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FINAL
SWAT REPORT
OLD UCD LANDFILL
UNIVERSITY OF CALIFORNIA, DAVIS

DAMES & MOORE

July 1990
Job No. 00234-213-044

DAMES & MOORE PROFESSIONAL LIMITED PARTNERSHIP
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July 1, 1990

California Regional Water Quality Control Board
Central Valley Region
3443 Routier Road
Sacramento, CA 95827

Attention: Mr. Steve Rosenbaum

Certification
Old UCD Landfill SWAT
Davis, California
Job No. 00234-213-044

Dear Mr. Rosenbaum:

I certify that this Solid Waste Assessment Test (SWAT) Report prepared for the University of California Davis's Old UCD Landfill contains an analysis of groundwater and surface water adjacent to the landfill and that this data represents a reasonable indication that groundwater beneath the site has been impacted by leakage.

I am a Registered Geologist, registered pursuant to Section 7850 of the Business and Professions Code. I have at least five years experience in groundwater hydrology.

Sincerely,

DAMES & MOORE

REGISTERED GEOLOGIST ANDREW A. KOPANIA No. 4711 STATE OF CALIFORNIA

Andrew A. Kopania
Registered Geologist No. 4711
Expires 6/30/92

AAK/tv

Enclosure

UCD2.031

FINAL
SWAT REPORT
OLD UCD LANDFILL
UNIVERSITY OF CALIFORNIA, DAVIS

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EXECUTIVE SUMMARY

This Solid Waste Water Quality Assessment Test (SWAT) Report has been prepared by Dames & Moore for the University of California, Davis. The SWAT investigation was performed to assess the possibility of leakage from the Old UCD Landfill and the potential for impacts to groundwater, surface water, vadose zone water, and soil. The SWAT report has been prepared in accordance with the requirements specified in the Calderon Bill (AB 3525) and Title 23, Chapter 3, Subchapter 15 of the California Code of Regulations.

The Old UCD Landfill is located off Old Davis Road approximately one mile south of the University campus in Davis, California. The landfill is located on University-owned land, a portion of which is the Laboratory for Energy-Related Health Research (LEHR facility), a U.S. Department of Energy (DOE) research facility in operation since 1958. The remainder is on land administered by the Department of Animal Resources Services (ARS). The South Fork of Putah Creek is located along the southern edge of University property approximately 200 to 300 feet south of the landfill.

The landfill consists of three separate disposal areas, each operated during a different time period by the University of California. All three disposal areas are inactive and have been so since the mid-1960s. Two of the disposal areas are partially covered by LEHR facility structures and the other is beneath presently unused ARS land. The landfill accepted University-generated wastes which included municipal-type wastes, Physical Plant-generated wastes, and campus laboratory-generated wastes.

Previous investigations at the site have centered on potential soil and groundwater contamination due to LEHR and UCD-related activities such as the known burials of radioactive waste in trenches at the facility. Several burial trenches have been located by backhoe excavation. Elevated levels of heavy metals (primarily chromium and lead) and nitrate were detected in groundwater. Some volatile organic compounds and the radionuclides tritium, strontium-90, and radium-226 were detected in soil.

The SWAT investigation consisted primarily of quarterly monitoring for one year of groundwater in upgradient and downgradient wells and surface water in Putah Creek.

The following is a listing of the monitoring points, whether upgradient or downgradient, and the number of sampling rounds conducted for each point.

Groundwater: UCD-2, downgradient, 3 rounds
UCD-4, upgradient, 4 rounds
UCD-8/13, (well pair), downgradient, 4 rounds
UCD-9/12, (well pair), downgradient, 3 rounds
UCD-10, downgradient, 3 rounds
UCD-11, downgradient, 3 rounds, and
UCD-14, downgradient, 3 rounds.

Surface water: PCU-1, upstream, 3 rounds,
PCU-1D, upstream, 3 rounds, and
PCD-1, downstream, 3 rounds.

Vadose zone water: L-1, downgradient, 3 attempts,
L-2, downgradient, 3 attempts,
L-3, upgradient, 3 attempts, and
L-4, downgradient, 3 attempts.

Soil samples were collected during installation of SWAT monitoring wells and analyzed for the SWAT investigation. Collection of vadose zone water samples was attempted, but low permeability soils yielded virtually no water during several collection attempts.

Subsurface strata beneath the landfill consists primarily of silty clay and very fine sandy clayey silt to a depth of approximately 80 feet below ground surface. These sediments were deposited by fluvial processes associated with Putah Creek. Laboratory-determined vertical permeabilities for the shallow water-bearing zone (water table) in these sediments range from 1.52×10^{-9} to 4.78×10^{-9} centimeters per second (cm/sec). Below 80 to 85 feet is a coarse sand and gravel layer that is shown in drilling logs for many wells in the vicinity of the site.

Groundwater beneath the site is approximately 50 to 60 feet deep but can vary seasonally more than 15 feet in some locations. Groundwater flow direction is primarily towards the northeast away from Putah Creek, but can also vary seasonally following large precipitation events. Groundwater recharge to the shallow water-bearing zone appears to be primarily by losses from Putah Creek. Temporary changes in groundwater flow direction and gradient can occur when recharge from Putah Creek increases following precipitation events.

Reported results from chemical analyses show elevated levels of volatile organic compounds (primarily chloroform, 1,1-dichloroethane, and 1,1-dichloroethene) in downgradient well pair UCD-9/12. Chloroform was also reported for samples from the upgradient well UCD-4, but at much lower levels than in UCD-9/12 samples. Reported levels of some volatile organic compounds in samples from UCD-9/12 exceed maximum contaminant levels (MCLs) but are not hazardous as defined in Title 22.

Levels of hexavalent chromium and total chromium exceeding the maximum contaminant level (MCL) were reported for samples from well UCD-2, UCD-11, and UCD-12. The highest levels reported were for UCD-11 samples. Levels of nitrate exceeding the MCL were reported for wells UCD-2, UCD-8, UCD-9, and UCD-12 with the highest levels reported for UCD-9 and UCD-12 samples.

Reported detections for surface water samples were scattered and showed little pattern between upstream and downstream samples. Only sodium, chloride, and nitrate concentrations were consistently higher in downstream samples compared to upstream.

Results of chemical analysis of soil samples showed few or no detections of volatile and semivolatile organic compounds, pesticides, and PCBs. Reported detections of chloroethane and dichloromethane for soil samples may be due to laboratory errors as these compounds were detected in laboratory method blanks. Only in the case of nickel do levels of metals in soil exceeded the guideline of 10 times the soluble threshold limit concentration (10 x STLC).

Based on the results of the SWAT investigation of the Old UCD Landfill we conclude the following:

- The existing groundwater monitoring wells UCD-2 (now abandoned), UCD-4, UCD-8 and new SWAT wells UCD-10, UCD-11, UCD-12, UCD-13, and UCD-14 appear to have provided representative groundwater samples both upgradient and downgradient of the three disposal areas based on groundwater flow direction data.

- Groundwater downgradient of disposal area #2 appears to have been impacted by leakage. Several volatile organic compounds were reported for samples from the well pair UCD-9/12 with particularly high levels of chloroform. A likely source of the leakage is the known waste disposal trenches in disposal area #2. However, the presence of low levels of chloroform in samples from UCD-4 (upgradient well) suggests the possibility of other sources.

- Reported levels of hexavalent chromium exceeding the MCL in samples from UCD-11 suggest possible leakage from a source immediately upgradient of this well. The only known potential source immediately upgradient of UCD-11 is disposal area #1. Reported levels of volatile organics, however, are low in samples from UCD-11.

- General water quality parameters are elevated in downgradient well samples relative to upgradient samples which suggests leakage to groundwater. Nitrate was reported at levels exceeding the MCL of 45 mg/l in wells UCD-2 (now abandoned), UCD-8, UCD-9, and UCD-12. The amount of contribution of nitrate in groundwater from the landfill is unknown. Other potential sources such as research animals at LEHR or surrounding agricultural practices may contribute nitrate to groundwater.

- Results of analysis of surface water samples combined with groundwater flow direction data suggest that the landfill disposal areas have no affect on Putah Creek water quality.

- Results of chemical analyses of soil show no residual affects of leakage.

- Results of physical testing show that vertical permeabilities of selected soil samples collected from the shallow-water bearing zone are very low. Groundwater flow rates calculated using the laboratory-determined permeabilities consequently are also very low.

The relatively fast response of water levels in wells completed in the shallow water-bearing zone following precipitation events and increased recharge from Putah Creek suggests that greater horizontal (or lateral) permeability, and therefore greater flow rates, must exist due to heterogeneous conditions in the subsurface.

