



FEASIBILITY STUDY REPORT
VIRGIN ISLAND CHEMICAL SITE
ST. CROIX, U.S. VIRGIN ISLANDS



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1.0 INTRODUCTION

1.1 Overview

This Feasibility Study (FS) Report for the Virgin Island Chemical (VICHEM) Site, St. Croix, U.S. Virgin Islands, has been prepared by Golder Associates, Inc. (Golder), on behalf of Berlex Laboratories, Inc. (Berlex) and Pharmacia & Upjohn Company (P&U). The FS Report is submitted in accordance with the requirements of the 1994 Administrative Order on Consent (AOC) entered between the U.S. Environmental Protection Agency (USEPA), Berlex, and others. The FS builds upon the results of the Remedial Investigation (RI) for the Site, conducted principally by Harding Lawson Associates (1995 to 1997) and McLaren/Hart (M/H) (1997 to 2000), as well as a Treatability Study conducted by M/H in Spring 2000.

The purpose of the RI/FS process is to gather sufficient information to support informed risk management decisions and enable USEPA to select a remedy that will be protective of human health and the environment, consistent with the National Contingency Plan (NCP). Specifically, the primary objectives of an FS are to:

- develop a sound Conceptual Site Model, including the nature, extent, fate and transport of contamination;
- support the identification of preliminary remediation goals (PRGs) for the media that have been identified as impacted with constituents of concern (COCs);
- develop general response actions (GRAs);
- identify, screen, and select remedial technologies and process options applicable to the impacts associated with the Site; and
- develop and analyze potential remedial action alternatives for the Site.

The FS screening and a preliminary evaluation of alternatives was conducted and summarized in a Feasibility Study Technical Memorandum (FS Tech Memo) submitted in March 1999 (M/H, 1999). This FS Report includes the results and conclusions of the FS Tech Memo, as modified by USEPA's comments, together with focused development of remedial alternatives and the detailed evaluation of these alternatives against the criteria contained in the NCP.

The remainder of the FS Report is organized as follows:

- Section 1 provides a brief background of the Site setting, operational history, and regulatory history;
- Section 2 provides the Conceptual Site model, including a characterization of the Site-specific and regional geology and hydrogeology. The model includes a discussion of the nature and extent of soil and groundwater contamination at the Site, and summarizes the resulting risks as defined in the Risk Assessment included in the Revised Final RI Report (2000);
- Section 3 describes the Remedial Action Objectives for the Site, which are used to develop and evaluate Site-specific remedial alternatives. This section also includes a discussion of preliminary remedial goals based on applicable or relevant and appropriate requirements (ARARs) and other "To Be Considered" (TBC) standards;
- Section 4 provides a discussion and summary of the general response actions, screening of technology and process options, and development and screening of alternatives based upon the previous FS Tech Memo;
- Section 5 provides a detailed description of the remedial alternatives that were retained for further analysis;
- Section 6 contains a listing and brief description of the seven NCP evaluation criteria considered in this FS; and,
- Section 7 provides a detailed and comparative evaluation of each of the retained alternatives, including analyses against each of the criteria defined in Section 6. Cost estimates for each alternative are also included.

1.2 Site Description and History

Site Description

The VICHEM Site is located on Plot 13Q of Estate Bethlehem Middle Works in the south-central portion of St. Croix in the U.S. Virgin Islands (see Figure 1). Site access is via Route 66, which traverses the island east and west and abuts the south-southwest boundary of the Site. The Site is bordered to the north and east by an intermittent stream, the River Gut, which originates north of the Site and drains to the Caribbean Sea.

Land use surrounding the VICHEM Site includes a mix of commercial and industrial purposes. A water service company and an undeveloped lot exist immediately to the west and northwest of the Site. A concrete batch plant and two automobile repair shops are located east-northeast of the Site, on the opposite side of the River Gut, while two paving companies are located north-

northwest of the Site across the River Gut. The Henry Rohlsen Airport is situated approximately 1500 feet south of the Site with a prison 0.25 miles to the northwest. Two residential properties are located approximately 0.33 miles north and 0.75 miles northwest of the Site, respectively (M/H, 2000).

The VICHEM Site itself was initially developed during the early 1970's and a variety of pharmaceutical manufacturing and blending operations, under a number of different corporate entities, occurred until 1982. However, specific timeframes for the operation of the manufacturing processes are uncertain. In general, toluene, pyridine, and quinidine (chemicals used by many of the occupants) represent the historically largest volume spills or other releases at the Site. The Site is owned by the Charles H. Steffey Holding Corporation and is currently abandoned and overgrown with heavy vegetation. A chain-link fence was installed in Spring 2000 to encompass the Site boundary and secure the area. A layout of the Facility is shown on Figure 2. Several structures remain on-site, including:

- laboratory/warehouse building ;
- maintenance building;
- nine reportedly empty (M/H, 2000) aboveground storage tanks (ASTs) identified as T-3 through T-11, an unlabeled AST, and eleven concrete pads at former AST locations;
- production area;
- stainless-steel and glass reactor areas;
- loading dock (former location of laboratory pit);
- concrete storage pad adjacent to the loading dock and next to the scalehouse;
- cooling towers;
- generator building;
- generator and fire pump building; and
- one 250,000-gallon fire water AST.

Two storm drains are located on-site. The Central Storm Drain runs beneath the paved area between the laboratory and maintenance buildings. The Southern Storm Drain, where observed, is a concrete-lined depression along the southern wall of the maintenance building and the edge of the reactor area. Both storm drains discharge to the River Gut (M/H, 2000). Two former production wells, P-1 and P-2, are also located on Site as shown on Figure 3. P-1 was sealed during RI activities in Spring 2000.

Further details about the Site, its operational history, and surrounding land and water use are included in the Revised Final Remedial Investigation Report (2000).

Site Regulatory History

In October 1982, EPA was notified of the facility's impending closure and off-site removal of waste materials. Between 1984 and 1991, several investigations were conducted at the Site by USEPA, Island Chemical Company, and the VICHEM Company. The following six areas of environmental concern were identified through this investigative work:

- Laboratory and Warehouse Building;
- AST Area;
- Former Process Pit (FPP) Area;
- Loading Dock/Formal Laboratory Pit Area;
- Soil Beneath Concrete Pad Near ASTs (northern corner of the Site); and
- Concrete Storage Pad (north of the Laboratory and Warehouse Buildings).

During the initial assessment stages of the VICHEM Site by the regulatory agencies, several response activities were conducted by both USEPA and Berlex. These activities included soil excavation with on-site treatment (e.g., drying trays) or off-site disposal, drum removals, and off-site disposal of the AST contents (2000).

The VICHEM Site was placed on the National Priorities List (NPL) on January 18, 1994. On October 6, 1994, the U.S. Environmental Protection Agency (EPA) entered into an Administrative Order on Consent (AOC), Index No. II CERCLA-94-0401, with Berlex, one of the Respondents to the AOC. Pursuant to Section 106(a) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, 42 U.S.C. §9606(a), the AOC required the performance of a Remedial Investigation/Feasibility Study (RI/FS) at the Site.

2.0 CONCEPTUAL SITE MODEL

Four phases of RI field work took place between 1995 and 2000 to further assess potential impacts in the previously identified areas of concern. The Phase IV RI work was supplemented in Spring 2000 with the abandonment and replacement of former Production Well P-1 (Golder, 2000). Based upon the results of the RI (M/H, 2000 and Golder, 2000), a Conceptual Site Model has been developed that includes the geology, hydrogeology, nature and extent of contamination, and exposure pathways/risks.

2.1 Site Geologic / Hydrogeologic Model

Physical Setting

The Site is located in the southern lowland valley portion of the River Gut, which is the largest intermittent stream on St. Croix (M/H, 2000) encompassing a drainage area of approximately 11 square miles. The Site falls entirely within the 100-year floodplain of the River Gut, as mapped by the Federal Emergency Management Agency. In the vicinity of the Site, the River Gut extends across the southern plain of St. Croix, and at its confluence with the Bethlehem Gut (located approximately 800 feet to the southeast of the Site), it becomes the Fair Plains Gut. All of the stream channels in the drainage basin are identified as intermittent. The River Gut drains to the Caribbean Sea, via the Fair Plains Gut and Manning Bay, located approximately one mile southeast of the Site.

In the vicinity of the Site, topographic ridges are present to the southwest and northeast of the Site. These ridges rise to an elevation of approximately 200 feet mean sea level (MSL). The existing land surface elevation at the Site ranges from approximately 30 feet MSL in the southwestern portion of the Site to approximately 40 feet MSL in the northeastern portion. The land surface bordering the east-northeast Site boundary slopes steeply downward approximately 12 to 15 feet into the River Gut.

A comparison was made of present topographic contours to those from 1963 (i.e., prior to Site development). The current ground surface at the Site has been regraded from its original topography by as much as five feet in some areas (e.g., eastern corner of Site and the FPP area). In addition, the relocation of the course of the River Gut is clearly evident.

Regional Geology and Hydrogeology

St. Croix is underlain by rocks of Cretaceous to Pliocene Age. Structurally, the island is basically comprised of parallel fault-blocked ridges trending northeast to southwest. Superimposed on these structures is a northeast- to southwest-trending, trough-like sedimentary basin. The older volcanoclastic and igneous intrusive rocks outcrop in the northern and eastern highland areas of the island. The central basin is underlain by the Jealousy Formation (Pliocene), which is overlain by the Kingshill Formation. The Kingshill Formation consists of a carbonate sequence of variable texture and composition. The interbedded lithologies of the Kingshill Formation include a sandy to conglomerate marl composed of terrigenous material and calcareous skeletal debris, indurated chalks, and calcareous sandstones. The chalks and marls are the dominant lithology types of the Kingshill Formation (M/H, 2000).

Recent Alluvial deposits mantle much of the area underlain by the Kingshill Formation. The maximum thickness of the Alluvium is estimated to be approximately 100 feet at the mouth of the River Gut. The Alluvium is composed mostly of montmorillonite clay of low permeability. In certain locations, it is difficult to distinguish the Alluvial clay from the underlying marl of the Kingshill Formation. Interbedded with the clays are thin (two to four feet) lenses of terrigenous sand and gravel. The coarse material is more prevalent in the river valleys, but the layers of coarse material are isolated and limited in horizontal extent (M/H, 2000).

The Kingshill Formation is considered the principal water-bearing deposit on St. Croix. The maximum saturated thickness of the Kingshill Formation is 200 feet, and in some areas, where the entire formation is screened, it can yield as much as 100 gallons per minute (gpm). In general, however, the Kingshill Formation is a poor-producing formation due to its fine-grained texture and high total dissolved solids (TDS) and chloride content.

The Alluvium is tapped by many private and public supply wells and is the principal aquifer in the Fair Plains, Golden Grove, and Adventure well fields. Like the Kingshill Formation, yields within the Alluvium are highly variable. Due to the stratigraphic nature of the Alluvium (i.e., interbedded clay and sands), hydraulic conductivity contrasts between beds result in greater horizontal than vertical hydraulic conductivity, with the Alluvium typically exhibiting confined or semiconfined aquifer conditions. This is especially prevalent in the deeper deposits; whereas the shallow, coarser material found near the River Gut may exhibit unconfined properties (M/H, 2000).

Site Geology

The Site geology is characterized by approximately 85 feet of fill and Alluvial material overlying the clayey marl of the Kingshill Formation. Figure 3 presents the location of the existing Site monitoring wells and the location of the geologic cross-section. Figure 4 presents a geologic cross-section across the Site and indicates the interpreted original ground surface based on the historic topography and interpreted from the lithologic descriptions contained in boring logs. Much of the fill appears to be reworked natural material and so its composition is very similar to the Alluvium described below. The Alluvium at the Site is comprised of olive brown sandy-clay to sandy-silt, to clayey-sand with occasional amounts of clayey-gravel and sand in the upper 30 to 40 feet. Between a depth of approximately 30 feet to 60 feet, the Alluvium is comprised mainly of a medium brown to gray clay with only occasional trace fine sand and gravel. From approximately 60 feet to 90 feet, the Alluvium consists of silty-clay and sand to medium to coarse sand and clay. A cobble zone was intercepted between an elevation of -39 feet MSL and -45 feet MSL in monitoring wells MW-7, MW-8 and MW-9. At each location, this zone appeared to be approximately 2 feet thick. Beneath the Alluvium, the Kingshill Formation was intercepted at several deep borings across the Site including MW-12 and MW-14. At these locations, the contact between the Alluvium and the Kingshill Formation is not well defined, however below approximately 100 feet bgs, the Kingshill Formation is described as a light brown to white clay.

Site Hydrogeology

The water table is typically encountered approximately 10 to 30 feet below ground surface and is subject to significant fluctuation due to seasonal changes and precipitation. Based on the groundwater data presented in the Revised Final RI Report (2000) there are two distinct water bearing zones within the Alluvium. The hydrographs presented in Figures 5 and 6 present data collected at shallow/deep well pairs MW-2 and MW-7 in the FPP Area, and MW-6 and MW-8 in the AST Area. Hydrographs for these well pairs are presented for the period from January 22, 1998 to February 11, 1998. At each location, the hydrograph for the deeper wells (i.e., MW-7 and MW-8) clearly show a response to off-site pumping, which appears to cycle on and off on a daily basis. In contrast, the shallow wells at each location show a general decline in head over the monitoring period, but with no response to pumping. Similarly, during the development of deep well MW-9, no drawdown was observed in the adjacent shallow well MW-4 (M/H, 2000). This information demonstrates that the Alluvial clay acts as an aquitard such that the upper and lower water bearing zones within the Alluvium are not in hydraulic communication within the Site area.

Interpreted groundwater elevation contours for the shallow and deep Alluvium (October 21, 1998), as presented in the RI Report, are shown in Figures 7 and 8. For comparison, interpreted groundwater elevation contours for more recent data, under high groundwater conditions, are shown on Figure 9 (January 31, 2000), and Figure 10 (March 6, 2000). These figures show the predominant flow direction within the upper Alluvium is generally southward in the central part of the Site, consistent with the results of earlier RI investigations. As indicated in Figures 9 and 10, in the immediate vicinity of the AST area, flow is initially towards the east and south away from the vicinity of MW-6. The easterly component of flow is not significant and likely only results in an easterly groundwater flow component of approximately 100 to 150 feet before the predominant south-southeasterly flow direction returns. It is notable that this easterly flow direction does not occur under the highest groundwater conditions (i.e., November 30, 1999), or for the majority of measured events presented in the RI Report, indicating that this is a transient phenomenon.

Interpreted groundwater elevation contours for the deep Alluvial zone are shown on Figure 11 (March 6, 2000). This figure shows a flow potential within the deeper Alluvium as generally southeasterly. The previous RI investigations indicate that the deep zone exhibits a generally southerly flow potential, similar to that of the shallow zone (M/H, 2000).

Horizontal hydraulic gradients in the upper Alluvium in the AST area ranged from approximately 0.002 feet per foot [ft/ft] to 0.008 ft/ft, with an average value of 0.006 ft/ft. In the FPP area, horizontal hydraulic gradients ranged from 0.009 ft/ft to 0.014 ft/ft with an average of 0.012 ft/ft. Horizontal hydraulic gradients within the lower Alluvium were slightly lower ranging from 0.003 ft/ft to 0.014 ft/ft.

Vertical hydraulic gradients between the upper and lower Alluvium are consistently downward. In the AST area, the vertical hydraulic gradients ranged from -0.005 ft/ft to -0.09 ft/ft. In the FPP area, the vertical hydraulic gradients ranged from -0.008 ft/ft to -0.11 ft/ft.

Slug testing was completed in numerous wells at the Site throughout various phases of the RI in the shallow and deep Alluvium, and the Kingshill Formation. Within the AST area, the geometric mean hydraulic conductivity on the shallow Alluvium is 6.3×10^{-3} cm/sec, and in the FPP area, the geometric mean conductivity is 5.9×10^{-4} cm/sec for the same unit.

In summary, the Site hydrogeology is characterized by the presence of a largely unconfined to semi-confined shallow (uppermost) Alluvium aquifer with a predominant flow direction to the south-southeast. Underlying the shallow aquifer is an aquitard or aquitards, comprised of a stiff clay which confines the lower Alluvium and acts as a significant hydraulic barrier isolating the upper Alluvium from the lower Alluvium aquifer and the underlying Kingshill Formation. The lower Alluvium aquifer exhibits a predominant flow direction to the southeast.

2.2 Nature and Extent of Contamination

Soil samples from approximately 100 borings and groundwater samples from about 45 temporary and permanent wells were analyzed for Target Compound List Volatile Organic Compounds (VOCs) and Semi-volatile Organics (SVOCs), Target Analyte List metals, and field parameters during the RI. The following sections summarize the nature and extent of contamination, defined by this program. Discussion is focused on those constituents that exceed background, USEPA Soil Screening Level (SSL) concentrations¹ or risk-based concentrations (RBCs) where SSLs have not been established, for soil and Maximum Contaminant Levels (MCLs) for groundwater. A more comprehensive presentation and analysis of all detected concentrations is contained in the RI Report. Areas of concern originally identified for the Site included the Former Laboratory Pit Area and Former Drum Areas; the RI data established that these areas were not in fact impacted.

2.2.1 Soil Quality

Surface soil in the AST Area shows evidence of VOC contamination at relatively low levels (e.g., 30 ppb). Subsurface Soil in the AST Area is impacted by ethylbenzene and xylenes at depths up to 24 feet below ground surface (bgs). Concentrations of ethylbenzene and xylenes exceeded MGW SSLs. The portion of the AST Area impacted by ethylbenzene and xylenes in subsurface soil is shown on Figure 12, where the majority of the contamination is located in the former vicinity of Tanks 7, 8, and 9

Shallow soil samples from the FPP Area are not impacted, however, chloroform was detected at levels up to 410 ppb (estimated values) in soil samples between 21 ft to 27 ft bgs at or below the groundwater table. The assumed zone of chloroform impacts in the FPP Area encompasses a 5-foot interval (approximately 20 to 25 feet bgs) within a 400 square-foot surface area (M/H, 2000).

Pentachlorophenol and isophorone were also detected in surface soils above the MGW SSL. However, pentachlorophenol was not detected in groundwater and was not consequently considered to be of concern. Isophorone, which was detected in the Southern Storm Drain above the MGW SSL, was eliminated as a surface soil concern in the Human Health Risk Assessment (HHRA) because of its minor contribution to carcinogenic/non-carcinogenic risk for exposure to groundwater (M/H, 2000).

Methylene chloride concentrations previously reported in Site soil samples are artifacts resulting from blank contamination (laboratory method blanks, field blanks, and trip blanks) and do not represent field conditions. Therefore, methylene chloride should not be considered a Constituent of Concern (COC) for the Site. A detailed explanation follows:

- In past data validation reports, blank action levels were not properly calculated. The blank action levels must include trip blanks and field blanks in addition to method blanks. Previous data validators attempted to isolate samples by method blanks and did not use the other quality control (QC) blanks in calculating action levels. Since methylene chloride and acetone are common laboratory contaminants, it is inappropriate to rely on one method blank for assessing potential contamination.
- Previously, blank action levels were not applied correctly. Many soil and groundwater samples were highly diluted due to concentrations of other constituents in the sample matrix. In such cases, the data validator must adjust the blank action levels by the dilution factor. Since this was not done, blank contaminants were erroneously reported as detected constituents in these samples.
- Previously, results attributable to blank contamination were not properly qualified. In accordance with USEPA Region II data validation Standard Operating Procedures (USEPA 1996), results that are attributable to blank contamination should be qualified as non-detect ("U") and treated as such. Results below the sample quantitation limits (SQLs) should be changed to the SQL and qualified as U. Results above the SQL are not changed and are qualified as U. In either case, the constituent should have appropriately been considered as undetected in the sample.

The methylene chloride and acetone data presented in the Final RI Report (M/H, 2000) showed results below the Contract Required Quantitation Limit that were neither changed to the SQL nor correctly qualified. Qualifiers of "BJ", "B" or simply "J" were used rather than the correct qualifier, which is "U." Examination of these data by Golder revealed that methylene chloride is not present in groundwater or soil, and that acetone detections are limited to low levels. Acetone

¹ SSLs were established using a Dilution and Attenuation Factor (DAF) of 20 in the RI, subsequent comparisons use a DAF of 10 as agreed with USEPA. Subsurface soil data was also compared to Migration to Groundwater (MGW) SSLs.

was detected in thirteen samples at concentrations ranging from 17 ppb to 580 ppb. However, these data are below the soil screening level and acetone should therefore not be considered a COC for the Site. Regardless, the inclusion or exclusion of acetone and methylene chloride data does not materially affect the Risk Assessment results.

Background levels of arsenic in surface soil range from 0.7 parts per million (ppm) to 1.3 ppm. In general, arsenic detections in surface soil, soil/sediment from the Gut System, and subsurface soil samples were consistent with the background screening criterion of 1.64 ppm except for two surface soil samples from the Central Storm Drain that had arsenic at 3.7 ppm and 8.8 ppm. These levels (including background) exceed the arsenic soil screening level (SSL) for ingestion of 0.4 ppm. Arsenic also exceeded this SSL (at a concentration of 0.87 ppm) in the Southern Storm Drain.

Background levels of chromium in surface soil range from 9.8 ppm to 13.6 ppm. In general, chromium detections in surface soil samples did not exceed the background screening criteria except for a sample from the Central Storm Drain that contained chromium at 32 ppm. The detected concentrations of chromium, however, did not exceed any SSLs.

Surface soil samples in some areas of the Site (e.g., the AST Area) exhibited concentrations of iron and manganese (naturally occurring minerals) greater than background levels. As noted in Section 2.1, some areas of the Site contain fill which was used for regrading. However, since fill had not likely been placed in the areas where background samples were collected during the RI, background fill concentrations of iron and manganese are not known. Several samples exceeded the MGW SSL for iron and manganese.

Other metals detected in surface soils and which were classified as COCs include vanadium and zinc. Based on a comparison to MGW SSLs and groundwater data, no SVOCs or metals detected in subsurface soils were considered to be of significant concern.

2.2.2 Groundwater Quality

In general, the following VOCs were detected above Maximum Contaminant Levels (MCLs) in groundwater: ethylbenzene, total xylenes, and chloroform. Several metals (antimony, arsenic,

barium, chromium, iron, lead, manganese, vanadium) were detected in groundwater but did not generally exceed MCLs (M/H, 2000).

Shallow groundwater in the AST Area exhibits contamination by ethylbenzene and xylenes in excess of MCLs. Groundwater isoconcentrations for the 1998 data (reflecting the maximum concentrations detected) are provided on Figures 13 and 14. Current concentrations are reduced, as measured in the Spring 2000 sampling event, and are noted on the figures.

Shallow groundwater in the FPP area contains chloroform at concentrations in excess of MCLs². Groundwater isoconcentrations for the 1998 data (reflecting the maximum concentrations detected) are provided on Figure 15. Current concentrations are generally lower, as measured in the Spring 2000 sampling event, and are noted on the figure. Concentrations up to 4 ppm were detected in a geoprobe sample located near the Former Process Pit in 1998. Shallow well MW-2, in the same area, exhibited a chloroform concentration of 2.4 ppm during the March 1998 sampling event. However, the current concentration of chloroform in this well, as measured during the Spring 2000 event, was two orders of magnitude lower.

In the deep Alluvial groundwater, MCLs have not been exceeded at any wells. No SVOCs have been detected in the deep Alluvium or the Production Wells P-1 and P-2. The Kingshill Formation groundwater, characterized by wells MW-12 and MW-14 and Hydropunch samples, does not exhibit concentrations of any Site Target Compounds above MCLs.

Arsenic has been sporadically detected in groundwater on Site. The March and January 1998 sampling events were the most recent events in which metals samples were collected. During these events, arsenic was detected in wells MW-3, MW-7, and upgradient well MW-10³, with the highest concentration in MW-10. Arsenic levels did not exceed the MCL of 50 ppb.

Likewise, the highest concentrations of chromium and lead during the January and March 1998 sampling events were detected in upgradient well MW-10. Total lead was detected above its Treatment Technique Action Level (TTAL) of 15 ppb twice in MW-5, at concentrations of 17

² The MCL for total trihalomethanes is 100 ppb. In the 1994 Proposed Rule for Disinfectants and Disinfection By-Products, a total THM number of 80 ppb was proposed. In the Final RI Report, a value of 80 ppb was used as the screening criteria.

³ References to "upgradient" well MW-10 here and elsewhere signify that MW-10 was upgradient at the time of sampling, based on water level measurements taken at the time of the sampling event.

and 20 ppb. Total lead was also detected above the TTAL in one sample at MW-10, at a concentration of 50.7 ppb. However, lead was not detected in monitoring wells MW-1 and MW-6 during the same sampling event. Antimony was quantified at 6.2 ppb in one sample at MW-6, which is slightly above the MCL of 6 ppb. No other samples exceed the MCL for antimony.

2.3 Natural Attenuation

2.3.1 General

The reduction in contaminant mass, concentration, volume, mobility or toxicity which has been identified as the basis of the natural attenuation of contaminants in groundwater can occur through a number of physical, chemical and microbiological processes. The dominant attenuating process within a contaminant plume will depend on given site conditions and on the interaction of the major contaminant with other co-existent contaminants. The term 'natural attenuation' is, however, commonly used interchangeably with the idea of biodegradation and the remediating effects of microbes. Specific lines of evidence are assessed to determine the extent of natural attenuation at a particular site. These include comprehensive site wide analysis of the biogeochemistry of the groundwater system and fate and transport modeling studies to confirm and quantify the rates of remediation by natural attenuation.

The following natural attenuation analyses have been performed for the VICHEM Site:

- An evaluation of natural attenuation processes within the aquifer to delineate areas of aerobic and anaerobic conditions, and identify the natural attenuation mechanisms occurring within the aquifer using natural attenuation indicator parameter data from site-specific sampling;
- A trend analysis of select constituents to document the decrease in concentrations over time at locations both downgradient of the Site as well as near source areas; and,
- Solute transport modeling, using 1- and 2-dimensional (1D and 2D) analytical models, to estimate contaminant mass reductions with time downgradient of the contaminant sources.

The following sections provided an analysis of each of these three lines of evidence.

2.3.2 Assessment of Natural Attenuation Processes

Aromatic Compounds Biodegradation Mechanisms: AST Area

The biodegradation of petroleum hydrocarbons (e.g., ethylbenzene and xylene) occurs through their use by microorganisms as primary substrates (sources of carbon and energy). During the metabolism process, electrons are transferred from the hydrocarbon to facilitate the release of energy. The hydrocarbon is therefore termed an "electron donor". The process also requires an "electron acceptor" for the transferred electrons, and nutrients such as nitrate or phosphate. Typical electron acceptors are oxygen, nitrate, iron III, sulfate, and carbon dioxide, which are utilized strictly in that order. Under some circumstances, manganese IV or chlorinated solvents may also be used as electron acceptors. The degradation of petroleum hydrocarbons occurs most effectively under aerobic (oxygen reducing) conditions, and reaction efficiency reduces significantly down the scale of electron acceptors. Howard et. al., 1991 provide aerobic half-lives for the Site constituents xylene and ethylbenzene of 3 to 10 days and 7 to 28 days, respectively.

The efficient biodegradation of petroleum hydrocarbons has been commonly considered not to occur under anaerobic (particularly sulfate reducing and methanogenic) conditions, although it is now becoming recognized that in terms of total mass removal, the slower but more prevalent anaerobic degradation processes may be significant. The degradation process is limited by the supply of electron acceptors, but since these are generally present in abundance in the natural environment, the biodegradation of petroleum hydrocarbons under anaerobic conditions typically proceeds to complete degradation to non-toxic by-products. Howard et. al., 1991 provide anaerobic half-lives for the Site constituents xylene and ethylbenzene of 176 to 228 days and 182 to 365 days, respectively

At the AST Area, the aromatic hydrocarbons are susceptible to degradation under aerobic and anaerobic conditions. Toluene, xylene and ethylbenzene are the most bioavailable of the BTEX compounds to act as substrate, and in fact are degraded at appreciable rates and quantities within the plume boundary. The degree to which all natural attenuation mechanisms (dispersion, dilution, sorption and biodegradation) contribute to plume containment at the AST Area is significant, based on a plume that has been delineated by 5 years of sampling, (see Figures 14 and 15) and whose overall length is only of the range of 120 feet to 150 feet even though the plume may be more than 20 or so years old. Based on the hydraulic characterization, ethylbenzene

and xylene subject to sorption but not biodegradation would have traveled 688 feet, if the plume were assumed to be 20 years old.

Chlorinated Solvents Biodegradation Mechanisms: FPP Area

The process of biodegradation of chlorinated solvents can occur in three ways:

- Where the chlorinated solvent acts as electron donor. Under aerobic and occasionally under ferric iron reducing conditions, this is the primary mechanism for the biodegradation of the less chlorinated solvents in the field but is not considered to be effective for the more highly chlorinated compounds such as PCE or Chloroform. The oxidation of vinyl chloride is the only known example of chlorinated solvents acting as an electron donor under anaerobic conditions;
- Where the chlorinated solvent acts as electron acceptor. In this process, known as reductive dehalogenation, chlorine atoms are replaced sequentially with hydrogen atoms so that, for example, carbon tetrachloride degrades to chloroform, which degrades further to dichloromethane. [Note: half-lives for reductive dehalogenation of carbon tetrachloride and chloroform are estimated at 7 to 28 days, Howard et.al., 1991] Reductive dehalogenation is the most important process for the natural biodegradation of the more highly chlorinated solvents, and occurs best under reducing conditions (sulfate reducing and methanogenic, and occasionally iron III or nitrate reducing conditions). Reductive dehalogenation also occurs for the less chlorinated solvents (dichloromethane is known to degrade to chloromethane and then to methane via this pathway at half-lives of 1 to 4 months, Howard et.al., 1991); and
- Where the chlorinated solvent is degraded fortuitously by an enzyme or co-factor produced during the microbial metabolism of another compound (co-metabolism). The co-metabolic process is described as slow and incomplete, and may be limited under natural conditions although dichloromethane and chloromethane have been noted as readily and very efficiently co-metabolized under aerobic conditions. [Note: half-lives for aerobic cometabolism of dichloromethane and chloromethane are estimated at 7 to 28 days, Howard et.al., 1991]

At the FPP Area of the Site, chloroform is the primary constituent of concern, with only an occasional historic detect of BTEX compounds at low levels (<10ug/L), and no BTEX detections during air sparge test sampling in the Spring of 2000 (see Draft SVE/AS Pilot Study Report, Golder, October 2000). For the FPP area, concentrations of chloroform appear to be diminishing very rapidly in the anaerobic and reducing groundwater environment that is present at this area of the Site. The mechanism for biodegradation of the chloroform in this area is most likely a reductive dehalogenation process. The degree to which all natural attenuation mechanisms (dispersion, dilution, sorption and biodegradation) contribute to plume containment at the FPP Area is significant, based on a plume that has been delineated by 5 years of sampling, (see Figure 15) and whose overall length is only of the range of 80 feet to 100 feet, even though the plume

may be more than 20 or so years old. Based on hydraulic characterization, chloroform subject to sorption but not biodegradation would have traveled 457 feet, if the plume were assumed to be 20 years old.

Natural Attenuation Indicator Parameters

As described in Section 1.1, the evaluation of natural attenuation involves the interpretation of several key chemical and geochemical parameters. In addition to the VOC data typically available for sites, select "natural attenuation indicator" analytical parameters are collected as part of the groundwater sampling effort to demonstrate the degree to which natural attenuation is occurring at the Site. The following focused list of natural attenuation indicator parameters to be assessed was developed by Golder for the Site using Site-specific information, the information from studies provided by the United States Environmental Protection Agency (USEPA, 1999), and industry guidance on the evaluation of natural attenuation (Wiedemeier, 1997). The natural attenuation indicator parameters are listed below:

Parameter	Indication/Reason
Primary spill contaminants	Assists in the delineation of the contaminant plume and contaminant concentrations.
Degradation products of primary spill contaminants	Evidence for the biodegradation of the primary contaminant. Dichloromethane is an indicator of chloroform degradation. Similarly, the ratio of o-xylene to the m and p isomers would be expected to increase as BTEX degrades.
Dissolved Oxygen (DO)	The electron acceptor most thermodynamically favored by microorganisms for the degradation of natural or anthropogenic organic carbon. Concentrations less than 1 mg/l generally indicate an anaerobic environment. At DO greater than about 0.5 mg/l anaerobic bacteria generally cannot function, and reductive dehalogenation of chlorinated solvents is unlikely to occur. It will not occur at concentrations greater than 1 mg/l. Petroleum hydrocarbons and vinyl chloride may be oxidized aerobically at DO concentrations in excess of 1 mg/l.
Eh	Indicates the redox state of the groundwater and hence the types of attenuation processes which may occur. <+50 mV indicates reductive pathway is possible.
Total Organic Carbon	Carbon and energy source for aerobic respiration and electron donor for anaerobic reductive dechlorination.
Nitrate	Substrate for microbial respiration (electron acceptor) if oxygen is depleted. At concentrations in excess of 1 mg/l, nitrate may compete with reductive pathway.
Nitrite	Results from nitrate reduction (denitrification).
Iron III	An analysis of biologically available iron III can be used to estimate the potential for attenuation where iron III is reduced. Iron III may be used as an electron acceptor during anaerobic degradation of electron donors where dissolved oxygen and nitrate are depleted.

Iron II	Iron II may indicate the anaerobic biodegradation of petroleum hydrocarbons where dissolved oxygen, nitrate and manganese are depleted (iron III is used as an electron acceptor), although precipitation when combined with other substances may lead to an underestimate of the quantities produced. At concentrations greater than about 1 mg/l, reductive pathway is possible.
Sulfate	Substrate for anaerobic microbial respiration (electron acceptor). At concentrations in excess of 20 mg/l, sulfate may compete with reductive pathway.
Sulfide	Results from sulfate reduction. At concentrations greater than about 1 mg/l, reductive pathway is possible. May not be detected even if sulfate-reducing bacteria are active because it can react with various oxygenated chemical species and metals.
Methane/Ethane/Ethene	Indicators of complete dechlorination of spill solvents. Methane is produced under methanogenic conditions ($E_h < -240$ mV) from BTEX degradation, and is the end product of degradation of the chloromethane sequence. Ethane and ethene are produced from chlorinated ethane and ethene degradation.

Geochemical parameters were sampled during RI sampling events (M/H,2000), and during air sparge testing during the Spring of 2000. The Spring 2000 data are included in the Draft SVE/AS Pilot Study Report (Golder, 2000).

Natural Attenuation Indicator Parameters: AST Area

Dissolved Oxygen (DO)

For the shallow monitoring wells (MW-1 and MW-6), DO concentrations ranged from 0.24 mg/L to 0.52 mg/L prior to sparge testing, which is indicative of oxygen consumption. Post-sparge testing of samples in MW-1 showed a significant increase in DO (from 0.41 mg/l to 9.64 mg/l), implying that the groundwater in the impacted area of the AST plume is indeed under-saturated with respect to DO and that the sparge test was successful in adding this electron acceptor.

Oxidation-Reduction Potential (Eh)

Eh measurements for the shallow monitoring wells were reported as ranging from - 291mV to +52 mV prior to sparge testing, indicating strongly reducing (or anaerobic) conditions. These values characterize the aquifer conditions as an iron reducing to sulfate reducing environment.

Total Organic Carbon (TOC)

TOC in AST area soils ranges from 1650 mg/kg to 23,000 mg/kg (M/H, 1999). No AST area groundwater samples have been analyzed for TOC, though these high soil concentrations are indicative of available carbon substrate for aerobic respiration.

Nitrate/Nitrite

Nitrite (a by-product of nitrate reduction) was not detected in shallow wells at the AST area.

Ferrous Iron (Fe^{+2})

Ferrous iron (a by-product of ferric iron reduction) was observed in both shallow wells (MW-1 and MW-6) at 0.9 mg/l and 3.1 mg/L, respectively, prior to sparge testing. As supported by the corresponding Eh conditions (see above), iron reduction may be a significant biodegradation mechanism at the Site.

Sulfate/Sulfide

Sulfate concentrations in the contaminated areas show markedly lower concentrations than background. Prior to sparge testing, in MW-10 (a background well), sulfate was detected at 286 mg/L, while in MW-1 and MW-6, sulfate was non-detect and 47 mg/L, respectively, indicating significant sulfate reduction occurring in the AST contaminated area. Sulfide (a by-product of sulfate reduction) was detected in both shallow wells (MW-1 and MW-6) at 0.51 mg/l and 0.11 mg/L, respectively. As presented in Section 1.2.2, the efficient biodegradation of petroleum hydrocarbons is commonly considered not to occur under anaerobic (particularly sulfate reducing and methanogenic) conditions, although it is now widely recognized that in terms of total mass removal, the slower but more prevalent anaerobic degradation processes are significant. Along with the sulfide detections, Eh conditions (-291 mV to -275 mV) at wells MW-1 and MW-6 indicate that sulfate reduction is likely an anaerobic biodegradation mechanism at the AST area.

Methane/Ethane/Ethene

Light hydrocarbon analyses have not been performed at the AST area of the Site.

Natural Attenuation Indicator Parameters: FPP AreaDissolved Oxygen (DO)

For the shallow monitoring wells (MW-2, MW-3, MW-11 and MW-13), DO concentrations ranged from below detection to 2.22 mg/L prior to sparge testing, which is indicative of oxygen consumption. The single post-sparge testing sample in a shallow well (MW-2) showed a marked increase in DO (from 0.36 mg/l to 3.04 mg/l), implying that the groundwater in the impacted area of the FPP plume is indeed deficient in DO and that the sparge test was successful in adding this electron acceptor.

Oxidation-Reduction Potential (Eh)

Eh measurements for the shallow monitoring wells were reported as ranging from -120 mV to +63 mV prior to sparge testing, indicating reducing (or anaerobic) conditions. These values characterize the aquifer conditions as an iron reducing to sulfate reducing environment.

Total Organic Carbon (TOC)

TOC ranges from 3.4 mg/L to 4.4 mg/L (RI Report). These concentrations are acceptable for sustaining reductive dechlorination with TOC acting as a carbon and energy source.

Nitrate/Nitrite

Nitrite (a by-product of nitrate reduction) was detected in one shallow groundwater sample (MW-2) at a concentration of 0.01 mg/L in the FPP area of the Site, coincident with the area of highest chloroform concentration. Nitrate was lower (potentially indicating nitrate consumption) in the three shallow wells (MW-2, MW-3 and MW-11) within the impacted plume area compared to those wells outside the plume at the FPP area.

Ferrous Iron (Fe^{+2})

Ferrous iron (a by-product of ferric iron reduction) was observed in one shallow well (MW-3) at 4.6 mg/L, prior to sparge testing. In 1998, dissolved iron (an indicator of ferrous iron) was reported ranging from 0.18 mg/l to 1.25 mg/l in shallow wells. As supported by the corresponding Eh conditions (see above), iron reduction may be the most significant biodegradation mechanism at the Site.

Sulfate/Sulfide

Sulfate concentrations in the shallow contaminated areas are moderately lower than background concentrations and at the fringe of the plume. In MW-3, MW-11, and MW-13, which are background and plume fringe wells, sulfate was detected at 182-243 mg/L, while in MW-2, a shallow source area well, sulfate was detected at 151 mg/L, suggesting sulfate reduction may be occurring. Sulfide (a by-product of sulfate reduction) was detected in MW-2 at a concentration of 0.02 mg/L in the FPP Area, coincident with the area of highest chloroform concentration.

Methane/Ethane/Ethene

Light hydrocarbon analyses have not been performed at the FPP area of the Site.

2.3.3 Trend Analysis

Figures 16 and 17 provide the time trends for VOC contamination at the FPP and AST areas, respectively. As shown on Figure 16, chloroform has significantly decreased in the FPP near source area well MW-2, from 5990 ug/l in 1996 to three measurements less than or equal to about 40 ug/l in the Spring of 2000 (37, 40.7 and 21.1 ug/l, respectively). Downgradient, at MW-11, data only exists since 1998, showing a slight increase in chloroform from 3 ug/l to 40.4 ug/l. Two-dimensional modeling suggests that such minor increases can occur under transient conditions (see Section 2.3.4). Importantly however, of the twenty-eight (28) samples taken in the FPP area since January 2000 (including duplicates), all but one are below 100 ug/l⁴. Only VMP-1D (sparge test monitoring probe) in the source area had a concentration of 137 ug/l on May 1, 2000.

Concentrations of the principal VOCs in the AST area (ethylbenzene and xylene) are shown on Figure 17⁵. Of particular interest is the sharp decline in VOC concentrations at MW-1 in response to the SVE/AS test conducted in April 2000. Concentrations of total xylenes in groundwater decreased from 108,000 ug/l to 8,700 ug/l, then rebounded after testing to 40,100 ug/l. For ethylbenzene, concentrations decreased from 21,600 ug/l to 1,040 ug/l, then rebounded after testing to 7,680 ug/l. These results imply that in the AST Area, where the permeabilities allow for vapor transfer, significant improvement in the groundwater conditions can be achieved by sparging and vapor phase extraction as well as by the introduction of oxygen to permit the faster aerobic biodegradation mechanism.

2.3.4 Fate and Transport Modeling

To assess whether the groundwater constituents at the Site have reached a steady state condition as a result of mass removal by natural attenuation, solute transport analysis was performed. The objective of solute transport analysis is to evaluate the contribution of biodegradation to the overall attenuation rate. This is accomplished by using an analytical solution that represents advection, dispersion, sorption, dilution, and decay (biodegradation). Analyses have been conducted for:

⁴ The MCL for total trihalomethanes is 100 ug/l. The proposed THM limit of 80 ug/l is only exceeded in one additional sample at the same location.

⁵ The first two sample dates for MW-1 are qualified E&D indicating that the instrument calibration range was exceeded for a diluted sample; these results may therefore be underestimated.

- Ethylbenzene and total xylenes in the AST area, and
- Chloroform in the FPP area.

One-Dimensional Solute Transport Modeling (de Marsily)

The analytical model selected for this evaluation is presented in "Quantitative Hydrogeology" prepared by de Marsily (1986). The solution of the one-dimensional advection-dispersion equation for groundwater flow and solute transport utilized accounts for degradation of the constituents by natural attenuation (a first order reaction rate for the sum of natural chemical and biological processes). The parameter used to estimate the rate of degradation is the half-life time (i.e., the amount of time it takes for the concentration of a compound to decrease by one-half due to degradation processes). The solution appropriately accounts both for constituents released into the groundwater (mass increase) and constituents treated through natural attenuation processes (mass decrease). Steady state conditions occur when the mass of constituents dissolved into groundwater at the source is balanced by the mass removed, or treated, through natural attenuation processes.

Following de Marsily (1986), a one-dimensional case is chosen to model the concentration of a constituent in a semi-infinite medium. The governing equation is:

$$D \frac{\partial^2 C}{\partial x^2} - U \frac{\partial C}{\partial x} = \omega R \left(\frac{\partial C}{\partial t} + \lambda C \right) \quad (1)$$

where:

C	=	concentration (ug/L);
t	=	time (days);
x	=	distance (feet);
U	=	Darcy velocity (considered constant for one-dimensional flow) (feet/day);
D	=	the dispersion coefficient (considered constant, using only longitudinal dispersion for one-dimensional model) (ft ² /day);
ω	=	porosity;
R	=	the retardation factor of the constituent due to adsorption; and,
λ	=	the coefficient of exponential decay (day ⁻¹).

Here, λ is determined from:

$$C = C_0/2 = C_0 \exp(-\lambda t_{1/2})$$

where:

C_o = initial concentration; and
 $t_{1/2}$ = half-life of constituent;

The solute transport model input parameters are Darcy velocity, porosity, dispersion coefficient, retardation factor, bulk density, and half-life time.

Site-specific hydrogeologic and fate and transport parameters used in the analysis are listed in the following tables, along with the source of the data:

AST Area:

Parameter	Value	Units	Source
Hydraulic Conductivity, K	6.3×10^{-3}	cm/sec	Section 2.1
Hydraulic Gradient, I	0.006	ft/ft	Section 2.1
Effective porosity, n_e	20	%	Estimate for sandy clayey silts
Seepage velocity, v	196	ft/yr	$v = Ki/n_e$

FPP Area:

Parameter	Value	Units	Source
Hydraulic Conductivity, K	5.9×10^{-4}	cm/sec	Section 2.1
Hydraulic Gradient, I	0.012	ft/ft	Section 2.1
Effective porosity, n_e	20	%	Estimate for sandy clayey silts
Seepage velocity, v	36.6	ft/yr	$v = Ki/n_e$

Chemical Information:

Parameter	K_{oc} (L/Kg) ¹	f_{oc} (-) ²	Soil Density, (g/ml) ²	Bulk ρ_b	Retardation Coefficient, R^3 (-)
Chloroform	31	0.0027	1.44		1.6
Ethylbenzene	240	0.0027	1.44		5.7
Total Xylenes	240	0.0027	1.44		5.7

¹USEPA, 1986

²M/H 2000 (RI)

³ $R = 1 + K_{oc} \cdot f_{oc} \cdot \rho_b / n$

A starting point for estimating longitudinal dispersivity, α_L , was determined using the well-known formula by Xu and Eckstein (Xu and Eckstein, 1995) which is dependent on the plume length. In the AST area, α_L was modified to reflect the hydrogeology of the AST area in which

groundwater direction likely changes in response to seasonal or climatic variations in rainfall, drought conditions, etc. This variability increases the "smearing" of the plume front, thus, in effect, increasing the α_L value. A value of 50 ft was used for α_L in the AST area. The Xu and Eckstein formula was used in the FPP area and the calculated value for α_L was 10.4 ft, assuming a plume length of 180 ft.

Models were calibrated utilizing the October 1998 RI data. Calibration of the model consisted of iteratively fitting the model predictions to field measurements using the degradation half-life as the fitting parameter and assuming steady-state conditions. The model produces a centerline concentration output chart, depicting concentration over distance at a given time. This concentration profile was compared to the field values and adjusted accordingly until the best fit, using engineering judgment, was achieved.

Figures 18 and 19 provide the results of xylene modeling and Figures 22 and 23 provide results for ethylbenzene modeling. Figures 22 and 23 provide the results of chloroform modeling. The simulations resulted in the following calibrated half-lives:

- xylene 150 days;
- ethylbenzene 100 days; and,
- chloroform 100 days.

These values are consistent with literature values (see Section 1.2), and indicate a significant attenuation rate for both Areas of the Site.

As shown on Figures 19, 21, and 23, the distance at which applicable Site remediation standards (MCLs) are met were estimated by interpreting the distance from a source area point (i.e., MW-6 for the AST Area and GWPP-27 for the FPP Area) at which the concentration curve intersects the concentration represented by the MCL for that compound. The MCLs that are used as point of compliance target concentrations are 700 ug/L for ethylbenzene, 10,000 ug/L for total xylenes and 100 ug/L for chloroform. As discussed above, the 1-D model was used to initially solve for the decay rate rather than the distance to compliance, based on field data.

Based on the results of 1-D modeling, the distance at which compliance is attained for each COC is as follows:

- xylene 110 ft;
- ethylbenzene 125 ft; and,
- chloroform 60 ft.

For comparison, in the AST Area, the Site boundary (at Route 66) in the direction of groundwater flow is approximately 300 feet. Historical analytical results in the AST Area show evidence of groundwater contamination approximately fifty feet beyond the Site fenceline immediately adjacent to this Area in the "upgradient" direction. This may be the result of historical seasonal variations in groundwater flow (i.e., temporary flow gradients to the northeast). To account for this possibility, the input parameter for longitudinal dispersivity was modified as discussed above. The compliance distances listed above are applicable to the predominant direction of groundwater flow. In the FPP Area, the Site boundary (assumed coincident with the fenceline) in the direction of groundwater flow, is approximately 100 feet.

Two-Dimensional Solute Transport Modeling (Bioscreen)

To further assess whether the groundwater constituents at a site are undergoing biodegradation of mass, 2-D solute transport analysis was performed. The objective of this 2-D solute transport analysis is to evaluate the contribution of biodegradation to the natural attenuation mechanisms believed to be occurring at the Site as well as to verify the results of 1-D modeling.

The primary objectives of this modeling effort are to:

- construct a calibrated model based on Site-specific information and conservative assumptions that can be used to simulate the natural attenuation of the COCs;
- using the calibrated model, estimate the distance at which COCs would naturally attenuate to levels below regulatory benchmarks;
- using the calibrated model in a transient analysis, estimate the mass of source COCs present at the Sites; and,
- using the calibrated model in a transient analysis, predict the time to compliance for the entire plume length.

The model used for this exercise is *Bioscreen – Natural Attenuation Decision Support System: Version 1.4* (USEPA 1997). The Bioscreen model is endorsed by the U.S. Environmental

Protection Agency (EPA) Center for Subsurface Modeling Support (CSMoS) (<http://www.epa.gov/ada/csmos.html>). The Bioscreen model is considered especially useful in screening-level modeling for dissolved hydrocarbons and similar-type organic chemicals. The model is based on the same analytical equation for advection, dispersion, adsorption, and decay of constituents in groundwater as was used in the 1-D modeling.

Bioscreen requires information about Site hydrogeology, dispersion/dispersivity, adsorption characteristics for the COCs, chemical biodegradation data for the COCs, and Site-specific concentrations and source dimensions. These parameter values were consistent with those used in the 1-D modeling, presented above.

Bioscreen can incorporate a source mass value ("soluble mass") for estimating the time to source depletion, assuming a source depletion rate, an internal Bioscreen parameter that is keyed to the magnitude of the source mass. The soluble mass in the source was estimated by multiplying the average soil and groundwater concentrations by the estimated affected soil and groundwater volumes. M/H estimated that 1,338 lb of ethylbenzene and 6,239 lb of xylene are present in the source areas. These estimates were incorporated into the steady-state Bioscreen model runs for mass balance calculations (see Figures 25 and 27). For chloroform, an infinite source mass was assumed in the steady-state Bioscreen runs, as this is the most conservative assumption and it is consistent with the continuing source assumption used in the 1-D model.

Steady State Bioscreen Model Results

Results of the calibration modeling for these constituents are shown on Figures 24 through 29 for each COC. The calibrated half-lives for the three models are as follows:

- xylene 200 days;
- ethylbenzene 160 days; and,
- chloroform 200 days.

The calibrated half-lives are slightly higher in the 2-D model due to the effects of transverse dispersion on the centerline concentrations. Based on the results of 2-D modeling, the distance at which compliance is attained for each COC is as follows:

- xylene 80 ft;
- ethylbenzene 110 ft; and,
- chloroform 60 ft.

Combining these results with the 1-D model results reveals that, using the most conservative estimates, compliance for xylene and ethylbenzene contamination in the AST Area is anticipated at 110 feet and 125 feet, respectively, from well MW-1. In the FPP Area, compliance for chloroform is anticipated at 60 feet from well MW-2. Plume mass analysis by Bioscreen revealed that 88%, 96%, and 97% of the chloroform, total xylenes and ethylbenzene mass, respectively, that has left the source areas has been biodegraded. The source masses of xylene and ethylbenzene are shown to degrade by 20% and 33% (whereas an infinite source of chloroform was assumed in the model). Thus, the model indicates that for these compounds, concentrations at the source would still exceed MCLs at the time compliance is achieved at the distances stated above. However, the source mass estimates used in this model were likely overpredicted, as discussed below. Further, the transient Bioscreen model runs show depletion of the source mass below MCLs within the timeframes to attain full compliance over the plume lengths, as discussed below. The Bioscreen output for the steady-state results is provided in Figures 25, 27, and 29 for xylene, ethylbenzene and chloroform, respectively.

