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Phase 2 data report_ Quarry Pilot

Final
Phase II Data Report and Interpretation Additional Site Characterization Quarry Pilot Study

May 1999

MeOH
extraction of
Bedrock.

Installation Restoration Program

Loring Air Force Base, Maine

Final
Loring Air Force Base

Phase II Data Report and Interpretation
Additional Site Characterization
Quarry Pilot Study

May 1999

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Final
Loring Air Force Base

Phase II Data Report and Interpretation
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This document was prepared for the U.S. Army Corps of Engineers – Baltimore District on behalf of the Air Force Base Conversion Agency – Division A, Loring. The engineering evaluations and professional opinions rendered in this document were conducted or developed in accordance with commonly accepted procedures consistent with applicable standards of practice. This document is not intended to be used for construction of any of the remedial alternatives. This document has been reviewed by a qualified professional.

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PHASE II DATA REPORT AND INTERPRETATION
ADDITIONAL SITE CHARACTERIZATION
QUARRY PILOT STUDY
LORING AIR FORCE BASE, MAINE

TABLE OF CONTENTS

PHASE II DATA REPORT AND INTERPRETATION
ADDITIONAL SITE CHARACTERIZATION
QUARRY PILOT STUDY
LORING AIR FORCE BASE, MAINE

TABLE OF CONTENTS

PHASE II DATA REPORT AND INTERPRETATION
ADDITIONAL SITE CHARACTERIZATION
QUARRY PILOT STUDY
LORING AIR FORCE BASE, MAINE

LIST OF FIGURES

PHASE II DATA REPORT AND INTERPRETATION
ADDITIONAL SITE CHARACTERIZATION
QUARRY PILOT STUDY
LORING AIR FORCE BASE, MAINE

LIST OF TABLES

1.0 INTRODUCTION

This Site Data Report (SDR) for the Quarry Pilot Project has been prepared by Harding Lawson Associates (HLA), under contract number DACA31-94-D-0061, Delivery Order 0013, for the U. S. Army Corps of Engineers, Baltimore District (USACE). The Quarry Pilot Project is in progress for the U.S. Air Force (USAF) through the Air Force Base Conversion Agency (AFBCA) at the former Loring Air Force Base (LAFB), currently known as the Loring Commerce Center, Limestone, Maine (see Figure 1-1). The SDR presents the results of the final (second) phase of additional site investigation data collected in October and November of 1998 at the Quarry site. This site had been investigated previously, in Phase 1, in May and June of 1998 (HLA, 1998a,b) and in the Loring Installation Restoration Program (IRP) as source area Operable Unit 7, (OU 7), and under Flow Field Number 8 (FF8) within the Basewide Groundwater Operable Unit (OU 12). Remedial Investigations (RI) data from OU 7 and OU 12 (ABB-ES, 1997) supported the interpretation of the suspected presence of Dense Non-Aqueous Phase Liquids (DNAPL) in fractured bedrock groundwater at the site and a recommendation for additional investigations and evaluation of potential innovative technologies for DNAPL removal or in-situ destruction. The principal contaminant of the DNAPL was tetrachloroethylene, also known as perchloroethylene (PCE), a chlorinated solvent commonly used for degreasing operations in dry cleaners and machine shops.

The purpose of this report is to transmit, to the Base Restoration and Closure (BRAC) Closure Team (BCT), data from Fall 1998 investigations concerning the presence and distribution of NAPL sources, and provide recommendations concerning applicability of in-situ chemical oxidation by permanganate as an innovative technology for DNAPL source removal and reduction of contaminant mass in the fractured bedrock system. The focus of the Fall 1998 field work was to develop a better understanding of the nature of the suspected source of DNAPL and associated groundwater contamination through installation and testing at four new borehole locations in three drum removal source areas (DRSA). In addition an existing borehole was lengthened.

The scope of this report is restricted to transmitting new data collected specifically during this phase of work and providing a brief interpretation of these and previous data. This report focuses on refinements to the conceptual model for the site. The results of this work, discussed in Section 2.0, include:

- Borehole drilling observations and analytical results from borehole rock chip samples using the methanol extraction rock chip (MERC) procedure outlined in the Phase I report;
- Borehole geophysical logging results;
- Groundwater packer sampling and analytical results;
- NAPL measurement results; and

- Heat pulse flow meter results under pumping conditions of a selected borehole.

A general interpretation of these data as they relate to revisions of the existing site conceptual model is presented in Section 3.0. Section 4.0 provides an evaluation of NAPL presence, distribution and potential treatability, and Section 5.0 completes the report with recommendations and conclusions. Sections 4.0 and 5.0 constitute the most important portions of this report in presenting analysis, based in part on the field data, of how the conceptual contaminant distribution and transport model is expected to behave to a conceptualized remedial treatment process. Field data and geologic and geophysical logs collected during Phase II are included in Appendix A through Appendix H. Appendix I provides contaminant mass and aquifer restoration timeframe estimates. Appendix J presents costs for remedial approaches and treatment scenarios.

2.0 SITE CHARACTERIZATION RESULTS SUMMARY

This section provides a brief summary of the methods employed and results of the Phase II additional site characterization conducted to support the Quarry Pilot Study. Specific technical details of the methods of exploration are described in the field work notification (HLA, 1998a) and the Phase I Site Data Report (HLA, 1998b). This final phase site characterization was conducted after removal of 301 drums from three drum disposal areas. The removal actions are described in the Phase I Report and in a removal report prepared by Bechtel Environmental (Bechtel, 1999). An important finding of the removal action was that no definitive source was confirmed by soil or drum content sampling and analysis for the PCE observed in groundwater. This work, in conjunction with borings, surface geologic and surface geophysical surveys, and other Phase I data was intended to support the following general objectives and, ultimately, bring the Quarry Pilot Study toward a well-informed implementation decision point:

- characterize the location, distribution, and mass of residual chlorinated solvent contamination, in particular PCE, and relate this distribution to storage mechanisms within specific fracture types at the Quarry;

- confirm the approximate entry location (source area) for DNAPL with regard to DRSAs 1,2, and 3;

- evaluate the horizontal and vertical distribution of contaminants in the source area, with an emphasis placed on techniques that will increase the probability of directly confirming the presence or absence of DNAPL and assessing potential volume or mass of DNAPL or PCE present; and,

- develop hydrogeologic information appropriate for understanding passive or active injection / extraction strategies which may be required to successfully implement potential treatment systems.

The program implemented to support these objectives included:

- installing cored boreholes in each of the source areas;

- collecting MERC samples from rock fracture intervals;

- conducting borehole geophysics to understand bedrock fracture orientation, and ambient borehole flow conditions;

- collecting borehole sump groundwater grab samples for Sudan IV dye testing used for direct observation of DNAPL; and

- collecting packered groundwater samples for evaluation of dissolved phase contaminant distribution and hydrophysical testing of boreholes.

The following subsections and supporting appendices provide a brief synopsis of the scope of these activities and results;

Subsection 2.1	Borehole Drilling Observations and Analytical Results
Subsection 2.2	Borehole Geophysical Logging Results
Subsection 2.3	Groundwater Analytical Results
Subsection 2.4	NAPL Measurement Results
Subsection 2.5	Heat Pulse Flow Meter Results Under Pumping Conditions

2.1 BOREHOLE DRILLING OBSERVATIONS AND ANALYTICAL RESULTS

The three drum removal source areas were investigated by completion of a bedrock borehole in proximity to the location where the majority of drums were situated. The exploration locations are depicted relative to the drum removal areas shown on Figure 2-1. The borehole sequencing (order in which they were drilled) was dependent on access, as the two large drum removal areas along the Quarry rim were being backfilled while the boreholes in the upper tier were being drilled. The location of the boreholes in the two drum removal areas along the Quarry rim were also dependent upon final grade and location of the crest of the earthen slope. The location of bedrock borehole JBW-7818 was as close to the drum removal area as slope stability and access conditions allowed. In fact, this borehole was terminated fifteen feet above its 100-foot target depth due to progressive but shallow, rotational failure of soil along the slope up to the edge of the drill pad. With the exception of JBW-7820, a 6-inch air hammer borehole, all boreholes were advanced with a nominal 5 1/2-inch outside diameter core barrel which produces a 4-inch diameter core.

Bedrock Drilling Program. Two boreholes, JBW-7817A, (deep) and JBW-7817B (shallow) were completed in DRSA Number 3 where the majority of the drums in this location were removed. JBW-7817 B was cased to a depth of 10.5 feet below ground surface (bgs) and was cored to a depth of 36.5 feet bgs. An amber brown, viscous light (L)NAPL was noted accumulating in this borehole within 12 hours after its installation. JBW-7817 A was cased to 25 feet bgs to extend this adjacent borehole through the LNAPL encountered in JBW-7817B and cored to 98.5 feet bgs.

One borehole, JBW-7821, was installed at the far downgradient edge of the upper tier DRSA Number 3. This location is approximately fifteen feet upgradient of bedrock vadose zone piezometer number 19 which detected relatively high concentrations of PCE, 460 parts per billion by volume (ppbv), and lower concentrations of trichloroethylene (TCE), carbon tetrachloride, and benzene, ethylbenzene, toluene, and xylenes (BTEX) compounds in an air sample collected after the borehole was purged using a small Rotron blower (HLA, 1998a). Based on these results, the location was inferred to be in proximity to a potential source area, and a recommendation to install JBW-7821 was made by the Maine Department of Environmental Protection (MEDEP) and U.S. Environmental Protection Agency (USEPA). This borehole was cased to 12 feet bgs and cored to 50 feet bgs to provide an indication of upgradient source contaminants and provide greater lateral spread to the distribution of boreholes. In addition, the existing cored borehole JBW-7816 was extended from 80 feet bgs to 150 feet bgs to provide a deeper exploration immediately downgradient of the inferred source areas DRSA Nos. 1 and 3.

In the Quarry rim area, two boreholes, JBW-7818 (DRSA 1) and JBW-7820 (DRSA 2) were installed. JBW-7818 was cased to 50 feet bgs to case off LNAPL observed in the adjacent borehole JBW-7819, and then cored to 86.5 feet bgs. The intended completion depth of 100 feet bgs was not attained due to soil stability concerns underlying the drill pad. JBW-7820 was cased to 25 feet bgs then advanced by air hammer to 100 feet bgs. Air hammer drilling was selected at this location based on the presumption that the drums removed (1950s vintage lubricants) were not a likely source of the PCE in nearby groundwater.

Appendix A contains rock coring logs for the extended JBW-7816 boring (80-150 feet), JBW-7817 A&B, JBW-7818, JBW-7819 and the air hammer log for JBW-7819. All 6-inch steel casings and JBW-7819 were installed with a dual head drive Guss Peck 22R rotary/core rig. Five-foot core runs were advanced with a 5.5 inch OD bit, yielding 4-inch diameter rock cores. Appendix B contains the borehole geophysical results which includes color Borehole Image Processing System (BIPs) logs. These logs provide photographic images of the interior of the borehole with oriented interpretation of the observed borehole features. Interpreted dip direction and dip angle of bedding and fracture sets, including bedding plane, axial plane and regional joint fractures patterns (see also Phase I Report, (HLA, 1998b) for additional detail) are presented on these logs. These data, with the drilling logs, provide a concise yet complete summary of the bedrock and borehole conditions. The existing site conceptual model concerning the nature, distribution, orientation and degree of interconnection of fractures has generally been confirmed by these newer data. Therefore, a borehole by borehole summary of rock drilling observations will not be provided as it was in the Phase I Report. However, general observations concerning fractures and bedrock conditions are provided. Some of these observations are interpretative and it should be understood that they represent the viewpoint of the person rendering the observation. These "interpretive observations" are provided as potential insights to assist others as they form their own impressions from the data presented in the appendices, especially for those who did not have the opportunity to inspect the core first hand. These observations are as follows:

- JBW-7817A and B, JBW-7819, JBW-7820 encountered LNAPL, though not of measurable thickness. Borehole JBW-7820 was a dry borehole to 100 feet and water did not recover in the borehole for several weeks after it was drilled. LNAPL and some water did enter the borehole from a fracture near 37 feet and accumulated in the borehole sump. A sample of LNAPL from each borehole location was collected for analysis.

