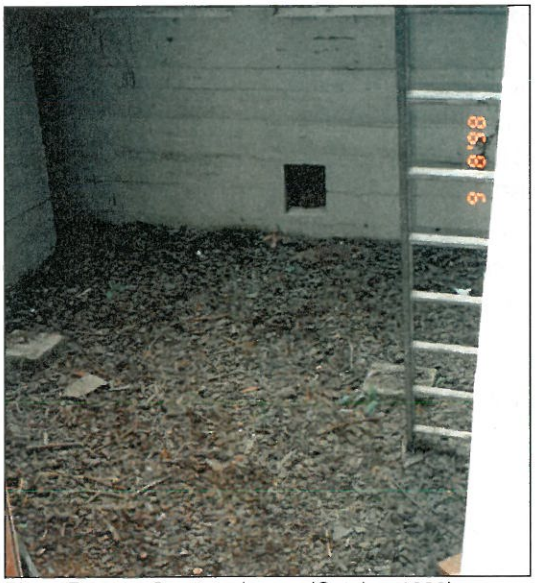


Photo R1_13. Courtyard area. (October 1998)

3.2.5 *Boiler Rooms*

There are three former boiler rooms in the 50 Series Complex; these rooms are located in Buildings 58, 65(A), and 65(B) (Jacobs, 1999). The objective of the investigation in these areas was to assess the potential impact to soil from possible leakage of fuels and oils associated with the former boiler houses.

Photo P1190004. Bricked area between Building 56A and 56B where soil from the Building 65(B) Boiler Room has been spread out and covered by bricks. (January 2001)

The Building 65(B) Boiler Room had a dirt floor, which was noticeably stained during a site visit in March 1998. During a return visit on September 8, 1998, it was observed that the floor had been recently paved with concrete. It was also observed that there was a new layer of soil covered with brick along the east side of Building 56. This soil came from the Building 65(B) Boiler Room. Sampling activities focused on an area in the middle of the bricked area (Photo P1190004) to assess the soil removed from Building 65(B). Table 3-1 lists the borings, depths sampled, and analyses performed. Plate 2 (Appendix B) illustrates the boring locations.

Photo PIC00031. Looking at the location of the former degreaser in Building 57. (October 1998)

3.2.6 *Continuous Degreaser and Oil and Water Separator*

A continuous degreaser, located on ground floor of Building 57, may have leaked solvents during its operation (Photo PIC00031 and Figure 1-4) (Jacobs, 1999). An oil/water separator was located west of Building 57(C) (Figure 1-4). One boring, B057AHP001, is located next to the oil/water separator to assess the potential impact to soil and groundwater from the possible leakage of solvents, oils, or fuels. Table 3-1 lists the borings, depths sampled, and analyses performed to determine if soil and/or groundwater contain COI. Plate 2 (Appendix B) illustrates the boring locations. Table 3-1 lists the depths sampled and analyses performed at these locations.

3.2.7 *Foundry Facilities*

A foundry may have been located in Building 56B (Jacobs, 1999). Three borings, B056BHA002, B056BHA003, B056BHA003, were also used to determine if metals from foundry activities, impacted the subsurface. As a result of the existing woodworking equipment and wood materials, the sample locations were placed along an aisle-way (Plate 2, Appendix B). Table 3-1 lists each boring, depths sampled, and analyses performed.

Photo disk1_13. Suspected location of two USTs beneath the southeast corner of Building 56A. (September 1999)

3.2.8 *USTs and Fuel Storage Features*

There were several USTs associated with the 50 Series Complex. USTs were suspected and/or found near Buildings 53, 56A, 58, 59(A), 120, 154, and inside the Utility Tunnel (Jacobs, 1999). Table 3-1 lists each boring, depths sampled, and analyses performed at these buildings.

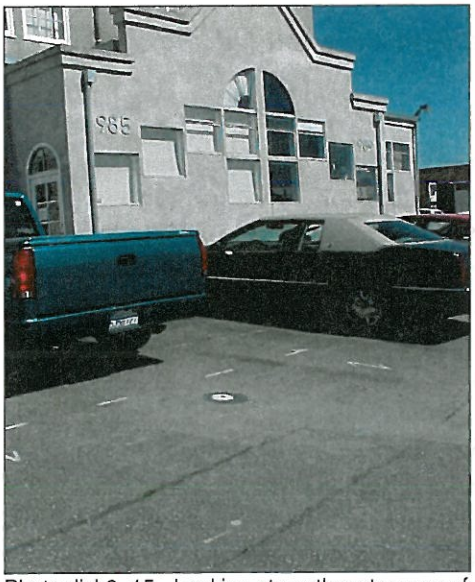


Photo disk2_15. Looking at southeast corner of Building 56A. Well B057AHP005 (shown by white lid) in foreground. (September 1999)

A 1,000-gallon diesel fuel and 10,000-gallon high octane UST were reportedly installed as part of the Building 53 fueling system (this system is described in detail in the Technical Memorandum Area I Fuel Facilities at Buildings 53, 73, 103, and 154 [FA/BC, 2000]). The locations of these USTs were suspected to be beneath the southeast corner of Building 56A (Photo Disk1_13). A total of four borings were advanced to determine potential COI resulting from these USTs.

Two soil borings (B053SB001 and B053SB002) were advanced to assess the presence of fuels in soil and groundwater associated with the Building 53 USTs. Boring B057AHP005, located at the southeast corner of Building 56A (Plate 2, Appendix B and Photo disk2_15), was advanced to assess the potential impact to soil and groundwater from possible leakage of fuels from the Building 53 UST, the potential impact to soil and groundwater from leakage of oils stored in former Building 59(A) and the storage of fuels and oils in the former Tool House, Building 59(A). B057AHP006 is located along the south side of Building 56A (Plate 2, Appendix B and Photo disk2_13) and was used to assess the potential impact to soil and groundwater from possible leakage of fuels from the Building 154 USTs and to assess the potential impact to soil and groundwater from leakage of fuels and oils associated with the former boiler houses at Buildings 58 and 65(A).

Photo disk2_13. Looking at well B057AHP006 along the south side of Building 56A (well shown by white lid.) (September 1999)

There is a potential for fuels and oils to be released from the former AST (only the tank stand remains) located in the Equipment and Transformer Rooms in Building 56A (Photo r1_14). Boring B056AHA004 was advanced and sampled to assess potential releases.

Photo r1_14. Tank stand in Building 56A equipment room. Floor drain located in front of tank stand. (October 1998)

The boiler room in former Building 58 was a potential release site of fuels and oils used during its operation. Boring B056AHA002 was advanced to determine if subsurface soil was impacted by boiler room activities.

A tank was constructed in the utility tunnel under a section of Building 57B by turning a drum

(approximately 80-gallons) on its side and cutting a hole in the area that is now the top (Photo R1#3, above in Section 1.3.2). Hand auger boring B057BHA001 was positioned next to the tank (Plate 2, Appendix B) to evaluate potential releases from this tank.

3.2.9 *Miscellaneous Features*

This section describes borings advanced near minor features: a utility tunnel, a paint shed/shop, an incinerator/smoke stack, an oil/water separator, and a transformer room. Table 3-1 lists each boring, depths sampled, and analyses performed at these buildings.

There were no visual signs of chemicals along the utility tunnel. As a result, sampling locations were based on a systematic grid pattern The subsurface investigation within the utility tunnel included 4 hand auger borings (B055HA001, B056BHA001, B056HA002, and B057BHA001). While on a site walk on September 23, 1999, the USACE, regulatory agencies, and FA/BC added a grab sample (B056GR001) from blast-out material piled in the utility tunnel (Plate 2, Appendix B). The solid material originated from former sandblasting operations in Building 56.

Photo PIC00025. Oil/water separator north of Building 57A. (October 1998)

A former Paint Shop existed within Building 66(A). A shed was located nearby that also stored paints. Samples from boring B066ASB001 were collected to assess the potential impact of metals and oils stored in the former Paint Shed/Shop. This boring was also used to assess the impact of explosives and metals from the former Smoke Stack/Incinerator located to the west of the former Paint Shed/Shop.

B057AHP001 is located near an oil/water separator (Plate 2, Appendix B and Photo PIC00025). The objective of this boring was to assess the potential impact to soil and groundwater from the operation of the oil/water separator. Additionally, the data from this boring was used to assess the potential impact from possible dumping of process fluids into a nearby cistern and presence of COIs in groundwater from the parkerizing vat in Building 57A.

Boring B056AHA005 was advanced inside Building 56A to assess potential releases into surface soil from the former transformers (Plate 2, Appendix B).

3.3 IDW Disposal

IDW, generated as part of the field effort, included soil from drilling and sampling activities, decontamination rinsate from drilling and shallow soil/soil gas sampling equipment, and disposable protective clothing and ground covers.

Table 3-2 presents the quantities of IDW generated during this investigation. The soil and groundwater containers were stored at a temporary waste staging area at 900 Jackson Street (Building 103). Building 103 is a secure site with perimeter fencing and lockable gates.

Decontamination of drilling equipment was also staged at Building 103. All decontamination was performed as specified in the QAPP (FA/BC, 1999b). Decontamination of sampling equipment during hand auguring was staged at the FA/BC Benicia Arsenal Field Office at 952A Tyler Street (Building 55A).

Table 3-2. Quantities of IDW

Media	Number of Drums
Soil	26
Water (development, decontamination, and purge water)	2

Based on analytical results, soils from this investigation contained low levels of petroleum hydrocarbons and chlorinated solvents. Integrated Waste Management of Milpitas, California transported the 26 drums of soil to Bay Soil Remediation in Richmond, California. The 2 drums of water were transported to Seaport Environmental in Redwood City, California on January 19 and 24, 2001. All drums of soil and water were disposed as non-hazardous waste. IDW manifests are included in Appendix F.

Excess disposable wastes derived from sampling, such as personal protective equipment (PPE), gloves, and bailers were disposed by BFI, which provides local garbage disposal service for the area.

4.0 GEOLOGY AND HYDROGEOLOGY

The Arsenal is located at the southern end of California's Northern Coast Range. The geologic history of the region is complex, with episodes of compression and the effects of lateral movement on the nearby San Andreas strike-slip fault system. A summary of the regional, local, and site-specific geologic and hydrogeologic setting is presented below. The site lithologic data and groundwater quality parameters are also discussed.