Transient Bioscreen Modeling and Results

Transient analyses were performed in Bioscreen to estimate the mass of COCs present at the Sites, and to predict the time to compliance along the entire length of the plume(s). Source mass estimates were obtained by matching the two sets of analytical data available for 1998 and 2000. The 1998 data was used as initial conditions and the source mass was calibrated to obtain a match with the 2000 data. Using the calibrated mass, extended simulations were run to determine the estimated time to full compliance. At the request of USEPA, the hydraulic gradient in the AST area was reduced by 50 percent (i.e., to 0.003 ft/ft) to account for possible intermittent variations in the groundwater flow direction. The half-life of chloroform was also modified from 0.55 years to 0.25 years in order to fit the downgradient data accurately.

The results of the simulations are included in Figures 30 to 35 for xylene and ethylbenzene in the AST area, and Figures 36 and 38 for chloroform in the FPP area. Three figures are presented for each COC: the first figure presents the data input; the second presents the centerline concentrations after two years (to show the 2000 data matching); and the third figure presents the centerline concentrations after full compliance has been attained.

The times to attain full compliance over the plume lengths for each COC as predicted by the model are the following:

- xylene 20 years;
- ethylbenzene 21 years; and,
- chloroform 2.5 years.

The estimated source masses for each COC which best fit the data are the following:

- xylene 528 pounds (AST Area);
- ethylbenzene 95 pounds (AST Area); and,
- chloroform 0.26 pounds (FPP Area).

The total mass of xylene and ethylbenzene in the AST area is estimated to be 623 pounds. These source mass estimates are discussed further in the following section.

The change in chloroform concentration in MW-11 (FPP Area), noted in Section 2.3.3, is consistent with the results of transient modeling using Bioscreen. Figure 39 presents the input data for a simulation in which the initial concentration was set to 4 ppm, which is used (the measured concentration in the FPP source area in 1998) with a simulation time of 8 years. After three years, a pulse of chloroform was present at a distance of 80 feet from the source (Figure 40) and by year 8 (Figure 41), the pulse had traveled a distance of 180 feet from the source and reached a concentration of 40 ug/l (i.e., the distance and concentration corresponding to MW-11). At that time, source area concentrations of chloroform in the model are essentially zero. This simulation indicates that small transient increases in concentration can occur at selected locations such as MW-11, but this is not indicative of escalating concentrations in the FPP Area or an expanding plume, considering such increases are anticipated to be of short duration.

Source Mass Estimates

The mass estimates previously made by M/H and the source mass estimates based on the transient Bioscreen modeling are in very close agreement for the FPP Area but differ in the AST Area. In relative terms, the mass estimates of ethylbenzene in the AST Area is estimated to be greater than xylene by both methods but the Bioscreen estimates are lower by an order of magnitude.

The original mass analysis performed by M/H utilized conservative assumptions that are expected to result in an overprediction of the source masses for total xylenes and ethylbenzene. The soil concentration data used included seven soil borings over an estimated 112-foot by 76-foot

impacted area for which two to three samples per boring were collected in 2-foot intervals over a depth of 20 feet in the unsaturated zone. The arithmetic mean of seven borings was used to represent the average concentration over the entire impacted soil volume. However, the data are highly variable, ranging from 0.006 to 1,800 mg/kg of xylene, with most samples less than 200 mg/kg, and the calculation method will likely overestimate mass. For example, the concentration of xylene used at soil boring SBB-17, 1800 mg/kg, was an average of estimated results based on two sampling intervals (14-16 ft and 20-22 ft). The results had been estimated due to an exceedance of the calibration range of the instrument of the analytical laboratory. This concentration was then assumed to represent the entire depth (i.e., 20 feet) of the impacted soil. The contribution to the overall mass estimate based on this boring alone is 65% of the total mass estimate. Further, the averaging approach assumes that each boring represents one-seventh of the total area, or 1216 ft². In the above example, due to the proximity of nearby borings, the area over which SBB-17 should more realistically be applied is approximately 400 ft². This adjustment would reduce the source mass attributable to SBB-17 by 67%. Similarly, the second most contaminated boring, SBB-4, exhibiting an "average" concentration of 583 mg/kg, should more appropriately represent 500 ft² in area. The effect of these two changes alone would reduce the M/H total mass estimate for xylene by about 60%.

The approach used by M/H is therefore considered likely to overpredict the source mass of total xylenes and ethylbenzene in the AST Area. Whereas M/H's total mass estimate for ethylbenzene plus xylenes was 7580 lb, a more realistic prediction would be about 25% of this estimate, or 1900 lb. The transient Bioscreen model indicated a source mass estimate of 708 lb of ethylbenzene plus xylenes. In order to reflect this uncertainty, subsequent calculations of cleanup time in this FS utilize a total source mass estimate of 1300 lb of total xylenes and ethylbenzene in the AST Area. Since the two approaches were in agreement for chloroform, a total source mass estimate for chloroform in the FPP Area remains assumed as 0.26 lb.

Summary

Strong evidence exists that natural attenuation processes are occurring in the shallow groundwater system. Major electron acceptors (dissolved oxygen, nitrate, ferric iron and sulfate) all appear to be involved in Site processes, and are coincident with the observed oxidation-reduction state. Trend analysis has shown significantly decreasing concentrations of chloroform to below MCLs and steady concentrations of xylene and ethylbenzene. Mathematical modeling calibrated to the Site data indicates half-lives of the order of 100 to 200 days for these three compounds, indicative

of a very robust natural attenuation environment. Both measured and modeled extent of the plumes indicates the plumes are currently contained and off-site migration is not expected.

2.4 Summary of Site Risks

The Revised Final Human Health Risk Assessment (HHRA) (2000) considered the following current and future use scenarios and receptors:

Current Use Scenario

- Residential (adult and child) exposure to groundwater via off-site wells was evaluated. This pathway was deemed incomplete as no constituents of potential concern (COPCs) were identified in groundwater from off-site wells.
- Trespasser (pre-adolescent and adult) exposure to COPCs in the surface soil/sediment collected from the Site and the stream system (Gut System) was evaluated for three pathways (ingestion, dermal contact, and inhalation of particulates). Pre-adolescent children are assumed to be those between 7 and 12 years of age.

Future Use Scenario

- Industrial/Commercial (adult) exposures on-site to COPCs in groundwater, surface soil and sediment were evaluated for three pathways (ingestion, dermal contact, and inhalation of particulates or VOC vapors).
- Construction worker (adult) exposures on-site to COPCs in surface soil, sediment, and subsurface soil (up to 12 feet bgs) were evaluated for three pathways (ingestion, dermal contact, and inhalation of particulates).
- Off-site residential (adult and child) exposures to COPCs in groundwater were evaluated for three pathways (ingestion, dermal contact, and inhalation of particulates or VOC vapors).

For the purposes of the future off-site residential scenario, the Risk Assessment assumed that the on-site concentrations could be present in an off-site well for the entire exposure duration. In reality, no COPCs were detected in the off-site wells or in the wells at the edge of the Site nor are they expected to reach these areas in the future (see Section 2.3). Therefore, the exposure assumptions used in this scenario are extremely conservative.

Summary of Health Risks

The HHRA presented two risk calculations, based on Reasonable Maximum Exposure (RME) and the Central Tendency (CT) exposures. RME risks are based upon reasonable maximum

exposures and, necessarily, use conservative default exposure assumptions. CT risk calculations are based upon more realistic Site-specific exposure assumptions which are more representative. CT risks were calculated only for those exposure scenarios where the calculated risks based on RME were greater than $1\text{E-}06$ for carcinogens and the Hazard Index (HI) was greater than 1.

Trespassers

Calculated risks to an adult trespasser result from the presence of arsenic in surface soil in the Central Storm Drain area. As shown on Table 1, the carcinogenic risk from arsenic is not unacceptable and is at the lower end of the USEPA acceptable risk range ($1\text{E-}06$). There were no unacceptable non-carcinogenic risks to adult trespassers (Hazard Index less than 1). There are no unacceptable carcinogenic or non-carcinogenic risks to pre-adolescent trespassers.

Industrial/Commercial Worker

The risks to future on-site industrial or commercial workers result primarily from exposure to chloroform and arsenic⁶ in groundwater. The exposure scenario assumed that the on-site groundwater would be used as a potable water source for drinking and bathing. As shown by Table 1, the risks from on-site groundwater yield carcinogenic risks greater than $1\text{E-}04$ for both the RME and CT set of calculations. Additionally, the HIs for both the RME and the CT calculations exceed 1 (331 and 330, respectively), due to the concentrations of chloroform in groundwater. Exposures to surface soil and sediment do not result in unacceptable calculated carcinogenic or non-carcinogenic risks.

Construction Worker

As indicated in Table 1, there are no unacceptable carcinogenic risks to future construction workers at the Site. Non-carcinogenic risks to future on-site construction workers are primarily based upon exposure to iron and manganese in surface soil. As shown by Table 1, the cumulative non-carcinogenic hazard index is 1.2 for surface soil based on RME assumptions. CT calculated risks and RME risks for the Gut system soil/sediment are within acceptable ranges.

Future Off-Site Residential Use

Calculated risks to future residents primarily result from chloroform, iron, manganese, and arsenic in groundwater. As shown in Table 1, the risks to adult and child residents from exposure

⁶ Calculated risks due to arsenic are based on data from well MW-10, which is upgradient of the Site, and may therefore not represent Site-related risks.

to Site groundwater yield carcinogenic risks greater than $1\text{E-}04$ for the RME set of calculations, while the CT set of calculations yields risks in the $9\text{E-}05$ to $1\text{E-}04$ ranges for adults and children, respectively. Additionally, the hazard indices for both the RME and the CT calculations exceed 1 for both the adult and child receptors due to chloroform in the groundwater. As noted previously, this exposure scenario assumed that on-site concentrations would be present off-site. This is not the case, nor can it be anticipated in the future, and so the calculated risks (both RME and CT) are extremely conservative.

Screening Ecological Risk Assessment (SERA)

The Screening Ecological Risk Assessment (SERA), conducted as part of the RI, focused on the drainage channels adjacent and downstream of the Site including the River Gut, Bethlehem Gut, and Fairplains Gut. The SERA was developed using data obtained through a surface soil/sediment sampling program conducted within the three drainage channels (M/H, 2000).

In general, aluminum exposure may potentially impact herbivorous, insectivorous, and piscivorous wildlife foraging in the Gut System. Aluminum and several other constituents of potential ecological concern (COPECs), identified for plants, measured adjacent to or downstream of the Site were found at similar or lower concentrations to those measured at the upstream reference location. This suggests that the COPECs have been transported from upgradient sources. Soil data from 1986 and 1997 at the Central and Southern Storm Drains suggest that several metals (e.g., aluminum, manganese, and zinc) may have been historically discharged to downstream areas of the River Gut (M/H, 2000).

The potential contribution of aluminum to the Gut System has decreased with time, as evidenced by a substantial reduction in concentrations in 1997. The aluminum concentrations measured in soil from storm drains in 1997 were similar to those measured in soil collected from the River Gut upstream of the drain discharge points. Therefore, it is unlikely that there is a current on-Site source of aluminum to the River Gut. The Bethlehem Gut contained the next highest concentration of aluminum. However, a bauxite plant is located in close proximity to the Site and may serve as a source of aluminum (M/H, 2000).

The concentrations of manganese and zinc were elevated in 1997 soil samples from the Storm Drains. The SERA showed that these concentrations, if discharged to the Gut System, would result in minimal to negligible risk to ecological receptors in the drainage channels (M/H, 2000).

3.0 REMEDIAL ACTION OBJECTIVES

Based on the Conceptual Site Model and the results of the risk assessment, the following specific⁷ Remedial Action Objectives (RAOs) have been established:

- Mitigate the toxicity, mobility and/or volume of VOCs (notably ethylbenzene and xylene) in soils in the AST area so as to minimize continued leaching to groundwater;
- Mitigate the toxicity, mobility and/or volume of VOCs (notably ethylbenzene and xylene) in shallow groundwater in the AST area and downgradient so as to protect potential future groundwater users;
- Mitigate the toxicity, mobility and/or volume of chloroform in shallow groundwater in the FPP area and downgradient so as to protect future potential groundwater users;
- Restrict groundwater use on-site for potable purposes until the quality is restored to MCLs; and,
- Restrict the use of the Site to non-residential purposes until the quality of soil and groundwater media are restored.

3.1 Preliminary Remediation Goals

3.1.1 ARARs and TBCs

Section 121(d) of CERCLA requires that remedial actions at CERCLA sites comply with legally applicable or relevant and appropriate cleanup standards, standards of control, and other substantive environmental protection requirements, criteria or limitations promulgated under Federal or State/U.S. Territorial law, which are collectively referred to as "ARARs", unless such ARARs are waived under CERCLA § 121(d)(4).

"Applicable" requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria or limitations promulgated under Federal or State law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site. "Relevant and appropriate" requirements are those requirements that, while not legally "applicable", address problems or situations sufficiently similar to those encountered at the site that their use is well suited to the particular site. Only those State/U.S. Territory standards that are promulgated, are identified by

⁷ These RAOs are consistent with those previously identified in the FS Tech Memo but provide greater specificity based on the results of the Final RI Report, including the Addendum, and the Final Risk Assessment.

the State/U.S. Territory in a timely manner, and are more stringent than Federal requirements may be applicable or relevant and appropriate. ARARs may relate to the substances addressed by the remedial action (chemical-specific), to the location of the site (location-specific), or the manner in which the remedial action is implemented (action-specific).

In addition to applicable or relevant and appropriate requirements, the lead agency may, as appropriate, identify other advisories, criteria, or guidance to be considered for a particular release. The "to be considered" (TBC) category consists of advisories, criteria, or guidance that were developed by USEPA, other federal agencies or states/territories that may be useful in developing CERCLA remedies.

The following discussion identifies chemical-specific ARARs and TBCs for the Site which are then used to establish the Preliminary Remediation Goals (PRGs). Location-specific and action-specific ARARs and TBCs are discussed in Section 7 (Detailed Evaluation of Alternatives).

Chemical-Specific ARARs and TBCs

Chemical-specific ARARs and TBCs represent health or risk-based concentration limits in various environmental media for specific contaminants. They are used to establish cleanup criteria for remedial actions in order to protect human health and the environment. Generally, State/U.S. Territorial ARARs are used only where they are more stringent than the Federal ARAR-equivalent. As such, where equivalent Federal and State/U.S. Territorial ARARs exist, only the Federal ARARs are cited. The following chemical-specific standards are available for the media covered by the RAOs:

- National Primary Drinking Water Standards (40 CFR Part 141) establishes primary maximum contaminant levels (MCLs) for public water systems measured at the tap based on protection of health and consideration of technical and economic feasibility. The MCLs provides the standards for groundwater and are applicable to the Site.
- USEPA Soil Screening Levels (SSLs) (EPA 1996) are unpromulgated and as such are not ARAR but are classified as "To Be Considered" (TBC). As stated in the USEPA Soil Screening Guidance: User's Guide (USEPA, July 1996) the "SSLs are not national cleanup standards. SSLs alone do not trigger the need for a response actions or define 'unacceptable' levels or contaminants in soil".

3.1.2 Preliminary Remediation Goals

Preliminary Remediation Goals (PRGs) derived from the ARARs and TBCs are provided in Table 2 for the key constituents of concern (COCs) identified in the Risk Assessment. The PRGs consist of numerical targets for the COCs in a specific media and are intended to guide the development of remedial alternatives⁸. Based on correspondence between Berlex, P&U, M/H, and USEPA during the RI process, a Site-specific Dilution and Attenuation Factor (DAF) of 10 was developed and agreed upon by the parties. This value has been utilized for the development of the PRGs reflected in Table 2.

⁸ Performance standards (as distinct from PRGs) will be established following remedy selection by USEPA.

4.0 DEVELOPMENT AND SCREENING OF ALTERNATIVES

4.1 General Response Actions

Existing response actions at the VICHEM Site are described in the Revised Final RI Report (2000). These generally include removal of waste materials and contaminated soils. In addition, a security fence was installed around the Site in early 2000.

For the purposes of the identification and screening of potential final remedial technologies, general response actions (GRAs) are developed in accordance with the remedial action objectives (see Section 3.1). GRAs are those that, singly or in combination, satisfy the RAOs for the identified media by reducing the concentration of hazardous substances or reducing the likelihood of contact with hazardous substances. Typical GRAs include treatment, containment, institutional controls, excavation, extraction, disposal, or combinations of these methods.

The Feasibility Study Technical Memorandum (M/H, March 1999) identified the following GRAs for the VICHEM Site:

- No action;
- Institutional controls;
- Containment;
- Removal/collection;
- Treatment; and,
- Disposal/discharge.

These GRAs were further investigated and screened for specific technologies and process options.

4.2 Screening of Technology and Process Options

FS Technical Memorandum

The FS Tech Memo includes a preliminary screening of technologies and process options for groundwater and soil.

Soil

Based on the FS Tech Memo, the following remedial technologies and process options for soil were retained for further evaluation:

<u>Remedial Technology</u>	<u>Process Option</u>
None (No Action)	Not applicable
Access / Use Restrictions	Land use restrictions, deed/zoning restrictions, fencing
Environmental Monitoring	All media
Surface Controls	All processes
Excavation	All processes
Structure Dismantling / Demolition	All processes
Biological (In-Situ)	Bioventing, biodegradation
Chemical / Physical (In-Situ)	Soil vapor extraction
Biological (Ex-Situ)	Solid phase
Thermal (Ex-Situ)	Incineration, thermal desorption
On-site Disposal	Staging, backfill treated material

After further evaluation of implementability and cost, the following process options were eliminated from further consideration: bioventing, biodegradation, incineration, and thermal desorption.

USEPA CERCLA guidance (USEPA, 1993) states that soil vapor extraction (SVE), thermal desorption, and incineration are the presumptive remedies for Superfund sites with VOC-contaminated soil, provided that the site characteristics meet certain criteria. In the present case, SVE is the presumptive remedy for the VOC-contaminated soils (e.g., ethylbenzene and xylene in the AST Area) at the VICHEM Site. Although the use of a presumptive remedy typically precludes the need for identification and screening of alternatives, the screening work performed in this FS has been included for completeness.

EPA's presumptive remedy guidance references the BTEX compounds, among others, as those amenable to SVE. In accordance with the evaluation criteria in this guidance, the presence of VOCs has been confirmed in soil and a Site-specific SVE pilot study has been performed that indicates that SVE is feasible for the AST Area. The Spring 2000 SVE pilot study description, results, and conclusions are contained in the Draft SVE/AS Pilot Study Report (Golder, 2000), the results and conclusions of which are discussed below and in Section 5.3.

Groundwater

The FS Tech Memo identified the following remedial technologies and process options for groundwater to be retained for further evaluation:

<u>Remedial Technology</u>	<u>Process Option</u>
None (No Action)	Not Applicable
Access / Use Restriction	Groundwater use restrictions, deed/zoning restrictions
Alternate Water Supply	All processes
Monitored Natural Attenuation	Groundwater monitoring
Environmental Monitoring	All Media
Extraction	Extraction Wells
Biological (In-Situ)	Bioventing, chemical bioaugmentation
Physical (In-Situ)	Air sparging, vertical recirculation wells, air or steam stripping
Physical (Ex-Situ)	Sedimentation, filtration
Chemical(Ex-Situ)	Carbon adsorption, precipitation/coagulation/flocculation
On-site Discharge	Surface water, injection wells, infiltration
Off-site Discharge	Publicly Owned Treatment Works (POTW)

After further evaluation of implementability and cost, the following process options were eliminated from further consideration: vertical recirculation wells, steam stripping, injection wells, infiltration, and off-site discharge to POTW.⁹

Air Sparging Evaluation

The field Treatability Study conducted by M/H in Spring 2000 included the evaluation of air sparging (AS) as a potential technology to be used in conjunction with SVE to enhance the removal of VOCs in groundwater. The results of this study, plus additional groundwater sampling conducted concurrently with the SVE/AS Treatability Study (see RI Addendum, Golder, 2000), provided the basis for additional analysis of potential groundwater remedial alternatives. The results of this study are presented and discussed in detail in the Draft SVE/AS Pilot Study Report (Golder, 2000) and include vacuum/pressure responses in the vapor probes, dissolved oxygen levels in groundwater, mass removal rates of COCs, and changes in concentration of Site COCs in groundwater during testing. The SVE/AS Pilot Study Report also includes figures depicting the layout of SVE and AS wells and monitoring probes, the process schematic, and well/probe construction details.

⁹ In subsequent correspondence, USEPA indicated that discharge to POTW should be retained.

Evidence of the effectiveness of the air sparging system in the AST Area during the pilot test includes reduction in groundwater concentrations and attainment of significant mass removal rates. A 92% reduction in total ethylbenzene and xylene concentrations in groundwater was achieved during the SVE/AS test in the AST Area, based on data from monitoring well MW-1 (i.e., pre-test value of 130 ppm and post-test value of 10 ppm). Data collected during the pilot test indicated minimum removal rates of 8 lb/day¹⁰ for a single air sparge well.

Pilot testing conducted with air sparging and SVE together showed much higher removal rates compared with SVE alone. Based on a total estimated mass of ethylbenzene and xylenes in soil and groundwater of 1300 pounds and a removal rate of 8 lb/day, remediation of the AST Area could potentially be achieved within six months. Given that removal of residual mass would be increasingly controlled by diffusion, rather than by advection, over time, the actual cleanup time would likely be somewhat greater. However, the effects of natural attenuation via biodegradation would be expected to significantly reduce the estimated cleanup time. Therefore, for the purposes of this FS evaluation, an estimated cleanup time of one year has been assumed.

The total mass removal of chloroform over the three-day extended SVE/AS pilot test was estimated to be 11 grams, which is small, but is approximately 9% of the total estimated source mass of 0.26 pounds. Vapor pressures and dissolved oxygen measurements indicate that the radius of influence in the FPP Area was substantially less than the AST Area. This is likely due to the difference in subsurface soil conditions between the FPP Area and the AST Area. The borehole logs from SVE wells in the AST Area indicate that there is a more permeable, sandy layer from approximately 7-16 feet bgs, which is within the screened interval of the SVE wells. Vapor probes screened at 15 feet bgs indicated the strongest pressure responses. In contrast, a mostly uniform clay was indicated to a depth of 18 feet bgs in the FPP Area.

As discussed further in Section 2.3, biodegradation of chloroform in the FPP Area is occurring under anaerobic conditions. The introduction of oxygen via air sparging in the FPP Area would be counterproductive by altering the subsurface biogeochemical conditions such that natural attenuation processes may be disrupted in that Area.

¹⁰ This rate is approximate due to uncertainty in the velocity measurements.

Therefore, based on the results of the SVE/AS Treatability Study and the natural attenuation conditions of the FPP Area subsurface, the use of air sparging as a remedial technology for groundwater in the FPP Area was eliminated on the basis of limited effectiveness, and was retained in the AST Area on the basis of cost, effectiveness, and implementability. SVE could be used for source treatment (control) of chloroform in the FPP Area; however, remaining source amounts are minimal (e.g., 0.26 lb).

Groundwater Extraction and Treatment Evaluation

At the request of USEPA, groundwater extraction and treatment ("pump and treat") was retained as a process for further detailed evaluation.

The investigation performed by M/H in Spring 2000, which involved the replacement of former production well P-1 and Site-wide groundwater sampling, verified that neither the deep Alluvial aquifer nor the Kingshill aquifer are impacted. Therefore, the pump and treat evaluations for both the AST and FPP Areas consider the upper Alluvium only. Further, the sampling and modeling data indicate that the shallow groundwater plumes in both Areas are not growing and have attenuated significantly. This is evidenced by the limited extent of contamination and by reductions in source concentrations compared to those measured in the earlier phases of the RI. The latest RI investigations also show that shallow aquifer contamination above MCLs does not extend to off-Site receptors, nor is it expected to do so in the future. Regardless, the pump and treat evaluation for both Areas was conducted in a conservative manner, using the historical RI data that indicates higher concentrations and a greater extent of impacts than recent groundwater data would suggest.

FPP Area

The constituent of concern in the groundwater in the FPP Area is chloroform, the historical soil and groundwater concentrations of which are provided in the RI Report (McLaren/Hart, 2000). For this evaluation, a worst-case design concentration of 1000 ppb of chloroform in groundwater was used. This value is on the order of the highest detected groundwater concentrations during 1998 in the FPP Area, but is conservative compared to the highest detected concentrations in the most recent Spring 2000 monitoring event (i.e., 40 ppb, which is below the MCL).

A pump and treat system for the FPP Area would conceptually comprise a pumping system (i.e., extraction wells with submersible pumps), an ex-situ treatment train to degrade or remove chloroform from the water, and a treated water discharge system.

The number of extraction wells and their combined pumping rate was estimated to effect sufficient capture of the groundwater within the upper alluvium in the FPP Area, since only the shallow groundwater in the FPP Area has contained chloroform at concentrations in excess of MCLs.

An appropriate pumping rate to achieve reasonable drawdown over the required capture zone was estimated using the following steady-state solution from Todd (1980):

$$h = \sqrt{H_0^2 - \frac{Q \ln \frac{r_0}{r}}{\pi k}}$$

where: h = hydraulic head at radial distance r from the pumping well [L]

H_0 = Initial hydraulic head [L] = saturated thickness

Q = Pumping rate [L^3/T]

r_0 = Radius of influence [L] = $\sqrt{\frac{Q}{\pi R}}$

R = Precipitation recharge [L^2/T]

r = Radial distance [L]

k = Horizontal hydraulic conductivity [L/T]

The horizontal hydraulic conductivity was taken from the slug test analysis for MW-2 in conjunction with a recharge rate of 2.64 inches per year, and a saturated thickness of 15 feet based on remedial investigation data (M/H, 2000).

Based on this analysis, an estimated pumping rate 0.8 gpm from each of two wells spaced approximately 100 feet apart, was selected. The primary extraction well would be located in the source area where the highest concentrations of chloroform in groundwater have been historically encountered. The capture zone exhibited by this well would essentially include the entire plume of impacted groundwater. The secondary extraction well would be located

downgradient of the source area within the historical chloroform plume area, in order to capture residual chloroform contamination that has already migrated beyond the source area, and as a backup for the primary extraction well. The calculations and combined drawdown cone established by superposition, as shown on Table 3, indicate a minimum drawdown of 2 feet between the wells, and approximately 0.8 feet at a distance of 100 feet from each well.

The stagnation point (i.e., the point furthest downgradient from which a particle of water will be drawn back into the well), and the width of the capture zone were estimated from the following formulae, which consider the effects of horizontal hydraulic gradient on the width of the capture zone:

$$x = \frac{Q}{2\pi Ti}$$

where: x = Stagnation point distance [L]

i = Horizontal hydraulic gradient [dim]

T = Aquifer transmissivity [L^2/T] = KH_0

and:

$$y = \frac{Q}{2Ti}$$

where: y = half-width of the capture zone [L]

These calculations confirm that these pumping rates would produce a capture zone of sufficient size (theoretically, about 285 feet in width and 46 feet to stagnation point).

Several factors may affect the ultimate pumping rate of the extraction system. Aquifer heterogeneities, as seen in the variability in hydraulic conductivity, may result in slightly higher or lower pumping rates. During construction of some Site wells, increased water yields were noted (e.g., MW-15), however the storage of any potential zones of higher transmissivity is not likely to be high, therefore the increased yields may not be sustainable.

The average design extraction rate would be refined and established in design but was assumed to be 1.6 gpm for the purpose of the FS. A worst-case pumping rate of 3 gpm was also assumed.

Three treatment trains for the extracted groundwater were evaluated:

- (1) air stripping;
- (2) aeration and filtration with granular activated carbon (GAC) adsorption; and,
- (3) ultraviolet irradiation/oxidation (UV/ox).

Air Stripping

Air stripping would be accomplished with a low-profile tray air stripper. The extracted groundwater would be pumped to a storage/equalization tank and then to the air stripper where it would flow across multiple aeration trays. Air is blown countercurrently through small holes in the aeration trays, forming a froth of bubbles to provide a large mass transfer surface area where the contaminants are volatilized. Because of the scouring produced by the froth, the trays are relatively resistant to fouling by iron. In addition, the trays can be cleaned with pressure-washing wands via cleanout ports at each tray level. The air stripper is expected to remove 99.9% of the chloroform in the contaminated groundwater to achieve an effluent concentration below 1 ppb.

Based on an assumed influent concentration of 1000 ppb (based on RI data) and a 3 gpm flow rate, the worst-case (i.e., 100% stripping efficiency) emissions of chloroform would be 0.0015 lb/hr (0.007 tons per year) or 0.5 ppmv. This mass loading is well below the Title V major source thresholds for hazardous air pollutants (40 CFR 51; Subpart Q 51.322) and is also less than the limits imposed by VIDPNR at other remedial sites in the Virgin Islands.

Aeration and Filtration with GAC Adsorption

Aeration is necessary to remove contaminants, such as iron, that may interfere with the effectiveness of the GAC in removing chloroform. Conversion of ferrous iron to the ferric state occurs rapidly upon aeration. The resulting ferric hydroxide would be removed by filtration using a bag filter system. If such contaminants were to remain in the water, they would adsorb to the GAC and consume much of the available surface area for chloroform adsorption. In addition, a portion of the dissolved solids in the groundwater would deposit on the carbon, thereby increasing the pressure drop associated with the carbon unit. Thus, the effective life of the GAC would be greatly reduced, and material and operational costs would magnify. With aeration as pretreatment, these problems are reduced; however, this pretreatment step would introduce operational and maintenance costs associated with aeration equipment (e.g., blower and diffusers or mechanical agitator), and changing and disposing of the bag filters.

Following aeration, the water would be pumped to the GAC system. Chloroform is poorly absorbed to carbon and so requires an extended contact time compared to other organic contaminants. A GAC system comprising two 55-gallon drums of carbon (approximately 165 pounds of carbon in each) in a lead-lag configuration has been evaluated. Each drum would provide about 15 minutes of contact time, for a total of 30 minutes. With this contact time, the GAC is expected to remove the chloroform in the groundwater to non-detect levels.

The worst-case air emissions of chloroform would be lower than for air stripping and so off-gas controls are not expected to be required.

Based on the design assumptions and a 50% working efficiency of the carbon as compared to equilibrium conditions, the expected life of a carbon unit would be 2-3 weeks, or 18 units per year. The spent carbon would require off-site disposal or regeneration. Monitoring would also be required to evaluate breakthrough of chloroform. In addition, the spent bag filters, containing iron precipitate and sediments, would require frequent changing and disposal. Based on the relatively high operations and maintenance requirements and associated expense for this system, it has been eliminated from further consideration.

Ultra Violet Irradiation/Oxidation

In the ultraviolet irradiation/oxidation (UV/OX) process, UV radiation is emitted into the contaminated water, and an oxidizing agent (such as hydrogen peroxide) is added. The UV light activates the oxidizing agent to form oxidizing species called hydroxyl radicals, which then destroy the organic compounds in the water. In the case of chloroform destruction, a catalyst may be required. There are no air emissions from this process.

The 1.6 gpm flow rate expected from the groundwater extraction wells is not high enough to produce the turbulence needed for effective UV/ox. Thus, the groundwater would be pumped to a batch tank and then run through the UV/ox system in intermittent batches at 15 gpm. The UV/ox system would consist of a skid mounted 30 kW system with built-in programmable logic controller. Secondary containment and a safety shower with eyewash would be required. Wastes generated would include spent UV bulbs and empty hydrogen peroxide containers.

Capital costs for the UV/ox system are high and as this is an energy-intensive process, the operational costs are also high. These costs are anticipated to be much higher than the costs for the other technologies. For this reason, UV/ox has been eliminated from further evaluation.

Three options were considered for the disposal of the treated water:

- (1) surface water discharge to the River Gut;
- (2) groundwater discharge via on-site reinfiltration pond; and,
- (3) discharge to a publicly-owned treatment works (POTW).

Surface Water Discharge

Discharge to the River Gut involves pumping the treated groundwater from the treatment plant to the River Gut that runs along the eastern and southern borders of the property. The discharge water quality will need to meet or exceed the USEPA's National Recommended Water Quality Criteria for Priority Toxic Pollutants; the level for chloroform, based on human health criteria is 5.7 µg/L. All of the treatment train alternatives discussed above are expected to achieve this criterion. This option is therefore feasible and economical.

Reinfiltration

Reinfiltration would be accomplished via a bermed re-infiltration pond that would be constructed in a location with sufficient surface area. An estimate for the approximate area required for the recharge basin was established using the following formula:

$$A = \frac{Q}{Ki}$$

where:

A = Area of the recharge basin [L²/T];

Q = Discharge rate of extraction system [L³/T];

K = hydraulic conductivity [L/T]; and,

i = hydraulic gradient [L/L].

The vertical hydraulic conductivity used in this estimation was assumed to be ten percent of the horizontal value derived from the slug test results for MW-2 (i.e., 1.04 x 10⁻³ cm/sec). To account for potential clogging of the basin, this value was reduced by twenty percent (i.e., 8.3 x

10^{-5} cm/sec). As described above, the average discharge rate of the extraction system was estimated to be 1.6 gpm from two wells. Throughout most of the year, the depth to groundwater is between twenty and thirty feet below ground surface, and therefore infiltration would not be expected to result in excessive mounding. Consequently, the vertical hydraulic gradient was assumed to be equal to 1. Using these input parameters, a basin measuring approximately 36 feet by 36 feet would be of sufficient size to infiltrate the treated groundwater.

Factors that may affect the required size of the basin are the hydraulic conductivity of the shallow alluvium in the area where the basin is constructed and the degree of clogging that the basin undergoes with time. For example, the actual hydraulic conductivity may be lower than that of the strata represented by MW-2. In light of the vicinity of the local airport, operating a surface water unit on this Site is not preferable, as the water would attract animals and fowl, which may interfere with airport operations.

POTW Discharge

There is one POTW on the island of St. Croix. The closest sewer manhole to the site is approximately 1/8 mile from the site, across the River Gut. Approval from the Department of Public Works would be required in order to discharge to the POTW, and pretreatment standards would likely correspond to MCLs. Since the treatment trains described above would meet the more stringent surface water quality criteria, and since the River Gut is much closer to the treatment facility than the sewer, this option was eliminated from further consideration.

Cleanup Time

The time required for cleanup of the chloroform impacted groundwater was estimated using the batch flush analytical model developed by USEPA (National Academy Press, 1994). This model allows the estimation of cleanup time based on the number of pore volumes required to be pumped from the contaminated groundwater in order to attain the desired cleanup goal. This approach assumes simple advective displacement of contaminated water, neglecting dispersive transport. The other significant assumption is that the extracted pore volume is replaced with clean influent water, which instantaneously reaches equilibrium with the remaining sorbed contaminant mass. The equation to determine the number of required pore volumes is as follows:

$$PV = -R \ln C_{wr} / C_{wo}$$

where PV = Number of pore volumes
R = Retardation factor
 C_{wr} = Cleanup concentration
 C_{wo} = Initial contaminant concentration

For chloroform, the retardation factor used was 1.6 (see Section 2.3.4), the initial concentration was 1000 ppb, and the cleanup concentration was 80 ppb. This resulted in a calculated requirement of 4 pore volumes. The plume was estimated to encompass a volume of approximately 480,000 cubic feet, based on 1998 RI Data as shown in Figure 15. Based on 20% porosity and a pumping rate of 1.6 gpm, the estimated time required for cleanup based on this model would be 3.4 years.

In general, this model will underestimate cleanup time, therefore, this estimate should be considered as the minimum practicable cleanup time, given the assumptions outlined above. More importantly, this model does not account for heterogeneities in soil, which are significant in the FPP Area since contaminant migration is likely to be more diffusion-controlled than advection-controlled given the clayey nature of the Alluvium at these depths. Conversely, some conservative assumptions were built into the calculations, including the areal extent of the plume (200 feet by 120 feet) and the initial concentration of 1000 ppb, in order to develop a more realistic estimate. For the purposes of this FS, including costing, a cleanup time of 5 years has been assumed.

A groundwater pump and treat system would be a relatively aggressive means of source removal; however, the implementation in the FPP Area of an aggressive method of hydraulic containment and/or source removal of chloroform is not warranted for the following reasons:

- The Site data suggests the chloroform plume is not growing, has attenuated significantly, and does not pose a risk to off-site receptors.
- As described earlier in Section 2.0, the chloroform plume is naturally attenuating via anaerobic reductive dechlorination. The action of pumping groundwater will disrupt the anaerobic geochemical environment that currently supports natural attenuation processes, due to the influx of oxygenated water from upgradient as a result of the groundwater extraction.
- The Spring 2000 data shows significant reductions in chloroform over the last two years, and only one monitoring point that slightly exceeds MCLs.

- The influx of clean water caused by pumping will likely increase the rate of attenuation by dilution, and, as noted by USEPA, may result in the extraction of water that – *untreated* – would probably meet the cleanup goals from the start.
- Based on the results of the transient Bioscreen modeling, full compliance with cleanup goals for chloroform would be achieved by natural attenuation in *less* time as would be required for pump and treat in the FPP Area.

AST Area

At the request of USEPA, a detailed pump and treat evaluation was conducted for the AST Area in the same manner as the evaluation for the FPP Area. The constituents of concern in the AST Area groundwater are xylene and ethylbenzene. Based on the RI Report data from 1998 (McLaren/Hart, 2000), reasonable worst-case influent concentrations of 23 ppm and 110 ppm for ethylbenzene and xylene, respectively, were assumed for this evaluation.

The analysis for groundwater extraction rates and capture zone was conducted in the same manner as described above for the FPP Area. The average horizontal hydraulic conductivity was taken from the slug test analysis for MW-6 in conjunction with a recharge rate of 2.64 inches per year and a saturated thickness of 15 feet. The results, as shown on Table 4, indicate that two extraction wells each pumping at an average rate of 3.5 gpm (5 gpm worst-case), spaced 100 feet apart, will produce a minimum 2-foot drawdown between the wells and over one foot of drawdown at a distance of 100 feet from the well. The stagnation point was calculated to be 67 feet. As discussed above, intermittent zones of higher transmissivity may contribute to higher extraction rates, but these higher yields are not expected to be sustainable and were therefore not factored into the design pumping rates.

Based on the results of the treatment train evaluation conducted for the FPP Area, and given the much higher concentrations of xylene and ethylbenzene in groundwater than chloroform, as well as the chemical properties of these compounds, a treatment train of equalization followed by air stripping was selected. Based on a 2-tray low profile air stripper, an air flow of 150 scfm would be required for removal of these constituents in order to meet discharge standards (assumed to be 3100 ppb for ethylbenzene based on the National Recommended Water Quality Criteria and 10,000 ppb for xylene based on the MCL). The estimated air effluent concentration would be 212 ppmv or 0.53 pounds per hour, and off-gas controls were assumed not to be required.

Based on the same rationale as for the FPP Area, direct surface water discharge of the treated water to the nearby River Gut was selected based on feasibility, cost-effectiveness, and maintenance considerations.

The time required for cleanup of impacted groundwater in the AST Area was estimated using the same analysis described for the FPP Area. A retardation factor of 5.7 was used for both ethylbenzene and xylene, and MCLs were used as the cleanup concentrations. The estimated number of required pore volumes to be extracted was 19.9 for ethylbenzene and 13.7 for xylene. Based on an ethylbenzene impacted plume volume of approximately 396,000 cubic feet (which effectively contains the xylene plume see Figure 14), 20% porosity, and 7 gpm pumping rate, the estimated cleanup time was 3.2 years. Again, this number likely represents a minimum practicably achievable cleanup time, due to the assumptions inherent in this approach. In addition to the heterogeneous nature of the soil, the other significant factor in the AST Area is the continuing leaching of ethylbenzene and xylene from the vadose zone into the groundwater, which is not accounted for in this model. These two factors together likely result in an underestimated cleanup time in the AST Area. For the purposes of FS, costing, a cleanup time of 5 years has been assumed.

Although the minimum estimated cleanup times (i.e., 3-4 years) for both Areas are relatively short, the presence of geologic heterogeneities in both the AST and FPP Areas, as well as the presence of a significant source mass above the water table in the AST Area, could extend the estimated cleanup time by anywhere from a few years to more than 100 years and render these cleanup time predictions highly uncertain (National Academy Press, 1994).

4.3 Development of Alternatives

Based on the foregoing discussion, the following alternatives are retained for detailed analysis:

- Alternative 1: No further action (required by the NCP);
- Alternative 2: Monitored Natural Attenuation (MNA) with the institutional controls (deed restrictions on groundwater and property use);
- Alternative 3: Source control via soil vapor extraction/air sparging in the AST Area, combined with MNA and institutional controls. SVE would be retained as a contingent remedy for MNA in the FPP Area, if needed;

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- Alternative 4: SVE/AS in AST Area combined with Groundwater Extraction and Treatment in FPP Area and institutional controls; and,
 - Alternative 5: Groundwater Extraction and Treatment in AST Area combined with MNA and institutional controls.

5.0 ALTERNATIVES RETAINED FOR DETAILED EVALUATION

5.1 Alternative 1: No Further Action

The consideration of a No Further Action remedial alternative is required under the NCP. This option would not include the initiation of any new response actions. Under this option, the security fence installed in Spring 2000 would remain and be maintained, but the existing soil vapor extraction / air sparging system that was installed for the Treatability Study in Spring 2000 would be rendered non-operational.

5.2 Alternative 2: Monitored Natural Attenuation (MNA) with Institutional Controls

This alternative would include monitored natural attenuation (MNA) for COCs in groundwater in the AST Area and FPP Area. There is strong evidence to suggest that natural attenuation is effectively occurring and expected to continue at these two areas. A detailed discussion of natural attenuation indicator parameters, and evaluation of existing conditions provided in Section 2.3. A conceptual remediation plan for this alternative is depicted in Figure 42.

This remedial alternative would include monitoring of shallow groundwater conditions over a period of 15 years using existing wells at the Site, plus additional monitoring wells at the AST and FPP Areas. The following parameters would be monitored: ethylbenzene and xylene isomers (AST Area only), chloroform and dichloromethane (FPP Area only), dissolved oxygen, redox potential, total organic carbon, ferrous iron, sulfate, sulfide, and methane. As shown on Figure 42, approximately three shallow groundwater monitoring wells would be added at the AST Area, and two shallow wells would be added at the FPP Area for performance monitoring of MNA. The locations of these new wells are conceptual, and final locations would be determined during design, with respect to Site topography and other physical features. Recent data through Spring 2000 indicate that the deeper Alluvium is not impacted above MCLs by any Site COCs. Therefore, vertical groundwater profiles would be obtained during drilling of select shallow wells in order to verify no impacts to the deeper zone as well as to identify appropriate screen locations. Therefore, the conceptual network of monitoring wells for performance monitoring would initially include a total of 15 new and existing shallow and deep wells (i.e., MW-1, 6, 8, 10, 18, 19, and 20 in the AST Area; and MW-2, 3, 7, 11, 12, 15, 16, and 17 in the FPP Area) at which natural attenuation parameters and concentrations of Site COCs would be monitored. This network may be refined during design and over time based on trends in the analytical data. For

the purposes of this FS, the monitoring frequency is assumed to consist of quarterly sampling during the first year, semiannual sampling for the second and third years, and annual sampling thereafter of the entire network.

Institutional controls, which are implemented to reduce the potential for human exposure to constituents, would be a further component of this remedial alternative. For example, the security fence installed in 2000 would be maintained as an institutional control to discourage on-Site trespassers. A second institutional control would be continued industrial zoning use of the Site. Based on discussions with the Virgin Islands Department of Planning and Natural Resources (VIDPNR), the VICHEM Site is currently zoned as I-2 (Light Industry). VIDPNR has indicated that the draft zoning plan for St. Croix proposes that the Site and surrounding area remain zoned as industrial (M/H, 2000).

A third institutional control includes use and access restrictions. Such restrictions would include a deed notice that would run with the land prohibiting installation of extraction wells on-site and any residential use of the Site. The current Amended Agreement between Berlex, P&U, and CHS Holding Corporation (i.e., current property owner) states that CHS will "refrain from using the Site in any manner, or engage in any other activities that would interfere with or adversely affect the integrity or protectiveness of the remedial measures implemented or to be implemented at the Site." The Site owner also agreed to record the Amended Agreement in the St. Croix land records office, as well as to record end use deed restrictions to restrict future ownership or operation of the Site. Under this Agreement, the owner will also provide prior notification to Berlex and P&U of any anticipated changes in Site ownership or operation.

5.3 Alternative 3: Source Control (SVE/AS) with Monitored Natural Attenuation

In addition to the institutional controls identified in Section 5.2, this remedial alternative consists of two primary components, (1) an SVE/AS system to remediate source zone groundwater, saturated soil and vadose zone soil at the AST area and Monitored Natural Attenuation for residual groundwater contamination and (2) a Monitored Natural Attenuation (MNA) remedy for the remediation of groundwater in the FPP area and downgradient. SVE would be available for source control (treatment) in the FPP Area, if needed. A conceptual remediation plan for this alternative is depicted in Figure 43.

For the AST Area, this remedial alternative includes an air sparging system for volatilizing VOCs in shallow groundwater and saturated soil and a soil vapor extraction system to capture sparged vapors and to volatilize and capture vadose zone soil VOC contamination. MNA would be implemented for low-level residual VOC contamination in downgradient groundwater. The SVE/AS system would treat the contaminated soil and underlying groundwater in the AST tank area as described in the Draft Final Treatability Study Workplan (M/H, 1999b). Periodic monitoring of pressure or vacuum response in SVE wells and vapor monitoring points would occur. In addition, field measurements of total organics (e.g., with a photoionization detector) and oxygen at each SVE well, as well as dissolved oxygen in groundwater, would be taken in order to balance the system and assess performance. Periodic samples of the extracted gas would be analyzed either by an on-site mobile laboratory or off-site laboratory for individual VOC analytes. Removal rates would be estimated in the final design and during operations in order to determine compliance with the applicable air emissions standards and/or permit requirements. If emissions limits are likely to be exceeded, then appropriate off-gas controls or operational modifications would be instituted in order to comply with applicable emissions limits.

SVE/AS system design parameters will be updated based on pilot SVE/AS field tests performed in Spring 2000 (refer to Draft SVE/AS Pilot Study Report, Golder, 2000). SVE would be accomplished using a blower equipped with a moisture separator and filter to protect the blower in conjunction with the currently installed configuration of six SVE wells. Pilot test results indicated that the SVE radius of influence (ROI) was approximately 30-40 feet. The SVE wells are located at 35-foot centers (Figure A-1). The total SVE system flow rate during pilot testing was approximately 100-150 standard cubic feet per minute (scfm).

Sparging would be accomplished using an oil-free air compressor able to deliver 70 scfm at pressures of up to 200 psi. The design sparge rate would be established in the final design but is likely to be approximately 4-7 scfm per well. The design sparge (compressor) pressure would be approximately 150 psi. The final remedial design would consider the effective ROI for air sparge and SVE wells and any appropriate system upgrades.

Pilot tests conducted with sparging and SVE together showed much higher removal rates compared with SVE alone. The mass removed during the pilot test demonstrates the effectiveness of these technologies. Although the VOC mass is primarily in the soil phase, much of the soil contamination is located at depths greater than 20 feet (M/H, 2000), which, during the

pilot test, was below the water table. As the water table may be higher than 20 feet for a significant portion of the year, sparging of the groundwater would be an integral component of this remedial alternative.

Cycling (on and off) of the sparge flow is known to produce higher mass removal rates than a constant sparge flow (Marley and Bruell, 1995). Cycling, which was not utilized in the pilot tests, will be considered as an enhancement during the final remedial design. Other enhancements will be considered, such as automation of the system in terms of data collection and operational controls.

For the reasons discussed in Section 4.0, AS is not considered appropriate for the FPP Area and may be counterproductive. The absence of a chloroform source in FPP vadose-zone soils does not warrant the use of SVE in this area for active removal; nevertheless, this source control technology is available for use in the FPP Area, if needed, in conjunction with MNA. Monitored natural attenuation to treat groundwater is therefore proposed in this remedial alternative for the FPP Area, as discussed in Section 5.2. For costing purposes, the same network and sampling scheme for groundwater monitoring as stated in Alternative 2 would be employed for an assumed 15 years.

5.4 Alternative 4: SVE/AS with Groundwater Extraction and Treatment

In addition to the institutional controls identified in Section 5.2, this remedial alternative includes two additional primary components, (1) SVE/AS to remediate source zone groundwater, saturated soil and vadose zone soil at the AST Area and Monitored Natural Attenuation for residual groundwater contamination, and (2) groundwater extraction and treatment system for the remediation of impacted groundwater at the FPP Area. A conceptual remediation plan for this alternative is depicted in Figure 44.

The SVE/AS portion of the remedy in the AST Area would be the same as described in Section 5.3.

At the FPP Area, the groundwater extraction system would be comprised conceptually of two extraction wells, located approximately 70 feet apart, each with a average design pumping rate of

0.8 gpm and a worst-case pumping rate of 1.5 gpm. The wells would each be equipped with a submersible pump. The extraction system is described further in Section 4.2.

As shown on Figure 44, the primary extraction well (EW-1) would be located in the source area where the highest concentrations of chloroform in groundwater have been historically encountered. The capture zone exhibited by this well would essentially include the entire plume of impacted groundwater. The secondary extraction well (EW-2) would be located downgradient of the source area within the historical chloroform plume area, in order to capture residual chloroform contamination that has already migrated beyond the source area, and as a backup for the primary extraction well. These locations are considered to be conceptual in nature; final locations would be determined during design, with respect to Site topography and other physical features.

The treatment system would consist of an storage/equalization tank, from which groundwater would be pumped to a low profile air stripper for removal of chloroform. Treated water would be discharged via pipeline to the River Gut. System monitoring would include pre- and post-air stripper water sampling in order to evaluate removal efficiency in the air stripper and compliance with surface water discharge limits. Also, an air flow indicator would be monitored periodically to ensure sufficient air flow from the blower for mass transfer in the stripper. Differential pressure across the air stripper would also be monitored, in addition to periodic visual inspection of the trays, to evaluate whether fouling or other impediments to air flow have occurred. Mass emissions from the air stripper would be calculated by using the measured concentrations of chloroform in the influent water and treated water and the flow rate from the storage tank to the stripper.

The cone of depression and extent of the capture zone induced by the extraction wells would be assessed by measuring water levels at new and existing groundwater monitoring wells. For costing purposes, the same network of wells and sampling frequency described in Alternative 2 has been assumed initially. Although MNA is not an explicit component of this alternative for the FPP Area, natural attenuation parameters would be monitored periodically in the FPP Area to assess the effects of the pumping system on anaerobic biodegradation processes. However, it is expected that the network of wells to be monitored for chloroform would be reduced over time, given that Spring 2000 data suggest only a very localized area of contamination slightly exceeding the MCL. Also, the monitoring is expected to continue only through the duration of

the operation of the extraction system (i.e., until the attainment of cleanup goals), plus two years of post-shutdown monitoring.

5.5 Alternative 5: Groundwater Extraction and Treatment with MNA and Institutional Controls

In addition to the institutional controls identified in Section 5.2, this remedial alternative includes two additional primary components, (1) Monitored Natural Attenuation for impacted groundwater in the FPP Area, and (2) a groundwater extraction and treatment system to capture and treat impacted groundwater at the AST Area. A conceptual remediation plan for this alternative is depicted in Figure 45.

