DRAFT FINAL
REMEDIAL INVESTIGATION ADDENDUM
MONITORING EXPANSION REPORT
DRY CLEANING FACILITIES STUDY AREA
FORT RILEY, KANSAS

Prepared for
United States Army Engineer District, Kansas City
CENWK-EP-EG
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Kansas City, Missouri 64106-2896

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March 1998

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A MEMBER OF THE BERGER GROUP

March 24, 1998

Commander
U. S. Army Engineer District, Kansas City
ATTN: CENWK-EP-EG (Rick Van Saun)
601 E. 12th Street
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RE: DACA41-92-0001 Indefinite Delivery Contract for Various Military Hazardous Waste Cleanup Projects at Fort Riley, Kansas
Delivery Order 11, Draft Final Remedial Investigation Addendum Monitoring Expansion Report
Dry Cleaning Facilities Study Area (JH 1021U)

Dear Mr. ~~Van Saun~~: Rick

Louis Berger & Associates, Inc. is pleased to submit 4 copies of the Draft Final Remedial Investigation Addendum Monitoring Expansion Report for the Dry Cleaning Facility Area at Fort Riley, Kansas. Also included in the pocket in the front of the binder are the Response to Comments.

This document has been subjected to Berger's internal Quality Control process prior to release.

Copies have been distributed according to the list found at the bottom of this letter.

Should you have any questions or comments regarding this submission, please contact either Tom Lewis at 201 678-1960, extension 755 or me at the same number, extension 737.

Sincerely,

LOUIS BERGER & ASSOCIATES, INC.

Susan E. Knauf
Program Director

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Responses to Comments

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Appendices

List of Acronyms and Abbreviations

AEC	Army Environmental Center
AOC	Area of Concern
ARAR	Applicable or Relevant and Appropriate Requirement
bgs	Below Ground Surface
BLRA	Baseline Risk Assessment
BOD	Biochemical Oxygen Demand
BRAC	Base Realignment and Closure
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
BTP	Below Top of Pump
°C	Degrees Centigrade
CEMRD	US Army Corps of Engineers, Missouri River Division
CENWK	US Army Corps of Engineers, Northwest Division, Kansas City District
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CHPPM	Center for Health Promotion and Preventive Medicine
COD	Chemical Oxygen Demand
DA	Department of the Army
DCE	Dichloroethylene
DNAPL	Dense Non-Aqueous Phase Liquid
DCF	Dry Cleaning Facility
DCFA	Dry Cleaning Facility Area

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List of Acronyms and Abbreviations (Continued)

DO	Dissolved Oxygen
DRO	Diesel Range Organics
DSR	Data Summary Report
Elev.	Elevation
EPA	Environmental Protection Agency
°F	Degrees Fahrenheit
FFA	Federal Facility Agreement
GRO	Gasoline Range Organics
gpm	Gallons per Minute
IAG	Interagency Agreement
INORG	Inorganics and Water Quality Parameters (in analysis)
KDHE	Kansas Department of Health and Environment
KSWQS	Kansas Surface Water Quality Standards
kg	Kilogram
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
METS	Metals (in analysis)
mg/kg	Milligram per Kilogram
mg/l	Milligram per Liter
MH	Manhole
MRD	Missouri Division Laboratory
msl	Mean Sea Level
MS/MSD	Matrix Spike/Matrix Spike Duplicate
NA	Not Analyzed
Nav	Not Available
NCP	National Contingency Plan
ND	Not Detected (above method detection limit)
No.	Number
NP	Not Planned for Sampling
NR	Not Reported
NS	Not Sampled
NTU	Nephelometric Turbidity Units
ORP	Oxidation Reduction Potential
PA/SI	Preliminary Assessment/Site Investigation
PAH	Polycyclic Aromatic Hydrocarbons
PCE	Tetrachloroethylene (Perchloroethylene)

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List of Acronyms and Abbreviations (Continued)

PID	Photoionization Detector
PP	Priority Pollutant
PQL	Practical Quantitation Limit
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
QCSR	Quality Control Summary Report
RCRA	Resource Conservation and Recovery Act
RI/FS	Remedial Investigation/Feasibility Study
SAP	Sampling and Analysis Plan
SDWA	Safe Drinking Water Act
SVE	Soil Vapor Extraction
SVOC	Semivolatile Organic Compound
SWMU	Solid Waste Management Unit
TAL	Target Analyte List
TCE	Trichloroethylene
TCL	Target Compound List
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
μg/kg	Microgram per Kilogram
μg/l	Microgram per Liter
USAEHA	US Army Environmental Hygiene Agency
USATHAMA	US Army Toxic and Hazardous Materials Agency
U.S.EPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
UST	Underground Storage Tank
VOC	Volatile Organic Compound
VC	Vinyl Chloride

EXECUTIVE SUMMARY

Executive Summary

E.1 Introduction and Background Information

The United States Army Corps of Engineers, Northwest Division, Kansas City District (CENWK), under contract DACA41-92-D-0001, retained Louis Berger & Associates, Inc. (Berger) in support of the Fort Riley, Directorate of Environment and Safety, Installation Restoration Program to perform a Remedial Investigation/Feasibility Study (RI/FS) at the Dry Cleaning Facility (DCF) Study Area comprising the Dry Cleaning Facility Area (DCFA) and the Island area at Fort Riley, Kansas. The Department of the Army (DA)—Fort Riley, the U.S. Environmental Protection Agency (U.S. EPA) Region VII and the State of Kansas Department of Health and Environment (KDHE) negotiated a Federal Facility Agreement (FFA) for Fort Riley, Docket No. VII-90-F-0015 (U.S. EPA, 1991). This agreement, also referred to as the Interagency Agreement (IAG), was signed by DA in August 1990 and by U.S. EPA Region VII and KDHE in February 1991. The IAG became effective on June 28, 1991.

During an initial Site Assessment, the inactive dry cleaning facility (Buildings 180 and 181) was identified for additional study based on unconfirmed reports of the disposal of still bottom residues from the solvent distillation process on to the ground behind Building 180/181 prior to 1980. Field investigations for a Preliminary Assessment/Site Investigation (PA/SI) occurred in February through July 1992. Because the data from the PA/SI clearly indicated the need for further investigation (CENWK, 1992), the parties to the IAG agreed in October 1992 to proceed with the performance of an RI/FS. The RI field activities began in November 1993, and a Draft RI report was completed in November 1994. Regulatory agencies provided review comments and suggestions, and the *Draft Final Remedial Investigation Report Dry Cleaning Facilities Area, Fort Riley, Kansas* was completed in March 1995 (CENWK, 1995). Subsequent to the Draft Final RI, it was decided that an expanded delineation of groundwater contamination was necessary and that, in particular, the Island required further characterization to assist in evaluating compliance with state surface water regulations. In May 1996 the *Work Plan for Monitoring Network Expansion Including Additional Characterization of the Island* (CENWK, 1996b) was prepared in order to develop and execute additional groundwater sampling and analysis to further characterize impacts to the alluvial Island immediately downgradient of the DCFA and identify the potential for deep contamination. This Remedial Investigation Addendum Monitoring Expansion Report (RIAMER) presents the results of this subsequent sampling and analysis.

The Fort Riley Military Reservation is located just north of Junction City in northeast Kansas. Fort Riley covers 101,058 acres, including portions of Riley and Geary Counties. The reservation was founded near the confluence of the Republican and Smoky Hill Rivers, which merge to form the Kansas River. As shown in Figure 1-2 and Figure 1-3, the DCFA consists of the northern and southern building complexes separated by Custer Road. The northern complex consists of a steam-generating plant (Building 184) and the current DCF (Building 183), a metal building and woodframe building, respectively. The southern complex consists of the former DCF (Building 180/181), a limestone/brick building currently used as a warehouse. Figure 1-2 presents the location of the DCFA and the remainder of the Study Area, including "The Island," Tributary A, and Tributary B.

The Island is an approximately 50 acre, undeveloped, wooded area on the floodplain of the Kansas River (Figure 1-2). It has formed from the deposition of alluvial materials by the Kansas River. The Kansas River has continually reshaped the Island through deposition and erosion. The Island has developed into an area of unique ecological importance, as it has become a winter (November through March) roosting area for bald eagles, a threatened species.

The primary contaminants of concern at the DCFA have been determined to be PCE and its breakdown products--trichloroethylene (TCE), *cis*-Dichloroethylene (DCE) and vinyl chloride.

The former DCF (Building 180/181) commenced operations as early as 1915. Laundry operations began in Building 180 in 1915, and dry cleaning operation began in Building 181 in 1930. Laundry and dry cleaning operations ceased at the southern complex in October 1983 and were transferred to the northern complex in Building 183. Stoddard solvent was the cleaning solution used at the DCFA until 1966, at which time tetrachloroethylene (PCE) cleaning solution was used. Two situations have been identified in the Draft Final RI as the mechanisms for releasing contaminants to the environment. The first mechanism that has been identified is leaky sewer lines. PCE may have reached the DCFA building drains and been transported to sanitary sewer lines, where leaky sewers could release PCE-contaminated wastewater to the environment. The second mechanism is discharges to the ground surface on the west side of Building 180/181. Prior to 1966 Stoddard solvents and up to 1980, PCE was released to the environment when still bottoms were dumped on the west side of Building 180/181. To eliminate sources of contamination to the environment, improved DCF waste management practices were invoked and the floor drains in Building 183 were sealed with a cement grout. In addition, the sanitary leaky sewer lines in the DCFA underwent repairs in May of 1994 and additional repairs and rerouting during the June to August period of 1996.

E.2 Current Project Scope and Objectives

Based on discussions and communications between the parties of the IAG subsequent to the Draft Final RI, the original objectives of the additional investigations reported herein were as follows:

- To evaluate the vertical extent of contamination under the Island and specifically the potential for previously undetected deep non-aqueous phase contamination sources;
- To further evaluate the horizontal extent of contamination under the Island;
- To further evaluate the groundwater flow regime under the Island;
- To evaluate the alluvial stratigraphy of the Island; and
- To evaluate what effects, if any, repairs to the sewer lines had on the hydrogeology and contaminant distribution within the DCF Study Area.

In response to discussions regarding the questionable need to expend the necessary time and resources studying the alluvial stratigraphy on the Island, this particular original objective was not met in the sense that the originally contemplated seismic testing and subsurface soil sampling/logging was dropped from the investigative program.

E.3 Expanded Groundwater Monitoring Network and Sampling

To maximize cost effectiveness and reduce adverse impacts to the Island ecology, vibratory driven wells (MicroWells) and piezometers were utilized to install fourteen (14) new monitoring points in May 1996.

From May 1995 through February 1997, groundwater sampling was performed as part of the on-going groundwater monitoring program. Samples were typically analyzed for VOCs and TPH. In addition, in May 1996, the suite of groundwater analyses was expanded from the original VOCs and TPH to include parameters used to assess the existence of and potential for natural attenuation processes. Parameters included methane, ethane, ethylene, total organic carbon (TOC), chemical oxygen demand (COD), nitrate, sulfate, alkalinity, oxidation/reduction (ORP), chloride, orthophosphate, target analyte list (TAL) metals.

Sampling and analysis was performed in general accordance with relevant work plans, with some isolated deviations which did not adversely impact results.

E.4 Updated Description of Geology and Hydrogeology

The new wells and piezometers installed in May 1996 were driven, and so little additional geological information was obtained during their installation other than observation of materials visible from the surface and the inference that the bottom of the alluvial soils are at least as deep as the refusal depth for the deep alluvial wells. Groundwater elevation data were recorded monthly at these locations, along with the existing wells at DCFA, resulting in a greater understanding of the groundwater flow regime across the Island and the relationship between the Kansas River and groundwater flow in the upland.

Groundwater occurs in the bedrock, unconsolidated material, and alluvium. Flow is primarily to the southwest, in both the bedrock and unconsolidated material. The Kansas River controls the groundwater movement on the Island, and flow there is primarily to the south and east. In the area to the north of Custer Road the groundwater table is not present in the unconsolidated material. To the south and southeast of Custer Road the unconsolidated material becomes thicker and groundwater is encountered above the bedrock in these materials.

At low river stage groundwater enters the site through the bedrock, flows primarily to the southwest and discharges into the alluvium. Flow within the unconsolidated material is primarily to the southwest with discharges into the alluvium. High river stage and/or high precipitation events will temporarily alter the flow regime and redirect the groundwater movements within the Island, although discharge is still ultimately from the upland to the river via the Island.

E.5 Data Summary and Evaluation

With regard to the hydrogeology within the DCF Study Area, the combined inception to date results from the RI and the monitoring expansion related groundwater elevation monitoring activities strengthen and further the findings and data trends presented in the Draft Final RI. Inception to date hydrographs illustrate the influence of the Kansas River and precipitation events on the groundwater elevations within the DCF Study Area, with the magnitude of the influence being related to the relative distance from the river and the specific characteristics of the formation in which a well is located.

With regard to contamination data, inception to date sampling and analysis data and the associated analytical data plots, clearly illustrate that the chemical data collected since the submission of the Draft Final RI are consistent with and further support the findings presented in the Draft Final RI. In particular, these data show that:

1. maximum contaminant levels within the DCF Study Area continue to decrease as the center of contaminant mass migrates (although it is noted that, as would be expected, this does not mean that contaminant levels in particular wells located in front of the center of contaminant mass will not show increasing levels of contamination until the center of mass passes them);
2. natural attenuation (including biodegradation) is absolutely occurring to varying degrees within the DCF Study Area; and,
3. there is no evidence that any deep non-aqueous phase contamination exists within the DCF Study Area.

The chemical data are presented in summary format as a series of combined plots and figures. The plots present the change, over time, of the contaminants of concern including PCE, TCE, 1,2-DCE (total) and vinyl chloride. To better focus the analysis, the plots were developed for several different groupings of wells which illustrate:

- background conditions;
- conditions within the unconsolidated materials in bedrock erosional feature in the upland area;
- conditions in the bedrock in the upland area; and,
- conditions within the alluvium beneath the Island.

E.6 Conclusions and Recommendations

While a large amount of new and valuable data has been obtained since the Draft Final RI, it only enhances the previous understanding of the hydrogeology and the nature, extent, fate and transport of the contamination within the DCF Study Area. This new data does not, however, change any of the overall conclusions in the Draft Final RI, namely that: (1) groundwater and contaminants migrate and attenuate in a dissolved state from the upland area to the Kansas River via the alluvial Island at low levels; and, (2) there are no identified unacceptable risks to current or likely future human or ecological receptors associated with the contamination. This conclusion is based on the fact that:

- contaminant levels continue to be well below the conservative past maximum concentrations that were used to perform the BLRA;
- land use conditions have not changed; and,
- the types and locations of potential receptors has not changed.

The combined inception to date results from the RI and the monitoring expansion related groundwater elevation monitoring activities strengthen and further the findings and data trends presented in the Draft Final RI. Inception to date hydrographs clearly illustrate the influence of the Kansas River and precipitation events on the groundwater elevations within the DCF Study Area, with the magnitude of the influence being related to the relative distance from the river and the specific characteristics of the formation in which a well is located.

Inception to date sampling and analysis data clearly illustrate that the new information collected since the submission of the Draft Final RI are consistent with, and further support the findings presented in the Draft Final RI. In particular, these data show that:

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2. natural attenuation (including biodegradation) is absolutely occurring to varying degrees within the DCF Study Area; and,
3. there is no evidence that any deep non-aqueous phase contamination exists within the DCF Study Area.

Based on the foregoing data, discussions and conclusions, continued monitoring of existing wells is recommended but no additional monitoring locations or interim remedial activity is needed while the remedial alternative development and selection process proceeds. This recommendation is based on the following factors:

- The baseline risk assessment in the Draft Final RI remains conservative and appropriate as is, and it identified no unacceptable risks;
- Contaminant levels generally are decreasing across the DCF Study Area with distance from the assumed sources and over time;

- Continued adherence to proper waste management practices should eliminate any potential for ongoing sources of PCE at the DCFA; and,
- Natural attenuation is occurring and the monitoring data indicates specifically that the PCE contamination is biodegrading to TCE, DCE and vinyl chloride within the DCF Study Area (it is also important to note that this point, in particular, has directly supports the remedial alternative development and selection process since natural attenuation and continued monitoring is one of the most promising alternatives to be considered).

1.0 INTRODUCTION

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The United States Army Corps of Engineers, Northwest Division, Kansas City District (CEMRK), under contract DACA41-92-D-0001, retained Louis Berger & Associates, Inc. (Berger) in support of the Fort Riley, Directorate of Environment and Safety, Installation Restoration Program to perform a Remedial Investigation/Feasibility Study (RI/FS) at the Dry Cleaning Facility (DCF) Study Area at Fort Riley, Kansas. The DCF Study Area includes the Dry Cleaning Facility Area (DCFA), which is defined as the upland area of the site comprising Buildings 180/181 and 183, and the Island area which is defined by the alluvial deposits south of the upland area adjacent to the Kansas River. The Department of the Army (DA) - Fort Riley, the U.S. Environmental Protection Agency (U.S. EPA) Region VII and the State of Kansas Department of Health and Environment (KDHE) negotiated a Federal Facility Agreement (FFA) for Fort Riley, Docket No. VII-90-F-0015 (U.S. EPA, 1991). This agreement, also referred to as the Interagency Agreement (IAG), was signed by the Army in August 1990 and by U.S. EPA Region VII and KDHE in February 1991, and became effective on June 28, 1991.

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1.1 Summary of the Draft Final RI Findings and Monitoring Expansion Related Negotiations and Decisions

The Draft Final RI (CENWK, 1995) presented the findings from the investigations, sampling and analysis through January 1995 for the environmental setting and the contamination nature, extent, migration and potential risks/receptors associated with the DCF Study Area. A brief summary of the findings in the Draft Final RI and the monitoring expansion related activities which triggered the execution of additional investigations follows.

1.1.1 Summary of the Draft Final RI Findings

The environmental setting, contamination and potential contaminant migration pathways and risks associated with the DCF Study Area were investigated in detail as part of the RI, resulting in a strong understanding of each of these issues. The following findings were particularly noteworthy and are important to a proper understanding of DCF Study Area:

- Groundwater within the DCF Study Area has become contaminated, primarily with chlorinated VOCs as a result of past practices and activities within the DCFA, but these contamination sources have since been addressed and maximum contamination concentrations have been generally decreasing for well over three years as a result;

- The entrance pathways for the chlorinated VOC contamination (primarily PCE) were by direct discharge to the ground surface of wastes from the DCF and via leaky sewer systems carrying the sometimes contaminated effluent from the DCF;

- Downward migration of contaminants occurs through the unsaturated zone, into the underlying groundwater, then laterally to the southwest and eventually into the alluvium parallel with, and eventually discharging to the Kansas River via the Island;

- The Funston Limestone is more than 20 feet above the saturated zone and, therefore, is not a water-bearing formation;

- The Upper and Lower Crouse Limestone are interconnected through common lateral connections as a result of being exposed in the unconsolidated materials within the subsurface erosional feature in the bedrock located adjacent to and beneath Building 180/181 - this is as opposed to a vertical interconnection through the intervening shale;

- Vertical movement of groundwater from the Upper Crouse Limestone to the Lower Crouse Limestone, although possible, is unlikely because the Lower Crouse Limestone is in a confined condition (i.e., water level is above the top of the formation);

- Vertical downward groundwater movement is limited by the confining Easly Creek Shale;

- Detections of PCE and its breakdown products in the Lower Crouse Limestone (DCF93-19 and DCF93-20) are attributable to lateral movement of groundwater from the unconsolidated materials to the Lower Crouse and lateral groundwater movement from the alluvium to the Lower Crouse;

- Groundwater flow in the saturated soils overlying bedrock is generally in the south-southwest direction in the erosional/trough feature, and then turns in a southeasterly direction once it reaches the Island;

- Groundwater flow in the bedrock units is not considered to be a significant pathway and appears to be very limited - it is characterized as a diffuse-flow system with flow occurring intermittently along horizontal bedding planes and fractures;

- Preferential pathways exist in the unsaturated zone due to the presence of trenches of buried utilities/pipelines, steam line tunnel, and naturally occurring seams or layers of increased permeability soils;

- During periods of flood, groundwater flow is from the river to the alluvium and the DCFA and groundwater flow direction is redirected from its typical and more direct flow path from the upland to the river; and,

- The mean annual water level in the Kansas River is above the elevation of the Lower Crouse limestone - this provides the head in the Lower Crouse and along with the Crouse and Easly Creek shales (above and below the Lower Crouse Limestone respectively) results in the confined condition of the Lower Crouse.

Results from analytical data in the Draft Final RI showed a general trend towards reductions in maximum contaminant levels at or near the DCFA; specifically, that concentrations of PCE, DCE, TCE, and vinyl chloride in the groundwater were in 1995 at levels substantially below their past/maximum concentrations. The data also indicated that water table elevations had significantly decreased (approximately three to five feet) since 1993 primarily due to climatological variations.

The Draft Final RI projected that the general decrease in contaminant levels would likely continue due to several factors, including:

- Enhanced management/housekeeping practices at the laundry and dry cleaning facility: the floor drains at the DCF have been plugged; spill control equipment is used to clean spills; and, if blankets or mattress pads are used to clean spills, they are dry cleaned as opposed to laundering;
- Sanitary sewer repairs that were undertaken to address leaks;
- Completion of a Soil Vapor Extraction Pilot Test responsible for removing approximately 21 lbs of VOCs;
- Cleaning of sediments from an abandoned manhole (MH-363B) in May 1994, sediments were impacted with acetone, 1,1-dichloroethylene, DCE, TCE, and PCE;
- Removal of 2 USTs and abandonment of 1 in place (including removal of UST contents);
- Most of the site (over 80 percent) is paved, which minimizes potential surface water infiltration and subsequent leaching of residual contaminants in soils to the extent that residuals exist; and
- Natural attenuation of the contaminants evidenced by consistently declining maximum PCE contamination levels combined with the presence of PCE breakdown products.

Based on the identified site conditions and the reasonably foreseeable land uses in the vicinity of the DCF, the following findings were presented in the Draft Final RI regarding contaminant migration pathways and receptors:

- The air pathway is not of concern for fugitive releases or volatilization from surface soils because there were no contaminants of concern detected in surface soils;
- Groundwater in the vicinity of the DCFA and on the Island will not be used as a drinking water source. Fort Riley's actual daily consumption is approximately 42 percent of its available capacity. Based on this, installation of new water supply wells is not likely;
- The current or less intensive types of site activities and non-residential land use will persist;
- The ecological assessment considered risk to vegetation and to terrestrial and aquatic animal life at, and adjacent to, the DCF. The results of the ecological assessment did not indicate a risk to ecological receptors; and,
- Hazard Index and carcinogenic risk values were calculated as part of the Baseline Risk Assessment (BLRA) included in the Draft Final RI, and were 0.1 and 3×10^{-8}, respectively [If a Hazard

Quotient for an individual chemical is less than 1, adverse health effects are not likely and for CERCLA activities, residual risks on the order of 10^{-6} or less are the primary goal stated in the NCP - therefore calculated carcinogenic risks and Hazard Index values for the DCF were considered to be below acceptable values].

It was noted in the BLRA that future residents are not considered because the site is unsuitable for residential development for the following reasons:

- The potentially buildable land immediately around Buildings 180/181 and 183 is small in area and bisected by Custer Road, one of the main roads on Post. The site is bordered by a buffalo corral to the north, a historic cemetery to the west, the Union Pacific Railroad right-of-way to the south, and a steep ravine of Tributary A to the east (Figure 1-2). According to the Fort Riley Buildable Area Map for Main Post and Marshall Airfield (CENWK, 1995), the area surrounding the DCFA is marked with a designation of "soils least suitable for development." The only exception is the area immediately north of the DCFA which includes the present buffalo corral;

- The DCFA lies within the Main Post historic district and, therefore, is subject to certain restrictions and architectural requirements for building construction (CENWK, 1995). These requirements do not preclude the construction of new buildings but make them more costly;

- The floodplain adjacent to the DCFA is an ecologically sensitive area and an important wintering habitat for bald eagles (USFWS, 1992); it is unsuitable for development because of restrictions of the Endangered Species Act and restrictions on floodplain development due to its location within a 10-year floodplain (FEMA, 1988);

- The restrictions and limitations of the site for future residential development exist regardless of whether the site remains under Army control. Should Fort Riley be designated for BRAC and the DCFA be designated for sale or transfer in the future the site may need to be re-evaluated and decisions made based on the site conditions existing at that time relative to the potential disposition and land use under consideration. In either case, there is no reasonable expectation that future land use will be substantially different from the historical and present-day use.

1.1.2 Summary of the Monitoring Expansion Related Negotiations and Decisions

Subsequent to the submission of the Draft Final RI in March 1995, there were discussions between the parties to the IAG regarding the possibility that further work might be required; specifically: (1) whether or not there was sufficient evidence that no deep non-aqueous phase source of contamination might exist at the DCFA or on the Island; and, (2) whether the State of Kansas surface water regulations were applicable to the alluvial aquifer at the Island. If deemed applicable, these regulations would likely require that remedial action be pursued as long as groundwater contaminant levels in the alluvium exceeded the U.S. E.P.A. Maximum Contaminant Levels (MCLs) for drinking water, since the adjacent Kansas River is protected as a potential drinking water source (even though the river is not currently used as such in the vicinity of the DCFA or within the area potentially impacted by the DCFA-related contamination). As a result of these discussions, it was agreed that additional investigations would be performed on the Island and that the upland area monitoring program would also be continued. Regarding the Island, KDHE deemed that groundwater quality in the alluvial aquifer did have to satisfy the surface water quality criteria (i.e., MCLs) and it was agreed that additional groundwater monitoring points would be installed to increase both the horizontal and vertical delineation of the alluvial aquifer and to confirm that no deep non-aqueous phase contamination existed.

A work plan was thus developed for the installation of new monitoring points on the Island as described in Section 1.3, as well as the additional rounds of groundwater sampling and analysis that would be necessary for the entire study area. The work plan development also included numerous negotiations and discussions with appropriate regulatory and natural resources representatives regarding the requirement that impacts to the sensitive bald eagle habitat on the Island be minimized during all activities. As a result of the development and execution of this work plan, and specifically the expansion of the groundwater monitoring network on the Island, the Draft Final RI received written approval of the Draft Final RI from KDHE on 2 April 1996.

1.2 Background Information and Investigative History

The following sections provide information on the Dry Cleaning Facility (DCF) Study Area (including both the DCFA and the Island), including a description of the site setting, a history of site operations, and results of previous investigations.

1.2.1 Site Setting

The Fort Riley Military Reservation is located just north of Junction City in northeast Kansas, approximately between latitudes 39°02′ and 39°18′ and longitudes 96°41′ and 96°58′. Fort Riley covers 101,058 acres, including portions of Riley and Geary Counties (Figure 1-1). The reservation was founded near the confluence of the Republican and Smoky Hill Rivers, which merge to form the Kansas River. The more widely developed areas of Fort Riley are in the southern portion of the reservation along the Republican and Kansas Rivers. As shown in Figure 1-1, the developed areas are divided into six cantonment areas: Main Post, Camp Forsyth, Camp Funston, Camp Whitside, Marshall Army Airfield, and Custer Hill.

For this report, the "Dry Cleaning Facilities Area" or DCFA will be defined as the area of current and former dry cleaning and laundry operations and related facilities. The approximately 7-acre site is situated on a rock promontory southwest of the Main Post and about 1,500 feet downstream from the confluence of the Smoky Hill and Republican Rivers. As shown in Figure 1-2, the DCFA consists of the northern and southern building complexes separated by Custer Road. The northern complex consists of a steam-generating plant (Building 184) and the current DCF (Building 183), a metal building and woodframe building, respectively. The southern complex consists of the former DCF (Building 180/181), a limestone/brick building currently used as a warehouse. Numerous buried utilities, including a gas main, water main, storm and sanitary sewer lines, telephone lines, and fiber-optics lines, run along Custer Road and across the site.

The surface around both complexes is mostly asphalt or concrete pavement with a small area of landscaped grass cover and crushed rock. The entire DCFA is isolated from the heavily populated areas, although both complexes are accessed by commercial and military vehicular traffic along Custer Road during business hours (0800 to 1600 hours).

A buffalo corral and open ground occupy the area immediately to the north. An officers' family housing complex is about 500 feet to the northeast; a commissary and veterinarian complex are about 2,000 feet to the east. The Union Pacific railroad is immediately to the south, and the Kansas River is about 1,000 feet to the south. Vacant land (formerly Mullins Park) is immediately to the west, and the Post cemetery is to the northwest. DCFA boundaries are shown on Figure 1-2.

There are 25 to 30 full-time employees at the current DCF and 20 employees at the Installation Property Book Office and Warehouse located in the former DCF. Approximately 75 people reside at the officers' family housing complex.

1.2.2 Description of the Island Area

The Island is an approximately 50 acre, undeveloped, wooded area on the floodplain of the Kansas River (Figure 1-2). It has formed from the deposition of alluvial materials by the Kansas River. The Kansas River has continually reshaped the Island through deposition and erosion. Recently, during the 1993 flood event, a major portion of the Island was eroded away, leaving the shoreline as depicted in Figure 1-2. Maps created before 1993 show the outline of the Island before erosion removed roughly 15 acres along the southern edge.

The Island has developed into an area of unique ecological importance. It has become a winter (November through March) roosting area for local bald eagles (CENWK, 1995). The eagles, which are federally-listed as a"threatened" species, are attracted to the Island because of the combination of numerous tall trees adjacent to the Kansas River and the proximity of these trees to the nearby bluffs to the north. It is believed that the combination of the bluffs, the large roost trees, and the thermal cover provided by the understory protect the area from the cold winter winds and make it an excellent roosting area.

1.2.3 Site History and Operations

The former DCF (Building 180/181) commenced operations as early as 1915. Laundry operations began in Building 180 in 1915, and dry cleaning operations began in Building 181 in 1930. The two buildings were structurally connected in 1945 following a fire in Building 180. Laundry operations ceased at the southern complex in October 1983 and were transferred to the northern complex in Building 183. Stoddard solvent, a naphthalene-based fluid, was the cleaning solution used at the DCFA until 1966. Since then, tetrachloroethylene (PCE) has been used.

Two situations have been identified in the Draft Final RI as the mechanisms for releasing contaminants to the environment. The first mechanism that has been identified is leaky sewer lines. Accidental spills of PCE which may have reached the DCFA building floor drains, and direct discharge of dry cleaning wastewater to floor drains located inside the DCFA buildings, are transported to sanitary sewer lines, where leaky sewers release PCE contaminated wastewater to the environment. The second suspected mechanism is discharge to the ground surface on the west side of Building 180/181. In previous reports it was stated that prior to 1966 contaminants may have been released to the environment when still bottoms were dumped on the west side of Building 180/181 (CENWK, 1995). However, the reports of this practice could never be confirmed and soil investigations in the area did not identify any contamination source that might be associated with this type of practice. To eliminate continuing sources of contamination from Building 183, the floor drains in that building were sealed with a cement grout in the fall of 1993. In addition, the sanitary sewer lines in the DCFA underwent repairs in May of 1994 and additional repairs and rerouting during the June to August period of 1996, as detailed below.

Since 1993, various investigations and repairs of the sanitary sewer system within the DCFA have been conducted. These have included video inspections, sanitary sewer segment replacement, flow diversion studies, hydrostatic testing, groundwater temperature and elevation monitoring, and sanitary sewer rerouting. The following subsections outline the known sanitary sewer system investigations and modifications conducted at the DCFA from 1993 to the present.

- **1993 Sewer Line Investigation**

In April 1993, a video survey of the sanitary and storm sewer lines in the DCFA was performed to evaluate pipe conditions and intersecting pipe locations that are not observable in the manholes. Approximately 500 feet of the 1,490 feet of sanitary sewer lines and 490 feet of the 590 feet of storm sewer lines at the DCFA were surveyed with a remote video camera (CENWK, 1993b). In addition, smoke and dye testing was performed at Building 183 to identify the discharge locations for the floor drains in that building. Numerous breaks, offsets, cracks, and root intrusion were identified within both the sanitary and storm sewer lines and are discussed in detail in Section 3.1.4.1 of the Draft Final RI. Figure 3-5 of the Draft Final RI shows the locations of the breaks and blockages along the sanitary sewer lines.

- **May 1994 Sanitary Sewer Line Repair**

The sewer line repair work performed in May 1994 involved the replacement of a section of piping between sanitary MH 365, located in the middle of Custer Road, and MH 363, located adjacent to Building 180/181 (Figure 1-3). During excavation, the sanitary sewer line being replaced was found to be disconnected from the manhole, representing a potentially significant contributing source to the groundwater beneath the site (CENWK, 1994b). This repair work is discussed in Section 3.3.1 of the Draft Final RI.

- **1994 Sanitary Sewer Investigation and Diversion**

In June 1994, construction of a pilot test system was initiated that included the installation of monitoring and extraction wells. During this stage of the preparation for the pilot study, elevated groundwater temperatures were detected, averaging 29° C, 31° C, and 32° C in the newly installed extraction wells DCF94ES-2B, 1B, and 3B, respectively. Typical background groundwater temperature levels for the region where Fort Riley is located range from approximately 13°C to 14.5°C (56°F to 58°F) (van der Leeden, 1990). In an effort to identify the source of the elevated temperatures (suspected to be the sanitary sewers) and to evaluate the effects on the local groundwater conditions, the following activities were conducted:

1. Diversion of sanitary flow closest to the suspected source of the elevated groundwater temperatures, with the intent to restore the local DCF groundwater to background hydraulic conditions.

2. Performance of a flow study and pipeline integrity evaluation between MH 363 and MH 345 to determine the flow loss through this sanitary section and its potential impact to the local aquifer.

3. Monitoring of groundwater temperatures, conductivity and elevations prior to and throughout the diversion process to assess aquifer response to the sewer flow diversion.

Detailed discussion of the 1994 sanitary sewer investigation, including tabulated data results, are presented in Section 3.3.1 and Appendix A (Technical Memorandum V - *Supplemental Investigative Findings and Proposed Activities* dated August 23, 1994) of the Draft Final RI.

Diversion of the sanitary flow from MH 363 to MH 345 was initiated on July 22, 1994 by constructing a bypass and pumping the sanitary flow entering MH 363 across the downgradient tributary to MH 345. Pre-diversion temperature, conductivity, and water table elevations were recorded in groundwater within wells DCF94ES-1B, 2B and 3B, DCF92-02, DCF92-03, DCF92-05, DCF93-13, DCF92-01, and DCF94-21 from June 16, 1994 to establish baseline trends. Monitoring well DCF92-01 was utilized as a background well for temperature, conductivity, and elevation monitoring to compare readings with the impacted aquifer wells. Based on the temperature and groundwater elevation monitoring, it appeared that while it was apparent that there was a leak between MH 363 and MH 345, it could not be concluded that this was the only section with potential leaks to the groundwater aquifer. Sewer diversion was discontinued on August 10, 1994.

- **Flow Study and Piping Integrity Evaluation**

Prior to initiating the flow diversion at MH 363, a survey logger was placed in the sanitary pipe discharging to MH 345 to record daily sanitary flow. The sanitary flow through the system, less any leakage, was observed to follow a cyclical pattern consistent with regular steam plant discharges. Flows generally increased between the morning hours of 0600 and 1100, and decreased between the hours of 1100 and 1800. Peak flow was recorded shortly before 1100 hours at approximately 200 gallons per minute (gpm), decreasing to a low of 15 gpm. The daily average flow rate was calculated at approximately 60 gpm.

Upon diverting the sanitary flow, a flow study and piping integrity evaluation was performed on the pipe section from MH 363 to MH 345. The flow study was performed using the survey logger placed in MH 345 while introducing various controlled flows of clean water to compare influent to effluent flow rates. The pipe integrity study was performed via a hydrostatic test on the sanitary sewer section, measuring the drop in water level with pressure transducers. In general, the results of the flow study and piping integrity evaluation indicated a loss of approximately five to eight percent of flow under a flow rate of 160 gpm, and losses of 1.3 and 6.5 gpm under flow rates of 80 and 130 gpm, respectively. The results of the hydrostatic test indicated a loss through the system of 5.5 gpm.

Groundwater monitoring was continued for a period of 19 days beyond the diversion date to August 10, 1994 to record potential changes to temperature, conductivity, and groundwater elevations. As stated above, based on the temperature and groundwater elevation monitoring, it appeared that while it was apparent that there was a leak between MH 363 and MH 345, it could not be concluded that this was the only section with potential leaks to the groundwater aquifer. The sanitary sewer diversion system was disengaged on August 10 and 11, 1994. Although it was initially proposed to perform an upgradient (Phase II) diversion, it was determined that such a diversion would not be undertaken since it would involve significant construction efforts more consistent with a capital improvements project, and that it would adversely impact scheduling of the pending pilot test.

Detailed discussion of the 1994 sanitary sewer investigation, including tabulated data results, are presented in Section 3.3.1 and Appendix A (Technical Memorandum V - *Supplemental Investigative Findings and Proposed Activities* dated August 23, 1994) of the Draft Final RI.

- **Sanitary Sewer Improvements and Rerouting in 1996**

Prompted by the findings of previous investigations and reported observations of backed up sanitary sewage overflowing from MH 366, sewer repairs were conducted in June and July of 1996. These repairs ultimately resulted in the rerouting of the sanitary sewer line from Building 183 eastward, around the buried valley, and then southward to MH 345, thus bypassing the sewer connection between Buildings 183 and Building 180/181 (Based on Sheet 1 of 1 dated April 5, 1996 of a sewer line profile and plan as received from Fort Riley Public Works). Specifically, the following repairs were made (refer to Figure 1-3):

- MH 365 was demolished, and its north, south, and west sanitary sewers were plugged and abandoned in place. At MH 363, the corresponding north sanitary sewer was plugged and abandoned in place. This was the same line that had been replaced previously in May of 1994.

- MH 366 was demolished, and its north and east sanitary sewers were plugged and abandoned in place. At MH 367, the corresponding south sanitary sewer was plugged, and a new 6″ PVC sewer was tapped into the southeast side of the manhole, which runs to the newly constructed MH 368B. From MH 368B, a new sanitary line was run through the newly constructed MH 368A to the newly constructed MH 368-1, thus replacing the old sanitary line running from former MH 369 to former MH 368, which was plugged and abandoned in place.

- From MH 368-1, the new 8″ sanitary sewer was continued to MH 370, where it joins with the original sanitary system running to the northeast to MH 434, then southward to MH 353, and then to the southwest to MH 352 and then to MH 345.

As a result of the 1996 repairs on the sanitary sewer, the only sanitary flow past Building 180/181 is from sanitary flow generated in that building, whereas the sanitary sewage from Buildings 183 and 184 is now diverted to the northeast, and then back around to the southwest to MH 345, essentially bypassing the buried valley adjacent to Building 180/181.

1.2.4 Investigative History

Several investigations have been conducted within the DCFA, including those conducted by the Army Environmental Center (AEC), formerly the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA); the Center for Health Promotion and Preventive Medicine (CHPPM), formerly the U.S. Army Environmental Hygiene Agency (USAEHA); and the U.S. Army Corps of Engineers, Northwest Division, Kansas City District (CENWK). The following is a brief summary of prior investigative work conducted at the DCFA. A more complete discussion of previous investigations is contained in the March 1995 Draft Final RI report for the DCFA. (CENWK, 1995).

In December 1983, USATHAMA conducted an Installation Assessment of Fort Riley (USATHAMA, 1984) to assess past and current use of toxic and hazardous materials, as well as the potential for these substances to migrate off the installation. No sampling and analysis was conducted, but record reviews and visual observations concluded that Stoddard solution was used in the past (prior to 1966) as the dry cleaning solvent at the former DCF (Building 181). This Installation Assessment reported spills of the Stoddard solvent on the grounds behind Building 181, however, there were no records provided to support this statement.

In June 1986, USAEHA (1986) collected two soil samples from a grassy area along the west side of Building 181 just north of the old boiler room. The samples were analyzed for PCE, but neither had a reported concentration above the quantifiable detection limit of 0.02 mg/kg.

In 1988, USAEHA conducted an evaluation study of all solid waste management units (SWMUs) at Fort Riley. The report concluded that no evidence was observed outside Building 181 that would have indicated repeated spilling of dry cleaning solvents, nor was there a high potential for solvent (PCE) release to the environment. A recommendation was given that no further sampling be conducted at the site (USAEHA, 1988).

A Preliminary Assessment/Site Investigation (PA/SI) was conducted to confirm the presence or absence of contamination at the site resulting from potential releases due to past waste management practices or from other types of releases in the vicinity of the former DCF. The PA/SI was completed in September 1992 (CENWK, 1992). The results of these investigations indicated elevated levels of contamination associated with the DCFA and ultimately gave rise to the decision to implement an RI/FS program (CENWK, 1993c).

The RI program began in November 1993, and investigations and evaluations continued through the Draft Final RI in March 1995. The Draft Final RI provided a disputed evaluation of the nature and extent of DCFA-related contamination, its projected fate and transport, and the potential for human health and ecological risks associated with the contamination. This risk assessment, referred to as the Baseline Risk Assessment or BLRA, showed that there were no receptors reasonably within the contaminant migration pathway. However, it was agreed subsequent to the Draft Final RI that the Island area downgradient of the DCFA required further characterization and that this RIAMER would be necessary.

During previous investigations in the DCF and during the installation of groundwater extraction wells for a pilot study within the DCFA (June 1994), groundwater temperatures were found to be elevated substantially in the area to the northeast of Building 180/181 (groundwater temperatures of 29°C to 32°C were recorded, compared to expected background groundwater temperatures for this area which are 13°C to 14.5°C). Based on a review of the facilities in this area, it was determined that the most likely cause for the elevated temperatures was leaks from the nearby sanitary sewer line. As detailed in Section 1.2.3 of this report, repairs were effected by Fort Riley and, in an effort to quantify the impacts of the sewer discharges on the shallow groundwater and the effectiveness of the repairs in ameliorating these impacts, groundwater temperature monitoring was implemented at selected monitoring wells. The monitoring was instituted on 1 November 1994 and has been continued to the present time. The original monitoring wells included DCF92-03, DCF92-04, DCF93-15 DCF93-17, and DCF93-19. Subsequently, due to difficulties with the logging unit and with insufficient water in monitoring well DCF93-15, the logging unit was removed and a replacement unit was installed in monitoring well DCF92-02. In addition, groundwater elevations were also monitored as part of this effort at each of the aforementioned monitoring wells and at monitoring well DCF94-22, located on the Island. Groundwater elevation monitoring at DCF94-22 was commenced in advance of the additional wells during July of 1994.

1.3 Current Project Scope and Objectives

Based on discussions and communications between the parties of the IAG subsequent to the Draft Final RI, the original objectives of the additional investigations reported herein were as follows:

- To evaluate the vertical extent of contamination under the Island and specifically the potential for previously undetected deep non-aqueous phase contamination sources;
- To further evaluate the horizontal extent of contamination under the Island;
- To further evaluate the groundwater flow regime under the Island;
- To evaluate the alluvial stratigraphy of the Island; and
- To evaluate what effects, if any, repairs to the sewer lines had on the hydrogeology and contaminant distribution within the DCF Study Area.

In response to discussions regarding the need to expend the necessary time and resources studying the alluvial stratigraphy on the Island, this particular original objective was not met in the sense that the originally contemplated seismic testing and subsurface soil sampling/logging was dropped from the investigative program. In an attempt to meet the balance of the original objectives, the scope of the investigations that were ultimately performed included: expansion of the monitoring well network on the Island by installing and developing six piezometers on the Island for monitoring of groundwater elevations; and, the installation, development, and sampling of three shallow and four deep alluvial wells on the Island and one deep alluvial well on the south side of the Kansas River (Figure 1-2) (CENWK 1996b).

Water levels from the wells and piezometers were compared with the water levels from the wells in the DCFA and with water level data from the data loggers in six of the wells in the existing DCF Study Area monitoring network. These data were used to determine what effect, if any, repairing the sewers had on the DCF Study Area water levels.

1.4 Technical Approach

The four existing hand-driven well points installed on the Island provided groundwater quality data from the upper portion of the alluvial aquifer. Expansion of the monitoring well network on the Island included the installation of deep alluvial wells, requiring access to the Island by all-terrain vehicles and portable motorized well installation equipment, due to the site's limited access. In addition to the site's accessibility, ecological considerations had to be made. A survey was conducted of the vegetation and wildlife in the DCF Study Area and especially the Island, and this information was also used in the evaluation of the drilling and access methods.

It is important to note that the work stated above was planned in consultation with appropriate base and state Natural Resources personnel, and was performed in a manner that minimized negative impacts on the bald eagle roosting habitat established on the Island. Every precaution was taken to ensure that the integrity of the eagle habitat was maintained while work was performed during this investigation, and that the work was timed to avoid eagle roosting periods. In particular, the drilling method used was chosen to minimize impacts to the Island environment and to facilitate the quickest/easiest ingress and egress.

1.4.1 Rationales for Well and Piezometer Installation

The purpose of the deep alluvial wells was to better define the horizontal and vertical extent of contamination in the groundwater of the alluvial aquifer, as well as the hydrogeology of the aquifer. The three shallow alluvial wells were installed to help further evaluate the horizontal extent of the contamination in the alluvium and for use in monitoring groundwater flow directions and gradients. The six piezometers were installed to provide groundwater measurements to establish groundwater gradients and flow directions in the alluvial aquifer for the western side of the Island.

1.4.2 Rationales for Access and Drilling Method Selections

Access options and drilling method were evaluated and compared with respect to three criteria:

- ability to meet the investigation data quality objectives;
- the impact on the highly sensitive eagle habitat; and,
- the cost of the methods.

The decision was ultimately made to access the site via all-terrain vehicles, and to install the wells and piezometers using a portable vibrating drive drill rig. Driven wells are ideal in unconsolidated formations, and can often provide the greatest amount of chemical data per well location because a drive point can be stopped at selected depths to collect groundwater grab samples. It is noted, however, that the use of driven wells precludes the logging of subsurface stratigraphy since no depth-discrete soil samples are obtained.

There are no roads providing access to or within the Island; there was an abandoned road which led from near well DCF93-14 along Tributary A to a permanent underpass below the railroad. This underpass was designed so that it served as a conduit for water flow from Tributary A as well as providing vehicle and pedestrian traffic.

In the summer of 1996, the abandoned road was improved by the Fort Riley Public Works Department to provide access to a manhole located north of the railroad underpass at the same time as access was being constructed for drilling. Public Works changed the profile of the road, raising it about 12 feet at the underpass end for their project, which made it unusable for direct access to the underpass. Therefore, a side ramp was constructed of large stone to allow vehicular access from the road to below the underpass.

The outflow side of the underpass had deteriorated badly and the concrete "floor" was badly undercut. When it was functioning properly, access to either the east or west side of the Island was possible. The west side is bisected by Tributary B. Approximately 100 feet from the underpass exists a concrete bridge across Tributary B, which was inspected and, though deteriorated, found suitable to carry limited [up to 10 tons] vehicle traffic.

By placing several truck loads of large stone to fill the undercut at the egress and clearing a small amount of brush at each side of the egress, the drilling equipment could access either the east or west side of the Island. The existing bridge was used without improvements for access to the west side of the Island.

Tributary A serves as the major storm water conduit in this area. During the mobilization for drilling, the surge from a major storm washed away some of the stone at the lowest few feet of the ramp and from the egress area. Railroad ties were used to provide a temporary "bridge" over these bad spots and then removed when the tasks were completed.

1.4.3 Groundwater Elevation Data Validation Protocol

In response to some questions as to the exact depths of the different wells installed over the years at the DCF Study Area and as part of the quality control procedures implemented for data management at DCFA, a protocol whereby groundwater elevation data can be validated prior to incorporation into groundwater elevation contour maps and graphs has been initiated. The intent of this protocol is to identify suspect data points, ensuring accurate representation of groundwater conditions and that water in well sumps not be mistaken as groundwater. The need for this protocol arises as some wells, installed following flooding (and subsequent anomalously high groundwater elevations), are periodically dry or the groundwater elevation is at or below the elevation of lowest screen slot. The description of the adopted protocol follows:

A minimum groundwater elevation was established for all wells, below which all recorded groundwater elevations were rejected. These elevations are referred to as "Bottom of Screen Elevation". The bottom elevation of the well screens have been established based on the total depth of the well, minus the effective sump length. The total depth of the wells is based on well soundings conducted on 31 May 1997. The length of the effective well sumps are the as-built sump lengths plus 0.5 feet (which is a conservative estimate of the distance from the bottom of the well screen pipe section, including threads, to the bottom of the screen slot). For example, the total depth of DCF92-01 was 49.45 feet from the top of the PVC casing (elevation 1092.04 feet msl) and the effective sump length is 1.1 feet (the reported sump length of 0.6 feet plus 0.5 feet). The "Bottom of Screen Elevation" is therefore 1043.69 feet msl. For driven well points (DCF93-09, DCF93-10, DCF93-11, and DCF94-22) the effective sump length is 0.1 foot and for microwells and piezometers the effective sump length is 1.0 foot. Rejected data are qualified with an "R" in the data summary tables (Table 3-1) and are ignored on graphical plots. For groundwater contour figures, wells with rejected data show the designated bottom elevation of the screen prefixed with a "less than" sign (<) and are be relied upon for purposes of drawing contours.

Groundwater elevations within 0.1 foot above the designated "Bottom of Screen Elevation," the estimated typical range of reading/repeatability error in taking water levels, are qualified in data tables with a "J" but are still included in graphical plots. These data are also still be used in constructing the groundwater elevation contour maps, but are treated as suspect and contour lines honoring these points are dashed. Section 3.2 presents an analysis of groundwater elevations and contours.

1.5 Changes from Planned Activities

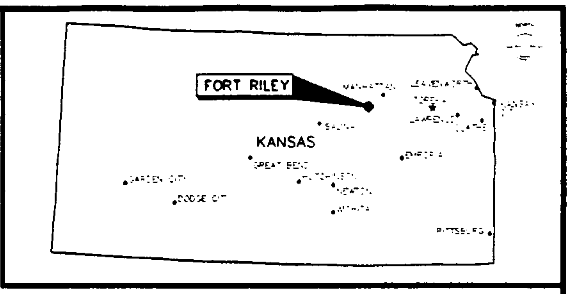
Based on the site conditions and field requirements encountered during the field investigation, certain changes in the planned activities were made during execution of the work plan.

After the installation of DCF96-24, a second well, designated DCF96-24R, was installed approximately 10 feet south of DCF96-24. The rationale behind installing a second well next to DCF96-24 was to confirm the depth to refusal that was encountered at the well DCF96-24 location. Refusal was encountered at approximately the same depth at both locations, indicating either bedrock or a layer of coarser alluvial material (such as gravel). DCF96-24R was removed after it was determined, through on-site analyses, that the groundwater screening analytical results for DCF96-24R were the same as the groundwater screening results obtained for well DCF96-24.

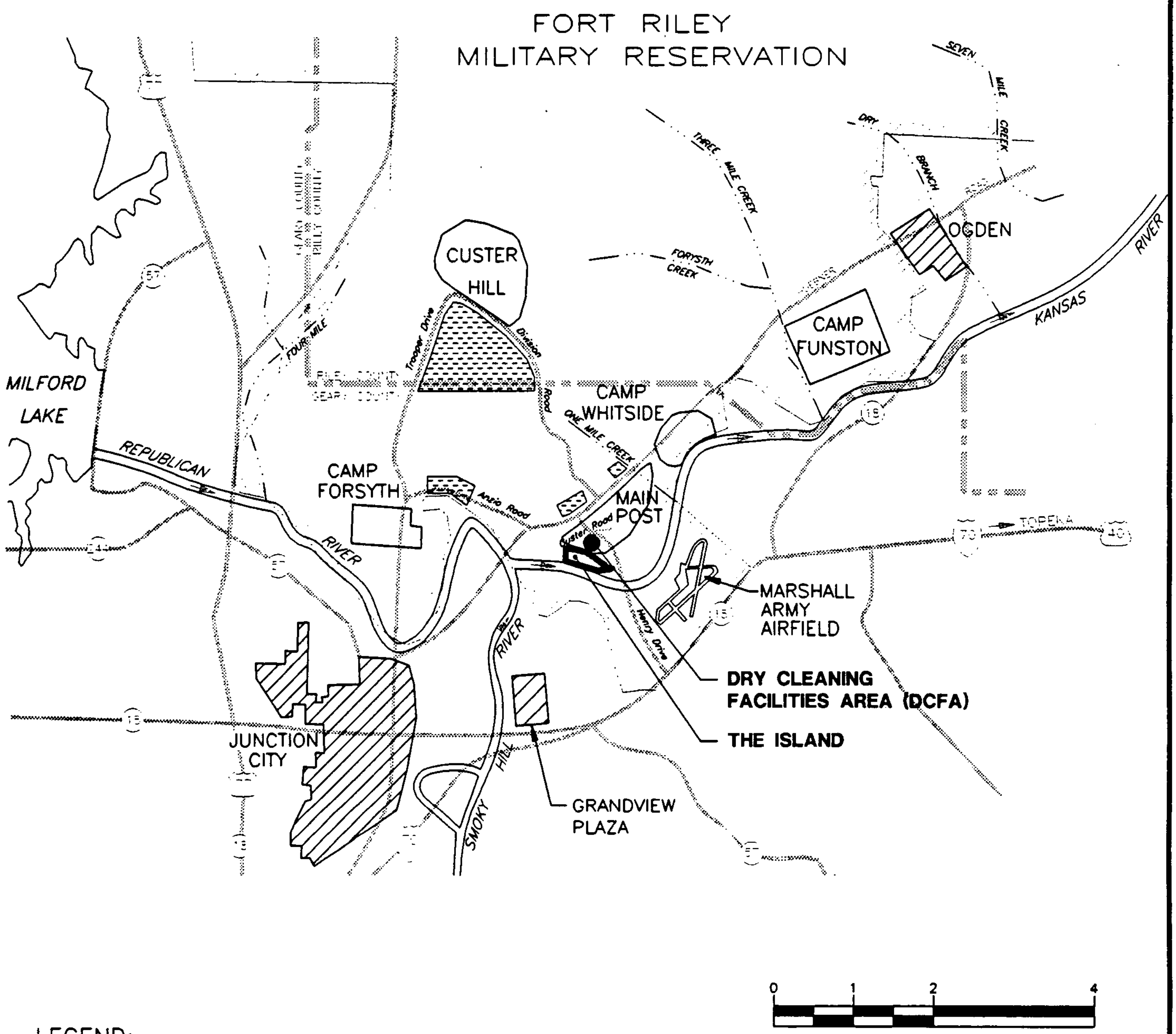
During the well installation phase of the monitoring network expansion on the Island, it was discovered that the sediments consisted predominately of very fine silty sands. After well installation, the task of well development commenced. Because of the extremely fine nature of the formation comprising the Island alluvium, it was not possible to develop the newly installed monitoring wells to less than 30 nephelometric turbidity units (NTUs), in accordance with the procedures outlined in the Work Plan (CENWK, 1996b). As their is no sand/filter pack around the drive points, filtering of the fines could not be accomplished. The goal of enhancing the hydraulic communication between the formation material and the sand pack and well, as required for conventional wells, was not necessary. In addition, as these wells were driven no fluids were introduced during their installation, eliminating the requirement of removing all fluids introduced during installation. Monitoring well development in accordance with the work plan was therefore only attempted on wells DCF96-23, DCF96-24, and DCF96-34. No attempt was made to develop the remaining five wells, including DCF96-25, DCF96-26, DCF96-27, DCF96-35, and DCF96-36. Although these wells were not formally developed, purging of three well volumes prior to sampling was completed to ensure that samples were obtained from the formation groundwater.

