DRAFT FINAL
[redacted] FEASIBILITY STUDY
DRY CLEANING FACILITIES STUDY AREA
FORT RILEY, KANSAS

Prepared for
United States Army Engineer District, Kansas City
CENWK-EP-EG
601 East 12th Street
Kansas City, Missouri 64106-2896

Prepared by
Louis Berger & Associates, Inc.
30 Vreeland Road, Bldg.B
Florham Park, New Jersey 07932

March 1998

Louis Berger & Associates, Inc.
100 Halsted Street, East Orange, New Jersey 07019
Tel 973.678.1960 • Telex 138.152 • Fax 973.672.4284
ENGINEERS • PLANNERS • SCIENTISTS • ECONOMISTS • ARCHAEOLOGISTS

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
Kansas City, MO 64106-2896

RE: DACA41-92-0001 Indefinite Delivery Contract for Various Military Hazardous Waste Cleanup Projects at Fort Riley, Kansas
Delivery Order 35, Draft Final Revised Feasibility Study, Dry Cleaning Facilities Study Area (JH1127/JG1199)

Dear Mr. ~~Van Saun~~: Rick

Louis Berger & Associates, Inc. is pleased to submit 4 copies of the Revised Feasibility Study Report for the Dry Cleaning Facility Area at Fort Riley, Kansas. Also included in the pocket in the front of the binder are the Responses 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

SEK
Enclosures (4)

Copy: Directorate of Environment & Safety
AFZN-ES-L (Attn. John Cook)
Building 407 Main Post
Fort Riley, Kansas 66442-6016
(5 copies)

Bob Koke (2 copies)
Federal Facilities/Special Emphasis Section
Superfund Division
U. S. EPA Region VII
726 Minnesota Ave.
Kansas City, KS 66101

Randy Carlson (2 copies)
Bureau of Environmental
Remediation
KDHE
Forbes Field, Building 740
Topeka, KS 66620

U. S. Army Environmental Center
(2 copies)
ATTN: ENAEC-IR-P/Joe King
Aberdeen Proving Ground, MD
21010-5401

Commander (5 copies)
Center for Health Promotion &
Preventative Medicine
ATTN: HSHB-ME-SR/Larry Tannenbaum
Aberdeen Proving Ground, MD 21010-5401

U. S. Army Corps of Engineers
HTRW-CX (1 copy)
ATTN: CENWO-HX-S (Document
Distribution
12565 West Center Road
Omaha, NE 68144-3869

LBA: T. Lewis
B. Millman
J. Vandervliet

F:\HOME\SKNAUF\RILEY\RFSTRAN.DFI

TABLE OF CONTENTS

Table of Contents

Page

Table of Contents (Continued)

Page

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

Table of Contents (Continued)

References

Appendices

List of Tables

Table of Contents (Continued)

List of Tables (Continued)

List of Figures

List of Acronyms and Abbreviations

AOC	Area of Concern
amsl	Above Mean Sea Level
AR	Army Regulation
ARAR	Applicable or Relevant and Appropriate Requirement
as/sve	Air Sparging/Soil Vapor Extraction
ASTM	American Society of Testing Materials
AWQC	Ambient Water Quality Criteria
bgs	Below Ground Surface
BLRA	Baseline Risk Assessment
BOD	Biochemical Oxygen Demand
BRAC	Base Realignment and Closure
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes

Table of Contents (Continued)

List of Acronyms and Abbreviations (Continued)

°C	Degrees Celsius
CAL	Corrective Action Level (RCRA)
CAMU	Corrective Action Management Unit
CEMRD	U.S. Army Corps of Engineers, Missouri River Division
CEMRO	U.S. Army Corps of Engineers, Omaha Division
CENWK	U.S. Army Corps of Engineers, Northwest District
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation and Liability Information System
CFR	Code of Federal Regulations
cfs	Cubic Feet per Second
CH_4	Methane
CHPPM	Center for Health Policy and Preventive Medicine (formerly USAEHA)
CLP	Contract Laboratory Program
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
COE	Corps of Engineers
CSM	Conceptual Site Model
CWA	Clean Water Act
DA	U.S. Department of the Army
DCA	Dichloroethane
DCE	Dichloroethylene
DEH	Directorate of Engineering and Housing
DNAPL	Dense Non-Aqueous Phase Liquid
DCFA	Dry Cleaning Facilities Area
DSER	Data Summary and Evaluation Report
Elev.	Elevation
ECD	Electron Capture Detector
ESI	Expanded Site Investigation
°F	Degrees Fahrenheit
FEMA	Federal Emergency Management Agency
FFA	Federal Facilities Agreement
FID	Flame Ionization Detector
FOTW	Federally Owned Treatment Work
Ft.	Feet
GAC	Granular Activated Carbon
GC	Gas Chromatography
GC/MS	Gas Chromatography/Mass Spectroscopy
gpm	Gallons per Minute
GRA	General Response Action

Table of Contents (Continued)

List of Acronyms and Abbreviations (Continued)

HRS	Hazard Ranking System
HSWA	Hazardous and Solid Waste Amendments
IAG	Interagency Agreement
IDW	Investigation-Derived Waste
IWSA	Installation-Wide Site Assessment
KDHE	Kansas Department of Health and Environment
KDWP	Kansas Department of Wildlife Protection
KWQS	Kansas Water Quality Standards
kg	Kilogram
KGS	Kansas Geological Survey
MAAF	Marshall Army Airfield
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MDL	Method Detection Limit
mg/m^3	Milligram per Meter Cubed
mg/kg	Milligram per Kilogram
mg/l	Milligram per Liter
mnhr	Manhours
MRD	Missouri River Division Laboratory
msl	Mean Sea Level
MS/MSD	Matrix Spike/Matrix Spike Duplicate
NAAQS	National Ambient Air Quality Standard
NCP	National Contingency Plan
ND	Not Detected (Above Method Detection Limits)
NDA	No Data Available
NEPA	National Environmental Policy Act
No.	Number
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NS	Not Sampled
NYSDEC	New York State Department of Environmental Conservation
O&M	Operations and Maintenance
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PA	Preliminary Assessment
PAH	Polynuclear Aromatic Hydrocarbon
PAOC	Potential Area of Contamination
PA/SI	Preliminary Assessment/Site Investigation

Table of Contents (Continued)

List of Acronyms and Abbreviations (Continued)

PCB	Polychlorinated Biphenyl
PCE	Tetrachloroethylene (Perchloroethylene)
PID	Photoionization Detector
POTW	Publicly Owned Treatment Works
PP	Priority Pollutant
PQL	Practical Quantitation Limit
PSI	Pounds per Square Inch
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
QCSR	Quality Control Summary Report
RA	Removal Action
RAA	Removal Action Alternatives
RAGS	U.S. EPA Risk Assessment Guidance for Superfund
RAO	Remedial Action Objective
RBC	Risk-Based Concentration
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
RG	Remedial Goal
RIAMER	Remedial Investigation Addendum Monitoring Expansion Report
RI/FS	Remedial Investigation/Feasibility Study
RME	Reasonable Maximum Exposure
ROD	Record of Decision
RO	Reverse Osmosis
SA	Site Assessment
SACM	Superfund Accelerated Cleanup Model
SAP	Sampling and Analysis Plan
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SI	Site Investigation
SQL	Sample Quantitation Limit
SVE	Soil Vapor Extraction
SVOC	Semivolatile Organic Compound
TBC	To-Be-Considered
TCE	Trichloroethylene
TCL	Target Compound List
TCLP	Toxicity Characteristic Leaching Procedure
THM	Trihalomethane

Table of Contents (Continued)

List of Acronyms and Abbreviations (Continued)

TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TOX	Total Organic Halogens
TPH	Total Petroleum Hydrocarbons
TSC	U.S. EPA Technical Support Center
TSS	Total Suspended Solids
UCL	Upper Confidence Limit
μg/kg	Micrograms per Kilogram
μg/l	Micrograms per Liter
$\mu g/m^3$	Micrograms per Meter Cubed
UKN	Unknown
UV	Ultraviolet
USAEHA	United States Army Environmental Hygiene Agency
USATHAMA	United States Army Toxic and Hazardous Materials Agency
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UST	Underground Storage Tank
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

Executive Summary

E.1 Introduction and Background Information

Louis Berger & Associates (LBA), under contract DACA41-92-D-0001 with the U.S. Army Corps of Engineers, Northwest Division, Kansas City District (CENWK), has conducted a Remedial Investigation/Feasibility Study (RI/FS) of the Dry Cleaning Facilities Area (DCFA), Fort Riley, Kansas. The DCF Study Area includes the DCFA, which includes approximately 5 acres of upland located at the southwest corner of the Main Post area, and the downgradient alluvial lowland area bounded by the Union Pacific Railroad and the Kansas River, herein referred to as the Island (Figures 1-1 through 1-3). The RI was an extension of a Preliminary Assessment/Site Investigation (PA/SI) conducted in compliance with an Interagency Agreement (IAG) between Fort Riley, the Kansas Department of Health and Environment (KDHE), and the U.S. Environmental Protection Agency (U.S. EPA), Region VII, which was implemented as a result of Fort Riley being placed on the National Priorities List (NPL) on August 30, 1990. The *Draft Final Remedial Investigation Report Dry Cleaning Facilities Area (DCFA-RI) Fort Riley, Kansas* was submitted in March 1995 (CENWK, 1995a) and the *Draft Feasibility Study* was prepared and submitted in April 1995. The Draft of the original FS concluded, based on the lack of risk to human health and/or the environment indicated by the Baseline Risk Assessment (BLRA) in the RI, that it was not appropriate to pursue active remediation to address either soils or groundwater contamination associated with the DCFA. However, regulatory acceptance of the Draft Final RI and the original FS were postponed and the *Work Plan for Monitoring Network Expansion Including Additional Characterization of the Island* (CENWK, 1996b) was prepared to execute additional groundwater sampling and analysis for better characterization of the impacts to the alluvial Island immediately downgradient of the DCFA. Based on the planned program of additional work, KDHE ultimately approved the Draft Final RI in April 1996 conditioned upon completion of the planned work. The planned work was completed, and an evaluation of this subsequent sampling and analysis was incorporated into an addendum to the RI entitled *Draft RI Addendum, Monitoring Expansion Report* (RIAMER) (CENWK, 1997a). The RIAMER indicated continued decreasing maximum contaminant levels within the DCF Study Area and identified no previously unforeseen or adverse conditions which impact the conclusions in the approved Draft Final RI including the BLRA.

The Revised FS has therefore been updated to include this new information, and also to incorporate the revised Kansas State Surface Water Quality Standards (KAR 28-16-28b; implementing KSA 65-165 and KSA 65-171d) as they apply to the alluvial Island. These standards require, regardless of the lack of risk, that an alluvial aquifer deemed to be "associated" with a surface waterbody is to be protected to the same extent as the surface water it is associated with. In this case, the associated surface water is the Kansas River (protected as a potential source of drinking water) and thus requires that groundwater quality within the alluvial aquifer meet the Kansas Water Quality Standards (KWQS) for surface waters that may potentially be used as a drinking water source. Based only on this regulatory driver for addressing the contamination in the alluvial aquifer, and the lack of any other risk or regulatory driver, the Revised FS has therefore been refocused upon addressing the groundwater contamination within the alluvial Island.

Stoddard solvent was the cleaning solution used at the DCF until 1966, but the constituents of Stoddard solvent (a naphthalene-based fluid) are not present with the primary constituents of concern for the DCFA. The contaminants of concern within the DCF Study Area are instead a result of the tetrachloroethylene (PCE) cleaning solution that was used subsequent to the Stoddard solvent. The primary contaminants of concern have been determined to be PCE and its breakdown products--trichloroethylene (TCE), *cis*-dichloroethylene (DCE) and vinyl chloride.

14

Two situations have been identified as the mechanisms for releasing contaminants of concern to the environment. The first mechanism that has been identified is leaky sewer lines (accidental spills of PCE and/or direct discharge of dry cleaning wastewater or clean-up rinseate containing PCE are released to drains located inside the DCFA buildings are transported and released via leaky sewers). The second suspected mechanism is ground surface discharges on the west side of Building 180/181 (still bottoms were dumped on the west side of Building 180/181). 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. In the Fall of 1993, the floor drains in Building 183 were sealed with a cement grout to eliminate additional contamination to the environment. A third possible source of contamination at the DCFA was identified to be three underground storage tanks (USTs). Upon removing two of the USTs and abandoning one in place, collection and analysis of post-excavation soil samples confirmed negligible contamination.

Table 1-1 provides a chronology of events, including the regulatory history, associated with the DCFA.

E.2 Baseline Risk Assessment (BLRA)

As part of the previous DCFA-RI work, risks were evaluated for both potential human and potential ecological receptors based on the data collected during the PA/SI (CENWK, 1992) and the RI (CENWK, 1995a). The results of the evaluation did not indicate a concern for current or potential risk to public health for either systemic (non-carcinogenic) or carcinogenic endpoints. The ecological risk assessments did not indicate that any unacceptable risks existed (CENWK, 1995a). Based upon an evaluation of the data gathered after January 1995, showing continued decreasing maximum contaminant levels and no previously unforeseen adverse conditions, it was concluded that the existing BLRA would not be changed or revisited as a result.

E.3 Summary of Conceptual Site Model

A Conceptual Site Model (CSM) was developed for the DCF Study Area as part of the RI (CENWK, 1995a) and RIAMER (CENWK, 1997a), and is summarized below. The key components of the CSM include contaminant sources, contaminants of concern, contaminated media, trends in detections of contamination, risk assessment and land uses. Relevant findings regarding these components are summarized as follows:

- the contaminant sources at the DCFA have been identified as the release of contaminated effluent from leaky sanitary sewers and storm sewers and disposal/spills of still bottoms behind Building 180/181;
- one migration pathway is believed to be subsurface leakage from sewers migrating through preferential paths in the unsaturated zone to Tributary A;
- another migration pathway is believed to be downward migration of contaminants through the unsaturated zone, into the underlying groundwater, then laterally from the upland area into the Island alluvium, parallel with the Kansas River;
- documented periodic overflow of sanitary effluent from manhole 366, located southeast of the Building 183 steam plant, could have flowed westward (downhill and likely downgradient) along Custer Road, and eventually ponded in the topographic low located directly upgradient from well DCF96-25;
- typical of river valleys, the predominant vertical flow direction for shallow groundwater is likely downward near the upland side of the Island, and then prior to discharge to the Kansas River, is likely upward into the river bed;

- groundwater and contaminants observed in DCF96-25 continue to flow and move towards the river channel with a downstream deflection likely due to subsurface sedimentary structures such as old channels, bars, and cutoff meanders that act as preferential pathways and carry contaminants to monitoring wells DCF96-23 and DCF96-26;
- the primary contaminants of concern have been determined to be tetrachloroethylene (PCE) and its breakdown products trichloroethylene (TCE), dichloroethylene (DCE), and vinyl chloride;
- absolute maximum contaminant concentrations within the DCF Study Area have been consistently decreasing for several years;
- there is no reasonable expectation that future land use will be substantially different from historic and present day use;
- the baseline risk assessment indicated no risk above acceptable levels; and,
- natural attenuation processes (especially hydrodynamic dispersion) will promote consistent decreases in maximum contaminant concentrations observed over time within the DCF Study Area.

In addition to natural attenuation, the following factors appear to have contributed to the general decrease in maximum contamination levels over time:

- 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 now dry cleaned as opposed to the former practice of laundering and then disposing the contaminated waste water through the sewer system;
- the sanitary sewer repairs for the leaking sanitary sewers beneath the DCFA;
- completion of a Soil Vapor Extraction Pilot Test responsible for removing approximately 21 lbs of volatile organic compounds (VOCs) (CENWK 1996a); and,
- cleaning of sediments from an abandoned manhole (MH-363B) in May 1994 (sediments were impacted with acetone, 1.1-dichloroethylene, DCE, TCE, and PCE).

E.4 Remedial Action Objectives and General Response Actions

Remedial Action Objectives (RAOs) were developed for the Dry Cleaning Facilities Study Area (DCF Study Area) by considering the contaminants of concern, the associated environmental media, and potential human health risks (including consideration of reasonable exposure pathways and receptors), as well as the probable impacts on the environment. The selection of RAOs is based the absence of unacceptable risk and the satisfaction of the requirements of the Kansas Surface Water Quality Standards, and therefore only applies to the alluvial aquifer that underlies the Island

The RAOs considered for the contaminated groundwater are the following:

- to minimize exposure to contaminated groundwater (from ingestion, inhalation, and/or dermal contact);
- to confirm that groundwater contaminants will not reach potential off-site receptors at concentrations above levels of concern; and,
- to reduce contaminant levels, to the extent feasible and appropriate, to chemical-specific regulatory levels through natural and/or active remedial processes.

Based on the RAOs, several General Response Actions (GRAs) were identified. GRAs are developed with the intention of satisfying the selected RAOs. The GRAs that are developed are as follows: No Action; Institutional Controls; Containment Actions; Treatment Actions and Off-Site Removal/Disposal Actions.

The remedial technologies associated with these GRAs are presented in Section 4.1. The development of quantitative Remedial Goals (RGs) for groundwater at the Island consist of the chemical-specific potential ARARs applicable through the State Surface Water Quality Standards, including the KWQS for surface waters potentially used as a drinking water source.

E.5 Identification, Development and Screening of Remedial Technologies and Alternatives

The technology identification and screening process represents the first step in the development and evaluation of remedial alternatives for the DCF Study Area. The approach utilized in developing this section of the FS was to identify potentially applicable general response actions and then develop associated subcategories of currently available and accepted remedial technologies and process options. During initial screening, any one of the remedial technologies or process options can be omitted from further analysis based on its likely poor performance regarding effectiveness, implementability, cost, or overall lack of relevance or appropriateness in consideration of the specific site conditions at the DCF Study Area. After initial screening, the following technologies/process options were retained for further consideration:

- No Action (Retention required by the NCP)
- Natural Attenuation
- Access and Use Restrictions/Well Installation Restrictions and Groundwater Use Prohibitions
- Worker Safety Measures
- Surface Controls/Maintenance of Surface Cover and Drainage Systems
- Monitoring/Sampling and Analysis
- Subsurface Drain/Interceptor Trench
- Hydraulic Containment/Extraction Using Wells and/or Trenches
- Physical or Chemical Effluent Treatment by Air Stripping, Sedimentation-Filtration, Coagulation-Flocculation, and/or Carbon Adsorption
- Extraction Using Air Sparging
- Passive Chemical Treatment and Partial Containment Using the Funnel & Gate Method

The technologies and process options retained for alternative development are combined into alternatives that address the remedial action objectives for the DCF Study Area and provide a range of control, treatment and/or containment combinations. After these alternatives are developed, screening of the alternatives is then performed based on the following three criteria: effectiveness; implementability; and, cost.

Based on the site specific conditions and the RAOs, the following remedial action alternatives were developed for consideration:

- Alternative 1 — No Further Action beyond Established Source Controls (Inclusion required by NCP)
- Alternative 2 — Source and Institutional Controls with Groundwater Monitoring and Contingency for Future Action
- Alternative 3 — Source Controls and Natural Attenuation with Groundwater Monitoring and Contingency for Future Action
- Alternative 4 — Source Controls and Extraction, Treatment and Hydraulic Containment of Groundwater
- Alternative 5 — Source Controls and Groundwater Contaminant Extraction Using Air Sparging with Treatment of Extracted Vapor
- Alternative 6 — Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate

It is noted that all of the alternatives inherently include continuation of the current land use (military, light industrial and commercial) and associated access control. It is also noted that Alternative 4 includes treatment of the extracted groundwater which is considered to be necessary prior to discharge in order to comply with ARARs. Based on the alternatives screening, Alternative 5 is not retained for further consideration and analysis based primarily on its questionable implementability (especially regarding potential environmental and ecological impacts that would be associated with the significant construction activity for such a system), and to a lesser extent on its negligible increased protectiveness in comparison to the other active remediation alternative being considered (Alternative 4). Therefore, only Alternatives 1, 2, 3, 4 and 6 are retained for detailed analysis.

E.6 Detailed Evaluation and Analysis of Alternatives

In order to address the CERCLA requirements adequately, the alternatives are assessed relative to the nine evaluation criteria provided by the NCP, namely:

1. Overall protection of human health and the environment
2. Compliance with applicable or relevant and appropriate requirements (ARARs)
3. Long-term effectiveness
4. Reduction of toxicity, mobility or volume
5. Short-term effectiveness
6. Implementability
7. Cost
8. State acceptance
9. Community acceptance

The first two criteria are applied as threshold criteria, the next five criteria are considered balancing criteria, and the last two criteria are considered modifying factors to be incorporated and evaluated during the Record of Decision (ROD) development and public comment process. Alternative 1, 2, 3, 4, and 6 all satisfy the threshold criteria and are therefore evaluated for the five balancing criteria. The detailed analysis indicates that Alternative 1, through continued implementation of site maintenance, land use/access controls, and a five year reassessment/review, performs well under each of the balancing criteria but provides no monitoring or assurance of the level of protection and effectiveness actually achieved. Alternatives 2 and 3 perform equally well for the balancing criteria, but provide an increased level of confidence and effectiveness because they include a monitoring program and the contingency for future removal/treatment action (to be implemented if such an action is ever deemed appropriate based on changed conditions). Alternatives 4 and 6 also perform effectively from a technical standpoint, but may be questioned on administrative feasibility and cost concerns (due to the potential for unavoidable and possibly permanent damage to the bald eagle habitat, and increased cost for only marginal additional benefits). Alternative 4 does, however, provide the only possibility for satisfying the RGs more rapidly than they would be satisfied by natural processes alone (an estimated thirty to fifty percent time savings at best).

Although very difficult to calculate accurately, time to compliance with remedial goals and associated time-related cost increases are of extreme importance to the detailed analysis. Time durations for each alternative were based on modeling a "fast flush" and "slow flush" scenario to represent the expected reasonable range of prevailing long-term flow velocities. Because it is an aggressive remedial action, time durations for Alternative 4 could not be readily modeled and were based on engineering judgement and the most applicable pumping formula. The resulting time durations for Alternative 4 are eight years (fast flush) and 25 years (slow flush). Because Alternatives 1, 2, 3, and 6 are passive remedial actions, a groundwater model was used to estimate the fast and slow flush time durations. The results were dependent primarily on the continued movement of groundwater across the Island subsurface and the concurrent natural attenuation processes (i.e., advection, volatilization, dispersion, solute retardation, and anaerobic biodegradation). The resulting time durations for Alternative 1, 2, 3, and 6 are 10 years (fast flush) and 30 years (slow flush).

Table 5-1, 5-2, 5-3, 5-4 and 5-5 present an order of magnitude cost estimate for each of the alternatives. The estimates indicate that Alternative 4 and 6 are significantly more costly than Alternative 1, 2, and 3.

The remaining two criteria, State acceptance and community acceptance, will be assessed after publication of the Proposed Plan as part of the ROD development and public comment process.

E.7 Comparison and Rating of Alternatives

All of the alternatives retained for detailed analysis satisfied the two threshold criteria and may be considered as technically viable alternatives. They were therefore evaluated, compared and rated using a 1 to 10 rating scale for each of the five balancing criteria, with a 1 being given to the most favorable alternative and a 10 only being given in the event that an alternative completely fails the criteria. This and any semi-quantitative rating or ranking system are subject to debate, however, and final recommendations must also consider community and regulatory input, as well as fiscal constraints.

A summation of the ratings for each alternative over the five criteria is as follows, with the best overall rating being represented by the lowest number:

Alternative 2	12
Alternative 3	13
Alternative 1	17
Alternative 4	17
Alternative 6	20

After an evaluation of each alternative based on the two threshold criteria and the five balancing criteria, Alternative 2 ranks as the most highly rated alternative, with Alternative 3 ranked a close second. The following paragraphs provide further comparisons, distinctions, conclusions and evaluations that qualify and supplement the results of the semi-quantitative ratings that were provided.

One clear distinction that can be made is that Alternative 1 (No Further Action beyond Established Source Controls) is the only alternative that could result in a lack of overall protectiveness of human health and the environment should currently unforeseen changes in environmental conditions occur, because it does not include a means of monitoring for unexpected changes in contamination levels or trends. Such unforeseen changes are, however, considered to be unlikely. The other four alternatives are similarly protective compared to each other and all include the means to monitor, and adjust to, any unforeseen changes in conditions.

Another obvious conclusion that may be drawn is that there appears to be no clear advantage in implementing Alternative 6 as compared to Alternative 4, because they both include similar short-term benefits and potential ecological disturbance, yet Alternative 6 is likely to be both slower and more costly than Alternative 4.

There is another distinction that can be made regarding Alternatives 4 and 6 in that technical issues and the sensitivity and importance of the bald eagle habitat on the Island make the ultimate implementability of Alternatives 4 and 6 suspect at best since the significant ecological damage that could result is not balanced by any tangible improvements over the other alternatives from the standpoint of environmental conditions and levels of risk. A more arguable but somewhat related conclusion is that, in light of the fact that there are no unacceptable current or foreseeable risks associated with the contamination, the much increased expenditures of funds necessary for Alternatives 4 and 6 would be difficult to justify.

1.0 INTRODUCTION AND SUMMARY OF REMEDIAL INVESTIGATIONS

1.0 Introduction and Summary of Remedial Investigations

1.1 Introduction

The United States Army Corps of Engineers, Northwest Division, Kansas City District (CENWK), under contract DACA-41-92-D-0001, retained Louis Berger & Associates, Inc. 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 including the Dry Cleaning Facility Area (DCFA) 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 the Army in August 1990 and by U.S. EPA Region VII and KDHE in February 1991, and became effective on June 28, 1991.

The following subsections present the purpose and organization of this FS Report.

Purpose and Organization of Report

The purpose of the original Feasibility Study (FS), submitted in Draft during April 1995 (CENWK, 1995b), was to utilize the findings from the *Draft Final Remedial Investigation Report Dry Cleaning Facilities Area (DCFA-RI) Fort Riley, Kansas* (CENWK, 1995a) to develop and evaluate remedial action alternatives for contamination within the DCF Study Area (both the upland area where the DCFA is located and the lowland area between the upland and the Kansas River, referred to as the Island). The Draft of the original FS concluded that it was not appropriate to pursue active remediation to address contamination at the DCFA. However, finalization of the original FS was postponed and 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. An evaluation of this subsequent sampling and analysis was incorporated into an addendum to the RI entitled *RI Addendum Monitoring Expansion Report* (RIAMER) (CENWK, 1997a).

The Revised FS therefore includes this new information and also includes an interpretation of the revised Kansas State Surface Water Quality Standards (KAR 28-16-28b; implementing KSA 65-165 and KSA 65-171d) as they apply to the alluvial Island. These standards require that an alluvial aquifer associated with a surface waterbody is to be protected to the same extent as the surface water, which in this case requires that groundwater quality within the alluvial aquifer meet the Kansas Water Quality Standards (KWQS) for surface waters that may potentially be used as a drinking water source.

This document presents the *Draft Revised Feasibility Study (FS) Report for the Dry Cleaning Facility at Fort Riley, Kansas* as a part of the RI/FS work performed at the DCF Study Area (including the DCFA and the Island) and has been developed in accordance with the U.S. EPA *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*, OSWER Directive 9355.3-01, October 1988 (U.S. EPA, 1988a). Following is a brief description of each chapter.

Chapter 1.0 Introduction and Summary of Remedial Investigation provides a brief discussion of the DCF Study Area (including the DCFA and the Island) and its background, a summary of previous investigations and, specifically, the *Draft Final Remedial Investigation Report for the Dry Cleaning Facility*

Area at Fort Riley, Kansas (CENWK, 1995a) and the evaluation of subsequent sampling and analysis data. This chapter also includes a summary of current site conditions.

Chapter 2.0 Applicable or Relevant and Appropriate Requirements provides an in-depth discussion of all federal, state, local and other statutes, regulations and guidance documents that may be pertinent to the DCF Study Area. This chapter also discusses why statutes, regulations and/or guidance documents have (or have not) had an impact on remedial action decisions at the DCF Study Area.

Chapter 3.0 Remedial Action Objectives and General Response Actions provides a discussion of the development of the goals and clean-up criteria at the DCF Study Area.

Chapter 4.0 Identification, Development and Screening of Remedial Technologies and Alternatives provides a list, description and evaluation of all remedial alternatives being considered at the DCF Study Area. A subsection is provided summarizing the evaluation of each alternative and defining screened alternatives as options that will be analyzed further.

Chapter 5.0 Detailed Evaluation and Analysis of Alternatives evaluates the alternatives from Chapter 4.0 for the nine Comprehensive Environmental Response Compensation Liability Act (CERCLA) evaluation criteria. This chapter also includes the estimated costs associated with each of the alternatives.

Chapter 6.0 Comparative Evaluation compares the retained alternatives with respect to each other in relation to the nine evaluation criteria discussed in Chapter 5.0.

1.2 Background Information

During the 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 onto the ground behind Building 180/181 prior to 1980. Field investigations for the 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. RI/FS scoping activities occurred in the fall and winter of 1992. Detailed planning documents were developed and finalized in July 1993. 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 to preliminary versions of the RI, and the Draft Final RI was completed in March 1995 (CENWK, 1995a). The Draft FS was completed in April 1995.

Discussions subsequent to these two document submissions focused on the possibility of deep, previously unseen contamination and the definition of a "surface water" as presented in the Kansas State Surface Water Quality Standards (KAR 28-16-28b) and whether the standards would classify the groundwater underneath the Island as a surface water. KDHE decided that classification of the alluvial Island as a surface water was appropriate and resulted in identifying the Kansas State Surface Water Quality Standards being an applicable standard that might warrant remedial action. Therefore, to further evaluate the DCF Study Area including the Island, development and execution of additional sampling and analysis of the groundwater underlying the Island were performed. Evaluation of these results are included in the RIAMER (CENWK, 1997a) and are incorporated in the analysis in this Revised FS, which focuses on what remedial alternatives are appropriate to address elevated contamination levels within the alluvial Island.

Therefore, the following are the specific basis of the analyses and conclusions in this FS report:

- The integrated data and evaluations presented in the 1995 RI report (including the Baseline Risk Assessment) based on information available through the January 1995 sampling events;
- The evaluation of sampling and analysis data since January 1995 as presented in the 1997 RIAMER; and
- The interpretation of federal and state potential ARARs as they apply to the DCFA and the alluvial Island, primarily the Kansas State Surface Water Quality Standards.

Table 1-1 provides a chronology of events associated with the DCF Study Area, consisting of the DCFA, the alluvial Island, and the immediate vicinity.

1.3 Site Setting

Fort Riley encompasses 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. 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.

The DCF Study Area for this report includes the DCFA (upland area) and lowland locations outside of the DCFA which either have, or could potentially be, impacted by migrating groundwater contamination from the DCFA. Specifically, the locations and features downgradient of the DCFA (generally due south) are considered in this study, including: Tributaries A and B (ephemeral streams), the Union Pacific Railroad right-of-way, and the Island. These areas are shown on Figure 1-2.

The DCFA will be defined as the area of current and former dry cleaning and laundry operations and related facilities. The approximately five 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 1-3, the DCFA consists of the northern and southern building complexes separated by Custer Road. The northern complex consists of a steam-generating plant 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. The surface around both complexes is mostly asphalt or concrete pavement with a small area of landscaped grass cover and crushed rock.

A buffalo corral and open ground occupy the area immediately to the north of the DCFA. 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 located immediately to the west, and the Post cemetery is to the northwest. DCFA boundaries and physiographic features are shown on Figure 1-4.

The Island (also referred to as the alluvium or alluvial material) is defined as the lowland area consisting of forested alluvial soils bounded on the north by the Union Pacific Railroad right-of-way at the base of the upland rise and on the south by the Kansas River.

1.4 Baseline Risk Assessment (BLRA) for the DCFA

As part of the previous DCFA-RI work, risks were evaluated for both potential human and potential ecological receptors based on the data collected during the PA/SI (CENWK, 1992) and the RI (CENWK, 1995a). The results of the evaluation of receptors and reasonably likely risks did not indicate a concern for current or potential risk to public health for either systemic (non-carcinogenic) or carcinogenic endpoints. The ecological risk assessments also failed to indicate that any unacceptable risks existed (CENWK, 1995a).

It should be noted that it was not necessary to perform a new BLRA based on an evaluation of the data gathered after January 1995 and that the conclusions from the existing BLRA would not be impacted by this data since maximum levels of contamination have decreased and no new receptors have been identified.

1.5 Summary of Conceptual Site Model

A Conceptual Site Model (CSM) was developed for the DCF Study Area as part of the RI (CENWK, 1995a) and RIAMER (CENWK, 1997a) is summarized below. In order to gain an understanding of the nature and extent of contamination in the vicinity of the DCFA, data was collected to determine contaminants of concern, sources of contaminants, release mechanisms, transformation processes, fate and transport of contaminants (including migration pathways) and potential receptors.

To summarize the CSM, a narrative description supported by figures describes information and conclusions regarding:

- potential contaminant sources;
- hydrogeologic setting and migration pathways;
- contaminant releases, migration, and fate;
- trends in data;
- potential pathways;
- receptors; and
- potential future land use.

1.5.1 Identification of the Potential Contaminant Source(s)

The focus of the DCFA studies is on the two sources believed to be responsible for the contaminants present at the DCFA.

The release of contaminated DCF-related effluent from leaky sanitary sewers and storm sewers. Two activities at the DCF are believed to be responsible for contaminant releases to sewer lines. The first activity is associated with inadvertent spills of Tetrachloroethylene (PCE) on the floor of the laundry facilities that were washed into floor drains as part of past clean-up procedures, resulting in PCE entering the sewer lines. The second activity is associated with the use of blankets, mattress pads and/or other fabrics to clean up other sporadic indoor spills of PCE, followed by rinsing and/or laundering these fabrics such that PCE-contaminated rinseate was conveyed to the sewer system. Once in the sewer system, wastewater containing PCE appears to have entered the subsurface environment through leaks in the sanitary and/or storm sewers. In addition, blockages in various parts of the sewers may have reduced flow capacity which caused sewer backups, occasional overflows from manholes and/or increased hydraulic pressure which would have resulted in greater leakage through any joints, cracks or breaks. Contamination in dissolved form thus entered either the unsaturated zone through subsurface infiltration.

Disposal/spills of still bottoms behind Building 180/181. The second potential source is associated with reported disposal of still bottoms or PCE behind Building 180/181. There is little information or documentation available to determine past waste handling practices or possible spills regarding still-bottom waste. This practice was however reported via an unconfirmed eyewitness account in the *Installation Assessment of Fort Riley, Kansas* (USATHAMA, 1984). Through leaching and infiltration, these alleged spills may have resulted in the migration of contaminants to the unsaturated zone and ultimately to the groundwater.

It is important to note, however, that the potential for future accidental releases of contaminants to the environment at the DCFA has been addressed through the sealing of floor drains and the enforcement of enhanced waste management practices at the current DCF as well as the repair, cleaning, replacement and/or diversion of a significant portion of the sanitary sewer lines within the DCFA (August 1996). Figure 1-3 presents the locations of abandoned and repaired sanitary sewer lines within the DCFA. These repairs also effectively reduce one of the driving forces behind contaminant migration within the DCFA.

1.5.2 Hydrogeologic Setting and Migration Pathways

Figure 1-4 presents the surface water features and drainage basin in the vicinity of the DCF Study Area, and the site stratigraphy is illustrated in Figure 1-5. Figure 1-6 presents a typical potentiometric contour map and illustrates the prevailing horizontal flow regime in the area.

Historically there have been two dominant migration pathways associated with the DCF Study Area:

- It is currently believed that subsurface leakage from sewers migrated horizontally through preferential paths in the unsaturated zone (e.g., utility trenches), in some cases resulting in documented surface seeps along the embankment behind Building 180/181 and the embankment adjacent to Tributary A. Water discharged from the documented seeps subsequently entered the nearby ephemeral stream (Tributary A) and eventually flowed to the Kansas River. Analytical data indicate that contamination from the seeps attenuates quickly in the surface water (due to dilution and volatilization);

- Downward migration of contaminants through the unsaturated zone, into the underlying groundwater, then laterally from the upland area into the Island alluvium, parallel with the Kansas River at the eastern end of the Island.

These two pathways (horizontal and vertical) are considered to be independent of each other, since the groundwater elevations downgradient of the DCFA are below the stream bed elevations in the tributaries, and flow in the tributaries is ephemeral, occurring only during/after storm events. Further details regarding the migration pathways can be found in the Draft Final RI (CENWK, 1995a) and the RIAMER (CENWK, 1997a). In addition, as a result of studies that have been performed to support the preparation of the RIAMER, newly identified potential pathways have been detected that might further explain contaminant migration within the Island alluvial material and more specifically, explain the elevated contaminants levels seemingly across gradient from the DCF. These potential pathways are as follows:

- Observed periodic overflows from the newly abandoned manhole 366, located southeast of the Building 183 steam plant, resulting in effluent which flowed westward along or under Custer Road, and eventually ponded in a lowland area directly upgradient from well DCF96-25;

- 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 (Figure 3-4 in the Draft Final RIAMER); and

- Groundwater and contaminants observed in DCF96-25 continue to flow and move towards the river channel with a downstream deflection due to depositional structures such as old channels, bars, and/or cutoff meanders that act as preferential pathways and carry contaminants to monitoring well DCF96-26 and eventually DCF96-23.

The identification of these potential pathways suggests that while the contaminant distribution presented on Figure 1-7 is representative of the same historical contaminant source, it is also representative of a variety of initially divergent contaminant pathways which later rejoin as migration beneath the Island proceeds toward the Kansas River. Further details regarding these newly identified migration pathways can be found in the Section 5.2.4 of the Draft Final RIAMER (CENWK, 1997a).

1.5.3 Processes Affecting Contaminant Release, Migration and Fate

Dilution, dispersion, degradation, and the adsorption/desorption of contaminants are the most significant processes which affect the release, migration and environmental distribution of contaminants at the DCF Study Area. These natural processes are generally controlled by the characteristics of the water, soils and rocks in which the contamination exists and moves (i.e., solubility characteristics, partition and adsorption coefficients, pH, temperature, etc.). Occurrence of these and other natural processes results in naturally decreasing contaminant concentrations over time, or "natural attenuation". Natural attenuation processes are responsible for the consistent and continuing decreases in maximum contaminant concentrations observed over time within the DCF Study Area.

Natural attenuation can be broken down into three components (physical, chemical and biological).The following subsections present brief discussions of the three components of natural attenuation, and how they affect release, migration, and fate.

1.5.3.1 Physical Processes

Physical processes are affected by the site-specific groundwater flow regime, potential receptors (i.e., surface water stages), and physical characteristics of the geologic medium. Specific physical processes that may affect contaminant release, migration, and fate in the environment are dilution, dispersion, and volatization. Dilution is a significant factor in the nature of the contaminants released at the DCFA, because much of the contaminants are believed to have already been dissolved into the water flowing through the sanitary sewer prior to discharge and are thus readily diluted. In addition to rainwater infiltration, subsequent laundry wastewater sewer leakage would have caused further dilution in the environment. Groundwater recharge due to upgradient surface water recharge is also a factor that increases dilution. Dispersion can also significantly modify the behavior and distribution of contaminants in surface water, sediments, and groundwater by spreading a given amount of contaminant over a larger area/volume. Volatilization is often also a dominant mechanism affecting levels of organic contaminants in the environment.

1.5.3.2 Chemical Processes

Chemical processes are affected by chemical degradability of contaminants, chemical characteristics of the groundwater, and chemical characteristics of the geologic medium. Specific chemical processes that may attenuate contamination levels are adsorption, desorption, and chemical reaction or transformation. Specifically, adsorption will affect the migration of contaminants at the DCF Study Area. PCE and other

chlorinated solvents are known to readily attach to soil particles, reducing the concentration levels in migrating groundwater.

1.5.3.3 Biological Processes

Biological process are affected by the biological degradability of the contaminant and the biological characteristics of the groundwater and geologic medium. The specific biological process that may attenuate contamination levels is microbial biodegradation under either aerobic or anaerobic conditions, depending on the chemical being degraded. Biological degradation (i.e., decay of contaminants due to consumption by naturally occurring microorganisms) is often a dominant mechanism affecting levels of organic contaminants in the environment.

1.5.4 Trends in the Data

Concentrations of PCE and its breakdown products, 1,2-Dichloroethylene (DCE), Trichloroethylene (TCE), and vinyl chloride in the groundwater are currently at levels below their past maximum concentrations for the wells in or around the DCFA (i.e., on the upgradient side of the center of mass of the contamination). At the same time, many of the wells on the downgradient side show the expected and characteristic increase in contaminant levels consistent with the advance of the contaminant mass (Figure 1-7).

Absolute maximum contaminant concentrations associated with the DCFA have been consistently decreasing for several years, indicative of the improvements associated with the DCF as well as ongoing natural attenuation. This general decrease in maximum contaminant levels will likely continue due to the following factors:

- 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 now dry cleaned as opposed to the former practice of laundering and then disposing the contaminated waste water through the sewer system;

- The sanitary sewer repairs for sections of sewer beneath the DCFA that were known to be leaking have been repaired;

- Completion of a Soil Vapor Extraction Pilot Test responsible for removing an estimated 21 pounds (lbs) of volatile organic compounds (VOCs) (CENWK, 1996a);

- Removal of a potential source by cleaning sediments from an abandoned manhole (MH-363B) in May 1994 (sediments were impacted with acetone, 1.1-dichloroethylene, DCE, TCE, and PCE); and,

- Natural attenuation of the contaminant concentrations.

1.5.5 Potential Exposure Pathways and Media of Concern

Based on the results of the BLRA, the most important potential exposure pathways are: inhalation of volatiles and fugitive dust by on-site workers and nearby residents; ingestion of, and dermal contact with, soil, sediment and surface water by workers and nearby residents; and ingestion of, and dermal contact with, sediment and surface water by children playing. Furthermore, ingestion of groundwater (the most impacted media within the DCF Study Area) is not an exposure pathway, because no new drinking water wells from areas of previous contamination are planned for Fort Riley or the surrounding communities. As reported in the Draft RI, installation of a new water supply well is neither reasonable nor foreseeable because current consumption of available supply is only 42 percent (CENWK, 1995a). Table 1-2 presents chemicals detected in soil samples. Contaminants of concern detected in groundwater at the site are shown in Table 1-3. Chemicals detected in sediments are presented in Table 1-4. Table 1-5 presents chemicals detected in surface waters.

1.5.6 Identification of Potential Receptors and Risks

Based on the identified site conditions, the current and reasonably foreseeable land uses in the vicinity of the DCFA and on the conclusions drawn in the BLRA (CENWK, 1995a), the following are primary media-specific receptor types and locations identified for the DCFA:

- Air—inhalation of volatiles and particulates by utility workers during subsurface repairs;
- Surface water/sediments—utility workers performing repair activities and children playing along Tributary A and/or B; and
- Subsurface soils—shallow subsurface soils at the DCFA to which site/utility workers might reasonably be exposed.

Based upon the results of the BLRA in 1995, calculated carcinogenic risks and Hazard Index values for the DCFA are both below acceptable values (CENWK, 1995a). Furthermore, none of the data collected since the BLRA was completed indicates a worsened condition. Therefore, risk to human health and environment is not considered to be a driver in the requirement for remedial action associated with the DCFA.

This assessment of potential risks is of course based on the specific conditions at the DCFA and Fort Riley. Use of the area as green space or continued office/light industrial use under DA control is the only reasonable and foreseeable future use of the Study Area. Therefore, on-site residents are not included as a potentially exposed population. In addition, future residents are not considered in the BLRA because neither the DCFA or the Island are suitable for residential development (CENWK, 1995a).

The restrictions and limitations of the site for future residential development exist regardless of whether the site remains under DA control. Should Fort Riley be designated for Base Realignment and Closure (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.

TABLES

TABLE 1-1
CHRONOLOGY OF EVENTS ASSOCIATED WITH THE DCF STUDY AREA
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Date	Activity/Reports
1914 1915	Building 180 constructed (as Bldg 109, Stone) Laundry operations began in Building 180.
1930 1931	Building 181 constructed (as Bldg 213, Brick) Dry cleaning operations in Building 181.
1940	Building 182 constructed (as Bldg 214, Stone), Inflammable Storage
1941	Building 183 constructed (as Bldg 216T, Wood), Laundry Building 184 constructed (as Bldg 239), Laundry Boiler House
1944	Building 180 burned (10 Sep 44)
1944/45	Solvent Used - Stoddard - Flash Point minimum of 100 F
1945	Building 181 reconstructed, 180 & 181 joined
1966 (1971 ?)	Change from Stoddard Solvent to Tetrachloroethylene (PCE) as dry cleaning fluid. (Report & Interview differ on date.) Also, dry cleaning operations started in Building 180, Drums of PCE stored near single unit. (Unclear, but apparently dry cleaning ceased in 181 at this time.) Interviewee also reported that diatomaceous earth filter material was "broadcast" and used as "fill" behind the building along southwest slope and that contents of "muck tank" holding still bottoms, distillate residue and filter material were discharged to the sanitary sewer. Manager also recalled 3 tanks on north side of Bldg 180 - held Stoddard Solvent but not PCE.
1974	Building 180 re-designated from Laundry/Steam Plant to Warehouse (but Dry Cleaning operations apparently continued)
1979 - mid 80's	PCE delivered by tanker truck. Pumped through window north side of 181 into barrels near machines. Initially filter cartridges & sludge (1-2 gallons every 3 months) disposed of in dumpster - later (approx. 1983) disposed (off-post) through Property Disposal Office.
October 1983	All dry cleaning (and laundry if this hadn't occurred previously) activities moved to Building 183. Buildings 180/181 become General Purpose Warehouse (Installation Consolidated Property Book Office).
1984	U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) Installation Assessment reported still bottom residue was being dumped behind the building.
1985	Contractor provides solvent supply and disposal/ recycling services

TABLE 1-1 (CONTINUED)
CHRONOLOGY OF EVENTS ASSOCIATED WITH THE DCF STUDY AREA

Date	Activity/Reports
June 1986	Fort Riley collected and USAEHA analyzed (GC) two soil samples from the west side of Building 181. Results indicated no detections and no recommendations for further sampling were made.
1988	Evaluation of Solid Waste Management units on Fort Riley; included former Dry Cleaning Plant area. No observational evidence of systematic spilling of solvent or sludge.
August 1990	Fort Riley placed on National Priority List.
June 1991	Federal Facilities Agreement effective; requires site investigation of former Dry Cleaners
1991-1992	PA/SI Planning Draft Planning Documents, Sept.'91 Draft Final Planning Documents, Dec. '91 Revisions to Planning Documents, Jan '92 Draft Modified Planning Documents, May '92 Draft Final Mod Planning Documents, Sep '92
1991-1992	PA/SI Field Work Soil Gas Survey, Oct 29 - Nov 2, '91 Soils Borings, Mar - Apr '92 Monitoring Well Installation, Apr '92 Monitoring Well Development, May - Jun '92 Groundwater Sampling, July '92 Exploratory Monitoring Well DCF92-07 installed (dry), Aug '92
September 1992	Working Draft PA/SI is submitted. A decision was made to have EPA and KDHE review this document instead of extending the schedule for submission of a Draft. A meeting was held on 16 Oct 92, during which the project managers for the parties to the IAG decided that the Working Draft would be approved as Final with comments attached.
1992 - 1993	Periodic groundwater sampling of six monitoring wells installed during the PA/SI. Nov '92 Feb '93 May '93 Nov '93
February - April 1993	RI/FS Initial Field Investigations (IFI), Feb - Mar '93 Soil Gas Survey Sewer/Surface Water/Sediment Sampling Supplemental IFI Activities, Mar - Apr '93 Sewer Survey and Tracing Dry Cleaning Operations Sampling
July 1993	Draft Final RI/FS Work Plan Submitted.
October 1993	Revised Draft Final RI Sampling and Analysis Plan. (Result of change in Contractor performing work.)

TABLE 1-1 (CONTINUED)
CHRONOLOGY OF EVENTS ASSOCIATED WITH THE DCF STUDY AREA

Date	Activity/Reports
November - December 1993	RI field work. Soil Borings Surface Soil, Surface Water & Sediment Sampling
December 1993	"Baseline" RI groundwater sampling including new RI monitoring wells.
February 1994	Periodic groundwater sampling (PA/SI & RI wells, 1st Round after "Baseline")
May 1994	Sewer line repair. A portion of sanitary sewer line was replaced between manholes 365 and 363 (portion of line serving 183 above 180/182) due to suspected leakage of the aged line.
May 1994	Soil sampling in conjunction with SVE Pilot Study
April 1994 May 1994	USTs located. (Interview information about tanks unclear if removed or not. An electromagnetic survey performed by US Army Construction Engineers Laboratory [USCERL] revealed the presence of the tanks. Previous methods had been unsuccessful.) UST contents sampled
July 1994	UST removal (2 removed, 1 abandoned in place due to depth & proximity to building foundation and utilities.
May 1994	Soil Vapor and Groundwater Extraction Pilot Studies initiated near Building 180/181.
June 1994	Installation of soil vapor and groundwater extraction wells. (Subsequent pumping tests performed on the groundwater wells proved extraction to be impractical due to extremely low yield rates; therefore the groundwater extraction pilot test was terminated.)
June 1994	Periodic groundwater sampling (PA/SI & RI wells - 2nd round).
June - July 1994	Supplemental Sewer (flow) Investigations
August 1994	Monitoring Well DCF94-22 installed (driven well point) as a replacement for DCF94-11 which had gone dry.
August 1994	Periodic groundwater sampling (PA/SI & RI wells - 3rd round)
October 1994	UST area soil borings performed
November 1994	Draft RI Report
Nov - Dec 1994	Soil Vapor Extraction Pilot Test - 30-day test performed
January 1995	Periodic groundwater sampling (PA/SI & RI wells - 4th round)
January 1995	Additional surface water and sediment sampling.
February 1995	Surface water and sediment sampling
March 1995	Draft Final RI.

