

Groundwater Quality Evaluation Using Westbay Monitoring Well Systems, Former Fort Ord, California

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BIOGRAPHICAL SKETCHES

Mike has been with Harding ESE, Inc. since 1994 and works mostly with the ongoing groundwater monitoring and RI/FS activities at the Former Fort Ord Army base near Monterey, California. Activities have included installing numerous monitoring wells, coordinating the quarterly groundwater monitoring program, designing and conducting aquifer tests, constructing and maintaining the Modflow/Modpath groundwater flow model, and routinely presenting program information to the public. He received his Master's Degree in Geology and Hydrogeology from the University of South Florida in 1993 and his Bachelor's Degree in Geosciences from Pennsylvania State University in 1990.

Carlene has been a consultant with Harding ESE, Inc. since 1986. She has been the Harding ESE project manager for groundwater issues at Former Fort Ord since 1996. Her career began with geophysical projects involving reflection seismology. Her consulting activities have also included data management and evaluation, information technology integration as well as business development and client support. She completed her Master's Degree course work in Geophysics at Cornell University in 1983 and received her Bachelor's Degree in Geology from Adelphi University in 1981.

Glen has been a project manager with the US Army Corps of Engineers, Sacramento District since 1996. Currently, he manages the Hazardous and Toxic Waste projects for the Base Realignment and Closure program at the Former Fort Ord complex in Monterey California. He received his Bachelor's Degree in Earth Sciences from Sonoma State University in 1986.

ABSTRACT

Previously used municipal wells with insufficient sanitary seals have allowed for carbon tetrachloride (CT) to migrate from a shallow aquifer to two underlying and significantly thicker confined aquifers. Although the plume had been reasonably well characterized in the shallow aquifer, the prospect of investigating the deepest aquifer (called the Lower 180-Foot Aquifer) posed several challenges. This aquifer is located between 350 and 500 feet below grade and consists primarily of coarse sands and gravels. Historical groundwater flow directions in the Lower 180-Foot Aquifer have varied significantly over the past 30 years influenced first by municipal pumping and second by the subsequent cessation of pumping due to seawater intrusion. Variable historical flow directions, significant thickness and depth all contributed to the conclusion that an investigation utilizing standard single-screen monitoring wells with 20 to 30 foot long screens would be too expensive and time consuming. Thus, the Army began delineating the extent of contamination in the Lower 180-Foot Aquifer using Westbay technology. This technology provides high quality groundwater pressure and quality data from specific depths using multiple monitoring ports and minimizes drilling and subsequent sampling costs. Six multi-port Westbay wells, with a total of 35 monitoring ports, were installed in November 2001 to further characterize the aquifer(s) and CT plume. These new wells have yielded valuable groundwater pressure and quality data that have dramatically improved the characterization of the complex distribution of dissolved CT in a very short period of time.

INTRODUCTION

In November 2001, Harding ESE, Inc. (Harding ESE) installed 35 Westbay monitoring ports (designed by Westbay Instruments, Inc.) at the former Fort Ord Army Base in Monterey, California (Figure 1) as part of the continuing characterization of a CT groundwater plume. The monitoring ports were installed in six borings at depths between 250 and 580 feet within what are called the Lower 180-Foot and 400-Foot Aquifers. The Westbay system allows for the measurement of groundwater pressures and collection of groundwater samples at specific depths and in multiple aquifers within a single borehole.

This paper discusses groundwater elevation measurements and analytical results from the December 2001 and March 2002 sampling events and the benefits of utilizing Westbay technology in a groundwater investigation and monitoring program.

Objectives

The primary objectives of the CT investigation in the Lower 180-Foot and 400-Foot Aquifers were to confirm the site hydrostratigraphy, measure groundwater elevations, and assess water quality in both aquifers at specific depths in a cost-effective manner within a specific time window (prior to the onset of the wet season beginning in December). A large portion of the site under investigation includes an area designated as a biological reserve and all work in the reserve is carefully controlled to minimize impact to the area and is subjected to rigorous seasonal access restrictions.

Basic site hydrostratigraphy at these depths was derived from logs from previously used drinking water wells in the area, and the two aquifers of interest were each anticipated to be 150 to 250 feet thick and comprised primarily of sand to coarse sand and gravel. The majority of water quality data from the site prior to this investigation came from historical samples from the same drinking water wells. Most of those wells have since been destroyed and groundwater flow conditions were anticipated to have significantly changed since pumping had ceased. Therefore, current conditions throughout the area (with respect to groundwater flow directions and CT concentrations) were difficult to anticipate.

The history of the site, including the extraction of groundwater from drinking water wells and the potential presence of several vertical conduits, presented a potentially complex distribution of CT contamination extending from the shallowest unconfined aquifer to the main drinking water aquifer in the area. The lack of existing monitoring wells screened within the two target aquifers combined with deadline and budgetary concerns made an iterative program of installing single-screen wells unattractive.

The Westbay wells were therefore primarily selected to establish a three-dimensional skeleton framework in order to characterize the two target aquifers and delineate the extent of CT contamination within a short timeframe. Data from these wells will be incorporated into a remedial investigation and feasibility study to address potential remedial alternatives, if necessary.

Westbay MP38 System

The Westbay MP38 System consists of a casing (38 millimeter diameter) designed to allow the monitoring of multiple discrete levels in a single borehole, thus minimizing drilling costs. Each level or monitoring zone has a valved connection to a central access tube that is sealed along its entire length – maintaining the natural distribution of formation fluid pressures and chemistry (Figure 2).