- Results of radiological analyses of shallow groundwater samples from the UCD 8/13 well pair have shown hydrogen-3 (tritium or ^{3}H) and carbon-14 (^{14}C) in excess of drinking water standards in three of four quarterly sampling rounds. In Round IV sampling, both radionuclides were reported as "not detected" from this well pair. Elevated levels (above drinking water standards) of radium-226 (^{226}Ra) were reported for UCD-8 samples in Round II, but could not be confirmed by the laboratories. Elevated levels (above drinking water standards) of ^{3}H and ^{14}C were also reported for UCD-4 and UCD-14 in Round III, but were not confirmed by the laboratory. No other radioactive materials above natural background have been detected in groundwater samples. A potential source of radiological contamination is radioactive waste burial trenches adjacent to disposal area #2. Location and sampling of these trenches is ongoing.

- No radionuclides were reported for surface water samples above natural background levels. Radioactive waste burials in the vicinity of the landfill do not appear to affect surface water in Putah Creek.

SWAT REPORT
OLD UCD LANDFILL

1.0 INTRODUCTION

This report presents the results of an investigation conducted for the University of California, Davis (UCD) involving three waste disposal units at the Laboratory for Energy-Related Health Research (LEHR Facility) near Davis, California (Figure 1). The investigation was conducted in order to generate the necessary data for preparation of a Solid Waste Water Quality Assessment Test (SWAT) Report. The goal of a SWAT investigation and Report is to provide an assessment as to whether or not a landfill has impacted or is impacting the waters of the State in order to satisfy the requirements of Section 13273 of the California Water Code, Title 23, Subchapter 15 and the Calderon Bill (1984, AB 3525).

1.1 REPORT PREPARATION

This report has been prepared using the August 1988 SWAT Technical Guidance Manual prepared by the Water Quality Division of the State Water Resources Control Board. The introductory section describes the project regulatory compliance, report format, and certification. The second section describes the purpose of the study, negotiated scope of work, and provides a brief overview of previous work performed at the site. The third section supplies information on site history, construction, and waste characteristics. Section four presents information about on- and off-site groundwater wells. The fifth section addresses surface water and springs within one mile of the site. Section six summarizes regional and site geology and hydrogeology and lastly, sections seven and eight present the results of soil, surface water, and groundwater chemical and radiological characterization, and conclusions, respectively.

1.1.1 Qualifications of Project Manager and Reviewer

The Project Manager for the SWAT Report, Mr. Joseph J. Niland, has over nine years of professional experience as a geologist. Mr. Niland's focus over the last three years has been on solid waste and landfill investigations such as this one. He has successfully completed investigations for public and private operators throughout the State.

The Technical Reviewer, Mr. Andrew Kopania, is a Registered Geologist in California (RG No. 4711). Mr. Kopania has been responsible for oversight of subsurface investigations involving soil and groundwater for over five years. His resume is presented in Appendix A of this report.

2.0 PURPOSE AND SCOPE

2.1 PURPOSE

The purpose of the SWAT process it to evaluate whether a waste disposal unit is adversely impacting waters of the State. The purpose of the investigation was to generate data required to complete the SWAT Report as required by the Central Valley Regional Water Quality Control Board (RWQCB) in compliance with the Calderon Bill (AB 3525).

2.2 SCOPE

The SWAT Proposal (work plan) for the Old UCD Landfill was submitted to the RWQCB in May of 1989 and accepted in June of 1989. The RWQCB presented comments on the proposal which were incorporated into the final SWAT Implementation Proposal to UCD dated 28 July 1989. The approved scope of work is outlined below.

2.2.1 Groundwater Investigation

Nine groundwater monitoring wells were installed at the site by Wahler Associates for a previous investigation. Installation and completion information for these wells is included in Appendix D of this report. Four of these existing on-site wells were utilized as points for the SWAT monitoring program because of their proximal location to one of the waste disposal units. In order to evaluate the impact of all three waste disposal units on groundwater below the site, Dames & Moore installed four additional wells at the site. An additional well, UCD-14, was installed adjacent to wells UCD-8 and UCD-13 for characterization of potential radiological contamination in a deeper aquifer downgradient of known radioactive waste burials. The location of the wells and the reason for their locations are described in Table 1. Details of drilling, well installation, and sample collection are included in Appendix B - Field Investigation.

The first round of SWAT groundwater and surface water sampling was performed in June of 1989 prior to installation of the five SWAT wells described above and consisted of samples collected from wells UCD-2, UCD-4, and UCD-8. An agreement was made between UCD and the RWQCB to have

sampling of these wells constitute the first quarterly round of monitoring for the SWAT investigation (Written communication, Holdstock to Marshall, June 28, 1989). This agreement was made in order to maintain a schedule to complete four rounds of monitoring and the SWAT Report by the July 1, 1990 dead line. Rounds II, III, and IV were conducted in October/November 1989, January 1990, and April 1990, respectively. Well UCD-2 was abandoned following Round III, because of concern by UCD and DOE that its completion through the Old landfill might act as a conduit for leakage to groundwater.

Groundwater samples were analyzed for the following analyses:

- EPA 601 (halogenated volatile organic compounds);
- EPA 602 (aromatic volatile organic compounds);
- ICP metals;
- As, Hg, and Se by atomic absorption;
- K, Na, Mg, Ca;
- Nitrate nitrogen;
- Ammonia nitrogen;
- Total dissolved solids (TDS);
- Chemical oxygen demand (COD);
- Chloride;
- Bicarbonate alkalinity;
- Electrical conductivity;
- pH;
- Turbidity;
- Carbon-14;
- Tritium;
- Gamma spectral analysis;
- Radium-226;
- Strontium-90;
- Thorium-232;
- Cesium-137; and
- Gross alpha and beta radiation.

The SWAT Proposal called for analysis of Total Kjeldahl Nitrogen (TKN), however, nitrate and ammonia were substituted per a RWQCB request (Holdstock-Marshall letter, June 28, 1989). Chlorinated pesticides and PCB's (EPA 608) were analyzed for in the following samples:

Round I - UCD-2, UCD-4, UCD-8
Round II - all SWAT wells
Round III - UCD-4, UCD-8
Round IV - UCD-4, UCD-8

The results of chemical analysis of groundwater are discussed in Section 7.0 of this report.

Depth to groundwater was measured and groundwater elevations calculated in SWAT wells for each round of sampling. Depth to groundwater is also measured by UCD in all groundwater monitoring wells in the vicinity of the landfill on a daily basis. Groundwater elevation contour maps were generated for measurements taken beginning in June 1989. The hydrogeology of the site is discussed in Section 6.0.

2.2.2 Vadose Zone Investigation

Dames & Moore installed four vadose zone wells for collection of water contained in soil pores in the vadose zone. Each well consists of a soil-suction lysimeter set approximately twenty feet below ground surface. The location of vadose zone wells and purpose are described in Table 2. Details of lysimeter installation procedures are included in Appendix B.

Attempts to collect vadose zone water samples were made during Rounds 2, 3, and 4 as the lysimeters were installed subsequent to Round 1 sampling. Only vadose zone well L-1 yielded water in any round of sampling (Round 4). All lysimeters were cleaned and tested prior to installation and worked properly during each sampling attempt. The inability of the lysimeters to draw water from the soil is likely due to the high retention pressure of the soil (predominantly silty clay) caused by relatively dry conditions during the investigation period, and the fine-grained nature of the soil.

Soil samples collected during drilling of borings for the SWAT wells were analyzed for a suite of chemical, radiological, and physical parameters described below. Chemical analysis of soil samples provides some information on the chemical nature of vadose zone water samples, however soil samples were collected during drilling and not on a quarterly basis.

2.2.3 Soil Investigation

Soil samples were collected above the water table in borings for wells UCD-10, UCD-11, UCD-12, and UCD-13 and analyzed for the following parameters:

- EPA 8010 (Halogenated volatile organics);
- EPA 8020 (Aromatic volatile organics);
- EPA 8270 (Semivolatile organics);
- EPA 8080 (Chlorinated pesticides and PCBs);
- CAM metals;
- Hexavalent chromium;
- Nitrate as nitrogen;
- Soil pH;
- Tritium;
- Carbon-14; and
- Gamma spectral analysis.

Problems were encountered with the analytical laboratory such as analyses not performed and sample holding times exceeded. The results of chemical analysis of soil samples are discussed in Section 7.0.

In addition to chemical and radiological analysis of soil samples, physical testing was performed on selected soil samples. Tests performed included permeability, soil moisture/density, and grain size analysis. Results of physical testing of soil samples are discussed in Section 6.2.1.

Further investigation of soil for radionuclide contamination in the vicinity of disposal area #2 is ongoing. This work includes ground penetrating radar (GPR) for location of radioactive waste burials

and backhoe trench excavation for location and sampling of waste burials. Soil borings and/or monitoring wells for collection of soil and/or groundwater samples in the vicinity of waste burials may be included. A report of findings will be submitted upon completion of the investigation.