TABLE 1-1 (CONTINUED)
CHRONOLOGY OF EVENTS ASSOCIATED WITH THE DCF STUDY AREA

Date	Activity/Reports
April 1995	Draft Feasibility Study.
May 1995	Periodic groundwater sampling (PA/SI & RI wells - 5th round)
June 1995	Periodic groundwater sampling (PA/SI & RI wells - 6th round)
July 1995	Periodic groundwater sampling (PA/SI & RI wells - 7th round)
October 1995	Periodic groundwater sampling (PA/SI & RI wells - 8th round)
Summer 1995	Rescoping evaluations/discussion
March 1996	Draft Final Pilot Test Study Results Report
May 1996	Work Plan for Monitoring Network Expansion Including Additional Characterization of the Island
May 1996	Installed new wells for monitoring expansion (ME)
May 1996	Periodic groundwater sampling (PA/SI & RI & ME wells - 9th round)
October 1996	Periodic groundwater sampling (PA/SI & RI & ME wells -10th round)
February 1997	Periodic groundwater sampling (PA/SI & RI & ME wells -11th round)
May 1997	Periodic groundwater sampling (PA/SI & RI & ME wells -12th round)
July 1997	Draft Remedial Investigation Addendum Monitoring Expansion Report
July 1997	Draft Revised Feasibility Study
March 1998	Draft Final Remedial Investigation Addendum Monitoring Expansion Report
March 1998	Draft Final Revised Feasibility Study

<u>Note</u>:
HADR Historical and Architectural Documentation Reports for Fort Riley, Kansas, October 1993.

TABLE 1-2
CHEMICALS DETECTED IN SHALLOW SUBSURFACE SOIL SAMPLES (≤25 FEET BGS)
March 1992 through October 1994
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

All results shown in μg/kg, expressed as dry weight.

Parameter	Frequency of Detection[a]	Quantitation Limit[b]	Range of Detected Concentration[c]
VOLATILE ORGANICS:			
Carbon disulfide	1/101	3.2 - 25	9.2
Dibromochloromethane[3]	1/101	2.4 - 25	190(I2)
Dichloromethane[2]	28/101	5 - 25	22 - 180
Tetrachloroethylene[1]	22/101	3.2 - 15	3.7(J) - 960
1,1,2-Trichloroethane	1/101	5.0 - 25	8.6(I2)
Toluene[3]	6/101	5.2 - 29	5.8 - 31
Trichloroethylene[1]	1/101	3.2 - 29	4.2(J)
SEMIVOLATILE ORGANICS:			
Benzo(a)anthracene	1/58	100 - 900	380(J)
Benzo(a)pyrene	1/58	240 - 900	270(J)
Chrysene	1/58	100 - 900	300(J)
bis(2-Ethylhexyl)phthalate[2]	3/58	330 - 900	380(J) - 2400
Fluoranthene	1/58	140 - 900	610(J)
2-Methylnaphthalene	1/58	140 - 900	220(J)
Phenanthrene	2/58	140 - 900	290(J) - 610(J)
Pyrene	2/58	100 - 900	110(J) - 530(J)

Notes:

1 DCFA operations-related chemical of concern that have been retained for BLRA.
2. Common laboratory contaminants and are not DCFA operations-related.
3 Laboratory contaminants and are not DCFA operations-related.

a Number of samples in which the chemical was positively detected divided by the number of samples available.
b Range reflects variation in sample quantitation limits (SQLs) between different sampling and analytical rounds.
c Only one value is noted when there was a single detection in the medium.

(J) Sample quantitation is estimated.
(I2) Low internal standard response and high surrogate recovery. Result is biased high.
BGS Below Ground Surface.

Source CEMRK (1995a)

TABLE 1-3
CHEMICALS DETECTED IN GROUNDWATER SAMPLES
July 1992 through February 1997
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

All results shown in $\mu g/l$.

Parameter	Frequency of Detection[a]	Quantitation Limit[b]	Range of Detected Concentrations[c]
VOLATILE ORGANICS:			
Benzene	5/246	0.4-20	0.5(J)-5.5
Trichloromethane (THM)[3]	36/246	0.5-25	0.5(J)-36
1,2-Dichloroethylene[1]	147/246	0.5-25	4.1-110
Ethylbenzene	1/246	0.7-35	1.1
Dichloromethane[2]	9/246	0.9-45	5-130
Tetrachloroethylene[1]	154/246	1.1-5.5	1.5(J)-1600
Toluene	14/246	0.4-100	0.4-26
Trichloroethylene[1]	126/246	0.6-30	0.6-200
Vinyl Chloride[1]	31/246	0.8-40	0.8-54
Carbon disulfide	1/246	3-250	21
SEMIVOLATILE ORGANICS:			
2,6-Dinitrotoluene	1/68	4-26	12(S)
bis(2-Ethylhexyl)phthalate[2]	5/68	6-26	10-44
Hexachloroethane	1/68	5-26	43(S)
Naphthalene[1]	3/68	3-26	5.4(S)-7
N-Nitrosodi-n-propylamine	1/68	5-26	38(S)
1,4-Dichlorobenzene	1/68	4-26	11

Notes:

1 DCFA operations-related chemical of concern that have been retained for BLRA.
2 Common laboratory contaminants and are not DCFA operations-related.
3 Laboratory contaminants and are not DCFA operations-related.

a Number of samples in which the chemical was positively detected, divided by the number of samples available.
b Range reflects variation in sample quantitation limits (SQLs) between different sampling and analytical rounds.
c Only one value is noted when there was a single detection in the medium.
(J) Sample quantitation is estimated.
(S) Estimated result, may be biased high.

Source CEMRK (1995a, 1996c, 1996d, 1996e, & 1997b)

TABLE 1-4
CHEMICALS DETECTED IN SEDIMENT SAMPLES FROM TRIBUTARIES A AND B
March 1992 through February 1993
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

All results shown in μg/kg (dry weight).

Parameter	Frequency of Detection[a]	Quantitation Limit[b]	Range of Detected Concentrations[c]
VOLATILE ORGANICS:			
Acetone[2]	2/29	120 - 130	1800(E) - 2100(E)
Dichloromethane[2]	4/29	5 - 14	80.0(B) - 1100
Tetrachloroethylene[1]	1/29	3 - 14	6.6
SEMIVOLATILE ORGANICS:			
Pyrene	1/25	940	120(J)

Notes:

1 DCFA operations-related chemical of concern that have been retained for BLRA.
2 Common laboratory contaminants and are not DCFA operations-related.

a Number of samples in which the chemical was positively detected, divided by the number of samples available.
b Range reflects variation in sample quantitation limits (SQLs) between different sampling and analytical rounds.
c Only one value is noted when there was a single detection in the medium.

(E) Estimated result, quantitation uncertain based on exceeded calibration range.
(J) Sample quantitation is estimated.

Source CEMRK (1995a).

TABLE 1-5
CHEMICALS DETECTED IN SURFACE WATER SAMPLES FROM TRIBUTARIES A AND B
March 1992 through January 1995
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

All results shown in μg/l.

Parameter	Frequency of Detection[a]	Quantitation Limit[b]	Range of Detected Concentrations[c]
VOLATILE ORGANICS:			
Bromodichloromethane (THM)[3]	3/14	0.6 - 0.9	0.5 - 5.8
Bromoform (THM)[3]	2/14	1.6 - 1.8	1.6 - 4.6
Dibromochloromethane (THM)[3]	4/14	0.6 - 2.0	1.4 - 6.7
Tetrachloroethylene[1]	1/14	1.1 - 3.0	4.5
Trichloromethane (THM)[3]	5/14	0.6 - 0.9	3.1 - 27.0
SEMIVOLATILE ORGANICS:			
bis(2-Ethylhexyl)phthalate[2]	3/14	6.0 - 10.0	11.5 - 69.0
Di-n-octylphthalate[3]	1/14	6.0 - 10.0	19.0

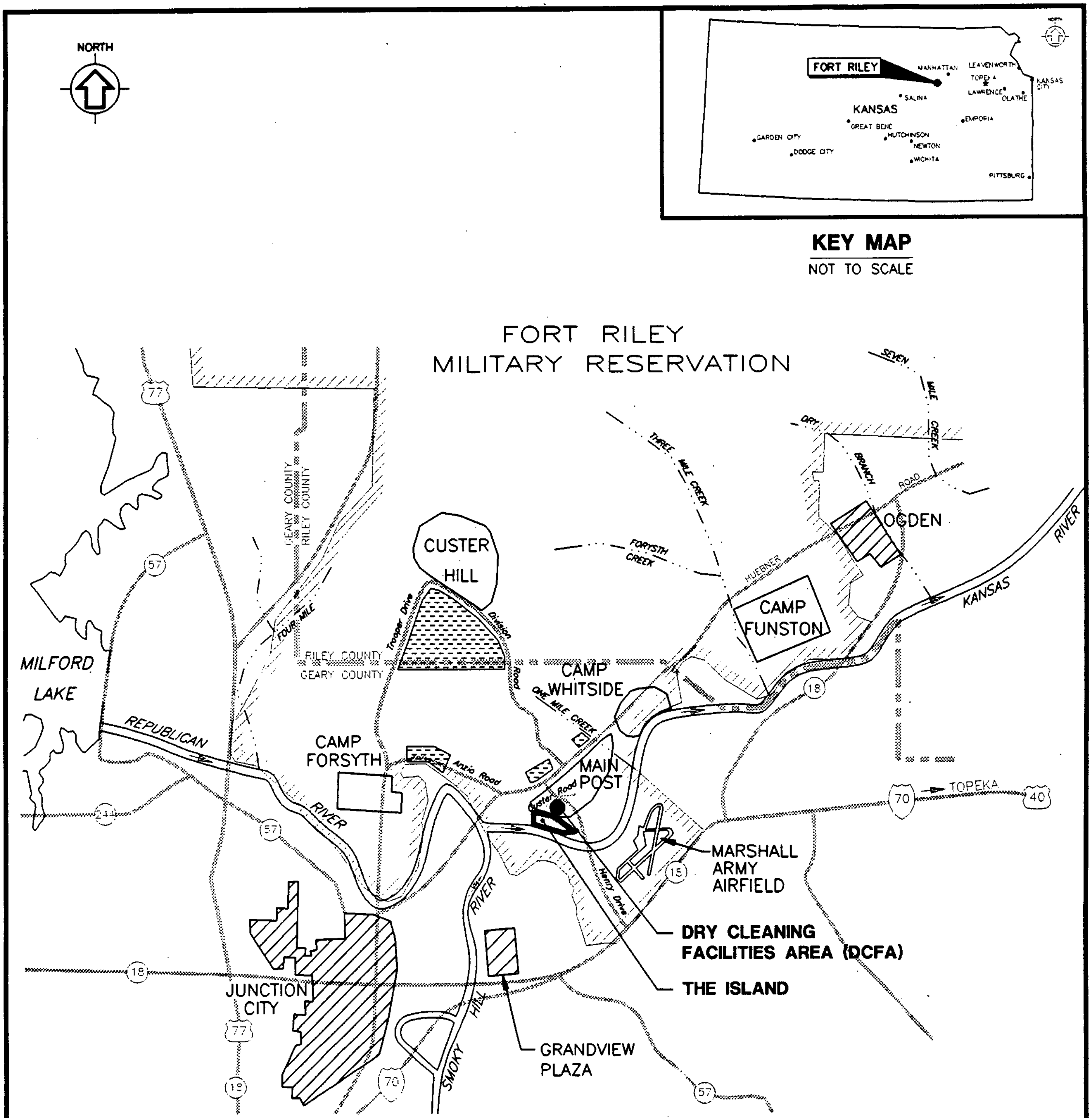
Notes:

1 DCFA operations-related chemical of concern that have been retained for BLRA.
2 Common laboratory contaminants and are not DCFA operations-related.
3 Laboratory contaminants and are not DCFA operations-related.

a Number of samples in which the chemical was positively detected, divided by the number of samples available.
b Range reflects variation in sample quantitation limits (SQLs) between different sampling and analytical rounds.
c Only one value is noted when there was a single detection in the medium.

Source CEMRK (1995a).

FIGURES



0 1 2 4

SCALE IN MILES
1" = 2 MILES

LEGEND:

MILITARY HOUSING

CANTONMENT AREA

MUNICIPALITY

MILITARY RESERVATION BOUNDARY

U.S. ARMY CORPS OF ENGINEERS

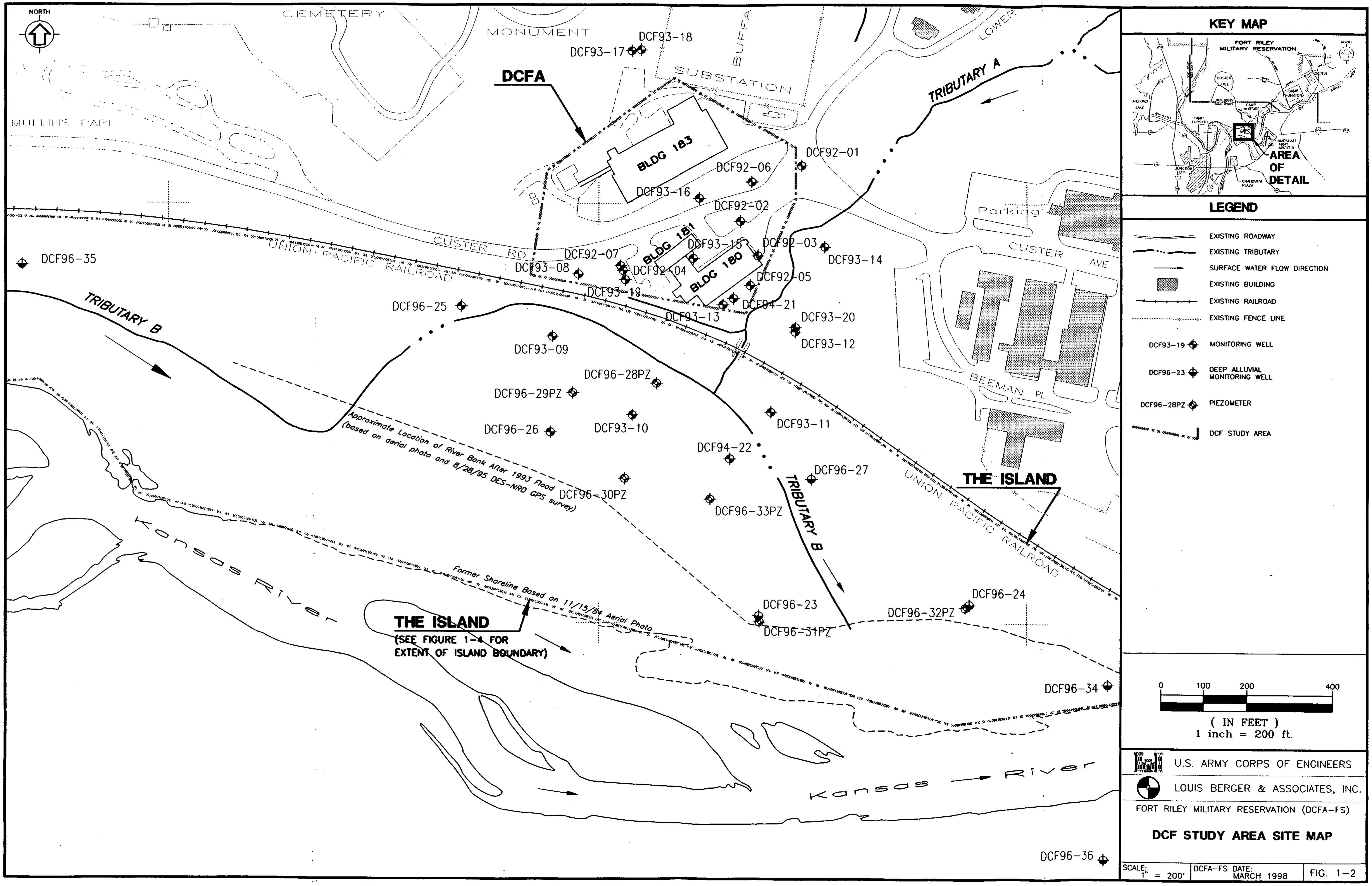
LOUIS BERGER & ASSOCIATES, INC.

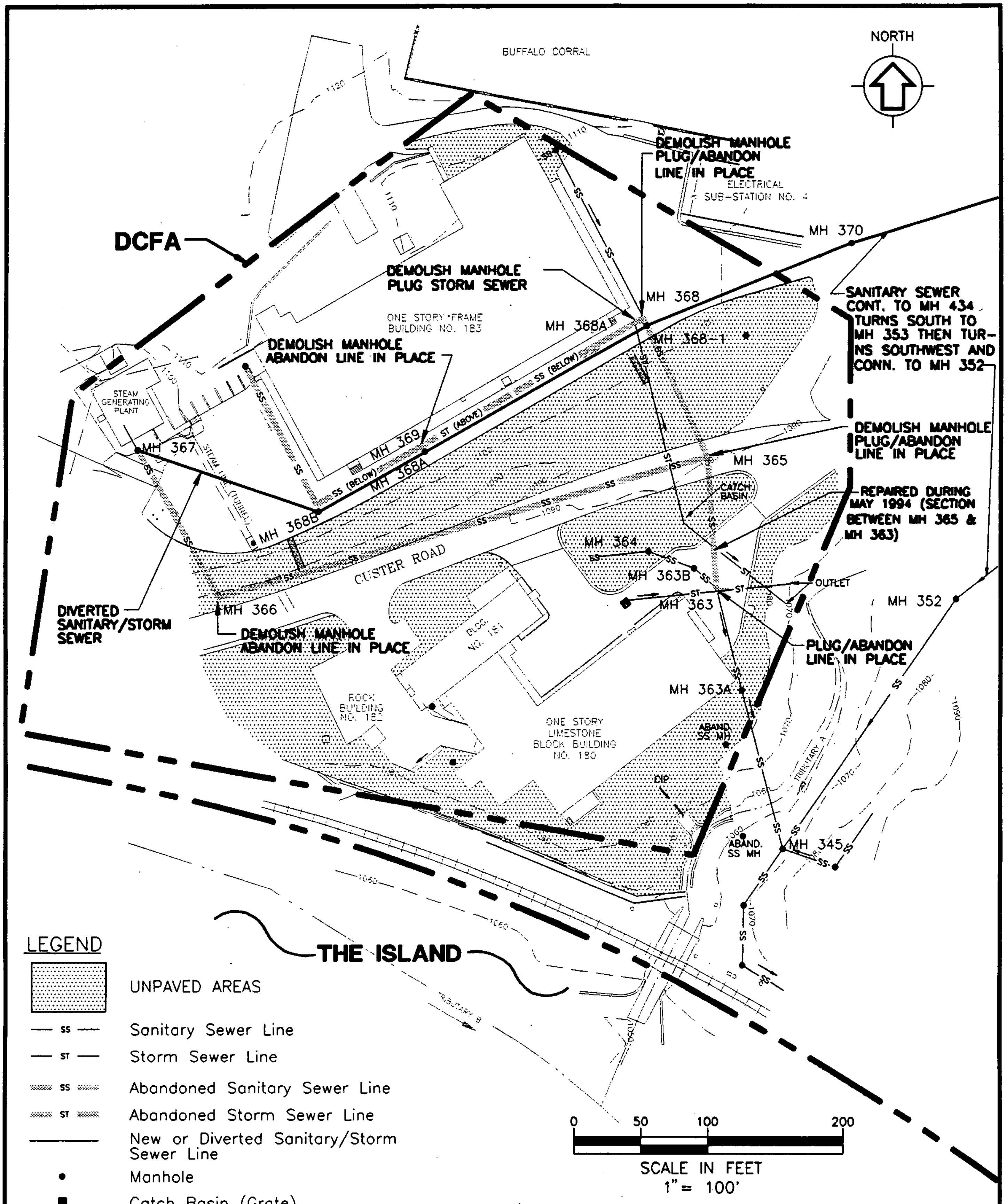
FORT RILEY MILITARY RESERVATION (DCFA-FS)

GENERAL VICINITY MAP

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

FS-GVM/25MAR98/04


NORTH
CEMETERY
MONUMENT
MULLINS PARK
SUBSTATION
LOWER
DCFA
BLDG 183
BLDG 181
BLDG 180
CUSTER RD
UNION PACIFIC RAILROAD
TRIBUTARY A
TRIBUTARY B
Parking
CUSTER AVE
BEEMAN PL
DCF93-17
DCF93-18
DCF92-01
DCF92-06
DCF93-16
DCF92-02
DCF92-03
DCF93-14
DCF93-15
DCF92-07
DCF93-08
DCF92-04
DCF92-05
DCF93-19
DCF94-21
DCF93-13
DCF93-20
DCF93-12
DCF96-35
DCF96-25
DCF93-09
DCF96-28PZ
DCF96-29PZ
DCF96-26
DCF93-10
DCF93-11
DCF94-22
DCF96-27
DCF96-30PZ
DCF96-33PZ
DCF96-23
DCF96-31PZ
DCF96-32PZ
DCF96-24
DCF96-34
DCF96-36
Approximate Location of River Bank After 1993 Flood (based on aerial photo and 8/28/95 DES-NRD GPS survey)
Former Shoreline Based on 11/15/84 Aerial Photo
THE ISLAND
THE ISLAND (SEE FIGURE 1-4 FOR EXTENT OF ISLAND BOUNDARY)
Kansas River
Kansas River
KEY MAP
FORT RILEY MILITARY RESERVATION
AREA OF DETAIL
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.
U.S. ARMY CORPS OF ENGINEERS
LOUIS BERGER & ASSOCIATES, INC.
FORT RILEY MILITARY RESERVATION (DCFA-FS)
DCF STUDY AREA SITE MAP
SCALE: 1" = 200'
DCFA-FS DATE: MARCH 1998
FIG. 1-2



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.
2. SEE FIGURE 1-4 FOR EXTENT OF ISLAND BOUNDARY.

U.S. ARMY CORPS OF ENGINEERS

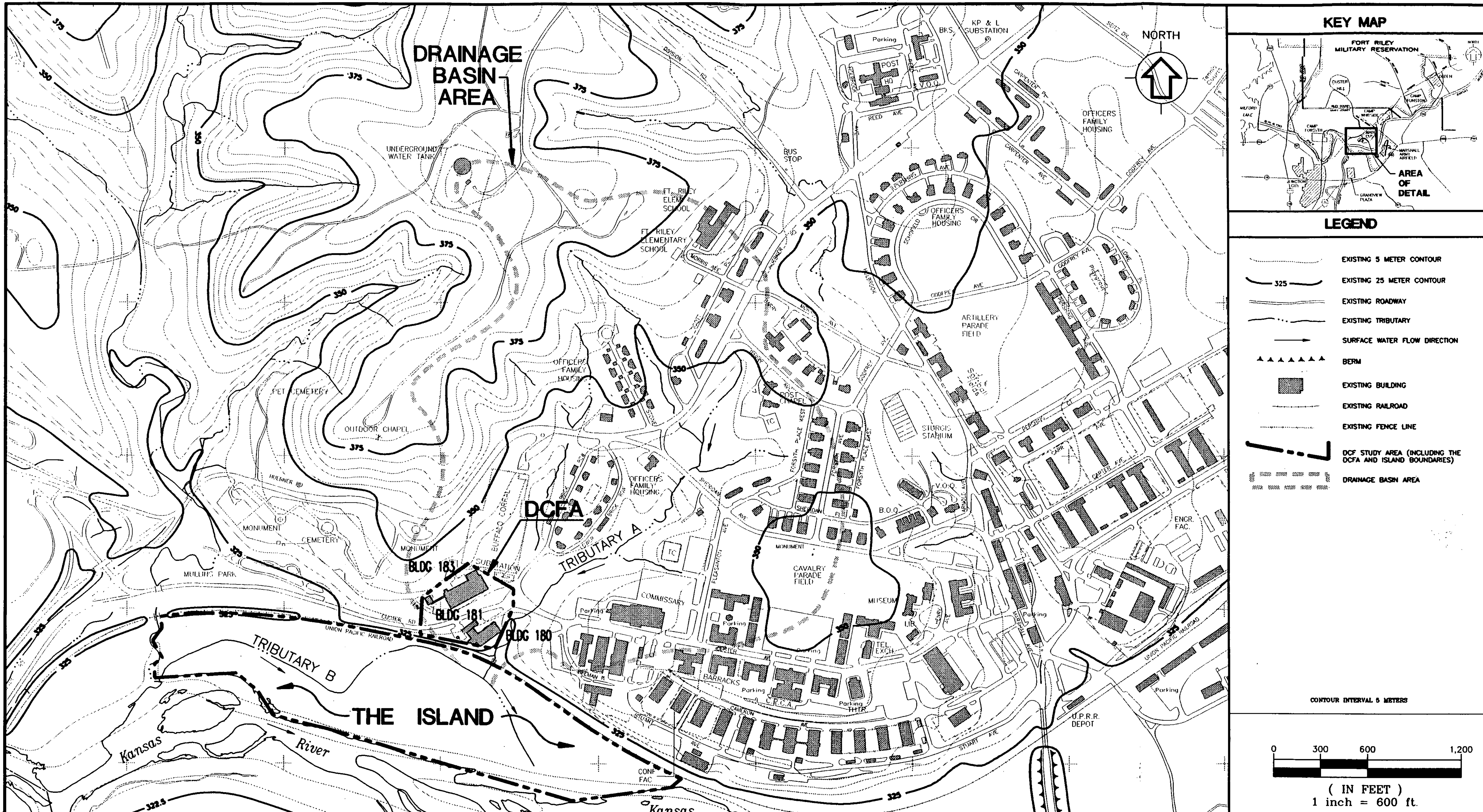
LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-FS)

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

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

FS-SM/25MAR98/04



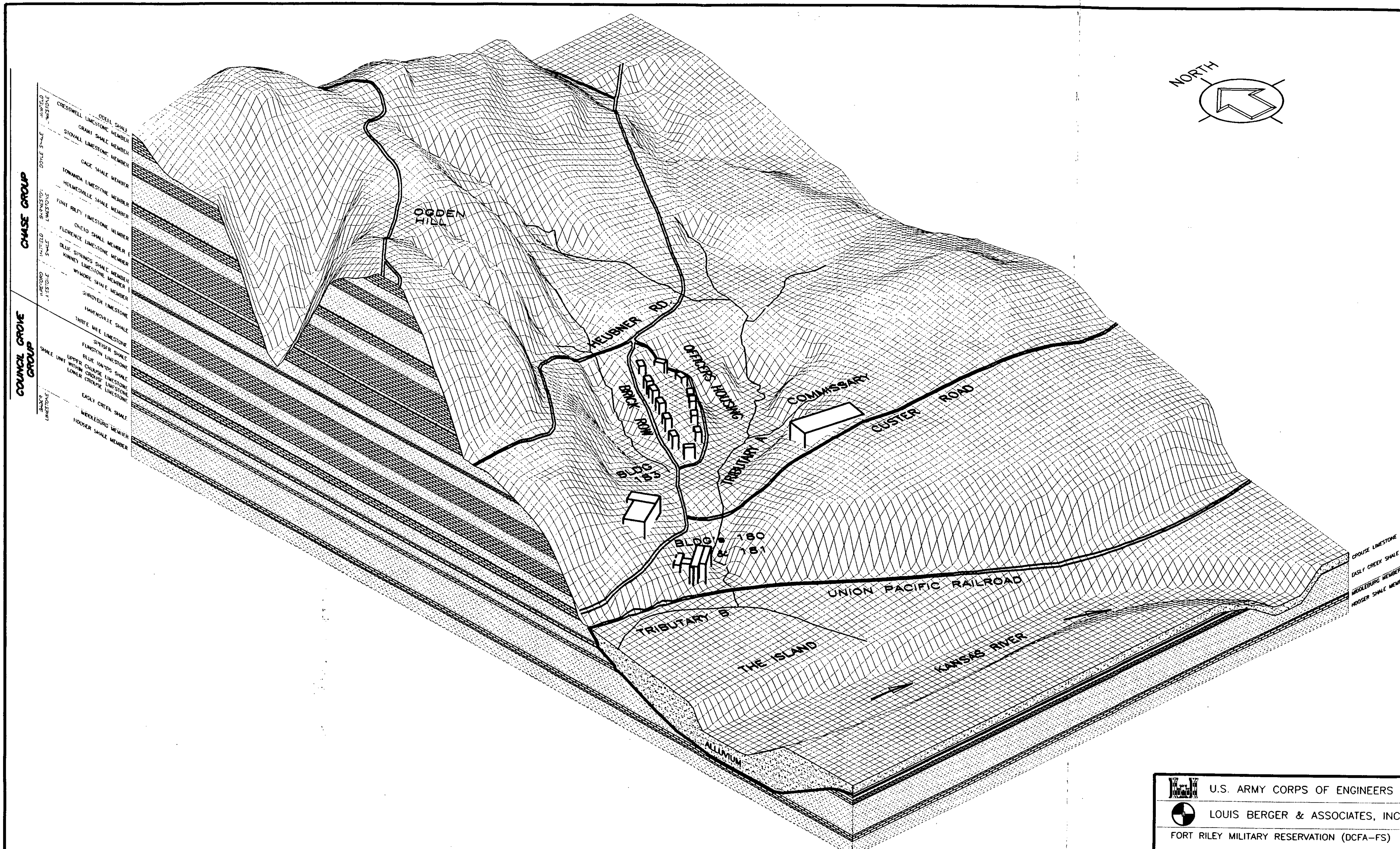
U.S. ARMY CORPS OF ENGINEERS

LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-FS)

DCF STUDY AREA SHOWING PHYSIOGRAPHIC FEATURES

SCALE: 1" = 600' | DCFA-FS DATE: MARCH 1998 | FIG. 1-4



Source: Geology (Zeller, 1968)
For Generalized Stratigraphy shown

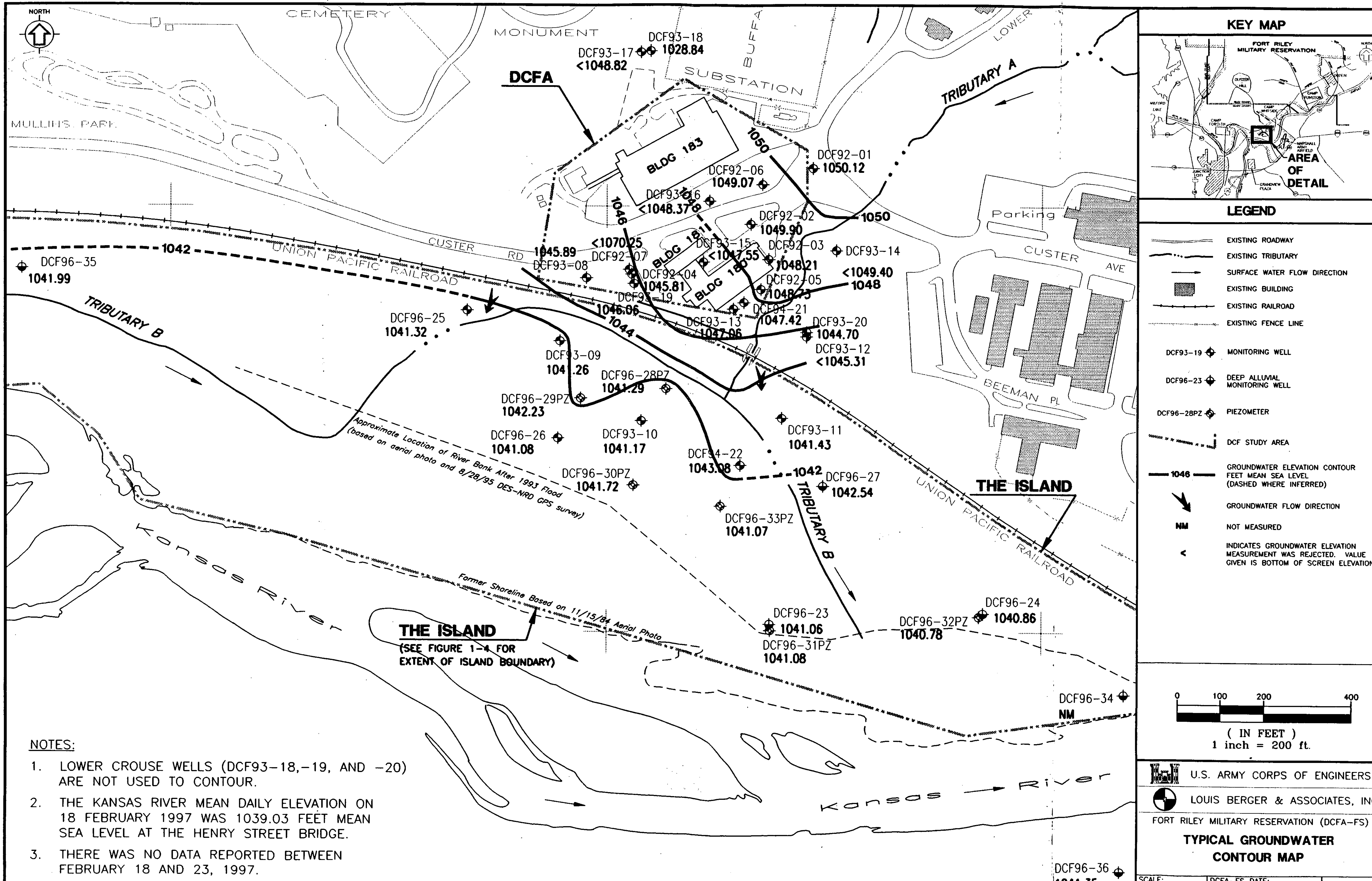
U.S. ARMY CORPS OF ENGINEERS

LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA–FS)

GEOLOGIC BLOCK DIAGRAM
DCFA AND VICINITY

SCALE: NONE	DCFA–FS DATE: MARCH 1998	FIG. 1–5



NOTES:

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

U.S. ARMY CORPS OF ENGINEERS

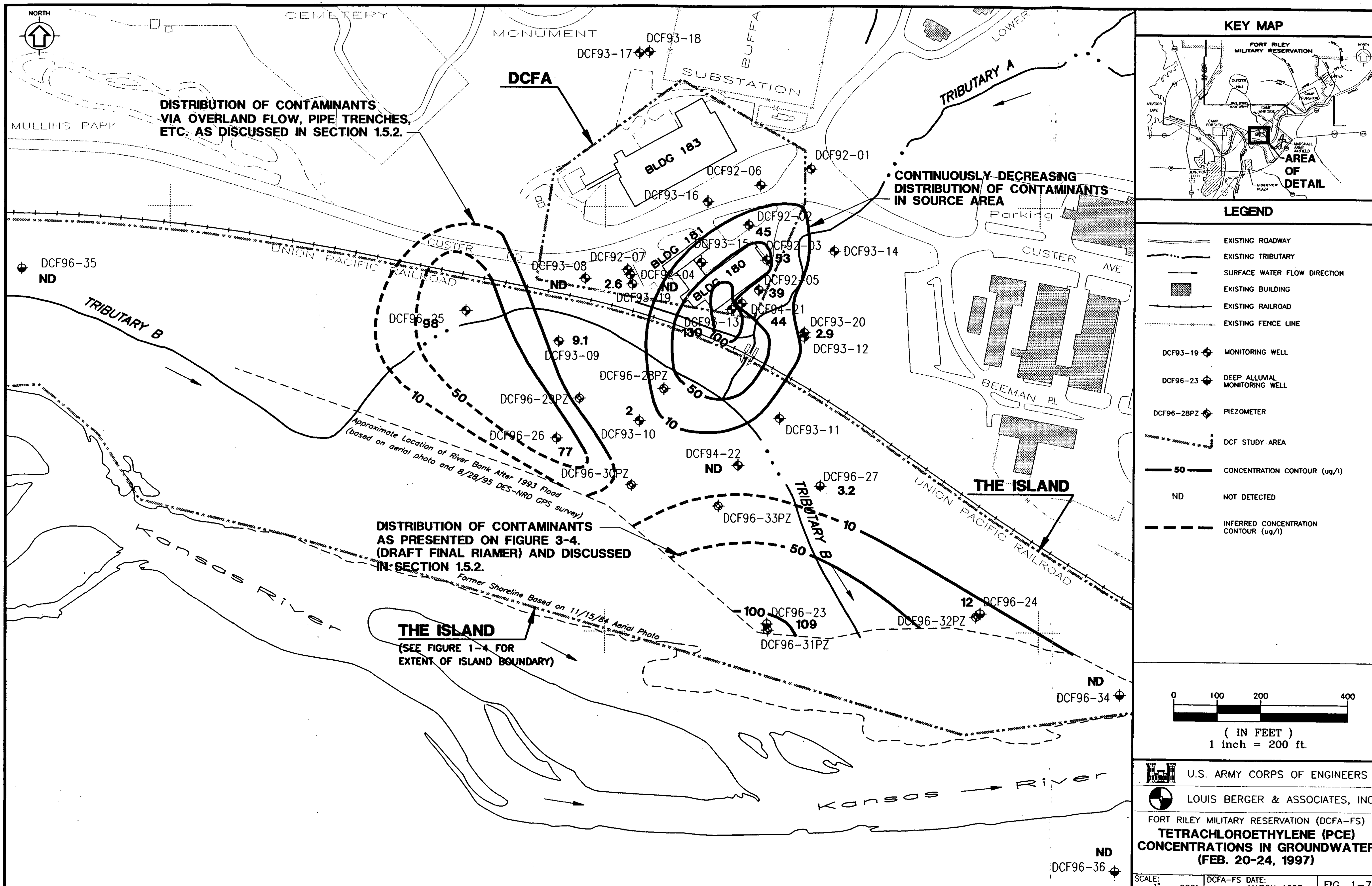
LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-FS)

TYPICAL GROUNDWATER CONTOUR MAP

SCALE: 1" = 200' | DCFA-FS DATE: MARCH 1998 | FIG. 1-6

FS-545M/25MAR98/FS-GCM


NORTH
CEMETERY
MONUMENT
MULLIN'S PARK
DCFA
DISTRIBUTION OF CONTAMINANTS VIA OVERLAND FLOW, PIPE TRENCHES, ETC. AS DISCUSSED IN SECTION 1.5.2.
SUBSTATION
BLDG 183
BLDG 181
BLDG 180
TRIBUTARY A
TRIBUTARY B
CONTINUOUSLY DECREASING DISTRIBUTION OF CONTAMINANTS IN SOURCE AREA
CUSTER RD
CUSTER AVE
BEEMAN PL
Parking
UNION PACIFIC RAILROAD
THE ISLAND
DISTRIBUTION OF CONTAMINANTS AS PRESENTED ON FIGURE 3-4. (DRAFT FINAL RIAMER) AND DISCUSSED IN SECTION 1.5.2.
Approximate Location of River Bank After 1993 Flood (based on aerial photo and 8/28/95 DES-NRD GPS survey)
Former Shoreline Based on 11/15/84 Aerial Photo
THE ISLAND (SEE FIGURE 1-4 FOR EXTENT OF ISLAND BOUNDARY)
Kansas River
DCF93-17
DCF93-18
DCF92-01
DCF92-06
DCF93-16
DCF92-02 45
DCF93-15
DCF92-03 53
DCF93-14
DCF92-07
DCF93-08 ND
DCF92-04 ND
2.6
DCF93-19
DCF92-05 39
DCF94-21 44
DCF93-13 130
DCF93-20 2.9
DCF93-12
DCF96-35 ND
DCF96-25 98
DCF93-09 9.1
DCF96-28PZ
DCF96-29PZ
DCF93-10 2
DCF93-11
DCF96-26 77
DCF96-30PZ
DCF94-22 ND
DCF96-27 3.2
DCF96-33PZ
DCF96-23 100 109
DCF96-31PZ
DCF96-32PZ
DCF96-24 12
DCF96-34 ND
DCF96-36 ND
10
50
100
KEY MAP
FORT RILEY MILITARY RESERVATION
AREA OF DETAIL
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
50 CONCENTRATION CONTOUR (ug/l)
ND NOT DETECTED
INFERRED CONCENTRATION CONTOUR (ug/l)
0 100 200 400
(IN FEET)
1 inch = 200 ft.
U.S. ARMY CORPS OF ENGINEERS
LOUIS BERGER & ASSOCIATES, INC.
FORT RILEY MILITARY RESERVATION (DCFA-FS)
TETRACHLOROETHYLENE (PCE) CONCENTRATIONS IN GROUNDWATER (FEB. 20-24, 1997)
SCALE: 1" = 200'
DCFA-FS DATE: MARCH 1998
FIG. 1-7
FS-SASM, 25MAP98/TCR2.DGN

2.0 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

2.0 Applicable or Relevant and Appropriate Requirements

Environmental statutes and other regulatory requirements are critical to the evaluation, selection and implementation of all remedial actions. These statutes and requirements are especially important to the remedial process for the DCF Study Area, however, because of the absence of unacceptable risks to human or environmental receptors in the vicinity of the DCF Study Area. As a result, statutory and regulatory requirements are the sole driving force behind the need for remedial action associated with the DCFA.

2.1 Definition of Applicable or Relevant and Appropriate Requirements (ARARs)

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund"), the Superfund Amendments and Reauthorization Act (SARA) and the associated implementing regulations provided by the National Contingency Plan (NCP) indicate that the development and evaluation of remedial action alternatives generally should meet promulgated and substantive federal standards, requirements, criteria or limitations that are determined to be legally applicable or relevant and appropriate requirements. Also included in the NCP is the provision that state standards that are "more stringent" than federal standards are also potential ARARs that might have to be met, as long as they are promulgated and consistently applied (the state ARAR is considered more stringent than the federal requirements if no federal ARAR exists or if the state ARAR is broader in scope).

The NCP provides further that "ARARs will be determined by the lead agency based upon its analysis of which requirements are *applicable or relevant and appropriate to the distinctive set of circumstances and actions contemplated at a specific site"* (emphasis added). The DA is the lead agency for the Fort Riley CERCLA projects, in accordance with an IAG including the DA, the U.S. EPA, and the KDHE. More specifically, Section X (F) of the FFA for Fort Riley establishes in an IAG that draft ARAR determinations will be prepared by Fort Riley in accordance with the NCP, CERCLA and pertinent guidance published by the U.S. EPA. The IAG provides further that the DA determine the ARARs that are applicable or relevant and appropriate based on the distinctive set of circumstances and actions contemplated at a specific site. It is noted that ARAR identification is an iterative process that requires input from KDHE and the U.S. EPA, but Section 121 of CERCLA provides that ARAR identification by regulatory agencies shall be accomplished as early in the remedial process as possible.

2.1.1 Permits and the Distinction Between Substantive and Administrative Requirements

Consistent with CERCLA Section 121(d)(2), "response actions should be subject only to substantive, not administrative, requirements. [Further, Congress] specifically provided in Section 121(e)(1) of CERCLA that federal and state permits would not be required for such on-site response actions" (Preamble to the Final NCP, 55 FR 8756, March 8, 1990). The Preamble further states that, since CERCLA has its own procedures and requirements for remedy selection, ARAR implementation, and state and community involvement, "it would be wholly inappropriate to formally subject CERCLA response actions to the multitude of administrative requirements of other federal and state offices and agencies."

For example, statutes such as National Environmental Policy Act (NEPA) would not be applicable, because the CERCLA program satisfies the mandates of NEPA which require consideration of all reasonable alternatives to proposed government action. Likewise, permits pursuant to regulatory programs such as the National Pollutant Discharge Elimination System (NPDES) would not be required. In summary, cleanup standards and other substantive requirements should be complied with as appropriate, but administrative procedures such as permitting and formal consultation with other agencies are not required.

If the classification of a requirement as either substantive or administrative is not immediately clear, several considerations must be balanced to make the determination that a substantive requirement should be imposed. Such considerations include: the basic purpose of the requirement; any adverse effects on human health or the environment if the requirement were not met; the existence of other requirements at the site which perform the same purpose; and classifications performed previously in other CERCLA situations.

2.1.2 Definition of "Applicable" Requirements

Applicable requirements are those legal standards, criteria, protective requirements or limitations that are promulgated under federal or state law and that specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site. In the review of a potential ARAR, it is first determined whether that ARAR is applicable. If it is not applicable, it may still be binding as an ARAR if it is found to be relevant and appropriate.

2.1.3 Definition of "Relevant and Appropriate" Requirements

To consider whether a non-applicable requirement is relevant and appropriate, a comparison of a number of site-specific factors is performed in light of standards, criteria, protective requirements or limitations that are promulgated under federal or state law which are not applicable, but which address problems or situations that are sufficiently similar to those encountered at the site in question such that their use is well suited to the given conditions.

A requirement may be relevant if it addresses problems or situations sufficiently similar to the circumstances of the release or remedial action contemplated, and it may also be appropriate if it is well suited to application at the CERCLA site in question. If it is not both relevant and appropriate, it is not adopted as an ARAR. It is possible for only a portion of a requirement to be relevant and appropriate, while other parts are not appropriate for the site-specific circumstances.

Comparisons between the non-applicable requirement and the site conditions in question should be made according to the following criteria: (i) purpose, (ii) medium affected, (iii) substances regulated, (iv) actions or activities regulated, (v) variances, waivers or exemptions granted, (vi) type of place, (vii) type and size of structure or facility affected by the release and (viii) use or potential use of affected resources (40 CFR 400[g][2][i] through [viii]).

2.1.4 Waiver of ARARs

Occasionally, ARARs may be waived. Section 121(d)(4) of CERCLA identifies six circumstances under which ARARs may be waived:

- The remedial action selected is only a part of a total remedial action (interim remedy) and the final remedy will attain the ARAR upon its completion;
- Compliance with the ARAR will result in a greater risk to human health and the environment than alternative options;
- Compliance with the ARAR is technically impracticable from an engineering perspective;

- An alternative remedial action will attain an equivalent standard of performance through the use of another method or approach;

- The ARAR is a state requirement that the state has not consistently applied (or demonstrated the intent to apply consistently); or,

- For Section 104 Superfund-financed remedial actions, compliance with the ARARs will not provide a balance between protecting human health and the environment and the availability of Superfund money for response at other facilities.

2.2 Definition of To-Be-Considered Information (TBCs)

Other information that does not qualify as an ARAR may be needed during the development of remedies. TBCs are non-promulgated advisories, criteria or guidance issued by federal, state, or local governmental agencies that are not legally binding. While they do not carry the weight of ARARs in the determination of remediation goals, TBCs are considered in conjunction with ARARs during site risk assessment, and they may be used in determining remediation goals and/or in developing remedies. TBC information generally falls within the following three categories:

- Health effects information with a high degree of credibility;
- Technical information on how to perform or evaluate site investigations or response actions; and,
- Policy of administrative agencies.

2.3 Categories of ARARs

The preliminary identification of potential ARARs and TBCs is intended to assist in the development of remedial alternatives and remediation goals as outlined in the NCP. ARARs may be categorized as chemical, location, and action-specific under CERCLA guidelines. The ARARs that are eventually applied will be dependent upon accumulated site contaminant data, specific site conditions, and the selected remedial action alternatives.

2.3.1 Chemical-Specific ARARs

Chemical-specific ARARs are usually health or risk-based numerical values which, when applied to site conditions, result in establishment of numerical action values. These values establish the acceptable amount or concentration of a chemical in a medium or discharge stream. Potential chemical-specific ARARs are generally applied to contaminants in a specific media such as soil, surface waters, sediments and/or groundwater. Primary examples include the Safe Drinking Water Act Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs), Federal Ambient Water Quality Criteria, and National Ambient Air Quality Standards.

2.3.2 Location-Specific ARARs

Location-specific ARARs are geographically determined requirements or limitations on potential remedial actions at the site because of the site's location. Location-specific ARARs are restrictions placed on the concentration of a hazardous substance or the conduct of activities solely because they are in specific locations. Federal and state location-specific ARARs include those established to protect endangered species, fish and wildlife, surface water quality, wetlands, water wells, floodplains and cultural resources. Primary examples include: RCRA location requirements; National Historic Preservation Act; Endangered Species Act; Wild and Scenic Rivers Act; and Clean Water Act.

2.3.3 Action-Specific ARARs

Action-specific ARARs are technology- or activity-based requirements or limitations triggered by the proposed remedial actions for the site. Since there are often several alternative remedies being considered for a given site, very different requirements can be considered. These action-specific ARARs do not, however, determine a remedial alternative but rather indicate how selected remedies are achieved. Primary examples include: RCRA Corrective Action requirements; Clean Air Act emissions requirements; and Clean Water Act discharge requirements.