- JBW-7818 was cased through the watertable to avoid introduction of suspected LNAPL into the borehole. Extensive, weak to moderate oxidation is present over several foot thick zones in this borehole.

- JBW-7817A and B, as well as the upper portion of JBW-7816 indicates that strong to moderate oxidation within the matrix parallel to bedding plane fractures tends to be a relatively shallow weathering feature. Beyond a depth of 80-100 feet bgs, weathered bedding plane fractures were not observed nor was surficial iron oxidation observed along fracture surfaces in JBW-7816.

- Weathering, or oxidation along the margins of axial plane fractures and regional joints does not appear to be extensive or to extend far into the fracture margin (usually less than 1 millimeter (mm) or 0.04 inches if present). These fractures cross-cut stratigraphy and where they intersect oxidized bedding planes the oxidation may extend locally along the margins of these steeper fracture sets.

- Not all bedding planes are oxidized. The degree of oxidation appears to be dependent on the mineralogy that is stratigraphically constrained parallel to the beds and the fracture surface. The presence of finely crystallized, disseminated calcite, within the silty calcareous matrix adjacent to the fracture surface may favor weathering processes that increase matrix porosity adjacent to the fracture within a thin weathering rind (typically 0.1 - 0.5 inches thick on each side of fracture).

- Bedding planes and other slickensided fracture surfaces that have a phyllitic or mylonitic mineralogical texture are likely to exhibit less weathering (i.e., more presence of iron oxide-FeOx) and have no significant increase in adjacent porosity.

- In addition to the major fracture sets, “spidery” calcite healed micro-fractures, oriented parallel to foliation may be present locally, in addition to calcite healed breccias, and micro breccias (box work fracture sets). These secondary fractures, though wet when removed from the core barrel, do not appear to be significant transmitters of water, nor do they appear to be well connected to the major fracture systems.

Methanol Extraction Rock Chip Sampling Results. A procedure to provide fracture and location specific data on the distribution of contaminants was developed for this project. The procedure was the result of input of several individuals and experimentation of the method during the Phase I investigation. The purpose of the MERC method is to ascertain what amount of contaminant mass is extractable from the rock matrix (weathered or unweathered) adjacent to the fracture surface. This information can be used to better understand fracture specific distribution of contaminant mass in the fracture/rock matrix system and, therefore assists in establishing estimates of the "system mass" requiring removal by treatment or natural attenuation. In addition, MERC concentration data supported by site specific porosity and fraction of organic carbon (foc) data help in refining the conceptual understanding of where and how DNAPL mass is potentially stored in the system.

The MERC method is described in detail, with proposed improvements for Phase II, in the Phase I report (HLA, 1998b). In summary, rock chips are collected from the face of a fracture in the 4-inch core. Care is taken to "flake" the oxidized surface of the fracture in small chips or flakes with a rock hammer or with the aid of a cold chisel. This rock sample, depending on the degree of weathering, is generally composed of weathered (more porous) and unweathered rock chip fragments (less porous). Approximately 50-80 grams of these rock chips are placed in a 4 ounce soil jar with a teflon cap seal which has been pre-weighed with a known (and weighed) volume of 80-100 milliliters (ml) of purge and trap grade methanol. The total sample is weighed to allow calculation of the rock mass in grams. After 12-24 hours the methanol is pipetted into two 40 ml VOA vials and submitted for off-site analysis. The aqueous results can then be converted to represent the mass of contaminant leached per mass of rock (e.g., μg PCE / gram rock).

Sequential extractions were also conducted on two samples to assess how much additional mass can readily be removed by the methanol. These extractions were done by placing the same rock fragments in a new batch of methanol after they were visually air dried. This replicate extraction (XR), was followed in one sample by a third or triplicate extraction (XT). Review of the limited sequential extractions data suggests the first extraction may account for about 50-60 percent of the total cumulative mass reported from the other sequential extractions for both chlorinated volatile organic contaminants (CVOCs) and fuel hydrocarbons.

The MERC results are presented in Table 2-1. Review of these data indicates potential presence of a PCE source in the vicinity of JBW-7817A and JBW-7816 as well a potential source in the vicinity of JBW-7814. Whether these two general locations form a contiguous or separate source areas is unknown. The highest PCE concentrations in the JBW-7816 and JBW-7817 tend to be deeper (60-90 feet bgs) than the relatively shallow, high concentrations in the proximity to the downgradient area around JMW-0201 and JBW-7814 (30-60 feet bgs). LNAPL samples collected from JBW-7817 and JBW-7819 did not detect PCE, and transport of PCE on the water table as a mixed NAPL is not considered a likely conceptual model component at the site. Thus, the potential for two separate sources, one near JBW-7814/JMW-0201 and one in the immediate vicinity of JBW-7816/JBW-7817 (DRSA 3) is interpreted from these data. Moreover, an increase in PCE and TCE concentrations in the MERC data with depth to approximately 90-100 feet bgs is indicated by the samples collected in JBW-7817 and JBW-7816, suggesting past vertical transport, as DNAPL, in this area was possible. Evaluation of MERC data in JBW-7821 indicates TCE (dissolved phase), not PCE, is present at that location. Review of MERC data from JBW-7818 and JBW-7820 does not indicate these locations to be PCE sources.

Samples for analysis of matrix porosity were prepared by collection of small diameter cored samples from the margins of three fractures. The weathering of the rock matrix adjacent to the fractures produces an oxidized halo or rind that varies from less than 1 mm to more than 50 mm in thickness on each side of the fracture. The unweathered primary porosity of the bedrock is low, less than 0.5 percent (ABB-ES, 1997). Groundwater is transmitted primarily along secondary porosity features (fractures) and to a limited extent within weathered bedrock porosity adjacent to the fractures. The matrix porosity samples were selected to provide a range of weathered conditions (e.g., strongly, moderately and weakly weathered limestone) seen within the core. The results of matrix porosity tests are as follows: 3.9 percent in JBW-7816 at 59 ft bgs, 1.1 percent in JBW-7818 at 63 feet bgs, and 0.61 percent in JBW-7816 at approximately 37 feet bgs. These samples were also analyzed for grain density (bulk density) which decreased slightly as porosity increased with increased degree of oxidation or weathering.

Additional rock samples were crushed and acidified to drive off inorganic carbon from calcite and then analyzed for foc by USEPA Method 9060. Results the foc data are presented in Appendix C. To provide a representative section with depth samples were collected from JBW-7817 at 32 and 63 feet bgs, and from JBW-7816 at 121 feet bgs. Foc results were 16,000 milligrams per kilograms (mg/kg), 14,000 mg/kg and 15,000 mg/kg respectively. At first impression these values appear high and whether this is a true reflection of the organic content of the rock, or excess inorganic carbon (calcite) that was not driven off in the process of acidifying the pulverized rock samples is unknown. For the purpose of subsequent evaluations of data, the foc values will be considered as potentially biased high.

These foc and porosity data, collectively with the MERC data, were used to conduct phase relationship calculations to determine if the highest MERC PCE results were potentially indicative of DNAPL. In addition, the MERC sample data were used in conjunction with borehole geophysical data and fracture observations from drill logs, to refine the conceptual model for the distribution of chlorinated solvent mass and fuel contaminants within the fracture system. This evaluation considered the mass distributed among the fractures and the total potential mass contained in the system indicated by the average MERC mass data. This mass was compared to the estimated total mass flux leaving the system in the dissolved phase groundwater and it is apparent from this comparison that using the MERC, porosity, and foc data with the conceptual fracture model, significantly underestimates the total mass in the system. Therefore, although MERC data are useful in understanding the distribution of contaminants in the system, it is not a definitive assessment tool for total mass and therefore can only be employed as a qualitative tool in assessing the presence of DNAPL. The specifics of these evaluations will be discussed in greater detail in later sections of this report.

2.2 BOREHOLE GEOPHYSICAL LOGGING RESULTS

Borehole Geophysical Results. Borehole geophysical data were collected following advancement of each borehole. Logs were generally run in the following order: (1) BIPs logging, (2) temperature and fluid resistivity logging, (3) three-arm caliper logging, (3) single point resistance and spontaneous potential logging, and if required, (4) ATV logging, and (5) Heat Pulse Flow Meter (HPFM) logging. These logging techniques were conducted to identify the presence of water-bearing fractures and determine fracture orientation. Data collected from these logs were also used to guide the location of packer testing and sampling intervals and assisted in refining the site conceptual model.

Appendix B contains borehole geophysical memos summarizing field results and packer sampling interval recommendations, structural interpretations for each borehole in the form of BIPs data, and final log plots. Appendix G contains heat-pulse flow meter testing under pumping conditions of a selected borehole.

All borehole feature strike and dip direction measurements within this section are reported to true north unless specified otherwise. Raw data in supporting appendices present all strike and dip measurements to magnetic north which is approximately 21 degrees west of the north.

Figure 2-2 shows strike rosettes obtained from ATV and BIPs data. For the purposes of visual presentation these rosettes are oriented to Loring grid north. Each fracture strike rosette generally shows a bimodal fracture distribution.

Table 2-2 provides a summary of borehole geophysical findings. Review of structural data indicates that the study area has a fairly strong east-west fracture set that most likely dominates groundwater flow direction. This fracture set bears between N80E to N60W.

Downward flow was measured in JBW-7814, JBW-7815, JBW-7816, JBW-7817, JBW-7818, and JBW-7819 under non-pumping conditions. Measurable vertical flow rates within these boreholes ranged from 0.01 to 0.2 gallons per minute (gpm) downward. Average flow rates were 0.08 gpm downward per borehole. JBW-7820 was dry and no measurable flow to very weak downward flow was observed in JBW-7821 under non-pumping conditions. Review of these data show that vertical gradients are downward within the study area (see HPFM data in Figure 2-3). Table 2-3 provides a listing of hydraulically active fractures observed in each borehole. Figure 2-4 shows a summary of hydraulically active fractures

2.3 GROUNDWATER ANALYTICAL RESULTS

Packered groundwater samples were collected in two rounds, one preceding and one following completion of the new boreholes. The packer interval used was ten feet. The first round of samples included re-packering of one zone in JBW-7814 (30-40 feet), JBW-7815 (35-45 feet) and JBW-7816 (51-61 feet) to confirm the VOA results of samples collected earlier that spring. JBW-7816 (51-61 feet) was also re-sampled again with the second round of packer sampling, after the core drilling was completed to enable a final comparison of results to discern if introduction of drilling waters was affecting packer testing results. The pre-drilling results for JBW-7814 and JBW-7815 are discussed below, followed by the pre-drilling and post-drilling results for JBW-7816. This discussion is then followed by results from the new boreholes, JBW-7817, JBW-7818, JBW-7821 and JBW-7816 (80-150 feet). JBW-7820 was not packer sampled since it was a dry borehole. The discussion focuses on parent chlorinated solvent (PCE and TCE) and BTEX compounds. The vertical distribution of principal contaminants are also presented in the site cross-section Figure 2-3.