At the FPP Area, the MNA portion of the remedy would be the same as described in Section 5.2.

At the AST Area, the groundwater extraction system would consist of two extraction wells, as depicted in Figure 45. Each well would have a design flow rate of 3.5 gpm and a worst-case flow rate of 5 gpm. The two wells (EW-3 and EW-4) are located within the zone of highest xylene and ethylbenzene impacts. The expected combined capture zones of these wells would encompass the entire AST Area and extent of the xylene and ethylbenzene plumes (both on-Site and off-Site).

The treatment system would be comprised of the same components and be subject to the same monitoring scheme as described in Section 5.4. Treated water would be discharged to the River Gut at a location northeast of the AST Area.

For costing purposes, the network of monitoring wells and sampling frequencies has been assumed to be the same as identified in Alternative 2. The duration of monitoring in the FPP Area would be 15 years, and in the AST Area would be 7 years (i.e., five years during extraction system operation and two years of post-shutdown monitoring).

6.0 NCP EVALUATION CRITERIA

The selection of a remedial alternative is based on an evaluation of nine criteria established in the NCP. Two criteria (state acceptance and community acceptance) will not be evaluated in this report because they will be evaluated during the public comment period. The remaining seven criteria are listed below.

Threshold criteria are those which must be met in order for a remedy to be eligible for selection. The two threshold criteria are described below.

- Overall Protection of Human Health and the Environment

Under this criterion, an alternative should be assessed to determine whether it can adequately protect human health and the environment, in both the short-term and long-term, from unacceptable risks posed by hazardous substances, pollutants or contaminants present at the site, by eliminating, reducing or controlling exposures to levels established during development of remediation goals. This criterion is an overall assessment of protection based on a composite of factors assessed under other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

- Compliance with ARARs

This criterion evaluates whether and how the alternative attains applicable or relevant and appropriate requirements under federal environmental laws and state environmental or facility siting laws, or provides grounds for invoking the legal waiver of such requirements.

Primary Balancing criteria are used to weigh the alternatives in order to determine the best selection for the Site. The 5 balancing criteria are described below.

- Short-Term Effectiveness

This criterion evaluates the impacts of the alternative during implementation with respect to human health and the environment. The short-term impacts of an alternative shall be assessed considering: short-term risks that might be posed to the community during implementation of an alternative; potential impacts on workers during remedial action and the effectiveness and reliability of protective measures; potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation.

- Reduction of Toxicity, Mobility, and Volume Through Treatment

Under this criterion, the degree to which an alternative employs recycling or treatment that reduces toxicity, mobility, or volume shall be assessed, including how treatment is used to address the principal threats posed at the site. Factors that shall be considered include: the treatment or recycling processes; the alternatives employed and the materials they will treat; the amount of hazardous substances, pollutants or contaminants that will be destroyed, treated, or recycled; the degree of expected reduction in toxicity, mobility or volume of the waste due to treatment or recycling and the specification of which reduction(s) are occurring; the degree to which the treatment is irreversible; the type and quantity of residuals that will remain following treatment considering the persistence, toxicity, mobility, and propensity to bio-accumulate of such hazardous substances and their constituents; and the degree to which treatment reduces the inherent hazards posed by principal threats at the site.

- Long-Term Effectiveness and Permanence

Under this criterion, an alternative shall be assessed for the long-term effectiveness and permanence it affords, along with the degree of uncertainty that the alternative will prove successful. Factors that shall be considered, as appropriate, include: the magnitude of residual risk remaining from untreated waste or treatment residuals remaining at the conclusion of the remedial activities; and the adequacy and reliability of controls such as containment systems and institutional controls that are necessary to manage treatment residuals and untreated waste.

- Implementability

This criterion addresses the technical and administrative feasibility of implementing the alternative as well as the availability of various services and materials required.

- Cost

Cost items evaluated include capital and operation and maintenance expenditures to implement the alternative, presented as a present worth analysis.

7.0 DETAILED EVALUATION OF ALTERNATIVES

7.1 Alternative 1: No Action

Overall Protection of Human Health and the Environment

The No Action remedy would be adequately protective of human health and the environment under current conditions because there are no unacceptable risks posed by the Site. However, under future exposure scenarios, a No Action remedy provides no reduction in potential risk to human health posed by hypothetical future exposure of on-site workers to COCs in groundwater. Natural attenuation processes would continue to remediate groundwater but this would not be verifiable given the absence of environmental monitoring.

Compliance with ARARs

The No Action option relies upon natural attenuation for attainment of groundwater ARARs. Given adequate time, this option is expected to meet these standards. There are no ARARs for soil and so compliance is not an issue for this medium.

Short-Term Effectiveness

No additional short-term risks to the community, workers, or the environment are posed by implementation of this option. Natural attenuation processes will require a period of years to be fully effective.

Long-Term Effectiveness and Permanence

Natural attenuation of groundwater constituents is an effective long-term measure that utilizes permanent treatment. Migration to groundwater of contaminants in subsurface soils within the AST Area would be a long-term concern.

Because Site contaminants would be left in place, a five-year review would be required to assess the continued effectiveness of this option.

Reduction of Toxicity, Mobility, and Volume Through Treatment

Natural attenuation processes, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These processes include biodegradation, dispersion, dilution, sorption, volatilization chemical or biological stabilization and transformation, among others (USEPA

1999). Ongoing natural attenuation processes at the Site, in particular biodegradation, will effectively treat and reduce the volume, toxicity, and mobility of chloroform, ethylbenzene and xylene in groundwater. Some degradation by-products, such as dichloromethane, do exhibit similar toxicity; however, the expected half-lives of these by-products are short and are not present on-Site at concentrations above MCLs. The progress of natural attenuation would not be verifiable under this alternative, given the absence of environmental monitoring. Also, mobility of subsurface soil contaminants in the AST Area into groundwater would not be addressed.

Implementability

The No Action option is straightforward to implement.

Cost

A cost estimate for this remedial alternative is shown in Table 5. The only costs associated with this remedy would be those associated with the Site security fence. The total present worth cost for this alternative is \$57,000, based upon 30 years of maintenance.

7.2 Alternative 2: MNA with Institutional Controls

Overall Protection of Human Health and the Environment

The MNA with Institutional Controls remedial alternative will provide short-term and long-term protection of human health and the environment. The mass of VOCs in groundwater in the AST and FPP Areas would be permanently reduced over time by natural physical and biological processes that have been shown to be occurring. Evaluation of the historical groundwater concentrations and natural attenuation geochemical parameters measured at the Site reveal that conditions are favorable for the anaerobic degradation of chloroform in the FPP Area, and that degradation of ethylbenzene and xylene will also proceed anaerobically in the AST Area.

Institutional controls will provide the necessary protection while natural attenuation processes effectively treat and mitigate VOCs in groundwater. Continued monitoring of reduction in groundwater concentrations and of natural attenuation indicator parameters at both the AST and FPP Areas would provide assurance and verification of the protectiveness of this remedial alternative.

Compliance with ARARs

MNA is expected to achieve compliance with chemical-specific groundwater ARARs over time.

Action-Specific ARARs

On-site actions (i.e., within the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action) need comply only with the substantive aspects of ARARs, not with the corresponding administrative requirements (e.g., consultation, issuance of permits, documentation, record keeping and enforcement). Actions for this remedial alternative will include: installation, sampling, and potential decommissioning of wells, and generation of contaminated media waste. Potential action-specific ARARs, therefore, include:

- Virgin Islands Well Driller Requirements (VIC, Title 12, 157) requires well drillers to obtain a license and for all non-private wells to be drilled by a licensed driller. Permits are also required for new wells.
- Virgin Islands Requirements for Sealing Wells (VIC, Title 12, 161) requires effective sealing of well if highly mineralized water is encountered or well is abandoned.
- Virgin Islands Solid and Hazardous Waste Management Act (VIC, Title 19, Part IV, Chapter 58) provides for the establishment of regulations for the storage, collection, transportation, and disposal of solid and hazardous waste (e.g., drill cuttings).
- Department of Transportation Rules for the Transportation of Hazardous Materials (49 CFR Parts 107, 171.1 through 171.500) specify the procedures for packing, labeling manifesting, and transporting hazardous materials from point of generation to the point of treatment, storage or disposal.
- Occupational Safety and Health Standards for Hazardous Response Contractors (29 CFR 1926) establish worker health and safety program goals for CERCLA cleanup projects.

Location-Specific ARARs

Location-specific ARARs set restrictions on the conduct of remedial activities in particular locations (e.g., floodplains). Generally, State/U.S. Territorial ARARs are used only where they are more stringent than the federal ARAR-equivalent. As such, where equivalent Federal and State/U.S. Territorial ARARs exist, only the Federal ARARs are cited. Potential location-specific ARARs therefore include:

- Executive Orders on Floodplain Management and Wetlands Protection (CERCLA Floodplain and Wetlands Assessments-EO 11988 and 11990) require federal agencies to assess potential effects of remediation on surrounding wetlands and in the floodplain. Wetlands have been identified within the River Gut Channel adjacent to the Site, and are

classified as a "PFO3A" wetland (M/H, 2000). This remedial alternative is not expected to impact wetlands. In the event that wetlands were to be impacted by the implementation of this remedial alternative, a wetlands assessment would be conducted in accordance with EPA's 1985 "Statement of Policy on Floodplains/Wetlands Assessments for CERCLA Actions, which includes:

- Wetlands delineation;
- Discussion of the respective impacts of the remedial alternative;
- Characterization of existing flora and fauna;
- Discussion of the effects of contaminants on wetlands resources;
- Measures to minimize potential adverse impacts that cannot be avoided;
- A mitigation plan, if necessary; and,
- Post-mitigation monitoring plan.

Since the Site lies within the 100-year floodplain of the River Gut, a floodplain assessment would need to be conducted, if construction were to occur in the floodplain, to minimize or avoid the adverse effects of the 100 and 500-year flooding event. The assessment would include a discussion of the effects of the remedial alternative on the floodplain, a comparison to the effects of the non-selected alternatives on the floodplain, possible measures to minimize potential adverse floodplain impacts, and measures undertaken to prevent spreading of Site contamination by a flooding event during implementation of this remedial alternative.

- Coastal Zone Management Act (16 USC 1451, 15 CFR 298, 40 CFR 6.302(d) requires approval that the remedial action be consistent with the policies of the Virgin Island Coastal Zone Management Plan (CZMP) for actions affecting the coastal zone, including lands thereunder and adjacent shorelands. The Site falls outside the designated coastal zone and so actions must only comply with the general goals of the CZMP.
- Archaeological National Historic Preservation Act (16 USC 469; 40 CFR 6.301(c)) requires actions to recover and preserve artifacts if alteration of terrain threatens significant scientific, prehistorical, historical, or archeological data. EPA has determined that the majority of the site area has already been disturbed. Any actions that occur in undisturbed areas could require a Cultural Resource Survey, however, this is not expected as a part of this alternative.
- Earth Change plans and permits (VIC Title 12, Chapter 13, Sections 533 and 534) requires approval of an earth change plan and issuance of an earth change permit for clearing, grading, filling, or otherwise disturbing real property for any purpose. As noted above, compliance with the substantive requirements only is required.

Design and implementation of this alternative is expected to comply with ARARs.

Short-Term Effectiveness

MNA will require a period of years to become fully effective. No additional short-term risks are posed to the community, workers or the environment by implementation of this alternative.

Appropriate measures would be taken to protect on-site personnel during construction of monitoring wells and groundwater sampling activities. The use of the existing Site security fence as part of the institutional controls provide short-term effectiveness to discourage trespassers from accessing the Site.

Long-Term Effectiveness and Permanence

This remedial alternative will provide long-term permanent protection of human health and the environment by permanently treating the mass of VOC contaminants in groundwater at the AST and FPP Areas, which will restore the groundwater conditions to acceptable levels. In addition, long-term monitoring would be an integral part of the MNA remedial alternative to ensure the continued effectiveness of the remedy. PRGs for soil in the AST Area would not be attained for a number of years.

The Institutional Controls described in Section 5.0 are expected to be effective in the long-term to prevent unauthorized access to the Site and future use of the Site for other than industrial purposes.

Reduction of Toxicity, Mobility, and Volume Through Treatment

The natural biochemical and physical treatment associated with the ongoing natural attenuation processes at the Site will permanently reduce the toxicity, mobility, and volume of Site contaminants in groundwater and satisfies the statutory preference for treatment. Currently, the low groundwater velocity combined with natural attenuation has effectively imposed a steady state condition of the contamination such that the plumes in both Areas are not expanding in areal extent or depth. Intermediate degradation products of natural attenuation have very short half-lives and are not expected to contribute to future exposure risks. Modeling of the AST Area indicates that 99% and 97% of the ethylbenzene and total xylenes, respectively, that have left the source areas have already biodegraded. Modeling of the chloroform plume in the FPP Area indicates that 88% of the chloroform mass that has left the source area has been biodegraded.

Implementability

The MNA remedial alternative is easily implementable, since it relies on natural biochemical processes that are already existing and that do not require enhancement. The services and materials required to implement this alternative are standard within the industry and readily available.

Cost

A preliminary cost estimate for the MNA remedial alternative is presented in Table 6. The estimated capital costs and O&M costs for this alternative are \$161,560 and \$545,530, respectively. The total estimated present worth cost is \$707,000. The MNA aspect of this cost includes the installation/replacement of monitoring wells and annual monitoring for 15 years.

7.3 Alternative 3: Source Control (SVE/AS) with MNA***Overall Protection of Human Health and the Environment***

The Source Control (SVE/AS) with MNA remedial alternative will provide short-term and long-term protection of human health and the environment. Active in-situ treatment of the groundwater and subsurface soil in the AST Area will rapidly and permanently reduce the mass of VOCs in the saturated/unsaturated soil and groundwater. This action will also increase the effectiveness of aerobic biodegradation processes in the area of SVE and air sparging. Aerobic and anaerobic natural attenuation processes for groundwater VOC contamination beyond the influence of the SVE/AS system will address residual groundwater contamination, considering that ethylbenzene and xylene readily biodegrade. SVE will effectively treat the source to prevent any potential further groundwater contamination caused by migration of soil contaminants to groundwater.

In the FPP Area, this remedial alternative would adequately protect human health and the environment by the reduction of the mass of chloroform by natural physical and biological processes that have been documented at the Site. Drastic decreases in maximum concentrations within the FPP Area over the past two years indicate that strong natural attenuation processes are at work. Evaluation of the historical natural attenuation geochemical parameters measured at the Site confirms that conditions are favorable for the anaerobic degradation of chloroform.

Continued monitoring of reduction in groundwater concentrations and of natural attenuation indicator parameters at both the AST and FPP Areas would provide assurance and verification of the protectiveness of this remedial alternative. SVE would also be available as a contingency measure if further source control were needed should MNA performance monitoring data indicate a residual source concentration that was not protective of groundwater.

Compliance with ARARs

The SVE/AS and MNA alternative is expected to achieve compliance with chemical-specific ARARs for groundwater.

Action-Specific ARARs

In addition to the action-specific ARARs identified for the MNA alternative above, the following potential action-specific ARARs apply for the SVE/AS aspects of this alternative:

- Virgin Islands Air Pollution Control (VIC, Title 12, Chapter 9, Section 206-20) requires permitting of controlled air discharges to atmosphere. During remedial activities at the Site, emissions must be controlled and treated, if necessary, to comply with these standards.
- Clean Air Act National Emissions Standards for Hazardous Air Pollutants (NESHAPS, 40 CFR Pt 61) establishes emissions standards for various hazardous contaminants. Soil vapor extraction and groundwater air sparging will involve air emissions of Hazardous Air Pollutants (xylenes, ethylbenzene) and the resulting discharges must meet these emission standards.
- Control of Air Emissions from Superfund Air Strippers at Superfund Groundwater Sites (OSWER Directive 9355.0-28) establishes guidance control of air emissions from air strippers used at Superfund Sites for groundwater treatment and established procedures for implementation. Although this guidance applies to air strippers, USEPA recognizes the potential for applicability to other VOC sources in this document. Generally, the guidelines described for air strippers are suitable for VOC air emissions from other vented extraction techniques such as soil vapor extraction. This directive is unpromulgated and as such is not ARAR but as "To Be Considered" (TBC) requirement.

Location-Specific ARARs

Location-specific ARARs are the same as for the MNA Alternative discussed above.

Design and implementation of this Alternative is expected to comply with ARARs.

Short-Term Effectiveness

Construction activities associated with the Source Control with MNA alternative introduce limited short-term risks but the remedy itself will be effective in a relatively short time-frame, as demonstrated by the Pilot Study Results (Golder, 2000). Appropriate health and safety measures would be taken to protect workers during construction of the SVE/AS system, and subsequent monitoring. A major portion of the SVE/AS system has been constructed already for the Spring 2000 Treatability Study.

The existing security fence provides short-term protectiveness and discourages trespassers from accessing the Site.

Long-Term Effectiveness and Permanence

The Source Control with MNA remedial alternative provides long-term permanent protection of human health and the environment by permanently reducing the mass of VOC contaminants in the subsurface soils and groundwater in the AST Area, which will enhance the effectiveness of the natural attenuation remedy for groundwater and restore the soil and groundwater conditions to acceptable levels. Chloroform contamination in groundwater at the FPP Area will continue to undergo natural attenuation. The degradation processes involved in natural attenuation in both Areas will permanently reduce levels of the Site COCs.

Operation, inspection, monitoring, and maintenance will be regularly conducted to ensure the continued long-term effectiveness of the SVE/AS and MNA aspects of the remedy.

Reduction of Toxicity, Mobility, and Volume Through Treatment

The soil vapor extraction (SVE) and groundwater air sparging will rapidly reduce the toxicity, mobility and volume of VOC contaminants in the subsurface soils and groundwater in the AST area. For example, the Spring 2000 Treatability Study showed a 92% reduction in groundwater concentrations of ethylbenzene and xylenes in an AST Area shallow monitoring well following short-term air sparging. Natural attenuation of residual contamination in the groundwater, will also reduce the toxicity, mobility, and volume of remaining low-level VOCs in the groundwater. Chloroform contamination in groundwater at the FPP Area will continue to undergo natural attenuation reducing its toxicity, mobility, and volume. Currently, the low groundwater velocity combined with natural attenuation has effectively imposed a steady state condition of the contamination such that the plumes in both Areas are not expanding in areal extent or depth. Intermediate degradation products of natural attenuation have short half-lives and are not expected to contribute to future exposure risks.

Implementability

Implementation of the Source Control with MNA remedial alternative utilizes established practices and the services and materials needed are standard within the industry and readily available. Moreover, these process technologies have been implemented successfully at the Site.

The basic infrastructure and most of the equipment needed to perform this remedial alternative was installed during the Treatability Study, although some system upgrades are envisioned. Other than a slightly lengthened implementation schedule due to the remote location of the Site, no technical or administrative problems are envisioned which would adversely affect the construction or schedule for implementation of this alternative. Similarly, long-term operation and maintenance requirements can be readily performed, although the availability of personnel, equipment, and spare parts is extremely limited on the Island.

Cost

A preliminary cost estimate for the Source Control with MNA remedial alternative is presented in Table 7. The estimated capital costs and O&M costs for this alternative are \$850,760 and \$565,860, respectively. The total estimated present worth cost is \$1,417,000. The SVE/AS aspect of the cost includes the installation of additional wells, one year of SVE/AS operation, and three years of groundwater monitoring in the AST Area (i.e., quarterly during Year 1 and semiannually during Years 2 and 3). The MNA component includes 15 years of groundwater monitoring in the FPP Area with the same frequency as the AST Area for Years 1-3 and annually thereafter.

7.4 Alternative 4: SVE/AS With Groundwater Extraction and Treatment

Overall Protection of Human Health and the Environment

This remedial alternative will provide short-term and long-term protection of human health and the environment. Active treatment of the groundwater in both the AST and FPP Areas will permanently reduce the mass of VOCs in the saturated zone. Further, active treatment of soil by SVE in the AST Area will also rapidly and permanently reduce the mass of VOCs in the unsaturated zone. Natural attenuation processes for groundwater VOC contamination beyond the influence of the SVE/AS system will address residual groundwater contamination. SVE will effectively prevent any potential further groundwater contamination caused by migration of soil contaminants to groundwater.

Continued monitoring of reductions in groundwater concentrations in both Areas would provide assurance and verification of the protectiveness of this remedial alternative.

Compliance with ARARs

The Groundwater Extraction and Treatment with SVE/AS alternative is expected to achieve compliance with chemical-specific ARARs for groundwater.

Action-Specific ARARs

The action-specific ARARs include those listed above in Section 7.2 for MNA, Section 7.3 for the SVE/AS aspects of this alternative as well as the following:

- Federal and Virgin Islands requirements for National Pollution Discharge Elimination System (NPDES) discharges to surface water

Location-Specific ARARs

The location-specific ARARs are the same as for the MNA alternative described in Section 7.2 above.

Design and implementation of this Alternative is expected to comply with ARARs.

Short-Term Effectiveness

Construction activities associated with this alternative introduce limited short-term risks, but the remedy itself will be effective in a relatively short time frame. Appropriate health and safety measures would be taken to protect workers during construction of the SVE/AS system, construction of the extraction and treatment system, and subsequent monitoring. A major portion of the SVE/AS system has been constructed already for the Spring 2000 Treatability Study. The groundwater extraction system would conceptually involve two additional extraction wells, and the installation of the equipment required for the treatment system units and appurtenances (tank, air stripper, blower, pumps, housing) is straightforward, but would require labor and materials from the mainland.

The existing security fence provides short-term protectiveness and discourages trespassers from accessing the Site.

Long-Term Effectiveness and Permanence

This alternative provides long-term permanent protection of human health and the environment by permanently reducing the mass of VOC contaminants in the subsurface soils and groundwater in the AST Area, which will restore the soil and groundwater conditions to acceptable levels.

Permanent reductions in the mass of chloroform will also be permanently achieved in the long-term at the FPP Area via groundwater extraction, although these reductions are not expected to exceed the magnitude or rate that will be attained by natural attenuation *alone* in the absence of groundwater extraction.

Operation, inspection, monitoring, and maintenance will be regularly conducted to ensure the continued long-term effectiveness of the SVE/AS and groundwater extraction/treatment aspects of the remedy.

Reduction of Toxicity, Mobility, and Volume Through Treatment

The SVE and AS will rapidly reduce the toxicity, mobility, and volume of VOC contaminants in the subsurface soils and groundwater in the AST Area, as evidenced by the Spring 2000 Treatability Study results. Natural attenuation processes, including biodegradation, of residual groundwater contamination will also reduce the toxicity, mobility and volume of any remaining low-level VOCs in the groundwater.

The groundwater extraction and treatment system will also reduce the toxicity, mobility, and volume of chloroform in groundwater at the FPP Area due to mass removal via extraction wells. However, Spring 2000 monitoring data indicate that minimal mass remains, with groundwater concentrations below or near MCLs. Therefore, any reductions in toxicity and volume via pump and treat in the FPP Area would be minimal. Ongoing anaerobic biodegradation processes that are currently responsible for the natural attenuation of chloroform in the FPP Area are expected to diminish due to the introduction of oxygenated water associated with the pumping action. This net effect is likely to be no additional reduction of toxicity, mobility, and volume beyond that which will occur due to natural biodegradation *alone* in the absence of groundwater extraction.

Implementability

Implementation of this remedial alternative utilizes established practices and the services and materials needed are standard within the industry and readily available. In the case of SVE/AS, these technologies have been implemented successfully at the Site. The basic structure of this system was installed during the Treatability Study, and minor upgrades are envisioned.

For the groundwater extraction and treatment system, a lengthened implementation schedule would be expected due to the remote location of the Site. Also, certain units such as the

equalization tank and air stripper system would likely need to be manufactured and shipped from the U.S. mainland, which may extend the implementation schedule. However, no technical or administrative problems are envisioned which would adversely affect the construction of this alternative. For both groundwater extraction/treatment and SVE/AS, long-term operation and maintenance requirements can be readily performed, although the availability of personnel, equipment, and spare parts is extremely limited on the Island.

Cost

A preliminary cost estimate for this remedial alternative is presented in Table 8. The estimated capital costs and O&M costs for this alternative are \$1,219,240 and \$877,330, respectively. The total estimated present worth cost is \$2,097,000 based on one year of SVE/AS operation and five years of groundwater extraction and treatment. Cost include the installation of additional wells and MNA groundwater monitoring in the FPP Area for 15 years according to the following schedule: quarterly for Year 1, semiannually for Years 2 and 3, annually from Years 3 to 15; costs for groundwater monitoring in the AST Area for three years are included (i.e., one year of SVE/AS operation and two years of post-shutdown monitoring).

7.5 Alternative 5: Groundwater Extraction and Treatment with MNA

Overall Protection of Human Health and the Environment

The Groundwater Extraction and Treatment with MNA remedial alternative will provide short-term and long-term protection of human health and the environment. Active treatment of the groundwater in the AST Area will permanently reduce the mass of VOCs in the saturated zone. The remaining source mass in the AST Area vadose zone would be subject to anaerobic biodegradation processes, and a portion of this source mass would leach to groundwater for ultimate capture and removal by the active groundwater extraction and treatment system.

In the FPP Area, this remedial alternative would adequately protect human health and the environment by the reduction of the mass of chloroform by natural physical and biological processes that have been documented at the Site, as discussed in Sections 2 and 7.3 above.

Continued monitoring of reductions in groundwater concentrations in both Areas, and natural attenuation parameters in the FPP Area, would provide assurance and verification of the protectiveness of this remedial alternative.

Compliance with ARARs

The Groundwater Extraction and Treatment with MNA alternative is expected to achieve compliance with chemical-specific ARARs for groundwater.

Action-Specific ARARs

The action-specific ARARs include those listed above in Section 7.4 above.

Location-Specific ARARs

The location-specific ARARs are the same as described in Section 7.2 above.

Design and implementation of this Alternative is expected to comply with ARARs.

Short-Term Effectiveness

Construction activities associated with the Groundwater Extraction and Treatment with MNA Alternative introduce limited short-term risks, but the remedy itself will likely be effective in a relatively short time frame. Appropriate health and safety measures would be taken to protect workers during construction of the groundwater extraction and treatment system, and subsequent monitoring. The extraction system would only involve two additional extraction wells, and the installation of the equipment required for the treatment system units and appurtenances (tank, air stripper, blower, pumps, housing) is straightforward, but would require labor and materials from the U.S. mainland.

The existing security fence provides short-term protectiveness and discourages trespassers from accessing the Site.

Long-Term Effectiveness and Permanence

The Groundwater Extraction and Treatment with MNA alternative provides long-term permanent protection of human health and the environment by permanently reducing the mass of VOC contaminants in the groundwater in the AST Area. Preliminary remedial goals for soils in the AST Area would not be attained for many years and migration to groundwater would continue. Also, the long-term effectiveness of pump and treat is uncertain, considering the heterogeneous nature of subsurface strata on-Site. Chloroform contamination in groundwater in the FPP Area will continue to undergo natural attenuation, which will permanently reduce levels of chloroform over a short time period.

Operation, inspection, monitoring, and maintenance would be regularly conducted to optimize the long-term effectiveness of the groundwater extraction/treatment aspects of the remedy. Continued monitoring of groundwater concentrations of chloroform and natural attenuation parameters in the FPP Area will be regularly conducted to ensure the continued long-term effectiveness of the MNA aspect of the remedy.

Reduction of Toxicity, Mobility, and Volume Through Treatment

The groundwater extraction/treatment will reduce the toxicity, mobility, and volume of VOC contaminants in the groundwater in the AST Area. Natural attenuation processes, including biodegradation, of residual soil contamination will also reduce the toxicity, mobility and volume of remaining VOCs in the vadose zone. Spring 2000 groundwater monitoring results indicate that the remaining plume mass of chloroform is minimal with concentrations generally below MCLs. Therefore, any reduction in toxicity and volume by pump and treat in the FPP Area would be minimal. Similarly, chloroform contamination in the FPP Area groundwater will continue to undergo rapid natural attenuation reducing its toxicity, mobility, and volume.

Implementability

Implementation of the Groundwater Extraction and Treatment with MNA remedial alternative utilizes established practices and the services and materials needed are standard within the industry and readily available.

For the groundwater extraction and treatment system, a lengthened implementation schedule would be expected due to the remote location of the Site. Also, certain units such as the equalization tank and air stripper system would likely need to be manufactured and shipped from the U.S. mainland, which may extend the implementation schedule. However, no technical or administrative problems are envisioned which would adversely affect the construction of this alternative. For both groundwater extraction/treatment and MNA, long-term operation and maintenance requirements can be readily performed, although the availability of personnel, equipment, and spare parts is extremely limited on the Island.

Cost

A preliminary cost estimate for the Groundwater Extraction and Treatment with MNA remedial alternative is presented in Table 9. The estimated capital costs and O&M costs for this alternative are \$1,121,480 and \$1,030,370, respectively. The total estimated present worth cost is

\$2,152,000. The MNA aspect of the cost includes the installation of additional wells and groundwater monitoring for 15 years according to the following schedule: quarterly for Year 1, semiannually for Years 2 and 3, annually from Years 3 to 15. The groundwater extraction and treatment aspect of the cost includes the installation of two extraction wells, materials and installation of the treatment and discharge system, groundwater monitoring at the same frequency as described above, and 5 years of operation.

7.6 Comparative Evaluation

Overall Protection of Human Health and the Environment

Under the current use scenario, all five alternatives provide a similar degree of protection of human health and the environment. However, the No Action alternative does not address risks to future on-site workers, and the lack of any institutional control other than the security fence would potentially allow unrestricted future use of the Site.

The remaining alternatives all include a monitoring component that would provide a means to evaluate the protectiveness of the remedy. Although natural attenuation would still occur under the No Action alternative, there would be no verification or measure of the extent to which these processes are occurring.

Alternative 3 would be more efficient than MNA alone (e.g., Alternatives 2) in overall protection of human health, since the inclusion of SVE/AS would remove mass from the AST source area more quickly, and reduce the amount of time to achieve remedial goals. Similarly, Alternative 3 would be more efficient than Alternative 5 in three ways: (1) SVE will rapidly remove and reduce the source mass in the vadose zone whereas groundwater extraction does not address the vadose zone; (2) AS is expected to be much more effective at removing mass than groundwater extraction, and will better facilitate aerobic biodegradation processes via introduction of air; and (3) SVE/AS could be more readily implemented considering operational system costs. Each of the five alternatives is expected to fully protect human health and the environment.

With respect to Alternative 4, and as noted previously, cleanup in the FPP Area is expected to occur no more rapidly than via natural attenuation by itself (included as a component in Alternatives 1, 2 3 and 5). Further, groundwater data from Spring 2000 show that only one monitoring well currently exhibits chloroform concentrations above MCLs, which indicates that

natural attenuation is adequately protective without the need for any active extraction system. As noted by USEPA, the Spring 2000 data indicates that extracted groundwater may potentially meet discharge standards, *as extracted*, with no treatment. Therefore, implementing an active extraction system (i.e., Alternative 4) will not likely be any more effective or more protective than allowing natural attenuation to continue to remediate the low residual mass of chloroform in the FPP Area.

Compliance with ARARs

Although the No Action alternative is expected to eventually comply with chemical-specific ARARs for groundwater, there would be no monitoring component to verify attainment. All five alternatives can be implemented to achieve compliance with chemical-specific, action-specific, and location-specific ARARs.

Short-Term Effectiveness

All five alternatives are effective in the short-term. Alternatives 3, 5, and 4, in this order, provide increasingly greater degrees of on-Site and subsurface construction, and therefore present increasing concern with short-term effectiveness as it pertains to worker health and safety. However, Alternatives 3 and 5 are more effective than Alternatives 1 and 2 in the short-term, since they provide for more aggressive source removal of Site contaminants in the soil and/or groundwater in the AST Area. Alternative 3 is more effective in the short-term than Alternatives 4 and 5, considering it can be readily implemented. Alternative 4 is unlikely to be significantly more effective than the other Alternatives in the FPP Area in the short-term, given the low mass of chloroform and the current rate of natural biodegradation.

Long-Term Effectiveness and Permanence

All five alternatives afford a similar degree of long-term effectiveness and permanence for groundwater. However, Alternative 1 does not provide a monitoring component to verify the long-term effectiveness of natural attenuation. Alternatives 2 and 5 will allow Site contaminants to remain in the AST Area for a greater period of time than Alternatives 3 and 4; however, off-Site risks to human health and the environment are not expected with any Alternative. A permanent remedy will be achieved more quickly by Alternatives 3, and 4, since a large mass of contaminants will be removed more quickly from the soil and groundwater rather than by reliance on natural biological and physical processes. Alternatives 3 and 4 are expected to perform similarly in the long term.

Reduction of toxicity, mobility, and volume through treatment

All five remedial alternatives provide reduction of toxicity, mobility and volume through treatment by natural biodegradation processes to convert ethylbenzene, xylene, and chloroform to intermediate transformation products, and eventually, to non-toxic final products. For Alternatives 3, 4, and 5, active removal will occur via SVE/AS and/or groundwater extraction, but treatment may not be required to comply with emissions standards. For example, based on Spring 2000 data, it is likely that groundwater extracted from the FPP Area (i.e., Alternative 4) may already meet discharge standards without treatment. Consequently, minimal benefit in reducing toxicity and volume would be realized through groundwater extraction and treatment. Also, chloroform emissions from the air stripper are not expected to require treatment. Natural attenuation, which is a component of Alternatives 1, 2, 3, and 5, will not result in mass transfer of contaminants from groundwater to as part of the treatment processes.

Implementability

In general, all five alternatives are implementable. Alternative 1 is the simplest to implement, followed in order of ease by Alternatives 2, 3, 5, and 4, considering that an operational system for Alternative 3 exists.. However, materials, services, and equipment associated with the implementation of each remedial alternative are generally available on the mainland and on larger islands such as Puerto Rico. More specialized equipment such as the low profile air stripper (i.e., Alternatives 4 and 5) and associated spare parts are somewhat less widely available, and would need to be manufactured and shipped from the U.S. Therefore, a longer lead time would be required for certain equipment. Also, Alternatives 3, 5, and 4 (in that order) are increasingly more intensive in terms of operations and maintenance than Alternatives 1 and 2. Finally, although a Site security fence is present and would be maintained under all Alternatives, vandalism and theft are significant concerns at the Site; therefore, the installation of any additional equipment under Alternatives 3, 4, and 5 will increase the risk of loss due to theft/vandalism and potentially inhibit the implementability of these alternatives.

Cost

Costs for each remedial alternative increase in the following order: Alternative 1, Alternative 2, Alternative 3, Alternative 5, and Alternative 4. However, most of the costs for the SVE/AS system associated with Alternatives 3 and 4 have already been incurred as a result of the Treatability Study.

Summary

The following table provides a summary of the relative rankings of the five remedial alternatives for each of the seven NCP criteria. Alternatives assigned a rank of "First" were considered to be the most preferable in the associated category (i.e., least cost, most effective, most easily implemented, etc.).

<i>Relative Ranking</i>	<i>Protection of Human Health and Environment</i>	<i>Compliance With ARARs</i>	<i>Short-Term Effectiveness</i>	<i>Long-Term Effectiveness</i>	<i>Reduction of Toxicity, Mobility, Volume</i>	<i>Implementability</i>	<i>Cost</i>
<i>First*</i>	Alt. 3, 4	Alt. 2, 3, 4, 5	Alt. 3	Alt. 3, 4	Alt. 3, 4 (AST Area) Alt. 3 (FPP Area)	Alt. 1	Alt. 1
<i>Second</i>	-	-	Alt. 5	-	Alt. 4	Alt. 2	Alt. 2
<i>Third</i>	Alt. 5	-	Alt. 4	Alt. 5	Alt. 5	Alt. 3	Alt. 3
<i>Fourth</i>	Alt. 2	-	Alt. 2	Alt. 2	Alt. 1, 2	Alt. 5	Alt. 5
<i>Fifth</i>	Alt. 1	Alt. 1	Alt. 1	Alt. 1	-	Alt. 4	Alt. 4

* Indicates most preferable alternative(s) in given category.

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Table 1
Summary of Calculated Risks
Virgin Island Chemical Site

Receptor	Reasonable Maximum Exposure				Central Tendency			
	Cancer Risk/ Hazard Index	Media Analyzed	Contaminants ¹ with Significant Risk	Exposure Pathways	Cancer Risk/ Hazard Index	Media Analyzed	Contaminants ¹ with Significant Risk	Exposures Pathways
Current - Adult Trespasser	1.E-06 HI= 5.3E-02	Surface Soil	Arsenic	Ingestion ² Dermal Contact Inhalation	1.E-07	Surface Soil	--	Ingestion Dermal Contact Inhalation
	3.E-07 HI= 2.5E-02	Soil/Sediment (Gut System)	--	Ingestion Dermal Contact Inhalation	NC	Soil/Sediment	--	Ingestion Dermal Contact Inhalation
Current - Pre-adolescent Trespasser	5.E-07 HI= 1.6E-01	Surface Soil	--	Ingestion Dermal Contact Inhalation	NC	Surface Soil	--	Ingestion Dermal Contact Inhalation
	1.E-07 HI= 7.5E-02	Soil/Sediment (Gut System)	--	Ingestion Dermal Contact Inhalation	NC	Soil/Sediment	--	Ingestion Dermal Contact Inhalation
Future - Adult Resident	8.E-04 HI= 2.5E+02	Groundwater	Chloroform Arsenic Iron Manganese Methylene Chloride	Ingestion ² Dermal Contact ² Inhalation ²	9.E-05 HI= 8.2E+01	Groundwater	Chloroform Manganese Arsenic	Ingestion ² Dermal Contact ² Inhalation ²
Future - Child Resident	4.E-04 HI= 6.0E+02	Groundwater	Chloroform Methylene Chloride Arsenic Iron Manganese	Ingestion ² Dermal Contact Inhalation ²	1.E-04 HI= 2.0E+02	Groundwater	Chloroform Methylene Chloride Arsenic Iron Manganese	Ingestion ² Dermal Contact Inhalation ²
Future - Adult and Child Resident ³	1.E-03	Groundwater	Chloroform Methylene Chloride Arsenic	Ingestion ² Dermal Contact ² Inhalation ²	2.E-04	Groundwater	Chloroform Methylene Chloride Arsenic Iron	Ingestion ² Dermal Contact ² Inhalation ²
Future - Industrial/Commercial Worker	9.E-04 HI= 3.3E+02	Groundwater	Chloroform Methylene Chloride Arsenic	Ingestion ² Dermal Contact ² Inhalation ²	2.E-04 HI= 3.3E+02	Groundwater	Chloroform Arsenic	Ingestion ² Dermal Contact ² Inhalation ²
	3.E-06 HI= 1.3E-01	Surface Soil	Arsenic	Ingestion ² Dermal Contact Inhalation	5.E-07 NC	Surface Soil	--	Ingestion Dermal Contact Inhalation
	6.E-07 HI= 6.1E-02	Soil/Sediment (Gut System)	--	Ingestion Dermal Contact Inhalation	NC NC	Soil/Sediment	--	Ingestion Dermal Contact Inhalation
Future - Construction Worker	7.E-07 HI= 1.2E+00	Surface Soil	-- ⁷	Ingestion Dermal Contact Inhalation	NC HI= 2.5E-01	Surface Soil	--	Ingestion Dermal Contact Inhalation
	2.E-07 HI= 5.6E-01	Soil/Sediment (Gut System)	--	Ingestion Dermal Contact Inhalation	NC NC	Soil/Sediment	--	Ingestion Dermal Contact Inhalation

Notes:

- Only those contaminants exceeding a 1E-6 cancer risk or HI = 1 are listed.
- Denotes exposure pathways within a media where the calculated risk exceeded a 1E-6 or HI = 1.
- indicates no contaminants are contributing significant risk to the receptor.
- Pre-adolescent trespassers are those between 7 and 12 years of age.
- Risks and hazards include contributions from the contribution of methylene chloride and acetone.
The presence of these analytes in samples is a result of blank contamination and does not represent site conditions.
- NC indicates the central tendency risks/hazards were not calculated because the RME risks were below benchmark levels.
- Although in cumulative risk exceeds 1, individual risks are all <1.
- Cumulative non-carcinogenic risks for adult and child residents are calculated separately.

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Table 2
Preliminary Remediation Goals
VICHEM Site, St. Croix, USVI

Constituent of Concern	Preliminary Remediation Goal	Reference
<i>Groundwater</i>		
Chloroform	80 ug/l	Agreement between USEPA, Berlex, and P&U; Proposed MCL
Arsenic	50 ug/l	40 CFR Part 141 - Primary MCLs
Ethylbenzene	700 ug/l	40 CFR Part 141 - Primary MCLs
Methylene Chloride	5 ug/l	40 CFR Part 141 - Primary MCLs ⁽¹⁾
Xylene	10,000 ug/l	40 CFR Part 141 - Primary MCLs
<i>Surface Soil</i>		
Arsenic	3.83 mg/kg	Risk Based Calculation based on future industrial worker exposure ⁽²⁾
Iron	31,933 mg/kg	Two times background concentration per Final RI Report McLaren/Hart, 2000)
Manganese	1,600 mg/kg	Risk Based Calculation (via ingestion) (McLaren/Hart, 2000)
<i>Subsurface Soil</i>		
Acetone	8,000 ug/kg	SSL DAF 10
Ethylbenzene	6,500 ug/kg	SSL DAF 10
Xylenes	90,000 ug/kg	No SSL has been established for total xylenes so the most conservative isomer (o-xylene) has been used; DAF 10

Notes:

(1) - The methylene chloride data presented in the Final RI Report (M/H, 2000) showed results below the Contract Required Quantitation Limit that were neither changed to the Sample Quantitation Limits nor correctly qualified. Qualifiers of "BJ", "B", or simply "J" were used rather than the correct qualifier, which is "U" (non-detect).

(2) - The PRG is a site-specific, risk-based concentration developed using site-specific exposure assumptions for the future industrial/commercial worker. The PRG was calculated using the intake value from Table 8.11a of the Risk Assessment, using a 1E-06 end point and a ratio of the intake.

See also "Summary of Calculated Risks" table herein.

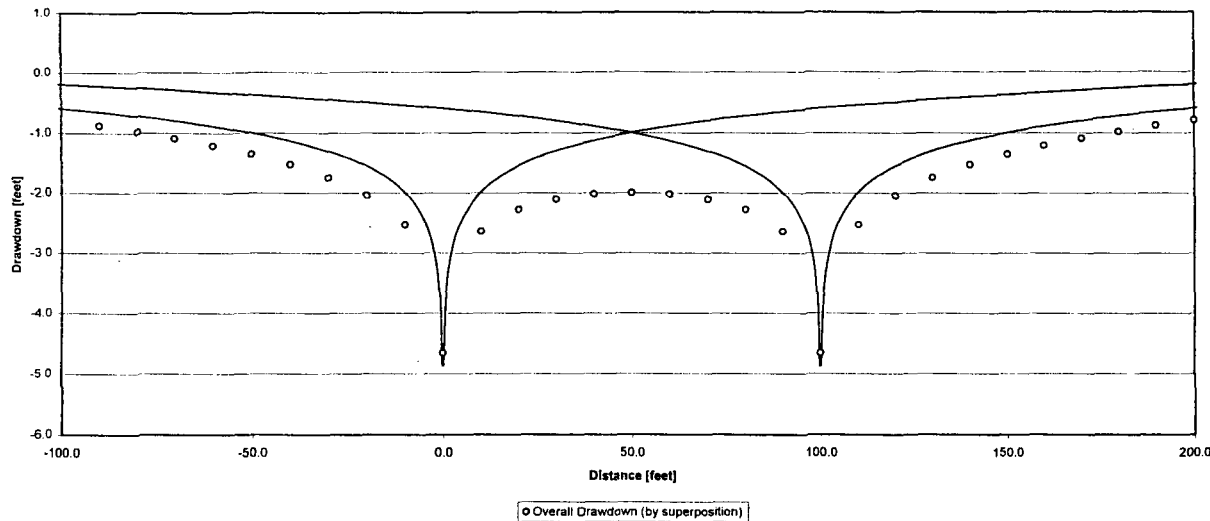
TABLE 3
ESTIMATED DRAWDOWN, PUMPING RATE AND WELL SPACING IN FPP AREA

Hydraulic Conductivity			Thickness	Transmissivity	Well Pumping Rate		Hydraulic Gradient	Stagnation Point Coordinates (y=0)	Width of Capture Zone		Precipitation Recharge for R ₀ Calculation	Radius of Influence	Water Level above Base of Aquifer		Drawdown	Distance for Well 1		Distance for Well 2	
K			b	T = K b	Q		I	x	y	2y	R	$r_0 = [Q/(\pi R)]^{0.5}$	No Pumping Conditions	Pumping Conditions	D = H ₀ -h	Pumping	Yes	Pumping	Yes
[ft/s]	[ft/day]	[cm/s]	[ft]	[ft ² /day]	[gpm]	[ft ³ /day]	[ft/ft]	[ft]	[ft]	[ft]	[ft/day]	[inch/year]	[ft]	[ft]		[ft]	Well Diam. =	0.50	Reinjection
h ₀														h			r	Well Spacing	
h = [H ₀ ² -Qln(ro/r)/{πK}] ^{0.5}																		100.00	

3.4E-05	2.95	1.04E-03	15.0	44.23	0.80	154	0.012	46	145	290	6.0E-04	2.64	285	15.00	10.93	-4.07	0.50	-0.50	100.50	99.50
															10.14	-4.86	0.18	-0.18	100.18	99.82
															10.59	-4.41	0.32	-0.32	100.32	99.68
															10.93	-4.07	0.50	-0.50	100.50	99.50
															11.21	-3.79	0.73	-0.73	100.73	99.27
															11.46	-3.54	1.02	-1.02	101.02	98.98
															11.69	-3.31	1.41	-1.41	101.41	98.59
															11.91	-3.09	1.91	-1.91	101.91	98.09
															12.11	-2.89	2.57	-2.57	102.57	97.43
															12.31	-2.69	3.42	-3.42	103.42	96.58
															12.49	-2.51	4.52	-4.52	104.52	95.48
															12.68	-2.32	5.96	-5.96	105.96	94.04
															12.85	-2.15	7.83	-7.83	107.83	92.17
															13.03	-1.97	10.26	-10.26	110.26	89.74
															13.20	-1.80	13.41	-13.41	113.41	86.59
															13.36	-1.64	17.52	-17.52	117.52	82.48
															13.53	-1.47	22.85	-22.85	122.85	77.15
															13.69	-1.31	29.79	-29.79	129.79	70.21
															13.85	-1.15	38.81	-38.81	138.81	61.19
															14.01	-0.99	50.53	-50.53	150.53	49.47
															14.16	-0.84	65.77	-65.77	165.77	34.23
															14.32	-0.68	85.58	-85.58	185.58	14.42
															14.47	-0.53	111.33	-111.33	211.33	-11.33
															14.62	-0.38	144.81	-144.81	244.81	-44.81
															14.77	-0.23	188.34	-188.34	288.34	-88.34
															14.92	-0.08	244.92	-244.92	344.92	-144.92

UNCONFINED AQUIFER

○ Overall Drawdown (by superposition)

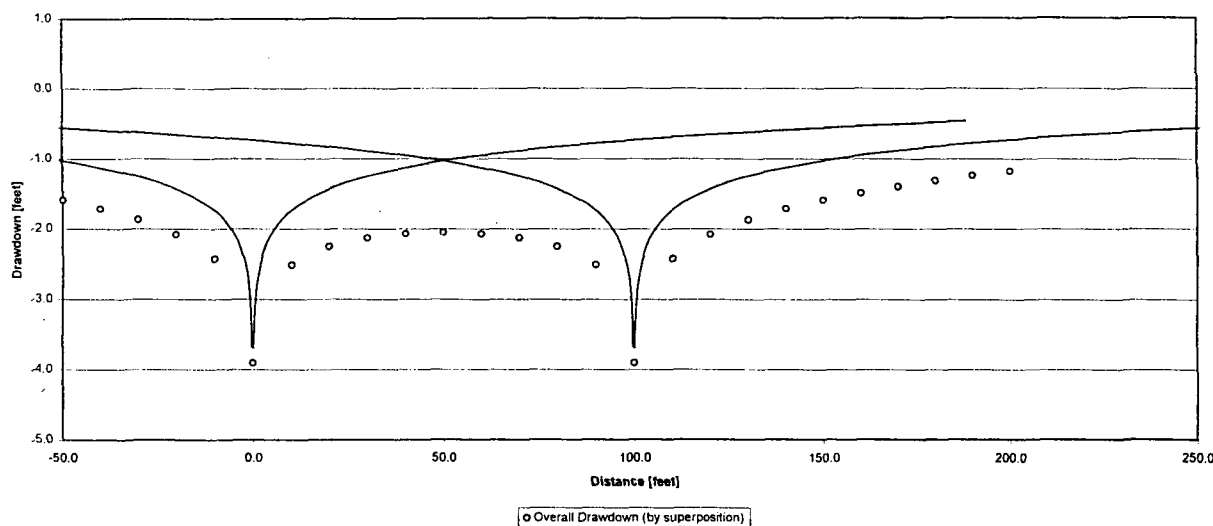


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TABLE 4
ESTIMATED DRAWDOWN, PUMPING RATE AND WELL SPACING IN AST AREA

Hydraulic Conductivity			Thickness	Transmissivity	Well Pumping Rate		Hydraulic Gradient	Stagnation Point Coordinates (y=0)	Width of Capture Zone		Precipitation Recharge for Ro Calculation	Radius of Influence	Water Level above Base of Aquifer		Drawdown	Distance for Well 1		Distance for Well 2		
K			b	T = K b	Q		I	x	y	2y	R	$ro = [Q/(\pi R)]^{0.5}$	No Pumping Conditions Ho	Pumping Conditions h	D = Ho-h	Pumping Well Diam. =	Yes 0.50	Pumping Reinjection	Yes No	
[ft/s]	[ft/day]	[cm/s]	[ft]	[ft ² /day]	[gpm]	[ft ³ /day]	[ft/ft]	[ft]	[ft]	[ft]	[ft/day]	[inch/year]	[ft]	[ft]		[ft]	[ft]	[ft]	Well Spacing 100.00	
UNCONFINED AQUIFER																				
2.1E-04	17.86	6.30E-03	15.0	267.91	3.50	673.8	0.006	67	210	419	6.0E-04	2.64	596	15.00	11.83	-3.17	0.50	-0.50	100.50	99.50
															11.31	-3.69	0.18	-0.18	100.18	99.82
															11.60	-3.40	0.32	-0.32	100.32	99.68
															11.83	-3.17	0.50	-0.50	100.50	99.50
															12.02	-2.98	0.73	-0.73	100.73	99.27
															12.19	-2.81	1.02	-1.02	101.02	98.98
															12.34	-2.66	1.41	-1.41	101.41	98.59
															12.49	-2.51	1.91	-1.91	101.91	98.09
															12.63	-2.37	2.57	-2.57	102.57	97.43
															12.77	-2.23	3.42	-3.42	103.42	96.58
															12.90	-2.10	4.52	-4.52	104.52	95.48
															13.03	-1.97	5.96	-5.96	105.96	94.04
															13.15	-1.85	7.83	-7.83	107.83	92.17
															13.27	-1.73	10.26	-10.26	110.26	89.74
															13.40	-1.60	13.41	-13.41	113.41	86.59
															13.51	-1.49	17.52	-17.52	117.52	82.48
															13.63	-1.37	22.85	-22.85	122.85	77.15
															13.75	-1.25	29.79	-29.79	129.79	70.21
															13.86	-1.14	38.81	-38.81	138.81	61.19
															13.98	-1.02	50.53	-50.53	150.53	49.47
															14.09	-0.91	65.77	-65.77	165.77	34.23
															14.20	-0.80	85.58	-85.58	185.58	14.42
															14.31	-0.69	111.33	-111.33	211.33	-11.33
															14.42	-0.58	144.81	-144.81	244.81	-44.81
															14.53	-0.47	188.34	-188.34	288.34	-88.34