2.2.4 Surface Water Investigation

The surface water portion of the SWAT investigation focused on the South Fork of Putah Creek. Putah Creek is a tributary to the Sacramento River, although it normally loses all water to infiltration and evaporation as it reaches the Yolo Bypass. Surface water samples were collected upstream and downstream of the Old UCD Landfill at points shown on Figure 2 during Rounds 2, 3, and 4. Surface water sampling locations were also designated for a drainage canal on the east side of the Far Eastern Disposal Area, however, the canal contained no water during any sampling round.

Surface water samples were analyzed for the same suite of chemical parameters as groundwater samples. The results of chemical analysis of surface water samples are discussed in Section 7.0.

2.3 SUMMARY OF PREVIOUS INVESTIGATIONS

Previous work has been conducted at the site by Dames & Moore (1990, 1989), Wahler Associates (1988, 1989), the Department of Energy (1988) and by Rockwell International (1984). The Rockwell investigation was termed an "Initial Assessment Survey" and was conducted for the DOE to assess radiological and chemical contamination associated with LEHR activities.

The 1984 Rockwell investigation concluded that radiological contamination of soil was limited to areas in which it was expected due to known disposal practices. No hazardous levels of chemical contamination were found in soil samples analyzed. The 1988 DOE investigation was primarily a document research investigation to assess past site activities so that the site could be priority ranked by the DOE for future investigation. The 1988 DOE investigation describes past disposal practices at or near the LEHR facility and concludes that these are potential sources of soil and groundwater contamination beneath the site.

The Wahler Associates work was performed for both the DOE and UCD and targeted potential radioactive contamination in an effort to evaluate the potential for impact on soil and groundwater downgradient of the site. A total of nine wells (eight completed at the water table, one completed in the deep aquifer) were constructed, 43 soil borings drilled, and 36 backhoe trenches excavated during the Wahler Associates investigations.

The Wahler Associates investigation concluded that:

- Chromium and lead were detected in groundwater beneath the site at levels exceeding maximum contaminant levels (MCLs);
- Nitrate as nitrogen exceeds MCL in groundwater samples;
- Radium-226 (^{226}Ra) was detected in one well. No strontium-90 (^{90}Sr) was detected;
- Tritium (^{3}H), ^{90}Sr, and ^{226}Ra were detected in soil samples collected beneath the site; and
- Chloroform and methylene chloride were detected at elevated levels in UCD-8 and 9.

Additionally, several radioactive burial trenches were located by backhoe excavation. Not all documented trenches were located, however.

In June 1989 Dames & Moore performed an investigation to assess high turbidity in on-site wells. The investigation consisted of redevelopment and sampling of the wells to evaluate potential causes of high turbidity. Dames & Moore concluded that turbidity was due to improper sizing of well construction materials (well screen and filter pack) and not to the geochemical character of the groundwater or improper development procedures.

In March 1990 Dames & Moore conducted an investigation to assess elevated levels of hexavalent chromium and nitrate as nitrogen in off-site wells (neighbor's wells). The study was designed to evaluate the potential contribution of nitrate to groundwater by various sources, including the LEHR facility. The

study concluded that the LEHR facility was not a likely source of high nitrate concentrations in groundwater and that more likely sources were: UCD sewage treatment outfall into Putah Creek adjacent to the Old Davis Road Bridge, agricultural fertilizer application on surrounding farm land, animal enclosures, and domestic septic systems. No definite conclusions could be made concerning hexavalent chromium due to a lack of regional data.

3.0 SITE DESCRIPTION

3.1 GENERAL SITE DESCRIPTION

The Old UCD Landfill is located on Old Davis Road approximately one and one half miles south of Davis, California in Section 21, Township 8 North, Range 2 East, MDB&M (Figure, 1). The landfill is no longer active and the site is currently occupied by the Laboratory for Energy-Related Health Research (LEHR), a Department of Energy (DOE) radiological research facility in operation at this location since 1958 (then the Atomic Energy Commission - AEC). The land is owned by the Regents of the University of California and all structures are owned by the DOE (DOE, 1988). The landfill was operated by the UCD Physical Plant. Figure 2 shows the location of the project site in relation to County Assessor's parcels.

Figure 3 shows the estimated boundaries of the landfill disposal areas in relationship to the LEHR facility. Three disposal areas were used at separate times (described below in Section 3.3) and for the purposes of this investigation, are designated as:

1. Disposal area #1;
2. Disposal area #2; and
3. Disposal area #3.

3.2 CURRENT PERMITS AND REGULATORY ORDERS

There are no permits for the landfill which is designated as Rank 4 under the SWAT compliance program regulated by the California Water Resources Control Board. This ranking calls for the submittal of the SWAT Report to the Regional Water Quality Control Board (RWQCB) by July 1, 1990.

3.3 WASTE DISPOSAL HISTORY

The landfill, which last accepted waste in 1967, consists of three separate disposal areas operated at different times. The oldest of the three disposal areas is presently covered by the ^{60}Co Irradiation field (disposal area #1). According to a 1988 Department of Energy (DOE) report for the facility, disposal

in this area began in the 1940s and ceased in the 1950s. An Army Corps of Engineers aerial photo dated February 28, 1940 reveals no evidence of landfill activity in the area. A Bureau of Reclamation aerial photo dated April 9, 1949 did reveal a linear east-west oriented surficial disturbance in the present location of the ^{60}Co-Field. Several dirt roads were also noted leading towards this linear feature. The disturbance may be a trench excavation used for waste disposal which is consistent with known methods of operation at the other disposal areas of the landfill. UCD employees familiar with landfill operations at this site stated that the area now covered by the ^{60}Co field was used as a landfill until the late 1950s to early 1960s.

The next oldest disposal area, disposal area #2, received wastes from 1956 to 1967 and consisted of twelve east-west oriented disposal trenches (DOE, 1988). Currently, this area is partially covered with the eastern most of two sets of dog pens used for animal research at the LEHR facility (Figure 3). A 1958 engineering drawing for the site (referred to on the drawing as the Veterinary Science Strontium 90 Project) shows an area labeled as the "University Dump" in the location of the present day eastern set of dog pens. The pens overlying the disposal area are no longer used. UCD employees confirmed this disposal area location and period of operation.

Disposal area #3 was the most recently used disposal area according to UCD employees. It is located east of the old sewage treatment plant (Figure 3). UCD employees stated that this disposal area received University-generated wastes from 1963 to 1967. Wastes disposed of in this area were placed into two large pit-like excavations then covered with a soil cap. Some liquid wastes were reported to have been incinerated in these pits.

The combined total acreage for the three disposal areas is estimated at approximately six acres based on information in the 1988 DOE report and from discussions with UCD employees.

3.3.1 Waste Description

According to UCD employees, wastes generated by UCD included: municipal wastes, construction wastes, laboratory chemical wastes, Physical Plant petroleum wastes, and campus incinerator ash. The quantity of wastes disposed of in disposal area #2 is estimated at 19,260 cubic yards (DOE,

1988). There are no records pertaining to types or quantities of wastes disposed of in disposal area #1 or disposal area #3.

3.3.2 Operational Methods

The method of operation was fill and cover. According to Physical Plant employees, each disposal area consisted of a series of trenches or pits into which trucks would dump their waste loads. Cover material was placed on the waste during the closure of each trench or pit. UCD employees stated that some liquid wastes were incinerated after disposal into the far eastern disposal area.

3.4 SITE CONSTRUCTION DETAILS

Physical Plant employees indicated that pits and trenches at the three disposal areas were excavated approximately 10 to 12 feet below grade prior to being filled. The excavations were apparently unlined and no leachate collection systems were installed. No construction plans, drawings, or maps are known to exist.

3.5 SITE CLOSURE DETAILS

The three disposal areas are inactive. Apparently, when the disposal areas were closed, approximately two to three feet of compacted soil was placed over the waste disposal trenches and pits. No detailed drawings, compaction records, or additional data regarding closure procedures exist.

Currently, disposal area #1 and 2 are partially covered by structures associated with the LEHR facility. These structures were built after the closure of the disposal areas. Movement of disposal practices from disposal area #2 to disposal area #3 was probably due to expansion of the research facilities at LEHR (DOE, 1988). Several storage buildings are located in the vicinity of the far eastern disposal area, however, the area immediately overlying the disposal area remains open and has been unused since its closure. According to Mr. Dick Yamaichi (personal communication, March 1990) of UCD Office of Environmental Health and Safety, no future development of these areas is currently planned.

3.6 LAND USE WITHIN ONE MILE OF THE SITE

Land surrounding the Old UCD landfill is owned by both private landowners and UCD and is used for agriculture and animal research. South and east of the facility are privately owned lands on which wheat, tomatoes, corn, barley and oats are grown by local farmers. The property west and north of the facility is owned by UCD and is currently used for various types of animal, agricultural, and health research.

The South Fork of Putah Creek flows from west to east along the southern boundary of the site (Figure 3). The creek area is used for recreational purposes including hiking, bicycling and wildlife observation. The narrow strip of land between Putah Creek and the landfill is maintained by the UCD Arboretum.