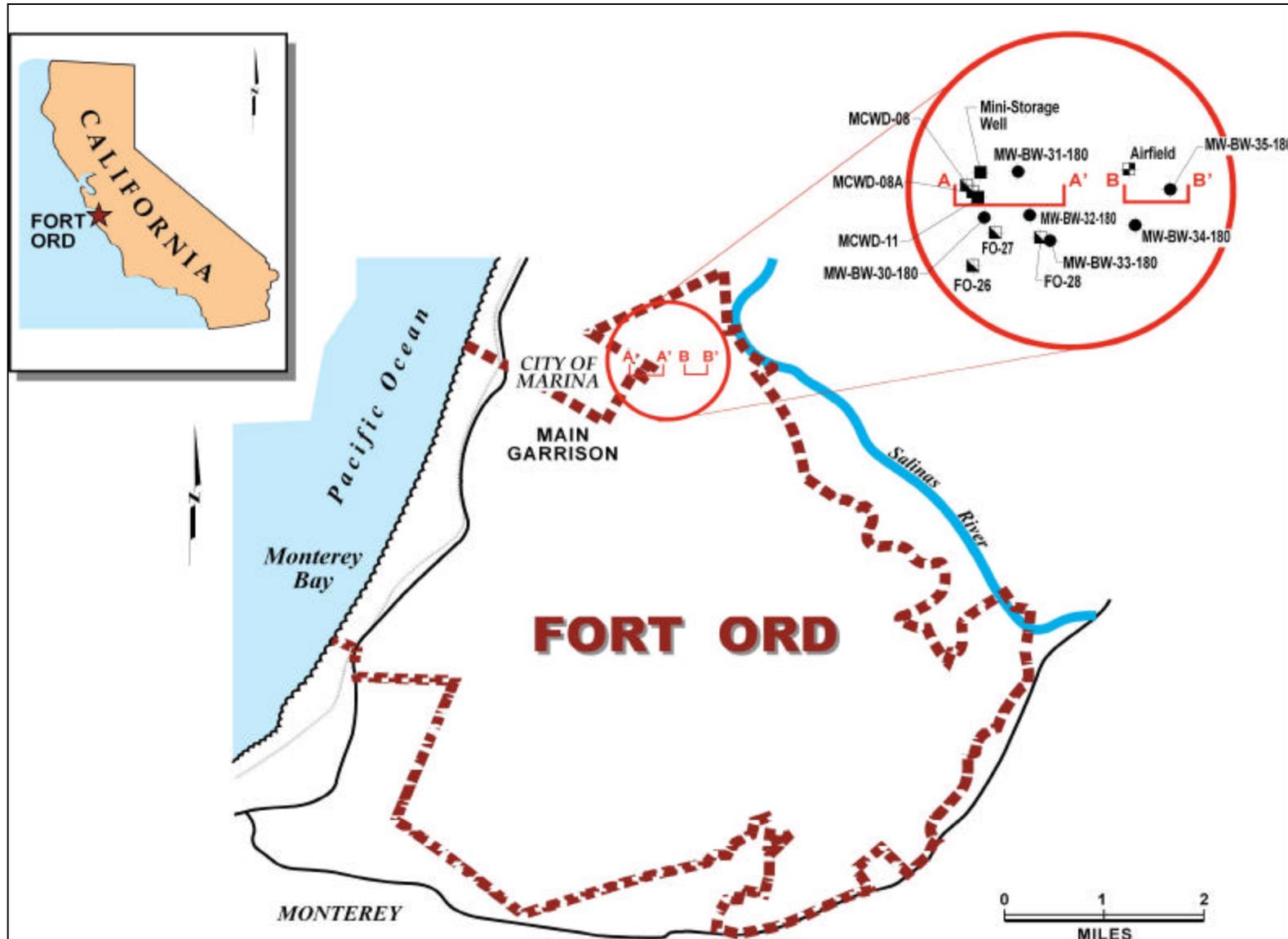


Figure 1. Map of Former Fort Ord and Westbay Monitoring Well Locations

The two target aquifers include unconsolidated fluvial, alluvial, and marine sediments prone to heaving and hence require the use of drilling mud to stabilize the boreholes. In order to install the Westbay system in each borehole, an outer monitoring well was first installed (referred to by Westbay as a ‘cased well’ scenario). The design of the outer monitoring well was based on drilling cuttings, core samples, and geophysical data and resulted in multiple screened sections correlating with suspected zones of high hydraulic conductivity, and hence a higher probability of CT contamination. The Westbay monitoring zones were then installed to match each of the outer monitoring well screen zones, using MP System packers between monitoring zones to prevent the vertical flow of groundwater. Westbay tools used to measure groundwater pressures and collect groundwater samples are also used to inflate the packers and operate some of the casing components.