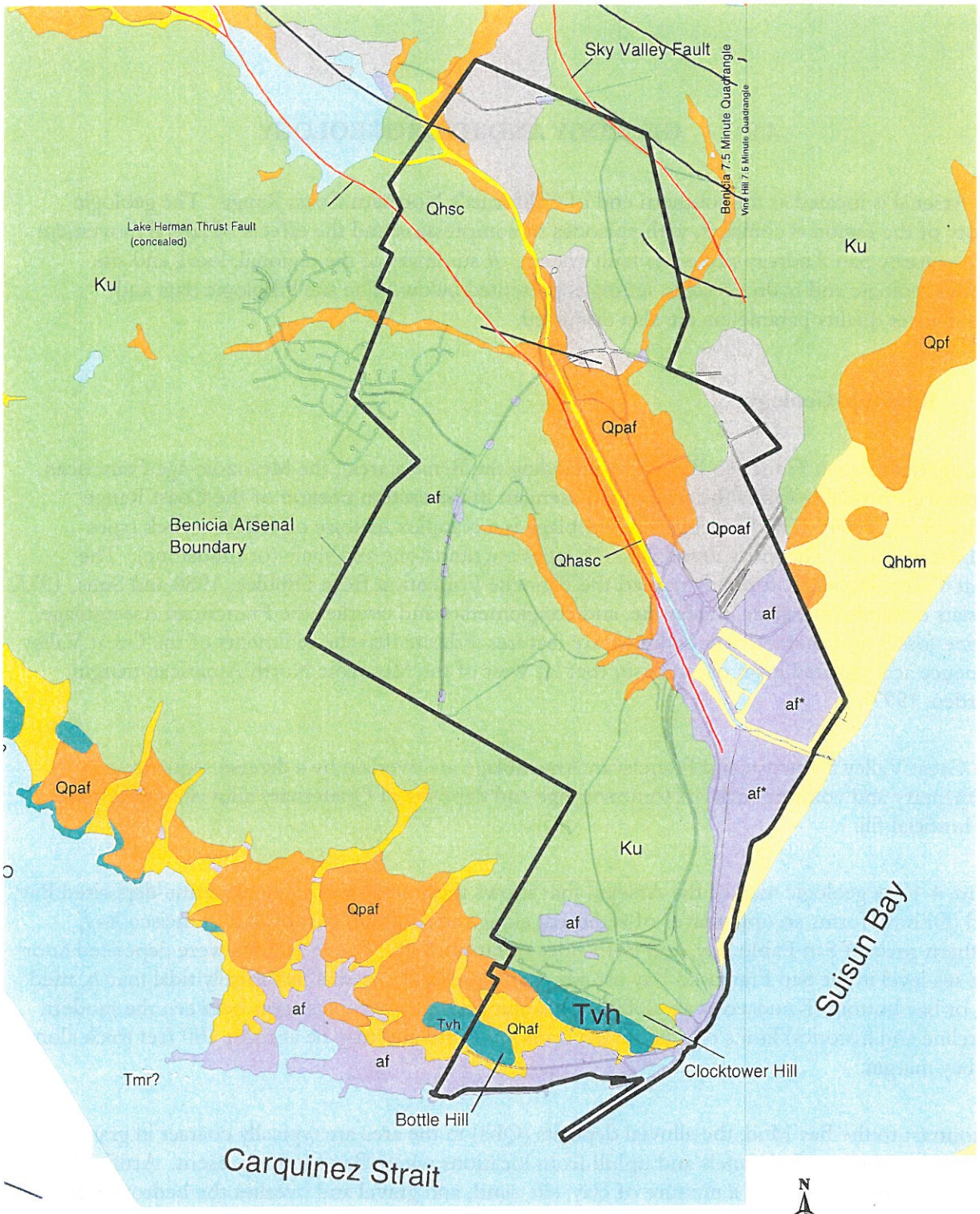
4.1 Regional Geology

Throughout the San Francisco Bay Area (including the Benicia area), the Mesozoic-age Franciscan Assemblage probably forms the structural basement in the eastern portion of the Coast Range (Bailey et. al., 1964). The Franciscan Assemblage is a complex mixture of different rock types jumbled together. The most abundant rock types are sandstone and shale (or mudstone). The Great Valley Sequence, formerly named the Panoche Formation from Dibblee, 1980 and Sims, 1973, consists of sandstone, shale, mudstone, and conglomerate and overlies the Franciscan Assemblage. Marine fossils and characteristic sedimentary features indicate that the sediments of the Great Valley Sequence accumulated in an ocean basin that lay west of the Mesozoic North American margin (Harden, 1997).

The Great Valley Sequence and Franciscan Assemblage are overlain by a diverse sequence of sedimentary and volcanic rocks of Cenozoic age and deposits of Quaternary alluvial, fluvial, mud and artificial fill.

Figure 4-1 is a geologic map of the Arsenal that shows these soil types. The estuarine-deposited Bay Mud (Qhbm), forms an upper layer of sediment along the southern part of San Francisco Bay, northern parts of San Pablo Bay, and both sides of Suisun Bay. The sediments were deposited at or near sea level in the San Francisco Bay estuary that is presently, or was historically tidal marsh, mud flat, or bay bottom (Knudsen et al., 2000). This unit generally occupies areas between the modern shoreline and historical limits of tidal marsh thins landward and may be at most 100 feet thick along the bay margin.

In contrast to the Bay Mud, the alluvial deposits (Qha) in the area are typically coarser in grain size and are found in small channels and uphill from locations where Bay Mud is present. Artificial fill in the Benicia area consists of a mixture of clay, silt, sand, and gravel and overlies the bedrock units and the Bay Mud in most of the low-lying areas. It varies in thickness from a few inches to approximately 20 feet. Artificial fill overlying Bay Mud (afbm) was mapped by comparing the present day shorelines with those of the mid-19th century, and by using topographic maps and aerial photos (Knudsen et al., 2000). The line delineating the landward extent of the artificial fill over Bay Mud is based on the mid-19th century extent of marshland.



Legend

Water
Main roads
Faults (dashed where buried)
Anticline

Surficial Geologic Units (Graymere, 1999 and 1988 aerial photo)

- Artificial fill - af (Historic) and af* (1988 photo)
- Stream channel deposits - Qhsc and Qhasc (Holocene)
- Bay mud - Qhbm (Holocene)
- Alluvial fan and fluvial deposits - Qhaf (Holocene)
- Alluvial fan and fluvial deposits - Qpaf and Qpf (Pleistocene)
- Older alluvial fan deposits - Qpoaf (Pleistocene)
- Vine Hill Sandstone of Weaver (1953) - Tvh (Paleocene)
- Great Valley Sequence - undivided sandstone and shale - Ku (Cretaceous)

N W E S

0 1,500 3,000 Feet

Figure 4-1
Geologic Map of the Benicia Area

Area I 50 Series Complex SI Report

Benicia Arsenal, Benicia, CA

Forsgren Associates/Brown and Caldwell
S:\Benicia_USTRA\geomap.apr

The Sky Valley Fault and the Lake Herman Fault are located in the Benicia area and are related to the Green Valley Fault zone (Graymer et. al., 1999). The Southampton Fault is west of the Benicia area and is a steep, west dipping reverse fault that places west-dipping Cretaceous strata up, over, and against east-dipping Tertiary strata in the Benicia area (Graymer et. al., 1999). Faults within the Arsenal are shown on Figure 4-1. Although there are no active faults identified locally, Benicia is within the 50-kilometer radius of damage from historical seismic activity of the San Andreas fault to the west (California Department of Conservation, Division of Mines and Geology, 1996).

Approximately 50 percent of all historical liquefaction occurrences in the San Francisco Bay Area and about 80 percent of the liquefaction occurrence resulting from the 1989 Loma Prieta earthquake are related to the artificial fill over Bay Mud (afbm) and Bay mud (Knudsen et al., 2000). It is not known whether the liquefaction was in the fill material or in the underlying Bay Mud. The high percentage of structural failures occurring in artificial fill over Bay Mud may reflect amplification of the shaking by the soft Bay Mud (Knudsen et al., 2000).

4.2 Local Geology of Area I

The industrial area is comprised of the low-lying hills surrounding the 50 Series Complex, Figure 4-1. The geology in the area, from oldest to youngest, consists of the Vine Hill Sandstone (Tvh) (formerly the Martinez Formation in Dibblee, 1980 and Sims, 1973) overlain by artificial fill and/or alluvial/fluvial material. The Vine Hill Sandstone is a marine-derived sandstone interbedded with thin fossiliferous shale (Photo Q3_1).

Photo Q3_1. Steeply dipping Vine Hill Sandstone. (June 2001)

Quaternary artificial fill (afbm) and alluvial/fluvial material (Qhaf) overlies the Vine Hill Sandstone in most low-lying areas, and ranges from a few feet thick to more than 80 feet thick. Typically the alluvial/fluvial material is comprised of brown to tan gravelly sand or sandy gravel that grades upward to sandy or silty clay. Fluvial deposits are generally found near the distal portions of the alluvial fans, and are typically comprised of brown (never reddish), fine sand to sandy or silty clay (Graymer et. al., 1999). Typically the alluvial/fluvial material is found uphill from the artificial fill. The artificial fill commonly overlies the Bay Mud. This sequence is predominantly present in the low-lying areas south of the 50 Series Complex, where marshlands were filled during the development of the Arsenal (Figure 4-1).

Six piezometers (PZ-1 through PZ-6) were drilled in the industrial area for the Site Hydrogeological Model (SHM) investigation conducted by the USACE in 2002 (FA/BC, 2003). The piezometers are located within the area of a former marshland, west and south of Lincoln Street and toward Suisun Bay (Plate 3, Appendix B). The area has an asphalt cover and up to 3 feet of road base. The road base overlies material used to fill in the marsh. The artificial fill ranges from 1 foot to 8 feet thick and consists of silts, silty sands, and sands. Beneath the artificial fill is Bay Mud, which consists of clay with lenses of silt and fine-grained sand. The Bay Mud is at least 40 feet thick, very dark brown

to greenish black, contains an abundance of organic matter, and has a mild to strong organic odor. At PZ-6, the Bay Mud is present to a depth of 32 feet bgs and is underlain by a low to medium plastic olive-brown clay. At PZ-3, sandstone bedrock (probably Vine Hill Sandstone) was encountered at a depth of approximately 63 feet bgs.

4.3 Site-Specific Geology of the 50 Series Complex

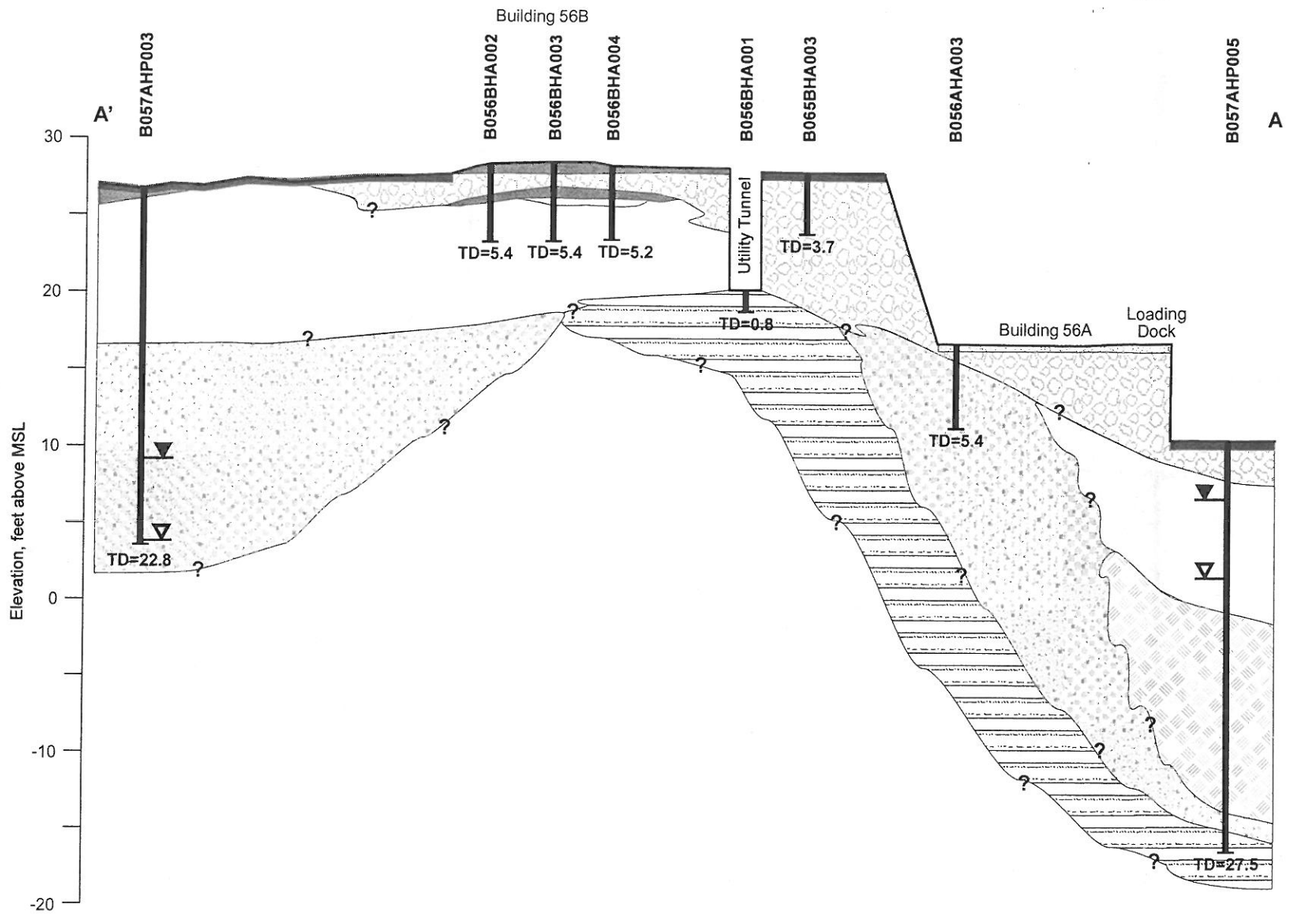
Boring logs advanced during this field investigation are documented in Appendix E. Figure 4-2, Figure 4-3, and Figure 4-4 are cross sections showing the geology beneath the 50 Series Complex. Vine Hill Sandstone outcrops are present in the steeply sloping area between Buildings 56A and 53. The outcrops consist of steep southwesterly dipping beds of massive sandstone, siltstone, and shale.