A UCD sewage treatment outfall discharges to Putah Creek on the west (upstream) side of the Old Davis Road Bridge. The outfall is operated under a National Pollution Discharge Elimination System (NPDES) permit administered by the U.S. Environmental Protection Agency (EPA) and monitored by the RWQCB.

5.0 SURFACE WATER WITHIN ONE MILE OF THE SITE

Figure 1 shows surface water bodies within one-mile of the site. There are no springs within one mile of the site. The South Fork of Putah Creek forms the southern boundary of the University property south of the landfill and contains water year round, though flow is greatly reduced during the dry summer months. The North Fork of Putah Creek is located within one mile of the landfill (Figure 1) in the UCD Arboretum on the south side of the campus. Here, the creek is known as Mrak Lake and is enclosed on both ends so that there is no flow into or out of this section of the creek. There is no flow through the North Fork of Putah Creek as all flow is diverted into the South Fork (Kevin Williams, UCD Arboretum, personal communication; DOE, 1988).

Two other surface water bodies are located within one mile of the site. These are impoundments located at the intersection of Highway 113 North and Interstate 80 and, according to Mr. Jack Sandman of Cal Trans, are used for storm runoff retention and evaporation.

6.0 GEOLOGIC AND HYDROGEOLOGIC SETTING

6.1 REGIONAL SETTING

6.1.1 Physiography

The Old UCD Landfill is located south of Davis, California in the southern portion of the Sacramento Valley. The Sacramento Valley extends from Red Bluff in the North to the Sacramento-San Joaquin Delta region in the south. The Sacramento River, the primary drainage of the Sacramento Valley, is approximately 12 miles east of the landfill. The South Fork of Putah Creek, a tributary of the Yolo Bypass and eventually the Sacramento River, flows west to east along the southern boundary of the landfill and is separated from the landfill by a levee. The landfill is situated on relatively flat-lying land termed the Putah Plain. The average elevation at the site is 50 feet above sea level with a land surface slope of approximately 0.001 foot/linear foot to the east/northeast.

6.1.2 Regional Geologic Setting

The Sacramento Valley is a large asymmetrical structural trough bordered by the Coast Ranges to the west, the Klamath Mountains and Cascade Range to the north, and the Sierra Nevada Mountains to the east. The valley has been filled with sediments derived from both marine and continental sources. The older sediments (Jurassic to Eocene) were deposited primarily in marine environments whereas the younger sediments (Eocene to Recent) were deposited in continental environments including lacustrine, fluvial and alluvial fan environments (Olmsted and Davis, 1961) (Figure 4). Near the eastern margin of the valley the sediments form a thin veneer on crystalline basement rocks. Norris and Webb (1976), indicate a greatest thickness of over 50,000 feet of Jurassic age and younger sediments just west of the central axis of the valley. Figure 5 is a regional cross section of the Sacramento Valley and shows the variation in thickness of the sediment fill.

The site and the surrounding area are located on the geomorphic unit termed "low alluvial plains and fans" (Department of Water Resources (DWR), 1978). This surface represents the distal portions of the alluvial fan deposits associated with Putah Creek.

The sediments which form these alluvial fans consist mainly of silts and clays with coarse grained sediments found locally. The fine grained sediments represent overbank deposits whereas the coarse grained sediments represent channel deposits. The age of these deposits range from late Pleistocene to Recent. The thickness of the alluvial fan deposits is approximately 180 feet (DWR, 1978).

Alluvial fan deposits conformably overlie the Tehama Formation beneath the site. There is some evidence to suggest that farther west, this contact is unconformable (Hubbard, 1989). The Tehama Formation is Plio-Pleistocene in age and is the principal water-bearing formation on the west side of the Sacramento Valley. It is thought to be contemporaneous with the Laguna Formation of the east side of the valley (DWR, 1978; Olmsted and Davis, 1961).

Figure 6 is a map of surface soils in the site vicinity as mapped by the U.S. Department of Agriculture (USDA) Soil Conservation Service for Solano County (Bates, 1977). These soils have formed on the surface of alluvial deposits discussed above and are described as follows:

- Capay silty clay loam (Ca) - dark grayish brown to grayish brown, 40 inches thick over pale brown and yellowish brown clay loam to 60 inches +.

- Reiff fine sandy loam (Ra, Rw) - grayish brown to light yellowish brown fine sandy loam to greater than 60 inches depth.

- Yolo loam, loam clay substratum, and silty clay loam (Yo, Yr, Ys) - dark grayish brown silty clay loam to approximately 20 inches depth over a brown clay layer approximately 8 inches thick over brown loam to greater than 60 inches depth (Bates, 1977).

The above soils are relatively young, weakly-developed soils formed in alluvial parent material during late Pleistocene to Recent time. The A horizons (soil horizon nearest the surface) are relatively thick and organic rich which makes these soils valuable for agricultural uses (Bates, 1977).

6.1.3 Structural Geology

The structure of the Sacramento Valley is generally characterized by sedimentary deposits which dip from the sides of the valley towards its axis. Figure 5 is a regional east-west oriented cross section of the Sacramento Valley near the latitude of the site showing the dip of these deposits. This figure also shows a western offset to the axis of the valley (closer to the Coast Ranges than to the Sierra Nevada Mountains.) As a result of this asymmetry, the sedimentary deposits on the western margin of the valley dip much more steeply than the deposits on the eastern margin. Beneath the central part of the valley where the site is located, shallow sedimentary deposits are relatively flat-lying.

6.1.4 Regional Hydrogeology

The hydrogeology of the Sacramento Valley is characterized by both unconfined and confined aquifers in the nearly flat-lying or gently sloping sedimentary deposits in the upper 3,000 feet of section beneath the valley. No regionally identified confining units exist in the deposits of the Sacramento Valley such as the Corcoran Clay of the San Joaquin Valley. Confining conditions, therefore, are not well-defined on a regional basis.

Groundwater is recharged to the basin primarily through losses of streams where they enter the valley from the surrounding mountains. Groundwater flow direction, in a general sense, is towards the center of the valley from the west and east sides. In the vicinity of the site, regional groundwater flow is easterly towards the Sacramento River and the lowest part of the valley (Figure 7, Dames & Moore, 1990).

At various depths beneath the valley floor, freshwater gives way to saline water in the sedimentary deposits as a result of entrapment during formation of the deposits in a marine environment. The depth to the base of fresh water in the Sacramento Valley varies from as little as 400 feet to over 3,000 feet. Shallowest depths to saline water occur at the edges of the valley and around the Sutter Buttes where the marine deposits are shallowest. The greatest depths to the base of fresh water are found in the southwest portion of the valley where the marine deposits are deepest (DWR, 1978).

6.2 SITE GEOLOGY

Site stratigraphy was observed and logged from soil cores and undisturbed samples collected by Dames & Moore during drilling of borings for wells UCD-10, UCD-11, UCD-12, and UCD-13. Cores were not collected during the drilling of the boring for UCD-14, however continuous return of cuttings to the surface by airlift allowed logging of those sediments.

Site stratigraphy was also observed and logged by Dames & Moore in samples collected by Wahler Associates during the drilling of the borings for wells UCD-1 through UCD-9. Samples from these borings were available for every five foot interval from the ground surface to total depth of drilling.

Borings for all on-site wells penetrated to an average depth of 62.75 feet with a greatest depth attained of 90 feet in the boring for UCD-7. All soil cores, undisturbed samples, and cuttings were logged by qualified Dames & Moore geologists.

Figures 8 shows the location of schematic geologic cross-sections (Figures 9, 10, and 11) of stratigraphy beneath the Old UCD Landfill and the LEHR Facility. These figures show, and it was observed in samples collected, that sediments beneath the site from the ground surface to, and including, the water table zone are predominantly fine-grained. Coarser sediments were observed in the two borings that penetrated beneath the water table zone (UCD-7 to 90 feet and UCD-14 to 86.5 feet). These two borings encountered coarse sand and gravel from approximately 80 feet to total depth (Appendix D).

Sediments above the water table are typically red brown, brown, or yellow brown clayey silt to clay, have medium stiff to very stiff consistency, and low moisture content. The upper five to ten feet encountered in most borings is predominantly a fine sandy silt. A softer consistency, silty layer exists at about 30 feet in most of the borings.

At approximately 40 to 50 feet below the ground surface a very fine sandy silt with variable amounts of clay is encountered. Wells UCD-1 through 6, and UCD-8 and 9 were completed in this zone as this is where the water table was during the time of their construction. In the boring for well UCD-4

this zone is somewhat coarser (sandy silt to sand). UCD-4 is located closest to Putah Creek of all wells on-site and therefore may be penetrating the edge of an old stream channel associated with Putah Creek.