○ Overall Drawdown (by superposition)



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Table 5
Preliminary Cost Estimate - Alternative No. 1
No Action
Virgin Island Chemical Site

Activity	Estimated Cost
EXISTING DIRECT CAPITAL COSTS	
Fence Installation	\$45,000
Total Existing Direct Capital Costs	\$45,000
TOTAL DIRECT CAPITAL COST	
ESTIMATED INDIRECT CAPITAL COSTS	
Gen. Engineering Services (15%)	\$0
Permitting/Regulatory Coordination (3%)	\$0
Implement Health & Safety Plan (20%)	\$0
Construction Oversight/QA/QC (20%)	\$0
Contingency (30%)	\$0
TOTAL CAPITAL COSTS	\$45,000
O & M COSTS	
<u>General Site Maintenance</u>	
Fence Repair	\$1,000
TOTAL ANNUAL Site Maintenance O & M COST	\$1,000
PRESENT WORTH General Site Maintenance (30 YEARS @ 7%)	\$12,000
TOTAL O&M COST FOR THIS ALTERNATIVE	\$12,000
COST OF REMEDY	\$57,000

Table 6
Preliminary Cost Estimate - Alternative No.2
Monitored Natural Attenuation
Virgin Island Chemical Site

Activity	Cost
EXISTING DIRECT CAPITAL COSTS	
<u>Fence Installation</u>	\$45,000
Total Existing Direct Capital Costs	\$45,000
ESTIMATED DIRECT CAPITAL COSTS	
<u>Monitored Natural Attenuation</u>	
Monitoring Wells (5)	\$12,000
<u>General</u>	
Mobilization/Demobilization for Drilling	\$50,000
TOTAL DIRECT CAPITAL COST	\$62,000
ESTIMATED INDIRECT CAPITAL COSTS	
Gen. Engineering Services (15%)	\$9,300
Permitting/Regulatory Coordination (3%)	\$1,860
Implement Health & Safety Plan (20%)	\$12,400
Construction Oversight/QA/QC (20%)	\$12,400
Contingency (30%)	\$18,600
TOTAL CAPITAL COSTS	\$161,560
O & M COSTS	
<u>General Site Maintenance</u>	
Fence Repair	\$1,000
TOTAL ANNUAL Site Maintenance O & M COST	\$1,000
PRESENT WORTH General Site Maintenance (30 YEARS @ 7%)	\$12,410
<u>Monitored Natural Attenuation - Annual</u>	
Mobilization/Demobilization	\$10,000
IDW Disposal	\$5,000
TOTAL ANNUAL MNA Mob/Demob and IDW Costs	\$15,000
PRESENT WORTH MNA Mob/Demob and IDW (15 Years @ 7%)	\$136,620
Sampling (15-well network at \$1,913/well/event):	
Year 1, quarterly: Present Worth (1 yr @7%)	\$107,000
Years 2-3, semiannually: Present Worth (2 yrs@7%)	\$97,000
Years 4-15, annually: Present Worth (12 yrs @ 7%)	\$186,000
TOTAL PRESENT WORTH, Annual Sampling	\$390,000
<u>Monitored Natural Attenuation</u>	
<u>O & M COSTS One Time - Yr Seven</u>	
Well Rehabilitation	\$10,400
TOTAL One Time Monitored Natural Attenuation O & M COST	\$10,400
PRESENT WORTH (7th YEAR @ 7%)	\$6,500
TOTAL O&M COST FOR THIS ALTERNATIVE	\$545,530
COST OF REMEDY	\$707,000

Table 7
Preliminary Cost Estimate - Alternative No. 3
Air Sparging/SVE and Monitored Natural Attenuation
Virgin Island Chemical Site

Activity	Cost
EXISTING DIRECT CAPITAL COSTS	
<u>Fence Installation</u>	\$45,000
<u>Existing SVE Pilot System (actual costs incurred)</u>	\$520,000
Total Existing Direct Capital Costs	\$565,000
ESTIMATED DIRECT CAPITAL COSTS	
<u>Air Sparge/SVE</u>	
Wells & Accessories	\$40,000
Below Ground Conveyance System	\$5,000
Mechanical & Controls	\$20,000
Compressor & Blowers	\$25,000
<u>Monitored Natural Attenuation</u>	
MNA and Groundwater Monitoring Wells (5)	\$12,000
<u>General</u>	
Mobilization/Demobilization for Drilling	\$50,000
TOTAL DIRECT CAPITAL COST	\$152,000
ESTIMATED INDIRECT CAPITAL COSTS	
Gen. Engineering Services (15%)	\$22,800
Permitting/Regulatory Coordination (3%)	\$4,560
Implement Health & Safety Plan (20%)	\$30,400
Construction Oversight/QA/QC (20%)	\$30,400
Contingency (30%)	\$45,600
TOTAL CAPITAL COSTS	\$850,760
O & M COSTS	
<u>General Site Maintenance</u>	
Fence Repair	\$1,000
TOTAL ANNUAL Site Maintenance O & M COST	\$1,000
PRESENT WORTH General Site Maintenance (30 YEARS @ 7%)	\$12,410

Table 7
Preliminary Cost Estimate - Alternative No. 3
Air Sparging/SVE and Monitored Natural Attenuation
Virgin Island Chemical Site

Activity	Cost
Soil Vapor Extraction/Air Sparging:	
O & M cost for Year 1	\$20,000
Mobilization/Demobilization	\$15,000
Monitoring and Testing - soil vapor, off-gas, dissolved oxygen, pressures, flows	\$10,000
Trailer	\$3,210
Utility Services (Gas/Electric)	\$42,000
TOTAL ANNUAL SVE/ AIR SPARGING O & M COST	\$90,210
PRESENT WORTH SVE/AIR SPARGING (1 yr @7%)	\$84,350
Monitored Natural Attenuation	
Mobilization/Demobilization	\$10,000
IDW Disposal	\$5,000
TOTAL ANNUAL MNA Mob/Demob and IDW O & M COST	\$15,000
PRESENT WORTH Monitored Natural Attenuation (15 YEARS @ 7%)	\$136,620
Monitored Natural Attenuation - Sampling	
Year 1, quarterly: Present Worth (1 yr @ 7%) - AST and FPP Areas	\$107,000
Years 2-3, semiannually: Present Worth (2 yrs @ 7%) - AST and FPP Areas	\$97,000
Years 4-15, annually: Present Worth (12 yrs @ 7%) - FPP Area only	\$122,000
TOTAL PRESENT WORTH MNA Sampling	\$326,000
Monitored Natural Attenuation	
O & M COSTS One Time - Yr Seven	
Well Rehabilitation	\$10,400
TOTAL One Time Monitored Natural Attenuation O & M COST	\$10,400
PRESENT WORTH (7th YEAR @ 7%)	\$6,480
TOTAL O&M COST FOR THIS ALTERNATIVE	\$565,860
COST OF REMEDY	\$1,417,000

Table 8
Preliminary Cost Estimate - Alternative 4
Air Sparging/SVE/Groundwater Extraction and Treatment
Virgin Island Chemical Site

Activity	Cost
EXISTING DIRECT CAPITAL COSTS	
Fence Installation	\$45,000
Existing SVE Pilot System (actual costs incurred)	\$520,000
TOTAL EXISTING DIRECT CAPITAL COSTS	\$565,000
ESTIMATED DIRECT CAPITAL COSTS	
Air Sparge/SVE	
Wells & Accessories (3 new AS wells)	\$24,000
Below Ground Conveyance System	\$3,000
Mechanical & Controls	\$12,000
Compressor & Blowers	\$25,000
Groundwater Extraction and Treatment	
Extraction and Discharge	\$150,000
Treatment Setup	\$69,000
Monitoring Wells	\$15,000
General	
Mobilization/Demobilization for Drilling	\$50,000
TOTAL DIRECT CAPITAL COST	\$348,000
ESTIMATED INDIRECT CAPITAL COSTS	
Gen. Engineering Services (15%)	\$52,200
Permitting/Regulatory Coordination (3%)	\$10,440
Implement Health & Safety Plan (20%)	\$69,600
Construction Oversight/QA/QC (20%)	\$69,600
Contingency (30%)	\$104,400
TOTAL CAPITAL COSTS	\$1,219,240
O & M COSTS	
General Site Maintenance	
Fence Repair	\$1,000
TOTAL ANNUAL Site Maintenance O & M COST	\$1,000
PRESENT WORTH General Site Maintenance (30 YEARS @ 7%)	\$12,410
Soil Vapor Extraction/Air Sparging:	
O & M cost for 1 year	\$6,000
Mobilization/Demobilization	\$10,000
Analytical Testing	\$7,500
Trailer	\$3,210
Utility Services (Gas/Electric)	\$42,000
TOTAL ANNUAL SVE/ AIR SPARGING O & M COST	\$68,710
PRESENT WORTH SVE/AIR SPARGING (1 YEARS @ 7%)	\$64,240

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Table 8
Preliminary Cost Estimate - Alternative 4
Air Sparging/SVE/Groundwater Extraction and Treatment
Virgin Island Chemical Site

Activity	Cost
Extraction and Air Stripping	
Equipment O&M Cost	\$26,000
Mobilization/Demobilization	\$15,000
Compliance/Performance Monitoring and Sampling - soil vapor, off-gas and (pre-) treated water	\$75,000
IDW Disposal	\$5,000
Trailer	\$3,210
Utility Services (Gas/Electric)	\$10,000
Permits	\$1,000
TOTAL ANNUAL Extraction and Air Stripping O & M COST	\$135,210
PRESENT WORTH Extraction and Air Stripping (5 YEARS @ 7%)	\$554,360
Groundwater Monitoring (MNA and Extraction System)	
-Year 1, quarterly: Present Worth (1 yr @ 7%)	\$107,000
-Years 2-3, semi-annually, Present Worth (2 yrs @ 7%)	\$97,000
-Years 4-7, annually, 8 wells only, Present Worth (4 yrs @ 7%)	\$42,320
PRESENT WORTH Annual Sampling	\$246,320
TOTAL O&M COST FOR THIS ALTERNATIVE	\$877,330
COST OF REMEDY	\$2,097,000

400092

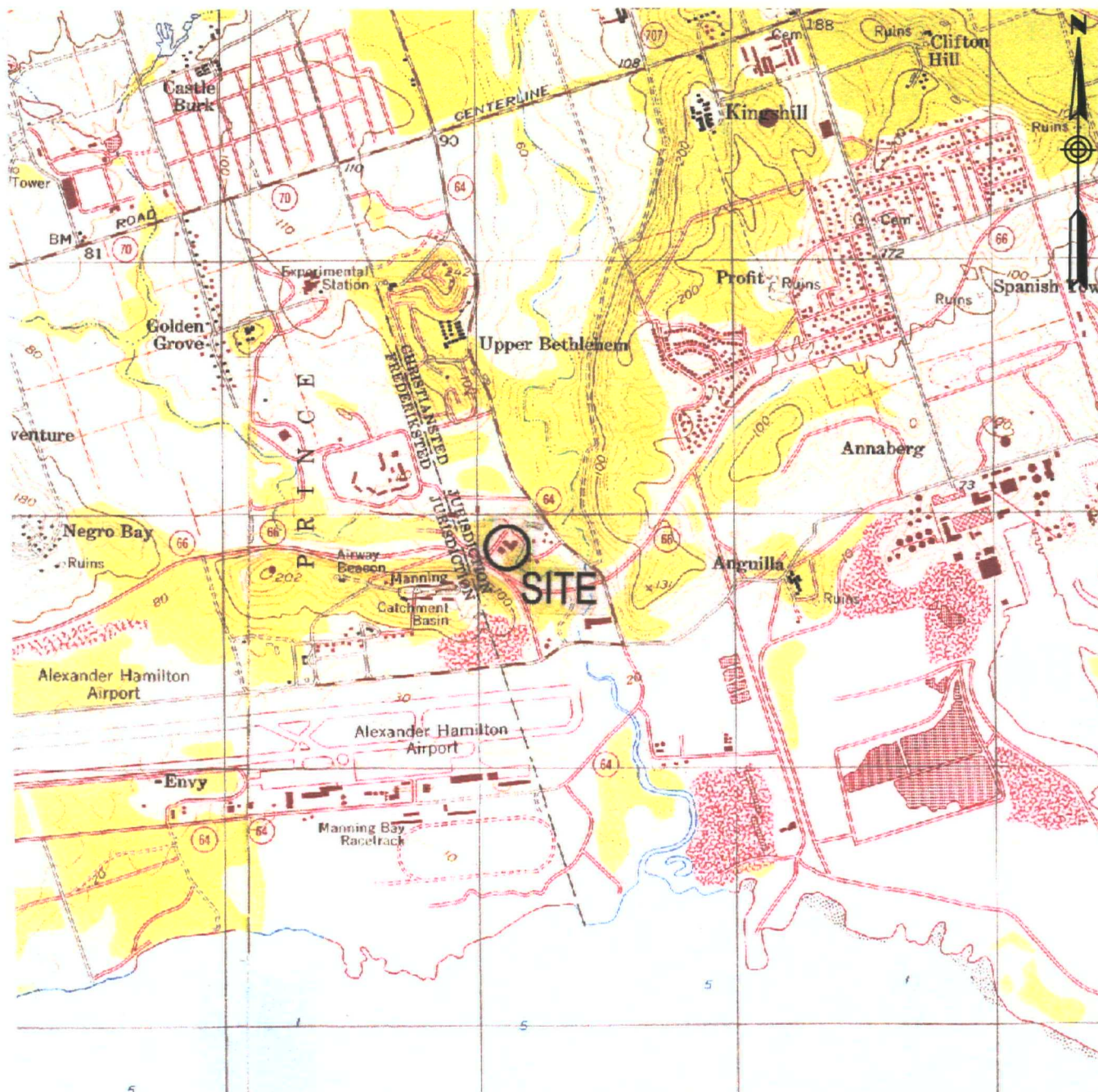
Table 9
Preliminary Cost Estimate - Alternative 5
MNA/Groundwater Extraction and Treatment
Virgin Island Chemical Site

Activity	Cost
EXISTING DIRECT CAPITAL COSTS	
<u>Fence Installation</u>	\$45,000
<u>Existing SVE Pilot System (actual costs incurred)</u>	\$520,000
TOTAL EXISTING DIRECT CAPITAL COSTS	\$565,000
ESTIMATED DIRECT CAPITAL COSTS	
<u>MNA</u>	
Monitoring Wells	\$12,000
<u>Groundwater Extraction and Treatment</u>	
Extraction and Discharge	\$150,000
Treatment Setup	\$69,000
Monitoring Wells	\$15,000
<u>General</u>	
Mobilization/Demobilization for Drilling	\$50,000
TOTAL DIRECT CAPITAL COST	\$296,000
ESTIMATED INDIRECT CAPITAL COSTS	
Gen. Engineering Services (15%)	\$44,400
Permitting/Regulatory Coordination (3%)	\$8,880
Implement Health & Safety Plan (20%)	\$59,200
Construction Oversight/QA/QC (20%)	\$59,200
Contingency (30%)	\$88,800
TOTAL CAPITAL COSTS	\$1,121,480
O & M COSTS	
<u>General Site Maintenance</u>	
Fence Repair	\$1,000
TOTAL ANNUAL Site Maintenance O & M COST	\$1,000
PRESENT WORTH General Site Maintenance (30 YEARS @ 7%)	\$12,410
<u>Monitored Natural Attenuation</u>	
Mobilization/Demobilization	\$10,000
IDW Disposal	\$5,000
TOTAL ANNUAL Mob/Demob & IDW O & M COST	\$15,000
PRESENT WORTH Mob/Demob & IDW (15 YEARS @ 7%)	\$136,620
<u>Monitored Natural Attenuation - Annual Sampling (8 wells)</u>	
-Year 1, quarterly: Present Worth (1 yr @ 7%)	\$57,000
-Years 2-3, semi-annually, Present Worth (2 yrs @ 7%)	\$52,000
-Years 4-15, annually, Present Worth (12 yrs @ 7%)	\$99,000
PRESENT WORTH Annual Sampling	\$208,000

Table 9
Preliminary Cost Estimate - Alternative 5
MNA/Groundwater Extraction and Treatment
Virgin Island Chemical Site

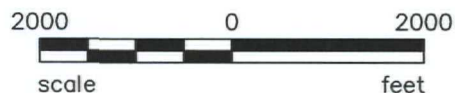
Activity	Cost
<u>Monitored Natural Attenuation</u>	
O & M COSTS One Time - Yr Seven	
Well Rehabilitation	\$12,000
TOTAL One Time Monitored Natural Attenuation O & M COST	\$12,000
PRESENT WORTH (7 YEARS @ 7%)	\$7,480
<u>Extraction and Air Stripping</u>	
Equipment O&M Cost	\$26,000
Mobilization/Demobilization	\$10,000
Monitoring and Sampling	\$75,000
IDW Disposal	\$5,000
Trailer	\$3,210
Utility Services (Gas/Electric)	\$10,000
Permits	\$1,000
TOTAL ANNUAL Extraction and Air Stripping O & M COST	\$130,210
PRESENT WORTH Extraction and Air Stripping (5 YEARS @ 7%)	\$533,860
<u>Groundwater Extraction/ Treatment Monitoring (7 wells)</u>	
-Year 1, quarterly: Present Worth (1 yr @ 7%)	\$50,000
-Years 2-3, semi-annually, Present Worth (2 yrs @ 7%)	\$45,000
-Years 4-7, annually, Present Worth (4 yrs @ 7%)	\$37,000
PRESENT WORTH Annual Sampling	\$132,000
TOTAL O&M COST FOR THIS ALTERNATIVE	\$1,030,370
COST OF REMEDY	\$2,152,000

400094



REFERENCE

1.) MAP TAKEN FROM U.S.G.S. 7.5 MINUTE QUADRANGLE OF CHRISTIANSTED, VIRGIN ISLANDS.



JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	AM	DATE:	11/07/00
CHK BY:	SDM	FILE No.:	US01-029
REV BY:	PGL	DR SUBTITLE:	03

Golder Associates

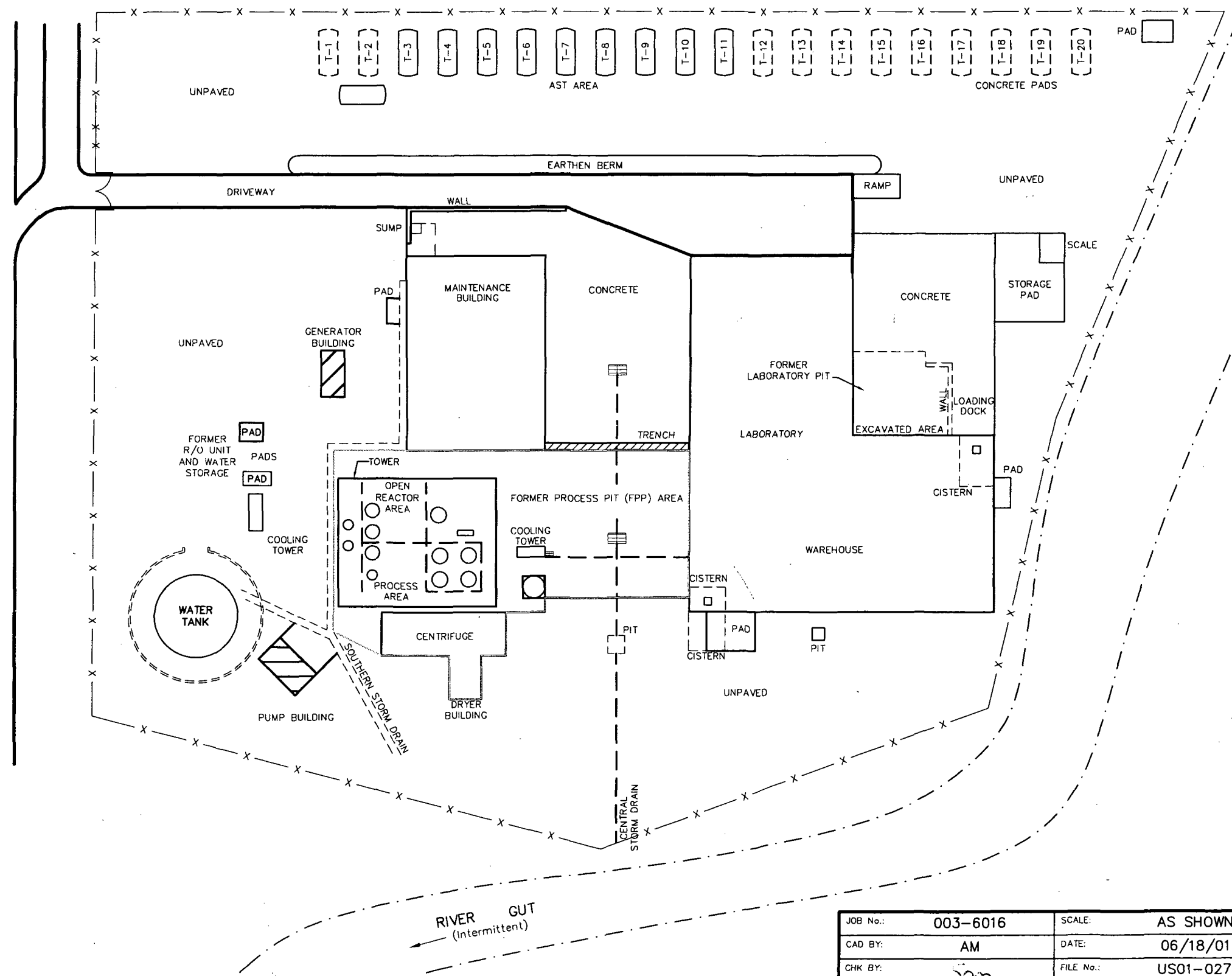
VIRGIN ISLAND CHEMICAL SITE

FIGURE

1

400095

ROUTE 66
MELVIN EVANS HIGHWAY



LEGEND

- STORMWATER INLET
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION

REFERENCE

1.) DRAWING BASED ON FIGURE 2-2 OF THE R.I. REPORT ENTITLED "MONITORING WELL LOCATION MAP" DATED 1/11/99, BY McLAREN/HART, INC.



JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	AM	DATE:	06/18/01
CHK BY:	SON	FILE No.:	US01-027
REV BY:	R.L.	DR SUBTITLE:	03

Golder Associates

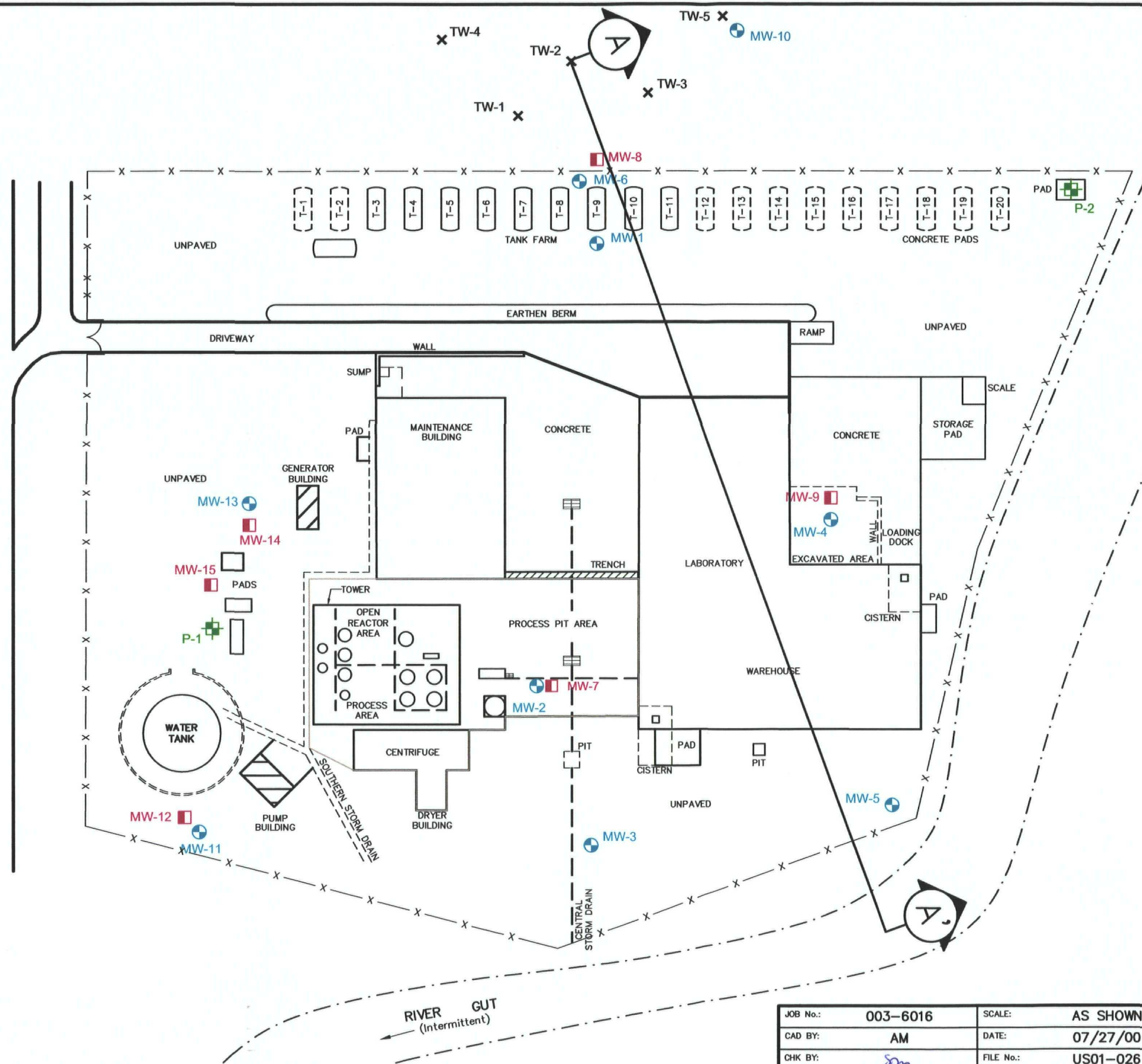
FACILITY LAYOUT

VIRGIN ISLAND CHEMICAL SITE

FIGURE 2

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ROUTE 66
MELVIN EVANS HIGHWAY



LEGEND

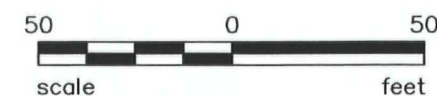
- PRODUCTION WELL LOCATION
- SHALLOW MONITORING WELL LOCATION
- DEEP MONITORING WELL LOCATION
- STORMWATER INLET
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION
- CROSS-SECTION LOCATION

NOTES

1.) MONITORING WELL LOCATIONS ARE APPROXIMATE.

REFERENCE

1.) DRAWING BASED ON FIGURE 3-7 OF THE R.I. REPORT ENTITLED "MONITORING WELL LOCATION MAP" DATED 1/11/99, BY McLAREN/HART, INC.



JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	AM	DATE:	07/27/00
CHK BY:	Sam	FILE No.:	US01-026
REV BY:	Rf	DR SUBTITLE:	03

Golder Associates

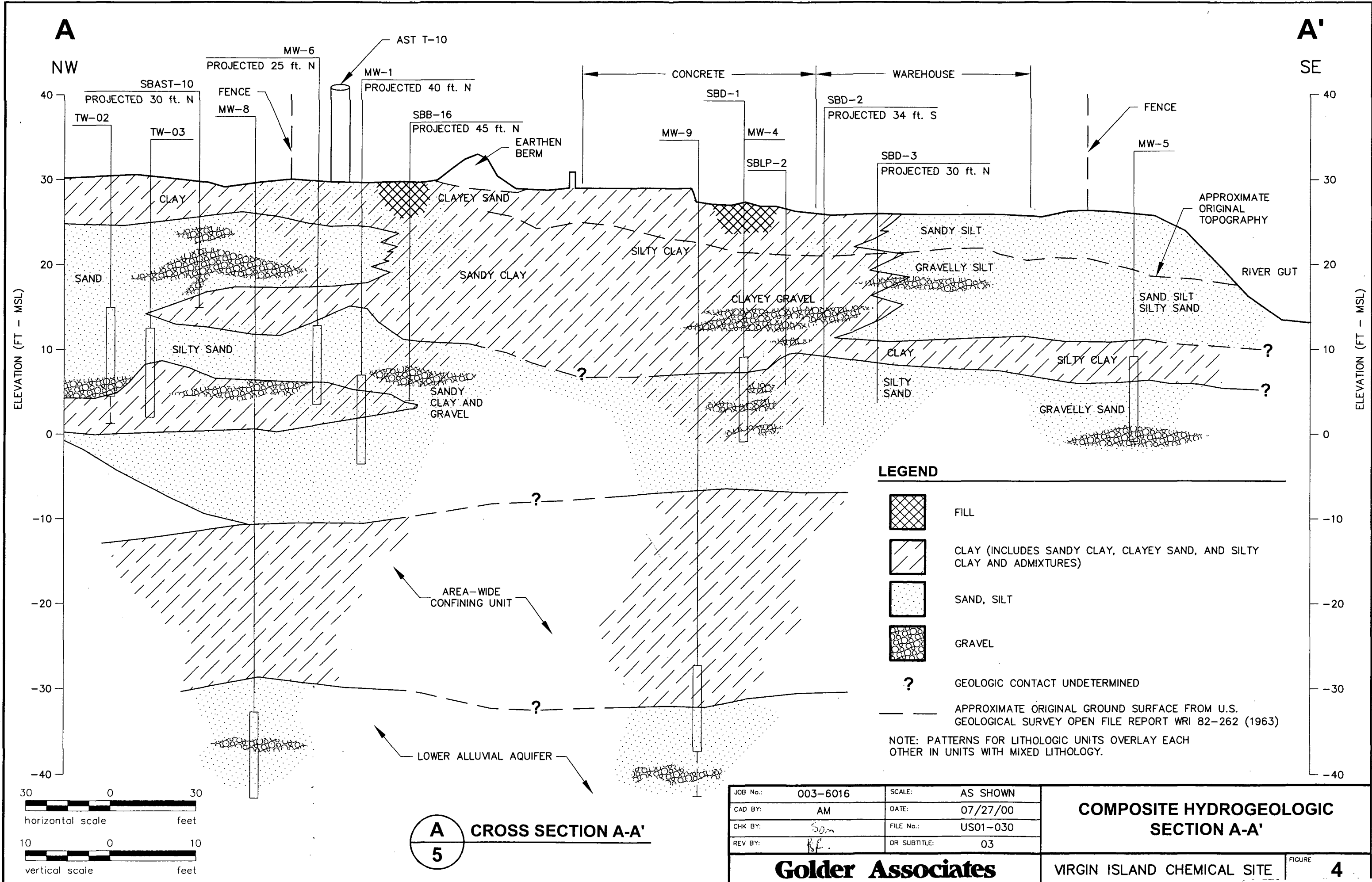
MONITORING WELL LOCATION MAP

VIRGIN ISLAND CHEMICAL SITE

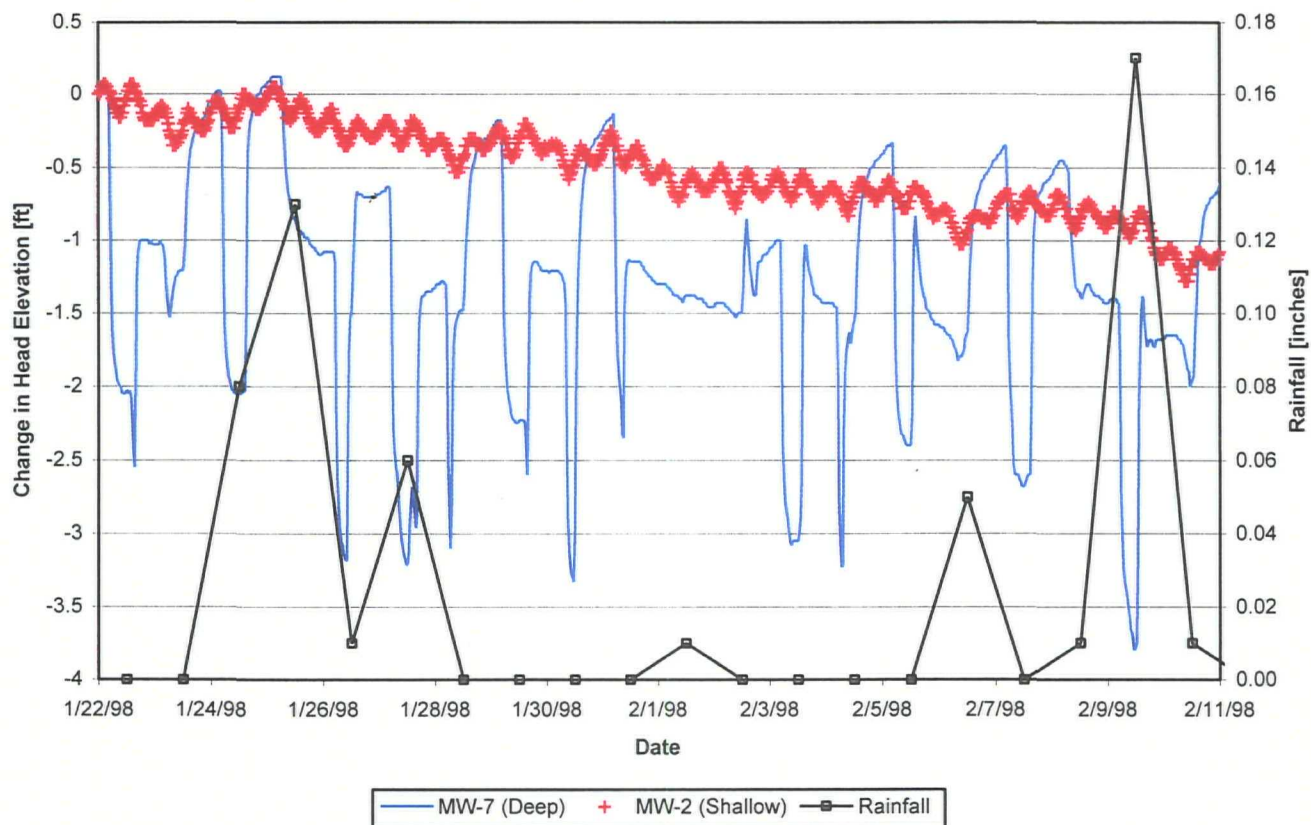
FIGURE

3

400097



Hydrographs for wells in FPP Area



JOB No.:	003-6016	SCALE:	AS SHOWN
DR BY:	DSL	DATE:	07/27/00
CHK BY:	DSL	FILE No.:	Hydrographs.XLS
REV BY:	SAS	DIRECTORY:	Golder\FS\Hydrogeo

HYDROGRAPHS FOR SHALLOW AND DEEP
WELLS IN FPP AREA

Golder Associates

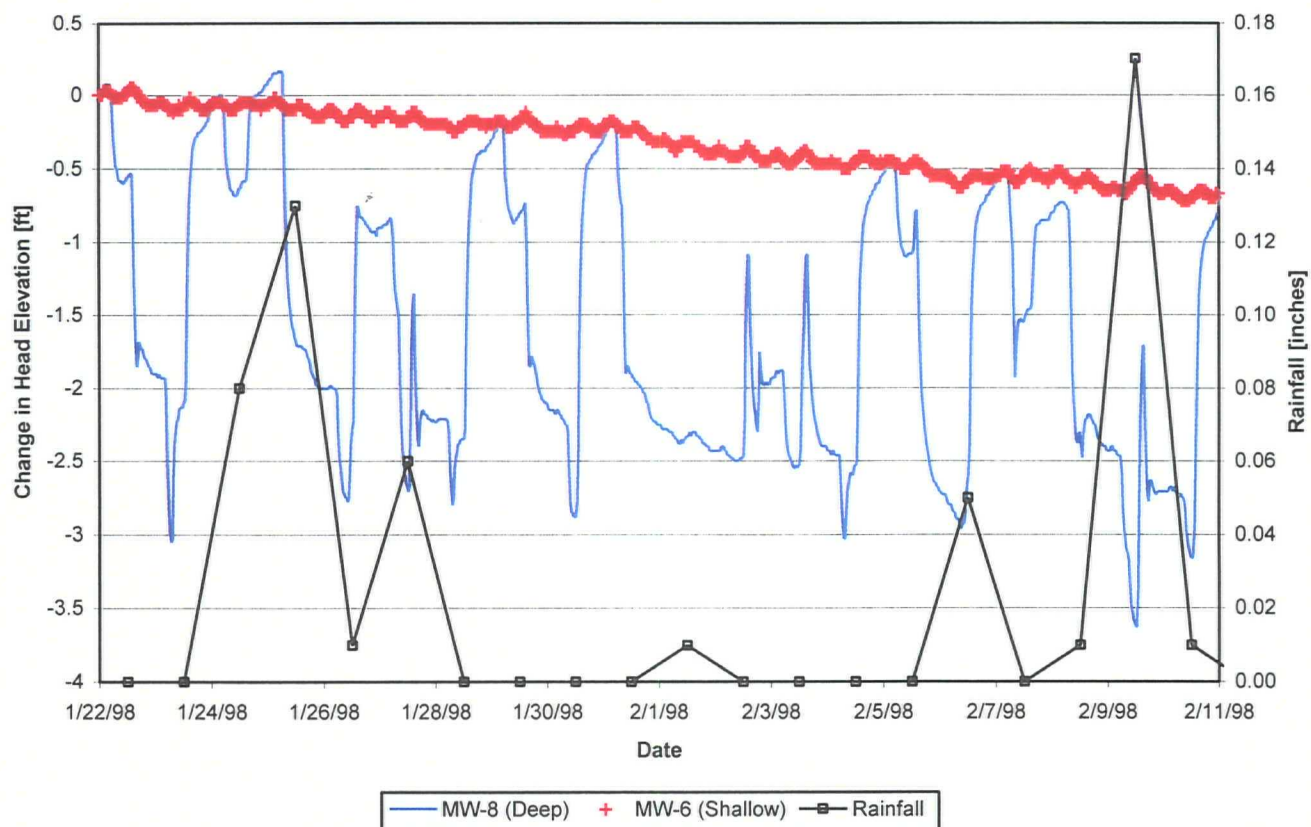
VIRGIN ISLAND CHEMICAL SITE

FIGURE:

5

400099

Hydrographs for wells in AST Area



JOB No.:	003-6016	SCALE:	AS SHOWN
DR BY:	DSL	DATE:	07/27/00
CHK BY:	DSL	FILE No.:	Hydrographs.XLS
REV BY:	SAS	DIRECTORY:	Golder\FS\Hydrogeo

HYDROGRAPHS FOR SHALLOW AND DEEP
WELLS IN AST AREA

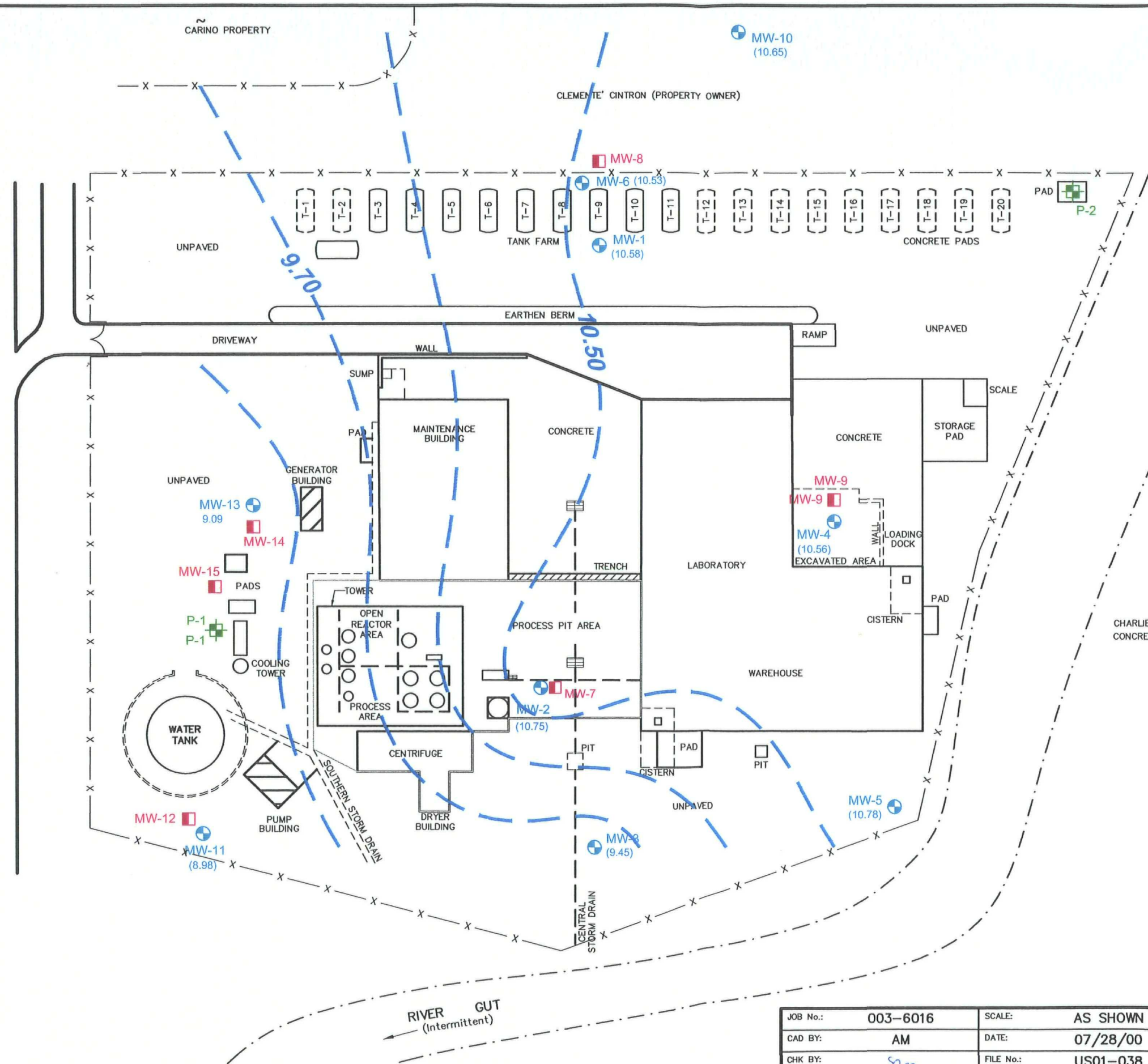
Golder Associates

VIRGIN ISLAND CHEMICAL SITE

FIGURE: **6**

400100

ROUTE 66
MELVIN EVANS HIGHWAY

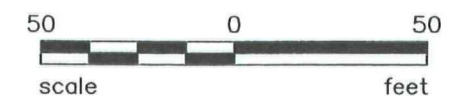


LEGEND

- PRODUCTION WELL LOCATION
- SHALLOW MONITORING WELL LOCATION
- DEEP MONITORING WELL LOCATION
- STORMWATER INLET
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION
- SHALLOW GROUNDWATER CONTOUR
- SHALLOW GROUNDWATER ELEVATION (FT MSL)
- GROUNDWATER ELEVATION (FT MSL)

REFERENCE

1.) DRAWING TAKEN FROM FIGURE 4-6 OF THE R.I. REPORT ENTITLED "SHALLOW GROUNDWATER ELEVATION CONTOURS OCTOBER 21, 1998" DATED 2/17/98, AND WATER LEVEL MEASUREMENTS TAKEN ON OCTOBER 21, 1998 BY McLAREN/HART, INC.



JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	AM	DATE:	07/28/00
CHK BY:	SM	FILE No.:	US01-038
REV BY:	RF	DR SUBTITLE:	03

Golder Associates

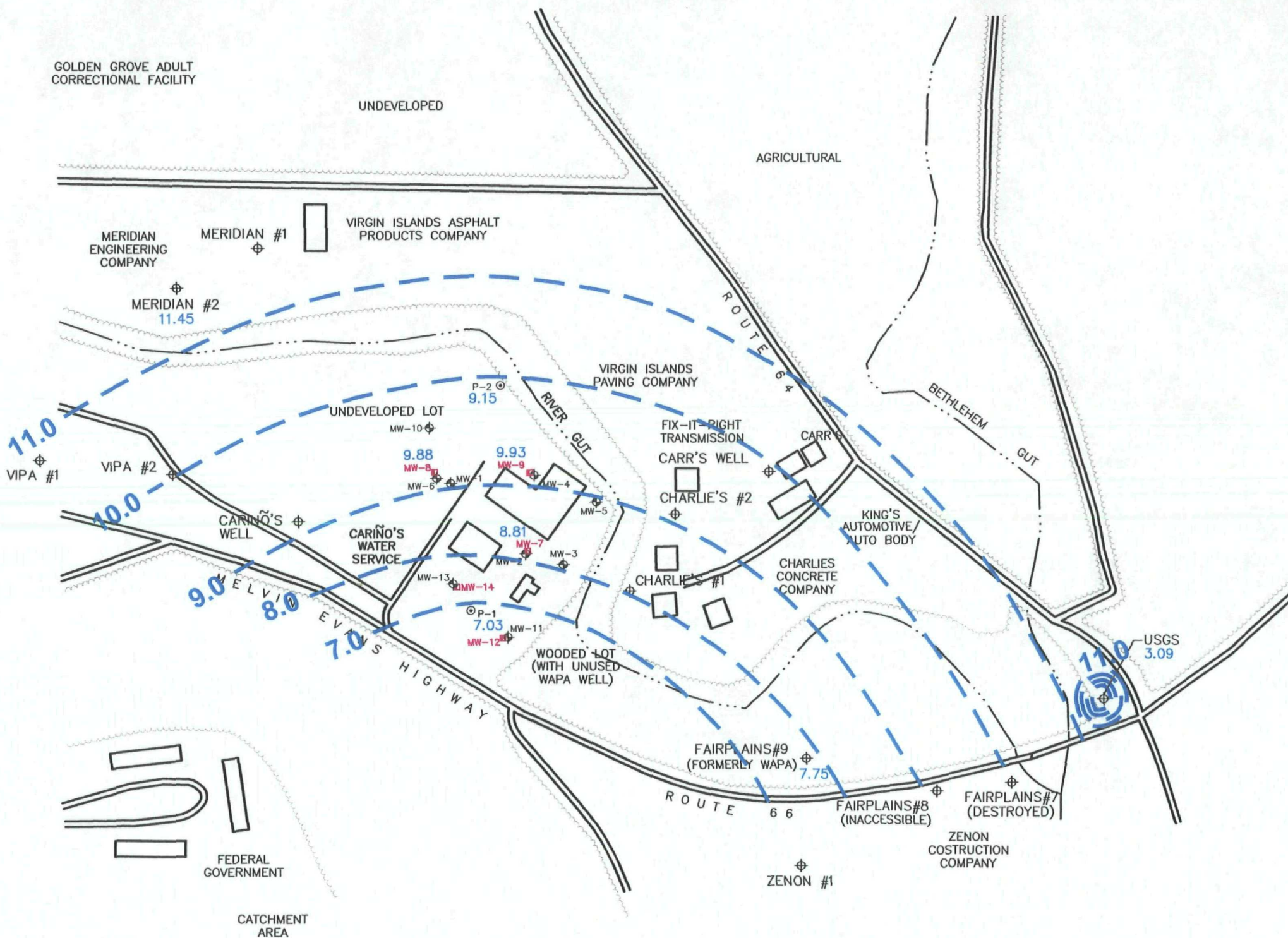
SHALLOW GROUNDWATER CONTOUR MAP - 10/21/98

VIRGIN ISLAND CHEMICAL SITE

FIGURE

7

400101

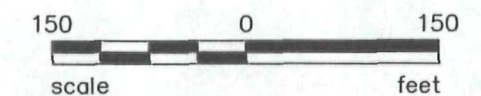


LEGEND

- BUILDING
- STREAM
- ROAD
- TREE LINE
- APPROX. LOCATION OF OFFSITE WELLS
- SHALLOW MONITORING WELL LOCATION
- ONSITE PRODUCTION WELL LOCATION
- DEEP MONITORING WELL LOCATION
- GROUNDWATER CONTOUR (FEET MSL)
- GROUNDWATER ELEVATION (FEET MSL)

REFERENCE

1.) DRAWING TAKEN FROM FIGURE 4-9 OF R.I. REPORT ENTITLED "DEEP GROUNDWATER ELEVATION CONTOURS OCTOBER 21, 1998", DATED 02/17/00 AND WATER LEVEL MEASUREMENTS TAKEN ON 10/21/98 BY McLAREN/HART, INC.



JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	AM	DATE:	07/28/00
CHK BY:	SoM	FILE No.:	US01-037
REV BY:	BL	DR SUBTITLE:	03

Golder Associates

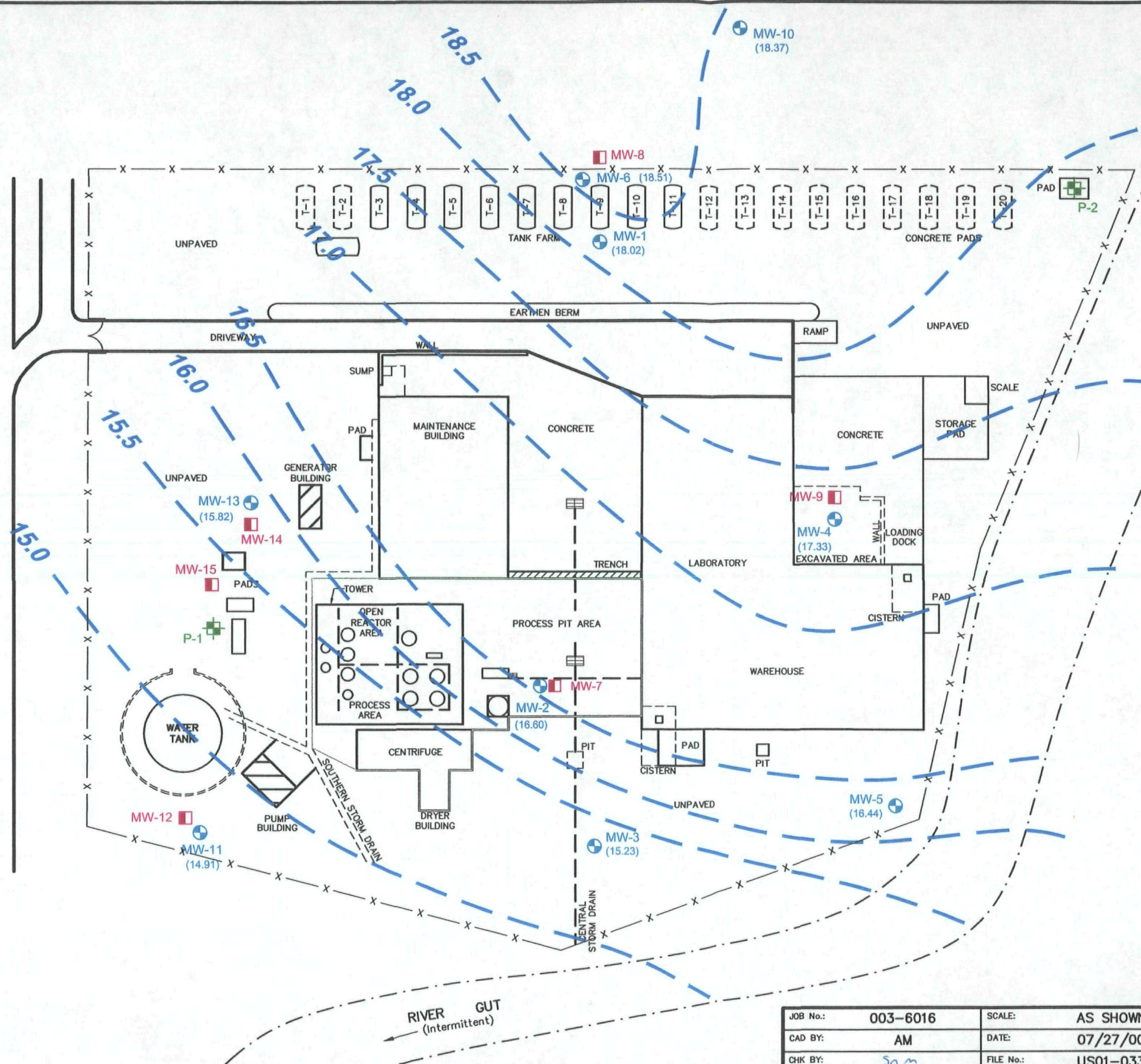
DEEP GROUNDWATER CONTOUR MAP - 10/21/98

VIRGIN ISLAND CHEMICAL SITE

FIGURE
8

400102

ROUTE 66
MELVIN EVANS HIGHWAY



LEGEND

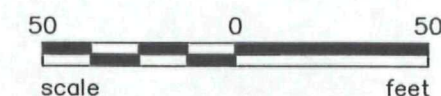
- PRODUCTION WELL LOCATION
- SHALLOW MONITORING WELL LOCATION
- DEEP MONITORING WELL LOCATION
- STORMWATER INLET
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION
- SHALLOW GROUNDWATER CONTOUR
- SHALLOW GROUNDWATER ELEVATION (FT MSL)

NOTES

- 1.) FORMER PRODUCTION WELL P-1 IS ABANDONED.

REFERENCE

- 1.) DRAWING BASED ON FIGURE 3-7 OF THE R.I. REPORT ENTITLED "MONITORING WELL LOCATION MAP" DATED 1/11/99, AND WATER LEVEL MEASUREMENTS TAKEN ON JANUARY 31, 2000 BY McLAREN/HART, INC.



JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	AM	DATE:	07/27/00
CHK BY:	SGM	FILE No.:	US01-033
REV BY:	BL	DR SUBTITLE:	03

Golder Associates

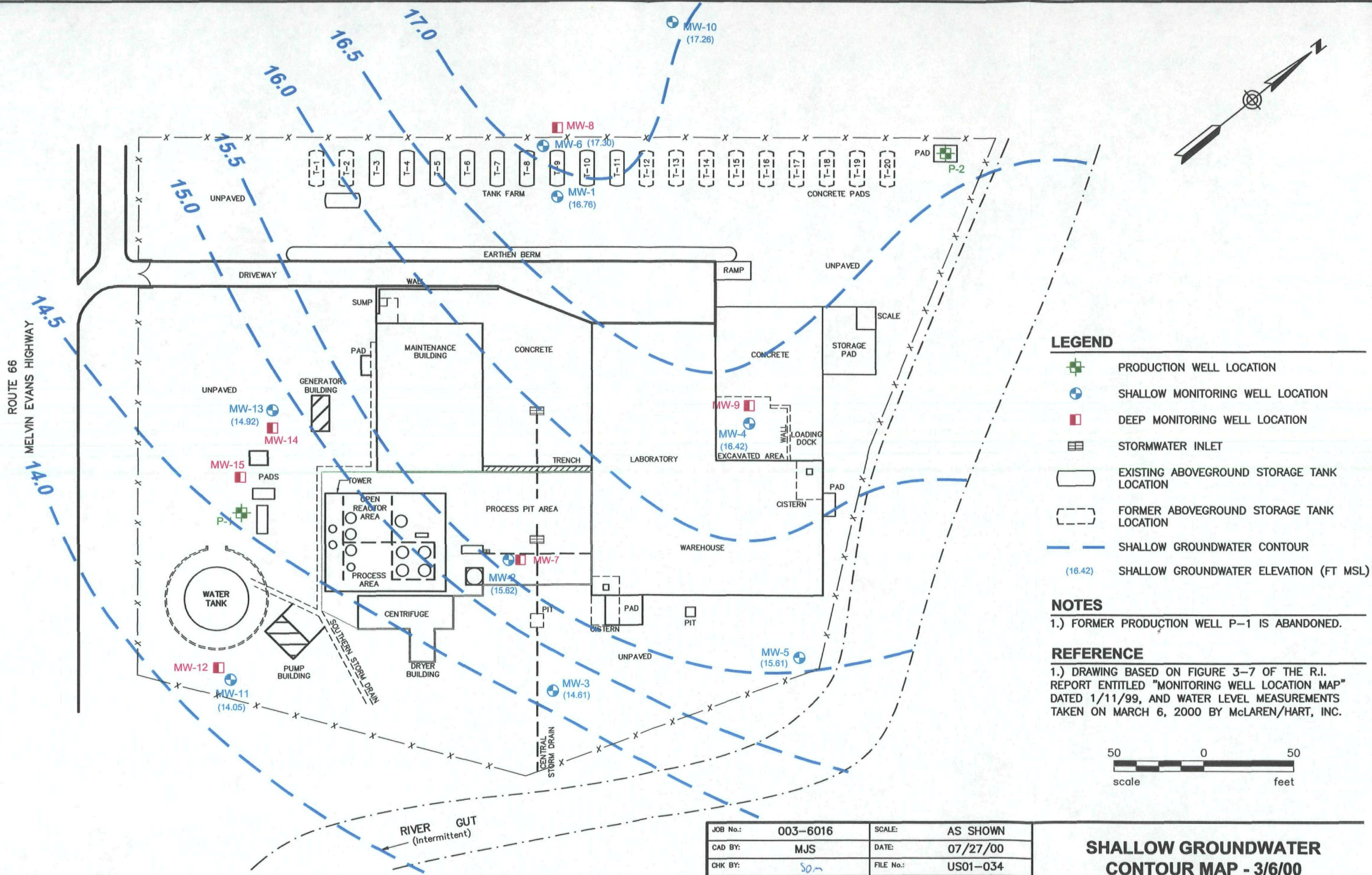
SHALLOW GROUNDWATER CONTOUR MAP - 1/31/00

VIRGIN ISLAND CHEMICAL SITE

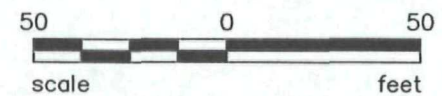
FIGURE

9

400103



- LEGEND**
- PRODUCTION WELL LOCATION
 - SHALLOW MONITORING WELL LOCATION
 - DEEP MONITORING WELL LOCATION
 - STORMWATER INLET
 - EXISTING ABOVEGROUND STORAGE TANK LOCATION
 - FORMER ABOVEGROUND STORAGE TANK LOCATION
 - SHALLOW GROUNDWATER CONTOUR
 - SHALLOW GROUNDWATER ELEVATION (FT MSL)
- NOTES**
- FORMER PRODUCTION WELL P-1 IS ABANDONED.
- REFERENCE**
- DRAWING BASED ON FIGURE 3-7 OF THE R.I. REPORT ENTITLED "MONITORING WELL LOCATION MAP" DATED 1/11/99, AND WATER LEVEL MEASUREMENTS TAKEN ON MARCH 6, 2000 BY McLAREN/HART, INC.



JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	MJS	DATE:	07/27/00
CHK BY:	SPM	FILE No.:	US01-034
REV BY:	RF	DR SUBTITLE:	03

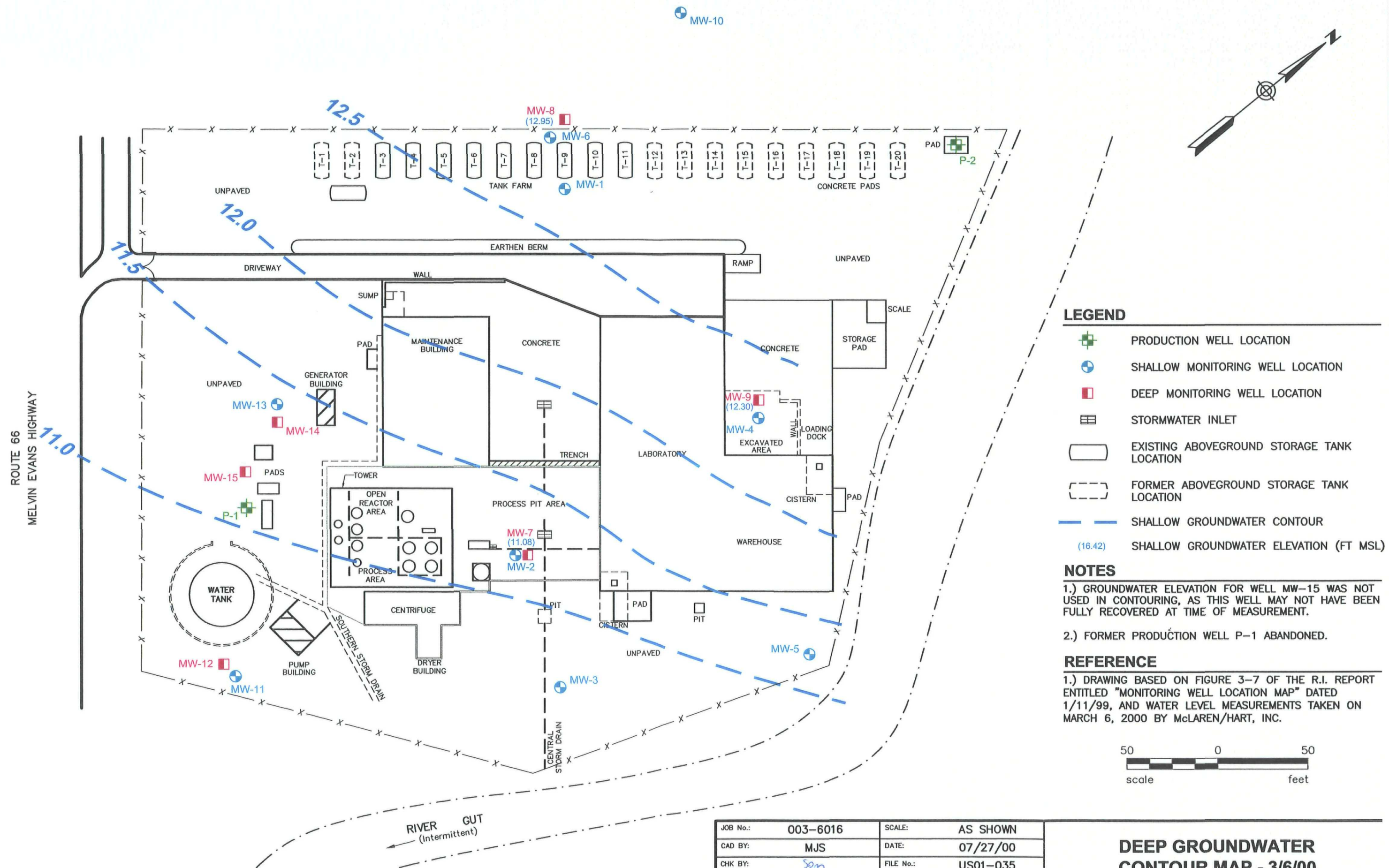
Golder Associates

**SHALLOW GROUNDWATER
CONTOUR MAP - 3/6/00**

VIRGIN ISLAND CHEMICAL SITE

FIGURE **10**

400104



JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	MJS	DATE:	07/27/00
CHK BY:	S.M.	FILE No.:	US01-035
REV BY:	P.S.	DR SUBTITLE:	03

Golder Associates

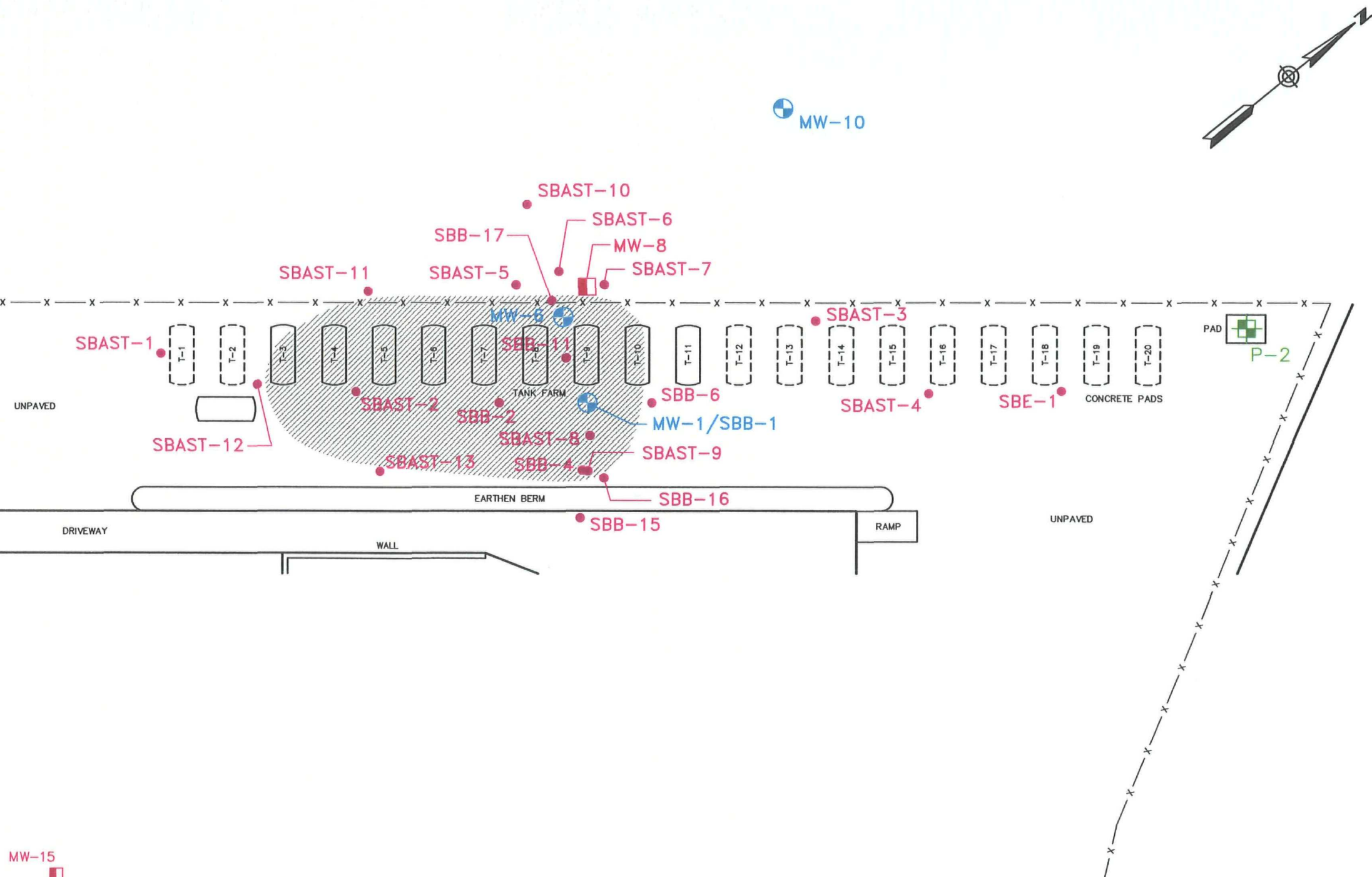
DEEP GROUNDWATER CONTOUR MAP - 3/6/00

VIRGIN ISLAND CHEMICAL SITE

FIGURE
11

400105

ROUTE 66
MELVIN EVANS HIGHWAY



NOTES

- 1.) SOIL BORING LOCATIONS ARE APPROXIMATE.
- 2.) SOIL BORINGS SHOWN WITHIN SHADED AREA EXHIBITED DETECTIONS OF ETHYLBENZENE AND XYLENE ABOVE MGW SSLs (DAF=10)

REFERENCE

1.) DRAWING BASED ON FIGURE 4-11 OF THE R.I. REPORT ENTITLED "ESTIMATED AREAL EXTENT OF IMPACTED SOIL - AST AREA" DATED 2/17/00, PROVIDED BY McLAREN/HART, INC.

LEGEND

- PRODUCTION WELL LOCATION
- SHALLOW MONITORING WELL LOCATION
- DEEP MONITORING WELL LOCATION
- SOIL BORING SAMPLE LOCATION
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION
- APPROXIMATE AREA OF IMPACTED SOIL ABOVE SSLs

JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	MJS	DATE:	11/07/00
CHK BY:	SDM	FILE No.:	US01-022
REV BY:	BT	DR SUBTITLE:	03

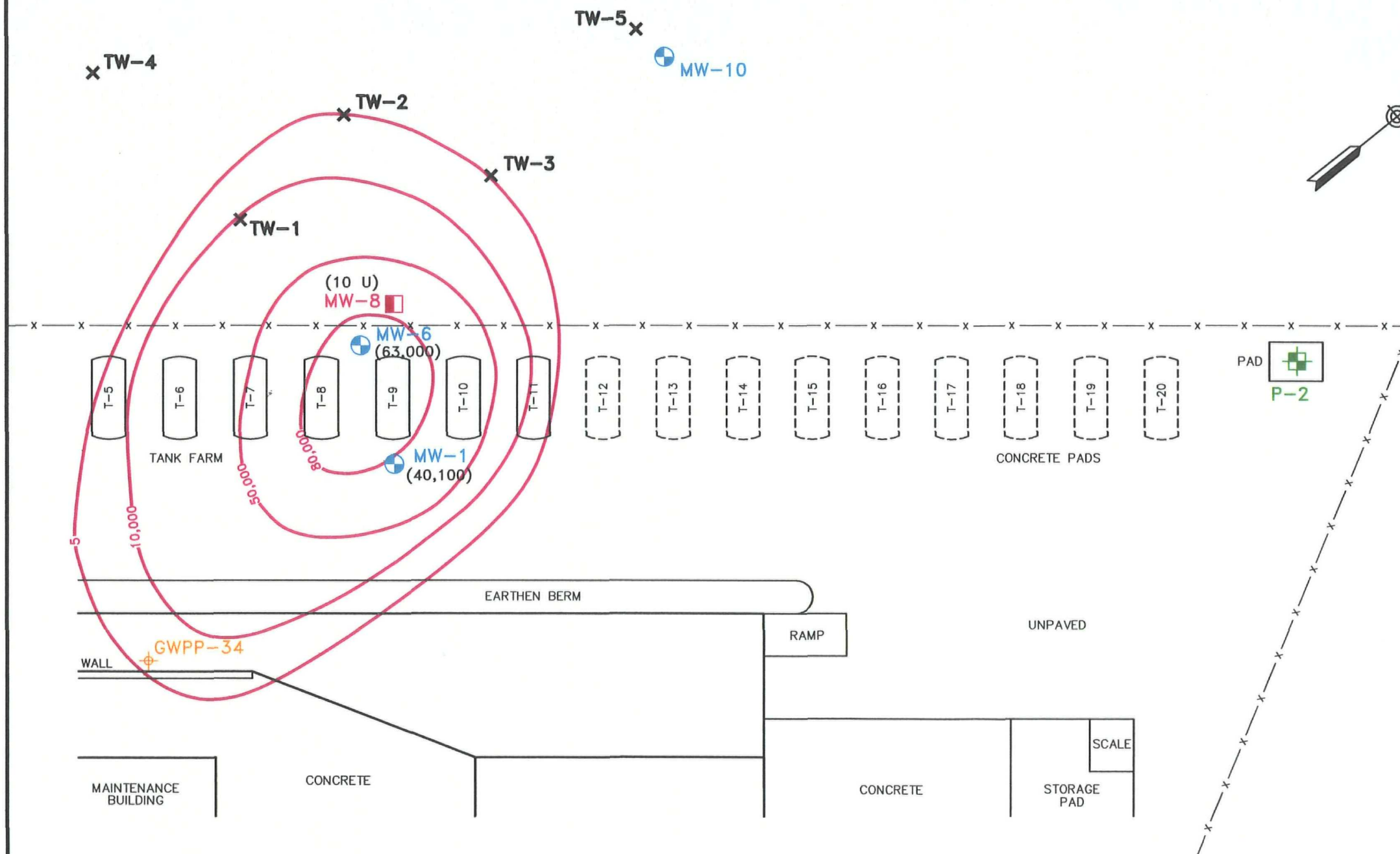
Golder Associates

**ESTIMATED AREAL EXTENT
OF IMPACTED SOIL
- AST AREA**

VIRGIN ISLAND CHEMICAL SITE

FIGURE **12**

400106



LEGEND

- PRODUCTION WELL LOCATION
- SHALLOW MONITORING WELL LOCATION
- DEEP MONITORING WELL LOCATION
- GEOPROBE GROUNDWATER SAMPLE LOCATION
- TEMPORARY WELL LOCATION
- XYLENE CONTOUR (ppb)
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION

NOTES

1.) FOR COMPARISON, CONCENTRATIONS FROM THE MAY 2000 SAMPLING EVENT ARE REPORTED IN PARENTHESES NEXT TO WELL ID. ALL UNITS ARE ppb.

REFERENCE

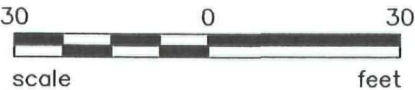
1.) DRAWING BASED ON FIGURE 4-12 OF THE R.I. REPORT ENTITLED "ESTIMATED AREAL EXTENT OF XYLENE-IMPACTED SHALLOW GROUNDWATER - AST AREA" DATED 2/17/00, PROVIDED BY McLAREN/HART, INC.

NOTES:

- J ESTIMATED CONCENTRATION
- U ANALYTE NOT DETECTED ABOVE REPORTING LIMIT
- E ESTIMATED CONCENTRATION
- 18,000 CONCENTRATION EXCEEDS MCL (ETHYLBENZENE - 700 ppb, XYLENE - 10,000 ppb)
- * CONCENTRATIONS FROM TEMPORARY WELLS ARE SCREENING RESULTS FROM ONSITE GC (SEPTEMBER 1997)

ALL RESULTS ARE FROM MARCH/APRIL 1998 INVESTIGATION EXCEPT SCREENING RESULTS FROM TEMPORARY WELLS (SEPTEMBER 1997)

SAMPLE ID	DEPTH (ft bgs)	CONCENTRATION (ppb)	SAMPLE ID	DEPTH (ft bgs)	CONCENTRATION (ppb)
MW-1	23-33	TOLUENE - 460 UJ ETHYLBENZENE - 18,000 XYLENE - 80,000	TW-1*	19-29	TOLUENE - 5 U ETHYLBENZENE - 8,000 E XYLENE - 15,000 E
MW-6	17.4-26.7	TOLUENE - 600 UJ ETHYLBENZENE - 20,000 XYLENE - 98,000	TW-2*	19-29	TOLUENE - 5 U ETHYLBENZENE - 5 U XYLENE - 5 U
MW-8	63-73	TOLUENE - 0.2 UJ ETHYLBENZENE - 17 XYLENE - 79	TW-3*	19-29	TOLUENE - 5 U ETHYLBENZENE - 720 J XYLENE - 5 U
MW-10	22-32	TOLUENE - 1 U ETHYLBENZENE - 0.8 UJ XYLENE - 5 U	TW-4*	22-32	TOLUENE - 5 U ETHYLBENZENE - 5 U XYLENE - 5 U
P-2	UNKNOWN	TOLUENE - 1 U ETHYLBENZENE - 1 U XYLENE - 7 U	TW-5*	20-30	TOLUENE - 5 U ETHYLBENZENE - 3 J XYLENE - 5 U
GWPP-34	32-35	TOLUENE - 8 ETHYLBENZENE - 10 U XYLENE - 13			



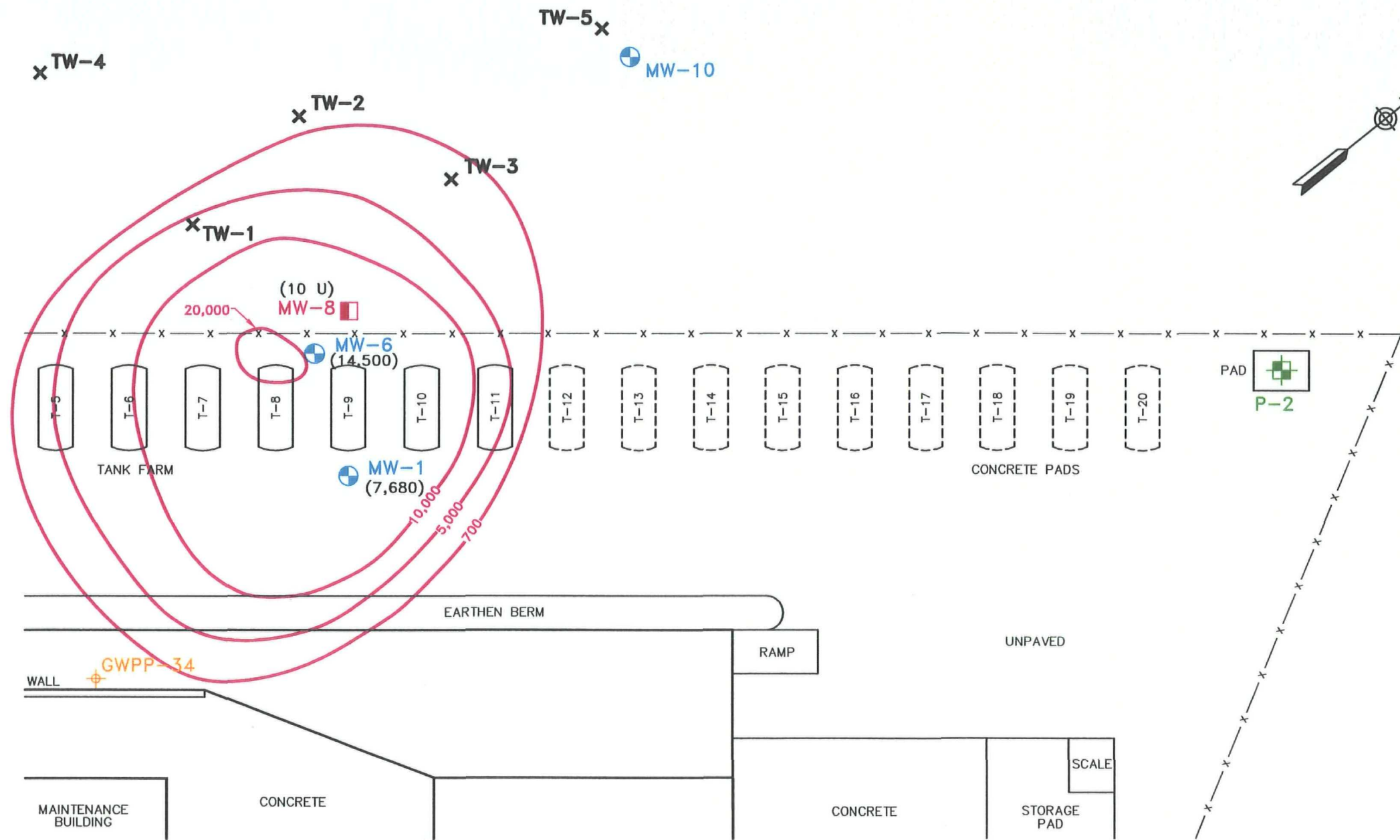
JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	MJS	DATE:	11/07/00
CHK BY:	son	FILE No.:	US01-023
REV BY:	BL	OR SUBTITLE:	03

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ESTIMATED AREAL EXTENT OF XYLENE-IMPACTED SHALLOW GROUNDWATER IN 1998 - AST AREA

VIRGIN ISLAND CHEMICAL SITE

FIGURE 13



LEGEND

- PRODUCTION WELL LOCATION
- SHALLOW MONITORING WELL LOCATION
- DEEP MONITORING WELL LOCATION
- GEOPROBE GROUNDWATER SAMPLE LOCATION
- TEMPORARY WELL LOCATION
- ETHYLBENZENE CONTOUR (ppb)
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION

NOTES

1.) FOR COMPARISON, CONCENTRATIONS FROM THE MAY 2000 SAMPLING EVENT ARE REPORTED IN PARENTHESES NEXT TO WELL ID. ALL UNITS ARE ppb.

REFERENCE

1.) DRAWING BASED ON FIGURE 4-13 OF THE R.I. REPORT ENTITLED "ESTIMATED AREAL EXTENT OF ETHYLBENZENE-IMPACTED SHALLOW GROUNDWATER - AST AREA" DATED 2/17/00, PROVIDED BY McLAREN/HART, INC.

SAMPLE ID	DEPTH (ft bgs)	CONCENTRATION (ppb)	SAMPLE ID	DEPTH (ft bgs)	CONCENTRATION (ppb)
MW-1	23-33	TOLUENE - 460 UJ ETHYLBENZENE - 18,000 XYLENE - 80,000	TW-1*	19-29	TOLUENE - 5 U ETHYLBENZENE - 8,000 E XYLENE - 15,000 E
MW-6	17.4-26.7	TOLUENE - 600 UJ ETHYLBENZENE - 20,000 XYLENE - 98,000	TW-2*	19-29	TOLUENE - 5 U ETHYLBENZENE - 5 U XYLENE - 5 U
MW-8	63-73	TOLUENE - 0.2 UJ ETHYLBENZENE - 17 XYLENE - 79	TW-3*	19-29	TOLUENE - 5 U ETHYLBENZENE - 720 J XYLENE - 5 U
MW-10	22-32	TOLUENE - 1 U ETHYLBENZENE - 0.8 UJ XYLENE - 5 U	TW-4*	22-32	TOLUENE - 5 U ETHYLBENZENE - 5 U XYLENE - 5 U
P-2	UNKNOWN	TOLUENE - 1 U ETHYLBENZENE - 1 U XYLENE - 7 U	TW-5*	20-30	TOLUENE - 5 U ETHYLBENZENE - 3 J XYLENE - 5 U
GWPP-34	32-35	TOLUENE - 8 ETHYLBENZENE - 10 U XYLENE - 13			

NOTES:

- J ESTIMATED CONCENTRATION
 - U ANALYTE NOT DETECTED ABOVE REPORTING LIMIT
 - E ESTIMATED CONCENTRATION
 - 18,000 CONCENTRATION EXCEEDS MCL (ETHYLBENZENE - 700 ppb, XYLENE - 10,000 ppb)
 - * CONCENTRATIONS FROM TEMPORARY WELLS ARE SCREENING RESULTS FROM ONSITE GC (SEPTEMBER 1997)
- ALL RESULTS ARE FROM MARCH/APRIL 1998 INVESTIGATION EXCEPT SCREENING RESULTS FROM TEMPORARY WELLS (SEPTEMBER 1997)

JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	MJS	DATE:	11/07/00
CHK BY:	SDM	FILE No.:	US01-024
REV BY:	PL	DR SUBTITLE:	03

Golder Associates

ESTIMATED AREAL EXTENT OF ETHYLBENZENE-IMPACTED SHALLOW GROUNDWATER IN 1998 - AST AREA

VIRGIN ISLAND CHEMICAL SITE **FIGURE 14**

SAMPLE ID	DEPTH (ft bgs)	CHLOROFORM CONCENTRATION (ppb)
GWPP-7	20-25	ND
GWPP-8	20-25	ND
GWPP-9	22-27	318
GWPP-10	28-33	94
GWPP-11	21-26	74
GWPP-12	26-31	78
GWPP-13	22-30	157
GWPP-14	21-24	ND
GWPP-15	8-10	1,178
GWPP-16	27-30	ND
GWPP-17	27-32	3
GWPP-19	8-12	480
GWPP-20	23-28	7
GWPP-21	21-26	ND
GWPP-23	22-27	1,000
GWPP-24	23-28	53
GWPP-25	24-29	3
GWPP-26	6-10	54
GWPP-27	24-29	3,994
GWPP-28	26-31	234
GWPP-29*	31-34	96
GWPP-30	34-37	ND
GWPP-31	22-27	1,661
GWPP-32	23-28	6
GWPP-33*	31-34	63
GWPP-34	32-35	ND
GWPP-35	27-30	29
GWOR-1	22-29	31
MW-2	18.9-28.2	2,400
MW-3	18.5-28.5	ND
MW-7	64-74	4
MW-11	30-40	3J
MW-12	137-147	ND
MW-13	30-40	ND
MW-14	124-134	ND
P-1	UNKNOWN	46E
MW-15	88-98	SEE NOTE 1

NOTES:

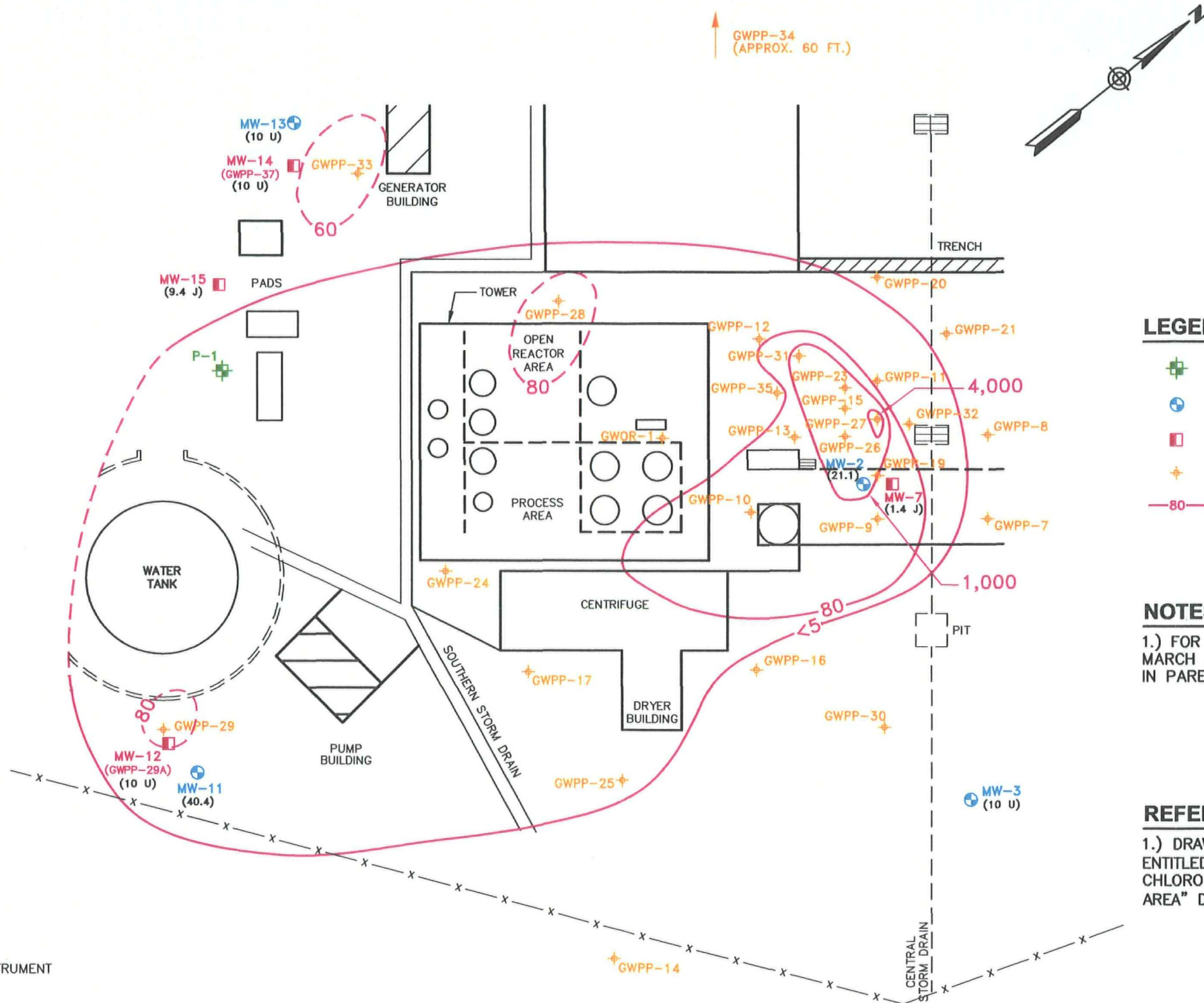
E EXCEEDS CALIBRATION RANGE OF INSTRUMENT

J ESTIMATED CONCENTRATION

ND NON DETECTED

1,700 CONCENTRATION EXCEEDS MCL (80 ppb)

* FOR PREPARATION OF PLUME MAP, RESULTS FROM SCREENING POINTS GWPP-29 AND GWPP-33 WERE REPLACED WITH RESULTS FROM MONITORING WELLS MW-11 AND MW-13 RESPECTIVELY. THESE PERMANENT POINTS ARE ASSUMED TO BE MORE REPRESENTATIVE OF ACTUAL GROUNDWATER CONDITIONS. ALL RESULTS ARE FROM MARCH/APRIL 1998 INVESTIGATION EXCEPT MONITORING WELLS MW-11 THROUGH MW-14 (OCTOBER 1998) AND MW-15 (MAY 2000).



LEGEND

- + PRODUCTION WELL LOCATION
- + SHALLOW MONITORING WELL LOCATION
- + DEEP MONITORING WELL LOCATION
- + GEOPROBE GROUNDWATER SAMPLE LOCATION
- 80 CHLOROFORM CONTOUR (ppb)

NOTES

1.) FOR COMPARISON, CONCENTRATIONS FROM THE MARCH AND MAY 2000 SAMPLING EVENT ARE REPORTED IN PARENTHESES NEXT TO WELL ID. ALL UNITS ARE ppb.

REFERENCE

1.) DRAWING BASED ON FIGURE 4-16 OF THE R.I. REPORT ENTITLED "ESTIMATED AREAL EXTENT OF CHLOROFORM-IMPACTED SHALLOW GROUNDWATER - AST AREA" DATED 2/17/00, PROVIDED BY McLAREN/HART, INC.

JOB No.:	003-6016	SCALE:	AS SHOWN
CAD BY:	MJS	DATE:	11/07/00
CHK BY:	Sm	FILE No.:	US01-025
REV BY:	BL	DR SUBTITLE:	03

Golder Associates

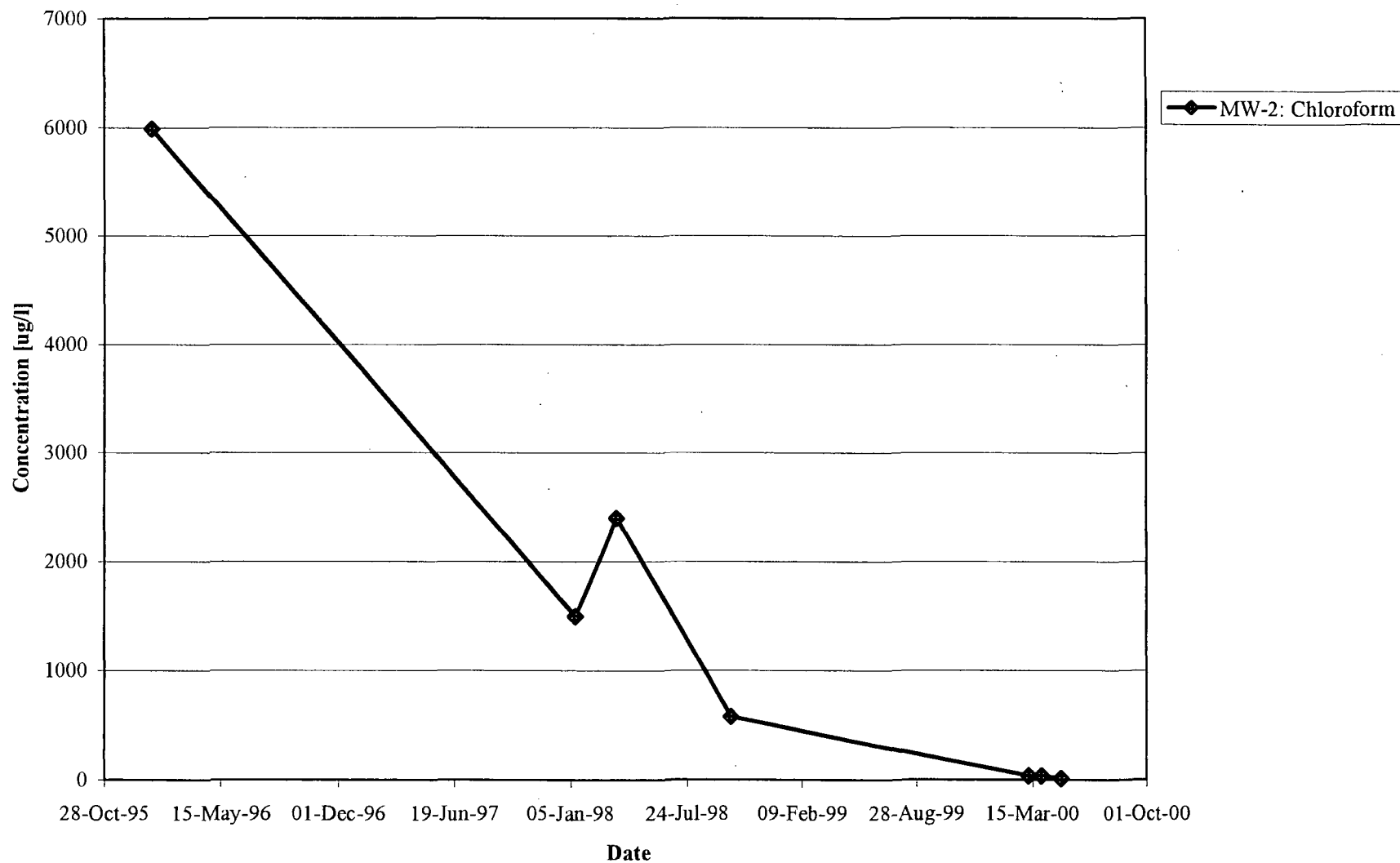
**ESTIMATED AREAL EXTENT OF
CHLOROFORM-IMPACTED SHALLOW
GROUNDWATER IN 1998 - PROCESS PIT AREA**

VIRGIN ISLAND CHEMICAL SITE

FIGURE
15

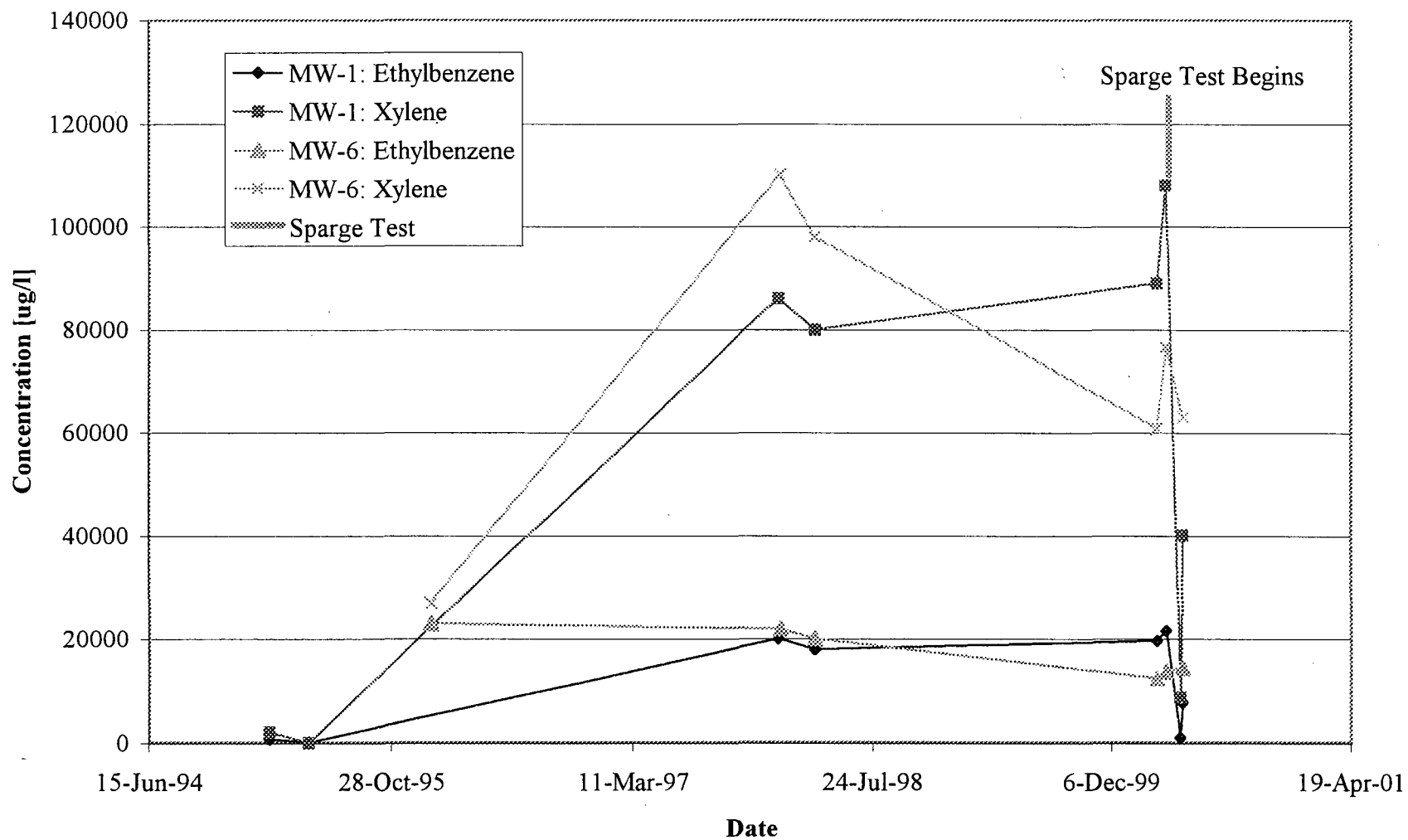
400109

Historic VOCs at FPP Area

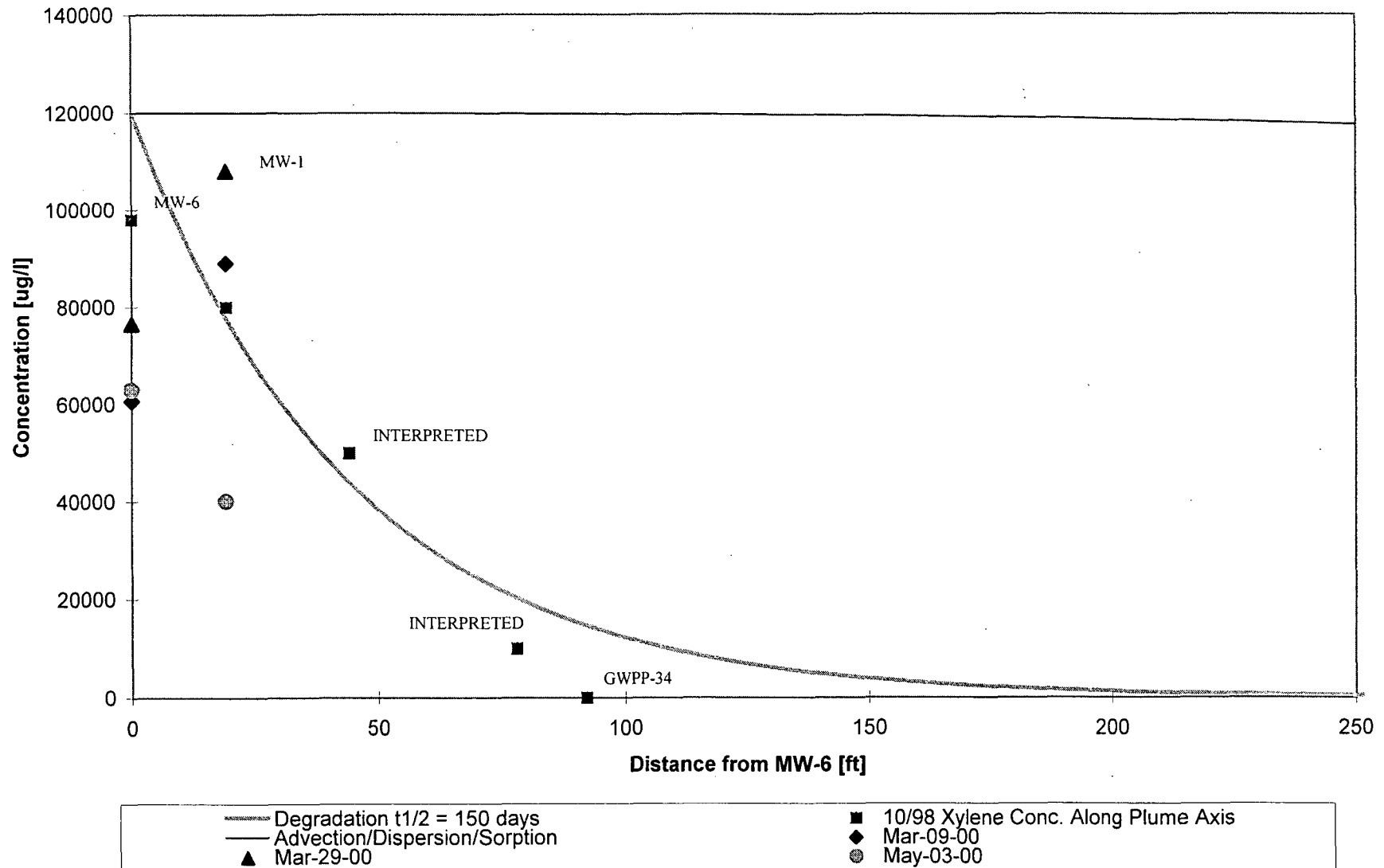


400110

Historic VOCs at AST Area



Model vs. Actual Xylene Concentrations Downgradient of Source
1-D Advection/Dispersion with Linear Sorption (upper curve),
with First-Order Decay (half-life = 150 days)