2.4 Identification of Potential ARARs

The ARARs pertinent to the general response actions that are currently being considered for the DCFA Study Area are identified as either potentially "applicable" or potentially "relevant and appropriate." The word "potentially" is used because, if another set of technologies (or general response actions) were considered, the same requirements might be identified in a different category. While the applicability determinations do not consider all conceivable actions, they do address the remedial actions that are being considered and analyzed in detail as part of the FS.

The first step in identifying potential ARARs is to develop a list of all of the known requirements that might reasonably be applied to the proposed remedial action and/or might assist in the determination of remediation goals. The subsequent step is to screen this list with regard to the subject site. Lists of the potential chemical-, location-, and action-specific ARARs identified during this screening step are presented in Tables 2-1, 2-2, and 2-3, respectively. Lists of TBCs are presented in Table 2-4. In addition to identifying the list of potential ARARs and TBCs, the tables also include a brief description of the ARAR/TBC, followed by a determination of its status (applicability, relevance, etc.) with regard to the specific conditions at the DCFA based on the types of remedial actions currently being considered.

Tables 2-5, 2-6, 2-7 and 2-8 list the quantitative chemical-specific limits or guidance criteria found in the potential ARARs and TBCs for groundwater/drinking water, surface water, sediments and soils, respectively. Chemicals indicated for each media type correspond to the constituents which were detected in samples from that media and which were considered for inclusion in the BLRA; chemicals in boldface indicate which constituents were ultimately retained as a chemical of concern in the BLRA.

The ARAR/TBC screening tables (Table 2-1, 2-2, 2-3, and 2-4) are provided as a summary to explain the logic utilized in the determination process for the DCFA based upon the site-specific conditions. For the sake of clarity and conciseness, the screening summary is not repeated here such that there are many potential ARARs/TBCs that are not discussed in the text of this report. A more detailed description of the determination process is provided, however, for those potential ARARs/TBCs considered to be either more critical and/or more complex, such that the process cannot be adequately described in the tables (see Section 2.5 for ARARs and 2.6 for TBCs).

2.5 Discussion of Selected Potential ARARs

The discussions in this section are intended to provide additional details and information beyond those provided in Tables 2-1, 2-2 and 2-3, for those potential ARARs that are considered to be complex or to have the greatest potential effect on the selection and/or implementation of the response actions currently being considered for the DCFA.

Based on the specific site conditions, the types of remedial alternatives currently being considered are control options (i.e., engineered controls and/or institutional controls with monitoring programs), natural attenuation, passive treatment (i.e., funnel and gate), and removal/treatment alternatives. Alternatives that consist of control options and natural attenuation with monitoring also include a potential contingency action if future monitoring data and/or site use deviates substantially from current conditions or foreseeable future conditions.

Potential ARARs are important because they trigger an action, affect the selection purpose, or constrain the implementation of an action. While contaminant levels exceeding the Kansas State Surface Water Quality Criteria on the Island are the trigger for remedial action (see Section 2.5.4), other ARARs that would become more important during the implementation of the remedial action are of a more ecological nature due to the sensitive habitat located on the Island. Requirements pursuant the Endangered Species Act are therefore particularly critical (see Section 2.5.6). While it may be difficult to quantify the impacts of these ARARs, satisfaction of each of these requirements is anticipated to be a factor that would have a large impact on the selection and implementation of a particular alternative.

2.5.1 Safe Drinking Water Act (42 USC 300) and Amendments of 1996 (42 USC 201), Including the National Primary Drinking Water Regulations (40 CFR 141)

- **Description**

The Safe Drinking Water Act (SDWA) is the federal statute which requires the regulation of public water supply systems, including the creation of enforcement powers and penalty provisions. Under the SDWA, a "public water supply system" is defined as a system for the provision to the public of piped water for human consumption if such system includes at least fifteen service connections or regularly serves at least twenty-five individuals.

The National Primary Drinking Water Regulations (NPDWR) are the implementing regulations under the SDWA which apply to each public water system in each state (with a few minor exceptions irrelevant to this report). The NPDWR provides drinking water standards that apply to community water systems (defined as systems which have at least 15 service connections used by year-round residents). This regulation also applies to non-transient water systems (defined as public water systems which do not meet the definition of community water systems but can serve 25 or more people over six months out of each year).

The NPDWR establishes MCLs and MCLGs for many specific chemical constituents in drinking water. MCLGs are health-based goals set at a level which no adverse health effects will arise (therefore, MCLGs for many carcinogens are set at zero). MCLs are set as close as feasible to MCLGs, but taking into consideration the best technology, treatment techniques, and other factors such as cost. The SDWA also establishes the requirement for setting Secondary MCLs and MCLGs, which generally regulate the odor or appearance of public drinking water and also are deemed to be generally protective of the public welfare.

MCLs are the legally enforceable standards under the SDWA as applied to the quality of drinking water "at the tap" (in other words, at the point of consumption) and are considered to be an ARAR, if it is determined to be relevant and appropriate. While MCLGs are not enforceable under the SDWA, the NCP does provide that remediation goals "shall be developed *considering*" [emphasis added] several factors including cited subsection (B), which states that non-zero MCLGs ". . . shall be attained . . . where the MCLGs are relevant and appropriate under the circumstances of the release based on factors in § 300.400(g)(2)" (NCP 300.430[e][2][i]). In other words, MCLs and non-zero MCLGs may be an ARAR (and their attainment may be a cleanup goal), if they are determined to be relevant and appropriate requirements considering the circumstances at the site in question, including whether or not the contaminated groundwater and/or surface water is to be used for drinking water currently, or is reasonably expected to be so used in the future.

The SDWA also protects underground sources of drinking water utilized by public water supply systems. It specifically regulates all underground injection activities (defined as the subsurface emplacement of fluids by well injection) and requires the establishment of state well-head protection programs. Underground sources of drinking water are defined by the SDWA as sources which supply or can reasonably be expected to supply any public water system.

Additionally the Safe Drinking Water Act Amendments of 1996 were recently signed into law. Once implementing regulations are developed by the U.S. EPA, the amendments to the SDWA will bring substantial changes and greater regulatory power to federal, state and water utility agencies. The impending changes can be summarized as follows:

1. New and stronger approaches to prevent contamination of drinking water;
2. Better information for consumers;
3. Regulatory improvements, including appropriate application of scientific principals and methods, prioritization of effort, better use of risk assessment techniques, and appropriately setting or adjusting specific regulatory standards as a result of the improvements; and
4. New funding for states and communities through the Drinking Water State Revolving Fund.

Though the Amendments bring substantial change to the SDWA, the most significant change is that individual agencies will have more power to adjust/revise drinking water regulations and standards within their own jurisdiction.

- **Applicability Analysis**

This potential ARAR is categorized as both chemical-specific (MCLs/MCLGs) and action-specific (i.e., restrictions on underground injection of pollutants). Under the NCP, and as applied to the specific site conditions, MCLs and non-zero MCLGs are potentially relevant and appropriate in that they should only be used as cleanup standards if the groundwater or surface water at or near the DCF Study Area is reasonably expected to be used as drinking water in the future. The SDWA restrictions regarding the protection of underground sources of drinking water (injection controls and wellhead protection) are similarly categorized and considered regarding the contingency that pumping and reinjection actions are to be applied.

The SDWA Amendments of 1996 will be applicable to the extent that the U.S. EPA and/or the State of Kansas revise their drinking water regulations as a result of the 1996 Amendments. In particular, a potential impact that revised regulations may have on the DCF Study Area is the provision that the 1996 Amendments give more authority to U.S. EPA to set and/or adjust chemical-specific standards and water quality requirements based on affordability and that increased health benefits must justify remediation costs.

2.5.2 State Surface Water Quality Standards (KAR 28-16-28b; implementing KSA 65-165 and KSA 65-171d)

- **Description**

The KDHE has developed and promulgated Surface Water Quality Standards which generally provide that: levels of water quality in surface waters of the state shall be maintained at levels which protect existing and designated uses; permanent (i.e., non-ephemeral) degradation of existing water quality shall be avoided except where otherwise approved by KDHE based on a showing of important social and economic considerations; and artificial sources of pollution will not be allowed which result in harmful effects on populations of threatened or endangered species. Numeric water quality criteria are provided for specified pollutants based upon which designated use category a given surface water is placed in, although KDHE reserves the authority to: (1) promulgate more stringent criteria if site-specific conditions warrant it; and (2) permit temporary sources of pollution producing only ephemeral surface water quality degradation not harmful to existing or designated uses. Furthermore, concentrations of certain pollutants may legally exceed water quality criteria applied in most other portions of the receiving surface waters if they are still within the mixing zone (where the mixing zone is that portion of a stream where an effluent is incompletely mixed with the receiving surface water based on seven-day, ten-year low flow conditions, or "7Q10 flow").

Designated uses are adopted based upon the results of a "Use Attainability Analysis" conducted or accepted by KDHE, and a registry of surface water use designations is maintained by KDHE. Where a surface water is designated for more than one use, the most stringent water quality criteria applies. Of all the designated use categories, domestic water supply use is generally the most stringent and requires compliance with the KWQS as they apply to a surface waters that could potentially be used as a drinking water source.

Under KAR 28-16-28b, "surface waters" are defined to mean, in pertinent part, "streams, including rivers, creeks, . . . , seeps and cavern streams, and any alluvial aquifers associated with these surface waters." Alluvial aquifers are in turn defined as "the sediment that is associated with and deposited by a stream, and that contains water capable of being produced from a well." There is no detail in the regulations (or in other available documents or guidance from KDHE) on specifically how to determine when an alluvial aquifer is "associated with" surface waters as opposed to being of minimal enough impact to surface waters so as to be deemed outside the requirements of this regulation. As a result, determinations are made on a case-by-case basis by evaluating the site-specific conditions (personal communication, KDHE, May 8, 1996, Appendix A).

- **Applicability Analysis**

This potential ARAR is characterized as location-specific and, with respect to the KWQS, as chemical-specific. As with the Federal AWQC, the Kansas Surface Water Regulations are applicable to contaminants which migrate to, or are discharged into the Kansas River. In contrast to the Federal AWQC, however, the alluvial aquifer underlying the Island is also subject to the Kansas Surface Water Quality Standards because of its very close proximity to the Kansas River and its location inside the bend of the river bed's historic limits, thus rendering much of the alluvial aquifer as "associated" with the Kansas River. As a result of their adoption within the context of the Surface Water Regulations, KWQS may therefore be considered as applicable chemical-specific criteria for both the Kansas River and the alluvial aquifer underlying the Island. Based on the current exceedances of KWQS associated with the groundwater at the Island, this ARAR therefore requires that some form of remedial action be implemented and maintained until contaminant levels are reduced to below KWQS

2.5.3 Clean Water Act (33 USC 1251-1375)

- **Description**

The Clean Water Act (CWA) amended the Federal Water Pollution Control Act and is intended to restore and maintain the chemical, physical and biological integrity of the nation's "navigable" waters (where navigable waters is broadly defined by 40 CFR 122.2 as waters of the United States, including territorial seas, all other surface water bodies, and other areas designated as regulated wetlands in accordance with criteria developed by U.S. EPA and/or approved state agencies). The ultimate goal of this act is to eliminate the discharge of all pollutants into navigable waters of the United States. Under the CWA, pollution is defined as any man-made or man-induced alteration of the chemical, physical, biological or radiological integrity of water. The CWA divides pollutants into three categories: priority pollutants consisting of the listed toxic compounds adopted by U.S. EPA pursuant to Section 307(a)(1); conventional pollutants such as total suspended solids, fecal coliform, etc.; and nonconventional pollutants consisting of all pollutants not classified as priority or conventional.

The CWA regulates discharges of pollutants from any point source, including both direct point discharges (e.g., ditches, culverts, pipes, fill, etc.) and indirect point discharges (via waste water treatment facilities) to U.S. waters. It is noted, however, that contaminated groundwater that naturally flows to surface waters is not considered a point source discharge, and therefore, such contaminated groundwater may only be subject to regulation to the extent that the CWA requires that applicable water quality criteria or standards should not be exceeded as a result (U.S. EPA 1988b). See Section 2.5.3 for a discussion of the Federal Ambient Water Quality Criteria and its application.

Title III of the CWA outlines standards and enforcement provisions for limitations on pollutant discharges while Title IV defines permitting and licensing requirements (although it is reiterated that administrative permit requirements do not apply to remedial actions under CERCLA). In particular, Title IV requires the development and administration of several regulatory permit programs including: the NPDES for effluent discharges; and Section 404 permits for discharges of dredged or fill material to wetlands. In addition to discharge limitations, it is noted that NPDES also includes monitoring requirements and the use of best management practices as provided in 40 CFR 122-125. The Section 404 requirements are implemented through regulations set forth at 33 CFR 320-330 and 40 CFR 230 and are intended to ensure that discharges are evaluated with respect to impacts on the aquatic ecosystem, which is balanced against the gains of performing the dredge and/or fill activity.

Also included in the CWA are administrative procedures and judicial review provisions, along with a granting of state authority to administer its own permit program if approved upon review by the lead administrator (U.S. EPA). Kansas is a NPDES delegated state without general permitting authority. This means that, where required, individual NPDES permits must be applied for through the KDHE. The State of Kansas has not, however, been granted authority to grant wetland permits; therefore, Section 404 permits must be obtained through the U.S. Army Corps of Engineers.

NPDES limitations on pollutant discharges in effluent streams are technology-based in that chemical discharge limits are set based on the application of the best practicable and currently available control technology (including considerations of costs to the regulated community). These effluent limitations are required to be written into NPDES permits issued to all regulated dischargers. The CWA also requires the development of site-specific pretreatment standards for discharge to a Publicly Owned Treatment Works (POTW); and, according to Section 313, federally owned facilities are generally regulated to the same extent as any facilities owned by nongovernment entities. Section 108(F) of the Federal Facilities Compliance Act provides one exception to this whereby the exclusion regarding the addition of a listed waste to existing effluent streams is generally not available to federally owned treatment works, or FOTWs, whereas it is available to POTWs.

Pursuant to Section 404 of the CWA, U.S. EPA developed guidelines for specifying disposal sites for dredged or fill material (40 CFR 230). The purpose of these regulations is to restore and maintain the chemical, physical and biological integrity of U.S. waters through the control of discharges of dredged or fill material. This regulation requires that dredged or fill material should not be discharged into the aquatic ecosystem unless it can be demonstrated that such a discharge will not have an unacceptable adverse impact. Absent an approved state program, these guidelines are under the regulatory authority of the U.S. Army Corps of Engineers.

- **Applicability Analysis**

This potential ARAR is categorized as action-specific, in that, it seeks to regulate actions involving discharges to protected surface waters or, by extension, to regulated wastewater treatment works. Only the substantive requirements are considered for on-site activities such as treatment and/or discharge to a surface water body in the area of contamination or in close proximity via pipes, ditches or other discrete conveyance. Both the substantive and the administrative/permit requirements could apply to off-site treatment and discharges, which generally include discharges to wastewater treatment facilities.

Based on the wetlands determination prepared by the U.S. Army Corps of Engineers, Kansas City District, dated March 17, 1993, Tributaries A and B did not qualify as delineated wetlands, and the only wetlands identified in the study area are located immediately adjacent to the Kansas River.

Therefore, this requirement is determined to be neither applicable nor relevant and appropriate to alternatives that do not involve construction in wetlands or any discharges to protected surface waters or regulated wastewater treatment facilities. It would be applicable, however, to any response action or contingency alternatives which impacts the protected waters of the Kansas River as a result of the installation of pipes or channels for site runoff (resulting in discharges of effluents), or on-site treatment and associated discharge of effluents. If deemed to be an ARAR, appropriate discharge limitations would need to be developed and/or complied with. Further, the substantive requirements of the NPDES and/or Section 404 permit programs would need to be satisfied for any off-site discharges to the extent that they are proposed.

2.5.4 Federal Surface Water Quality Requirements (40 CFR 131)

- **Description**

Pursuant to Section 304 of the CWA, U.S. EPA has developed Ambient Water Quality Criteria (AWQC) for constituents in surface waters for the protection of aquatic life and for the protection of human health from the ingestion of contaminated water and/or organisms. Under the CWA, these criteria are potentially applicable to all U.S. waters as defined therein.

The AWQC for the protection of aquatic organisms are based on two types of criteria: (1) acute criteria representing the maximum concentrations permissible at any time; and (2) chronic criteria representing the maximum permissible concentration averaged over a 24-hour time period. The AWQC for the protection of human health are based on the ingestion of contaminated water and/or the ingestion of contaminated fish from surface waters. The AWQC for the protection of human health from the ingestion of water and fish assumes a daily water intake of two liters and a daily fish intake of 6.5 grams.

- **Applicability Analysis**

The AWQC are categorized as potentially chemical-specific and location-specific ARARs. The AWQC are a potential ARAR with regard to significant impacts on the water quality in the Kansas River from either migration of contaminants from the DCFA or from direct discharges of pollutants resulting from response actions. The AWQC are not applicable or appropriate to Tributaries A and B because of their non-wetland status and ephemeral nature (i.e., ambient conditions have not been established at the tributaries and they are not a drinking water source or used for fishing).

2.5.5 Protection of Wetlands (Executive Order 11990; 40 CFR 6.302a)

- **Description**

This requirement holds that federal agencies should avoid, to the extent possible, any adverse impacts associated with the destruction or loss of wetlands and the support of new construction in wetlands if a practicable alternative exists. The requirement would be applicable to remedial actions in any contaminated wetlands or to actions including discharges of pollutants, fills, etc., to wetlands. Reasonable alternatives to such actions must first be considered and, if unavoidable, mitigative measures (such as wetland replacement) must be developed and implemented to minimize impacts.

- **Applicability Analysis**

This potential ARAR is categorized as location-specific with regard to natural contaminant migrations and as action-specific with regard to remedial actions involving construction in, or discharges to wetlands at or near the DCF Study Area. Based on the wetlands determination prepared by the U.S. Army Corps of Engineers, Kansas City District, dated March 17, 1993, Tributaries A and B did not qualify as delineated wetlands, and the only wetlands identified in the study area are located immediately adjacent to the Kansas River. Assuming that no natural contaminant migrations are significantly impacting any wetlands, this requirement is determined to be neither applicable, nor relevant and appropriate to remedial actions that do not involve construction in wetlands or any discharges of pollutants to wetlands. It would be applicable, however, to any response action or contingency alternatives which impact protected wetlands as a result of the installation of pipes or channels for site runoff (resulting in discharges of effluents), or, on-site treatment construction and associated discharge of effluents to protected wetlands.

2.5.6 Endangered Species Act [16 USC §§ 1531-1544]

- **Description**

The purpose of The Endangered Species Act is to conserve endangered, threatened and rare species of wildlife and plants. This act specifically requires action to conserve any critical habitats upon which any species, falling under one of these categories, may depend.

- **Applicability Analysis**

This ARAR is applicable, because there are identified endangered/threatened species habitating in the greater Ft. Riley area. Specifically, portions of the Island are confirmed bald eagle roosting habitats during some parts of the year (CENWK, 1995a). This ARAR is categorized as location-specific with regard to any activities or contaminant migrations that might occur in the DCF Study Area and could potentially impact an identified endangered/threatened species. In particular, this ARAR would be a very important consideration for activities proposed at the Island, as any real or potential adverse impacts to protect habitat would require the evaluation and implementation of a mitigation program, including intensive coordination with regulatory agencies responsible for habitat protection.

2.5.7 Floodplain Management (Executive Order 11988, 16 USC § 661 et.seq., 40 CFR § 6.302 Appendix A)

- **Description**

This Executive Order requires federal agencies to evaluate that potential effects of actions conducted within a designated floodplain. The requirement establishes procedures that ensure that all actions to be conducted within floodplains should avoid, to the extent possible, any adverse impacts associated with the destruction of a floodplain. The requirements of the Order would be applicable to remedial actions in any contaminated floodplain or to actions including development of a floodplain. Reasonable alternatives to such actions must first be considered and, if action is unavoidable, the action must be developed and implemented to minimize impacts.

- **Applicability Analysis**

This potential ARAR is categorized as location-specific with regard to remedial actions involving construction in floodplains near the DCF Study Area. Based on floodplain information documented in the Draft Final RI (CENWK, 1995a), the surface of the alluvial Island exists almost entirely below designated floodplains. In fact, the Island would be almost entirely submerged during a 50 year flood and would be approximately 50 percent submerged during a 10 year flood (Section 5.1). Therefore, these requirements would be applicable to any response action or contingency alternatives that would require development, remedial construction, or operations and maintenance activities on the Island.

2.5.8 Resource Conservation and Recovery Act (42 USC 6901-6992) and Associated Implementing Regulations (40 CFR 261-270)

- **Description**

The Resource Conservation and Recovery Act (RCRA) extensively amended the Solid Waste Disposal Act and sought to protect human health and the environment, conserve natural resources and reduce, eliminate or at least control the generation of hazardous wastes (a waste is considered hazardous if it is either a RCRA listed waste, a RCRA-defined characteristic waste, or a mixture containing a RCRA hazardous waste). Of the numerous subtitles in RCRA, Subtitle C (Hazardous Waste Management) and Subtitle D (Solid Waste Management) are most likely to be the basis of a CERCLA ARAR; with Subtitle C being the most likely since it mandates the creation of a "cradle-to-grave" management system by regulating the generation, transportation, treatment, storage and disposal (TSD) of hazardous wastes. In general, Subtitle C is an applicable requirement if a combination of the following criteria are met:

- the waste is a listed (40 CFR 261 Subpart D) or characteristic waste (40 CFR 261 Subpart C) under RCRA;
- the waste was treated, stored or disposed (TSD) as defined in 40 CFR 260.10; or,
- the activity at the CERCLA site constitutes TSD as defined by RCRA.

These two scenarios are contingent upon the presence of a RCRA Subtitle C hazardous waste. To determine if a waste is listed, the source must be known. If the source is not ascertainable, then the wastes are generally not considered listed, and may only be considered RCRA wastes if other information becomes available which indicates that materials to be treated, stored, or disposed as part of the CERCLA action exhibit any of the required characteristics. If the wastes exhibit hazardous characteristics, RCRA requirements may be potentially applicable. If Subtitle C is found to be not applicable, it may be relevant and appropriate if waste at a CERCLA site is tested and found to be "sufficiently similar" to a RCRA hazardous waste. "Sufficiently similar" waste is described in the CERCLA Compliance With Other Laws Manual (U.S. EPA 1988b) as follows:

> "When evaluating whether Subtitle C requirements are relevant and appropriate, the mere presence of hazardous constituents in a CERCLA waste does not mean the waste is sufficiently similar to a RCRA hazardous waste to trigger Subtitle C as an ARAR. Judgment should be used in assessing whether the waste closely resembles a RCRA hazardous waste, considering the chemical composition, form, concentration, and any other information pertinent to the nature of the waste... [i.e.] low concentrations of a hazardous constituent, dispersed in soil over a wide area, would generally not trigger Subtitle C as relevant and appropriate."

In addition, the following general principles are provided in the CERCLA Compliance With Other Laws Manual:

- RCRA permits are not required for CERCLA actions taken entirely on site;
- Administrative RCRA requirements, such as reporting and record keeping requirements, are not applicable or relevant and appropriate for on-site activities; and
- In some cases, the source or prior use of a CERCLA waste may not be identifiable, but the waste may be "sufficiently similar" (as described above) to a RCRA listed or characteristic waste, therefore determining relevance. However, appropriateness must be determined by taking site characteristics and the remedial activity into consideration.

Some of the more pertinent regulation sections promulgated by EPA pursuant to RCRA include: Land Disposal Restrictions (40 CFR 268); Standards Applicable to Generators of Hazardous Waste (40 CFR 262); and, The Hazardous Waste Permit Program (40 CFR 270). Additionally, 40 CFR 264 Subpart S introduces the concept of Corrective Action Management Units (CAMUs) which are areas designated under RCRA for the purpose of implementing remedies more cost-effectively and without being subject to all RCRA criteria such as minimum technology requirements and land disposal restrictions. Wastes currently present within a CAMU may, therefore, remain in place under certain conditions (such as not creating unacceptable risks to humans and the environment and minimizing future releases to the extent practicable).

- **Applicability Analysis**

Referring in particular to the hazardous waste provisions of RCRA Subtitle C, this potential ARAR is characterized as action-specific, since it is a hazardous waste management requirement. Since the original source (including inventory amounts, timeframe of release(s), etc.) of the waste at the DCFA cannot be definitively ascertained through proper manifests or other sufficiently detailed records, it is not possible to affirmatively classify the contaminated media at the DCFA as a listed hazardous waste. If the waste is not listed, the substantive requirements of RCRA may nonetheless be potentially relevant and appropriate to contaminated materials at the site if they are found to be similar or identical to a RCRA listed or characteristic hazardous waste <u>and</u> are treated, transported or disposed as part of a response action.

Furthermore, if such treatment, storage and/or disposal would occur off site, the administrative/permit provisions of RCRA would also need to be satisfied.

2.6 Discussion of Selected TBCs

All identified TBCs have been presented in Tables 2-4, 2-5, 2-6, 2-7 and 2-8. TBCs have been identified and tabulated for each media discussed at the DCF Study Area. However, based on evaluation of all identified TBC's, none are considered to require a detailed discussion, because none are believed to be appropriate for consideration.

TABLES

TABLE 2-1
POTENTIAL CHEMICAL-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
National Primary Drinking Water Standards [SDWA 40 CFR 141 Subpart B]	Regulations implemented under the SDWA that establish chemical-specific MCLs and MCLGs for drinking water from public, community, and non-transient water systems.	Not applicable since no water supply wells in the area. Potentially relevant and appropriate if a migrating or discharged contaminant adversely affects current or reasonably expected future source of public drinking water such that MCLs or non-zero MCLGs are exceeded. The recent SDWA Amendments of 1996 give more authority to U.S.EPA to set contaminant standards/adjust MCLs based on affordability and that increased health benefits must justify remediation costs. The regulations, however, have yet to be modified pursuant to these recent amendments.
Kansas Surface Water Quality Standards [KAR 28.16.28, 1995]	Provides for maintenance and protection of public health through protection of surface waters by regulating uses and potential impacts to surface waters. In addition to surface waters, the Kansas Surface Water Quality Standards are also applicable to alluvial aquifers demonstrated to be "associated with" a surface water body. For surface waters protected as a potential drinking water source, federal MCLs apply by incorporation.	Potentially applicable to the Kansas River if ambient water quality is significantly affected by natural migration of contaminants and/or discharges of pollutants associated with response actions. Tributaries A and B are not jurisdictional wetlands and do not have ambient conditions due to their ephemeral nature.Applicable to the alluvial aquifer on the Island, since contaminant levels exceed MCLs and the associated Kansas River is protected as a potential drinking water source.

Kansas Drinking Water Rules [KAR 28.15]	Defines contaminant levels for microbiological and radiological contaminants, inorganic and organic chemicals, and turbidity of waters used for public water supply. Federal MCLs/MCLGs are currently adopted/applied rather than State-specific criteria.	Not applicable since not more stringent than Federal Drinking Water Regulations.

TABLE 2-2

POTENTIAL LOCATION-SPECIFIC ARARs

Dry Cleaning Facilities Study Area

Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Endangered Species Act [16 USC §§ 1531-1544]	The purpose of this act is to conserve endangered, threatened and rare species of wildlife and plants. This act specifically requires action to conserve any critical habitats upon which any species, falling under one of these categories, may depend.	Potentially applicable because there are identified endangered/threatened species habitating in the greater Ft. Riley area. Proper precautions and coordination with appropriate regulators will be required if any protected species are found to be potentially impacted by migration of contaminants or by any proposed response actions. Mitigation would be required for any damage done to a protected habitat.
Fish and Wildlife Protection [16 USC §§ 661-668, 16 USC §§ 2901 et. seq., 33 CFR §§ 320-330, 40 CFR § 6.302(g)]	Requires consultation when federal department or agency proposes or authorizes any modification of any stream or other waterbody, and adequate provision for protection of fish and wildlife resources. Lists actions prohibited in areas belonging to National Wildlife Refuge System.	Not an ARAR because there are no stream or river modifications required.
Scenic River Act [16 USC § 1271, 40 CFR § 6.302(e)]	Prohibits adverse effects on a scenic river.	Not an ARAR because there are no designated scenic rivers in the vicinity of the site.
Wilderness Act [16 USC § 1131, 50 CFR § 35.1]	Administers federally-owned wilderness area to leave it unimpacted.	Not an ARAR because there are no designated wilderness areas in the vicinity of the site.
National Wildlife Refuge System [16 USC 668, 50 CFR 27]	Restricts activities within a National Wildlife Refuge.	Not an ARAR because there are no National Wildlife Refuge areas in the vicinity of the site.

TABLE 2-2 (CONTINUED)
POTENTIAL LOCATION-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Historic Site Preservation [Executive Order 11593, 16 USC § 461 et.seq., 16 USC § 469 et.seq., 16 USC § 470 et.seq., 40 CFR § 6.301(b)]	Requires federal agencies to take into account the effect of any federally-assisted undertaking or licensing on any district, site, building, structure, or object that is included in or eligible for inclusion in the National Register of Historic Places (NRHP). Provides for protection, enhancement, and preservation of sites with archeological or historical significance.	Potentially applicable because the DCFA Site is located in an area containing structures of cultural significance. However, the structures associated with the former and current DCFs are designated as non-contributing to the cultural significance of the area. Proper precautions will be required if any proposed actions will have potentially adverse effects on a culturally significant structure.
State of Kansas Historic Preservation Act [KSA 75-2715-2725]	Requires protection and preservation of sites and buildings listed on State or Federal Historic Registries.	Potentially applicable because the DCFA Site is located in an area containing structures of cultural significance. However, the structures associated with the former and current DCFs are designated as non-contributing to the cultural significance of the area. Proper precautions will be required if any proposed actions will have potentially adverse effects on a culturally significant structure.
Floodplain Management [Executive Order 11988, 16 USC § 661 et.seq., 40 CFR § 6.302 Appendix A]	Requires federal agencies to evaluate the potential effects of actions they may take in a floodplain to avoid adverse impacts associated with direct or indirect development of a floodplain. Establishes procedures on floodplain management.	Potentially applicable to the extent that any proposed response actions will adversely effect the floodplain within which the site is located. If applicable, an impact evaluation would need to be incorporated into the analytical process and proper precautions would be required.

TABLE 2-2 (CONTINUED)
POTENTIAL LOCATION-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Protection of Wetlands [Executive Order 11990]	Requires that federal agencies evaluate the potential effects of actions on wetlands to avoid negative impacts. Establishes procedures on wetlands protection. Under this Executive Order, the protection of species, habitat diversity, stability, fish and wildlife will also be considered.	Potentially applicable to the extent that wetlands in the vicinity of the site are potentially impacted by proposed actions or contaminant migration. The only jurisdictional wetlands identified currently are immediately adjacent to the Kansas River. If applicable, an impact evaluation would need to be incorporated into the analytical process and proper precautions would be required.
Federal Antidegradation Policy [40 CFR § 131.12]	Requires each state to enact an Antidegradation Policy. Protects waters by use classification. Highest quality waters (most protected) are "of exceptional recreational or ecological significance" and deterioration of such waters is not permitted. The Kansas Surface Water Quality Implementation Procedure establishes an Antidegradation Policy that creates a permitting procedure for effluent discharges and will be used to maintain existing surface water quality conditions.	Substantive requirements are potentially applicable if ambient water quality in Kansas River is adversely affected by discharges of pollutants associated with response actions.

POTENTIAL LOCATION-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
State of Kansas, Designation of Critical Water Quality Management Area [KAR 28.16.70]	State can designate an area as a Critical Water Quality Management Area (CQMA)if a pollutant source is responsible or may reasonably be expected to cause damages to resources of the State.	Not an ARAR because the stretch of the Kansas River in the vicinity of Fort Riley is not designated a CQWMA.
Federal Facilities Compliance Act [42 USC 9620]	State laws concerning removal and/or remedial activity shall apply to removal and remedial activity at facilities owned and operated by the US Government.	Applicable because Fort Riley is a federal facility.

TABLE 2-3

POTENTIAL ACTION-SPECIFIC ARARs

Dry Cleaning Facilities Study Area

Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) [42 USC §§ 9601-967, CERCLA 40 CFR 300-302]	Protects human health and the environment from actual or threatened releases of hazardous and toxic chemicals. Regulates and provides guidelines for activities completed under the National Contingency Plan at sites on National Priorities List (NPL).	Applicable because the DCFA Site is on the NPL.
Clean Air Act (CAA) [42 USC 7401-7671]	Protects the ambient air quality in the US through pollutant source control. Establishes National Emission Standards for Hazardous Air Pollutants (NESHAP) released to the atmosphere (40 CFR 61). Regulates sources for emission standards.	Potentially applicable if a proposed response action involves emission of a regulated constituent. If applicable, emissions controls would be incorporated into the remedial action as appropriate.
National Ambient Air Quality Standards (NAAQS) [CAA 40 CFR 50]	Defines levels of air quality which are necessary to protect the public health.	Potentially applicable if a proposed response action involves emission of a regulated constituent. If applicable, emissions controls would be incorporated into the remedial action as appropriate.
Clean Water Act of 1977 [33 USC 1251-1375]	Regulates overall quality of all US waters as well as allowable discharges of pollutants to wastewater treatment plants, surface waters, or to wetlands. Permit programs under the CWA include NPDES and Section 404 dredge/fill programs.	Potentially applicable if water quality in the Kansas River is adversely affected by natural migration of contaminants and/or discharges of pollutants associated with response actions. Administrative/permit requirements are only applicable to off-site discharges of pollutants.

TABLE 2-3 (CONTINUED)
POTENTIAL ACTION-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Protection of Wetlands [Executive Order 11990, 40 CFR 6.302 Appendix A]	Requires that federal agencies evaluate the potential effects of actions on wetlands to avoid negative impacts. Establishes procedures on wetlands protection. Under this Executive Order, the protection of species, habitat diversity, stability, fish and wildlife will also be considered.	Potentially applicable to the extent that wetlands in the vicinity of the site are potentially impacted by proposed actions or contaminant migration. If applicable, an impact evaluation would need to be incorporated into the analytical process and proper precautions would be required.
Safe Drinking Water Act and Amendments of 1996 [42 USC 300, 42 USC 201]	Regulates public, community, and non-transient water systems water supply systems as defined in the Act. Action-specific provisions include restrictions on underground injection activities and a requirement for state wellhead and recharge area protection programs.	Action-specific provisions are potentially applicable to the extent that proposed response actions include underground injection wells which might impact current or future water supply systems. On-site injection wells would have to conform to the substantive requirements, but off-site injection wells would also have to meet administrative/permit requirements.
Toxic Substance Control Act (TSCA) [15 USC 2601-2692, RCRA 40 CFR 761]	Regulates the manufacturing, storage, transportation and disposal of specific toxic chemicals along with PCB's, asbestos, radon and lead exposure.	Not applicable because there are no TSCA regulated wastes identified at the site.

TABLE 2-3 (CONTINUED)
POTENTIAL ACTION-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Guidelines for Specification of Disposal Sites for Dredged or Fill Material [40 CFR 230]	Regulations pursuant to the CWA designed to restore and maintain the chemical, physical, and biological integrity of waters of the United States through control of the location and extent of discharges of dredged or fill materials to all US waters.	Potentially applicable if there will be discharges of pollutants consisting of dredge/fill material to US waters associated with response actions. Administrative/permit requirements are only applicable to off-site discharges of pollutants. Tributaries A and B are not jurisdictional wetlands and do not have ambient conditions due to their ephemeral nature.
National Environmental Policy Act (NEPA) [42 USC 4321-4347]	Requires the consideration of all reasonable alternatives for proposed government actions which substantially impact the environment.	Not applicable because the CERCLA process inherently satisfies the substantive requirements of NEPA.
Resource Conservation and Recovery Act (RCRA) [42 USC 6901 - 6992] (As expanded by the Hazardous and Solid Waste Amendments of 1984)	RCRA extensively amended the Solid Waste Disposal Act of 1965. The goals of RCRA are to protect human health and the environment, conserve natural resources, and reduce or eliminate the generation of hazardous waste. Included are corrective action requirements, land disposal restrictions, and technical requirements associated with the generation, treatment, storage, and disposal (TSD) of hazardous wastes. Permit requirements are included.	Potentially applicable to the extent that contaminated materials being treated, stored or disposed qualify as RCRA hazardous wastes. If applicable, on-site TSD actions would have to comply with the substantive requirements of RCRA, whereas off-site TSD actions would also have to satisfy administrative/permit requirements under RCRA. Materials potentially qualifying as RCRA hazardous wastes might include excavated soils, carbon treatment filters or other treatment media, and/or investigation derived wastes; analytical testing is likely to be required to make determinations.

TABLE 2-3 (CONTINUED)
POTENTIAL ACTION-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
RCRA-Identification and Listing of Hazardous Waste [RCRA 40 CFR 261]	Defines a hazardous waste and a conditionally exempt waste generator. Provides criteria for determining hazardous versus solid wastes.	Potentially applicable to the extent that contaminated materials being treated, stored or disposed qualify as RCRA hazardous wastes and conditional exemption is not applicable.
RCRA-Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF) [RCRA 40 CFR 264]	Regulates facilities that treat, store, or dispose of hazardous waste. Includes closure requirements for TSDFs, and allows the designation of Corrective Action Management Units (CAMUs).	Not applicable unless the DCFA becomes a regulated TSDF under RCRA in the future.
RCRA-Land Disposal Restrictions [RCRA 40 CFR 268]	Defines hazardous wastes that are restricted from land disposal and provides limited circumstances under which prohibited wastes may be land-disposed. Disposal site closure requirements are also provided.	Potentially applicable to the extent that contaminated materials being disposed qualify as RCRA hazardous wastes.
RCRA-Treatment Requirements [RCRA 40 CFR 264]	Establishes prerequisites associated with different treatment techniques if they are used to treat RCRA hazardous wastes.	Potentially applicable to the extent that contaminated materials being treated qualify as RCRA hazardous wastes and a treatment technique is used for which RCRA prerequisites are available.
RCRA-Standards Applicable to Generators of Hazardous Waste [RCRA 40 CFR 262]	Defines a small quantity generator and large quantity generators. Establishes the classification of, and standards applicable to, small and large quantity generators.	Potentially applicable to the extent that response actions generate RCRA hazardous wastes in sufficient quantities to trigger this requirement.

TABLE 2-3 (CONTINUED)
POTENTIAL ACTION-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
RCRA-Standards Applicable to Transporters of Hazardous Waste [RCRA 40 CFR 263]	Defines the requirements for transporting hazardous wastes off-site, if the transport requires a manifest.	Potentially applicable to the extent that response actions include the off-site transportation of RCRA hazardous wastes.
Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA) [33 USC 11,000-11,050]	Sets guidelines for facilities handling hazardous or toxic chemicals regarding emergency planning and notification as well as establishes reporting requirements.	Not applicable unless the use of regulated substances are required as part of any response action.
National Pollutant Discharge Elimination System [40 CFR 122]	Pursuant to the CWA, this regulation covers permitting requirements for discharge of pollutants from any point source into waters of United States.	Potentially applicable if response action includes discharges of effluent/pollutants to US waters and/or to a permitted wastewater treatment facility. Administrative/permit requirements are only applicable to off-site discharges of pollutants.
Transportation: Hazardous Materials Regulations [49 CFR 171-173]	Defines the requirements for transporting hazardous waste or hazardous materials off-site.	Potentially applicable if response actions include the off-site transportation of RCRA hazardous wastes.
Kansas Water Well Contractor's License; Water Well Construction and Abandonment [KAR 28.30]	Regulates the construction, treatment and closure of water wells in State of Kansas aquifers; including contractor licensing and per well fee requirements. "Aquifer" is defined in the regulation as an underground formation that contains and is capable of transmitting groundwater.	Potentially applicable if wells are installed in subsurface formations deemed to be aquifers. If applicable, substantive well construction requirements would need to be complied with.

4p

TABLE 2-3 (CONTINUED)
POTENTIAL ACTION-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Kansas Underground Injection Control Regulations [KAR 28.46]	Regulates the installation and use of injection wells in the State of Kansas.	Potentially applicable if proposed response actions include underground injection wells which might impact current or future water supply systems.
Kansas Wastewater Discharge Control Law [KSA 65.161-171w]	Regulates wastewater discharges from industrial and other sites in the State of Kansas.	Potentially applicable if proposed response actions include wastewater discharges.
State of Kansas, Hazardous Waste Management Regulations [KAR 28.31]	Pursuant to RCRA, regulates hazardous waste generation, treatment and disposal in the State of Kansas. Defines the "Kansas Generator" as a generator of greater than or equal to specified amounts of hazardous waste per month.	Potentially applicable if response actions generate hazardous wastes in sufficient quantities to trigger this requirement.
Kansas Solid Waste Management Regulations [KAR 28.29 Part II]	Regulates the management of solid wastes in the State of Kansas including treatment, storage and disposal of such wastes.	Potentially applicable if response actions involve the generation, treatment, storage and/or disposal of solid wastes.
State of Kansas, Water Pollution Control Regulations [KAR 28.16]	Regulates effluent discharged to surface waters to assure State water quality levels are satisfied and designated uses of existing waters are maintained.	Potentially applicable if ambient water quality in Kansas River is significantly affected by natural migration of contaminants and/or discharges of pollutants associated with response actions.
State of Kansas, Ambient Air Quality Standards and Air Pollution Control Regulations [KAR 28.19]	Provides state emission standards for listed hazardous air pollutants and state air quality standards to protect public health. Outlines permit requirements for new sources.	Potentially applicable if a proposed response action involves emission of a listed constituent. If applicable, substantive emissions controls requirements would be incorporated into the on-site remedial action as appropriate.

TABLE 2-3 (CONTINUED)
POTENTIAL ACTION-SPECIFIC ARARs
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Occupational Safety & Health Standards for Air Contaminants [OSHA 29 CFR 1910.1000, OSHA 29 CFR 1926]	Provides national standards of worker exposure to listed air contaminants and other environmental contaminants.	Potentially applicable if a proposed response action or other site activity creates a potential exposure to a listed air contaminant.

TABLE 2-4
TO-BE-CONSIDERED INFORMATION (TBCs)
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Federal Ambient Water Quality Criteria (FAWQC) [CWA 40 CFR Part 131]	Establishes water quality criteria for US waters for the protection of aquatic life and human health, as well as methods and requirements for states in the development of location-specific ambient water quality criteria.	Potentially applicable if ambient water quality in Kansas River is significantly affected by natural migration of contaminants and/or discharges of pollutants associated with response actions. Tributaries A and B are not jurisdictional wetlands and do not have ambient conditions due to their ephemeral nature.
National Secondary Drinking Water Standards [SDWA 40 CFR 141 Subpart B]	Establishes welfare-based secondary standards for public water systems. Secondary standards generally apply to the odor or appearance of public drinking water and are deemed to be generally protective of the public welfare.	Not applicable since no water supply wells in the area. Potentially relevant and appropriate if a migrating or discharged contaminant adversely affects current or reasonably expected future source of public drinking water such that MCLs or non-zero MCLGs are exceeded.

TABLE 2-4 (CONTINUED)
TO-BE-CONSIDERED INFORMATION (TBCs)
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
Risk-Based Concentration (RBC) Tables [EPA Region III, April 1996 Update] *Note: Also adopted by EPA Region X; thus superseding previous Region X RBCs*	Back-calculated contaminant-specific concentration limits based on assumed risk thresholds and exposure conditions. Used by several EPA regions as screening tool only - significant limitations are acknowledged and quantitative risk assessment still required. Levels are provided for residential soils, industrial soils, ambient air, tap water and fish.	Regarding soils contamination, suitable for consideration as preliminary remedial goals or for guidance if specific site conditions are such that their use is deemed appropriate. Although no specific groundwater or surface water levels are provided, the tap water risk-based concentrations that is provided is directly applicable groundwater or surface water. Although not listed, sediment risk-based concentrations are also included, because they are considered soils in human health risk assessments. When evaluating clean up levels, MCLs are generally considered over these levels.
Preliminary Remedial Goals (PRGs) Tables [EPA Region IX, August 1996 Update]	Back-calculated contaminant-specific concentration limits based on assumed risk thresholds and exposure conditions. Used by several EPA regions as screening tool only - significant limitations are acknowledged and quantitative risk assessment still required. Levels are provided for residential soils, industrial soils, ambient air, tap water and fish.	Regarding soils contamination, suitable for consideration as preliminary remedial goals or for guidance if specific site conditions are such that their use is deemed appropriate. Although no specific groundwater or surface water levels are provided, the tap water risk-based concentrations that is provided is directly applicable to groundwater or surface water. Although not listed, sediment risk-based concentrations are also included, because they are considered soils in human health risk assessments. When evaluating clean up levels, MCLs are generally considered over these levels.

TABLE 2-4 (CONTINUED)
TO-BE-CONSIDERED INFORMATION (TBCs)
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Statute or Regulation	Summary of Requirement	Analysis and Comment
RCRA Corrective Action Levels [Proposed Rules, 55 FR 145, July 27, 1990]	Unpromulgated/proposed clean-up levels for soils at RCRA Solid Waste Management Units.	Generally considered to be insufficiently developed to be relied upon for guidance in lieu of more quantitative guidance such as EPA RBCs/PRGs.
Soil Screening Levels (SSLs) [EPA, 1996]	Screening levels for soil contamination based on the lower of ingestion and inhalation risk values that are protective of human health.	Generally considered to be insufficiently developed to be relied upon for guidance in lieu of more quantitative guidance such as EPA RBCs/PRGs.
Alternate Cleanup Levels [RCRA 40 CFR 246.54]	Establishes alternate cleanup levels (ACLs) for public water systems.	If it is determined that there is a potential for a nearby water supply source that is not in compliance with MCLs, ACLs could be considered a target cleanup level.
National Oceanic and Atmospheric Administration (NOAA) Marine Sediment Standards [NOAA, September 1995]	Guidance for evaluation of marine sediment contaminant levels.	Because there is no marine environment in the vicinity of the site, these standards will only be considered to the extent that no other, more suitable, criteria for sediments are available and to the extent that it is deemed appropriate/ necessary.

TABLE 2-5

QUANTITATIVE CRITERIA FROM POTENTIAL ARARs AND TBCs FOR GROUNDWATER AND DRINKING WATER

Dry Cleaning Facilities Study Area

Fort Riley, Kansas

ANALYTE	DRINKING WATER LIMITS, POTENTIAL ARAR		DRINKING WATER LIMITS, TO-BE-CONSIDERED INFORMATION (TBC)	
	FEDERAL MAXIMUM CONTAMINANT LEVEL(a) (mg/l)	FEDERAL MAXIMUM CONTAMINANT LEVEL GOAL(a) (mg/l)	EPA REGION III RBCs FOR TAP WATER(b) (mg/l)	EPA REGION IX PRGs FOR TAP WATER(c) (mg/l)
Benzene	0.005	0	0.00036	0.0004
Trichloromethane	NAv	NAv	0.00015	0.00016
1,2-Dichloroethylene[1]	0.07 (cis) 0.1 (trans)	0.07 (cis) 0.1 (trans)	0.061 (cis) 0.12 (trans)	0.061 (cis) 0.12 (trans)
Toluene	1	1	0.75	0.72
Dichloromethane	0.005	0[P]	0.0041	0.0043
Tetrachoroethylene[1]	0.005	0	0.0011	0.0011
Ethylbenzene	0.7	0.7	1.3	1.3
Trichloroethylene[1]	0.005	0	0.0016	0.0016
Vinyl Chloride[1]	0.002	0	0.000019	0.00002
2,6-Dinitrotoluene	NAv	NAv	0.037	0.037
bis(2-Ethylhexyl) phthalate	NAv	NAv	0.0048	0.0048
Hexachloroethane	NAv	NAv	0.00075	0.0048

TABLE 2-5 (CONTINUED)
QUANTITATIVE CRITERIA FROM POTENTIAL ARARs AND TBCs FOR GROUNDWATER AND DRINKING WATER

ANALYTE	DRINKING WATER LIMITS, POTENTIAL ARAR		DRINKING WATER LIMITS, TO-BE-CONSIDERED INFORMATION (TBC)	
	FEDERAL MAXIMUM CONTAMINANT LEVEL(a) (mg/l)	FEDERAL MAXIMUM CONTAMINANT LEVEL GOAL(a) (mg/l)	EPA REGION III RBCs FOR TAP WATER(b) (mg/l)	EPA REGION IX PRGs FOR TAP WATER(c) (mg/l)
Naphthalene[1]	NAv	NAv	1.5	0.24
n-Nitrosodi-n-propylamine	NAv	NAv	0.0000096	0.0000096

Notes:

1 Indicates site-related chemical of concern, retained for BLRA.

P Proposed MCL/MCLG

NAv Not Available

a Maximum Contaminant Levels and Maximum Contaminant Goal (40 CFR 141 Subpart B).

b Risk Based Concentration (RBC) Tables, EPA Region III, April 1996 Update.

c Preliminary Remediation Goals (PRGs) Table, EPA Region IX, August 1996 Update.