FIGURES

NORTH



KEY MAP
NOT TO SCALE



SCALE IN MILES
1"= 2 MILES

LEGEND:

▤ MILITARY HOUSING

□ CANTONMENT AREA

▨ MUNICIPALITY

┄ MILITARY RESERVATION BOUNDARY

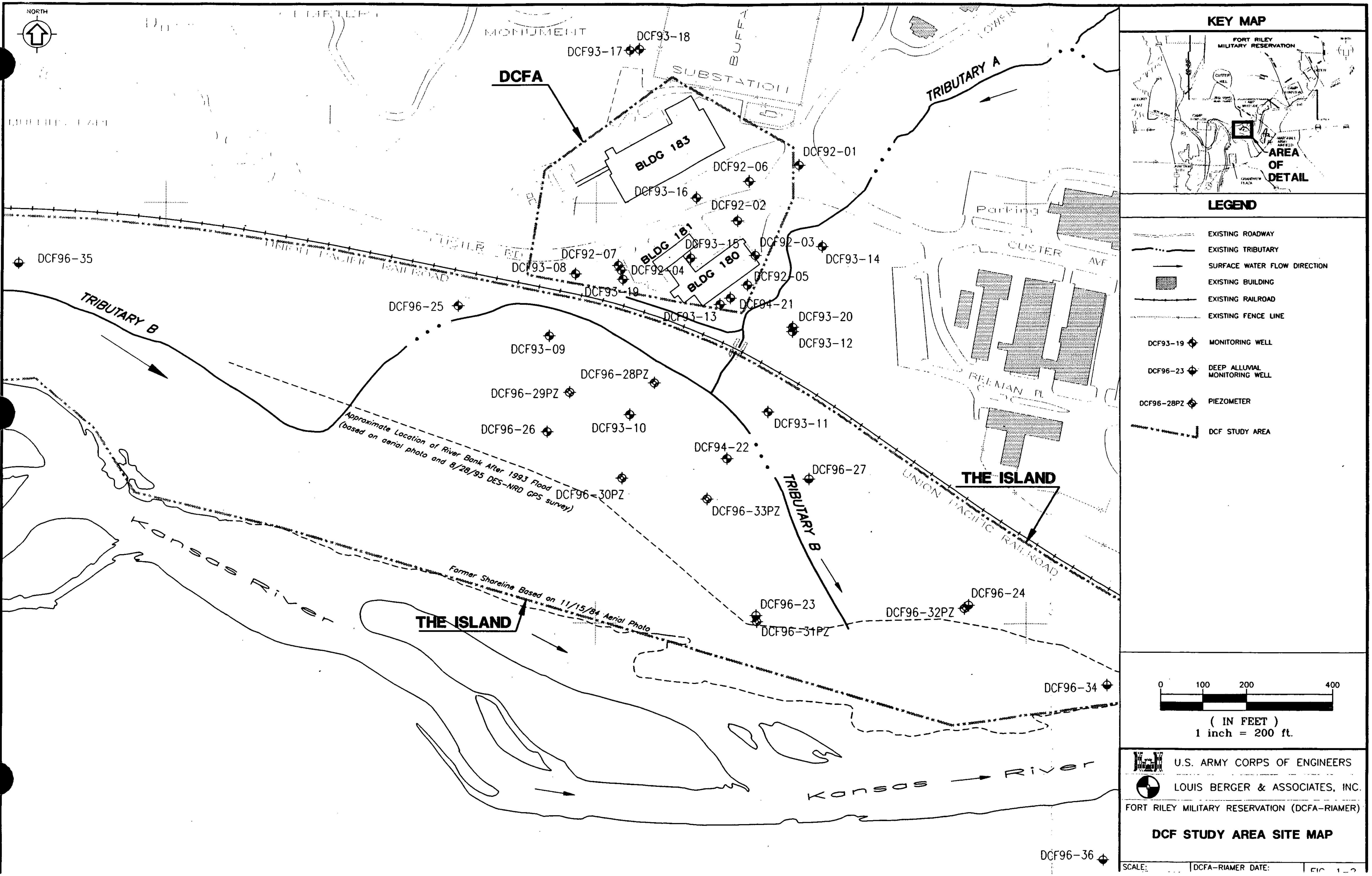
U.S. ARMY CORPS OF ENGINEERS

LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA–RIAMER)

GENERAL VICINITY MAP

SCALE: AS SHOWN	DCFA–RIAMER DATE: MARCH 1998	FIG. 1–1



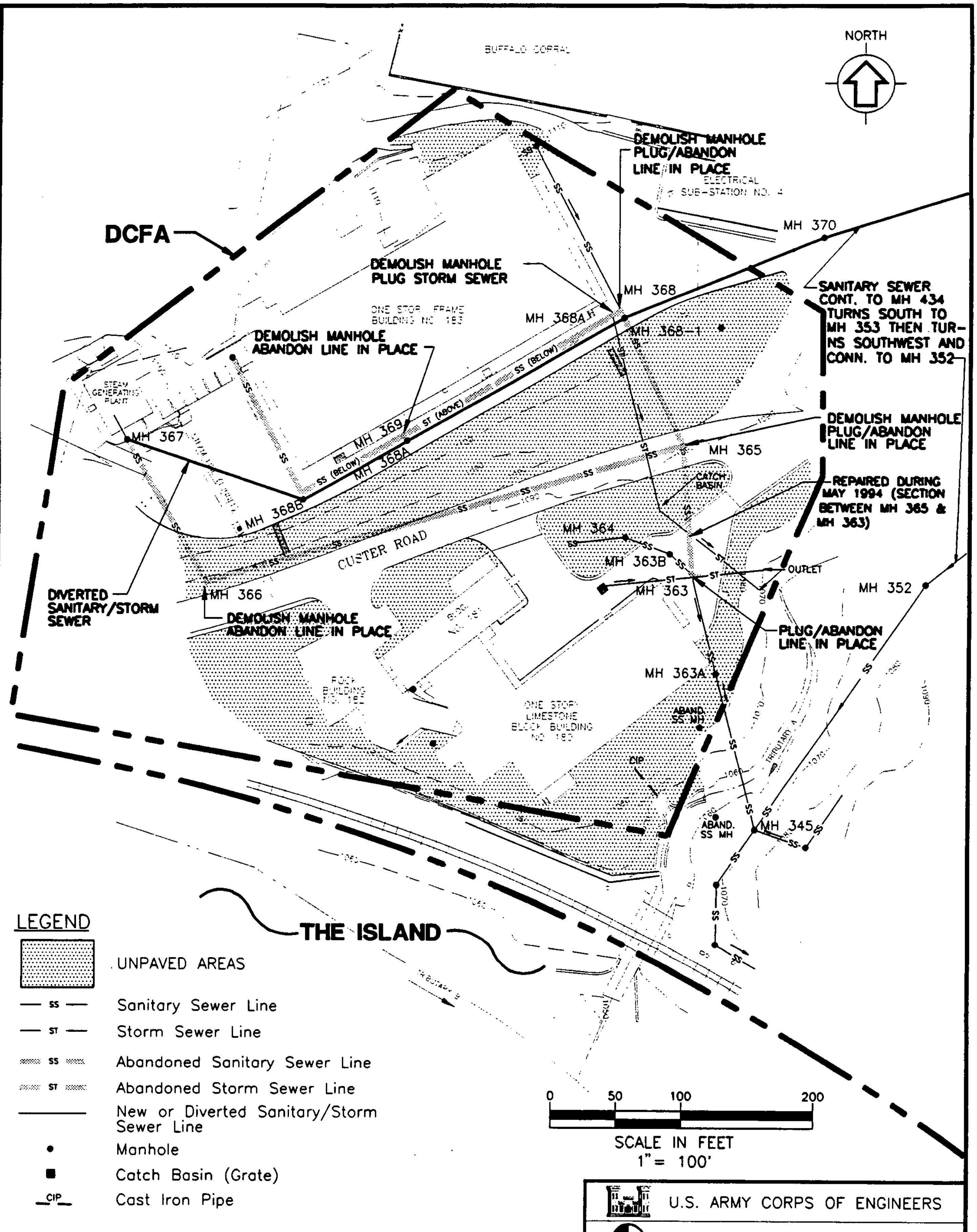
U.S. ARMY CORPS OF ENGINEERS

LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-RIAMER)

DCF STUDY AREA SITE MAP

SCALE: | DCFA-RIAMER DATE:



NOTE:

1. EXCEPT FOR SECTION BETWEEN MH 365 & MH 363, BOLDFACE NOTES REFLECT SEWER DIVERSION INFORMATION AS SHOWN ON SHEET 1OF1 (4-5-96) BY PUBLIC WORKS FORT RILEY, KANSAS.

U.S. ARMY CORPS OF ENGINEERS

LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-RIAMER)

DCFA SITE MAP AND SUMMARY OF SEWER REPAIRS FROM 1994 & 1996

SCALE:	DCFA-RIAMER DATE:	
AS SHOWN	MARCH 1998	FIG. 1-3

2.0 GROUNDWATER MONITORING NETWORK AND SAMPLING

2.0 Groundwater Monitoring Network and Sampling

2.1 Description and Location of New Monitoring Wells and Piezometers

This study involved the installation of eight permanent monitoring wells and six piezometers at locations shown in Figure 1-2 from May 8 through May 15, 1996.

Driven well points were installed for groundwater sampling and water level measurements which consist of half-inch (ie., piezometer) or one-inch (i.e., microwell) steam cleaned steel pipe whose leading end is fitted with a drive point. Well screens, manufactured from the same steel material, consist of a double row of longitudinal slots 0.015-inch wide on the piezometers. Screens installed in the microwells consist of double or quadruple rows of longitudinal slots 0.015-inch wide. For both the piezometers and microwells, each slot is two inches long and is separated from the next slot by a quarter-inch unslotted section.

2.1.1 Installation of New Monitoring Wells and Piezometers

The microwells were installed by a high frequency vibratory hammer mounted on a VibraDrill all-terrain drill rig. A total of eight permanent microwells constructed of one-inch I.D. steel pipe and ten foot screens were installed during this field investigation. Well depths ranged from 31 to 53 feet below grade. Six piezometers were also installed. The wells and piezometers were set in a gravel pad, the extension of the well above grade is protected by a steel casing with a locking cap set in a concrete pad. The microwell completion summaries, in addition to completion summaries of all of the DCF Study Area wells and piezometers are presented in Table 2-1.

2.1.2 Monitoring Well Development

As discussed in Section 1.5, five of the eight microwells were not developed according to the procedures outlined in CENWK 1996b. Each well was pumped, however, using either an inertial tube or peristaltic pump during installation and initial sampling to remove silt and fine sand that had entered the screen slots. The pumping continued until the discharge water was as free of sediment as possible so that groundwater samples could be collected for VOC analysis at the on-site mobile laboratory. When groundwater samples were collected during the screening process, at least three well volumes were removed prior to collecting the groundwater sample for chemical analysis.

2.2 Groundwater Sampling Activities

This section provides an overview of the field activities related to groundwater sampling and analyses performed as part of the on-going groundwater monitoring program at the DCF Study Area. These discussions cover the period from May 1995, which was the first sampling period subsequent to the completion and submission of the Draft Final RI (CENWK, 1995), to February 1997, the most recent sampling and analysis period reported. The section is organized similarly to the format of the Data Summary Reports (DSRs) which are submitted at the conclusion of each sampling and analysis effort. Each subheading addresses a particular sampling event and includes the activities performed, the overall number of wells sampled and the analyses requested from the laboratory (results from the sampling events are discussed in Section 4).

2.2.1 May 1995 DSR Summary

This DSR covered the period from May 1 through 3, 1995 (CENWK, 1996a). During this period, water level measurements were performed at all 22 monitoring wells and groundwater samples were collected and analyzed from 18 monitoring wells and from three groundwater treatment pilot test study wells at the DCFA. The samples were collected in accordance with Draft Final Work Plan Pilot Test Study Dual Phase Extraction System (CENWK 1994). The specifics on the field observations, sample collection methods and analyses are contained in the DSR summary for May 1995. All of the groundwater samples were analyzed for volatile organic compounds (VOCs) and samples from four of the wells were also analyzed for diesel range/gasoline range organics (DRO/GRO). See Section 4.2.2 for analytical results from the May 1995 sampling event.

2.2.2 June 1995 DSR Summary

This DSR covered the groundwater sampling and elevation monitoring performed on June 2, 1995 (CENWK, 1996a). According to a communication from Fort Riley to the Kansas Department of Health and Environment (KDHE) and the Environmental Protection Agency (EPA), the number of wells scheduled for analytical sampling during this period was reduced to 12 wells. Groundwater level measurements, however, were collected from 22 monitoring wells. The selection of sampling locations was based on the stratum in which the respective wells were completed. Of the 12 wells, four were completed in the Upper Crouse Formation, two were completed in the Lower Crouse Formation, and three each were completed in the upland unconsolidated material and the Island alluvium in the river flood plain. The rationale for selection was discussed in detail in the Sampling and Analysis Plan (CENWK, 1993a) and a memo to KDHE and EPA (June 1, 1995).

The samples were collected in accordance with the Work Plan (CENWK 1994). The field observations, specifics on the sample collection methods, and analyses are contained in the DSR for June 1995. All of the groundwater samples were analyzed for VOCs and samples from three of the wells were also analyzed for DRO/GRO. See Section 4.3.2 for analytical results from the June 1995 sampling event.

2.2.3 July 1995 DSR Summary

This DSR covered the period from July 12 through 14, 1995 (CENWK, 1996a). Groundwater samples were collected from 21 site monitoring wells and water level data were collected from 22 wells. The samples were collected in accordance with (CENWK 1994). The specifics on the sample collection methods, field observations and analyses are contained in the DSR for June 1995. All of the groundwater samples were analyzed for VOCs and samples from three of the wells were also analyzed for DRO/GRO. See Section 4.4.2 for analytical results from the July 1995 sampling event.

2.2.4 August 1995 DSR Summary

This DSR covered the period from August 24 and 25, 1995 (CENWK, 1996a). The groundwater sampling during this period was performed in accordance with the communication from Fort Riley to the Kansas Department of Health and Environment (KDHE) and the Environmental Protection Agency (EPA). The number of wells scheduled for analytical sampling during this period was reduced to 12 wells. Groundwater level measurements, however, were collected from 22 monitoring wells. The selection of sampling locations was the same as for June 1995, discussed above.

The samples were collected in accordance with the Draft Final Work Plan (CENWK 1994). The field observations, specifics on the sample collection methods and analyses are contained in the DSR summary for August 1995. All of the groundwater samples were analyzed for VOCs and samples from three of the wells were also analyzed for DRO/GRO. See Section 4.5.2 for analytical results from the August 1995 sampling event.

2.2.5 October 1995 DSR Summary

This DSR covered the period from October 23 and 24, 1995 (CENWK, 1996c). During this period, water level measurements were performed at all 22 monitoring wells and groundwater samples were collected and analyzed from 17 monitoring wells. Four wells, DCF92-01, DCF92-06, DCF92-07 and DCF93-14, were permanently removed from the sampling program at this junction based on a review of previous monitoring data which showed these wells to exhibit background concentrations of analytes, as documented in a memorandum from Berger to KDHE dated October 19, 1995. Samples were collected in accordance with the Draft Final Work Plan (June 1994). The specifics on the field observations, sample collection methods and analyses are contained in the DSR summary for October 1995. All of the groundwater samples were analyzed for VOCs and samples from three of the wells were also analyzed for DRO/GRO. See Section 4.6.2 for analytical results from the October 1995 sampling event.

2.2.6 May/June 1996 DSR Summary

This DSR covered the period from May 9 through June 14, 1996 (CENWK, 1996d). During the May 1996 monitoring period, seven additional monitoring wells and six piezometers were installed on the Island using vibratory methods and were screened in the alluvial deposits. Wells DCF96-25, DCF96-26 and DCF96-27 were shallow (31 feet bgs) wells, while wells DCF96-23, DCF96-24, DCF96-34, DCF96-35 and DCF96-36 were deep (39 to 49.5 feet bgs) (see Table 2-1 for construction details). The piezometers, installed at this time, were designated DCF96-28PZ, DCF96-29PZ, DCF96-30PZ, DCF96-31PZ, DCF96-32PZ, and DCF96-33PZ. One additional deep alluvium well was installed on the opposite side of the Kansas River, south of the DCFA, and was designated as DCF96-36. The rationale for the installation of these additional wells and piezometers is provided in Section 1.4.1.

During May 1996, periodic groundwater monitoring was performed as in previous sampling events. Re-sampling was performed during June 1996 to include the newly installed wells and to collect additional groundwater for analyses which could not be performed subsequent to the May sampling due to laboratory errors and inadequate sample volumes from slow recharging wells. In addition, the suite of groundwater analyses was expanded from the original VOCs and TPH to include analytes and water quality parameters which facilitate a better evaluation of natural attenuation, such as methane, ethane, ethylene, total organic carbon (TOC), chemical oxygen demand (COD), nitrate, sulfate, alkalinity, oxidation/reduction (REDOX), chloride, orthophosphate, target analyte list (TAL) metals, and volatile hydrocarbons.

During this period, water level measurements were performed at 29 monitoring wells and six piezometers. Groundwater samples were collected and analyzed from 24 monitoring wells. Samples were collected in accordance with the Work Plan for Monitoring Expansion Including Additional Characterization of the Island (CENWK, 1996b). The specifics on the field observations, sample collection methods and analyses are contained in the DSR summary for May/June 1996 (CENWK, 1996d). See Section 4.7.2 for analytical results from the May/June 1996 sampling event.

2.2.7 October 1996 DSR Summary

This DSR covered the period from October 11 through 17, 1996 (CENWK, 1996e). During this period, water level measurements were performed at 28 monitoring wells and six piezometers. Groundwater samples were collected and analyzed from 20 monitoring wells. During the previous monitoring period, additional analytes were added to those sampled and analyzed during previous rounds. These compounds were also included in the October 1996 period with the exception of orthophosphate, COD, and TAL metals which were removed from any subsequent sampling and analyses as they were not considered necessary for assessment of natural attenuation. In addition, dissolved oxygen (DO) was added to this and future monitoring. Samples were collected in accordance with the Work Plan for Monitoring Expansion Including Additional Characterization of the Island (CENWK, 1996b). The specifics on the field observations, sample collection methods and analyses are contained in the DSR summary for October 1996 (CENWK, 1996e). See Section 4.8.2 for analytical results from the October 1996 sampling event.

2.2.8 February 1997 DSR Summary

This DSR covered the period from February 20 through 24, 1997 (CENWK, 1997). In addition, this DSR includes groundwater level measurements collected during the period from December 1996 through March 1997. Groundwater samples were collected and analyzed from 20 monitoring wells in February 1997. Samples were collected in accordance with the Work Plan for Monitoring Expansion Including Additional Characterization of the Island (CENWK, 1996b). The specifics on the field observations, sample collection methods and analyses are contained in the DSR summary for February 1997 (CENWK, 1997). See Section 4.9.2 for analytical results from the February 1997 sampling event.

TABLES

Table 2-1
Summary of Well Construction Details
Dry Cleaning Facilities Area, Fort Riley, Kansas

Well ID	Formation Screened	Top of Rock Elevation	Top of UC Elevation	Top of Screen Elevation	Top of Casing Elevation	Sounded Well Depth (ft. T.O.C.)	Diff. bet. Sounded & As-Built Depth (Ft.)	Length of Sump (ft.)	Bottom of Screen Elevation	Length of Screen (ft.)
DCF92-01	Upper Crouse	1061.70	NE	1053.10	1092.04	49.45	0.04	1.10	1043.69	9.41
DCF92-02	Upper Crouse	1058.20	NE	1048.91	1088.98	47.56	-0.10	1.06	1042.48	6.43
DCF92-03	Unconsolidated	1039.27	NE	1051.67	1086.53	47.10	-0.20	1.10	1040.53	11.14
DCF92-04	Upper Crouse	1075.30	NE	1055.65	1087.33	44.28	0.21	1.08	1044.13	11.52
DCF92-05	Unconsolidated	1042.00	NE	1049.44	1082.73	41.76	-1.06	0.82	1041.79	7.65
DCF92-06	Upper Crouse	1060.80	1053.30	1052.28	1092.35	50.50	-1.77	1.00	1042.85	9.43
DCF92-07	Unconsolidated	NE	NE	1079.75	1087.98	18.73	Data not available	1.00	1070.25	9.50
DCF93-08	Upper Crouse	1080.14	1050.74	1050.74	1086.49	42.50	0.75	1.50	1045.49	5.25
DCF93-09	Alluvial	NE	NE	1039.63	1,059.93	25.02	-0.28	0.10	1035.01	4.62
DCF93-10	Alluvial	NE	NE	1040.20	1,060.37	22.72	-0.03	0.10	1037.75	2.45
DCF93-11	Alluvial	NE	NE	1044.88	1,060.18	18.91	-1.84	0.10	1041.37	3.51
DCF93-12	Upper Crouse	1077.77	1053.00	1050.77	1,088.97	45.16	0.96	1.50	1045.31	5.46
DCF93-13	Unconsolidated	1041.86	NE	1046.93	1,082.86	41.55	-0.30	1.42	1042.73	4.20
DCF93-14	Upper Crouse	1073.63	1073.63	1054.10	1,083.33	35.44	0.20	1.51	1049.40	4.70
DCF93-15	Upper Crouse	1067.12	1052.12	1052.12	1,085.62	39.57	0.07	1.50	1047.55	4.57
DCF93-16	Upper Crouse	1079.21	1053.00	1053.21	1,091.67	44.83	0.34	1.53	1048.37	4.84
DCF93-17	Upper Crouse	1111.07	1053.07	1053.07	1,129.22	81.90	-0.25	1.50	1048.82	4.25
DCF93-18	Lower Crouse	1118.59	1053.09	1038.59	1,128.74	102.42	0.27	2.50	1028.82	9.77
DCF93-19	Lower Crouse	1078.04	1052.04	1037.04	1,087.54	63.14	0.74	2.40	1026.80	10.24
DCF93-20	Lower Crouse	1077.71	1052.77	1037.71	1,088.98	59.11	-4.16	2.50	1032.37	5.34
DCF94-21	Unconsolidated	NE	NE	1054.24	1,082.37	40.40	-0.35	2.80	1044.77	9.47
DCF94-22	Alluvial	NE	NE	1037.77	1,060.77	28.85	0.05	0.10	1032.02	5.75
DCF96-23	Alluvial	NE	NE	1,025.10	1,061.10	52.07	-0.05	1.00	1010.03	15.07
DCF96-24	Alluvial	NE	NE	1,024.85	1,059.85	49.84	0.75	1.00	1011.01	13.84
DCF96-25	Alluvial	NE	NE	1,040.92	1,060.92	31.12	-2.42	1.00	1030.80	10.12
DCF96-26	Alluvial	NE	NE	1,042.31	1,062.31	34.08	-0.01	1.00	1029.23	13.08
DCF96-27	Alluvial	NE	NE	1,040.81	1,060.81	33.90	-0.16	1.00	1027.91	12.90
DCF96-28PZ	Alluvial	NE	NE	1,041.42	1,061.42	30.97	-3.11	1.00	1031.45	9.97
DCF96-29PZ	Alluvial	NE	NE	1,045.31	1,065.31	33.30	-0.76	1.00	1033.01	12.30
DCF96-30PZ	Alluvial	NE	NE	1,042.33	1,062.33	34.02	0.00	1.00	1029.31	13.02
DCF96-31PZ	Alluvial	NE	NE	1,041.08	1,061.08	31.84	-1.98	1.00	1030.24	10.84
DCF96-32PZ	Alluvial	NE	NE	1,040.31	1,060.31	33.32	-0.61	1.00	1027.99	12.32
DCF96-33PZ	Alluvial	NE	NE	1,042.32	1,062.32	33.17	-0.68	1.00	1030.15	12.17
DCF96-34	Alluvial	NE	NE	1,023.06	1,051.06	NM	NM	1.00	NM	NM
DCF96-35	Alluvial	NE	NE	1,023.26	1,065.26	56.70	0.73	1.00	1009.56	13.70
DCF96-36	Alluvial	NE	NE	1,021.80	1,061.30	52.02	-0.48	1.00	1010.28	11.52

Notes:

1. Monitoring well construction details for DCF92-07 are not available. Top of casing elevation was obtained from survey monument. A one-foot length of sump and a 10-foot screen length was assumed.
2. NE indicates not encountered .
3. Well DCF96-34 was damaged (bent) in January 1997.
4. NM - indicates not measured.
5. For differances between sounded depths and as-built depths; positive values indicate shallower sounded depths while negitive values indicate deeper sounded depths.

3.0 UPDATED DESCRIPTION OF GEOLOGY AND HYROGEOLOGY

Table 3-1

Water Level Elevations, DCF Study Area Monitoring Wells

Dry Cleaning Facility Study Area, Fort Riley, Kansas

All results shown in feet above mean sea level unless otherwise indicated

Well ID	Formation Screened	Top of Casing Elevation	Bottom of Screen Elevation	Groundwater Elevation																
				31-Mar-95	13-Apr-95	1-May-95	1-Jun-95	12-Jul-95	24-Aug-95	15-Sep-95	23-Oct-95	10-Nov-95	15-Dec-95	19-Jan-96	23-Feb-96	25-Mar-96	11-Apr-96	21-May-96	1-Jun-96	16-Jul-96
DCF92-01	Upper Crouse	1092.04	1043.69	1049.74	1050.04	1050.04	1058.52	1053.07	1050.82	1050.49	1050.34	1050.16	1050.02	1050.02	1050.00	1049.84	1050.08	1050.09	1050.20	1050.31
DCF92-02	Upper Crouse	1088.98	1042.48	1047.50	1047.83	1047.85	1058.05	1051.60	1048.16	1047.88	1047.84	1047.83	1047.83	1047.80	1047.81	1047.70	1047.85	1047.86	1048.09	1047.85
DCF92-03	Unconsolidated	1086.53	1040.53	1047.80	1048.00	1048.39	1055.74	1049.12	1048.60	1048.36	1048.33	1048.16	1048.46	1048.06	1048.75	1048.43	1048.59	1048.56	1049.47	1048.45
DCF92-04	Upper Crouse	1087.33	1044.13	1046.08	1046.33	1046.53	1057.90	1050.66	1047.53	1046.83	1045.72	1045.78	1045.33	1045.23	1045.16	1044.97	1045.16	1046.29	1049.62	1045.60
DCF92-05	Unconsolidated	1082.73	1041.79	1047.46	1047.66	1048.00	1055.70	1048.91	1048.44	1048.13	1048.06	1047.90	1048.12	1047.83	1048.48	1048.31	1048.37	1048.31	1049.42	1048.29
DCF92-06	Upper Crouse	1092.35	1042.85	1048.73	1049.02	1049.04	1058.18	1052.14	1048.43	1049.25	1049.09	1049.15	1048.99	1049.00	1049.09	1047.92	1049.13	1048.95	1051.46	1049.12
DCF92-07	Unconsolidated	1087.98	1070.25	1069.56 R	1069.78 R	1069.95 R	1070.34 J	1069.64 R	1069.37 R	1069.38 R	1069.36 R	1069.37 R	DRY	1069.37 R	1069.38 R	1069.28 R	1069.38 R	1069.37 R	1069.37 R	1069.40 R
DCF93-08	Upper Crouse	1086.49	1045.49	DRY	DRY	DRY	1057.96	1050.11	1047.13	1046.42	1046.02	1045.82	1045.47 R	1045.35 R	1045.79	1044.87 R	1044.89 R	1045.68	1049.93	1046.50
DCF93-09	Alluvial	1059.93	1035.01	1040.63	1040.33	1040.35	1055.13	1046.77	1043.75	1041.29	1039.37	1039.29	1041.16	1040.66	1040.49	1039.76	1039.80	1041.05	1045.55	1042.89
DCF93-10	Alluvial	1060.37	1037.75	1042.47	1040.32	1040.29	1055.02	1050.56	1043.20	1041.05	1039.27	1039.70	1041.27	1040.78	1040.32	1039.67	1039.60	1040.83	1046.26	1042.72
DCF93-11	Alluvial	1060.18	1041.37	DRY	DRY	DRY	1054.93	1047.77	1044.42	1041.63	DRY	DRY	1041.83	DRY	DRY	DRY	DRY	1041.34 R	1047.13	1043.03
DCF93-12	Upper Crouse	1088.97	1045.31	DRY	DRY	DRY	1054.53	1048.54	1046.55	1045.37 J	1044.65 R	1044.70 R	1046.20	1044.80 R	1046.24	1045.70	1046.00	1045.95	1049.01	1046.14
DCF93-13	Unconsolidated	1082.86	1042.73	1046.39	1046.62	1046.82	1055.76	1049.16	1047.74	1047.21	1047.07	1046.90	1047.18	1046.96	1047.65	1047.21	1047.33	1047.27	1041.97 R*	1041.13 R*
DCF93-14	Upper Crouse	1083.33	1049.40	1048.82 R	1049.17 R	1049.16 R	1055.77	1049.33 R	1049.22 R	1049.19 R	1049.20 R	1049.18 R	1049.14 R	1049.20 R	1049.17 R	1049.08 R	1049.23 R	1049.18 R	1049.50 J	1049.15 R
DCF93-15	Upper Crouse	1085.62	1047.55	BTP	BTP	1047.45 R	1057.99	1051.47	1048.22	1047.50 R	1047.37 R	1047.30 R	1047.22 R	1047.18 R	1047.32 R	1047.21 R	1047.36 R	1047.17 R	1044.73 R	1043.89 R
DCF93-16	Upper Crouse	1091.67	1048.37	1047.17 R	1047.41 R	1047.52 R	1057.93	1051.31	1047.84 R	1047.53 R	1047.51 R	1047.52 R	1047.49 R	1047.52 R	1047.52 R	1047.43 R	1047.55 R	1047.51 R	1047.77 R	1047.49 R
DCF93-17	Upper Crouse	1129.22	1048.82	1047.92 R	1048.23 R	1048.25 R	1057.65	1053.10	1049.42	1048.29 R	1048.52 R	1047.47 R	1048.41 R	1048.37 R	1048.49 R	1048.22 R	1048.39 R	1048.23 R	1048.33 R	1047.49 R
DCF93-18	Lower Crouse	1128.74	1028.82	1029.47	1029.46	1029.99	1027.76 R	1028.24 R	1028.10 R	1028.38 R	1028.74 R	1028.52 R	1027.81 R	1028.30 R	1028.74 R	1028.97	1029.24	1029.38	1026.97 R	1026.87 R
DCF93-19	Lower Crouse	1087.54	1026.80	1046.11	1046.30	1046.44	1057.79	1050.41	1047.44	1046.52	1046.05	1045.99	1045.78	1045.63	1045.99	1045.24	1045.60	1046.28	1046.65	1045.81
DCF93-20	Lower Crouse	1088.98	1032.37	1044.26	1044.45	1044.73	1055.49	1048.52	1046.02	1044.80	1044.66	1044.47	1045.12	1044.84	1045.18	1044.84	1045.13	1045.03	1048.95	1045.56
DCF94-21	Unconsolidated	1082.37	1044.77	NM	1047.57	1045.94	1055.72	1048.95	1048.08	1047.57	1047.47	1047.29	1047.58	1047.27	1048.04	1047.67	1047.77	1047.66	1041.48 R*	1040.64 R*
CF94-22	Alluvial	1060.77	1032.02	1040.72	1040.62	1040.57	1055.35	1046.63	1043.57	1041.40	1039.70	1039.50	1041.75	1041.66	1041.26	1039.97	1039.92	1041.06	1046.51	1043.07
CF96-23	Alluvial	1061.10	1010.03	Wells not installed until May 1996														1040.45	1047.35	1042.47
DCF96-24	Alluvial	1059.85	1011.01															1040.41	1046.20	1042.37
DCF96-25	Alluvial	1060.92	1030.80															1041.11	1046.02	1042.95
DCF96-26	Alluvial	1062.31	1029.23															1040.81	1048.56	1042.71
DCF96-27	Alluvial	1060.81	1027.91															1040.62	1046.15	1042.18
DCF96-28PZ	Alluvial	1061.42	1031.45															1040.97	1047.67	NM
DCF96-29PZ	Alluvial	1065.31	1033.01															1040.98	1045.91	NM
DCF96-30PZ	Alluvial	1062.33	1029.31															1040.72	1048.58	NM
DCF96-31PZ	Alluvial	1061.08	1030.24															1040.46	1047.29	NM
DCF96-32PZ	Alluvial	1060.31	1027.99															1040.33	1046.56	NM
DCF96-33PZ	Alluvial	1062.32	1030.15															1040.63	1046.30	NM
DCF96-34	Alluvial	1051.06	NM															1039.88	NM	NM
DCF96-35	Alluvial	1065.26	1009.56															1041.73	1047.04	1043.59
DCF96-36	Alluvial	1061.30	1010.28															1040.39	NM	1042.42

Notes:

1. Monitoring well construction details for DCF92-07 are not available.
   Top of casing elevation was obtained from survey monument.
2. R indicates rejected water elevation data, based on bottom of screen elevation.
3. J indicates water elevations which are within 0.10 foot above the bottom of screen elevation.
4. * - indicates that the data point was not used for contouring because it is anomalously high or low.
5. Well DCF96-34 was damaged (bent) in January 1997.
6. NM - indicates not measured.
7. BTP - indicates groundwater was below top of pump.

Table 3-1
Water Level Elevations, DCF Study Area Monitoring Wells

Dry Cleaning Facility Study Area, Fort Riley, Kansas
All results shown in feet above mean sea level unless otherwise indicated

Well ID	Formation Screened	Top of Casing Elevation	Bottom of Screen Elevation	Groundwater Elevation									
				17-Aug-96	24-Sep-96	11-Oct-96	16-Nov-96	11-Dec-96	21-Jan-97	18-Feb-97	27-Mar-97	17-Apr-97	1-May-97
DCF92-01	Upper Crouse	1092.04	1043.69	1050.14	1050.37	1050.32	1048.06	1050.12	1050.14	1050.12	1050.12	1050.26	1050.38
DCF92-02	Upper Crouse	1088.98	1042.48	1047.84	1047.88	1047.84	1047.75	1048.01	1048.06	1047.90	1048.05	1048.05	1048.13
DCF92-03	Unconsolidated	1086.53	1040.53	1048.42	1048.55	1048.23	1048.04	1048.28	1048.08	1048.21	1048.32	1048.67	1048.65
DCF92-04	Upper Crouse	1087.33	1044.13	1046.19	1046.28	1046.45	1045.88	1046.68	1046.48	1045.81	1046.21	1047.38	1047.51
DCF92-05	Unconsolidated	1082.73	1041.79	1048.26	1048.17	1047.97	1047.70	1047.99	1047.88	1048.73	1048.08	1048.60	1048.48
DCF92-06	Upper Crouse	1092.35	1042.85	1049.02	1049.12	1049.10	1048.88	1049.03	1049.09	1049.07	1049.12	1049.14	1049.16
DCF92-07	Unconsolidated	1087.98	1070.25	DRY	1069.35 R	1069.34 R	DRY	DRY	1069.38 R	DRY	1069.73 R	1070.24 R	DRY
DCF93-08	Upper Crouse	1086.49	1045.49	1045.82	1045.55 J	1045.83	1045.55 J	1046.37	1046.24	1045.89	1047.77	1047.32	1047.24
DCF93-09	Alluvial	1059.93	1035.01	1041.97	1043.81	1044.87	1039.33	1042.52	1041.80	1041.26	1041.05	1042.87	1043.55
DCF93-10	Alluvial	1060.37	1037.75	1042.17	1043.71	1041.72	1040.31	1042.94	1042.69	1041.17	1040.92	1042.78	1043.37
DCF93-11	Alluvial	1060.18	1041.37	DRY	1043.48	DRY	DRY	1043.45	1042.23	1041.43 J	1041.47 J	1043.68	1044.15
DCF93-12	Upper Crouse	1088.97	1045.31	1046.23	1046.41	1044.57 R	1045.52	1044.81 R	1044.70 R	1044.82 R	1045.08 R	1047.02	1047.16
DCF93-13	Unconsolidated	1082.86	1042.73	1047.34	1047.45	1046.98	1046.74	1047.12	1047.18	1047.06	1047.10	1047.84	1047.86
DCF93-14	Upper Crouse	1083.33	1049.40	1049.17 R	1049.21 R	1049.15 R	1049.14 R	1049.19 R	1049.23 R	1049.18 R	1049.21 R	1049.21 R	1049.22 R
DCF93-15	Upper Crouse	1085.62	1047.55	1047.33 R	1047.34 R	1047.32 R	1047.51 R	1047.71	1047.62 J	1047.51 R	1047.51 R	1047.82	1047.97
DCF93-16	Upper Crouse	1091.67	1048.37	1047.48 R	1047.55 R	DRY	DRY	1047.49 R	1047.61 R	DRY	1047.56 R	1047.57 R	1047.71 R
DCF93-17	Upper Crouse	1129.22	1048.82	1048.56 R	1048.52 R	1048.34 R	1048.40 R	1048.45 R	1048.82 R	1048.62 R	1048.99	1048.86 J	1049.36
DCF93-18	Lower Crouse	1128.74	1028.82	1027.18 R	1027.79 R	1027.72 R	1027.79 R	1028.18 R	1028.64 R	1028.84 J	1029.14	1029.21	1029.38
DCF93-19	Lower Crouse	1087.54	1026.80	1046.23	1046.61	1046.44	1045.62	1046.68	1046.44	1046.06	1047.25	1047.79	1047.79
DCF93-20	Lower Crouse	1088.98	1032.37	1045.32	1045.76	1044.94	1042.14	1043.99	1045.23	1044.70	1045.06	1046.00	1046.28
DCF94-21	Unconsolidated	1082.37	1044.77	1047.76	1047.82	1047.51	1047.41	1047.60	1047.42	1047.42	1047.45	1048.10	1048.15
CF94-22	Alluvial	1060.77	1032.02	1042.61	1044.02	1042.01	1040.09	1042.65	1041.62	1043.08	1042.23	1042.92	1043.60
CF96-23	Alluvial	1061.10	1010.03	1042.58	1043.61	1041.41	1039.70	1042.25	1041.19	1041.06	1040.50	1043.33	1042.90
DCF96-24	Alluvial	1059.85	1011.01	1042.17	1043.61	1041.33	1039.45	1042.66	1041.23	1040.86	1040.44	1042.51	1043.00
DCF96-25	Alluvial	1060.92	1030.80	1042.10	1044.00	1041.92	1039.96	1048.55*	1041.82	1041.32	1041.23	1042.88	1043.72
DCF96-26	Alluvial	1062.31	1029.23	1042.30	1043.84	1043.65*	1039.81	1049.47*	1041.46	1041.08	1040.91	1042.71	1043.33
DCF96-27	Alluvial	1060.81	1027.91	1042.17	1043.71	1041.52	1039.64	1046.66*	1042.26	1042.54	1040.75	1042.40	1043.14
DCF96-28PZ	Alluvial	1061.42	1031.45	1042.22	1043.94	1041.89	1039.92	1042.63	1042.84	1041.29	1041.12	1043.42	1043.76
DCF96-29PZ	Alluvial	1065.31	1033.01	1042.13	1043.93	1041.91	1039.83	1043.80	1042.34	1042.23	1041.10	1043.13	1043.69
DCF96-30PZ	Alluvial	1062.33	1029.31	1042.36	1044.21*	1041.68	1039.79	1042.51	1041.33	1041.72	1040.81	1042.62	1043.38
DCF96-31PZ	Alluvial	1061.08	1030.24	1042.62	1043.63	1041.47	1039.69	1042.25	1041.45	1041.08	1040.64	1043.86	1043.02
DCF96-32PZ	Alluvial	1060.31	1027.99	1042.04	1043.57	1041.31	1039.32	1042.52	1042.41	1040.78	1040.49	1042.50	1043.11
DCF96-33PZ	Alluvial	1062.32	1030.15	1042.26	1043.75	1041.59	1039.69	1042.56	1041.30	1041.07	1040.67	1042.54	1043.32
DCF96-34	Alluvial	1051.06	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
DCF96-35	Alluvial	1065.26	1009.56	1042.95	1044.40	1042.42	1040.85	1052.63*	1042.69	1041.99	1041.86	1043.61	1044.31
DCF96-36	Alluvial	1061.30	1010.28	1042.15	1043.03	1041.40	1039.71	1047.96	1046.37	1041.35	1040.43	1042.31	1042.59

Notes:
1. Monitoring well construction details for DCF92-07 are not available.
   Top of casing elevation was obtained from survey monument.
2. R indicates rejected water elevation data, based on bottom of screen elevation.
3. J indicates water elevations which are within 0.10 foot above the bottom of screen elevation.
4. * - indicates that the data point was not used for contouring because it is anomalously high or low.
5. Well DCF96-34 was damaged (bent) in January 1997.
6. NM - indicates not measured.
7. BTP - indicates groundwater was below top of pump.

3.0 Updated Description of Geology and Hydrogeology

Since the submission of the Draft Final RI in March 1995, fourteen (14) new monitoring wells and piezometers have been installed on the Island at the DCF Study Area. The wells and piezometers installed in May 1996 were driven, rather than drilled/sampled during installation and so little additional geological information was obtained during their installation other than observation of materials visible from the surface and the inference that the bottom of the alluvial soils must be at least as deep as the refusal depth for the deep driven wells. Groundwater elevation data were recorded monthly at these locations, along with the existing wells at the DCF Study Area, resulting in a greater understanding of the groundwater flow regime across the Island and its relationship between the Kansas River and groundwater flow in the upland.

3.1 Geology

A detailed description of the geology for the DCF Study Area is provided in Sections 2.4 and 3.2 of the Draft Final RI (CENWK, 1995). The geological setting of the DCF Study Area is composed of horizontally bedded sedimentary rocks (limestone and shale) forming upland areas, with overlapping alluvial deposits adjacent to the Kansas River. A summary of the unconsolidated and bedrock geology studied during the RI field activities follows.

The bedrock at the DCFA consists of nearly horizontal lying, alternating beds of shale and limestone formations. The rock units encountered within the DCFA consist of the Council Grove and Chase Groups. The formations within these groups include, in order of increasing age, the Havensville Shale and Threemile Limestone of the Council Grove Group, and the Speiser shale, Funston Formation, Blue Rapids Shale, Crouse Limestone, and Easly Creek Shale of the Chase Group. All of these units are of Permian age.

The shales of these formations are relatively unfractured. They are generally gray, but maroon and green-gray variegations occur. The limestones are massive, cherty, occasionally vuggy, with occurrences of shaley partings. Both shale and limestone units are approximately 15 feet thick. Detailed descriptions of each formation is given in Section 2.4.2 of the Draft Final RI (CENWK, 1995). The dip of the bedrock, as determined from the top of the Upper Crouse (see Figure 3-1).

Overlying the bedrock are unconsolidated materials ranging from a thin, dark, sandy soil to various fill materials, underlain by silts, clayey silts, and sands. These materials ranged in thickness from 3 feet along the west side of Building 183, to 42 feet south of Building 180/181. The deepest accumulations occur in the bedrock erosional feature (possibly an abandoned stream channel) located beneath and adjacent to Building 180. Figure 3-1 shows the structure contour map of the top of the Upper Crouse, with the bedrock erosional feature indicated.

The material on the Island consists of silts and fine sands. As part of the feasibility study, two grab samples of the alluvial material were collected from along the river bank in the vicinity of DCF96-30. Grain size distribution curves for these samples are provided in Appendix B. As indicated in the grain size distribution curves the material is a silt. This is not necessarily representative of the entire thickness of the materials present, since it is typical for sandy fluvial deposition environments such as the Island to have variable stratification both vertically and laterally, with features such as abandoned channels and buried sand bars present. Access constraints for heavier rotary drilling equipment at the Island have limited the feasibility of conventional drilling and geological logging of the Island materials and depositional features.

Only one monitoring well, installed on the Island, has potentially penetrated the full thickness of the alluvial deposits. Well DCF96-24 encountered refusal at 46 feet bgs.

3.2 Hydrogeology

The hydrogeology of the DCFA has been extensively studied during the RI and earlier activities, although the Island has only recently been evaluated in detail. A detailed discussion if the DCFA hydrogeolgy is provided in Section 3.2.4 of the Draft Final RI (CENWK, 1995). Groundwater elevation ranges from approximately 1050 feet above mean sea level (amsl) in the northern area of the DCFA to approximately 1042 feet amsl on the Island. Groundwater occurs in the bedrock, unconsolidated material overlying bedrock, and alluvial deposits. Flow is primarily to the southwest, in both the bedrock and unconsolidated material. The Kansas River generally controls the groundwater movement on the Island and flow there is primarily to the south and east. In the area to the north of Custer Road the groundwater table is not present in the unconsolidated material. To the south and southeast of Custer Road, the unconsolidated material becomes thicker and groundwater is encountered above the bedrock in these materials. Typical groundwater flow patterns for the site are shown on Figures 3-2 and 3-3. However, groundwater contour maps for each of the gauging events since March 1995 are provided in the DSRs (CENWK, 1996a, 1996c, 1996d, 1996e, and 1997a).

Groundwater flow within the bedrock is primarily through the limestone formations. Flow within each limestone unit is believed to be through fractures, solution cavities, and along bedding planes. It is noted that the flow direction in the bedrock units corresponds to the dip direction of the limestone beds. The low hydraulic conductivity of the shale beds inhibits vertical groundwater movement between the limestone units. Discharge from the bedrock is to the alluvial material at the buried escarpment which runs parallel to the rail track to the south of Building 180/181. Groundwater also discharges from the bedrock to the unconsolidated material at the head of the bedrock erosional feature. The connection between the bedrock and the unconsolidated and alluvial material, with respect to groundwater movement, is therefore believed to be along the face of the buried bedrock escarpment. A vertically downward gradient is believed to exist along this escarpment which reverses to an upward gradient towards with discharge to the river (Figure 3-4). Typical of river valleys, the vertical flow of shallow groundwater likely consists of a predominantly downward flow component near the upland side of the Island, causing contaminants to flow beneath DCF93-11, DCF94-22, and DCF96-27 and thus not be detected in these wells. Then the deeper, contaminated groundwater turns upward as it nears the Kansas River such that contaminants are again detected in wells such as DCF96-23.

At low river stage, groundwater enters the site through the bedrock, flows primarily to the southwest, and discharges to the alluvium. Figure 3-2 illustrates the typical groundwater flow pattern at low river stage (approximate elevation 1040 feet amsl). Discharge to the unconsolidated material within the bedrock erosional feature may account for the groundwater mound which is apparent to varying degrees in the groundwater table mapping for the unconsolidated material to the east of Building 180. It is also possible that Tributary A is contributing to this groundwater mounding. Tributary A is at an approximate elevation of 1060 feet amsl at this location, approximately 10 feet above the groundwater table. Leaks from sewer lines which would contribute to this mounding effect include past leaks from sanitary sewer lines (which have now been abated through completed sanitary sewer replacement and diversion activities) as well as past and current exfiltration from the storm sewer system at the DCF Study Area. Repair of the sanitary sewer lines in May 1994 and June through August 1996 has eliminated or at least greatly reduced the leak as a source of recharge.

Flow within the unconsolidated material is primarily to the southwest with discharge to the alluvial material on the Island. The mounding has, however, resulted in groundwater gradients and subsequent flow back towards the bedrock units at some locations and times. Recharge from the unconsolidated material to the bedrock units on either side of the bedrock erosional feature is, therefore, occurring to some limited degree.

Apparent groundwater mounding is also seen in the alluvial material near the center of the Island at low river stages based on groundwater table mapping (Figure 3-2). Flow within the alluvial is primarily to the south with discharge to the Kansas River. Vertical gradients measured at the two well pairs, DCF96-23 and DCF96-31PZ, and DCF96-24 and DCF96-32PZ, were variable from month to month and between well pairs during any measurement period. However, both the deep and shallow wells/piezometers have a greater head than that of the river (except during occasional flood events) indicating an upward vertical gradient and discharge to the river.

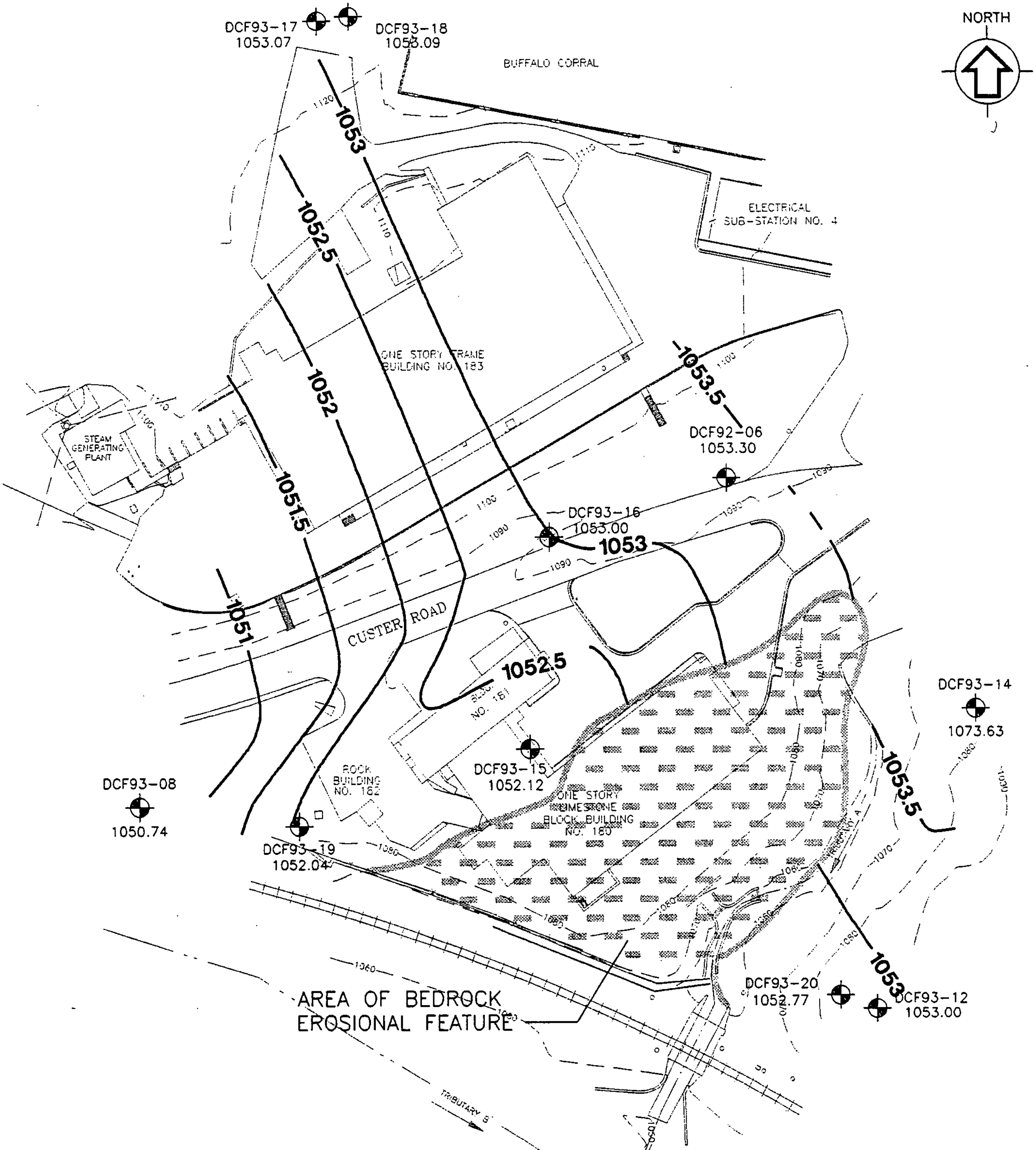
The groundwater flow regime discussed above is altered during heavy precipitation events and high river stage, to varying degrees. Figure 3-3 illustrates the typical groundwater flow pattern at river flood stage (approximate elevation 1053 feet msl). Both tend to occur simultaneously except when flow in the Kansas River at the DCF Study Area is artificially controlled by the upstream Milford Dam. An extreme example of a change in flow regime occurred between May and June 1995 (Figure 3-3). Heavy precipitation occurred during that period and a net rise of 14.49 feet in the Kansas River was recorded by the USGS between the May 1, 1995 and June 1, 1995 sampling events. The highest river level during this period was recorded on May 28, 1995 and was reported by the USGS at 14.63 feet. Similar changes in groundwater elevations were also recorded (i.e., groundwater elevation rose from approximately 1040 feet amsl to 1055 feet amsl in the Island wells). As the river rises, groundwater flow is into the Island for most of the area. Higher groundwater heads on the Island therefore impede flow from the bedrock and unconsolidated material. The groundwater mound on the Island and in the unconsolidated material is thus masked during extreme high water events. Groundwater elevation increases of up to 10 feet were recorded in the bedrock wells. This increase is believed to also be attributable to precipitation recharge at the outcrop area of the Crouse Limestone. These higher groundwater elevations resulted in a component of flow to the southeast in the bedrock.

Localized anomalous groundwater elevation readings occur following heavy precipitation events and high river stage caused by depression focused recharge and varying hydrogeological properties of the alluvial materials. The variation of hydrogeological material on the Island will result in different reaction rates to the same hydrological event. The configuration of the groundwater table contours depicting conditions immediately following a hydrological event will appear distorted as wells screened in finer material will take longer to return to equilibrium (steady-state conditions).

Since the installation of the fourteen additional wells and piezometers on the Island, monthly groundwater elevation measurements have been collected. Table 3-1 summarizes the groundwater elevation measurements in these and existing wells. Figures 3-2 and 3-3 are representative examples of groundwater table mapping during low (or steady state) river periods and high river periods. As shown on these figures, the groundwater flow regime on the Island is variable whereas the flow regime in the upland area of the DCFA is consistent for the most part.

TABLES

FIGURES



LEGEND

DCF93-08
4.60 GROUNDWATER MONITORING WELL LOCATION; NO. UPPER CROUSE ELEVATION VALUE (FT)

— **40** — TOP OF UPPER CROUSE ELEVATION (FT) CONTOUR

0 50 100 200
SCALE IN FEET
1" = 100'

NOTE:

1. THE ONLY WELLS SHOWN ARE THOSE IN WHICH THE LOCATION OF THE UPPER CROUSE COULD BE CONFIRMED.

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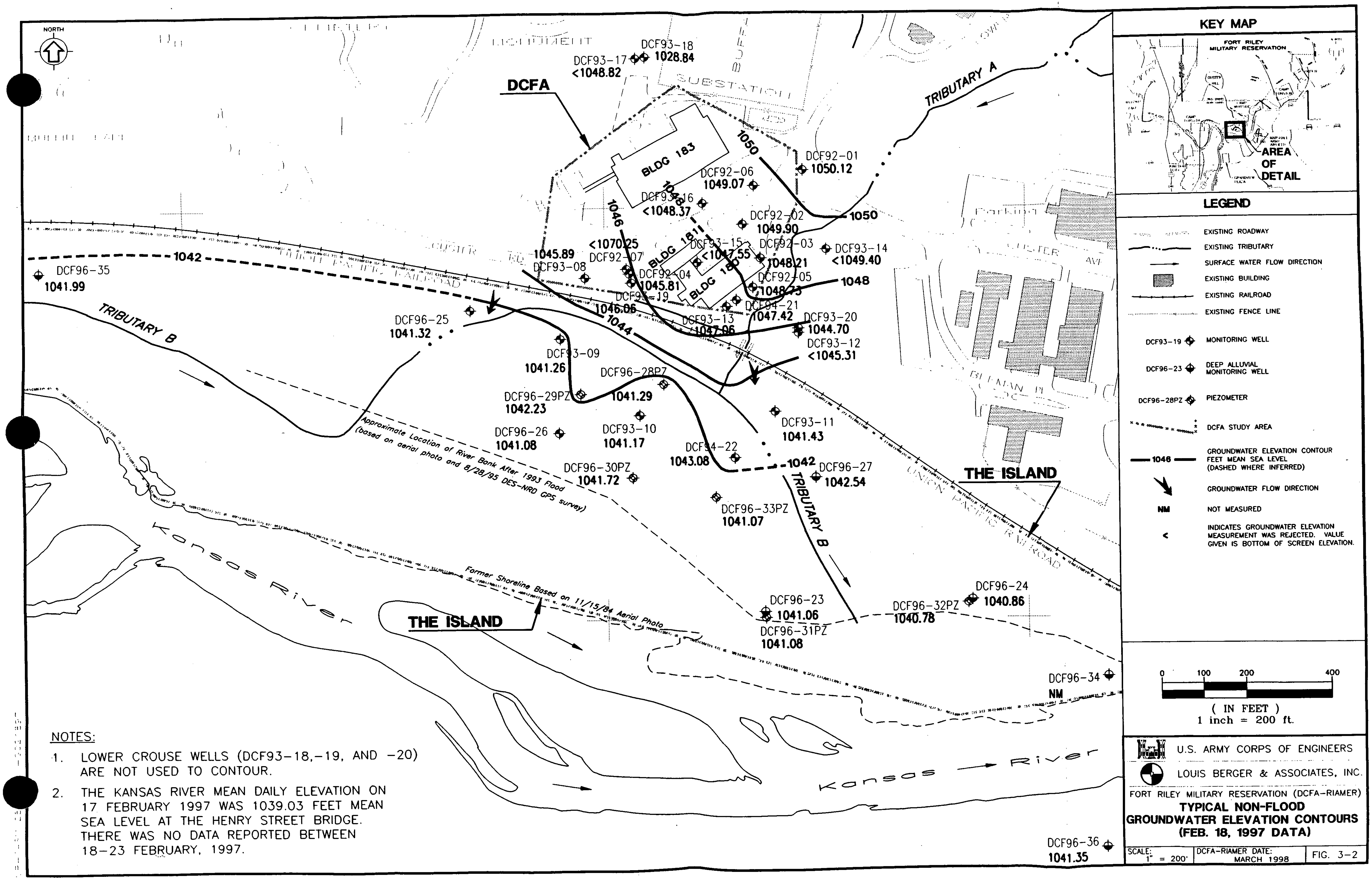
STRUCTURE CONTOUR MAP
TOP OF UPPER CROUSE

SCALE: AS SHOWN	DATE: MARCH 1998	FIG. 3-1



NOTES:

1. LOWER CROUSE WELLS (DCF93-18,-19, AND -20) ARE NOT USED TO CONTOUR.
2. THE KANSAS RIVER MEAN DAILY ELEVATION ON 17 FEBRUARY 1997 WAS 1039.03 FEET MEAN SEA LEVEL AT THE HENRY STREET BRIDGE. THERE WAS NO DATA REPORTED BETWEEN 18-23 FEBRUARY, 1997.