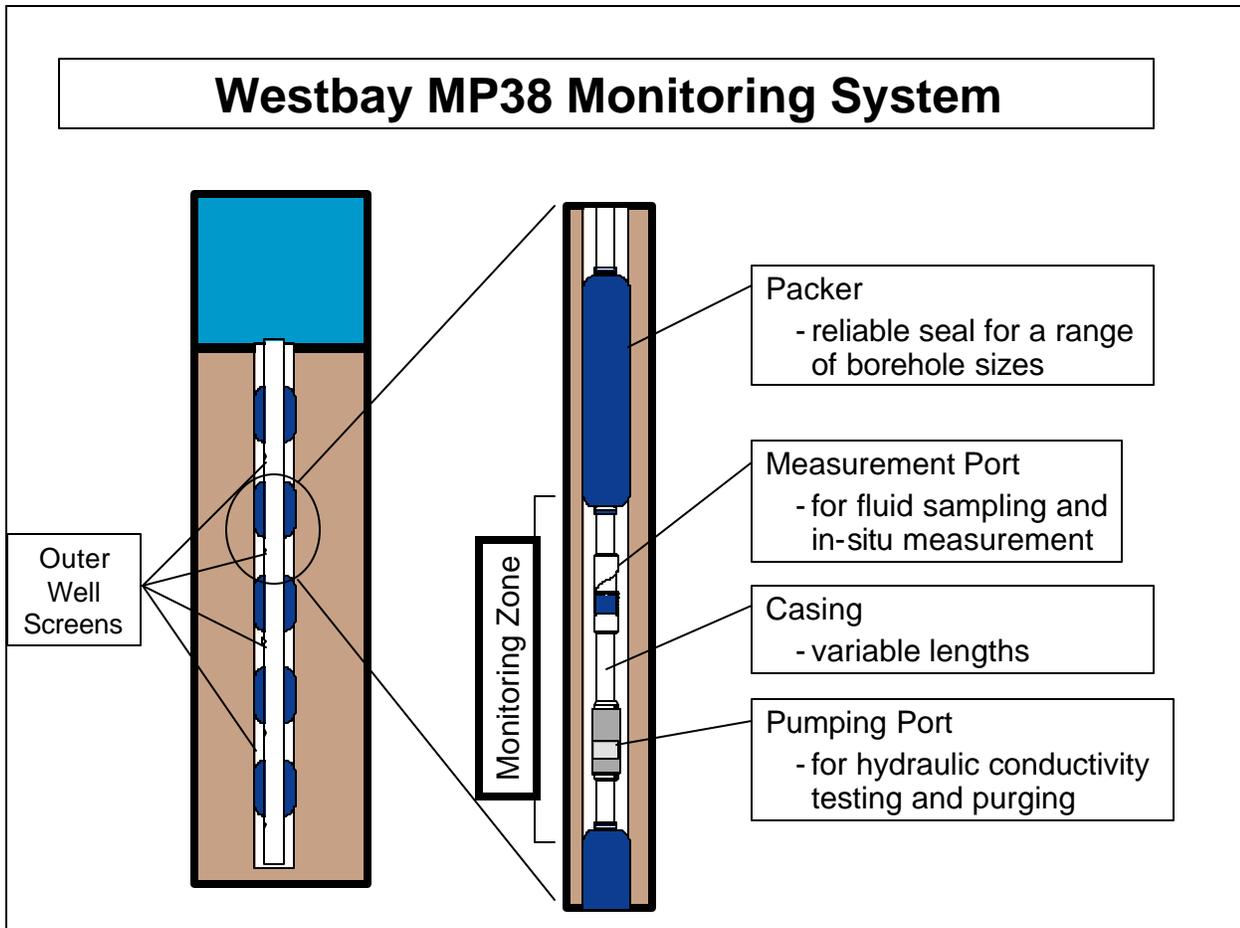


Figure 2 Schematic of a Westbay Monitoring Well

The data is collected by one or more tethered probes with sensors that are lowered down the delivery tube or casing to each monitoring zone to measure fluid pressure and temperature, collect fluid samples or test hydrogeologic parameters (*Westbay, 2002*). This approach eliminates the need to purge the well and minimizes the time required to collect a sample. Typically up to one liter of water may be retrieved from each port within 15 minutes.

SITE BACKGROUND

Fort Ord History

Fort Ord is located adjacent to Monterey Bay in western Monterey County, California, approximately 80 miles south of San Francisco (Figure 1). The former Army base comprised approximately 28,000 acres, although the area of CT contamination is limited to the northernmost third of the former base. Since opening in 1917, Fort Ord was used primarily as a training and staging facility for infantry troops. No permanent improvements were made until the late 1930's, when administrative buildings, barracks, mess halls, tent pads, and a sewage treatment plant were constructed. From 1947 to 1975, Fort Ord was a basic training center. Before 1947 and after 1975, the 7th Infantry Division occupied Fort Ord. The base was officially closed in 1994 under the Base Realignment and Closure (BRAC) program.

Site Hydrogeology

Hydrostratigraphic units at Fort Ord are located in the Salinas and Seaside groundwater basins. The areas identified in the RI/FS requiring routine groundwater monitoring, including the area contaminated with CT, lie only within the Salinas Basin. The four aquifers being investigated fall into one of three categories with increasing depth: recent dune sand (A-Aquifer), valley fill deposits (Upper and Lower 180-Foot Aquifers), and Aromas/Paso Robles Formation (400-Foot Aquifer). The Westbay monitoring ports were installed in the Lower 180-Foot or 400-Foot Aquifers.

The Lower 180-Foot Aquifer is composed of 120 to 200 feet of alluvial gravel and coarse sand interbedded with clay and silt lenses. About 30 feet of a fine silty unit overlies this aquifer and results in confined conditions. Depths to water range from 100 to 250 feet below ground surface. Groundwater flows to the southeast or east, toward a major agricultural center within the Salinas Valley dependent upon groundwater for seasonal irrigation.

The 400-Foot Aquifer is composed of 150 to 250 feet of fine to medium sand. The 400-Foot Aquifer is hydraulically distinct from the overlying Lower 180-Foot Aquifer by only minor head differences. Depths to water range from 150 to 250 feet below ground surface. Groundwater also flows to the southeast or east toward the Salinas Valley, as in the Lower 180-Foot Aquifer.