400112

Figure 19
Predicted Xylene Concentrations Downgradient of MW-6

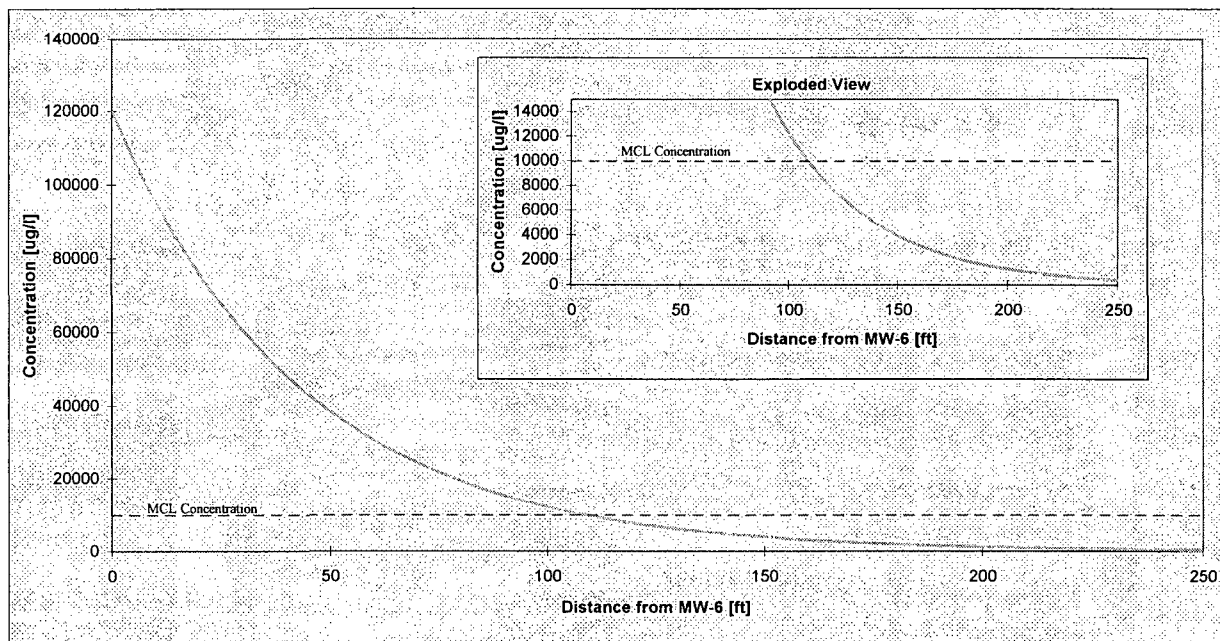
Steady State One-Dimensional Advection/Dispersion Model with Reaction Terms (Degradation)

$$C(x,t) = \frac{C_o}{2} \exp\left(\frac{Ux}{2D}\right) \left\{ \exp(-Bx) \operatorname{erfc}\left[\frac{x - t\sqrt{(U/\omega R)^2 + 4\lambda D/\omega R}}{2\sqrt{Dt/\omega R}}\right] + \exp(Bx) \operatorname{erfc}\left[\frac{x + t\sqrt{(U/\omega R)^2 + 4\lambda D/\omega R}}{2\sqrt{Dt/\omega R}}\right] \right\}$$

where: $B = \sqrt{(U/2D)^2 + (\lambda\omega R/D)}$

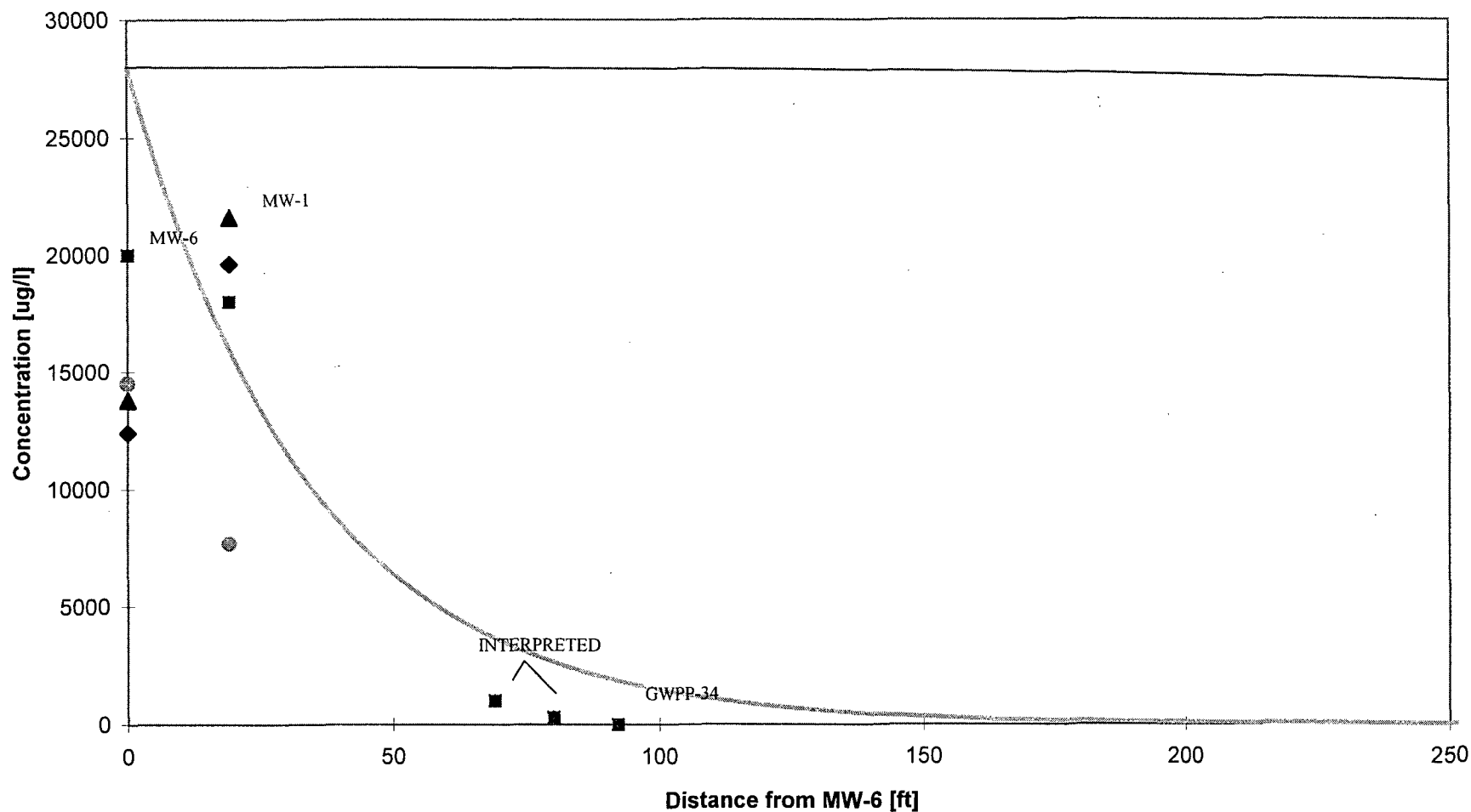
Model Input Parameters

Darcy Velocity	U = K I	1.07E-01	[ft/day]
Dispersivity	α_L	50	[ft]
Dispersion Coefficient	D = $\alpha_L \cdot U$	5.36	[ft ² /day]
Effective Porosity	ω	0.2	[Dimensionless]
Initial Concentration	C _o	120000	[ug/l]
Partition Coefficient	K _{oc}	240	[cm ³ /g]
Bulk Density	ρ_b	1.44	[g/cm ³]
Fraction of Organic Carbon	F _{oc}	0.0027	[Dimensionless]
Retardation Factor	R = 1 + K _{oc} *F _{oc} * ρ_b/n	5.67	[Dimensionless]
Decay Coefficient	$\lambda = (\ln 2) / t_{1/2}$	0.004621	[day ⁻¹]
Half-Life Time	t _{1/2}	150	[days]
	t _{1/2}	0.41	[years]
Simulation Time	t	7300	[days]
	t	20	[years]



Model vs. Actual Ethylbenzene Concentrations Downgradient of Source

1-D Advection/Dispersion with Linear Sorption (upper curve),
with First-Order Decay (half-life = 100 days)



Degradation $t_{1/2} = 200$ days
— Advection/Dispersion/Sorption
▲ Mar-29-00

■ 10/98 Ethylbenzene Conc. Along Plume Axis
◆ Mar-08-00
● May-08-00

400114

Figure 21
Predicted Ethylbenzene Concentrations Downgradient of MW-6

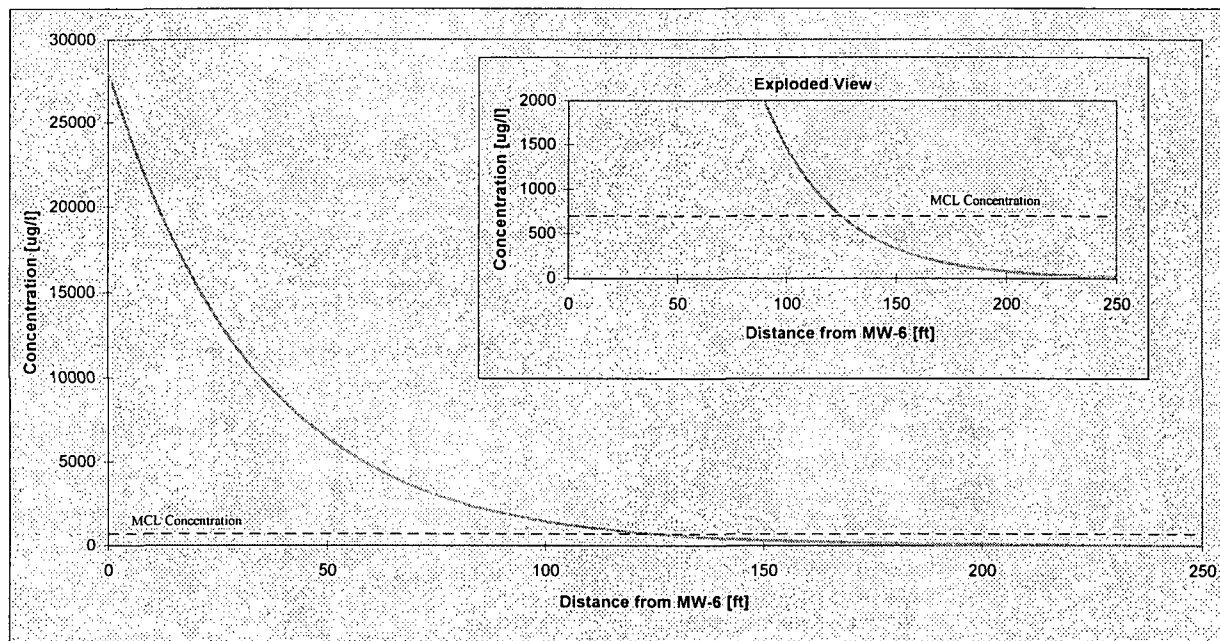
Steady State One-Dimensional Advection/Dispersion Model with Reaction Terms (Degradation)

$$C(x,t) = \frac{C_o}{2} \exp\left(\frac{Ux}{2D}\right) \left\{ \exp(-Bx) \operatorname{erfc}\left[\frac{x - t\sqrt{(U/\omega R)^2 + 4\lambda D/\omega R}}{2\sqrt{Dt/\omega R}}\right] + \exp(Bx) \operatorname{erfc}\left[\frac{x + t\sqrt{(U/\omega R)^2 + 4\lambda D/\omega R}}{2\sqrt{Dt/\omega R}}\right] \right\}$$

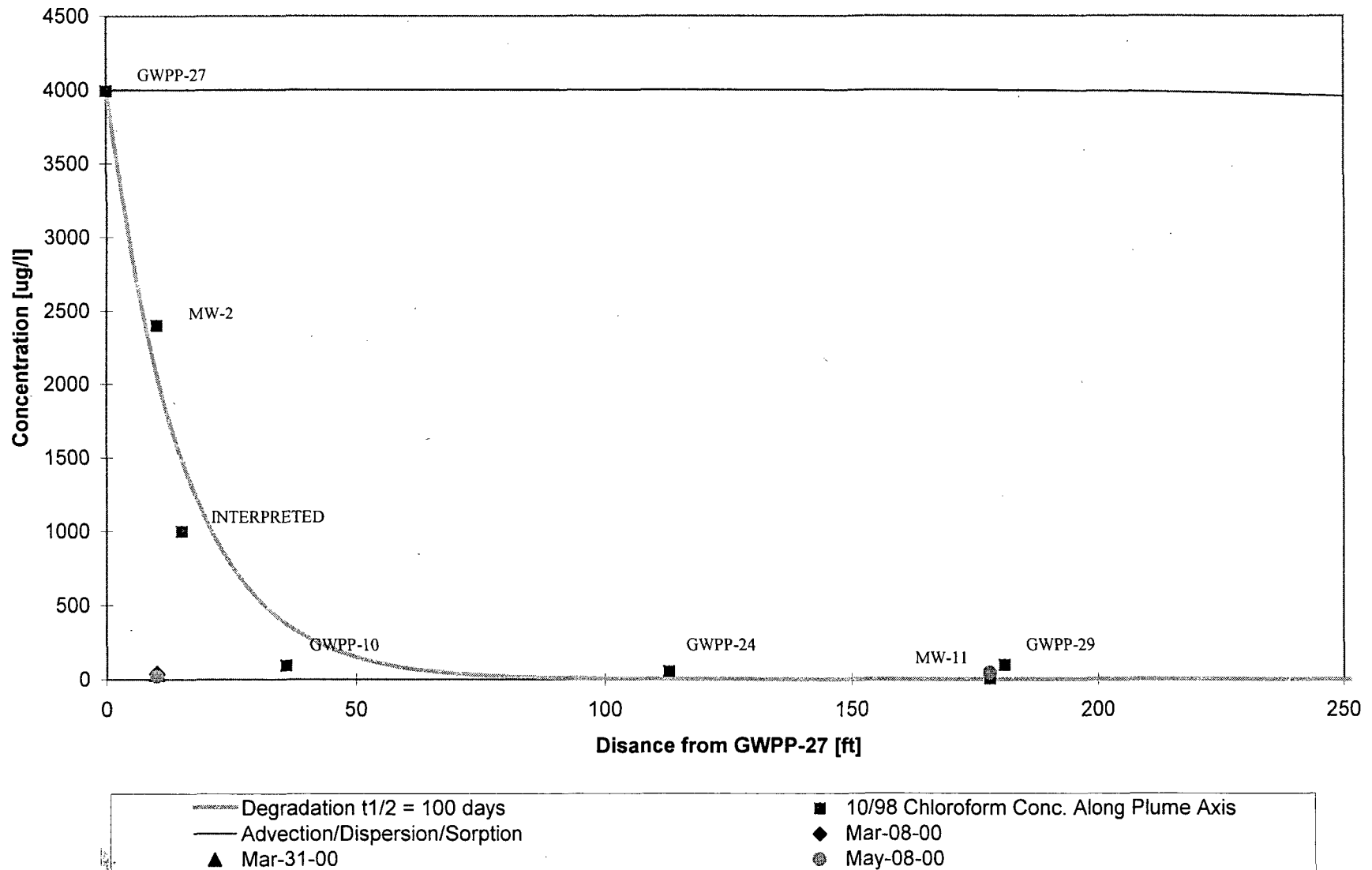
where: $B = \sqrt{(U/2D)^2 + (\lambda\omega R/D)}$

Model Input Parameters

Darcy Velocity	$U = KI$	1.07E-01	[ft/day]
Longitudinal Dispersivity	α_L	50	[ft]
Dispersion Coefficient	$D = \alpha_L * U$	5.36	[ft ² /day]
Effective Porosity	ω	0.2	[Dimensionless]
Initial Concentration	C_o	28000	[ug/l]
Partition Coefficient	Koc	240	[cm ³ /g]
Bulk Density	ρ_b	1.44	[g/cm ³]
Fraction of Organic Carbon	Foc	0.0027	[Dimensionless]
Retardation Factor	$R = 1 + Koc * Foc * \rho_b / n$	5.67	[Dimensionless]
Decay Coefficient	$\lambda = (\ln 2) / t_{1/2}$	0.0069315	[day ⁻¹]
Half-Life Time	$t_{1/2}$	100	[days]
	$t_{1/2}$	0.27	[years]
Simulation Time	t	7300	[days]
	t	20	[years]



Model vs. Actual Chloroform Concentrations Downgradient of Source
1-D Advection/Dispersion with Linear Sorption (upper curve),
with First-Order Decay (half-life = 100 days)



400116

Figure 23
Predicted Chloroform Concentrations Downgradient of GWPP-27

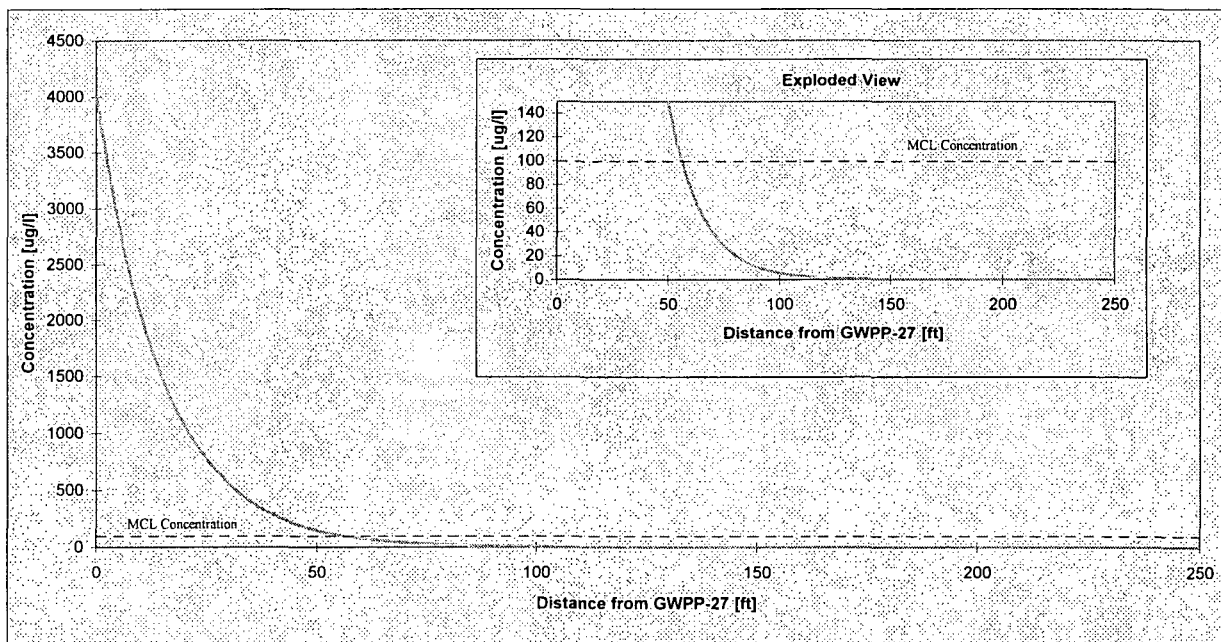
Steady State One-Dimensional Advection/Dispersion Model with Reaction Terms (Degradation)

$$C(x,t) = \frac{C_o}{2} \exp\left(\frac{Ux}{2D}\right) \left\{ \exp(-Bx) \operatorname{erfc} \left[\frac{x - t\sqrt{(U/\omega R)^2 + 4\lambda D/\omega R}}{2\sqrt{Dt/\omega R}} \right] + \exp(Bx) \operatorname{erfc} \left[\frac{x + t\sqrt{(U/\omega R)^2 + 4\lambda D/\omega R}}{2\sqrt{Dt/\omega R}} \right] \right\}$$

where: $B = \sqrt{(U/2D)^2 + (\lambda\omega R/D)}$

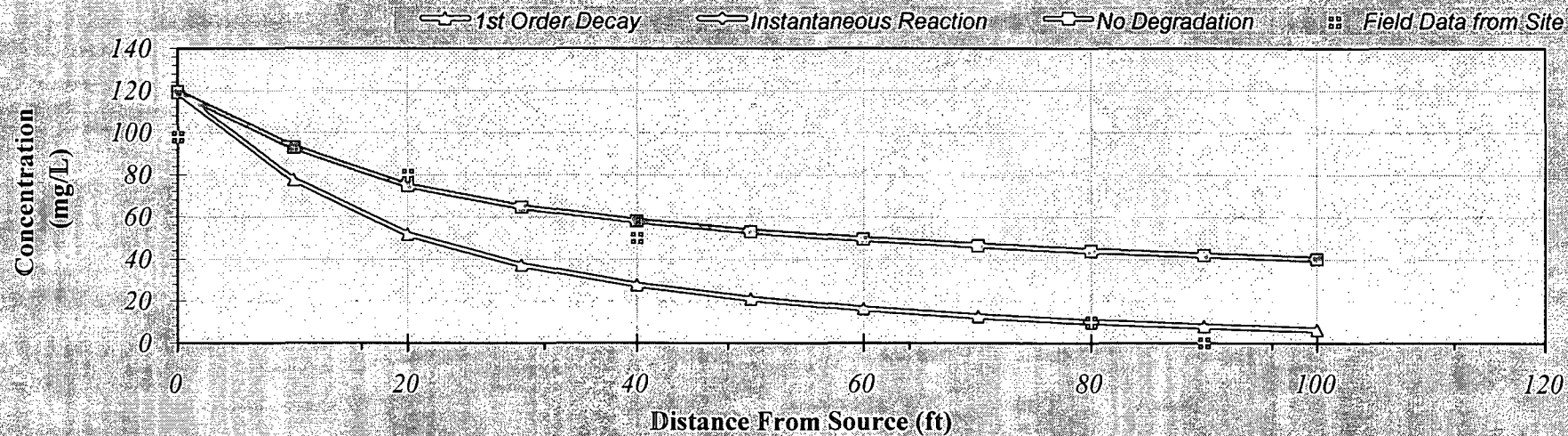
Model Input Parameters

Darcy Velocity	$U = K I$	2.01E-02	[ft/day]
Dispersivity	α_L	1.04E+01	[ft]
Dispersion Coefficient	$D = \alpha_L * U$	0.21	[ft ² /day]
Effective Porosity	ω	0.2	[Dimensionless]
Initial Concentration	C_o	4000	[ug/l]
Partition Coefficient	K_{oc}	31.00	[cm ³ /g]
Bulk Density	ρ_b	1.44	[g/cm ³]
Fraction of Organic Carbon	F_{oc}	0.0027	[Dimensionless]
Retardation Factor	$R = 1 + K_{oc} * F_{oc} * \rho_b / n$	1.60	[Dimensionless]
Decay Coefficient	$\lambda = (\ln 2) / t_{1/2}$	0.0069315	[day ⁻¹]
Half-Life Time	$t_{1/2}$	100	[days]
	$t_{1/2}$	0.27	[years]
Simulation Time	t	7300	[days]
	t	20	[years]



XYLENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	10	20	30	40	50	60	70	80	90	100
No Degradation	119.475	93.065	74.761	64.600	57.930	53.100	49.380	46.395	43.926	41.837	40.037
1st Order Decay	119.475	77.556	51.706	37.082	27.601	21.001	16.212	12.646	9.941	7.862	6.248
Inst. Reaction	119.475	93.065	74.761	64.600	57.930	53.100	49.380	46.395	43.926	41.837	40.037
Field Data from Site	98.000		80.000		50.000				10.000	0.013	



Calculate
Animation

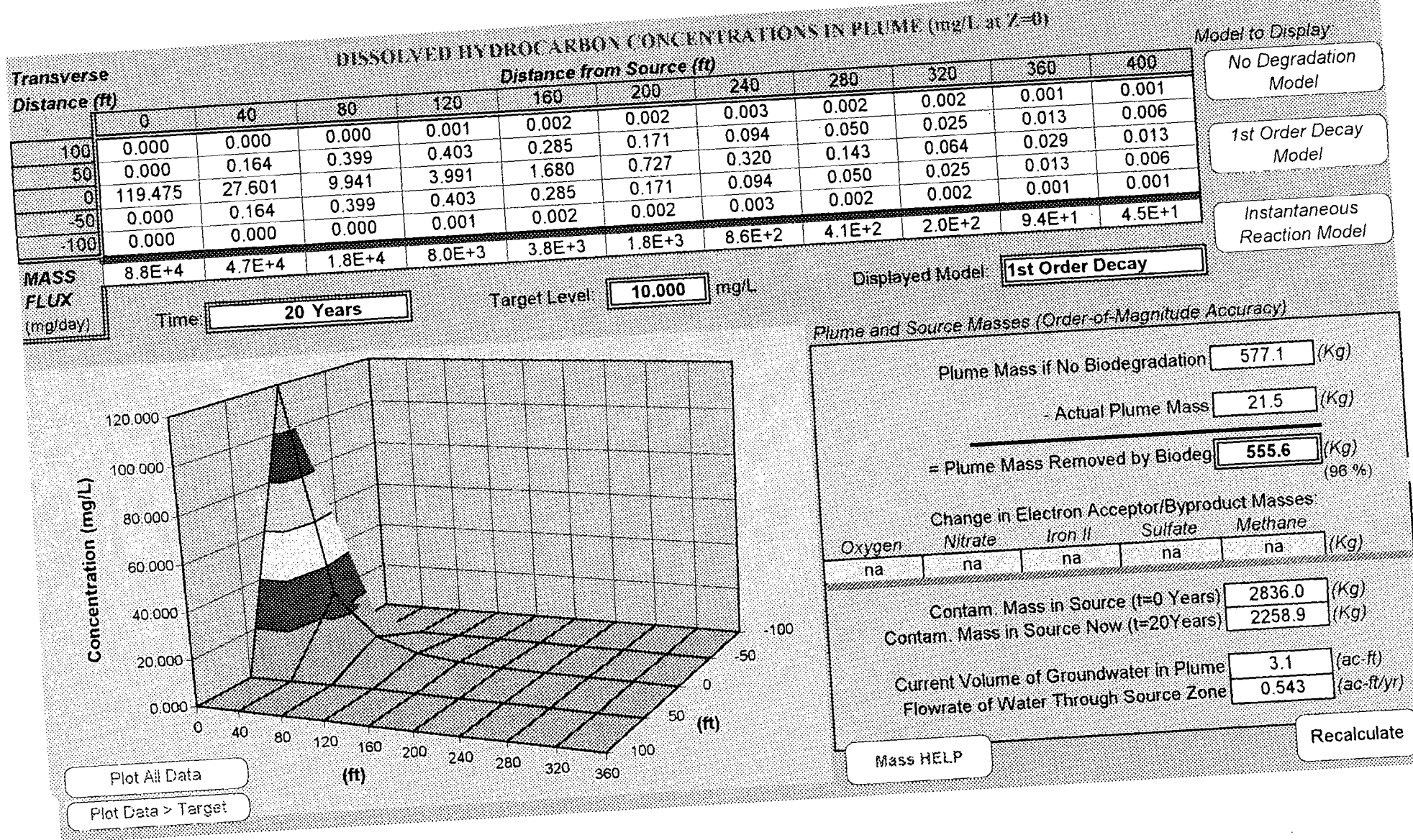
Time:
20 Years

Return to
Input

Recalculate This Sheet

August 2000

Figure 25
Total Xylenes Model Mass Balance



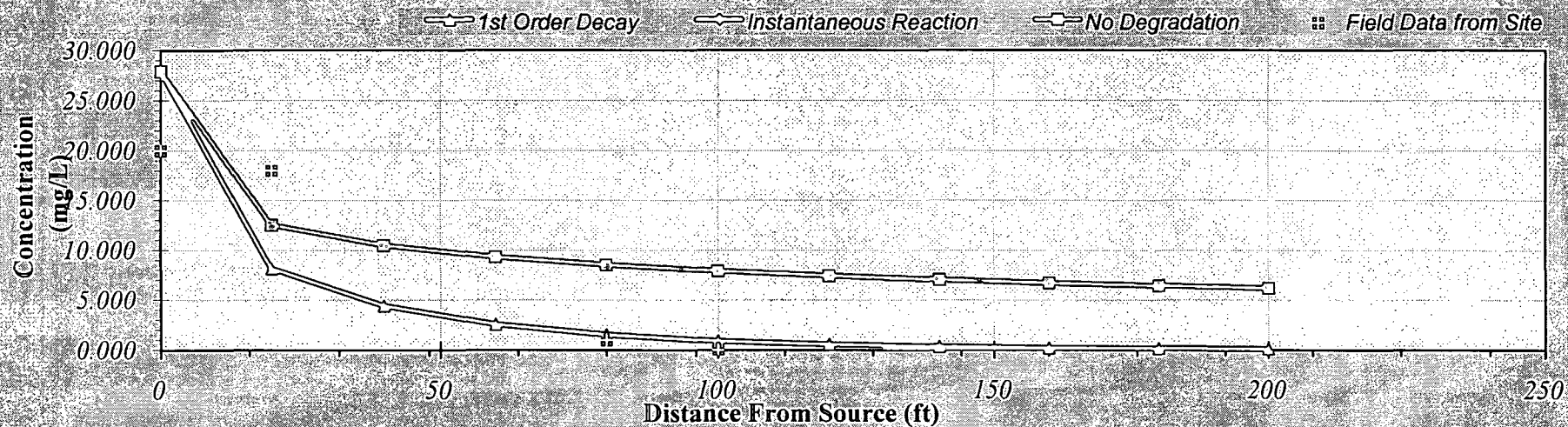
Note: Model length set = 400 ft for this calculation.
 Gxylene.xls

Golder Associates

400119

ETHYLBENZENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	20	40	60	80	100	120	140	160	180	200
No Degradation	27.915	12.516	10.489	9.320	8.506	7.896	7.415	7.023	6.695	6.415	6.169
1st Order Decay	27.915	8.124	4.402	2.529	1.493	0.897	0.545	0.334	0.207	0.128	0.080
Inst. Reaction	27.915	12.516	10.489	9.320	8.506	7.896	7.415	7.023	6.695	6.415	6.169
Field Data from Site	20.000	18.000			1.000	0.001					



Calculate
Animation

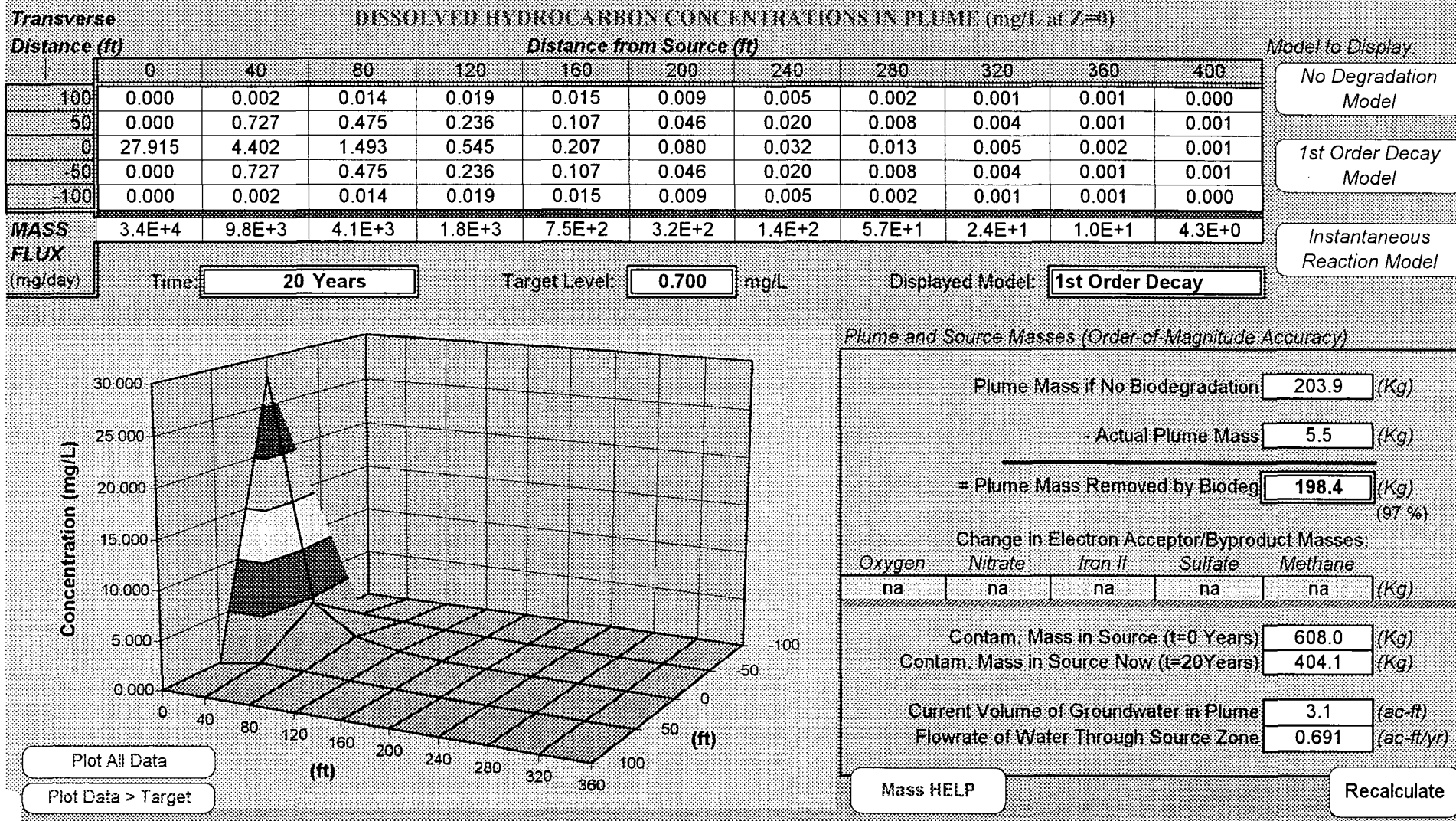
Time:

20 Years

Return to
Input

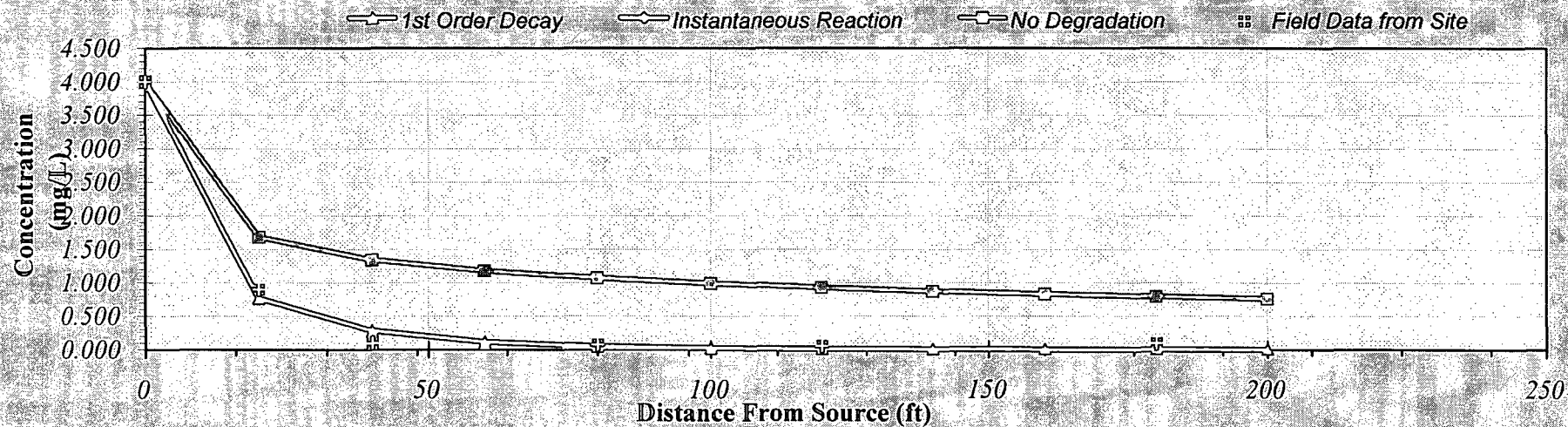
Recalculate This Sheet

Golder Associates



CHLOROFORM CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	20	40	60	80	100	120	140	160	180	200
No Degradation	4.000	1.677	1.339	1.174	1.066	0.986	0.923	0.871	0.828	0.790	0.756
1st Order Decay	4.000	0.767	0.280	0.112	0.047	0.020	0.008	0.004	0.002	0.001	0.000
Inst. Reaction	4.000	1.677	1.339	1.174	1.066	0.986	0.923	0.871	0.828	0.790	0.756
Field Data from Site	4.000	0.900	0.094		0.075		0.053			0.096	

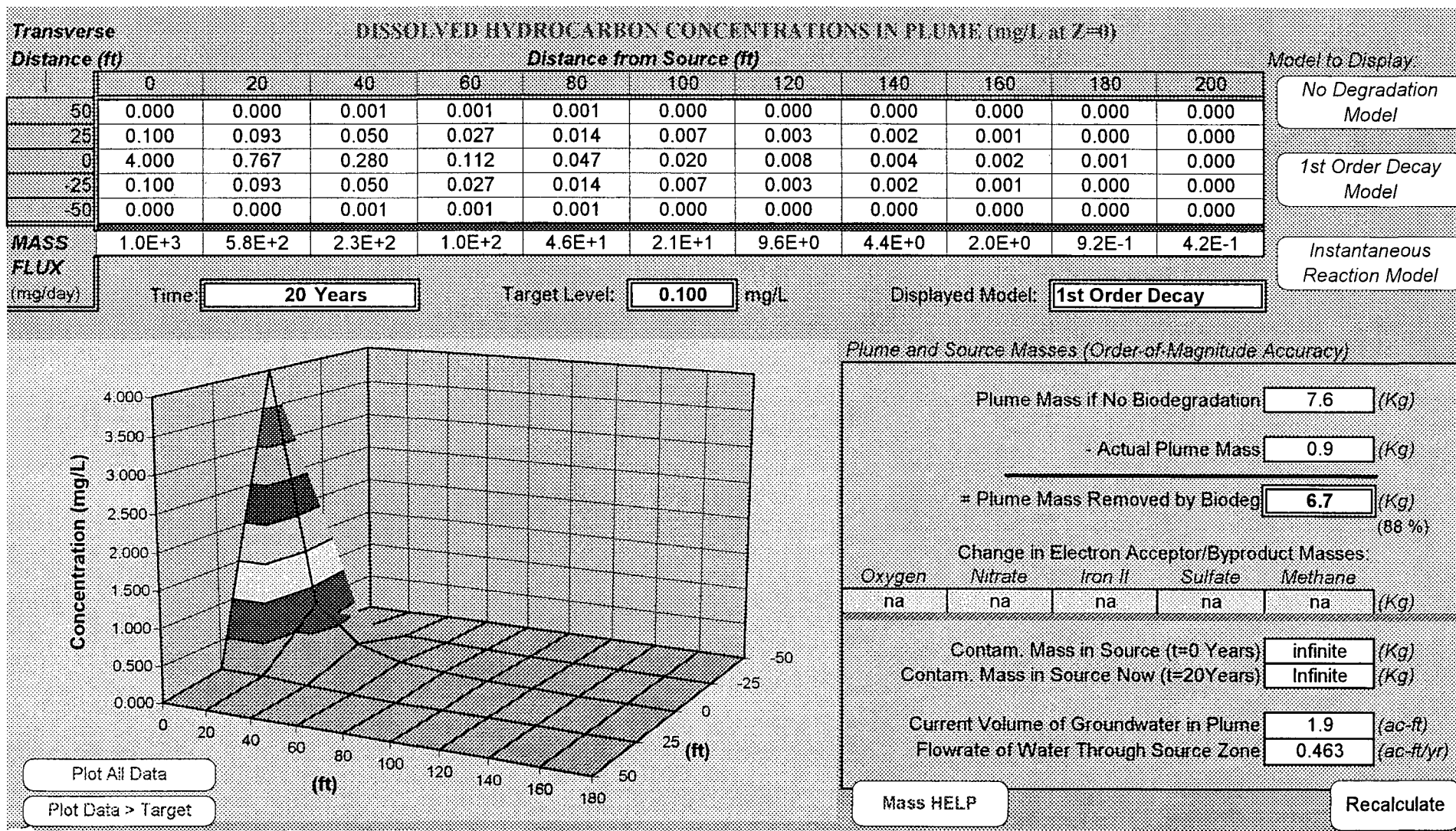


Calculate
Animation

Time:
20 Years

Return to
Input

Recalculate This Sheet



BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

Island Chemical

Xylene 1998-00

Run Name

Data Input Instructions:

115

0.02

Variable*

20

1. Enter value directly, or
 2. Calculate by filling in gray cells below. (To restore formulas, hit button below)
- Data used directly in model
- Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	97.8	(ft/yr)
or			
Hydraulic Conductivity	K	6.3E-03	(cm/sec)
Hydraulic Gradient	i	0.003	(ft/ft)
Porosity	n	0.2	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	50.0	(ft)
Transverse Dispersivity*	alpha y	2.0	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or			
Estimated Plume Length	Lp	120	(ft)

3. ADSORPTION

Retardation Factor*	R	5.6	(-)
or			
Soil Bulk Density	rho	1.44	(kg/l)
Partition Coefficient	Koc	240	(L/kg)
Fraction Organic Carbon	foc	0.00267	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.26	(per yr)
or			
Solute Half-Life	t-half	0.55	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO		(mg/L)
Delta Nitrate*	NO3		(mg/L)
Observed Ferrous Iron*	Fe2+		(mg/L)
Delta Sulfate*	SO4		(mg/L)
Observed Methane*	CH4		(mg/L)

5. GENERAL

Modeled Area Length*	200	(ft)
Modeled Area Width*	200	(ft)
Simulation Time*	2	(yr)

6. SOURCE DATA

Source Thickness in Sat Zone* 20 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
0	0
10	5
30	80
10	5
0	0

Source Halflife (see Help):

6 6 (yr)

Inst. React 1st Order

Soluble Mass 240 (Kg)

In Source NAPL Soil

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	63.0	40.0				001								
Dist. from Source (ft)	0	20	40	60	80	100	120	140	160	180	200			

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN
CENTERLINE

View Output

RUN ARRAY

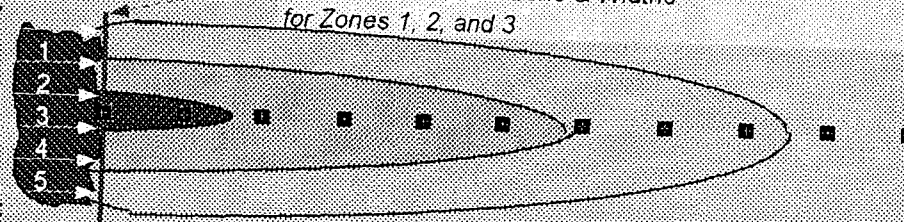
View Output

Help

Recalculate This
Sheet

Paste Example Dataset

Restore Formulas for Vs,
Dispersivities, R, lambda, other

Vertical Plane Source: Look at Plume Cross-Section
and Input Concentrations & Widths
for Zones 1, 2, and 3


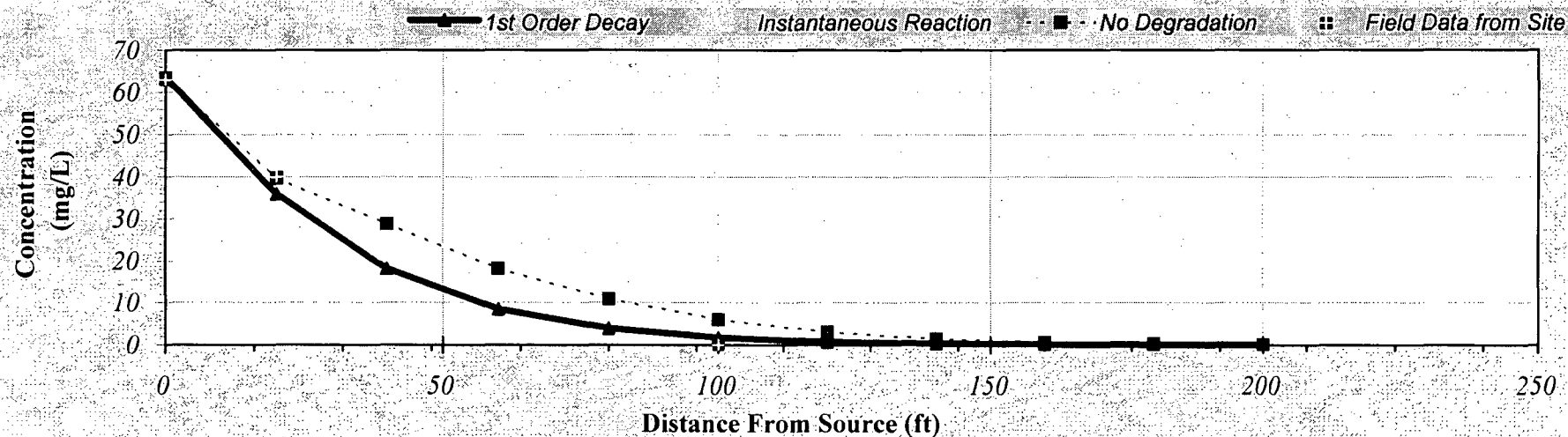
View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

Transient Bioscreen Analysis - Xylene
2000 Data Match

XYLENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	20	40	60	80	100	120	140	160	180	200
No Degradation	63.526	39.630	28.876	18.252	10.894	6.058	3.108	1.461	0.626	0.244	0.086
1st Order Decay	63.526	35.913	18.244	8.478	3.911	1.758	0.758	0.309	0.118	0.042	0.014
Inst. Reaction	63.526	39.630	28.876	18.252	10.894	6.058	3.108	1.461	0.626	0.244	0.086
Field Data from Site	63.000	40.000				0.001					



Calculate
Animation

Time:

2 Years

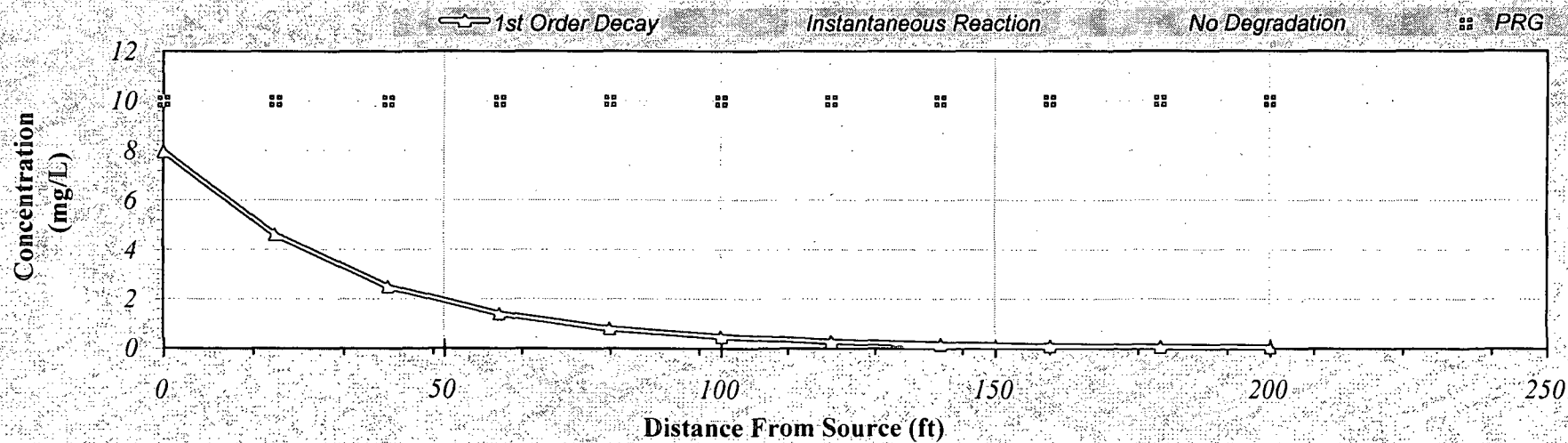
Return to
Input

Recalculate This Sheet

Transient Bioscreen Analysis - Xylene
Time to Compliance Simulation

XYLENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft)										
	0	20	40	60	80	100	120	140	160	180	200
No Degradation	7.974	7.976	7.667	7.586	7.679	7.889	8.184	8.541	8.945	9.385	9.849
1st Order Decay	7.974	4.617	2.495	1.391	0.795	0.462	0.272	0.162	0.097	0.059	0.035
Inst. Reaction	7.974	7.976	7.667	7.586	7.679	7.889	8.184	8.541	8.945	9.385	9.849
Prelim. Remed. Goal	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000



Calculate
Animation

Time:

20 Years

Return to
Input

Recalculate This Sheet

Transient Bioscreen Analysis - Ethylbenzene
Data Input

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

Island Chemical

Ethylbenzene 98-00

Run Name

Data Input Instructions:

115

↑

0.02

Variable*

20

1. Enter value directly... or
 2. Calculate by filling in grey cells below. (To restore formulas, hit button below)
- Data used directly in model
Value calculated by model
(Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	97.8	(ft/yr)
or		↑	
Hydraulic Conductivity	K	6.3E-03	(cm/sec)
Hydraulic Gradient	I	0.003	(ft/ft)
Porosity	n	0.2	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	50.0	(ft)
Transverse Dispersivity*	alpha y	5.0	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or		↑ or	
Estimated Plume Length	Lp	120	(ft)

3. ADSORPTION

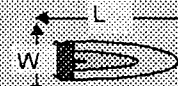
Retardation Factor*	R	22.4	(-)
or		↑ or	
Soil Bulk Density	rho	1.44	(kg/l)
Partition Coefficient	Koc	1100	(L/kg)
Fraction Organic Carbon	foc	0.0027	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.26	(per yr)
or		↑	
Solute Half-Life	t-half	0.55	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO		(mg/L)
Delta Nitrate*	NO3		(mg/L)
Observed Ferrous Iron*	Fe2+		(mg/L)
Delta Sulfate*	SO4		(mg/L)
Observed Methane*	CH4		(mg/L)

5. GENERAL

Modeled Area Length*	200	(ft)
Modeled Area Width*	200	(ft)
Simulation Time*	2	(yr)



6. SOURCE DATA

Source Thickness in Sat Zone* 20 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
0	0
30	10
30	20
30	10
0	0

Source Half-life (see Help):

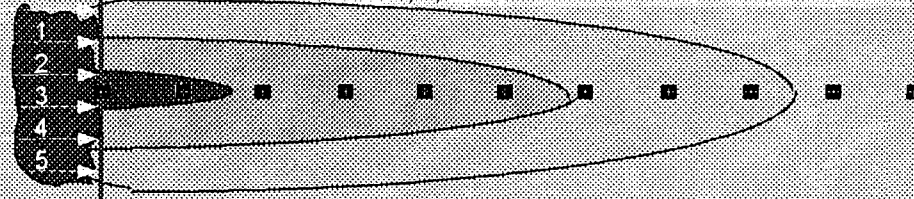
4	4	(yr)
---	---	------

Inst. React ☒ 1st Order

Soluble Mass 82 (Kg)

In Source NAPL, Soil

Vertical Plane Source. Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	14.5				.1	.001													
Dist. from Source (ft)	0	20	40	60	80	100	120	140	160	180	200								

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN
CENTERLINE

View Output

RUN ARRAY

View Output

Help

Recalculate This
Sheet

Paste Example Dataset

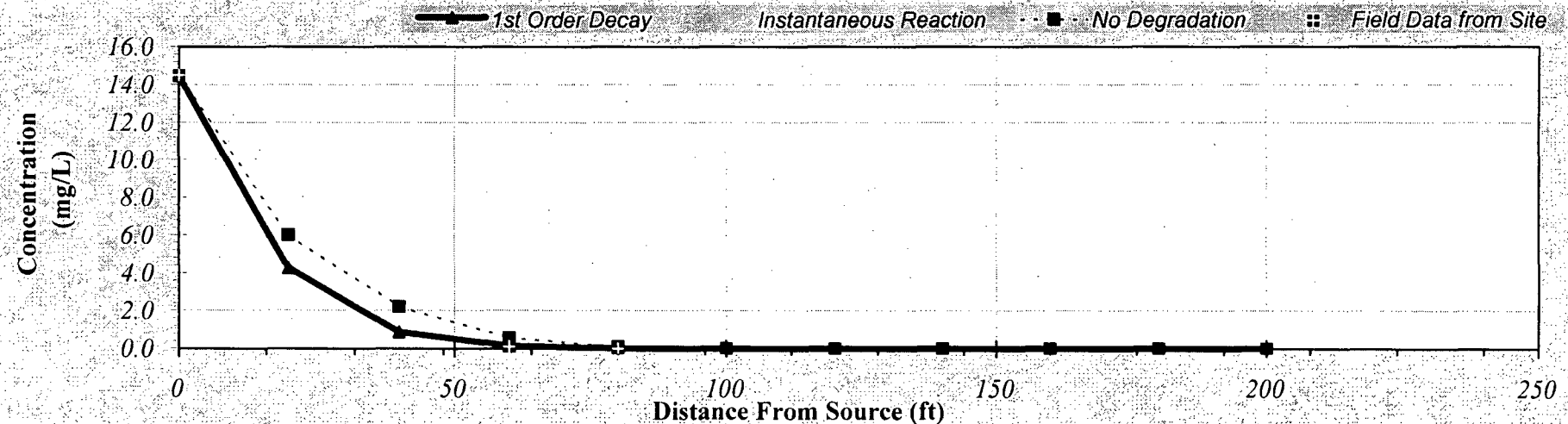
Restore Formulas for Vs, Dispersivities,
R, lambda, other