Sediments encountered in the boring for UCD-10, the furthest east of all borings has a consistently higher percentage of clay than borings located further west on the site. Though cross-sections A-A', B-B' and C-C' (Figures 9, 10, and 11, respectively) suggest some degree of lateral continuity from boring to boring, they are interpretative. The cross-sections can not accurately show the configuration of all gradations of one sediment type into another or the actual shape of three-dimensional masses of sediment. These deposits were formed in a fluvial environment associated with deposition from Putah Creek. Common sedimentary features in this type of depositional environment include (from coarser to finer): channel deposits, point-bar sequences, overbank deposits, and flood plain deposits (Leeder, 1982). Gradation of one depositional type (grain size) into another is common and deposits are often complex because of the shifting nature of the location of deposition. As an example, the boring for well UCD-15, which was drilled for a recent DOE site investigation, encountered a gravel from 53 to 58 feet below the ground surface. Well UCD-15 is only 30 feet from UCD-4 and no such gravel was encountered in UCD-4, although this boring penetrated to a depth of 56.5 feet.

No physical testing was performed by Wahler Associates on sediment samples collected from the borings for UCD-1 through UCD-9. Physical testing was performed on samples collected from borings for UCD-10 through 13 and is presented below.

6.2.1 Results of Physical Testing

Physical analyses included constant head permeability (ASTM D2434), soil moisture (ASTM D4318)/density, and sieve analysis (ASTM 1140). Samples selected for physical analysis were collected from depths at which SWAT wells were completed (approximately 55 to 65 feet below ground surface). The results of physical analysis are shown on Table 4. Physical analysis data sheets are included in Appendix F.

Reported permeabilities are extremely low, ranging from 1.52×10^{-9} centimeters per second (cm/sec) for the sample from the boring for UCD-10 at 60 feet to 4.87×10^{-9} cm/sec for UCD-13 at 60 feet.

Results of sieve analysis show that the majority of the sediment (74.5 to 93.1 percent) passes through the #200 sieve which indicates silt to clay size sediments.

Soil density ranges from 1.323 to 1.74 grams per centimeter cubed (gm/cm^3). Soil moisture (original) ranges from 18.1 percent to 28.4 percent.

6.3 SITE HYDROGEOLOGY

Groundwater is encountered beneath the site at approximately 50 to 60 feet below the ground surface. Depth to groundwater varies greatly at this site on a seasonal basis as shown on Table 5.

The water table zone or shallow water bearing zone occurs in relatively fine-grained sediments varying from very fine-grained sandy silt or silty sand to sandy clay. Pumping rates during development of these monitoring wells installed in this zone were correspondingly low (as little as 0.50 gallons per minute).

Wells UCD-12 and 13 were installed adjacent to wells UCD-9 and 8 respectively, to allow collection of groundwater samples from the shallow water bearing zone when the water table is lower than the screen sections of UCD-8 and 9. The materials in which UCD-12 and 13 were screened appear to be similar to those logged in the completion zones of wells UCD-8 and 9, however water levels are consistently lower in wells UCD-12 and 13 (Table 5) suggesting that there is some separation of water bearing "zones" between these well pairs. Evidence of such a separation, however, was not seen logging of soil cores. The zone penetrated by wells UCD-10, 11, 12 and 13 is termed the "intermediate water bearing zone" because of its apparent separation from the shallow water bearing zone exhibited by the difference in their respective water levels.

Drilling of borings for both monitoring well UCD-7 (installed by Wahler Associates) and UCD-14 (installed by Dames & Moore) encountered a dark gray coarse sand to cobble gravel below a depth of about 80 feet. This is termed the deep aquifer. A gravel layer is seen at similar depths in several logs for wells located within one mile of the site (Appendix C) and so appears to be relatively extensive in this area. The gravel underlies silty/sandy clay in which shallower wells are completed and, so, is at least semi-confined.

6.3.1 Groundwater Elevations and Gradients

Figures 12 through 21B are groundwater elevation contour maps for on-site wells. Figures 12, 13, 14, 15 and 16A through 21A are contour maps for groundwater elevations in wells UCD-1 through 6, and UCD-8 and 9 (shallow depth wells). Figures 16B through 21B are contour maps for groundwater elevations in wells UCD-10 through 13 (intermediate depth wells). Table 6 summarizes gradients and directions of flow based on water level elevations in both shallow and intermediate depth wells. Comparison of Figure A versus B maps and Table 6 gradients shows that groundwater direction and gradient is much more variable in the shallow zone than in the intermediate zone. The groundwater gradient in the shallow water bearing zone (water table surface) varies from a low of 0.001 foot per linear foot (foot/foot) in December 1989 to a high of 0.019 foot/foot in September 1989.

In a three month period from September 1989, through November 9, 1989, the direction of groundwater flow beneath the site changed dramatically. Following a precipitation event on September 16 and 17, 1989, the highest groundwater levels on-site were in wells UCD-3 and 5 as opposed to more normal conditions where the highest levels are in UCD-4. Temporary reversals in groundwater flow direction were indicated on contour maps of groundwater elevations at that time. The reversed flow direction continued following another precipitation event October 21-23, 1989, then became northeasterly again by December 1989 (Figures 14, 15, and 16A). Following a large precipitation event in February 1990, groundwater flow directions appear to have been affected as evidenced by contours (Figure 18A), but remained north to northeast away from Putah Creek.

Reversals or changes in groundwater flow direction beneath the site appear to be a direct result of recharge from Putah Creek following precipitation events. It is unclear, however, in what way recharge from the creek moves through the subsurface. Water recharging into the system may move uniformly as a "pulse" or "wave form" or more likely, by movement of water through buried stream channel deposits. Water levels in wells closer to such channels may change quicker than in wells further away.

6.3.2 Groundwater Flow Rates

Groundwater flow rates for the shallow and intermediate water-bearing zones were calculated based on average water table gradients calculated from 1989/90 groundwater, laboratory-determined permeabilities, and assumed average porosities for shallow water-bearing zone geologic materials. The flow rate V, is calculated as:

$$V = KI/n$$

where: K = hydraulic conductivity (permeability)

I = average water table gradient

n = average porosities of fine sand, silt, and clay (40 to 60 percent)

Calculated groundwater flow rates for the shallow water bearing zone range from 2.56×10^{-6} feet per year (ft/year) to 1.89×10^{-4} ft/year based on the range of laboratory-determined permeabilities and assumed porosities for the site. A significant degree of error exists with such calculations because of the inherent heterogeneity of the hydrogeology beneath the site.

Sedimentary deposits such as those in this region are generally anisotropic in terms of permeability. In other words, permeability varies significantly with respect to direction of measurement. In sedimentary deposits this translates to horizontal permeability that exceeds vertical permeability by several orders of magnitude (Freeze and Cherry, 1979).

The above calculated flow rates are extremely low because of the use of extremely low reported laboratory permeabilities. Laboratory permeabilities are vertical permeabilities performed by maintaining a head of water on the sample until water begins to flow through. Horizontal groundwater flow rates are probably significantly higher in subsurface sediments because of buried channel deposits and/or lenses of coarser-grained sediments that provide pathways for horizontal or lateral flow. The fact that water levels in wells respond quickly (within a day or two) following precipitation events suggests that horizontal flow rates in the shallow and intermediate-water bearing zones are, in reality, much greater than the calculated rates.

7.0 RESULTS OF CHEMICAL ANALYSES

Chemical analyses were performed on groundwater, surface water, vadose zone water, and soil samples collected at or near the site. Results of chemical analysis are used to assess the possibility of leakage from the site. Conclusions based on an analysis of the results are presented in Section 8.0.

Four rounds of water sampling were conducted for the SWAT monitoring program. The first round was conducted in June, 1989 and consisted only of groundwater samples collected from wells UCD-2, 4, and 8. Well UCD-9 was to be sampled at this time also, but was dry. Rounds II, III, and IV were complete rounds of groundwater, surface water, and vadose zone sampling conducted in October/November, 1989, January, 1990, and April, 1990. Well UCD-2, which was completed through disposal area #2, was abandoned following Round III. Round II water and soil analyses were performed by Thermo Analytical, Inc. Laboratory (TMA) of Richmond, California. Analysis of Round I, III, and IV samples was performed by Controls for Environmental Pollution, Inc. Laboratory (CEP) of Santa Fe, New Mexico. Soil samples were collected during drilling in October, 1989. Chemical analysis data sheets are included in Appendix E.

Analysis of some soil and water samples by TMA was performed beyond specified holding times. A complete listing of analyses for which holding times were exceeded is included on Table 7.