Most soil borings in the area include artificial fill overlying alluvial/fluvial material consisting of native silt and clay with minor sands. The fill material consists of gravelly silt, low to medium plasticity clay, silty sand, with some wood and brick. The thickness of the fill averages 2 feet to 3 feet in a majority of the borings, except B065BHA002 and B055HA003, where it is at least 8 feet thick. The fill material at B055HA003 contains a combination of concrete, fill, soil, and wood.

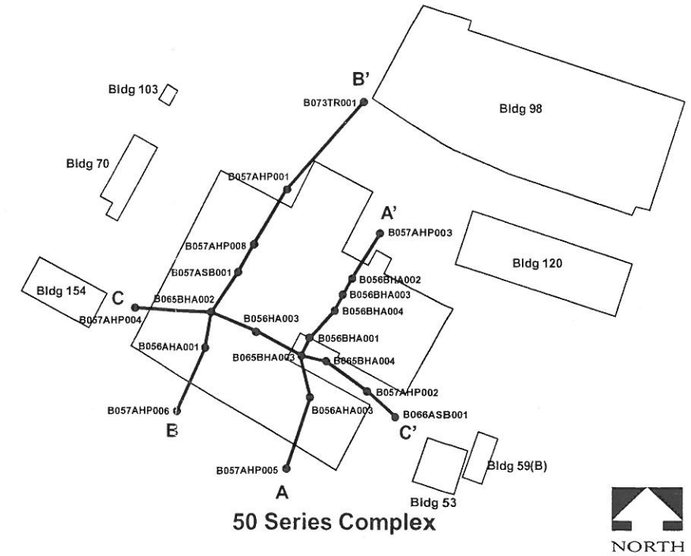
The alluvial/fluvial material found in the boreholes is characterized as silty clay with low to medium plasticity, low to moderate toughness and dilatancy, moist to dry with blocky structure. The color ranges from brownish-gray to brown to greenish-gray. Test pits excavated at Buildings 53 and 154, which were associated with USTs and located at the southeast and southwest corners of the complex, indicate a correlation of the change in soil color with depth (from brown to greenish-gray) with a noticeable petroleum hydrocarbon smell. However, a hydrocarbon odor did not always correlate with this color change for the 50 Series Complex investigation. The color change may also be the result of higher organic content of materials in the greenish-gray material.

Beneath the Quaternary alluvial/fluvial material, Vine Hill Sandstone was encountered in 13 borings. The depth to the sandstone bedrock ranged from 1 foot bgs in the utility tunnel area, to 3 feet bgs at the ground floor, to 25 feet bgs at B057AHP005. The shallower occurrence of sandstone correlates to areas of excavation and removal of native soils to create firing ranges in the basement. The sandstone bedrock is deeper in areas to the south and west of the complex (14 feet bgs in B057AHP007 and 63 feet bgs in PZ-3).

Particle Size Analysis. Vadose zone soil samples of clayey silt were selected for grain-size analysis from borings B057HP007 and B057AHP005. These samples were selected because this soil type was observed consistently beneath the 50 Series Complex. Approximately 72 percent from B057HP007 and 70 percent from B057AHP005 was determined to be in the silt and clay range (0.063 to 0.000375 millimeter [mm]). The particle size analysis results are included in Appendix G.

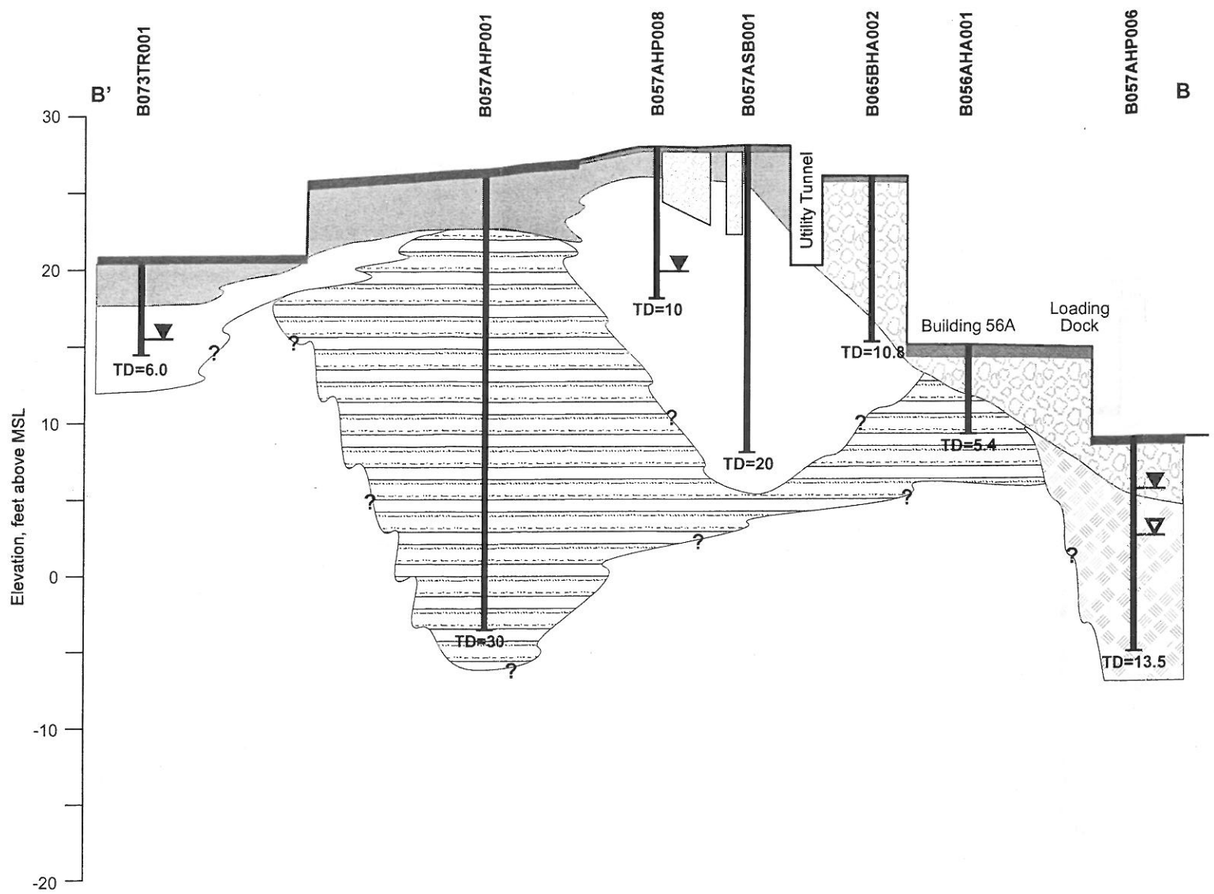


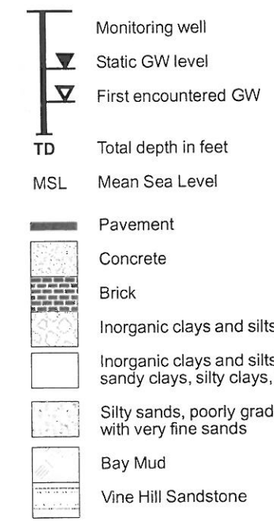
Monitoring well
Static GW level
First encountered GW
TD Total depth in feet
MSL Mean Sea Level
Pavement
Concrete
Brick
Inorganic clays and silts, poorly graded gravels used as fill
Inorganic clays and silts of low plasticity, gravelly clays, sandy clays, silty clays, lean clays very fine sands
Silty sands, poorly graded sand silt mixtures, inorganic silts with very fine sands
Bay Mud
Vine Hill Sandstone

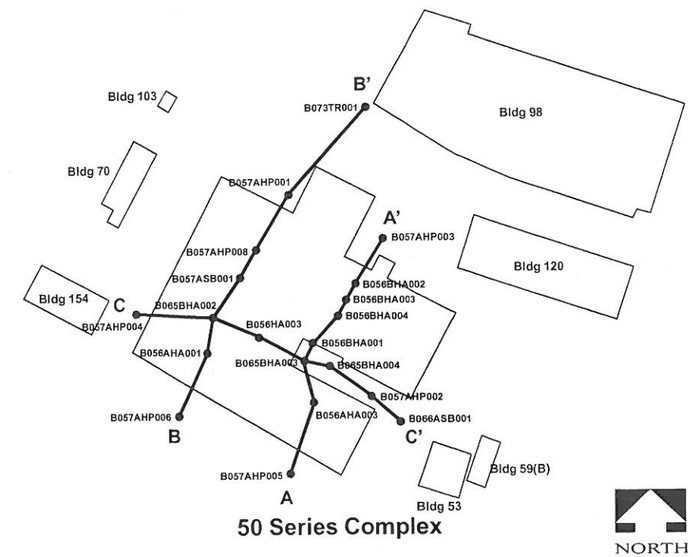


50'
10'
Scale in Feet

Figure 4-2
Geologic Cross Section A-A'
Area I 50 Series Complex SI Report
Benicia Arsenal, Benicia, CA





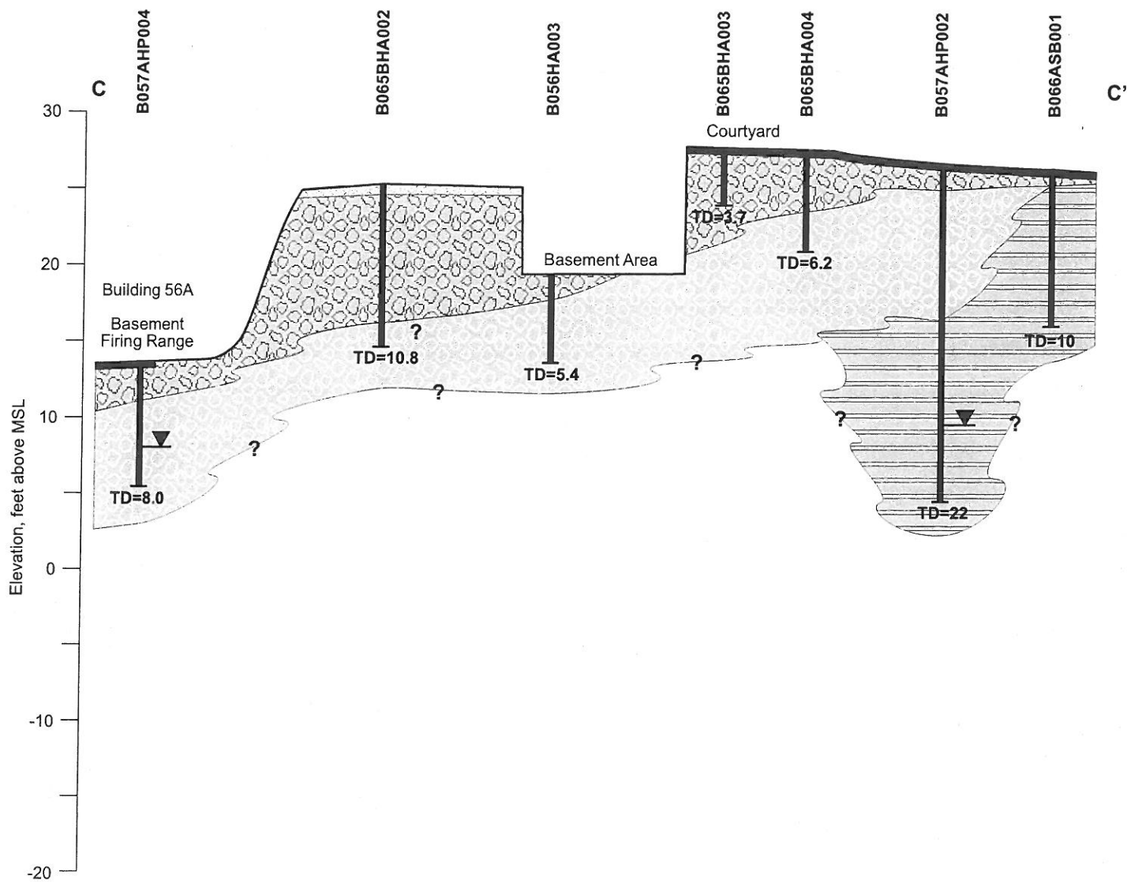


50'