Site History – Carbon Tetrachloride

Fort Ord was added to the Superfund List in 1990 when elevated concentrations of TCE were detected in a neighboring municipal drinking water well from a plume emanating from formerly used landfills south of the site. An RI/FS was initiated in 1992 that led to a basewide groundwater monitoring program begun in 1993 (HLA, 1994; 1995). CT was unexpectedly detected at an isolated well couplet that had been installed as part of a previous investigation in 1975; one well was screened in the A-Aquifer, the other in the Upper 180-Foot Aquifer. Concentrations of CT in samples collected from the monitoring wells exceeded the state and federal clean-up levels (0.50 and 5.0 µg/L, respectively) and both wells were subsequently included in the quarterly groundwater monitoring program. Between 1998 and 2001, Harding ESE installed 36 A-Aquifer wells and seven Upper 180-Foot Aquifer wells to further delineate the CT plume.

The original well couplet was located near five formerly used drinking water wells that had been abandoned or destroyed several years earlier. Upon review, it was determined that some of the formerly used drinking water wells had been constructed with insufficient sanitary seals and may have acted as vertical conduits from the shallow aquifer to the deeper drinking water aquifer (including the Lower 180-Foot and 400-Foot Aquifers). In 1999, the pumps within three of the remaining abandoned drinking water wells were removed, groundwater samples were collected with a depth-specific sampling device, and the wells themselves were destroyed to eliminate potential further downward migration of CT.

The installation of additional monitoring wells in the A-Aquifer and the Upper 180-Foot Aquifer indicated a complex variety of groundwater flow directions, including the apparent historical influence of the vertical

conduits. Quasi-regional data indicated that flow directions in the Lower 180-Foot and 400-Foot Aquifers represented yet another direction of flow with significant seasonal gradient fluctuations that are dominated by the irrigation cycle of the Salinas Valley agricultural industry.

At the time this site investigation began (1998), water quality data from the Lower 180-Foot and 400-Foot Aquifers were limited to historical data from the drinking water wells when they were operational and sampled for VOCs (1985-1991), from an off-post private irrigation well (“Mini-Storage well”) that is currently active, and a well installed in 1963 to monitor seawater intrusion (“Airfield well”). Historical data indicate a maximum concentration of 11 µg/L but with average concentrations at each well ranging from 0.8 to 4.7 µg/L (state cleanup level is 0.5 µg/L). Samples collected from the off-post private irrigation well, screened in the Lower 180-Foot Aquifer, indicate that CT is still present at concentrations between 5 and 7 µg/L. CT was recently detected at the Airfield well range at 3.0 µg/L.

Due to the presence of CT in an off-post private well and the unknown potential for contamination at a nearby active drinking water well (screened in a much deeper aquifer than the original wells), regulatory agencies requested in 2001 that the Army further characterize the Lower 180-Foot and 400-Foot Aquifers.

RECENT CARBON TETRACHLORIDE INVESTIGATION

Six locations were selected based on (1) historical groundwater flow patterns based on previous groundwater extraction, (2) quasi-regional data indicating likely current groundwater flow directions, and (3) areas of known current or historical CT contamination (*Harding ESE, 2002*). Because at least one of the previously used municipal wells appeared to have acted as a vertical conduit, borings were installed downgradient from the previously used drinking water wells in a pattern to account for anticipated seasonal gradient and flow direction variations. Figure 1 illustrates the location of each of the boreholes, labeled MP-BW-30, MP-BW-31, MP-BW-32, MP-BW-33, MP-BW-34, and MP-BW-35. “MP” stands for multiple-port and “BW” stands for basewide.

Borehole Installation

Prior to installing the boreholes, Monterey County permits and subsurface utility and biological clearances were obtained for each well location. Because each borehole was completed with multiple monitoring ports, each monitoring port has been named to identify its relative depth. Borehole drilling and outer well construction activities began the week of August 20 and ended the week of October 15, 2001.

Each borehole was drilled using a truck-mounted mud rotary drilling rig owned and operated by Water Development Corporation (Zamora, California) under the field supervision of a Harding ESE geologist. Two drilling rigs had been made available during this field program. All work was supervised by a Harding ESE California registered geologist. All boreholes were logged from the drill cuttings; soil was classified according to ASTM D 1586-84. A continuous core sample was collected at MW-BW-32-180 from below a depth of approximately 200 feet. The total depth of each borehole was pre-determined by the depth of the deepest suspected vertical conduit in the area, a now-destroyed municipal well. With the exception of MW-BW-32-180, each borehole was drilled with a 10^{5/8}-inch diameter bit; MW-BW-32-180 was first cored with a 2-inch wire-line core barrel.

Once the pre-determined total depth for each borehole was reached, geophysical logs were run by Welenco, Inc. (Salinas, California) using resistivity (16 and 64 normal and point), natural gamma, spontaneous potential, and caliper sondes.

Outer Well Design, Installation, and Development

The combined data from the geophysical and lithologic logs were used to design the outer monitoring well that would ultimately house the Westbay monitoring system (Figures 3, 4, and 5). Each outer well was constructed with 4-inch diameter Schedule 80 PVC casing and 5-foot PVC screen sections (0.020-inch slot size). Each well was built with six screened intervals except for MP-BW-33 and MP-BW-34 (five screens each) and MP-BW-35 (seven screens). To aid in the installation of the individual sand pack and bentonite seals associated with each screened interval, the tremmie pipe with centralizers was installed to the total depth of the borehole before placing the outer well. Centralizers were installed immediately above and below each well screen and every 40 feet above the well screen to provide a minimum 2-inch clearance between the borehole wall and the well casing during construction activities.