JBW-7814. The 40-foot zone sample (referenced from the bottom packer) from JBW-7814 contained PCE at 730 microgram per liter (μg/L), TCE (17 μg/L) and benzene (52 μg/L). In May of 1998, the packer sample from the 43-foot zone contained higher concentrations of PCE (3,400 μg/L), TCE (130 μg/L) and cis-1,2 dichloroethylene (DCE) at 11 μg/L but only 4 μg/L of benzene. The PCE concentration detected in the spring round was approximately 4.7 times that of the fall sample.

JBW-7815. The 45-foot zone sample from JBW-7815 contained PCE (120 μg/L), benzene (50 μg/L) and xylenes (4 μg/L). TCE was estimated below the linear quantitative range (J) at 1J μg/L. In May of 1998, a packer sample from this zone contained PCE (520 μg/L), TCE (5 μg/L) but was non-detect for benzene. The PCE concentration detected in the spring round was approximately 4.3 times that of the fall sample.

JBW-7816. The pre-drilling 61-foot zone sample from JBW-7816 contained PCE (530 μg/L), TCE (14 μg/L), benzene (150 μg/L), toluene (51 μg/L), ethylbenzene (6 μg/L) and xylenes (13 μg/L). The post-drilling packer sample of this zone contained PCE (1,500 μg/L), TCE (19 μg/L), benzene (28 μg/L), toluene (19 μg/L), ethylbenzene (5 μg/L) and xylenes (32 μg/L). In May of 1998, a packer sample from this zone contained PCE

(23,000 µg/L), TCE estimated greater than the linear quantitative range (E) at 450E µg/L, benzene (13 µg/L), toluene (39 µg/L), and ethylbenzene (16 µg/L). The PCE concentration detected in the spring round was an order of magnitude greater than either of these fall samples.

In the extended JBW-7816 borehole (80-150 feet bgs), three additional packer zones were selected for sampling based on borehole geophysical and MERC test results. These included samples from zones at 98, 125, and 149 feet. The 98-foot zone sample analyses included volatile organic analysis (VOA), semivolatile organic analysis (SVOA), gasoline range organics (GRO), diesel range organics (DRO), inorganics, alkalinity, and total organic carbon (TOC). The 125- and 149-foot zones were sampled for VOA and GRO only.

The 98-foot zone sample from JBW-7816 contained PCE (650 µg/L), TCE (71 µg/L), chlorobenzene (1 µg/L), 1,2-DCA (6 µg/L), benzene (16 µg/L), toluene (8 µg/L), ethylbenzene (3 µg/L), xylenes (14 µg/L), GRO (290 µg/L) and DRO (510 µg/L). Chrysene (18 µg/L) was the only semivolatile petroleum-related compound detected. The 125-foot zone sample from JBW-7816 contained PCE (220 µg/L), TCE (49 µg/L), benzene (14 µg/L), toluene (7 µg/L), ethylbenzene (2 µg/L), xylenes (10 µg/L) and GRO (140 µg/L). The 149-foot zone sample contained PCE (570 µg/L), TCE (56 µg/L), benzene (16 µg/L), toluene (8 µg/L), ethylbenzene (3 µg/L), xylenes (14 µg/L) and GRO (240 µg/L).

JBW-7817A In JBW-7817A three packer zones were selected for sampling based on borehole geophysical and MERC test results. These included samples from zones at 43, 80, and 90 feet. The 90-foot zone sample analysis included VOA, SVOA, GRO, and DRO, inorganics, alkalinity and TOC. The 43 and 80 foot zones were sampled for VOA and GRO only.

The 43-foot zone sample from JBW-7817A is believed to be cross-labeled with the rinsate sample SBK002XXXX04XX. The results in that rinsate sample are consistent with the results and chromatography of the other samples from this well. The results reported for this interval in the following text are from this sample number and these data are also reflected on the cross section in Figure 2-3. Analysis of this sample detected PCE (780 µg/L), benzene (440 µg/L), toluene (390 µg/L), ethylbenzene (47 µg/L), xylenes (200 µg/L) and GRO (1,500 µg/L). The 80-foot zone sample detected PCE (2,800 µg/L), TCE (17 µg/L), chlorobenzene (0.6J µg/L), benzene (430 µg/L), toluene (360 µg/L), ethylbenzene (51 µg/L), xylenes (220 µg/L) and GRO (2,100 µg/L). The 90-foot zone sample from JBW-7817A detected PCE (6,500 µg/L), TCE (110 µg/L), chlorobenzene (2 µg/L), cis-1,2-DCE (4 µg/L), carbon tetrachloride (6 µg/L), benzene (410 µg/L), toluene (390 µg/L), ethylbenzene (49 µg/L), xylenes (210 µg/L), GRO (2,300 µg/L) and DRO (210 µg/L). Napthalene (18 µg/L), and methyl napthalene (18 µg/L) were the only semivolatile petroleum-related compounds detected.

JBW-7817 B A product sample was collected from the surface of the water table and submitted for VOA analysis. Results for this sample, JBW781700004XX, are in Appendix C and include detections of benzene (24,000 µg/L), toluene, (360,000 µg/L), ethylbenzene (160,000 µg/L), and xylenes (780,000 µg/L). PCE was not detected at a practical quantitation limit (PQL) of 120 µg/L. Packer samples were not collected from this borehole due to the proximity and relatively shallow depth of the first zone in JBW-7817A, and after review of the MERC data which indicated the presence of fuel compounds and not chlorinated solvents in the shallow rock.

JBW-7818 Only one interval, 69 feet, was packer sampled in this borehole. The borehole was cased to 50 feet bgs to avoid LNAPL product and subsequently terminated at 82.6 feet due to slope instability problems adjacent to the drilling rig. The one packer location was selected based on geophysical, geologic, and MERC data. Data from this sample does not suggest a PCE source area. The results included detections of PCE (9 µg/L), 1,2-DCA (21 µg/L), carbon tetrachloride (31 µg/L), carbon disulfide (0.8J µg/L), chloroform (23 µg/L), benzene (1,400 µg/L), toluene (1,600 µg/L), ethylbenzene (120 µg/L), xylenes (540 µg/L) and GRO (5,900 µg/L). These results do however suggest proximity to the source of some of the more unusual contaminants identified JBW-7821, such as carbon disulfide, chloroform and carbon tetrachloride.

JBW-7819 A product sample was collected from the surface of the water table and submitted for VOA analysis. Results for this sample, JBW781900004XP, are in Appendix C and include detections of benzene (2,100,000 µg/L), ethylbenzene (3,500,000 µg/L), and xylenes (1,600,000 µg/L). PCE was not detected at a PQL of 120 µg/L.

JBW-7820 JBW-7820 was a 5 7/8–inch diameter air hammered borehole installed within the central portion of drum disposal area number 3. This borehole encountered one fracture at 37 feet bgs which was sampled for a MERC analysis. The borehole remained dry except for a weeping or slow seepage of fluid from that fracture which ultimately pooled on the bottom of the borehole. The fluid appeared to be a mixture of water and product which was sampled for VOAs by lowering a 40 ml VOA vial down to the bottom of the borehole at 105 feet bgs. The results of this water/product sample are included in Appendix C. These results indicate the presence of benzene (200 µg/L), ethylbenzene, (1,700 µg/L), and xylenes (9,900 µg/L). The MERC results indicated a very small amount of TCE (0.062 µg/g) was present in the rock sample. These data do not suggest a source of PCE, nor a significant source of TCE, or benzene in the source area.

JBW-7821 This borehole, completed to fifty feet bgs, was packer sampled at two depths, 27 feet and 43 feet, referenced from the bottom of the packer interval. A duplicate VOA sample was collected from the 27-foot zone which was also sampled for SVOCs, DRO, inorganics, alkalinity and TOC. The sample from the 27-foot zone sample contained PCE (19 µg/L), TCE (55 µg/L), carbon tetrachloride (160 µg/L), carbon disulfide (3 µg/L), chloroform (130 µg/L), benzene (11 µg/L), toluene (1 µg/L), xylenes (2 µg/L), GRO (78 µg/L), and DRO (130J µg/L). No SVOCs were detected. The sample from the 43-foot zone sample contained PCE (14 µg/L), TCE (480 µg/L), carbon tetrachloride (3,800 µg/L), carbon disulfide (26 µg/L), chloroform (440 µg/L), benzene (10 µg/L), toluene (2 µg/L), ethylbenzene (0.6J µg/L) xylenes (2 µg/L), and GRO (78 µg/L).

The relatively low levels of PCE and BTEX places this well on the outside edge of the PCE and fuel plume source region indicated by nearby wells JBW-7816 and JBW-7817. The chloroform in this well is likely present from sequential dechlorination of the carbon tetrachloride. The presence of these compounds and carbon disulfide in both JBW-7818 and JBW-7821 suggest these wells are close to alignment along a common flowpath.

Discharge Piezometers Discharge piezometers JPZ-7808 (overburden) and JPZ-7807 (shallow bedrock), located near the edge wetland adjoining the West Branch of Greenlaw Brook (WBGB) wetland, were sampled and analyzed for VOA, GRO and DRO. The bedrock groundwater sample from JPZ-7807 contained PCE (27 µg/L), and DRO (1,200 µg/L) but no GRO. The sample from JPZ-7808 contained only DRO (92 µg/L).

Summary Evaluation of the pre- and post-drilling event packer sampling and analysis of the 63-foot interval of JBW-7816 indicates that the packer data have not been biased by the hydraulic disruption of the core drilling activities. Several general differences in contaminant concentrations were apparent from the spring and fall sampling events and are noted in this report. Possible explanations for these differences were discussed at the BCT January 26, 1999 meeting. Since only two measurement are available, a trend cannot be determined and the significance of the data should not be over stated. The data may represent variations that are in part natural or influenced by external, temporal events (e.g., drilling, open borehole communication, and construction activities). Further evaluation and/or verification of trends should not be made until longer term monitoring data are available.

Possible explanations identified for the source area decrease in PCE and TCE concentrations included:

- Ambient borehole flow artificially connecting specific fractures within the source area could have resulted in advective loss of contaminants in the fractures by flushing, thereby resulting in subsequently lower concentrations in later sampling rounds.
- More recent fall recharge events could have increased groundwater gradients, groundwater flux, and additional dilution of chlorinated contaminants deeper within the shallow portion of the bedrock aquifer. For example, during October and

November water levels in JBW-7816 were approximately five feet higher than measurements collected in mid-August.

The possible explanations discussed for increases in fuel-related compound concentrations included:

- Disturbance and flushing of the LNAPL zones during advancement of the boreholes,
- Increased flushing of LNAPL and smeared vadose zone fuel contaminants while the DRSA number three was open to precipitation immediately prior to, and during the fall Phase II sampling program.