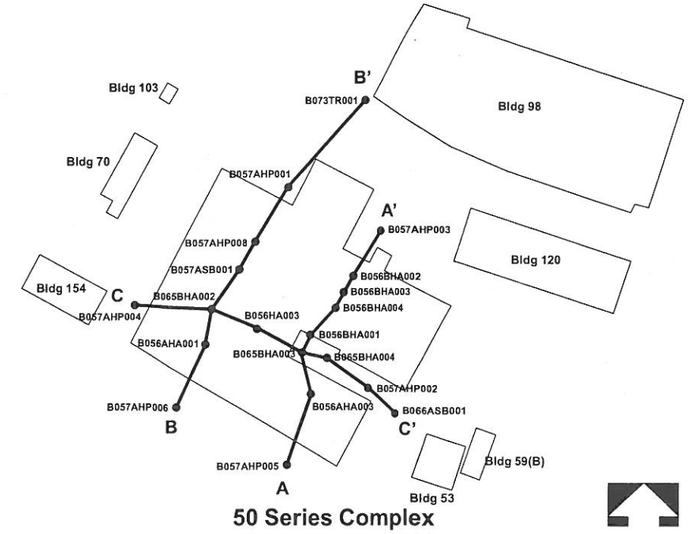
10'

Scale in Feet

Figure 4-3
Geologic Cross Section B-B'
Area I 50 Series Complex SI Report
Benicia Arsenal, Benicia, CA



Monitoring well
Static GW level
First encountered GW
TD Total depth in feet
MSL Mean Sea Level
Pavement
Concrete
Brick
Inorganic clays and silts, poorly graded gravels used as fill
Inorganic clays and silts of low plasticity, gravelly clays, sandy clays, silty clays, lean clays very fine sands
Silty sands, poorly graded sand silt mixtures, inorganic silts with very fine sands
Bay Mud
Vine Hill Sandstone



50'
10'
Scale in Feet

Figure 4-4
Geologic Cross Section C-C'
Area I 50 Series Complex SI Report
Benicia Arsenal, Benicia, CA

Soil pH. Soil pH or soil reaction is an indication of the acidity or alkalinity of soil. Below pH 7 the soil is increasingly more acidic, and from pH 7 to pH 14 the soil is increasingly more alkaline or basic (Table 4-1). Data from the United States Department of Agriculture (USDA) indicated the regional soil in the area was strongly acid to saline and may also coincide with the Vine Hill area (USDA, 1977). The soil on ridge crests and the south-facing slopes are derived from the underlying sandstone and range from 6.1 pH (slightly acid) to 7.3 pH (neutral). In contrast, regional pH data of silty clays in lowlands areas ranges from 4.5 pH (very strongly acid) to 8.4 pH (moderately alkaline) (USDA, 1977).

Table 4-2 shows the range of soil pH results for soil samples collected at the 50 Series Complex. Ninety-four percent of the samples were slightly to strongly alkaline, 3 percent very strongly alkaline, 1 percent neutral and 1 percent moderately acidic. The 50 Series Complex lies in the area where the soil is a combination of the sandstone–derived alluvium and the silty clays, where the pH could be very strongly acidic to moderately alkaline. The majority of the soil data from the 50 Series Complex lies within this range. Table 4-3 and Plate 3 (Appendix B) presents the soil pH results in soil.

Table 4-1. pH Ranges

Description	Range
Extremely acid	< than 4.5
Very strongly acid	4.5–5.0
Strongly acid	5.1–5.5
Moderately acid	5.6–6.0
Slightly acid	6.1–6.5
Neutral	6.6–7.3
Slightly alkaline*	7.4–7.8
Moderately alkaline*	7.9–8.4
Strongly alkaline*	8.5–9.0
Very strongly alkaline	> than 9.1

*Majority of the pH data at the 50 Series Complex

Table 4-2. pH Data for 50 Series Complex

# of samples	67
# of extremely acid	0
# of very strongly acid	0
# of strongly acid	0
# of moderately acid	1
# of slightly acid	0
# of neutral	1
# of slightly alkaline	7
# of moderately alkaline	39
# of strongly alkaline	17
# of very strongly alkaline	2
maximum	10.2
minimum	5.8
mean	8.2

Bicarbonate Alkalinity, Chloride, Nitrate, Nitrite, and Sulfate. Table 4-3 shows the results of bicarbonate alkalinity, chloride, nitrate (as Nitrogen), nitrite (as Nitrogen), and sulfate. Plate 3 (Appendix B) presents the data. Ranges of concentrations for these analytes are summarized in Table 4-4 and grouped for samples collected from the gunite target material in the firing ranges, soil near the firing ranges, and the remaining soil samples (non firing range soil samples). The ranges of analyte concentrations between these groupings are not much different except for the nitrate (as Nitrogen). The highest concentrations of nitrate (as nitrogen) are from the soil samples near the firing ranges and the gunite target material samples (Table 4-4). Gun powder contains nitrogen and would have been present in the gunite target material and around the firing ranges. The elevated concentrations of nitrate (as nitrogen) may be a product of the decomposition of the nitrogen in the gun powder to nitrate.

Table 4-3. Detected Analytes in Soil – Wet Chemistry (mg/L)

Location-ID	Sample Date	Depth (feet)	Soil Code	ALKALINITY, BICARBONATE	CHLORIDE	NITRATE (AS N)	NITRITE (AS N)	pH	SULFATE
B055HA002	September 9, 1999	0.5-1	ML					8.43	
B055HA002	September 9, 1999	4-4.5	ML					8.5	
B055HA003	September 9, 1999	0.5-1	ML					8.34	
B056SB001	September 17, 1999	0.5-1	CL					8.35	
B056SB001	September 17, 1999	6.5-7.5	SM					8.48	
B056SB001	September 17, 1999	10-11	SM					8.2	
B056AHA001	September 24, 1999	0.7-1.2	CL					8.21	
B056AHA001	September 24, 1999	2.5-3	CL					7.94	
B056AHA002	September 24, 1999	0.1-0.6	CL					8.5	
B056AHA002	September 24, 1999	4.5-5	CL					5.8	
B056AHA003	September 24, 1999	0.5-1	ML					8.46	
B056AHA003	September 24, 1999	4.5-5	SM					8.31	
B056AHA004	September 7, 1999	0.8-1.4	CL		23.9	2.58	< 0.195		61
B056AHA004	September 7, 1999	3.8-4.4	ML		51.2	2.22	< 0.168		97.2
B056BHA001	September 23, 1999	0.0-0.4	SM					8.4	
B056BHA002	September 20, 1999	0.9-1.1	CL					7.4	
B056BHA002	September 23, 1999	4.5-5.5	CL					8.07	
B056BHA003	September 20, 1999	0.6-1.8	CL					7.76	
B056BHA003	September 23, 1999	4.0-5	ML					8.5	
B056BHA004	September 20, 1999	0.6-1.2	CL					7.98	
B056BHA004	September 23, 1999	4.7-5.2	ML					7.96	
B056HA001	September 21, 1999	0.8-1	SM					8.23	
B056HA001	September 22, 1999	3-3.5	SM					8.01	
B056HA002	September 22, 1999	0.1-0.5	SM					7.81	
B056HA002	September 23, 1999	3-3.5	SM					8.12	
B056HA003	September 22, 1999	0.3-0.6	ML					7.5	
B056HA003	September 23, 1999	4.7-5.5	CL					8.19	
B056HA004	September 23, 1999	0.1-0.6	SM					8.15	
B056SB001	September 17, 1999	0.5-1	ML					8.26	
B056SB001	September 17, 1999	5-5.6	CL					8.82	
B056SB002	September 16, 1999	3-3.5	CL					9.1	
B056SB002	September 16, 1999	9.5-10	CL					8.73	
B056SB003	September 17, 1999	0.5-1	CL					8.36	
B056SB003	September 17, 1999	4-4.5	CL					8.34	
B056SB004	September 15, 1999	0.5-1	ML					8.21	
B056SB004	September 15, 1999	6.5-7.5	ML					8.34	
B056SB004	September 15, 1999	0.5-0.8	ML					8.58	
B057AHP001	September 13, 1999	3.5-4	SM					8.7	
B057AHP001	September 13, 1999	10-10.5	SM					8.54	
B057AHP001	September 13, 1999	20-20.5	SM					8.5	
B057AHP002	September 15, 1999	0.5-1	CL					8.24	
B057AHP002	September 15, 1999	2-2.3	CL		2.69 J	1.42 J	< 0.167		39.7
B057AHP002	September 15, 1999	5.5-6.6	SM					8.4	
B057AHP002	September 15, 1999	6.9-7.8	SM		3.09 J	0.327 J	< 0.165		20.3
B057AHP002	September 15, 1999	10.5-11.5	SM					8.57	
B057AHP002	September 15, 1999	12.5-13	SM		1.68 J	< 0.107	< 0.154		13.9 J
B057AHP002	September 15, 1999	20.5-21.5	SM					8.42	
B057AHP002	September 15, 1999	21.5-22	SM		8.2	< 0.106	< 0.153		100

Table 4-3. Detected Analytes in Soil – Wet Chemistry (mg/L) (continued)

Location-ID	Sample Date	Depth (feet)	Soil Code	ALKALINITY, BICARBONATE	CHLORIDE	NITRATE (AS N)	NITRITE (AS N)	pH	SULFATE
B057AH2001	[illegible]	[illegible]	[illegible]					8.87	
B057AH2001	[illegible]	[illegible]	[illegible]					8.64	
B057AH2001	[illegible]	[illegible]	[illegible]					9	
B057AH2001	[illegible]	[illegible]	[illegible]					6.84	
B057AH2001	[illegible]	[illegible]	[illegible]	105				8	
B057AH2001	[illegible]	[illegible]	[illegible]	156				8.06	
B057AH2001	[illegible]	[illegible]	[illegible]					8.05	
B057AH2001	[illegible]	[illegible]	[illegible]					7.71	
B057AH2001	[illegible]	[illegible]	[illegible]					8.67	
B057AH2001	[illegible]	[illegible]	[illegible]					8	
B057AH2001	[illegible]	[illegible]	[illegible]					10.2	
B057AH2001	[illegible]	[illegible]	[illegible]					8.17	
B057ASB001	[illegible]	[illegible]	[illegible]					8.21	
B057ASB001	[illegible]	[illegible]	[illegible]					8.73	
B057ASB001	[illegible]	[illegible]	[illegible]						
B057BHA001	September [illegible]	[illegible]	[illegible]		6.13	3.77	< 0.173	7.97	33.5
B057BHA001	September [illegible]	[illegible]	[illegible]					7.87	
B057HA001A	September [illegible]	[illegible]	[illegible]		13.6	1.31 J	1.13 J		76.8
B057HA001B	September [illegible]	[illegible]	[illegible]		2.6 J	< 0.0987	< 0.142		13.8 J
B057HA002A	September [illegible]	[illegible]	[illegible]		16.3	40.9	0.831 J		121
B057HA002B	September [illegible]	[illegible]	[illegible]		10.2	131	2.43		141
B057HA003A	September [illegible]	[illegible]	[illegible]		49.3	64.3	13.2		292
B057HA003B	September [illegible]	[illegible]	[illegible]		10.7	5.67	2.16		181
B057HA004	September [illegible]	[illegible]	[illegible]		17.3	< 0.128	< 0.184	8.26	41.5
B057HA005	September [illegible]	[illegible]	[illegible]		17.7	32.6	< 0.165	7.75	132
B057HA006	September [illegible]	[illegible]	[illegible]		45	13.3	< 0.201	8.2	247
B085BHA002	September [illegible]	[illegible]	[illegible]		10.9	3.96	< 0.166		48.6
B085BHA002	September [illegible]	[illegible]	[illegible]		10.4	4.24	< 0.162		78.7
B096ASB001	September [illegible]	[illegible]	[illegible]		2.09 J	0.278 J	< 0.152		22.1
B096ASB001	September [illegible]	[illegible]	[illegible]		0.842 J	0.203 J	< 0.153		8.57 J
B096ASB001	September [illegible]	[illegible]	[illegible]		0.873 J	< 0.106	< 0.154		7.04 J
Number of Detects:				2	21	16	5	61	21
Total Number of Analyses:				78	78	78	78	78	78
Minimum Concentration:				105	0.842	0.203	0.831	5.8	7.04
Maximum Concentration:				156	51.2	131	13.2	10.2	292
Mean Detected Concentration:				131	14.509	19.255	3.950	8.2	84.61

QUALIFIER LEGEND:

J The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.