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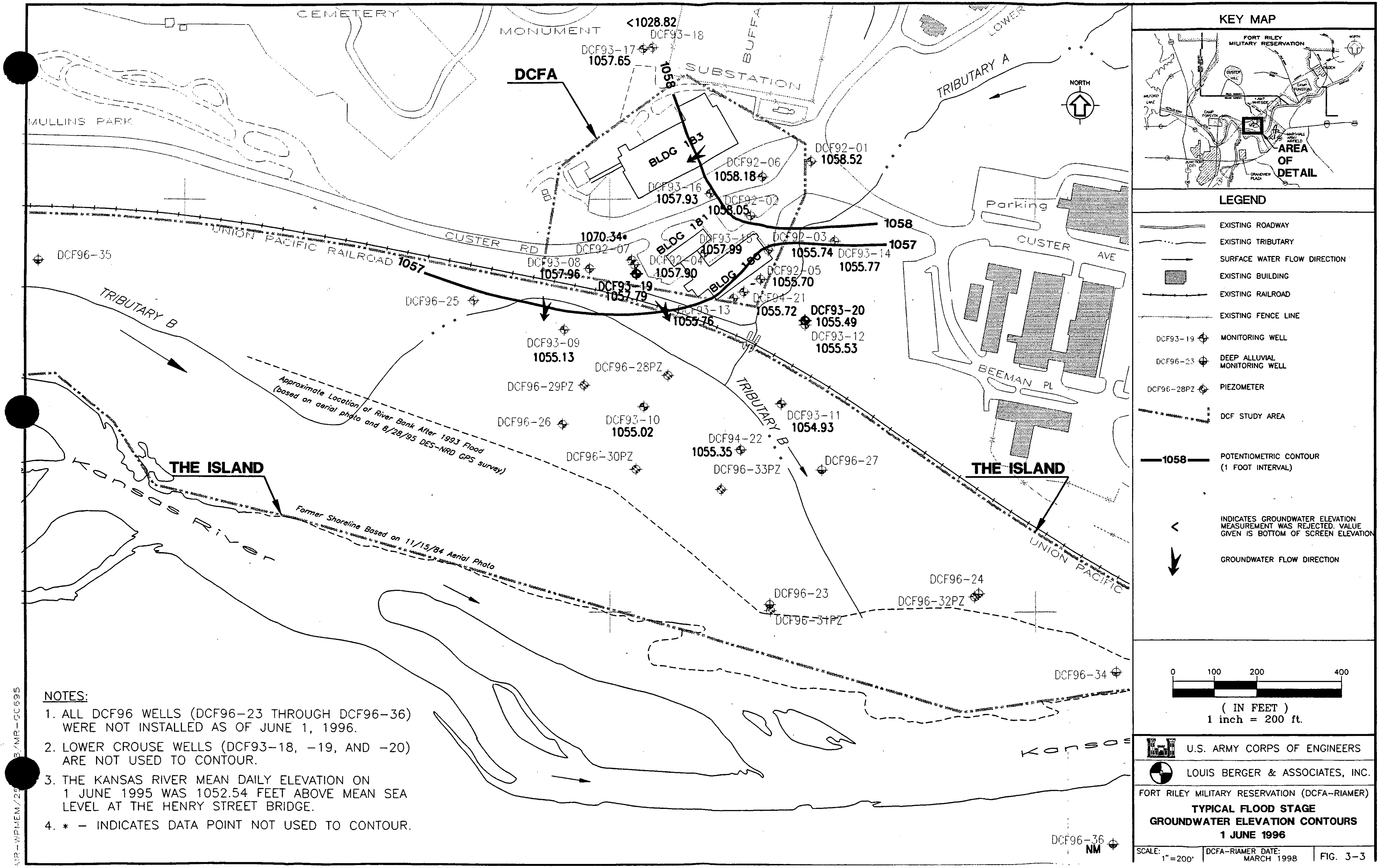
TYPICAL NON-FLOOD GROUNDWATER ELEVATION CONTOURS (FEB. 18, 1997 DATA)

SCALE: 1" = 200'	DCFA-RIAMER DATE: MARCH 1998	FIG. 3-2



LEGEND

	EXISTING ROADWAY
	EXISTING TRIBUTARY
	SURFACE WATER FLOW DIRECTION
▨	EXISTING BUILDING
	EXISTING RAILROAD
	EXISTING FENCE LINE
DCF93-19	MONITORING WELL
DCF96-23	DEEP ALLUVIAL MONITORING WELL
DCF96-28PZ	PIEZOMETER
	DCF STUDY AREA
1058	POTENTIOMETRIC CONTOUR (1 FOOT INTERVAL)
<	INDICATES GROUNDWATER ELEVATION MEASUREMENT WAS REJECTED. VALUE GIVEN IS BOTTOM OF SCREEN ELEVATION
	GROUNDWATER FLOW DIRECTION

NOTES:

1. ALL DCF96 WELLS (DCF96-23 THROUGH DCF96-36) WERE NOT INSTALLED AS OF JUNE 1, 1996.
2. LOWER CROUSE WELLS (DCF93-18, -19, AND -20) ARE NOT USED TO CONTOUR.
3. THE KANSAS RIVER MEAN DAILY ELEVATION ON 1 JUNE 1995 WAS 1052.54 FEET ABOVE MEAN SEA LEVEL AT THE HENRY STREET BRIDGE.
4. * – INDICATES DATA POINT NOT USED TO CONTOUR.

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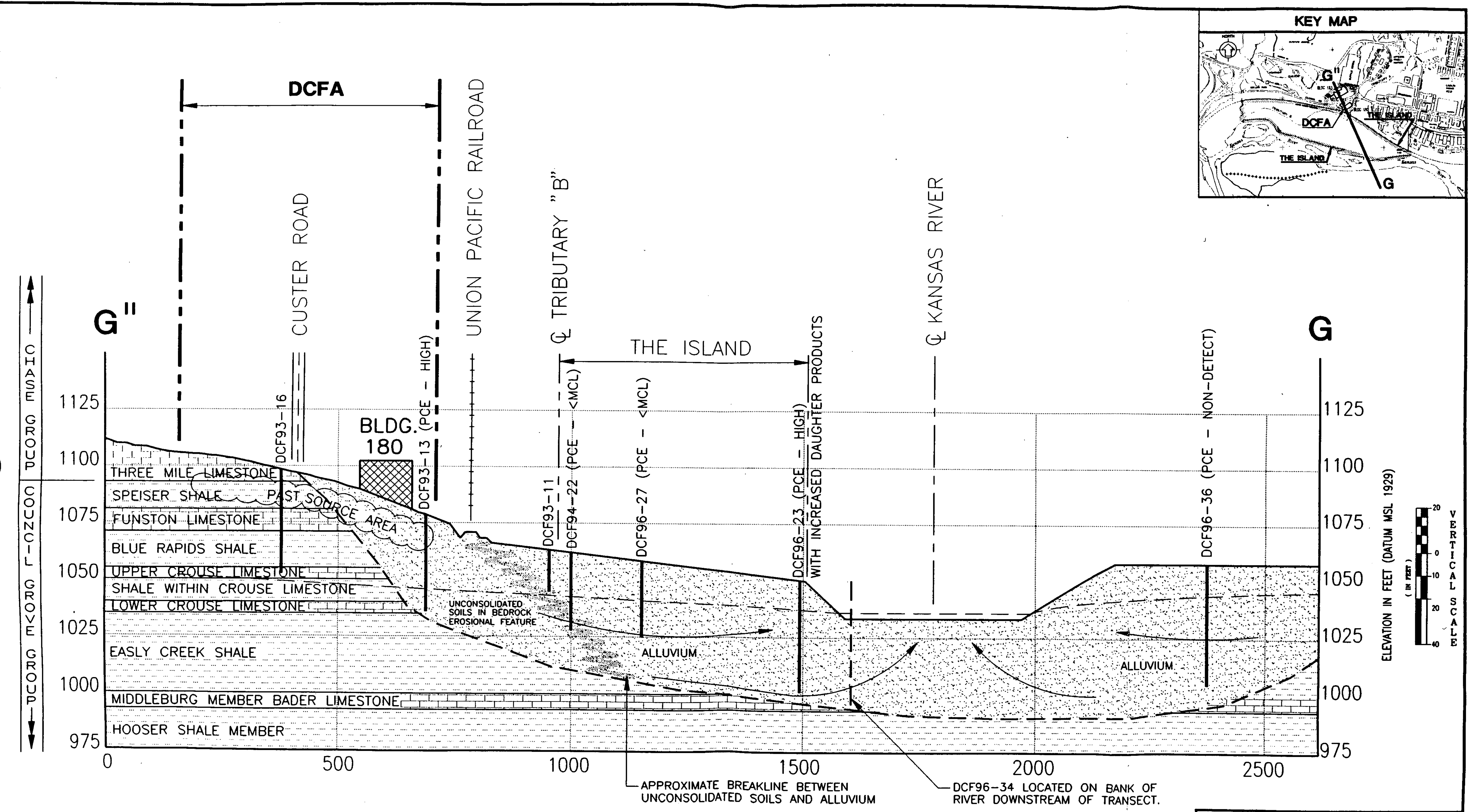
FORT RILEY MILITARY RESERVATION (DCFA-RIAMER)

TYPICAL FLOOD STAGE
GROUNDWATER ELEVATION CONTOURS
1 JUNE 1996

SCALE: 1"=200' | DCFA-RIAMER DATE: MARCH 1998 | FIG. 3-3



NOTES:

1. Geology After Zeller, 1989.
2. Location of Section Line Also Shown on Figure 2-1.
3. PCE (TETRACHLOROETHYLENE) Relative concentrations are based upon 1997 sampling events.

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FORT RILEY MILITARY RESERVATION (DCFA-RIAMER)

DCFA AND VICINITY GEOLOGIC CROSS SECTION AND VERTICAL FLOW REGIME

SCALE: AS SHOWN	DCFA-RIAMER DATE: MARCH 1998	FIG. 3-4

4.0 GROUNDWATER DATA SUMMARY

4.0 Groundwater Data Summary

This section provides an overview of the results of the groundwater-related RI activities through January 1995, followed by a presentation of the results of groundwater sampling and analyses performed as part of the monitoring expansion groundwater monitoring program at the DCF Study Area. The former results are reported in detail in the Draft Final RI (CENWK, 1995), and the latter results are reported in detail in the DSRs for all of the sampling events since the Draft Final RI. In addition, a summary of the results of data collected by continuous-read data loggers is presented in this section.

The Draft Final RI covers the period from July 1992 through January 1995. As reported in the Draft Final RI, the most frequently detected contaminants and the only contaminants detected at levels exceeding regulatory standards are chlorinated VOCs (PCE and its breakdown products TCE, DCE, and vinyl chloride). Infrequent detections of PAHs, SVOCs, BTEX compounds, phthalates, and trihalomethanes are also noted, but at low concentrations which do not trigger the need for further action. PCE was reported as the source contaminant and the most widespread contaminant at the site. PCE concentrations ranged up to a historic maximum of 1,600 mg/l in 1993, but with the maximum levels decreasing since that date.

PCE concentrations were also shown in the Draft Final RI to decrease with migration distance from the upland source area. The highest concentrations were reported at DCF92-03, near the center of the contaminant source area within the DCFA, with concentrations decreasing in wells along the migration pathway towards the Kansas River. Higher concentrations of PCE breakdown ("daughter") products were also observed in the down gradient wells, indicative of natural attenuation.

The DSR results from the monitoring expansion work include all the groundwater monitoring results from the DSR for May 1995 (CENWK, 1996a), which was the first sampling period subsequent to the Draft Final RI, to the DSR for February 1997 (CENWK, 1997a), the most recent DSR which has been completed and finalized. Since they have never been summarized together in a single document, each of these DSRs are briefly summarized in the subsections below with the description of the specific sampling activity as previously described in Section 2.2.

The combined inception to date results from the RI and the monitoring expansion related groundwater elevation monitoring activities strengthen and further the findings and data trends presented in the Draft Final RI. Inception to date hydrographs are presented as Figures 4-1 and 4-2; depicting the inter-related Kansas River stage data, precipitation data, and groundwater elevation data. Tables 4-1 through 4-3 include inception to date sampling and analysis data. These data clearly illustrate that the chemical information collected since the submission of the Draft Final RI are consistent with and further support the findings presented in the Draft Final RI, especially with regard to continuing decreases in the maximum contaminant levels within the DCF Study Area as well as additional evidence that natural attenuation (including biodegradation) is absolutely occurring. These data are discussed and evaluated in more detail in Section 5.0, and natural attenuation is specifically evaluated in Section 5.3.

4.1 Continuous Reading Groundwater Elevation and Sewer Impact (Temperature) Datalogging Activities

- **Field Activities**

On 28 July 1994, a Leupold-Stevens water level data logger was installed in well DCF94-22 to collect water level data that could be compared to the Kansas River stage data as collected and reported by the

USGS. DCF94-22 was chosen because the monitoring well was centrally located on the Island downgradient from the DCFA, the well is two inch diameter which can accommodate the logging unit and it contained a sufficient water column for the continuous-read data logger to obtain readings. The data collected from DCF94-22 were used to evaluate the influence of the river stage on the water levels on the Island and to examine what effect the river stages and water levels have on contaminant transport.

In October 1995, five data loggers were installed in existing monitoring wells located near the DCFA buildings to monitor the temperature and groundwater elevation influences due to leaks from the sanitary sewer lines. Geoguard continuous-read data loggers were installed in monitoring wells DCF92-03, DCF92-04, DCF93-15, DCF93-17, and DCF93-19, as discussed in a Berger technical memorandum.

Monitoring Well	Geologic Unit Screened	Rationales
DCF92-02 (installed in October 1996)	Upper Crouse Formation	Screened in Upper Crouse Formation, sufficient water column, proximal to sewer line
DCF92-03 (installed in October 1995)	Unconsolidated Materials	Screened in unconsolidated materials, sufficient water column, primary pathway for contamination, proximal to sewer line
DCF92-04 (installed in October 1995)	Upper Crouse Formation	Screened in Upper Crouse Formation, sufficient water column, monitors the west end of the dry cleaning facility area
DCF93-15 (installed in October 1995, removed and installed in DCF92-02 in October 1996)	Upper Crouse Formation	Installed in the Upper Crouse Formation, monitors an "off loading area" of the DCFA, proximal to sewer line
DCF93-17 (installed in October 1995)	Upper Crouse Formation	Upper Crouse Formation, most upgradient location at the DCFA
DCF93-19 (installed in October 1995)	Lower Crouse Formation	Installed in and monitors the Lower Crouse Formation, at the west end of the DCFA
DCF94-22 (installed in July 1994)	Alluvium	Alluvium, sufficient water column, monitors the alluvium on the island, closest well to the Kansas River that can accommodate a data logger

Initially, a data logger was installed in monitoring well DCF93-15. Problems were experienced both with the logger unit and with an insufficient column of water in DCF93-15. In October 1996, the data logger in

DCF93-15 was removed and a replacement data logger was installed in DCF92-02. These locations are shown in Figure 1-2 and a summary of the wells, geologic intervals monitored, and the rationales for logger placement are presented in summary format. There were additional difficulties experienced with the equipment and with questionable water levels in some of the monitoring wells. These are summarized in this section, however, it should be noted that overall, sufficient data were assembled, during the continuous-read data collection, to assess the groundwater temperatures and elevations at the DCFA.

During the period April through May 1996, the water level in monitoring well DCF93-17 dropped below the level of the data logger probe. The water level subsequently returned to an acceptable level in the well and the data logger continued to collect and record temperature and elevation data. Based on a recent re-evaluation of the well construction details, the potential exists for the data logger to be recording standing water in the well sump during most periods. Recommendations were made to remove the data logging unit from DCF93-17 and reinstall it into monitoring well DCF93-20. The questionable water levels in DCF93-17 have made continued logging in this well unnecessary and, by installing the unit in DCF93-20, a clearer picture of the background groundwater temperatures can be obtained.

A review of the groundwater temperature data collected from DCF92-03 during the May/June 1997 monitoring period indicated extreme variations on a daily basis. It was assumed that the data logger probe was damaged, possibly during removal and replacement during the May 1997 groundwater sampling event. Therefore, the logging unit was returned to the manufacturer for inspection servicing. The unit was subsequently determined by the manufacturer to be damaged and non-functioning, and a repaired unit was re-installed in monitoring well DCF92-03

The data logger in DCF93-19 malfunctioned until April 1996 and malfunctioned again briefly during the July/August 1996 period. These problems were resolved with the manufacturer's assistance in March 1996. The data logger in monitoring well DCF94-22 did not record water levels from February to May of 1996 and from mid-June to December of 1996. This was found to be due primarily to a faulty battery and to fouling on the sensor probe. The data logger was serviced in May of 1996 and, subsequent to the additional difficulties, the unit was replaced with a Geoguard data logger.

- **Data Summary November 1995 - June 1997**

Since installation of the data loggers, data have been downloaded periodically by Berger field team personnel on-site for water level measurements or groundwater sampling events. The downloaded data were used to generate the graphical displays presented as Figures 4-1 and 4-2 in this report which present the groundwater elevation and temperature data from November 1995 to June 1997.

- **Monitoring Well DCF92-02**

Groundwater elevations recorded in monitoring well DCF92-02 have generally remained at approximately 1048 feet AMSL over the course of data collection. There were no exceptionally high river stages since the data logger unit was installed in DCF92-02, therefore there are no obvious responses in the groundwater elevations to changes in the river elevations.

As discussed previously, the data logger was installed in DCF92-02 after the other units were installed in monitoring wells, therefore, the length of the records for DCF92-02 are approximately half of the other temperature records. Since the data logger was installed in DCF92-02, the temperature readings have generally been stable in the 17°C to 17.5°C range, just slightly above typical background levels (13°C to 14.5°C). A slight, long term rise and fall in temperature was recorded in DCF92-02 however it was not sufficient to change the temperature by more than one half of a degree.

- **Monitoring Well DCF92-03**

Groundwater elevations recorded in monitoring well DCF92-03 have generally remained within the 1050 to 1045 foot range over the course of data collection. During exceptionally high river elevations, such as those recorded in May and June of 1996, a response was recorded in DCF92-03 which raised the elevation of groundwater to approximately 1052 feet AMSL.

Groundwater temperature data have indicated that since the inception of monitoring in November 1995, there has been a decline in temperature albeit not on a constant or steady basis. The decline in groundwater temperature in DCF92-03 recorded between November 1995 and May 1996 was approximately two and one half degrees with an initial temperature of approximately 19.5°C and a final temperature of approximately 17°C. The records for the period from May 1996 through the first half of January 1997 were found to document a more gradual decline in temperature of less than one half a degree with one period showing a slight increase. From mid-January through April of 1997, the decline in temperature closely reflects the decline seen during the November 1995 through May 1996. There is an approximate decline in temperature of one degree from 17°C to 16°C. These recorded levels are slightly higher than documented temperature levels for this area (13°C to 14.5°C). It is after this period that the data logger appears to begin malfunctioning. From early May through the middle of June of 1997 the reported temperatures vary widely ranging from almost 13°C to slightly less than 16°C during the beginning of May 1997 to a series of highs and lows between 16°C and 15°C. These variations appear on the graph at daily intervals and the previously seen gradual decline in temperature is no longer in evidence due to these seemingly erratic readings.

- **Monitoring Well DCF92-04**

The groundwater elevation data for monitoring well DCF92-04 generally shows a good correlation with the river elevation data for the November 1995 through June 1997 period. From November 1995 through April 1996, the river elevations tended to stay below 1040 feet AMSL with the exception of one high water event in December of 1995 when the river elevation reached an approximate elevation of 1041 feet AMSL. The trace of the groundwater elevation in DCF92-04 for the same period is generally flat at approximately 1046 feet AMSL with a slightly higher elevation corresponding to the aforementioned high river stage in December 1995. From about May of 1996 the elevations in both DCF92-04 and the Kansas River show a matching trend, becoming more erratic with a high degree of variability in high water elevations. These peaks not only correlate well with each other but also with the records of precipitation during this period.

The records of groundwater temperatures as measured in DCF92-04 are, overall, not very variable. Groundwater temperatures were reported to be approximately 17 °C during most of the period between November 1995 and June 1997 (as compared to documented temperature levels for this area (13°C to 14.5°C). Minor variations of less than one half a degree were recorded over the duration of monitoring.

- **Monitoring Well DCF93-17**

As discussed above, the data from this well have been determined to be suspect and have been rejected based on the newly adopted groundwater elevation validation protocol (see Section 1.4.3). The groundwater elevations have been determined to be below the minimum acceptable elevation for DCF93-17 and it is now assumed that any data collected are not representative of true groundwater conditions but of standing water in the well sump. Based on the foregoing, the temperature data are also now rejected.

These data have been removed from the hydrographs and are not considered in the evaluation of the continuous-read groundwater data set.

- **Monitoring Well DCF93-19**

The results of groundwater elevation and temperature monitoring in DCF93-19 are very similar to those collected at DCF92-04. These wells are close to one another on the southern edge of the DCF main area of operations and north of the Island area. The good correlation between groundwater elevations and Kansas River water elevations, documented in DCF92-04, are virtually mirrored in the data collected from DCF93-19.

The groundwater temperature data collected from DCF93-19 are lower than those collected from DCF92-04, however, not by more than one half of a degree. Generally, the groundwater temperatures measured in DCF93-17 are at 17 °C for most of the duration of monitoring. Minor variations in the reported from the data logger, moved the temperature slightly above or below 17 °C, however the total variation was negligible. The recorded levels are slightly higher than documented temperature levels for this area (13°C to 14.5°C).

- **Monitoring Well DCF94-22**

The data logging unit installed in DCF94-22 commenced recording groundwater elevation data from the end of July of 1994 however, as discussed previously, the data logger did not provide usable groundwater elevation data over most of the monitoring period from November 1995 to June 1997. The periods where the logger did function correlated very well with the reported elevations of the Kansas River. These groundwater elevations were recorded in DCF94-22 between July 1994, November and December of 1995, an May and June of 1996. The reported data are very similar to the high and low water stage elevations in the Kansas River reported during the same periods. As discussed above, a new data logger has been installed in DCF94-22 and it is anticipated that the groundwater elevations recorded in the monitoring well will correlate well with the river water elevations.

The logger unit installed in DCF94-22 was a groundwater elevation recorder only. There are no groundwater temperature data available for this well.

4.2 May 1995 DSR

4.2.1 Groundwater Levels and Discussion

Monthly groundwater measurements were performed at 22 monitoring wells and at three groundwater extraction wells installed for the pilot study at the DCFA. Wells DCF93-08, and DCF93-11 were reported dry. The general groundwater flow at the DCF is from northeast to southwest with localized variations noted along Custer Road where flow is to the west, and in the area of wells DCF94-21 and DCF93-13 where flow is reported to be toward the south and east.

4.2.2 Analysis Results

Concentrations of contaminants, above their respective detection limits, were reported in the analyses of samples from 18 wells. VOCs were reported in all of the samples and TPH was reported in two of the four samples analyzed for this suite of compounds.

The highest concentrations of VOCs were reported in the sample collected from DCF93-13 located southeast of Building 180. Tetrachloroethylene (PCE) and trichloroethylene (TCE) were detected at 210 μg/l and 190 μg/l, respectively both of which are above their Maximum Contaminant Level (MCL) of 5 μg/l. These compounds were also detected at DCF93-15 at reported concentrations of 150 μg/l and 12 μg/l, respectively, also above the MCL for PCE and TCE.

PCE and TCE were detected at varying concentrations above either or both of the previously specified criteria at monitoring wells DCF93-10, DCF92-02, DCF92-03, DCF92-05, DCF93-09, DCF93-12, and DCF94-21. In addition, these compounds were detected at the three extraction wells numbered DCF94ES-1B, 2B and 3B. Other VOCs detected by laboratory analysis, at levels below their respective MCLs, were 1,2-dichloroethylene (1,2-DCE), trichloromethane, bromodichloromethane, benzene, ethylbenzene, and xylenes. Groundwater extraction well DCF94ES-1B exhibited detections of VOC compounds not previously identified at the DCFA but all at concentrations below their respective MCLs. These included 1,1,1-trichloroethane, 1,4-dichlorobenzene, dibromochloromethane, tribromomethane and chlorobenzene.

TPH concentrations were reported from monitoring wells DCF92-04 and DCF93-15. GRO concentrations ranged from 1,300 μg/l in well DCF92-04 to 140 μg/l in well DCF93-15. DRO concentrations ranged from 4,100 μg/l in the sample from DCF92-04 to 430 μg/l in well DCF93-15. There is no MCL for these suites of compounds.

4.2.3 May 1995 Results Discussion

The results of the May 1995 sampling and analysis effort indicates that the highest reported concentrations of PCE, above its appropriate MCL, were found in samples from wells DCF93-13 and DCF93-15. Similarly, the highest concentration of TCE was reported from well DCF93-13 and 1,2-DCE from wells DCF93-13 and DCF93-10. The contaminant contours generally describe a mass of contaminants, centered around DCF93-13. The individual contaminant contours describe a variable area, however, the general trend shows the contaminants extending south/southwest toward DCF93-10. This is in general agreement with the overall direction of groundwater flow which is also toward the south and southwest.

4.3 June 1995 DSR

4.3.1 Groundwater Levels and Discussion

Due to the high precipitation of mid- to late-May, groundwater levels in all but one of the site monitoring well had risen an average of 10 feet above those seen during the May 1995 sampling. The one exception noted was well DCF93-18 in which the water level dropped 2.23 feet from the May 1995 level. The precipitation and associated rise in the water level in the Kansas River altered the general groundwater flow pattern at the DCF from the previously documented northeast to southwest flow to an almost uniformly southeast flow direction. In addition, the new contours appear to describe a groundwater mound centered at well DCF92-02 with definite flow on one side to the southeast and the suggestion of flow to the northwest on the other side of a groundwater divide.

The June 1995 DSR report also documents an apparent rapid decline in water levels prior to sampling. The initial water level data were collected on June 1. The sampling was performed on June 2 and at that time the levels in the wells were reported to have dropped between 0.2 feet and 1.19 feet in the wells sampled.

It should be noted that the plot of the groundwater contours shows an apparent flow towards the location of Tributary A. This area has been shown by previous investigation results to be a bedrock erosional feature and the trend of groundwater to flow through bedrock to this feature is readily apparent from the June 1995 series of measurements. The flow lines also tend to flare out as they approach the alluvium in the Kansas River channel, further illustrating the anticipated flow pattern as water moves from the restricted confines of the bedrock erosional feature into the main river channel.

4.3.2 Analysis Results

Concentrations of contaminants, above their respective detection limits, were reported in the analyses of samples from all 12 wells. TPH was reported in all three of the samples analyzed for this suite of compounds.

The highest concentrations of VOCs were reported in the sample collected from DCF93-13 located southeast of Building 180. PCE and TCE both exceeded their respective MCL limit of 5 μg/l with reported concentrations of 240 μg/l for PCE and 56 μg/l for TCE. The second highest levels of PCE were reported from monitoring well DCF92-03 where PCE was detected at a reported concentration of 160 μg/l. PCE was also detected above the MCL in wells DCF93-15 (21 μg/l), DCF92-05 (43 μg/l), DCF93-09 (22 μg/l), DCF93-11 (14 μg/l) and DCF93-16 (120μg/l).

TCE was also detected above its MCL in samples from wells DCF93-15 (7.6 μg/l), DCF93-11 (7.0 μg/l) and DCF93-20 (22 μg/l). Vinyl chloride was detected at concentrations above its MCL of 2 μg/l in wells DCF93-15 (4.9 μg/l), DCF92-04 (2.9 μg/l), DCF93-08 (5.8 μg/l) and DCF93-19 (6.0 μg/l). The sample from well DCF93-16 was reported to have benzene at a concentration of 5.5 μg/l which is slightly above the MCL of 5.0 μg/l.

The results of analyses for GRO/DRO indicated that these suites of compounds were present in all three of the samples analyzed. The concentrations of DRO ranged from highs of 950 μg/l and 740 μg/l in the samples from DCF92-04 and DCF93-15 to a low of 110 μg/l in well DCF93-19. The GRO compound concentrations ranged from highs of 990 μg/l and 130 μg/l in samples from DCF92-04 and DCF93-15 to non-detect at 100 μg/l in the sample from DCF93-19.

4.3.3 June 1995 Results Discussion

The shift in the groundwater flow pattern seen between the May 1995 and the June 1995 monitoring periods are reflected in the contaminant isopleths provided in the DSR. Contaminants were centered around wells DCF93-15 and 16 during the May 1995 sampling period however, the isopleth plots connoting the area with the highest contaminant concentration, based on the June sampling data, are now offset to the east/southeast away from DCF93-15. The highest concentration area now includes DCF93-13 which previously fell outside the PCE isopleth. The shape of the contaminant mass, while still essentially describing net flow and discharge to the Kansas River, now shows a movement to the southeast rather than to the south as was previously seen during the May 1995 sampling.

The overall trend, as indicated in the June 1995 DSR, is towards lower concentrations of all contaminants with the exception of PCE. In addition, the presence of PCE, TCE, 1,2-DCE and vinyl chloride, in order of greatest to least concentration, is consistent with the model for degradation of PCE to daughter products.

4.4 July 1995 DSR

4.4.1 Groundwater Levels and Discussion

Water level monitoring during July 1995 demonstrated that the groundwater elevation had dropped an average of 6.6 feet since the high water levels noted in June of 1995. A notable exception to this is well DCF92-07 which dropped only 0.7 feet. The contours of the groundwater elevation data depict a mound in the vicinity of Buildings 180 and 181 causing the local flow in this area to vary from the overall south/southwest flow trend.

4.4.2 Analysis Results

Concentrations of contaminants, above their respective detection limits, were reported in the analyses of samples from all 21 wells sampled. TPH was reported in all three of the samples analyzed for this suite of compounds.

The highest concentration of VOCs were reported in the sample collected from well DCF94-21 located southeast of Building 180. PCE and TCE were both detected above their respective MCL limits at concentrations of 350 μg/l and 29 μg/l respectively. PCE, TCE and/or DCE were also detected above their appropriate MCL values at wells DCF92-05 (130 μg/l PCE and 10 μg/l TCE), DCF93-11 (13 μg/l PCE and 6.8 μg/l TCE) and DCF93-13 (270 μg/l PCE and 120 μg/l TCE).

Wells with detections of PCE only, above the MCL, were DCF92-02 (8.7 μg/l), DCF92-03 (170 μg/l), DCF93-09 (9.8 μg/l), DCF93-12 (9.0 μg/l), DCF93-15 (16 μg/l) and DCF93-16 (53 μg/l). Only one of the sampled wells, DCF93-20, had TCE alone at a reported concentration of 9.9 μg/l which is in excess of the MCL. Two wells, DCF93-08 and DCF93-19 had vinyl chloride above the MCL at reported concentrations of 3.1 μg/l and 4.0 μg/l respectively. Additional VOCs were detected at various site wells but at concentrations below their respective MCLs. Detected compounds included toluene, trichloromethane, and 1,2-DCE.

TPH was detected in each of the three samples collected for analysis. The reported concentrations for DRO compounds ranged from a high of 720 μg/l in the sample from DCF92-04 to 210 μg/l and 170 μg/l at DCF93-19 and DCF93-15 respectively. The GRO suite of compounds was not detected above the MDL of 100 μg/l in any of the three samples.

4.4.3 July 1995 Results Discussion

The contaminant isopleths and comparison to previous results define a southward migrating mass of contaminants with an overall north-south elongation. The contaminant limits are wider at the south end as defined by the isopleths and the overall mass of the body has shifted south relative to the June 1995 sampling and analysis period. The configuration and limits of the contaminants continue to support the assumption that the contaminants are moving toward the Kansas River and that the presence of PCE and its daughter products TCE, 1,2-DCE and vinyl chloride indicate continued degradation of the contaminants by natural processes.

4.5 August 1995 DSR

4.5.1 Groundwater Levels and Discussion

Water level monitoring during August 1995 demonstrated that the groundwater elevations had returned to their steady state conditions, similar to those seen during the May 1995 monitoring. It appears that the effects of the late May-early June high water conditions have dissipated. The general groundwater flow across the DCF is towards the southwest and observed levels during the two day monitoring and sampling event did not vary by more than several hundredths of a foot and of these variations, none were observed in wells installed in alluvial deposits. Wells installed in bedrock and upland unconsolidated material displayed insignificant variations ranging from 0.01 to 0.27 foot.

4.5.2 Analysis Results

Concentrations of contaminants, above their respective detection limits, were reported in the analyses of samples from 11 of the 12 wells sampled. VOCs were reported in all of the samples with the exception of well DCF94-22 and TPH was reported in two of the three samples analyzed for this suite of compounds.

The highest concentration of VOCs were reported in the sample collected from well DCF93-13, located southeast of Building 180. PCE and TCE were detected above their individual MCLs at reported concentrations of 200 μg/l and 140 μg/l respectively. PCE was also detected above its MCL in wells DCF92-03 (160 μg/l), DCF92-05 (34 μg/l), DCF93-09 (11 μg/l) and DCF 93-16 (28 μg/l).

TCE was detected above its MCL in two monitoring wells. TCE was reported in samples collected from DCF93-15 (6.3 μg/l) and DCF93-20 (11 μg/l). Vinyl chloride was detected above its MCL in samples collected from DCF93-08 (7.9J μg/l) and DCF93-15 (28 μg/l). 1,2-DCE was not detected in any of the samples above its MCL during this sampling and analysis period. Only one additional VOC, trichloromethane, was identified above its MDL but at a concentration below its MCL.

TPH DRO compounds were detected in two of the three analyzed samples at concentrations of 2,200 μg/l (DCF93-15) and 410 μg/l (DCF92-04). The sample from DCF93-19 showed no DRO compounds above the MDL of 100 μg/l and none of the samples had GRO compounds above the MDL of 100 μg/l.

4.5.3 August 1995 Analytical Discussion

The contaminant isopleths continue to define a southward migrating mass of contaminants with an overall north-south elongation. The isopleths for PCE continue to describe an irregularly shaped body with the northern most limit generally centered around Building 180. The isopleth lines for TCE are more circular and the center of this portion of the contaminant mass is located south or downgradient relative to the PCE. The plot of the DCE contamination is generally further downgradient relative to both the PCE and TCE. Based on the August 1995 sampling, vinyl chloride was identified at its highest concentrations since the commencement of monitoring expansion related sampling. The contaminant mass configuration and limits continue to support the assumption that the contaminants are moving toward the Kansas River and that the presence of PCE and its daughter products TCE, 1,2-DCE and vinyl chloride indicate continued degradation of the contaminants by natural process.

4.6 October 1995 DSR

4.6.1 Groundwater Levels and Discussion

Water level monitoring during October 1995 demonstrated that the groundwater elevations continued the same general pattern seen during the July and August 1995 monitoring periods wherein the return to steady state conditions was noted. The general groundwater flow across the DCF is towards the southwest and observed levels during the two day monitoring and sampling event did not vary by more than 0.5 foot In general the water levels observed in October differed from those of the previous monitoring period by an average of 1.4 feet.

4.6.2 Analysis Results

Concentrations of contaminants, above their respective detection limits, were reported in the analyses of samples from 14 of the 17 wells sampled. VOCs were reported in all of the samples with the exception of wells DCF93-17, DCF93-18, and DCF94-22 and TPH was reported in two of the three samples analyzed for this suite of compounds.

The highest concentration of VOCs were reported in the sample collected from well DCF93-13, located southeast of Building 180. PCE and TCE were detected above their individual MCLs at reported concentrations of 230 μg/l and 140 μg/l respectively. PCE was also detected above its MCL in wells DCF92-02 (6.6 μg/l), DCF92-03 (72 μg/l), DCF92-05 (33 μg/l), DCF93-09 (8.8 μg/l) DCF93-13 (230 μg/l), DCF93-15 (48 μg/l), DCF 93-16 (24 μg/l) and DCF94-21 (39 μg/l).

TCE was detected above its MCL in five monitoring wells. TCE was reported in samples collected from DCF92-05 (6.6 μg/l), DCF93-13 (140 μg/l), DCF93-15 (5.7 μg/l), DCF93-20 (21 μg/l) and DCF94-21 (6.2 μg/l). Vinyl chloride was detected above its MCL in samples collected from DCF93-08 (5.7 μg/l) and DCF93-15 (3.6 μg/l). 1,2-DCE was not detected in any of the samples above its MCL during this sampling and analysis period. Only one additional VOC, trichloromethane, was identified above its MDL but at a concentration below its MCL.

TPH DRO compounds were detected in two of the three samples at concentrations of 3,700 μg/l (DCF93-15) and 4,500 μg/l (DCF92-04). The sample from DCF93-19 showed no DRO compounds above the MDL of 100 μg/l and none of the samples had GRO compounds above the MDL of 100 μg/l.

4.6.3 October 1995 Results Discussion

The contaminant isopleths continue to define the previously documented southward migrating mass of contaminants with an overall north-south elongation. During this period however, the extent of the contaminant components appears to have migrated out further to the south from the source area in the vicinity of Building 180. The groundwater elevation monitoring over the past three periods (July, August and October of 1995) has documented what appears to be a return to steady state conditions and the normal groundwater flow pattern after the precipitation induced high water readings from June of 1995. It would appear that under normal flow conditions, the contaminant mass continues its south to southwesterly pattern of migration with the highest concentrations of PCE, TCE and 1,2-DCE centered around monitoring well DCF93-13. The configuration of each of these contaminant components describes an irregularly shaped body, extending primarily to the southwest, with an overall pattern of decreasing concentrations. The trend in decreasing concentration can be seen within each contaminant and between PCE and each of its daughter products.

The configuration of the contaminant mass and limits of the contaminant mass continue to support the assumption that the contaminants are moving toward the Kansas River and that the presence of PCE and TCE, 1,2-DCE and vinyl chloride, the natural degradation products, indicate continued degradation of the contaminants by natural processes.

4.7 May/June 1996 DSR

4.7.1 Groundwater Levels and Discussion

Water level monitoring during May 1996 demonstrated that the groundwater elevations continued the same general pattern seen during the previous monitoring periods. During this monitoring period the well network was expanded to include more of the Island and therefore provides a more comprehensive picture of flow in the vicinity of the Kansas River. The groundwater gradient trends generally southwest across the DCF. The groundwater mound, noted in previous monitoring events in the area of a bedrock erosional feature northeast of Building 180, continues to be expressed during this period. Based on the groundwater elevation data, groundwater flow into the alluvium is generally perpendicular to the Kansas River.

Water levels varied between the initial elevation data collection and the actual well sampling. The greatest variability was found in the alluvial wells close to the river, presumably where precipitation and changes in river level have the greatest influence. In general, water levels decreased by less than 0.4 foot in the upland wells and increased up to 2.68 feet in the alluvial wells.

4.7.2 Analysis Results

Concentrations of contaminants, above their respective detection limits, were reported in the analyses of samples from 18 of the 24 wells sampled. VOCs, excluding the newly established parameter of methane, were reported in all of the samples with the exception of well DCF92-04, DCF93-08, DCF93-17, DCF93-18, and DCF96-35, and DCF96-36 and TPH was reported in all three of the samples analyzed for this suite of compounds.

As has been seen in previous sampling periods, the highest concentrations of VOCs were reported in the sample collected from well DCF93-13, located southeast of Building 180. PCE and TCE were detected above their individual MCLs at reported concentrations of 130 μg/l and 38 μg/l respectively. PCE was also detected above its MCL in wells DCF92-02 (9.1 μg/l), DCF92-03 (31 μg/l), DCF92-05 (36 μg/l), DCF93-09 (12 μg/l), DCF93-15 (23 μg/l), DCF94-21 (34 μg/l), DCF96-23 (17 μg/l), DCF96-26 (47J μg/l), and DCF96-25 (81 μg/l).

TCE was detected above its MCL in five monitoring wells. TCE was reported in samples collected from DCF92-05 (6.1 μg/l), DCF93-15 (5.2 μg/l), DCF93-20 (29 μg/l), DCF96-25 (6.7 μg/l), and DCF96-26 (33J μg/l). Vinyl chloride was detected above its MCL in the sample from DCF93-19 (2.1 μg/l). 1,2-DCE was not detected in any of the samples above its MCL during this sampling and analysis period.

TPH DRO compounds were detected in the three analyzed samples at concentrations of 390 μg/l and 175 μg/l in wells DCF93-15 and DCF93-19 respectively and a high of 18,000 μg/l reported in the sample from DCF92-04. The samples from DCF93-15 and DCF93-19 showed no GRO compounds above the MDL of 100 μg/l however, the sample from DCF92-04 was reported to contain GRO compounds at a reported concentration of 4,600 μg/l.

During this sampling and reporting period, the highest concentration for chemical oxygen demand (COD) and oxidation/reduction potential (ORP) value, expressed in millivolts (mv), was reported from well DCF93-18 situated in an upgradient location outside the contaminant mass boundary (1,350 mg/L and 251 mv respectively). The lowest values for COD were non-detect reported from several site wells and -22 mv for ORP reported from well DCF96-27. Alkalinity values ranged from a low of 307 mg/L at well DCF93-20 to a high of 3,300 mg/L at well DCF96-34. TOC values ranged from a low of 3.1 mg/L at well DCF96-34 to a high of 460 mg/L at DCF93-18. Additional inorganic parameters were analyzed during this sampling and reporting period and their results and impacts on natural attenuation are discussed more fully in Section 5.0.

4.7.3 May/June 1996 Results Discussion

The contaminant isopleths continue to define the previously documented southward migrating mass of contaminants with an overall north-south elongation. During this period however, the extent of the contaminants appears to have migrated out further to the south from the source area in the vicinity of Building 180. It would appear that under normal flow conditions, the contaminant mass continues its south to southwesterly pattern of migration with the highest concentrations of PCE, TCE and 1,2-DCE centered around monitoring well DCF93-13. The configuration of each of these contaminant components describes an irregularly shaped body, extending primarily to the southwest, with an overall pattern of decreasing concentrations. The trend in decreasing concentration can be seen for each contaminant over time and with distance from the source areas and an inverse trend between PCE and each of its daughter products over time can be seen in a number of site monitoring wells.

The configuration and limits of the mass continues to support the assumption that the contaminants are moving toward the Kansas River and that the presence of PCE and TCE, 1,2-DCE and vinyl chloride, the natural degradation series, indicates continued degradation of the contaminants by natural process.

4.8 October 1996 DSR

4.8.1 Groundwater Levels and Discussion

The groundwater elevation data for this period were collected from wells and piezometers screened in the Lower Crouse Limestone, upland unconsolidated material, the Upper Crouse Limestone and the river valley alluvium. These three later geologic units function as one water bearing unit due to their hydraulic connection. Water level monitoring during October 1996 demonstrated that the groundwater elevations continued the same general pattern seen during the previous monitoring periods. The groundwater gradient trends generally southwest across the DCF. The groundwater mound, noted in previous monitoring events in the area of a bedrock erosional feature northeast of Building 180, continues to be expressed during this period Based on the groundwater elevation data, groundwater flow into the alluvium is generally perpendicular to the Kansas River.

4.8.2 Analysis Results

Concentrations of contaminants, above their respective detection limits, were reported in the analyses of samples from 16 of the 20 wells sampled. VOCs, excluding the newly established parameter of methane, were reported in all of the samples with the exception of well DCF92-08, DCF94-22, DCF96-35, and DCF96-36. TPH was reported in both of the samples analyzed for this suite of compounds.

As has been seen in previous sampling periods, the highest concentrations of VOCs were reported in the sample collected from well DCF93-13. PCE and TCE were detected above their individual MCLs at reported concentrations of 160 μg/l and 93 μg/l respectively. Total 1,2-DCE was also reported in the sample from DCF93-13 at a concentration of 19.7 μg/l.

PCE was also detected above its MCL in wells DCF92-02 (15 μg/l), DCF92-03 (43 μg/l), DCF92-05 (29 μg/l), DCF93-09 (14 μg/l), DCF94-21 (27 μg/l), DCF96-23 (79 μg/l), DCF96-24 (12 μg/l), DCF96-25 (91 μg/l) and DCF96-26 (66 μg/l).

TCE was detected above its MCL in four monitoring wells. TCE was reported in samples collected from DCF93-10 (5.5 μg/l), DCF96-23 (11 μg/l), DCF96-25 (6.6 μg/l) and DCF96-26 (82 μg/l). Vinyl chloride was not detected above its MCL during this sampling period and 1,2-DCE, with the exception of the sample from DCF93-13, was not detected in any other samples above its MCL during this sampling and analysis period.

TPH DRO compounds were detected in the two analyzed samples at concentrations of 2,700J μg/l and 160 μg/l in wells DCF92-04 and DCF93-19 respectively. In addition, the sample collected from DCF92-04 was reported to contain GRO compounds at 530 μg/l. The sample from DCF93-19 showed no GRO compounds above the MDL of 100 μg/l.

Attenuation parameters were measured both in the field at the time of sampling and by subsequent laboratory analysis. The field parameters included DO, ORP and ferrous iron while the laboratory parameters included methane, ethane, ethylene, sulfate, chloride, nitrate and alkalinity. Based on the QA evaluation of field techniques used during this event, the values for DO, and ORP have been rejected. The results of these tests indicated that ethane and ethylene were not detected in any of the samples. Methane ranged from a low of 3 μg/l in the sample from DCF93-10 to a high of 900 μg/l in the sample from DCF92-04. The lowest nitrate value was reported in the sample from DCF93-10 (0.1 mg/L) while the highest value was reported from DCF92-02 (8.8 mg/L). Groundwater alkalinity values ranged from 202 mg/L to 594 mg/L in wells DCF94-20 and DCF96-26 respectively. Sulfate ranged from a low of 1.0 mg/L in the sample from DCF92-04 to a high of 1,100 mg/L in the sample from DCF93-20. Chloride concentrations ranged from 24 mg/L to 290 mg/L in wells DCF96-36 and DCF93-10 respectively. Ferrous iron ranged from a low of 0.02 mg/L at well DCF92-03 to a high of 10.76 mg/L in well DCF93-10. These results are discussed more fully in Section 5 particularly as they relate to and impact upon natural attenuation of the PCE at the DCF.

4.8.3 October 1996 Results Discussion

The contaminant isopleths continue to define the previously documented southward migrating mass of contaminants with an overall north-south elongation. To date, 16 of the 18 non-background wells at DCF (DCF92-02, 92-03, 92-04, 92-05, 93-08, 93-09, 93-10, 93-11, 93-12, 93-13, 93-15, 93-16, 93-19, 93-20, 94-21 and 94-22) continue to show an overall decline in contaminant concentrations during the period of monitoring. There remains a consistent, overall decline in the levels of PCE, TCE, total 1,2-DCE and vinyl chloride in the groundwater at DCF. The overall pattern of contaminant distribution over time remains consistent with past data, however, the concentrations of PCE and TCE have increased in certain wells in the Island alluvium during this sampling and reporting period. The configuration and limits of the contaminant mass continue to support the assumption that the contaminants are moving toward the Kansas River. Furthermore, the detection of TCE, DCE and vinyl chloride, the breakdown products of PCE, indicates that biodegredation continues to occur.

4.9 February 1997 DSR

4.9.1 Groundwater Levels and Discussion

Groundwater level measurements were collected on a monthly basis to evaluate groundwater flow patterns beneath the DCF. These data were collected during December of 1996 and January through March of 1997. The results of these groundwater measurements indicate that the southwest trend of the gradient across the DCF is consistent with the historical trends. Flow variations can be discerned between the monitoring periods however, the mound adjacent to Buildings 180/181 is apparent through all the monitoring periods and flow across the site and the Island is generally toward the Kansas River.

4.9.2 Analysis Results

Concentrations of contaminants above their respective detection limits were reported in 19 of the 20 wells sampled. VOCs, with the exception of methane, were reported in all of the samples except DCF96-36 (and DCF93-08 for which VOCs were rejected based on a QA review). Two samples, from wells DCF92-04 and DCF93-19, were analyzed for TPH. The sample from DCF92-04 was reported above the detection limit of 100ug/L and the sample from DCF93-19 was reported as non-detect.

The highest total concentration of VOCs was detected in monitoring well DCF93-13, located southeast of Building 180. PCE and TCE were detected at concentrations of 130J μg/l and 98 μg/l respectively. Although the reported concentration for PCE was qualified, historically, samples from this well have exceeded the federal and Kansas limits for PCE and therefore this value is considered as an exceedance. DCE was also detected in DCF93-13 below its respective limits at a reported concentration of 30.7 μg/l. The following wells also had detection of PCE above the regulatory limit of 5 μg/l: DCF92-02 (45 μg/l), DCF92-03 (53 μg/l), DCF92-05 (39 μg/l), DCF93-09 (9.1 μg/l), DCF94-21 (44 μg/l), DCF96-23 (100 μg/l), DCF96-24 (12 μg/l), DCF96-25 (98 μg/l) and DCF96-26 (77 μg/l). TCE was detected above its regulatory limit in wells DCF92-05 (7.4 μg/l), DCF93-20 (15 μg/l), DCF94-21 (8.3 μg/l), DCF96-23 (10 μg/l), DCF96-25 (8.1 μg/l) and DCF96-26 (79 μg/l). It should be noted that no quantitation value for either PCE or vinyl chloride can be stated for monitoring well DCF93-08. The values were rejected by QA because of the dilution of the sample resulting in a PQL above the respective regulatory limits.

Monitoring well DCF92-04 was the only well from which there was a detection of TPH during the February 1997 sampling event. The reported concentrations for DRO compounds was 22,000 μg/l and GRO compounds were detected at a reported concentration of 570 μg/l.

Attenuation parameters were measured both in the field at the time of sampling and by subsequent laboratory analysis. The field parameters included DO, ORP and ferrous iron while the laboratory parameters included methane, ethane, ethylene, sulfate, chloride, nitrate and alkalinity. The results of these tests indicated that ethane and ethylene were not detected in any of the samples. Methane ranged from a low of 2.7 μg/l in the sample from DCF96-26 to a high of 3,800 μg/l in the sample from DCF92-04. The lowest nitrate value was reported in the sample from DCF96-24 (0.2 mg/L) while the highest value was reported from DCF92-02 (7.1 mg/L). Groundwater alkalinity values ranged from 268 mg/L to 675 mg/L in wells DCF94-20 and DCF94-22 respectively. Sulfate ranged from a low of 1.0 mg/L in the sample from DCF92-04 to a high of 359 mg/L in the sample from DCF93-20. Chloride concentrations ranged from 21 mg/L to 421 mg/L in wells DCF96-36 and DCF94-21 respectively. DO values were found to range from 0.10 mg/L at DCF96-27 to 7.6 mg/L at well DCF93-10. ORP values ranged from -205 mv at well DCF92-02 to 222 mv at well DCF96-27. Ferrous iron ranged from a low of 0.02 mg/L at wells DCF92-02 and DCF93-21 to a high of 9.94 mg/L in well DCF93-04. These results are discussed more fully in Section 5 particularly as they relate to and impact upon natural attenuation of the PCE at the DCF.

4.9.3 February 1997 Results Discussion

The results of the February 1997 sampling and analysis, agree with the results of previous sampling events. The contaminant isopleths continue to define the previously documented southward migrating contaminants with an overall north-south elongation. Results of monitoring well sampling and analysis continue to show an overall decline in contaminant concentrations. The overall pattern of contaminant distribution over time remains consistent with past data. The concentrations of PCE and TCE have increased in certain wells in the Island alluvium during this sampling and reporting period which was also noted during the October 1996 reporting. The configuration and limits of the contaminant mass continues to support the assumption that the contaminants are moving toward the Kansas River and that the presence of PCE and TCE, 1,2-DCE and vinyl chloride indicates continued degradation of the contaminants by natural processes.

TABLES

TABLE 4-1

SUMMARY OF CHEMICAL DETECTIONS (VOCs, SVOCs and TPH) OF GROUNDWATER SAMPLES
Dry Cleaning Facilities Area
Fort Riley, Kansas
July 1992-February 1997

Notes for Table 4-1:

NA	Not Analyzed.
NC	Not collected; with pilot system in place, unable to sample.
ND	Not Detected.
NG	Not Gauged.
NIAv	No Information Available.
NP	Not Planned for sampling for that round and subsequent rounds. Eliminated in an October 17,1995 memo; wells affected were -01, -06, -07, and -14.
NPP	The objective for the June 1995 and August 1995 sampling events was to evaluate specific wells for seasonal flucuations; all wells were not scheduled to be sampled during this event. Wells not planned for this event were -01, -02,-06,-07,-10,-12,-14,-17,-18,-21.
NS	No sample collected, wells dry or insufficient water to sample.
B	Compound detected in sample is less than 10× the amount detected in the method blank. Result is estimated
J	Sample quantitation is estimated.
R	Data Point Rejected through data validation process.
+	Before October 1996, the individual isomer was not determined.
c	Indicates cis isomer for 1,2-dichloroethylene
t	Indicates trans isomer for 1,2-dichloroethylene
@	Value indicates detection limit for each isomer, cis and trans, at the quantitation limit indicated in the parathesis.
[a]	This sample was additionally analyzed for iron, manganese, and TSS (See Table 4-24). DCF94-21 was analyzed for U.S. EPA Method 8010.
[b]	Detection is of the cis- isomer.
[c]	Calculation from 1:5 dilution; analyzed outside of holding time.
*	PCE reported from diluted sample analysis; all others from initial undiluted sample analysis.
**	SVOC reporting limit raised due to limited sample volume.
***	The May 9, 1995 date also includes the data for one sample collected on June 14, 1996
^	Xylenes detected in this sample at 13.4 μg/l (m,p-xylenes 8.0 μg/l; o-xylene 5.4 μg/l).
^^	Bromodichloromethane detected in this sample at 2.1 μg/l.
^^^	Xylenes detected in this sample at 0.9 μg/l.

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

All results shown in µg/l unless otherwise noted.