Review of the chemistry of groundwater samples from JBW-7816 and JBW-7817A suggests they are related to the same source area, and are likely in close proximity to the entry point of PCE into the bedrock groundwater system. The more unusual chemical species detected in JBW-7821 and JBW-7818, namely carbon disulfide, chloroform and carbon tetrachloride suggest a hydraulic and source relationship between these two wells that is not related directly to the source of PCE in JBW-7816 and JBW-7817A. With the exception of some effects from lubricating oils, the groundwater near JBW-7820 (drum removal area number 2) does not appear to have been affected by significant concentrations of chlorinated solvents or lighter petroleum hydrocarbons. As identified in the Phase I report, groundwater contamination surrounding JMW-0201 JBW-7814 and JBW-7815 is chemically quite similar to upgradient groundwater in JBW-7816 and JBW-7817A. The possibility exists that the areas around JMW-0201/JBW-7814 and JBW-7817/JBW-7816 represent separate spill locations from similar solvent drums. LNAPL samples collected from JBW-7817B and JBW-7819 are likely representative of lubricant / fuel and weathered gasoline respectively. Samples of these LNAPLs do not contain PCE or any other chlorinated solvents.

2.4 NAPL MEASUREMENT RESULTS

Prior to initiating any of the Phase II site investigation activities, each Phase I borehole was physically checked for the presence of DNAPL accumulations in the bottom of the borehole sumps. The borehole sumps were completed in unfractured, unweathered bedrock based on physical inspection of the core. A bottom loading bailer was gently lowered to the bottom of the borehole to visually check the fluid in the sump. Next, the sumps were pumped out with a bottom loading Whale™ pump and the water decanted in a five-gallon container. The bottom water was decanted through a valve and the water/sediment was then checked for DNAPL with Sudan IV dye. DNAPL was not identified in any of the boreholes. Results for both DNAPL and LNAPL measurements are presented in Table 2-4. LNAPL was identified in JBW-7817 and JBW-7819 floating on the water table, but was not sufficiently thick to measure (e.g., < 0.2 feet). Samples were collected from these LNAPLs for VOA analysis and results are contained in Appendix C. Details of these chemical analyses were discussed in Section 2.3. Based on the color, relative observed viscosity and chemical results, the LNAPL in JBW-7817 appears to be an oil lubricant and the LNAPL in JBW-7819 a mixture of weathered fuel (presumed to be gasoline) and possibly lubricants. JBW-7820 was a dry hole, completed with an air hammer, but did have one fracture at approximately 37 feet bgs, that allowed LNAPL and a trace of water to seep into the borehole. The volume of fluid in the borehole (about 1-inch) did not allow it to be sampled by conventional methods. A VOA sample was collected by lowering a 40 ml vial, to the bottom of the borehole and allowing it to rest on its side in the sump prior to retrieval. Results of this sample were discussed previously in Section 2.3.

2.5 HEAT PULSE FLOW METER RESULTS UNDER PUMPING CONDITIONS

Heat pulse flow measurements were collected under non-pumping conditions in all site boreholes in order to evaluate the vertical movement of groundwater. All boreholes exhibit downward flow which in turn suggests downward vertical gradients prevail throughout this portion of the aquifer system. In order to evaluate the effect of pumping on borehole flow regimes, heat pulse flow meter logging was conducted in JBW-7816 and JBW-7821 while pumping on JBW-7817A. Appendix G contains a summary of heat pulse flow meter logging under pumping conditions.

JBW-7817A was outfitted with a Whale™ pump lowered into the borehole at a depth of 35 feet bgs. Groundwater was pumped at a rate of approximately 0.25 gpm. Heat pulse data were collected in JBW-7816 and JBW-7821 during pumping. It appears that some effect was observed in both boreholes. Pumping JBW-7817A seems to have reduced the rate of downward flow in JBW-7816 within the shallow portion of the aquifer. This is most likely due to the fact that drawdown caused by JBW-7817A reduced the amount of head in the shallow portion of the aquifer which manifests itself in reduced vertical flow in JBW-7816. JBW-7821 went from no measurable flow/weak downward flow under non-pumping conditions to downward flow under pumping conditions from JBW-7817A. Water exits JBW-7821 from a bedding plane fracture at 39 feet bgs and is along strike of JBW-7817A. These wells may, therefore, be hydraulically connected. However, it should be noted that a localized recharge event may be responsible for downward flow observed in JBW-7821. Drilling water from JBW-7818 was discharged immediately upgradient of JBW-7821 prior to the HPFM test.

3.0 DATA INTERPRETATION AND REVISED SITE CONCEPTUAL

The following discussion provides refinements to the site conceptual model in the Quarry source areas. The larger scale site conceptual model, including interpretations from geologic mapping and surface geophysics on gross geologic structure, the relationship between geologic structure and fracture patterns and similar topics were presented in the Phase I Site Data Report (HLA, 1998b). This report builds on that conceptual model by focusing on the location and nature of the PCE source(s), the current understanding of the distribution of contaminant mass within the fracture network, and the general spatial distribution of the source area(s). These refinements provide a framework or boundary in which to attempt quantification of the total contaminant mass and mass storage mechanisms. The following discussion will review the following components of the site conceptual model.

- Bedrock Structure and Fracture Networks;
- Bedrock Hydraulic Conductivity and Water Transmission in the Fracture Network;
- Phase Relationships and Storage Mechanisms for Residual DNAPL; and
- Primary Sources and Distribution of DNAPL.

Bedrock Structure and Fracture Networks. The gross general bedrock structure at the Quarry site is a small scale faulted anticline, which developed along the flank of a larger regional anticline that bisects LAFB. The structural fabric of these two geologic structures dictate the type and relative age (cross-cutting relationships) between fractures at the Quarry. This fracture network is composed of bedding and axial plane fractures related to progressive folding during development of the Quarry fold. These fractures are cross-cut by the regional joints that are parallel to the axial trace of the regional LAFB fold. Development of this conceptual model of fracturing is discussed in detail in the Phase I report.

The direction of groundwater flow at the Quarry Site in the vicinity of the drum removal source areas, is approximately east to west. Shallow bedrock groundwater flowing through or recharging to the upper tier and upgradient areas, discharges locally to the lower tier, in part along shallow and steep fault zones. Deeper groundwater discharges farther downgradient along the WBGB and adjoining wetlands. Detailed description of geologic structure and its relationship to groundwater discharge at the site is provided in the Phase I Site Data Report (HLA, 1998b) and the final OU 12 RI (ABB-ES, 1997). Hydraulically significant fault structures are not evident within the upper tier and Quarry rim areas of the site.

Based on the compilation of all Phase I and Phase II fracture orientation and frequency data, the general frequency of these fractures has been further refined. The general conceptual model block of Quarry rock dimensions of 10 feet by 10 feet by 10 feet. This unit of rock typically contains one to two bedding plane fractures (1.5 on average), one axial plane fracture and two steeply dipping regional joints. Both the axial plane fractures and the regional joints cross-cut the bedding plane fractures. This conceptual model is illustrated in Figure 3-1.

Based on multiple borehole observations, the extent of weathering or oxidation is greatest around the bedding plane fractures, likely due to the fact that lithologic variations in the carbonate and detrital mineralogy also parallel bedding. The degree of oxidation in vertically dipping axial and regional fractures is markedly less and more variable. Average thickness of oxidation rinds surrounding bedding plane fractures may be somewhat less than half an inch in the top 100 feet of bedrock. Observations of deeper bedrock in JBW-7816 (100-150 feet bgs) suggest that fractures are less frequent and that such weathering is not present.

Porosity data collected adjacent to weathered fractures suggest matrix porosity values can be as high as 4 percent, and probably higher locally at the fracture surface. Unweathered rock has a matrix porosity typically less than 0.5 percent, often as low as 0.2 percent. Foc data from both oxidized and unoxidized core indicate foc between 1.4 and 1.6 percent. This value may be biased high due to the amount of inorganic carbon in the limestone. Literature indicates the average organic content of ancient limestones to be about 0.2 percent (Gehman, 1962).

Hydraulic Conductivity and Water Transmission in the Fracture Network. Specific capacity data review indicates low values for rock in the source area at the Quarry. A short duration, qualitative pumping test was conducted in JBW-7817A with observation of water levels in surrounding wells. These data are contained in Appendix H. Due to the short duration of the test (4 hours), only one observation well (JBW-7817B) provided sufficient time- drawdown data that could be used to estimate bulk hydraulic conductivity (K). The bulk K estimate from this well is 0.08 ft/day, and is likely to be an upper limit of "average K".

Figure 2-4 provides a review of the borehole flow measurement data and indicates the magnitude and frequency of ambient flow in the three fracture types in the conceptual model. Clearly, the volume of water transmitted and the frequency of water-bearing fractures is dominated by the bedding plane fractures. The regional joint fractures appear to be less frequent, however, it is important to recognize this is due largely to the steep (75-85 degree) dip angle of that fracture set.

The average aperture of these fractures is hard to estimate, but based on rock core and BIPS images, they are known to be very small. An aperture in the range of 0.006 inches (0.00050 feet) is probably reasonable for the average bedding planes, and 0.002 inches (0.0002 feet) is probably reasonable for the other axial and regional joints. These estimates were made by visual comparison to a feeler gauge that has gradations of 0.002

inches. Given the estimated bulk K and fracture frequency, these values for fracture aperture are reasonable according to theoretical calculation methods provided by Cherry, (Cherry, 1997). With these small apertures, advective velocities in the fractures should be relatively high. Fracture K may be on the order of 1380 ft/day at the Quarry Site (see calculations in Appendix H). The bulk K is low due to the frequency of the fractures and the low storage capacity of the fracture network. Average linear seepage velocity is then a function of fracture tortuosity and gradient and is estimated to be in the range of 270 to 625 ft/day at the Quarry (see Appendix H).

Based on these estimates of fracture frequency, aperture, matrix porosity, and weathering rind thickness for individual fractures, a spreadsheet calculation of water storage in the bedrock unit block (10x10x10) was developed. This calculation is presented in Appendix I, with other calculations of contaminant mass storage and clean-up time estimates. These water storage estimates are summarized below:

Water Storage	Oxidized Matrix (gal)	Fractures (gal)
Bedding planes	1.07	0.65
Axial planes	0.04	0.13
Regional Joints	0.15	0.26
Total bedrock unit block	1.26	1.04

The water stored in the matrix should be considered as immobile, compared to water stored in the fractures. Although advection is likely to occur in the oxidized matrix to a limited extent, the dominant contaminant mass transport process in the weathered rock matrix is likely to be diffusion.

Phase Relationships and Storage Mechanisms for Contaminant Mass. The principal storage mechanisms for DNAPL has not changed significantly in the conceptual model but the concepts have been refined in terms of distribution. Fracture specific distribution of contaminants present in the system is reflected by the MERC data presented in Table 2-1. These data suggest that the majority of the contaminant mass (possibly in excess of 70 percent) is associated with the bedding plane fractures (most frequent and highest concentration detections). Conceptually this makes sense considering the frequency of hydraulic activity in the bedding planes discussed previously.