Table 4-4. Bicarbonate Alkalinity, Chloride, Nitrate (as Nitrogen), Nitrite (as Nitrogen) and Sulfate Concentrations in Soil

Concentration Range (mg/kg)	Bicarbonate Alkalinity	Chloride	Nitrate (as Nitrogen)	Nitrite (as Nitrogen)	Sulfate
Gunite Target Material*	--	2.6 – 49.3	<0.0987 - 131	<0.142 – 13.2	13.8 – 292
Near Firing Ranges**	--	17.3 – 45	<0.128 – 32.6	<0.184 – <0.201	41.5 – 247
Non-Firing Range	--	0.842 – 51.2	<0.106 – 4.24	<0.142 – <0.195	20.3 – 100

*Soil samples B057HA001A, B057HA001B, B057HA002A, B057HA002B, B057HA003A and B057HA003B collected from the end of the firing ranges in the basement of Building 57.
**Soil samples B057HA004 and B057HA005.
-- Not analyzed.

Total Organic Carbon. One clayey silt soil sample (B057AHP005) was analyzed for total organic carbon (TOC) by method Walkley-Black with a concentration less than the method detection limit of 592 mg/kg. This result indicates low organic carbon in soil at this location.

4.4 Regional Hydrogeology

This section presents a summary of the regional hydrogeologic setting. The principal water-yielding materials in the north San Francisco Bay Area valleys are unconsolidated and semi-consolidated marine and continental sediments with tuffaceous beds in volcanic rocks (Planert and Williams, 1995). Consolidated rocks that underlie the entire area have little permeability and form the boundaries of the groundwater flow system. The permeability and extent of water-yielding deposits varies considerably. In all the valleys, alluvial-fan deposits and stream-valley alluvium compose the major part of the aquifer (Planert and Williams, 1995).

Groundwater is under unconfined, or water table, conditions in shallow alluvial deposits. The groundwater is confined or semiconfined in deeper parts of the alluvial deposits and nonalluvial formations (Planert and Williams, 1995). Many of the deep deposits are displaced by faults and as a result, the valleys are a collection of variously connected and isolated aquifers. Generally, the alluvial-fan and stream-valley alluvial deposits in each basin are sufficiently continuous to be considered single aquifers. However, the geology is complex and the exact extent and degree of continuity of many deep aquifers is unknown (Planert and Williams, 1995).

Recharge to the groundwater flow system enters permeable sediments at the valley margins primarily as precipitation runoff from the surrounding mountains and hills. Other sources of recharge are precipitation that falls directly on permeable deposits in low-lying areas of the valleys and seepage through streambeds (Planert and Williams, 1995).

Groundwater movement generally follows surface water drainages. The discontinuous nature of deep water-yielding materials often makes it impossible to construct accurate basin-wide water level maps (Planert and Williams, 1995). However, the groundwater flow pattern in deep aquifers is likely to be similar to that of shallow aquifers. Withdrawals alter the direction of groundwater movement

locally and can affect significant changes in regional flow patterns if withdrawal rates are relatively large. Present day (1995) flow patterns, in general, do not differ significantly from those of predevelopment conditions except locally near withdrawal centers (Planert and Williams, 1995). Withdrawal in the past, however, has reversed the freshwater gradient and induced the intrusion of saltwater in the lower parts of the Napa, Sonoma, and Petaluma Valleys (Planert and Williams, 1995).

4.5 Hydrogeology of the Arsenal

The Arsenal is within the Suisun Basin and is on the western edge of the Suisun-Fairfield Valley Groundwater Basin (California Regional Water Quality Control Board [RWQCB], San Francisco Bay Region, 1995). The location, quantity, and quality of groundwater beneath the Arsenal are not well known. This investigation and the concurrent investigation for the Arsenal SHM focused on collecting stratigraphic and groundwater data to evaluate the site's hydrogeologic setting, which is summarized below.

To better understand the hydrogeology at the Arsenal, 17 piezometers were installed as part of the SHM investigation. The piezometers are PZ-1 through PZ-7, PZ-9 through PZ-15, and PZ-17 through PZ-20 (FA/BC, 2003). Plate 5 (Appendix B) illustrates the locations of these piezometers and groundwater elevation data for water levels measured on September 25, 2002. Groundwater elevations and stratigraphy indicate 2 key hydrogeologic zones at the Arsenal that are briefly described below.

- Southern portion of the Arsenal (Area I). Groundwater elevations ranged from 2.15 feet mean sea level (msl) in PZ-1 to 5.74 feet msl in PZ-6 on September 25, 2002. Groundwater in PZ-3 is under artesian conditions. On October 29, 2002, groundwater level in PZ-3 was measured approximately 0.6 feet above the reference point, which is approximately 8.6 feet msl. The reason for this condition based on the available geological and hydrogeologic data in the area is not well understood.

- Sulphur Springs Creek Drainage basin. This is the major surface water drainage basin at the Arsenal. The name of the drainage comes from Sulphur Springs Creek, which flows into Lake Herman at the northern boundary of the Arsenal. Overflow from Lake Herman is diverted into the Sulphur Springs Creek drainage canal, which outflows to Suisun Bay. Eight piezometers, PZ-11, PZ-12, PZ-9, PZ-10, PZ-7, PZ-14, PZ-13, and PZ-18, have been installed to evaluate groundwater in this zone. On September 25, 2002, groundwater elevations ranged from 4.37 feet msl at PZ-11 to 32.02 feet msl at PZ-18.

Three piezometers are not located in wither Area I or Sulphur Springs Creek Drainage Basin. PZ-17 is located on the western hills of the Arsenal. PZ-19 and PZ-20 are located in an isolated valley between the Sulphur Springs Creek Drainage basin and the Vine Hill area. On September 25, 2002, groundwater levels were measured in PZ-17 at 152.22 feet msl. PZ-17 is approximately 4,000 feet from the nearest piezometer in the Sulphur Springs Creek Drainage basin. It is unknown if there is a hydrogeologic connection to the Sulphur Springs Creek Drainage Canal and PZ-17 based on this

distance. The groundwater elevation data for September 25, 2002 ranged from 74.09 feet msl at PZ-19 to 142.13 feet msl at PZ-20. Likewise, it is not clear if groundwater is connected between these piezometers, because the gradient between the two piezometers is very steep (0.06 feet/feet). These conditions could occur if the piezometers were screened across the same steeply dipping water zone.

In general, water levels at the Arsenal are less than 20 feet deep. Table 4-5 summarizes the water levels measured in the piezometers and 3 monitoring wells around the 50 Series Complex (B057AHP003, B057AHP005, and B057AHP006). At times, groundwater has been measured in PZ-2, PZ-3 and PZ-4 flowing out of these piezometers, which are located in the former marshland of the industrial area. Depth to water in the other piezometers (PZ-1, PZ-5, and PZ-6) and the monitoring wells in the industrial area range from approximately 1 to 8 feet deep. Whereas, depth to water measured in all of the remaining piezometers; located north of the industrial area, range from approximately 5 feet to 20 feet deep.

Table 4-5. Summary of Historical Groundwater Elevation Data, Benicia Arsenal

Name	Measurement date	Ground surface elevation (ft-msl)	Reference elevation (TOC, ft-msl)	Depth-to-groundwater (ft below TOC)	Groundwater elevation (ft-msl)	Change since last measurement (ft)	Notes
B057AHP003	4/17/2000	26.97	26.66	8.01	18.65	--	
	5/5/2000			9.92	16.74	-1.91	
	5/30/2000			10.09	16.57	-0.17	
	6/19/2000			10.82	15.84	-0.73	
	1/14/2002			10.54	16.12	0.28	
	1/28/2002			11.07	15.59	-0.53	
	3/15/2002			11.03	15.63	0.04	
	4/25/2002			10.97	15.69	0.06	
	5/24/2002			10.98	15.68	-0.01	
	6/27/2002			10.61	16.05	0.37	
	7/24/2002			10.93	15.73	-0.32	
	8/28/2002			12.05	14.61	-1.12	
	9/25/2002			12.21	14.45	-0.16	
B057AHP005	4/17/2000	10.46	10.19	3.34	6.85	--	
	5/5/2000			3.45	6.74	-0.11	
	5/30/2000			3.53	6.66	-0.08	
	6/19/2000			3.57	6.62	-0.04	
	1/14/2002			4.25	5.94	-0.68	
	1/28/2002			4.05	6.14	0.20	
	3/15/2002			4.02	6.17	0.03	
	4/25/2002			3.99	6.20	0.03	
	5/24/2002			4.18	6.01	-0.19	
	6/27/2002			3.77	6.42	0.41	
	7/24/2002			4.26	5.93	-0.49	
	8/28/2002			4.37	5.82	-0.11	
	9/25/2002			3.20	6.99	1.17	

Table 4-5. Summary of Historical Groundwater Elevation Data, Benicia Arsenal (continued)

Name	Measurement date	Ground surface elevation (ft-msl)	Reference elevation (TOC, ft-msl)	Depth-to-groundwater (ft below TOC)	Groundwater elevation (ft-msl)	Change since last measurement (ft)	Notes
B057AHP006	4/17/2000	9.54	9.31	2.01	7.30	–	
	5/5/2000			2.88	6.43	-0.87	
	5/30/2000			3.17	6.14	-0.29	
	6/19/2000			3.09	6.22	0.08	
	1/14/2002			2.86	6.45	0.23	
	1/28/2002			3.03	6.28	-0.17	
	3/15/2002			2.99	6.32	0.04	
	4/25/2002			2.94	6.37	0.05	
	5/24/2002			2.69	6.62	0.25	
	6/27/2002			2.12	7.19	0.57	
	7/24/2002			2.41	6.90	-0.29	
	8/28/2002			3.16	6.15	-0.75	
	9/25/2002			3.15	6.16	0.01	
PZ-1	1/14/2002	6.40	6.09	dry	–	–	1
	1/17/2002			13.02	-6.93	–	1
	1/18/2002			12.02	-5.93	1.00	1
	1/28/2002			7.71	-1.62	4.31	1
	3/15/2002			7.68	-1.59	0.03	
	4/11/2002			6.56	-0.47	1.12	
	4/25/2002			6.47	-0.38	0.09	
	5/24/2002			2.22	3.87	4.25	
	6/27/2002			3.47	2.62	-1.25	
	7/24/2002			3.00	3.09	0.47	
	8/28/2002			3.87	2.22	-0.87	
	9/25/2002			3.90	2.19	-0.03	
	10/29/2002			4.39	1.70	-0.49	
PZ-2	1/18/2002	8.57	8.02	4.12	3.90	–	1
	1/28/2002			3.93	4.09	0.19	1
	3/15/2002			3.90	4.12	0.03	
	4/11/2002			0.00	>8.02	–	2
	4/25/2002			0.00	>8.02	–	2
	5/24/2002			2.26	5.76	–	
	6/27/2002			0.00	>8.02	–	2
	7/24/2002			2.63	5.39	–	
	8/28/2002			5.10	2.92	-2.47	
	9/25/2002			5.87	2.15	-0.77	
	10/29/2002			5.34	2.68	0.53	
PZ-3	1/17/2002	8.55	8.05	6.35	1.70	–	1
	1/18/2002			4.02	4.03	2.33	1
	1/28/2002			3.60	4.45	0.42	1
	3/15/2002			3.60	4.45	0.00	
	4/11/2002			0.00	>8.05	–	2
	4/25/2002			0.00	>8.05	–	2
	5/24/2002			0.00	>8.05	–	2
	6/27/2002			0.00	>8.05	–	2
	7/24/2002			0.00	>8.05	–	2
	8/28/2002			0.00	>8.05	–	2
	9/25/2002			0.00	>8.05	–	2
	10/29/2002			0.00	8.6	–	3

Table 4-5. Summary of Historical Groundwater Elevation Data, Benicia Arsenal (continued)