Well No. & Sample Date	**Volatiles**										**Semivolatiles**						**TPH**	
	1,2-Dichloro ethylene +	**Dichloro methane**	**Tetra chloro ethylene**	**Toluene**	**Trichloro ethylene**	**Vinyl Chloride**	**Trichloro methane**	**Benzene**	**Carbon Disulfide**	**Ethyl benzene**	**Bis (2-ethyl-hexyl)-phthalate**	**2,6-Dinitro-toluene**	**Hexachloro-ethane**	**Naph-thalene**	**N-nitroso-di-n-propyl amine**	**1,4-di-chloro-benzene**	**DRO**	**GRO**
DCF92-01																		
7/92	ND(5.0)	5.0	ND(3.0)	ND(5.0)	ND(3.0)	ND(10)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
11/92	ND(5.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(3.0)	ND(10)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
2/93	ND(5.0)	ND(10)	ND(2.5)	ND(1.5)	ND(1.0)	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
5/93	ND(5.0)	11	ND(2.5)	ND(1.5)	ND(1.0)	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
11/93	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
12/93	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	1.1B	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
2/94	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/95***	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	ND(0.5)	ND(0.9)	1.2	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
DCF92-02																		
7/92	ND(5.0)	130B	660	ND(5.0)	ND(3.0)	ND(2.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
11/92	ND(5.0)	5.4B	360	ND(5.0)	ND(3.0)	ND(2.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
2/93	ND(5.0)	ND(10)	470	ND(1.5)	ND(1.0)	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
5/93	ND(5.0)	ND(10)	240	ND(1.5)	ND(1.0)	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
11/93	ND(0.5)	ND(0.9)	32	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
12/93	ND(2.5)	ND(4.5)	38	ND(2.0)	ND(3.0)	ND(4.0)	ND(2.5)	ND(2.0)	ND(25)	ND(3.5)	NA	NA	NA	NA	NA	NA	NA	NA
2/94	ND(5.0)	ND(9.0)	86	ND(4.0)	ND(6.0)	ND(8.0)	ND(5.0)	ND(4.0)	ND(50)	ND(7.0)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94'	ND(0.5)	ND(0.9)	64	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94	ND(0.5)	ND(0.9)	84	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	ND(0.5)	1.3B	77	ND(0.4)	ND(0.6)	ND(0.8)	8.9	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/95	ND(0.5)	ND(0.9)	15	ND(0.4)	ND(0.6)	ND(0.8)	1.4	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	ND(0.5)	ND(0.9)	8.7	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	ND(0.5)	ND(0.9)	6.6	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	ND(0.5)	ND(0.9)	9.1	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	ND(0.5)[@]	ND(0.9)	15	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	ND(0.5)[@]	ND(0.9)	45	ND(0.4)	ND(0.6)	ND(0.8)	4.0	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

Well No. & Sample Date	Volatiles										Semivolatiles						TPH	
	1,2-Dichloro ethylene +	Dichloro methane	Tetra chloro ethylene	Toluene	Trichloro ethylene	Vinyl Chloride	Trichloro methane	Benzene	Carbon Disulfide	Ethyl benzene	Bis (2-ethyl-hexyl)-phthalate	2,6-Dinitro-toluene	Hexachloro-ethane	Naph-thalene	N-nitroso-di-n-propyl amine	1,4-di-chloro-benzene	DRO	GRO
DCF92-03																		
7/92	5.5	13.0	80	ND(5.0)	6.8	ND(2.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
11/92	12	ND(5.0)	190	ND(5.0)	13	ND(2.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
2/93	9.1	ND(10)	160	ND(1.5)	11	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
5/93	ND(5.0)	ND(10)	410	ND(1.5)	12	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
11/93	ND(25)	ND(45)	1600	ND(20)	ND(30)	ND(40)	ND(25)	ND(20)	ND(250)	ND(35)	NA	NA	NA	NA	NA	NA	NA	NA
12/93	ND(25)	ND(45)	820	ND(20)	ND(30)	ND(40)	36	ND(20)	ND(250)	ND(35)	NA	NA	NA	NA	NA	NA	NA	NA
2/94	ND(5.0)	ND(9.0)	260	ND(4.0)	ND(6.0)	ND(8.0)	13	ND(4.0)	ND(50)	ND(7.0)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	2.3	ND(0.9)	230	ND(0.4)	5.0	ND(0.8)	7.6	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94*	1.3	ND(0.9)	140	ND(0.4)	4.4	ND(0.8)	4.7	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	ND(5.0)	ND(9.0)	94	ND(4.0)	ND(6.0)	ND(0.8)	ND(5.0)	ND(4.0)	ND(50)	ND(7.0)	NA	NA	NA	NA	NA	NA	NA	NA
5/95	0.9	ND(0.9)	89	ND(0.4)	1.5	ND(0.8)	1.8	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	2.1	ND(0.9)	160	ND(0.4)	2.3	ND(0.8)	2.1	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
7/95	ND(0.5)	ND(0.9)	170	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	ND(0.5)	ND(0.9)	160	ND(0.4)	0.6	ND(0.8)	1.1	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/95	ND(0.5)	ND(0.9)	72	ND(0.4)	1.6	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	1.6	ND(0.9)	31	ND(0.4)	1.3	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	1.5(c) ND(0.5) (t)	ND(0.9)	43	ND(0.4)	0.8	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	9.1(c) ND(0.5) (t)	ND(0.9)	53	ND(0.4)	3.9	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

Well No. & Sample Date	Volatiles										Semivolatiles						TPH	
	1,2-Dichloro ethylene +	**Dichloro methane**	**Tetra chloro ethylene**	**Toluene**	**Trichloro ethylene**	**Vinyl Chloride**	**Trichloro methane**	**Benzene**	**Carbon Disulfide**	**Ethyl benzene**	**Bis (2-ethyl-hexyl)-phthalate**	**2,6-Dinitro-toluene**	**Hexachloro-ethane**	**Naph-thalene**	**N-nitroso-di-n-propyl amine**	**1,4-di-chloro-benzene**	**DRO**	**GRO**
DCF92-04																		
7/92	5.0	ND(5.0)	9.3	ND(5.0)	ND(3.0)	11	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	7.0	ND(6.0)	ND(6.0)	NA	NA
11/92	35	5.0B	3.7	ND(5.0)	ND(3.0)	12	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	10	12J	43J	5.4	38J	ND(6.0)	NA	NA
2/93	24	ND(10)	ND(2.5)	ND(1.5)	ND(1.0)	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
5/93	21	ND(10)	ND(2.5)	ND(1.5)	ND(1.0)	22	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	6.7	ND(5.0)	ND(4.0)	NA	NA
11/93	18	ND(0.9)	ND(1.1)	ND(0.4)	2.8	40	ND(0.5)	0.5	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
12/93	27	ND(0.9)	ND(1.1)	ND(0.4)	1.7	42	ND(0.5)	0.5	ND(5.0)	1.1	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	7	ND(1.8)	ND(2.2)	ND(0.8)	ND(1.2)	18	ND(1.0)	ND(0.8)	ND(10)	ND(1.4)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	2.1	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95$^{\Delta}$	1.9	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.7)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	4100	1300
6/95	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	2.9	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	950	990
7/95	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	720	ND(100)
8/95	2.8J	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	410	ND(100)
10/95	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	4500	ND(1000)
5/96	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	18000	4600
10/96	0.7(c) ND(0.5) (t)	ND(0.9)	ND(1.1)	0.5	ND(0.6)	1.0	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	2700J	530
02/97	0.9(c) ND(0.5) (t)	ND(0.9)	ND(1.1)	0.4	ND(0.6)	1.1	ND(0.5)	0.8	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	22000	570
DCF92-05																		
7/92	69	14.0B	160	ND(5.0)	33	ND(2.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
11/92	51	ND(5.0)	95	ND(5.0)	19	ND(2.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
2/93	33	ND(10)	72	26	14	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
5/93	15	ND(10)	140	ND(1.5)	14	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
11/93	ND(25)	ND(45)	430	ND(20)	ND(30)	ND(40)	ND(25)	ND(20)	ND(250)	ND(35)	NA	NA	NA	NA	NA	NA	NA	NA
12/93	ND(25)	ND(45)	710	ND(20)	ND(30)	ND(40)	29	ND(20)	ND(250)	ND(35)	NA	NA	NA	NA	NA	NA	NA	NA
2/94	ND(5.0)	ND(9.0)	210	ND(4.0)	ND(6.0)	ND(0.8)	5	ND(4.0)	ND(50)	ND(7.0)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	12	ND(0.9)	62	ND(0.4)	7.6	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94*	18	ND(0.9)	55	ND(0.4)	7.1	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	2.2	ND(0.9)	30	ND(0.4)	1.5	ND(0.8)	3.1	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/95	4.2	ND(0.9)	34	ND(0.4)	2.2	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	2.2	ND(0.9)	43	ND(0.4)	2.8	ND(0.8)	ND(0.7)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
7/95	ND(0.5)	ND(0.9)	130	ND(0.4)	10	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	15	ND(0.9)	34	ND(0.4)	4.9	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/95	15	ND(0.9)	33	ND(0.4)	6.6	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	12	ND(0.9)	36	ND(0.4)	6.1	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	9.7(c) ND(0.5) (t)	ND(0.9)	29	ND(0.4)	4.1	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	18(c) 0.6(t)	ND(0.9)	39	ND(0.4)	7.4	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

Well No. & Sample Date	Volatiles										Semivolatiles						TPH	
	1,2-Dichloro ethylene +	Dichloro methane	Tetra chloro ethylene	Toluene	Trichloro ethylene	Vinyl Chloride	Trichloro methane	Benzene	Carbon Disulfide	Ethyl benzene	Bis (2-ethyl-hexyl)-phthalate	2,6-Dinitro-toluene	Hexachloro-ethane	Naph-thalene	N-nitroso-di-n-propyl amine	1,4-di-chloro-benzene	DRO	GRO
DCF92-06																		
7/92	ND(5.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(3.0)	ND(2.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
11/92	ND(5.0)	ND(10)	ND(3.0)	ND(5.0)	ND(3.0)	ND(2.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(3.0)	ND(10)	ND(7.0)	ND(7.0)	ND(3.0)	ND(6.0)	ND(6.0)	NA	NA
2/93	ND(5.0)	ND(10)	ND(2.5)	ND(1.5)	ND(1.0)	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
5/93	ND(5.0)	ND(10)	ND(2.5)	ND(1.5)	ND(1.0)	ND(2.0)	ND(1.0)	ND(1.0)	ND(3.0)	ND(1.0)	ND(6.0)	ND(4.0)	ND(5.0)	ND(3.0)	ND(5.0)	ND(4.0)	NA	NA
11/93	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
12/93	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	0.9B	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
2/94	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94	ND(0.5)	ND(0.9)	1.2	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	ND(0.5)	ND(0.9)	1.5	ND(0.4)	ND(0.6)	ND(0.8)	0.5	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/95	ND(0.5)	ND(0.9)	1.5	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	ND(0.5)	ND(0.9)	1.4	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
DCF92-07																		
7/92	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv
11/92	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv
2/93	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv
5/93	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv	NIAv
11/93	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
12/93	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG	NG
2/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95	ND(0.5)	ND(0.9)	1.7	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	ND(100)	ND(400)
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
DCF93-08																		
12/93	77	ND(4.5)	ND(5.5)	ND(2.0)	16	54	ND(2.5)	ND(2.0)	ND(25)	ND(3.5)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	25	ND(1.8)	ND(2.2)	ND(0.8)	ND(1.2)	51	ND(1.0)	ND(0.8)	ND(10)	ND(1.4)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/95	4.2	ND(0.9)	4.8	ND(0.4)	ND(0.6)	5.8	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
7/95	1.4	ND(0.9)	ND(1.1)	ND(0.4)	0.6	3.1	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	3.4J	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	7.9J	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/95	4.7	ND(0.9)	ND(1.1)	ND(0.4)	1.5	5.7	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	ND(0.5)[@]	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	ND(2.5)[@]	ND(4.5)	5.5R	ND(2.0)	ND(3.0)	4.0R	ND(2.5)	ND(2.0)	ND(25)	ND(3.5)	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

Well No. & Sample Date	Volatiles										Semivolatiles						TPH	
	1,2-Dichloro ethylene +	Dichloro methane	Tetra chloro ethylene	Toluene	Trichloro ethylene	Vinyl Chloride	Trichloro methane	Benzene	Carbon Disulfide	Ethyl benzene	Bis (2-ethyl-hexyl)-phthalate	2,6-Dinitro-toluene	Hexachloro-ethane	Naph-thalene	N-nitroso-di-n-propyl amine	1,4-di-chloro-benzene	DRO	GRO
DCF93-09																		
12/93	68	ND(4.5)	64	ND(2.0)	10	ND(4.0)	ND(2.5)	ND(2.0)	ND(25)	ND(3.5)	44	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	22	ND(9.0)	160	ND(4.0)	13	ND(8.0)	ND(5.0)	ND(4.0)	ND(50)	ND(7.0)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	5.3	ND(0.9)	48	ND(0.4)	5.2	ND(0.8)	1.1	ND(0.4)	ND(5.0)	ND(0.7)	30	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94*	ND(0.5)	ND(0.9)	28	ND(0.4)	3.9	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	2.2	ND(0.9)	28	ND(0.4)	2.5	ND(0.8)	0.8	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/95	1.5	ND(0.9)	21	ND(0.4)	2.6	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	ND(0.5)	ND(0.9)	22	ND(0.4)	2.0	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
7/95	1.0	ND(0.9)	9.8	ND(0.4)	1.3	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	ND(0.5)	ND(0.9)	11	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/95	1.4	ND(0.9)	8.8	ND(0.4)	1.9	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	0.8	ND(0.9)	12	ND(0.4)	1.1	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	1.7(c) ND(0.5) (t)	ND(0.9)	14	ND(0.4)	1.8	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	1.9(c) ND(0.5) (t)	1.8B	9.1	ND(0.4)	1.7	ND(0.8)	2.1	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF93-10																		
12/93	8.1	ND(0.9)	ND(1.1)	ND(0.4)	0.8	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	3.4	ND(0.9)	ND(1.1)	ND(0.4)	1.4	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	3.5	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94	7.6	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	7.6	ND(0.9)	2.6	ND(0.4)	3.4	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/95	14	ND(0.9)	6.8	ND(0.4)	9.1	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	4	ND(0.9)	ND(1.1)	0.9	1.6	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	12	ND(0.9)	ND(1.1)	ND(0.4)	4	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	15	ND(0.9)	ND(1.1)	ND(0.4)	2.2	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	14(c) ND(0.5) (t)	ND(0.9)	3.6	ND(0.4)	5.5	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	14(c) ND(0.5) (t)	ND(0.9)	2.0	ND(0.4)	5.0	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF93-11																		
12/93	110	ND(4.5)	42	ND(2.0)	20	ND(4.0)	ND(2.5)	ND(2.0)	ND(25)	ND(3.5)	15	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	90	ND(1.8)	21	ND(0.8)	17	ND(1.6)	ND(1.0)	ND(0.8)	ND(10)	ND(1.4)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	78	ND(0.9)	ND(1.1)	ND(0.4)	2.1	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/95	5.1	ND(0.9)	14	ND(0.4)	7.0	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
7/95	6.4	ND(0.9)	13	ND(0.4)	6.8	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	28	ND(0.9)	ND(1.1)	ND(0.4)	2.2	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

Well No. & Sample Date	Volatiles										Semivolatiles						TPH	
	1,2-Dichloro ethylene +	**Dichloro methane**	**Tetra chloro ethylene**	**Toluene**	**Trichloro ethylene**	**Vinyl Chloride**	**Trichloro methane**	**Benzene**	**Carbon Disulfide**	**Ethyl benzene**	**Bis (2-ethyl-hexyl)-phthalate**	**2,6-Dinitro-toluene**	**Hexachloro-ethane**	**Naph-thalene**	**N-nitroso-di-n-propyl amine**	**1,4-di-chloro-benzene**	**DRO**	**GRO**
DCF93-12																		
12/93	30	ND(0.9)	32	ND(0.4)	3.8	ND(0.8)	6.0B	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	3.5	ND(0.9)	5	ND(0.4)	1.7	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95	ND(0.5)	ND(0.9)	7.1	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	2.5	ND(0.9)	9.0	0.7	1.2	ND(0.8)	4.4	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	ND(0.5)	ND(0.9)	4.9	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	ND(0.5)	ND(0.9)	ND(1.1)	0.6	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DCF93-13																		
12/93	ND(25)	ND(45)	420	ND(20)	140	ND(40)	ND(25)	ND(20)	ND(250)	ND(35)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	5.9	ND(9.0)	230	ND(4.0)	47	ND(8.0)	ND(5.0)	ND(4.0)	ND(50)	ND(7.0)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	ND(2.5)	ND(4.5)	160	ND(2.0)	35	ND(4.0)	ND(2.5)	ND(2.0)	ND(25)	ND(3.5)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94*	31	ND(0.9)	420	ND(4.0)	200	ND(8.0)	ND(5.0)	ND(0.4)	ND(5.0)	ND(7.0)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	14	ND(4.5)	220	ND(2.0)	150	ND(4.0)	5.0	ND(2.0)	ND(25)	ND(3.5)	NA	NA	NA	NA	NA	NA	NA	NA
5/95$^{\Delta\Delta}$	25	ND(0.9)	210	ND(0.4)	190	ND(0.8)	1.2	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	7.2	ND(0.9)	240	ND(0.4)	56	ND(0.8)	1.5	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
7/95	8.9	ND(1.8)	270	ND(0.8)	120	ND(1.6)	ND(1.0)	ND(0.8)	ND(10.0)	ND(14)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	18	ND(0.9)	200	ND(0.4)	140	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/95	19	ND(0.9)	230	ND(0.4)	140	ND(0.8)	1.1	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	12	ND(0.9)	130	ND(0.4)	38	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	18(c) 1.7(t)	ND(0.9)	160	ND(0.4)	93	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	28(c) 2.7(t)	ND(0.9)	130J^{c}	ND(0.4)	98	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF93-14																		
12/93	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2/94**	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(20)	ND(20)	ND(20)	ND(20)	ND(20)	ND(20)	NA	NA
6/94**	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(26)	ND(26)	ND(26)	ND(26)	ND(26)	ND(26)	NA	NA
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	ND(0.5)	ND(0.9)	ND(1.1)	0.6	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

Well No. & Sample Date	Volatiles										Semivolatiles						TPH	
	1,2-Dichloro ethylene +	Dichloro methane	Tetra chloro ethylene	Toluene	Trichloro ethylene	Vinyl Chloride	Trichloro methane	Benzene	Carbon Disulfide	Ethyl benzene	Bis (2-ethyl-hexyl)-phthalate	2,6-Dinitro-toluene	Hexachloro-ethane	Naph-thalene	N-nitroso-di-n-propyl amine	1,4-di-chloro-benzene	DRO	GRO
DCF93-15																		
12/93	ND(25)	ND(45)	490	ND(20)	ND(30)	ND(40)	30	ND(20)	ND(250)	ND(35)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	15	ND(1.8)	52	ND(0.8)	14	ND(1.0)	ND(1.0)	ND(0.8)	ND(10)	ND(1.4)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95	7.4	ND(0.9)	150	ND(0.4)	12	ND(0.8)	2.9	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	430	140
6/95	9.9	ND(0.9)	21	ND(0.4)	7.6	4.9	2.2	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	740	130
7/95	19	ND(0.9)	16	0.5	3.3	ND(0.8)	1.6	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	170	ND(100)
8/95	27	ND(0.9)	2.9	ND(0.4)	6.3	28	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	2200	ND(100)
10/95	3.8	ND(0.9)	48	ND(0.4)	5.7	3.6	1.6	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	3700	ND(100)
5/96	6.2	ND(0.9)	23	ND(0.4)	5.2	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	390	ND(100)
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DCF93-16																		
12/93	ND(13)	ND(23)	200	ND(10)	ND(15)	ND(20)	ND(13)	ND(10)	ND(130)	ND(18)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/95	ND(0.5)	ND(0.9)	120	ND(0.4)	ND(0.6)	ND(0.8)	6.7	5.5	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
7/95	ND(0.5)	ND(0.9)	53	ND(0.4)	ND(0.6)	ND(0.8)	1.4	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	ND(0.5)	ND(0.9)	28	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/95	ND(0.5)	ND(0.9)	24	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DCF93-17																		
12/93	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2/94	ND(0.5)	ND(0.9)	ND(1.1)	0.9	ND(0.6)	ND(0.8)	ND(0.5)	0.6	21	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	11	NA	NA
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	ND(0.5)	ND(0.9)	ND(1.1)	0.7	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	ND(0.5)	ND(0P.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

Well No. & Sample Date	Volatiles										Semivolatiles						TPH	
	1,2-Dichloro ethylene +	Dichloro methane	Tetra chloro ethylene	Toluene	Trichloro ethylene	Vinyl Chloride	Trichloro methane	Benzene	Carbon Disulfide	Ethyl benzene	Bis (2-ethyl-hexyl)-phthalate	2,6-Dinitro-toluene	Hexachloro-ethane	Naph-thalene	N-nitroso-di-n-propyl amine	1,4-di-chloro-benzene	DRO	GRO
DCF93-18																		
12/93	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2/94	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	14	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
1/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/95	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	ND(0.5)	ND(0.9)	ND(1.1)	0.7	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
02/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DCF93-19																		
12/93	54	ND(4.5)	ND(5.5)	ND(2.0)	3.3	15	ND(2.5)	ND(2.0)	ND(25)	ND(3.5)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	11	ND(1.8)	ND(2.2)	ND(0.8)	3.8	15	ND(1.0)	ND(0.8)	ND(10)	ND(1.4)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	5.5	ND(0.9)	2.3	ND(0.4)	1.2	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94	8.7	ND(0.9)	5.4	ND(0.4)	2.8	4.4	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	8.5	ND(0.9)	ND(1.1)	ND(0.4)	1.0	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/95	5.3	ND(0.9)	ND(1.1)	ND(0.4)	1.0	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	ND(100)	ND(100)
6/95	5.5	ND(0.9)	1.1	ND(0.4)	ND(0.6)	6.0	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	110	ND(100)
7/95	4.7	ND(0.9)	ND(1.1)	1.9	ND(0.6)	4.0	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	210	ND(100)
8/95	2.4	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	ND(100)	ND(100)
10/95	1.3	ND(0.9)	ND(1.1)	1.3	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	ND(100)	ND(100)
5/96	2.9	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	2.1	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	175	ND(100)
10/96	3.3(c) ND(0.5) (t)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	1.9	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	160	ND(100)
02/97	3.2(c) ND(0.5) (t)	ND(0.9)	2.6	ND(0.4)	1.0	1.0	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	ND(100)	ND(100)
DCF93-20																		
12/93	36	ND(4.5)	29	ND(2.0)	9.2	ND(4.0)	ND(2.5)	ND(2.0)	ND(2.5)	ND(3.5)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
2/94	ND(0.5)	ND(0.9)	5	ND(0.4)	13	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
6/94	3.8	ND(0.9)	2.2	ND(0.4)	9.9	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94	5.7	ND(0.9)	10	ND(0.4)	14	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	14	ND(0.9)	14	ND(0.4)	60	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/95	18	ND(0.9)	3.4	ND(0.4)	21	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	31	ND(0.9)	3.3	ND(0.4)	22	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
7/95	17	ND(0.9)	1.5	ND(0.4)	9.9	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	32	ND(0.9)	1.5	ND(0.4)	11	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/95	27	ND(0.9)	3.4	ND(0.4)	21	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	14	ND(0.9)	3.3	ND(0.4)	29	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	19(c) ND(0.5) (t)	ND(0.9)	ND(1.1)	ND(0.4)	4.8	0.8	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	20(c) ND(0.5) (t)	ND(0.9)	2.9	ND(0.4)	15	1.7	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

Well No. & Sample Date	Volatiles										Semivolatiles						TPH	
	1,2-Dichloroethylene +	Dichloromethane	Tetrachloroethylene	Toluene	Trichloroethylene	Vinyl Chloride	Trichloromethane	Benzene	Carbon Disulfide	Ethylbenzene	Bis (2-ethylhexyl)-phthalate	2,6-Dinitrotoluene	Hexachloroethane	Naphthalene	N-nitroso-di-n-propylamine	1,4-dichlorobenzene	DRO	GRO
DCF94-21																		
6/94^{a}	12^{b}	ND(1.0)	62	NA	4.5	ND(1.0)	1.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/94	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
1/95	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
5/95	4.4	ND(0.9)	28	ND(0.4)	2.2	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
7/95	3.5	ND(0.9)	350	ND(0.4)	29	ND(0.8)	2.1	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP	NPP
10/95	15	ND(0.9)	39	ND(0.4)	6.2	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	8.1	ND(0.9)	34	ND(0.4)	4.6	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	10(c) ND(0.5) (t)	ND(0.9)	27	ND(0.4)	4.3	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	22(c) 1.0(t)	ND(0.9)	44	ND(0.4)	8.3	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF94-22																		
7/94	4.1	ND(0.9)	ND(1.1)	0.5	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	ND(10)	NA	NA
8/94	1.0	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
1/95	3.3	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/95$^{\Delta\Delta\Delta}$	4.4	ND(0.9)	1.2	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.7)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
6/95	2.0	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
7/95	3.0	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
8/95	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/95	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
5/96	2.0J	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	ND(0.5)$^{@}$	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	2.0(c) ND(0.5) (t)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF96-23																		
5/96	5.4	ND(0.9)	17	ND(0.4)	3.2	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	9.3(c) ND(0.5) (t)	ND(0.9)	79	ND(0.4)	11	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	8.0(c) ND(0.5) (t)	ND(0.9)	100	ND(0.4)	10	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF96-24																		
5/96	8.3J	ND(0.9)	2.6J	ND(0.4)	0.8J	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	18(c) ND(0.5) (t)	ND(0.9)	12	ND(0.4)	3.7	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	21(c) ND(0.5) (t)	ND(0.9)	12	ND(0.4)	3.7	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF96-25																		
5/96	4.2	ND(0.9)	81	ND(0.4)	6.7	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	5.9(c) ND(0.5) (t)	ND(0.9)	91	ND(0.4)	6.6	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	8.0(c) ND(0.5) (t)	ND(0.9)	98	ND(0.4)	8.1	ND(0.8)	1.2	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 4-1
SUMMARY OF CHEMICAL DETECTIONS OF GROUNDWATER SAMPLES

Well No. & Sample Date	Volatiles										Semivolatiles						TPH	
	1,2-Dichloro ethylene +	Dichloro methane	Tetra chloro ethylene	Toluene	Trichloro ethylene	Vinyl Chloride	Trichloro methane	Benzene	Carbon Disulfide	Ethyl benzene	Bis (2-ethyl-hexyl)-phthalate	2,6-Dinitro-toluene	Hexachloro-ethane	Naph-thalene	N-nitroso-di-n-propyl amine	1,4-di-chloro-benzene	DRO	GRO
DCF96-26																		
5/96	14J	ND(0.9)	47J	ND(0.4)	33J	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	14 ND(0.5) (t)	ND(0.9)	66	ND(0.4)	82	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	23(c) 0.6 (t)	ND(0.9)	77	ND(0.4)	79	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF96-27																		
5/96	30	ND(0.9)	3.6	ND(0.4)	3.3	1.6	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	24(c) ND(0.5) (t)	ND(0.9)	3.2	ND(0.4)	2.6	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	37(c) 0.5(t)	ND(0.9)	3.5	ND(0.4)	2.3	1.5	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF96-34																		
5/96	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	1.8(c) ND(0.5) (t)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	2.8(c) ND(0.5) (t)	ND(0.9)	1.3	ND(0.4)	1.2	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF96-35																		
5/96	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	ND(0.5)$^{@}$	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	ND(0.5)$^{@}$	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	1.2	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
DCF96-36																		
5/96	ND(0.5)	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
10/96	ND(0.5)$^{@}$	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8)	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA
02/97	ND(0.5)$^{@}$	ND(0.9)	ND(1.1)	ND(0.4)	ND(0.6)	ND(0.8))	ND(0.5)	ND(0.4)	ND(5.0)	ND(0.7)	NA	NA	NA	NA	NA	NA	NA	NA

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June 1997

TABLE 4-2

SUMMARY OF CHEMICAL DETECTIONS FOR MISCELLANEOUS PARAMETERS IN GROUND WATER
Dry Cleaning Facilities Area
Fort Riley, Kansas
May 1995-February 1997

All Results Shown are in mg/l Unless Otherwise Noted

J: Estimated Concentration.
NA: Not Analyzed.
NAv: Not Available.
ND(): Not Detected (detection limit).
NS: Not Sampled.
R: Rejected by Data Validator.
*: Measured in Field.
**: Measured in Laboratory.
mv: millivolts.
Results from December 1993 to January 1995 contain data from CEMRK (1994a,b,d,e,f,g,i; 1995a) as referenced in the Draft Final DCFA-RI Report, March 1995.
For a complete list of analytes from December 1993 to January 1995, see Appendix D of the Draft Final DCFA-RI Report, March 1995.
For a complete list of analytes from May 1995 through February 1997, please see CEMRK 1995a, CEMRK 1995b, CEMRK 1995c, CEMRK 1995d, CEMRK 1996b, CEMRK 1996c, CEMRK 1997b.

Well No. & Sample Date	Alkalinity, Total as $CaCO_3$	Oxidation Reduction Potential (mv)*	Chemical Oxygen Demand	Total Organic Carbon, Sparged	Dissolved Oxygen, (DO)*	Chloride	Nitrate (as N)	Orthophosphate (as P)	Sulfate	Calcium	Iron	Magnesium	Manganese	Potassium	Sodium	Iron (II), Ferrous*	Methane (mg/l)
DCF92-02																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NP	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	390	235**	ND(10)	5.6	6.9	220	6.8	0.2	122	200	ND(0.1)	40	ND(0.01)	8	82	NA	ND(2.0)
10/96	384	13R	NA	15	ND(0.1)R	190	8.8	NA	110	182	ND(0.1)	38	ND(0.01)	5	72	0.03	ND(2.0)
2/97	378	161	NA	2.2	4.74	126	7.1	NA	66	172	ND(0.1)	38.7J	ND(0.01)	5.8	77	0.02	ND(2.0)
DCF92-03																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	372	237**	ND(10)	5.3	5.06	467	7	0.3	133	214	ND(0.1)	37	ND(0.01)	10	182	NA	ND(2.0)
10/96	402	9R	NA	18	ND(0.1)R	280	6.9	NA	130	195	0.5	35	0.02	9	140	0.02	ND(2.0)
2/97	401	222	NA	3.4	5.12	355	7.4	NA	91	215	ND(0.1)	42J	ND(0.01)	9.6	169	0.04	ND(2.0)
DCF92-04																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	488	108**	NA	NA	7.84	127	ND(0.1)	ND(0.1)	ND(10)	132	6.2	39	0.85	6	70	NA	120
10/96	456	-216R	NA	7.7	0.14R	190	ND(0.1)	NA	1	151	8.8	40	1.21	4	79	9.02	900
2/97	544	-88	NA	49	1.41	118	ND(0.1)	NA	1	161	13.9	43.5J	1.3	5.3	73.2	9.94	3800

TABLE 4-2

SUMMARY OF CHEMICAL DETECTIONS FOR MISCELLANEOUS PARAMETERS IN GROUND WATER
Dry Cleaning Facilities Area
Fort Riley, Kansas
May 1995-February 1997

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DCF92-05																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	354	231**	ND(10)	4.9	9.24	320	3.1	0.2	107	181	ND(0.1)	30	ND(0.01)	8	154	NA	ND(2.0)
10/96	412	40R	NA	4.6	ND(0.1)R	220	2.8	NA	110	162	ND(0.1)	27	ND(0.01)	6	116	0.04	ND(2.0)
2/97	358	200	NA	17	2.61	420	3.8	NA	105	221	ND(0.1)	36J	ND(0.01)	7.2	184	0.12	ND(2.0)
DCF93-08																	
5/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	453	188**	81	22	2.99	215	ND(0.1)	0.2	36	162	4.6	49	1.13	4	88	NA	1000
10/96	538	-225R	NA	13	0.11R	230	ND(0.1)	NA	3	159	6.8	49	1.36	3	89	7.18	570
2/97	451	2	NA	31	2.98	226	ND(0.1)	NA	46	153	5.39	50J	1.38	3.6	91.1	4.62	630
DCF93-09																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	342	39**	13	15	4.05	281	1.9	ND(0.1)	111	148	11.5	41	0.13	3	88	NA	ND(2.0)
10/96	382	-262R	NA	18	0.26R	270	2.2	NA	87	168	55.3	44	0.21	4	103	5.05	ND(2.0)
2/97	366	-63	NA	1.7	1.71	226	1.6	NA	88	146	67.4	45.2J	0.3	7.4	94.7	3.98	3.1

TABLE 4-2

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Fort Riley, Kansas
May 1995-February 1997

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DCF93-10																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	466	-21**	29	9	6.48	251	ND(0.1)	0.1	165	191	34.1	47	0.78	9	112	NA	13
10/96	384	-269R	NA	15	0.04R	290	0.1	NA	160	189	164	44	1.11	8	120	10.76	3
2/97	500	-87	NA	3.7	7.6	256	ND(0.1)	NA	216	194	72.7	45.7J	0.742	8.7	122	8.02	7.2
DCF93-11																	
5/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
5/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DCF93-12																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	372	72**	ND(10)	4.3	7.8	229	4.1	0.2	90	171	0.1	25	ND(0.01)	4	91	NA	ND(2.0)
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

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DCF93-13																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	353	229**	ND(10)	5.3	6.25	340	3.3	0.2	184	220	ND(0.1)	46	ND(0.01)	6	129	NA	ND(2.0)
10/96	315	-4R	NA	7.4	ND(0.1)R	260	2.5	NA	190	212	0.2	47	0.03	4	94	0.07	ND(2.0)
2/97	350	170	NA	18	2.61	353	1.9	NA	178	220	0.13	47.8J	0.014	5.3	117	0.05	ND(2.0)
DCF93-15																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	373	210**	12	19	NA	282	4.7	0.1	98	213	0.2	39	0.23	10	115	NA	17
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DCF93-16																	
5/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

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DCF93-17																	
5/95	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	394	228**	22	7.1	NA	125	2.6	0.3	354	210	7.4	70	0.14	6	67	NA	1100J
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DCF93-18																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	376	251**	1350	460	NA	166	5.7	0.7	3620	NA	NA	NA	NA	NA	NA	NA	6
10/96	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
2/97	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
DCF93-19																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	389	218**	20	6.9	8.8	188	ND(0.1)	0.2	19	127	2.4	34	0.5	4	83	NA	670
10/96	372	-270R	NA	14	0.09R	140	ND(0.1)	NA	24	148	3.3	37	0.68	4	89	2	910
2/97	286	-36	NA	2.8	0.39	130	0.3	NA	69	125	0.59B	31.6J	0.42	3.2	78.3	0.6	330

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DCF93-20																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	307	63**	ND(10)	6.7	6.5	262	0.4	ND(0.1)	273	165J	2.1	43	0.09	5	110	NA	ND(2.0)
10/96	202	314R	NA	5.1	0.2R	230	ND(0.1)	NA	1100	380	1.9	127	0.21	5	107	1.19	ND(2.0)
2/97	268	-36	NA	12	1.3	351	0.4	NA	359	232	1.15	52.3J	0.044	5.7	121	0.84	ND(2.0)
DCF94-21																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	378	239**	ND(10)	10	6.63	355	4.1	0.4J	99	267	14.2	36	0.27	9	165	NA	10
10/96	393	40R	NA	8.9	ND(0.1)R	230	4.2	NA	110	184	1.7	30	0.05	7	126	0.04	ND(2.0)
2/97	388	142	NA	6.4	5.9	421	4	NA	109	218	0.62	36.9J	0.016	7.6	187	0.02	ND(2.0)
DCF94-22																	
5/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10/95	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
5/96	554	45**	ND(10)	9.7	4.43	282	ND(0.1)	0.3	65	209	13.6	46	2.25	10	101	NA	210J
10/96	752	-238R	NA	19	0.06R	240	0.2	NA	72	239	28.4	60	2.5	12	120	7.34	120
2/97	675	-11	NA	9.2	1.35	225	ND(0.1)	NA	79	238	24.3	54.2J	2.56	11.3	131	6.18	67

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DCF96-23																	
5/96	406	36**	16	5.7	3.2	166	1.3	0.2	189	198	42.7	59	0.4	8	83	NA	4.8
10/96	564	145R	NA	11	ND(0.1)R	200	1.9	NA	200	189	18.1	55	0.15	5	80	0.34	12
2/97	420	-1	NA	29	3.8	166	2	NA	150	179	13.6	53.7J	0.1	5.1	73.7	0.57	6.6
DCF96-24																	
5/96	543	106**	ND(10)	10	2.38	148	0.7	0.3	266	387	64.8	61	0.91	12	103	NA	ND(2.0)
10/96	582	-115R	NA	17	ND(0.1)R	190	0.5	NA	270	299	7.7	57	0.35	7	105	0.39	3.4
2/97	586	-34	NA	10	3.93	130	0.2	NA	161	245	6.8	56.1J	0.307	6.9	103	0.45	4.1
DCF96-25																	
5/96	366	29**	30	5.4	2.89	176	4.5	0.2	121	183	24.2	44	0.31	7	83	NA	ND(2.0)
10/96	539	-129R	NA	11	ND(0.1)R	230	5.1	NA	140	219	42.6	47	0.38	6	93	0.18	ND(2.0)
2/97	420	8	NA	1.7	2.57	232	4.1	NA	108	197	26	48.4J	0.25	6.9	92.7	0.1	ND(2.0)
DCF96-26																	
5/96	473	88**	ND(10)	14	NA	145	0.3	0.3	269	236	49.9	69	0.65	12	75	NA	ND(2.0)
10/96	594	-182R	NA	11	ND(0.1)R	230	ND(0.1)	NA	280	238	55.2	65	1.16	10	86	2.63	7
2/97	468	-80	NA	6.5	2.07	205	ND(0.1)	NA	223	228	17.6	66.9J	0.895	10.1	82.9	2.14	2.7
DCF96-27																	
5/96	600	-22**	61	19	3.43	271	ND(0.1)	0.2	73	236	44.7	50	2.96	12	134	NA	70
10/96	344	-205R	NA	12	0.1R	270	0.1	NA	220	313	39.6	64	2.66	17	130	3.1	48
2/97	555	-20	NA	16	2.85	194	ND(0.1)	NA	113	237	25	53.4J	1.93	13.9	109	2.08	54
DCF96-34																	
5/96	3300	22**	ND(10)	3.1	3.89	105	ND(0.1)	0.2	227	249	57.9	54	1.19	17	63	NA	6.8
10/96	428	-259R	NA	11	0.16R	150	ND(0.1)	NA	200	328	47	62	1.21	15	67	2.64	34
2/97	504	-76	NA	21	3.4	72	ND(0.1)	NA	186	159	6.72	36.4J	0.596	7.8	59.6	5.31	43

TABLE 4-2

SUMMARY OF CHEMICAL DETECTIONS FOR MISCELLANEOUS PARAMETERS IN GROUND WATER
Dry Cleaning Facilities Area
Fort Riley, Kansas
May 1995-February 1997

All Results Shown are in mg/l Unless Otherwise Noted

J: Estimated Concentration.
NA: Not Analyzed.
NAv: Not Available.
ND(): Not Detected (detection limit).
NS: Not Sampled.
R: Rejected by Data Validator.
*: Measured in Field.
**: Measured in Laboratory.
mv: millivolts.
Results from December 1993 to January 1995 contain data from CEMRK (1994a,b,d,e,f,g,i; 1995a) as referenced in the Draft Final DCFA-RI Report, March 1995.
For a complete list of analytes from December 1993 to January 1995, see Appendix D of the Draft Final DCFA-RI Report, March 1995.
For a complete list of analytes from May 1995 through February 1997, please see CEMRK 1995a, CEMRK 1995b, CEMRK 1995c, CEMRK 1995d, CEMRK 1996b, CEMRK 1996c, CEMRK 1997b.

Well No. & Sample Date	Alkalinity, Total as $CaCO_3$	Oxidation Reduction Potential (mv)*	Chemical Oxygen Demand	Total Organic Carbon, Sparged	Dissolved Oxygen, (DO)*	Chloride	Nitrate (as N)	Orthophosphate (as P)	Sulfate	Calcium	Iron	Magnesium	Manganese	Potassium	Sodium	Iron (II), Ferrous*	Methane (mg/l)
DCF96-35																	
5/96	672	198**	ND(10)	6.6	NA	22	0.3	0.3	57	158	50.2	30	0.65	5	27	NA	ND(2.0)
10/96	403	-115R	NA	4.9	ND(0.1)R	42	0.4	NA	49	98	11.6	24	0.18	3	26	0.08	ND(2.0)
2/97	374	25	NA	1.1	1.78	43	0.2	NA	64	106	18.9	29.5J	0.213	3.8	29.6	0.19	ND(2.0)
DCF96-36																	
5/96	391	66**	ND(10)	8.9	2.54	20	ND(0.1)	0.4	93	138	45.5	26	2.15	9	24	NA	ND(2.0)
10/96	490	-126R	NA	7.6	ND(0.1)R	24	ND(0.1)	NA	70	116	42.4	22	2.19	7	26	0.6	9
2/97	352	0	NA	4.9	6.33	21	ND(0.1)	NA	66	124	8.95	22.6J	1.99	6.5	27.7	0.86	3.4

TABLE 4-3

SUMMARY OF FIELD PARAMETERS IN GROUND WATER SAMPLES
Dry Cleaning Facilities Area
Fort Riley, Kanasas
May 1995-February 1997

Notes:
All measurements taken for final purge volume, immediately prior to sampling.
NP= Not Planned.
NA= Not Analyzed.
NR= Not Recorded.
R= Rejected.
> Value greater than meter's highest value.

Well No. & Sample Date	pH	Specific Conductivity (umhos)	Temperature (C)	Turbidity (NTU)
DCF92-01				
05-95	7.14	1890	14.9	1.59
06-95	NP	NP	NP	NP
07-95	7.23	1710	12.0	29.0
08-95	NP	NP	NP	NP
10-95	NP	NP	NP	NP
05-96	NP	NP	NP	NP
10-96	NP	NP	NP	NP
02-97	NP	NP	NP	NP
DCF92-02				
05-95	6.84	1770	17.2	0.45
06-95	NP	NP	NP	NP
07-95	6.97	1630	18.8	10.4
08-95	NP	NP	NP	NP
10-95	7.19	1520	16.0	2.98
05-96	6.58	1370	18.4	3.47
10-96	6.66	1518	16.1	1.90
02-97	7.18	1210	14.9	10.7
DCF92-03				
05-95	6.93	2030	21.7	0.35
06-95	7.04	2090	22.3	0.58
07-95	6.96	2000	24.5	1.06
08-95	7.37	2160	22.7	0.59
10-95	7.06	1860	19.3	2.45
05-96	5.96	1670	19.5	6.65
10-96	6.70	1881	16.8	9.40
02-97	7.21	1167	14.6	2.10
DCF92-04				
05-95	6.92	1200	16.2	116
06-95	6.87	1270	18.6	8.08
07-95	6.76	1460	19.8	5.40
08-95	7.03	1440	18.5	75.6
10-95	6.93	1370	16.0	908
05-96	6.45	1160	18.7	59.6
10-96	6.73	1367	16.2	31.3
02-97	8.51	2790	8.2	14.9

TABLE 4-3

SUMMARY OF FIELD PARAMETERS IN GROUND WATER SAMPLES
Dry Cleaning Facilities Area
Fort Riley, Kanasas
May 1995-February 1997

Notes:
All measurements taken for final purge volume, immediately prior to sampling.
NP= Not Planned.
NA= Not Analyzed.
NR= Not Recorded.
R= Rejected.
> Value greater than meter's highest value.

Well No. & Sample Date	pH	Specific Conductivity (umhos)	Temperature (C)	Turbidity (NTU)
DCF93-09				
05-95	7.09	1720	13.3	35.5
06-95	7.28	1510	14.5	11.4
07-95	7.23	1510	14.5	73.4
08-95	6.95	1470	17.0	>1000
10-95	6.91	1420	17.3	372
05-96	7.34	1087	15.1	14.5
10-96	6.82	1430	15.1	84.4
02-97	8.06	930	13.6	13.8
DCF93-10				
05-95	7.04	1670	13.0	83.7
06-95	NP	NP	NP	NP
07-95	7.02	1650	14.7	121
08-95	NP	NP	NP	NP
10-95	6.97	2370	17.1	>1000
05-96	7.38	1480	14.8	32.4
10-96	6.80	1815	15.3	91.9
02-97	8.50	1200	13.1	12.6
DCF93-11				
05-95	NS	NS	NS	NS
06-95	7.09	1610	13.8	46.5
07-95	7.20	1790	14.5	18.9
08-95	6.93	1820	17.7	>1000
10-95	NS	NS	NS	NS
05-96	NS	NS	NS	NS
10-96	NS	NS	NS	NS
02-97	NS	NS	NS	NS
DCF93-12				
05-95	7.24	1850	14.2	>1000
06-95	NP	NP	NP	NP
07-95	7.04	1830	14.7	118
08-95	NP	NP	NP	NP
10-95	7.07	1350	13.0	>1000
05-96	7.73	940	NA	15.5
10-96	NS	NS	NS	NS
02-97	NS	NS	NS	NS

TABLE 4-3

SUMMARY OF FIELD PARAMETERS IN GROUND WATER SAMPLES
Dry Cleaning Facilities Area
Fort Riley, Kanasas
May 1995-February 1997

Notes:
All measurements taken for final purge volume, immediately prior to sampling.
NP= Not Planned.
NA= Not Analyzed.
NR= Not Recorded.
R= Rejected.
> Value greater than meter's highest value.

Well No. & Sample Date	pH	Specific Conductivity (umhos)	Temperature (C)	Turbidity (NTU)
DCF93-17				
05-95	NS	NS	NS	>1000
06-95	NP	NP	NP	NP
07-95	7.00	1580	14.1	22.0
08-95	NP	NP	NP	NP
10-95	7.11	1440	14.2	>1000
05-96	NR	NR	NR	NR
10-96	NS	NS	NS	NS
02-97	NS	NS	NS	NS
DCF93-18				
05-95	7.07	6290	18.9	10.1
06-95	NP	NP	NP	NP
07-95	7.05	6990	15.0	21.8
08-95	NP	NP	NP	NP
10-95	7.13	7110	17.0	449
05-96	NR	NR	NR	NR
10-96	NS	NS	NS	NS
02-97	NS	NS	NS	NS
DCF93-19				
05-95	7.10	1150	16.3	0.24
06-95	7.05	1270	17.9	0.77
07-95	7.02	1390	18.5	0.75
08-95	7.61	1390	18.7	1.30
10-95	7.57	1380	16.1	13.9
05-96	7.29	1100	18.5	10.7
10-96	7.47	1362	16.2	3.66
02-97	7.63	800	8.8	7.20
DCF93-20				
05-95	7.22	2630	14.3	26.3
06-95	7.15	2690	15.1	14.0
07-95	7.06	2910	14.5	19.8
08-95	7.42	2620	16.2	27.2
10-95	6.71	1720	13.0	10.4
05-96	8.40	1380	16.3	64.0
10-96	6.83	1831	13.0	19.6
02-97	7.60	1670	9.7	7.68

TABLE 4-3

SUMMARY OF FIELD PARAMETERS IN GROUND WATER SAMPLES
Dry Cleaning Facilities Area
Fort Riley, Kanasas
May 1995-February 1997

Notes:
All measurements taken for final purge volume, immediately prior to sampling.
NP= Not Planned.
NA= Not Analyzed.
NR= Not Recorded.
R= Rejected.
> Value greater than meter's highest value.

Well No. & Sample Date	pH	Specific Conductivity (umhos)	Temperature (C)	Turbidity (NTU)
DCF96-27				
05-96	9.20	1310	17.2	70.6
10-96	6.90	1908	14.0	56.6
02-97	7.37	1020	13.4	12.8
DCF96-34				
05-96	7.41	1160	17.5	>200
10-96	7.11	1488	16.5	115
02-97	8.31	2420	7.9	119
DCF96-35				
05-96	NA	NA	15.0	124
10-96	7.03	680	15.0	146
02-97	6.54	560	12.8	8.40
DCF96-36				
05-96	NA	1090	14.8	148
10-96	7.08	766	14.2	128
02-97	7.02	480	13.7	12.0

FIGURES

FIGURE 4-1

CONTINUOUS READING GROUNDWATER ELEVATION DATA LOGGER RESULTS AND KANSAS RIVER ELEVATION DATA

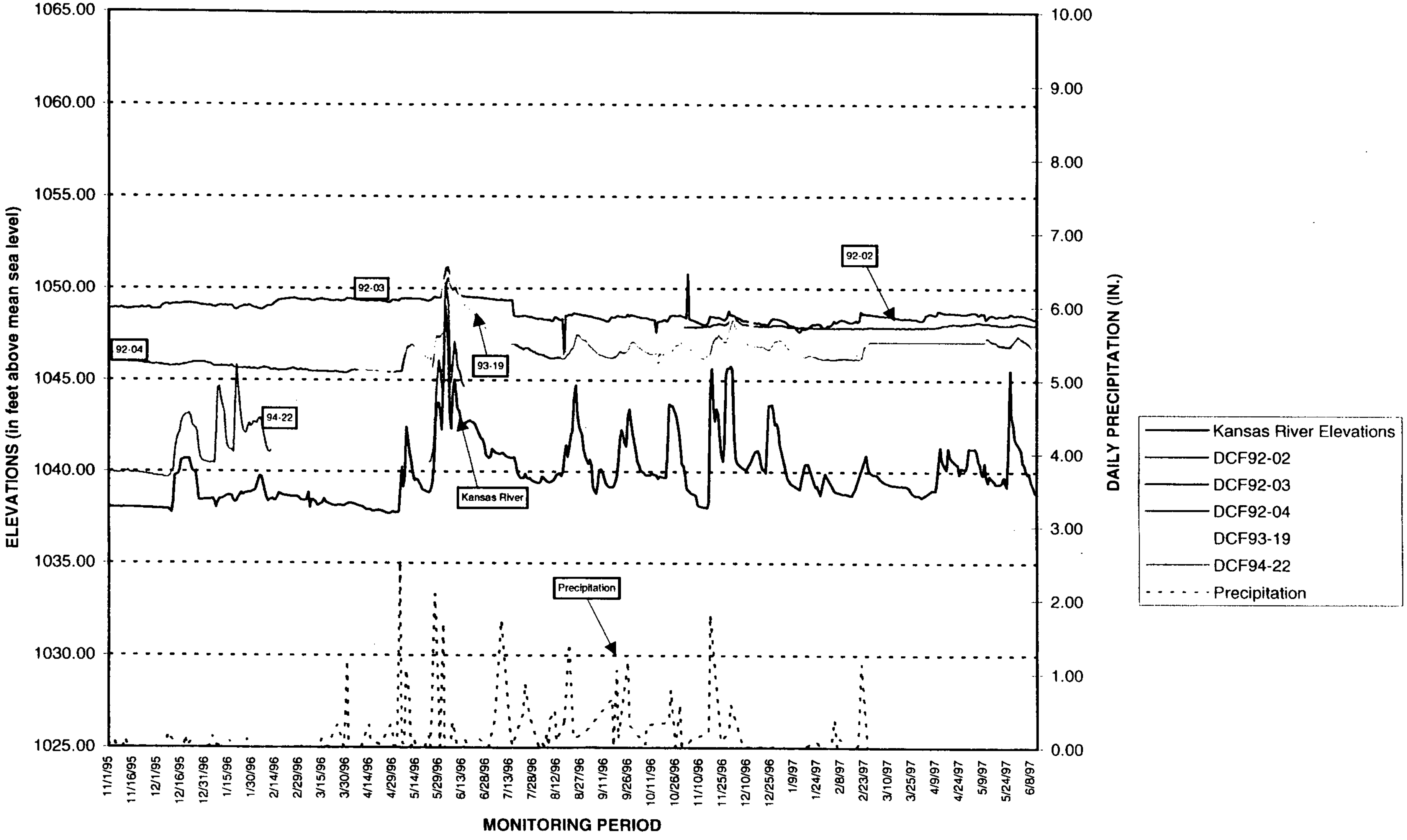
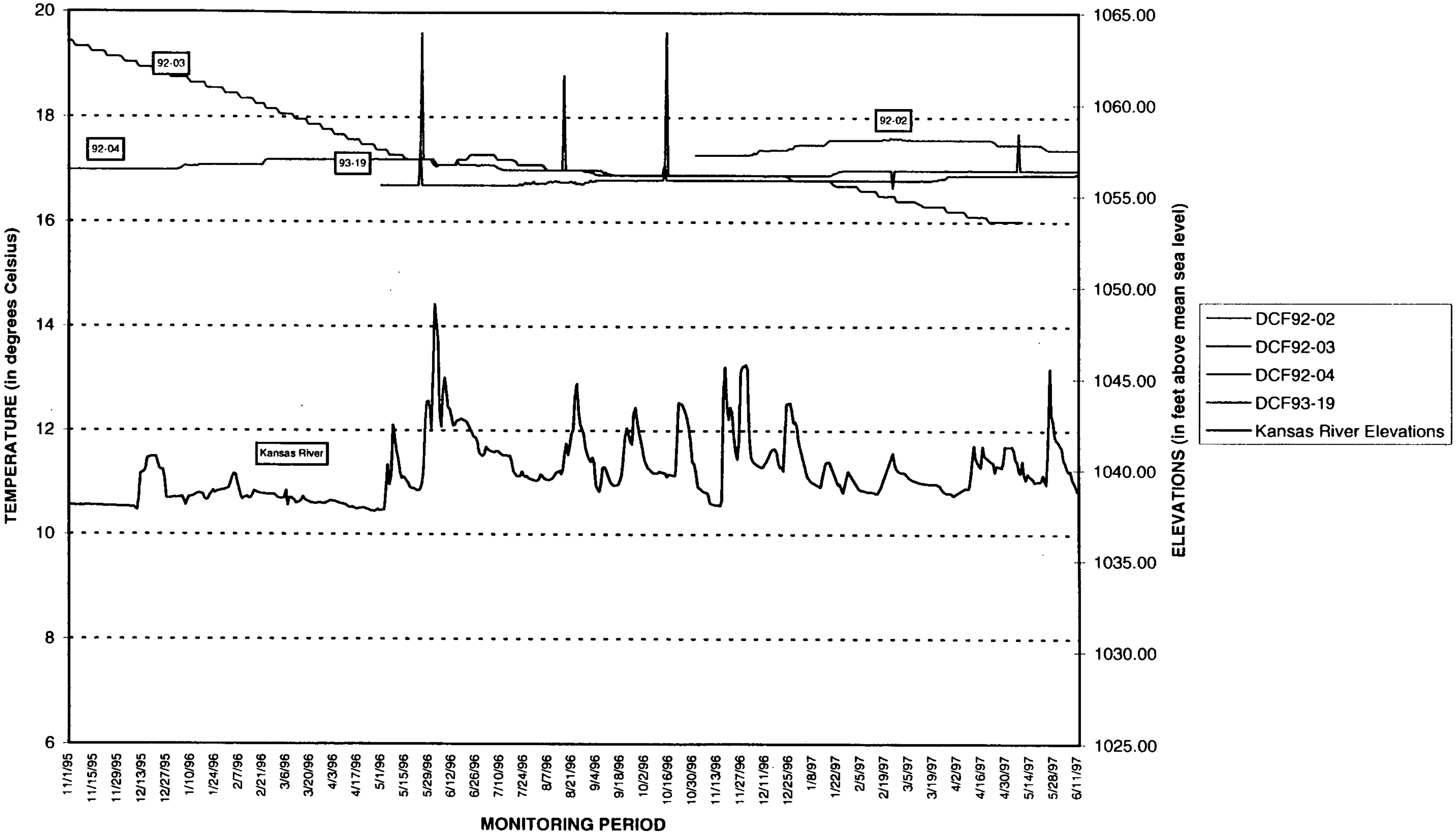
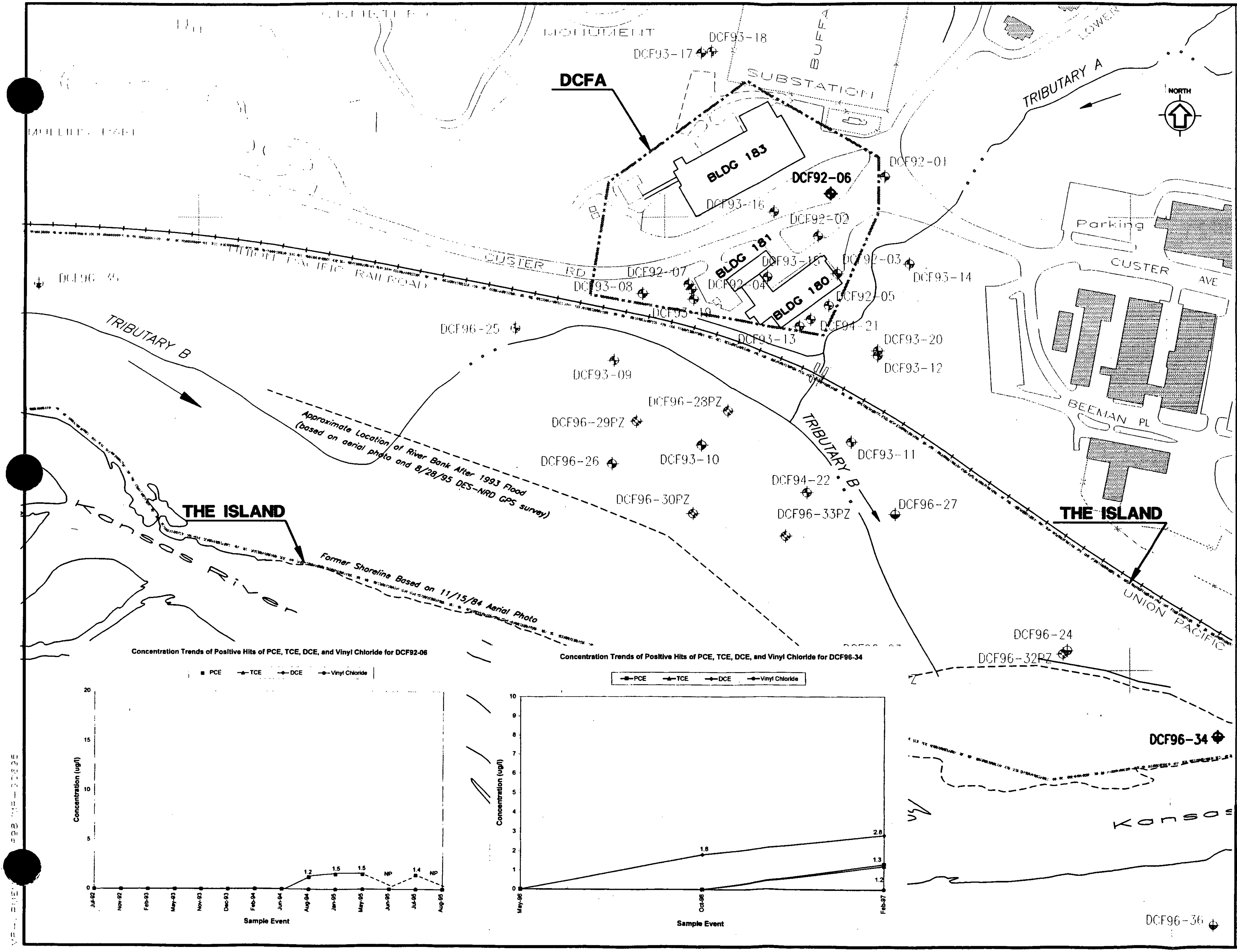
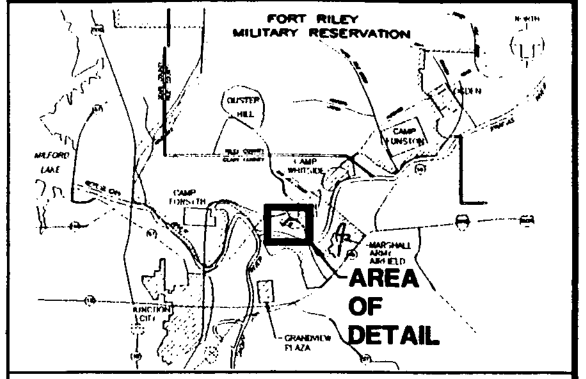


FIGURE 4-2
CONTINUOUS READING TEMPERATURE DATA LOGGER RESULTS AND KANSAS RIVER ELEVATION DATA





KEY MAP



LEGEND

EXISTING ROADWAY
EXISTING TRIBUTARY
SURFACE WATER FLOW DIRECTION
EXISTING BUILDING
EXISTING RAILROAD
EXISTING FENCE LINE
DCF93-19 MONITORING WELL
DCF96-23 DEEP ALLUVIAL MONITORING WELL
DCF96-28PZ PIEZOMETER
DCF STUDY AREA

0 100 200 400
(IN FEET)
1 inch = 200 ft.