The mass extracted as part of the MERC sample analysis was subsequently averaged by fracture type and applied to the unit volume of the oxidized aquifer material assigned to the fractures in the conceptual model. This value was subsequently applied over the entire area inferred to represent the residual source area in the bedrock to estimate "extractable mass" represented by the MERC data. This value was then compared to the mass that is believed to fluxing out of the system in groundwater flux was estimated at two cross sections through the plume. The cross sections included the lower tier discharge fault (JBW-7812) and the source area JBW-7817/JBW-7816. The estimated mass flux at both sections were reasonably close (0.7 kg/year PCE and 1.0 kg/year PCE respectively in Appendix I). These mass flux values were roughly twice the total mass represented by the MERC extraction data averaged over the source area. MERC extractable mass is possibly representative of the mass stored in the aqueous phase in the weathered rock adjacent to the fractures, (i.e., immobile groundwater in the weathered matrix porosity which is in equilibrium with sorbed contaminants and DNAPL phases in nearby fractures). Given this improved understanding of the MERC data, it is still possible to use the data as an indirect indicator of the presence of DNAPL or large masses of sorbed solvent in the matrix porosity. For material with a given range of porosity of 1-4 percent, MERC concentrations in excess of approximately 1 to 2 mg/kg (µg PCE/g rock) are probably indicative of a pore water mass that is in equilibrium with DNAPL or a high concentration of sorbed solvent. This relationship is easily calculated from the unit mass of contaminant stored in porosity at or near solubility (see Appendix I).

Partitioning of the DNAPL phase in fractures to sorbed and aqueous phases within the matrix adjacent to the fractures will be most strongly influenced by the foc in the formation. PCE has a moderate partitioning coefficient (Koc) and will be relatively strongly partitioned to organic matter if present in high concentrations. The foc data results from rock core (14,000 – 16,000 mg/kg) are very high (1.4 – 1.6 percent) and if high, may not provide a realistic value to assess the partitioning of contaminant mass within the system. For example, if 1,500 mg/kg of PCE is stored in a low porosity matrix (2.5 percent) with 1.4 percent foc, approximately 80 percent of that mass will be distributed as sorbed material and approximately 10 percent as NAPL in adjoining fractures or open porosity. Under these same conditions with 0.14 percent foc, about 92 percent of the mass would be stored as NAPL in the fractures (equivalent to a residual saturation of 8.8 percent in matrix porosity), and about 8 percent of the mass would be stored as sorbed material (see Appendix I). Foc has a profound effect on partitioning of phases within the system. Thus for the purpose of the conceptual model, it is likely that the distribution of phases falls somewhere within these bounds. With no sorption, a PCE mass as low as 10 mg/kg is potentially indicative of very low (less than 0.05 percent) DNAPL residual saturation within the fracture/weathered matrix system.

Summary. The site conceptual model has progressed from refinement of the overall geologic structural model, to consider the frequency, type and interconnectedness of fractures, and finally storage mechanisms for contaminant mass within fractures and oxidized porosity in bedrock adjacent to those fractures. In the areas surrounding JBW-7816 and JBW-7817 and JMW-0201, it is believed that PCE was released and migrated vertically through axial plane and regional joint fracture systems, to the bedding plane fractures where a majority of the solvent mass appears to be stored, as residual sorbed mass and potentially as low residual concentrations of DNAPL in fractures and possibly within weathered matrix. The findings of this investigation with regard to DNAPL presence, distribution and accessibility are summarized in Section 4.0.

4.0 NAPL DECISION CRITERIA EVALUATION

4.1 NAPL PRESENCE

DNAPL has not been directly observed in borehole sumps, or through Sudan IV dye staining of rock samples, return waters or bailer samples. However based on dissolved phase groundwater and MERC data for PCE it is likely that residual PCE DNAPL is present in the study area.

The primary indicators of the presence of a residual PCE DNAPL are dissolved phase groundwater PCE concentrations greater than 1 percent of the solubility limit of PCE and MERC PCE concentrations greater than 2 mg/kg. This threshold criteria were exceeded in boreholes JBW-7816 and JBW-7817A located in the upper tier in DRSA 3 as well as the area surrounding JMW-0201 and JBW-7814. Based on these indicators, it is believed that DNAPL is present in the fractured bedrock system.

In DRSA 1 and 2 threshold criteria for PCE in MERC and dissolved phase groundwater results were not exceeded. LNAPL, primarily consisting of petroleum – based constituents, is present to varying degrees in all three DRSAs.

4.2 NAPL DISTRIBUTION

The distribution of PCE at concentrations that suggest DNAPL is relatively well defined. Using threshold criteria of dissolved phase PCE concentrations exceeding 1 percent of the solubility limit and MERC PCE concentration exceeding 2 mg/kg, it is possible to reasonably approximate horizontal and vertical bounds to the distribution of PCE that is likely related to residual DNAPL.

As discussed in Section 4.1, the horizontal distribution of PCE DNAPL appears to be confined to the upper tier of the Quarry around DRSA 3 and the area near JBW-7814 and JMW-0201. The lateral limit for DNAPL is not constrained to the north by JBW-7817A. Vertical distribution in these areas appears to be primarily confined to the upper 100 feet of bedrock (see also Figure 2-3). Although some deeper detections of PCE are apparent in JBW-7816 at greater depth (up to 149 feet bgs), those concentrations are below the threshold criteria for DNAPL.

The DNAPL appears to be related primarily to the bedding plane fractures that strike NW-SE and dip from 20 to 50 degrees to the NE.

4.3 NAPL HYDRAULIC ACCESSIBILITY

The hydraulic accessibility of residual contaminants is fundamental to the potential effectiveness of any remedial strategy implemented in bedrock.

The hydraulic accessibility of residual contaminants, which include both sorbed phases of PCE and PCE in DNAPL form will be dependent on the distribution within the fracture system and matrix relative to where groundwater flow is occurring in that system, and the time required for advective and diffusional processes to convey treatment reagents to that contaminant mass. Three lines of evidence suggest the DNAPL and other contaminant phases have a reasonable probability of being accessible under ambient flow conditions. In addition to these lines of evidence, there are several important areas of uncertainty which will ultimately affect overall hydraulic accessibility. These three lines of evidence and associated uncertainties are identified summarized below.

Lines of Evidence for Reasonable Degree of Hydraulic Accessibility

1. The distribution of contaminant mass is weighted to the bedding plane fractures based on MERC data, and to some degree, the packer sampling results. The ambient flow within the system, characterized by HPFM, favors these same fractures, and also shows appreciable flow in the other fractures as well. The fracture flow system and corresponding fracture flow regime appears to be reasonably uniform, and singular dominant geologic faults or dominant large fractures are not present. Thus, it is reasonable to expect that under ambient flow conditions and an adequate number of injection wells, a well distributed treatment zone could be established. DNAPL stored in fractures within the treatment zone should, to a reasonable extent, be hydraulically accessible under ambient flow conditions.

2. MERC sample data indicates that contaminant mass adjacent to fractures is accessible to methanol in an extraction process that is likely to be dominated by diffusion. Thus, PCE mass adjacent to fractures should also be accessible to treatment reagents (e.g. oxidants) through diffusion mechanisms, so long as reagents can be effectively delivered to the fracture.

3. The thickness of the oxidized zones around the fractures are not appreciably thick. Therefore, the time for diffusion to transport reactants from the fracture to the weathered, oxidized rind surrounding the fracture is small. Using a one dimensional diffusion equation (see Appendix I), the matrix would theoretically reach 78 percent of the fracture reactant concentration in 4 days, and 90 percent in 18 days. Thus, fairly rapid delivery of the reactant to the immobile water and PCE mass located in the weathered fracture matrix is also not an unreasonable expectation.

Uncertainties

1. The maximum distance from the fracture surfaces that a significant contaminant mass could potentially migrate by diffusion is unknown. If the low porosity of the fresh rock matrix is reasonably well connected, it would not be unreasonable to expect appreciable dissolved mass to be distributed beyond the weathered matrix in less accessible portions of the competent bedrock.

2. The amount of contaminant mass that is associated with dead-end or otherwise hydraulically isolated fractures, (either as DNAPL or sorbed phases) is unknown. Both MERC and packer data with greater depth in JBW-7816 (120-150 feet bgs) suggests some migration and residual mass is associated with deeper, hydraulically tight, fractures. This could also be typical of dead-end fractures throughout the system. The ability to hydraulically access these fractures is uncertain, although it is not expected that dead-end fractures will be readily accessed, if at all, compared to the higher K fractures.

4.4 NAPL VOLUME ESTIMATES

The methodology and supporting calculations developed to estimate DNAPL volumes are presented in Appendix I. This Appendix also contains estimates of clean-up times for a range of spill volumes, under several treatment and non-treatment scenarios.

The volume of contaminant mass partitioned as DNAPL in the bedrock system is difficult to confirm due to uncertainties in the following:

- the original spill volume;
- the foc of the bedrock and the degree of partitioning to sorbed phases in the weathered rock adjacent to the fractures; and,
- the mass of dissolved contaminants that have potentially diffused to the rock matrix beyond the weathered rinds surrounding fractures.

In light of these considerations, a range of potential spill volumes was developed that could be described in terms of residual DNAPL and residual sorbed phases within the conceptual model of the fractured bedrock at the site. The purpose of this approach was to allow a range of clean-up time and cost estimates to be developed for BCT review. Based on the fact that DNAPL has not been observed in any of the wells, and the rock mass did not show abundant and persistent indications of pervasive or gross contamination, it is presumed that the maximum residual DNAPL content is likely to be less than 10 percent. This provides an upper bound for the total mass that can be expected in the bedrock system. The amount of residual DNAPL is highly dependent on the foc. The initial range of spill volumes considered to be upper bounds at corresponding foc values, included a 40 gallon spill at foc of 0.014 percent, a 121 gallon spill at an foc of 0.14 percent and a 242 gallon spill at an spill at an foc of 1.4 percent. At the request of the MEDEP a spill volume of 12 gallons has been included as a minimum value for this range.

To illustrate the importance of foc, if 242 gallons of PCE were contained in the system at an foc of 1.4 percent, approximately 145 gallons of that mass would be partitioned as residual DNAPL and the remaining 97 gallons would be stored as sorbed and dissolved phases. To what extent DNAPL is able to enter the weathered matrix adjacent to fractures is unknown and the majority of the DNAPL is therefore presumed to reside within the fracture apertures. A 40 gallon spill at 1.4 percent foc could result in no residual DNAPL, since this total mass could be completely accounted for by partitioning as a sorbed phase. If foc is varied one order of magnitude to 0.14 percent, a 40 gallon spill within the system could result in approximately 31 gallons of residual DNAPL, and 38.9 gallons at an foc of 0.014 percent. To keep these volumes in perspective, the site conceptual model for the fractured bedrock would store approximately 785 gallons of water in the fracture system with approximately 900 gallons of additional storage in the weathered porosity adjacent to the fractures. This yields a total storage volume of 1685 gallons, within and immediately adjacent to the fracture network. At an average porosity of 0.5 percent, the remaining bedrock matrix could store an additional 3,750 gallons of water.

The estimated range of residual DNAPL present at the Quarry site considered in subsequent evaluations is 12 to 145 gallons. It is likely that the lower end of this estimate is closer to site conditions based on the lack of evidence of extensive quantities of PCE in drums and soil from the drum removal action. The basis for these estimates is included in Appendix I.