TABLE 2-6

QUANTITATIVE CRITERIA FROM POTENTIAL ARARs FOR SURFACE WATER

Dry Cleaning Facilities Study Area

Fort Riley, Kansas

ANALYTE	FEDERAL AMBIENT WATER QUALITY CRITERIA* (mg/l)				KANSAS WATER QUALITY STANDARDS***(mg/l)		
	For Aquatic Life		For Human Health		For Aquatic Life		For Public Health
	Acute	Chronic	Water & Fish Consumption	Fish Consumption	Acute	Chronic	Domestic Water Supply
Bromodichloromethane	11	NAv	0.00027**[b]	0.022**[b]	11	NAv	0.1
Trichloromethane	28.9	1.24	0.0057**[b]	0.470**[b]	28.9	1.24	0.1
Dibromochloromethane	11	NAv	0.00041**[b]	0.034**[b]	11	NAv	NAv
bis(2-Ethylhexyl)phthalate	NAv	NAv	0.0018**[b]	0.0059**	0.4	0.36	NAv
Tetrachloroethylene[1]	5.28[a]	0.84[a]	0.0008**[b]	0.00885**[b]	5.28	0.84	0.005

1 Bolding indicates site-related chemical of concern, retained for BLRA.

NAv Not Available.

a Insufficient data to develop criteria. Value presented is lowest observed effect level.

b Human health criteria for carcinogens reported for three risk levels. Value presented is the most conservative (10^{-6}) risk level.

Sources: *Quality Criteria for Water - 1986. EPA 440/5-86.001, 1 May, 1987.

**40 CFR 131.36 - Toxic Criteria for states not complying with Clean Water Act Section 303(c)(2)(B).

***Kansas water classified for the following uses must follow this criteria: consumptive use; special expected, or restricted aquatic life use waters; and domestic water supply waters. The Kansas River is classified for consumptive use in the Fort Riley area.

***Kansas Surface Water Quality Standards (KAR 28.16.28), January 1995.

TABLE 2-7

QUANTITATIVE CRITERIA FROM TBCs FOR SURFACE WATER SEDIMENTS

Dry Cleaning Facilities Study Area

Fort Riley, Kansas

ANALYTE	NOAA CRITERIA FOR MARINE SEDIMENTS(a) (mg/kg)	
	ER-L Concentration	ER-M Concentration
Pyrene	665	2600

ER-L Effects Range-Low

ER-M Effects Range-Median

a National Oceanic and Atmospheric Administration, Publication in *Environmental Management*, Vol. 19, No. 1, pp 81-97.

TABLE 2-8

QUANTITATIVE CRITERIA FROM TBCs FOR SOILS

Dry Cleaning Facilities Study Area

Fort Riley, Kansas

ANALYTE	EPA REGION III RBCs (a) (mg/kg)		EPA REGION IX PRGs (b) (mg/kg)	
	Residential	Industrial	Residential	Industrial
Carbon Disulfide	7,800	200,000	7.5	24
Dibromochloromethane	7.6	68	5.3	23
Dichloromethane	85	760	7.8	18
Tetrachloroethylene[1]	12	110	5.4	17
Toluene	16,000	410,000	792	880
Trichloroethylene[1]	58	520	3.2	7.0
1,1,2-Trichloroethane	11	100	0.65	1.5
Benzo[a]anthracene	0.88	7.8	0.61	2.6
Benzo[a]pyrene	0.088	0.78	0.061	0.26
Chrysene	88	780	7.2	7.2
bis(2-Ethylhexyl) phthalate	46	410	32	140
Fluoranthene	3,100	82,000	2,600	27,000
2-Methylnaphthalene	NAv	NAv	NAv	NAv
Phenanthrene	NAv	NAv	NAv	NAv
Pyrene	2,300	61,000	100	100

1 Indicates site-related chemical of concern, retained for BLRA.

NAv Not Available.

a Risk Based Concentration values for soil (U.S. EPA Region III, April 1996 Update).

b Preliminary Remedial Goals for soil (U.S. EPA Region IX, August 1996 Update).

3.0 REMEDIAL ACTION OBJECTIVES AND GENERAL RESPONSE ACTIONS

3.0 Remedial Action Objectives and General Response Actions

Remedial Action Objectives (RAOs) and General Response Actions (GRAs) must be developed for sites where risk levels and/or regulatory criteria are not within acceptable ranges. A Baseline Risk Assessment has been completed for the DCF Study Area and indicates that there are no unacceptable levels of risk associated with the Study Area (CENWK, 1995a) which would compel remedial action other than maintaining the Army's current institutional controls and implementing a groundwater monitoring program. Furthermore, the additional investigations and monitoring performed since the BLRA was completed indicate no new condition which would affect the findings in the BLRA. However, the Kansas State Surface Water Quality Standards have been identified as a potential ARAR which would compel the remedial action to address the alluvial aquifer underlying the Island. This chapter, therefore, focuses mostly on the RAOs and GRAs associated with the State Surface Water Quality Standards as applicable to the alluvial Island.

3.1 Development of Remedial Action Objectives and General Response Actions

In accordance with the NCP (40 CFR 300), the primary remedial goal at any Superfund site is to protect human health and the environment. RAOs are therefore media-specific goals developed to achieve this protection. The RAOs discussed below were developed by considering the contaminants of concern, associated environmental media, potential human health risks (including consideration of reasonable exposure pathways and receptors), as well as the probable impacts on the environment. In general, the basis for the selection of RAOs is the Reasonable Maximum Exposure (RME) Scenario that has been determined based on the current understanding of the DCFA and the surrounding area. The RAOs for the specific media are discussed in Section 3.2. RAOs are eventually confirmed, revised or removed from further consideration after finalization of the DCFA-RI, BLRA, FS and the Record of Decision (ROD).

The NCP indicates that the lead agency, in developing remedial alternatives, shall establish remedial action objectives and remedial goals (RGs). Remedial alternatives are generally selected which achieve predetermined concentration-based RGs developed based on ARARs, TBCs, and/or risk-based concentration limits; except where site-specific conditions or other technical considerations indicate that this would be inappropriate or impracticable. Such conditions/considerations might include foreseeable future land use(s), the nature and extent of contamination, the effectiveness of past/ongoing interim response actions and/or the impracticability of successfully implementing currently available removal/treatment technologies. Where concentration-based remedial goals/ARARs are deemed inappropriate and/or impracticable such that contaminants remain at the site above levels that would allow unconditional use and unlimited exposure, the NCP indicates that the lead agency shall periodically review the selected remedial action no less often than every five years after the initiation of such a remedial action. During these reviews, new actions may be proposed and taken in light of any changes in site conditions and/or land use (and associated human exposures) that might warrant reconsideration of the previously selected response action(s).

In contrast with the groundwater underlying the Island , several factors relevant to conditions at the DCFA itself indicate that the selection of RAOs and GRAs intended to achieve concentration-based remedial goals is not appropriate. As summarized in Chapter 1, these factors include:

- Future land use at the DCFA will not foreseeably include residential or other uses that would include unacceptable human exposures to the existing contamination;

- There is no unacceptable risk associated with the DCFA (CENWK, 1995a) and maximum levels of contaminants found within the DCF Study Area have been consistently decreasing;

- The soil vapor extraction (SVE) pilot system is documented to have removed 21 pounds of the existing VOC contamination in the vadose zone; and,

- The potential for adverse effects from exposure onsite is not unacceptable based on likely exposure scenarios and foreseeable area land uses [it is noted that Fort Riley is not currently being considered for Base Realignment and Closure (BRAC) and continued military presence is therefore assumed for the foreseeable future].

As a result, the impacted groundwater underlying the Island is the only area/media for which quantitative RGs need to be discussed.

3.2 Remedial Action Objectives

As required by the NCP, RAOs are provided for consideration for each media of interest. Based on the lack of an ARAR or risk trigger associated with the DCFA upland area, continued Army control and monitoring is all that is necessary for elevated contamination levels in this area. Therefore, the only medium of interest requiring the development of specific additional RAOs and GRAs is the alluvial aquifer underlying the Island.

The available capacity of the existing potable water supply system in the vicinity of the DCFA renders it highly unlikely that groundwater in the area will need to be utilized for water supply purposes in the foreseeable future (CENWK, 1995a). With regard to the Island alluvial aquifer, this potential is further diminished because the surface area is highly protected from unnatural disturbances (such as construction and operation of well fields) due to its identification as a bald eagle roosting site. Notwithstanding these facts, however, the alluvial aquifer is subject to meeting chemical-specific regulatory criteria since it is "associated" with the Kansas River pursuant to the Kansas State Surface Water Quality Standards. The Kansas River's status as a potential drinking water supply therefore subjects the alluvial aquifer to meeting KWQS for surface waters that may potentially be used as a drinking water source.

As a result, the RAOs considered for groundwater in the alluvium at the Island are the following:

- To minimize exposure to contaminated groundwater at the Island (from ingestion, inhalation, and/or dermal contact);

- To confirm that groundwater contaminants will not reach potential off-site receptors at concentrations above levels of concern; and

- To reduce contaminant levels, to the extent feasible and appropriate, to chemical-specific regulatory levels through natural and/or active remedial processes.

3.3 General Response Actions

Pursuant to the NCP, GRAs and the associated remedial action alternatives must be defined for consideration and subsequent analysis in the FS report. GRAs are generally based on all of the media of concern and are determined by defining actions that satisfy at least one of the RAOs which are under consideration (with the exception of the "No Further Action" alternative, which is included as a baseline alternative). GRAs involve activities that directly impact the source of, migration of, and/or exposures to contaminated materials to minimize the potential hazard to human health and the environment. Additionally, a single GRA or a combination of GRAs may be considered and analyzed.

General response actions describe those actions that will satisfy the remedial action objectives. No Action, Natural Attenuation, Institutional Controls, Containment Actions, Treatment Actions, and Off-Site Removal/Disposal Actions were identified as the general response actions for the contamination associated with the DCFA. The remedial technologies associated with these general response actions are presented in Section 4.1. It is noted that the FS screening and analysis process starts with the identification of the universe of GRAs and progressively refines them into more defined alternatives and process options, while concurrently "screening-out" those that are not relevant and appropriate to the specific site in question. A description of the GRAs being considered follows.

3.3.1 No Action

No Action presents the baseline against which the other alternatives are compared. No remedial measures are implemented and monitoring programs are discontinued. The No Further Action alternative does not meet the remedial objectives, but must be considered as an option in accordance with the NCP such that it serves as a baseline, against which the other alternatives are compared.

3.3.2 Natural Attenuation

Natural attenuation is not an "action" per se, although it may be considered to be an acceptable remedial action provided certain regulatory and legal requirements are complied with and assuming natural processes (advection, dispersion, biodegradation, etc.) will eventually reduce contaminant concentrations to acceptable levels. This determination is based on an evaluation of contaminant degradation rates to determine its feasibility without resulting in unacceptable impacts on human health or the environment. Typically, this GRA also involves institutional controls and groundwater sampling and monitoring as an integral part of the remedial action.

3.3.3 Institutional Controls

This general response category includes institutional controls which prevent or limit access to the contaminated media as well as to restrict current and future uses of the media/area while continuing to monitor and evaluate contaminant concentrations. In general, institutional controls do not physically control contaminants or reduce the toxicity, inventory or volume of contamination. Examples of institutional controls can include fencing, warning signs, master plan restrictions, easements, other access restrictions, and on-site work/management procedures. When enforced, institutional controls are an effective means of eliminating the exposure pathways of primary concern. Institutional controls are sometimes considered in combination with other actions to prevent exposure to contaminants. Environmental monitoring is often combined with institutional control actions to ensure that contamination is not migrating such that off-site receptors are adversely impacted. Routine maintenance of existing site surfaces (e.g., seeding/mowing of grass, patching of paved surfaces, etc.) is also included with institutional control, because current maintenance activities associated with the military presence at Fort Riley are assumed to continue for the foreseeable future.

Although installation of a surface cap would be considered a containment action, maintenance of an existing pavement is included in institutional controls since it already exists. However, an existing paved surface can create a barrier rain cannot readily penetrate and cause the transport of contaminants from soils to groundwater.

Groundwater monitoring is considered to be a subset of institutional controls. Groundwater monitoring consists of the maintenance of a program of periodic and regular groundwater well sampling and analysis. Monitoring does not prevent or minimize exposure to contaminants but does allow assessment of natural attenuation rates and identifies any migration of the environmental contamination.

3.3.4 Containment Actions

Containment is the use of barriers or other engineered control systems to control routes of exposure and/or contaminant migration. Containment response actions generally do not treat or reduce the toxicity or volume of contamination and generally utilize a surface cover, a vertical subsurface wall (such as a slurry wall) or groundwater pumping for containment purposes. In the instance of groundwater pumping used for containment, the containment action often also results in an unavoidable reduction of toxicity or volume of contamination since the extracted portion of the groundwater typically requires pre-discharge treatment.

3.3.5 Treatment Actions

Treatment actions refer to the use of chemical, physical, thermal or biological treatment methods to reduce or eliminate the toxicity, mobility, or volume of contamination. Treatment actions may involve the extraction of contaminated media prior to treatment (referred to as ex situ), or the in-place application of treatment processes at or beneath the site surface (referred to as in situ). Treatment technologies typically alter the characteristics of the contaminants by changing the chemical structure or isolating or destroying the contaminant. In most cases, a single treatment method is not capable of treating all potential constituents of concern, and a combination of technologies is utilized to achieve cleanup standards.

3.3.6 Off-Site Removal/Disposal Action

The off-site removal/disposal action includes the collection of groundwater, soils, or other media and packaging and transporting or placing these media in a secure off-site location. For groundwater, off-site disposal typically constitutes discharge to a receiving stream or wastewater treatment works, and this action often requires treatment prior to discharge. For contaminated soils, removal/disposal of contaminated soils is generally less preferable than treatment and/or control alternatives and is typically limited to "hot spots" (the areas that pose a prominent threat at the site). From a public policy standpoint, removal/disposal simply moves the problem to a new location and is therefore only practical when efforts are focused on hot spots. It is noted, however, that the data collected for the DCFA does not indicate the presence of any localized areas of soil contamination that present a "prominent threat" at the site.

3.4 Remedial Goals

Remedial Goals (RGs) are usually quantitative chemical-specific concentration targets for each individual contaminant of concern for each specific medium and land use combination. RGs must be protective of human health and the environment and must comply with ARARs. When chemical-specific ARARs are not available or appropriate, risk-based RG concentrations are often back-calculated using the results of the RME risk estimates. In essence, RGs are the quantification of the RAOs.

For the DCFA (upland area), no RGs are designated because there are no current or foreseeable risks to the relevant points of exposure and there are no ARARs compelling remedial action.

For the groundwater in the alluvium at the Island, the RGs would be equivalent to the KWQS for surface water and associated alluvial aquifers protected as a potential drinking water source.

4.0 IDENTIFICATION, DEVELOPMENT AND SCREENING OF REMEDIAL TECHNOLOGIES AND ALTERNATIVES

4.0 Identification, Development and Screening of Remedial Technologies and Alternatives

This chapter of the FS addresses two issues regarding potential actions which address the existing levels of groundwater contamination at the Island: Identification and Description of Technologies and Process Options; and Development and Screening of Alternatives.

The technology identification and screening process represents the first step in the development and evaluation of remedial alternatives for groundwater at the Island. Media-specific technologies and process options determined to be applicable to the Island are combined into remedial alternatives which address the remedial action objectives. The approach utilized in developing this chapter of the FS was to identify potentially applicable general response actions and then develop subcategories of general response actions called remedial technologies. The general response actions are those broad category actions which potentially satisfy the remedial action objectives presented in Section 3.2. The remedial technology types are identified, after which specific process options are identified and screened. During screening, any one of the general response actions, remedial technologies, or process options can be omitted from further analysis based on effectiveness, implementability, cost, or overall lack of relevance/appropriateness in consideration of the specific site conditions.

Effectiveness is based upon how proven and reliable the technology or process option is with respect to the site-specific media and constituents of concern. Effectiveness also considers potential impacts to human health and the environment that may result from the implementation of the process option.

Implementability addresses the ability to install and operate a technology or process option considering site-specific characteristics and the ability to obtain regulatory concurrence for the particular technology being considered. Those technologies that are ineffective or unworkable considering contaminant-specific conditions and/or difficulty with meeting ARARs are eliminated from further consideration under this criteria.

Costs are evaluated based upon relative capital cost and operation and maintenance (O&M) cost in comparison with the other process options presented for a specific technology type. The cost evaluation is based upon engineering judgement. Initial opinions of cost for comparison between selected alternatives are presented in the detailed evaluation and analysis of alternatives (Chapter 5.0).

In accordance with the findings in Chapter 3.0, the remedial technologies and alternatives have been selected and evaluated based upon their overall feasibility for application at this site and on their ability to meet the defined remedial action objectives (RAOs) and remedial goals (RGs). As a result, a technology or alternative has been deemed applicable if it is feasible and maintains protection of human and/or ecological receptors. The chosen alternatives would therefore be deemed successful and complete once groundwater contamination levels at the Island are shown to have been permanently reduced to below KWQS for surface waters that may potentially be used as a drinking water source.

4.1 Identification and Description of Technologies and Process Options

The potentially applicable remedial technologies and process options were identified based upon effectiveness and upon consideration of the site characteristics and the remedial action objectives for the

DCF Study Area. As such, remedial technologies and process options which exclusively address soil contamination issues are not included based upon the site specific RAOs and RGs developed in Chapter 3.

Remedial technology types refer to the broad and general categories of technologies, while the process options refer to specific remedial technology processes that are applied within that category. It is noted that some of the "technologies" identified and discussed below are not technologies per se, but may rather be the implementation of administrative or other non-technological processes. Implementation of these types of processes is intended to accomplish a specific goal pursuant to one or more remedial action objectives and are, therefore, properly included in the technology development and screening process.

4.1.1 No Action

No Action presents the baseline against which the other alternatives are compared. No remedial measures are implemented and monitoring programs are discontinued with the exception of the CERCLA-required five year reassessments that must be performed when contamination above levels of current or future concern remain in place. Even if the No Action alternative does not meet the RAOs or RGs, it must still be considered as an option since the NCP requires that it be evaluated such that it can be used as a baseline against which the other alternatives are compared.

4.1.2 Natural Attenuation

Natural attenuation is the term used for one or many natural processes that reduce mass or concentration of a contaminant in groundwater. These naturally occurring processes can be physical, chemical and biological processes. A more detailed discussion of these natural attenuation processes can be found in the RIAMER (CENWK, 1997a). The following subsections represent a summary of the discussions presented in the RIAMER (CENWK, 1997a).

4.1.2.1 Dilution in Groundwater

Dilution of contamination in groundwater occurs upon the introduction of additional water into the groundwater system. This can occur through precipitation (e.g., rainfall events) or increased surface water elevations (e.g., flooding). While this process does not reduce that volume of the contaminant, it does effectively reduce the contaminant concentration levels in the groundwater by spreading a finite contaminant mass over a larger volume of water.

4.1.2.2 Hydrodynamic Dispersion

Hydrodynamic dispersion includes two, generally inseparable processes, mechanical dispersion and molecular diffusion. Under normal adjective flow systems (i.e., other than no flow or very low flow conditions), mechanical dispersion is the dominant mechanism causing the spreading and mixing of contaminants in groundwater and the contribution of dispersion is negligible. Similar to dilution, dispersion does not reduce the mass of contaminant but does effectively reduce the contaminant concentration levels in the groundwater. In addition to spreading and mixing, dispersion can facilitate biodegradation by introducing more electron acceptors and/or donors from the aquifer materials.

4.1.2.3 Volatization

Volatization causes a mass loss of groundwater contaminants when volatile compounds go from the liquid to vapor phase (soil gas in pore space). The rate of volatization is a function of chemical properties such as Henry's Law Constant and the site-specific conditions such climate, depth to water and soil types. The soil gas then moves into the atmosphere above the ground surface. Due to depth to groundwater at the Island being more than just a few feet deep, volatization of contaminants in groundwater is considered to be insignificant relative to other processes. However, volatization can quickly reduce contaminant levels upon discharges to the Kansas River, due to PCE's volatile nature.

4.1.2.4 Adsorption to Soil Particles

Adsorption of chlorinated solvents such as PCE to soil particles, while not reducing contaminant volumes, can reduce contaminant concentration and rate of migration. The measure of the effect of adsorption on contaminant fate and transport is often described by the retardation coefficient (R). R measures the relative velocity of contaminant migration to the velocity of groundwater flow. For example, because R_{PCE} = 13 to 40, the velocity of the contaminant plume is expected to be 13 to 40 times slower than the velocity of the groundwater. In addition, it is noted that rates of biodegradation are often directly related to adsorption.

4.1.2.5 Chemical Transformation

Chemical (abiotic) transformation of chlorinated solvents can occur in natural environments. Abiotic transformation generally results in a partial transformation of a compound. However, in the absence of an iron catalyst, the abiotic transformation of chlorinated organics is typically very slow.

4.1.2.6 Biological Degradation

Biological degradation of PCE and other chlorinated organics is a microbial biodegradation process that is generally believed to occur through reductive dehalogenation, an anaerobic process that requires both electron acceptors and an adequate supply of electron donors such as natural organic carbons and/or other fuel contaminants. Biodegradation of PCE results in a series of degradation products (i.e., TCE, 1,2-DCE, vinyl chloride, and finally ethene, ethane and/or methane).

4.1.3 Institutional Controls

4.1.3.1 Access Restrictions and Other Land Use Controls

Surface access restrictions include perimeter fencing and warning signs as well as administrative restrictions on the activities on and use of a particular parcel of land. Access to groundwater could be restricted by engineered controls and/or by imposing an administrative restriction on the installation/use of wells within the area influenced by the existing contamination. Land use controls can be administrative and/or physical. Since the site is part of a military installation (both currently and for the foreseeable future), there is a pre-existing mechanism for controlling land use at the DCFA. In accordance with DA regulations, all proposed site development and similar activities are subject to an administrative review process to assure that proposed activity is consistent with the facility-wide master plan. Fort Riley has the authority to adopt site-specific restrictions and requirements, and to enforce them through this review process.

Specific land use controls that could be implemented at the DCF Study Area include:

- Restrictions or prohibitions on site development and on-site activities (controls are currently in place);

- Conditional access to existing utilities;

- Restrictions or prohibitions on future utility easements; and,

- Prohibition on groundwater use.

4.1.3.2 Enhanced Facility Management

Enhancing facility management procedures decrease the potential for releases of contaminants to the environment. Typical facility management procedures that could be implemented are an effective recycling program, replacement of damaged equipment, and increased efficiency of housekeeping practices. For the DCF Study Area, several activities were implemented to increase facility management and to decrease the potential for releases to the environment. These activities generally consisted of improved housekeeping procedures such as: floor drains that eventually discharged at Tributary A were plugged with cement grout; wastewater that was once disposed of by being dumped into the floor drains or disposed of on the ground behind building 180/181 is now collected and recycled by the same commercial company that provides it; and materials that were used to contain spills (blankets, mattress pads, etc.) were once laundered, introducing PCE wastewater to the leaky sewer system, and are now dry cleaned.

4.1.3.3 Groundwater Monitoring

Monitoring of groundwater consists of a periodic sampling and analysis program similar to the on going groundwater monitoring activities at the DCF Study Area associated with the remedial investigations; however, the analyte list could be narrowed to include only the specific constituents of concern. For the DCF Study Area, a long term groundwater monitoring program will use and maintain existing monitoring wells, including the periodic replacement of wells/Microwells since they have a finite useful lifespan. In accordance with CERCLA and the NCP, and as specified in the IAG, results of the monitoring program would be reviewed periodically and as part of the reassessment of decision-making to be performed at least once every five years for remedial actions which leave contamination in place (NCP Section 300.430(f)(4)(ii)).

4.1.3.4 Surface Drainage Controls

Surface drainage controls generally consists of installing and/or maintaining physical site surface characteristics such as pavement, vegetation, drainage basins, channels, culverts, etc, which reduce surface water infiltration. The intent of this type of controls is typically to minimize any further migration (through leaching) of residual contaminants remaining in the soil matrix, although it can also impact groundwater movement. By maintaining surface characteristics, percolation of precipitation downward through the soil matrix is prevented. Maintenance of surface materials can also minimize direct human contact with subsurface materials.

4.1.3.5 Worker Safety Measures

Exposure of utility/maintenance workers to contaminants in the shallow subsurface soils can be controlled by informing appropriate personnel of the presence of contamination to ensure that proper health and safety measures and protocols are implemented. Workers performing groundwater sampling/analysis would also be fully informed and required to utilize appropriate procedures to limit exposures.

4.1.4 Containment/Control Technologies

4.1.4.1 Capping

Capping is a containment action that provides isolation of contaminated soils from the surrounding environment by providing a horizontal surface barrier. Capping of contaminated soil could be achieved by using any one or a combination of clay caps, asphalt caps, synthetic membranes, chemical sealants and multimedia caps. Although no treatment of the contaminated soils is achieved, capping is beneficial, since potential exposures via the direct contact, inhalation and ingestion pathways is potentially eliminated and capping also provides a barrier to reduce leaching of contaminants from the soil to the groundwater.

4.1.4.2 Vertical Barriers

Vertical barriers typically consist of a vertical subsurface cut-off wall around the perimeter of contamination, which would limit the potential horizontal migration of contaminated groundwater. The cut-off wall could consist of either a slurry wall, a plastic concrete (PC) wall, a grouted sheet-pile wall, a grout curtain or some combination of the above. Another (non-containment) application of this technology is the use of a vertical barrier as a collection or redirection technique by altering the natural flow of groundwater to a predetermined destination. This application is referred to as a "funnel" and can be used in conjunction with a permeable treatment wall (i.e. "funnel and gate"). The vertical barrier which forms the funnel may be constructed using slurry wall techniques or water-tight sheet pile walls.

4.1.4.3 Interception Trenches

Interception trenches, ditches and drains are used to intercept lateral migration of contaminants in the groundwater by passively collecting the groundwater for subsequent removal and/or treatment. This is accomplished by the construction of a subsurface trench, ditch or "French" drain system that intercepts and collects shallow groundwater.

Highly permeable materials (e.g., gravel) are often used in the trenches as a part of a subsurface drainage system to convey flow to a collection sump. Subsurface drains essentially can be used to provide a hydraulic containment similar to a closely spaced line of groundwater extraction wells. The accumulated water could be pumped to an on-site water treatment system.

4.1.4.4 Hydraulic Containment

A set of recovery wells with overlapping influence zones can be used to extract contaminated groundwater and create a hydraulic barrier at the leading edge of contamination, thus restricting off-site migration of groundwater contaminants. Recovery wells generally consist of a drilled and cased vertical hole within which an electric pump is placed. The pump is used to establish a capture zone and to withdraw groundwater and convey it to the surface for subsequent on-site or off-site treatment and/or discharge to surface water or an injection well.

4.1.4.5 Horizontal Barriers

Horizontal barriers above and/or below contaminated zones are created by pressure injecting grout at depth through closely spaced drilled holes, or by using horizontal drilling techniques. These techniques are used for similar reasons as surface capping techniques; however, horizontal barriers can be installed below the ground surface and can act as a barrier to prevent vertical migration of contamination.

4.1.4.6 Source Containment

Unlike other containment technologies, source containment refers to the containment of contaminants before they are released to the environment. While these technologies may not actually consist of remedial or response technologies, they are responsible for effectively reducing the quantity and potential for contaminant release to the atmosphere. Examples of some technologies that fall into this category are double walled tanks, containment structures, leak detection systems, etc. For the DCF Study Area, several activities were implemented that are considered source controls. In particular, the sanitary sewer line repairs and clearings are considered source containment in that they prevent/reduce further migration of contaminants into the soils surrounding the sewer lines and subsequently migrating to groundwater.

4.1.5 Treatment Technologies

Treatment technologies are available for different media and are generally grouped as follows: immobilization technologies, physical/chemical technologies, biological technologies and thermal technologies. It is noted that for most of the treatment technologies discussed below, the contaminated media must be extracted or removed before the *ex situ* treatment can begin. This is in contrast to *in situ* treatments which are performed on the contaminated medium in place. Extraction/removal technologies are discussed separately in Section 4.1.6.

4.1.5.1 Physical/Chemical Treatment Technologies (ex situ, unless otherwise noted)

This groundwater treatment technology section includes technologies that are generally ex situ and are considered aggressive. The technologies listed below are included as a contingency in this section of the FS if the risk of groundwater exposure should increase to unacceptable levels. In situ technologies that could be considered ineffective or not immediately responsive are not included in this section.

- **Carbon Adsorption**

Activated carbon adsorption is primarily used to remove trace organic compounds from aqueous or gaseous waste streams. In this process, the dissolved contaminants adsorb to the carbon particles and stay adsorbed while the treated liquid or gas is released. This process has proven effective in removing certain organic compounds and a few inorganic compounds from liquid and vapor waste streams.

- **Air Stripping (*in situ* or *ex situ*)**

Air stripping is a process option in which the contaminated liquid and air are fed through either a packed tower or a low-profile stripper, and dissolved molecules from the contaminated liquid are transferred into an airstream. Residuals from the process include contaminated off gas and treated water. The contaminated off gas can be treated through air pollution control equipment, if required. This method is effective in removing VOCs. Air stripping can also be used in conjunction with carbon adsorption where the carbon adsorption is used for polishing.

- **Sedimentation and Coagulation/Flocculation**

Sedimentation is a solids removal technique used to remove settleable solids from water. In this process, solids are allowed to settle by gravity into a tank, lagoon, etc. This process effectively removes suspended solids such as sand, sediment and insoluble metals from the water. Sedimentation is typically used in conjunction with other processes to provide solids removal prior to treatment for organics removal, such as coagulation/flocculation. Coagulation/flocculation involves the addition of a coagulating reagent to coagulate small, unsettleable particles suspended in a liquid medium. The addition of the flocculating agents to the liquid is typically followed by rapid mixing to disperse the agent through the liquid, and then slow and gentle mixing to allow for contact between small particles and agglomeration into larger particles. Other process options such as neutralization, sedimentation and filtration are typically necessary during the coagulation/flocculation process to facilitate the removal of suspended solids.

- **Filtration**

Filtration is a solids removal technique in which water is passed through a filter media to remove suspended solids and insoluble metals (after chemical treatment) from the water. Filtration is typically used in conjunction with other processes to provide solids removal prior to treatment to remove organics.

- **Reverse Osmosis**

Reverse osmosis (RO) is a system which separates contaminants from a liquid through the use of semi-permeable membranes. RO is primarily utilized for water purification and for treating liquid wastewater containing high metals concentrations. A drawback of this technology is that organics may attack the RO membrane, causing fouling and resulting in higher maintenance costs.

- **Neutralization**

Neutralization is the addition of either an acid or an alkali for controlling pH. Typically, sulfuric acid, sodium hydroxide, or calcium hydroxide is used to control pH. For the treatment of heavy metals in the groundwater, neutralization is typically utilized with coagulation/flocculation, chemical precipitation and sedimentation.

- **Chemical Precipitation**

Chemical precipitation involves utilizing a chemical reaction to convert a soluble substance into an insoluble form. This can be accomplished by adding precipitating agents or changing the actual composition of the solvent so that the solubility of the dissolved substance is decreased. The insoluble precipitate is thus removed by filtering or coagulation/flocculation and sedimentation from the water. The two most widely used precipitating agents are hydroxide and sulfide compounds. Sulfides have some advantage over hydroxides due to their lower solubilities, however sulfides dictate additional health and safety considerations. These technologies are effective at handling metal contamination and could be applicable in conjunction with technologies that are better suited for removing organics.

- **UV Oxidation**

Ultraviolet (UV) oxidation treatment systems generally combine UV light with ozone and hydrogen peroxide to produce highly reactive hydroxyl radicals. The hydroxyl radicals react with and break down VOCs in the groundwater. Although highly effective, UV oxidation demands a high recycle rate of groundwater to achieve complete destruction of organics. Inorganics tend to oxidize and foul the UV light, causing operational concerns.

- **Oxidation/Reduction**

Oxidation/Reduction (redox) reactions are those in which the oxidation state of at least one reactant is raised while that of another is lowered. Chemical oxidation is used primarily for detoxification of cyanide and for treatment of organics such as aldehydes, mercaptans, phenols, benzidine, unsaturated acids, and certain pesticides. Commercially available oxidants include potassium permanganate, hydrogen peroxide, chlorine gas, and hypochlorite. Chemical reduction involves additions of reducing agent which lowers the oxidation of a substance in order to reduce toxicity or solubility. A typical example is a reduction of hexavalent chromium to trivalent chromium using sulfur dioxide.

- **Passive Treatment Gate *(in situ)***

Passive treatment gate technology is typically used in conjunction with an impermeable barrier wall that acts as a funnel to redirect the flow of groundwater (i.e., funnel and gate). The currently emerging "Funnel and Gate" technology uses vertical barrier containment to "funnel" groundwater through a localized "gate," which contains an in situ passive treatment cell which cleans the groundwater as it passes through the cell. Typically, oxidation/reduction is the actual treatment technology that is used in order to treat chlorinated organic contaminants. This is achieved by installing reactive metals (usually iron filings) in the gate area. The iron is used to replace the halogen atoms in halogenated compounds with hydrogen atoms which makes the compounds less toxic. The resultant byproduct compounds may be ethylene, ethane, methane and/or chloride ions. Other media which could be used for the treatment gate include activated carbon and ion exchange media for organics and inorganics, respectively.

4.1.5.2 Thermal Treatment Technologies (in situ or ex situ)

- **Steam Stripping**

Steam stripping utilizes steam to extract organic constituents from a liquid. This process may be performed through direct contact in a packed tower similar to an air-stripping unit or through indirect contact in a multiple-pass heat exchanger.

4.1.5.3 Biological Treatment Technologies (in situ or ex situ)

The primary biological treatment options for treatment of groundwater include activated sludge and in situ bioremediation.

- **Activated Sludge *(ex situ)***

With activated sludge treatment, nutrients are added to the contaminated groundwater and indigenous microbes or cultured microbes biodegrade the contaminants. In the first step of the activated sludge process, the contaminated water is mixed and aerated with the existing biological sludge (microorganisms). Organics which come in contact with the microorganisms are utilized as food and oxidized to carbon dioxide and water. After the aeration step, clarification is used to remove the suspended organisms, and the treated water is discharged. The sludge is either returned to the aeration step to support growth or washed from the system.

- **Bioremediation *(in situ)***

With in situ bioremediation, catalysts (such as oxygen and nutrients) are added to the contaminated groundwater and indigenous microbes or cultured microbes biodegrade the contaminants. In this process, groundwater is extracted downgradient of the zone of contamination through a series of recovery wells and injected upgradient.

4.1.6 Removal/Extraction Technologies

4.1.6.1 Groundwater Recovery Wells

As described in Section 4.1.4.4 Hydraulic Containment, conventional recovery wells can be used to extract contaminated groundwater from the subsurface. For removal purposes, however, the goal of groundwater recovery is to reduce the levels of contamination through ex situ treatment (on or off site) and discharge rather than to simply control the migration of the contamination. Discharge may be to an injection well or to a surface water body, assuming that all discharge-related ARARs are satisfied.

4.1.6.2 Air Sparging/Soil Vapor Extraction (in situ)

Air sparging is typically applied as a collection or removal technique, and refers to injecting air via a network of wells into a contaminated aquifer to promote the vaporization and upward transport of volatile contaminants from the groundwater to the vadose zone where they can then be collected, treated and/or discharged to the atmosphere. Placement of injection wells is determined once a contaminated area is completely defined. Once the contaminants have volatized and migrated to the vadose zone, soil vapor extraction techniques are typically used to transport the vapor phase contaminants to the surface. Air sparging techniques are subject to the same limitations as soil vapor extraction technology. In addition, due to the vapor waste stream that is generated, treatment of a contaminated air stream may also be required depending upon the concentrations of contaminants and the corresponding regulatory limits.

The soil vapor extraction process is a technique for the removal of VOCs from the vadose (or unsaturated) zone of soils. This is the subsurface soil zone located between the surface soil and the groundwater. In general, VOCs are present in these soils in one of the following ways: as dissolved constituents in the aqueous phase; as constituents adsorbed on the solid soil material; or as free constituents in the liquid and vapor phases in the void space of the soil. Once a contaminated area is completely defined, an extraction well or wells, depending on the extent of the contamination, is to be installed. The extraction well is connected by piping to a separator device.

Site conditions, soil properties and the contaminant chemical properties are the important considerations in determining the success of a soil vapor extraction system. The depth of the vadose zone should be at least ten feet for cost-effectiveness, since beyond this depth excavation costs become expensive and far outstrip the costs of installing a soil vapor extraction system. The soil should have sufficient air-permeability to facilitate in situ stripping of the VOCs from the soil matrix as a result of air flow introduced in the soil by a soil vapor extraction system. Water is a deterrent to this stripping action, as the water reduces the air-permeability of unsaturated soils. Assuming soil conditions are favorable, contaminants with a Henry's Law Constant of 0.001 or more are typically considered appropriate for soil vapor extraction.

4.1.6.3 Electrical Separation (in situ)

Electrical separation is achieved by creating an underground electrokinetic/electrochemical (EK/EC) gradient. This is done by applying a low intensity direct current between positive electrodes (anodes) made up of hydrogen ions and molecular oxygen and negative electrodes (cathodes) made up of hydroxyl ions and molecular hydrogen. The hydrogen ions create an acid front that moves from the anode to the cathode due to the EK/EC gradient. As the acid front moves from the anode to the cathode, it extracts organic compounds from the soil matrix while it creates a "sweep" that collects contaminants from the groundwater. Contaminants are accumulated and recovered at the cathode. This technology works for both saturated and unsaturated zones and is an U.S. EPA-designated emerging technology.

4.2 Initial Screening of Technologies and Process Options

Sections 3.3 and 4.1 identify and summarize a list of the general response actions, technology types and process options which are considered to be potentially relevant and appropriate for the DCF Study Area, and specifically the groundwater contamination at the alluvial Island. The identified technologies and process options were then screened, with several being dropped from further consideration on the basis of lack of technical implementability or lack of appropriateness, by using site-specific information. Particular factors that commonly influenced the technology screening are the absence of inorganic contaminants, the relatively low concentrations of contaminants (and associated minimal risks) especially for soils, the current and foreseeable military land use, and the complex site conditions.

Several technologies and process options described in Section 4.1 are, therefore, deemed inappropriate to the DCF Study Area (i.e., they are "screened out") and will not be considered or discussed any further. Several conventional and innovative technologies that were successful for other sites or research projects were screened out in this section based on the site conditions at the DCF Study Area and, more specifically, the relatively low levels of contamination combined with the ecological and economic constraints that exist (especially at the Island). The rationale for the screening of specific technologies and process options is provided in Figure 4-1.

All groundwater removal/treatment technologies are screened out for the upland DCFA because there is no risk or ARAR exceedance. Extraction is potentially appropriate and practicable at the Island, and is therefore retained for further consideration in that context along with associated ex situ treatment technologies and process options that pass the initial screening.

For groundwater, engineered barriers (i.e., slurry wall, grout curtain, etc.) to be used solely for containment are screened out based on effectiveness concerns since groundwater would simply back up behind the barriers and eventually result in constant overtopping. Engineered barriers as funnels in conjunction with passive treatment gates are, however, retained for consideration. When considered as funnels, back up is not a concern and temporary loss of effectiveness based on occasional overtopping during high river stage does not justify removing the technology from consideration. Off-site disposal and active biological and thermal treatment technologies have also been screened out based on their ineffectiveness to treat organic contaminants at low concentrations such as those that exist at the DCFA and the Island.

The remaining removal/treatment technologies and process options are retained for further consideration. This list includes, no action, natural attenuation, groundwater monitoring, institutional controls, groundwater extraction and reinjection, chemical treatment and physical treatment.

Based upon this initial screening, and as illustrated in Figure 4-1, the remedial technology types and process options indicated in Table 4-1 are retained for further consideration. The specific technologies and process options that have been retained for further consideration are as follows:

- no action (retention required by the NCP)
- natural attenuation
- access and use restrictions/well installation restrictions and groundwater use prohibitions
- worker safety measures
- monitoring/sampling and analysis
- funnel system/impermeable barrier wall
- hydraulic containment/extraction using wells
- extraction using air sparging/soil vapor extraction (AS/SVE)
- on site disposal/reinjection or surface water discharge
- physical or chemical effluent treatment by air stripping, sedimentation-filtration, coagulation-flocculation, carbon adsorption and/or passive treatment funnel and gate method

4.3 Development and Screening of Alternatives

The technologies and process options retained for alternative development are combined into alternatives that address the remedial action objectives for the DCF Study Area and provide a range of control, treatment and/or containment combinations. After these alternatives are developed, screening of the alternatives is then performed based on the following three criteria: effectiveness; implementability; and cost.

The evaluation of effectiveness for each alternative considers the following:

- overall protection of human health and the environment;
- reduction in mobility, toxicity and volume through treatment;
- short-term impacts (construction and implementation phase); and
- long-term impacts (after remedial action is complete).

The evaluation of implementability considers technical and administrative feasibility. Technical feasibility addresses whether the alternative can be constructed, operated reliably and maintained. The administrative feasibility refers to the ability to obtain regulatory approval and the availability of services and equipment necessary to implement the alternative.

The cost evaluation considers capital and operation and maintenance costs. For alternatives screening, relative costs are assessed based on the other alternatives in terms of low, medium and high. To facilitate cost estimates, a two-dimensional analytical transport model was used to estimate the time required for contamination levels to meet RGs (KWQS for surface waters that may potentially be used as a drinking water source) through natural processes alone. The assumptions and results for the model are presented in Section 5.1.2. Consistent with the level of available data, it was determined that more appropriate results could be obtained by presenting the results of the modeling in the form of a range. The model was therefore run for two scenarios using what was deemed a reasonable range for the required model input parameters. The two scenarios were termed the "slow flush" (maximum estimated time to meet KWQS) and the "fast flush" (minimum time to meet KWQS). The results of the modeling suggest that, barring the implementation of an active remedial alternative, it would take approximately 30 years to meet KWQS under the "slow flush" and ten years to meet KWQS under the "fast flush." Parameters used for the model are presented in Table 4-2. Estimated costs are more fully developed for the alternatives retained for detailed analysis in Chapter 5.0.

The alternatives developed and presented in the following subsection are:

- Alternative 1 — No Further Action beyond Established Source Controls (inclusion required by NCP);
- Alternative 2 — Source and Institutional Controls with Groundwater Monitoring and Contingency for Future Action;
- Alternative 3 — Source Controls and Natural Attenuation with Groundwater Monitoring and Contingency for Future Action;
- Alternative 4 — Source Controls and Extraction, Treatment and Hydraulic Containment;
- Alternative 5 — Source Controls and Groundwater Contaminant Extraction Using Air Sparging with Treatment of Resulting Soil Vapor; and
- Alternative 6 — Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate.

Of these six alternatives, only Alternatives 4 and 5 are considered active options for which time savings are possible and the ten/thirty year estimate of time to meet KWQS does not apply.

4.3.1 Alternative 1–No Further Action beyond Established Source Controls

4.3.1.1 Description

The No Further Action alternative is included in feasibility studies as a baseline for making comparisons to the other alternatives. This alternative assumes site conditions to be as they were prior to the DCF Study Area becoming a CERCLA site. It therefore includes continued military presence and institutional control at the site, which effectively limits the use of the site and provides an inherent level of control on exposures to the existing contamination at the site (i.e., residential type exposures cannot occur). This alternative also includes already established source controls and a previously executed removal action.

The source controls consist of enhanced facility management and repairs/cleaning of the sanitary sewer lines. Enhanced facility procedures implemented at the DCF consist mostly of improved housekeeping procedures. Several activities were implemented to increase facility management and to decrease the potential for releases to the environment. Floor drains that eventually discharged to Tributary A were plugged with cement grout. Wastewater that was once disposed of by being dumped into the floor drains or disposed of on the ground behind building 180/181 is now collected and recycled by the same commercial company that supplies it. Materials that were used to contain spills (blankets, mattress pads, etc.) were once laundered, introducing PCE wastewater to the leaky sanitary sewer system, and are now dry cleaned. In addition to measures taken within the DCF, steps were taken to reduce the potential for discharge to the environment along the sanitary sewer lines. Sanitary sewer lines were replaced and repaired as presented on Figure 1-3. Sewer lines and manholes were also cleaned and potential contaminated sediments were removed to prevent further migration of contaminants to the environment. Finally, in November 1994 through December 1994 a 30-day Soil Vapor Extraction Pilot Test Study was implemented at the DCFA. VOCs were removed at a rate of between 0.78 and 0.41 lbs/day and at the end of the 30-day test, approximately 21 lbs of VOCs had been removed (CENWK, 1996a).

This alternative does not actively monitor, remove, treat and/or immobilize the already existing contamination. The natural processes that impact the groundwater are necessarily considered in the evaluation of this alternative. In accordance with the requirements of the NCP regarding remedial alternatives that leave contaminants in place, the No Further Action alternative also includes a five year administrative reassessment program to be implemented for as long as groundwater contamination levels are expected to be above KWQS. The reassessments would include a visual site inspection, review of any data which might be available, reporting and coordination and review with the appropriate regulatory agencies. Due to the absence of any groundwater monitoring, however, it would be difficult in practice to ever prove the effectiveness of this alternative to react to changed conditions, or to know when the five year reassessment program could be discontinued.

Since the BLRA essentially presumes no action above and beyond current institutional controls, this alternative would have an associated risk to human health and the environment that is less than or equal to the BLRA-indicated risks assuming that no unexpected changes in site conditions occur.

4.3.1.2 Screening Evaluation

- **Effectiveness**

In accordance with the NCP, a No Further Action alternative cannot include proactive remedial technologies and cannot actively reduce the mobility, toxicity or volume of contamination through treatment. However, the No Further Action beyond Established Source Controls alternative will eventually reduce contaminant levels as a result of ongoing natural processes. This alternative is protective of human health and the environment based on current land use controls because on-site activities and land uses are limited, and the contaminated groundwater is not used. There are no site specific institutional controls included, however, and this alternative does not address, control, or monitor the remaining groundwater contamination and therefore could fail to properly address any unexpected future changes in conditions should they occur. The contamination levels will continue to be in exceedance of regulatory limits (i.e., KWQS) and the RGs until natural processes sufficiently reduce the contaminant levels.

- **Implementability**

This alternative is readily implementable. Land use controls inherently exist as part of the ongoing military presence at Fort Riley. Five year reassessments will be performed as required, although no monitoring data will be available. This may raise implementability concerns from a regulatory and community approval perspective since there will be no way to monitor the contamination or react to unexpected changes in the contaminant levels.

- **Cost**

The cost of this alternative is comparatively low, because the only costs are from the labor and administration associated with performing the five year reassessment required by the IAG and the NCP. Costs associated with ongoing base-wide controls are not included, because they are pre-existing Fort Riley physical plant costs and are not part of any CERCLA activities. It is estimated that this alternative would be the least expensive of all alternatives. Cost estimates for this alternative have been based on the estimated ten to thirty year time durations for natural processes to reduce contaminant levels to within KWQS.

4.3.2 Alternative 2–Source and Institutional Controls with Groundwater Monitoring and Contingency for Future Action

4.3.2.1 Description

As with the No Further Action beyond Established Source Controls alternative, this alternative would have an associated risk to human health and the environment no greater than those levels identified in the BLRA. However, this alternative includes additional protection components beyond those which are considered to be included in the No Further Action beyond Established Source Controls alternative. Specifically included are site-specific administrative controls on subsurface access and utility easements, and the development and implementation of an information distribution campaign at Fort Riley to ensure that proper health and safety protocols are followed when performing maintenance/construction work in the vicinity of the DCF Study Area. This alternative also includes already established source controls and a previously executed removal action. This alternative also includes a continued groundwater monitoring program designed to track groundwater contamination levels (with emphasis on the perimeter of the impacted area), identify any unexpected changes which might require more aggressive future action, and to assist with the performance of the five year reassessments. These additional components beyond the No Further Action beyond Established Source Controls alternative are considered to be valuable additions to monitor for any unexpected adverse changes in conditions and to minimize the potential for unacceptable exposures associated with on-site maintenance/construction activities and unexpected and dangerous levels of off-site migration of contaminants. As with the No Further Action beyond Established Source Controls alternative, contaminant reductions associated with natural processes are an inherent part of this alternative.

It is assumed that semi-annual monitoring would be performed for the first five years, with annual monitoring thereafter. The most appropriate monitoring program would include a background well (or wells), monitoring wells on the Island, and monitoring wells which would provide information on any migration of contaminants from the site to the Kansas River. Table 4-3 presents a list of the wells to be used in the monitoring program, along with a rationale for each well. With the additional wells that have already been installed at the Island as part of the 1996 groundwater monitoring expansion program, existing wells would be sufficient for such a groundwater monitoring program. It is also noted that some of the existing upland monitoring wells would be used to monitor the source area as well as upgradient conditions.

Specifically, the groundwater monitoring program would likely consist of the following elements:

- preparation of a long term monitoring plan (including the rationale and design for the program, as well as procedures for coordination and reporting);
- periodic monitoring (including collection of water level measurements from all wells in the vicinity of the Island and the DCFA);
- sampling and analysis, primarily for VOCs;
- periodic replacement of wells/Microwells which have passed their useful life;
- preparation of data reports, subsequent to periodic sampling, presenting the chemical and hydrogeologic data, interpretation of data, conclusions, and recommendations as appropriate (the recommendations would most likely consist of: no-action until the next scheduled sampling round; proposed changes to the monitoring program; and/or an expedited and more focused assessment of an area identified as a concern and potential candidate for aggressive remedial action); and,
- review and comment on the periodic report by the regulators.