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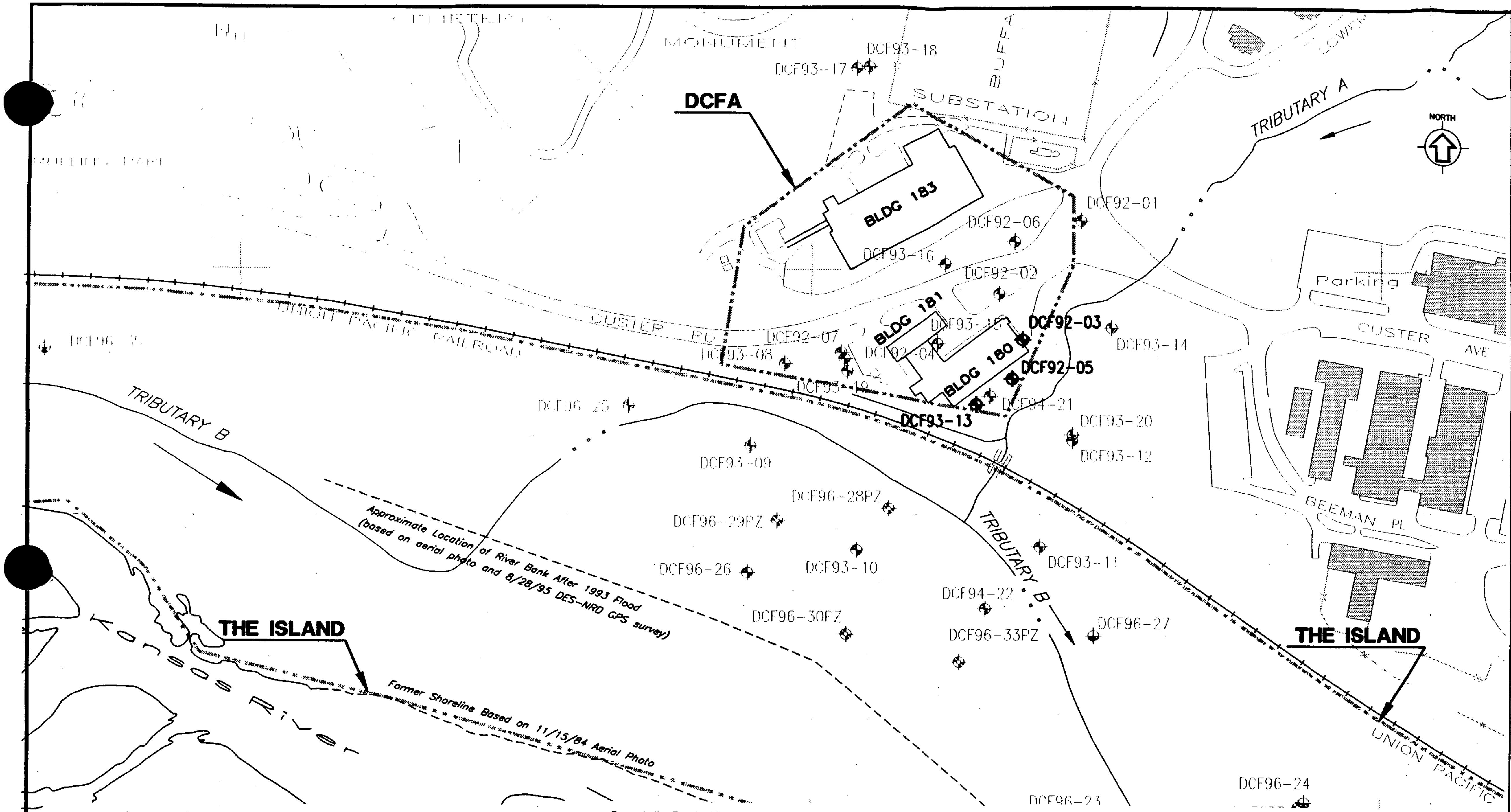
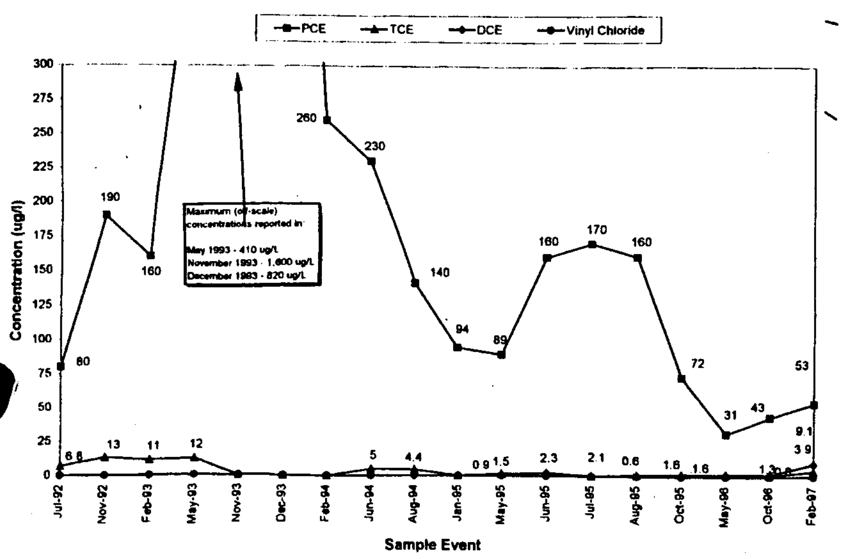
FORT RILEY MILITARY RESERVATION (DCFA-RIAMER)

LOCATIONS AND SELECTED CONTAMINANT PLOTS FOR BACKGROUND MONITORING WELLS

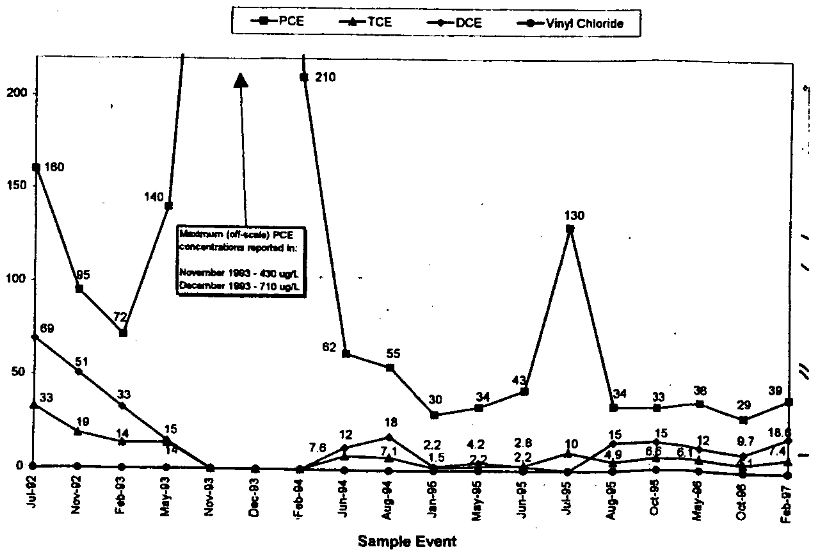
SCALE: 1"=200'	DCFA-RIAMER DATE: MARCH 1998	FIG. 4-3



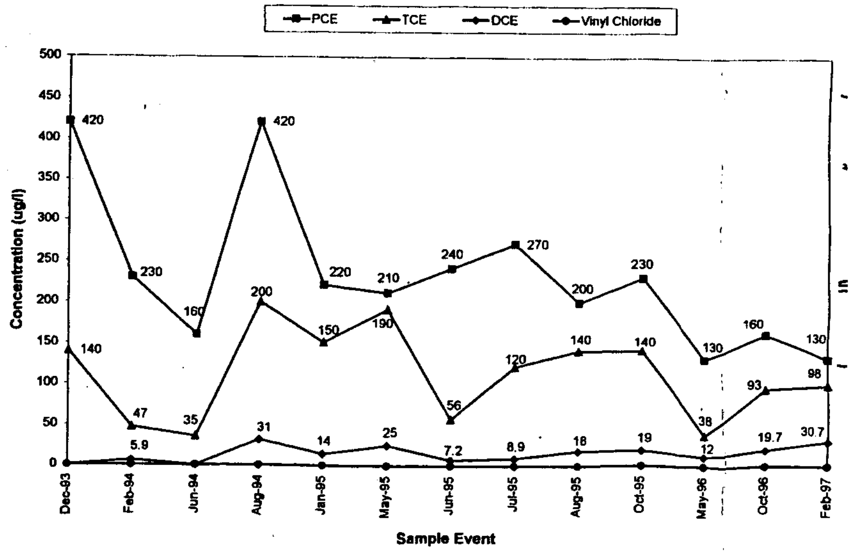
Concentration Trends of Positive Hits of PCE, TCE, DCE, and Vinyl Chloride for DCF92-03



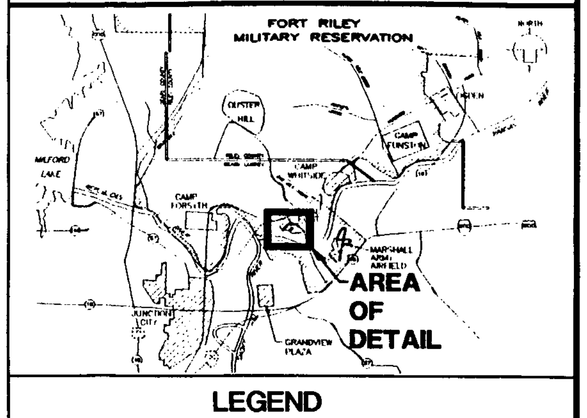
Concentration Trends of Positive Hits of PCE, TCE, DCE, and Vinyl Chloride for DCF92-05



Concentration Trends of Positive Hits of PCE, TCE, DCE, and Vinyl Chloride for DCF93-13



KEY MAP



LEGEND

EXISTING ROADWAY
EXISTING TRIBUTARY
SURFACE WATER FLOW DIRECTION
▨ EXISTING BUILDING
EXISTING RAILROAD
EXISTING FENCE LINE
DCF93-19 ⊕ MONITORING WELL
DCF96-23 ⊕ DEEP ALLUVIAL MONITORING WELL
DCF96-28PZ ⊕ PIEZOMETER
DCF STUDY AREA

0 100 200 400
(IN FEET)
1 inch = 200 ft.

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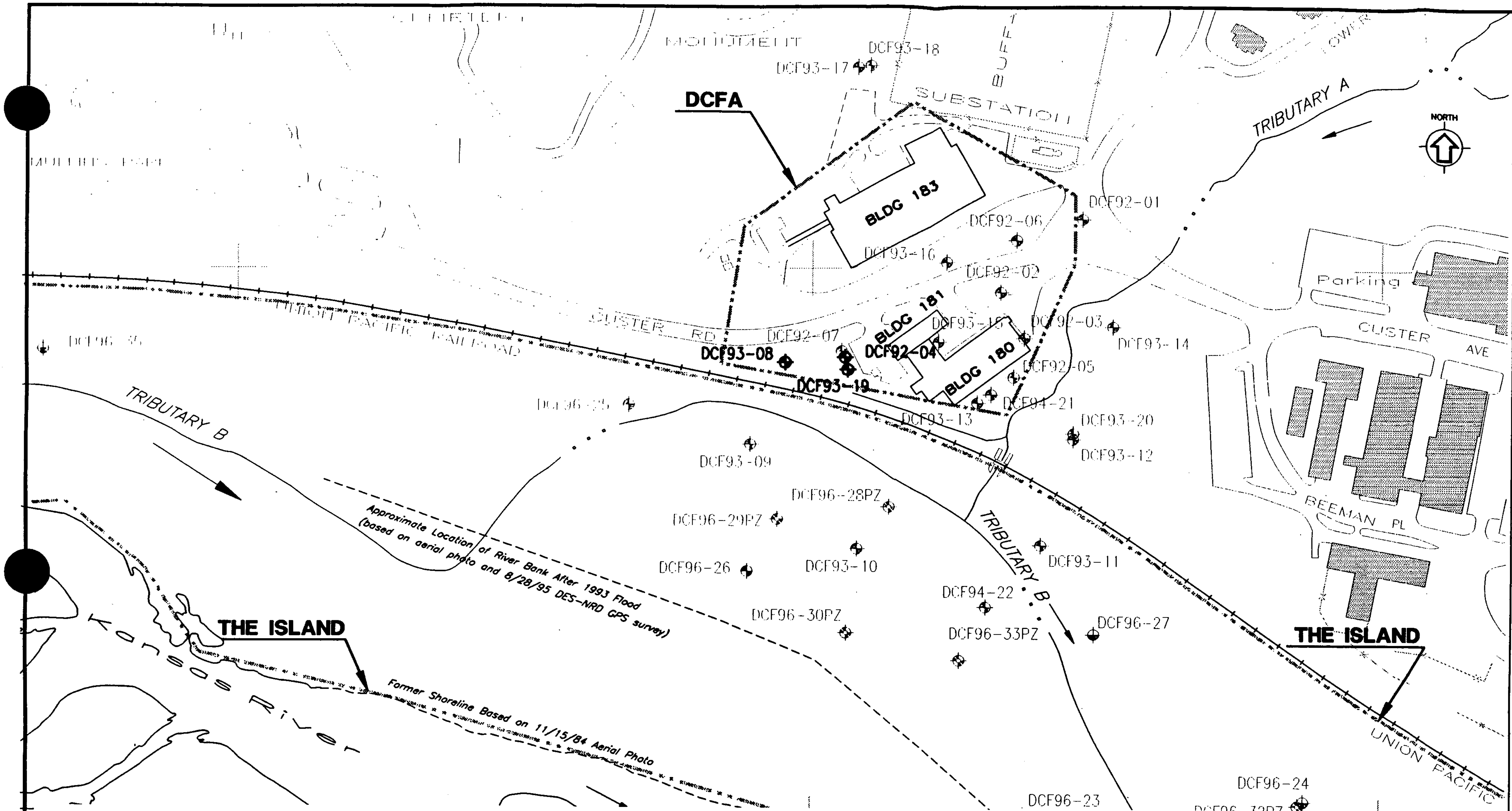
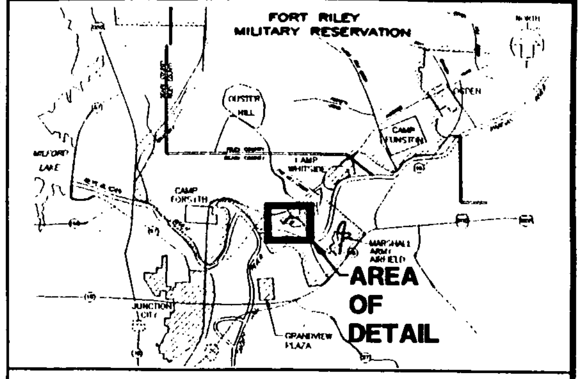
FORT RILEY MILITARY RESERVATION (DCFA–RIAMER)

LOCATIONS AND SELECTED CONTAMINANT PLOTS FOR THE BEDROCK EROSIONAL FEATURE/SEWER LINE AREA MONITORING WELLS

SCALE: 1"=200'	DCFA–RIAMER DATE: MARCH 1998	FIG. 4–4



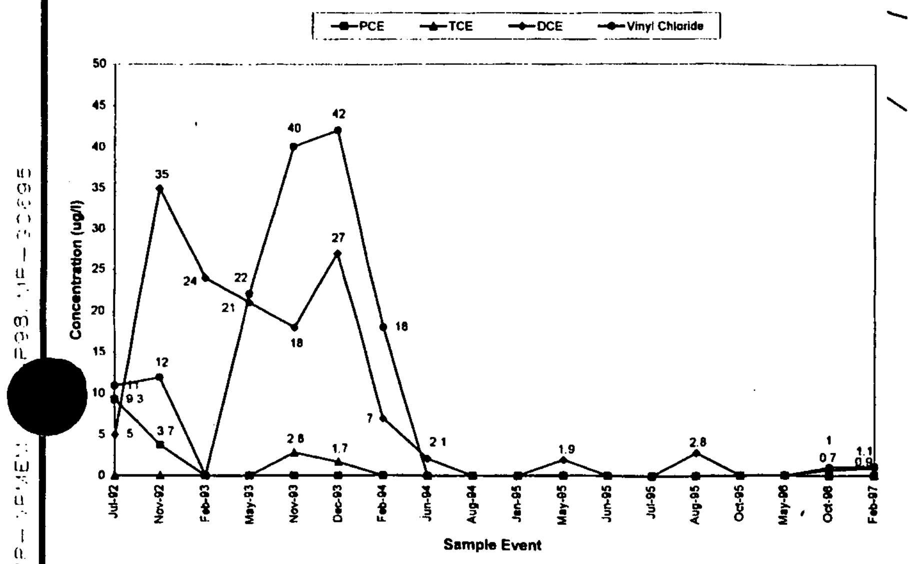
KEY MAP



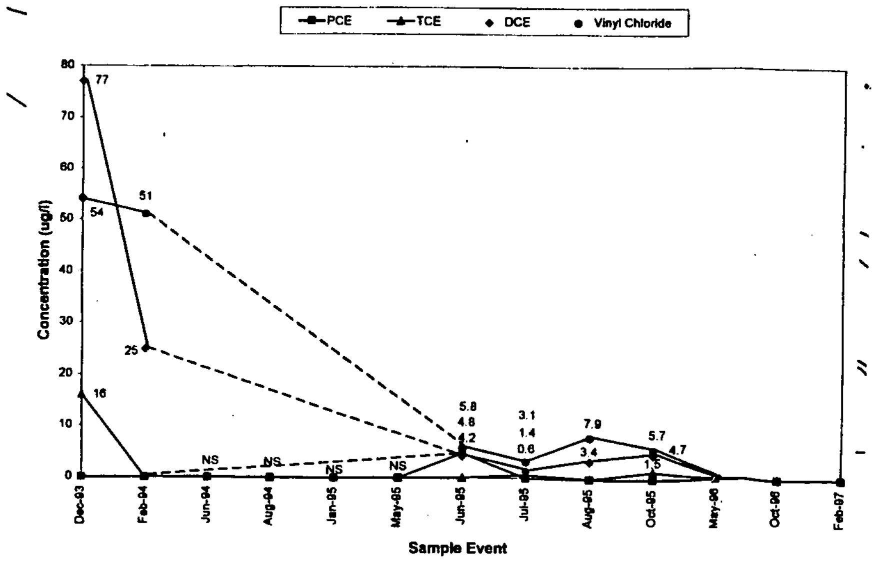
LEGEND

═══	EXISTING ROADWAY
—··—	EXISTING TRIBUTARY
→	SURFACE WATER FLOW DIRECTION
▨	EXISTING BUILDING
┼┼┼	EXISTING RAILROAD
······	EXISTING FENCE LINE
DCF93-19 ◈	MONITORING WELL
DCF96-23 ◈	DEEP ALLUVIAL MONITORING WELL
DCF96-28PZ ◈	PIEZOMETER
·-·-·-	DCF STUDY AREA

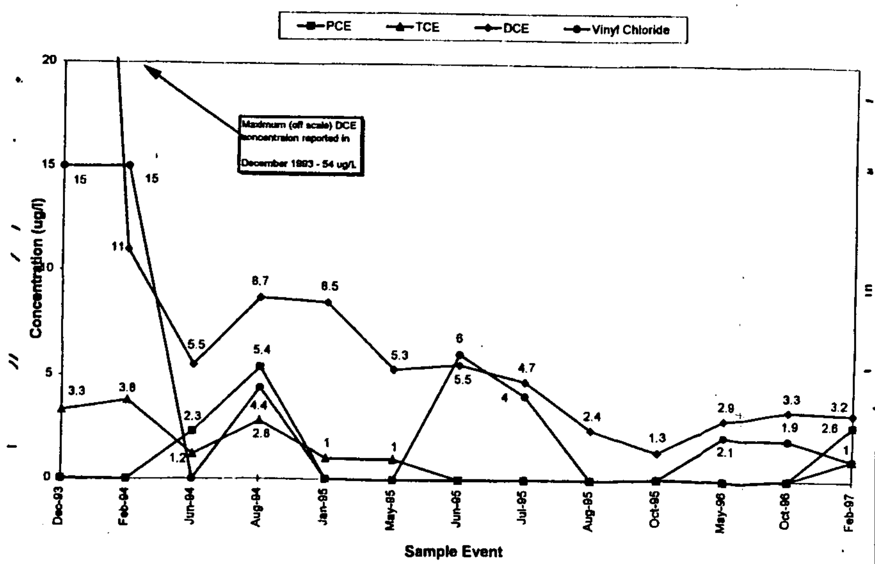
Concentration Trends of Positive Hits of PCE, TCE, DCE, and Vinyl Chloride for DCF92-04



Concentration Trends of Positive Hits of PCE, TCE, DCE, and Vinyl Chloride for DCF93-08



Concentration Trends of Positive Hits of PCE, TCE, DCE, and Vinyl Chloride for DCF93-19



(IN FEET)
1 inch = 200 ft.

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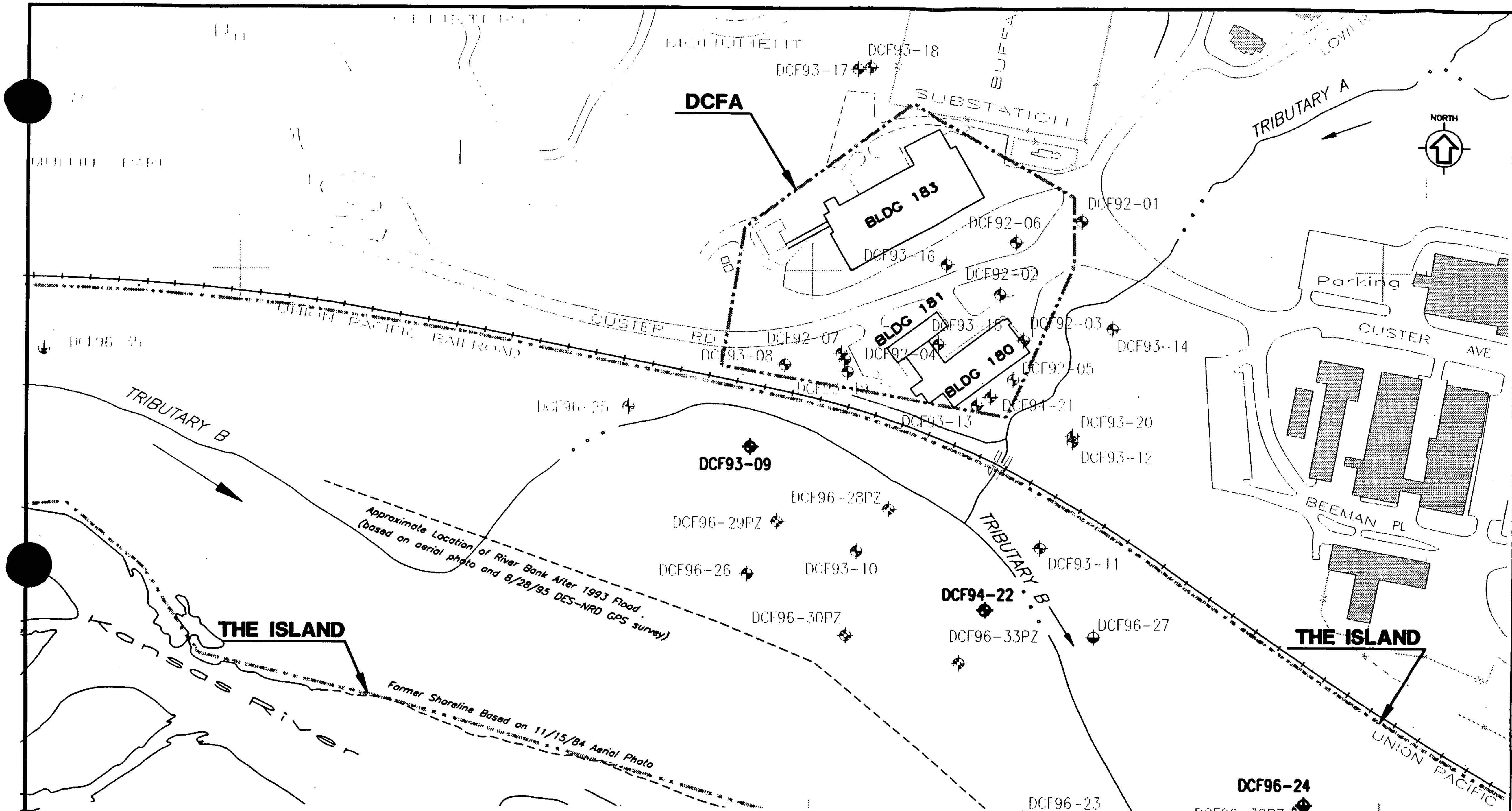
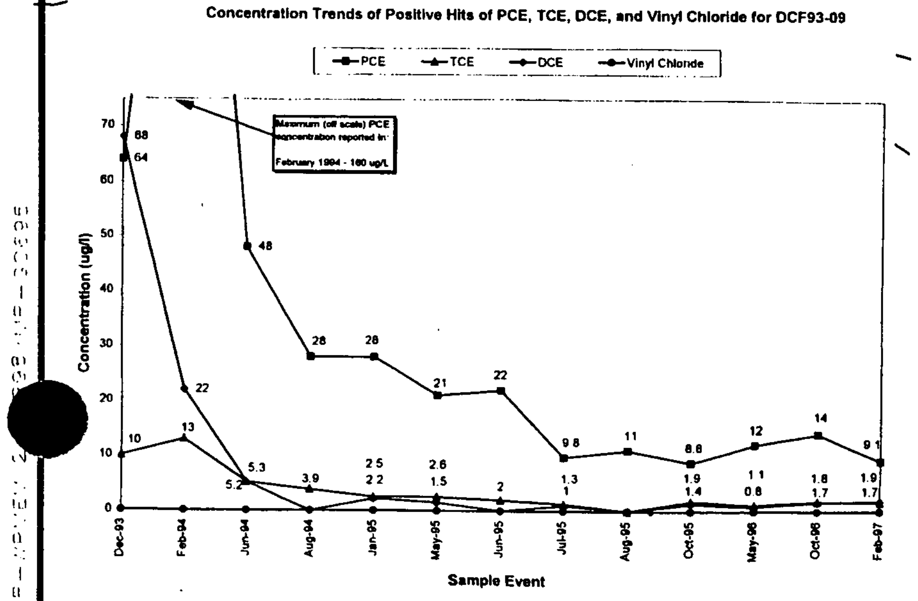
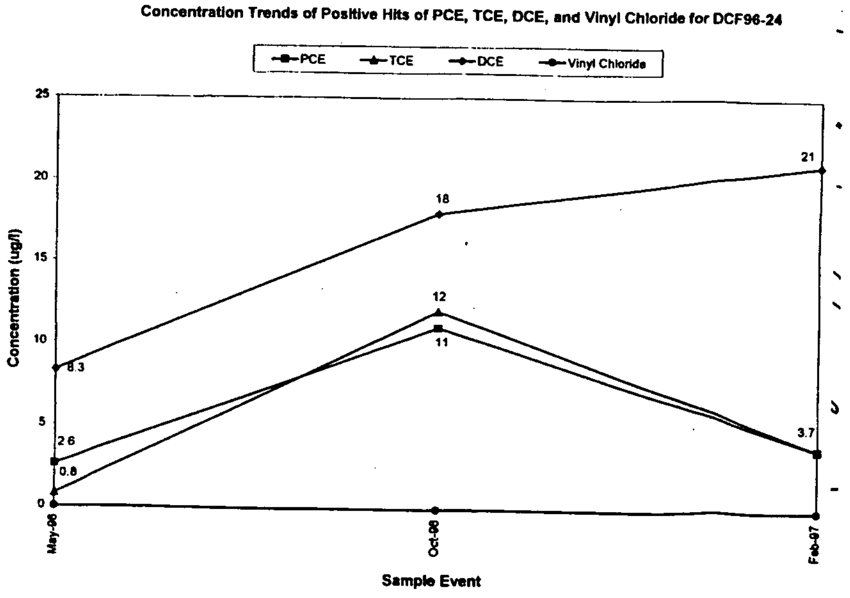
FORT RILEY MILITARY RESERVATION (DCFA–RIAMER)

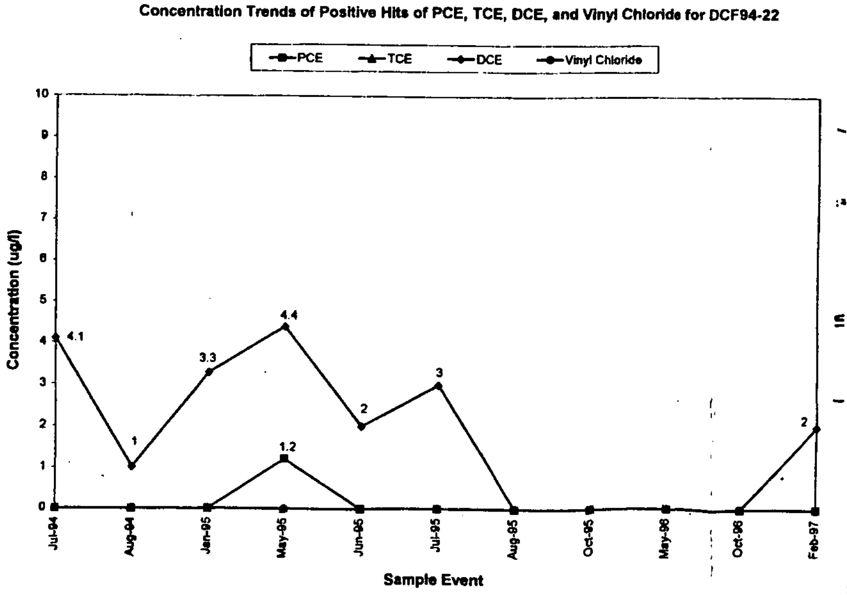
LOCATIONS AND SELECTED CONTAMINANT PLOTS FOR THE BUILDING 180/181 AREA MONITORING WELLS

SCALE: 1"=200'	DCFA–RIAMER DATE: MARCH 1998	FIG. 4–5

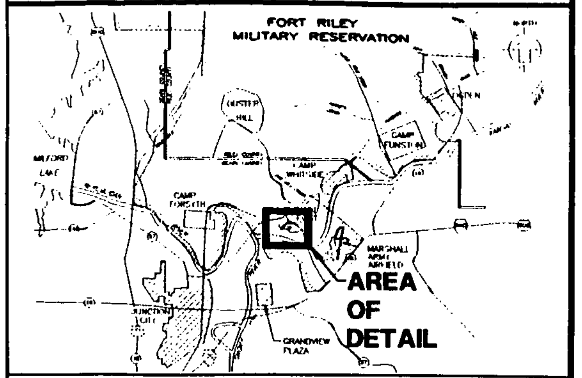








KEY MAP



LEGEND

═══	EXISTING ROADWAY
—·· —	EXISTING TRIBUTARY
→	SURFACE WATER FLOW DIRECTION
▨	EXISTING BUILDING
—+—+—	EXISTING RAILROAD
········	EXISTING FENCE LINE
DCF93-19 ⊕	MONITORING WELL
DCF96-23 ⊕	DEEP ALLUVIAL MONITORING WELL
DCF96-28PZ ⊕	PIEZOMETER
✱ ✱ ✱	DCF STUDY AREA

0 100 200 400

(IN FEET)
1 inch = 200 ft.

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FORT RILEY MILITARY RESERVATION (DCFA–RIAMER)

LOCATIONS AND SELECTED CONTAMINANT PLOTS FOR THE ISLAND/ALLUVIAL DEPOSIT AREA

SCALE: 1"=200'	DCFA–RIAMER DATE: MARCH 1998	FIG. 4–6

5.0 DATA EVALUATION

5.0 Data Evaluation

This section presents a detailed evaluation of the results of the expanded groundwater sampling and analysis performed at site wells within the DCF Study Area. In addition, the results presented in the Draft Final RI (CENWK, 1995) are included to present as comprehensive a picture as possible of the groundwater flow regime, the contaminant migration, and its continued degradation over the period of monitoring. Finally, this section will also address the current evidence of and future potential for natural attenuation of the chlorinated organic contaminants of concern within the DCF Study Area.

The overall goal of this chapter is to update the conclusions of the Draft Final RI with regard to nature and extent of groundwater contamination, with emphasis on the alluvial Island since this is the only portion of the DCF Study Area where previously available data was deemed to be insufficient and where a potential trigger for remedial action has been identified (namely, the Kansas Surface Water Quality Standards and the incorporated Federal drinking water standards as applied to alluvial aquifers which are deemed to be associated with surface waters protected as real or potential sources of drinking water).

With regard to the hydrogeology within the DCF Study Area, the combined inception to date results from the RI and the monitoring expansion related groundwater elevation monitoring activities strengthen and further the findings and data trends presented in the Draft Final RI. Inception to date hydrographs (Figure 4-1) clearly illustrate the influence of the Kansas River and precipitation events on the groundwater elevations within the DCF Study Area, with the magnitude of the influence being related to the relative distance from the river and the specific characteristics of the formation in which a well is located.

With regard to contamination data, inception to date sampling and analysis data (Tables 4-1 through 4-3) and the associated analytical data plots presented in this chapter, clearly illustrate that the chemical data collected since the submission of the Draft Final RI are consistent with and further support the findings presented in the Draft Final RI. In particular, these data show that:

1. maximum contaminant levels within the DCF Study Area continue to decrease as the center of contaminant mass migrates (although it is noted that, as would be expected, this does not mean that contaminant levels in particular wells located in front of the center of contaminant mass will not show increasing levels of contamination until the center of mass passes them);
2. natural attenuation (including biodegradation) is absolutely occurring to varying degrees within the DCF Study Area; and,
3. there is no evidence that any deep non-aqueous phase contamination exists within the DCF Study Area.

The chemical data are presented in summary format as a series of combined plots and figures. The plots present the change, over time, of the primary contaminants of concern including PCE, TCE, 1,2-DCE (total) and vinyl chloride. To better focus the analysis, the plots were developed for several different groupings of wells which illustrate:

- background conditions;
- conditions within the unconsolidated materials in bedrock erosional feature in the upland area;
- conditions in the bedrock in the upland area; and,
- conditions within the alluvium beneath the Island.

The plots are presented on a series of figures in this chapter, with the corresponding well locations depicted.

Issue- and location-specific discussions and evaluations are presented below.

5.1 Groundwater Flow Regime Evaluation

5.1.1 Continuous Reading Groundwater Elevation and Temperature Results

Although there are some discontinuities in the data for several of the wells, sufficient information has been collected from the continuous reading dataloggers to fulfill the original objectives of: (1) establishing a more complete understanding of the hydrogeologic regimes that exist within the DCF Study Area; and, (2) evaluating what, if any, impacts on the hydrogeology occurred as a result of sewer leaks and repairs.

The groundwater elevation monitoring data confirmed the previous understanding of the overall hydrogeology of the DCF Study Area. As shown in the hydrograph presented in Chapter 4 (Figure 4-1), the groundwater flow regimes within the DCF Study Area respond to varying degrees, as expected, to fluctuations in the river stage and/or to precipitation events. This response is seen in all of the formations monitored with data loggers, including the Upper and Lower Crouse bedrock, in the upland unconsolidated material, and in the Island alluvial deposits; with the magnitude of response dependent on the particular horizontal and vertical location of each well screen relative to the river and/or ground surface.

With regard to the impact of sewer repairs, the results of temperature monitoring contain some discontinuities but are sufficient to assess impacts to the groundwater from discharges from the formerly leaking sanitary sewer lines (see Figure 4-2). In contrast to the groundwater temperatures, however, it does not appear that addressing the leaks from the sanitary sewer had a discernable effect on the groundwater levels in any of the wells near the sewers. Groundwater temperatures recorded during the sewer diversion study in 1994 ranged up to 30°C in wells adjacent to the sewer line, presumably as a result of the sewers carrying and leaking the heated effluent which was periodically discharged from the steam generation plant at the DCFA. These temperatures have since been reduced by over 10°C as indicated by continuous reading dataloggers which have been monitored since 1995, including the period subsequent to the 1996 sewer repair program described in Section 1.1.3. Based on the data, the effects of addressing the formerly leaking sewers appear to be localized and are most clearly seen in DCF92-03 (Figure 4-2); with a temperature decrease from 19.5 °C to approximately 16 °C recorded over the period from November 1995 to May 1997. However, even with the decrease, these recorded levels are still slightly higher than documented temperature levels for this area (13°C to 14.5°C).

A well-by-well analysis of the continuous reading datalogger information follows.

- **Monitoring Well DCF92-02**

The groundwater levels recorded in DCF92-02, installed in the Upper Crouse Formation, in general appear to be marginally affected by river stages. It should be noted however, that the monitoring period for DCF92-02 is much shorter than that for monitoring wells DCF92-03, DCF94-04, and DCF93-19 and was not in operation during the reported high river stages. In addition, during the period in which water level data have been collected from DCF92-02, there have not been periods with extraordinarily high river levels which may be required in order to see a response in the groundwater in DCF92-02. Two elevated river stages with associated high precipitation exhibited a slight influence on the groundwater levels in DCF92-02. The first event was reported during November 1996 and the second was reported during May 1997. During both of these events the river level rose substantially and, as seen on the hydrograph in Figure 4-1, there is a gentle increase in the groundwater elevation plot for DCF92-02.

The results of temperature monitoring in DCF92-02, indicate that there have been no substantive changes to the groundwater temperature. In Figure 4-2, the plot of temperatures recorded in DCF92-02 indicate that there was a slight rise from the inception of monitoring in this well to the beginning of January of 1997.

The temperature appears to have stabilized until April of 1997, whereupon, it begins to decrease and by June of 1997 it has almost returned to its original temperature. The exact cause for this is unknown at present, however, the possibility exists that the slight variation is an artifact of variations in the loggers performance. The variation also may be real and due to other sewers leaking and elevating groundwater temperatures. Alternatively, the elevated temperatures may be attributable to normal effects on precipitation in a developed area. Roadway surfaces, building roofs and concrete and asphalt ground surfaces may tend to elevate the overall temperature of water prior to its entrance into the groundwater regime. Over time, these features may have a cumulative effect, tending to raise the overall temperature of the groundwater within the developed area.

- **Monitoring Well DCF92-03**

DCF92-03, installed in the upland unconsolidated deposits, overall does not show a substantial response to elevated river stages in Figure 4-1, most probably due to its location upland from the river. During high river stages, however, a definite response is observed in the hydrographs. It is uncertain whether this response is directly related to the increase in the river water elevation, to the high amounts of precipitation recorded during the same period or if the changes in groundwater elevation in DCF92-03 are due to the combined influences of the river and precipitation. It would appear that an increase in the elevation of the river, above 1045 feet amsl does have an influence on the groundwater levels in DCF92-03. Other periods with high precipitation, but in which the river elevation does not rise above 1045 feet amsl, do not appear to affect DCF92-03 as substantially as periods with river water elevations above 1045 feet amsl.

The record of temperatures in DCF92-03 appears to reflect ameliorating groundwater temperatures subsequent to the repair of the leaking sewer as shown in Figure 4-2. DCF92-03 is the monitoring well closest to and immediately downgradient of the formerly leaking sanitary sewer. Based on this it was anticipated to exhibit the largest amount of change after the sewer repairs were completed.

Prior to the initiation of data collection by continuous reading logger units, the groundwater temperature was reported to be slightly in excess of 27 °C in DCF92-03 (CENWK 1995). As discussed above, the temperatures in DCF92-03 have been declining during the period of continuous monitoring from a recorded high of approximately 19.5 °C to a final low of approximately 16 °C, immediately prior to the reported difficulties with the data logging unit. Overall, during the course of continuous data collection and based on information collected previously, the temperature in the vicinity of DCF92-03 has shown a substantial decline since the sanitary sewer repairs were effected. One elevated spike in the plot of the groundwater temperatures recorded in DCF92-03 is artificial and is the result of removal of the data logger probe during periodic manual monitoring at this well. The data logger has been inspected and repaired by the manufacturer, and was re-installed in DCF92-03 in July 1997. It is anticipated that the results of continued data collection will document that the groundwater temperature will either continue to decline to approximately 14°C, which, based on the results of previous monitoring and references (van der Leedan, 1990), appears to be the average background temperature in the area or it will stabilize at a slightly higher temperature. If the temperature stabilizes above the expected 14°C, the cause may be attributable to the same causes though to be causing elevated temperatures in monitoring well DCF92-02.

- **Monitoring Wells DCF92-04 and DCF93-19**

Monitoring wells DCF92-04 and DCF93-19 are installed in the same area of the DCFA and their water levels are similar to each other. These two wells will be discussed together although DCF92-04 is installed in the Upper Crouse Formation and DCF93-19 is installed in the Lower Crouse Formation. Typically, the Upper and Lower Crouse Formations are not thought to be hydraulically connected. In the area of the Kansas River however, both of these units exist in outcrop, albeit buried. This would create a localized connection between both of these units and would also create a direct connection between these units and the alluvial deposits of the Island and with the Kansas River.

The groundwater elevation measurements recorded at DCF92-04 and DCF93-19 are similar to each other. The similarities can be observed on Figure 4-1 where the similarities appear both during high and low water stages in the Kansas River. Minor fluctuations in the river water elevations below 1040 feet Amsl, recorded during the period November 1995 to May 1996 are not clearly reflected in the groundwater elevations in DCF92-04 (during this period, the logger unit in DCF93-19 was not functioning properly therefore there are no data for this period). Subsequent to this period, the river levels fluctuated more strongly, ostensibly due to increases in precipitation as shown on Figure 4-1. Monitoring wells DCF92-04 and DCF93-19 responded to these fluctuations and show a good correlation to the changes in river water elevations. These units are not exposed along the river due to overlying unconsolidated material however, these units are seen in outcrop within the ravine of Tributary A. It is felt that the proximity of both of these units to the river and their exposure to the alluvial sediments of the Island and the direct influences of the Kansas River accounts for the similarity in responses to fluctuations in river stages.

The groundwater temperatures recorded in monitoring wells DCF92-04 and DCF93-19 are similar and are separated by no more than one half a degree. The trends of each, as shown on Figure 4-2, do not display substantial variations and are generally within the 16.5°C to 17.5°C range. A number of short duration spikes are evident on the plots presented on Figure 4-2, however, these are artificial and are attributable to removal of the data logger probe during periodic sampling and monitoring. As has been noted in the previous discussions, the 17°C temperature appears to be somewhat elevated above what would be anticipated for the background groundwater temperature of approximately 14°C (van der Leedan, 1990). As with other monitoring wells it is assumed that there are possible unidentified leaking sewers within the DCFA which may be causing the elevated temperatures or the temperature may reflect an overall elevated and variable groundwater temperature in the main operations area of the DCFA as mentioned previously in the discussion of DCF92-02.

- **Monitoring Well DCF94-22**

The data recorded by the constant reading water level data logger, installed in DCF94-22 in July 1994, for the period 30 July 1994 through 6 June 1995 are included in Appendix A of this report. The data indicate that the groundwater responded rapidly to changes in the Kansas River water elevations. There is a good correlation between the high and low river stages and changes in the groundwater elevations with only one apparently anomalous point recorded in January of 1995. The water level in the Kansas River was reported to be elevated during this period, however, the data logger did not record a corresponding increase in the groundwater elevation in DCF94-22. It is assumed that the data logger malfunctioned during this event especially in view of the generally constant response seen between the river and groundwater during the remainder of the monitoring during the July 1994 to June 1995 period.

Due to difficulties experienced with the data logging unit in DCF94-22, very little data were collected during the course of monitoring from November 1995 to present. The brief periods wherein the data logger appears to have functioned properly however, appear to demonstrate that the alluvial deposits respond rapidly to changes in river water elevation and that the response seen in the groundwater is similar to the trace of the river stages (Figure 4-1). The data from December of 1995 for the Kansas River show a rise in the river elevation from approximately 1038 feet amsl to approximately 1041 feet amsl. The corresponding data from DCF94-22 show a similar duplicate of the river data starting at elevation 1040 feet amsl and rising to approximately elevation 1043 feet amsl. The high river stage experienced during May and June of 1996 shows a similar response between the river elevation and the groundwater in DCF94-22. Although these are the only data sets which appear to be usable from the data logging in DCF94-22, there appears to be a direct correlation between changes in river stages and the elevation of groundwater in the Island alluvial deposits.

5.1.2 Periodic Groundwater Elevation Monitoring

The results of manual groundwater elevation monitoring illustrates that there is a constant flow across the DCF Study Area from the upland to the Kansas River via the Island alluvium. The groundwater flow can be demonstrated to go from the northeast in the upland areas towards the south and southwest as the groundwater enters the alluvial deposits. There is a general redirection of the groundwater flow pattern toward the downstream direction as the groundwater from the upland enters the alluvial deposits and begins to flow with the overall pattern in this river valley regime. Changes in the river level and subsurface features such as the bedrock erosional feature east of Buildings 180 and 181 do create temporal or localized variations to the groundwater flow pattern; however, the net effect is flow towards and discharge to the alluvial sediments in the river valley.

During low water stages in the Kansas River, a distinct mound can be described in the groundwater beneath the DCF at the foot of the bedrock erosional feature which terminates in the Kansas River valley. This is most probably due to channeled groundwater flow through the bedrock erosional feature. It is assumed that shallow water moves through the bedrock and, in the area east of Buildings 180 and 181, is collected in the bedrock erosional feature. Water which enters the bedrock erosional feature flows through permeable sediments and discharges into the finer alluvial sediments in the Kansas River valley. At this point in the unconsolidated material there is a surcharge of water which, due to the finer grained nature of the alluvial sediments, is temporarily restricted in its flow thereby causing a mound to be formed. The water from the bedrock erosional feature flows out radially into the alluvial sediments from the mound, where it reaches equilibrium with the alluvial water table and enters the river valley flow regime. The mound effect cannot be seen during periods where the Kansas River is at flood stage. At these times the groundwater levels in the alluvium are sufficiently high to mask the presence of the mound and it is only as the water table returns to steady state conditions that the mounding effect can be seen in the plots of the groundwater elevation contours. Examples of the overall flow regime are included as Figures 3-1 and 3-2. Figure 3-1, based on the groundwater elevation contour data from the February 1997 monitoring period, illustrates the mounding as seen during normal river levels. Figure 3-2, which is based on the June 1995 groundwater elevation measurements, shows that subsequent to the flooding preceding this monitoring period the presence of a groundwater mound is less prominent. Subsequent groundwater elevation data shows the return to steady state conditions and the identification of the groundwater mound.

Individual hydrographs are included in this section which detail the water elevations in the Kansas River and the groundwater elevations and responses to surface water fluctuations in four regimes within the DCF. The Kansas River elevation data and the precipitation data were obtained from the USGS gauging station at the Henry Street Bridge approximately 4,000 feet south of the DCF and the Manhattan, Kansas Airport respectively. The groundwater elevations are those collected manually during periodic sampling and monitoring, discussed previously in Section 4 of this report. The regimes examined in this discussion are as follows:

- The Island alluvium for which there are two hydrographs depicting surface and groundwater responses through both a longitudinal section and a transverse section across the Island;
- The bedrock erosional feature;
- The Upper Crouse Formation; and
- The Lower Crouse Formation.

- **Island Alluvium - Longitudinal Section/Transverse Section**

Figures 5-1 and 5-2 illustrate the collected groundwater elevation data for selected Island wells along two transects. Figure 5-1 presents wells along an east-west trending line running longitudinally along the length of the island. Figure 5-2 presents groundwater elevation data from a series of wells which cross the island transversely from the foot of the upland to the edge of the Kansas River.

The results of these data evaluations confirm that the Island wells, installed in alluvial deposits, react rapidly to changes in the river elevations. In addition, the correlation between river elevations and those measured in the Island monitoring wells is, in most cases, consistent. Both sets of water elevation data correlate well with the records of precipitation with corresponding rises in the Kansas River and the Island groundwater levels evident throughout the period for which precipitation data have been secured.

- **Bedrock Erosional Feature**

The groundwater elevations measured in the unconsolidated sediments in the bedrock erosional feature (Figure 5-3) display a response to and a good correlation with low water stages in the Kansas River and also to elevated river stages particularly those above 1045 feet amsl. The high river water, recorded by the USGS during May and June of 1995 and again during May and June of 1996, are generally reflected in the measured groundwater levels. Two exceptions to this were noted during preparation of Figure 5-3. During the May and June 1996 high water event in the Kansas River, the reported groundwater elevations in DCF93-13 and DCF94-21, the most downgradient monitoring wells in the bedrock erosional feature, showed what appeared to be a reversal, with a downward trend during elevated river levels. Conversely, groundwater levels in wells DCF92-03 and DCF92-05, the upgradient wells in the bedrock erosional feature, displayed the expected elevated response to the high river stage and increased precipitation. It has been reasoned that the groundwater elevation data, reported for monitoring wells DCF93-13 and DCF94-21 for this period are in error. These data are not included in the hydrograph, however, they are presented in the groundwater data table (Table 4-1) as rejected based on the protocol for groundwater elevation data validation.

The second apparent exception to the general response of the erosional feature wells (DCF92-03, DCF92-05, DCF93-13, and DCF94-21) to higher river stages and probable increased precipitation occurred during the Kansas River floods in mid 1993. At this time the Kansas River elevations rose above 1050 feet amsl in May 1993 and above 1063 feet amsl during July 1993. Two wells had been installed within the bedrock erosional feature prior to this flood event, DCF92-03 and DCF92-05, however, an increase in groundwater levels was not recorded in either well. The groundwater elevation gauging event subsequent to the flood event in July 1993 was in November 1993 and so response which may have occurred was not observed. The records of groundwater elevations in DCF93-13 and DCF94-21, installed after the 1993 flood, appear to show a gradual decline in groundwater elevations, presumably due to the return of the river to seasonal elevations. This would tend to support further the presumption that some effect of the flood at DCF92-03 and DCF92-05 occurred but was not recorded.

- **Upper Crouse Formation**

Generally, wells completed in the Upper Crouse Formation show a response to influences from the Kansas River which varies directly with increasing distance from the river (Figure 5-4). Monitoring wells DCF92-01 and DCF92-02, the furthest upland of the Upper Crouse wells included in the hydrograph, show the least response to river stage changes. Exceptions to this are the May and June 1995 and May and June 1996 high river water stages and periods with increased precipitation. The remaining three Upper Crouse Formation wells depicted on Figure 5-4, DCF92-04, DCF92-08 and DCF93-12, are located nearer to the Kansas River and consequently show a greater response to changes in the river water elevations. The mid 1993 flood, again is not reflected in the groundwater elevations recorded at the three wells installed prior to this event. The groundwater elevations in DCF92-01, DCF92-02 and DCF92-04 show a gradual increase across the plot of the Kansas River flood and subsequently show a gradual decline instead of the rapid rise and fall of elevations seen during the subsequent lower magnitude high water stages in the river. The possible reasons and contradictions for this apparently anomalous behavior in DCF92-01, DCF92-02 and DCF92-04 are the same as those discussed in the previous section on the bedrock erosional feature.

- **Lower Crouse Formation**

Figure 5-5 illustrates the relationships between the measured groundwater elevations in monitoring wells DCF93-19 and DCF93-20 and the Kansas River elevations and precipitation records. Generally, the groundwater elevations in these wells, installed in the Lower Crouse Formation, show a good response to and correlation with changes in the river stages and increases and decreases in precipitation. Isolated measurements made during June and November of 1996 appear to create anomalously high and low readings respectively. These measurements do not however, alter the overall trend of the groundwater elevations which are very similar to the elevation trends seen in the Kansas River data.

5.2 Groundwater Contaminant Evaluation

The contaminants of concern at the DCF Study Area are limited to PCE, TCE, 1,2-DCE (total) and vinyl chloride. PCE is used as the primary dry cleaning agent and the remaining compounds are the natural biological degradation products derived from sequential dehalogenation. The overall trend in the collected data is toward decreasing concentrations of PCE. This can be readily observed on contaminant isopleth plots (CENWK, 1996a, 1996c, 1996d, 1996e, and 1997a) with the highest concentrations reported from the primary area of concern centered near the east side of Buildings 180 and 181 to steadily decreasing concentrations as the contaminants move toward the south and the Kansas River. The plots also document the trend of increasing numbers and concentrations of degradation products with a corresponding decrease in PCE. Due to an almost persistent lack of water in some of the site monitoring wells, and two abbreviated sampling periods, not all of the site wells were used in this evaluation. The wells which were suitable however provide a picture of the contaminant trends across the DCF Study Area.

The groundwater contaminants, as reported in the DSR documents, generally can be grouped into four identifiable areas at the DCF Study Area which can be discussed individually and when taken together present a clearer picture of conditions at the DCF Study Area. These areas are as follows:

- Background/outside contaminant mass limits;
- Bedrock Erosional Feature/leaky sewer line area;
- Building 180/181 area; and
- The Island/alluvial deposit area.

These areas are based on contaminant characteristics, facility structures and/or the localized physiography. The background area is based on the contaminant limits and an upgradient location. The bedrock erosional feature area is based on the contaminant characteristics within the bedrock trough and the impacts from facility operations discharging to the sewer line previously located at the valley head within the DCFA. The Building 180/181 area is based on contaminant characteristics and reported previous discharge practices in the former location of the dry cleaning facility. The Island / alluvial deposit area is based on the contaminant characteristics, the groundwater flow regime and the overall physiography of the Island.

5.2.1 Background/Outside Contaminant Mass Limits

The limit of the groundwater contaminants has been defined by the absence of detections in wells and the hydraulic boundary represented by the Kansas River at the downgradient end. The upgradient limit is monitored in well DCF92-06. This well is located in a grassed area adjacent to Custer Road southeast of Building 183 (92-06). One additional well DCF92-01, located upgradient of DCF92-06 provided additional documentation that the upgradient limit of the mass of contaminants had been defined. The eastern edge of the contaminant mass is defined by analytical results from wells DCF93-14 and DCF96-34 respectively located east of Buildings 180 and 181 and southeast of the DCFA on the Island. The northwestern edge of the contaminant mass is defined by wells DCF93-17 and DCF93-18 located adjacent to the western side of the buffalo corral and on the southwestern edge by well DCF96-35 located on the Island at the western-most limit of the investigation area. Currently, the Kansas River defines the overall southern boundary of the contaminants. This is confirmed by well DCF96-36 located south of the DCF on the opposite side of the Kansas River.

Plots of contaminant concentrations over the duration of sampling and analysis at DCF92-06 (upgradient well) and DCF96-34 (downgradient well) are portrayed on Figure 4-3. The results of sampling and analysis indicate that none of the wells in the outer limits of the contaminant mass had concentrations of the contaminants detected above their respective MCLs. PCE was detected in monitoring well DCF92-06 and the concentrations ranged from 1.2 μg/l to 1.5 μg/l, well below the 5 μg/l MCL. In addition, PCE was detected during one round of sampling in monitoring well DCF92-01 at a reported concentration of 1.2 μg/l. 1,2-DCE was detected in monitoring well DCF96-34 at a reported concentration of 1.8 μg/l well below its MCL of 70 μg/l. PCE, TCE, 1,2-DCE and vinyl chloride were not detected during any of the sampling and analysis episodes in wells DCF93-14, DCF93-17, DCF93-18, DCF96-35 and DCF96-36. Based on the foregoing, these wells define the limits of the area impacted by discharges from the DCF.

5.2.2 Bedrock Erosional Feature/Leaky Sewer Line Area

The area immediately to the north and east of Buildings 180/181 is considered here as a separate area with a localized hydrogeologic regime and discharge impacts from formerly leaking sections of sewer line. The wells included in this area are DCF92-03, DCF92-05, DCF93-21 and DCF93-13 which generally follow the line of the bedrock erosional feature in the order presented. Well DCF92-02 is located a short distance north and west of the bedrock erosional feature (Figure 4-4).

Based on the historical records review and personnel interviews documented in the RI report (CENWK, 1995), previous practices for disposal of spent or spilled drycleaning fluids included discharge to the storm sewer system via floor drains in Building 183. The floor drains were sealed and subsequent disposal or spill cleanup contaminants was to the sanitary sewer line via sink drains or laundry equipment drains. There were unconfirmed reports of accidental spills of dry cleaning fluids in Building 183, which were reportedly soaked up with blankets, mattresses and other such articles that were then washed. The resulting wash water was thus discharged to the sanitary sewer line. It was ultimately determined that the sanitary sewer line which services Buildings 183, 181 and 180 was leaking from a section between Buildings 183 and 180. It is therefore assumed that the spent cleaning fluid was able to migrate to the bedrock surface and into the sediments within the bedrock erosional feature where it is now being detected in the previously referenced monitoring wells. The leaky sewer line has since been repaired and was subsequently rerouted to the east of the bedrock erosional feature presumably removing or greatly reducing any ongoing discharges, hydraulic driving force, and impacts to the underlying and downgradient soils.

PCE was detected at its highest concentrations in DCF92-03 which is located immediately downgradient from the former leaking section of sewer line. The concentrations at this well ranged from highs of 1,600 μg/l, 820 μg/l and 410 μg/l documented on November, December, and May of 1993 to lows of 31 μg/l and 43 μg/l on May and October of 1996 respectively. Very low concentrations of TCE and DCE, the degradation products, were also detected during sampling and analysis of this well.

The next downgradient well, DCF92-05, was found to have elevated levels of PCE during approximately the same period as DCF92-02. The levels however, are generally lower than those documented in DCF92-03 and the peak concentration of 710 μg/l in DCF92-05 is one month later than the peak seen in DCF92-03 in November 1993. TCE and DCE were also detected in this well at much higher concentrations than those reported from DCF92-03. The maximum concentrations of TCE and DCE reported from analysis of samples from DCF92-05 were 33 μg/l and 69 μg/l respectively as compared with the maximum reported values from DCF92-03 which were 3.9 μg/l and 13 μg/l for the same compounds.

DCF93-13, the farthest downgradient well in the bedrock erosional feature, showed the lowest concentrations of PCE with values ranging from 420 μg/l in December 1993 and August 1994 to 130 μg/l in May 1996 and February 1997. These are the lowest values for PCE seen in samples collected from the bedrock erosional feature wells. In addition, it appears reasonable to assume that the 420 μg/l of PCE reported during the August 1994 sampling and analysis of DCF93-13, documents the arrival of the contaminant peak seen in DCF92-03 in November 1993 and subsequently in DCF92-05 in December. The reported contaminant levels for TCE and DCE appear to verify the continued degradation of PCE with time and migration through the bedrock erosional feature. DCE was reported at 31 μg/l in August 1994 and TCE was reported at 200 μg/l during the same sampling period.