Also included in Appendix I, are cleanup time estimates for these spill volumes under no-action scenarios. Although simplistic, these estimates are based on the site conceptual model, and on the assumption that biological processes cannot effectively degrade the residual mass in the source area until most of the DNAPL is removed first by advection. Based on this basic approach, which is described in detail in Appendix I the contaminant mass represented by a 242 gallon spill would persist for at least 1,152 years and 12 gallon spill would persist for at about 168 years

4.5 PILOT APPROACH AND TECHNOLOGY EFFICIENCY

The pilot technology selected for evaluation at the Quarry was in-situ chemical oxidation using potassium permanganate as the oxidant. The technology selection is discussed in detail in the Preliminary Analysis of Alternatives Report (PAAR) (HLA, 1998). In this application, permanganate would be injected just up gradient of the source area and within the source area, at concentrations sufficient to drive first order reaction kinetics. Potassium permanganate has a high solubility (63,800 mg/L) and favorable reaction kinetics are attainable. The compound is considered a moderate oxidant that involves direct electron transfer or free radicals based on pH. The balanced equation of permanganate oxidation of PCE is provided below:

$2KMnO4 + C_2Cl_4 = 2CO_2 + 2MnO_2 + 2KC1 + 2HC1$
(2 moles oxidant to 1 mole PCE constitutes one stochiometric ratio).

The principal advantage of the permanganate over other oxidants is its persistence and prolonged reactivity allowing it time to diffuse into areas such as weathered rock matrix, where contaminant mass is also retained. Primary disadvantages include precipitation of Mn oxides (pyrolusite) which could partially clog the aquifer, and potential for increased dissolved Mn concentrations that could pose ecological risks at groundwater discharge locations.

During pilot evaluation, injection of permanganate would occur in a closely space fence of reagent delivery wells depicted in Figure 4-1. Up to one stochiometric ratio of permanganate would be injected, based on an estimate of the PCE mass contained in the source area. During pilot evaluation, down gradient wells would be monitored for non-reacted permanganate, Cl, Mn, and other inorganics, VOCs, TOC, and GRO. This would allow assessment of the hydraulic mixing/dispersion and gross loss of reagent within the fractured bedrock system, as well as changes in target contaminant concentrations. If the pilot phase proved favorable, full scale implementation could occur by continuation of reagent injection up to an estimated five stochiometric ratios, including injection source area wells within the upper tier, including potential installation of three additional wells in the existing casings located upgradient of JBW-7814/ JBW-7815. Other wells or injection type galleries could also be installed as interpretation of conditions may warrant.

The pilot technology efficiency is dependent on numerous factors including but not limited to: 1) the ratio of contaminant mass to the concentration and rate that permanganate can be delivered, 2) the oxidative demand exerted by the ambient condition of the aquifer matrix, 3) the treatment time and the depth to which significant contaminant mass has diffused into the bedrock, and 4) hydraulic conditions.

Because of the relatively uniform groundwater flow conditions, it is believed that a reasonably efficient transfer of the permanganate to a large portion of the aquifer fracture system and adjacent matrix can be achieved. However, due to the low hydraulic capacity of the fractured bedrock, the permanganate would need to be added at very high concentrations (in the 0.5 to 1 percent) range to achieve target mass ratios in a reasonable treatment time frame. This could potentially result in unacceptably high concentrations of unreacted permanganate and deposition of manganese oxides in the discharge areas in the lower tier and the WBGB. Achievable destruction efficiencies may be in the middle to high ninety-percent range for portions of the aquifer that are accessible hydraulically. For contaminant mass within the aquifer that is less accessible (e.g., deeply diffused matrix contaminants, dead-end and extremely low K fractures), it is not expected that efficient transfer of reagents and effective mass destruction would occur. The amount of untreated mass that these sources encompass is uncertain. Based on input from the BCT, a lower bound of 80 percent treatment efficiency was used in the clean-up time frame estimates contained in Appendix I. Eighty percent mass removal may be optimistic. In addition, loss of hydraulic capacity in the aquifer may result from precipitation of manganese oxides (pyrolusite), further limiting hydraulic accessibility. An estimate of the amount of pyrolusite formed in the treatment process is provided in Appendix I.

Depending upon the spill size, and the manner in which contaminants are partitioned, a certain percentage of original mass will need to be destroyed before matrix and fracture concentrations decline to a point where biological processes can effectively reduce residual sources. If aggressive treatment levels can be achieved, and sources of carbon are still available and sufficient to support biological activity, it is estimated that approximately 82 years of biological degradation and matrix diffusion may be required to reduce remaining groundwater concentrations to acceptable levels. Therefore any treatment scheme would also require up to 82 years of long term monitoring after removal of DNAPL.

The amount of reagent and the time required for treatment is also dependent on the oxidative demand exerted by the aquifer matrix. Aqueous TOC results are between 8 and 21 µg/L and would suggest a limited oxidative demand in the ambient groundwater. However, if foc in rock is significant, (1.4 to 1.6 percent), it potentially could signal a much higher oxidative demand from the rock matrix. The ambient oxidative demand is a very important and potentially the largest uncertainty that could have very significant consequences on the effectiveness and cost of permanganate oxidation.

4.6 PILOT TECHNOLOGY COST EFFECTIVENESS

Based on the current conceptual model of the site, and how a treatment system would be expected to function, it is not an unreasonable expectation that a large portion of contaminant mass could be destroyed in-situ. However, due to uncertainties in the ultimate mass of PCE and fuel related contaminants stored as NAPL, sorbed or diffused phases, uncertainties in the amount of ambient oxidative demand from the aquifer matrix, and the hydraulic efficiency of the system, a definitive remedial cost cannot be established. A cost range is provided in Appendix J-1 and J-2 for several treatment scenarios and a Groundwater Management Zone Alternative. The treatment scenarios are based on injection of permanganate as a means of delivering the reagent in the treatment wells. The aquifer oxidative demand is reflected in the sensitivity analysis on reagent cost and treatment, assuming an effective range of 0.014 to 0.00014 for direct aquifer matrix oxidative demand as organic carbon.

The range of present worth costs for treatment of a 12 gallon spill up to a 242 gallon spill vary from at least $1,139,290 to $17,120,130 depending on the amount of aquifer matrix oxidative demand. Clearly, all the previously mentioned uncertainties make evaluation of cost effectiveness extremely difficult.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Review of the Phase II site investigation results and subsequent evaluation of potential effectiveness of in-situ chemical oxidation as a treatment technology suggest DNAPL to be present and that it may be hydraulically accessible. However, there are some very important uncertainties, some of which cannot be quantified, which make it difficult to predict both the ultimate efficiency and cost effectiveness of the treatment technology. These uncertainties include the actual mass of contaminants present, the amount of contaminant mass which is inaccessible to the reagents, the actual time required to achieve acceptable levels of treatment, and ultimately, the total cost to effectively treat the residual source area.

In addition to these uncertainties, implementation of treatment poses potential for impacts on the aquatic environments in the lower tier and potentially within the WBGB wetland, which cannot be quantified at this time. The site currently poses no risk to existing receptors and future risks can be controlled through alternative approaches (e.g., a Groundwater Management Zone alternative).

Although the technology in theory is promising and the Quarry site has attributes favorable to a pilot implementation, several important technical and source area uncertainties are evident that increase risk of significant change in cost and ultimate success that are not easily controlled or predicted. Based on these uncertainties, and other considerations mentioned previously, it is recommended that a pilot test not be conducted.

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

AFBCA	Air Force Base Conversion Agency
BCT	BRAC Closure Team
bgs	below ground surface
BIPs	Borehole Image Processing System
BRAC	Base Restoration and Closure
BTEX	benzene, toluene, ethylbenzene, xylenes
CVOC	chlorinated volatile organic contaminants
DCE	dichloroethene
DNAPL	Dense Non-Aqueous Phase Liquid
DRO	diesel range organics
DRSA	drum removal source area
FF	Flow Field
Foc	fraction of organic carbon
GPM	gallon per minute
GRO	gasoline range organics
HLA	Harding Lawson Associates
HPFM	Heat Pulse Flow Meter
Koc	hydraulic conductivity
IRP	Installation Restoration Program
LAFB	Loring Air Force Base
LNAPL	light non-aqueous phase liquid
MEDEP	Maine Department of Environmental Protection
MERC	methanol extraction rock chip
mg/kg	milligrams per kilogram
ml	milliliter
mm	millimeter
NAPL	non-aqueous phase liquid
OU	operable unit
PCB	polychlorinated biphenyl

GLOSSARY OF ACRONYMNS AND ABBREVIATIONS

PCE	tetrachloroethene
PID	photoionization detector
PITT	partitioning interwell tracer test
ppbv	parts per billion by volume
PRG	Preliminary Remediation Goals
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RQDs	rock quality designations
SDR	Site Data Report
SI	site investigation
SVOA	semivolatile organic analysis
SVOC	semivolatile organic compound
TOC	total organic compound
TCE	trichloroethene
TMB	trimethyl benzene
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force
USEPA	U.S. Environmental Protection Agency
VOA	volatile organic analysis
VOC	volatile organic compound
WBGB	West Branch of Greenlaw Brook
µg/L	micrograms per liter
µg/g	micrograms per gram
XR	replicate extraction
XT	triplicate extraction

ABB Environmental Services, Inc., 1998. Field Work Notification, Installation Restoration Program, Loring Air Force Base, Maine. April 1998

ABB Environmental Services, Inc. 1997. Basewide Groundwater Operable Unit (OU 12) Final Remedial Investigation Report, Installation Restoration Program, Loring Air Force Base, Maine. December, 1997

Gehman, H.M., Jr., (1962) "Organic Matter in Limestones" Geochem Cosmochimica V. 26 pgs 885-897. 1962