Monitoring well filter packs consisted of #3 Lonestar sand tremied into place from the bottom of the boring to approximately five feet above and below each screen. A bentonite/sand seal was placed above each sand pack to completely isolate each screened section and maintain vertical competency of the final monitoring well. Sand was mixed with the bentonite seal to aid in the confirmation of each seal by a weighted line; a pure bentonite seal would not be easily confirmed (tagged) and its use might have produced an improper placement of the seal. The sanitary seal consisted of a bentonite/cement slurry.

After the grout had set for at least 24 hours, each outer well screened section was developed by bailing and air-lifting using a well development rig. Indicator parameters (pH, temperature, and conductivity) were monitored and recorded during development. Well development typically continues until the indicator parameters stabilize or 15 well volumes of groundwater are removed. However, due to the use of drilling mud, substantially more than 15 well volumes were removed. Although not a criteria to evaluate development progress, turbidity values were also recorded and provided a visual indication of the development progress. Development continued until turbidity values dropped below 50 NTU, since other parameters generally stabilized much earlier.

In addition to providing criteria for evaluating the status of development, conductivity data were also used to indicate water quality in the native formation. Typically conductivity values would be elevated due to the presence of drilling mud in the borehole and would be expected to decrease over time. However, conductivity increased over time at several monitoring zones and proved to be an indication of elevated salinity levels. In fact, the higher conductivity values measured during development correlate with borehole resistivity logs indicative of seawater intrusion. As will be discussed below, chloride concentrations measured in groundwater samples also indicate significant seawater intrusion.

Purged groundwater from MP-BW-31 and MP-BW-32 located within the biological reserve was transferred to a storage tank for chemical characterization and disposal. Purge water from the remaining wells was transferred to a trailer-mounted 4,000 gallon tank prior to sampling using EPA Test Method 8260B. No organic compounds were detected in samples collected from either storage tank. Water from the storage tank was discharged to the sanitary sewer; water from the 4,000 gallon trailer-mounted tank was discharged to the ground with regulatory approval.

Westbay MP38 System Installation

Once the development process was complete for each outer well screen section, a Westbay MP38 monitoring system was installed. A Westbay representative was available on-site to oversee the installation of each system in two mobilization events (three wells per mobilization).

Wells MP-BW-30, MP-BW-33, and MP-BW-32 were installed during the first Westbay mobilization. The two-day installation process for each well included: confirming the total depth of the well, laying out each Westbay component on-site, assembling the couplings to each component, and then assembling each component with the assistance of the development rig.

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May 12, 2002

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The assembly is a time-consuming (one day per well) but thorough process that includes pressurizing each component joint for approximately one minute to ensure that the O-ring completely seals the joint. Once each joint was fitted together, a shear wire was installed to attach each coupling to the Westbay casing. Each Westbay system is designed to be entirely water tight upon completion to ensure that formation water only enters the well when the sampling tool is attached to a sample port.

The second day at each well was spent pressurizing the Westbay packers located above and below each monitoring zone aligned with the screened intervals. Thus, just as the bentonite/sand seals placed outside of the four-inch diameter outer well casing isolate each sand pack, the Westbay packers isolate each monitoring zone within the outer well, thereby isolating each monitoring zone.

Because each Westbay well consists of multiple monitoring zones, each zone has been named according to its depth from ground surface. The name of each monitoring port is based on (1) the name of the borehole names, and (2) the depth of each monitoring port from ground surface. Therefore, the monitoring well as a whole (including all ports) is referred to by the well name (e.g., MP-BW-30) and individual ports are referred to by the complete monitoring port name (e.g., MP-BW-30-282).

Following the complete installation of each Westbay system, pressures were read from each monitoring port as well as from quality control (QC) ports located between the packers. Pressures were read at each monitoring port prior to and after opening the monitoring port to ensure that the valve opened and closed properly. Pressures were also read from each QC port installed between the Westbay packers to monitor the pressure in the blank section of the well; a change in pressure at one or more of these QC ports over time could indicate that a packer has failed and needs to be replaced.

MONITORING RESULTS

Groundwater Elevations and Flow Directions

Groundwater pressures measured in December 2001 and March 2002 indicate that a potential for upward flow from the 400-Foot to the Lower 180-Foot Aquifer exists with a minor differential head of about one foot (Figure 3). It is not yet known whether this pressure gradient is stable throughout the annual irrigation season or not.

Within the Lower 180-Foot Aquifer, groundwater pressures were lowest within the middle portions in December 2001, possibly reflecting vertical heterogeneity, although no clear correlation with a specific lithologic unit was observed at these depths. The lowest groundwater pressures in March 2002 were in the upper and middle portions (Figure 3) which may reflect the seasonal rise in groundwater elevations typically observed at the end of the winter wet season and prior to the onset of the irrigation season in nearby Salinas Valley.

Both sets of measurements indicate generally the same southeast to east direction of groundwater flow in each aquifer. Although the gradients in each aquifer were similar in December 2001, the gradient in the 400-Foot Aquifer in March 2002 was roughly double that of the Lower 180-Foot Aquifer, presumably due to preferential withdrawal from the 400-Foot Aquifer for irrigation purposes (which had begun in February 2002). Subtle differences between December 2001 and March 2002 groundwater flow directions reflect the seasonal influences of the active drinking water wells to the southeast and the many irrigation wells to the east. The seasonal influence of irrigation from the Salinas Valley cannot yet be determined until a full year of monitoring data has been evaluated (*Harding ESE, 2002*).