7.1 GROUNDWATER

7.1.1 Volatile Organic Compounds

Table 8A shows results reported for halogenated volatile organics analysis (EPA 601). The highest reported levels are for chloroform in samples collected from UCD-9 and/or 12. This well pair is located downgradient of disposal area #2 (Figure 3). Reported levels of chloroform varied from a low of 6,700 micrograms per liter (μg/l) in the UCD-12, Round IV sample to a high of 17,000 μg/l in the UCD-12, Round II and UCD-9, Round III samples. Chloroform was also consistently reported for samples from UCD-4, the upgradient well. Reported levels for UCD-4 samples, however, were much lower than for UCD-9/12, with a low of 0.12 μg/l in Round I (detection limit = 0.08 μg/l) to a high of

5.4 μg/l in Round II. Chloroform was also reported for UCD-8/13 samples at levels comparable to UCD-4 levels.

Other groundwater samples for which volatile organic compounds were consistently reported were the UCD-12, Round II and IV samples. These samples had 1, 1 dichloroethene levels of 23.0 μg/l and 30 μg/l (duplicate) for Round II and 31 μg/l for Round IV. Round III samples were collected from well UCD-9 instead of 12 because this was the only round in which UCD-9 contained water. Laboratory dilution of UCD-9 samples in order to get a value for chloroform (17,000 μg/l) caused detection limits to be abnormally high. The detection limit for 1, 1 dichloroethene in that sample was 65 μg/l and therefore 1,1-dichloroethene was reported as less than the detection limit.

Several other detections of volatile organic compounds were reported, but few consistently. Other reported detections of halogenated volatile organic compounds are as follows:

UCD-2 Samples:

- 1,1-dichloroethane - 0:170 μg/l, Round I;
- 1,1-dichloroethene - 0.270 μg/l, Round III;
- bromoform - 9.2 μg/l, Round I;
- methylene chloride - 13.0 μg/l, Round II;
- tetrachloroethene - 0.950 μg/l, Round III; and
- trichloroethene - 0.180 μg/l, Round I; 0.390 μg/l, Round III.

UCD-4 Samples:

- methylene chloride - 12.0 g/l, Round II; 0.910, Round IV; and
- trichlorofluoromethane - 0.850 μg/l, 0.960 μg/l (duplicate), Round IV

UCD-8 Samples:

- 1,1,2-trichloroethane - 0.270 μg/l, Round III, 0.130 μg/l, Round IV;
- 1,1-dichloroethene - 0.071 μg/l, Round I;
- 1,2-dichloroethane - 0.260 μg/l, Round III;
- dibromochloromethane - 0.090 μg/l, Round I;
- tetrachloroethane - 0.060 μg/l, Round III;

- tetrachloroethene - 0.110 μg/l, Round I; 0.049 μg/l, Round IV;
- trichloroethene - 0.500 μg/l, Round I; 0.690 μg/l, Round III; 0.710 μg/l, Round IV; and
- trichlorofluoromethane - 0.760 μg/l, Round IV.

UCD -10 Samples:

- methylene chloride - 32.0 μg/l, Round II;
- 1,1,1-trichloroethane - 1.40 μg/l, Round III; 0.054 μg/l, Round IV;
- 1,1-dichloroethene - 0.140 μg/l, Round III;
- chloroform - 0.060 μg/l, Round III; 0.550 μg/l, Round IV; and
- trichlorofluoromethane - 0.650 μg/l, Round IV.

UCD-11 Samples:

- 1,1,1-trichloroethane - 0.450 μg/l, Round III; 0.057 μg/l, Round IV;
- methylene chloride - 33.0 μg/l, Round II; and
- trichlorofluoromethane - 0.50 μg/l, Round IV.

UCD-12 Samples:

- 1,1,1-trichloroethane - 36.0 μg/l, Round II;
- 1,1,2-trichloroethane - 1.0 μg/l, Round IV;
- 1,2-dichloropropane - 3.5 μg/l, 4.3 μg/l (duplicate), Round II; 1.3 μg/l, Round IV;
- bromodichloromethane - 19.0 μg/l (duplicate sample), Round II;
- methylene chloride - 28.0 μg/l, 26.0 μg/l (duplicate), Round II; 6.7 μg/l, Round IV; and
- trichloroethene - 0.80 μg/l, 0.70 μg/l (duplicate), Round II.

UCD-13 Samples:

- methylene chloride- 20.0 μg/l, Round II.

UCD-14 Samples:

- 1,2-dichloropropane - 0.280, Round III; 0.790, Round IV; and
- chloroform - 2.1 μg/l, Round II; 2.7 μg/l, Round III; 2.2 μg/l, Round IV.

Travel control samples, which were supplied by the laboratory and analyzed during Rounds III and IV, had low levels of the following compounds:

- 1,1,1-trichloroethane - 0.110 μg/l, 0.091 μg/l, 0.051 μg/l Round III (three samples - one for each day of sampling);
- chloroform - 0.140 μg/l, 0.084 μg/l, 0.091 μg/l, Round III;
- methylene chloride - 1.7 μg/l, 0.48 μg/l, 0.49 μg/l, Round III; 0.69 μg/l, 0.94 μg/l, Round IV; and
- trichlorofluoromethane - 0.770 μg/l, 0.540 μg/l, Round IV.

These samples are filled at the lab and accompany well samples during transport. Reported detections in travel control samples may be laboratory related.

Table 8B shows reported detections of aromatic volatile organics (EPA 602) as follows:

UCD-12 Samples:

- benzene - 24.0 μg/l, 59.0 μg/l (duplicate), Round II; and
- ethylbenzene - 22.0 μg/l, Round II.

Benzene and ethylbenzene were not reported for previous or subsequent rounds.

UCD-13 Samples:

- ethylbenzene - 14.0 μg/l, Round II;
- m-xylene - 18.0 μg/l, Round II; and
- o/p-xylenes - 9.7 μg/l, Round II.

UCD-14 Samples:

- benzene - 0.50 μg/l, Round IV.

Four out of five travel control samples had reported levels of toluene as follows:

- 1.1 μg/l for each sample in Round III; and
- 0.43 μg/l for second day sample in Round IV.

7.1.2 Pesticides and PCBs

Pesticide and PCB analyses (Table 8C) were performed on the following samples:

- UCD-2, Round I, II,
- UCD-4, Round I, II, III, IV,
- UCD-8, Round I, III, IV,
- UCD-10, Round II,
- UCD-11, Round II,
- UCD-12, Round II,
- UCD-13, Round II, and
- UCD-14, Round II.

Three detections were reported for the following samples:

- UCD-4, Round II: endrin - 0.11 μg/l
- UCD-8, Round I: alpha-BHC - 0.0034 μg/l
- UCD-13, Round II: endrin - 0.1200 μg/l

No detections of PCBs were reported.

7.1.3 Metals

Metals analyses were performed for all SWAT wells (or well pairs) in all rounds (Table 8D). All samples were filtered through 0.45 micron filters prior to analysis.

The only metal reported at consistently elevated levels was hexavalent chromium. The highest levels were reported for samples from UCD-11 - 0.30 to 0.38 mg/l. Other wells for which elevated levels of hexavalent chromium were reported are as follows:

- UCD-2, Round I, II, III,
- UCD-8, Round I, III, IV,
- UCD-9, Round III,
- UCD-12, Round II, IV, and
- UCD-13, Round II.

7.1.4 General Analyses

Reported results of general water quality parameters are shown on Table 8E. These parameters are used primarily in assessing upgradient versus downgradient water quality at a site. Reported results of general water quality parameters were consistently elevated for samples from downgradient wells compared to upgradient samples. Reported results were as follows:

- Chloride:
  upgradient levels - UCD-4: 32 to 40 mg/l
  downgradient levels - UCD-9: 141 mg/l, Round III; and
  - UCD-12: 301 mg/l, Round IV to 400 mg/l, Round II;
- Nitrate:
  upgradient levels - UCD-4: 1.7 to 2.9 mg/l
  downgradient levels - UCD-2: 73 mg/l, Round II; 135 mg/l, Round III;
  - UCD-8: 55 mg/l, Round III;
  - UCD-9: 110 mg/l, Round III;
  - UCD-12: 100 mg/l, Round II; 90 mg/l (duplicate)

- Total dissolved solids (TDS):
  upgradient levels - UCD-4: 425 to 522 mg/l
  downgradient levels - UCD-2: 1160 mg/l, Round I;
  - UCD-8: 1222 mg/l, Round I; 1154 mg/l, Round IV;

- UCD-10: 1200 mg/l, Round II; 1140 mg/l, Round III; 1170 mg/l, Round IV;
- UCD-12: 1900 mg/l, Round II; 1800 mg/l, Round III; 1630 mg/l, Round IV; and
- UCD-13: 1100 mg/l, Round II.

7.1.5 Radionuclide Analyses

Groundwater samples were analyzed for the following radioactive constituents:

- Gross alpha;
- Gross beta;
- Gamma spectralanalysis (includes cesium-137 (^{137}Cs), radium-226 (^{226}Ra), and thorium-232 (^{232}Th);
- Hydrogen-3 (tritium or ^{3}H);
- Carbon-14 (^{14}C); and
- Strontium-90 (^{90}Sr).