The fourth element includes the contingency for evaluating planning, designing and implementing future remedial actions such as engineered controls and/or aggressive removal/treatment technologies. Such a review is required by CERCLA when contaminants remain in place and would take place every five years at a minimum. If justified by the review, additional remedial actions might be implemented. Additional remedial actions could be exercised if/when unexpected monitoring results (e.g., unexplainable increases in contaminant levels) or land use changes indicate that such action is warranted. As dictated by the NCP and site-specific conditions, all potentially appropriate technologies would be considered during the development of the contingency action should the unexpected occur and future changes in site and/or contaminant conditions show that institutional controls and monitoring under this alternative are no longer adequately protective of human health and the environment. The specific response activities and remedial technologies that might be part of the contingency action would depend on the future changes in conditions that ultimately triggered the contingency (e.g., changes in land use, identification of a new and/or imminently threatened receptor, monitoring data suggesting an unexpected worsening of the nature and/or extent of contamination). Examples of potentially appropriate technologies to be considered at that time would likely include air sparging/soil vapor extraction (AS/SVE), groundwater extraction/treatment, and barrier/treatment walls. For purposes of projecting costs, it is also assumed that the well replacement program will occur at the same time as the five year reassessment and will consist of replacing all of the actively monitored Microwells, since their lifespan is more in doubt based on their installation and construction.

4.3.2.2 Screening Evaluation

- **Effectiveness**

This alternative is protective of human health and the environment because on-site activities and land use are limited and the contaminated groundwater is not used. This alternative does not include active treatment or removal of contamination and therefore does not actively reduce the mobility, toxicity, or volume of contamination through treatment but will eventually reduce contaminant levels as a result of ongoing natural processes. This alternative also includes a contingency for evaluating and triggering more aggressive actions and is protective of human health and the environment based on current land use controls because on-site activities and land uses are limited, and the contaminated groundwater is not used. In addition, there are site specific institutional controls which would be implemented to provide restrictions and warnings regarding any maintenance or construction work in the impacted area.

The contamination levels will continue to be in exceedance of regulatory limits (i.e., KWQS) and therefore the RGs until natural processes sufficiently reduce the contaminant levels. Groundwater monitoring would allow tracking of overall groundwater conditions at the site as well as provide some indication of the extent to which contamination levels are decreasing. It also effectively provides early warning of any adverse changes in the degree or extent of contamination. Groundwater monitoring and institutional controls should eliminate the potential concerns for un-informed use of or exposure to the subsurface contamination in the future.

- **Implementability**

This alternative is readily implementable aside from the difficult site access for installation/replacement of monitoring points. Land use and access restrictions, a routine maintenance program, and a periodic groundwater monitoring program currently exist and only need to be continued and/or modified as necessary. Five year reassessments are easily executed. Integrating these requirements into procedures and planning at Fort Riley is a straightforward administrative process.

- **Cost**

This alternative has a relatively low cost of implementation consisting of sampling, laboratory analysis and reporting. Costs are also included for the labor associated with performing the five year assessment required by the IAG and the NCP. Costs associated with the other components of institutional controls are not included because they are pre-existing and/or are not part of any CERCLA activities. It is estimated that this alternative would be the second least expensive of all alternatives (costing more than only Alternative 1). Cost estimates for this alternative have been based on the estimated ten to thirty year time durations for natural processes to reduce contaminant levels to within KWQS. The estimated costs reflect the difficult site access associated with installation/replacement of monitoring points on the Island which necessitate installing and maintaining an access road across the Union Pacific Railroad tracks.

4.3.3 Alternative 3–Source Controls and Natural Attenuation with Groundwater Monitoring and Contingency for Future Action

4.3.3.1 Description

This alternative is identical to Alternative 2 in every way except that the Source Controls and Natural Attenuation alternative also includes the monitoring of a variety of parameters that will be used to assess ongoing contributions of biodegradation to the natural attenuation process. Currently available data strongly infer that biodegradation and other natural processes capable of reducing contaminant levels to below KWQS are occurring within the area of impacted groundwater (CENWK, 1997a). The monitoring well network would include the same wells used for Alternative 2 as well as an additional ten wells within the contaminated area would also be monitored to better identify and track the different zones of natural attenuation activity that typically develop and fluctuate over time within a groundwater plume. Table 4-4 presents a list of the existing wells to be monitored in association with Alternative 3 and the additional list of sampling and analysis parameters included specifically to monitor the different components of natural attenuation is included in Table 4-5. These additional parameters are considered to be valuable additions to the monitoring program because they would facilitate more detailed reviews and better updates to the time-to-complete projections.

As with Alternative 2, this alternative includes institutional controls, established source controls, five year reassessments, periodic replacement of wells/Microwells which have passed their useful life, and the contingency for evaluating planning, designing and implementing future remedial actions such as engineered controls and/or aggressive removal/treatment technologies. Additional remedial actions could be exercised if/when unexpected monitoring results (e.g., unexplained increases in contaminant levels) or land use changes indicate that such action is warranted. As dictated by the NCP and site-specific conditions, all potentially appropriate technologies would be considered during the development of the contingency action should the unexpected occur and future changes in site and/or contaminant conditions show that institutional controls and monitoring under this alternative are no longer adequately protective of human health and the environment. The specific response activities and remedial technologies that might be part of the contingency action would depend on the future changes in conditions that ultimately triggered the contingency (e.g., changes in land use, identification of a new and/or imminently threatened receptor, monitoring data suggesting an unexpected worsening of the nature and/or extent of contamination). Examples of potentially appropriate technologies to be considered at that time would likely include air sparging/soil vapor extraction (AS/SVE), groundwater extraction/treatment, and barrier/treatment walls.

4.3.3.2 Screening Evaluation

- **Effectiveness**

This alternative includes all of the components in the Source and Institutional Controls alternative and is therefore equally protective of human health and the environment because on-site activities and land use are limited and the contaminated groundwater is not used. In contrast to Alternatives 1 and 2, however, this alternative includes and monitors natural attenuation as a remedial "technology" rather than simply an unavoidable occurrence.

This alternative is considered to provide a small degree of additional effectiveness compared to Alternative 2 because monitoring of additional wells and natural attenuation indicators will allow for a more quantitative performance assessment to be included in the five year assessment as well as allow for faster and better warning of any unexpected adverse changes in conditions.

- **Implementability**

This alternative is readily implementable, and integrating the few additional administrative and monitoring requirements into existing procedures and planning at Fort Riley is a straightforward administrative process.

- **Cost**

Similar to Alternative 2, this alternative has a relatively low cost of implementation even considering the slightly increased level of sampling, laboratory analysis and reporting. It is estimated that this alternative would be more expensive than Alternatives 1 and 2 and less expensive than the remaining alternatives. Cost estimates for this alternative have been based on the ten to thirty year time durations for natural processes to reduce contaminant levels to within KWQS. The estimated costs reflect the difficult site access associated with installation/replacement of monitoring points on the Island which necessitate installing and maintaining an access road across the Union Pacific Railroad tracks.

4.3.4 Alternative 4—Source Controls and Extraction, Treatment and Hydraulic Containment

4.3.4.1 Description

Although this alternative shares the inclusion of established source controls with the first three alternatives, this alternative is different in that it is considered to be an active response action. The active extraction and hydraulic containment of groundwater can be accomplished by installing groundwater recovery systems consisting of either recovery wells or trench drains located at the Island. Removal/treatment technologies were screened out for the DCFA itself because there is no unacceptable risk or ARAR exceedance. This alternative also inherently includes institutional controls, established source controls, groundwater monitoring, periodic replacement of wells/Microwells which have passed their useful life, and the ex situ treatment and subsequent discharge of recovered groundwater. Recovery wells are preferred in this alternative rather than interception trenches due to concerns regarding the ecological impacts and more problematic constructability of a trench collection system in the Island adjacent to the Kansas River. Figures 4-2 and 4-3 present a conceptual plan view of a hydraulic containment system. The two separate figures are included to present both the "slow flush" and "fast flush" scenario. Parameters used for both scenarios are presented in Table 4-2 and Appendix D (Table D-1). A conceptual drawing of a typical extraction well and treatment train are presented as Figures 4-4 and 4-5. Further details on this alternative are discussed below.

- **Recovery Wells**

At least one extraction well could be placed near the point where the DCFA contamination enters the Island from the buried valley in the upland formation such that the highest levels of contamination can be kept from migrating and can begin to be reduced. In addition, in order to form an effective hydraulic barrier to contaminants entering the Kansas River, a line of deep penetrating recovery wells could be installed in the alluvium slightly in from the banks of the river. Other wells could then be installed within the area of contamination as necessary to facilitate the most efficient removal. These wells could be screened throughout the zone of saturated alluvial material overlying the bedrock (assumed to be at a depth of approximately 60 feet bgs). Well placement is based on the goal of prohibiting impacted groundwater from migration to the Kansas River. Actual design and implementation of the groundwater recovery system would depend on the results of remedial design investigations and/or a pilot pumping test prior to designing the full scale system.

- **Groundwater Treatment System**

For purposes of this analysis, it can reasonably be assumed that groundwater would be pumped from the extraction wells to an on site treatment plant equipped with a pre-filter and an air stripper for removal of the volatile organics prior to discharge to a groundwater reinjection system, or to surface water. A reinjection well could even be located within or near the zone of highest contamination to enhance the flushing action of the system. The specific design of the treatment system would consider operational requirements to remove the organic constituents, and the attainment of an effluent meeting any substantive NPDES or underground discharge criteria that are deemed to be applicable or relevant and appropriate. Component technologies of this system were discussed in Section 4.1.4.2 and a conceptual flow diagram for the treatment system is presented in Figure 4-5. Based upon the relatively low levels and quantities of VOC contaminants expected to be emitted from the air stripper (less than one pound per day), emissions control is not expected to be required.

Prior to treatment for organics in the air stripper, the influent stream would likely need to be filtered for removal of suspended solids. This filtration system would consist of an in-line filtration unit designed for the removal of solids. In the treatment system, the backwash from the filter and the cleaning waste from the air stripper would be collected in a building sump. Solids collected from the filtration system and the cleaning of the air stripper would be transferred to a filter screen for dewatering. The water generated from this operation would be pumped back through the air stripper. It is anticipated that the solids from this operation would be hazardous and therefore would be managed in accordance with applicable hazardous waste management regulations.

Based upon the design of the air stripper and solids removal systems, only trace amounts of volatile organics should be present in the groundwater as the water exits the air stripper. The treated groundwater could, however, also be passed through an activated carbon adsorption system as a final polishing step prior to discharge if necessary. Since the air stripper and solids removal systems are designed to reduce the concentration of volatile organics to meet effluent quality, minimal loading on the carbon vessels would be anticipated.

4.3.4.2 Screening Evaluation

- **Effectiveness**

The objectives of Alternative 4 are to reduce contaminant levels in the groundwater and to contain groundwater from migrating to the Kansas River or any other downgradient location of potential exposure. In order for this system to work, formation of overlapping cones of depression in the alluvium is imperative to direct and capture the groundwater flow. Due to the size of the impacted area of groundwater, several extraction wells would be necessary to achieve effective hydraulic containment. If subsurface conditions prove to be appropriate, this alternative could effectively collect the contaminated groundwater and thus reduce and control the volume of contaminated groundwater migrating to the Kansas River. This alternative could also reduce the toxicity and mobility of the groundwater contamination by removing the contaminated groundwater for treatment. Readily available treatment technologies can effectively be employed as part of this alternative. However, contaminant removal rates associated with groundwater extraction through pumping are difficult to predict and are frequently very limited in practice, often necessitating extended periods of operation and maintenance. Furthermore, there are indications that some of the alluvial materials in the Island may contain high levels of silt, which would also affect the performance and cost effectiveness of this alternative (See Appendix C for sieve results from hand samples taken from the bank of the Kansas River).

Another factor that needs to be considered when attempting to anticipate the effectiveness of a groundwater extraction system is the placement of the extraction wells. If the extraction wells are placed too close the Kansas River there would be an large volume of "clean" river water being needlessly extracted and treated at the groundwater treatment system. On the other hand, if the extraction wells are installed too far inland, there would be an unquantified amount of impacted groundwater escaping the radius of influence and migrating to the Kansas River. Because of this, hydrogeologic investigations, pumping tests, and extensive

modeling would need to be performed and the results evaluated prior to determining the optimum locations of the extraction wells.

This alternative is likely to provide increased effectiveness in comparison to Alternatives 1, 2, and 3 based on the fact that it would, to some extent, be actively reducing the contaminant levels in the groundwater at the Island. Reduction of contaminant levels at the Island to meet KWQS is desirable in that it more quickly satisfies the potential ARAR.

- **Implementability**

Aside from site access requirements, the physical installation of a groundwater treatment system would be a relatively straightforward process, but there are potentially difficult issues to be resolved regarding the location of the treatment system and the installation of the recovery wells in the sensitive and protected environs of the Island. The technically preferred location for the treatment system would be on the Island, in close proximity to the recovery wells. However, the Island is relatively difficult to access and is located in the ten-year floodplain and as well as in a bald eagle habitat, such that locating the treatment system relatively close to the pumping station may not be possible based on regulatory requirements/constraints. The other most likely location for the system would be the DCFA. Locating the system at the DCFA itself might also present problems, however, as the DCFA is located in the 50-year floodplain and in a culturally significant district. Additionally, system maintenance requirements and noise levels may be problematic in either location. Accessing the Island with a conventional drill rig for the purposes of installing the recovery wells, manifolds and piping would pose problems due to difficult access and potential environmental impacts. Figures 4-2 and 4-3 present the approximate area of clearing that would be required to install the extraction wells and manifold piping at the Island.

- **Cost**

Both the capital and operations/maintenance (O&M) costs for the proposed system are expected to be relatively high (especially compared to the costs of Alternatives 1, 2, and 3). Additional cost items potentially associated with this alternative are an aquifer pump test, restoring the ecological significance of the Island, and installing a pretreatment/filtration system to remove insoluble materials from the effluent stream to prevent system clogging. Pretreatment could as much as double costs for the treatment aspect of this alternative depending on the level of insoluble materials that may be present. Estimated costs for this alternative are based upon experience with similar groundwater treatment system installations. It is estimated that this alternative would be more expensive than Alternatives 1, 2, and 3 and less expensive than the remaining alternatives. Costs estimates for this alternative have been based on assumed hydrogeologic parameters and projected contaminant mass flushing efficiencies for the impacted Island aquifer, and also reflect the difficult access conditions for performing installation/replacement of monitoring points and other work on the Island.

It should be noted that costs associated with readily quantifiable ecological restoration items (i.e., landscaping and tree replanting) have been incorporated into the cost estimates. However, it is not possible to accurately include and quantify the total loss of ecological resources that are expected to occur should active remediation options be implemented on the Island. Examples of unquantifiable "costs" include noise-and activity-related disturbances to the current and desirable tranquility at the Island, as well as the loss of some large trees and smaller understory which represent future roosting trees.

4.3.5 Alternative 5 –Source Controls and Groundwater Contaminant Extraction Using Air Sparging

4.3.5.1 Description

Removal of contaminants from groundwater at the Island can be accomplished by promoting volatization of volatile organic groundwater contamination through air sparging. Air sparging systems consist of an air supply system, an extraction system and a vapor treatment/discharge system. The air supply system is made up of one or many injection wells that are used to supply air to the aquifer. As the air works its way up through the aquifer as it promotes volatization of the volatile organic contaminants and carries the contaminants to the vadose zone. The extraction system consists of recovery or vacuum wells that produce suction at the vadose zone and draw air to the surface along with the volatized contaminants. Once the air stream and contaminants are recovered at the surface, they will be run through treatment system designed for the specific contaminant levels and volumes. This alternative also inherently includes institutional controls, established source controls, groundwater monitoring, and periodic replacement of wells/Microwells which have passed their useful life. Figures 4-6 and 4-7 present a conceptual plan view of an air sparging/soil vapor extraction (as/sve) system . The two separate figures are included to present both the "slow flush" and "fast flush" scenario. Parameters used for both scenarios are presented in Table 4-2. A conceptual drawing of a typical system is presented as Figure 4-8. Further details on this alternative are discussed below.

- **Air Injection Wells**

In order to supply air to aquifer, several injection wells would need to be installed depending on the area and extent of the contamination. At a minimum, a line of injection wells would be installed such that they are located at the downstream end of the contaminant plume to prevent further migration of the contaminants, with well placement based on the goal of prohibiting contaminant migration to the Kansas River. Additional sparging wells could also be placed in the area of highest contamination to achieve quicker reductions in contamination levels and to assist with the control of migration of contaminants to the Kansas River. Actual design and implementation of the air injection system depends on the results of remedial design investigations and/or a pilot pumping test prior to design of the full scale system.

- **Vapor Recovery Wells**

In order to recover the vapor phase contaminants once they are brought to the vadose zone, a system of recovery/vacuum/extraction wells would be installed in conjunction with the injection wells. The recovery wells would be installed such that they are located towards the downstream end of the contaminant plume to prevent further migration of the contaminants. Actual design and implementation of the vapor recovery system depends on the results of remedial design investigations and/or a pilot test prior to design of the full scale system.

- **Vapor Treatment System**

The vapor recovered from the extraction wells may need to be treated prior to discharge to meets air emissions standards, especially in the early stages when removed concentrations are typically highest. If treatment is required, the vapor will be passed through a GAC column for removal of organics prior to discharge. The design of the treatment system would consider operational requirements to remove the organic constituents, and the attainment of an emissions stream meeting any substantive air quality requirements deemed to be applicable or relevant and appropriate. Based upon the relatively low groundwater contaminant levels and small quantities of VOC contaminants which may be recovered, emission control may not actually be required.

4.3.5.2 Screening Evaluation

- **Effectiveness**

The objectives of Alternative 5 are to remove volatile organic compounds from groundwater and to keep them from migrating to the Kansas River. In order for this system to work, material at the Island must be permeable enough to allow the flow of the injected air through the saturated zone, and vadose zone to promote extraction. In addition, it is imperative that the injection wells are placed such that the areas of highest concentrations are influenced by the injected air. Assuming that subsurface conditions prove to be appropriate, this alternative is effective in that it will reduce the toxicity of the groundwater flowing to the Kansas River and would satisfy related ARARs applicable to surface water discharge criteria. Readily available treatment technologies can effectively be employed as part of this alternative. However, contaminant removal rates associated with this technology are difficult to predict and may be very limited; often necessitating extended periods of operation and maintenance. Furthermore, there are indications that some of the alluvial materials in the Island may contain high levels of silt, which would also affect the performance and cost effectiveness of this alternative (See Appendix C for sieve results from hand samples taken from the bank of the Kansas River).

- **Implementability**

Implementability concerns similar to those for Alternative 4 would also exist for this alternative. The installation of an injection and extraction system would be a relatively straightforward process technically; but there are potentially difficult issues to be resolved regarding the location of the treatment system, relative to bald eagle habitat the installation of system piping, and the numerous injection and recovery wells that would be required based on the very limited radius of influence (50 to 100 feet maximum) typically associated with these wells. It is likely that a significantly large quantity of wells (25 to 75) would be required to ensure proper influence. Installing a large number of injection and extraction wells at the Island could result in an unacceptable ecologic/environmental impact. Figures 4-6 and 4-7 present the approximate extent of clearing that would be required to install the system. Additionally, system maintenance requirements, noise levels, and the limited access to the Island for the purposes of installing the system may be problematic from a cost and ecological impact standpoint.

- **Cost**

Combined capital and operations/maintenance (O&M) costs for the proposed system are expected to be relatively high (approximately $2.5 to $4.5 million) for Alternative 5, well above the costs of any of the other alternatives being analyzed. Increased cost of this alternative is associated with performing field testing to determine the permeability of the alluvial material, expected limited radius of influence for wells, difficult access for construction equipment, and restoring the ecological significance of the Island. The estimated costs reflect the difficult site access associated with installation/replacement of monitoring points on the Island which necessitate installing and maintaining an access road across the Union Pacific Railroad tracks.

Figures 4-6 and 4-7 outline the approximate area of clearing that would be required for the installation of the multiple air sparging/soil vapor extraction (as/sve) wells. While this would result in increased capital costs, more detrimental to the performance of the alternative is the unavoidable ecological destruction that would be caused at the Island. The above stated \$2.5 to \$4.5 million order of magnitude cost estimate for this alternative includes remedial design investigation and testing, capital costs, system operations and maintenance, groundwater monitoring, engineering/management/administration, site restoration, regulatory agency coordination, and five year reviews.

It should be noted that costs associated with readily quantifiable ecological restoration items (i.e., landscaping and tree replanting) have been incorporated into the cost estimates. However, it is not possible to accurately include and quantify the total loss of ecological resources that are expected to occur should active remediation options be implemented on the Island. Examples of unquantifiable "costs" include noise- and activity-related disturbances to the current and desirable tranquility at the Island, as well as the loss of some large trees and smaller understory which represent future roosting trees.

- **Screening Decision**

Based on the similar effectiveness and increased ecological damage caused at the Island compared to the other active removal/treatment alternative being considered (Alternative 4), Alternative 5 is not worthy of being retained for the detailed evaluation and is therefore screened out at this stage.

4.3.6 Alternative 6–Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate

4.3.6.1 Description

The funnel and gate alternative consists of partial containment and passive chemical treatment of groundwater as it flows toward the Kansas River. The partial containment associated with this alternative is not really containment at all, but more specifically a redirection of the groundwater to a flow through treatment gate using vertical barrier walls (i.e., sheet piling or slurry walls) which is constructed of a passive treatment media. As groundwater passes through the treatment media consisting of a permeable reactive material such as iron flakes or shavings, the chlorinated VOCs are chemically transformed into a less toxic material (i.e., ethane, ethylene, methane); thus reducing contamination levels significantly prior to migrating from the site. This alternative also inherently includes institutional controls, established source controls, groundwater monitoring, and periodic replacement of wells/Microwells which have passed their useful life. Figure 4-9 presents a conceptual plan of a funnel and gate system and Figure 4-10 presents a cross section of a typical funnel and gate system. Further details on this alternative are discussed below.

4.3.6.2 Screening Evaluation

- **Effectiveness**

The objectives of Alternative 6 are to partially control and redirect groundwater through passive permeable treatment media prior to migrating to the Kansas River, thus reducing the toxicity of groundwater and addressing potential off-site migration of the constituents of concern. For this system to work, the contaminated groundwater must come in contact with the permeable treatment gate to reduce the level of toxicity prior to discharging to the Kansas River. This alternative effectively treats the contaminated groundwater that comes in contact with the permeable wall and thus reduces the toxicity of contaminated groundwater prior to discharging to the Kansas River. One concern regarding this alternative would be periodic rises in groundwater levels that could cause groundwater to occasionally move over and past the permeable wall without coming in contact with the treatment element. Other concerns include the slow rate at which treatment will occur and the potential for periodic fouling (and therefore maintenance/replacement) of the treatment media if groundwater chemistry is not appropriate. Although this is a relatively new technology, there are readily available systems with some successful applications that can effectively be employed as part of this alternative. Contaminant reduction rates may be difficult to predict, however, and would require laboratory (bench scale) and/or in situ (pilot) testing.

It is specifically noted that this alternative is likely to provide increased effectiveness in comparison to Alternatives 1, 2, and 3 based on the fact that natural attenuation would still be occurring within the Island in addition to passive treatment of the groundwater prior to discharge to the Kansas River.

- **Implementability**

Although construction of the system would not be problematic in most other locations, the Island is difficult to access and is located in a ten-year floodplain, and construction activities may create some adverse impacts to the environmentally sensitive bald eagle habitat. In addition, construction of the funnel and gate system would likely be in close proximity to the Kansas River, posing potential erosion control problems, wetlands impacts, and encroachment concerns. Finally, another implementability question would be with regard to the required depth of impermeable barrier walls. For evaluation and costing purposes, bedrock is assumed to be at approximately 60 feet bgs based on available information from Microwell installations and regional geology. There is no definitive information, however, regarding actual bedrock depths and construction could become even more difficult should actual depths to bedrock be much deeper.

In summary, this alternative is more difficult to implement relative to Alternatives 1, 2, 3, and 4, but would be easier to implement than Alternative 5.

- **Cost**

The costs for the proposed system are expected to be relatively high, although lower than Alternative 5. Factors that increase the costs of this alternative are requirements associated with performing a bench scale or pilot test study to determine the effectiveness of this type of passive treatment, restoring the ecological significance of the Island, and the potential requirement of periodically removing and replacing the permeable reactive medium if/when the treatment media becomes clogged or exhausted. Using recent literature regarding funnel and gate installations and tests (Appendix E), it is estimated that this alternative would be the second most expensive of all alternatives (costing less than only Alternative 5). Cost estimates for this alternative have been based on the assumption that the system would remain in place and operate for a time period similar to the other passive alternatives (Alternatives 1, 2, and 3). The estimated costs also reflect the difficult site access associated with installation/replacement of monitoring points on the Island which necessitate installing and maintaining an access road across the Union Pacific Railroad tracks.

It should be noted that costs associated with readily quantifiable ecological restoration items (i.e., landscaping and tree replanting) have been incorporated into the cost estimates. However, it is not possible to accurately include and quantify the total loss of ecological resources that are expected to occur should active remediation options be implemented on the Island. Examples of unquantifiable "costs" include noise- and activity-related disturbances to the current and desirable tranquility at the Island, as well as the loss of some large trees and smaller understory which represent future roosting trees.

4.4 Results of Screening Evaluation

The following alternatives have been retained for further consideration during the detailed analysis:

- Alternative 1 — No Further Action beyond Established Source Controls;

- Alternative 2 — Source and Institutional Controls including Groundwater Monitoring and Contingency for Future Action;
- Alternative 3 — Source Controls and Natural Attenuation including Groundwater Monitoring and Contingency for Future Action;
- Alternative 4 — Source Controls and Extraction, Treatment and Hydraulic Containment; and
- Alternative 6 — Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate

Based on low cost, high implementability, and acceptable effectiveness, Alternatives 1, 2, and 3 are retained for detailed analysis. Alternatives 4 and 6 are also being retained for further consideration based on the potential for increased effectiveness relative to Alternatives 1 and 2, albeit at a significant cost and with potential implementability problems. Alternative 5 is not being retained for further consideration and analysis based on its questionable implementability due to increased ecological damage concerns, especially in comparison to the other less damaging yet similarly effective active removal/treatment alternative (Alternatives 4).

TABLES

TABLE 4-1
IDENTIFICATION OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS RETAINED AFTER INITIAL SCREENING
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

General Response Action	Remedial Technology	Process Options
• No Action	• NAp	• NAp
• Natural Attenuation	• Natural Attenuation	• Biological Chemical Physical
• Institutional Controls	• Access/Land Use Restrictions	• Administrative Controls • Well Installation Restrictions • Groundwater Use Prohibitions
	• Enhanced Facility Management	• Improved House Keeping Practices (i.e., plugged drains, spill control, wastewater control, etc.)
	• Worker Safety Measures	• NAp
	• Surface Controls	• Maintenance of Surface Cover and Drainage Systems
	• Groundwater Monitoring	• Sampling/Analysis
• Removal	• Extraction • On Site Disposal	• Extraction Wells • Air Sparging • Reinjection • Surface Water Discharge
• Containment	• Hydraulic Diversion	• Extraction and Discharge or Reinjection Using Wells
	• Source Containment	• Sewer Repair • Sewer Cleaning and Sediment Removal
• Collection/ Treatment	• Chemical	• Funnel & Gate
• Treatment	• Physical/Chemical Treatment	• Air Stripping • Filtration/Cooagulation/ Flocculation • Carbon Adsorption

NAp Not applicable, no remedial technology or process option is associated with the *No Action* General Response Action.

TABLE 4-2
SUMMARY OF PARAMETERS USED FOR MODELING AND COSTING
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Parameters	Values Used	
	Fast Flush	Slow Flush
Field Data (Measured Data)		
Hydraulic Gradient (Field Data)	0.014	0.007
Flow Direction (degrees counterclockwise)	280	280
Depth to Bedrock (ft below ground surface)	60	60
Literature or Estimated Data		
Hydraulic Conductivity (ft/day)	100	0.028
Seepage Velocity (ft/day)	4.67	0.00049
Soil Porosity	0.40	0.30
Soil Organic Content (foc) (Field Data)	1.10%	1.30%
Contaminant Koc (ml/g) [1]	240	440
Contaminant distribution Coefficient (Kd)	2.64	5.72
Retardation Factor [2]	13.01	41.99
Contaminant Decay Rate [3]	0.007	0.0004
Source Decay Rate	0.007	0.0004
Soil bulk density	1.82	2.15

(1) Mackay et al. 1993 (based on Koc data from soil media)
(2) Calculated using Equation R = (1+ Kd * density /porosity)
(3) Harward et al., 1991 (based on anaerobic biodegradation rate)

TABLE 4-3
GROUNDWATER MONITORING WELLS USED FOR LONG TERM MIGRATION MONITORING PLAN (ALTERNATIVES 2 and 6)
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Well	Rationale
DCF92-02	Located slightly upgradient of source area.
DCF93-13	Located in source area (highest detections historically).
DCF93-19	Located in Lower Crouse. Monitor potential downward contaminant migration.
DCF96-23	Monitor downgradient contaminant levels and migration at the Island.
DCF96-24	Monitor downgradient contaminant levels and migration at the Island.
DCF96-25	Monitor contaminant levels and migration at the Island. Historically highest concentrations of wells on the Island.
DCF96-26	Monitor downgradient contaminant levels and migration at the Island.
DCF96-27	Monitor downgradient contaminant levels and migration at the Island.
DCF96-34	Monitor downgradient contaminant levels and migration at the Island.
DCF96-35	Background levels, located at upriver end of Island. Historically non detect.
DCF96-36	Monitor across Kansas River.

TABLE 4-4
GROUNDWATER MONITORING WELLS USED FOR LONG TERM MIGRATION AND CONTAMINANT REDUCTION MONITORING PLAN (ALTERNATIVES 3, 4, AND 5)
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Well	Rationale
DCF92-02	Located slightly upgradient of source area.
DCF92-03	Located in source area.
DCF92-04	Located cross gradient to source area area.
DCF92-05	Located in source area.
DCF93-08	Located cross gradient to source area, recently non detect.
DCF93-09*	Monitor contaminant levels and migration at the Island.
DCF93-10*	Monitor contaminant levels and migration at the Island.
DCF93-13	Located in source area (highest detections historically).
DCF93-14	Background levels, located slightly upgradient of source area.
DCF93-17	Background levels, located upgradient of source area.
DCF93-19	Located in Lower Crouse. Monitor potential downward contaminant migration.
DCF94-22*	Monitor contaminant levels and migration at the Island.
DCF96-23*	Monitor downgradient contaminant levels and migration at the Island.
DCF96-24*	Monitor downgradient contaminant levels and migration at the Island.
DCF96-25*	Monitor contaminant levels and migration at the Island. Historically highest concentrations of wells on the Island.
DCF96-26*	Monitor downgradient contaminant levels and migration at the Island.
DCF96-27*	Monitor contaminant levels and migration at the Island.
DCF96-34*	Monitor downgradient contaminant levels and migration at the Island.
DCF96-35	Background levels, located at upriver end of Island. Historically non detect.
DCF96-36	Monitor across Kansas River.

Note:

* Wells will be monitored for natural attenuation parameters if Alternative 3 is chosen.

TABLE 4-5
MONITORING PARAMETERS USED TO DOCUMENT NATURAL ATTENUATION PROCESSES
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Parameters	Method
Dissolved Oxygen	Field Measurement with DO Meter
Nitrate	Iron chromatography (Method E300)
Iron	Colorimetric HACH (Method 8146)
Sulfate	Iron chromatography (Method E300)
Methane, Ethane, Ethylene	SW 3810 modified
Alkalinity	HACH alkalinity test
Oxidation/Reduction Potential	A2580B
pH	Field Measurement with pH Meter
Temperature	Field Measurement with Direct Meter
Conductivity	E120.1/SW9050
Chloride	Mercuric nitrate titration A4500
Chloride (optional)	HACH chloride test
Total Organic Carbon	SW9060

Source: *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* (Appendix F)

FIGURES

Figure 4-1
Initial Screening of Technologies and Process Options - Groundwater

General Response Action	Remedial Technology	Process Options	Description	Screening Comments
No Action	None	Not Applicable	Site will return to pre-CERCLA Action status. Activities will be limited to continued military presence and control. Five-year reviews to be performed to re-evaluate the No Action decision.	Retained as required for consideration by NCP.
Natural Attenuation	Natural Attenuation	Biological	Decreasing contaminant concentrations due to natural processes such as biodegradation.	Retained for further consideration.
		Chemical	Decreasing contaminant concentrations due to natural processes such as chemical transformation and adsorption.	Retained for further consideration.
		Physical	Decreasing contaminant concentrations due to natural processes such as dispersion, dilution and volatilization.	Retained for further consideration.
Institutional Controls	Access Restrictions	Well Installation Groundwater Use Restrictions	Restrictions on installation of wells. Prohibit groundwater use.	Retained for further consideration.
	Groundwater Monitoring	Quarterly Sampling	Groundwater is sampled on a quarterly or semi annual basis as a means of tracking contaminant migration.	Retained for further consideration.
Collection	Subsurface Drains	Interceptor Trenches (not retained)	Perforated pipe in trenches backfilled with porous media to collect contaminated water.	Not retained for further consideration in light of more applicable technologies (i.e. extraction wells).
	Funnel System	Impermeable Barrier Wall	Impermeable barrier walls are installed to redirect groundwater flow through a permeable treatment wall.	Retained for further consideration as a means of redirecting groundwater, not retained for the purpose of containment.

[hatched box] Indicates technology that is not retained.

Figure 4-1 (continued)
Initial Screening of Technologies and Process Options - Groundwater

General Response Action	Remedial Technology	Process Options	Description	Screening Comments
Containment	Vertical Barriers	Slurry Wall	Trench around areas of contamination is filled with a soil (or cement) bentonite slurry.	Not retained due to constructability problems.
		Grout Curtain	Pressure injection of grout in a regular pattern of drilled holes.	Not retained due to constructability problems.
		Sheet Piles	Sheet pile wall to cut off lateral flow.	Not retained due to constructability problems.
	Horizontal Barriers	Grout Injection	Pressure injection of grout at depth through closely spaced drilled holes or using horizontal drilling.	Not retained due to complex geology and associated constructability problems.
	Hydraulic Containment	Extraction and Injection Wells	Install Pumping Well System for diversion of contaminated groundwater. Effluent treatment system is included and applied prior to discharge.	Retained for further consideration.
Removal	Extraction	Extraction Wells at DCFA	Series of wells to extract contaminated groundwater.	Not retained due to determination that contaminated groundwater of concern has already migrated to the "Island".
		Extraction Wells in Alluvium	Series of wells to extract contaminated groundwater	Retained for further consideration.
		Air Sparging Soil Vapor Extraction	Injection of air into aquifer to volatilize contaminants and transport to vadose zone. Once in vadose zone contaminants are collec ted through vacuum extraction wells.	Retained for further consideration.
		Electrical Separation	Electrical gradients are used to "sweep" contaminants to an accumulation point for removal.	Not retained due to relative ineffectiveness for use on organic contaminants.
	On Site Disposal	Reinjection	Disposal of extracted groundwater via aquifer reinjection.	Retained for further consideration as part of hydraulic diversion system.
		Surface Water Discharge	Discharge to surface water after treatment.	Retained for further consideration as part of hydraulic diversion system.
		Surface Irrigation	Surface spray irrigation to dispose contaminated groundwater.	Not retained due adverse effects on current activities and missions associated with the DCF.

(hatched box) Indicates technology that is not retained.

Figure 4-1 (continued)
Initial Screening of Technologies and Process Options - Groundwater

General Response Action	Remedial Technology	Process Options	Description	Screening Comments
Treatment	Physical	Carbon Adsorption	Adsorption of contaminants onto activated carbon.	Retained for consideration as part of for hydraulic diversion treatment system.
		Filtration and Sedimentation	Removal of suspended solids or particles from wastewater.	Retained for consideration as part of hydraulic diversion treatment system as a pretreatment to remove natural inorganics and suspended solids.
		Coagulation/ Flocculation	Coagulants or Polyelectrolytes are added to water to coagulate suspended particles and facilitate separation.	Retained for consideration as part of hydraulic diversion treatment system as a pretreatment to remove natural inorganics and suspended solids.
		Reverse Osmosis	Differential movement of dissolved material across a membrane.	Not applicable for VOC contaminants.
		Air Stripping	Contact water with air in a packed column to promote transfer of VOCs to air.	Retained for consideration as part of hydraulic diversion treatment system.
	Chemical	Funnel & Gate	Groundwater passes through a window of permeable passive treatment media (i.e. iron filings).	Retained for consideration.
		UV Oxidation	Combines Ultraviolet light with Ozone and Hydrogen Peroxide.	Not retained for consideration in favor of more cost-effective options for treatment of organics.
		Neutralization	Addition of chemicals to neutralize wastewater.	Not retained for consideration as there are no applicable contaminants of concern.
		Precipitation	Reduction of contaminant solubility by addition of precipitating agent.	Not retained for consideration as there are no inorganic contaminants of concern.
		Oxidation/ Reduction	Chemical form of the contaminants are changed to less toxic forms via an oxidation or reduction reactor.	Not retained for consideration as this technology is not applicable to volatile organics.

continued on next page

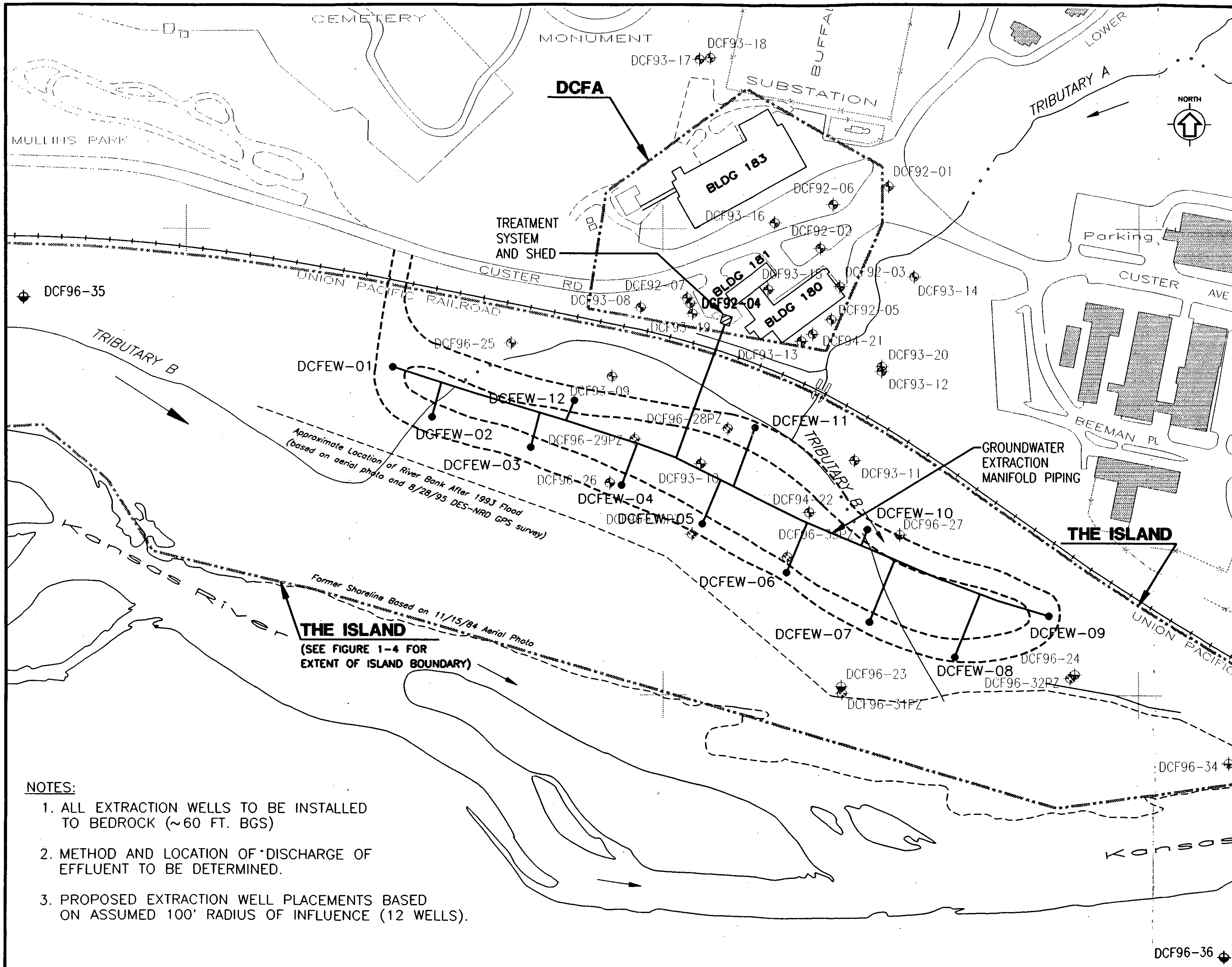
Indicates technology that is not retained.

Figure 4-1 (continued)
Initial Screening of Technologies and Process Options - Groundwater

continued from previous page

General Response Action	Remedial Technology	Process Options	Description	Screening Comments
Treatment	Biological	Activated Sludge	External degradation of organics using indigenous organisms in an aerobic environment.	Not cost effective for low concentrations of contaminants.
		In-situ Biodegradation	Degradation of organics using micro-organisms in in-situ environment.	Not cost effective for low concentrations of contaminants.
	Thermal	Steam Stripping	Uses steam to extract organics from effluent in a packed tower.	Not cost effective for low concentrations of contaminants.
Disposal	Off-site Disposal	POTW Discharge	Transport or pump contaminated groundwater to Wastewater Treatment Plant.	Not retained as NCP prefers an on-site method when viable.
		Off-site Transport and Disposal	Collection and transport of groundwater to off-site treatment.	Not retained as NCP prefers an on-site method when viable.

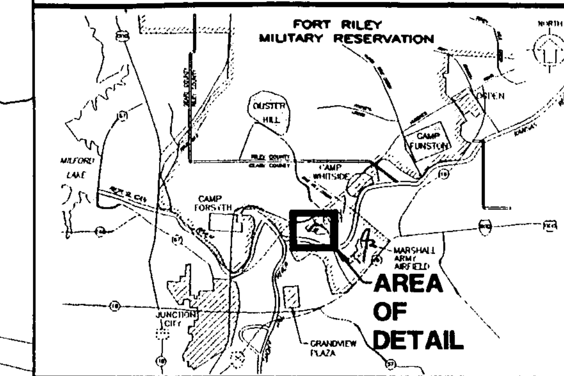
[hatched box] Indicates technology that is not retained.



NOTES:

1. ALL EXTRACTION WELLS TO BE INSTALLED TO BEDROCK (~60 FT. BGS)
2. METHOD AND LOCATION OF DISCHARGE OF EFFLUENT TO BE DETERMINED.
3. PROPOSED EXTRACTION WELL PLACEMENTS BASED ON ASSUMED 100' RADIUS OF INFLUENCE (12 WELLS).

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
- DCFEW-01 PROPOSED GROUNDWATER EXTRACTION WELL
- APPROXIMATE LOCATION AND EXTENTS OF PROPOSED ACCESS ROAD AND CLEARING REQUIRED FOR INSTALLATION OF EXTRACTION WELLS.

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

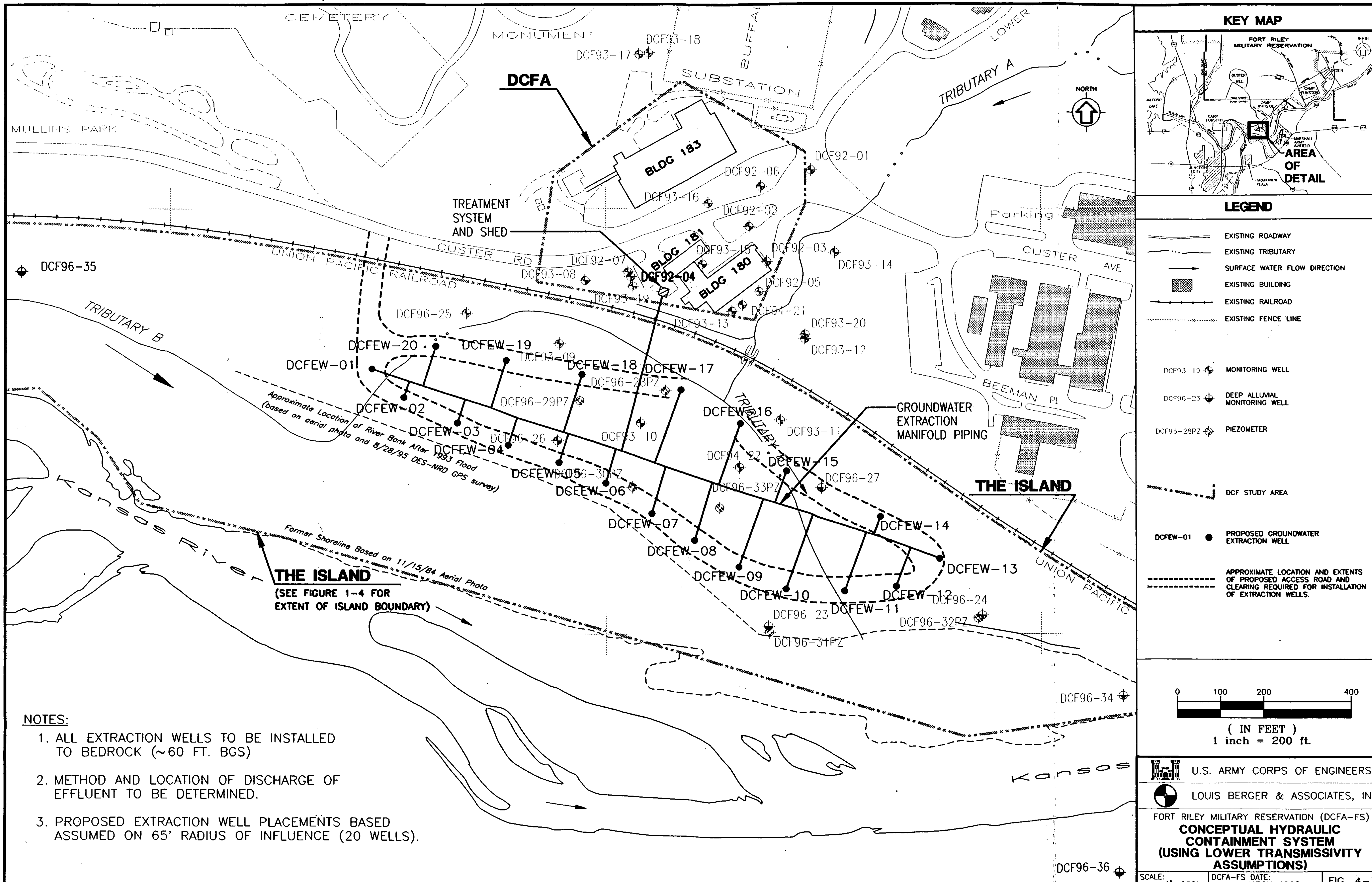
U.S. ARMY CORPS OF ENGINEERS
LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-FS)

CONCEPTUAL HYDRAULIC CONTAINMENT SYSTEM (USING HIGHER TRANSMISSIVITY ASSUMPTIONS)

SCALE: 1"=200'	DCFA-FS DATE: MARCH 1998	FIG. 4-2

FS-WPMEN/2.../APR98/FS-CHCSH



NOTES:

1. ALL EXTRACTION WELLS TO BE INSTALLED TO BEDROCK (~60 FT. BGS)
2. METHOD AND LOCATION OF DISCHARGE OF EFFLUENT TO BE DETERMINED.
3. PROPOSED EXTRACTION WELL PLACEMENTS BASED ASSUMED ON 65' RADIUS OF INFLUENCE (20 WELLS).