Name	Measurement date	Ground surface elevation (ft-msl)	Reference elevation (TOC, ft-msl)	Depth-to-groundwater (ft below TOC)	Groundwater elevation (ft-msl)	Change since last measurement (ft)	Notes
PZ-4	1/18/2002	6.25	5.70	13.44	-7.74	–	1
	1/28/2002			7.93	-2.23	5.51	1
	3/15/2002			7.91	-2.21	0.02	
	4/11/2002			5.31	0.39	2.60	
	4/25/2002			5.22	0.48	0.09	
	5/24/2002			0.00	>5.70	–	2
	6/27/2002			1.36	4.34	–	
	7/24/2002			0.00	>5.70	–	2
	8/28/2002			0.03	5.67	–	
	9/25/2002			0.50	5.20	-0.47	
	10/29/2002			1.05	4.65	-0.55	
PZ-5	1/17/2002	9.11	8.75	2.81	5.94	–	1
	1/18/2002			3.83	4.92	-1.02	1
	1/28/2002			4.83	3.92	-1.00	1
	3/15/2002			3.00	5.75	1.83	
	4/11/2002			2.96	5.79	0.04	
	4/25/2002			2.91	5.84	0.05	
	5/24/2002			2.87	5.88	0.09	
	6/27/2002			2.41	6.34	0.50	
	7/24/2002			2.99	5.76	-0.12	
	8/28/2002			4.37	4.38	-1.96	
	9/25/2002			3.31	5.44	-0.32	
	10/29/2002			3.45	5.30	0.92	
PZ-6	1/17/2002	9.11	8.45	3.48	4.97	–	1
	1/18/2002			2.98	5.47	0.50	1
	1/28/2002			3.21	5.24	-0.23	1
	3/15/2002			3.20	5.25	0.01	
	4/11/2002			3.00	5.45	0.20	
	4/25/2002			2.96	5.49	0.04	
	5/24/2002			2.75	5.70	0.25	
	6/27/2002			2.67	5.78	0.29	
	7/24/2002			2.62	5.83	0.13	
	8/28/2002			2.74	5.71	-0.07	
	9/25/2002			2.71	5.74	-0.09	
	10/29/2002			2.87	5.58	-0.13	
PZ-7	1/28/2002	25.17	24.73	10.59	14.14	–	1
	3/15/2002			10.55	14.18	0.04	
	4/11/2002			11.11	13.62	-0.56	
	4/25/2002			11.04	13.69	0.07	
	5/24/2002			11.17	13.56	-0.13	
	6/27/2002			10.72	14.01	0.45	
	7/24/2002			11.34	13.39	-0.62	
	8/28/2002			7.77	16.96	3.57	
	9/25/2002			11.90	12.83	-4.13	
	10/29/2002			11.94	12.79	-0.04	

Table 4-5. Summary of Historical Groundwater Elevation Data, Benicia Arsenal (continued)

Name	Measurement date	Ground surface elevation (ft-msl)	Reference elevation (TOC, ft-msl)	Depth-to-groundwater (ft below TOC)	Groundwater elevation (ft-msl)	Change since last measurement (ft)	Notes
PZ-9	1/28/2002	15.87	15.45	5.43	10.02	–	1
	3/15/2002			5.41	10.04	0.02	
	4/11/2002			5.80	9.65	-0.39	
	4/25/2002			5.82	9.63	-0.02	
	5/24/2002			5.51	9.94	0.31	
	6/27/2002			4.97	10.48	0.54	
	7/24/2002			5.80	9.65	-0.83	
	8/28/2002			6.02	9.43	-0.22	
	9/25/2002			5.98	9.47	0.04	
	10/29/2002			5.80	9.65	0.18	
PZ-10	1/28/2002	15.85	15.47	5.13	10.34	–	1
	3/15/2002			5.10	10.37	0.03	
	4/11/2002			6.40	9.07	-1.30	
	4/25/2002			6.42	9.05	-0.02	
	5/24/2002			6.57	8.90	-0.15	
	6/27/2002			6.96	8.51	-0.39	
	7/24/2002			7.01	8.46	-0.05	
	8/28/2002			7.10	8.37	-0.09	
	9/25/2002			7.11	8.36	-0.01	
	10/29/2002			7.01	8.46	0.10	
PZ-11	1/28/2002	12.38	11.99	7.50	4.49	–	1
	3/15/2002			7.49	4.50	0.01	
	4/11/2002			8.43	3.56	-0.94	
	4/25/2002			8.39	3.60	0.04	
	5/24/2002			7.80	4.19	0.59	
	6/27/2002			6.82	5.17	0.98	
	7/24/2002			7.45	4.54	-0.63	
	8/28/2002			7.35	4.64	0.10	
	9/25/2002			7.62	4.37	-0.27	
	10/29/2002			7.85	4.14	-0.23	
PZ-12	1/18/2002	14.93	14.59	6.52	8.07	–	1
	1/28/2002			6.69	7.90	-0.17	1
	3/15/2002			6.66	7.93	0.03	
	4/11/2002			6.89	7.70	-0.23	
	4/25/2002			6.82	7.77	0.07	
	5/24/2002			7.09	7.50	-0.27	
	6/27/2002			7.89	6.70	-0.80	
	7/24/2002			7.50	7.09	0.39	
	8/28/2002			7.65	6.94	-0.15	
	9/25/2002			7.77	6.82	-0.12	
	10/29/2002			7.89	6.70	-0.12	

Table 4-5. Summary of Historical Groundwater Elevation Data, Benicia Arsenal (continued)

Name	Measurement date	Ground surface elevation (ft-msl)	Reference elevation (TOC, ft-msl)	Depth-to-groundwater (ft below TOC)	Groundwater elevation (ft-msl)	Change since last measurement (ft)	Notes
PZ-13	1/28/2002	40.52	40.05	9.30	30.75	–	1
	3/15/2002			9.21	30.84	0.09	
	4/11/2002			10.12	29.93	-0.91	
	4/25/2002			10.06	29.99	0.06	
	5/24/2002			10.43	29.62	-0.37	
	6/27/2002			11.21	28.84	-0.78	
	7/24/2002			11.08	28.97	0.13	
	8/28/2002			11.17	28.88	-0.09	
	9/25/2002			11.26	28.79	-0.09	
	10/29/2002			11.23	28.82	0.03	
PZ-14	1/28/2002	30.47	30.01	8.62	21.39	–	1
	3/15/2002			8.59	21.42	0.03	
	4/11/2002			8.66	21.35	-0.07	
	4/25/2002			8.61	21.40	0.05	
	5/24/2002			8.78	21.23	-0.17	
	6/27/2002			8.16	21.85	0.62	
	7/24/2002			9.00	21.01	-0.84	
	8/28/2002			8.96	21.05	0.04	
	9/25/2002			8.99	21.02	-0.03	
	10/29/2002			9.06	20.95	-0.07	
PZ-17	1/28/2002	163.85	163.32	0.72	162.60	–	1
	3/15/2002			0.64	162.68	0.08	
	4/11/2002			3.79	159.53	-3.15	
	4/25/2002			3.67	159.65	0.12	
	5/24/2002			6.21	157.11	-2.54	
	6/27/2002			10.68	152.64	-4.47	
	7/24/2002			10.70	152.62	-0.02	
	8/28/2002			10.93	152.39	-0.23	
	9/25/2002			11.10	152.22	-0.17	
	10/29/2002			11.42	151.90	-0.32	
PZ-18	1/28/2002	45.07	44.63	10.04	34.59	–	1
	3/15/2002			10.01	34.62	0.03	
	4/11/2002			10.31	34.32	-0.30	
	4/25/2002			10.26	34.37	0.05	
	5/24/2002			10.57	34.06	-0.31	
	6/27/2002			11.03	33.60	-0.46	
	7/24/2002			11.29	33.34	-0.26	
	8/28/2002			11.48	33.15	-0.19	
	9/25/2002			11.61	33.02	-0.13	
	10/29/2002			11.66	32.97	-0.05	
PZ-19	1/28/2002	91.68	91.28	16.57	74.71	–	1
	3/15/2002			16.54	74.74	0.03	
	4/25/2002			16.22	75.06	0.32	
	5/24/2002			16.45	74.83	-0.23	
	6/27/2002			15.33	75.95	1.12	
	8/28/2002			17.11	74.17	-1.78	
	9/25/2002			17.19	74.09	0.08	
	10/29/2002			17.31	73.97	-0.12	

Table 4-5. Summary of Historical Groundwater Elevation Data, Benicia Arsenal (continued)

Name	Measurement date	Ground surface elevation (ft-msl)	Reference elevation (TOC, ft-msl)	Depth-to-groundwater (ft below TOC)	Groundwater elevation (ft-msl)	Change since last measurement (ft)	Notes
PZ-20	1/18/2002	164.18	163.54	13.88	149.66	–	1
	1/28/2002			14.46	149.08	-0.58	1
	3/15/2002			14.45	149.09	0.01	
	4/25/2002			14.10	149.44	0.35	
	5/24/2002			18.45	145.09	-4.35	
	6/27/2002			17.82	145.72	0.63	
	8/28/2002			20.89	142.65	-3.07	
	9/25/2002			21.41	142.13	-0.52	
	10/29/2002			21.82	141.72	-0.41	

Notes:
1 Measured before development.
2 Water flowing out of casing.
3 Water rose 0.6 feet above TOC

Acronyms
ft = feet msl = mean sea level TOC = top of casing

Plate 4 (Appendix B) shows the various directions of groundwater flow at the Arsenal based on the water level measurements from the 17 piezometers. Ultimately, groundwater flows from the surrounding hills into the Carquinez Strait, but the routes may be influenced locally. In the northern and central portion of the Arsenal, groundwater flows into the Sulphur Springs Creek Drainage from the north, west, and east and then turns south into the Carquinez Strait. In the southern portion of the Arsenal, where the 50 Series Complex is located, groundwater flows from the hills to the south and southeast into the Carquinez Strait.

A study was conducted on July 24 through 26, 2002 to measure water levels every 10 minutes for a 48-hour period in PZ-4, PZ-9, PZ-11, and PZ-12. The purpose of the study was to assess the potential influence of the tides on groundwater levels. PZ-4 is located within the industrial area and PZ-9, PZ-11, and PZ-12 are located within the Sulphur Springs Creek drainage basin. These piezometers are also the closest piezometers to the Carquinez Strait. Results indicate that there was little variation (less than a 0.15 foot) in each piezometer and the pattern of variation is consistent with the daily high tide/low tide/high tide/low tide pattern. The pattern is most evident in PZ-4, which is closest to the Carquinez Strait, and less clear in piezometers located farther inland.

Slow recharge rates were observed from several piezometers during development. PZ-1, PZ-4, PZ-6, and PZ-11 are located in the mud flats in the southern portion of the Arsenal and Sulfur Springs Creek drainage (PZ-11). Recharge estimates ranged from 0.001 ft/minute to 0.003 feet/minute (FA/BC, 2003).

4.6 Hydrogeology of Area I

Six piezometers (PZ-1 through PZ-6) were installed as part of the SHM effort in this area. Figure 4-5 is a hydrograph that shows water level elevations in these piezometers and the three monitoring wells around the 50 Series Complex (B057AHP003, B057AHP005, and B057AHP006). Plate 5 shows the locations of these piezometers and monitoring wells in this area of the Arsenal.