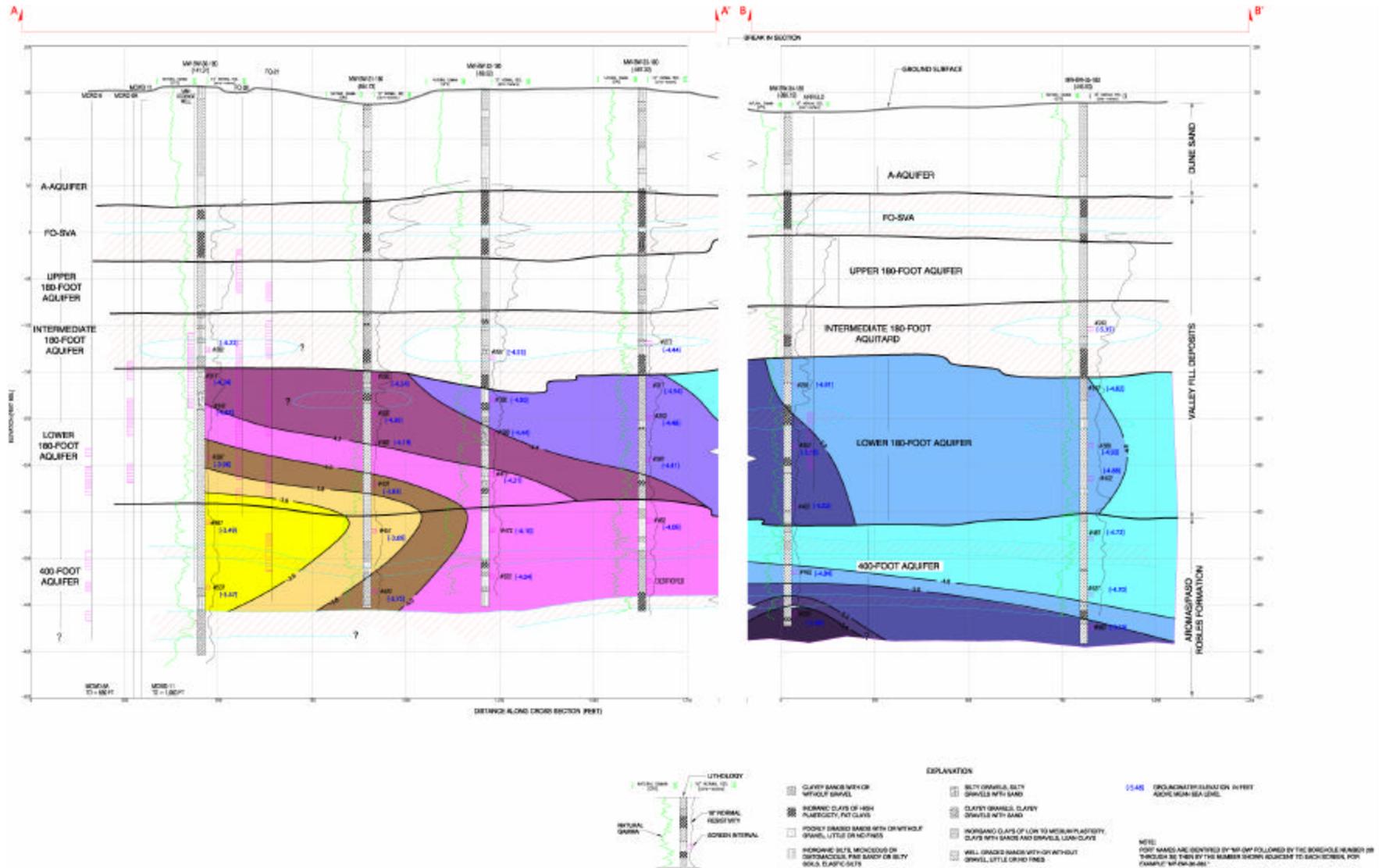


Figure 3 Groundwater Elevation Contours, March 2002

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Carbon Tetrachloride Distribution

Analytical data from the Westbay wells, private irrigation well, and the Airfield well collected in December 2001 and March 2002 suggest that CT is present in the Lower 180-Foot Aquifer and is not present in the 400-Foot Aquifer (Figure 4). CT concentrations in December 2001 from the Westbay monitoring ports were low, ranging from below the reporting limit (0.5 µg/L) to 2.9 µg/L. In March 2002 the maximum concentration rose to 4.1 µg/L. The state maximum concentration level (MCL) is 0.5 µg/L. The December 2001 concentrations are suspected to be biased somewhat low because of the recent drilling and installation activities that may have destabilized local water chemistry. Nonetheless, CT was detected near the detection limit in the two furthest downgradient Westbay wells (almost a mile) within the Lower 180-Foot Aquifer and were again detected in March 2002 at similar concentrations.

CT has not been detected in monitoring ports within the 400-Foot Aquifer, which is consistent with the upward groundwater flow direction from the 400-Foot to the Lower 180-Foot Aquifer. Assuming an upward potential for flow is maintained throughout the seasonal irrigation cycle, it is likely that the downward migration path of CT stops within the Lower 180-Foot Aquifer.

The width of the plume cannot yet be determined, but appears to be at least 1/3 mile wide and about one mile long (Plate 4). The horizontal east-west distribution of CT seems inconsistent with the southeasterly groundwater flow direction as measured during winter months; however, it is anticipated that horizontal flow directions will shift eastward during the irrigation season (summer months) toward the agricultural center of the Salinas Valley.

CT is found near the top of the aquifer near the suspected entry point (from shallower aquifers) and extends downgradient about one mile, progressively migrating downward to the lower half of the aquifer (Figure 4). The vertical distribution of CT appears to correlate well with groundwater pressure data that suggest a low-pressure zone in the middle to lower portion of this aquifer.