U.S. ARMY CORPS OF ENGINEERS

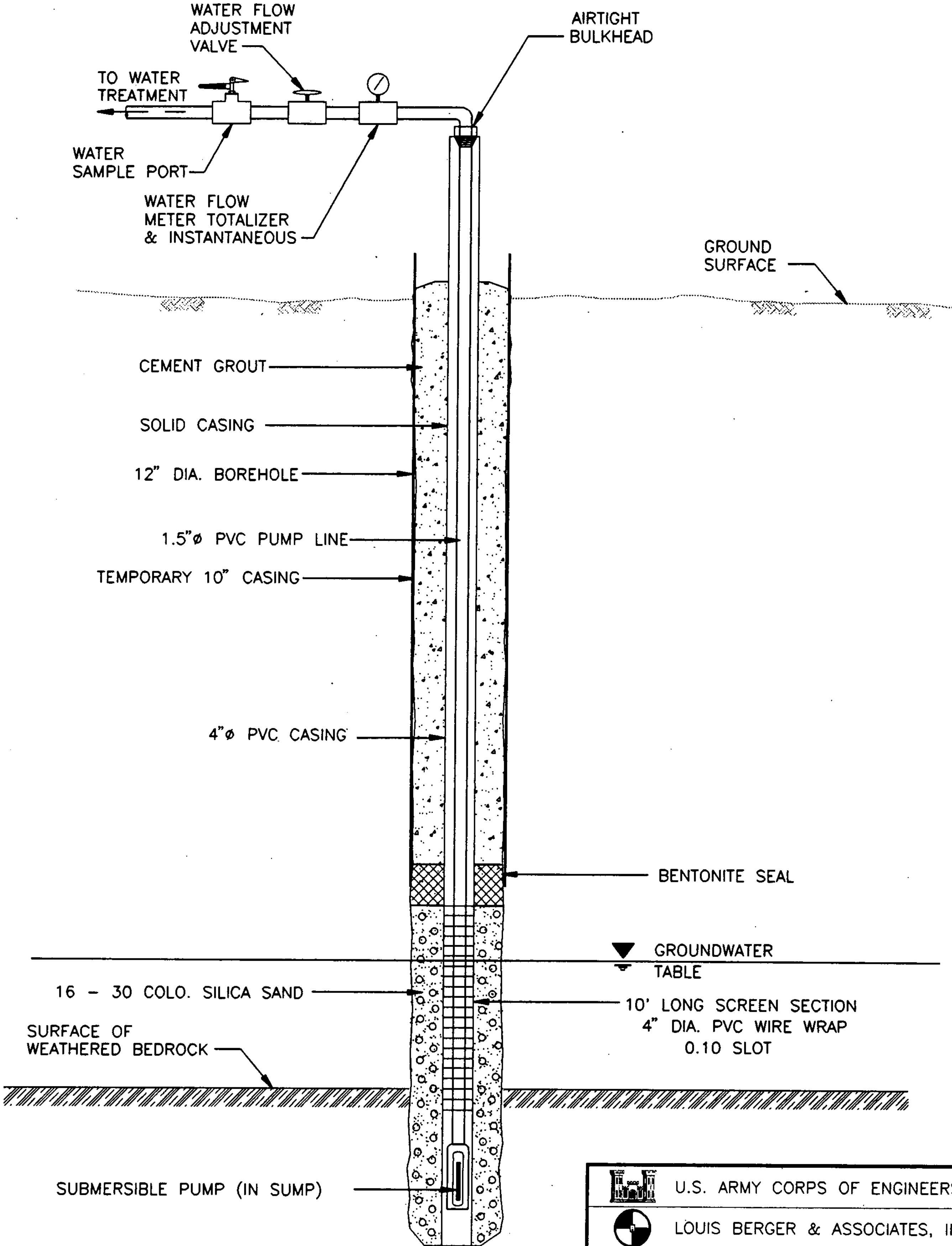
LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-FS)

CONCEPTUAL HYDRAULIC CONTAINMENT SYSTEM (USING LOWER TRANSMISSIVITY ASSUMPTIONS)

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

FS-WPMEM/2...AR98/FS-CHCSL



NOTE:
BOTTOM OF CASING TO VARY BASED
UPON DEPTH OF CONFINING LAYER.

U.S. ARMY CORPS OF ENGINEERS

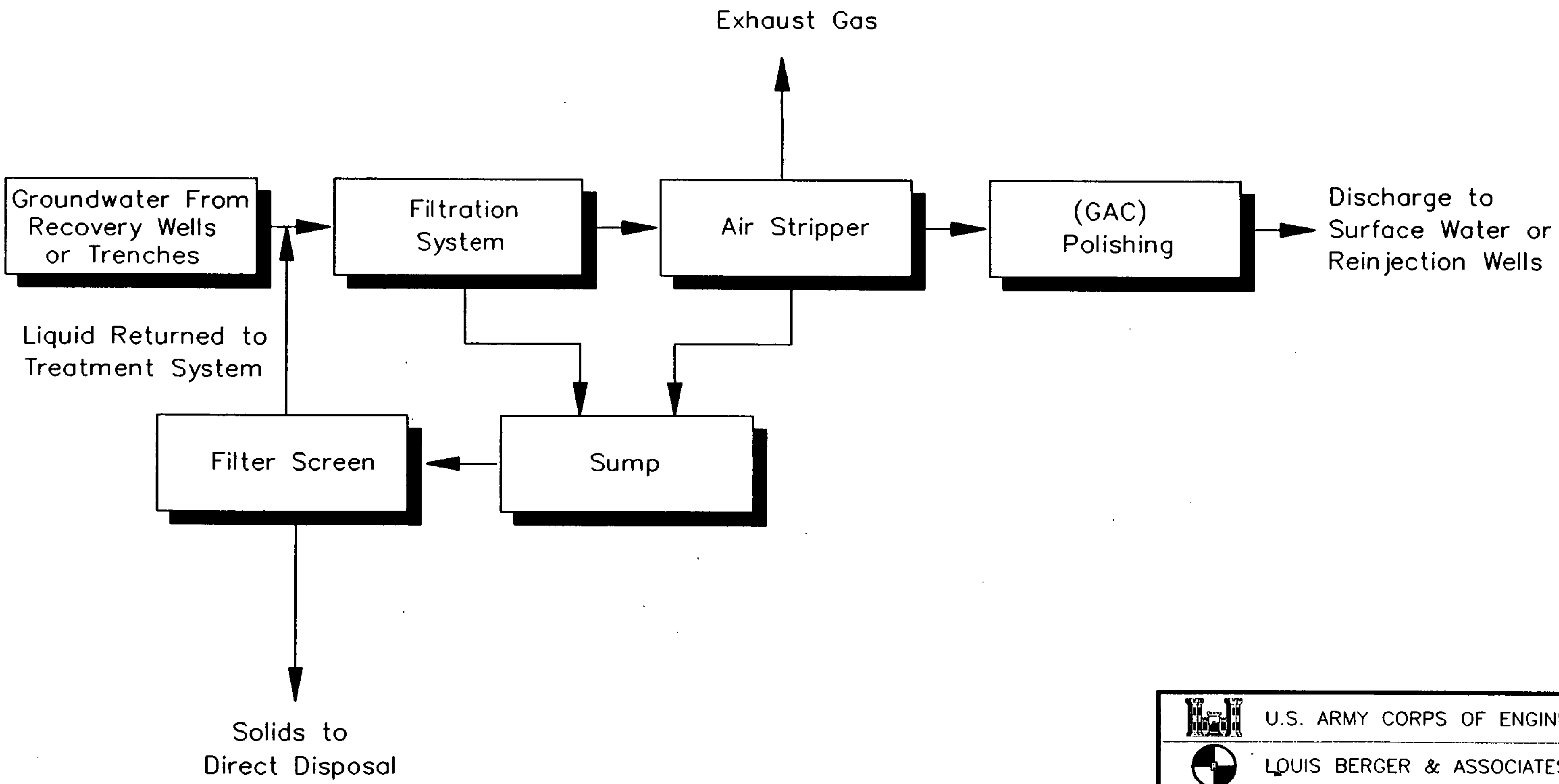
LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA–FS)

CONCEPTUAL
EXTRACTION WELL DETAIL

SCALE: N.T.S	DCFA–FS DATE: MARCH 1998	FIG. 4–4

FS-CLTSA/25MAR98/U4



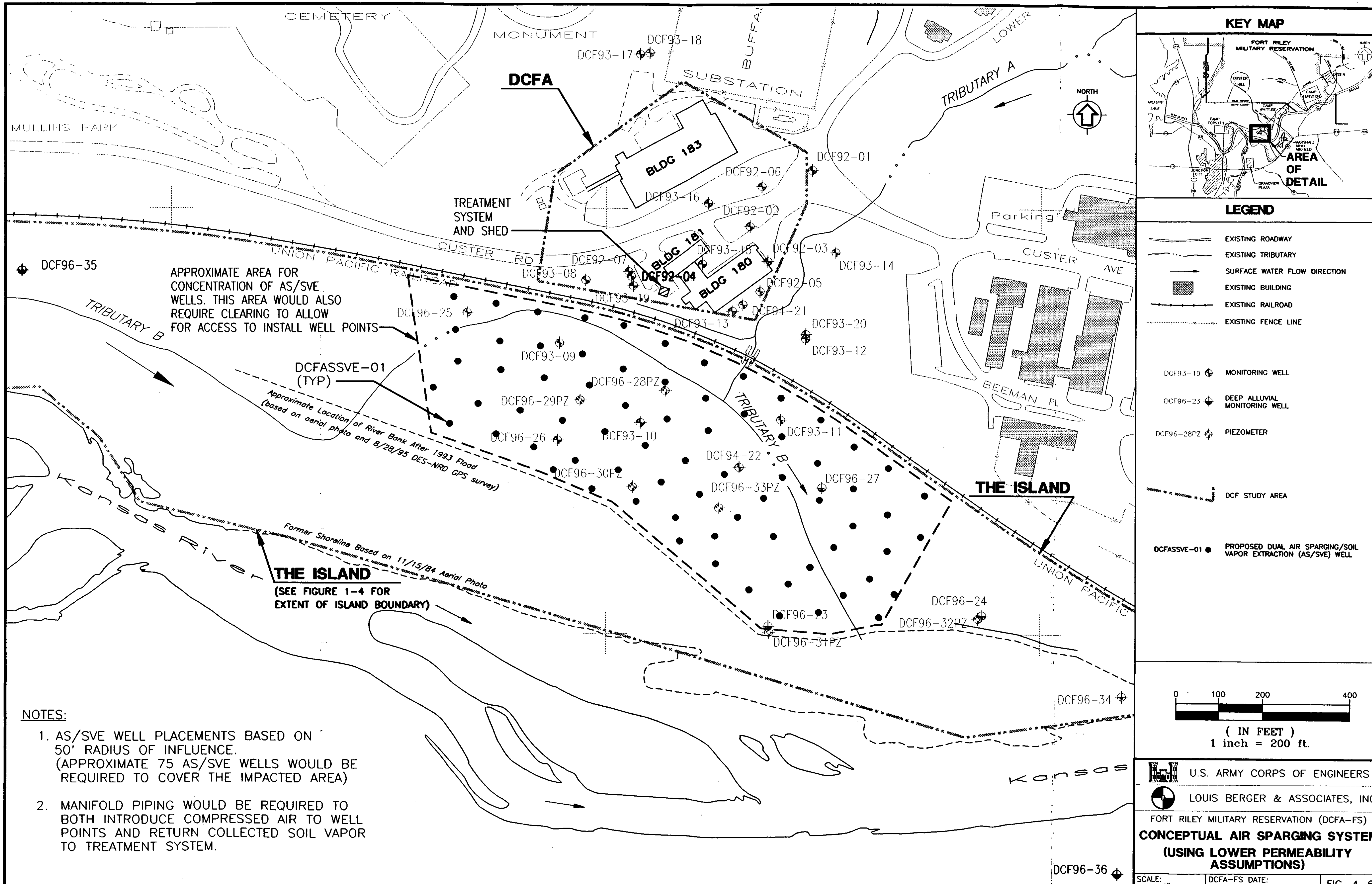
U.S. ARMY CORPS OF ENGINEERS

LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-FS)

CONCEPTUAL LAYOUT FOR TREATMENT SYSTEM INCLUDED IN HYDRAULIC CONTAINMENT ALTERNATIVE

SCALE: AS SHOWN	DCFA-FS DATE: MARCH 1998	FIG. 4-5



NOTES:

1. AS/SVE WELL PLACEMENTS BASED ON 50' RADIUS OF INFLUENCE. (APPROXIMATE 75 AS/SVE WELLS WOULD BE REQUIRED TO COVER THE IMPACTED AREA)
2. MANIFOLD PIPING WOULD BE REQUIRED TO BOTH INTRODUCE COMPRESSED AIR TO WELL POINTS AND RETURN COLLECTED SOIL VAPOR TO TREATMENT SYSTEM.

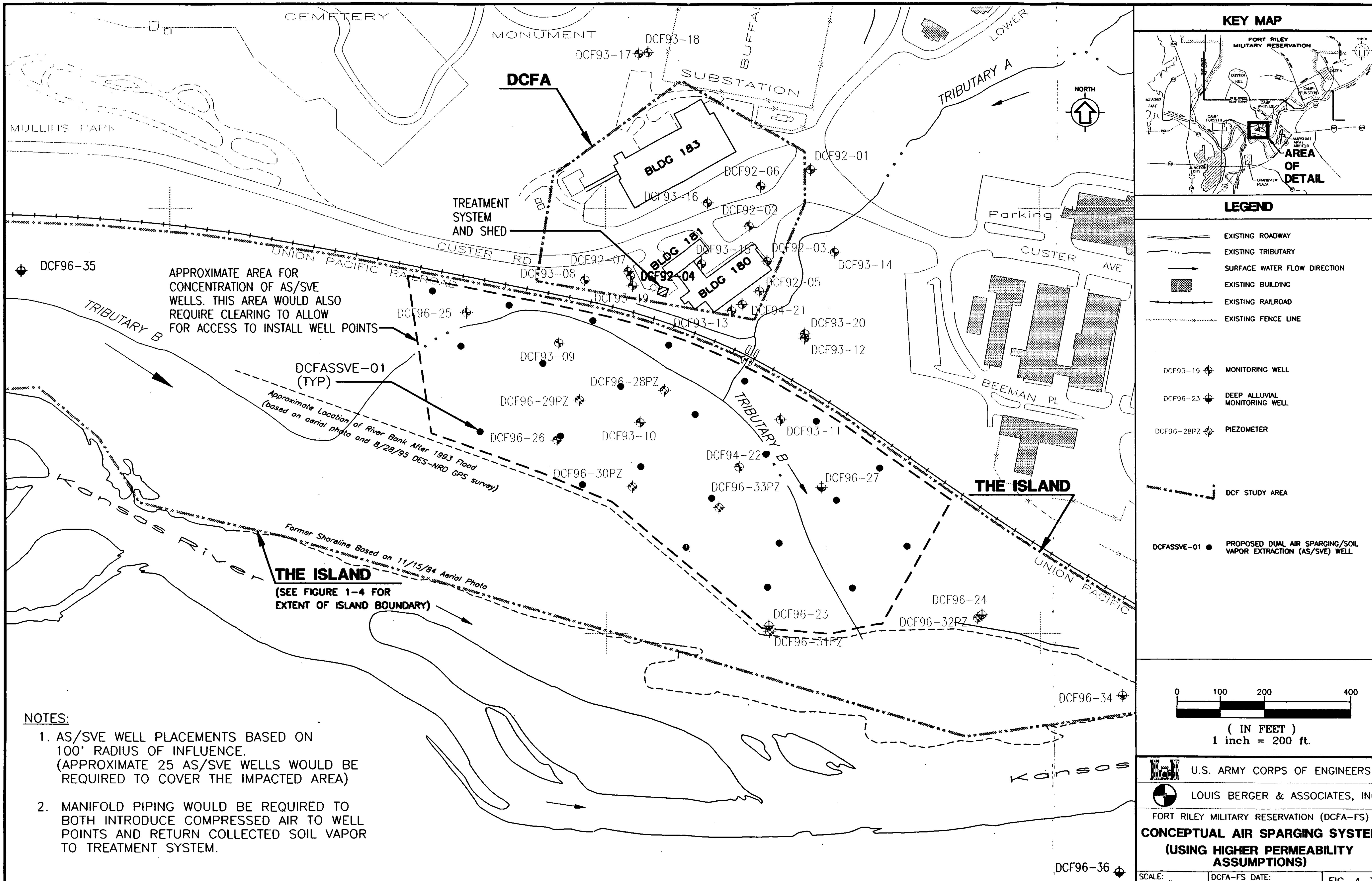
U.S. ARMY CORPS OF ENGINEERS

LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-FS)

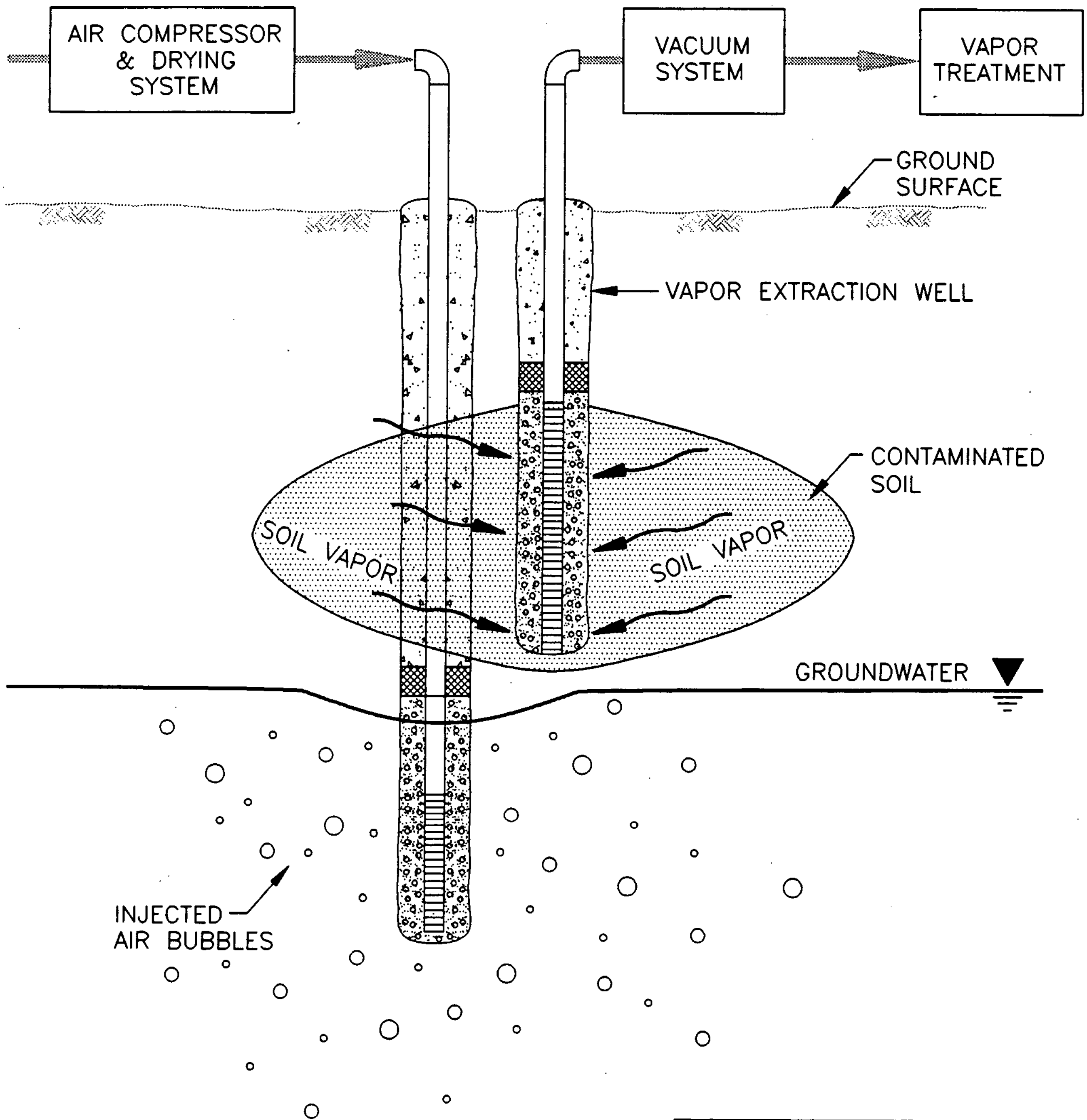
CONCEPTUAL AIR SPARGING SYSTEM (USING LOWER PERMEABILITY ASSUMPTIONS)

SCALE: 1"=200' | DCFA-FS DATE: MARCH 1998 | FIG. 4-6



CONCEPTUAL AIR SPARGING SYSTEM (USING HIGHER PERMEABILITY ASSUMPTIONS)

FIG. 4-7



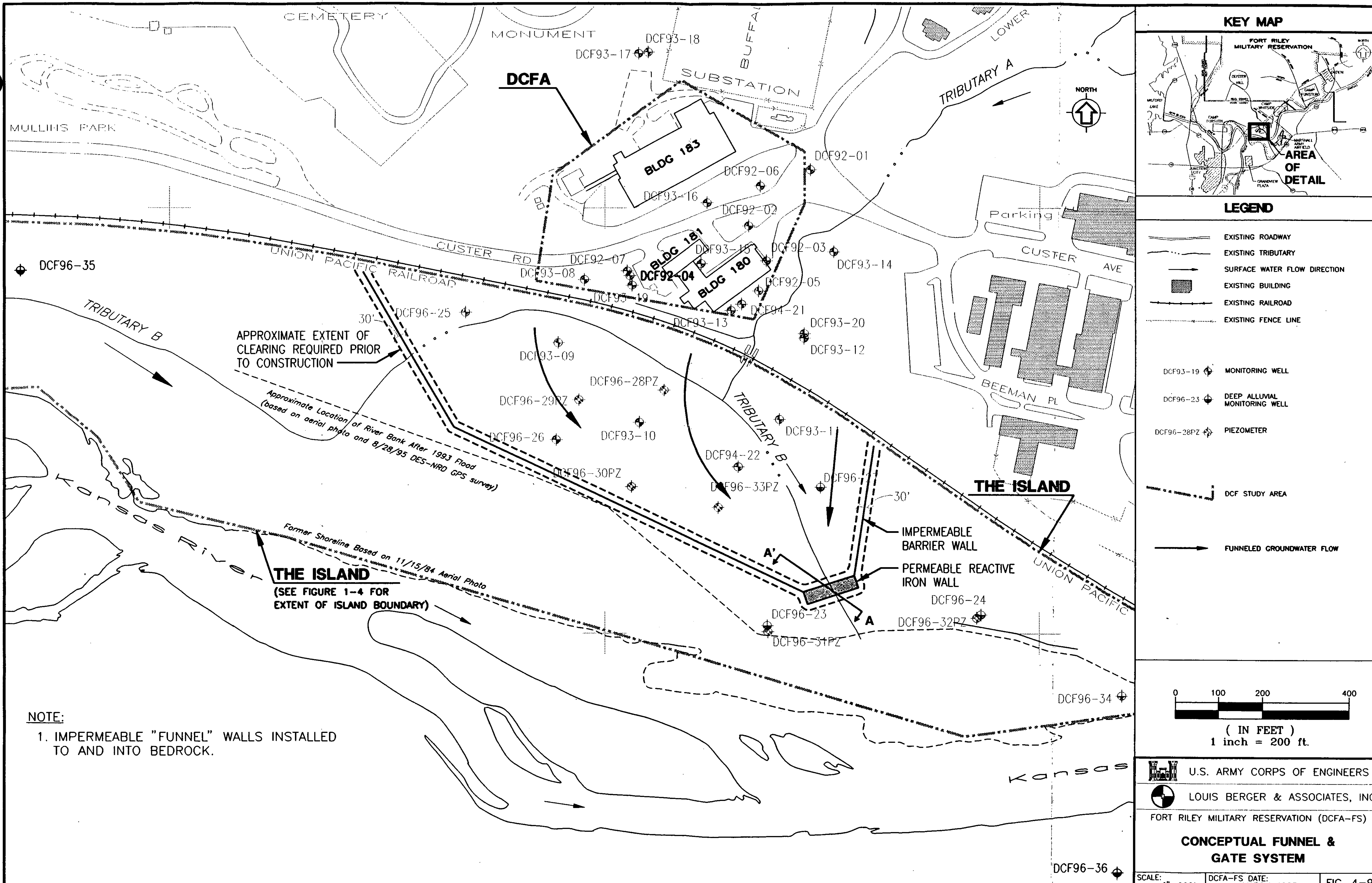
U.S. ARMY CORPS OF ENGINEERS

LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-FS)

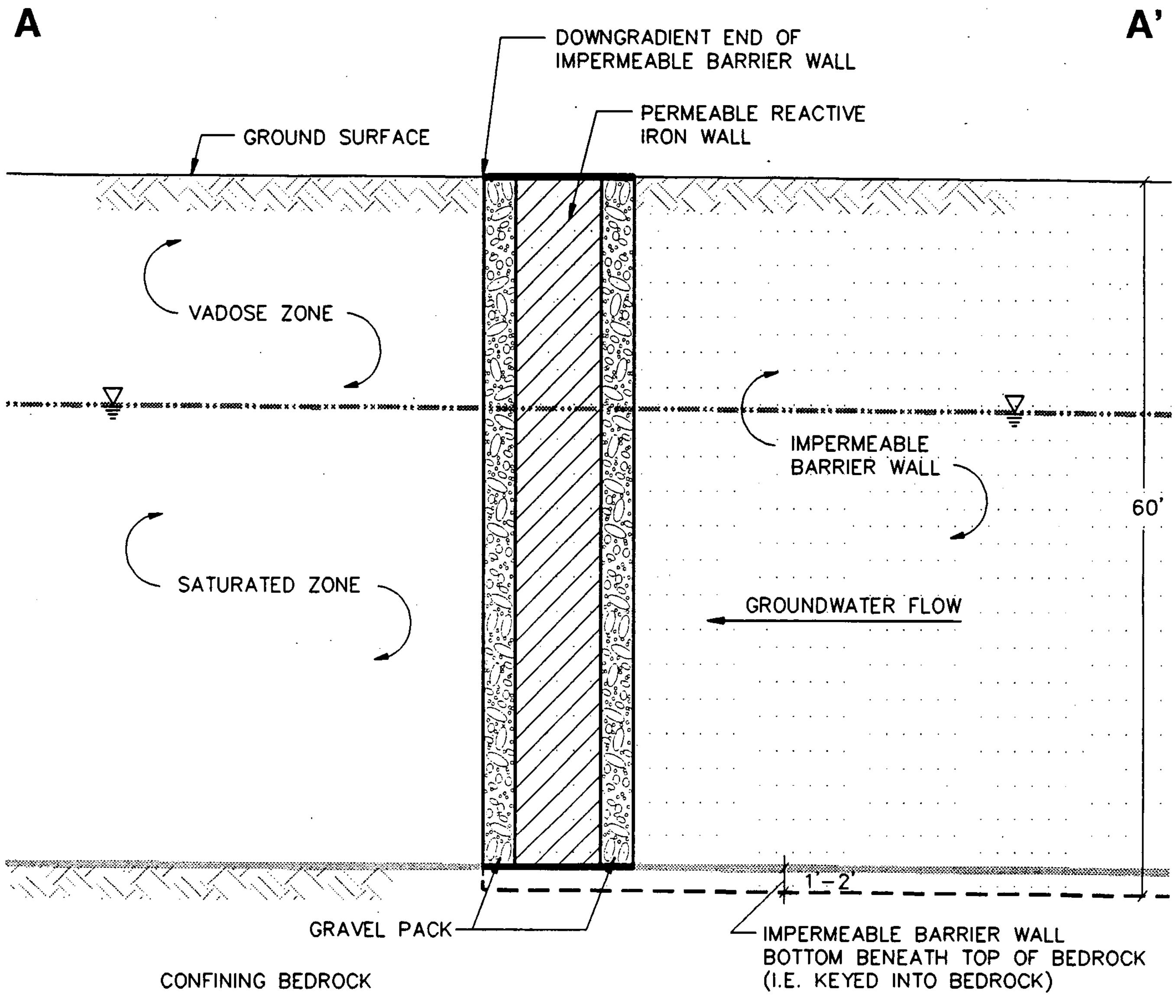
DUAL AIR SPARGING
SOIL VAPOR EXTRACTION SYSTEM

SCALE: N.T.S	DCFA-FS DATE: MARCH 1998	FIG. 4-8



CONCEPTUAL FUNNEL & GATE SYSTEM

FIG. 4-9



U.S. ARMY CORPS OF ENGINEERS

LOUIS BERGER & ASSOCIATES, INC.

FORT RILEY MILITARY RESERVATION (DCFA-FS)

TYPICAL CROSS SECTION OF GATE FOR FUNNEL & GATE SYSTEM

SCALE: AS SHOWN	DCFA-FS DATE: MARCH 1998	FIG. 4-10

FS-XSA/25MA..98/04

5.0 DETAILED EVALUATION AND ANALYSIS OF ALTERNATIVES

5.0 Detailed Evaluation and Analysis of Alternatives

The purpose of the detailed analysis of alternatives is to identify and discuss important issues and evaluate the remedial alternatives that passed the screening process (Chapter 4) to facilitate the selection of a remedy consistent with the nine CERCLA evaluation criteria.

5.1 Critical Evaluation Issues

Critical evaluation issues are site specific issues that have been identified to be so important to the remedial action decision-making process that they warrant dedicated discussions in this chapter prior to presenting the detailed evaluation of each alternative and criteria. Three critical evaluation issues have been identified for this Feasibility Study. Two issues that are critical to the comparative analysis are the effects of the sensitive Island ecology and physiography, including the presence of the protected bald eagle habitat and natural restrictions on access and the projected time duration estimates for each remedial alternative. To varying degrees, both of these issues are critical to the effectiveness, implementability, and cost for the remedial alternatives under consideration. An additional issue that is important to consider when evaluating remedial alternatives for the DCF Study Area is the completion and on going implementation of established source controls. While the established source controls are common to each alternative and are therefore not critical to the comparative analysis, they are important because they identify previously implemented actions and increase the effectiveness and protectiveness of each individual alternative.

5.1.1 Effects of Ecological and Physiographical Conditions on Alternative Selection

The following subsections discuss four important issues related to the Island ecology and physiography and how the effectiveness, implementation and cost of a remedial action would likely be affected. Section 4.2 of *Work Plan for Monitoring Network Expansion Including Additional Characterization of the Island Dry Cleaning Facilities Area (DCFA-FS) Fort Riley, Kansas* (CENWK, 1996b) presents a survey of the vegetation, wetlands, wildlife, and federally listed species likely to be found on the Island as well as the potential ecological impacts that were anticipated as a result of the installation of monitoring wells on the Island. It should be noted that the potential impacts presented in this section relate only to access and well installation, with impacts resulting from remedial system construction likely to be more damaging. A summary table, Table 5-1, is presented to facilitate a direct qualitative comparison of the relative effects of ecological and physiographic conditions based on each individual alternatives.

5.1.1.1 Bald Eagle Roosting Habitat

It has been documented that portions of the forested Island have become a roosting area for bald eagles during certain periods of the year presumably due to the numerous and closely spaced mature trees and the proximity to the Kansas River (CENWK 1995a). The Island is therefore assigned a high ecological significance and, because the bald eagle is listed as a "threatened" species pursuant to the federal Endangered Species Act, there are ecological concerns, ARARs and constraints attached to potential remedial activities on the Island that would otherwise not be a concern. The Endangered Species Act requires actions to be conducted in a manner that would conserve to the highest degree possible any critical habitat upon which an endangered, threatened, or rare species may depend (i.e., this act requires that minimal disturbance be introduced at the Island so as to conserve the bald eagle habitat). Depending on which remedial action alternative is selected, adverse impacts to the bald eagle roosting habitat may be introduced. Several activities which may impact the bald eagle habitat include: the generation of noise and/or air pollution associated with construction, system operations, and general human occupancy; the destruction of, or damage to the tall trees (roosting trees) and their future replacements, associated with clearance of access roads and the presence of active work areas or construction zones; and the disturbance of any other wildlife or vegetation which might impact the survival of the bald eagle.

As a result of these eagle-related issues, virtually any remedial activity taking place on the Island would have some impacts on the ecology, would require some mitigation measures (e.g., time constraints, access constraints, tree protection or replacement) and therefore would have an elevated site restoration/mitigation cost associated with it. Furthermore, while consultations with federal, state, and post natural resources representatives would occur and protection or mitigation measures would be implemented to the extent feasible, some impacts will almost certainly occur. It is difficult, however, to accurately quantify in monetary or other terms the amount of impact this will have on a particular alternative although attempts have been made to estimate costs associated with access or operational constraints as well as with tree protection and replacement measures. It is therefore always considered favorable from an ecological impact standpoint to select a remedial alternative that would create a minimum impact.

5.1.1.2 Floodplain

The ground elevation at the northern most portion of the Island (the base of the upland) has been measured at approximately 1065 to 1070 feet above mean sea level (ft amsl). The ground elevation at the southern most portion of the Island (mean annual water level of the Kansas River) has been reported to be 1042 ft amsl (CENWK 1995a). The 10 year flood elevation has been published as 1058 ft amsl and the 50 Year Flood elevation has been published as 1067 ft amsl (CENWK 1995a). Based on these elevations, it is noted that during a 50 year flood the majority of the Island is submerged, and during a 10 year flood approximately half of the Island is submerged. The federal Floodplain Management Act (Executive Order 11988) provides for specific procedures that must be followed when proposing development and construction within a floodplain. The procedures are designed to avoid any adverse impacts associated with the development of a floodplain. Implementation of a remedial action at the Island would certainly be subject to the substantive requirements of this regulation, although administrative permitting procedures could likely be avoided due to the CERCLA status of this site. If a remedial alternative is selected at the Island that requires development and disturbance of the floodplain, an impact evaluation would need to be performed for inclusion in the remedial design submission.

In addition to regulatory considerations, there are also practical issues to consider when evaluating the implementation of a remedial alternative at floodplain (i.e., the Island). Two of the five alternatives being evaluated include construction of substantial permanent/semi-permanent features on the Island. Flood waters may affect their performance or even cause shut downs during times of rising waters until the flood waters subside; thus giving rise to some long-term effectiveness concerns as well as the potential for increased operations and maintenance (O&M) or even replacement (capital) costs.

5.1.1.3 Wetlands

To a lesser degree than the presence of the eagle habitat and floodplain, the presence of jurisdictional wetlands on a small portion of the Island adjacent to the Kansas River (CENWK 1995a) might also impact the selection, planning, design, cost and/or implementation of a particular remedial alternative if work at or near the banks of the Kansas River was required. Protection of Wetlands (Executive Order 11990) requires that wetlands are protected by state and federal regulations promulgated pursuant to the federal Clean Water Act, which would require that specific precautions be taken and that all reasonable alternatives to wetland impacting activities (earth cutting and filling, altered drainage patterns, sedimentation, etc.) be studied and pursued prior to taking such actions. Administrative permitting procedures could, however, be avoided due to the CERCLA status of this site.

5.1.1.4 Access Restrictions

Access restriction issues arise due to the unavoidable difficulties with physically gaining access to the Island with vehicles and equipment due to the sensitive habitat and thick vegetation, the uneven terrain and intersecting stream beds of Tributaries A and B, and the existence of the Kansas River on one side of the Island and the active railroad right-of-way on the other (owned and operated by Union Pacific). River access via barges would be costly and somewhat difficult, while construction of access roads over or under the railroad would require access agreements with the owner. Furthermore, clearing and access construction activities would be significantly affected by the ecological protection issues discussed in Section 5.1.1 (recall that Figures 4-2, 4-3, and 4-9 presented approximate areas that would need to be cleared to facilitate implementation of Alternative 4 and 6 respectively). While much of this access-related impact would be temporary during construction activities (ingress and egress for heavy equipment, construction personnel, deliveries, etc.), varying levels of recurring access would also be required to implement the operations and maintenance (O&M) phase of each alternative. Recurring access becomes an issue for the periodic replacement of the Microwells that have been installed on the Island. In the past crushed stone has been placed beneath an existing railroad bridge to allow for access of smaller vehicles and equipment beneath the Union Pacific Railroad. While, for extended construction activities, that would be required for Alternatives 4 and 6, a temporary at grade crossing would be required for larger construction equipment to travel over the Union Pacific Railroad. Access-related difficulties during construction and O&M are expected to increase the costs of each alternative, although to a greater extent for alternatives with large capital construction components that necessitate the use of larger equipment.

Access timing restrictions related to the bald eagle roosting season also apply to the Island during the months of November through March. These access restrictions do not consist of physical obstructions to gaining access to the Island, but rather would restrict the times of human occupancy and remedial activity on the Island. As a result, specific guidelines would have to be developed that would allow access and work activities to take place at the Island only during the daytime if it was absolutely necessary to perform work during the months of November through March. This constraint could further increase the operating costs associated with any activity conducted at the Island during these months.

5.1.2 Time Duration Calculations

A critical consideration when evaluating a remedial alternative and estimating its projected cost is determining the duration that the alternative will need to be implemented to achieve the remedial goals (for this site, to achieve KWQS for surface waters that may potentially be used as a drinking water source and that are within the alluvial aquifer associated with the Kansas River, as required by the State surface water regulations). This O&M phase duration is key to determining how long the O&M activity related impacts discussed above will persist, what the long term effectiveness will be, and what it will cost for the operation and maintenance of the technology selected. Available information has been used to calculate these time durations. As a result, time projections have been developed using engineering assumptions and reasonable ranges for hydrogeological parameters such that a range of time duration has been estimated for each alternative. Table 5-2 presents a tabular comparison of time durations for each alternative. The following subsections present the methodologies, assumptions, and limitations associated with the calculations used to generate the time duration range for each alternative.

5.1.2.1 Duration Ranges for Alternatives with No Active Remediation

The duration for the groundwater contamination to attenuate to below KWQS as a result of only natural processes was estimated using the *Princeton Model 4*, one of the ten (10) analytical models from the PRINCE package developed by Princeton University for the U.S. EPA (Waterloo Hydrogeologic Software ©1994). A detailed mathematical description of this model is provided in Appendix B. As a brief introduction, this is a relatively simple two-dimensional transport model which can simulate the horizontal extent of a contamination plume at any given time. Typical applications of this model include, but are not limited to, plume size estimation, time rate and distance changes and health risk assessment. As presented in Appendix B, this model was used for the DCF Study Area to generate graphs that project PCE concentrations vs. distance traveled for various time periods.

This model does not maintain the ability to calculate vertical variations or to accept complex boundary conditions. It is, however, completely appropriate for analyzing this particular site. It is widely used in the industry as the primary model for sites where complex, data intensive, and costly three dimensional finite element/difference (numerical) modeling is not appropriate. Although a numerical model can more accurately simulate the fate and transport of contamination, it requires more site-specific data, with a minimum data set of the following parameters: 2-dimensional hydraulic conductivities, annual recharge, accurate definition of groundwater boundaries (e.g., the river bed and top of bedrock), soil porosity, organic carbon content, and historical and current contaminant distribution in both the vertical and horizontal planes.

The groundwater model was primarily utilized to estimate how long it would take natural processes to reduce contaminant levels to below KWQS, which is the defining time constraint associated with Alternatives 1, 2, 3, and 6. Time durations for these four alternatives have been estimated using the model and were found to range from a minimum of 10 years to a maximum of 30 years to reach compliance. It should be noted that due to the fact that Alternative 6 (funnel and gate) does not involve any active removal of groundwater, the time duration estimate for this alternative is identical to the alternatives which make no attempt (either actively or passively) to control or treat the contaminated groundwater. It should also be noted, however, that the presence of a passive treatment wall at the Island/Kansas River interface would provide additional protection and reduced impacts to the river which are not reflected in time savings.

The remainder of this subsection presents the primary assumptions which were used to model this site, as well as noting some of the limitations in performing such modeling assessments. Based on the expected relatively high contribution of hydrodynamic dispersion toward attenuation of contaminant concentrations with migration, and the lower expected contribution of other natural processes (including anaerobic biodegradation), two different scenarios have been developed to estimate durations for natural processes to meet KWQS at this site, namely: the "fast flush" scenario; and, the "slow flush" scenario.

The fast flush scenario represents the fastest time to meet KWQS but the worst case with regard to maximum contaminant concentrations discharged to the Kansas River; it assumes the shortest reasonable contaminant travel distance from the upland to the river, the fastest reasonable groundwater flow velocity, and the least retardation and biodegradation. The slow flush scenario, represents the slowest time to meet KWQS but the best scenario with regard to maximum concentrations of contaminants reaching the Kansas River; it assumes the longest reasonable path length, the lowest reasonable groundwater flow velocity, and the highest but still relatively conservative level of chemical retardation and biodegradation. Solely in terms of cost and duration, therefore, the fast flush represents the optimistic scenario (less conservative) whereas the slow flush represents the least optimistic scenario (most conservative).

The assumed model inputs (parameter values) associated with these two scenarios were presented in Table 4-2. It is reiterated that these scenarios are based on typical parameter ranges from sites with similar geotechnical and chemical properties. Using the typical ranges of parameters rather than a site-specific data set, was necessary and deemed to be prudent, based on the current understanding of site conditions and the absence of unacceptable risk levels associated with the contamination at the Island. [Furthermore, it would be cost-prohibitive, if not futile from a modeling standpoint, to attempt to develop the exhaustive hydrogeologic data set for the Island necessary to do a numerical (3-D) simulation of the impact of the adjacent and ever-fluctuating Kansas River on groundwater flow regime within the alluvial soils under the Island.

Several other assumptions and simplifications were made to facilitate the use of the model, including:

- the primary mechanism for solute transport is advection;
- dispersion of the solute occurs in both x and y directions;
- in addition to hydrodynamic dispersion, attenuation also includes solute retardation and anaerobic biodegradation (as a first order reaction) [noting that the assumed anaerobic biodegradation decay rates used are conservative];
- the aquifer has infinite width in both the x and y directions;
- the pollutant source is a strip source and at any particular time the source concentration is equal along the strip;
- the groundwater flow and contaminant migration is two-dimensional in the area of interest, with specified velocities in the x and y direction only and no variation of flow or contaminant concentrations exist with depth;
- the aquifer parameters are constant, both temporally and spatially;
- distances downgradient are much larger than the length of the analysis (i.e., the variable effects of the Kansas River are not, and cannot be, incorporated by this or any other analytical model);
- the two-dimensional solute transport equation is solved as a function of time and of distance from the source; and,
- the two-dimensional solute transport equation is solved as a function of the initial source concentration and relative concentrations are calculated beneath the source and downgradient of the source.

5.1.2.2 Duration Range for Hydraulic Containment and Treatment of Groundwater

Time-duration calculations for Alternative 4 required the only analysis of an active extraction and/or treatment alternative to address the contaminated groundwater, and is therefore the only alternative for which the evaluation did not rely upon the transport modeling described above. Similar to the modeling, however, calculation of a time-duration range for Alternative 4 also included a fast flush and slow flush scenario, and utilized the same hydraulic conductivities (see Table 4-2). Because Alternative 4 includes an active extraction/treatment component, time durations are expected to decrease relative to the other alternatives; although practical experience with pumping contaminated groundwater often provides less than expected removal efficiencies, especially when used to reduce contaminant levels to the low concentrations required to meet drinking water standards, as is required here.

In order to estimate time durations for Alternative 4, the impacted volume of groundwater and the reasonable number of flushing iterations was estimated. The volume was based on a conservative review of the most recent contaminant contour maps and an assumed depth to bedrock. The number of flushing iterations was set to ten based on engineering judgment. Then to ensure complete containment, the expected flow rate, radius of influence, and quantity of groundwater pumping wells was developed using engineering judgment and basic pumping equations. The flow rate for each well and the total number of wells is then used to calculate the total extraction system flowrate. Based on this flow rate, a time duration is thus calculated.

Based on knowledge of the general hydrogeologic conditions, several assumptions were made to select the most applicable pumping formula. The formula that was used is based on steady state pumping conditions, and is as follows:

$$q = \frac{k\pi(h_1^2 - h_2^2)}{2.303 \log_{10}(r_1/r_2)}$$

Where:

k	hydraulic conductivity (ft/day)
h_1	drawdown at observation Well 1
h_2	drawdown at observation Well 2
r_1	radius to observation well 1
r_2	radius to observation well 2

To summarize and to apply this formula to the time duration calculation, engineering judgement was used and the following assumptions, estimations, calculations and simplifying decisions were necessarily made:

- the range of hydraulic conductivities used are the same as those values used for the natural attenuation modeling;
- pumping conditions would remain steady state;
- the aquifer parameters are constant, temporally and spatially;
- assumed radius of influence for the conservative-slow flush duration would be approximately 100 feet;
- assumed radius of influence for the optimistic-fast flush duration would be approximately 65 feet;
- number of wells for each scenario was based on radius of influence and downgradient edge of impacted groundwater mass (allowing for an approximate 0.25 radius overlap);
- number of wells for the slow flush and fast flush was assumed to be 12 and 20, respectively;
- several iterations were calculated to determine reasonable drawdowns (h_1 and h_2) at r_1 and r_2;
- calculated flow rates were based on assumed reasonable radius of influence and drawdown;
- estimated quantity of groundwater that would require pumping and treatment was based on 10 times the single pore volume for the impacted area of groundwater; and,
- additional assumptions and inputs are presented in Table D-1 (Appendix D).

Based on the above estimation and assumptions, the time durations were calculated to be approximately 25 years for the slow flush scenario and 8 years for the fast flush scenario (compared to 30 years and 10 years for the other alternatives being evaluated). Additional support and back up for this calculation is presented in Appendix D. As noted above and as indicated by the small time savings which are projected, this is a common problem with pump and treat options in that they are not typically cost- and/or time-effective when used to meet low concentration-based goals associated with drinking water KWQS, as is mandated for the alluvial aquifer.

5.1.3 Source Controls

Based on the fact that Fort Riley has already undertaken several interim response actions to address the source and sewer-related pathways associated with the DCFA-related contamination, each remedial alternative inherently includes these previously implemented source control and abatement measures. The source controls directly related to the active dry cleaning facility (Building 183) consist of enhanced facility management and pollution prevention practices as well as repair work, floor drain grouting, cleaning and permanent diversion of the sewer lines servicing Building 183. Enhanced pollution prevention procedures consist mostly of improved housekeeping practices at the DCF. Spills and/or wastewater that was once occasionally disposed of by being dumped into floor or sink drains is now collected and stored at Building 183 and ultimately reclaimed by the same commercial company that supplies it. Materials that were used to contain or clean-up spills (blankets, mattress pads, etc.) are now dry cleaned rather than being laundered (thus introducing PCE wastewater into the sanitary sewer system). Floor drains that eventually discharged to Tributary A via the old leaky storm sewer lines were plugged with cement grout. In addition to measures taken within the DCF, steps were taken to reduce the potential for discharge pathway to the environment via the old leaky sanitary sewer lines. Sanitary sewer lines were replaced, repaired or diverted as presented on Figure 1-3. Sewer lines and manholes were cleaned and potentially contaminated sediments removed to prevent further migration of contaminants to the environment. Finally, in 1994 a Soil Vapor Extraction Pilot Test Study (including one test study period extension) was completed within the primary zone of contaminated soils which had been acting as a continuing groundwater contamination source. VOCs were removed at a rate of between 0.78 and 0.41 pounds per day and, at the end of the test, approximately 21 pounds of VOCs had been removed and the source contamination in the vadose zone had been reduced by well over 90 percent (CENWK, 1996a).

Based on the soil and groundwater sampling results from investigation activities after the completion of these interim response actions, the actions have effectively abated the contamination source and triggered a consistent overall downward trend in the contamination levels at the DCFA (and ultimately will do the same for the Island once the previously released contaminant mass migrates past the Island. The following subsections discuss the relevance of these source control interim response actions with respect to the NCP-required evaluation criteria such that the evaluation discussion does not need to be repeated as part of the discussion for each separate alternative.

5.1.3.1 Overall Protection of Human Health and the Environment

The overall protection of human health and the environment achieved as a result of each alternative is increased by the source control interim response actions that have already been established by Fort Riley. Enhanced pollution prevention and waste management practices are effective in preventing potential discharges to the environment, which in turn reduces risk and achieves protection over time. The sewer-related response actions also reduce risk by resulting in the prevention of further discharge to the environment. Finally, the pilot test study was effective in reducing the source of contamination in the vadose zone soils at the DCFA.

5.1.3.2 Compliance with Applicable or Relevant and Appropriate Requirements

The source control interim response actions are in accordance with ARARs. When a discharge was identified, source controls and contaminant reduction activities (SVE pilot study) were quickly implemented to address the identified past and ongoing release potential. Finally, implementation of these source controls will ultimately play a large part in reducing groundwater contamination concentrations to below levels of concern.

5.1.3.3 Long-term Effectiveness

Similar to overall protection of human health and the environment and ARAR compliance, the long-term effectiveness of each alternative is greatly enhanced by the source control interim response actions that have already been implemented. Enhanced pollution prevention and waste management practices are effective in preventing potential discharges to the environment, which in turn reduces risk and achieves protection over time. Response actions related to the sewer lines also reduce risk by resulting in the prevention of further discharge to the environment. Finally, the pilot test study was effective in reducing the source of contamination which reduces further migration of contaminants to the groundwater table.

5.1.3.4 Reduction of Toxicity, Mobility, or Volume

Reduction of toxicity has not been achieved as a result of the source control interim response actions, however, a reduction in the mobility and volume of the contamination has been achieved. Reduction of mobility was achieved as a result of repairing the sewer lines by removing a migratory driving force associated with the exfiltration of sewer water. This will also result in the prevention of further discharge of contaminated wastewater to the environment. The SVE pilot test was responsible for reducing the volume of the contaminants in the environment by removing a large percentage of contaminant mass (21 pounds) from the vadose zone source area.

5.1.3.5 Short-term Effectiveness

Improvements in the short-term effectiveness of each alternative associated with the source control interim response actions result from the enhanced housekeeping practices which will in turn decrease potential release of and exposure to improperly discharged contaminants. Furthermore, the SVE pilot test effectively and quickly reduced the volume of the contaminants in the environment by removing a large percentage of contaminant mass (21 pounds) from the vadose zone source area.

5.1.3.6 Implementability

Based on the fact that these interim response measures have already been completed, their implementability is not questionable. Furthermore, the enacting of these source controls does not adversely impact or diminish the implementability of any of the remedial alternatives being evaluated herein. In fact, these measures actually enhance the implementability of the alternatives, especially the No Further Action, Institutional Controls and Groundwater Monitoring, and the Natural Attenuation alternatives. The implementability of these alternatives has been increased because they are now much more likely to be effective and acceptable to the regulators and the community based on the established source control and previously executed source removal.