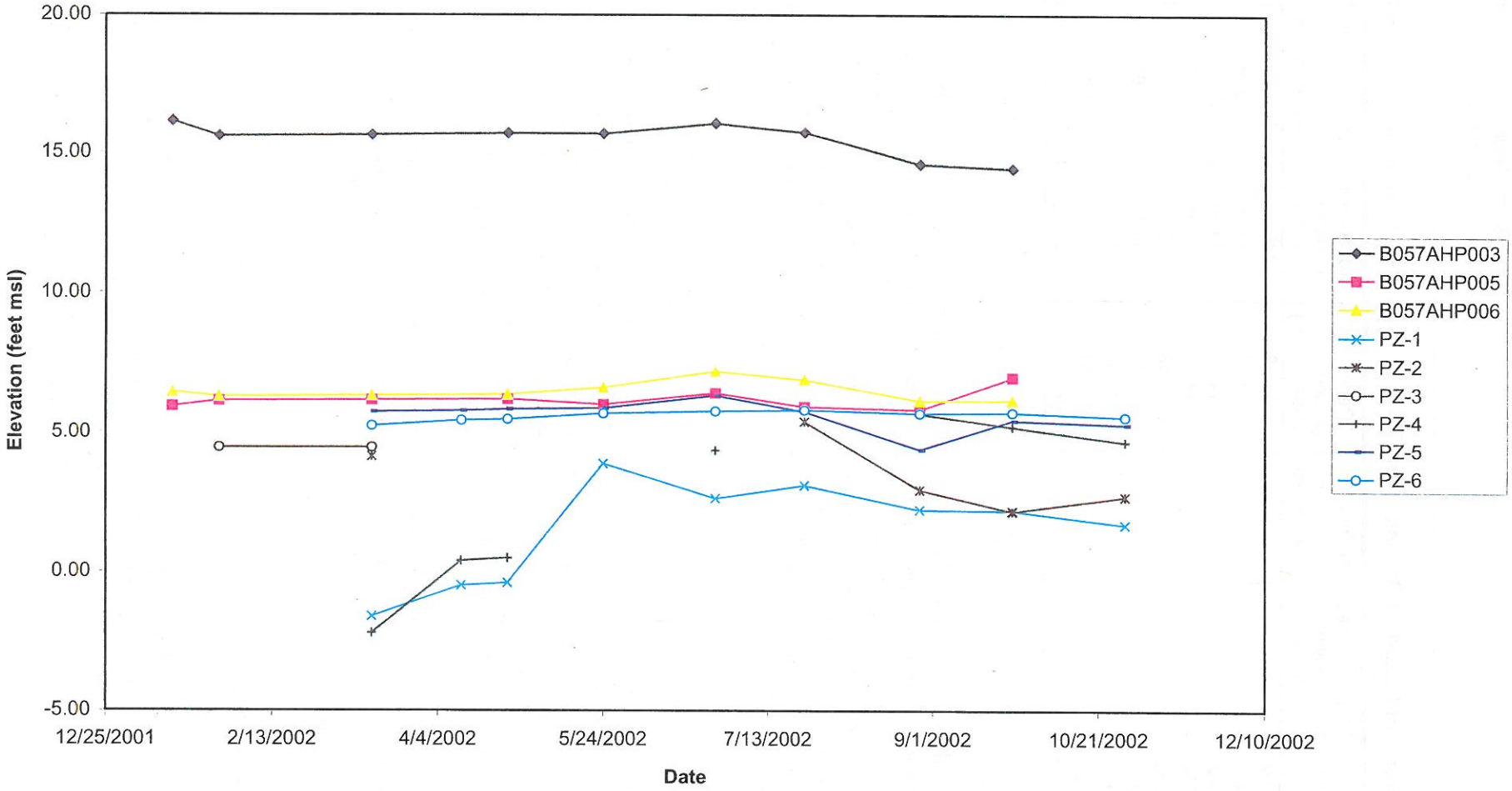


Figure 4-5
Area I Hydrograph
Area I 50 Series Complex SI Report
Benicia Arsenal, Benicia, CA

The piezometers and monitoring wells have similar trends in water levels over this time with the exception of PZ-1, PZ-4 and B057AHP003. The difference in water level trends may be due to the close proximity to the Carquinez Strait for PZ-1 and PZ-4. Other possible influences, such as localized pumping or water leaks from water lines need to be investigated. The difference in water levels for monitoring well B057AHP003 appears to be due the location of the monitoring well on top of a bedrock high.

Two Area I piezometer pairs, PZ-2/PZ-3 and PZ-5/PZ-6 were installed to help evaluate water levels in different stratigraphic intervals. The two piezometers in each pair are installed next to each other, but are screened across different permeable units (Table 4-6). The screened interval and water levels measured in each piezometer pair from March 2002 to October 2002 is summarized in Table 4-6. Water levels in piezometer pair PZ-5/PZ-6 show both upward and downward vertical gradients but generally appear to fluctuate in a similar manor over time. In contrast piezometer pair PZ-2/PZ-3 shows an upward vertical gradient each month, and both wells were under artesian conditions for several months.

Table 4-6. Water Level Measurements in Paired Piezometers within Area I March 15, 2002 to October 29, 2002

Date	Groundwater Elevation (feet msl)			
	PZ-2	PZ-3	PZ-5	PZ-6
3/15/2002	4.12	4.45	5.75	5.25
4/11/2002	>8.02 (artesian)	>8.05 (artesian)	5.79	5.45
4/25/2002	>8.02 (artesian)	>8.05 (artesian)	5.84	5.49
5/24/2002	5.76	>8.05 (artesian)	5.88	5.70
6/27/2002	>8.02 (artesian)	>8.05 (artesian)	6.34	5.78
8/28/2002	5.39	>8.05 (artesian)	5.76	5.83
9/25/2002	2.92	>8.05 (artesian)	4.38	5.71
10/29/2002	2.15	8.6 (artesian)	5.44	5.74
Screened Interval (feet msl)	-2 to -12	-46 to -56	4 to –6	-15 to -25
Screened Interval Soil Type	Clay	Clay	Silty sand	Clay
Comments	Screen placed across water table	Screen placed on top of Vine Hill Sandstone	Screen placed across water table	Screen placed within an intermediate permeable unit

Groundwater Elevation (feet msl) > screened interval = semi-confined to confined conditions

4.7 Hydrogeology of the 50 Series Complex

Water level data collected from the 3 monitoring wells surrounding the 50 Series Complex indicate a dramatic difference in groundwater elevation between the low-lying sandstone hill and the flat alluvial area to the south. Monitoring well B057AHP003 is located on top of the low-lying sandstone hill, and monitoring wells B057AHP005 and B057AHP006 are both located on the low-lying area south of the 50 Series Complex (Plate 5, Appendix B). Water level elevations in B057AHP005 and B057AHP006 ranged from 5.82 to 7.19 feet above msl since March 2002 (Table 4-7). In contrast, the elevation of the water in B057AHP003 ranged from 14.45 to 15.69 feet above msl during the same gauging period (Table 4-7). Despite the difference in groundwater elevation, all 3 monitoring wells have similar trends over time (Figure 4-5).

Table 4-7. Water Level Elevations in Monitoring Wells B057AHP003, B057AHP005, and B057AHP006

Date	3/15/02	4/25/02	5/24/02	6/27/02	7/24/02	8/28/02	9/25/02
B057AHP003	15.63	15.69	15.68	16.05	15.73	14.61	14.45
B057AHP005	6.17	6.20	6.01	6.42	5.93	5.82	6.99
B057AHP006	6.32	6.37	6.62	7.19	6.90	6.15	6.16

Water level data from these wells were not used to determine groundwater flow directions beneath the 50 Series Complex because the wells are not likely screened within the same water-bearing zone. Figure 4-2 is a cross section from B057AHP003 to B057AHP005. The cross section shows the bedrock high beneath the 50 Series Complex, which is positioned between B057AHP003 and B057AHP005. It appears that the shallow bedrock may be separating the water-bearing units south of the complex from any connection to groundwater on the northern side of the bedrock high.

4.8 Water Quality Parameters

Water quality information was used to help assess the hydrogeologic setting for the 50 Series Complex in the form of TDS, pH and concentrations of specific ions. Water quality parameters measured in the field from grab groundwater samples are shown in Table 4-8 and analytical results for TDS are presented in Table 4-9. These samples were not filtered and somewhat turbid. As such the data should be used as a general indication of water quality.

Values of TDS up to 1,000 mg/L are characterized as fresh water and values from 1,000 mg/L to 10,000 mg/L are considered brackish water (Driscoll, 1986). TDS values were reported at less than 1,000 mg/L, except for B057AHP005 (4,890 mg/L) and B057AHP008 (1,130 mg/L), which implies that the groundwater at the 50 Series Complex is mostly freshwater recharge from rainwater runoff or surface water infiltration. Additionally, pH ranged from pH 6.88 to pH 7.10 (corrected for temperature), which is typical for fresh water, whereas in brackish water pH is around pH 8.3 (Driscoll, 1986).

Table 4-8. Water Quality Field Measurements for 50 Series Complex

Trench	pH	Electrical conductivity (mhos/cm)	Temperature (°C)	Odor
B056SB002	6.84	484	18.4	None
B057AHA004	7.32	1,105	17.3	None
B057AHP002	7.56	1,122	19.2	None
B057AHP003	6.98	939	19.9	Strong hydrocarbon
B057AHP004	7.22	1,030	19.5	None
B057AHP005	6.52	5,030	21.5	None
B057AHP006	7.46	711	25.4	None
B057AHP008	7.55	1,516	16.9	None
B057AGR001 (from 18-inch standpipe)	7.20	170	19.0	Slight to moderate organic
B120SB001	6.28	1,150	22.4	None

cm = centimeter °C = degrees Celsius

Table 4-9. Detected Analytes in Water - Wet Chemistry (mg/L)

Location-ID	Sample Date	Depth (feet)	ALKALINITY, BICARBONATE	ALKALINITY, TOTAL	CHLORIDE	NITRATE (AS N)	SULFATE	TOTAL DISSOLVED SOLIDS
B056SB002	September 17, 1999	9.5	174	174	20.8	0.56	54.9	290
B057ACR001	September 7, 1999	6	241		138	0.134 J	295	985 J
B057AHP002	September 10, 1999	12	383	383	191	1.67	63.9	755
B057AHP003	September 15, 1999	17	544	544	68.4	0.208	27.3	655
B057AHP004	September 13, 1999	6	410	410	86.7	3.07	128	740
B057AHP005	September 10, 1999	8	969		2390	0.327 J	12.6 J	4890 J
B057AHP006	September 9, 1999	6	201		82.9	0.0817 J	37.3	395
B057AHP008	September 16, 1999	8	165	165	254	6.25	170	1130
B057AHP009	September 28, 1999	0.5	418	418	67.7	1.24	114	670
Number of Detects:			9	6	9	9	9	9
Total Number of Analyses:			9	9	9	9	9	9
Minimum Concentration:			165	165	20.8	0.0817	12.6	290
Maximum Concentration:			969	544	2390	6.25	295	4890
Mean Detected Concentration:			389	349	366.6	1.5045	100.3	1168

QUALIFIER LEGEND:

J The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.

The brackish water at B057AHP005 appears to be influenced by brackish/salt water sources trapped in former marsh sediments or water from the Carquinez Strait. The source of the brackish water at B057AHP008 is not understood. B057AHP008 is located within the vat in Building 57A. The water in this area may be stagnated and recharge from fresh water sources may not be influencing this area.

In addition to TDS and pH, other water quality parameters that elucidate the hydrogeologic setting are the concentrations of specific ions. Typically the ionic species present in groundwater are derived from contact with various mineral deposits. Major cations in groundwater include calcium, magnesium, sodium, and potassium. Anions include bicarbonate sulfate, chloride, and nitrate. Table 4-9 and Plate 6 (Appendix B) presents the results of these water quality parameters.

A graphical comparison of the chemical composition of groundwater in the 50 Series Complex with the chemical composition of seawater is presented in Plate 7 (Appendix B). The shape of the radial graph which represents seawater is not similar in shape to any of the radial plots for the groundwater samples, with the exception of B057AHP005, indicating that the groundwater at the site is not seawater, but may be mixed with seawater or fresh water. This conclusion is further supported by water level elevation data collected with transducers, which showed very little fluctuation in the water table elevation over a 48-hour period. B057AHP005's radial shape is similar to seawater, but it is clearly different than the nearest sample at B057AHP006. Both monitoring wells are located in clayey soils south of the 50 Series Complex.

Radial shaped graphs of water quality parameters measured from 9 borings and the standpipe in Building 57A were grouped based on shape (Table 4-10). The location and associated water quality relationships based on shape is described below.

Table 4-10. Groups with Similar Shaped Radial Plots

Group 1	Group 2	Group 3	Group 4
B057AHP005 (*4,890*)	B057AHP002 (*755*)	B056SB002 (*290*)	B057AHP008 (*1,130*)
Sea water	B057AHP006 (*395*)	B057HA004 (*670*)	B057AGR001 (*985*)
		B057AHP003 (*655*)	
		B057AHP004 (*740*)	

(Total dissolved solid concentrations in milligrams per liter)

- Group 1 is based on B057AHP005 at the southeast corner of the 50 Series Complex and seawater. The radial shapes are dominated by sodium/potassium and chloride with much lower proportions of bicarbonate and magnesium.