Because of the unexpected northern distribution of CT in the Lower 180-Foot aquifer indicated by the detection of CT at the Airfield well, the northern perimeter of the plume is not controlled and thus additional data will be required to further delineate the width and possibly the downgradient extent of the plume. Due to the possibility of a different vertical conduit location than was expected, additional upgradient control may also be required.

The analytical program will be expanded to include analytes indicative of natural attenuation conditions, such as major cations and anions, dissolved gases, REDOX potential, and speciated iron, sulfur, and nitrogen. Results from the March 2002 sampling event indicate that small pockets of reductive environments within an otherwise aerobic groundwater environment may be present within the Lower 180-Foot or 400-Foot Aquifers. Namely, a sulfur odor was noted along with persistent gas bubbles in samples from several of the deeper ports, which may be indicative of organic reduction in nearby clay layers. Also, chloromethane, a daughter product of CT, was detected in many samples collected during the March 2002 event. It is not yet clear whether this compound represents natural degradation of CT in these aquifers. The presence of dissolved gases and possible CT daughter products may be very influential when remedial options such as natural attenuation are evaluated.

Seawater Intrusion

Chloride and TDS have also been analyzed in samples from the Westbay monitoring ports in December 2001 and March 2002 (Figure 5) to evaluate the status of historical data seawater intrusion in the area (from previous municipal well activity). Additionally, the extensive development process was anticipated to be insufficient for each monitoring port to fully equilibrate with formation water quality with respect to VOC concentrations and thus chloride concentrations were used to track recovery.

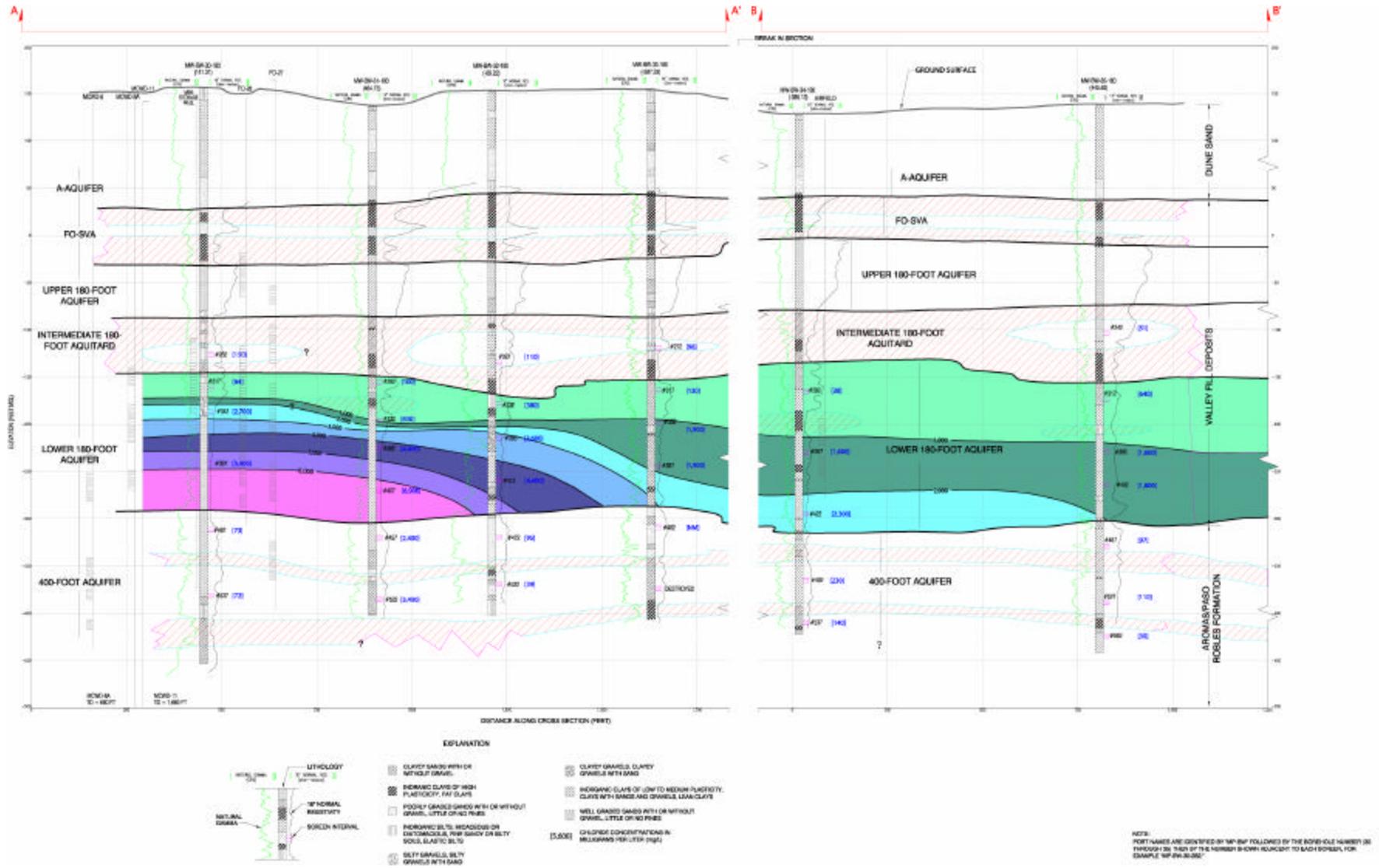


Figure 5 Chloride Concentrations, March 2002

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Knowing that chloride concentrations were elevated from historical seawater intrusion made this a better compound to monitor the development status than VOCs such as because it was not known how extensive the distribution of CT or any other VOC might have been or what concentrations could be expected. It is also not unusual for samples from deep wells at former Fort Ord to not reach equilibrium with respect to VOC concentrations for one or two quarterly sampling events after development due to the significant disturbance from the drilling activities.