Transient Bioscreen Analysis - Ethylbenzene
2000 Data Match

ETHYLBENZENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	20	40	60	80	100	120	140	160	180	200
No Degradation	14.466	6.011	2.209	0.577	0.103	0.012	0.001	0.000	0.000	0.000	0.000
1st Order Decay	14.466	4.258	0.868	0.152	0.021	0.002	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	14.466	6.011	2.209	0.577	0.103	0.012	0.001	0.000	0.000	0.000	0.000
Field Data from Site	14.500			0.100	0.001						



Calculate
Animation

Time:

2.0 Years

Return to
Input

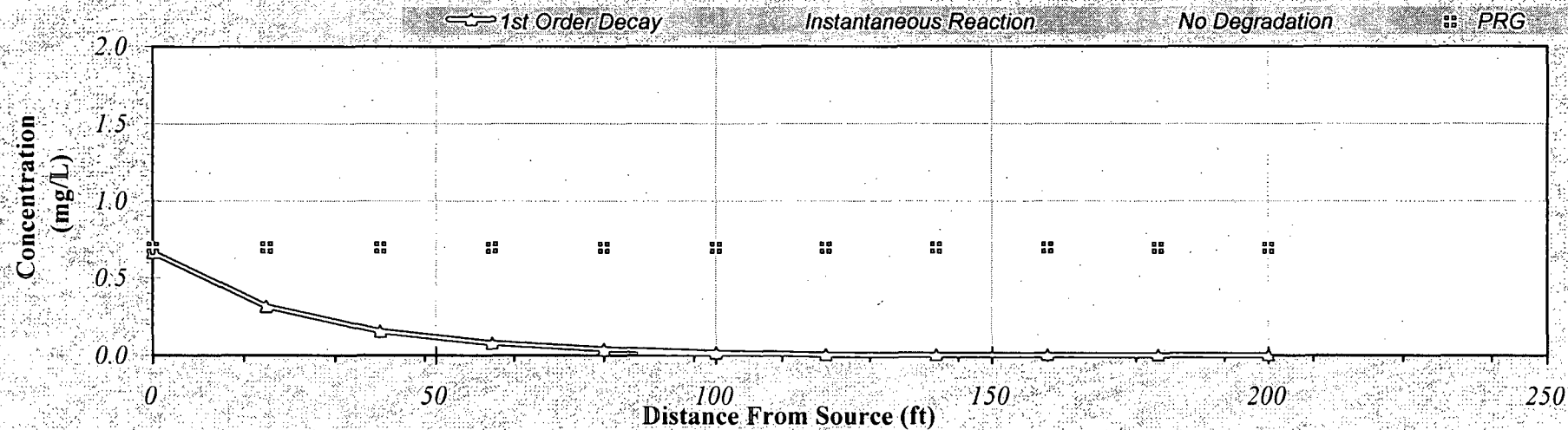
Recalculate This Sheet

Transient Bioscreen Analysis - Ethylbenzene
Time to Compliance Simulation

ETHYLBENZENE CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	20	40	60	80	100	120	140	160	180	200
No Degradation	0.667	0.925	1.577	2.706	4.591	5.634	4.381	3.324	2.455	1.761	1.225
1st Order Decay	0.667	0.316	0.156	0.079	0.041	0.015	0.004	0.001	0.000	0.000	0.000
Inst. Reaction	0.667	0.925	1.577	2.706	4.591	5.634	4.381	3.324	2.455	1.761	1.225
Prelim. Remed. Goal	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700	0.700



Calculate
Animation

Time:
21.0 Years

Return to
Input

Recalculate This Sheet

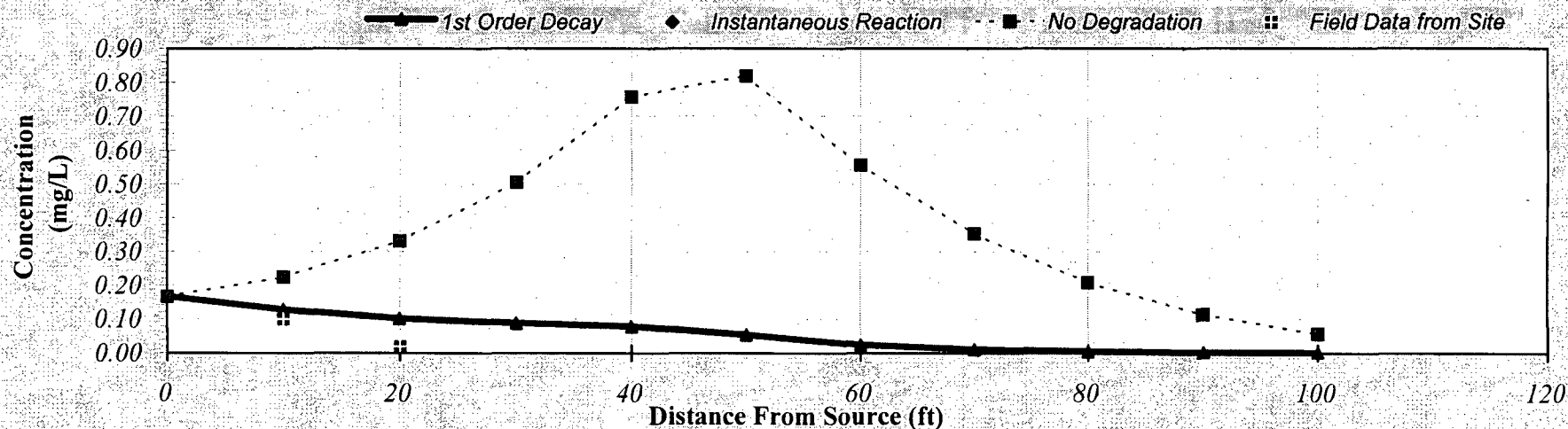
400130

Transient Bioscreen Analysis - Chloroform (FPP Area)
2000 Data Match

CHLOROFORM CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	10	20	30	40	50	60	70	80	90	100
No Degradation	0.166	0.224	0.332	0.506	0.758	0.820	0.557	0.354	0.209	0.114	0.057
1st Order Decay	0.166	0.127	0.102	0.088	0.079	0.054	0.025	0.011	0.005	0.002	0.001
Inst. Reaction	0.166	0.224	0.332	0.506	0.758	0.820	0.557	0.354	0.209	0.114	0.057
Field Data from Site		0.100	0.020								

Calculate
Animation

Time:

2.0 Years

Return to
Input

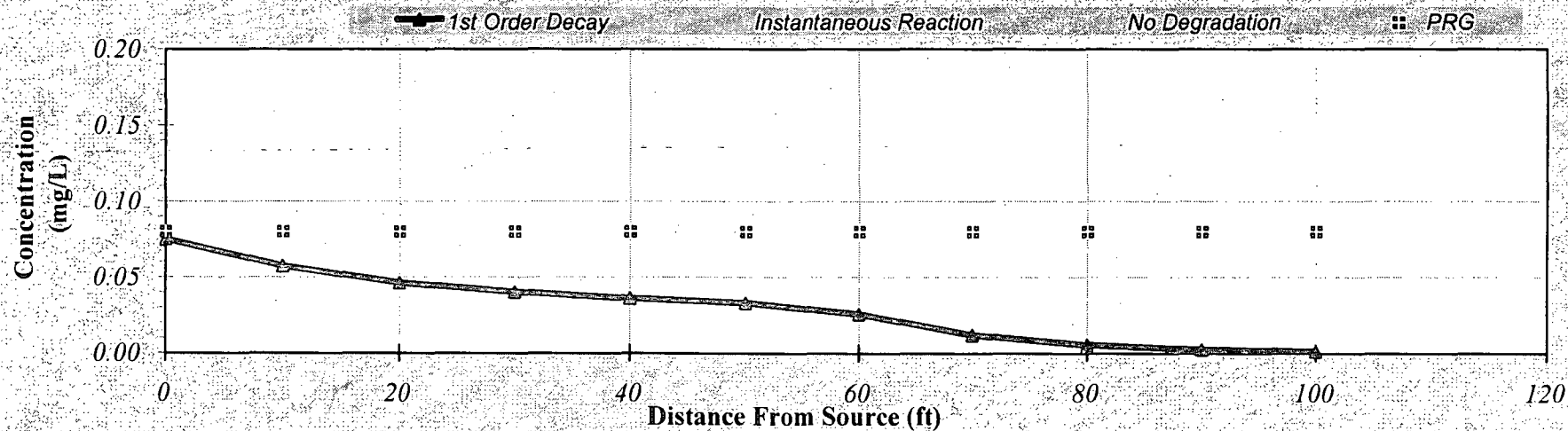
Recalculate This Sheet

Transient Bioscreen Analysis - Chloroform (FPP Area)
Time to Compliance Simulation

CHLOROFORM CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	10	20	30	40	50	60	70	80	90	100
No Degradation	0.075	0.106	0.161	0.257	0.411	0.643	0.808	0.582	0.397	0.256	0.155
1st Order Decay	0.075	0.057	0.046	0.040	0.036	0.033	0.026	0.012	0.006	0.003	0.001
Inst. Reaction	0.075	0.106	0.161	0.257	0.411	0.643	0.808	0.582	0.397	0.256	0.155
Prelim. Remed. Goal	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080



Calculate
Animation

Time:

2.5 Years

Return to
Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

Island Chemical

chloroform pulse

Run Name

Data Input Instructions:

115

0.02

Variable*

20

1. Enter value directly or
 2. Calculate by filling in gray cells below. (To restore formulas, hit button below)
- Data used directly in model
- Value calculated by model (Don't enter any data)

1. HYDROGEOLOGY

Seepage Velocity*	Vs	36.6	(ft/yr)
or			
Hydraulic Conductivity	K	5.9E-04	(cm/sec)
Hydraulic Gradient	i	0.012	(ft/ft)
Porosity	n	0.2	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	10.4	(ft)
Transverse Dispersivity*	alpha y	1.0	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or			
Estimated Plume Length	Lp	180	(ft)

3. ADSORPTION

Retardation Factor*	R	1.6	(-)
or			
Soil Bulk Density	rho	1.44	(kg/l)
Partition Coefficient	Koc	31	(L/kg)
Fraction Organic Carbon	foc	0.00267	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	0.35	(per yr)
or			
Solute Half-Life	t-half	2.00	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO		(mg/L)
Delta Nitrate*	NO3		(mg/L)
Observed Ferrous Iron*	Fe2+		(mg/L)
Delta Sulfate*	SO4		(mg/L)
Observed Methane*	CH4		(mg/L)

5. GENERAL

Modeled Area Length*	200	(ft)
Modeled Area Width*	100	(ft)
Simulation Time*	3	(yr)

6. SOURCE DATA

Source Thickness in Sat Zone* 15 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
12	0.1
19	0.5
5	4
19	0.5
12	0.1

Source Half-life (see Help):

<1 <1 (yr)

Inst. React 1st Order

Soluble Mass 0.10 (Kg)

In Source NAPL Soil

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	.1	.02								.04	
Dist. from Source (ft)	0	20	40	60	80	100	120	140	160	180	200

8. CHOOSE TYPE OF OUTPUT TO SEE:RUN
CENTERLINE

View Output

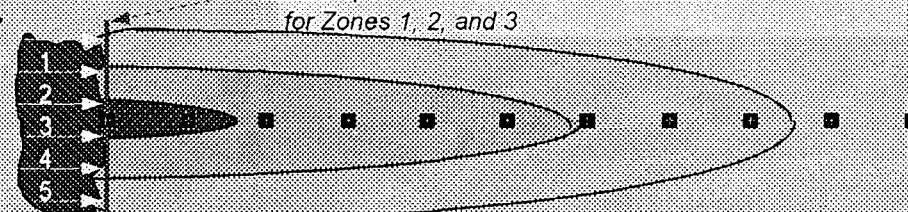
RUN ARRAY

View Output

Help

Recalculate This
Sheet

Paste Example Dataset

Restore Formulas for Vs,
Dispersivities, R, lambda, otherVertical Plane Source: Look at Plume Cross-Section
and Input Concentrations & Widths
for Zones 1, 2, and 3

View of Plume Looking Down

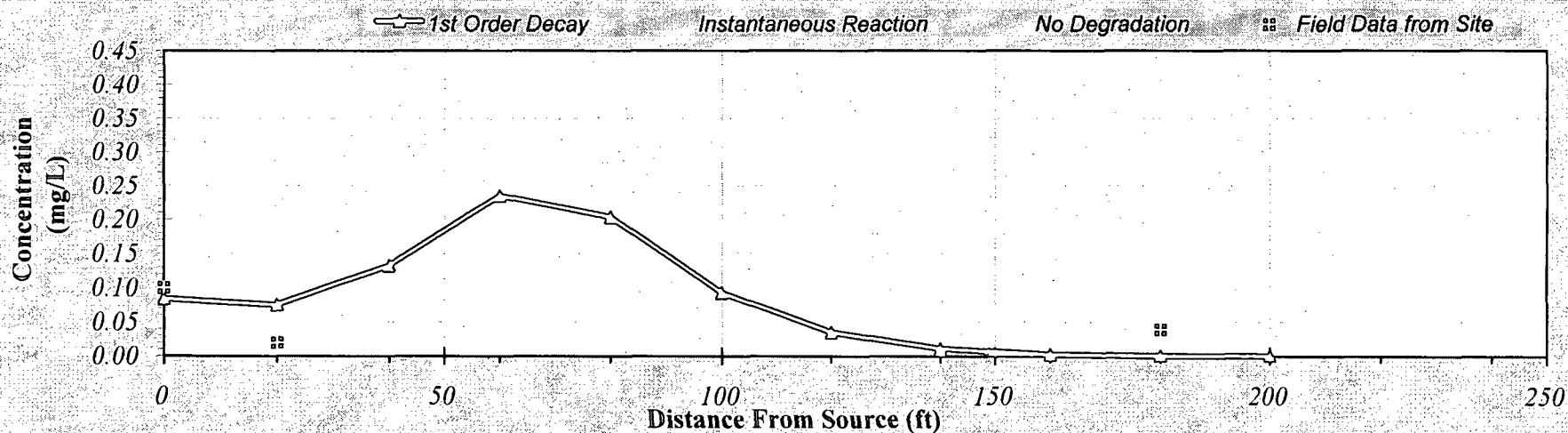
Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

Chloroform Pulse Simulation
3-year Travel Time

CHLOROFORM CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	20	40	60	80	100	120	140	160	180	200
No Degradation	0.084	0.092	0.195	0.401	0.388	0.192	0.077	0.025	0.006	0.001	0.000
1st Order Decay	0.084	0.075	0.132	0.235	0.204	0.093	0.035	0.011	0.003	0.001	0.000
Inst. Reaction	0.084	0.092	0.195	0.401	0.388	0.192	0.077	0.025	0.006	0.001	0.000
Field Data from Site	0.100	0.020								0.040	



Calculate
Animation

Time:

3.0 Years

Return to
Input

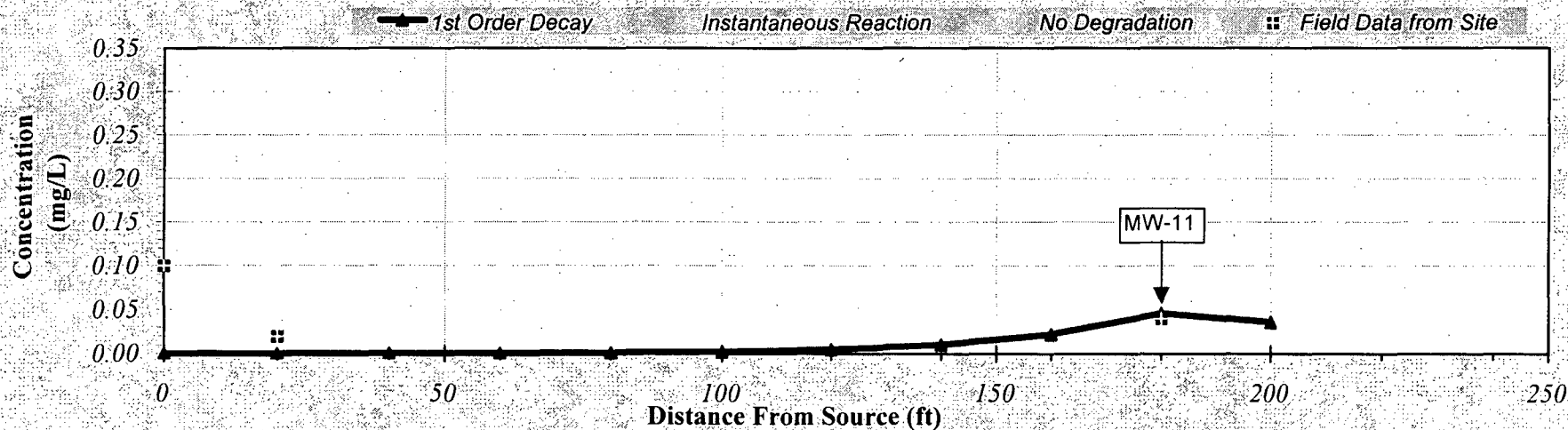
Recalculate This Sheet

Chloroform Pulse Simulation
8-year Travel Time with 40 ppb at MW-11

CHLOROFORM CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	20	40	60	80	100	120	140	160	180	200
No Degradation	0.000	0.000	0.000	0.001	0.003	0.008	0.021	0.055	0.137	0.323	0.287
1st Order Decay	0.000	0.000	0.000	0.000	0.001	0.002	0.005	0.011	0.022	0.046	0.036
Inst. Reaction	0.000	0.000	0.000	0.001	0.003	0.008	0.021	0.055	0.137	0.323	0.287
Field Data from Site	0.100	0.020								0.040	



Calculate
Animation

Time:

8.0 Years

Return to
Input

Recalculate This Sheet



LEGEND

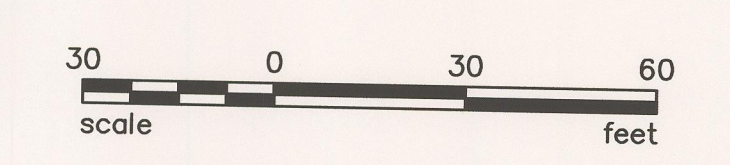
- PROPOSED GROUNDWATER MONITORING WELL
- PRODUCTION WELL LOCATION
- EXISTING SHALLOW MONITORING WELL LOCATION
- DEEP MONITORING WELL LOCATION
- STORMWATER INLET
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION
- SITE SECURITY FENCE
- 700
- 80
- NATURAL ATTENUATION MONITORING ZONE

NOTES

- MONITORING WELL LOCATIONS ARE APPROXIMATE. PROPOSED LOCATIONS ARE CONCEPTUAL AND SUBJECT TO REVIEW DURING REMEDIAL DESIGN.
- AREA IMPACTED BY ETHYLBENZENE INCLUDES AREA IMPACTED BY XYLENE ABOVE ITS MCL. (1997-1998 DATA)
- FENCE MAINTAINED AS INSTITUTIONAL CONTROL.

REFERENCE

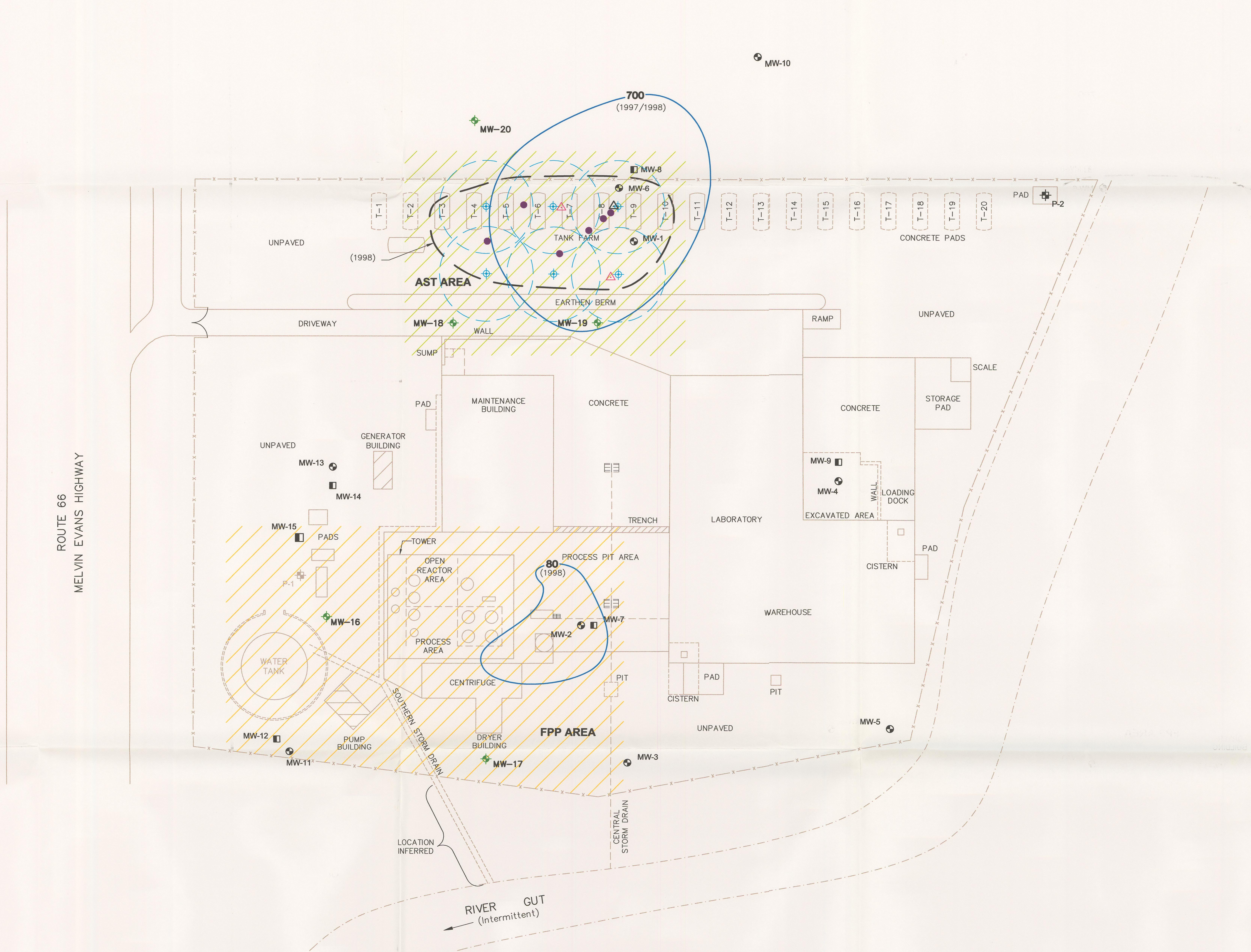
1.) DRAWING BASED ON FIGURE 3-7 OF THE R.I. REPORT ENTITLED "MONITORING WELL LOCATION MAP" DATED 1/11/99, AND FIGURE 4-3 OF THE DRAFT FINAL TREATABILITY STUDY WORKPLAN ENTITLED "PROPOSED PILOT SYSTEM LAYOUT MAP-AST AREA", DATED 3/5/99.



REV	DATE	DESCRIPTION	CAD BY	CHK BY	RVW BY
PROJECT: VIRGIN ISLAND CHEMICAL SITE ST. CROIX, U.S. VIRGIN ISLANDS					
SHEET TITLE: CONCEPTUAL REMEDIATION PLAN ALTERNATIVE NO. 2					
PROJECT No. 003-6016		FILE No.: US01-040			
CLIENT PROJ. No. SAS		DRAFTING SUBTITLE: 03			
DES BY SAS		SCALE: AS SHOWN			
CAD BY AM					
CHK BY BJB					
RVW BY SAS					

Golder Associates
Philadelphia USA

FIGURE 42



LEGEND

- EXISTING VAPOR MONITORING PROBE NESTS
- PROPOSED GROUNDWATER MONITORING WELL
- PRODUCTION WELL LOCATION
- EXISTING SHALLOW MONITORING WELL LOCATION
- DEEP MONITORING WELL LOCATION
- EXISTING SOIL VAPOR EXTRACTION WELL
- EXISTING AIR SPARGING WELL
- PROPOSED AIR SPARGING WELL
- STORMWATER INLET
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION
- SITE SECURITY FENCE
- SOIL AREA IMPACTED BY ETHYLBENZENE AND/OR XYLENE ABOVE SSLs (1998 DATA)
- SVE WELL APPROXIMATE AREA OF INFLUENCE
- 700 GROUNDWATER AREA IMPACTED BY ETHYLBENZENE ABOVE MCL (1997-1998 DATA)
- 80 GROUNDWATER AREA IMPACTED BY CHLOROFORM ABOVE 80 ppb (1998 DATA)
- NATURAL ATTENUATION MONITORING ZONE
- SVE/AS PERFORMANCE MONITORING ZONE

NOTES

- MONITORING WELL LOCATIONS ARE APPROXIMATE.
- SVE - SOIL VAPOR EXTRACTION
AS - AIR SPARGE
MNA - MONITORED NATURAL ATTENUATION
- FENCE MAINTAINED AS INSTITUTIONAL CONTROL.
- PROPOSED LOCATIONS ARE CONCEPTUAL AND SUBJECT TO REVIEW DURING REMEDIAL DESIGN.
- GROUNDWATER AREA IMPACTED BY ETHYLBENZENE INCLUDES AREA IMPACTED BY XYLENE ABOVE ITS MCL (1997-1998 DATA).

REFERENCE

1.) DRAWING BASED ON FIGURE 3-7 OF THE R.I. REPORT ENTITLED "MONITORING WELL LOCATION MAP" DATED 1/11/99, AND FIGURE 4-3 OF THE DRAFT FINAL TREATABILITY STUDY WORKPLAN ENTITLED "PROPOSED PILOT SYSTEM LAYOUT MAP-AST AREA", DATED 3/5/99.

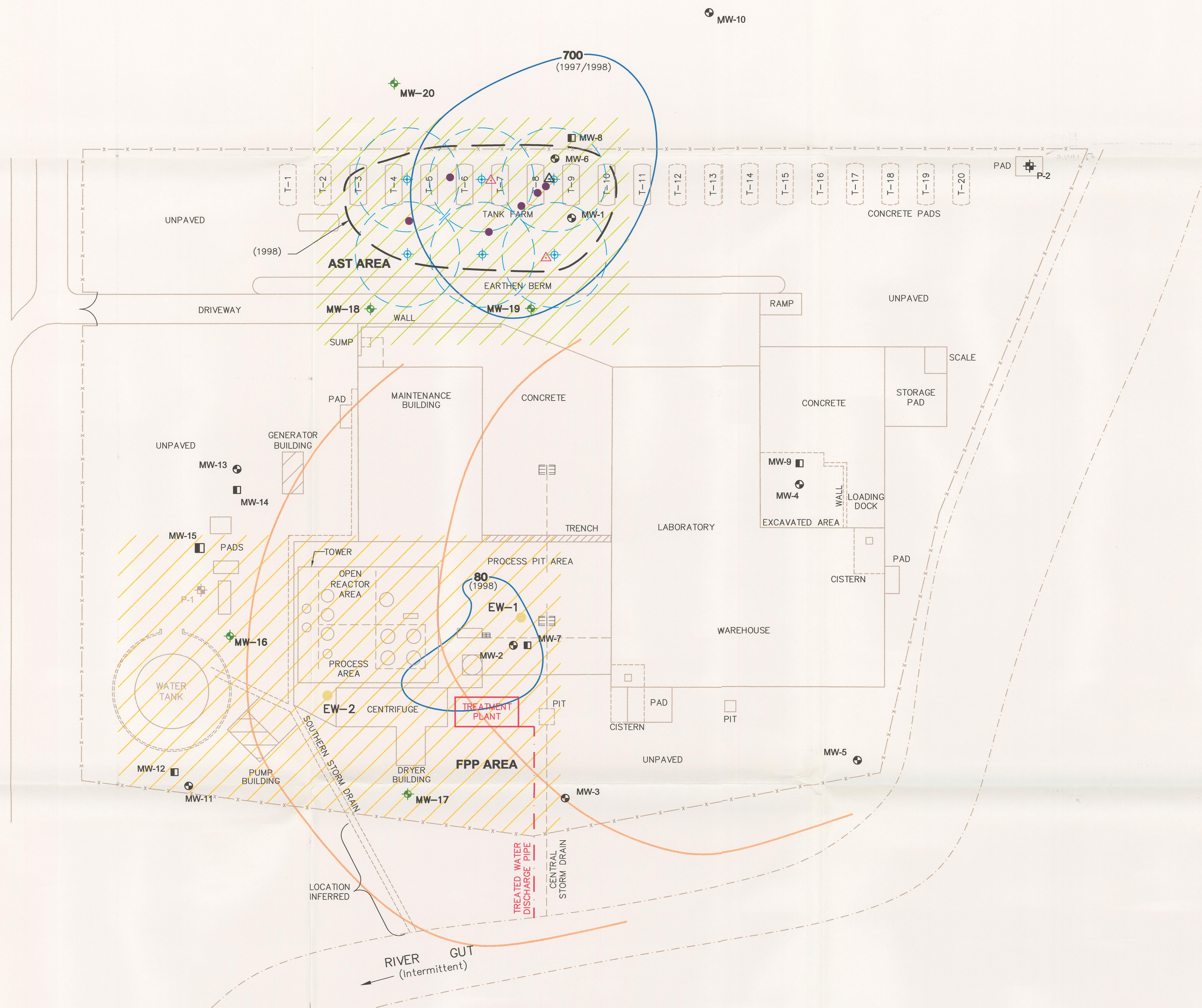


REV	DATE	DESCRIPTION	CAD BY	CHK BY	RVW BY
PROJECT: VIRGIN ISLAND CHEMICAL SITE ST. CROIX, U.S. VIRGIN ISLANDS					
SHEET TITLE: CONCEPTUAL REMEDIATION PLAN ALTERNATIVE NO. 3					
PROJECT No. 003-6016		FILE No.: US01-041			
CLIENT PROJ. No.		DRAFTING SUBTITLE: 03			
DES BY SAS 10/30/00		SCALE: AS SHOWN			
CAD BY AM 06/20/01					
CHK BY BJA 6/20/01					
RVW BY BJA 6/20/01					



FIGURE 43

ROUTE 66
MELVIN EVANS HIGHWAY



LEGEND

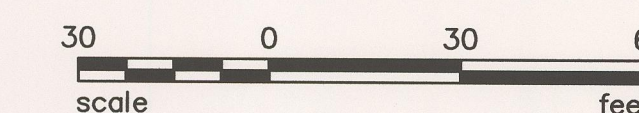
- EXISTING VAPOR MONITORING PROBE NESTS
- PROPOSED GROUNDWATER EXTRACTION WELL
- PROPOSED GROUNDWATER MONITORING WELL
- PRODUCTION WELL LOCATION
- EXISTING SHALLOW MONITORING WELL LOCATION
- DEEP MONITORING WELL LOCATION
- EXISTING SOIL VAPOR EXTRACTION WELL
- EXISTING AIR SPARGING WELL
- PROPOSED AIR SPARGING WELL
- STORMWATER INLET
- EXISTING ABOVEGROUND STORAGE TANK LOCATION
- FORMER ABOVEGROUND STORAGE TANK LOCATION
- SITE SECURITY FENCE
- SOIL AREA IMPACTED BY ETHYLBENZENE AND/OR XYLENE ABOVE SSLs
- APPROXIMATE AREA OF INFLUENCE OF EW
- SVE WELL APPROXIMATE AREA OF INFLUENCE
- 700
- 80
- GROUNDWATER AREA IMPACTED BY ETHYLBENZENE ABOVE MCL (1997-1998 DATA)
- GROUNDWATER AREA IMPACTED BY CHLOROFORM ABOVE 80 ppb (1998 DATA)
- NATURAL ATTENUATION MONITORING ZONE
- SVE/AS PERFORMANCE MONITORING ZONE

NOTES

- 1.) MONITORING WELL LOCATIONS ARE APPROXIMATE.
- 2.) FENCE MAINTAINED AS INSTITUTIONAL CONTROL.
- 3.) PROPOSED LOCATIONS ARE CONCEPTUAL AND SUBJECT TO REVIEW DURING REMEDIAL DESIGN.
- 4.) GROUNDWATER AREA IMPACTED BY ETHYLBENZENE INCLUDES AREA IMPACTED BY XYLENE ABOVE ITS MCL (1997-1998 DATA).

REFERENCE

- 1.) DRAWING BASED ON FIGURE 3-7 OF THE R.I. REPORT ENTITLED "MONITORING WELL LOCATION MAP" DATED 1/11/99, AND FIGURE 4-3 OF THE DRAFT FINAL TREATABILITY STUDY WORKPLAN ENTITLED "PROPOSED PILOT SYSTEM LAYOUT MAP-AST AREA", DATED 3/5/99.



REV		DATE	DESCRIPTION	CAD BY	CHK BY	RVW BY
PROJECT: VIRGIN ISLAND CHEMICAL SITE ST. CROIX, U.S. VIRGIN ISLANDS						
SHEET TITLE: CONCEPTUAL REMEDIATION PLAN ALTERNATIVE NO. 4						
PROJECT No. 003-6016			FILE No.: US01-042		DRAFTING SUBTITLE: 03	
CLIENT PROJ. No. 10/30/00			SCALE: AS SHOWN			
DES BY	SAS	10/30/00	FIGURE 44			
CAD BY	AM	06/20/01				
CHK BY	RTB	6/22/01				
RVW BY	PJL	6/22/01				



FIGURE 44

APPENDIX A
DETAILED COST INFORMATION

400140

**Table A-1
Cost Worksheet
Virgin Island Chemical Site
SVE/Air Sparging**

Activity	Unit Costs	Units	Quantity	Estimated Cost
ESTIMATED DIRECT CAPITAL COSTS				
Air Sparge/SVE				
Wells & Accessories				
Air Injection Wells (depth 50', 1" diameter, 2' screen)	\$3,888	per well	3	\$11,665
Pressure Gauge	\$120	per well	3	\$359
Flow Meter	\$844	per well	3	\$2,531
Body Check Valve	\$192	per well	3	\$577
Provision and Installation of all Fittings/Valves/Well Head Assemblies (15% of Well Costs)	\$756.61	per well	3	\$2,270
Protective Enclosure for Air Injection Wells	\$296	per well	3	\$889
SVE Well Modifications	\$625	per well	6	\$3,750
Below Ground Conveyance System				
Excavate Trench (1'x1')	\$16.56	CY	3	\$50
Backfill for Trench (1'x1')	\$25	CY	3	\$75
Geotextile to line Trench	\$0.26	SF	270	\$71
Piping (assume 2" PVC, Schedule 40, Connection Piping)	\$3.89	LF	90	\$350
2" PVC, 90 Degree Elbow	\$24.33	Each	3	\$73
Misc. conveyance pipe fittings - 15% of pipe and fittings cost	\$63.43	%	1	\$63
Mechanical & Controls				
Mechanical & Electrical Installation - 40% of Well & Accessory Cost	\$8,816.47	%	1	\$8,816
System Checkout & Cut off to Old System (20% Well & Accessory Cost)	\$2,075.25	%	1	\$2,075
Blowers & Treatment				
Blower (30.0 HP, 580 SCFM Vapor Extraction)	\$8,858	Each	1	\$8,858
Air Compressor for Air Sparging	\$14,184	Lump sum	1	\$14,184
General				
Mobilization/Demobilization for Drilling ⁽¹⁾	\$50,000	Lump Sum	1	\$50,000
TOTAL DIRECT CAPITAL COST				\$716,056
ESTIMATED INDIRECT CAPITAL COSTS				
Gen. Engineering Services (15%)	\$107,408	%	1	\$107,408
Permitting/Regulatory Coordination (3%)	\$21,482	%	1	\$21,482
Implement Health & Safety Plan (20%)	\$143,211	%	1	\$143,211
Construction Oversight/QA/QC (20%)	\$143,211	%	1	\$143,211
Contingency (30%)	\$214,817	%	1	\$214,817
O & M COSTS				
Soil Vapor Extraction/Air Sparging:				
O & M cost for 1 year (10%)	\$5,665.60	Year	1	\$5,666
Mobilization/Demobilization	\$10,000	Year	1	\$10,000
Analytical Testing - soil vapor, off-gas	\$7,500	Year	1	\$7,500
Trailer	\$3,210	Year	1	\$3,210
Utility Services (Gas/Electric)	\$42,000	Year	1	\$42,000

Notes and Assumptions:

1. Assume all drilling will occur under one mobilization and demobilization fee.
2. Cost estimate sources include Means (with 25% additional cost due to remote location), previous Golder projects, and vendor quotes

**Table A-2
Cost Worksheet
Virgin Island Chemical Site
Monitored Natural Attenuation**

Activity	Unit Costs	Units	Quantity	Estimated Cost
ESTIMATED DIRECT CAPITAL COSTS				
<u>Monitored Natural Attenuation</u>				
Monitoring Wells	\$2,350	Each	5	\$11,752
<u>General</u>				
Mobilization/Demobilization for Drilling ¹	\$50,000	Lump Sum	1	\$50,000
ESTIMATED INDIRECT CAPITAL COSTS				
Gen. Engineering Services (15%)	\$99,262.79	%	1	\$99,263
Permitting/Regulatory Coordination (3%)	\$19,852.56	%	1	\$19,853
Implement Health & Safety Plan (20%)	\$132,350.38	%	1	\$132,350
Construction Oversight/QA/QC (20%)	\$132,350.38	%	1	\$132,350
Contingency (30%)	\$198,525.57	%	1	\$198,526
<u>Monitored Natural Attenuation</u>				
Mobilization/Demobilization	\$10,000	Year	1	\$10,000
IDW Disposal	\$300	Well/Year	15	\$4,500
<u>Monitored Natural Attenuation - Annual Sampling</u>				
Annual Sampling - unit cost one round of sampling	\$1,913	Well	15	
-Year 1, quarterly: Present Worth (1 yr @ 7%)	\$28,688	Round	4	\$107,000
-Years 2-3, semi-annually, Present Worth (2 yrs @ 7%)	\$28,688	Round	2	\$97,000
-Years 4-15, annually, Present Worth (12 yrs @ 7%)	\$28,688	Round	1	\$186,000
PRESENT WORTH Annual Sampling				\$390,000
<u>Monitored Natural Attenuation</u>				
O & M COSTS One Time - Yr Seven				
Well Rehabilitation	\$800	Well	15	\$12,000

Notes and Assumptions:

1. Assume all drilling will occur under one mobilization and demobilization fee.

Table A-3
Cost Estimate
Focused Feasibility Study
Pump & Treat
(Extraction from Shallow Aquifer, Air Stripping, and Discharge to River Gut)

Activity	Unit Costs	Units	Quantity	Estimated Cost
ESTIMATED DIRECT CAPITAL COSTS				
<u>Mobilization/DeMobilization</u>				
For Drilling	\$50,000	Lump Sum	1	\$50,000
<u>Wells</u>				
Extraction Well	\$6,250	Each	2	\$12,500
Submersible pump plus spares	\$2,000	Each	4	\$8,000
Pitless adapter	\$2,065	Each	2	\$4,130
Pressure Transducer and Indicating Transmitter plus spares	\$1,400	Each	4	\$5,600
Flow Meter	\$675	Each	2	\$1,350
Leak Detection System	\$10	LF	250	\$2,500
Monitoring Well	\$7,000	Each	2	\$14,000
<u>Electrical</u>				
Electrical vaults - 3' by 3'	\$4,675	Each	1	\$4,675
Mechanical / electrical installation	\$15,000	Lump Sum	1	\$15,000
Control panel	\$1,000	Each	1	\$1,000
Monitoring panel	\$120	Each	1	\$120
Control wiring and 1" to control Panel	\$8.69	LF	20	\$174
Electrical wiring in 2" conduit to Monitoring panel	\$8.688	LF	200	\$1,738
conduit affixtures 25% cost of conduits	\$477.83	Lump Sum	1	\$478
Power distribution (new breaker and service)	\$10,000	Lump Sum	1	\$10,000
New phone service inc. autodialer	\$5,000	Lump Sum	1	\$5,000
<u>Conveyance</u>				
1" Polypropylene Pipe	\$4.46	LF	250	\$1,116
Misc. conveyance pipe fittings - 15% of pipe and fittings cost	\$167.34	Lump Sum	1	\$167
Trench excavation (1 ft wide by 1 ft high)	\$16.56	cy	2625	\$43,470
Place and spread excavated soil	\$9.00	cy	2625	\$23,625
Clean backfill, compacted in trench (pea gravel)	\$25.00	cy	2625	\$65,625
Geotextile used in trench as separation	\$0.26	sf	750	\$195
<u>Treatment Setup</u>				
10,000 gallon holding tank	\$8,899	Each	1	\$8,899
Steel Dike for tank	\$9,769	Each	1	\$9,769
Misc. holding tank fittings (30% of tank cost)	\$2,669.63	%	1	\$2,670
Air Stripper with Blower (no air control)	\$15,000	Each	1	\$15,000
Discharge Permits/Applications	\$10,000	Lump Sum	1	\$10,000
TOTAL DIRECT CAPITAL COST				\$316,799
O & M COSTS				
Mobilization/Demobilization	\$10,000	Year	1	\$10,000
Pavement Inspection/Repairs	\$5,000	Year	1	\$5,000
GW Extraction Well Maintenance and System Balancing	\$22,000	Year	1	\$22,000
Monitoring - GW sampling, off-gas sampling, water levels, flow rates	\$75,000	Year	1	\$75,000
Air Stripper & Blower Maintenance	\$10,000	Year	1	\$10,000
Treatment/Annual Discharge Fees	\$0	Year	1	\$0
Permits	\$1,000	Year	1	\$1,000
Utilities (electric, phone)	\$5,000	Year	1	\$5,000
Paint tank/Repairs	\$1,667	year	1	\$1,667
Startup Systems (5% equipment cost)	\$8,800	Each	1	\$8,800

Notes and Assumptions:

1. Assume all drilling will occur under one mob/demob fee.
2. Cost estimate sources include Means (with 25% additional cost due to remote location), previous Golder projects, and vendor quotes

APPENDIX B

EPA PRESUMPTIVE REMEDY GUIDANCE



Presumptive Remedies: Site Characterization and Technology Selection For CERCLA Sites With Volatile Organic Compounds In Soils

Office of Emergency and Remedial Response
Hazardous Site Control Division 5203G

Quick Reference Fact Sheet

Since Superfund's inception in 1980, the remedial and removal programs have found that certain categories of sites have similar characteristics, such as types of contaminants present, types of disposal practices, or how environmental media are affected. Based on information acquired from evaluating and cleaning up these sites, the Superfund program is undertaking an initiative to develop presumptive remedies to accelerate future cleanups at these types of sites. The presumptive remedy approach is one tool of acceleration within the Superfund Accelerated Cleanup Model (SACM).

Presumptive remedies are preferred technologies for common categories of sites, based on historical patterns of remedy selection and EPA's scientific and engineering evaluation of performance data on technology implementation. The objective of the presumptive remedies initiative is to use the program's past experience to streamline site investigation and speed up selection of cleanup actions. Over time presumptive remedies are expected to ensure consistency in remedy selection and reduce the cost and time required to clean up similar types of sites. Presumptive remedies are expected to be used at all appropriate sites except under unusual site-specific circumstances.

This directive identifies the presumptive remedies for Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites with soils contaminated by *volatile organic compounds (VOCs)*. In addition, EPA is developing guidance on presumptive remedies for wood treatment, municipal landfill, PCB, grain storage, coal gasification, and contaminated ground-water sites. EPA has also developed a directive entitled *Presumptive Remedies: Policy and Procedures*, (Directive 9355.0-47FS) which outlines and addresses the issues common to all presumptive remedies (e.g., role of *innovative technologies*, consistency with the NCP, State, community involvement).

PURPOSE

The purpose of this directive is to provide guidance on selecting a presumptive remedy at sites with soils contaminated with VOCs. Specifically this guidance:

- Presents the presumptive remedies for this site type;
- Describes the presumptive remedy process in terms of site characterization and technology screening steps; and
- Outlines the data required to select these presumptive remedies.

Since a presumptive remedy is a technology that EPA believes, based upon its past experience, generally will be the most appropriate remedy for a specified type of site, the presumptive remedy approach will accelerate

site-specific analysis of remedies by focusing the feasibility study efforts. Where several presumptive remedies are identified, EPA believes that all deserve substantial consideration before utilizing the presumptive remedy approach. EPA personnel should review the directive entitled *Presumptive Remedies: Policy and Procedures* (Directive 9355.0-47FS) for general information on the presumptive remedy process.

Soil vapor extraction (SVE), thermal desorption, and incineration are the presumptive remedies for Superfund sites with VOC-contaminated soil assuming the site characteristics meet certain criteria. Table 1 provides a brief description of each of these presumptive remedies.

The decision to establish these technologies as presumptive remedies for this site type is based on EPA's collective knowledge about site investigation and remedy selection for VOC-contaminated soils.

TABLE 1
Presumptive Remedies for VOCs
in Soil

Soil Vapor Extraction - Soil vapor extraction (SVE) is an in-situ or ex-situ process which physically removes contaminants from *vadose zone* soils by inducing air flow through the soil matrix. The flowing air strips volatile compounds from the solids and carries them to extraction wells. The recovered vapors may require further treatment. In-situ SVE is the primary focus of this document.

Thermal Desorption - Thermal desorption is an ex-situ process that uses direct or indirect heat exchange to vaporize organic contaminants from soil, sediment, sludge or other solid and semisolid matrices. The vapors are then condensed or otherwise collected for further treatment.

Incineration - Incineration is an ex-situ engineered process that employs thermal decomposition via oxidation at temperatures usually greater than 900 °C to destroy the organic fraction of the waste.

The major difference between thermal desorption and incineration is that incineration oxidizes organic compounds, thereby destroying the hazardous material. Thermal desorption volatilizes contaminants, then concentrates them. Thermal desorption reduces the volume of contamination, but the concentrated waste stream still requires treatment. Disposal or treatment of residual waste stream, ash, and concentrated VOC effluent is not covered by this directive. Options such as off-site disposal/regeneration or reuse should be considered.

including field experience from the Superfund, Resource Conservation and Recovery Act (RCRA), and Underground Storage Tank (UST) programs. In addition, EPA conducted an analysis of FY86 to FY91 Records of Decision (RODs) for sites where VOC contamination drove remedy selection. The results of this analysis, which are provided in Appendix A, demonstrate that these three technologies represent over 90% of the remedies selected in the RODs analyzed.

USE OF DOCUMENT

This directive is primarily intended for use by Superfund site managers. However, site managers in other programs (such as RCRA corrective action, the UST program, States), and the private sector, may also use this directive.

This directive is not a "stand alone" document. To ensure a full understanding of VOC site characterization and remedy selection, site managers should refer to all documents cited in the directive. For assistance in understanding complex site conditions, an experienced site manager, the presumptive remedy expert team, the Superfund Technical Assistance and Response Team (START) team, or the Environmental Response Team should be consulted.

ANTICIPATED BENEFITS OF PRESUMPTIVE REMEDIES

Use of this directive will reduce cost and time in remedy selection at VOC sites in the following ways:

1. The directive facilitates identification of the presumed or likely remedial options early in the investigation process, hence allowing for a more focused collection of data during the remedial investigation (RI) or removal site evaluation. In addition, knowledge of the presumptive remedy may facilitate collection of some remedial design data before the ROD or action memo, thereby allowing the action to proceed more quickly after signature of the decision document.
2. This directive eliminates the need for the initial step of identifying and screening a variety of alternatives during the Feasibility Study. Additionally, it will reduce the number of technologies identified and analyzed in the EE/CA. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (Section 300.430(e)(1)) states that "the lead agency shall include an alternatives screening step, when needed, (emphasis added) to select a reasonable number of alternatives for detailed analysis." EPA's analysis of feasibility studies for VOC-contaminated soil sites (see Appendix A) found that certain technologies are routinely screened out based on effectiveness, implementability, or excessive costs, consistent with NCP Section 300.430(e)(7). Accordingly, EPA has determined that, when using presumptive remedies at VOC-contaminated sites, site-specific identification and screening of alternatives is not necessary. However, this directive and supporting documentation (see "Feasibility Study Analysis for CERCLA Sites with Volatile Organic Compounds in Soils") should be included in the Administrative Record for all sites that use the presumptive remedy(ies) to document the basis for eliminating the "site-specific identification and

TABLE 2
Typical VOCs Addressed by this
Directive

Halogenated Volatile Organics

Carbon Tetrachloride
Chlorobenzene
Chloroethane
Chloroform
1,1-Dichloroethane
1,1-Dichloroethylene
1,2-Dichlorobenzene
1,2-Dichloroethane
1,2-Dichloroethylene
1,2-Dichloropropane
1,4-Dichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
Ethylene Dibromide
Methylene Chloride
Tetrachloroethylene
Trichloroethylene
Vinyl Chloride

Non-Halogenated Volatile Organics

Ketones/Furans

Acetone
Methyl Ethyl Ketone
Methyl Isobutyl Ketone

Aromatics

Benzene
Ethyl Benzene
Styrene
Toluene
m-Xylene
o-Xylene
p-Xylene

Note: Other compounds that have physical/chemical characteristics similar to the compounds listed may also be addressed by the presumptive remedy process.

screening of technologies" section. In addition, other supporting materials (e.g., FS reports included in the analysis, technical reports) will be made available at EPA Headquarters and are available for inclusion in the Administrative Record if needed.

3. This directive streamlines the detailed analysis portion of the FS. Remedial alternatives developed for a site must be evaluated against the nine criteria (required under NCP Section 300.430(e)(9)). Under this

presumptive remedy approach, the detailed analysis can be limited to the three presumptive remedies (in addition to the no-action alternative), thereby streamlining that portion of the FS. Appendix B provides a generic evaluation of the presumptive remedies for seven of the nine criteria. This evaluation may serve as a basis for each detailed analysis conducted under the presumptive remedy process and should be augmented, as needed, to address site-specific conditions.

One of these presumptive remedies is expected to be used for all VOC sites except under unusual circumstances. Such circumstances may include unusual site soil characteristics, demonstration of significant advantages of alternate (or other innovative) technologies over the presumptive remedies, or extraordinary community and state concerns. If such circumstances are encountered, additional analyses may be necessary or a more conventional detailed RI/FS may be performed.