A review of the plots (Figure 4-4) for this group of wells will show that there are additional examples of what are assumed to have been discharges from the sanitary sewer, although not at the levels seen in the previously discussed periods. The sample analyses confirm that the PCE levels decrease with time and distance traveled through the bedrock erosional feature and, at the same time, concentrations of the degradation products increase with time and distance traveled from the assumed sewer line release point. This supports the contention that natural attenuation is proceeding in this area and that, with elimination of the sewer leaks/discharges, these contaminants should continue to degrade.

5.2.3 Building 180/181 Area

According to the historical review, performed during the RI phase of work at the DCFA, the previous drycleaning facility was located in these buildings. Purportedly, disposal practices for spent fluids included direct discharge to the ground in the area directly behind these buildings (CENWK, 1995) (Figure 4-5). Consequently, any contaminants found to exist in this area should be older than any associated with the current operation in Building 183 and should display distinct characteristics from other areas.

The groundwater analytical results for samples collected from monitoring wells DCF92-04, DCF93-08 and DCF93-19, located in the subject area behind these buildings, appear to substantiate this proposition. Characteristically, the analytical results show high levels of DCE and vinyl chloride relative to the levels reported for PCE and TCE. (DCE and vinyl chloride are among the final degradation products produced by microbial metabolism of PCE indicating that the original PCE discharged in this area is from an older spill.) This assemblage of compounds is not reflected in groundwater samples from other areas within the

DCFA where contaminant releases related to the formerly leaking sewer line are believed to be more recent then those that reportedly occurred at the northwest corner of Building 180/181.

The levels of contaminants appear to vary widely over the duration of observation due to a variety of groundwater flow regimes affected by the Kansas River as detailed in Section 3.3. A review of high river levels however, does provide a plausible means for creating the variable levels documented in the analyses.

The peaks in the concentrations of DCE and vinyl chloride generally correspond to documented high water levels in the Kansas River. Flood stages in the Kansas River have generally been found to raise water levels in site monitoring wells especially those at the southern edge of the site, reflecting a rise in the shallow groundwater table. This will provide water to the typically unsaturated zone which, in turn, will most likely mobilize residual contaminants in the vadose zone into the groundwater regime where they can be detected during monitoring and sampling within the area of concern adjacent to the river valley.

The high contaminant concentrations commencing in May of 1993, as seen in the sample analyses for well DCF92-04, were probably the result of the 1993 flood which started early in the year and peaked in August. It is believed that the high groundwater levels caused flushing of residual contamination from the material above the water table. Vinyl chloride and DCE concentrations were at their peak in December of 1993. These peaks are reflected in the initial sampling events at wells DCF93-08 and DCF93-19, both installed in December of 1993. Subsequent peaks were noted in monitoring well DCF93-08 which correspond to the flooding documented in late May and early June of 1995.

The general trend for all three of these wells, disregarding the flood-triggered peaks, is downward. The highest concentrations were detected late in 1993 and in subsequent sampling. This is especially notable at monitoring well DCF93-19 where the contaminant concentrations are decreasing and in most cases are now within the MCL for each constituent.

5.2.4 The Island/Alluvial Deposit Area

A total of nine wells, including DCF93-09 through DCF93-11, DCF94-22, and DCF96-23 through DCF96-27, are located in what is considered the Island/alluvial deposit area. Generally, these wells continue to illustrate the overall pattern consistent with migration toward the river, decreasing contaminant concentrations, and degradation of PCE to TCE, DCE, and vinyl chloride at concentrations below the parent compound. The well locations and plots along a representative section through the alluvium displaying this trend are illustrated on Figure 4-6.

The plots illustrate the concentrations of PCE and its degradation products in monitoring wells DCF93-09, DCF94-22 and DCF96-24. The longest continuous sampling history is associated with well DCF93-09 where a steady decline in PCE concentrations has been documented since the inception of sampling at this well in December 1993. TCE, DCE, and vinyl chloride have also been following the trend of decreasing concentrations with time. The plot of DCF94-22 shows that since July of 1994, when the well was first sampled, only PCE and DCE have been detected and of these the degradation product DCE has been detected consistently at a higher concentration than PCE. The last well in the section, DCF96-24, was first sampled during the May 1996 period. Although the sampling history at this well is too short to document a contaminant trend, all three sampling episodes have shown that DCE concentrations are higher than PCE. In addition, during the October 1996 sampling event, TCE was found to be slightly higher in concentration than PCE.

Other wells not included in the section across the Island also appear to follow this pattern of overall decreasing contaminant concentrations, with degradation products rising in concentration while concentrations of PCE (the parent product) are decreasing. These wells include DCF93-10, DCF93-11, and DCF96-27.

The three remaining wells, DCF96-23, DCF96-25, and DCF96-26, show a reversed pattern to the other Island/alluvial area wells. It should be noted here that the same comment regarding extrapolation of trends after only three sampling episodes in well DCF96-24, also applies to these three wells. The reversed trend is significant enough, however, to warrant discussion here. DCF96-23 has been shown to have increasing levels of PCE over the three sampling periods. The concentrations have been reported at 17 μg/l in May of 1996, 79 μg/l in October of 1996 and 100 μg/l in February 1997. During the same periods low concentrations of TCE and DCE were reported in the samples from this well. The sampling results from DCF96-25 were very similar to those of DCF96-23. PCE was reported during the same periods at concentrations of 81 μg/l, 91 μg/l, and 98 μg/l and TCE and DCE were reported at equivalently low levels. The last of these wells is DCF96-26. In this well, PCE was reported at similar concentrations of 47 μg/l, 66 μg/l and 77 μg/l over the three sampling events. TCE was reported to range from 33 μg/l in May 1996 to 82 μg/l and 79 μg/l in October of 1996 and February of 1997, which is substantially higher than the previous two wells. DCE was also higher in well DCF96-26 than the preceding two wells with concentrations ranging from 14 μg/l during May and October of 1996 to 23.6 μg/l in February of 1997.

These three wells are not necessarily monitoring the same contaminant pathways as the remainder of the wells. A possible explanation is that DCF96-25 is directly downgradient from a documented sewer overflow point at manhole 366, southeast of the Building 183 steam plant. It was reported that, due to a probable blockage in the line, sanitary effluent periodically overflowed from the manhole and flowed westward along Custer Road directly upgradient from well DCF96-25. It would be expected that the time of transport for the contaminants would be short considering the close proximity of the low lying area to well DCF96-25, and therefore, there would be little degradation of the PCE to any of the daughter products.

DCF96-23 and DCF96-26 are located adjacent to the Kansas River on the southern limit of the Island and exhibit higher contaminant concentrations than the wells upgradient of them at the center of the Island. Two scenarios can explain the contaminant concentrations seen in these two wells.

Typical groundwater flow in the area of a large river, such as the Kansas River, is from the upland side of the valley toward the river, with eventual discharge to the river. The vertically downward flow component of shallow groundwater occurs at the upland side, and discharge will be vertically upward below the river elevation (Figure 3-4). Typical of river valleys, the vertical flow of shallow groundwater likely consists of a predominantly downward flow component near the upland side of the Island, causing contaminants to flow beneath DCF93-11, DCF94-22, and DCF96-27 and thus not be detected in these wells. Then the deeper, contaminated groundwater turns upward as it nears the Kansas River such that contaminants are again detected in wells such as DCF96-23. Therefore, it is assumed that in this scenario, samples from DCF96-23 and DCF96-26 are representative of groundwater which has been able to flow beneath DCF93-11, DCF94-22, and DCF96-27 that are shallower and are closer to the upland.

The second scenario assumes that the Island sediments are not homogeneous and that the Kansas River has, during the course of its existence, occupied numerous channels, some of which may be preserved under the island as preferential pathways. Groundwater is flowing from the upland approximately perpendicular to the Kansas River and typically, in groundwater regimes such as this, once groundwater reaches the alluvial deposits it will begin to deflect and flow in a downstream direction following fluvial sedimentary structures such as old channels, bars, cutoff meanders and the like. In this scenario, it is assumed that the contaminants observed in DCF96-25 continue to flow, past the monitoring well, and continue to move towards the river channel with a downstream deflection which may carry them to monitoring wells DCF96-23 and DCF96-26.

It is important to note, however, that the results of these three wells do not alter the initial assessment that contaminants are moving from the upland toward the river. In addition, although seen at low levels in these three wells, PCE is continuing to degrade to its daughter products similar to the degradation seen elsewhere at the DCF Study Area.

5.3 Evidence of and Potential for Natural Attenuation

Natural attenuation is typically defined as a reduction in the mass and/or concentration of a compound in groundwater over time or distance from the source of contamination due to naturally occurring physical, chemical and biological processes. The following are the specific processes that are likely to contribute to the attenuation of contaminants within the DCF Study Area:

1) Dilution in groundwater (by recharge from precipitation or surface water bodies);
2) Hydrodynamic Dispersion (i.e., the combination of dispersion and diffusion);
3) Volatilization;
4) Adsorption to soil particles;
5) Chemical transformation of contaminants; and,
6) Biological degradation of contaminants.

Processes one through four are non-destructive physical processes and, although they do not reduce the total contaminant mass, they can effectively lower the contaminant concentration at a given point and thus can effectively reduce the human health and ecological risks associated with contamination. In contrast, processes five and six are destructive processes that can reduce both the total contaminant mass (through destructive reactions) and the contaminant concentration.

Presented in the following sections are: a discussion and evaluation of the above natural processes that often contribute to the attenuation of the primary contaminant PCE and its daughter products TCE, DCE, and vinyl chloride at the DCF Study Area; evidence of the natural biodegradation of PCE occurring within the DCF Study Area; and, a specific discussion of the so-called "first line of evidence of natural attenuation" for the DCF Study Area (i.e., PCE concentration reduction over time and along the groundwater pathway) (AFCEE Protocol, included as Appendix C).

5.3.1 Physical and Chemical Processes

5.3.1.1 Dilution

Recharge to the groundwater due to infiltration of precipitation or from nearby surface waters such as rivers and streams introduces additional water into the groundwater system and thus will result in the dilution of any dissolved chemical which exists, effectively reducing its concentration by spreading its existing mass over a greater mass of groundwater. For the DCF Study Area, both precipitation infiltration and recharge from area surface water (primarily the Kansas River but also to a lesser extent from Tributaries A and B) can and does frequently occur. Recharge from the Kansas River specifically occurs when the water stage in the river is higher than the groundwater elevations, such as during flooding events or when large amounts of water are released from the upstream dam.

5.3.1.2 Hydrodynamic Dispersion

Hydrodynamic dispersion includes a combination of mechanical dispersion and molecular diffusion processes. These processes are usually combined for modeling and evaluation purposes because they are difficult to separate in nature. Mechanical dispersion is caused by interactions between advective movement of the chemical and the porous structure of soil and the tortuous flow path for groundwater moving in that soil. The results of mechanical dispersion are the longitudinal and transverse spreading of the contaminant plume as it migrates. Molecular diffusion is the molecular movement of a chemical in response to concentration gradients. Under normal groundwater flow systems (i.e., other than no flow or very low flow conditions) such as at the DCF Study Area, mechanical dispersion is the dominant mechanism causing the spreading and mixing of contaminants in groundwater, and thus the reduction of the contaminant concentration in the plume. Molecular diffusion is typically negligible in comparison.

It is also noted that, in addition to the concentration-reducing effect of plume spreading and mixing, dispersion can also facilitate biodegradation by introducing more electron acceptors and/or donors from the aquifer materials.

5.3.1.3 Volatilization

For a groundwater system, the volatilization process usually contains two steps: 1) the chemical from the impacted soil and/or groundwater volatilizes into the soil gas, i.e., the void space in the soil pores; and, 2) the volatilized chemical in the gas phase then moves into the atmosphere above the soil surface. As a result, volatilization can cause a mass loss of any VOCs such as PCE from the subsurface to the air.

The rate of mass loss due to volatilization is a function of chemical properties such as Henry's law constant for the chemical and the site-specific conditions, including climate, depth to groundwater and soil types. For the Island, volatilization is considered relatively insignificant due to the depth to groundwater, which is often more than 15 feet. Volatization would be significant, however, as the groundwater leaves the Island and discharges to the Kansas River. This is especially true for chlorinated solvents such as PCE, due to their high volatility.

5.3.1.4 Adsorption

Adsorption is a reversible mass transfer process during which a chemical moves from water and/or gas to soil particles and organic matter within the soil matrix. Chlorinated solvents such as PCE are non-polar organic chemicals and have a strong affinity for soil organic matter. As a result, a significant portion of contaminant mass can move out from the dissolved phase and into the surrounding soil matrix, associating with the organic matter in the soil. Thus, adsorption can lead to a significant concentration reduction in the dissolved contaminant plume. The effects of adsorption on contaminant fate and transport is often described by the retardation coefficient (R). The migration rate of the contaminant plume (i.e., the actual velocity of contaminant plume movement) is determined by both the groundwater flow velocity and the retardation coefficient. The retardation coefficient for PCE on the Island is estimated to be between 13 and 40. That is to say, the contaminant plume will migrate 13 to 40 times slower than the groundwater. It is noted that the assumed retardation coefficient for PCE is a general estimate and not the result of specific testing or rigorous modeling.

It is also noted that, in addition to the retardation effect, the adsorption process can also influence the relative importance of other processes. For example, the rates of the biodegradation of many chemicals are directly dependent upon the extent of adsorption.

5.3.1.5 Chemical Transformation

Chemical (abiotic) transformation of chlorinated solvents can also occur in the natural environment. For chlorinated solvents, the abiotic processes most frequently occurring in natural systems include hydrolysis and dehydrohalogenation (Norris et al., 1993). However, abiotic transformation generally results in only a partial transformation of a compound and abiotic processes for chlorinated solvents are generally very slow in the absence of catalysts such as iron. Therefore, it is likely that chemical transformation as a attenuation mechanism at the DCF Study Area is insignificant, when compared to other processes.

5.3.2 Evidence of Biological Degradation at the DCF Study Area

5.3.2.1 Biodegradation Mechanisms for Chlorinated Solvents

Biodegradation is typically the most important destructive mechanism for natural attenuation; but, it is also the most sensitive and complicated process (particularly for chlorinated solvents). Biodegradation processes for chlorinated aliphatic hydrocarbons such as PCE are fundamentally different from the processes involved in the biodegradation of fuel hydrocarbons. While fuel hydrocarbons are aerobically biodegraded through use as a primary substrate (electron donor), chlorinated aliphatic hydrocarbons may undergo biodegradation through three different pathways: through use as an electron acceptor, through use as an electron donor, or through co-metabolism where the degradation is catalyzed by an enzyme or cofactor. At a given site, one or all of these processes may be operating to varying degrees with migration distance and time.

Data collected in the last two decades from field or laboratory tests seem to indicate that use of chlorinated aliphatic hydrocarbons as electron acceptors is the most important pathway, particularly for the more highly chlorinated solvents such as PCE. There is no convincing evidence for aerobic transformation of PCE either through use as electron donor (Perry McCarthy, 1993) or through co-metabolisms (AFCEE Protocol, included as Appendix C). However, PCE daughter products such as TCE, DCE and VC (which are all present at the DCF Study Area) may undergo biodegradation through one or any combination of the three pathways. For example, TCE has been shown to be biologically degraded under both aerobic (as electron donor) and anaerobic conditions (as electron acceptor).

5.3.2.2 Evidence of PCE Biodegradation at the DCF Study Area

5.3.2.2.1 Reductive Dehalogenation

Because PCE is in a most oxidized state, PCE biological transformation is primarily through reductive dehalogenation (AFCEE Protocol, included as Appendix C). During this process, PCE is used as an electron acceptor and is biodegraded through a sequential dechlorination from PCE to TCE to DCE (***primarily cis-DCE, as opposed to trans-DCE***) to VC to ethylene. Depending on the environmental conditions, this sequence may easily be interrupted at a given time or location. During reductive dechlorination, all three isomers of DCE (i.e., 1,2-trans-DCE, 1,2-cis-DCE, and 1,1-DCE) can be, theoretically speaking, produced. However, it has been observed that under the influence of biodegradation, cis-DCE is the prevalent intermediate isomer. According to the AFCEE protocol (Appendix C), if the amount of cis-DCE is greater than 80% of total DCE, it is likely a daughter product of TCE, which in turn is a daughter product of PCE. As a result, the presence of cis-1,2-DCE as a significant portion of total DCE is very strong evidence that PCE biodegradation is occurring.

Reductive dehalogenation will occur under nitrate-, sulfate-reducing, and particularly, methanogenic conditions (Bouwer, 1994). This is because under anaerobic conditions and in the presence of sufficient organic carbon, microorganisms proliferate and exhaust the electron acceptors following the preferential sequence: oxygen, nitrate, ferric iron, halogenated compounds (PCE, then TCE, then DCE), sulfate, and carbon dioxide. Halogenated compounds such as PCE therefore typically undergo degradation only after the majority of the nitrate and ferric iron have been reduced and the redox potential is in the range where sulfate reduction occurs. The amounts and type(s) of daughter products that form are dependent on the redox potential and the amounts of sulfate and organic carbon present, with biodegradation thus being favored by low redox and sulfate values and high dissolved carbon concentrations.

In light of the above discussion, reductive dechlorination of PCE is believed to be occurring at the DCF Study Area based on the following:

1) PCE daughter products including TCE, DCE (especially cis-DCE), and VC have been detected throughout the DCF Study Area;

2) The prevalent isomer of DCE detected in groundwater is cis-DCE, more than 80% of the total DCE, clearly indicating the biodegradation of TCE;

3) The environmental conditions at the DCF Study Area favor the reduction of PCE through dehalogenation. The reducing/anaerobic condition is clearly indicated by the low redox values (most of them show negative values), reduced and/or low nitrate concentrations, and particularly the generation of methane apparent for wells located in Lower Crouse formation and on the Alluvial Island; and,

4) The awarded biodegradation rating points, as determined by following the rating system presented in the AFCEE protocol (Appendix C), is more than 20 points; very strong evidence for the occurrence of biodegradation of chlorinated organics.

In addition, groundwater temperatures and pH at the DCF Study Area are also in favor of the growth of microbial populations. Optimum temperatures (between 5 ^{0}C and 20 ^{0}C) and pH (5 to 9) for microbial growth exist within the DCF Study Area. Furthermore, the TOC analytical results indicate that there is a substantial amount of native organic matter present in the groundwater as electron donor/supply for reductive dechlorination to continue.

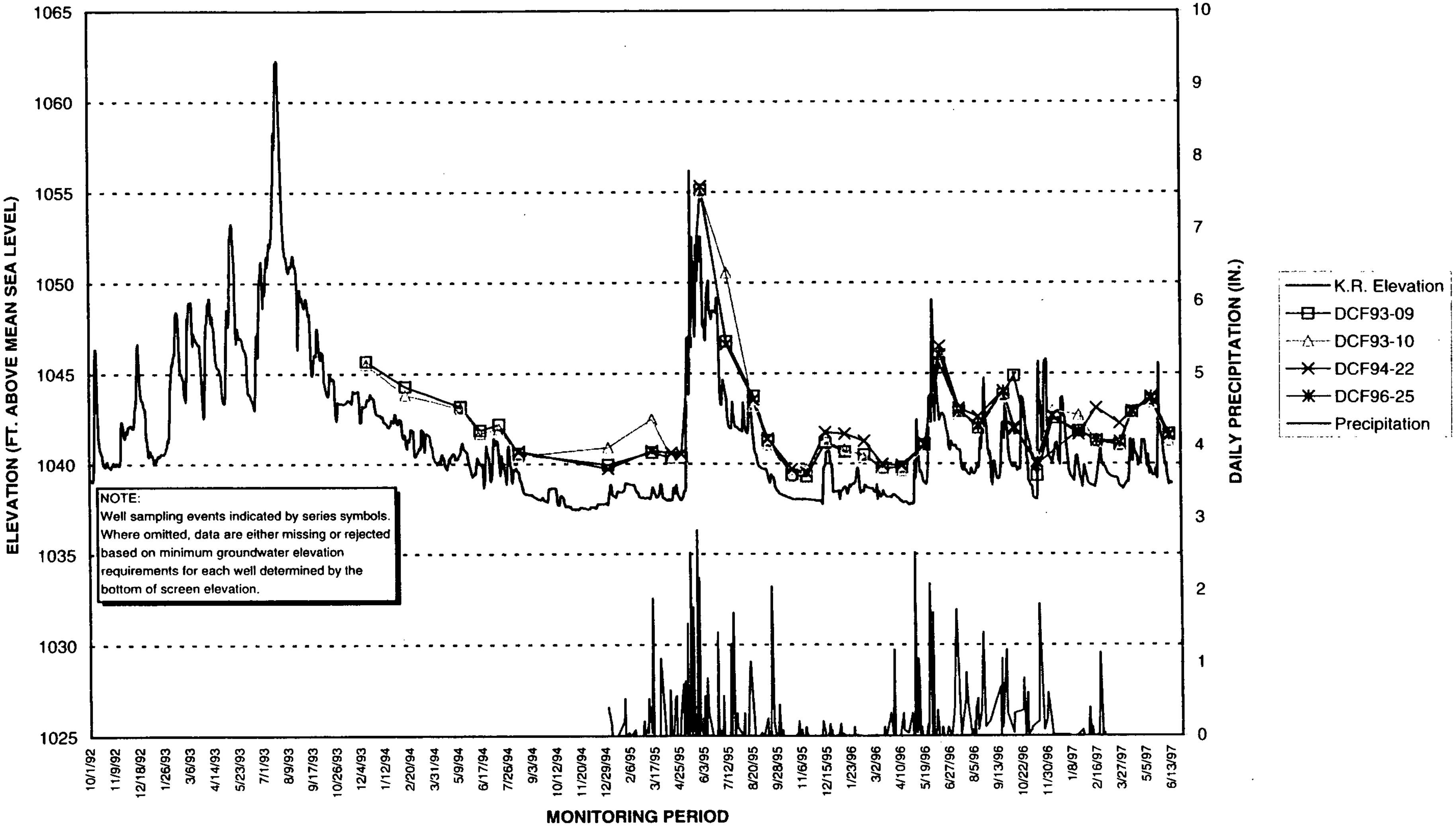
It should also be noted that the presence of other organics (GRO/DRO, methane, etc.) can enhance biological activity under certain conditions, and thus impact the biodegradation component of the natural attenuation process, as has been noted in case studies. However, it is also noted that the presence of elevated levels of DRO/GRO can give a false impression of enhanced chlorinated VOC breakdown in some cases because the DRO/GRO contamination can greatly impact achievable chlorinated VOC detection limits due to analytical interferences.

5.3.3 Evidence of Other (Non-Biological) Natural Attenuation Processes at the DCF Study Area

In addition to the biological evidence presented above, ongoing natural attenuation within the DCF Study Area is further confirmed by the decreasing concentration of PCE over time and with migration distance. The overall decreasing trends for PCE and its daughter products are illustrated in Figure 4-4, 4-5, and 4-6. Examination of PCE spatial distribution also specifically indicates a decreasing trend from the upland source areas to the down gradient alluvial soils at the Island (noting that the slightly rising concentrations detected in the furthest down-gradient wells along the river are suspected to be due to their position ahead of the center of contaminant mass and vertical flow gradients which give the false appearance of decreasing then increasing concentrations as migration proceeds across the Island).

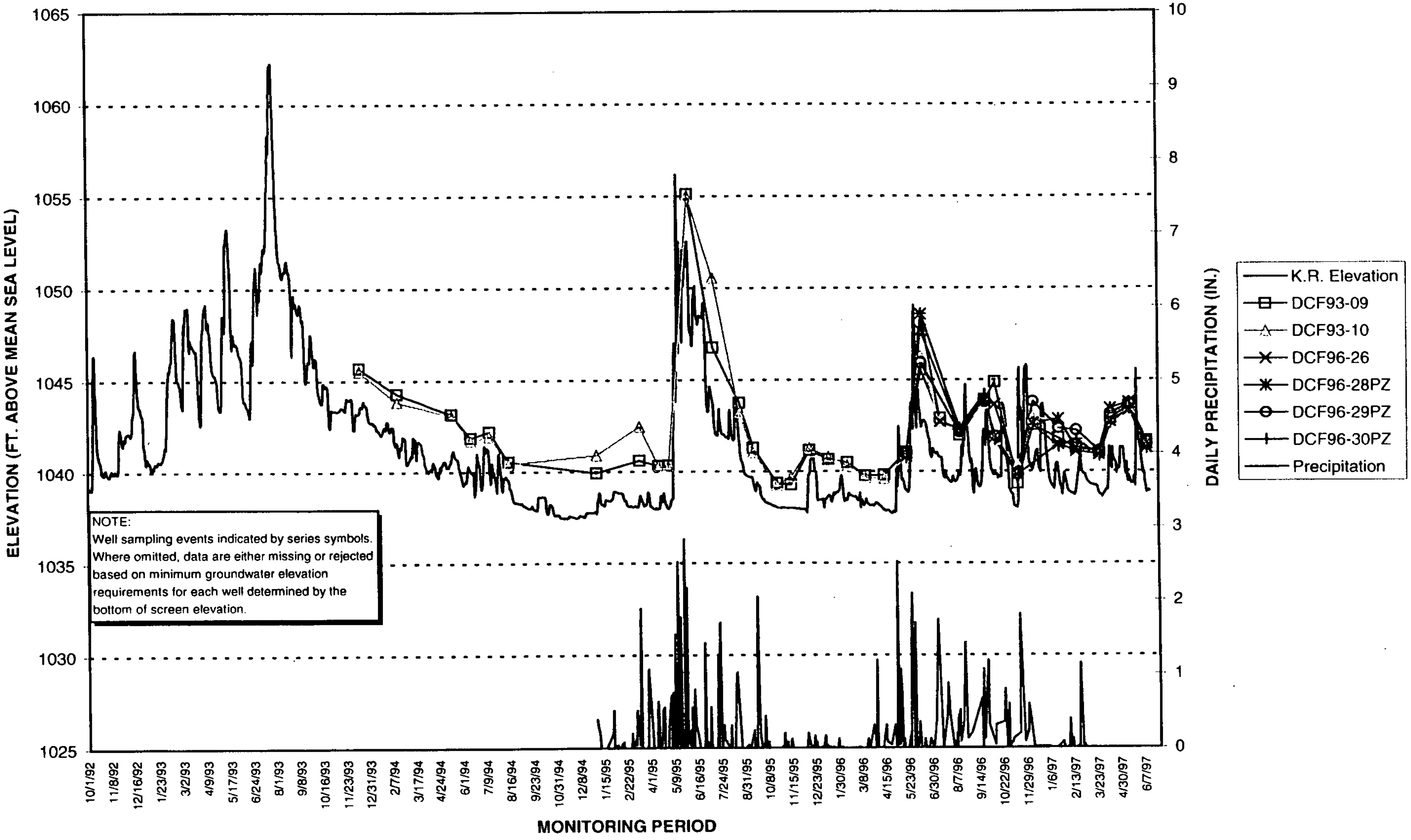
FIGURES

FIGURE 5-1
ISLAND ALLUVIUM WELL DATA (LONGITUDINAL SECTION) AND KANSAS RIVER ELEVATION AND DAILY PRECIPITATION DATA



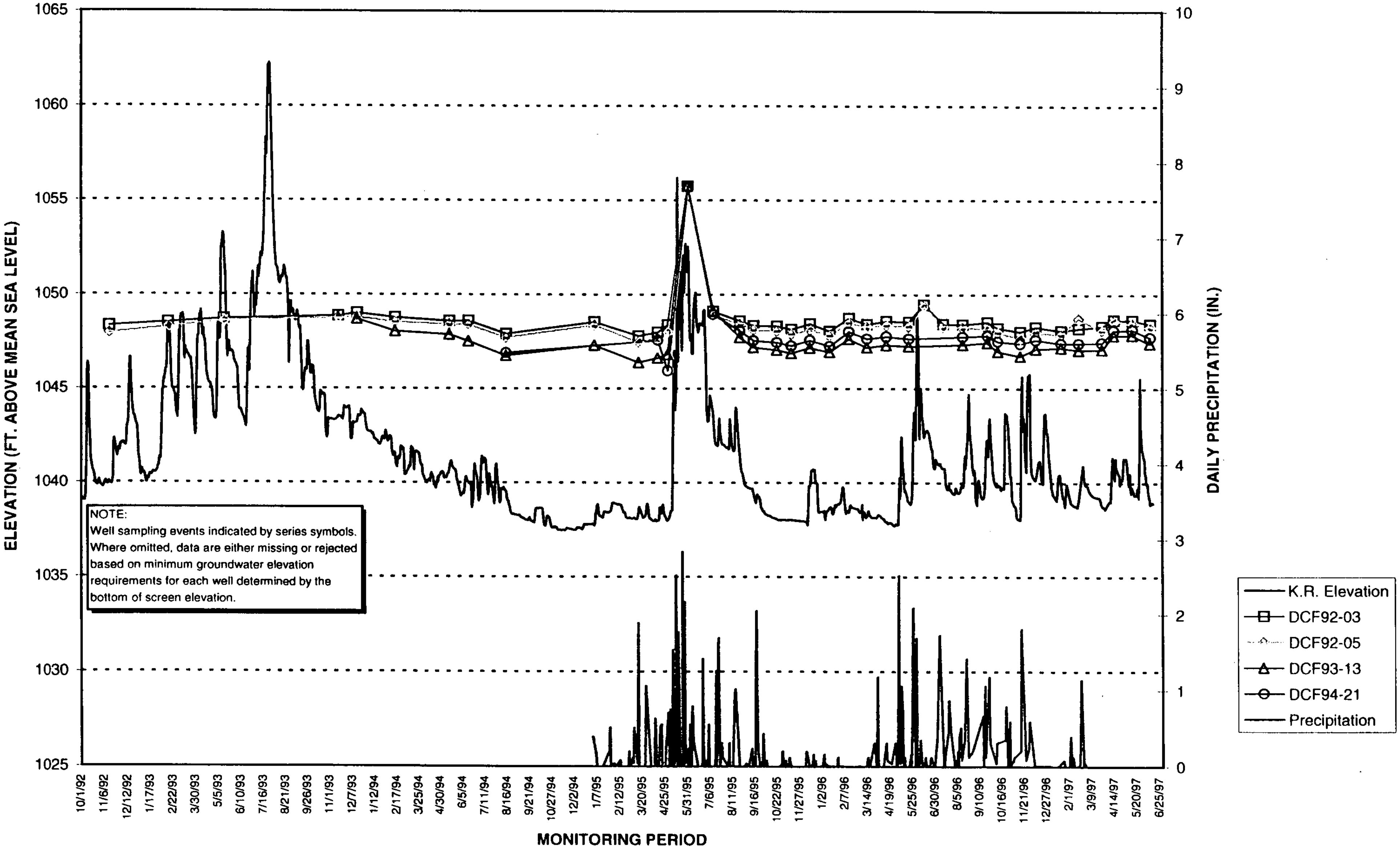
NOTE:
Well sampling events indicated by series symbols. Where omitted, data are either missing or rejected based on minimum groundwater elevation requirements for each well determined by the bottom of screen elevation.

FIGURE 5-2
ISLAND ALLUVIUM WELL DATA (TRANSVERSE SECTION) AND KANSAS RIVER ELEVATION AND DAILY PRECIPITATION DATA



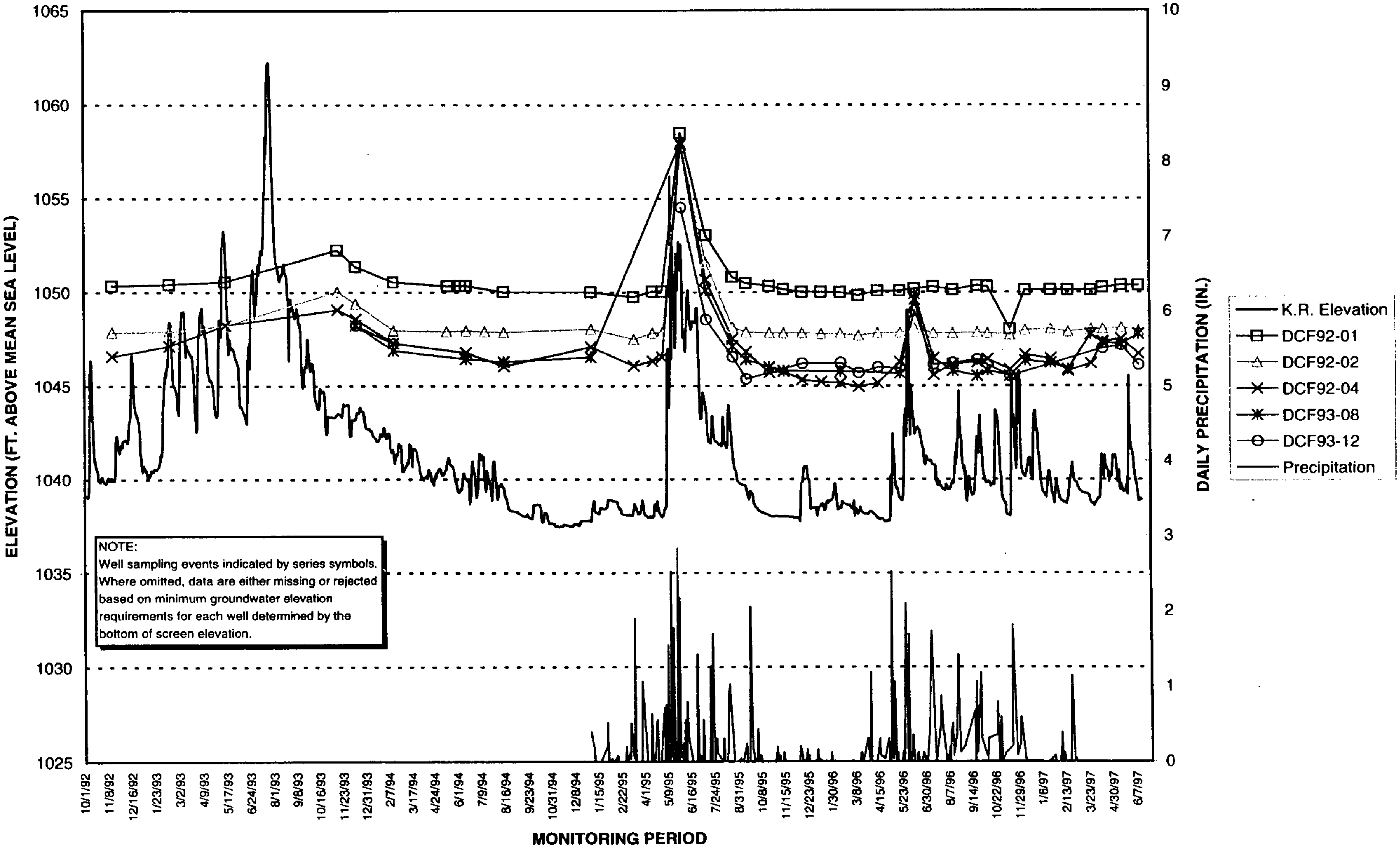
NOTE:
Well sampling events indicated by series symbols. Where omitted, data are either missing or rejected based on minimum groundwater elevation requirements for each well determined by the bottom of screen elevation.

FIGURE 5-3
BEDROCK EROSIONAL FEATURE WELL DATA AND KANSAS RIVER ELEVATION AND DAILY PRECIPITATION DATA



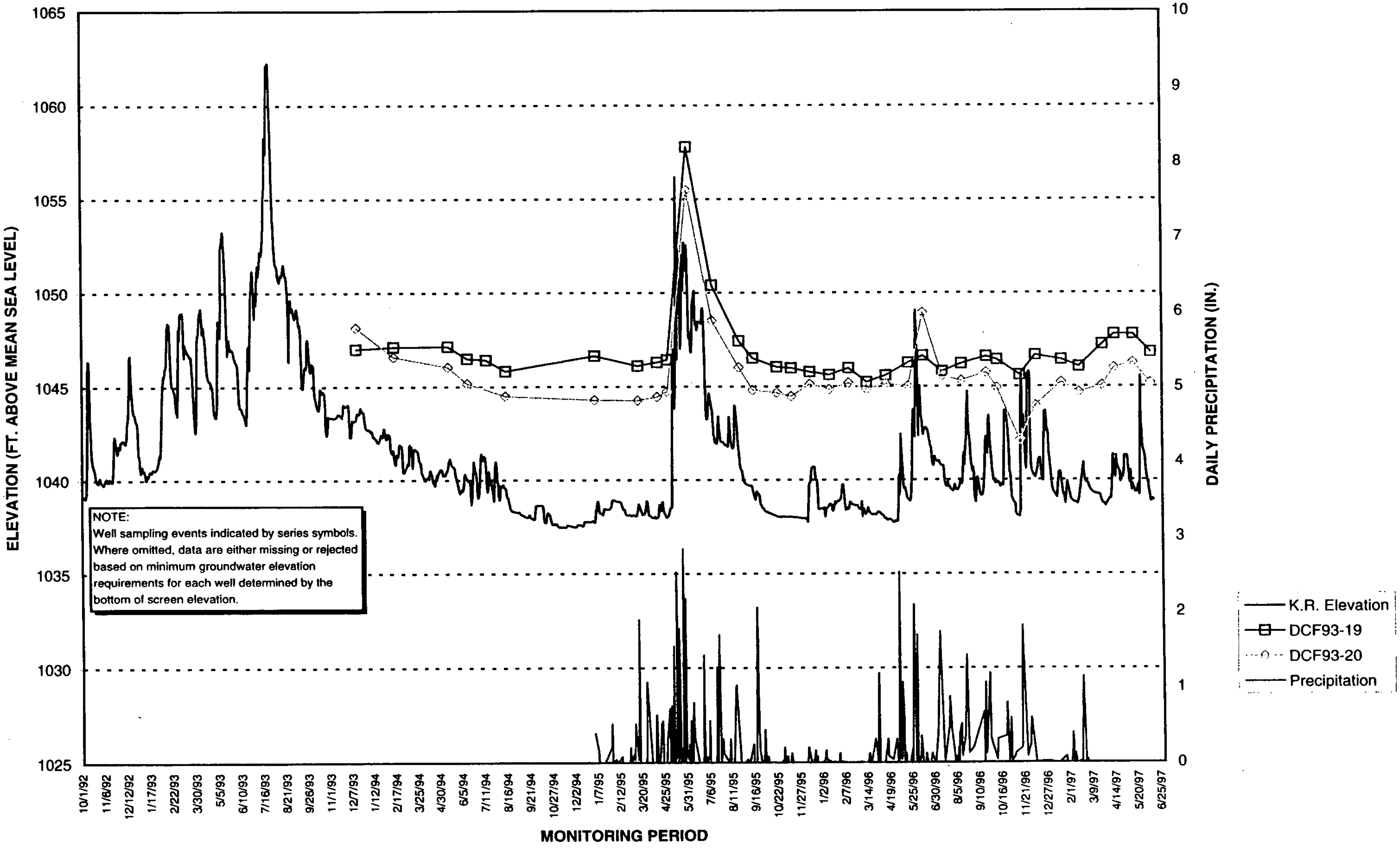
NOTE:
Well sampling events indicated by series symbols. Where omitted, data are either missing or rejected based on minimum groundwater elevation requirements for each well determined by the bottom of screen elevation.

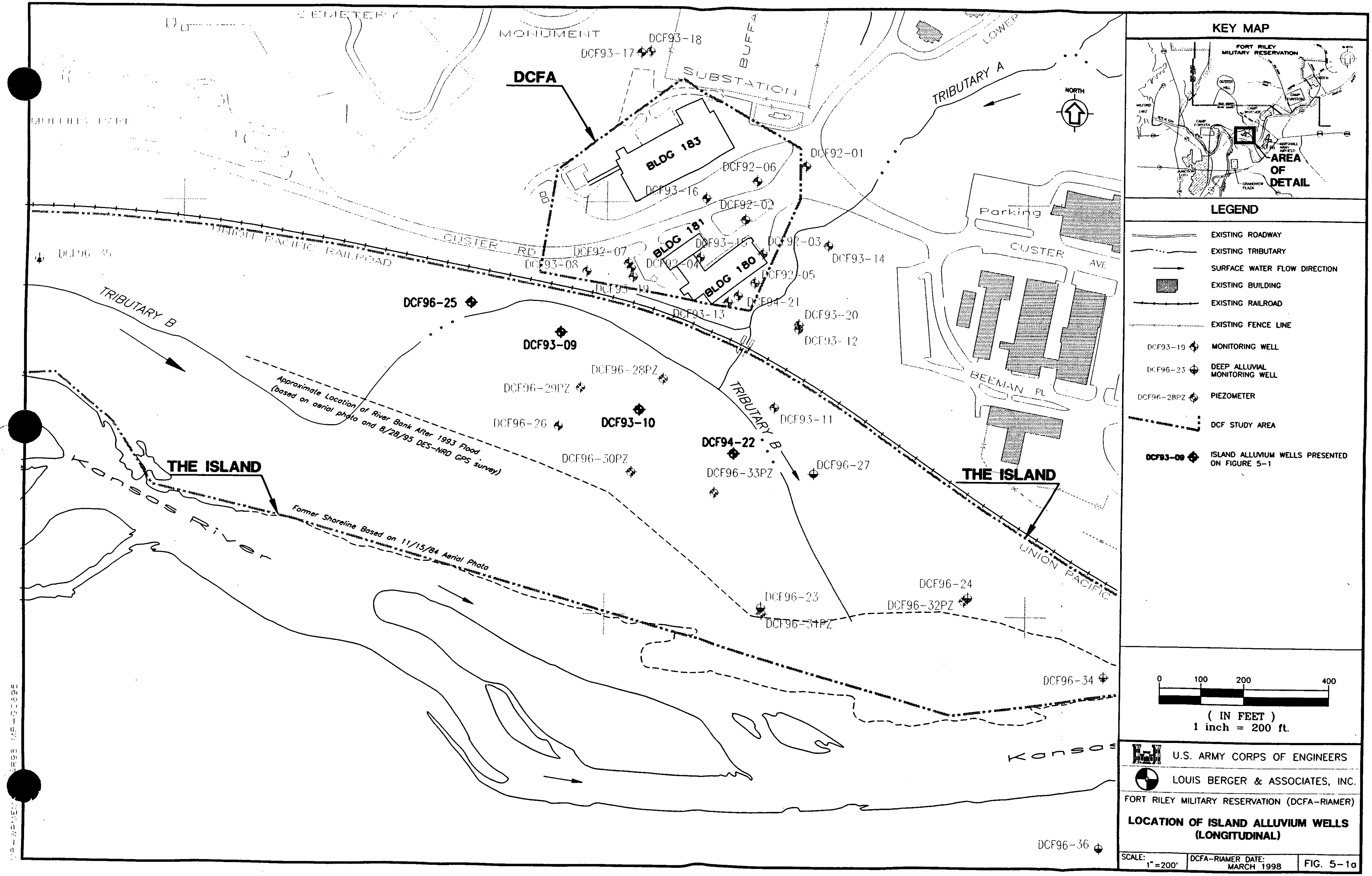
FIGURE 5-4
UPPER CROUSE LIMESTONE WELL DATA AND KANSAS RIVER ELEVATION AND DAILY PRECIPITATION DATA



NOTE:
Well sampling events indicated by series symbols. Where omitted, data are either missing or rejected based on minimum groundwater elevation requirements for each well determined by the bottom of screen elevation.

FIGURE 5-5
LOWER CROUSE LIMESTONE WELL DATA AND KANSAS RIVER ELEVATION AND DAILY PRECIPITATION DATA





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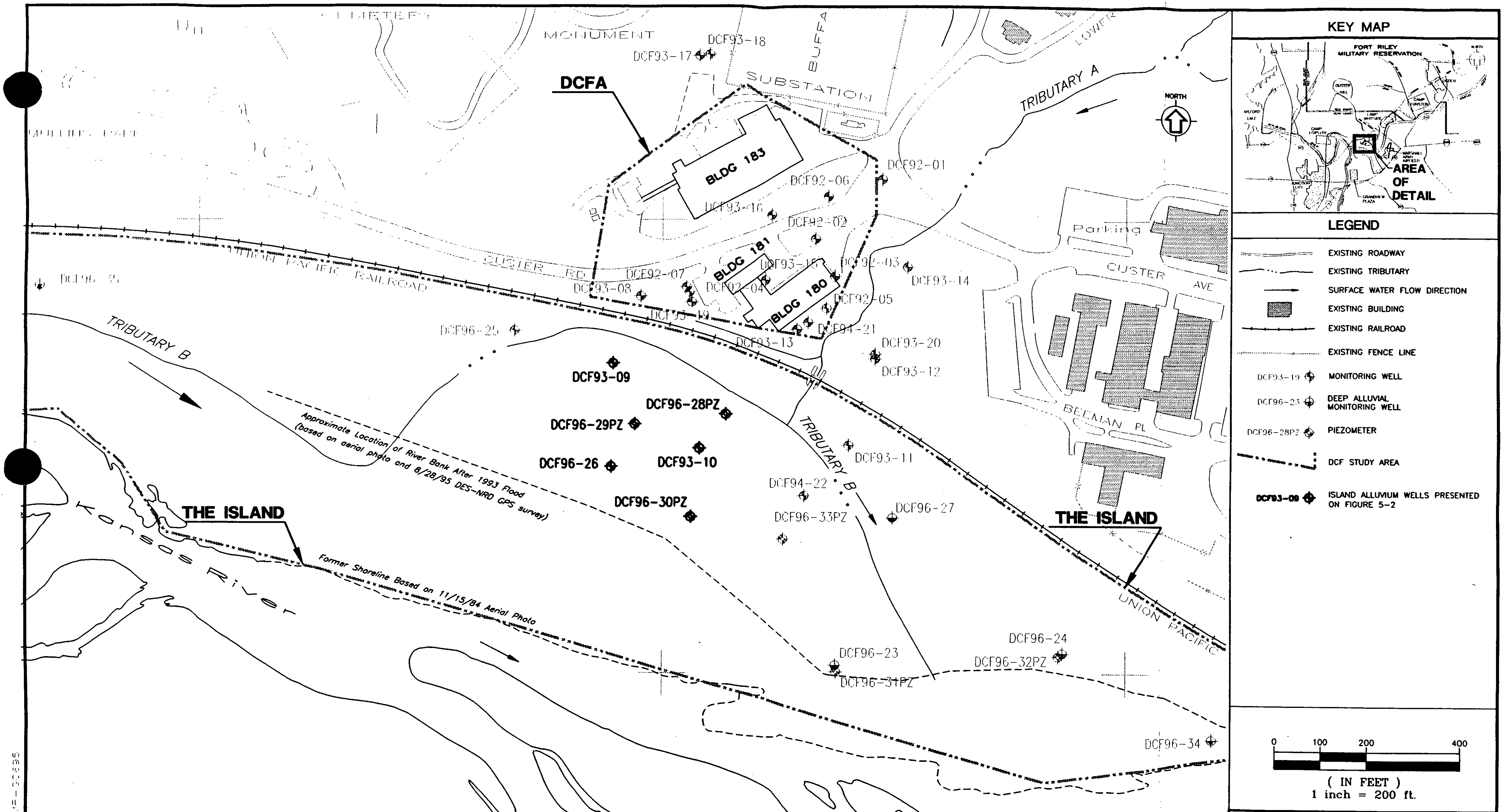
FORT RILEY MILITARY RESERVATION (DCFA-RIAMER)

LOCATION OF ISLAND ALLUVIUM WELLS (LONGITUDINAL)

SCALE: 1"=200'	DCFA-RIAMER DATE: MARCH 1998	FIG. 5-1a



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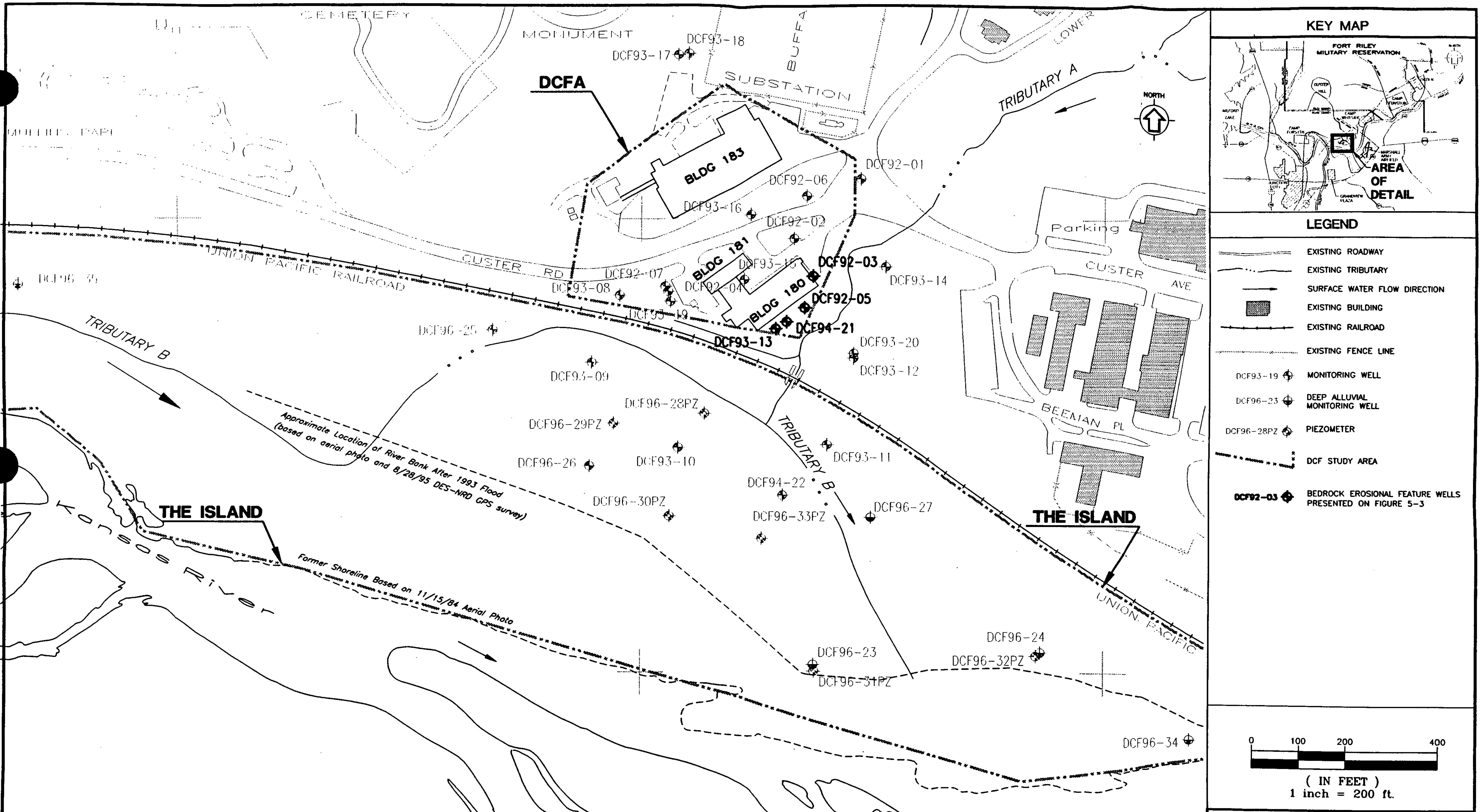
FORT RILEY MILITARY RESERVATION (DCFA-RIAMER)

LOCATION OF ISLAND ALLUVIUM WELLS (TRANSVERSE)

SCALE: 1"=200'	DCFA-RIAMER DATE: MARCH 1998	FIG. 5-2a



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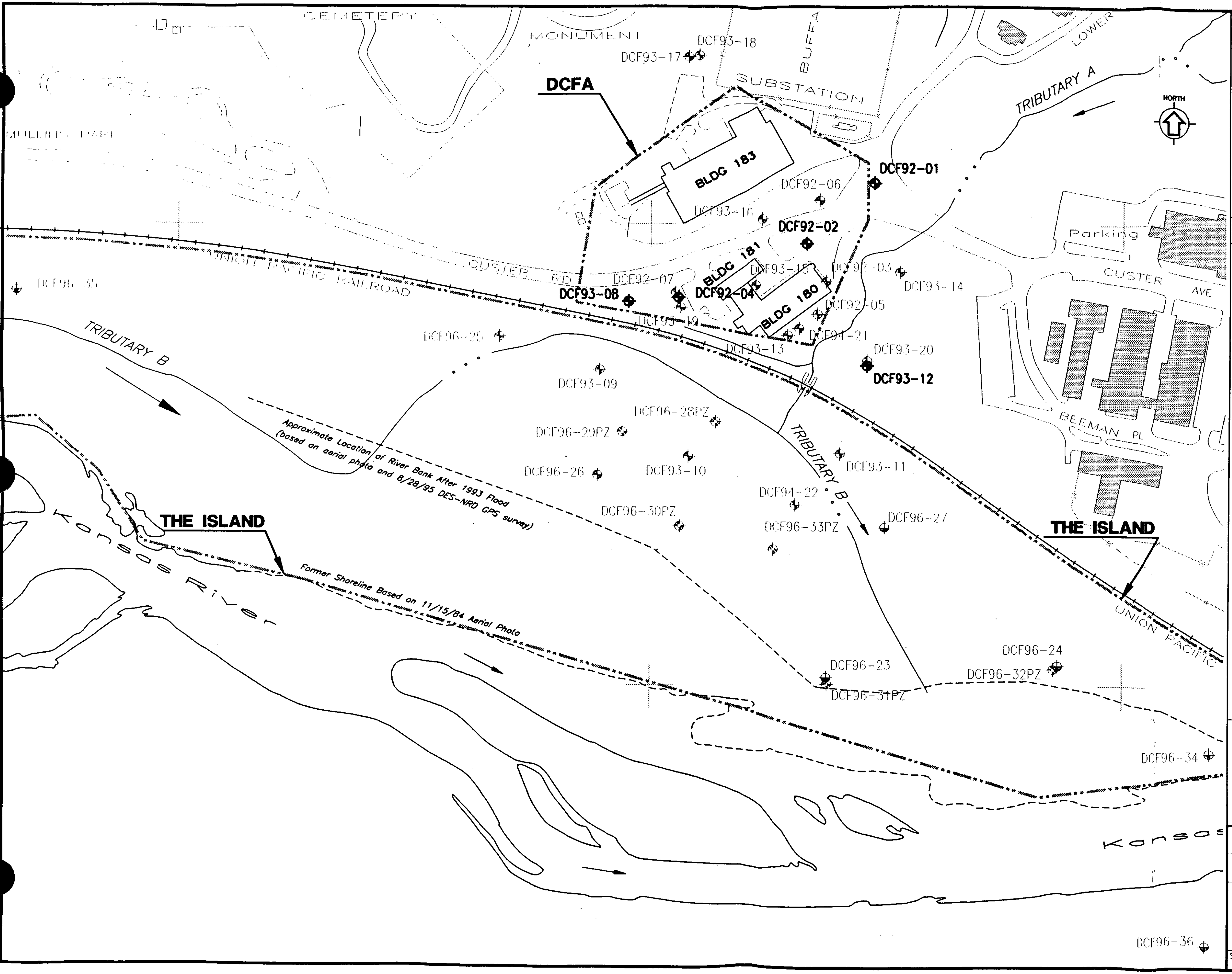
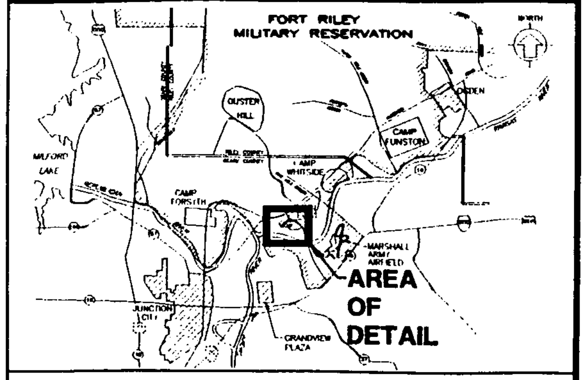
FORT RILEY MILITARY RESERVATION (DCFA–RIAMER)

LOCATION OF BEDROCK EROSIONAL FEATURE WELLS

SCALE:	DCFA–RIAMER DATE:	
1"=200'	MARCH 1998	FIG. 5–3a



KEY MAP



LEGEND

═══	EXISTING ROADWAY
—·—	EXISTING TRIBUTARY
→	SURFACE WATER FLOW DIRECTION
▨	EXISTING BUILDING
—+—	EXISTING RAILROAD
······	EXISTING FENCE LINE
DCF93-19 ⊕	MONITORING WELL
DCF96-23 ⊕	DEEP ALLUVIAL MONITORING WELL
DCF96-28PZ ⊕	PIEZOMETER
━·━	DCF STUDY AREA
DCF93-08 ⊕	UPPER CROUSE LIMESTONE WELLS ON FIGURE 5-4

0 100 200 400

(IN FEET)
1 inch = 200 ft.