BEDROCK DRILLING LOGS

BOREHOLE GEOPHYSICAL DATA

GROUNDWATER AND ROCK CHIP ANALYTICAL DATA RESULTS

GROUNDWATER SAMPLING LOGS

SPECIFIC CAPACITY DATA

ELEVATION SURVEY DATA

HPFM STRESS TEST DATA

GROUNDWATER PUMPING AND DATA EVALUATION

SPILL VOLUME AND CLEANUP TIME ESTIMATES

SPILL VOLUME CALCULATIONS

CLEANUP TIME CALCULATIONS

MANGANESE OXIDE PRECIPITATE AND PORE WATER AQUEOUS MASS CALCULATIONS

APPENDIX J

COST ANALYSIS FOR REMEDIAL ALTERNATIVES

GROUNDWATER MANAGEMENT ZONE

IN SITU CHEMICAL OXIDATION

CLEANUP TIME RANGES

SUPPORTING CALCULATIONS

RESPONSE TO AGENCY COMMENTS

TABLE 2-1
SUMMARY OF METHANOL EXTRACTION ROCK CHIP RESULTS
LORING AIR FORCE BASE QUARRY PILOT STUDY

BOREHOLE	DEPTH	TYPE	FRACTURE			OXID	PCE ug/gRock	TCE ug/gRock	DCE ug/gRock	CHLORO BENZENE ug/gRock	Total CVOCs ug/gRock	GRO ug/gRock	BENZENE ug/gRock	TOLUENE ug/gRock	ETHYL BENZENE ug/gRock	O,P&M XYLENE ug/gRock	TRI METHYL BENZENE ug/gRock	NAPTH ALENE ug/gRock
			PRIMARY	SECONDARY	COMMENT													
JBW-7816	90	XX	BP			NO	5.633	0.953			6.586	11.839						
JBW-7816	96	XX	AP	RJ		NO						5.761						
JBW-7816	106	XX	BP	AP	MECHANICAL	NO						10.879						
JBW-7816	119	XX	AP		MECHANICAL	NO	0.628	0.288			0.916	4.819						
JBW-7816	128	XX	BP		MECHANICAL	NO						8.169						
JBW-7816	140	XX	BP	RJ	MECHANICAL	NO		0.035			0.035	6.610						
JBW-7816	149	XX	BP		MECHANICAL	NO	0.400	0.151			0.551	10.816						
JBW-7817 A	39	XX	AP			MOD												
JBW-7817 A	44	XX	AP			MOD							0.054	0.406				
JBW-7817 A	49	XX	AP			MOD												
JBW-7817 A	66	XX	BP			STRONG	0.413				0.413					0.057		
JBW-7817 A	76	XX	BP			STRONG	5.452	0.522	0.093	0.118	6.185			0.201		0.036		0.066
JBW-7817 A	76	XR	BP			STRONG	2.470	0.294			2.764			0.094				
JBW-7817 A	83	XX	AP			MOD	0.331	0.076			0.407					0.044		0.038
JBW-7817 A	87	XX	BP	AP		MOD	0.931	0.161			1.093					0.000		
JBW-7817 B	15	XX	BP	AP		WK/MOD								0.092	0.046	0.073		
JBW-7817 B	20	XX	BP		BP W/PID 10.2	WK						8.241						
JBW-7817 B	23	XX	BP		BP W/PID 225	WK								0.107	0.076	0.360	0.133	
JBW-7817 B	23	XR	BP		BP W/PID 225	WK						9.009		0.077	0.068	0.306	0.071	
JBW-7817 B	23	XT	BP		BP W/PID 225	WK		0.102			0.102			0.054		0.112		
JBW-7817 B	34	XX	BP		BP W/PID 2.8	STRONG						8.235						
JBW-7818	57	XX	BP			STRONG		0.065			0.065		0.121	0.183	0.042	0.082	0.031	
JBW-7818	63	XX	BP			MOD		0.057			0.057		0.144	0.141		0.040		
JBW-7818	64	XX	BP			MOD		0.083			0.083		0.062	0.060				
JBW-7818	64	XD	BP			MOD		0.062			0.062	3.360	0.062	0.051				
JBW-7818	68	XX	BP			MOD		0.077			0.077	3.218	0.056	0.053				
JBW-7818	77	XX	BP		MECHANICAL	NO		0.100			0.100							
JBW-7820	37	XX	AP		AH BOREHOLE	MOD		0.062			0.062	2.362		0.022		0.026		
JBW-7821	18	XX	AP			MOD												
JBW-7821	24	XX	AP	RJ		WK/MOD		0.663			0.663							
JBW-7821	32	XX	AP			STRONG												
JBW-7821	39	XX	BP			MOD		1.517			1.517							
JBW-7821	47	XX	AP			WK												

TYPE
XX = ORIGINAL EXTRACTION
XR = REPLICATE EXTRACTION
XT = TRIPLICATE EXTRACTION
XD = EXTRACT DUPLICATE (NOT A DUPLICATE EXTRACT)

Blank cells = Non Detect

OXID
WK = WEAK
MOD = MODERATE
STRONG = STRONG
MECH = POSSIBLE MECHANICAL BREAK ALONG FRACTURE PLANE

FRACTURE
AP = AXIAL PLANE
BP = BEDDING PLANE
RJ = REGIONAL JOINT

Table 2-2
Borehole Geophysical Results Summary

Phase II Data Report and Interpretation
Additional Site Characterization

Quarry Pilot Study
Loring Air Force Base Maine

Exploration	Borehole Summary
JBW-7814	Structure. Eight fractures exhibiting a bimodal distribution were observed in the borehole. One set bears N 10 W dipping 17 and 60 NE, the other strikes N 60 E dipping 60 SE. Vertical spacing between fractures range from 1 foot to 5 feet and averages 3.6 feet. Fractures exhibit slight to moderate oxidation. Bedding strikes predominantly N 10 E dipping 32 SE Flow. Evaluation of vertical flow meter results indicates water enters the borehole from immediately below casing. Water moves downward at a rate ranging between 0.14 and 0.07 gpm exiting the borehole from a fracture at 25.9 feet striking N 5 W dipping 61 NE and from fractures at 37.4 feet bgs striking N 72 E dipping 62 SE. No measurable flow was observed from 37.4 feet bgs to the bottom of the borehole. Other. Sweet smelling odor was noted on the 32 to 37 foot core drilling run and the 37 to 42 foot run.
JBW-7815	Structure. Thirteen fractures exhibiting a bimodal distribution were observed in the borehole. One set bears N 0 E dipping 45 and 70 E, the other strikes N 80 W dipping 50 to 75 SW. Vertical spacing between fractures range from 0.5 foot to 9 feet and averages 2.1 feet. Fractures exhibit slight to moderate oxidation. Bedding appears to strike predominantly N10 E dipping 40 to 60 SE Flow. Elevation of vertical flow meter results indicates water enters the borehole from a fracture bearing N 13 E dipping 76 NW and moves downward at a rate of 0.02 gpm. Water exits the borehole from a fracture at 40.5 feet bgs bearing N 87 E dipping 78 NW.

Table 2-2
Borehole Geophysical Results Summary

Phase II Data Report and Interpretation
Additional Site Characterization

Quarry Pilot Study
Loring Air Force Base Maine

Exploration	Borehole Summary
JBW-7816	Structure. Twenty-two fractures were observed in the borehole. Fractures strike predominantly N 70 E dipping 35 to 70 SE. Other fractures bear N 10 E and dip 10 to 40 SE. Vertical spacing between fractures range from 0.5 feet to 9 feet and averages 2.5 feet. Bedding strikes N 5 E and dips 20 to 30 SE. Flow. Water enters the borehole from immediately below the casing. Additional water enters the borehole from a fracture at 21.3 feet bgs bearing N 67 E dipping 38 SE and moves downward at a rate of 0.08 gpm. Water exits the borehole from fractures at 34.5 feet bgs striking N 60 E dipping 37 SE and at 58.6 feet bgs striking N 5 E dipping 16 SE. Other. Fuel odor noted at 56.2 feet.
JBW-7816 extended	
JBW-7817	
JBW-7818	
JBW-7819	Structure. Two predominant sets of fractures appear, one bears N 30 W and the other N 70 E. Vertical fracture spacing is on the order of one every foot. Fractures are moderately to highly weathered. Bedding appears to strike N 50 W and dip 25 to 35 SW. Flow. Water appears to enter the borehole from a fracture at 38 feet bgs bearing N 0 E dipping 52 W and exits the borehole from a large breakout fracture at 44 feet bgs striking N 0 E dipping 68 W.

Table 2-2
Borehole Geophysical Results Summary

Phase II Data Report and Interpretation
Additional Site Characterization

Quarry Pilot Study
Loring Air Force Base Maine

Exploration	Borehole Summary
JBW-7820	Structure. Thirty-six fractures were observed and show a tendency to be associated primarily with bedding plane type fractures. Bedding features strike N 15 E and dip 40 to 60 degrees SE. Flow. Heat pulse flow measurements were not collected. Borehole was dry to 101 feet bgs. Water does seep into the borehole from a highly weathered fracture at 37 feet bgs. Other. Due to lack of borehole fluid this borehole was not recommended to be packer sampled.
JBW-7821	Structure. Nineteen fractures were profiled and show a tri-modal distribution where bedding plane, axial plane, and regional joint type orientations are apparent. Bedding features strike N 5 E and dip 15 to 30 degrees SE. Flow. Under non-pumping conditions flow

Table 2-4
Summary of Rock Chip Sample Results

Phase I Data Report and Interpretation Additional Site Characterization

Quarry Pilot Study
Loring Air Force Base, Maine

	PCE	TCE	PCE	TCE	PCE	TCE
	(µg/L extract)		(µg/ sample)		(µg/g rock)	
JBW-7814 at 22 feet	bd	33	bd	2.3	bd	0.03
JBW-7814 at 34 feet	41000	980	4900	120	126	3.1
JBW-7814 at 37 feet	850	31	100	3.7	1.3	.05
JBW-7815 at 21 feet	bd	bd	bd	bd	bd	bd
JBW-7815 at 41 feet	2700	120	190	8.4	1.6	0.08
JBW-7816 at 56 feet	2300	100	160	7	1.9	0.08
JBW-7816 at 59 feet	2600	140	180	9.8	nd	nd

PCE = tetrachloroethene
TCE = trichloroethene
µg/L = micrograms per liter
µg/sample = micrograms per sample
µg/g = micrograms per gram
bd = below detection
nd = not determined

Figure 2-4 Breakdown of Hydraulically Active Fractures in Existing Boreholes Phase II Quarry Pilot Test - Loring Air Force Base, Limestone, Maine