PRESUMPTIVE REMEDIES PROCESS

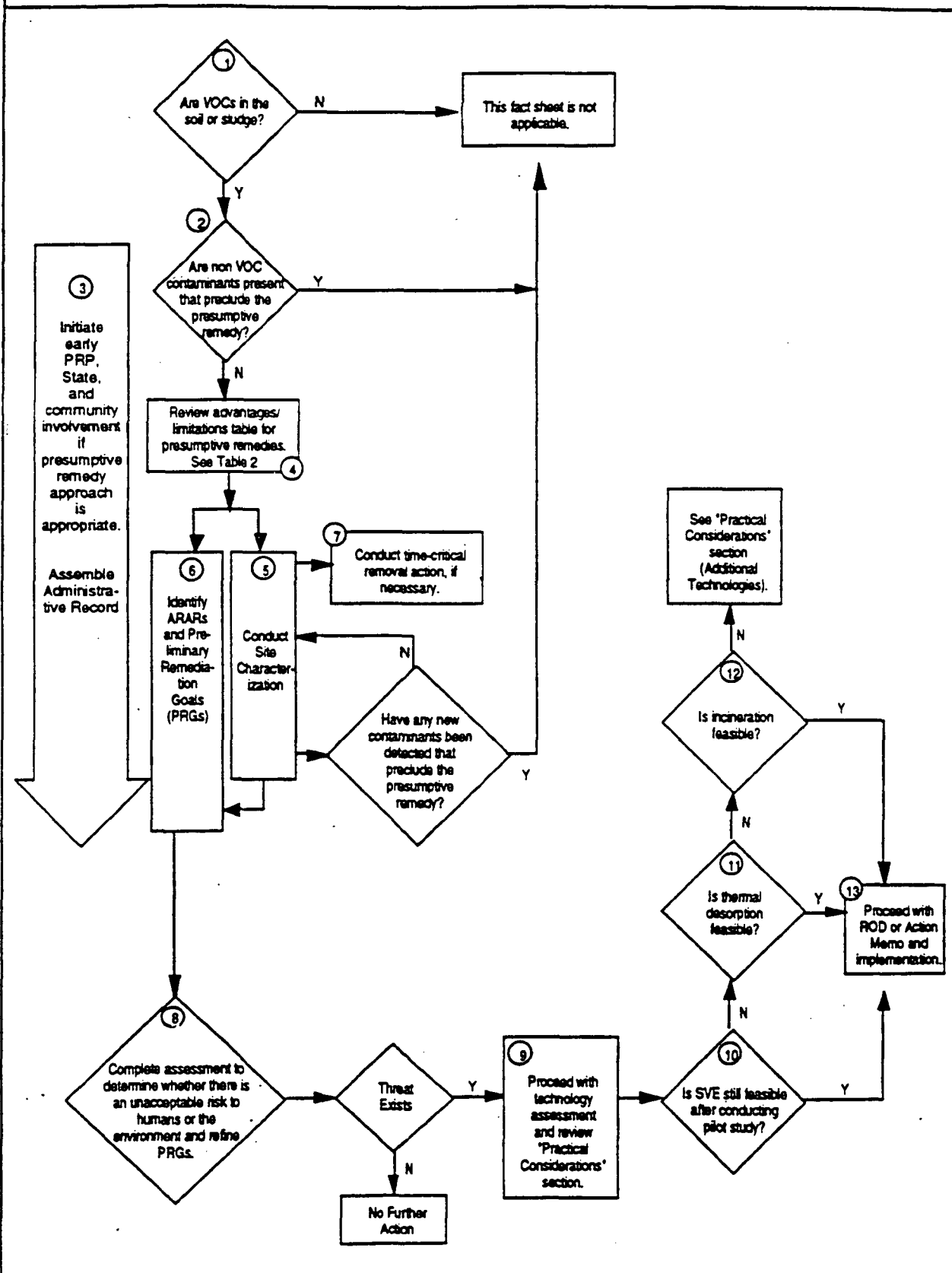
This section and the accompanying diagram (Figure 1) describe the sequence of steps involved in the presumptive remedy process (site characterization and technology selection) for sites containing soil contaminated with VOCs. While the process is not mandatory, EPA believes that following the steps outlined below will expedite the clean-up process for this category of sites.

SVE is the primary presumptive remedy. SVE has been selected most frequently to address VOC contamination at Superfund sites and initial performance data indicate that it effectively treats waste in place at a relatively low cost. In cases where SVE will not work or where there is very highly concentrated contamination, thermal desorption may be the more appropriate response technology. In a limited number of situations, incineration may be more appropriate.

The numbered paragraphs below correspond to the numbered steps in Figure 1 and provide a detailed discussion of each step.

1. *Are VOCs Present in the Soil?* The first step is to determine whether VOCs are the major contaminant present in soil at the site. Table 2 lists the VOCs that are amenable to the presumptive remedies outlined in this directive. If VOCs are present at levels of concern (see forthcoming guidance on soil screening levels), then the presumptive remedies outlined in this directive may be applicable. However, if it is confirmed (at this point or at any later point during the presumptive remedy process) that there are no VOCs present in the soil, then this directive is not applicable for use in technology selection at the site.

FIGURE 1
Decision Tree for Investigating and Selecting a Remedy at Solvent Sites



Most likely, this analysis will occur during scoping of the RI/FS or EE/CA. However, there may be only limited information available at that time about the site. Therefore, whatever information is available should be used to determine whether VOCs are present or suspected in the soil based on prior use. Chemical use at a site can be ascertained from a number of sources such as facility records, previous sampling efforts by local or State agencies or through Information Request letters.

2. *Are Non-VOC Contaminants Present That Preclude the Use of Presumptive Remedies?* In addition to determining whether VOCs are present in the soil, it is also necessary to identify other non-VOC contaminants, if any, present in the soil.

The site characterization and technology selection procedures outlined in this directive are recommended for use primarily on soil containing VOCs only. See Table 2 for VOCs that are amenable to the presumptive remedies.

For sites containing a mixture of VOCs and other contaminants in soil, the presumptive remedies should be considered only if they can also be effective in removing the non-VOC contaminants or combined with other, non-presumptive remedies in a treatment train, assuming the presumptive remedies do not exacerbate the problems presented by the non-VOCs. For example, sites with VOCs and metals commingled in soil may be effectively remediated by employing SVE to remove VOCs followed by fixation or solidification to address the metal contamination. In contrast, a VOC and polyaromatic hydrocarbons (PAHs) contaminant combination may be treated more appropriately with a single biological treatment scheme that would be effective for both the VOCs and PAHs. Note that sites containing mixtures of VOCs and non-VOCs are varied, and, for this reason, remedy selection may be more complicated than the framework presented in this directive; therefore, the presumptive remedy analysis may need to be supplemented or modified on a site-specific basis.

3. *Initiate Early Community, State, and Potentially Responsible Party (PRP) Involvement.* As early in the clean-up process as possible, EPA should notify the community, State, and any PRPs that a presumptive remedy is being considered for the site. It is important for all stakeholders to understand completely how the presumptive remedy process varies from the usual clean-up process and the benefits of using the presumptive remedies process.

Early identification of State applicable or relevant and appropriate requirements (ARARs) also is a critical part of this process. Because the presumption set forth in this directive is national in scope, it does

not take into account State ARARs. For this reason, State ARARs relating to the presumptive remedies should be considered on a site-specific basis. Regions may want to supplement this directive by compiling the requirements of the States in their Regions that are likely to be associated with the use of the presumptive remedies and placing them in the administrative record for a site where presumptive remedies are being considered. This directive along with the "Feasibility Study Analysis for CERCLA Sites with Volatile Organic Compounds in Soils" should be included in the administrative record for the site if one of the presumptive remedies is proposed for a particular VOC-contaminated site.

4. *Review Advantages/Limitations of the Presumptive Remedies.* During initial site characterization, Table 3 should be reviewed to consider the advantages and limitations of the presumptive remedies. This information may be useful in preparing for and/or modifying the site characterization or alternatives analysis process. The "Practical Considerations" section of this directive should also be reviewed at this time to ensure a comprehensive site characterization and remedy evaluation.

5. *Conduct Site Characterization.* Site characterization for sites using VOC presumptive remedies should be designed to:

- Positively identify the site type (i.e., VOC site);
- Obtain data to determine whether the presumptive remedy is feasible for the site;
- Focus (and possibly streamline) site characterization by collecting data to support the selection of presumptive remedy(ies) only (e.g., volume and cost information); and,
- Collect some design data (i.e., pilot studies to determine radius of influence and flow rates of SVE), thereby streamlining data collection during the remedial design stage.

Table 4 lists the data that are required for characterization of sites with soil contaminated with VOCs. This table also includes the rationale for collecting these data and references for established collection methods. Note that bench-scale and pilot/treatability studies should be performed whenever possible concurrent with site characterization to define the parameters that will be important to designing the system.

In areas with low organic content soil (e.g., alluvial basins), or where there are impediments to obtaining soil samples (e.g., under buildings), soil gas sampling

is highly recommended as a site characterization technique. In addition, the use of soil gas sampling during implementation of SVE and confirmatory soil sampling afterward is less expensive than constantly installing new soil borings, especially for deep contamination.

If incineration or thermal desorption is under serious consideration, bench-scale treatability studies may be conducted, especially if metals or other inorganic compounds are present. Thermal desorption generally should be considered if concentrations of VOCs are less than 5 to 10 percent; incineration may be appropriate if VOC concentrations exceed 5 to 10 percent. Note that excavation and mixing of soil can produce a desorber input of less than 10 percent contaminant concentration and allow thermal desorption to be chosen.

Additionally, the feasibility of excavation should be determined by evaluating surface conditions and depth of contaminants as well as the potential for any air emissions associated with the excavation. Test digs should be monitored closely to assure protection of the public and the environment.

It is important to note that during the site characterization, the volume and concentration of waste constituting the principal threats at the site should be identified. The NCP (Section 300.430(a)(1)(iii)(A) and *A Guide to Principal Threat and Low Level Threat Wastes*, Superfund Publication: 9380.3-06FS, November 1991, define principal threats as source materials, including liquids, that are highly toxic or highly mobile wastes which generally cannot be reliably contained or would present a significant risk to human health and or environment should exposure occur. In accordance with NCP expectations, waste constituting "principal threats" posed by a site generally are expected to be treated. The site manager is encouraged to characterize the site in terms of principal and low-level threat areas to determine materials to be targeted for treatment and containment.

6. *Identify Potential ARARs, To Be Considered (TBCs), and Preliminary Remediation Goals (PRGs).* Potential Federal and State ARARs and pertinent TBCs information should be identified on a chemical-, location-, and action-specific basis concurrent with site characterization. For a more detailed ARARs discussion, refer to the various ARARs fact sheets. (See *Compendium of CERCLA ARARs Factsheets and Directives*, EPA Publication 9347.3-15, October 1991).

At this step, PRGs should also be identified (NCP Section 300.430(e)(2)(c)). Note that different health

risk-based PRGs are often set for soils, depending on depth. Shallow soil levels are usually based both on direct contact exposure and protection of ground water, while levels for deeper soils are generally based only on mass transport modeling of effects on ground water. Ecological effects may also be important to consider in setting PRGs.

7. *Conduct Time-Critical Removal Action (if necessary).* During initial site characterization, data will be gathered to determine whether a time-critical removal action will be needed and to determine whether the contaminants present are amenable to the presumptive remedies. Time-critical removal actions, such as drum removal or actions addressing highly contaminated (typically small volumes) of soil, should be conducted in accordance with current guidance and regulations. The decision to take a time-critical removal action may be made by the Regional Decision Team (RDT) or if time does not permit, by an On-Scene Coordinator (OSC) or a Remedial Project Manager (RPM) in consultation with an OSC.
8. *Is There a Threat Posed by the Site?* A risk assessment must be conducted to determine if a sufficient health or environmental threat exists to warrant a removal or remedial action. (Refer to *Risk Assessment Guidance for Superfund, Volumes I and II*, EPA/540/1-89/002 and EPA/540/1-89/001). Where it is determined that such a threat exists, site-specific exposure data can be used to modify the PRGs identified in Step 6 (NCP Section 300.430(e)(2)(i)). If it is determined that such a threat does not exist, no further action at the site will be required.
9. *Proceed With Technology Assessment and Review "Practical Considerations" section.* If the analysis described in step 8 confirms that the contaminants are a threat to human health and/or the environment, a proposed remedy should then be identified.

If this project is a remedial action, a detailed analysis using the nine criteria will be required under NCP Section 300.430(e)(9)) to justify the selection of remedy decision. Appendix B provides an analysis of SVE, thermal desorption, and incineration against seven of the nine selection criteria. In addition to the seven criteria discussed in Appendix B, community, and State acceptance must also be evaluated. If a non-time critical removal action is planned, the streamlined analysis described in the EE/CA guidance will be required that uses the three criteria of effectiveness, implementability, and cost. During the technology assessment, the factors listed in the "Practical Considerations" section of this directive should be reviewed to ensure a comprehensive evaluation of alternatives.

10. *Does the Pilot/Treatability Study Indicate that SVE is Feasible?* SVE is the primary presumptive remedy. Pilot/treatability study testing of SVE should be conducted prior to final remedy selection. Such testing will provide information on the rate of removal of contaminants. EPA/540/2-91/091A cited in the References section of this directive provides guidance on conducting the pilot/treatability study. Removal efficiencies and treatment effectiveness must be carefully considered alongside the PRGs identified in the FS to estimate the potential for successful remedial action using SVE.

11. *Is Thermal Desorption Feasible?* If SVE will not be sufficiently effective in achieving PRGs due to low permeability, lithology or insufficient removal of contamination during the pilot study, thermal desorption should be considered as the primary ex-situ presumptive remedy.

Thermal desorption technologies cover a variety of vendors and processes. However, ample data are available to substantiate remedy selection of thermal desorption for soil contaminated solely with VOCs.

12. *Is Incineration Feasible?* If contaminant concentrations and bench-scale testing indicate thermal desorption will not achieve desired PRG levels, incineration is the second ex-situ presumptive remedy.

If incineration is planned, and a substantial number of inorganic contaminants are expected to be present based on site characterization data, materials handling problems, or slagging problems are likely.

If none of the three presumptive remedies is considered to be feasible at a particular site, it will be necessary to consider other technologies. (For more information, refer to the Practical Considerations section below.)

13. *Select Remedy for Remedial/Removal Action.* At this point, there should be enough data to identify a preferred remedy in the proposed plan and distribute the plan for public comment. Once the remedy has been selected in the ROD, the user can proceed to do a limited design which relies largely on the substantial amount of design-related data collected during the RI. The extent of additional or supplemental data required will be determined on a site-specific basis.

Practical Considerations

The following factors should be considered prior to taking any remedial action.

Enforcement: This directive applies to fund-lead sites as well as to sites where a PRP is conducting the investigation and/or response action. In the event that there is an

ongoing PRP-lead RI/FS, the scope of work may be amended to reflect the presumptive remedy approach to site characterization and remedy selection. The potential savings in time and money to be gained by using the presumptive remedy approach are expected to outweigh the burden of modifying the scope of work in many cases.

Initial Site Actions: If the VOC material is still in original, intact containers, it may be returned to the manufacturer (if the manufacturer is willing to accept these containers), assuming this response is a cost-effective and feasible action as opposed to treating the material. Reuse of material (i.e., process liquids and relocation of equipment to other permitted facilities) should also be considered. Further, phase separation should be conducted and recycling considered depending on the purity of the recovered phase or for any existing liquids that are high enough in concentration. Refer to Appendix C for a list of the currently recognized waste exchanges.

Site Characterization: Site characterization should proceed as a single, multi-media activity whenever possible. Field screening methods should be integrated into the sampling and analysis plan in order to accelerate information gathering. Data quality must reflect the ultimate use of the information.

Ground Water: The decision maker should consider the ground-water strategy for the site since soil clean-up levels are often set to protect ground-water quality. Therefore, ground-water clean-up levels may have a direct impact on the selected clean-up levels for soil. (See forthcoming guidance on Soil Screening Levels and the directive entitled *Presumptive Remedies: Remedial Strategy and Treatment Technologies for CERCLA Sites with Contaminated Ground Water*.) It should be noted that, of the VOC-type contaminants, listed in Table 2, the halogenated volatiles are dense nonaqueous phase liquids (dense NAPLs or DNAPLs) and many of the others are light NAPLs (LNAPLs) in their pure liquid form. If LNAPLs are present, it may be possible to address them by lowering the water table, removing free product (if present), and applying SVE. To address DNAPLs contamination, refer to the above mentioned ground-water guidance.

Management of Different Soils: A situation may arise where highly contaminated shallow material cannot be addressed by SVE. The action to address this contamination may differ from the rest of the soil contamination and will most likely involve incineration or thermal desorption. If it is suspected that soil contamination existing at greater depths will also be treated in this manner, then the excavated shallow material should be staged and stored in order to treat it with the deep material.

Another situation may arise where VOCs are mixed with metals, and none of the presumptive remedies can address both sets of contaminants. The action to address this situation may consist of a treatment train where VOCs are

addressed through SVE or thermal desorption and the metals are addressed through fixation.

Finally, the site manager should be aware of situations where a mixture of principal and low-level threat wastes call for the use of treatment (i.e., SVE or thermal treatment) of principal threat waste and containment (capping) of low-level contamination. (See *A Guide to Principal Threat and Low-Level Wastes* in Reference Section).

Off-Site Disposal: In general, it may not be cost-effective to ship quantities of contaminated soil in excess of 5,000 cubic yards for off-site disposal. For this reason, pretreatment of soil and water may be required prior to shipment or discharge to another treatment facility.

Capping: Capping alone is not recommended to control the migration of VOCs. However, capping can improve the effectiveness of SVE by decreasing the rate of infiltration of residual VOCs through the vadose zone into the ground water as well as possibly increasing the radius of influence and preventing "short circuiting" of air pathways in the vicinity of the extraction well. Capping can also be used to address non-principal threat waste unless it is more cost-effective to treat this waste along with more highly contaminated materials.

Patents: SVE is a patented technology. Royalty payments may be required under certain conditions of implementation.

Attainment of Remediation Goals: It should be noted that, like other in-situ technologies, it is difficult to ascertain with confidence whether SVE will attain remediation goals until the action is actually implemented.

However, the lower cost and ease of SVE implementation will often weigh heavily in its favor, as long as protection of human health and the environment is ensured.

Additional Technologies: If for some reason none of the presumptive remedies is applicable to a particular site, the site manager is encouraged to refer to EPA's forthcoming document entitled *Contaminants and Remedial Options at Solvent Sites* for a discussion of additional VOC treatment technologies. It should be noted that this comprehensive document, which identifies additional VOCs and technologies, may be appropriate to consider on a site-specific basis.

Thermal Treatment Technologies: The site manager should refer to EPA's Draft Strategy for Combustion of Hazardous Waste (May 18, 1993) when considering any thermal treatment technologies at a particular site.

Conclusion

For sites containing VOC-contaminated soil and appropriate soil characteristics, SVE is a relatively inexpensive and efficient technology. If material needs to be excavated, thermal desorption is preferred. In a few cases, incineration may be the most appropriate remedy - for example, where SVE and thermal desorption will not meet clean-up criteria based on contaminant concentrations or composition.

As remedies other than SVE, thermal desorption and incineration become more widely used in the future, this directive may be modified to reflect these trends. For further assistance on presumptive remedy related activities consult the Regional Presumptive Remedies contact.

Notice:

The policies set out in this document are intended solely as guidance to the U.S. Environmental Protection Agency (EPA) personnel; they are not final EPA actions and do not constitute rulemaking. These policies are not intended, nor can they be relied upon, to create any rights enforceable by any party in litigation with the United States. EPA officials may decide to follow the guidance provided in this document, or to act at variance with the guidance, based on an analysis of specific site circumstances. EPA also reserves the right to change this guidance at any time without public notice.

TABLE 3
Comparison of Technologies for VOC Sites

	PERFORMANCE ⁽¹⁾	ADVANTAGES	LIMITATIONS	COSTS ⁽¹⁾
Soil Vapor Extraction	Can be as high as 99% removal of VOC contaminants but is typically lower than other technologies with range of 85-99%	• High level of effectiveness in removing VOCs. • Relatively inexpensive. • Little site disturbance; no excavation required. • Effective for waste under buildings or other construction.	• Soil that is tight or has high moisture content (>50%) has a reduced permeability to air, hindering the operation of SVE. • Soil with a high degree of heterogeneity has highly variable permeabilities, resulting in uneven delivery of gas flow to the contaminated regions, which in turn reduces removal rates by SVE. • Soil with high organic content or that is extremely dry has a high sorption capacity for VOCs, which results in reduced removal rates. • SVE may require treating residual soil tailings, liquids, and spent activated carbon. • Air emissions must be controlled to eliminate possible harm to the public and the environment. • SVE is not effective in the saturated zone. However, lowering the aquifer can expose more media to SVE (this may address concerns regarding LNAPLs).	\$10 - 150/ton
Thermal Desorption	95-99% removal of VOCs	• All compounds that are listed on Table 2 are readily treated by thermal desorption. • Because of lower treatment temperatures and often lower oxygen levels, thermal desorbers should produce less nitrogen oxides and sulfur dioxide than incinerators. • Process can be performed onsite or offsite. • Lower temperatures produce fewer products of incomplete combustion (PICs).	• Requires excavation. If contamination is very deep or below the water table, excavation may be difficult and expensive. • Mercury, if present, can be removed from soil by thermal desorption and impose additional treatment costs for the offgas. • Soil containing high fractions of clay or silt may result in a high percentage of particulate carry-over from the desorber into downstream treatment devices. • Soil that contains constituents greater than 1 to 2 inches in diameter will require screening or crushing to prevent jamming the mechanical equipment. • Soil with a high moisture content (>30%) can result in low processing rates, high operating costs, and difficulty in materials handling. • High or low pH wastes may corrode the metal components of the system, requiring pretreatment. • Potential process residuals are treated solids, oversized debris, condensed contaminants and water, particulate control system solids, and contaminated activated carbon. • Air pollution control system required.	\$200-300/ton
Incineration	>99% removal of VOCs	• Capable of accepting a wide range of media. • Processes can be performed onsite or offsite. • Metals can be concentrated in the residuals.	• Requires excavation. If contamination is very deep or below the water table, excavation may be difficult and expensive. • Soil containing high fractions of clay or silt may result in a high percentage of particulate carry-over from the incinerator into downstream treatment devices. • Air pollution control equipment is required. • High treatment temperatures, as compared to thermal desorption, can produce nitrogen oxides, sulfur dioxides, and PICs. • Solids with volatile metals may require additional treatment or more elaborate air pollution equipment.	\$200 - 1700/ton

NOTES:

(1) Actual performance and cost for any remediation technology is highly site specific. Both depend upon the original and target clean-up level concentrations of contaminants, soil quantity to be treated, soil characteristics, and the design and operation of the remediation technology equipment used.

TABLE 4
Information Required for Characterization and Technology Selection at VOC Sites

INFORMATION	RATIONALE FOR COLLECTING INFORMATION	REFERENCE
All Technologies:		
Site Geology	SVE is most effective in porous, permeable, homogeneous soil. Highly heterogeneous soil (i.e., fractured porous rock or sands interspersed with clay lenses) may exhibit air flow channeling through highly permeable soils. Also, desorption kinetics may be slow in some situations (i.e., high organic content or high clay content soil). In these cases, mass transfer kinetics may reduce the rate of removal of SVE below that which is expected by calculations with a local equilibrium model or pilot scale experiments carried out for only a few days. Often diffusion kinetics limitations can be substantially reduced by proper design of the SVE facility.	Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (pp. 3-3 to 3-20) EPA/540/G-89/004
USGS Soil Classification	For SVE to be effective, the soil must have sufficient pneumatic permeability ($>10^{-6} \text{ cm}^2$) to permit air to move through the medium. Sandy, gravelly soils are the most conducive to SVE, while clays and silts are less conducive. However, remediations using SVE in clays and silts have been successful. Soil permeability may need to be measured in the field.	ASTM D 2487 ASTM D 2488
Soil Moisture	High moisture content in soil may drastically decrease its air permeability and, thus, the effectiveness of SVE. The site must be sufficiently well drained to prevent the severe reduction in air permeability, which occurs when the percent water saturation of the soil is greater than 50%. Conversely, organics can be strongly adsorbed onto extremely dry soils, which also impedes SVE. The moisture content of the soil will affect the amount of energy required to heat the soil, the target temperature and the handling properties of fine-grained soil. Thermal desorption requires that the moisture content of the soil be less than 30%.	ASTM D 2216 ASTM D 3017
Depth to Ground Water	SVE is not effective in saturated soil. However, the water table can be lowered by pumping. Thermal desorption and incineration are more expensive for high moisture soil.	Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (pp. 3-3 to 3-20) EPA/540/G-89/004
Contaminant Identity and Properties	<u>Boiling Point</u> - Thermal desorption target temperature is dependent on contaminant boiling point. <u>Vapor Pressure</u> - SVE is effective for compounds with a vapor pressure greater than 0.5 mm Hg at soil temperatures. <u>Dimensionless Henry's Constant</u> - SVE is effective for compounds with a dimensionless Henry's constant higher than 0.01 at soil temperatures. <u>Water Solubility</u> - SVE is more successful for compounds with lower solubilities. <u>Liquid and Vapor Density</u> - A contaminant with a density greater than water may form a DNAPL. A contaminant with a density less than water may form an LNAPL. The flow characteristics of a compound's vapor for SVE is a function of its vapor density.	CRC Chemical Handbook

TABLE 4
Information Required for Characterization and Technology Selection at VOC Sites
(Continued)

INFORMATION	RATIONALE FOR COLLECTING INFORMATION	REFERENCE
All Technologies: (continued)		
Contaminant Concentration, Location, Volume, and Depth	These data can be gathered via soil matrix and/or soil gas sampling. Soil gas sampling, both shallow and at depths, may be more appropriate, given depth to ground water and stratigraphy.	Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (pp. 3-3 to 3-20) EPA/540/G-89/004
Presence of Pipes or Subsurface Material	The presence of water or electrical conduits, soil fracture lines, debris, or any other objects that are more permeable than the surrounding soil will be the preferred pathway for the advecting gases.	Geotechnical Techniques
SVE Only:		
Soil/Air Filled Porosity	Porosity should be less than 40% for SVE to be effective.	Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (pp. 3-3 to 3-20) EPA/540/G-89/004
Soil/Air Permeability	Soil/air permeability should be greater than 10^{-6} cm^2 for air to move throughout the contaminated soil. SVE is potentially effective in less permeable soil (i.e., between 10^{-6} to 10^{-10} cm^2), but further pilot-scale testing and/or mathematical modeling is recommended to better predict the time for cleanup (which is likely to be prolonged for lower permeability soil).	Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (pp. 3-3 to 3-20) EPA/540/G-89/004
Soil Temperature	Contaminant vapor pressure, dimensionless Henry's Law constant, water solubility, and phase density are strong functions of temperature.	Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (pp. 3-3 to 3-20) EPA/540/G-89/004
Soil Humic Content	Solvents adhere strongly to soil with high humic content, which decreases the effectiveness of SVE.	Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (pp. 3-3 to 3-20) EPA/540/G-89/004
Contaminant Soil Sorption Coefficient K_d (Since K_d is less readily available, K_{oc} , the equilibrium between contaminants sorbed onto organic carbon versus the ground water is used.)	This parameter describes the tendency of the solvent to sorb onto soil or organic matter in the soil. Higher K_{oc} 's indicate that a subsurface is more likely to bind to carbon rich media (i.e., soil) than to remain in water.	RREL Treatability Database
Contaminant Adsorption Characteristics on Activated Carbon	This parameter is related to the feasibility of removing contaminants from residuals by carbon adsorption. This parameter is important since compounds such as MEK become unstable as they are adsorbed onto carbon.	RREL Treatability Database

TABLE 4
Information Required for Characterization and Technology Selection at VOC Sites
(Continued)

INFORMATION	RATIONALE FOR COLLECTING INFORMATION	REFERENCE
Incineration and Thermal Desorption Only:		
Soil Plasticity	Plastic soil, when subjected to compressive forces, can become molded into large particles that are difficult to heat.	Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (pp. 3-3 to 3-20) EPA/540/G-89/004
Soil BTU Content	The soil BTU content determines the fuel requirements for thermal desorption and incineration.	ASTM D 3286
Contaminant Combustion Characteristics	Information on combustion characteristics of a VOC is required in order to determine the combustion characteristics of the incinerator.	Bench/Pilot Testing
Soil Particle Size Distribution	Thermal desorption usually requires that soil be pretreated to a maximum soil particle size ranging from 1 to 2 inches.	ASTM D 422
Alkaline Metal Salts (e.g., NaSO ₄ , KSO ₄)	Alkaline metal salts may cause refractory attack and slagging at high temperatures.	Percentage of Na, K
Volatile Metals Content (e.g., Hg, Pb, Cd, Zn, Sn)	High metal content may cause ash leaching and stack emissions problems.	Heavy Metals Analysis

BTU = British Thermal Units

LNAPL = Light Nonaqueous Phase Liquid

DNAPL = Dense Nonaqueous Phase Liquid

mm Hg = millimeters of mercury pressure

NAPL = Nonaqueous Phase Liquid

PIC = Products of Incomplete Combustion

APPENDIX A

TECHNICAL BASIS FOR PRESUMPTIVE REMEDIES

This Appendix summarizes the analyses that EPA conducted of Record of Decision (ROD) and Feasibility Study (FS) data from VOC-contaminated sites which led to establishing soil vapor extraction (SVE), thermal desorption, and incineration as the presumptive remedies for Superfund sites with VOC-contaminated soil. The analyses consisted of:

- Identifying VOC-contaminated sites
- Determining the frequency of technology selection for VOC sites
- Identifying sites for the feasibility study (FS) analysis
- Conducting the FS analysis.

Results of these analyses, along with the scientific and engineering analysis of the performance data on technology application (Primary Reference document), provide a support for the decision to eliminate the initial alternatives identification and screening step for this site type. These technical reviews found that certain technologies are appropriately screened out based on effectiveness, implementability, or excessive costs. Review of technologies against the nine criteria led to elimination of additional alternatives. Provided below is a discussion of each analysis.

Identification of VOC-Contaminated Sites

The first analysis involved generating a list of signed Records of Decision (RODs) (post-SARA), documenting VOC contamination, from which data could be used for subsequent analyses. The ROD Information Directory database was used for this purpose. Of the 821 signed FY86-FY91 RODs, 418 are identified in the database as containing VOC contamination in source material. This list of RODs was subsequently divided into two lists: RODs where VOCs were the only contaminants of concern identified in the source material and RODs containing VOCs, as well as other contamination, in source material. For those RODs involving VOC plus other contaminants, a review of the ROD document was conducted to identify cases where only VOCs were driving the selection of remedy. To make this determination, the Remedial Response Objectives and Selected Remedy sections of the ROD were reviewed to identify specific language indicating that the remedial action was designed to address only the VOCs at the site. In addition, if cleanup goals were specified only for VOCs, the assumption was made that VOCs were driving the remedy.

As a result of this analysis, 88 RODs were identified as VOC-only RODs or VOCs plus other contaminants RODs where a clear determination could be made that VOCs were driving the selection of remedy.

Frequency of Technology Selection for VOC-Contaminated Sites

Table 1 presents the distribution of the 88 FY86-FY91 RODs among the treatment technologies used to address VOCs in soil. This table demonstrates that the three presumptive remedies (SVE, thermal desorption, and incineration) together were selected more often (over 90% of the RODs analyzed) than the other applicable technologies. Presumptive Remedies were also those remedies where a fair amount of performance data on technology implementation was available. Furthermore, SVE, chosen in over two-thirds of the RODs analyzed, was the primary presumptive remedy selected.

Identification of Sites for Feasibility Study Analysis

The purpose of the FS analysis was to document the technology screening step in FSs of VOC-contaminated soil/sludge sites and identify the principal reasons given for eliminating technologies from further consideration. To achieve a representative sample of FSs for the analysis, sites were selected using ROD data according to the following criteria:

APPENDIX A
TECHNICAL BASIS FOR PRESUMPTIVE REMEDIES
(Continued)

Table 1

**Presumptive Remedy VOC Site Treatment
Summary Table, FY86-FY91***

TECHNOLOGIES USED TO ADDRESS VOCs IN SOIL	TOTAL
Bioremediation ⁽¹⁾	3
Incineration	11
Soil Flushing/Washing ⁽¹⁾	3
Soil Vapor Extraction	62
Thermal Treatment ⁽²⁾	9
Total	88

Source: ROD Information Directory (RID), FY86 - FY91

Notes: (1) Relatively limited amount of performance data available for these technologies versus the presumptive remedies.

(2) Thermal treatment includes RODs employing thermal desorption, thermal aeration, low-temperature thermal desorption, and the generic remedy "thermal treatment".

* A population of 418 RODs was identified for this study based on the parameters: FY 1986-1991, and VOC contamination of source media.

- Sites were chosen, based on the selected remedy, to ensure an even distribution among the five treatment technologies for VOCs in soil (i.e., bioremediation, incineration, SVE, soil flushing, and thermal treatment).
- Whenever possible, both VOC-only sites and VOC and other contamination sites were represented under each technology.
- Sites were selected to ensure an even distribution in geographic location, ROD signature date, and site size.

Feasibility Study Analysis

The FS analysis involves a review of the technology screening phase, including any pre-screening steps, followed by a review of the detailed analysis and comparative analysis phases in each FS and ROD. Information derived from each review was documented on site-specific data collection forms, which are available for evaluation as part of the Administrative Record for this directive. (See "Feasibility Study Analysis for CERCLA Sites with Volatile Organic Compounds in Soils", September 1993, available at EPA Headquarters and Regional Offices.)

APPENDIX A
TECHNICAL BASIS FOR PRESUMPTIVE REMEDIES
(Continued)

For the screening phase, the full range of technologies considered was listed on the data collection forms, along with the key reasons given for eliminating technologies from further consideration. These reasons were categorized according to the screening criteria: cost, effectiveness, or implementability. The frequency with which specific reasons were given for eliminating a technology from further consideration was then tallied and compiled into a screening phase summary table (Table 2).

For the detailed analysis and comparative analysis, information on the relative performance of each technology/alternative with respect to the nine NCP criteria was documented on the site-specific data collection forms. The advantages and disadvantages associated with each clean-up option were highlighted. In some cases, a VOC technology was combined with one or more technologies that address minor site contaminants into one or more alternatives. Only the component of the alternative which addressed the VOC contamination was evaluated in this analysis. The disadvantages of a technology/alternative were then compiled into a detailed analysis/comparative analysis summary table, under the assumption that these disadvantages contributed to non-selection. All summary tables are available for review as part of the Administrative Record.

The FS analysis has been completed for 21 sites (representing approximately 25% of universe studied). The information from these FSs has been compiled and summarized in Table 2. Additional FS analysis is planned and will be added to the Administrative Record, when available. Table 2 demonstrates that technologies, other than the presumptive remedies, are consistently eliminated from further consideration in the screening phase due to effectiveness, implementability, or excessive costs. In addition, the analysis indicates that, although certain technologies routinely passed the screening phase, these technologies were selected infrequently because they did not provide the best overall performance with respect to the nine criteria. Together these analyses (Appendix A to this directive and "Feasibility Study Analysis for CERCLA Sites with Volatile Organic Compounds in Soils"), along with the scientific analysis of performance data (USEPA (In Progress) Contaminants and Remedial Options at Solvent Sites) will support the decision of using presumptive remedies and bypassing the technology identification and screening step for a particular site. As previously indicated, this factsheet and accompanying analysis should be part of the Administrative Record for the site. Further supporting materials, not found in the Regional files, can be provided by Headquarters, as needed.

TABLE 2 • SUMMARY OF SCREENING AND DETAILED ANALYSIS FOR VOC SITES¹[illegible]

TABLE 2 • SUMMARY OF SCREENING AND DETAILED ANALYSIS FOR VOC SITES (Continued)¹

REMEDIAL TECHNOLOGY OR TREATMENT ²	# FSs Where Technology Considered					# FSs Where Criterion Contributed To Screening Out ³			# RODs Tech. Selected		# RODs Tech. Not Selected		# RODs Where Criterion Contributed to Non-Selection		# RODs Where Criterion Contributed to Non-Selection		# RODs Where Criterion Contributed to Non-Selection	
	# FSs Tech. Passed Screening	# FSs Tech. Screened Out	Tech. Not Primary Component of Alternative	Cost	Effectiveness	Implement	# RODs Tech. Not Selected	Protect	ARARs	TMY Through Treatment	Long-term Effect.	Short-term Effect.	Cost	Implem.	State & Concerns	Community Concerns		
Other Chemical Destruction	3	0	3	0	0	3	0	0	0	0	0	0	0	0	--	--		
Reduction	7	0	8	1	0	5	1	0	0	0	0	0	0	0	0	--	--	
Neutralization	6	0	6	0	0	5	0	0	0	0	0	0	0	0	0	--	--	
Oxidation	6	1	5	0	0	4	0	0	1	0	0	0	1	1	1	--	--	
Offsite Incineration (unspecified)	16	7	8	1	5	5	2	0	7	2	0	1	0	7	6	2	--	--
Onsite Incineration (unspecified)	7	1	8	0	2	3	5	0	1	0	0	0	1	1	0	--	--	
Fluidized Bed	5	0	4	1	3	1	2	0	0	0	0	0	0	0	0	--	--	
Infrared	5	1	4	0	2	2	1	1	0	0	0	0	0	0	0	--	--	
Pyrolysis	3	0	3	0	2	1	1	0	0	0	0	0	0	0	0	--	--	
Multiple Hearth	5	0	4	1	2	4	1	0	0	0	0	0	0	0	0	--	--	
Rotary Kiln	11	6	3	2	3	2	3	2	4	1	0	0	0	5	3	4	--	--
Other Incineration	13	1	12	0	5	6	5	1	0	0	0	0	0	0	0	--	--	
Other Thermal Treatment	6	0	6	0	2	4	3	0	0	0	0	0	0	0	0	--	--	

TABLE 2 • SUMMARY OF SCREENING AND DETAILED ANALYSIS FOR VOC SITES (Continued)¹

REMEDIAL TECHNOLOGY OR TREATMENT ²	# FFSs Where Technology Considered					# FFSs Where Criterion Contributed To Screening Out					# RODs Where Criterion Contributed to Non-Selection							
	# FFSs Tech. Passed Screening	# FFSs Tech. Screened Out	Tech. Not Primary Component of Alternative	Cost	Effectiveness	Implement	# RODs Tech. Selected	# RODs Tech. Not Selected	Protect	ARARs	TMV Through Treatment	Long-term Effect.	Short-term Effect.	Cost	Implem.	State Concerns	Community Concerns	
Vitrification	12	0	11	1	2	8	5	0	0	0	0	0	0	0	0	0	--	--
Wet Air Oxidation	6	1	5	0	1	4	3	0	1	0	0	0	1	1	1	0	--	--
Low Temperature Thermal Desorp/ Stripping	13	10	3	0	1	1	2	3	7	2	1	1	2	7	3	4	--	--
In-situ Steam Stripping	3	2	1	0	0	1	0	2	0	0	0	0	0	0	0	0	--	--
Soil Flushing	15	3	12	0	0	9	5	0	3	1	1	1	2	2	1	3	--	--
Soil Washing	14	2	12	0	1	10	9	0	2	0	0	1	0	2	2	1	--	--
In-situ Vacuum Extraction	17	11	6	0	0	6	2	10	2	0	0	0	1	0	0	2	--	--
B.E.S.T. Process	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	--	--
Liquified Gas	1	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	--	--
Other Physical Extraction	4	0	4	0	0	3	0	0	0	0	0	0	0	0	0	0	--	--
Fixation	7	1	6	0	0	6	0	0	1	0	0	1	1	0	1	1	--	--
Stabilization/ Solidification	13	2	7	4	0	6	2	0	2	0	0	2	2	2	0	2	--	--
Aeration	12	2	10	0	1	9	2	1	1	0	0	0	1	1	1	0	--	--

TABLE 2 • SUMMARY OF SCREENING AND DETAILED ANALYSIS FOR VOC SITES (Continued)¹[illegible]

¹ This study was conducted on 21 RODs and their corresponding FSs.

2 This does not include the no-action or institutional control only alternatives. No RODs selected either of these as remedies.

³ FSs and RODs may contain more than one criterion for screening or non-selection of technology. Also, some FSs did not fully explain the criteria for screening out a technology. Thus, the totals for screening and non-selection criteria are not equal to the number of FSs and RODs considered.

⁴ Information on State and community concerns was not included in this analysis because FSs do not contain this information and RODs generally only reference supporting documentation (i.e., State concurrence letter and responsiveness summary).

APPENDIX B
Criteria Evaluation for Technologies Used to Treat VOC-Contaminated Soil

CRITERIA							
	Overall Protection of Human Health and the Environment	Compliance With Federal ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-Term Effectiveness	Implementability	Cost ⁽¹⁾
SOIL VAPOR EXTRACTION	• Provides both short- and long-term protection by reducing concentration and exposure to VOCs in soil. • Depending on site-specific conditions, prevents further ground water contamination.	• Does not trigger LDRs because it does not involve placement of waste. • Because waste is removed in place through limited construction and no excavation, few impacts to wetlands, floodplains, or water quality are likely. • Depending on site-specific conditions, treats wastes to levels that will prevent exceedance of groundwater clean-up levels. • Emission controls are needed to ensure compliance with air quality standards.	• Effectively removes contamination source. • Is a well-demonstrated technique for removing VOCs from soil/sludge. • Requires some treatment of residuals (spent carbon or concentrated VOC waste stream) generally through regeneration or disposal. • Hazardous wastes left in place will require 5-year review.	• Significantly reduces toxicity, mobility, or volume through treatment. • Produces few waste streams.	• Does not present substantive risks to onsite workers or community; potential for some dust generation during well installation. • Potential air emissions are easily controlled through activated carbon adsorption or other technologies. • Generally involves relatively short time frame to achieve clean-up levels; however, difficulty in estimating timeframe may exist due to site uncertainties (e.g., irregular soil permeabilities). • Effective for treating waste under buildings. Can be performed on active facilities. • Hardware, such as vacuum blower, is readily available from many sources, but SVE system performance is highly dependent upon the lithology of the site and system design.	• Few administrative difficulties. Technology is readily available from many sources. • Used successfully at numerous Superfund sites to address VOC contamination. • Installing and operating extraction wells requires fewer engineering controls than other technologies (i.e., excavation and incineration). • Requires series of soil gas sampling to determine when clean-up levels are achieved.	\$10 - 150/ton \$50/ton avg.

1. Note: Actual cost of a remediation technology is highly site-specific. It is dependent upon the original and target clean-up level concentrations of contaminants, soil characteristics, and the design and operation of the remediation technology used.

APPENDIX B
Criteria Evaluation for Technologies Used to Treat VOC-Contaminated Soil
(continued)

		CRITERIA						
		Overall Protection of Human Health and the Environment	Compliance With Federal ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-Term Effectiveness	Implementability	Cost ⁽¹⁾
THERMAL DESORPTION		Provides both short- and long-term protection by eliminating exposure to VOCs in soil/sludge.	Requires compliance with RCRA removal, treatment, transportation (if offsite treatment), and land disposal regulations (if a hazardous waste).	Effectively removes contamination source.	Significantly reduces toxicity, mobility, or volume of contaminants through treatment.	Presents potential short-term risks to workers and community from air release during excavation and treatment (if onsite treatment).	Construction and substantive permit requirements of an onsite treatment unit may present some difficulties. Mobile incineration units for onsite treatment are available.	\$200 - 300/ton
		Prevents further groundwater contamination and offsite migration.	Excavation, construction, and operation of onsite treatment unit may require compliance with wetlands and other location-specific ARARs.	Is a well-demonstrated technique for removing VOCs from soil/sludge.	Generally requires test runs to ensure effective treatment.	Involves potential short-term risks from handling and transporting waste (if offsite treatment).	Limited offsite treatment capacity exists.	\$250/ton avg.
		Requires measures to protect workers and community during excavation, handling, and treatment.	Treats hazardous waste to BDAT levels; thus, there is no LDR problem with residuals.	Involves some treatment or disposal of residuals generally through use of carbon adsorption/regeneration or disposal.		Relatively short timeframe to achieve clean-up levels.	Used successfully at other Superfund sites to address solvent contamination.	
			Generally, treats wastes to levels that will prevent exceedance of groundwater clean-up levels.			Requires engineering measures to control air emissions, fugitive dust, run-off, erosion and sedimentation, site access, and transportation.		
			Emission controls are needed to ensure compliance with air quality standards.					

1. Note: Actual cost of a remediation technology is highly site-specific. It is dependent upon the original and target clean-up level concentrations of contaminants, soil characteristics, and the design and operation of the remediation technology used.

APPENDIX B
Criteria Evaluation for Technologies Used to Treat VOC-Contaminated Soil
 (continued)

CRITERIA						
	Overall Protection of Human Health and the Environment	Compliance With Federal ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-Term Effectiveness	Implementability
Cost ⁽¹⁾						
INCINERATION	- Provides both short- and long-term protection by eliminating exposure to solvent contaminants in soil. - Prevents further ground-water contamination and offsite migration. - Requires measures to protect workers and community during excavation, handling, and treatment.	- Requires compliance with RCRA removal, treatment, transportation (if offsite treatment), and land disposal regulations (if a hazardous waste). - Excavation, construction, and operation of onsite incinerators may require compliance with wetlands and other location-specific ARARs. - Treats hazardous waste to BDAT levels; thus, there is no LDR problem with residuals. - Treats wastes to levels that will prevent exceedance of ground-water clean-up levels. - Emission controls may be needed to ensure compliance with air quality standards during excavation and construction.	- Effectively destroys source of contamination. - Is a well-demonstrated technique for treating VOCs in soil/sludge. - No organic residuals contamination will exist if treating soil/sludge contaminated only with VOCs.	Significantly reduces toxicity, mobility, or volume of contaminants through treatment.	- Presents potential short-term risks to workers and community from air release during excavation and treatment (if onsite treatment). - Involves potential short-term risks from handling and transporting waste (if offsite treatment). - Relatively short timeframe to achieve clean-up levels.	- Construction and substantive permit requirements of an onsite incinerator may be somewhat difficult. Mobile incinerators are readily available. - Limited offsite incineration capacity exists. - Used successfully at other Superfund sites to address VOC contamination.

1. Note: Actual cost of a remediation technology is highly site-specific and dependent upon the original and target clean-up level concentrations of contaminants, soil characteristics, and the design and operation of the remediation technology used.

**APPENDIX C
U.S. Waste Exchanges**

CALIFORNIA WASTE EXCHANGE

Robert McCormick
Department of Health Services
Toxic Substances Control Division
400 P Street
Sacramento, CA 95812
(916) 324-1807

INDIANA WASTE EXCHANGE

Environmental Quality Control
1220 Waterway Boulevard
P.O. Box 1220
Indianapolis, IN 46206
(317) 232-8188

**INDUSTRIAL MATERIAL EXCHANGE
SERVICE**

Diane Shockey
2200 Churchill Road, #31
Springfield, IL 62794-9276
(217) 782-0450
FAX: (217) 782-9142

INDUSTRIAL MATERIALS EXCHANGE

Bill Lawrence
172 20th Avenue
Seattle, WA 98122
(206) 296-4899
FAX: (206) 296-0188

PACIFIC MATERIALS EXCHANGE

Bob Smee
1522 North Washington Street, Suite 202
Spokane, WA 99205
(905) 325-0551
FAX: (509) 325-2086

NATIONAL WASTE EXCHANGE NETWORK

1-800-858-6625

RENEW

Hope Castillo
Texas Water Commission
P.O. Box 13087
Austin, TX 78711
(512) 463-7773
FAX: (512) 463-8317

**INDUSTRIAL WASTE INFORMATION
EXCHANGE**

William E. Payne
New Jersey Chamber of Commerce
5 Commerce Street
Newark, NJ 07102
(201) 623-7070

MONTANA INDUSTRIAL WASTE EXCHANGE

Don Ingles
Montana Chamber of Commerce
P.O. Box 1730
Helena, MT 59624
(406) 442-2405

NORTHEAST INDUSTRIAL WASTE EXCHANGE

Lewis M. Culter
90 Presidential Plaza, Suite 122
Syracuse, NY 13202
(315) 422-6572
FAX: (315) 422-9051

SOUTHEAST WASTE EXCHANGE

Maxi May
Urban Institute
Department of Civil Engineering
University of North Carolina
Charlotte, NC 28223
(704) 547-2307

**SOUTHERN WASTE INFORMATION
EXCHANGE**

Gene Jones
P.O. Box 960
Tallahassee, FL 32313
(904) 644-5516
FAX: (904) 574-6704

APPENDIX D GLOSSARY

Applicable or Relevant and Appropriate Requirements (ARARs) - CERCLA Section 121(d) and the NCP require that onsite remedial actions must attain (or justify a waiver of) requirements of environmental laws that are determined to be Federal or more stringent State applicable or relevant and appropriate requirements.

Dense Non-Aqueous Phase Liquid (DNAPL) - DNAPLs are immiscible hydrocarbon liquids that are denser than water, such as chlorinated solvents (either as a single component or as mixtures of solvents), wood preservative wastes, coal tar wastes, PCBs and some pesticides. DNAPLs can sink to great depths, can penetrate into bedrock fractures, can move as a liquid in a direction different from the flow of groundwater and can act as a continual source of groundwater contamination over time.

Engineering Evaluation/Cost Assessment (EE/CA) - An analysis of removal alternatives for non-time critical removal actions.

Ex-Situ Treatment - Removal of material from the ground for treatment.

Feasibility Study (FS) - A description and analysis of the potential clean-up alternatives for a site. It is generally conducted concurrently with the remedial investigation (RI); together the studies are referred to as an RI/FS. (See remedial investigation.)

In-Situ Treatment - The treatment or remediation of media occurring in-place.

Innovative Treatment Technologies - Technologies that have been tested, selected, or used for treatment of hazardous substances or contaminated materials but lack well-documented cost and performance data under a variety of operating conditions.

Land Disposal Restrictions (LDRs) - The Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA) include specific restrictions on the land disposal of RCRA hazardous wastes. These restrictions, known as LDRs, prohibit the land disposal of restricted RCRA hazardous wastes unless these wastes meet treatment standards specified in 40 CFR 268 or other compliance options.

Light Non-Aqueous Phase Liquids (LNAPL) - Like DNAPLs, LNAPLs are immiscible liquids, but are lighter than water and therefore float on water. As they are lighter than water, they are most frequently found at the groundwater table/vadoze zone interface.

Record of Decision (ROD) - A public document that explains the basis for selecting the clean-up alternative(s) that will be taken or served under CERCLA.

Remedial Design (RD) - The remedial action that involves designing and testing to determine whether the remedy will be effective at a site.

Remedial Investigation (RI) - An in-depth study designed to gather the data necessary to determine the nature and extent of the threat posed by contamination at a Superfund site. It also helps to establish the preliminary criteria for cleaning up the site in the FS and supports the technical and cost analyses of the alternatives. It is generally completed and combined with the FS and referred to as the RI/FS.

Risk Assessment - The qualitative and/or quantitative evaluation performed in an effort to define the risk posed to human health and/or the environment by actual and potential exposures to specific pollutants in air, water, soil or other media.

Superfund Accelerated Cleanup Model (SACM) - An initiative designed to accelerate all aspects of the Superfund clean-up process.

Vadoze Zone - The zone in soil that lies above the permanent water table.

Volatile Organic Compounds (VOCs) - Any organic compound which readily dissipates into the air.

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