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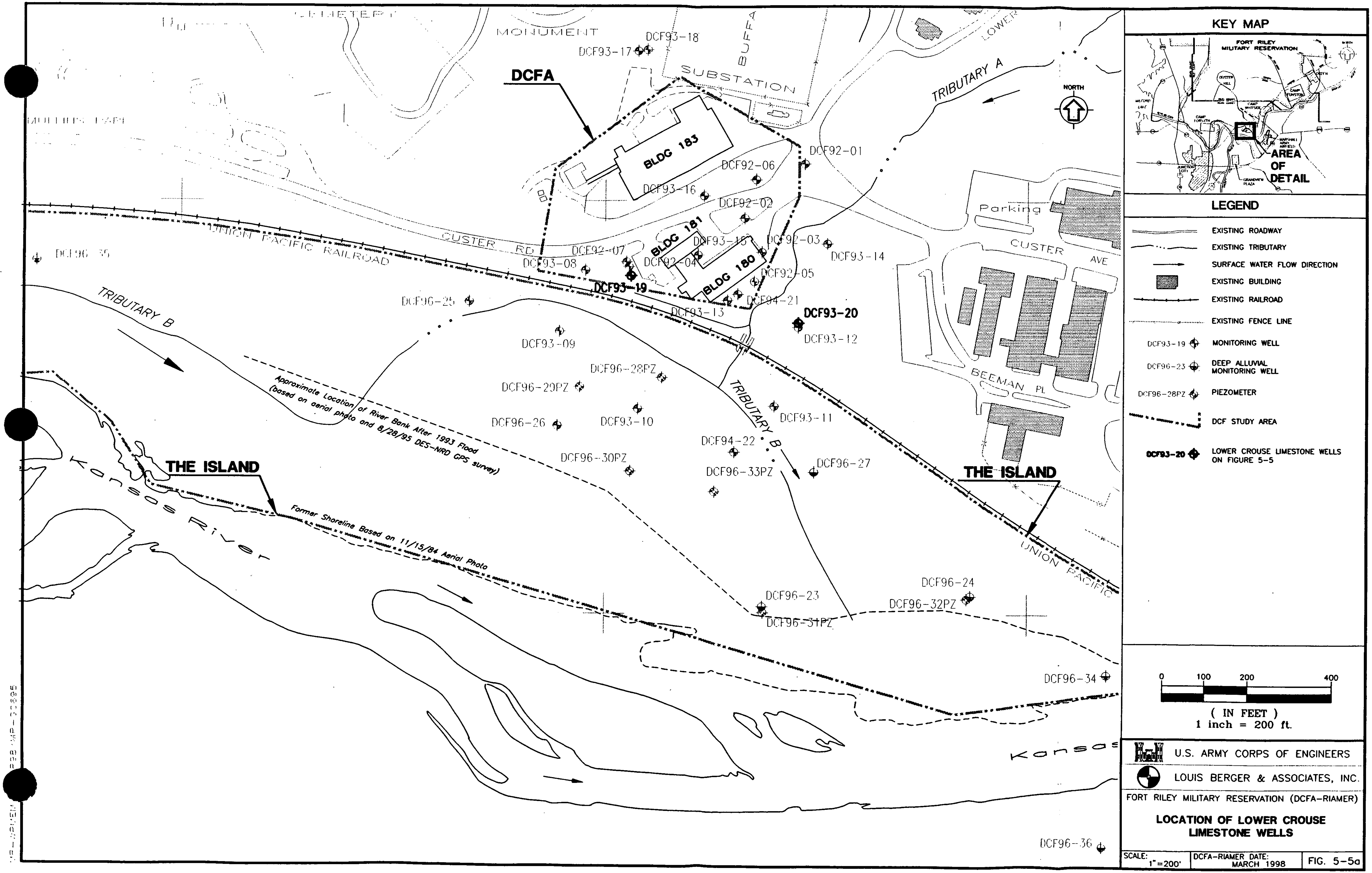
FORT RILEY MILITARY RESERVATION (DCFA-RIAMER)

LOCATION OF UPPER CROUSE LIMESTONE WELLS

SCALE: 1"=200'	DCFA-RIAMER DATE: MARCH 1998	FIG. 5-4a



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FORT RILEY MILITARY RESERVATION (DCFA-RIAMER)

LOCATION OF LOWER CROUSE LIMESTONE WELLS

SCALE: 1"=200'	DCFA-RIAMER DATE: MARCH 1998	FIG. 5-5a

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.0 Conclusions and Recommendations

This section documents the conclusions and recommendation regarding groundwater flow and contaminant migration and degradation based on the results of the Draft Final RI (CENWK, 1995) and the results of the monitoring network expansion program. Particular emphasis is placed on what if any changes to the conclusions in the Draft Final RI are indicated by the monitoring expansion related data.

6.1 Conclusions

While a large amount of new and valuable data has been obtained since the Draft Final RI, it only enhances the previous understanding of the hydrogeology and the nature, extent, fate and transport of the contamination within the DCF Study Area. This new data does not, however, change any of the overall conclusions in the Draft Final RI, namely that: (1) groundwater and contaminants migrate and attenuate in a dissolved state from the upland area to the Kansas River via the alluvial Island at low levels; and, (2) there are no identified unacceptable risks to current or likely future human or ecological receptors associated with the contamination. With regard to risks in particular, no new information has been identified since the baseline risk assessment (BLRA) was performed as part of the RI which warrants revisiting the BLRA. This conclusion is based on the fact that:

- contaminant levels continue to be well below the conservative past maximum concentrations that were used to perform the BLRA;
- land use conditions have not changed; and,
- the types and locations of potential receptors has not changed.

As a result, there appears to be no need for additional data gathering and evaluation which would further postpone the remedial alternative development, evaluation and selection process for this site.

More specific conclusions with regard to the updated understanding of the hydrogeology and contamination within the DCF Study Area follows.

6.1.1 Specific Conclusions Regarding Hydrogeology

The combined inception to date results from the RI and the monitoring expansion related groundwater elevation monitoring activities strengthen and further the findings and data trends presented in the Draft Final RI. Inception to date hydrographs clearly illustrate the influence of the Kansas River and precipitation events on the groundwater elevations within the DCF Study Area, with the magnitude of the influence being related to the relative distance from the river and the specific characteristics of the formation in which a well is located.

Groundwater flow is toward the south across the DCF Study Area. There are components of flow to the southwest and southeast at various locations and at differing times; however, the net flow and discharge is to the alluvial deposits in the Kansas River channel and ultimately to the Kansas River itself. The bedrock erosional feature tends to channelize water flow in the area east of Buildings 180 and 181, however, the net flow is still south towards the alluvial Island. Localized and temporal variations have been documented during the periods of monitoring. Flooding and rising river levels tend to redirect the groundwater flow to some extent across the Island, as seen in plots of the groundwater elevation contours included with the DSRs for such periods. Predominant flow direction remains from the upland toward the Island at all times, however, and when the river returns to seasonal levels the groundwater flow regime returns to its steady state conditions.

6.1.2 Specific Conclusions Regarding Contamination

Inception to date sampling and analysis data clearly illustrate that the new information collected since the submission of the Draft Final RI are consistent with, and further support the findings presented in the Draft Final RI. In particular, these data show that:

1. maximum contaminant levels within the DCF Study Area continue to decrease as the center of contaminant mass migrates (although it is noted that, as would be expected, this does not mean that contaminant levels in particular wells located in front of the center of contaminant mass will not show increasing levels of contamination until the center of mass passes them);
2. natural attenuation (including biodegradation) is absolutely occurring to varying degrees within the DCF Study Area; and,
3. there is no evidence that any deep non-aqueous phase contamination exists within the DCF Study Area.

Based on the data, the contaminants of concern at the DCF Study Area are migrating toward the Kansas River and, at the same time are proceeding through a natural degradation or attenuation process. The overall concentration trend is downward and the limits of the contaminant mass have been adequately defined.

The wells adjacent to the western side of Buildings 180 and 181 appear to be monitoring an older release than other wells at the DCF Study Area. The levels of vinyl chloride and DCE, two of the byproducts of the PCE biodegradation process, are among the highest reported from any of the wells at the DCF. This area also corresponds well to the reported location of waste or spent dry cleaning fluids discharged to the ground surface prior to the relocation of the dry cleaning operation to Building 183. Based on these factors, it is believed that the contaminants in this area are older than those monitored in other areas.

Instances of increasing concentrations have been noted at some monitoring locations. These spikes in the concentration plots are not surprising since they are in front of the center of contaminant mass, are of short duration, and as the passage of the center of mass is documented in each successive downgradient well, the level of PCE declines and the concentrations of TCE and DCE, the natural degradation products, increase.

Well DCF96-25 on the Island appears to be intercepting contaminants from a newly identified pathway. The primary contaminant is PCE with minor amounts of TCE and DCE (contrast to most of the other Island wells which display a higher concentration of the degradation products relative to PCE). It is theorized that sanitary sewer manhole overflows which occurred prior to the 1996 sewer repairs is the likely cause of the elevated levels of contaminants noted in samples from this well. DCF-related contamination following this pathway likely travels along Custer Road to the west, to a low-lying area immediately adjacent to Custer Road and upgradient of well DCF96-25. It is important to note, however, that this pathway eventually joins back with the previously known pathways once the contamination reaches the Island and becomes affected by the influence of the Kansas River.

Two other wells in the Island alluvial deposits, DCF96-23 and DCF96-26, also exhibit elevated levels of PCE relative to the degradation products. These wells are at the southern limit of the Island and may be intercepting either upward migrating groundwater or contaminants migrating along a preferential pathway associated with an alluvial feature such as a buried channel or cutoff river meander.

6.2 Recommendations

Based on the foregoing data, discussions and conclusions, continued monitoring of existing wells is recommended but no additional monitoring locations or interim remedial activity is needed while the remedial alternative development and selection process proceeds. This recommendation is based on the following factors:

- The baseline risk assessment in the Draft Final RI remains conservative and appropriate as is, and it identified no unacceptable risks;
- Contaminant levels generally are decreasing across the DCF Study Area with distance from the assumed sources and over time;
- Continued adherence to proper waste management practices should eliminate any potential for on-going sources of PCE at the DCF; and,
- Natural attenuation is occurring and the monitoring data indicates specifically that the PCE contamination is biodegrading to TCE, DCE and vinyl chloride within the DCF Study Area (it is also important to note that this point, in particular, has directly supports the remedial alternative development and selection process since natural attenuation and continued monitoring is one of the most promising alternatives to be considered).

Monitoring can be performed as a periodic check on the existing institutional controls and the conclusions of this report to document continued decreases in the levels of DCF-related contaminants and the lack of any actual risks to human health or the environment. Monitoring for favorable natural attenuation conditions and continued biodegradation of PCE into its known byproducts can also be accomplished by groundwater sampling and analysis in impacted areas and in areas downgradient from these. Finally, the effects of discharge to the alluvial Island and towards the Kansas River can be monitored by continued sampling and analysis of the existing monitoring well network, especially those at the southern limit of the Island adjacent to the river channel. Monitoring of surface water within the Kansas River for this purpose is not recommended based on the low levels of contaminants likely to be discharged from the Island to the river, and the likelihood that they will immediately dilute and/or volatilize to below detectable levels the instant that they enter the river bed.

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REFERENCES

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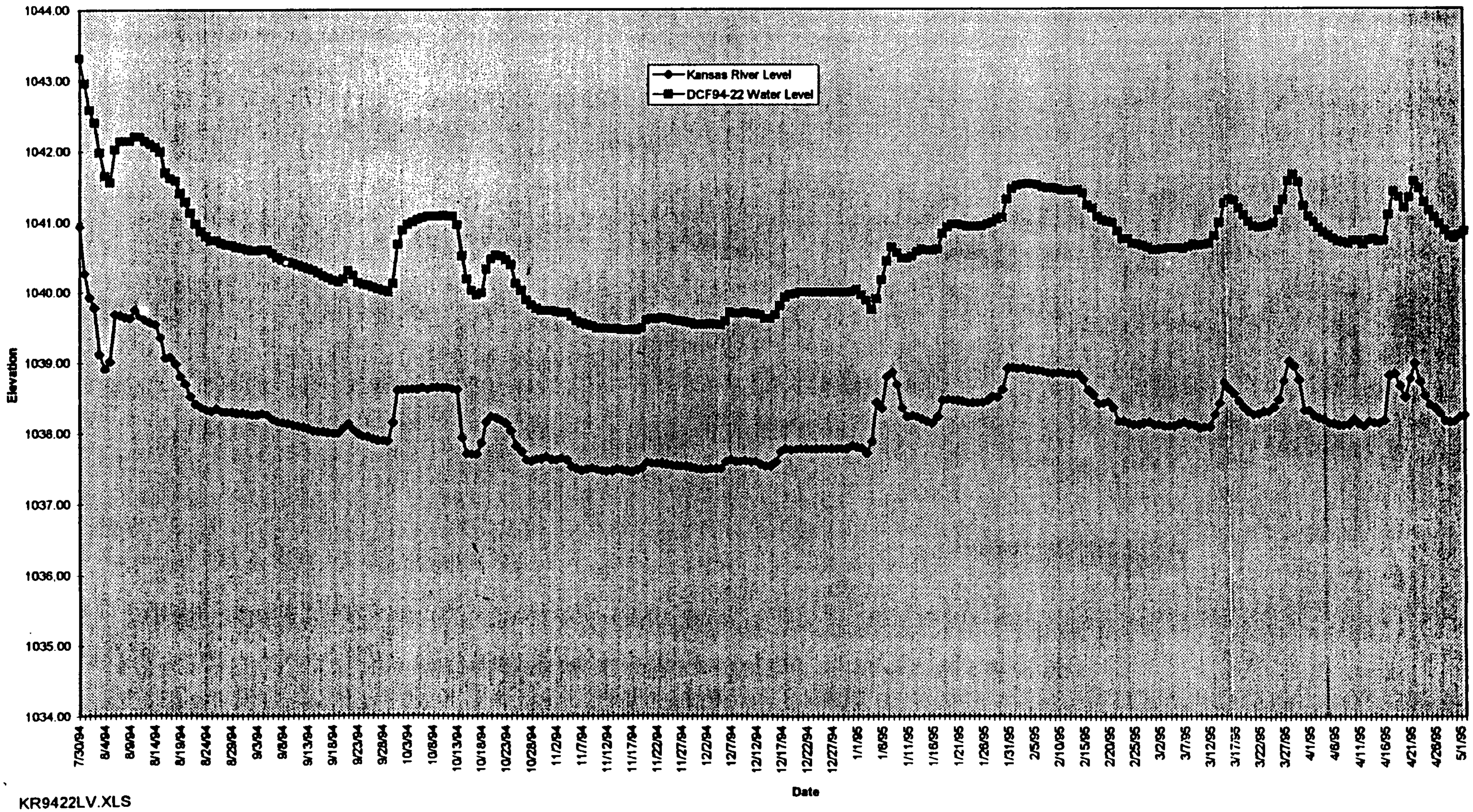
APPENDICES

APPENDIX A
ADDITIONAL DATA LOGGER RESULTS FOR MONITORING WELL DCF94-22

DCF94-22 and Kansas River Hydrograph, 30 July 1994 through 2 May 1995



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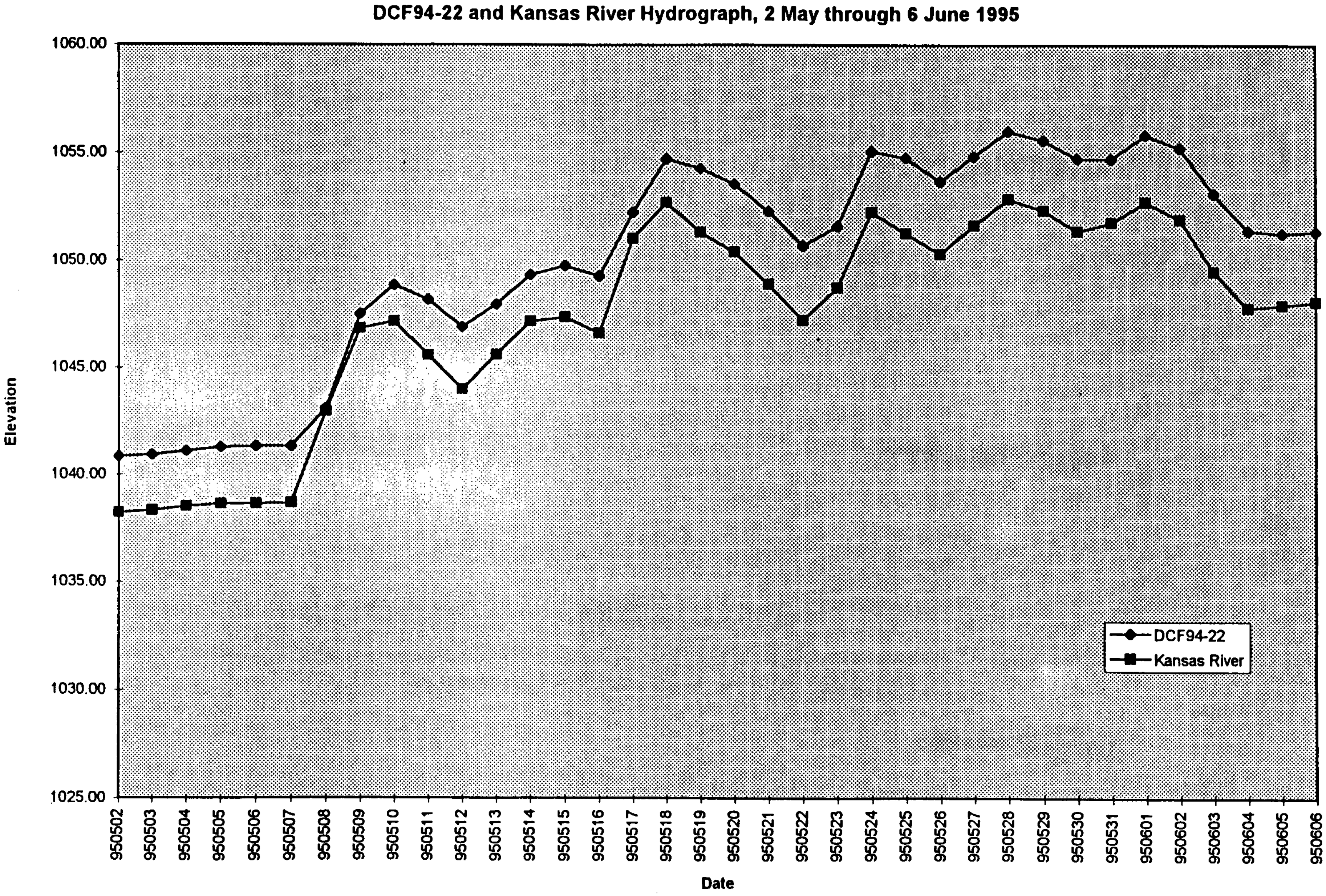
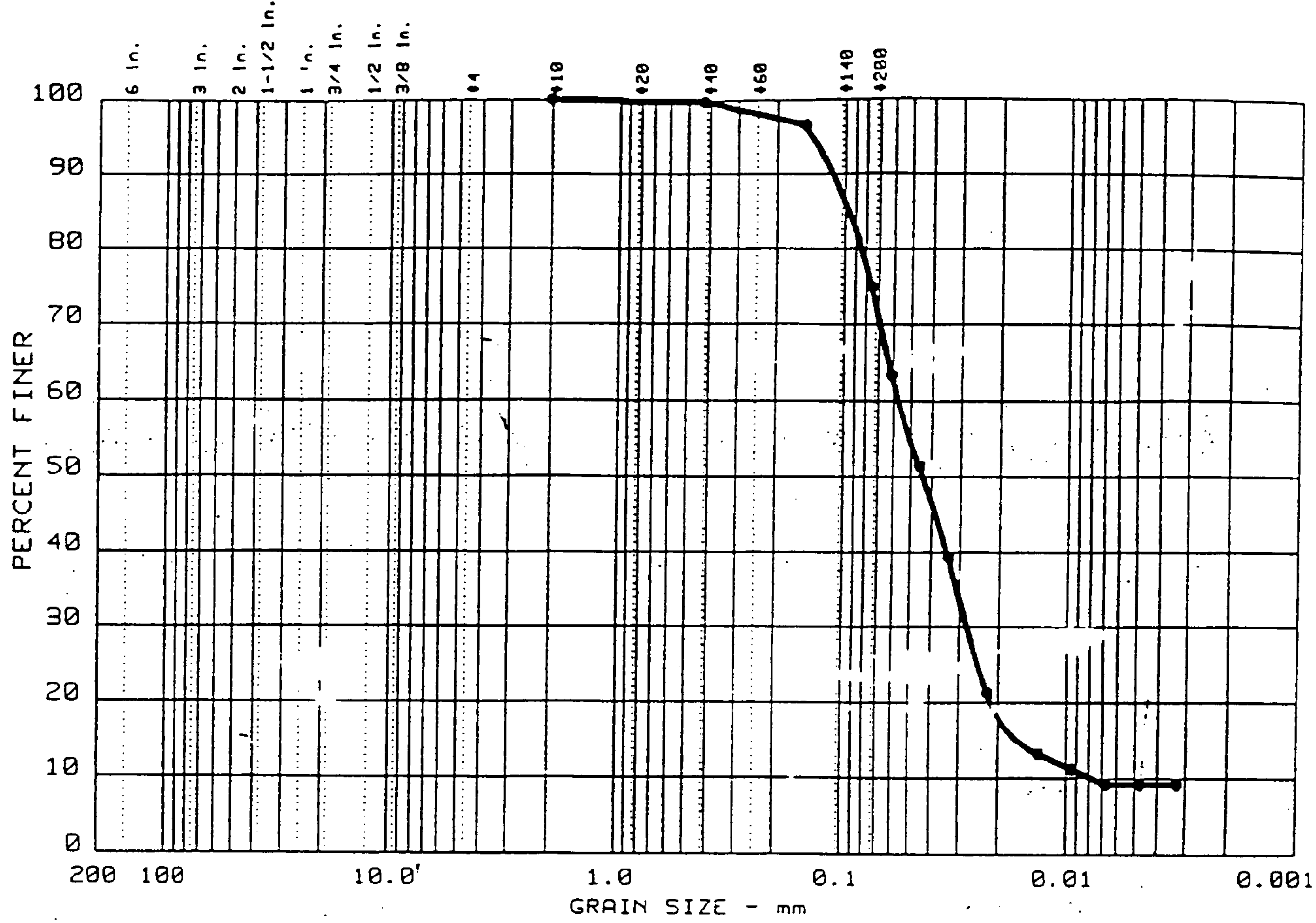


APPENDIX B
GRAIN SIZE DISTRIBUTION CURVES

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	1	0.0	0.0	25.2	65.6	9.2

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●	23	2	0.0955		0.0438	0.0276	0.0167	0.0077	1.74	7.4

MATERIAL DESCRIPTION	USCS	AASHTO
● BROWN SILT LITTLE FINE SAND FEW CLAY	ML	A-4

Project No.: ML8955-01
Project: LAB TESTING SERVICES
● Location: DCF-S1

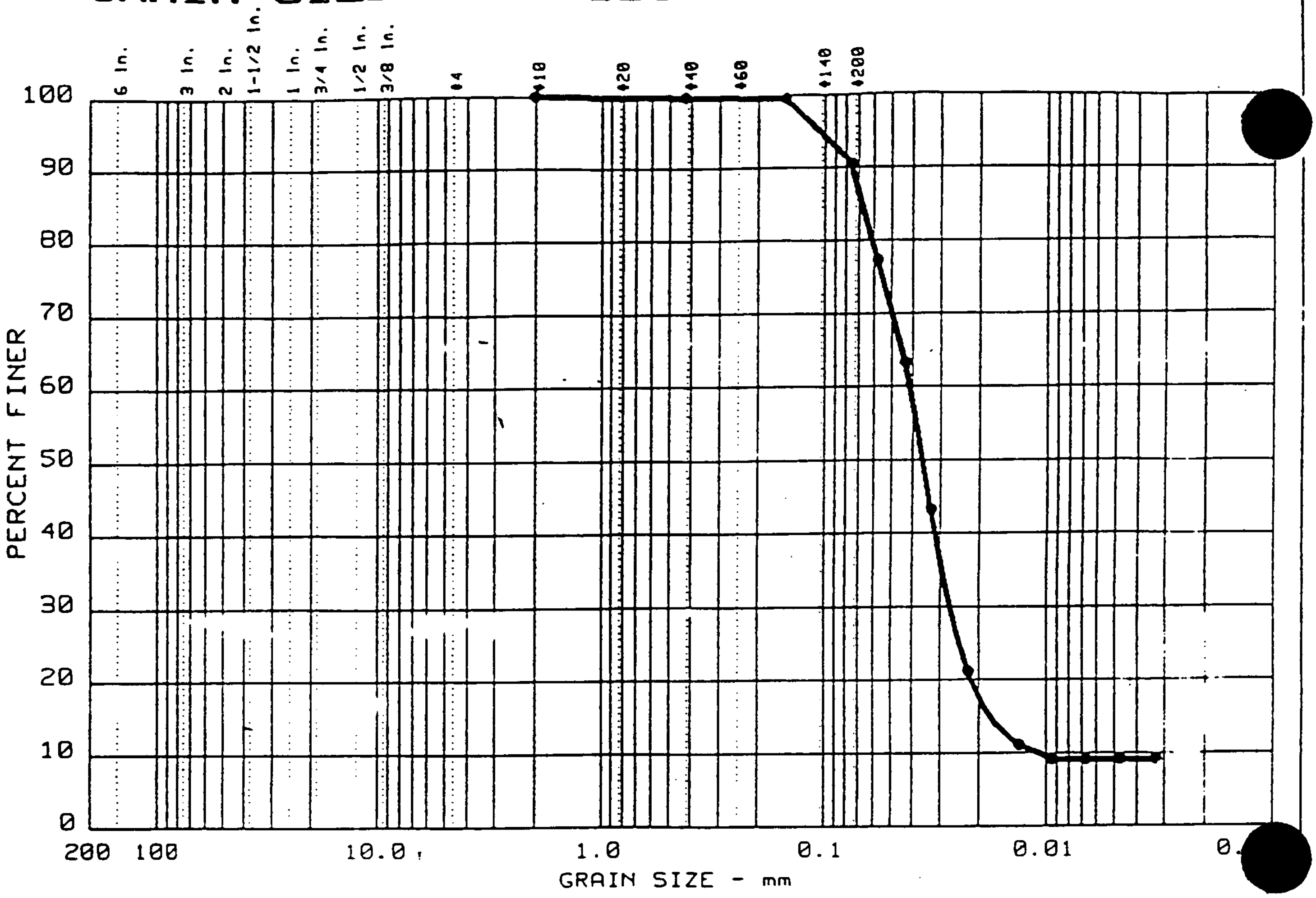
Date: 11-18-1996

Remarks:
"PROJECT NO. JG1199"

GRAIN SIZE DISTRIBUTION TEST REPORT
SITE-Blauvelt Engineers, Inc.

Figure No. 1

GRAIN SIZE DISTRIBUTION TEST REPORT



	Test	% +3"	% GRAVEL	% SAND	% SILT	% CLAY
●	2	0.0	0.0	9.5	81.3	9.2

	LL	PI	D_{85}	D_{60}	D_{50}	D_{30}	D_{15}	D_{10}	C_c	C_u
●		NP			0.0360	0.0269	0.0178	0.0109	1.63	3.8

MATERIAL DESCRIPTION	USCS	AASHTO
● BROWN SILT FEW FINE SAND FEW CLAY	ML	A-4

Project No.: ML8955-01
Project: LAB TESTING SERVICES
● Location: DCF-S2

Date: 11-18-1996

Remarks:

"PROJECT NO. JG1199"

GRAIN SIZE DISTRIBUTION TEST REPORT

SITE-Blauvelt Engineers, Inc.

Figure No. 2

SUMMARY OF L[illegible]ATORY TEST DATA

SAMPLE IDENTIFICATION					GRAIN SIZE DISTRIBUTION				PLASTICITY						VOLUMETRIC PROPERTIES			COMPACTION CHARACTERISTICS						
BORING NUMBER	SAMPLE NUMBER	DEPTH (FT.)	ELEVATION (FT.)	SOIL GROUP (USCS SYSTEM)	GRAVEL (%)	SAND (%)	SILT (%)	CLAY COLLOIDS (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	LIQUIDITY INDEX	SPECIFIC GRAVITY (* INDICATES ASSUMED VALUE)	MOISTURE CONTENT (%)	DRY UNIT WEIGHT (PCF) (+ INDICATES REMOLDED SAMPLE)	VOID RATIO	DEGREE OF SATURATION (%)	TYPE OF TEST	MAXIMUM DRY DENSITY (PCF)	OPTIMUM MOISTURE CONTENT (%)	CALIFORNIA BEARING RATIO-CBR (%)	pH	ORGANIC CONTENT (%)	MAXIMUM DENSITY (PCF)
DCF-S1																								
	S-1	0-0		ML	0	25	66	9	23	21	2												1.1	
DCF-S2																								
	S-2	0-0		ML	0	10	81	9			NP												1.3	

SITE-Blauvelt Engineers, Inc.

DRAWN: MO

DATE: 11/18/1996

LABORATORY TESTING SERVICES

FILE NO. 8955-01

APPENDIX C
OVERVIEW OF THE TECHNICAL PROTOCOL FOR NATURAL ATTENUATION OF CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER UNDER DEVELOPMENT FOR THE U.S. AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE

United States
Environmental Protection
Agency

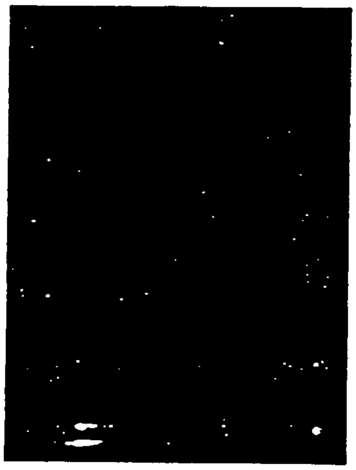
Office of Research and
Development
Washington, DC 20460

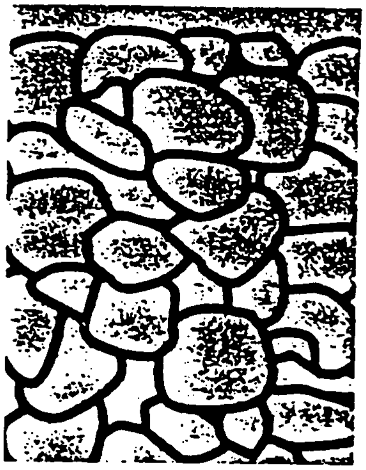
EPA/540/R-96/509
September 1996

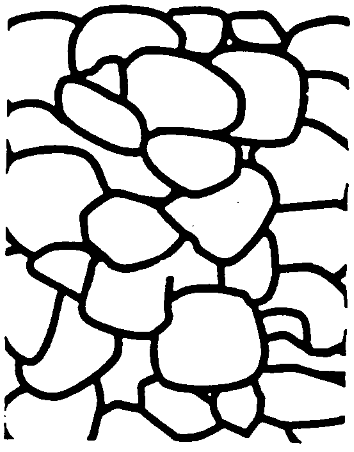
EPA

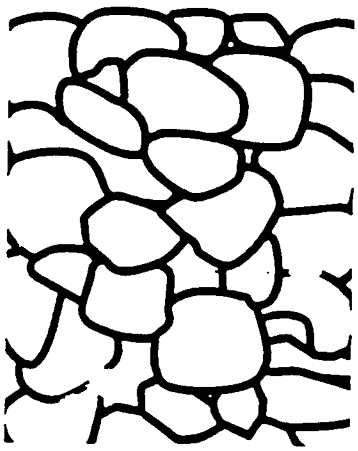
Symposium on Natural Attenuation of Chlorinated Organics in Ground Water

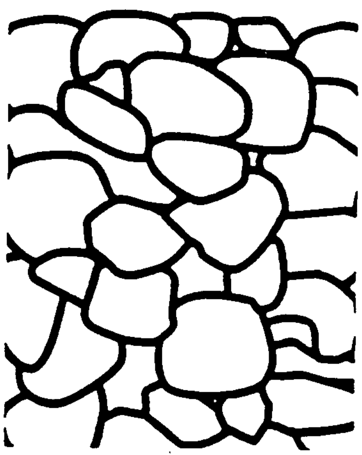
Hyatt Regency Dallas
Dallas, TX
September 11–13, 1996











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Overview of the Technical Protocol for Natural Attenuation of Chlorinated Aliphatic Hydrocarbons in Ground Water Under Development for the U.S. Air Force Center for Environmental Excellence

Todd H. Wiedemeier, Matthew A. Swanson, and David E. Moutoux
Parsons Engineering Science, Inc., Denver, Colorado

John T. Wilson and Donald H. Kampbell
U.S. Environmental Protection Agency, National Risk Management Research Laboratory, Ada, Oklahoma

Jerry E. Hansen and Patrick Haas
U.S. Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks Air Force Base, Texas

Introduction

Over the past several years, natural attenuation has become increasingly accepted as a remedial alternative for organic compounds dissolved in ground water. The U.S. Environmental Protection Agency's (EPA) Office of Research and Development and Office of Solid Waste and Emergency Response define natural attenuation as:

> The biodegradation, dispersion, dilution, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

In practice, natural attenuation has several other names, such as intrinsic remediation, intrinsic bioremediation, or passive bioremediation. The goal of any site characterization effort is to understand the fate and transport of the contaminants of concern over time in order to assess any current or potential threat to human health or the environment. Natural attenuation processes, such as biodegradation, can often be dominant factors in the fate and transport of contaminants. Thus, consideration and quantification of natural attenuation is essential to more thoroughly understand contaminant fate and transport.

This paper presents a technical protocol for data collection and analysis in support of remediation by natural attenuation to restore ground water contaminated with chlorinated aliphatic hydrocarbons and ground water contaminated with mixtures of fuels and chlorinated aliphatic hydrocarbons. In some cases, the information collected using this protocol will show that natural attenuation processes, with or without source removal, will reduce the concentrations of these contaminants to below risk-based corrective action criteria or regulatory standards before potential receptor exposure pathways are completed. The evaluation should include consideration of existing exposure pathways as well as exposure pathways arising from potential future use of the ground water.

This protocol is intended to be used within the established regulatory framework. It is not the intent of this document to replace existing EPA or state-specific guidance on conducting remedial investigations.

Overview of the Technical Protocol

Natural attenuation in ground-water systems results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Biodegradation is the most important destructive attenuation mechanism. Nondestructive attenuation mechanisms include sorption, dispersion, dilution from recharge, and volatilization. The natural attenuation of fuel hydrocarbons is described in the *Technical Protocol for Implementing Intrinsic Remediation With Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater*, recently published by the U.S. Air Force Center for Environmental

Excellence (AFCEE) (1). This document differs from the technical protocol for intrinsic remediation of fuel hydrocarbons because the individual processes of chlorinated aliphatic hydrocarbon biodegradation are fundamentally different from the processes involved in the biodegradation of fuel hydrocarbons.

For example, biodegradation of fuel hydrocarbons, especially benzene, toluene, ethylbenzene, and xylenes (BTEX), is mainly limited by electron acceptor availability, and biodegradation of these compounds generally will proceed until all of the contaminants are destroyed. In the experience of the authors, there appears to be an inexhaustible supply of electron acceptors in most, if not all, hydrogeologic environments. On the other hand, the more highly chlorinated solvents (e.g., perchloroethene and trichloroethene) typically are biodegraded under natural conditions via reductive dechlorination, a process that requires both electron acceptors (the chlorinated aliphatic hydrocarbons) and an adequate supply of electron donors. Electron donors include fuel hydrocarbons or other types of anthropogenic carbon (e.g., landfill leachate, BTEX, or natural organic carbon). If the subsurface environment is depleted of electron donors before the chlorinated aliphatic hydrocarbons are removed, reductive dechlorination will cease, and natural attenuation may no longer be protective of human health and the environment. This is the most significant difference between the processes of fuel hydrocarbon and chlorinated aliphatic hydrocarbon biodegradation.

For this reason, it is more difficult to predict the long-term behavior of chlorinated aliphatic hydrocarbon plumes than fuel hydrocarbon plumes. Thus, it is important to have a thorough understanding of the operant natural attenuation mechanisms. In addition to having a better understanding of the processes of advection, dispersion, dilution from recharge, and sorption, it is necessary to better quantify biodegradation. This requires a thorough understanding of the interactions between chlorinated aliphatic hydrocarbons, anthropogenic/natural carbon, and inorganic electron acceptors at the site. Detailed site characterization is required to adequately understand these processes.

Chlorinated solvents are released into the subsurface under two possible scenarios: 1) as relatively pure solvent mixtures that are more dense than water, or 2) as mixtures of fuel hydrocarbons and chlorinated aliphatic hydrocarbons which, depending on the relative proportion of each, may be more or less dense than water. These products commonly are referred to as "nonaqueous-phase liquids," or NAPLs. If the NAPL is more dense than water, the material is referred to as a "dense nonaqueous-phase liquid," or DNAPL. If the NAPL is less dense than water, the material is referred to as a "light nonaqueous-phase liquid," or LNAPL. In general, the greatest mass of contaminant is associated with these NAPL source areas, not with the aqueous phase.

As ground water moves through or past the NAPL source areas, soluble constituents partition into th moving ground water to generate a plume of dissolve contamination. After further releases have been stopped, these NAPL source areas tend to slowly weather away as the soluble components, such as BTEX or trichloroethene, are depleted. In cases where source removal or reduction is feasible, it is desirable to remove product and decrease the time required for complete remediation of the site. At many sites, however, mobile NAPL removal is not feasible with available technology. In fact, the quantity of NAPL recovered by commonly used recovery techniques is a trivial fraction of the total NAPL available to contaminate ground water. Mobile NAPL recovery typically recovers less than 10 percent of the total NAPL mass in a spill.

Compared with conventional engineered remediation technologies, natural attenuation has the following advantages:

- During natural attenuation, contaminants are ultimately transformed to innocuous byproducts (e.g., carbon dioxide, ethene, and water), not just transferred to another phase or location in the environment.
- Natural attenuation is nonintrusive and allows continuing use of infrastructure during remediation.
- Engineered remedial technologies can pose greater risk to potential receptors than natural attenuation because contaminants may be transferred into the atmosphere during remediation activities.
- Natural attenuation is less costly than currently available remedial technologies, such as pump-and-treat.
- Natural attenuation is not subject to the limitations of mechanized remediation equipment (e.g., no equipment downtime).
- Those compounds that are the most mobile and toxic are generally the most susceptible to biodegradation.

Natural attenuation has the following limitations:

- Natural attenuation is subject to natural and anthropogenic changes in local hydrogeologic conditions, including changes in ground-water gradients and velocity, pH, electron acceptor concentrations, electron donor concentrations, and/or potential future contaminant releases.
- Aquifer heterogeneity may complicate site characterization and quantification of natural attenuation.
- Time frames for complete remediation may be relatively long.

- Intermediate products of biodegradation (e.g., vinyl chloride) can be more toxic than the original contaminant.

This document describes those processes that bring about natural attenuation, the site characterization activities that may be performed to support a feasibility study to include an evaluation of natural attenuation, natural attenuation modeling using analytical or numerical solute fate-and-transport models, and the post-modeling activities that should be completed to ensure successful support and verification of natural attenuation. The objective of the work described herein is to quantify and provide defensible data in support of natural attenuation at sites where naturally occurring subsurface attenuation processes are capable of reducing dissolved chlorinated aliphatic hydrocarbon and/or fuel hydrocarbon concentrations to acceptable levels. A comment made by a member of the regulatory community (2) summarizes what is required to successfully implement natural attenuation:

> A regulator looks for the data necessary to determine that a proposed treatment technology, if properly installed and operated, will reduce the contaminant concentrations in the soil and water to legally mandated limits. In this sense the use of biological treatment systems calls for the same level of investigation, demonstration of effectiveness, and monitoring as any conventional [remediation] system.

To support remediation by natural attenuation, the proponent must scientifically demonstrate that degradation of site contaminants is occurring at rates sufficient to be protective of human health and the environment. Three lines of evidence can be used to support natural attenuation of chlorinated aliphatic hydrocarbons, including:

- Observed reduction in contaminant concentrations along the flow path downgradient from the source of contamination.
- Documented loss of contaminant mass at the field scale using:
  - Chemical and geochemical analytical data (e.g., decreasing parent compound concentrations, increasing daughter compound concentrations, depletion of electron acceptors and donors, and increasing metabolic byproduct concentrations).
  - A conservative tracer and a rigorous estimate of residence time along the flow path to document contaminant mass reduction and to calculate biological decay rates at the field scale.
- Microbiological laboratory data that support the occurrence of biodegradation and give rates of biodegradation.

At a minimum, the investigator must obtain the first two lines of evidence or the first and third lines of evidence. The second and third lines of evidence are crucial to the natural attenuation demonstration because they provide biodegradation rate constants. These rate constants are used in conjunction with the other fate-and-transport parameters to predict contaminant concentrations and to assess risk at downgradient points of compliance.

The first line of evidence is simply an observed reduction in the concentration of released contaminants downgradient from the NAPL source area along the groundwater flow path. This line of evidence does not prove that contaminants are being destroyed because the reduction in contaminant concentration could be the result of advection, dispersion, dilution from recharge, sorption, and volatilization with no loss of contaminant mass (i.e., the majority of apparent contaminant loss could be due to dilution). Conversely, an increase in the concentrations of some contaminants, most notably degradation products such as vinyl chloride, could be indicative of natural attenuation.

To support remediation by natural attenuation at most sites, the investigator will have to show that contaminant mass is being destroyed via biodegradation. This is done using either or both of the second or third lines of evidence. The second line of evidence relies on chemical and physical data to show that contaminant mass is being destroyed via biodegradation, not just diluted. The second line of evidence is divided into two components:

- Using chemical analytical data in mass balance calculations to show that decreases in contaminant and electron acceptor and donor concentrations can be directly correlated to increases in metabolic end products and daughter compounds. This evidence can be used to show that electron acceptor and donor concentrations in ground water are sufficient to facilitate degradation of dissolved contaminants. Solute fate-and-transport models can be used to aid mass balance calculations and to collate information on degradation.
- Using measured concentrations of contaminants and/or biologically recalcitrant tracers in conjunction with aquifer hydrogeologic parameters, such as seepage velocity and dilution, to show that a reduction in contaminant mass is occurring at the site and to calculate biodegradation rate constants.

The third line of evidence, microbiological laboratory data, can be used to provide additional evidence that indigenous biota are capable of degrading site contaminants at a particular rate. Because it is necessary to show that biodegradation is occurring and to obtain biodegradation rate constants, the most useful type of microbiological laboratory data is the microcosm study.

This paper presents a technical course of action that allows converging lines of evidence to be used to scientifically document the occurrence and quantify the rates of natural attenuation. Ideally, the first two lines of evidence should be used in the natural attenuation demonstration. To further document natural attenuation, or at sites with complex hydrogeology, obtaining a field-scale biodegradation rate may not be possible; in this case, microbiological laboratory data can be used. Such a "weight-of-evidence" approach will greatly increase the likelihood of successfully implementing natural attenuation at sites where natural processes are restoring the environmental quality of ground water.

Collection of an adequate database during the iterative site characterization process is an important step in the documentation of natural attenuation. Site characterization should provide data on the location, nature, and extent of contaminant sources. Contaminant sources generally consist of hydrocarbons present as mobile NAPL (i.e., NAPL occurring at sufficiently high saturations to drain under the influence of gravity into a well) and residual NAPL (i.e., NAPL occurring at immobile, residual saturation that is unable to drain into a well by gravity). Site characterization also should provide information on the location, extent, and concentrations of dissolved contamination; ground-water geochemical data; geologic information on the type and distribution of subsurface materials; and hydrogeologic parameters such as hydraulic conductivity, hydraulic gradients, and potential contaminant migration pathways to human or ecological receptor exposure points.

The data collected during site characterization can be used to simulate the fate and transport of contaminants in the subsurface. Such simulation allows prediction of the future extent and concentrations of the dissolved contaminant plume. Several models can be used to simulate dissolved contaminant transport and attenuation. The natural attenuation modeling effort has three primary objectives: 1) to predict the future extent and concentration of a dissolved contaminant plume by simulating the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the potential for downgradient receptors to be exposed to contaminant concentrations that exceed regulatory or risk-based levels intended to be protective of human health and the environment; and 3) to provide technical support for the natural attenuation remedial option at postmodeling regulatory negotiations to help design a more accurate verification and monitoring strategy and to help identify early source removal strategies.

Upon completion of the fate-and-transport modeling effort, model predictions can be used in an exposure pathways analysis. If natural attenuation is sufficient to mitigate risks to potential receptors, the proponent of natural attenuation has a reasonable basis for negotiating this option with regulators. The exposure pathways analysis allows the proponent to show that potential exposure pathways to receptors will not be completed.

The material presented herein was prepared through the joint effort of the AFCEE Technology Transfer Division; the Bioremediation Research Team at EPA's National Risk Management Research Laboratory in Ada, Oklahoma (NRMRL), Subsurface Protection and Remediation Division; and Parsons Engineering Science, Inc. (Parsons ES). This compilation is designed to facilitate implementation of natural attenuation at chlorinated aliphatic hydrocarbon-contaminated sites owned by the U.S. Air Force and other U.S. Department of Defense agencies, the U.S. Department of Energy, and public interests.

Overview of Chlorinated Aliphatic Hydrocarbon Biodegradation

Because biodegradation is the most important process acting to remove contaminants from ground water, an accurate estimate of the potential for natural biodegradation is important to obtain when determining whether ground-water contamination presents a substantial threat to human health and the environment. This information also will be useful when selecting the remedial alternative that will be most cost-effective in eliminating or abating these threats should natural attenuation alone not prove to be sufficient.

Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons and chlorinated solvents (3-23). Whereas fuel hydrocarbons are biodegraded through use as a primary substrate (electron donor), chlorinated aliphatic hydrocarbons may undergo biodegradation through three different pathways: through use as an electron acceptor, through use as an electron donor, or through co-metabolism, where degradation of the chlorinated organic is fortuitous and there is no benefit to the microorganism. At a given site, one or all of these processes may be operating, although at many sites the use of chlorinated aliphatic hydrocarbons as electron acceptors appears to be most important under natural conditions. In general, but in this case especially, biodegradation of chlorinated aliphatic hydrocarbons will be an electron-donor-limited process. Conversely, biodegradation of fuel hydrocarbons is an electron-acceptor-limited process.

In a pristine aquifer, native organic carbon is used as an electron donor, and dissolved oxygen (DO) is used first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbon) is present, it also will be used as an electron donor. After the DO is consumed, anaerobic microorganisms typically use additional electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how chlorinated aliphatic hydrocarbon biodegradation is occurring. In addition, because chlorinated aliphatic hydrocarbons may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds can provide evidence of the mechanisms of biodegradation working at a site. As with BTEX, the driving force behind oxidation-reduction reactions resulting in chlorinated aliphatic hydrocarbon degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in chlorinated aliphatic hydrocarbon reduction and oxidation do not proceed abiotically. Microorganisms are capable of carrying out the reactions, but they will facilitate only those oxidation-reduction reactions that have a net yield of energy.

Mechanisms of Chlorinated Aliphatic Hydrocarbon Biodegradation

Electron Acceptor Reactions (Reductive Dechlorination)

The most important process for the natural biodegradation of the more highly chlorinated solvents is reductive dechlorination. During this process, the chlorinated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a chlorine atom is removed and replaced with a hydrogen atom. In general, reductive dechlorination occurs by sequential dechlorination from perchloroethene to trichloroethene to dichloroethene to vinyl chloride to ethene. Depending on environmental conditions, this sequence may be interrupted, with other processes then acting on the products. During reductive dechlorination, all three isomers of dichloroethene can theoretically be produced; however, Bouwer (24) reports that under the influence of biodegradation, *cis*-1,2-dichloroethene is a more common intermediate than *trans*-1,2-dichloroethene, and that 1,1-dichloroethene is the least prevalent intermediate of the three dichloroethene isomers. Reductive dechlorination of chlorinated solvent compounds is associated with all accumulation of daughter products and an increase in the concentration of chloride ions.

Reductive dechlorination affects each of the chlorinated ethenes differently. Of these compounds, perchloroethene is the most susceptible to reductive dechlorination because it is the most oxidized. Conversely, vinyl chloride is the least susceptible to reductive dechlorination because it is the least oxidized of these compounds. The rate of reductive dechlorination also has been observed to decrease as the degree of chlorination decreases (24, 25). Murray and Richardson (26) have postulated that this rate decrease may explain the accumulation of vinyl chloride in perchloroethene and trichloroethene plumes that are undergoing reductive dechlorination.

Reductive dechlorination has been demonstrated under nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of chlorinated aliphatic hydrocarbons, occur under methanogenic conditions (24). Because chlorinated aliphatic hydrocarbon compounds are used as electron acceptors during reductive dechlorination, there must be an appropriate source of carbon in order for microbial growth to occur (24). Potential carbon sources include natural organic matter, fuel hydrocarbons, or other organic compounds such as those found in landfill leachate.

Electron Donor Reactions

Murray and Richardson (26) write that microorganisms are generally believed to be incapable of growth using trichloroethene and perchloroethene as a primary substrate (i.e., electron donor). Under aerobic and some anaerobic conditions, the less-oxidized chlorinated aliphatic hydrocarbons (e.g., vinyl chloride) can be used as the primary substrate in biologically mediated redox reactions (22). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded chlorinated aliphatic hydrocarbon. This is the process by which fuel hydrocarbons are biodegraded.

In contrast to reactions in which the chlorinated aliphatic hydrocarbon is used as an electron acceptor, only the least oxidized chlorinated aliphatic hydrocarbons can be used as electron donors in biologically mediated redox reactions. McCarty and Semprini (22) describe investigations in which vinyl chloride and 1,2-dichloroethane were shown to serve as primary substrates under aerobic conditions. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. In addition, Bradley and Chapelle (27) show evidence of mineralization of vinyl chloride under iron-reducing conditions so long as there is sufficient bioavailable iron(III). Aerobic metabolism of vinyl chloride may be characterized by a loss of vinyl chloride mass and a decreasing molar ratio of vinyl chloride to other chlorinated aliphatic hydrocarbon compounds.

Co-metabolism

When a chlorinated aliphatic hydrocarbon is biodegraded via co-metabolism, the degradation is catalyzed by an enzyme or cofactor that is fortuitously produced by the organisms for other purposes. The organism receives no known benefit from the degradation of the chlorinated aliphatic hydrocarbon; in fact, the co-metabolic degradation of the chlorinated aliphatic hydrocarbon may be harmful to the microorganism responsible for the production of the enzyme or cofactor (22).

Co-metabolism is best documented in aerobic environments, although it could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of perchloroethene, are susceptible to co-metabolic degradation (22, 23, 26). Vogel (23) further elaborates that the co-metabolism rate increases as the degree of dechlorination decreases. During co-metabolism, trichloroethene is indirectly transformed by bacteria as they use BTEX or another substrate to meet their energy requirements. Therefore, trichloroethene does not enhance the degradation of BTEX or other carbon sources, nor will its co-metabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources.

Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of biologically available organic carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being used. Individual plumes may exhibit all three types of behavior in different portions of the plume. The different types of plume behavior are summarized below.

Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate), and this anthropogenic carbon drives reductive dechlorination. When evaluating natural attenuation of a plume exhibiting Type 1, behavior the following questions must be answered:

1. Is the electron donor supply adequate to allow microbial reduction of the chlorinated organic compounds? In other words, will the microorganisms "strangle" before they "starve"—will they run out of chlorinated aliphatic hydrocarbons (electron acceptors) before they run out of electron donors?
2. What is the role of competing electron acceptors (e.g., DO, nitrate, iron(III), and sulfate)?
3. Is vinyl chloride oxidized, or is it reduced?

Type 1 behavior results in the rapid and extensive degradation of the highly chlorinated solvents such as perchloroethene, trichloroethene, and dichloroethene.

Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high concentrations of biologically available native organic carbon. This natural carbon source drives reductive dechlorination (i.e., is the primary substrate for microorganism growth). When evaluating natural attenuation of a Type 2 chlorinated solvent plume, the same questions as those posed for Type 1 behavior must be answered. Type 2 behavior generally results in slower biodegradation of the highly chlorinated solvents than Type 1 behavior, but under the right conditions (e.g., areas with high natural organic carbon contents) this type of behavior also can result in rapid degradation of these compounds.

Type 3 Behavior

Type 3 behavior dominates in areas that are characterized by low concentrations of native and/or anthropogenic carbon and by DO concentrations greater than 1.0 milligrams per liter. Under these aerobic conditions, reductive dechlorination will not occur; thus, there is no removal of perchloroethene, trichloroethene, and dichloroethene. The most significant natural attenuation mechanisms for these compounds is advection, dispersion, and sorption. However, vinyl chloride can be rapidly oxidized under these conditions.

Mixed Behavior

A single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of chlorinated aliphatic hydrocarbon plumes. For example, Wiedemeier et al. (28) describe a plume at Plattsburgh Air Force Base, New York, that exhibits Type 1 behavior in the source area and Type 3 behavior downgradient from the source. The most fortuitous scenario involves a plume in which perchloroethene, trichloroethene, and dichloroethene are reductively dechlorinated (Type 1 or 2 behavior), then vinyl chloride is oxidized (Type 3 behavior) either aerobically or via iron reduction. Vinyl chloride is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in a plume that exhibits this type of mixed behavior:

Perchloroethene → Trichloroethene →
Dichloroethene → Vinyl chloride → Carbon dioxide

The trichloroethene, dichloroethene, and vinyl chloride may attenuate at approximately the same rate, and thus these reactions may be confused with simple dilution. Note that no ethene is produced during this reaction. Vinyl chloride is removed from the system much faster under these conditions than it is under vinyl chloride-reducing conditions.

A less desirable scenario—but one in which all contaminants may be entirely biodegraded— involves a plume in which all chlorinated aliphatic hydrocarbons are reductively dechlorinated via Type 1 or Type 2 behavior. Vinyl chloride is reduced to ethene, which may be further reduced to ethane or methane. The following sequence of reactions occurs in this type of plume:

Perchloroethene → Trichloroethene →
Dichloroethene → Vinyl chloride → Ethene → Ethane

This sequence has been investigated by Freedman and Gossett (13). In this type of plume, vinyl chloride degrades more slowly than trichloroethene and thus tends to accumulate.

Protocol for Quantifying Natural Attenuation During the Remedial Investigation Process

The primary objective of the natural attenuation investigation is to show that natural processes of contaminant degradation will reduce contaminant concentrations in ground water to below risk-based corrective action or regulatory levels before potential receptor exposure pathways are completed. This requires a projection of the potential extent and concentration of the contaminant plume in time and space. The projection should be based on historic variations in, and the current extent and concentrations of, the contaminant plume, as well as the measured rates of contaminant attenuation. Because of the inherent uncertainty associated with such predictions, the investigator must provide sufficient evidence to demonstrate that the mechanisms of natural attenuation will reduce contaminant concentrations to acceptable levels before potential receptors are reached. This requires the use of conservative solute fate-and-transport model input parameters and numerous sensitivity analyses so that consideration is given to all plausible contaminant migration scenarios. When possible, both historical data and modeling should be used to provide information that collectively and consistently supports the natural reduction and removal of the dissolved contaminant plume.

Figure 1 outlines the steps involved in the natural attenuation demonstration. This figure also shows the important regulatory decision points in the process of implementing natural attenuation. Predicting the fate of a contaminant plume requires the quantification of solute transport and transformation processes. Quantification of contaminant migration and attenuation rates and successful implementation of the natural attenuation remedial option requires completion of the following steps:

1. Review available site data, and develop a preliminary conceptual model.
2. Screen the site, and assess the potential for natural attenuation.
3. Collect additional site characterization data to support natural attenuation, as required.
4. Refine the conceptual model, complete premodeling calculations, and document indicators of natural attenuation.
5. Simulate natural attenuation using analytical or numerical solute fate-and-transport models that allow incorporation of a biodegradation term, as necessary.
6. Identify potential receptors, and conduct an exposure-pathway analysis.
7. Evaluate the practicability and potential efficiency of supplemental source removal options.
8. If natural attenuation with or without source removal is acceptable, prepare a long-term monitoring plan.
9. Present findings to regulatory agencies, and obtain approval for remediation by natural attenuation.

Review Available Site Data, and Develop a Preliminary Conceptual Model

Existing site characterization data should be reviewed and used to develop a conceptual model for the site. The preliminary conceptual model will help identify any shortcomings in the data and will allow placement of additional data collection points in the most scientifically advantageous and cost-effective manner. A conceptual model is a three-dimensional representation of the ground-water flow and solute transport system based on available geological, biological, geochemical, hydrological, climatological, and analytical data for the site. This type of conceptual model differs from the conceptual site models that risk assessors commonly use that qualitatively consider the location of contaminant sources, release mechanisms, transport pathways, exposure points, and receptors. The ground-water system conceptual model, however, facilitates identification of these risk-assessment elements for the exposure pathways analysis. After development, the conceptual model can be used to help determine optimal placement of additional data collection points (as necessary) to aid in the natural attenuation investigation and to develop the solute fate-and-transport model.

Contracting and management controls must be flexible enough to allow for the potential for revisions to the conceptual model and thus the data collection effort. In cases where few or no site-specific data are available, all future site characterization activities should be designed to collect the data necessary to screen the site to determine the potential for remediation by natural attenuation. The additional costs incurred by such data collection are greatly outweighed by the cost savings that will be realized if natural attenuation is selected. Moreover, most of the data collected in support of natural attenuation can be used to design and support other remedial measures.

Table 1 contains the soil and ground-water analytical protocol for natural attenuation of chlorinated aliphatic hydrocarbons and/or fuel hydrocarbons. Table 1A lists a standard set of methods, while Table 1B lists methods that are under development and/or consideration. Any plan to collect additional ground-water and soil quality data should include targeting the analytes listed in Table 1A, and possibly Table 1B.