Table 8F shows the reported results of analyses for radioactive constituents in groundwater. The highest levels reported were for ^{3}H in well UCD-4, Round II split samples of 78,736+/-1,294 and 79,548+/-1,261 pCi/l. These results, however, were not confirmed when analysis of a distilled fraction of this water sample was performed. Reported results for the distilled fraction were not-detected (ND). The distillation process removes potential chemical, biological and physical interferences caused by non-radioactive material in the water.

Reported levels of ^{3}H in UCD-14, Round III samples were similar to results for UCD-4 samples. Prior to distillation, results of 72,171+/-1218 pCi/l and 69,743+/-1201 pCi/l were reported. Analysis of the distilled fraction again yielded a result of ND.

Reported results for UCD-8, Round III samples for ^{3}H are 29,341+/-812 pCi/l for a distilled sample fraction. UCD-8, Round I sample analysis yielded a result of 37,241+/-945 pCi/l. Well UCD-13 (adjacent to UCD-8) has a reported result for ^{3}H during Round II of 36,269+/-973 pCi/l.

Other reported detections of radioactive constituents are as follows:

UCD-2 samples:

- ^{226}Ra - 4.8+/-1 pCi/l, Round I;
- ^{232}Th - 4.1+/-0.6 pCi/l, Round I; and
- ^{3}H - 1643+/-530 pCi/l, Round I; 4874+/-608 pCi/l, Round III. 5286+/-597 pCi/l, Round III (rerun); ND, Round III (rerun of distilled fraction).

UCD-4 samples:

- ^{14}C - 1438+/-348 pCi/l, Round III; 1076+/-335 pCi/l, Round III (rerun); ND (rerun of distilled fraction), Round III;
- gamma spectralanalysis -- see Appendix E for radionuclides;
- ^{226}Ra - ND, 1.7+/-0.5 (blind duplicate), Round I;
- ^{232}Th - 1.8+/-0.5 pCi/l, 1.6+/-0.5 (blind duplicate), Round I; and
- ^{3}H - 539+/-469 (blind duplicate of non-detected sample), Round I; 78,736+/-1,294 pCi/l, 79,548+/-1,261 pCi/l (rerun), ND (rerun of distilled fraction), Round III.

UCD-8 samples:

- ^{14}C - 15,500+/-300 pCi/l, 15,400+/-300 (dissolved fraction), 2702+/-359, (lab split) Round I; 540+/-329 (rerun), ND (rerun), Round III;
- gamma spectralanalysis -- see Appendix E for radionuclides;
- ^{226}Ra - 5.2+/-3.7 pCi/l, ND (lab split), Round I;
- ^{232}Th - 4.8+/-0.8 pCi/l, ND (lab split), Round I; and

- ^{3}H - 37,241+/-945 pCi/l, Round I; 21978+/-813 pCi/l, 22650+/-805 (rerun), 29341+/-812 (rerun, distilled), Round III.

UCD-12 samples:

- gamma spectralanalysis -- see Appendix E for radionuclides;
- gross alpha - 4+/-3 pCi/l, Round IV.

UCD-11 samples:

- gross beta - 4.0+/-2.0 pCi/l, Round IV (a second lab found ND).

UCD-14 samples:

- ^{14}C - 5244+/-681 pCi/l, 1498+/-346(rerun),1401 +/- 341 (rerun), ND (rerun), Round III;
- gamma spectralanalysis -- see Appendix E for radionuclides;
- ^{3}H - 708+/-532 pCi/l, Round II; 3,650+/-pCi/l, 3,632+/-574 (rerun), 72,171+/-1,218 pCi/l (different sample fraction), 69,743+/-1,201 pCi/l (rerun), ND (rerun on distilled fraction), Round III.

Radiological analysis data sheets are included in Appendix E. Comparison of reported results to regulatory criteria is included in Section 7.5.

7.2 SURFACE WATER

Surface water samples were collected from two locations in the South Fork of Putah Creek - approximately 1,000 feet upstream of the Old Davis Road bridge (upstream of the site) and directly south of the southeast corner of disposal area #3 (Figure 3). Duplicate samples were collected at the upstream location. Surface water samples were collected during Rounds II, III, and IV.

7.2.1 Volatile Organic Compounds

Reported detections of halogenated volatile organic compounds are shown on Table 9A. The majority of the reported detections were for downstream samples, however methylene chloride and dichloromethane were reported for upstream samples. A summary of reported detections is as follows:

Downstream Samples:

- 1,2-dichloroethane - 0.30 μg/l, Round III;
- bromodichloromethane - 1.0 μg/l, Round II;
- chloroform - 8.0 μg/l, Round II; 0.68 μg/l, Round III; 0.51 μg/l, Round IV;
- dibromochloromethane - 0.093 μg/l, Round IV; and
- methylene chloride - 2.8 μg/l, Round II; 0.39 μg/l, Round III; 0.270 μg/l, Round IV.

Upstream Samples:

- methylene chloride - 14.0 μg/l, Round II; 4.4 μg/l (duplicate sample), Round II; 0.48 μg/l, Round III.

The only reported detection of aromatic volatile organic compounds was benzene at 0.54 μg/l in the Round IV upstream sample (Table 9B).

7.2.2 Pesticides and PCBs

No detections of pesticides or PCB's were reported for surface water samples (Table 9C).

7.2.3 Metals

Levels of metals reported for upstream samples are slightly greater than downstream samples. The majority of the metals were reported at or below detection limits (Table 9D).

7.2.4 General Analyses

Reported results of general water quality parameters do not show large differences between upstream and downstream samples (Table 9E). Downstream sample results are elevated relative to upstream samples results, but only by a minor amount if at all. Chloride nitrate, sodium, sulfate, and TDS levels are elevated in downstream samples relative to upstream samples in Round II samples.

An anomalous result is that of electrical conductivity for Round IV samples, both upstream and downstream samples - 7300 μmhos/cm to 7830 μmhos/cm. As was the case with groundwater samples this is due to laboratory error.

7.2.5 Radionuclide Analyses

Surface water samples were analyzed for the same set of radionuclides as groundwater. No radioactive materials in excess of natural background were reported for surface water samples from Putah Creek upstream or downstream of the landfill (Table 9F).

7.3 VADOSE ZONE WATER

Attempts to collect vadose zone water samples from wells L-1, L-2, L-3, and L-4 failed in all cases except L-1 in Round IV. Enough sample was collected from this well to analyze for TDS, the reported result of which is 1000 μg/l. All lysimeters were functioning properly during each sampling attempt. Failure to draw water from the soil is likely due to the extremely low permeability of clayey soils beneath the site.

7.4 SOIL

Soil samples were collected during drilling of borings for well installations at the site. Because virtually no vadose zone water samples were able to be collected, analysis of vadose zone soils provide the only data on potential impacts to the vadose zone from leakage.

7.4.1 Volatile Organic Compounds

Two halogenated volatile organic compounds (EPA 8010) were reported for the thirteen soil samples analyzed: chloroethane and dichloromethane (Table 10A). Both chloroethane and dichloromethane were also reported for laboratory method blanks (Appendix E). Reported units varied from μg/kg (parts per billion - ppb) to mg/kg (parts per million - ppm) and μg/g (ppm). The reason for variation in units was not explained by the laboratory.

Chloroethane was reported for samples from UCD-10 at 15 to 37 μg/kg (ppb). For the five UCD-11 samples analyzed, chloroethane was reported at 37 mg/kg (ppm). Dichloromethane was reported for samples from UCD-12 at 700 and 1100 μg/g (ppm) and for UCD-13 samples at 220 to 420 mg/kg and μg/g (two separate reports for same analyses).

Three soil samples were analyzed for aromatic volatile organic compounds (EPA 8020) - UCD-10 at 55, 65, and 70 feet below ground surface. No detections were reported for any of the samples (Table 10B).

Three soil samples were analyzed for semi-volatile organic compounds (EPA 8270): UCD-13 at 10, 35, and 50 feet below ground surface. No detections were reported for this analysis (Table 10C).

7.4.2 Pesticides and PCBs

Analysis for pesticides and PCBs were performed on a total of 18 soil samples from borings for wells UCD-11, 12, and 13. No detections were reported for any of the samples (Table 10D).

7.4.3 Metals

A total of 15 soil samples were analyzed for metals from the borings for wells UCD-10, 11, 12, and 13. The reported results (Table 10E) are compared to Total Threshold Limit Concentrations (TTLC) and 10x Soluble Threshold Limit Concentration (10xSTLC). The latter is a general guideline for the total concentration of a metal in a soil such that the soluble portion might exceed the STLC value. Only one

metal, nickel at 200 μg/kg in the UCD-11 - 11.5 feet sample and 210 μg/kg in the UCD-13 - 10.0 feet sample met or exceeded 10xSTLC (200 μg/kg for nickel).