5.1.3.7 Cost

Because these actions have already been implemented and paid for and are common to each of the alternatives, the cost of the source control interim response actions does not impact the cost component of the alternatives analysis. It is noted, however, that the costs of these actions to date are in excess of $750,000.

5.1.3.8 State Acceptance

These source controls are expected to increase State acceptance based on the fact that source control and abatement interim response actions have already been implemented to address the problems at this site and ensure that the contamination will not get any worse but rather will ultimately diminish under each alternative.

5.1.3.9 Community Acceptance

These source controls are expected to increase Community acceptance based on the fact that source control and abatement interim response actions have already been implemented to address the problems at this site and ensure that the contamination will not get any worse but rather will ultimately diminish under each alternative.

5.2 Evaluation Criteria

In order to address the CERCLA requirements adequately, nine evaluation criteria have been developed by the U.S. EPA. These criteria are defined in the NCP and are discussed in further detail in an RI/FS guidance document (U.S. EPA 1988a).

The first two criteria are the "threshold" factors. Any alternative that does not satisfy both of the following criteria is dropped from further consideration in the detailed analysis:

1. Overall protection of human health and the environment; and
2. Compliance with applicable or relevant and appropriate requirements (ARARs).

Five "primary balancing" criteria are then used to make comparisons and to identify the major trade-offs between the remedial alternatives. Alternatives that satisfy the threshold criteria are therefore evaluated using the following balancing criteria:

3. Long-term effectiveness;
4. Reduction of toxicity, mobility or volume;
5. Short-term effectiveness;
6. Implementability; and
7. Cost.

The remaining two criteria are "modifying" factors and are to be evaluated in the Record of Decision (ROD). The evaluation of these two factors can only be completed after the CERCLA Proposed Plan is published for comment and the public comment period is completed. These modifying factors are:

8. State acceptance; and
9. Community acceptance.

A more detailed discussion of the nine evaluation criteria is presented below. Each remedial alternative is then evaluated in Section 5.3 with respect to the first seven criteria.

5.2.1 Overall Protection of Human Health and the Environment

This evaluation criterion provides an overall assessment of protection based on an evaluation of the other criterion, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs. Evaluation of overall protection addresses:

- How well a specific site remedial action achieves protection over time;
- How well site risks are reduced; and
- How each source of contamination is to be eliminated, reduced, or controlled for each remedial alternative.

5.2.2 Compliance with ARARs

This evaluation criterion is used to determine how each remedial alternative complies with federal and state ARARs as defined in CERCLA Section 121. Each alternative is evaluated in detail for:

- Compliance with chemical-specific ARARs;
- Compliance with action-specific ARARs;
- Compliance with location-specific ARARs ; and
- Incorporation of appropriate criteria, advisories, and guidance (i.e., "To Be Considered" information or "TBCs").

Chapter 2.0 presents an overall list of ARARs and "To Be Considered" (TBC) information that were used as appropriate to evaluate the remedial alternatives.

5.2.3 Long-Term Effectiveness

This evaluation criterion addresses the results of the remedial action in terms of the risk remaining at the site after the remedial action objectives have been met. The components of this criterion include the magnitude of the remaining risks measured by numerical standards (such as cancer risk levels); the adequacy and suitability of controls used to manage treatment residuals or untreated wastes; and the long-term reliability of management controls for providing continued protection from residuals (i.e., the assessment of potential failure of the technical components).

5.2.4 Reduction of Toxicity, Mobility or Volume through Treatment

This evaluation criterion addresses the statutory preference that treatment results in the reduction of principal threats of the total mass of toxic contaminants, the irreversible reduction in contaminant mobility, and/or the reduction of the total volume of contaminated media. Factors to be evaluated in this criterion include the treatment process employed; the amount of hazardous material destroyed or treated; the degree of reduction in toxicity, mobility, or volume expected; and the type and quantity of treatment residuals.

5.2.5 Short-Term Effectiveness

This evaluation criterion addresses the impacts of the remedial action during the construction and implementation phases preceding the attainment of the remedial action objectives. Factors to be evaluated include protection of workers during the remedial actions, environmental impacts resulting from the implementation of the remedial actions, and the time necessary to achieve protection.

5.2.6 Implementability

This criterion addresses the technical and administrative feasibility of implementing a remedial action and the availability of various services and materials required during its implementation. *Technical feasibility* factors include construction and operation difficulties, reliability of the technology or technologies, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy. *Administrative feasibility* includes the ability and time required for permit approval, ability to obtain approvals from other agencies and coordination with other agencies. Factors employed in evaluating the *availability of services and materials* include availability of treatment, storage and disposal services with required capacities; availability of equipment and specialists; and availability of prospective technologies for competitive bidding.

5.2.7 Cost

The types of costs that would be addressed include: capital costs, operation and maintenance (O&M) costs, costs of five-year reviews where required, present worth of capital and O&M costs, and potential future remedial action costs. Capital costs consist of direct and indirect costs. Direct costs include expenditures for the equipment, labor and materials necessary to install remedial actions. Indirect costs include expenditures for engineering, financial, and other services required to complete the implementation of remedies. Annual O&M costs include auxiliary materials and energy, disposal of residues, purchased services, administrative costs, insurance, taxes, license costs, maintenance reserve and contingency funds, rehabilitation costs and costs for periodic site monitoring and review.

This assessment includes an evaluation of the costs of the remedial actions on the basis of present worth. Present worth analysis allows remedial alternatives to be compared on the basis of a single cost representing an amount that, if invested in the base year and disbursed as needed, would be sufficient to cover all costs associated with the remedial alternative over its planned life. A required operating performance period is assumed for present worth and is a function of the discount rate and time. In accordance with U.S. EPA/OSWER Directive 9355.3-20, a discount rate of seven percent (7.0%) is assumed for present worth calculations. The prescribed net 7% discount rate used for the present worth calculations is based on a +9% increase for an average long-term interest rate and a -2% decrease for an average long-term inflation rate. As a result of applying this factor to all expenditures beyond the initial construction phase of actions, the equivalent present cost of future expenditures is less than there actual total price; in essence making the assumption that the entire short- and long-term program could be covered by establishing an interest bearing account with the total present worth cost as an initial balance and making scheduled payments over time as indicated. The "study estimate" costs provided herein for the remedial actions are intended to reflect estimated actual costs with an accuracy of -30 to +50 percent (i.e., they are to be considered "order of magnitude" estimates).

5.2.8 State Acceptance

This assessment is to be performed as part of the ROD development and public comment process and evaluates the technical and administrative issues and concerns that administrative agencies from the State of Kansas may have regarding each of the remedial alternatives. The factors to be evaluated include features of the actions that the state supports, has reservations about, or opposes.

5.2.9 Community Acceptance

This assessment is also to be performed as part of the ROD development and public comment process and incorporates public input into the analysis of the remedial alternatives. Factors of community acceptance to be discussed include features of the support, reservations and opposition of the community. Fort Riley has an existing community relations plan and conformance with this plan will be a component of the assessment of this criterion.

5.3 Analysis of Alternatives

The process options potentially applicable to the DCFA and the Island were developed into alternatives and then screened in Chapter 4.0. This chapter presents the results of a detailed evaluation of those remedial action alternatives that were retained after the final screening. Alternative 5 (Air Sparging /Soil Vapor Extraction) was screened out in Chapter 4 based on its questionable implementability due to the more extreme ecological damage which it would inflict on the "Island." Furthermore, Alternative 5 would provide negligible if any increased protectiveness compared to the other remaining removal/treatment alternative being considered (Alternative 4).

The following alternatives passed the screening process in Chapter 4.0 and are to be evaluated in detail:

Alternative 1 No Further Action beyond Established Source Controls;

Alternative 2 Source and Institutional Controls Including Groundwater Monitoring and Contingency for Future Action;

Alternative 3 Source Controls and Natural Attenuation Including Groundwater Monitoring and Contingency for Future Action;

Alternative 4 Source Controls and Extraction, Treatment, and Hydraulic Containment; and

Alternative 6 Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate.

The referenced alternatives and technologies are described in Chapter 4.0. The results of the detailed evaluation are presented in the following subsections.

Prior to analyzing each alternative in detail, several site-specific factors were identified as important and as being inherent to all of the alternatives being evaluated. These factors are therefore listed together below, and are considered pertinent regardless of which alternative is ultimately selected:

- Human exposures to subsurface soil contaminants would not result in unacceptable risks under any reasonable scenario, both current and future;
- More than three years of sampling data show that the overall maximum groundwater contaminant levels within the DCF Study Area are consistently declining;
- Although contaminant levels within the alluvial aquifer underlying the Island exceed applicable regulatory limits (KWQS) and will continue to do so for some period of time under all alternatives, exposure to contaminated groundwater at the site is unlikely, both currently and in the future; and,
- Assuming no drastic and unreasonable changes in area land use occur, no human or ecological receptors have been identified which might currently or in the future be exposed to contaminants at levels representing unacceptable risks.

5.3.1 Overall Protection of Human Health and the Environment

5.3.1.1 Alternative 1—No Further Action beyond Established Source Controls

While no unacceptable risks are expected to result, this alternative does not provide for monitoring of groundwater and contamination migration in the event that unexpected changes in the nature and/or extent of the contamination occurs.

5.3.1.2 Alternative 2—Source and Institutional Controls Including Groundwater Monitoring and Contingency for Future Action

As with all of the alternatives, no unacceptable risks to human health or the environment are expected. Furthermore, this alternative also provides for monitoring of groundwater and contamination migration in the event that unexpected changes in the nature and/or extent of the contamination occurs. Based on this monitoring, the contingency for future remedial action could be triggered if a concern for contaminated groundwater impacting actual points of exposure should arise.

5.3.1.3 Alternative 3—Source Controls and Natural Attenuation Including Groundwater Monitoring and Contingency for Future Action

For purposes of this criteria, this alternative performs exactly the same as Alternative 2.

5.3.1.4 Alternative 4—Source Controls and Extraction, Treatment, and Hydraulic Containment

This alternative provides all the same protections as Alternatives 2 and 3, but also includes hydraulic containment and aggressive treatment/removal of contaminants as an added protection. This alternative will more actively and quickly reduce the volume and toxicity of the contaminants as well as minimize contaminant discharges to the Kansas River.

5.3.1.5 Alternative 6—Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate

For purposes of this criteria, this alternative performs similarly to Alternative 4 in that it minimizes contaminant discharges to the Kansas River through partial plume containment in addition to passive treatment of the contamination.

5.3.2 Compliance with ARARs

KWQS as they apply to surface waters that may potentially be used as a drinking water source represent the remedial goal (RG) for this remedial action, and are the controlling potential ARAR through their incorporation into the Kansas State Surface Water Quality Standards. All of the alternatives eventually satisfy this ARAR/RG based on either active remediation or the unavoidable natural processes that will occur over time to reduce contaminant concentrations. Some distinctions regarding compliance with other ARARs and regulatory issues are evident, however, and are discussed below.

5.3.2.1 Alternative 1—No Further Action beyond Established Source Controls

This alternative would meet the CERCLA/NCP requirement for periodic review and reassessment (at least once every five years), for any remedial action decision that involves leaving contamination in place. The reviews will be based on limited information, however, because no monitoring of the contamination will be performed. Since no remedial activities would occur that might be regulated or result in adverse impacts to the environment, no other ARAR compliance issues exist.

5.3.2.2 Alternative 2—Source and Institutional Controls Including Groundwater Monitoring and Contingency for Future Action

This alternative would also meet the CERCLA/NCP requirement for the five year review and reassessment of actions leaving contamination in place, and would facilitate appropriate modifications if appropriate based upon the monitoring that will be performed. Since no remedial activities would occur that might be regulated or result in adverse impacts to the environment, no other ARAR compliance issues exist unless the contingency for future action is triggered.

5.3.2.3 Alternative 3—Source Controls and Natural Attenuation Including Groundwater Monitoring and Contingency for Future Action

For purposes of this criteria, this alternative performs exactly the same as Alternative 2.

5.3.2.4 Alternative 4—Source Controls and Extraction, Treatment, and Hydraulic Containment

Extraction wells and piping systems installed on the Island would be constructed in accordance with applicable regulations. Prior to locating and constructing the treatment system to be used for the hydraulic containment alternative, all applicable Federal and State ARARs would be thoroughly reviewed for compliance (e.g., Endangered Species Act, Fish and Wildlife Protection, Historic Site Preservation, State of Kansas Historic Preservation Act, Floodplain Management, Protection of Wetlands). Some impacts to the bald eagle habitat on the Island would be unavoidable, however, but ecological ARAR compliance would be maintained to the maximum extent practicable based on consultation with appropriate regulatory agencies.

Prior to designing and constructing the treatment and effluent discharge system, all applicable ARARs would be thoroughly reviewed (e.g., Clean Air Act, National Ambient Air Quality Standards, National Pollutant Discharge Elimination System, Kansas Underground Injection Control Regulations, Kansas Wastewater Discharge Control Law). ARARs relating to remedial system operations would also be reviewed. These ARARs would also need to be complied with to the maximum extent practicable, and regulatory input would be obtained.

5.3.2.5 Alternative 6—Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate

As with Alternative 4, ARARs impacting design and constructability would be reviewed and complied with as appropriate. ARARs relating to remedial system operations would not be an issue, however, since this is a passive treatment system.

5.3.3 Long-Term Effectiveness

For all of the alternatives, current and long-term risks are negligible to non-existent based on the continuation and/or decline of existing contaminant levels, fate and transport modeling projections and risk/receptor evaluations.

- Groundwater monitoring program and contingency for future remedial action (where applicable) provides an additional level of confidence that effectiveness will be achieved.
- An additional decrease in contaminant levels can be anticipated over time as a result of natural processes.

The following subsections list the alternative specific Long-Term Effectiveness considerations of each alternative.

5.3.3.1 Alternative 1—No Further Action beyond Established Source Controls

Transport modeling results indicate that it would take 10 to 30 years to passively reduce contaminants to less than KWQS. However, the lack of a groundwater monitoring program and contingency for future remedial action means that, although extremely unlikely, unexpected changes in the future which might result in unacceptable adverse impacts that could go un-noticed for a period of time

5.3.3.2 Alternative 2—Source and Institutional Controls Including Groundwater Monitoring and Contingency for Future Action

Transport modeling results indicate that it would take 10 to 30 years to passively reduce contaminants to less than KWQS. In addition, the inclusion of a groundwater monitoring program and contingency for future remedial action provides an assurance that long-term effectiveness will be achieved even if natural processes do not attenuate the contamination as is currently projected.

5.3.3.3 Alternative 3—Source Controls and Natural Attenuation Including Groundwater Monitoring and Contingency for Future Action

Transport modeling results indicate that it would take 10 to 30 years to passively reduce contaminants to less than KWQS. For purposes of this criteria, this alternative performs similar to Alternative 2, although a groundwater monitoring program that includes additional monitoring points and natural attenuation parameters provides a somewhat increased ability to evaluate the effectiveness of natural processes at attenuating contaminant levels.

5.3.3.4 Alternative 4—Source Controls and Extraction, Treatment, and Hydraulic Containment

Hydraulic containment will be achieved and contaminant levels will continue to decline over time as a result of implementing this alternative. Application of the most applicable steady-state pumping rate formulas yield an estimated range of 8 to 25 years to reduce contaminants to less than KWQS . Although documented experience with pumping/treating groundwater contamination indicates limited success in expediting the achievement of quantitative cleanup levels do to rate limitations on processes such as adsorption/desorption and diffusion.

5.3.3.5 Alternative 6—Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate

Due to its passive nature, the primary method of reducing contaminants to less than KWQS at the Island through implementation of this alternative is expected to be natural processes. Transport modeling results indicate that it would take 10 to 30 years to passively reduce contaminants to less than KWQS. In addition, contamination levels will be reduced as the gate treats the groundwater before it discharges to the Kansas River.

5.3.4 Reduction of Toxicity, Mobility or Volume through Treatment

5.3.4.1 Alternative 1—No Further Action beyond Established Source Controls

This alternative does not involve treatment per se, but natural processes will effectively reduce the toxicity and volume of the existing contaminants over time.

5.3.4.2 Alternative 2—Source and Institutional Controls Including Groundwater Monitoring and Contingency for Future Action

For purposes of this criteria, this alternative performs similar to Alternative 1 except that it adds a contingency for additional remedial action, including treatment, should data indicate a concern for contaminated groundwater impacting actual points of exposure.

5.3.4.3 Alternative 3— Source Controls and Natural Attenuation Including Groundwater Monitoring and Contingency for Future Action

For purposes of this criteria, this alternative performs exactly the same as Alternative 2.

5.3.4.4 Alternative 4—Source Controls and Extraction, Treatment, and Hydraulic Containment

This alternative will effectively reduce the mobility of the contamination through hydraulic containment. This alternative will also reduce both the volume and toxicity of the contamination by extracting and treating the contaminated groundwater, although its level of extraction efficiency is in question and several aquifer pore volumes must likely be removed and treated (at least ten, and sometimes hundreds, of pore volumes are typically required).

5.3.4.5 Alternative 6—Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate

This alternative will impact the mobility of the contamination by redirecting flow of contaminated groundwater to the treatment gate rather than directly to the Kansas River, although the funnel could be temporarily ineffective during periods of high river stage. This alternative will reduce both the toxicity and volume of the contamination by passively treating/remediating the contaminated groundwater as it moves through the treatment gate and is chemically transformed.

5.3.5 Short-Term Effectiveness

None of the alternatives will satisfy the ARAR-based remedial goals in the short term, although it is noted that human health and ecological risks in both the short- and long-term are already within acceptable limits. For all but Alternative 1, there are potential remedial worker safety issues to consider but risks to workers performing monitoring and maintenance would be appropriately controlled assuming adherence to proper health and safety protocols and applicable OSHA requirements. These concerns would be most significant for Alternative 4 since it is by far the most labor intensive alternative. However, this alternative also offers the only potential for expediting the achievement of the ARARs/RGs.

5.3.6 Implementability

Both technical and administrative feasibility issues are evaluated under this criteria, and are discussed below for each alternative.

5.3.6.1 Alternative 1—No Further Action beyond Established Source Controls

Other than the lack of a means to track its effectiveness over time, no technical implementability problems exist because no actions are required other than maintained land use control and administrative reassessments every five years. Administrative implementability concerns could arise, however, if the regulatory agencies or the community do not accept non-action and a discontinuation of monitoring for a known area of contamination.

5.3.6.2 Alternative 2—Source and Institutional Controls Including Groundwater Monitoring and Contingency for Future Action

No technical implementability problems exist because no actions are required other than institutional controls, routine monitoring and administrative reassessments every five years. Administrative implementability concerns are also minimal since the monitoring and reassessment programs should reduce regulatory and community concerns over the contamination being left in place.

5.3.6.3 Alternative 3 —Source Controls and Natural Attenuation Including Groundwater Monitoring and Contingency for Future Action

For purposes of this criteria, this alternative performs exactly the same as Alternative 2.

5.3.6.4 Alternative 4—Source Controls and Extraction, Treatment, and Hydraulic Containment

This alternative raises both technical and administrative feasibility issues based on:

- identifying a suitable location for the treatment system;
- developing a design which will avoid pumping large quantities of clean water from the river while also minimizing the typical limits on groundwater extraction efficiencies;
- accessing and minimizing disturbance to the Island and its sensitive ecology for the purposes of installing extraction wells (as well as additional potential disturbances from ongoing system operations and maintenance on the Island);
- satisfying action-specific ARARs during construction and operations; and
- satisfactorily mitigating the unavoidable damage that will be done to the bald eagle habitat.

5.3.6.5 Alternative 6—Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate

With the exception of the systems/operational-related implementability concerns, this alternative raises all of the same concerns that Alternative 4 raises. In addition, this alternative raises an additional technical feasibility concern in that bedrock depths must be confirmed within the limits of conventional barrier technology (typically 100 feet maximum) and a treatment gate media must be identified which will be effective and will not require frequent replacement or maintenance.

5.3.7 Cost

Costs associated with each of the five alternatives being evaluated are presented in Tables 5-3 through 5-7. Consistent with the level of available data and the time duration range projections, an estimated cost range was prepared for each alternative, thus, the two cost tables for each alternative. Assumptions are noted as appropriate on the tables. Table 5-8 represents a cost summary table for all of the alternatives, with estimates ranging from as little as $14,000 to as much as $2,500,000.

5.3.8 State Acceptance

State acceptance will not be assessed until after publication of the Proposed Plan and as part of the ROD development and public comment process once a particular alternative has been selected.

5.3.9 Community Acceptance

Community acceptance will not be assessed until after publication of the Proposed Plan and as part of the ROD development and public comment process once a particular alternative has been selected.

TABLES

TABLE 5-1
COMPARISON OF RELATIVE ECOLOGICAL AND PHYSIOGRAPHICAL IMPACTS
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Ecological or Physiographical Impact		Relative Ecological or Physiographical Impact [1]			
		Bald Eagle Roosting Habitat	10 Year and 50 Year Flood Plain	Wetlands	Access Restrictions
Alternative 1	No Further Action beyond Established Source Controls	None	None	None	None
Alternative 2	Source and Institutional Controls Including Groundwater Monitoring and Contingency for Future Action	Small	Negligible	Negligible	Medium
Alternative 3	Source Controls and Natural Attenuation Including Groundwater Monitoring and Contingency for Future Action	Small	Negligible	Negligible	Medium
Alternative 4	Source Controls and Extraction, Treatment, and Hydraulic Containment of Groundwater at the Island	Large	Large	Medium/Large	Large
Alternative 6	Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate at the Island	Large	Large	Medium/Large	Large

Notes:

(1) Relative ecological and physiological impacts have been categorized as either "None", "Negligible", "Small", "Medium", or "Large" for each alternative based on comparison with other alternatives.

TABLE 5-2
COMPARISON OF TIME DURATIONS FOR ALTERNATIVE
Dry Cleaning Facilities Study Area
Fort Riley, Kansas

Ecological or Physiographical Impact		Conservative Time Duration Estimate (Slow Flush)	Optimistic Time Duration Estimate (Fast Flush)
Alternative 1	No Further Action beyond Established Source Controls	30 years (1)	10 years (1)
Alternative 2	Source and Institutional Controls Including Groundwater Monitoring and Contingency for Future Action	30 years (1)	10 years (1)
Alternative 3	Source Controls and Natural Attenuation Including Groundwater Monitoring and Contingency for Future Action	30 years (1)	10 years (1)
Alternative 4	Source Controls and Extraction, Treatment, and Hydraulic Containment of Groundwater at the Island	25 years (2)	8 years (2)
Alternative 6	Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate at the Island	30 years (1)	10 years (1)

Notes:
(1) Estimated based on groundwater modeling using an analytical transport model.
(2) Estimated based on the projected removal efficiency for groundwater pumping.

TABLE 5-3a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 1
No Further Action beyond Established Source Controls
Based on a 10 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

COST OF TEN YEAR DURATION[1] FOR FIVE YEAR REASSESSMENTS

Item	Quantity	Unit	Rate ($/unit)[4]	Cost ($)
Engineering/Management/Administration[2]	100	Hrs	110	11,000

Total Cost	**11,000**
Total Net Present Worth Cost for Year Five Reassessment[3]	**7,843**
Total Net Present Worth Cost for Year Ten Reassessment[3]	**5,592**
Total Net Present Worth Cost of Alternative 1 - 10 Year Duration	**$14,000**

<u>Notes and Assumptions for Table 5-3a:</u>

1 Estimated fastest time to meet MCLs based on modeling.
Support documentation for modeling presented as Appendix B.

2 Environmental Management and five year reassessment, including site visit for visual inspection, review of environmental data, preparation of five year reassessment report, and coordination with regulators.

3 Based on a 7% discount rate.

4 Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

TABLE 5-3b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 1
No Further Action beyond Established Source Controls
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

COST OF THIRTY YEAR DURATION[1] FOR FIVE YEAR REASSESSMENTS

Item	Quantity	Unit	Rate ($/unit)[4]	Cost ($)
Engineering/Management/Administration[2]	100	Hrs	110	11,000

Total Cost	**11,000**
Total Net Present Worth Cost for Year Five Reassessment[3]	**7,843**
Total Net Present Worth Cost for Year Ten Reassessment[3]	**5,592**
Total Net Present Worth Cost for Year Fifteen Reassessment[3]	**3,987**
Total Net Present Worth Cost for Year Twenty Reassessment[3]	**2,843**
Total Net Present Worth Cost for Year Twenty-Five Reassessment[3]	**2,027**
Total Net Present Worth Cost for Year Thirty Reassessment[3]	**1,445**
Total Net Present Worth Cost of Alternative 1 - 30 Year Duration	**$24,000**

Notes and Assumptions for Table 5-3b:

1 Estimated slowest time to meet MCLs based on modeling.
Support documentation for modeling presented as Appendix B.

2 Environmental Management and five year reassessment, including site visit for visual inspection, review of environmental data, preparation of five year reassessment report, and coordination with regulators.

3 Based on a 7% discount rate.

4 Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

TABLE 5-4a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 2
Source and Institutional Controls Incl GW Monitoring and Contingency for Future Action
Based on a 10 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

CAPITAL COST

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Longterm Monitoring Plan Development	80	Hrs	110	8,800

Total Cost **8,800**

Contingency Factor @ 20% **1,760**

Total Capital Cost **10,600**

COST OF TEN YEAR DURATION(1) FOR FIVE YEAR REASSESSMENT AND MICROWELL REPLACEMENT

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Engineering/Management/Administration(2)(6)	180	Hrs	110	19,800
Microwell Replacement Oversight(3)	15	Days	1400	21,000
Microwell Replacement(4)	8	Wells	2500	20,000

Total Cost **60,800**

Total Net Present Worth Cost for Year Five Reassessment(5) **43,350**

Total Net Present Worth Cost for Year Ten Reassessment(5) **30,908**

Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement **74,300**

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS, SEMI-ANNUAL MONITORING (YEARS 1-5)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Field Sampling (Groundwater)(7)	22	Wells	575	12,650
Sample Shipping Costs(8)	4	Shipments	100	400
Supplies, Disposables, etc.(9)	8	Days	25	200
Analytical/Lab Testing(10)	30	Each	275	8,250
Travel/Expenses(11)	2	Event	1,500	3,000
Project Management/Periodic Reporting(12)	200	Hrs	110	22,000
Contract Administration(13)	40	Hrs	110	4,400

Total Cost **50,900**

Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)(5) **209,000**

TABLE 5-4a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 2
Source and Institutional Controls Incl GW Monitoring and Contingency for Future Action
Based on a 10 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
ANNUAL MONITORING (YEARS 6-10)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Field Sampling (Groundwater)(7)	11	Wells	575	6,325
Sample Shipping Costs(8)	2	Shipments	100	200
Supplies, Disposables, etc.(9)	4	Days	25	100
Analytical/Lab Testing(10)	15	Each	275	4,125
Travel/Expenses(11)	1	Event	1,500	1,500
Project Management/Periodic Reporting(12)	100	Hrs	110	11,000
Contract Administration(13)	20	Hrs	110	2,200

Total Cost	**25,450**
Total Net Present Worth Cost for Annual Monitoring (6-10 Years)(5)	**74,500**
Total Capital Cost	**10,600**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**74,300**
Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)	**209,000**
Total Net Present Worth Cost for Annual Monitoring (6-10 Years)	**74,500**
Total Net Present Worth Cost of Alternative 2 - 10 Year Duration	**$370,000**

Notes and Assumptions for Table 5-4a:

1 Estimated fastest time to meet MCLs based on modeling. Support documentation for modeling presented as Appendix B.

2 Environmental Management and five year reassessment, including site visit for visual inspection, review of periodic monitoring data, preparation of five year reassessment report, and coordination with regulators.

3 Based on a daily rate for one Environmental Engineer/Geologist (10hrs/day). Includes labor, per diem, lodging, air fare, car and equipment rental, expendible supplies, well development, and coordination and scheduling.

4 Unit rates are based on the actual costs to install the original Microwells (DCF96-23, 24, 25, 26, 27, 34, 35 & 36). The unit rate includes a licensed driller, labor, material, per diem, lodging/travel expenses, Island access provisions, and mobilization/demobilization.

5 Based on a 7% discount rate.

6 Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

7 Based on 11 wells per sampling event. Sampling includes 2 worker crew, 2 days (10 hrs/day) per sampling event @ $110/mnhr (2 days does not include travel time). Includes sampling coordination and data interpretation 1 worker, 2 day (8 hrs/day) per sampling event @ $110/mnhr. Includes providing sampling equipment, handling and disposal of purge water, and periodic well inspection and maintenance.

8 Includes 2 shipments per sampling event @ approximately $100/shipment.

9 Based on $25/day/person for expendible supplies.

10 U.S. EPA Method 8240 (TCL Volatiles). Includes all quality control samples (field blanks, trip blanks, duplicates, etc.).

11 Includes air fare, car rental, per diem, and lodging.

12 Includes data review and validation and preparation of Data Summary Report (DSR) and Quality Control Summary Report (QCSR).

13 Based on environmental management labor for monitoring program @ 20 hrs/event.

TABLE 5-4b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 2
Source and Institutional Controls Incl GW Monitoring and Contingency for Future Action
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

CAPITAL COST

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Longterm Monitoring Plan Development	80	Hrs	110	8,800
			Total Cost	**8,800**
			Contingency Factor @ 20%	**1,760**
			Total Capital Cost	**10,600**

COST OF TEN YEAR DURATION[1] FOR FIVE YEAR REASSESSMENT AND MICROWELL REPLACEMENT

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Engineering/Management/Administration[2][6]	180	Hrs	110	19,800
Microwell Replacement Oversight[3]	15	Days	1400	21,000
Microwell Replacement[4]	8	Wells	2500	20,000
			Total Cost	**60,800**

Total Net Present Worth Cost for Year Five Reassessment[5]	**43,350**
Total Net Present Worth Cost for Year Ten Reassessment[5]	**30,908**
Total Net Present Worth Cost for Year Fifteen Reassessment[5]	**22,037**
Total Net Present Worth Cost for Year Twenty Reassessment[5]	**15,712**
Total Net Present Worth Cost for Year Twenty-Five Reassessment[5]	**11,202**
Total Net Present Worth Cost for Year Thirty Reassessment[5]	**7,987**

Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement **$132,000**

TABLE 5-4b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 2
Source and Institutional Controls Incl GW Monitoring and Contingency for Future Action
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
SEMI-ANNUAL MONITORING (YEARS 1-5)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Field Sampling (Groundwater)[7]	22	Wells	575	12,650
Sample Shipping Costs[8]	4	Shipments	100	400
Supplies, Disposables, etc.[9]	8	Days	25	200
Analytical/Lab Testing[10]	30	Each	275	8,250
Travel/Expenses[11]	2	Event	1,500	3,000
Project Management/Periodic Reporting[12]	200	Hrs	110	22,000
Contract Administration[13]	40	Hrs	110	4,400

Total Cost **50,900**

Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)[5] **209,000**

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
ANNUAL MONITORING (YEARS 6-30)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Field Sampling (Groundwater)[7]	11	Wells	575	6,325
Sample Shipping Costs[8]	2	Shipments	100	200
Supplies, Disposables, etc.[9]	4	Days	25	100
Analytical/Lab Testing[10]	15	Each	275	4,125
Travel/Expenses[11]	1	Event	1,500	1,500
Project Management/Periodic Reporting[12]	100	Hrs	110	11,000
Contract Administration[13]	20	Hrs	110	2,200

Total Cost **25,450**

Total Net Present Worth Cost for Annual Monitoring (6-30 Years)[5] **212,000**

Total Capital Cost	**10,600**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**132,000**
Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)	**209,000**
Total Net Present Worth Cost for Annual Monitoring (6-30 Years)	**212,000**
Total Net Present Worth Cost of Alternative 2 - 30 Year Duration	**$570,000**

TABLE 5-4b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 2
Source and Institutional Controls Incl GW Monitoring and Contingency for Future Action
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

Notes and Assumptions for Table 5-4b:

1 Estimated slowest time to meet MCLs based on modeling. Support documentation for modeling presented as Appendix B.

2 Environmental Management and five year reassessment, including site visit for visual inspection, review of periodic monitoring data, preparation of five year reassessment report, and coordination with regulators.

3 Based on a daily rate for one Environmental Engineer/Geologist (10hrs/day). Includes labor, per diem, lodging, air fare, car and equipment rental, expendible supplies, well development, and coordination and scheduling.

4 Unit rates are based on the actual costs to install the original Microwells (DCF96-23, 24, 25, 26, 27, 34, 35 & 36). The unit rate includes a licensed driller, labor, material, per diem, lodging/travel expenses, Island access provisions, and mobilization/demobilization.

5 Based on a 7% discount rate.

6 Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

7 Based on 11 wells per sampling event. Sampling includes 2 worker crew, 2 days (10 hrs/day) per sampling event @ $110/mnhr (2 days does not include travel time). Includes sampling coordination and data interpretation 1 worker, 2 day (8 hrs/day) per sampling event @ $110/mnhr. Includes providing sampling equipment, handling and disposal of purge water, and periodic well inspection and maintenance.

8 Includes 2 shipments per sampling event @ approximately $100/shipment.

9 Based on $25/day/person for expendible supplies.

10 U.S. EPA Method 8240 (TCL Volatiles). Includes all quality control samples (field blanks, trip blanks, duplicates, etc.).

11 Includes air fare, car rental, per diem, and lodging.

12 Includes data review and validation and preparation of Data Summary Report (DSR) and Quality Control Summary Report (QCSR).

13 Based on environmental management labor for monitoring program @ 20 hrs/event.

TABLE 5-5a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 3
Source Control and Natural Atten Incl GW Monitoring and Contingency for Future Action
Based on a 10 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

CAPITAL COST

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Longterm Monitoring Plan Development	80	Hrs	110	8,800

Total Cost	**8,800**
Contingency Factor @ 20%	**1,760**
Total Capital Cost	**10,600**

COST OF TEN YEAR DURATION(1) FOR FIVE YEAR REASSESSMENT AND MICROWELL REPLACEMENT

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Engineering/Management/Administration(2)(6)	180	Hrs	110	19,800
Microwell Replacement Oversight(3)	20	Days	1400	28,000
Microwell Replacement(4)	11	Wells	2500	27,500

Total Cost	**75,300**
Total Net Present Worth Cost for Year Five Reassessment(5)	**53,688**
Total Net Present Worth Cost for Year Ten Reassessment(5)	**38,279**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**$92,000**

TABLE 5-5a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 3
Source Control and Natural Atten Incl GW Monitoring and Contingency for Future Action
Based on a 10 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
SEMI-ANNUAL MONITORING (YEARS 1-5)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Field Sampling (Groundwater)(7)	40	Wells	575	23,000
Sample Shipping Costs(8)	6	Shipments	100	600
Supplies, Disposables, etc.(9)	12	Days	25	300
Analytical/Lab Testing(10)	60	Each	275	16,500
Natural Attenuation/Lab Testing(11)	60	Each	300	18,000
Travel/Expenses(12)	2	Events	2,250	4,500
Project Management/Periodic Reporting(13)	200	Hrs	110	22,000
Assessment of Natural Attenuation Process(14)	40	Hrs	110	4,400
Contract Administration(15)	40	Hrs	110	4,400

Total Cost	**93,700**
Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)(5)	**385,000**

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
ANNUAL MONITORING (YEARS 6-10)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Field Sampling (Groundwater)(7)	20	Wells	575	11,500
Sample Shipping Costs(8)	3	Shipments	100	300
Supplies, Disposables, etc.(9)	6	Days	25	150
Analytical/Lab Testing(10)	30	Each	275	8,250
Natural Attenuation/Lab Testing(11)	30	Each	500	15,000
Travel/Expenses(12)	1	Events	2,250	2,250
Project Management/Periodic Reporting(13)	100	Hrs	110	11,000
Assessment of Natural Attenuation Process(14)	20	Hrs	110	2,200
Contract Administration(15)	20	Hrs	110	2,200

Total Cost	**52,850**
Total Net Present Worth Cost for Annual Monitoring (6-10 Years)(5)	**155,000**

Total Capital Cost	**10,600**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**92,000**
Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)	**385,000**
Total Net Present Worth Cost for Annual Monitoring (6-10 Years)	**155,000**
Total Net Present Worth Cost of Alternative 3 - 10 Year Duration	**$650,000**

TABLE 5-5a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 3
Source Control and Natural Atten Incl GW Monitoring and Contingency for Future Action
Based on a 10 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

Notes and Assumptions for Table 5-5a:

1 Estimated fastest time to meet MCLs based on modeling. Support documentation for modeling presented as Appendix B.

2 Environmental Management and five year reassessment, including site visit for visual inspection, review of periodic monitoring data, preparation of five year reassessment report, and coordination with regulators.

3 Based on a daily rate for one Environmental Engineer/Geologist (10hrs/day). Includes labor, per diem, lodging, air fare, car and equipment rental, expendible supplies, well development, and coordination and scheduling.

4 Unit rates are based on the actual costs to install the original Microwells (DCF96-23, 24, 25, 26, 27, 34, 35 & 36). Includes replacement of Microwells and DCF93-09, DCF93-10, and DCF94-22. The unit rate includes a licensed driller, labor, material, per diem, lodging/travel expenses, Island access provisions, and mobilization/demobilization.

5 Based on a 7% discount rate.

6 Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

7 Based on 20 wells per sampling event. Sampling includes 2 worker crew, 3 days (10 hrs/day) per sampling event @ $110/mnhr (3 days does not include travel time). Includes sampling coordination and data interpretation 1 worker, 3 day (8 hrs/day) per sampling event @ $110/mnhr. Includes providing sampling equipment, handling and disposal of purge water, and periodic well inspection and maintenance.

8 Includes 3 shipments per sampling event @ approximately $100/shipment.

9 Based on $25/day/person for expendible supplies.

10 U.S. EPA Method 8240 (TCL Volatiles). Includes all quality control samples (field blanks, trip blanks, duplicates, etc.).

11 Based on natural attenuation monitoring parameters (parameters listed in Table 4-4).

12 Includes air fare, car rental, per diem, and lodging.

13 Includes data review and validation and preparation of Data Summary Report (DSR) and Quality Control Summary Report (QCSR).

14 Based on enivronmental management labor for the evaluation of the effectiveness of the natural attentuation processes @ 20 hrs/event.

15 Based on environmental management labor for monitoring program @ 20 hrs/event.

TABLE 5-5b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 3
Source Control and Natural Atten Incl GW Monitoring and Contingency for Future Action
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

CAPITAL COST

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Longterm Monitoring Plan Development	80	Hrs	110	8,800

Total Cost	**8,800**
Contingency Factor @ 20%	**1,760**
Total Capital Cost	**10,600**

COST OF TEN YEAR DURATION[1] FOR FIVE YEAR REASSESSMENT AND MICROWELL REPLACEMENT

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Engineering/Management/Administration[2][6]	180	Hrs	110	19,800
Microwell Replacement Oversight[3]	20	Days	1400	28,000
Microwell Replacement[4]	11	Wells	2500	27,500

Total Cost	**75,300**
Total Net Present Worth Cost for Year Five Reassessment[5]	**53,688**
Total Net Present Worth Cost for Year Ten Reassessment[5]	**38,279**
Total Net Present Worth Cost for Year Fifteen Reassessment[5]	**27,292**
Total Net Present Worth Cost for Year Twenty Reassessment[5]	**19,459**
Total Net Present Worth Cost for Year Twenty-Five Reassessment[5]	**13,874**
Total Net Present Worth Cost for Year Thirty Reassessment[5]	**9,892**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**$163,000**

TABLE 5-5b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 3
Source Control and Natural Atten Incl GW Monitoring and Contingency for Future Action
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
SEMI-ANNUAL MONITORING (YEARS 1-5)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Field Sampling (Groundwater)(7)	40	Wells	575	23,000
Sample Shipping Costs(8)	6	Shipments	100	600
Supplies, Disposables, etc.(9)	12	Days	25	300
Analytical/Lab Testing(10)	60	Each	275	16,500
Natural Attenuation/Lab Testing(11)	60	Each	300	18,000
Travel/Expenses(12)	2	Event	2,250	4,500
Project Management/Periodic Reporting(13)	200	Hrs	110	22,000
Assessment of Natural Attenuation Process(14)	40	Hrs	110	4,400
Contract Administration(15)	40	Hrs	110	4,400
			Total Cost	**93,700**

Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)(5) **385,000**

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
ANNUAL MONITORING (YEARS 6-30)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Field Sampling (Groundwater)(7)	20	Wells	575	11,500
Sample Shipping Costs(8)	3	Shipments	100	300
Supplies, Disposables, etc.(9)	6	Days	25	150
Analytical/Lab Testing(10)	30	Each	275	8,250
Natural Attenuation/Lab Testing(11)	30	Each	300	9,000
Travel/Expenses(12)	1	Event	2,250	2,250
Project Management/Periodic Reporting(13)	100	Hrs	110	11,000
Assessment of Natural Attenuation Process(14)	20	Hrs	110	2,200
Contract Administration(15)	20	Hrs	110	2,200
			Total Cost	**46,850**

Total Net Present Worth Cost for Annual Monitoring (6-30 Years)(5) **390,000**

Total Capital Cost	**10,600**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**163,000**
Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)	**385,000**
Total Net Present Worth Cost for Annual Monitoring (6-30 Years)	**390,000**
Total Net Present Worth Cost of Alternative 3 - 30 Year Duration	**$950,000**

TABLE 5-5b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 3
Source Control and Natural Atten Incl GW Monitoring and Contingency for Future Action
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

Notes and Assumptions for Table 5-5b:

1 Estimated slowest time to meet MCLs based on modeling. Support documentation for modeling presented as Appendix B.

2 Environmental Management and five year reassessment, including site visit for visual inspection, review of periodic monitoring data, preparation of five year reassessment report, and coordination with regulators.

3 Based on a daily rate for one Environmental Engineer/Geologist (10hrs/day). Includes labor, per diem, lodging, air fare, car and equipment rental, expendible supplies, well development, and coordination and scheduling.

4 Unit rates are based on the actual costs to install the original Microwells (DCF96-23, 24, 25, 26, 27, 34, 35 & 36). Includes replacement of Microwells and DCF93-09, DCF93-10, and DCF94-22. The unit rate includes a licensed driller, labor, material, per diem, lodging/travel expenses, Island access provisions, and mobilization/demobilization.

5 Based on a 7% discount rate.

6 Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

7 Based on 20 wells per sampling event. Sampling includes 2 worker crew, 3 days (10 hrs/day) per sampling event @ $110/mnhr (3 days does not include travel time). Includes sampling coordination and data interpretation 1 worker, 3 day (8 hrs/day) per sampling event @ $110/mnhr. Includes providing sampling equipment, handling and disposal of purge water, and periodic well inspection and maintenance.

8 Includes 3 shipments per sampling event @ approximately $100/shipment.

9 Based on $25/day/person for expendible supplies.

10 U.S. EPA Method 8240 (TCL Volatiles). Includes all quality control samples (field blanks, trip blanks, duplicates, etc.).

11 Based on natural attenuation monitoring parameters (parameters listed in Table 4-4).

12 Includes air fare, car rental, per diem, and lodging.

13 Includes data review and validation and preparation of Data Summary Report (DSR) and Quality Control Summary Report (QCSR).

14 Based on enivronmental management labor for the evaluation of the effectiveness of the natural attentuation processes @ 20 hrs/event.

15 Based on environmental management labor for monitoring program @ 20 hrs/event.

TABLE 5-6a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 4
Source Control and Extraction, Treatment, and Hydraulic Containment of GW at the Island
Based on a 8 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

CAPITAL COST

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Longterm Monitoring Plan Development	80	Hrs	110	8,800
Remedial Design and Testing[(1)]	1	Lump Sum	300,000	300,000
Installation of 20 Well Groundwater Extraction System[(2)(3)]	1	Lump Sum	273,000	273,000
Installation of Air Stripping System[(2)]	1	Lump Sum	29,000	29,000
Installation of Carbon Adsorption System[(2)]	1	Lump Sum	14,000	14,000
Installation of Catalytic Oxidation Unit[(2)]	1	Lump Sum	32,000	32,000
Design of Temporary Union Pacific Railroad Crossing[(4)]	1	Lump Sum	1,000	1,000
Installation of Temporary Union Pacific Railroad Crossing[(5)]	1	Lump Sum	10,000	10,000
Negotiation of Union Pacific Railroad Right-of-Way[(6)]	1	Lump Sum	50,000	50,000
Installation of Temporary Access Road[(2)(7)]	1	Lump Sum	21,000	21,000
Site Restoration/Tree Loss Mitigation[(8)]	500	Each	250	125,000
Coordination with Regulatory Agencies[(9)]	100	Hrs	110	11,000

Total Cost	**874,800**
Contingency Factor @ 20%	**174,960**
Total Capital Cost	**1,050,000**

COST OF EIGHT YEAR DURATION[(10)] FOR FIVE YEAR REASSESSMENT AND MICROWELL REPLACEMENT

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Engineering/Management/Administration[(11)(12)]	180	Hrs	110	19,800
Microwell Replacement Oversight[(13)]	20	Days	1400	28,000
Microwell Replacement[(14)]	11	Wells	2500	27,500

Total Cost	**75,300**
Total Net Present Worth Cost for Year Five Reassessment[(15)]	**53,688**
Total Net Present Worth Cost for Year Eight Reassessment[(15)]	**43,825**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**$97,600**

TABLE 5-6a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 4
Source Control and Extraction, Treatment, and Hydraulic Containment of GW at the Island
Based on a 8 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
SEMI-ANNUAL MONITORING (YEARS 1-5)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Groundwater Extraction System(16)	1	Lump Sum	6,000	6,000
Air Stripping System(17)	1	Lump Sum	4,900	4,900
Carbon Adsorption(18)	1	Lump Sum	21,600	21,600
Catalytic Oxidation(19)	1	Lump Sum	13,625	13,625
Field Sampling (Groundwater)(20)	40	Wells	575	23,000
Sample Shipping Costs(21)	6	Shipments	100	600
Supplies, Disposables, etc.(22)	12	Days	25	300
Analytical/Lab Testing(23)	60	Each	275	16,500
Travel/Expenses(24)	2	Events	2,250	4,500
Project Management/Periodic Reporting(25)	200	Hrs	110	22,000
Contract Administration(26)	40	Hrs	110	4,400

Total Cost **117,425**

Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)(15) **482,000**

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
ANNUAL MONITORING (YEARS 6-8)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Groundwater Extraction System(16)	1	Lump Sum	6,000	6,000
Air Stripping System(17)	1	Lump Sum	4,900	4,900
Carbon Adsorption(18)	1	Lump Sum	21,600	21,600
Catalytic Oxidation(19)	1	Lump Sum	13,625	13,625
Field Sampling (Groundwater)(20)	20	Wells	575	11,500
Sample Shipping Costs(21)	3	Shipments	100	300
Supplies, Disposables, etc.(22)	6	Days	25	150
Analytical/Lab Testing(23)	30	Each	275	8,250
Travel/Expenses(24)	1	Events	2,250	2,250
Project Management/Periodic Reporting(25)	100	Hrs	110	11,000
Contract Administration(26)	20	Hrs	110	2,200

Total Cost **81,775**

Total Net Present Worth Cost for Annual Monitoring (6-8 Years)(15) **154,000**

Total Capital Cost **1,050,000**

Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement **97,600**

Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years) **482,000**

Total Net Present Worth Cost for Annual Monitoring (6-8 Years) **154,000**

Total Net Present Worth Cost of Alternative 4 - 8 Year Duration **$1,800,000**

TABLE 5-6a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 4
Source Control and Extraction, Treatment, and Hydraulic Containment of GW at the Island
Based on a 8 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

<u>Notes and Assumptions for Table 5-6a:</u>

[1] Includes required pre-design testing (i.e. pilot and bench scale testing). Based on engineering judgement and past experience.

[2] Based on *Remedial Action Cost Engineering and Requirements (RACER) - Environmental Cost Engineering (ENVEST)* All supporting documentation for *RACER* cost estimates are presented in Appendix D.

[3] Extraction system consists of 20 extraction wells pumping at approximately 6 gallons per minute (Figure 4-3).

[4] Based on 10% of construction cost.

[5] Includes equipment operator, dozer, and laborer to place and compact a 30 foot wide crushed stone access road across drainage swale and Union Pacific Railroad track (*Means* 1996).

[6] Lump sum cost for right-of-way negotiation, based on engineering judgement and past experience.

[7] Includes clearing of brush and trees.

[8] Includes landscaping (i.e. seeding and tree planting). Based on $250/tree and one tree/150 square feet (*Means* 1996). It should be noted that costs for Site Restoration will not completely reverse the ecological impacts caused during construction at the Island.

[9] Based on environmental management required for regulatory coordination prior to construction with regard to ARARs (i.e. Floodplain Management, Endangered Species Act, Historic Preservation, etc).

[10] Based on calculations provided in Table D-1.

[11] Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

[12] Environmental Management and five year reassessment, including site visit for visual inspection, review of periodic monitoring data, preparation of five year reassessment report, and coordination with regulators.