Elevated chloride concentrations were detected consistently in December 2001 and March 2002 at monitoring ports in the Lower 180-Foot Aquifer, particularly in the bottom portion, and demonstrated a strong correlation with down-hole resistivity data and regional information. The contrast in chloride concentrations between the Lower 180-Foot and 400-Foot Aquifers reflects the high transmissivity of the Lower 180-Foot Aquifer relative to the 400-Foot Aquifer and thus the preferential intrusion of seawater through the Lower 180-Foot Aquifer, rather than the 400-Foot Aquifer (Figure 5).

Chloride concentrations along the bottom of the Lower 180-Foot Aquifer range from 6,900 mg/L (about 30 percent seawater) to 1,800 mg/L and reflects significant seawater intrusion throughout the area. Historical data from 15 to 20 years ago from nearby drinking water wells located upgradient of the Westbay wells prior to their abandonment indicated concentrations as high as 2,800 mg/L, presumably somewhat diluted from the longer screen intervals and cross-production from deeper aquifers.

The elevated chloride concentrations indicate that the Westbay well development process was successful and that samples reflect true formation conditions, at least with respect to chloride concentrations. It appears that the lack of a standing water column, as with a standpipe-type well construction, and the in-situ nature of the Westbay samples leads to a faster recovery time for each monitoring port. Additionally, data from the Westbay wells indicate that, despite inactivity from the drinking water wells for over 15 years, historical seawater intrusion has remained in the area and appears to have continued passively migrating inland toward the active drinking water wells serving the former Army base and the agricultural center of the Salinas Valley.

SUMMARY

Thirty-five Westbay monitoring ports were installed in six boreholes (five to seven ports per location) in November 2001 at former Fort Ord to further characterize the Lower 180-Foot and 400-Foot Aquifers with respect to CT contamination. The Westbay monitoring system was selected because multiple monitoring ports could be installed at specific depths within a very short time and with minimal drilling costs. The 35 Westbay monitoring ports were installed to depths of almost 600 feet at six locations within a three-month period.

Results indicate that the water quality equilibration time at each port is shorter relative to single-screen wells previously installed at former Fort Ord. Typically, several months may be needed before representative samples may be obtained from a single-screen well at former Fort Ord. The Westbay ports appear to have reached equilibrium, at least with respect to chloride concentrations, within weeks of their development.

Groundwater elevation data measured at each Westbay monitoring port reflect the high transmissivity of the Lower 180-Foot Aquifer relative to the 400-Foot Aquifer, and that significant seasonal pressure changes due to irrigation in the nearby Salinas Valley are observed throughout the each aquifer. These data also illustrate the potential upward gradient from the 400-Foot Aquifer to the overlying Lower 180-Foot Aquifer. Continued monitoring of aquifer pressures at specific depths should illustrate preferential pathways for potential contaminant migration under different seasonal conditions.

The CT plume originates in a shallow unconfined aquifer from an unknown source and was intercepted by one or more vertical conduits at previously used drinking water wells (now destroyed) that allowed the CT to migrate downward to underlying aquifers. Results from recent sample events indicate that CT is present in the Lower Draft

180-Foot Aquifer above the state cleanup level of 0.50 µg/L (the maximum CT concentration is 6.7 µg/L). The installation of Westbay wells resulted in the quick assessment of the site area both vertically and horizontally, and continued monitoring may identify the specific well or wells where the primary vertical conduit existed. Future remedial activity, if necessary, will be assisted considerably by the depth-specific characterization of the CT plume.

Seawater intrusion within the Lower 180-Foot Aquifer, as indicated by elevated concentrations of chloride, has been well characterized by the Westbay well data and preempts of a revision of the current level of understanding of intrusion with respect to the Salinas Valley region. Chloride concentrations as high as 6,900 mg/L indicate not only that historical seawater intrusion has not rebounded toward Monterey Bay upon the cessation of municipal well activity 20 years ago, but that it has continued to migrate toward the seasonally low pressure area below Salinas Valley in response to significant groundwater extraction for irrigation of a major agricultural center. Due to the depth-specific nature of the Westbay sampling system and the density-driven distribution of seawater relative to fresh water, Westbay wells may be particularly effective tools to monitor seawater intrusion.

ACKNOWLEDGEMENTS

Harding ESE thanks the Army and USACE – Sacramento District, for their technical support and helpful suggestions. We also thank and recognize Westbay Instruments, Inc. for their significant contribution of graphics and technical support.

REFERENCES

Harding Lawson Associates (HLA now known as Harding ESE, Inc. [Harding ESE]) 1994. *Draft Final Basewide Hydrogeologic Characterization, Fort Ord, California*. Prepared for U.S. Department of the Army, Corps of Engineers, Sacramento District. June 10.

_____, 1995. *Final Basewide Remedial Investigation/Feasibility Study, Fort Ord, California*. Prepared for U.S. Department of the Army, Corps of Engineers, Sacramento District. April 6.

Harding ESE, 2002. *Preliminary Draft Carbon Tetrachloride Investigation Drilling Letter Report – Westbay Wells, Former Fort Ord, California*. Prepared for U.S. Department of the Army, Corps of Engineers, Sacramento District. February 15.

Westbay, 2002. Westbay Instruments, Inc. at <http://www.westbay.com>.