- Sample locations in Group 2 are on the southern and eastern perimeter of the 50 Series Complex (Plate 7, Appendix B). Sodium/potassium and bicarbonate with lesser portions of chloride and calcium dominate Group 2 radial shapes.

- Group 3 includes sample locations on the western and north portions of the 50 Series Complex (Plate 7, Appendix B). Chloride concentrations are much lower in Group 3 than Group 1.

- Group 4 includes water samples within Building 57A (Plate 7, Appendix B). Group 4 is predominately sodium/potassium with much lower proportions of sulfate, bicarbonate, chloride, calcium, and magnesium. Water sample B057AGR001 was taken from a standpipe within the parkerizing vat. Water sample at B057AHP008 was in the middle of U-shaped vat. Similarities between these radial plots indicate that the water in the vat is connected with the underlying soil.

If the groupings are evaluated based on TDS concentrations, the groundwater may trend high TDS to low TDS in a southeast to northwest direction with B057AHP005 (high TDS) to Group 2, Group 3 and Group 4 (low TDS).

4.9 Evaluation of Ambient Metals Concentrations in Soil

This section documents the procedures used for calculating preliminary ambient metals concentrations in soil at the 50 Series Complex. The ambient metals concentrations were used in the human health risk screening analysis, which is described in Section 7.0 of this report. Specific methods that FA/BC used to determine background concentrations for metals in soil are presented. Sufficient detail is provided to allow the calculations to be repeated, if desired.

It is expected that the ambient metals concentrations calculated in this report will be revised as additional data become available. Also, an analysis of existing data is currently scheduled that will examine the effects of sample depth, soil type and stratigraphic unit on metals concentrations measured in soil. That analysis is described as a "preliminary data characterization" in Figure 7A-1 of the Arsenal-Wide Investigation Workplan (FA/BC, 1999c). The current effort (i.e., development of preliminary ambient metals concentrations for the 50 Series Complex) was not originally planned and, therefore, is not shown Figure 7A-1. However, the methods used to calculate the preliminary ambient metals concentrations in soil for the 50 Series Complex are in general accordance with the earlier document (FA/BC, 1999c).

4.9.1 *General Approach*

The statistical methodology for calculating ambient metals concentrations for the 50 Series Complex is based on the California Department of Toxic Substances Control (DTSC) guidance document entitled "Selecting Inorganic Constituents as Chemicals of Potential Concern in Risk Assessments at Hazardous Waste Sites and Permitted Facilities." (DTSC, 1997). The DTSC document presents an approach that extracts "ambient data sets" from larger "expanded data sets." Expanded data sets consist of site characterization data that are typically collected to assess the magnitude and extent of possible contamination. Because the number of site characterization samples is usually large, this method does not require the collection of "ambient-specific" or off-site samples. This is a particularly effective technique for soil samples that are analyzed for many metals because a sample contaminated with one metal may exhibit ambient concentrations for the remaining metals. Once

the ambient data sets are formed, a concentration that is representative of the upper range of ambient conditions is calculated, and measurements from impacted soil samples are compared to that limit.

In general, this method produces more accurate results than methods that calculate ambient concentrations from a small number of samples collected from known uncontaminated areas. One reason for this increased accuracy is that the ambient data sets prepared using the "expanded data set approach" are usually larger than traditional ambient data sets. Also, variability resulting from influencing factors such as soil type is likely to be less for the expanded data set approach because ambient samples are collected in closer proximity to contaminated samples.

4.9.2 *Data Compilation*

Data from all investigations conducted to date by FA/BC at the Arsenal were combined to form expanded data sets. These data are shown in Table H-1 and include results from the following investigations:

- Areas 53, 73, 103 and 154
- Fuel Only Facilities
- Landfills and Quarries
- 50 Series Complex
- Site Hydrogeologic Model

Ambient metals concentrations were calculated for all metals for which Benicia Screening Levels (BSLs) have been developed (FA/BC, 2002b). These metals include aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, tin, vanadium, and zinc. Ambient concentrations were not determined for hexavalent chromium, calcium, magnesium, sodium or potassium.

All primary (non quality control [QC]) soil samples were included in the analysis with the following exceptions:

Sample Name	Reason for Excluding
B053TR001-S03	Imported fill for UST
B053TR001-S06	Imported fill for UST
B056GR001-S01	Left-over material from sandblasting operations
B057HA001-S01A	Gunite target material from firing range
B057HA001-S02A	Gunite target material from firing range
B057HA002-S01A	Gunite target material from firing range
B057HA002-S02A	Gunite target material from firing range
B057HA003-S01A	Gunite target material from firing range
B057HA003-S02A	Gunite target material from firing range

Results from field duplicates (QC samples) were not included in the expanded data sets to avoid violating the assumptions of homoscedasticity and independence that underlie many statistical methods. Homoscedasticity means that the uncertainty associated with each measurement is identical, which would not be true if duplicate samples were averaged. Using duplicate samples without averaging them would cause the data to be serially correlated, thereby violating the assumption of independence.

Data that are qualified with a "J" (i.e., estimated values) were included in the expanded data sets and were treated in the same manner as other data.[1] The majority of J-qualified data represent concentrations that are between the method detection limit (MDL) and the method quantitation limit.

Non-detects that were greater than four times the minimum detected value were not included in the expanded data sets. A total of four results (one each for antimony, beryllium, molybdenum and tin) were excluded based on this criteria. Those values are identified in Table H-1.

Non-detects were set equal to one-half the reporting limit for all graphs and calculations associated with the ambient evaluation.

4.9.3 *Data Characterization*

In accordance with the DTSC guidance, a variety of summary statistics were calculated for the expanded data. Those summary statistics are defined below and presented in Table H-2. The median, mean, standard deviation, coefficient of variation and skewness were not calculated for data sets with fewer than 50 percent detected values.

number of observations – total number of results including detects and non-detects

number of detects – number of values at or above the reporting limit, which in this case is the MDL

number of non-detects – number of values reported as "< MDL"

percentage of detects – number of detected values/total number of values * 100

minimum detect – the minimum detected value, which may be at or above the reporting limit

maximum detect – the maximum detected value

minimum reporting limit – the lowest reporting limit which, for this project, is the MDL

maximum reporting limit – the highest reporting limit which, for this project, is the MDL

[1] There has been considerable research on the effects of using estimated data in statistical calculations, and the general consensus is that better results are obtained if the actual data are used versus the censored data (i.e. "3.2 J" provides more information than "<5").

median – the 50th percentile of the data

mean – the arithmetic average

standard deviation – a measure of variability

coefficient of variation – standard deviation/mean

skewness – measures the deviation of the distribution from symmetry

Also in accordance with DTSC guidance, data sets were identified in Table H-2 that display a range of detected values of more than two orders of magnitude and/or a coefficient of variation greater than one, because those data sets may be representative of more than one population. Arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, tin and zinc met one or both criteria.

The expanded data sets were further characterized by testing for normality using the Shapiro-Wilk hypothesis test. Normality tests indicate whether or not the data satisfy the assumption of normality, which underlies many statistical methods. Non-normal data can indicate the presence of multiple populations. Distributional tests were conducted on both non-transformed and the log-transformed expanded data. Results of those tests are presented in Table H-3. All data sets, with the exception of manganese and silver are neither normally nor lognormally distributed at a significance level of 5 percent. Manganese is lognormally distributed and silver is normally distributed.

Non-detects were not included in distributional testing for metals with fewer than 70 percent detected concentrations (i.e., antimony, cadmium, mercury, molybdenum, selenium, silver and tin). Although this approach is not strictly correct if one is attempting to determine the overall distribution of the data, it was only employed so that normality testing could be used as a tool for removing upper-end outliers. Nonparametric methods, which do not assume a particular distribution, were used to calculate ambient concentration limits for those metals with fewer than 70 percent detected values.

Ranked data plots and normal probability plots were constructed for each expanded data set (Figures H-1 and H-2, respectively). In some cases, extremely high values were removed prior to constructing the plots because outliers on graphs tend to obscure characteristics of the rest of the data (excluded values are identified in Table H-5). Non-detects were not included in the probability plots for metals with fewer than 70 percent detected values. The type of data used in the probability plots (i.e., non-transformed or log-transformed) is consistent with the distribution of the ambient data. Only non-transformed data were used to construct the ranked data plots.

4.9.4 *Formation of Ambient Data Sets*

Ambient data sets were formed for each metal by removing values from the expanded data that appear to lie outside the ambient population. Data points were removed in groups or individually, based on visual inspection of the ranked data plots and probability plots presented in Figures H-1 and H-2. Distributional testing and probability plotting were conducted following each removal operation. Outlier removal continued until the remaining data were shown to be either normally or lognormally distributed at a significance level of 5 percent. Results of normality testing for the ambient data are presented in Table H-4, and probability plots of the ambient data are shown in Figure H-2. Non-detects that were removed from data sets with fewer than 70 percent detects were added back in prior to calculation of ambient concentration limits.

In some cases, when it appeared that the expanded data include more than one distinct population, the population nearest the origin was selected to represent ambient conditions. This approach is consistent with the DTSC guidance. Further inspection of the data during the next phase of the ambient study, however, may show that there is more than one ambient population. For example, the population nearest the origin may represent ambient conditions in sandy soil, whereas the population further from the origin may represent ambient conditions in clay. Although low values were sometimes removed from the expanded data, the outlier removal effort focused on high values to avoid inadvertent removal of the population nearest the origin. Low values were not removed from data sets with fewer than 70 percent detects.

The expanded and ambient data are ordered from largest to smallest in Table H-5. Results are presented side-by-side so that values removed from the expanded data sets to form the ambient data sets can be readily identified.

4.9.5 *Calculation of Ambient Concentration Limits*

Ambient concentration limits for metals were calculated as the 95th percentile of the ambient data sets. Because sample sizes are large and there is minimal scatter in the data, the less conservative 99th percentile may be warranted. As mentioned previously, however, limits presented in this report are preliminary; it is planned that additional data will be included in the ambient metal analysis and a more in-depth data characterization will be conducted. If justified, future evaluations of ambient conditions will use the 99th rather than the 95th percentile to represent ambient conditions.

The method used to calculate the 95th percentile depended on the frequency of detected values and the distribution of the data. For analytes with fewer than 70 percent detects, a nonparametric approach was used that does not assume a particular statistical distribution. Although detected values in the data sets were shown to be normally or lognormally distributed, those distributional assumptions should not be applied to the entire data set. For analytes with greater than 70 percent detects, the 95th percentile was calculated with equations that assume a normal or lognormal distribution of the data, as appropriate.

The 95th percentile for analytes with fewer than 70 percent detects was calculated using the following nonparametric procedure, which is presented in Gilbert (1987).

1. The data were ordered from smallest to largest.
2. "k" was calculated as follows: k = p(n+1), where p=0.95 and n=number of observations.
3. The 95th percentile was set equal to the kth ordered value. If k was not an integer, the 95th percentile was obtained by interpolation between the appropriate ordered values.

The 95th percentile for data sets with at least 70 percent detected values was calculated using equations 11.1 and 13.24 presented in Gilbert (1987), as shown below.

normally distributed data

$$x_p = \text{mean} + (Z_p * \text{sdev}) \qquad \text{(equation 11.1)}$$

where: x_p = p^{th} percentile of the sample
Z_p = p^{th} percentile of the standard normal distribution

log-normally distributed data

$$x_p = \text{EXP}\,[\text{mean} + (Z_p * \text{sdev})] \qquad \text{(equation 13.24)}$$

Upper concentration limits for all ambient metals data sets are summarized in Table 4-11.

Table 4-11. Ambient Concentration Limits for Metals in Soil at Benicia Arsenal (Preliminary)

Analyte	Ambient Concentration Limit (mg/kg)
Aluminum	28,300
Antimony	8.52
Arsenic	16.9
Barium	224
Beryllium	0.829
Cadmium	0.866
Chromium	75.3
Cobalt	13.3
Copper	40.5
Iron	52,600
Lead	20.1
Manganese	1070
Mercury	0.287
Molybdenum	2.51
Nickel	38.3
Selenium	0.605
Silver	1.67
Thallium	0.850
Tin	19.0
Vanadium	92.2
Zinc	126