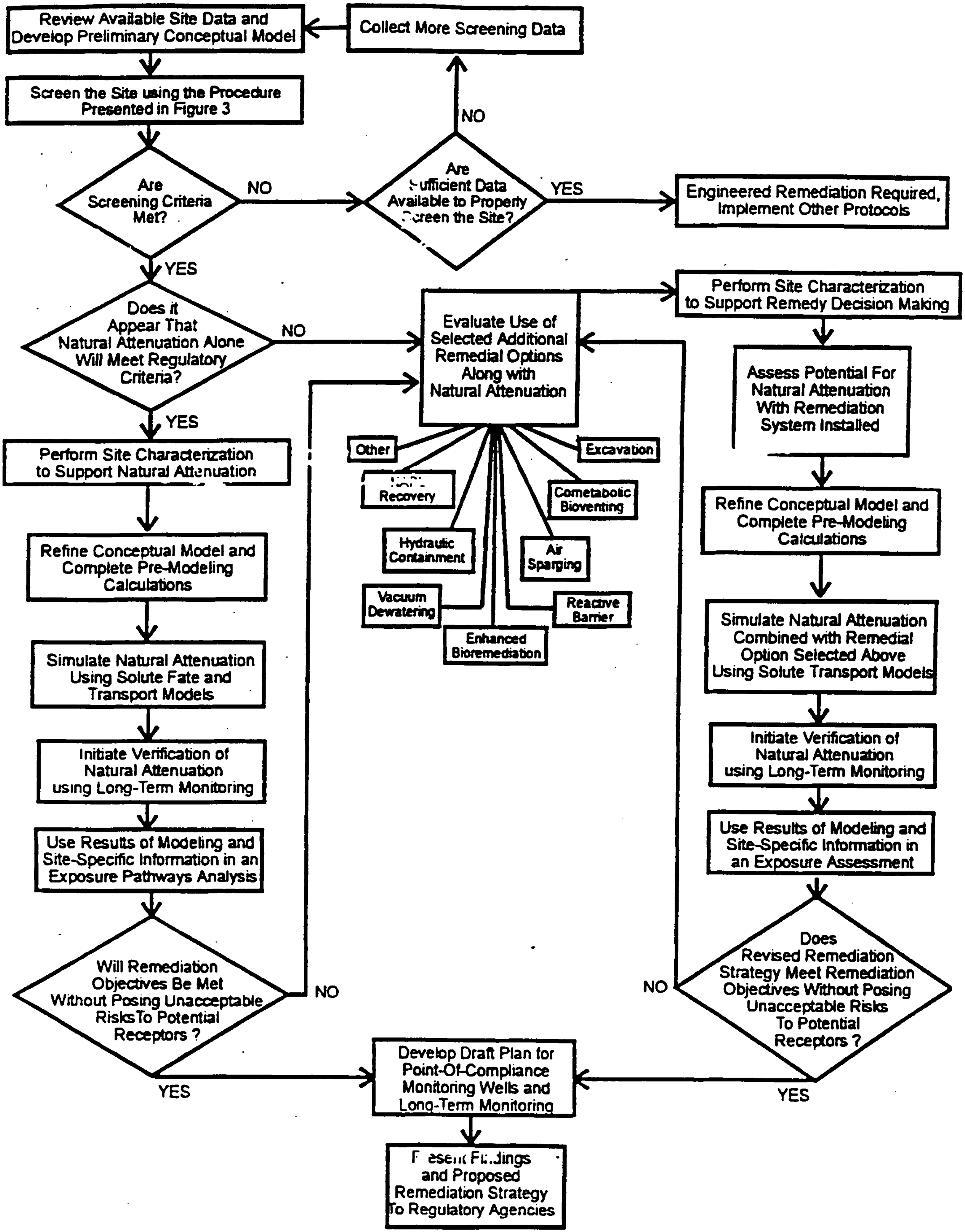

Figure 1. Natural attenuation of chlorinated solvents flow chart.

Table 1A. Soil and Ground-Water Analytical Protocol[a]

Matrix	Analysis	Method/Reference[b-e]	Comments[f,g]	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil	Volatile organic compounds	SW8260A	Handbook method modified for field extraction of soil using methanol	Useful for determining the extent of soil contamination, the contaminant mass present, and the need for source removal	Each soil sampling round	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil	Total organic carbon (TOC)	SW9060, modified for soil samples	Procedure must be accurate over the range of 0.5 to 15% TOC	The amount of TOC in the aquifer matrix influences contaminant migration and biodegradation	At initial sampling	Collect 100 g of soil in a glass container with Teflon-lined cap; cool to 4°C	Fixed-base
Soil gas	O_2, CO_2	Field soil gas analyzer		Useful for determining bioactivity in the vadose zone	At initial sampling and respiration testing	Reuseable 3-L Tedlar bags	Field
Soil gas	Fuel and chlorinated volatile organic compounds	EPA Method TO-14		Useful for determining the distribution of chlorinated and BTEX compounds in soil	At initial sampling	1-L Summa canister	Fixed-base
Water	Volatile organic compounds	SW8260A	Handbook method; analysis may be extended to higher molecular-weight alkyl benzenes	Method of analysis for BTEX and chlorinated solvents/byproducts	Each sampling round	Collect water samples in a 40-mL volatile organic analysis vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional; intended for diesel and other heavy oils)	Gas chromatography/ mass spectroscopy Method SW8270B; high-performance liquid chromatography Method SW8310	Analysis needed only when required for regulatory compliance	PAHs are components of fuel and are typically analyzed for regulatory compliance	As required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base
Water	Oxygen	DO meter	Refer to Method A4500 for a comparable laboratory procedure	Concentrations less than 1 mg/L generally indicate an anaerobic pathway	Each sampling round	Measure DO on site using a flow-through cell	Field
Water	Nitrate	Iron chromatography Method E300; anion method	Method E300 is a handbook method; also provides chloride data	Substrate for microbial respiration if oxygen is depleted	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; add H_2SO_4 to pH less than 2; cool to 4°C	Fixed-base
Water	Iron(II) (Fe^{+2})	Colorimetric HACH Method 8146	Filter if turbid	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese	Each sampling round	Collect 100 mL of water in a glass container	Field

Table 1A. Soil and Ground-Water Analytical Protocol[a] (Continued)

Matrix	Analysis	Method/Reference[b-e]	Comments[f,g]	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Sulfate (SO_4-2)	Iron chromatography Method E300 or HACH Method 8051	Method E300 is a handbook method, HACH Method 8051 is a colorimetric method; use one or the other	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	E300 = Fixed-base HACH Method 8051 = Field
Water	Methane, ethane, and ethene	Kampbell et al. (35) or SW3810, modified	Method published by EPA researchers	The presence of CH_4 suggests biodegradation of organic carbon via methanogensis; ethane and ethane are produced during reductive dechlorination	Each sampling round	Collect water samples in 50 mL glass serum bottles with butyl gray/Teflon-lined caps; add H_2SO_4 to pH less than 2; cool to 4°C	Fixed-base
Water	Alkalinity	HACH alkalinity test kit Model AL AP MG-L	Phenolphtalein method	Water quality parameter used to measure the buffering capacity of ground water; can be used to estimate the amount of CO_2 produced during biodegradation	Each sampling round	Collect 100 mL of water in glass container	Field
Water	Oxidation-reduction potential	A2580B	Measurements made with electrodes, results are displayed on a meter, protect samples from exposure to oxygen; report results against a silver/silver chloride reference electrode	The oxidation-reduction potential of ground water influences and is influenced by the nature of the biologically mediated degradation of contaminants; the oxidation-reduction potential of ground water may range from more than 800 mV to less than -400 mV	Each sampling round	Collect 100 to 250 mL of water in a glass container	Field
Water	pH	Field probe with direct reading meter	Field	Aerobic and anaerobic processes are pH-sensitive	Each sampling round	Collect 100 to 250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Temperature	Field probe with direct reading meter	Field only	Well development	Each sampling round	Not applicable	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/ Handbook methods	Water quality parameter used as a marker to verify that site samples are obtained from the same ground-water system	Each sampling round	Collect 100 to 250 mL of water in a glass or plastic container	Field
Water	Chloride	Mercuric nitrate titration A4500-Cl^- C	Ion chromatography Method E300; Method SW9050 may also be used	Final product of chlorinated solvent reduction; can be used to estimate dilution in calculation of rate constant	Each sampling round	Collect 250 mL of water in a glass container	Fixed-base

Table 1A. Soil and Ground-Water Analytical Protocol[a] (Continued)

Matrix	Analysis	Method/Reference[b-e]	Comments[f,g]	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Chloride (optional; see data use)	HACH chloride test kit Model 8-P	Silver nitrate titration	As above, and to guide selection of additional data points in real time while in the field	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Total organic carbon	SW9060	Laboratory	Used to classify plumes and to determine whether anaerobic metabolism of chlorinated solvents is possible in the absence of anthropogenic carbon	Each sampling round	Collect 100 mL of water in a glass container; cool	Laboratory

[a] Analyses other than those listed in this table may be required for regulatory compliance.
[b] "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods* (29).
[c] "E" refers to *Methods for Chemical Analysis of Water and Wastes* (30).
[d] "HACH" refers to the Hach Company catalog (31).
[e] "A" refers to *Standard Methods for the Examination of Water and Wastewater* (32).
[f] "Handbook" refers to the AFCEE *Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS)* (33).
[g] "Protocols" refers to the AFCEE *Environmental Chemistry Function Installation Restoration Program Analytical Protocols* (34).

Table 1B. Soil and Ground-Water Analytical Protocol: Special Analyses Under Development and/or Consideration[a,b]

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Container, Preservation	Field or Fixed-Base Laboratory
Soil	Biologically available iron(III)	Under development	HCl extraction followed by quantification of released iron(III)	To predict the possible extent of iron reduction in an aquifer	One round of sampling in five borings, five cores from each boring	Collect minimum 1-inch diameter core samples into a plastic liner; cap and prevent aeration	Laboratory
Water	Nutritional quality of native organic matter	Under development	Spectro-photometric method	To determine the extent of reductive dechlorination allowed by the supply of electron donor	One round of sampling in two to five wells	Collect 1,000 mL in an amber glass container	Laboratory
Water	Hydrogen (H_2)	Equilibration with gas in the field; determined with a reducing gas detector	Specialized analysis	To determine the terminal electron accepting process; predicts the possibility for reductive dechlorination	One round of sampling	Sampling at well head requires the production of 100 mL per minute of water for 30 minutes	Field
Water	Oxygenates (including methyl-*tert*-butyl ether, ethers, acetic acid, methanol, and acetone)	SW8260/8015[c]	Laboratory	Contaminant or electron donors for dechlorination of solvents	At least one sampling round or as determined by regulators	Collect 1 L of water in a glass container; preserve with HCl	Laboratory

[a] Analyses other than those listed in this table may be required for regulatory compliance.
[b] Site characterization should not be delayed if these methods are unavailable.
[c] "SW" refers to *Test Methods for Evaluating Solid Waste, Physical and Chemical Methods* (29).

Screen the Site, and Assess the Potential for Natural Attenuation

After reviewing available site data and developing a preliminary conceptual model, an assessment of the potential for natural attenuation must be made. As stated previously, existing data can be useful in determining whether natural attenuation will be sufficient to prevent a dissolved contaminant plume from completing exposure pathways, or from reaching a predetermined point of compliance, in concentrations above applicable regulatory or risk-based corrective action standards. Determining the likelihood of exposure pathway completion is an important component of the natural attenuation investigation. This is achieved by estimating the migration and future extent of the plume based on contaminant properties, including volatility, sorptive properties, and biodegradability; aquifer properties, including hydraulic gradient, hydraulic conductivity, porosity, and total organic carbon (TOC) content; and the location of the plume and contaminant source relative to potential receptors (i.e., the distance between the leading edge of the plume and the potential receptor exposure points). These parameters (estimated or actual) are used in this section to make a preliminary assessment of the effectiveness of natural attenuation in reducing contaminant concentrations.

If, after completing the steps outlined in this section, it appears that natural attenuation will be a significant factor in contaminant removal, detailed site characterization activities in support of this remedial option should be performed. If exposure pathways have already been completed and contaminant concentrations exceed regulatory levels, or if such completion is likely, other remedial measures should be considered, possibly in conjunction with natural attenuation. Even so, the collection of data in support of the natural attenuation option can be integrated into a comprehensive remedial plan and may help reduce the cost and duration of other remedial measures, such as intensive source removal operations or pump-and-treat technologies. For example, dissolved iron concentrations can have a profound influence on the design of pump-and-treat systems.

Based on the experience of the authors, in an estimated 80 percent of fuel hydrocarbon spills at federal facilities, natural attenuation alone will be protective of human health and the environment. For spills of chlorinated aliphatic hydrocarbons at federal facilities, however, natural attenuation alone will be protective of human health and the environment in an estimated 20 percent of the cases. With this in mind, it is easy to understand why an accurate assessment of the potential for natural biodegradation of chlorinated compounds should be made before investing in a detailed study of natural attenuation. The screening process presented in this section is outlined in Figure 2. This approach should allow the investigator to determine whether natural attenuation is likely to be a viable remedial alternative before additional time and money are expended. The data required to make the preliminary assessment of natural attenuation can also be used to aid the design of [illegible] engineered remedial solution, should the screening process suggest that natural attenuation alone is not feasible.

The following information is required for the screening process:

- The chemical and geochemical data presented in Table 2 for a minimum of six samples. Figure 3 shows the approximate location of these data collection points. If other contaminants are suspected, then data on the concentration and distribution of these compounds also should be obtained.
- Locations of source(s) and receptor(s).
- An estimate of the contaminant transport velocity and direction of ground-water flow.

Once these data have been collected, the screening process can be undertaken. The following steps summarize the screening process:

1. Determine whether biodegradation is occurring using geochemical data. If biodegradation is occurring, proceed to Step 2. If it is not, assess the amount and types of data available. If data are insufficient to determine whether biodegradation is occurring, collect supplemental data.
2. Determine ground-water flow and solute transport parameters. Hydraulic conductivity and porosity may be estimated, but the ground-water gradient and flow direction may not. The investigator should use the highest hydraulic conductivity measured at the site during the preliminary screening because solute plumes tend to follow the path of least resistance (i.e., highest hydraulic conductivity). This will give the "worst case" estimate of solute migration over a given period.
3. Locate sources and receptor exposure points.
4. Estimate the biodegradation rate constant. Biodegradation rate constants can be estimated using a conservative tracer found commingled with the contaminant plume, as described by Wiedemeier et al. (36). When dealing with a plume that contains only chlorinated solvents, this procedure will have to be modified to use chloride as a tracer. Rate constants derived from microcosm studies can also be used. If it is not possible to estimate the biodegradation rate using these procedures, then use a range of accepted literature values for biodegradation of the contaminants of concern.

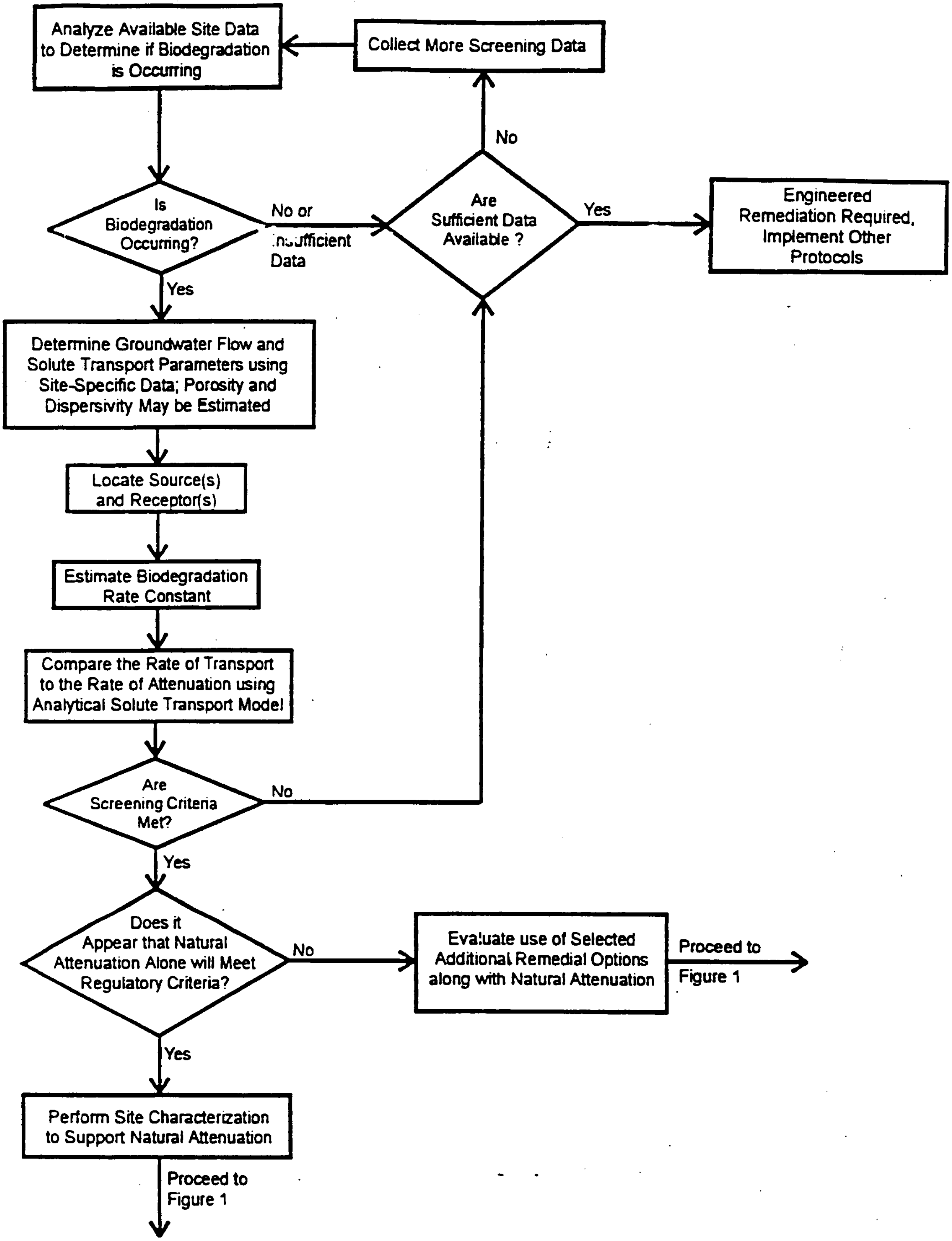

Figure 2. Initial screening process flow chart.

Table 2. Analytical Parameters and Weighting for Preliminary Screening

Analyte	Concentration in Most Contaminated Zone	Interpretation	Points Awarded
Oxygen[a]	< 0.5 mg/L	Tolerated; suppresses reductive dechlorination at higher concentrations	3
Oxygen[a]	> 1 mg/L	Vinyl chloride may be oxidized aerobically, but reductive dechlorination will not occur	-3
Nitrate[a]	< 1 mg/L	May compete with reductive pathway at higher concentrations	2
Iron (II)[a]	> 1 mg/L	Reductive pathway possible	3
Sulfate[a]	< 20 mg/L	May compete with reductive pathway at higher concentrations	2
Sulfide[a]	> 1 mg/L	Reductive pathway possible	3
Methane[a]	> 0.1 mg/L	Ultimate reductive daughter product	2
	> 1	Vinyl chloride accumulates	3
	< 1	Vinyl chloride oxidizes	
Oxidation reduction potential[a]	< 50 mV against Ag/AgCl	Reductive pathway possible	< 50 mV = 1 < -100 mV = 2
pH[a]	5 < pH < 9	Tolerated range for reductive pathway	
DOC	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2
Temperature[a]	> 20°C	At T > 20ÉC, biochemical process is accelerated	1
Carbon dioxide	> 2x background	Ultimate oxidative daughter product	1
Alkalinity	> 2x background	Results from interaction of carbon dioxide with aquifer minerals	1
Chloride[a]	> 2x background	Daughter product of organic chlorine; compare chloride in plume to background conditions	2
Hydrogen	> 1 nM	Reductive pathway possible; vinyl chloride may accumulate	3
Hydrogen	< 1 nM	Vinyl chloride oxidized	
Volatile fatty acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2
BTEX[a]	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2
Perchloroethene[a]		Material released	
Trichloroethene[a]		Material released or daughter product of perchloroethene	2[b]
Dichloroethene[a]		Material released or daughter product of trichloroethene; if amount of *cis*-1,2-dichloroethene is greater than 80% of total dichloroethene, it is likely a daughter product of trichloroethene	2[b]
Vinyl chloride[a]		Material released or daughter product of dichloroethenes	2[b]
Ethene/Ethane	< 0.1 mg/L	Daughter product of vinyl chloride/ethene	> 0.01 mg/L= 2 > 0.1 = 3
Chloroethane[a]		Daughter product of vinyl chloride under reducing conditions	2
1,1,1-Trichloroethane[a]		Material released	
1,1-dichloroethene[a]		Daughter product of trichloroethene or chemical reaction of 1,1,1-trichloroethane	

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[a] Required analysis.

[b] Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

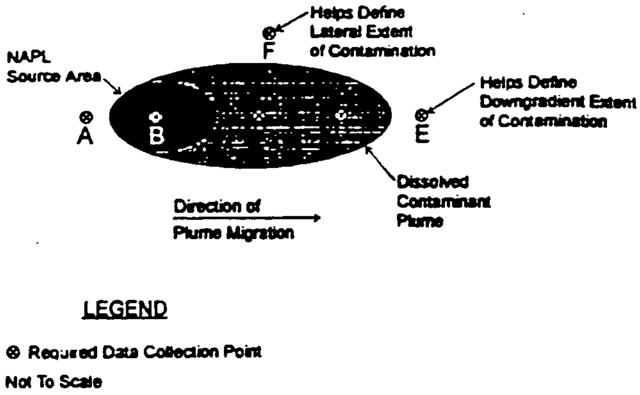


Figure 3. Data collection points required for screening.

5. Compare the rate of transport to the rate of attenuation, using analytical solutions or a screening model such as BIOSCREEN.
6. Determine whether the screening criteria are met.

Each of these steps is described in detail below.

Step 1: Determine Whether Biodegradation Is Occurring

The first step in the screening process is to sample at least six wells that are representative of the contaminant flow system and to analyze the samples for the parameters listed in Table 2. Samples should be taken 1) from the most contaminated portion of the aquifer (generally in the area where NAPL currently is present or was present in the past); 2) downgradient from the NAPL source area but still in the dissolved contaminant plume; 3) downgradient from the dissolved contaminant plume; and 4) from upgradient and lateral locations that are not affected by the plume.

Samples collected in the NAPL source area allow determination of the dominant terminal electron-accepting processes at the site. In conjunction with samples collected in the NAPL source zone, samples collected in the dissolved plume downgradient from the NAPL source zone allow the investigator to determine whether the plume is degrading with distance along the flow path and what the distribution of electron acceptors and donors and metabolic byproducts might be along the flow path. The sample collected downgradient from the dissolved plume aids in plume delineation and allows the investigator to determine whether metabolic byproducts are present in an area of ground water that has been remediated. The upgradient and lateral samples allow delineation of the plume and indicate background concentrations of the electron acceptors and donors.

After these samples have been analyzed for the parameters listed in Table 2, the investigator should analyze the data to determine whether biodegradation is occurring. The right-hand column of Table 2 contains scoring values that can be used for this task. For example, if the DO concentration in the area of the plume with the highest contaminant concentration is less than 0.5 milligrams per liter, this parameter is awarded 3 points. Table 3 summarizes the range of possible scores and gives an interpretation for each score. If the site scores a total of 15 or more points, biodegradation is probably occurring, and the investigator can proceed to Step 2. This method relies on the fact that biodegradation will cause predictable changes in ground-water chemistry.

Table 3. Interpretation of Points Awarded During Screening Step 1

Score	Interpretation
0 to 5	Inadequate evidence for biodegradation of chlorinated organics
6 to 14	Limited evidence for biodegradation of chlorinated organics
15 to 20	Adequate evidence for biodegradation of chlorinated organics
> 20	Strong evidence for biodegradation of chlorinated organics

Consider the following two examples. Example 1 contains data for a site with strong evidence that reductive dechlorination is occurring. Example 2 contains data for a site with strong evidence that reductive dechlorination is not occurring.

Example 1. Strong Evidence for Biodegradation of Chlorinated Organics

Analyte	Concentration in Most Contaminated Zone	Points Awarded
DO	0.1 mg/L	3
Nitrate	0.3 mg/L	2
Iron(II)	10 mg/L	3
Sulfate	2 mg/L	2
Methane	5 mg/L	3
Oxidation-reduction potential	-190 mV	2
Chloride	3x background	2
Perchloroethene (released)	1,000 µg/L	0
Trichloroethene (none released)	1,200 µg/L	2
cis-1,2-Dichloroethene (none released)	500 µg/L	2
Vinyl chloride (none released)	50 µg/L	2
	Total points awarded	23

In this example, the investigator can infer that biodegradation is occurring and may proceed to Step 2.

Example 2. Biodegradation of Chlorinated Organics Unlikely

Analyte	Concentration in Most Contaminated Zone	Points Awarded
DO	3 mg/L	-3
Nitrate	0.5 mg/L	2
Iron(II)	Not detected	0
Sulfate	10 mg/L	2
Methane	ND	0
Oxidation-reduction potential	100 mV	0
Chloride	Background	0
Trichloroethene (released)	1,200 µg/L	0
cis-1,2-Dichloroethene	Not detected	0
Vinyl chloride	ND	0
	Total points awarded	1

In this example, the investigator can infer that biodegradation is probably not occurring or is occurring too slowly to be a viable remedial option. In this case, the investigator cannot proceed to Step 2 and will likely have to implement an engineered remediation system.

Step 2: Determine Ground-Water Flow and Solute Transport Parameters

After biodegradation has been shown to be occurring, it is important to quantify ground-water flow and solute transport parameters. This will make it possible to use a solute transport model to quantitatively estimate the concentration of the plume and its direction and rate of travel. To use an analytical model, it is necessary to know the hydraulic gradient and hydraulic conductivity for the site and to have estimates of the porosity and dispersivity. The coefficient of retardation also is helpful to know. Quantification of these parameters is discussed by Wiedemeier et al. (1).

To make modeling as accurate as possible, the investigator must have site-specific hydraulic gradient and hydraulic conductivity data. To determine the ground-water flow and solute transport direction, the site must have at least three accurately surveyed wells. The porosity and dispersivity are generally estimated using accepted literature values for the types of sediments found at the site. If the investigator does not have TOC data for soil, the coefficient of retardation can be estimated; however, assuming that the solute transport and ground-water velocities are the same may be more conservative.

Step 3: Locate Sources and Receptor Exposure Points

To determine the length of flow for the predictive modeling conducted in Step 5, it is important to know the distance between the source of contamination, the downgradient end of the dissolved plume, and any potential downgradient or cross-gradient receptors.

Step 4: Estimate the Biodegradation Rate Constant

Biodegradation is the most important process that degrades contaminants in the subsurface; therefore, the biodegradation rate is one of the most important model input parameters. Biodegradation of chlorinated aliphatic hydrocarbons can commonly be represented as a first-order rate constant. Site-specific biodegradation rates generally are best to use. Calculation of site-specific biodegradation rates is discussed by Wiedemeier et al. (1, 36, 37). If determining site-specific biodegradation rates is impossible, then literature values for the biodegradation rate of the contaminant of interest must be used. It is generally best to start with the average value and then to vary the model input to predict "best case" and "worst case" scenarios. Estimated biodegradation rates can be used only after biodegradation has been shown to be occurring (see Step 1).

Step 5: Compare the Rate of Transport to the Rate of Attenuation

At this early stage in the natural attenuation demonstration, comparison of the rate of solute transport to the rate of attenuation is best accomplished using an analytical model. Several analytical models are available, but the BIOSCREEN model is probably the simplest to use. This model is nonproprietary and is available from the Robert S. Kerr Laboratory's home page on the Internet (www.epa.gov/ada/kerrlab.html). The BIOSCREEN model is based on Domenico's solution to the advection-dispersion equation (38), and allows use of either a first-order biodegradation rate or an instantaneous reaction between contaminants and electron acceptors to simulate the effects of biodegradation. To model transport of chlorinated aliphatic hydrocarbons using BIOSCREEN, only the first-order decay rate option should be used. BIOCHLOR, a similar model, is under development by the Technology Transfer Division of AFCEE. This model will likely use the same analytical solution as BIOSCREEN but will be geared towards evaluating transport of chlorinated compounds under the influence of biodegradation.

The primary purpose of comparing the rate of transport with the rate of attenuation is to determine whether the residence time along the flow path is adequate to be protective of human health and the environment (i.e., to qualitatively estimate whether the contaminant is attenuating at a rate fast enough to allow degradation of the contaminant to acceptable concentrations before receptors are reached). It is important to perform a sensitivity analysis to help evaluate the confidence in the preliminary screening modeling effort. If modeling shows that receptors may not be exposed to contaminants at concentrations above risk-based corrective action criteria, then the screening criteria are met, and the investigator can proceed with the natural attenuation feasibility study.

Step 6: Determine Whether the Screening Criteria Are Met

Before proceeding with the full-scale natural attenuation feasibility study, the investigator should ensure that the answers to all of the following criteria are "yes":

- Has the plume moved a distance less than expected, based on the known (or estimated) time since the contaminant release and the contaminant velocity, as calculated from site-specific measurements of hydraulic conductivity and hydraulic gradient, as well as estimates of effective porosity and contaminant retardation?
- Is it likely that the contaminant mass is attenuating at rates sufficient to be protective of human health and the environment at a point of discharge to a sensitive environmental receptor?
- Is the plume going to attenuate to concentrations less than risk-based corrective action guidelines before reaching potential receptors?

Collect Additional Site Characterization Data To Support Natural Attenuation, As Required

Detailed site characterization is necessary to document the potential for natural attenuation. Review of existing site characterization data is particularly useful before initiating site characterization activities. Such review should allow identification of data gaps and guide the most effective placement of additional data collection points.

There are two goals during the site characterization phase of a natural attenuation investigation. The first is to collect the data needed to determine whether natural mechanisms of contaminant attenuation are occurring at rates sufficient to protect human health and the environment. The second is to provide sufficient site-specific data to allow prediction of the future extent and concentration of a contaminant plume through solute fate-and-transport modeling. Because the burden of proof for natural attenuation is on the proponent, detailed site characterization is required to achieve these goals and to support this remedial option. Adequate site characterization in support of natural attenuation requires that the following site-specific parameters be determined:

- The extent and type of soil and ground-water contamination.
- The location and extent of contaminant source area(s) (i.e., areas containing mobile or residual NAPL).
- The potential for a continuing source due to leaking tanks or pipelines.
- Aquifer geochemical parameters.
- Regional hydrogeology, including drinking water aquifers and regional confining units.
- Local and site-specific hydrogeology, including local drinking water aquifers; location of industrial, agricultural, and domestic water wells; patterns of aquifer use (current and future); lithology; site stratigraphy, including identification of transmissive and nontransmissive units; grain-size distribution (sand versus silt versus clay); aquifer hydraulic conductivity; ground-water hydraulic information; preferential flow paths; locations and types of surface water bodies; and areas of local ground-water recharge and discharge.
- Identification of potential exposure pathways and receptors.

The following sections describe the methodologies that should be implemented to allow successful site characterization in support of natural attenuation. Additional information can be obtained from Wiedemeier et al. (1, 37).

Soil Characterization

To adequately define the subsurface hydrogeologic system and to determine the amount and three-dimensional distribution of mobile and residual NAPL that can act as a continuing source of ground-water contamination, extensive soil characterization must be completed. Depending on the status of the site, this work may have been completed during previous remedial investigation activities. The results of soils characterization will be used as input into a solute fate-and-transport model to help define a contaminant source term and to support the natural attenuation investigation.

The purpose of soil sampling is to determine the subsurface distribution of hydrostratigraphic units and the distribution of mobile and residual NAPL. These objectives can be achieved through the use of conventional soil borings or direct-push methods (e.g., Geoprobe or cone penetrometer testing). All soil samples should be collected, described, analyzed, and disposed of in accordance with local, state, and federal guidance. Wiedemeier et al. (1) present suggested procedures for soil sample collection. These procedures may require modification to comply with local, state, and federal regulations or to accommodate site-specific conditions.

The analytical protocol to be used for soil sample analysis is presented in Table 1. This analytical protocol includes all of the parameters necessary to document natural attenuation, including the effects of sorption and biodegradation. Knowledge of the location, distribution, concentration, and total mass of contaminants of regulatory concern sorbed to soils or present as residual and/or mobile NAPL is required to calculate contaminant partitioning from NAPL into ground water. Knowledge of the TOC content of the aquifer matrix is important for sorption and solute-retardation calculations. TOC samples should be collected from a background location in the stratigraphic horizon(s) where most contaminant transport is expected to occur. Oxygen and carbon dioxide measurements of soil gas can be used to find areas in the unsaturated zone where biodegradation is occurring. Knowledge of the distribution of contaminants in soil gas can be used as a cost-effective way to estimate the extent of soil contamination.

Ground-Water Characterization

To adequately determine the amount and three-dimensional distribution of dissolved contamination and to document the occurrence of natural attenuation, ground-water samples must be collected and analyzed. Biodegradation of organic compounds, whether natural or anthropogenic, brings about measurable changes in the chemistry of ground water in the affected area. By measuring these changes, documentation and quantitative evaluation of natural attenuation's importance at a site are possible.

Ground-water sampling is conducted to determine the concentrations and distribution of contaminants, daughter products, and ground-water geochemical parameters. Ground-water samples may be obtained from monitoring wells or with point-source sampling devices such as a Geoprobe, Hydropunch, or cone penetrometer. All ground-water samples should be collected in accordance with local, state, and federal guidelines. Wiedemeier et al. (1) suggest procedures for ground-water sample collection. These procedures may need to be modified to comply with local, state, and federal regulations or to accommodate site-specific conditions.

The analytical protocol for ground-water sample analysis is presented in Table 1. This analytical protocol includes all of the parameters necessary to document natural attenuation, including the effects of sorption and biodegradation. Data obtained from the analysis of ground water for these analytes is used to scientifically document natural attenuation and can be used as input into a solute fate-and-transport model. The following paragraphs describe each ground-water analytical parameter and the use of each analyte in the natural attenuation demonstration.

Volatile organic compound analysis (by Method SW8260a) is used to determine the types, concentrations, and distributions of contaminants and daughter products in the aquifer. DO is the electron acceptor most thermodynamically favored by microbes for the biodegradation of organic carbon, whether natural or anthropogenic. Reductive dechlorination will not occur, however, if DO concentrations are above approximately 0.5 milligrams per liter. During aerobic biodegradation of a substrate, DO concentrations decrease because of the microbial oxygen demand. After DO depletion, anaerobic microbes will use nitrate as an electron acceptor, followed by iron(III), then sulfate, and finally carbon dioxide (methanogenesis). Each sequential reaction drives the oxidation-reduction potential of the ground water further into the realm where reductive dechlorination can occur. The oxidation-reduction potential range of sulfate reduction and methanogenesis is optimal, but reductive dechlorination may occur under nitrate- and iron(III)-reducing conditions as well. Because reductive dechlorination works best in the sulfate-reduction and methanogenesis oxidation-reduction potential range, competitive exclusion between microbial sulfate reducers, methanogens, and reductive dechlorinators can occur.

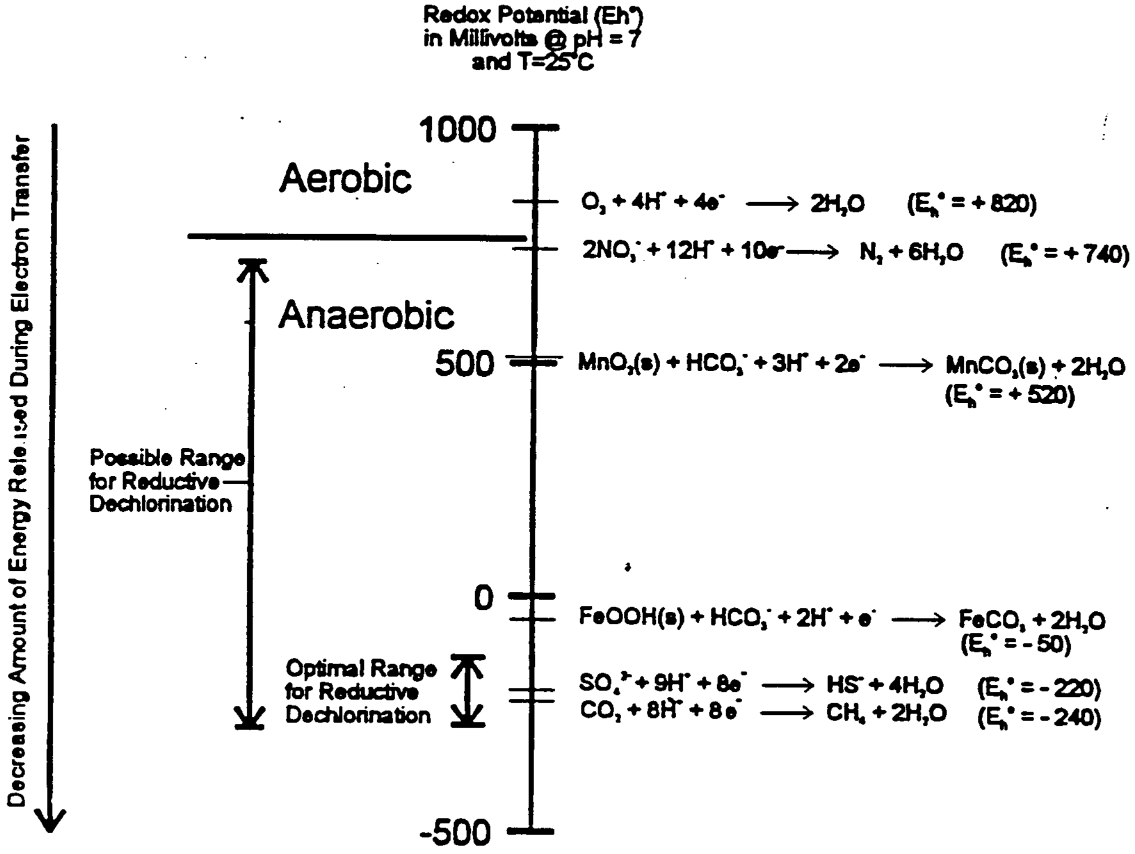
After DO has been depleted in the microbiological treatment zone, nitrate may be used as an electron acceptor for anaerobic biodegradation via denitrification. In some cases iron(III) is used as an electron acceptor during anaerobic biodegradation of electron donors. During this process, iron(III) is reduced to iron(II), which may be soluble in water. Iron(II) concentrations can thus be used as an indicator of anaerobic degradation of fuel compounds. After DO, nitrate, and bioavailable iron(III) have been depleted in the microbiological treatment zone, sulfate may be used as an electron acceptor for anaerobic biodegradation. This process is termed sulfate reduction and results in the production of sulfide. During methanogenesis (an anaerobic biodegradation process), carbon dioxide (or acetate) is used as an electron acceptor, and methane is produced. Methanogenesis generally occurs after oxygen, nitrate, bioavailable iron(III), and sulfate have been depleted in the treatment zone. The presence of methane in ground water is indicative of strongly reducing conditions. Because methane is not present in fuel, the presence of methane in ground water above background concentrations in contact with fuels is indicative of microbial degradation of fuel hydrocarbons.

The total alkalinity of a ground-water system is indicative of a water's capacity to neutralize acid. Alkalinity is defined as "the net concentration of strong base in excess of strong acid with a pure CO_2-water system as the point of reference" (39). Alkalinity results from the presence of hydroxides, carbonates, and bicarbonates of elements such as calcium, magnesium, sodium, potassium, or ammonia. These species result from the dissolution of rock (especially carbonate rocks), the transfer of carbon dioxide from the atmosphere, and the respiration of microorganisms. Alkalinity is important in the maintenance of ground-water pH because it buffers the ground-water system against acids generated during both aerobic and anaerobic biodegradation.

In general, areas contaminated by fuel hydrocarbons exhibit a total alkalinity that is higher than that seen in background areas. This is expected because the microbially mediated reactions causing biodegradation of fuel hydrocarbons cause an increase in the total alkalinity in the system. Changes in alkalinity are most pronounced during aerobic respiration, denitrification, iron reduction, and sulfate reduction, and are less pronounced during methanogenesis (40). In addition, Willey et al. (41) show that short-chain aliphatic acid ions produced during biodegradation of fuel hydrocarbons can contribute to alkalinity in ground water.

The oxidation-reduction potential of ground water is a measure of electron activity and an indicator of the relative tendency of a solution to accept or transfer electrons. Redox reactions in ground water containing organic compounds (natural or anthropogenic) are usually biologically mediated; therefore, the oxidation-reduction potential of a ground-water system depends on and influences rates of biodegradation. Knowledge of the oxidation-reduction potential of ground water also is important because some biological processes operate only within a prescribed range of redox conditions. The oxidation-reduction potential of ground water generally ranges from -400 to 800 millivolts (mV). Figure 4 shows the typical redox conditions for ground water when different electron acceptors are used.

Oxidation-reduction potential can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. Mapping the oxidation-reduction potential of the ground water while in the field helps the field scientist to determine the approximate location of the contaminant plume. To perform this task, it is important to have at least one redox measurement (preferably more) from a well located upgradient from the plume. Oxidation-reduction potential measurements should be taken during well purging and immediately before and after sample acquisition using a direct-reading meter. Because most well purging techniques can allow aeration of collected ground-water samples (which can affect oxidation-reduction



Modified From Bouwer (1994)

Figure 4. Redox potentials for various electron acceptors.

potential measurements), it is important to minimize potential aeration.

Dissolved hydrogen concentrations can be used to determine the dominant terminal electron-accepting process in an aquifer. Because of the difficulty in obtaining hydrogen analyses commercially, this parameter should be considered optional at this time. Table 4 presents the range of hydrogen concentrations for a given terminal electron-accepting process. Much research has been done on the topic of using hydrogen measurements to delineate terminal electron-accepting processes (42-44). Because the efficiency of reductive dechlorination differs for methanogenic, sulfate-reducing, iron(III)-reducing, or denitrifying conditions, it is helpful to have hydrogen concentrations to help delineate redox conditions when evaluating the potential for natural attenuation of chlorinated ethenes in ground-water systems. Collection and analysis of ground-water samples for dissolved hydrogen content is not yet commonplace or standardized, however, and requires a relatively expensive field laboratory setup.

Table 4. Range of Hydrogen Concentrations for a Given Terminal Electron-Accepting Process

Terminal Electron-Accepting Process	Hydrogen Concentration (nanomoles per liter)
Denitrification	< 0.1
Iron(III) reduction	0.2 to 0.8
Sulfate reduction	1 to 4
Methanogenesis	> 5

Because the pH, temperature, and conductivity of a ground-water sample can change significantly shortly following sample acquisition, these parameters must be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for DO and redox analyses. The measurements should be made in a clean glass container separate from those intended for laboratory analysis, and the measured values should be recorded in the ground-water sampling record.

The pH of ground water has an effect on the presence and activity of microbial populations in the ground water. This is especially true for methanogens. Microbes capable of degrading chlorinated aliphatic hydrocarbons and petroleum hydrocarbon compounds generally prefer pH values varying from 6 to 8 standard units. Ground-water temperature directly affects the solubility of oxygen and other geochemical species. The solubility of DO is temperature dependent, being more soluble in cold water than in warm water. Ground-water temperature also affects the metabolic activity of bacteria. Rates of hydrocarbon biodegradation roughly double for every 10°C increase in temperature ("Q"$_{10}$ rule) over the temperature range between 5°C and 25°C. Ground-water temperatures less than about 5°C tend to inhibit biodegradation, and slow rates of biodegradation are generally observed in such waters.

Conductivity is a measure of the ability of a solution to conduct electricity. The conductivity of ground water is directly related to the concentration of ions in solution; conductivity increases as ion concentration increases. Conductivity measurements are used to ensure that ground water samples collected at a site are representative of the water in the saturated zone containing the dissolved contamination. If the conductivities of samples taken from different sampling points are radically different, the waters may be from different hydrogeologic zones.

Elemental chlorine is the most abundant of the halogens. Although chlorine can occur in oxidation states ranging from Cl^- to Cl^{+7}, the chloride form (Cl^-) is the only form of major significance in natural waters (45). Chloride forms ion pairs or complex ions with some of the cations present in natural waters, but these complexes are not strong enough to be of significance in the chemistry of fresh water (45). The chemical behavior of chloride is neutral. Chloride ions generally do not enter into oxidation-reduction reactions, form no important solute complexes with other ions unless the chloride concentration is extremely high, do not form salts of low solubility, are not significantly adsorbed on mineral surfaces, and play few vital biochemical roles (45). Thus, physical processes control the migration of chloride ions in the subsurface.

Kaufman and Orlob (46) conducted tracer experiments in ground water and found that chloride moved through most of the soils tested more conservatively (i.e., with less retardation and loss) than any of the other tracers tested. During biodegradation of chlorinated hydrocarbons dissolved in ground water, chloride is released into the ground water. This results in chloride concentrations in the ground water of the contaminant plume that are elevated relative to background concentrations. Because of the neutral chemical behavior of chloride, it can be used as a conservative tracer to estimate biodegradation rates using methods similar to those discussed by Wiedemeier et al. (36).

Field Measurement of Aquifer Hydraulic Parameters

The properties of an aquifer that have the greatest impact on contaminant fate and transport include hydraulic conductivity, hydraulic gradient, porosity, and dispersivity. Estimating hydraulic conductivity and gradient in the field is fairly straightforward, but obtaining field-s[illegible] information on porosity and dispersivity can be difficult.

Therefore, most investigators rely on field data for hydraulic conductivity and hydraulic gradient and on literature values for porosity and dispersivity for the types of sediments present at the site. Methods for field measurement of aquifer hydraulic parameters are described by Wiedemeier et al. (1, 37).

Microbiological Laboratory Data

Microcosm studies are used to show that the microorganisms necessary for biodegradation are present and to help quantify rates of biodegradation. If properly designed, implemented, and interpreted, microcosm studies can provide very convincing documentation of the occurrence of biodegradation. Such studies are the only "line of evidence" that allows an unequivocal mass balance determination based on the biodegradation of environmental contaminants. The results of a well-designed microcosm study will be easy for decision-makers with nontechnical backgrounds to interpret. Results of such studies are strongly influenced by the nature of the geological material submitted for study, the physical properties of the microcosm, the sampling strategy, and the duration of the study. Because microcosm studies are time-consuming and expensive, they should be undertaken only at sites where there is considerable skepticism concerning the biodegradation of contaminants.

Biodegradation rate constants determined by microcosm studies often are much greater than rates achieved in the field. Microcosms are most appropriate as indicators of the potential for natural bioremediation and to prove that losses are biological, but it may be inappropriate to use them to generate rate constants. The preferable method of contaminant biodegradation rate-constant determination is in situ field measurement. The collection of material for the microcosm study, the procedures used to set up and analyze the microcosm, and the interpretation of the results of the microcosm study are presented by Wiedemeier et al. (1).

Refine the Conceptual Model, Complete Premodeling Calculations, and Document Indicators of Natural Attenuation

Site investigation data should first be used to refine the conceptual model and quantify ground-water flow, sorption, dilution, and biodegradation. The results of these calculations are used to scientifically document the occurrence and rates of natural attenuation and to help simulate natural attenuation over time. Because the burden of proof is on the proponent, all available data must be integrated in such a way that the evidence is sufficient to support the conclusion that natural attenuation is occurring.

Conceptual Model Refinement

Conceptual model refinement involves integrating newly gathered site characterization data to refine the preliminary conceptual model that was developed based on previously existing site-specific data. During conceptual model refinement, all available site-specific data should be integrated to develop an accurate three-dimensional representation of the hydrogeologic and contaminant transport system. This conceptual model can then be used for contaminant fate-and-transport modeling. Conceptual model refinement consists of several steps, including preparation of geologic logs, hydrogeologic sections, potentiometric surface/water table maps, contaminant contour (isopleth) maps, and electron acceptor and metabolic byproduct contour (isopleth) maps. Refinement of the conceptual model is described by Wiedemeier et al. (1).

Premodeling Calculations

Several calculations must be made prior to implementation of the solute fate-and-transport model. These calculations include sorption and retardation calculations, NAPL/water-partitioning calculations, ground-water flow velocity calculations, and biodegradation rate-constant calculations. Each of these calculations is discussed in the following sections. Most of the specifics of each calculation are presented in the fuel hydrocarbon natural attenuation technical protocol by Wiedemeier et al. (1), and all will be presented in the protocol incorporating chlorinated aliphatic hydrocarbon attenuation (37).

Biodegradation Rate Constant Calculations

Biodegradation rate constants are necessary to simulate accurately the fate and transport of contaminants dissolved in ground water. In many cases, biodegradation of contaminants can be approximated using first-order kinetics. To calculate first-order biodegradation rate constants, the apparent degradation rate must be normalized for the effects of dilution and volatilization. Two methods for determining first-order rate constants are described by Wiedemeier et al. (36). One method involves the use of a biologically recalcitrant compound found in the dissolved contaminant plume that can be used as a conservative tracer. The other method, proposed by Buscheck and Alcantar (47) involves interpretation of a steady-state contaminant plume and is based on the one-dimensional steady-state analytical solution to the advection-dispersion equation presented by Bear (48). The first-order biodegradation rate constants for chlorinated aliphatic hydrocarbons are also presented (J. Wilson et al., this volume).

Simulate Natural Attenuation Using Solute Fate-and-Transport Models

Simulating natural attenuation using a solute fate-and-transport model allows prediction of the migration and attenuation of the contaminant plume through time. Natural attenuation modeling is a tool that allows site-specific data to be used to predict the fate and transport of solutes under governing physical, chemical, and biological processes. Hence, the results of the modeling effort are not in themselves sufficient proof that natural attenuation is occurring at a given site. The results of the modeling effort are only as good as the original data input into the model; therefore, an investment in thorough site characterization will improve the validity of the modeling results. In some cases, straightforward analytical models of contaminant attenuation are adequate to simulate natural attenuation.

Several well-documented and widely accepted solute fate-and-transport models are available for simulating the fate-and-transport of contaminants under the influence of advection, dispersion, sorption, and biodegradation. The use of solute fate-and-transport modeling in the natural attenuation investigation is described by Wiedemeier et al. (1).

Identify Potential Receptors, and Conduct an Exposure-Pathway Analysis

After the rates of natural attenuation have been documented and predictions of the future extent and concentrations of the contaminant plume have been made using the appropriate solute fate-and-transport model, the proponent of natural attenuation should combine all available data and information to negotiate for implementation of this remedial option. Supporting the natural attenuation option generally will involve performing a receptor exposure-pathway analysis. This analysis includes identifying potential human and ecological receptors and points of exposure under current and future land and ground-water use scenarios. The results of solute fate-and-transport modeling are central to the exposure pathways analysis. If conservative model input parameters are used, the solute fate-and-transport model should give conservative estimates of contaminant plume migration. From this information, the potential for impacts on human health and the environment from contamination present at the site can be estimated.

Evaluate Supplemental Source Removal Options

Source removal or reduction may be necessary to reduce plume expansion if the exposure-pathway analysis suggests that one or more exposure pathways may be completed before natural attenuation can reduce chemical concentrations below risk-based levels of concern. Further, some regulators may require source removal in conjunction with natural attenuation. Several technologies suitable for source reduction or removal are listed in Figure 1. Other technologies may also be used as dictated by site conditions and local regulatory requirements. The authors' experience indicates that source removal can be very effective at limiting plume migration and decreasing the remediation time frame, especially at sites where biodegradation is contributing to natural attenuation of a dissolved contaminant plume. The impact of source removal can readily be evaluated by modifying the contaminant source term if a solute fate-and-transport model has been prepared for a site; this will allow for a reevaluation of the exposure-pathway analysis.

Prepare a Long-Term Monitoring Plan

Ground-water flow rates at many Air Force sites studied to date are such that many years will be required before contaminated ground water could potentially reach Base property boundaries. Thus, there frequently is time and space for natural attenuation alone to reduce contaminant concentrations in ground water to acceptable levels. Experience at 40 Air Force sites contaminated with fuel hydrocarbons using the protocol presented by Wiedemeier et al. (1) suggests that many fuel hydrocarbon plumes are relatively stable or are moving very slowly with respect to ground-water flow. This information is complemented by data collected by Lawrence Livermore National Laboratories in a study of over 1,100 leaking underground fuel tank sites performed for the California State Water Resources Control Board (49). These examples demonstrate the efficacy of long-term monitoring to track plume migration and to validate or refine modeling results. There is not a large enough database available at this time to assess the stability of chlorinated solvent plumes, but in the authors' experience chlorinated solvent plumes are likely to migrate further downgradient than fuel hydrocarbon plumes before reaching steady-state equilibrium or before receding.

The long-term monitoring plan consists of locating ground-water monitoring wells and developing a ground-water sampling and analysis strategy. This plan is used to monitor plume migration over time and to verify that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors. The long-term monitoring plan should be developed based on site characterization data, the results of solute fate-and-transport modeling, and the results of the exposure-pathway analysis.

The long-term monitoring plan includes two types of monitoring wells: long-term monitoring wells are intended to determine whether the behavior of the plume is changing; point-of-compliance wells are intended to detect movements of the plume outside the negotiated perimeter of containment, and to trigger an action to manage the risk associated with such expansion. Figure 5 depicts 1) an upgradient well in unaffected ground water, 2) a well in the NAPL source area, 3) a well downgradient of the NAPL source area in a zone of anaerobic treatment, 4) a well in the zone of aerobic treatment, along the periphery of the plume, 5) a well located downgradient from the plume where contaminant concentrations are below regulatory acceptance levels and soluble electron acceptors are depleted with respect to unaffected ground water, and 6) three point-of-compliance wells.

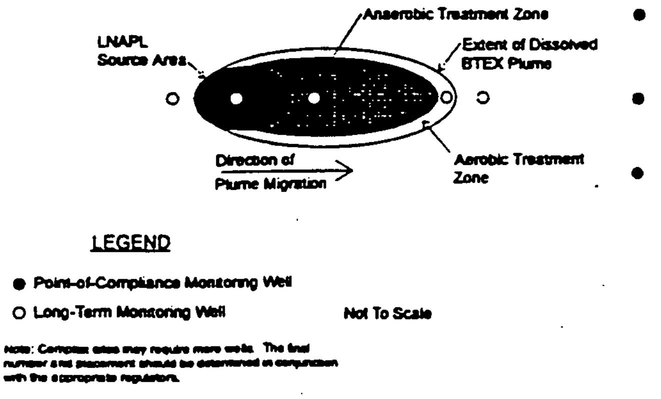


Figure 5. Hypothetical long-term monitoring strategy.

Although the final number and placement of long-term monitoring and point-of-compliance wells is determined through regulatory negotiation, the following guidance is recommended. Locations of long-term monitoring wells are based on the behavior of the plume as revealed during the initial site characterization and on regulatory considerations. Point-of-compliance wells are placed 500 feet downgradient from the leading edge of the plume or the distance traveled by the ground water in 2 years, whichever is greater. If the property line is less than 500 feet downgradient, the point-of-compliance wells are placed near and upgradient from the property line. The final number and location of point-of-compliance monitoring wells also depends on regulatory considerations.

The results of a solute fate-and-transport model can be used to help site the long-term monitoring and point-of-compliance wells. To provide a valid monitoring system, all monitoring wells must be screened in the same hydrogeologic unit as the contaminant plume. This generally requires detailed stratigraphic correlation. To facilitate accurate stratigraphic correlation, detailed visual descriptions of all subsurface materials encountered during borehole drilling should be prepared prior to monitoring-well installation.

A ground-water sampling and analysis plan should be prepared in conjunction with point-of-compliance and long-term monitoring well placement. For long-term monitoring wells, ground-water analyses should include volatile organic compounds, DO, nitrate, iron(II), sulfate, and methane. For point-of-compliance wells, ground-water analyses should be limited to determining volatile organic compound and DO concentrations. Any state-specific analytical requirements also should be addressed in the sampling and analysis plan to ensure that all data required for regulatory decision-making are collected. Water level and LNAPL thickness measurements must be made during each sampling event. Except at sites with very low hydraulic conductivity and gradients, quarterly sampling of long-term monitoring wells is recommended during the first year to help determine the direction of plume migration and to determine baseline data. Based on the results of the first year's sampling, the sampling frequency may be reduced to annual sampling in the quarter showing the greatest extent of the plume. Sampling frequency depends on the final placement of the point-of-compliance monitoring wells and ground-water flow velocity. The final sampling frequency should be determined in collaboration with regulators.

Present Findings to Regulatory Agencies, and Obtain Approval for Remediation by Natural Attenuation

The purpose of regulatory negotiations is to provide scientific documentation that supports natural attenuation as the most appropriate remedial option for a given site. All available site-specific data and information developed during the site characterization, conceptual model development, premodeling calculations, biodegradation rate calculation, ground-water modeling, model documentation, and long-term monitoring plan preparation phases of the natural attenuation investigation should be presented in a consistent and complementary manner at the regulatory negotiations. Of particular interest to the regulators will be proof that natural attenuation is occurring at rates sufficient to meet risk-based corrective action criteria at the point of compliance and to protect human health and the environment. The regulators must be presented with a "weight-of-evidence" argument in support of this remedial option. For this reason, all model assumptions should be conservative, and all available evidence in support of natural attenuation must be presented at the regulatory negotiations.

A comprehensive long-term monitoring and contingency plan also should be presented to demonstrate a commitment to proving the effectiveness of natural attenuation as a remedial option. Because long-term monitoring and contingency plans are very site specific, they should be addressed in the individual reports generated using this protocol.

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