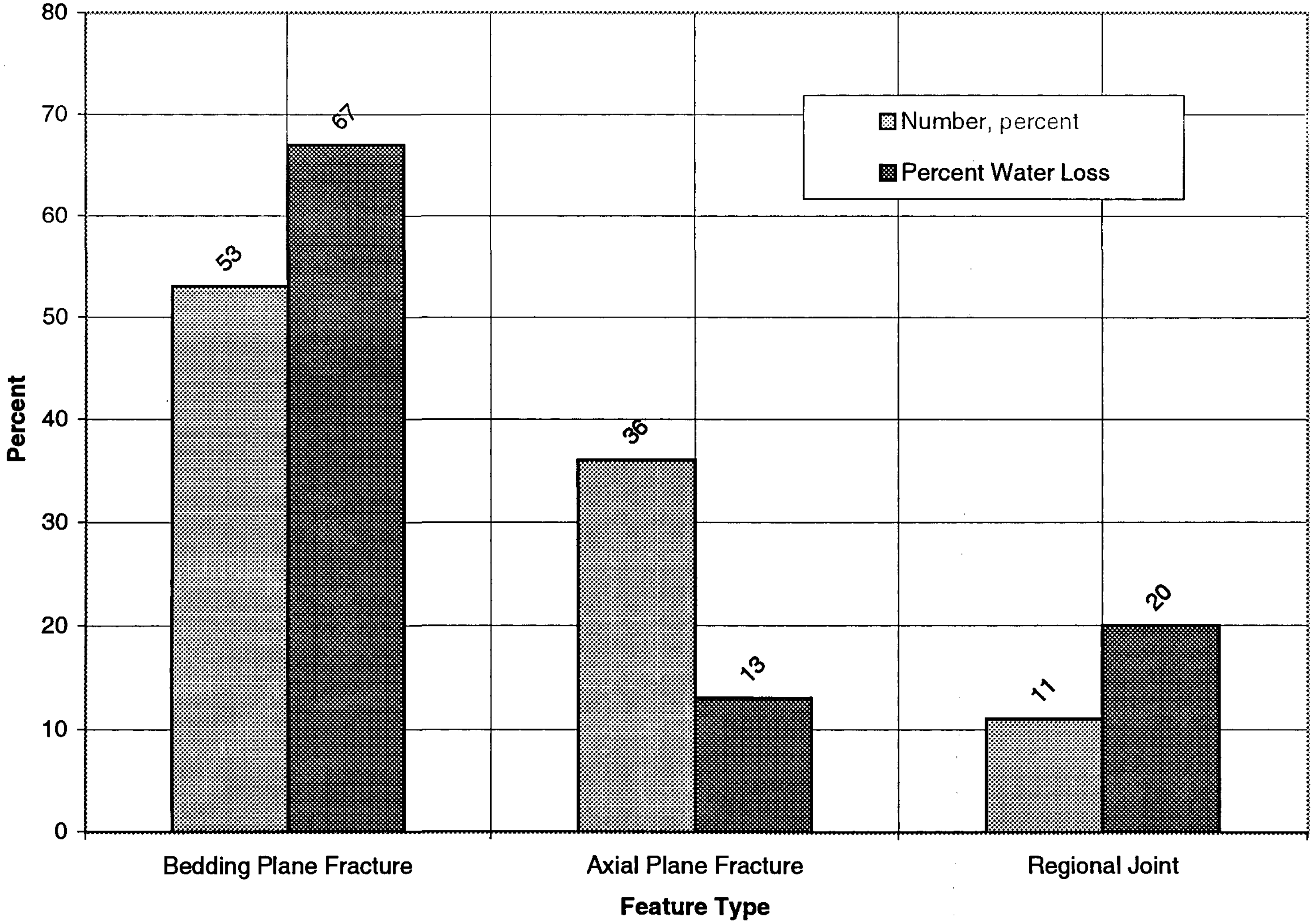
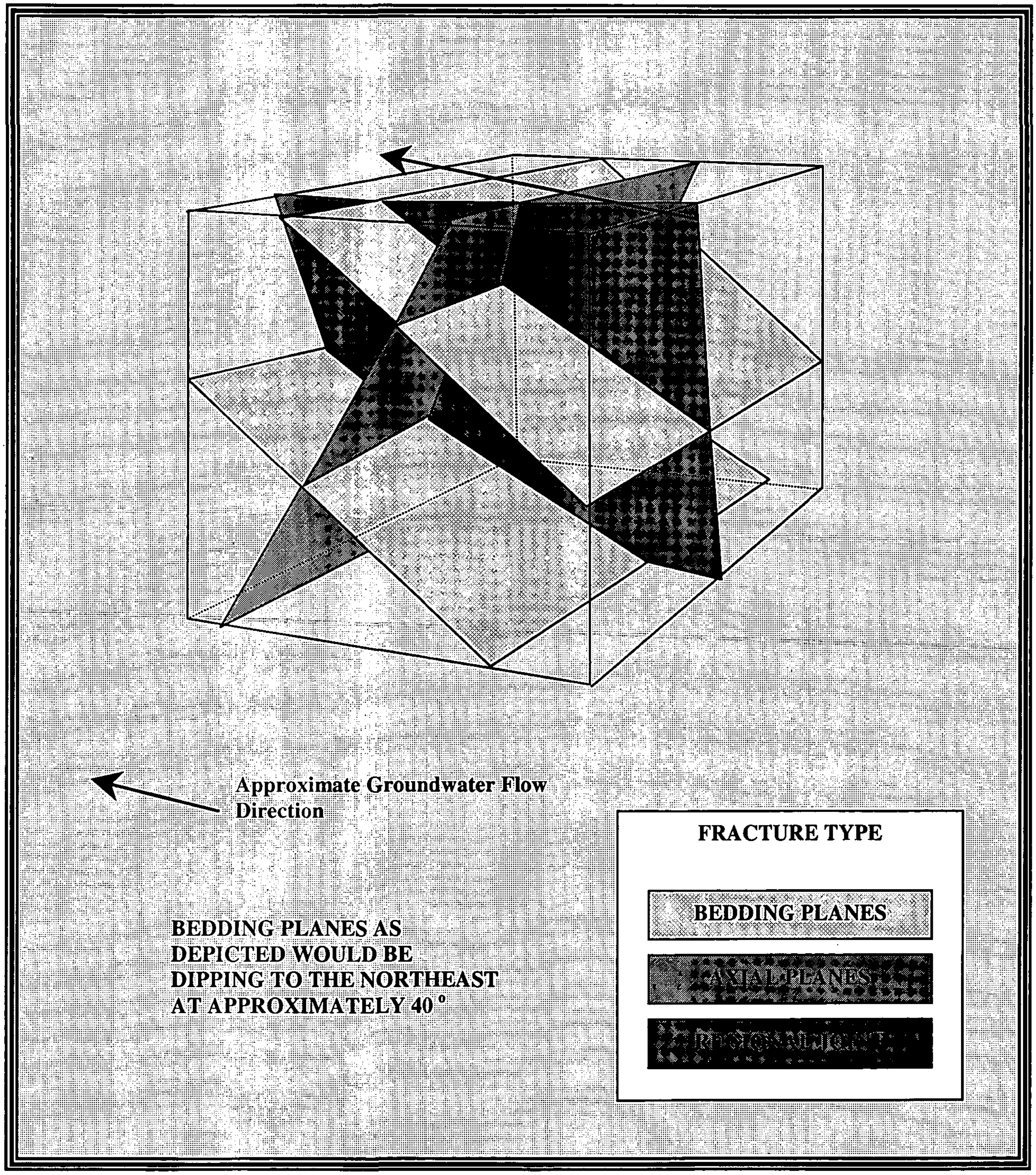


FIGURE 3-1
CONCEPTUAL FRACTURE NETWORK
IN A 10 X 10 X 10 BLOCK OF BEDROCK

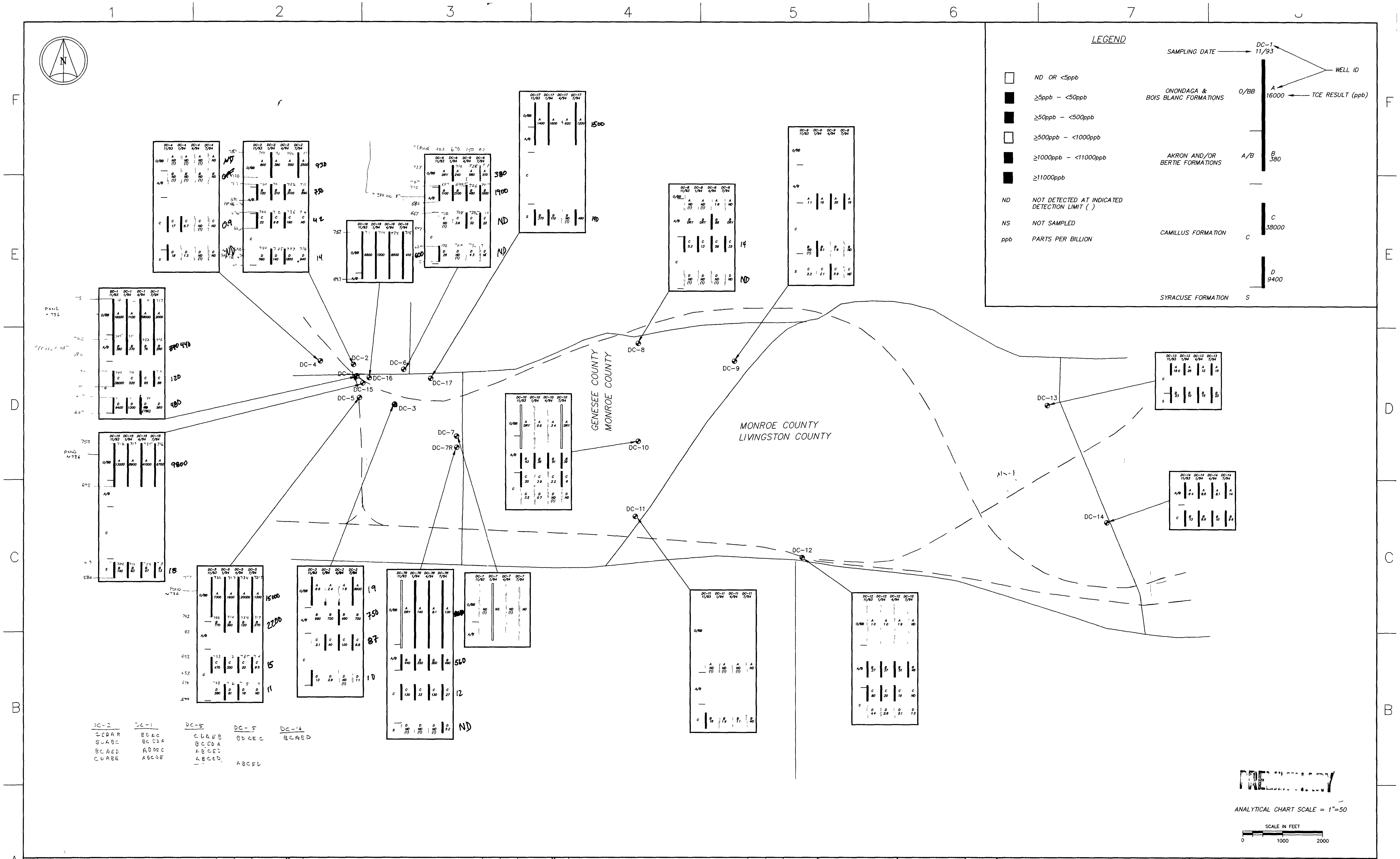
QUARRY PILOT PROJECT
LORING AIR FORCE BASE LIMESTONE, MAINE



BEDDING PLANES AS
DEPICTED WOULD BE
DIPPING TO THE NORTHEAST
AT APPROXIMATELY 40°

Copy

In
Color



LEGEND

☐	ND OR <5ppb
■	≥5ppb – <50ppb
■	≥50ppb – <500ppb
☐	≥500ppb – <1000ppb
■	≥1000ppb – <11000ppb
■	≥11000ppb
ND	NOT DETECTED AT INDICATED DETECTION LIMIT ( )
NS	NOT SAMPLED
ppb	PARTS PER BILLION

SAMPLING DATE → DC-1 11/93 → WELL ID

ONONDAGA & BOIS BLANC FORMATIONS O/BB A 16000 ← TCE RESULT (ppb)

AKRON AND/OR BERTIE FORMATIONS A/B B 380

CAMILLUS FORMATION C C 38000

D 9400

SYRACUSE FORMATION S

DC-2	DC-1	DC-5	DC-5	DC-16
CEDAB	BCDAE	CDAEB	BDAEC	BCAED
EDABC	BCEDA	BCEDA		
BCAED	ABDEC	AECED		
CDABE	ABCDE	ABCED	ABCEL	

NO	REVISIONS	MADE	CHK	DATE	NO	REVISIONS	MADE	CHK	DATE	NO	REVISIONS	MADE	CHK	DATE

NAMES		DATE
DRAWN	DAM	10/5/94
DESIGN	S CHOINIERE	10/5/94
CHECKED	S CHOINIERE	10/5/94
PE		
APP'D		
APP D		
APP D		

ANALYTICAL SUMMARY TCE

LEHIGH VALLEY RAILROAD DERAILMENT SITE
NYS DEPARTMENT OF ENVIRONMENTAL CONSERVATION
WORK ASSIGNMENT NO D 002520-15
TOWN OF LEROY GENESEE COUNTY NY

DUNN ENGINEERING COMPANY
DIVISION OF RUST ENVIRONMENT & INFRASTRUCTURE

PROJECT NUMBER 35090 400 DATE 10/5/94
RUST DWG NUMBER 35090-01 FILE NUMBER
CLIENT DWG NUMBER SHEET NUMBER
CAD FILE NAME
PLOT DATE 10/5/94