7.4.4 Nitrate

Fourteen soil samples from the borings for wells UCD-10, 11, 12, and 13 were analyzed for nitrate concentration. The highest levels were reported for samples from UCD-13 (19.0 mg/kg at 10 feet and 11.0 mg/kg at 50 feet) (Table 10F).

7.4.5 Radionuclides

A total of 10 samples were analyzed from UCD-10, UCD-11, UCD-12, and UCD-13 soil samples. The radiological analyses performed were ^{3}H, ^{14}C and gamma spectralanalysis. Gamma spectralanalysis had reported results for various gamma emitting radionuclides all of which are naturally occurring radionuclides. The highest reported radionuclide concentration was for ^{3}H in soil from UCD-13 at 50 feet at 8.47+/-0.77 pCi/g (pilocuries per gram).

Other reported radionuclide detections for soil samples were as follows:

- UCD-10-55 feet: ^{14}C at 0.23+/-0.17 pCi/gm;
- UCD-10-65 feet: ^{3}H at 0.98+/-0.28 pCi/gm;
- UCD-11-26 feet: ^{3}H at 0.5+/-0.4 pCi/gm; ^{232}Th at 1.11+/-0.93 pCi/gm;
- UCD-11-51 feet: Bismuth-214 at 0.55+/-0.39 pCi/gm;
- UCD-11-71 feet: Lead-212 at 0.60+/-0.54 pCi/gm; ^{226}Ra at 1.32+/-0.88 pCi/gm;
- UCD-12-25 feet: ^{3}H at 0.4+/-0.3 pCi/gm; ^{226}Ra at 0.96+/-0.68 pCi/gm;
- UCD-12-50 feet: Actinium-228 at 1.86+/-1.31 pCi/gm; Lead-214 at 1.43+/-0.98 pCi/gm; ^{226}Ra at 1.13+/-0.63 pCi/gm; and
- UCD-13-10 feet: ^{232}Th at 1.07+/-1.04 pCi/gm.

7.5 WATER/SOIL QUALITY STANDARDS

Analytical results presented above are compared to three types of regulatory criteria: Soluble Threshold Limit Concentrations (STLCs), California Drinking Water Standards, and Department of Health Services (DHS) Action Levels.

Table 11 shows exceedances any of the three regulatory criteria for water and soil samples collected during the SWAT investigation. These numbers are for comparison of site water/soil quality to background water/soil quality only and are not intended to imply the necessity for corrective action at the site.

7.5.1 Water Quality Criteria

STLCs are values above which a liquid is considered hazardous under Title 22, Section 66699 of the California Code of Regulations (CCR). Drinking water standards are divided into categories of primary and secondary. Primary drinking water standards, also known as Maximum Contaminant Levels (MCLs), are health-based criteria. Secondary standards (SMCLs) are applied to parameters that affect the aesthetics of drinking water such as taste, odor, or color. Drinking water standards are listed in Title 22, Sections 64433 and 64473 of the CCR.

Action levels (ALs) are levels at which the DHS requires purveyors of water to take corrective action to reduce levels of contamination in the water they supply. They are not formal standards such as STLCs or MCLs.

It is important to note that MCLs, SMCLs, and ALs apply only to public drinking water supplies and may or may not be similar to regulatory standards which could be applied to groundwater beneath the landfill. However, they form a good basis for comparison of levels detected in groundwater samples.

Table 11 shows that seven groundwater samples had reported concentrations of volatile organic compounds that met or exceeded MCLs or ALs. No STLCs were exceeded.

Reported concentrations of copper, chromium, and hexavalent chromium exceeded MCLs. Copper was reported for all wells sampled except UCD-12 and UCD-13. The highest levels of chromium and hexavalent chromium were for samples from UCD-11 and UCD-12. No reported metal concentrations exceeded STLCs.

Reported concentrations of nitrate, sulfate, TDS, and chloride exceeded MCLs or secondary MCLs (SMCLs). Nitrate concentrations exceeding the MCL were reported for samples from wells UCD-9 and UCD-12. TDS concentrations exceeding the SMCL were reported for all wells sampled, except UCD-9. The highest TDS levels were reported for well UCD-12 and the lowest for the upgradient well - UCD-4. The only sample collected from a vadose zone well had a TDS concentration that exceeded the SMCL.

Reported concentrations of sulfate and chloride exceeding the SMCLs were from wells UCD-10 and UCD-12 respectively.

Reported levels of radionuclides exceeded drinking water standards in wells UCD-8, 13, and UCD-14. Samples from Round III exceeded the MCL for ^{3}H of 20,000 pCi/l in UCD-8, UCD-13, and UCD-14. Reported levels of ^{3}H for UCD-8, Round I samples also exceeded the MCL for ^{3}H.

The MCL for ^{14}C of 3,000 pCi/l was exceeded by UCD-8, Round I samples and UCD-14, Round III samples.

The MCL for ^{226}Ra of 5 pCi/l was exceeded by UCD-8, Round I samples.

For surface water samples, benzene at 0.54 μg/l in the upstream sample from Round IV, was the only volatile organic compound detected. Benzene was not detected in any previous rounds in surface water.

Reported concentrations of copper, cadmium, and silver for surface water exceeded MCLs, but not STLC in four samples - all upstream.

7.5.2 Soil Criteria

Concentrations of metals and some organic compounds (primarily pesticides) are compared to Total Threshold Limit Concentration (TTLC) values under Title 22, Section 66699. If the concentration in a soil sample of a substance on the Title 22 list exceeds the TTLC, that soil is considered hazardous. If the concentration is less than the TTLC the Waste Extraction Test (WET Test) may be performed to determine the soluble concentration of the substance. However, unless the total concentration of the substance in the soil exceeds ten times the STLC (10 x STLC) the soluble concentration is not likely to exceed the STLC. If soluble concentrations exceed the STLC, then the soil is still considered hazardous.

Table 11 shows that the reported concentration of nickel in samples UCD-11-11.5 and UCD-13-10.0 exceeds its 10 x STLC value. Wet tests have not been performed on soil samples.

8.0 CONCLUSIONS

Based on the results of our investigation of the Old UCD Landfill, we conclude the following:

- The existing groundwater monitoring wells UCD-2 (now abandoned), UCD-4, UCD-8 and new SWAT wells UCD-10, UCD-11, UCD-12, UCD-13 and UCD-14 appear to have provided representative groundwater samples both upgradient and downgradient of the three disposal areas based on groundwater flow direction data.

- Groundwater downgradient of disposal area #2 appears to have been impacted by leakage. Several volatile organic compounds were reported for samples from UCD-9/12 with particularly high levels of chloroform. A likely source of the leakage is the known waste disposal trenches in disposal area #2. However, the presence of low levels of chloroform in samples from UCD-4 (upgradient well) suggests the possibility of other sources.

- Reported levels of hexavalent chromium exceeding the MCL in samples from UCD-11 suggest possible leakage from a source immediately upgradient of this well. The only known potential source upgradient of UCD-11 is disposal area #1. Reported results of other parameters, such as volatile organics, however, are low in samples from UCD-11.

- General water quality parameters are elevated in downgradient well samples relative to upgradient samples which suggests leakage to groundwater. Nitrate levels exceed the MCL of 45 mg/l for wells downgradient of disposal area #2. The level of contribution to nitrate in groundwater from the landfill, LEHR-related activities, or other sources is unknown.

- Results of analysis of surface water samples combined with groundwater flow direction data suggest that the landfill disposal areas have no affect on Putah Creek water quality. Slightly elevated levels of general water quality parameters and metals combined with detections of some volatile organic compounds may be brought into the creek from other upgradient sources.

- Results of chemical analysis of soil do not provide conclusive results indicative of leakage.

- Laboratory - determined vertical permeabilities of soil samples collected at the site are anomalously low - 1.52×10^{-9} to 4.87×10^{-9} cm/sec. Calculated flow rates for groundwater in the shallow water-bearing zone at 2.56×10^{-6} ft/yr to 1.89×10^{-4} ft/year are also anomalously low from use of laboratory-determined permeability in the calculations. Permeability and therefore, flow rates, are probably greater due to the inherent heterogeneity of subsurface conditions. The relatively fast response of water levels in on-site wells following precipitation events and recharge from Putah Creek is suggestive of greater lateral permeability than that calculated.

- Results of shallow groundwater samples from the UCD 8/13 well pair have shown ^{3}H and ^{14}C in excess of drinking water standards in three of the four quarterly samples. In Round IV sampling, both radionuclides were reported as "not detected" from this well pair. Elevated levels (above drinking water standards) of ^{226}Ra were reported for UCD-8 samples in Round II, but could not be confirmed by the laboratories. Also, elevated levels (above drinking water standards) of ^{3}H and ^{14}C were reported for UCD-4 and UCD-14 in Round III, but were also not confirmed by the laboratory. No other radioactive materials above natural background have been detected in groundwater samples.

- No radionuclides were reported for surface water samples above natural background levels.

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