[13] Based on a daily rate for one Environmental Engineer/Geologist (10hrs/day). Includes labor, per diem, lodging, air fare, car and equipment rental, expendible supplies, well development, and coordination and scheduling.

[14] Unit rates are based on the actual costs to install the original Microwells (DCF96-23, 24, 25, 26, 27, 34, 35 & 36). Includes replacement of Microwells and DCF93-09, DCF93-10, and DCF94-22. The unit rate includes a licensed driller, labor, material, per diem, lodging/travel expenses, Island access provisions, and mobilization/demobilization.

[15] Based on a 7% discount rate.

[16] Based on electric costs, pump and motor maintenance and repair, and $100/year for extraction well rehabilitation.

[17] Based on electric costs, packing reconditioning and pump and motor maintenance and repair.

[18] Based on removal, replacement and disposal of spent carbon.

[19] Based on replacement of precious metal catalysts and operational labor.

[20] Based on 20 wells per sampling event. Sampling includes 2 worker crew, 3 days (10 hrs/day) per sampling event @ $110/mnhr (3 days does not include travel time). Includes sampling coordination and data interpretation 1 worker, 3 day (8 hrs/day) per sampling event @ $110/mnhr. Includes providing sampling equipment, handling and disposal of purge water, and periodic well inspection and maintenance.

[21] Includes 3 shipments per sampling event @ approximately $100/shipment.

[22] Based on $25/day/person for expendible supplies.

[23] U.S. EPA Method 8240 (TCL Volatiles). Includes all quality control samples (field blanks, trip blanks, duplicates, etc.).

[24] Includes air fare, car rental, per diem, and lodging.

[25] Includes data review and validation and preparation of Data Summary Report (DSR) and Quality Control Summary Report (QCSR).

[26] Based on environmental management labor for monitoring program @ 20 hrs/event.

TABLE 5-6b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 4
Source Control and Extraction, Treatment, and Hydraulic Containment of GW at the Island
Based on a 25 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

CAPITAL COST

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Longterm Monitoring Plan Development	80	Hrs	110	8,800
Remedial Design and Testing(1)	1	Lump Sum	300,000	300,000
Installation of 12 Well Groundwater Extraction System(2)(3)	1	Lump Sum	164,000	164,000
Installation of Air Stripping System(2)	1	Lump Sum	21,000	21,000
Installation of Carbon Adsorption System(2)	1	Lump Sum	4,600	4,600
Installation of Catalytic Oxidation Unit(2)	1	Lump Sum	29,000	29,000
Design of Temporary Union Pacific Railroad Crossing(4)	1	Lump Sum	1,000	1,000
Installation of Temporary Union Pacific Railroad Crossing(5)	1	Lump Sum	10,000	10,000
Negotiation of Union Pacific Railroad Right-of-Way(6)	1	Lump Sum	50,000	50,000
Installation of Temporary Access Road(2)(7)	1	Lump Sum	20,000	20,000
Site Restoration/Tree Loss Mitigation(8)	500	Each	250	125,000
Coordination with Regulatory Agencies(9)	100	Hrs	110	11,000
			Total Cost	**744,400**
			Contingency Factor @ 20%	**148,880**
			Total Capital Cost	**894,000**

COST OF TWENTY-FIVE YEAR DURATION(10) FOR FIVE YEAR REASSESSMENT AND MICROWELL REPLACEMENT

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Engineering/Management/Administration(11)(12)	180	Hrs	110	19,800
Microwell Replacement Oversight(13)	20	Days	1400	28,000
Microwell Replacement(14)	11	Wells	2500	27,500
			Total Cost	**75,300**

Total Net Present Worth Cost for Year Five Reassessment(15)	**53,688**
Total Net Present Worth Cost for Year Ten Reassessment(15)	**38,279**
Total Net Present Worth Cost for Year Fifteen Reassessment(15)	**27,292**
Total Net Present Worth Cost for Year Twenty Reassessment(15)	**19,459**
Total Net Present Worth Cost for Year Twenty-Five Reassessment(15)	**13,874**

Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement **$153,000**

TABLE 5-6b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 4
Source Control and Extraction, Treatment, and Hydraulic Containment of GW at the Island
Based on a 25 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
SEMI-ANNUAL MONITORING (YEARS 1-5)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Groundwater Extraction System[16]	1	Lump Sum	5,700	5,700
Air Stripping System[17]	1	Lump Sum	2,200	2,200
Carbon Adsorption[18]	1	Lump Sum	20,000	20,000
Catalytic Oxidation[19]	1	Lump Sum	9,000	9,000
Field Sampling (Groundwater)[20]	40	Wells	575	23,000
Sample Shipping Costs[21]	6	Shipment	100	600
Supplies, Disposables, etc.[22]	12	Days	25	300
Analytical/Lab Testing[23]	60	Each	275	16,500
Travel/Expenses[24]	2	Event	2,250	4,500
Project Management/Periodic Reporting[25]	200	Hrs	110	22,000
Contract Administration[26]	40	Hrs	110	4,400

Total Cost	**108,200**
Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)[15]	**444,000**

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
ANNUAL MONITORING (YEARS 6-25)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Groundwater Extraction System[16]	1	Lump Sum	5,700	5,700
Air Stripping System[17]	1	Lump Sum	2,200	2,200
Carbon Adsorption[18]	1	Lump Sum	20,000	20,000
Catalytic Oxidation[19]	1	Lump Sum	9,000	9,000
Field Sampling (Groundwater)[20]	20	Wells	575	11,500
Sample Shipping Costs[21]	3	Shipment	100	300
Supplies, Disposables, etc.[22]	6	Days	25	150
Analytical/Lab Testing[23]	30	Each	275	8,250
Travel/Expenses[24]	1	Event	2,250	2,250
Project Management/Periodic Reporting[25]	100	Hrs	110	11,000
Contract Administration[26]	20	Hrs	110	2,200

Total Cost	**72,550**
Total Net Present Worth Cost for Annual Monitoring (6-25 Years)[15]	**472,000**
Total Capital Cost	**894,000**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**153,000**
Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)	**444,000**
Total Net Present Worth Cost for Annual Monitoring (6-25 Years)	**472,000**
Total Net Present Worth Cost of Alternative 4 - 25 Year Duration	**$2,000,000**

TABLE 5-6b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 4
Source Control and Extraction, Treatment, and Hydraulic Containment of GW at the Island
Based on a 25 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

Notes and Assumptions for Table 5-6b:

[1] Includes required pre-design testing (i.e. pilot and bench scale testing). Based on engineering judgement and past experience.

[2] Based on *Remedial Action Cost Engineering and Requirements (RACER) - Environmental Cost Engineering (ENVEST)* All supporting documentation for *RACER* cost estimates are presented in Appendix D.

[3] Extraction system consists of 12 extraction wells pumping at approximately 3 gallons per minute (Figure 4-2).

[4] Based on 10% of construction cost.

[5] Includes equipment operator, dozer, and laborer to place and compact a 30 foot wide crushed stone access road across drainage swale and Union Pacific Railroad track (*Means* 1996).

[6] Lump sum cost for right-of-way negotiation, based on engineering judgement and past experience.

[7] Includes clearing of brush and trees.

[8] Includes landscaping (i.e. seeding and tree planting). Based on $250/tree and one tree/150 square feet (*Means* 1996). It should be noted that costs for Site Restoration will not completely reverse the ecological impacts caused during construction at the Island.

[9] Based on environmental management required for regulatory coordination prior to construction with regard to ARARs (i.e. Floodplain Management, Endangered Species Act, Historic Preservation, etc).

[10] Based on calculations provided in Table D-1.

[11] Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

[12] Environmental Management and five year reassessment, including site visit for visual inspection, review of periodic monitoring data, preparation of five year reassessment report, and coordination with regulators.

[13] Based on a daily rate for one Environmental Engineer/Geologist (10hrs/day). Includes labor, per diem, lodging, air fare, car and equipment rental, expendible supplies, well development, and coordination and scheduling.

[14] Unit rates are based on the actual costs to install the original Microwells (DCF96-23, 24, 25, 26, 27, 34, 35 & 36). Includes replacement of Microwells and DCF93-09, DCF93-10, and DCF94-22. The unit rate includes a licensed driller, labor, material, per diem, lodging/travel expenses, Island access provisions, and mobilization/demobilization.

[15] Based on a 7% discount rate.

[16] Based on electric costs, pump and motor maintenance and repair, and $100/year for extraction well rehabilitation.

[17] Based on electric costs, packing reconditioning and pump and motor maintenance and repair.

[18] Based on removal, replacement and disposal of spent carbon.

[19] Based on replacement of precious metal catalysts and operational labor.

[20] Based on 20 wells per sampling event. Sampling includes 2 worker crew, 3 days (10 hrs/day) per sampling event @ $110/mnhr (3 days does not include travel time). Includes sampling coordination and data interpretation 1 worker, 3 day (8 hrs/day) per sampling event @ $110/mnhr. Includes providing sampling equipment, handling and disposal of purge water, and periodic well inspection and maintenance.

[21] Includes 3 shipments per sampling event @ approximately $100/shipment.

[22] Based on $25/day/person for expendible supplies.

[23] U.S. EPA Method 8240 (TCL Volatiles). Includes all quality control samples (field blanks, trip blanks, duplicates, etc.).

[24] Includes air fare, car rental, per diem, and lodging.

[25] Includes data review and validation and preparation of Data Summary Report (DSR) and Quality Control Summary Report (QCSR).

[26] Based on environmental management labor for monitoring program @ 20 hrs/event.

TABLE 5-7a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 6
Source Control and Passive Trtmnt and Partial Cont Using Funnel and Gate at the Island
Based on a 10 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

CAPITAL COST

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Longterm Monitoring Plan Development	80	Hrs	110	8,800
Remedial Design and Testing(1)	1	Lump Sum	300,000	300,000
Installation of Slurry Wall(2)(3)	1	Lump Sum	618,000	618,000
Installation of Passive Treatment Wall(4)	1	Lump Sum	280,000	280,000
Design of Temporary Union Pacific Railroad Crossing(5)	1	Lump Sum	1,000	1,000
Installation of Temporary Union Pacific Railroad Crossing(6)	1	Lump Sum	10,000	10,000
Negotiation of Union Pacific Railroad Right-of-Way(7)	1	Lump Sum	50,000	50,000
Clearing and Access Road(2)(8)	1	Lump Sum	6,000	6,000
Site Restoration/Tree Loss Mitigation(9)	340	Each	250	85,000
Coordination with Regulatory Agencies(10)	100	Hrs	110	11,000

Total Cost	**1,369,800**
Contingency Factor @ 20%	**273,960**
Total Capital Cost	**1,650,000**

COST OF TEN YEAR DURATION(11) FOR FIVE YEAR REASSESSMENT AND MICROWELL REPLACEMENT

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Engineering/Management/Administration(12)(13)	180	Hrs	110	19,800
Microwell Replacement Oversight(14)	15	Days	1400	21,000
Microwell Replacement(15)	8	Wells	2500	20,000

Total Cost	**60,800**
Total Net Present Worth Cost for Year Five Reassessment(16)	**43,350**
Total Net Present Worth Cost for Year Ten Reassessment(16)	**30,908**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**74,300**

TABLE 5-7a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 6
Source Control and Passive Trtmnt and Partial Cont Using Funnel and Gate at the Island
Based on a 10 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
SEMI-ANNUAL MONITORING (YEARS 1-5)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Replacement Passive Treatment Wall Media[17]	1	Lump Sum	30,000	30,000
Field Sampling (Groundwater)[18]	20	Wells	575	11,500
Sample Shipping Costs[19]	4	Shipments	100	400
Supplies, Disposables, etc.[20]	8	Days	25	200
Analytical/Lab Testing[21]	30	Each	275	8,250
Travel/Expenses[22]	2	Events	1,500	3,000
Project Management/Periodic Reporting[23]	200	Hrs	110	22,000
Contract Administration[24]	40	Hrs	110	4,400

Total Cost **79,750**

Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)[16] **327,000**

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
ANNUAL MONITORING (YEARS 6-10)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Replacement Passive Treatment Wall Media[17]	1	Lump Sum	30,000	30,000
Field Sampling (Groundwater)[18]	10	Wells	575	5,750
Sample Shipping Costs[19]	2	Shipments	100	200
Supplies, Disposables, etc.[20]	4	Days	25	100
Analytical/Lab Testing[21]	15	Each	275	4,125
Travel/Expenses[22]	1	Events	1,500	1,500
Project Management/Periodic Reporting[23]	100	Hrs	110	11,000
Contract Administration[24]	20	Hrs	110	2,200

Total Cost **54,875**

Total Net Present Worth Cost for Annual Monitoring (6-10 Years)[16] **161,000**

Total Capital Cost	**1,650,000**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**74,300**
Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)	**327,000**
Total Net Present Worth Cost for Annual Monitoring (6-10 Years)	**161,000**

Total Net Present Worth Cost of Alternative 6 - 10 Year Duration **$2,300,000**

TABLE 5-7a
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 6
Source Control and Passive Trtmnt and Partial Cont Using Funnel and Gate at the Island
Based on a 10 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

Notes and Assumptions for Table 5-7a:

[1] Includes required pre-design testing (i.e. pilot and bench scale testing). Based on engineering judgement and and past experience.

[2] Based on *Remedial Action Cost Engineering and Requirements (RACER) - Environmental Cost Engineering (ENVEST).* All supporting documentation for *RACER* cost estimates are presented in Appendix E.

[3] Based on a 1700 foot long, 60 foot deep slurry wall (Figure 4-9).

[4] Includes unit cost and installation of approximately 250 tons of granular iron. Based on typical unit costs of previous case studies (~$800/ton plus labor). Appendix E present case studies complete with cost data.

[5] Based on 10% of construction cost.

[6] Includes equipment operator, dozer, and laborer to place and compact a 30 foot wide crushed stone access road across drainage swale and Union Pacific Railroad track (*Means* 1996).

[7] Lump sum cost for right-of-way negotiation, based on engineering judgement and past experience.

[8] Includes clearing of brush and trees.

[9] Includes landscaping (i.e. seeding and tree planting). Based on $250/tree and one tree/150 square feet (*Means* 1996). It should be noted that costs for Site Restoration will not completely reverse the ecological impacts caused during construction at the Island.

[10] Based on environmental management required for regulatory coordination prior to construction with regard to ARARs (i.e. Floodplain Management, Wetlands, Endangered Species Act, Historic Preservation, etc).

[11] Estimated fastest time to meet MCLs based on modeling.
Support documentation for modeling presented as Appendix B.

[12] Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

[13] Environmental Management and five year reassessment, including site visit for visual inspection, review of periodic monitoring data, preparation of five year reassessment report, and coordination with regulators.

[14] Based on a daily rate for one Environmental Engineer/Geologist (10hrs/day). Includes labor, per diem, lodging, air fare, car and equipment rental, expendible supplies, well development, and coordination and scheduling.

[15] Unit rates are based on the actual costs to install the original Microwells (DCF96-23, 24, 25, 26, 27, 34, 35 & 36). The unit rate includes a licensed driller, labor, material, per diem, lodging/travel expenses, Island access provisions, and mobilization/demobilization.

[16] Based on a 7% discount rate.

[17] Complete removal and replacement of granular iron once every 10 years. Prorated annually over ten years. Based on case studies (Appendix E).

[18] Based on 10 wells per sampling event. Sampling includes 2 worker crew, 2 days (10 hrs/day) per sampling event @ $110/mnhr (2 days does not include travel time). Includes sampling coordination and data interpretation 1 worker, 2 day (8 hrs/day) per sampling event @ $110/mnhr. Includes providing sampling equipment, handling and disposal of purge water, and periodic well inspection and maintenance.

[19] Includes 2 shipments per sampling event @ approximately $100/shipment.

[20] Based on $25/day/person for expendible supplies.

[21] U.S. EPA Method 8240 (TCL Volatiles). Includes all quality control samples (field blanks, trip blanks, duplicates, etc.).

[22] Includes air fare, car rental, per diem, and lodging.

[23] Includes data review and validation and preparation of Data Summary Report (DSR) and Quality Control Summary Report (QCSR).

[24] Based on environmental management labor for monitoring program @ 20 hrs/event.

TABLE 5-7b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 6
Source Control and Passive Trtmnt and Partial Cont Using Funnel and Gate at the Island
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

CAPITAL COST

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Longterm Monitoring Plan Development	80	Hrs	110	8,800
Remedial Design and Testing(1)	1	Lump Sum	300,000	300,000
Installation of Slurry Wall(2)(3)	1	Lump Sum	613,000	613,000
Installation of Passive Treatment Wall(4)	1	Lump Sum	280,000	280,000
Design of Temporary Union Pacific Railroad Crossing(5)	1	Lump Sum	1,000	1,000
Installation of Temporary Union Pacific Railroad Crossing(6)	1	Lump Sum	10,000	10,000
Negotiation of Union Pacific Railroad Right-of-Way(7)	1	Lump Sum	50,000	50,000
Clearing and Access Road(2)(8)	1	Lump Sum	6,000	6,000
Site Restoration/Tree Loss Mitigation(9)	340	Each	250	85,000
Coordination with Regulatory Agencies(10)	100	Hrs	110	11,000

Total Cost	**1,364,800**
Contingency Factor @ 20%	**272,960**
Total Capital Cost	**1,640,000**

COST OF TEN YEAR DURATION(11) FOR FIVE YEAR REASSESSMENT AND MICROWELL REPLACEMENT

Item	Quantity	Unit	Rate ($/unit)(9)	Cost ($)
Engineering/Management/Administration(12)(13)	180	Hrs	110	19,800
Microwell Replacement Oversight(14)	15	Days	1400	21,000
Microwell Replacement(15)	8	Wells	2500	20,000

Total Cost	**60,800**

Total Net Present Worth Cost for Year Five Reassessment(16)	**43,350**
Total Net Present Worth Cost for Year Ten Reassessment(16)	**30,908**
Total Net Present Worth Cost for Year Fifteen Reassessment(16)	**22,037**
Total Net Present Worth Cost for Year Twenty Reassessment(16)	**15,712**
Total Net Present Worth Cost for Year Twenty-Five Reassessment(16)	**11,202**
Total Net Present Worth Cost for Year Thirty Reassessment(16)	**7,987**

Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement **132,000**

TABLE 5-7b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 6
Source Control and Passive Trtmnt and Partial Cont Using Funnel and Gate at the Island
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
SEMI-ANNUAL MONITORING (YEARS 1-5)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Replacement Passive Treatment Wall Media(17)	1	Lump Sum	30,000	30,000
Field Sampling (Groundwater)(18)	20	Wells	575	11,500
Sample Shipping Costs(19)	4	Shipments	100	400
Supplies, Disposables, etc.(20)	8	Days	25	200
Analytical/Lab Testing(21)	30	Each	275	8,250
Travel/Expenses(22)	2	Events	1,500	3,000
Project Management/Periodic Reporting(23)	200	Hrs	110	22,000
Contract Administration(24)	40	Hrs	110	4,400

Total Cost **79,750**

Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)(16) **327,000**

ANNUAL OPERATIONS & MAINTENANCE (O&M) COSTS,
ANNUAL MONITORING (YEARS 6-30)

Item	Quantity	Unit	Rate ($/unit)	Cost ($)
Replacement Passive Treatment Wall Media(17)	1	Lump Sum	30,000	30,000
Field Sampling (Groundwater)(18)	10	Wells	575	5,750
Sample Shipping Costs(19)	2	Shipments	100	200
Supplies, Disposables, etc.(20)	4	Days	25	100
Analytical/Lab Testing(21)	15	Each	275	4,125
Travel/Expenses(22)	1	Events	1,500	1,500
Project Management/Periodic Reporting(23)	100	Hrs	110	11,000
Contract Administration(24)	20	Hrs	110	2,200

Total Cost **54,875**

Total Net Present Worth Cost for Annual Monitoring (6-30 Years)(16) **357,000**

Total Capital Cost	**1,640,000**
Total Net Present Worth Cost for Five Year Reassessments and Microwell Replacement	**132,000**
Total Net Present Worth Cost for Semi-Annual Monitoring (1-5 Years)	**327,000**
Total Net Present Worth Cost for Annual Monitoring (6-30 Years)	**357,000**

Total Net Present Worth Cost of Alternative 6 - 30 Year Duration **$2,500,000**

TABLE 5-7b
ORDER OF MAGNITUDE COST ESTIMATE
FOR ALTERNATIVE 6
Source Control and Passive Trtmnt and Partial Cont Using Funnel and Gate at the Island
Based on a 30 Year Duration
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

Notes and Assumptions for Table 5-7b:

[1] Includes required pre-design testing (i.e. pilot and bench scale testing). Based on engineering judgement and past experience.

[2] Based on *Remedial Action Cost Engineering and Requirements (RACER) - Environmental Cost Engineering (ENVEST)* All supporting documentation for *RACER* cost estimates are presented in Appendix E.

[3] Based on a 1700 foot long, 60 foot deep slurry wall (Figure 4-9).

[4] Includes unit cost and installation of approximately 250 tons of granular iron. Based on typical unit costs of previous case studies (~$800/ton plus labor). Appendix E present case studies complete with cost data.

[5] Based on 10% of construction cost.

[6] Includes equipment operator, dozer, and laborer to place and compact a 30 foot wide crushed stone access road across drainage swale and Union Pacific Railroad track (*Means* 1996).

[7] Lump sum cost for right-of-way negotiation, based on engineering judgement and past experience.

[8] Includes clearing of brush and trees.

[9] Includes landscaping (i.e. seeding and tree planting). Based on $250/tree and one tree/150 square feet (*Means* 1996). It should be noted that costs for Site Restoration will not completely reverse the ecological impacts caused during construction at the Island.

[10] Based on environmental management required for regulatory coordination prior to construction with regard to ARARs (i.e. Floodplain Management, Wetlands, Endangered Species Act, Historic Preservation, etc).

[1] Estimated slowest time to meet MCLs based on modeling. Support documentation for modeling presented as Appendix B.

[12] Loaded labor rate including overhead, profit and other direct costs for document production, meetings, etc.

[13] Environmental Management and five year reassessment, including site visit for visual inspection, review of periodic monitoring data, preparation of five year reassessment report, and coordination with regulators.

[14] Based on a daily rate for one Environmental Engineer/Geologist (10hrs/day). Includes labor, per diem, lodging, air fare, car and equipment rental, expendible supplies, well development, and coordination and scheduling.

[15] Unit rates are based on the actual costs to install the original Microwells (DCF96-23, 24, 25, 26, 27, 34, 35 & 36). The unit rate includes a licensed driller, labor, material, per diem, lodging/travel expenses, Island access provisions, and mobilization/demobilization.

[16] Based on a 7% discount rate.

[17] Complete removal and replacement of granular iron once every 10 years. Prorated annually over ten years. Based on case studies (Appendix E).

[18] Based on 10 wells per sampling event. Sampling includes 2 worker crew, 2 days (10 hrs/day) per sampling event @ $110/mnhr (2 days does not include travel time). Includes sampling coordination and data interpretation 1 worker, 2 day (8 hrs/day) per sampling event @ $110/mnhr. Includes providing sampling equipment, handling and disposal of purge water, and periodic well inspection and maintenance.

[19] Includes 2 shipments per sampling event @ approximately $100/shipment.

[20] Based on $25/day/person for expendible supplies.

[21] U.S. EPA Method 8240 (TCL Volatiles). Includes all quality control samples (field blanks, trip blanks, duplicates, etc.).

[22] Includes air fare, car rental, per diem, and lodging.

[23] Includes data review and validation and preparation of Data Summary Report (DSR) and Quality Control Summary Report (QCSR).

[4] Based on environmental management labor for monitoring program @ 20 hrs/event.

TABLE 5-8
SUMMARY OF ORDER OF MAGNITUDE COST ESTIMATES
Dry Cleaning Facilities Study Area, Fort Riley, Kansas

Alternative	Low Cost ($)	High Cost ($)
Alternative 1 - No Further Action beyond Established Source Controls	14,000	24,000
Alternative 2 - Source and Institutional Controls with Groundwater		
Monitoring and Contingency for Future Action	370,000	570,000
Alternative 3 - Source Controls and Natural Attenuation with		
Groundwater Monitoring and Contingency for Future Action	650,000	950,000
Alternative 4 - Source Controls and Extraction, Treatment and		
Hydraulic Containment of Groundwater at the Island	1,800,000	2,000,000
Alternative 6 - Source Controls and Passive Treatment and Partial		
Containment Using Funnel and Gate at the Island	2,300,000	2,500,000

6.0 COMPARATIVE EVALUATION

6.0 Comparative Evaluation

In this chapter, the results of the detailed evaluation (Chapter 5.0) are used to compare each alternative based upon the first seven criteria. The initial part of this Chapter is a description of the evaluation system used in the comparative analysis. The remainder of the chapter is organized by each of the evaluation criteria. A fold out table has been included at the end of Chapter 6 to present the alternative numbers and alternative names that can be used as a cross reference as the reader progresses through this chapter.

6.1 Evaluation System for Comparative Analysis

The alternatives are scored on a pass/fail basis for the two threshold criteria (protection of human health and environment, and compliance with ARARs). Those alternatives passing the threshold criteria are then evaluated for the five primary balancing criteria on the basis of incremental differences between alternatives. Sections 6.4 through 6.8 summarize the evaluations for each of the balancing criteria.

A competitive and semi-quantitative comparison is performed at this point in the FS to facilitate a rating of the full list of alternatives which were subjected to the detailed analysis. Five alternatives were carried through the complete detailed analysis and, therefore, each will be given a rating based on how it compared to the other four alternatives. Equal ratings will be given if it is not possible to differentiate performance for the given criteria. The range of rating will be on a scale of 1 to 10. The most favorable alternative(s) will always be given a 1, and any alternative that completely fails the criteria will be given a 10. Other alternatives will be placed appropriately within the range based on their expected performance relative to the other alternatives and in accordance with the following further justification for specific ratings.

1. Most favorable alternative
3. Good, generally favorable
5. Fair, potentially unfavorable
7. Poor, unfavorable
10. Completely fails the criteria

A rating of 2, 4, 6, 8, and/or 9 will be used to differentiate between alternatives with similar qualifications but where one slightly outperforms the other (e.g., two alternatives considered "fair" but one is slightly more favorable). This rating method will be employed for each of the five balancing criteria (see Sections 6.4 through 6.8).

6.2 Overall Protection of Human Health and the Environment

This is a pass/fail criteria. Based on the BLRA (CENWK, 1995a) and the evaluations summarized in Chapter 5, all of the alternatives pass this threshold criteria and are considered to be protective of human health and the environment. It is noted, however, that this assertion is based on current data and modeling. Should conditions unexpectedly change for the worse, Alternative 1 is the only alternative for which no contingency for future action is provided, since no monitoring program is implemented.

6.3 Compliance with ARARs

This is a pass/fail criteria. Based on the evaluations summarized in Chapter 5, all of the alternatives pass this threshold criteria and are considered to be in compliance with ARARs in that they eventually satisfy the ARAR-based remedial goals (RGs) and are assumed to be properly designed and implemented. As was noted in Section 6.2, however, the assertion that RGs will eventually be achieved is based on current data and modeling and Alternative 1 is the only alternative which would not likely facilitate a proper modification in response to changed conditions, should they unexpectedly occur, since no monitoring program is implemented.

6.4 Long-Term Effectiveness and Permanence

This criteria is evaluated by assessing each alternative's effectiveness and permanence regarding the reduction of groundwater contamination levels at the Island. Based on currently available data and transport modeling results, natural attenuation processes will successfully and permanently achieve remedial goals within a few decades.

As a result, Alternative 1 will achieve long-term effectiveness and permanence; although, there will be no way to document or confirm when/if this occurs since no monitoring will be performed.

Alternative 2, will similarly achieve long-term effectiveness and permanence through natural processes. Alternative 2 also includes groundwater contaminant migration monitoring to assure that the effectiveness is being achieved and unexpected adverse changes do not go unaddressed by including a contingency for future additional remedial action.

Alternative 3 performs similarly to Alternative 2 in every way except that a few more monitoring points and parameters are included to provide more complete information on the effectiveness of natural attenuation within the contaminated aquifer as time goes on. This will enhance the ability to predict progress and to develop informative periodic review reports.

Alternative 4 would be equally permanent and effective compared to the other alternatives and may provide the added benefit of achieving permanence in a shorter time period depending on how effectively and evenly the pumping well network accelerates flushing of the entire alluvial aquifer. The potential time savings is estimated to be as much as thirty to fifty percent faster based on historical performance of pump and treat systems.

Alternative 6 would also be permanent and effective compared to the other alternatives, but only in the same time-frame as the first three alternatives since natural gradients and attenuation processes will be relied upon to remediate the residual contamination in the center and upland side of the Island. The funnel and treatment gate do, however, provide some additional effectiveness with regard to reduction of contaminant mass and discharge to the Kansas River. This added protection is dependent primarily on the ability to minimize periodic maintenance or replacement of the treatment media, and to a much lesser extent on the effects of periodic rises in the Kansas River causing water levels on the Island to rise above the top of the barrier.

Based on available data and current projections, all five alternatives will likely be permanent and effective in the long-term, but: Alternative 4 provides the only possibility of time savings and total discontinuation of contaminant releases to the Kansas River. Alternative 6 also provides the possibility of a near total discontinuation of contaminant releases to the Kansas River, but no time savings. While Alternative 2 and 3 will likely be permanent and effective in the long-term, neither alternative provides for a time savings or discontinuation contaminant release to the Kansas River. This latter factor is not considered to be problematic, however, due to the very low levels of contamination and the fact that dilution and volatization will immediately reduce levels to below detectable limits upon reaching the Kansas River. Alternative 1 is the only alternative which lacks the inherent ability to monitor, maintain and/or adjust the remedial program in the event that currently unforeseen changes in environmental conditions arise. The ratings for long-term effectiveness and permanence are therefore assigned as follows:

Alternative 1	5
Alternative 2	3
Alternative 3	3
Alternative 4	1
Alternative 6	2

6.5 Short-Term Effectiveness

All of the alternatives are considered effective in the short-term, because there are no current human health or ecological concerns that have been identified, even if no action is taken beyond maintained control of the use of the land. As is typical for most sites impacted by groundwater contamination which must meet drinking water quality criteria, however, none of the available and feasible remedial alternatives will meet the ARAR-based RGs in the short-term. Several years will likely elapse before even the most expedient alternative (Alternative 4) might be complete.

Although past performance of groundwater pump and treat systems have identified the limitations of pump and treat alternatives such as Alternative 4, it slightly exceeds the performance of the first three alternatives because it will immediately reduce and possibly discontinue all ongoing contaminant releases to the Kansas River. This benefit is somewhat diminished under this criteria, however, because of remedial worker health and safety concerns associated with system construction and O&M. Alternative 6 performs similarly to Alternative 4 in that it reduces contaminant releases to the Kansas River in the short-term (although not as quickly and completely as Alternative 4), but with somewhat offsetting worker health and safety concerns as well. Alternatives 1, 2, and 3 do not provide an immediate reduction in releases to the Kansas River, but this is not considered to be a problem due to the very low levels of contamination and the fact that dilution and volatization will immediately reduce levels to below detectable limits upon reaching the Kansas River.

The rankings for short-term effectiveness are therefore assigned as follows:

Alternative 1	3
Alternative 2	3
Alternative 3	3
Alternative 4	1
Alternative 6	2

6.6 Reduction of Mobility, Toxicity, and Volume through Treatment

Alternatives 1, 2, and 3 depend on passive natural processes to achieve eventual reductions in the toxicity and mass of contaminants, but these processes will ultimately achieve such reductions. These alternatives do not reduce mobility or volume, since contamination is allowed to spread as it attenuates, but there are no identified risks associated with allowing this spread to occur.

Alternative 4 is the only alternative which includes the potential for immediate reductions in the mobility/volume (through pumping and hydraulic control) and toxicity (through ex situ treatment) of the contamination.

Alternative 6 depends in part on natural gradients and processes, but includes additional reductions in toxicity as contaminated groundwater is funneled through the passive treatment gate.

The rankings for reduction of mobility, toxicity, and volume through treatment are therefore as follows:

Alternative 1	3
Alternative 2	3
Alternative 3	3
Alternative 4	1
Alternative 6	2

6.7 Implementability

Alternative 1 does not have any technical feasibility concerns associated with it because there are no disturbances or remedial construction/operations required. Significant administrative feasibility issues might arise, however, if regulatory agencies or the community voice concerns over discontinuation of monitoring for adverse changes.

Alternatives 2 and 3 have neither technical nor administrative feasibility concerns since no current or future unacceptable risks are expected, monitoring is already being performed, and flexibility for response to future changes is maintained.

Alternatives 4 and 6 would both have technical and administrative feasibility concerns. Administrative feasibility concerns would arise as a result of the substantial, unavoidable, and potentially irreversible ecological disruption that would be caused by performing remedial construction on the Island. This particular implementability problem would not only be related to disruptive remedial construction, but would also continue during operations and maintenance (especially for Alternative 4). Technical feasibility concerns would be associated with developing a design that will prove effective and not problematic to maintain, as well as with accessing and working on the Island without causing unacceptable damage to the bald eagle habitat (Section 5.1.1).

The rankings for implementability are therefore as follows:

Alternative 1	5
Alternative 2	1
Alternative 3	1
Alternative 4	7
Alternative 6	6

6.8 Cost

Tables 5-3, 5-4, 5-5, 5-6 and 5-7 have been prepared as order of magnitude cost estimates for each alternative, and are provided for comparison purposes only since they are based to varying degrees on some engineering judgement and reasonable assumptions. Based on the estimates contained in these tables, the rankings for cost are as follows:

Alternative 1	1
Alternative 2	2
Alternative 3	3
Alternative 4	7
Alternative 6	8

6.9 Summary

The alternatives retained for detailed evaluation (Alternatives 1, 2, 3, 4, and 6) each satisfy the two threshold criteria and may be considered as technically viable alternatives. They were therefore evaluated, compared and rated for each of the five balancing criteria using the rating system described in Section 6.1. This and any semi-quantitative rating or ranking system are subject to debate, however, and final recommendations must also consider community and regulatory input as well as fiscal constraints.

A summation of the ratings for each alternative over the five criteria is as follows, with the best overall ranking being represented by the lowest number:

Alternative 2	12
Alternative 3	13
Alternative 1	17
Alternative 4	17
Alternative 6	20

After an evaluation of each alternative based on the two threshold criteria and the five balancing criteria, Alternative 2 ranks as the most highly rated alternative, with Alternative 3 ranked second. The following paragraphs provide further comparisons, distinctions, conclusions, and evaluations that qualify and supplement the results of the semi-quantitative ratings that were provided.

One clear distinction that can be made is that Alternative 1 (No Further Action beyond Established Source Controls) is the only alternative that could result in a lack of overall protectiveness of human health and the environment should currently unforeseen changes in environmental conditions occur, as it does not include a means of monitoring for unexpected changes in contamination levels or trends. Such unforeseen are, however, considered to be unlikely. The other four alternatives are similarly protective compared to each other and all include the means to monitor, and adjust to, any unforeseen changes in conditions.

Another obvious conclusion that may be drawn is that there appears to be no clear advantage in implementing Alternative 6 as compared to Alternative 4 because they both include similar short-term benefits and potential ecological disturbance, yet Alternative 6 is likely to be both slower and more costly than Alternative 4.

There is another distinction that can be made regarding Alternatives 4 and 6 in that technical issues and the sensitivity and importance of the bald eagle habitat on the Island create the ultimate implementability concern. Alternatives 4 and 6 are suspect since the ecological damage that could result is not balanced by any tangible improvements over the other alternatives from the standpoint of environmental conditions and levels of risk. A more arguable but somewhat related conclusion is that, in light of the fact that there are no unacceptable current or foreseeable risks associated with the contamination, the much increased expenditures of funds necessary for Alternatives 4 and 6 would be difficult to justify.

As a final remark, please note that pursuant to the NCP, the final two evaluation criteria (State acceptance and community acceptance) will not be assessed until after publication of the selected remedy in the Proposed Plan, as part of the Record of Decision (ROD) development and public comment process.

REFERENCES

REFERENCES

CEMRK. 1997a. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Remedial Investigations Addendum Monitoring Expansion Report Dry Cleaning Facilities Area Fort Riley, Kansas*. Prepared by Louis Berger & Associates, Inc., Florham Park, N.J., for U. S. Army Corps of Engineers, Missouri River Division, Kansas City District. July 14, 1997.

CEMRK. 1997b. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Data Summary Report for Groundwater Sampling at the Dry Cleaning Facilities Area Fort Riley, Kansas (October 1996 and February 1997)*. Prepared by Louis Berger & Associates, Inc., Washington, D.C., for U. S. Army Corps of Engineers, Missouri River Division, Kansas City District. July 14, 1997.

CEMRK. 1996a. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Draft Final Pilot Test Study Results Report Dry Cleaning Facilities Area Fort Riley, Kansas*. Prepared by Louis Berger & Associates, Inc., East Orange, N.J., for U. S. Army Corps of Engineers, Missouri River Division, Kansas City District. March.

CEMRK. 1996b. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Work Plan for Monitoring Network Expansion Including Additional Characterization of the Island Dry Cleaning Facilities Area (DCFA-FS) Fort Riley, Kansas*. Prepared by Louis Berger & Associates, Inc., Gaithersburg, MD, for U. S. Army Corps of Engineers, Missouri River Division, Kansas City District. May 6.

CEMRK. 1996c. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Data Summary Report for Groundwater Sampling at the Dry Cleaning Facilities Area Fort Riley, Kansas (May, June, July & August 1995)*. Prepared by Louis Berger & Associates, Inc., Washington, D.C., for U. S. Army Corps of Engineers, Missouri River Division, Kansas City District. February 22, 1996.

CEMRK. 1996d. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Data Summary Report for Groundwater Sampling at the Dry Cleaning Facilities Area Fort Riley, Kansas (October 1995)*. Prepared by Louis Berger & Associates, Inc., Washington, D.C., for U. S. Army Corps of Engineers, Missouri River Division, Kansas City District. October 8, 1996.

CEMRK. 1996e. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Data Summary Report for Groundwater Sampling at the Dry Cleaning Facilities Area Fort Riley, Kansas (May/June 1996)*. Prepared by Louis Berger & Associates, Inc., Washington, D.C., for U. S. Army Corps of Engineers, Missouri River Division, Kansas City District. October 8, 1996.

CEMRK. 1995a. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Draft Final Remedial Investigations Report Dry Cleaning Facilities Area (DCFA-RI) Fort Riley, Kansas*. Prepared by Louis Berger & Associates, Inc., East Orange, NJ, for U. S. Army Corps of Engineers, Missouri River Division, Kansas City District. March.

CEMRK. 1995b. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Draft Feasibility Study Dry Cleaning Facilities Area (DCFA-FS) Fort Riley, Kansas*. Prepared by Louis Berger & Associates, Inc., East Orange, NJ, for U. S. Army Corps of Engineers, Missouri River Division, Kansas City District. April.

CEMRK. 1992. U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. *Preliminary Assessment/Site Investigation Report for Former Dry Cleaning Facility at Fort Riley, Kansas*. Prepared by Law Environmental, Inc., Kansas City, MO, for U.S. Army Corps of Engineers, Missouri River Division, Kansas City District. September.

Das, Braja, M. 1990. *Principles of Geotechnical Engineering*. PWS-KENT Publishing Company.

NCP. 1990. *National Contingency Plan*. March

U.S. EPA. 1991. U.S. Environmental Protection Agency Region VII. *Federal Facilities Agreement*. Docket Number VII-90-F-0015.

U.S. EPA. 1988a. U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*. EPA/540/G-89/004. October.

U.S. EPA. 1988b. U.S. Environmental Protection Agency. *Compliance with Other Laws Manual, Draft Guidance*.

USATHAMA. 1984. United States Army Toxic and Hazardous Material Agency. *Installation Assessment of Fort Riley, Kansas*. Report No. 341. December.

Zeller, D.E. 1968. *The Stratigraphic Succession in Kansas*. Kansas Geological Survey Bulletin 189.

Alternative Number and Alternative Name Cross Reference Table

Alternative Number	Alternative Name
Alternative 1	No Further Action beyond Established Source Controls
Alternative 2	Source and Institutional Controls including Groundwater Monitoring and Contingency for Future Action
Alternative 3	Source Controls and Natural Attenuation including Groundwater Monitoring and Contingency for Future Action
Alternative 4	Source Controls and Extraction, Treatment and Hydraulic Containment of Groundwater at the Island
Alternative 6	Source Controls and Passive Treatment and Partial Containment Using Funnel and Gate at the Island

APPENDIX A
PERSONAL COMMUNICATIONS

APPENDICES

LOUIS BERGER & ASSOCIATES, INC.
100 Halsted Street
P.O. Box 270
East Orange, New Jersey 07019-0270

Engineers • Economists • Planners
Telephone: (201) 678-1960
Telex: 138—152
Cable: BERGERENG
Telecopier: (201) 672-4284

587-6959

MEMORANDUM OF CONVERSATION

PROJECT: FORT RILEY DCFA/MAAF (towards to) RI/FS

PROJ. NO.: JG-1078

DATE: 5.8.96

TIME: 1500-1600

WRITER SPOKE WITH: BOB ANGELO OF KANSAS DEPARTMENT OF

OF: HEALTH AND ENVIRONMENT (KDHE)

TELEPHONE NO.: (913) 296-8027

REGARDING: INTERPRETATION OF ALLUVIAL AQUIFERS AS SURFACE WATER.

DISCUSSION: CALL STEVEN HURST OF THE KANSAS WATER OFFICE (913-368-6201) TO ASK ABOUT ANY DOCUMENTATION RELATED TO THE INTERPRETATION OF ALLUVIAL AQUIFERS (ASSOCIATED WITH SURFACE WATER) TO BE CONSIDERED A SURFACE WATER. S. HURST SAID THE KANSAS WATER OFFICE ~~HAS~~ DEALS MOSTLY WITH WATER USE, AND I MIGHT HAVE MORE LUCK SPEAKING TO BOB ANGELO OF THE ~~KB~~ KDHE. ~~AFTER~~ BOB ANGELO'S INTERPRETATION (BASED ON HIS EXPERIENCE) OF THIS DEFINITION IS THAT THIS INTERPRETATION/DEFINITION IS EVALUATED AND ENFORCED ON A CASE BY CASE BASIS. HOWEVER HE DID NOTE THAT TO HIS KNOWLEDGE SOME RIVERS IN KANSAS (i.e. ARKANSAS, KANSAS) HAVE (O...

SIGNED: [signature]

CC: ______

______

[illegible]
WATER THAT MAY EXTEND SEVERAL MILES FROM THE CENTERLINE OF THE RIVER. WHEN ASKED ABOUT THE KANSAS RIVER IN PARTICULAR HE ADDED THAT TO HIS KNOWLEDGE ~~ALMOST~~ THERE ARE ONLY A FEW SPECIFIC SITES ALONG THE KANSAS RIVER WHERE THE ALLUVIAL AQUIFER IS NOT "ASSOCIATED" WITH THE SURFACE WATER, AND IN ALL OTHER PLACES, AS FAR AS HE IS CONCERNED, THE ALLUVIAL AQUIFER WOULD BE HELD TO THE SURFACE WATER REGULATIONS.

APPENDIX B
GROUNDWATER MODELING SUPPORT DOCUMENTATION

GROUNDWATER MODEL SUMMARY

PRINCETON Model 4
Two-Dimensional Mass Transport; Infinite Aquifer; Infinite Strip Source

Model 4 solves the two-dimensional solute transport equation as a fraction of the initial source concentration. The model calculates these relative concentrations beneath a source and downgradient of the source. It is assumed that the aquifer is of infinite width and distances downgradient are much larger than the length of the analysis.

Processes Modelled:

(1) major mechanism for solute transport is advection
(2) dispersion of the solute plume occurs in both x and y directions
(3) solute retardation or decay as a first order reaction equation

Major Assumption and Limitations:

(1) the aquifer has infinite width in both the x and y directions
(2) the pollutant source is a strip source; at any particular time the source concentration is equal alon the strip
(3) the groundwater flow is two-dimensional in the area of interest with specified velocities in the x and y direction
(4) for covergence of the series approximation, the dispersion coefficient should be larger than (0.04 (v**1.84))
(5) the aquifer parameters are constant temporally and spatially

Boundary Conditions:

(1) the source releases solute into the aquifer system at an initial concentration and decays exponentially
(2) the background concentration is zero
(3) the concentration is at the background level at distances far from the source

Model 4 governing equation:

$$\frac{\partial c}{\partial t} + V_x \frac{\partial c}{\partial x} + V_y \frac{\partial c}{\partial y} = D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial y^2} - KC$$

Subject to:

$$C = C_0 e^{\gamma t} \qquad x = 0 \qquad Y_1 \leq Y \leq Y_2$$

$$C = 0 \qquad X = 0 \qquad \text{all other } y$$

$$\frac{\partial c}{\partial y} \to 0 \qquad Y \to \pm \infty$$

$$C = 0 \qquad t = 0$$

$$\frac{\partial c}{\partial x} \to 0 \qquad Y \to \infty$$

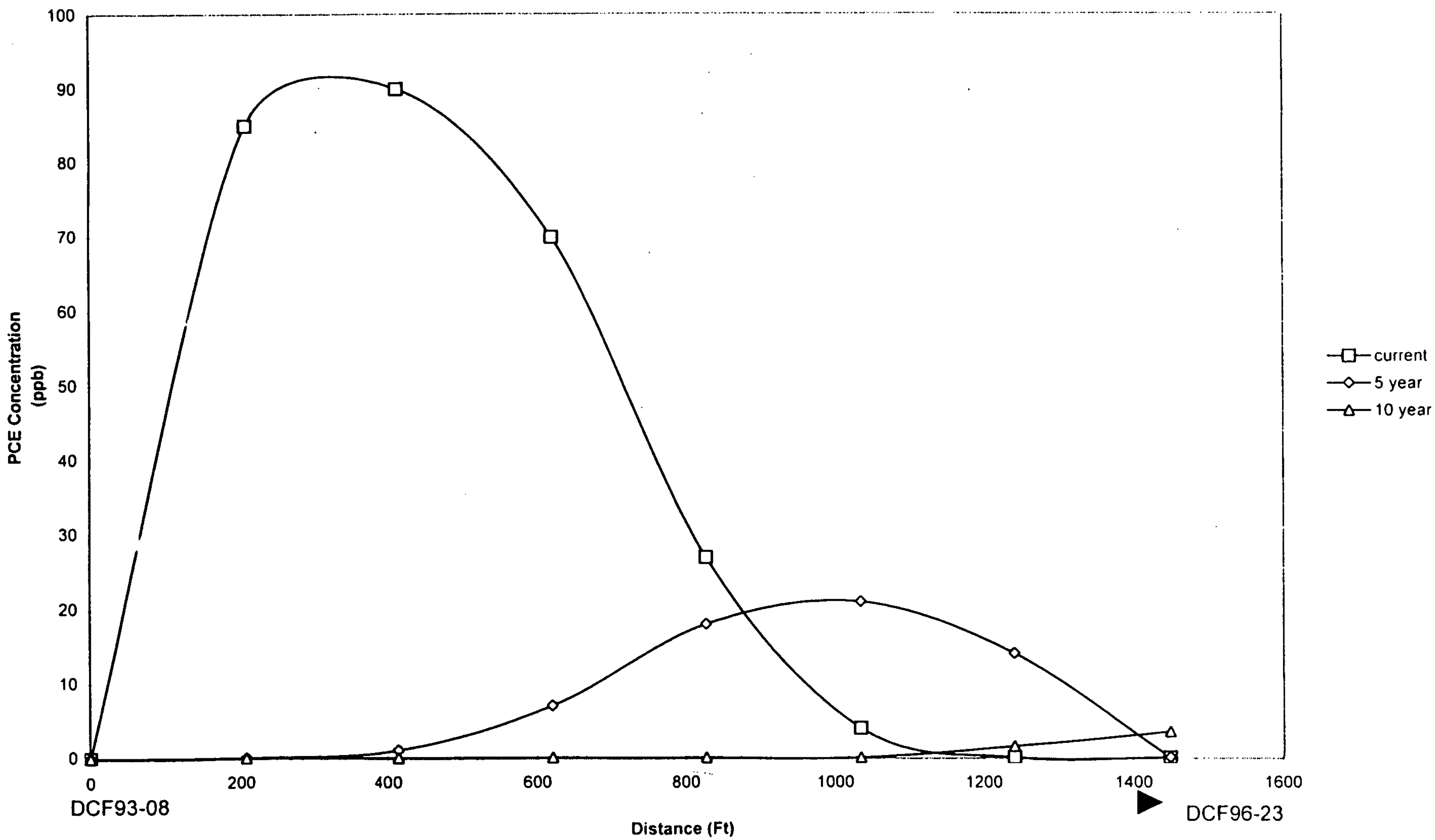
Definition of the terms used in the Princeton Model 4 governing equation:

C	contaminant concentration (ug/l)
t	time (day)
Dx	dispersion coefficient in the X-direction (ft^2/day);
Dy	dispersion coefficient in the Y-direction (ft^2/day);
Vx	velocity in the X-direction (ft/day);
Vy	velocity in the Y-direction (ft/day);
x	distance in the X-direction (ft);
y	distance in the Y-direction (ft);
k	first order biodegradation coefficient (1/day);
Y_1,Y_2	distance in the Y-direction to the location of the source (ft)

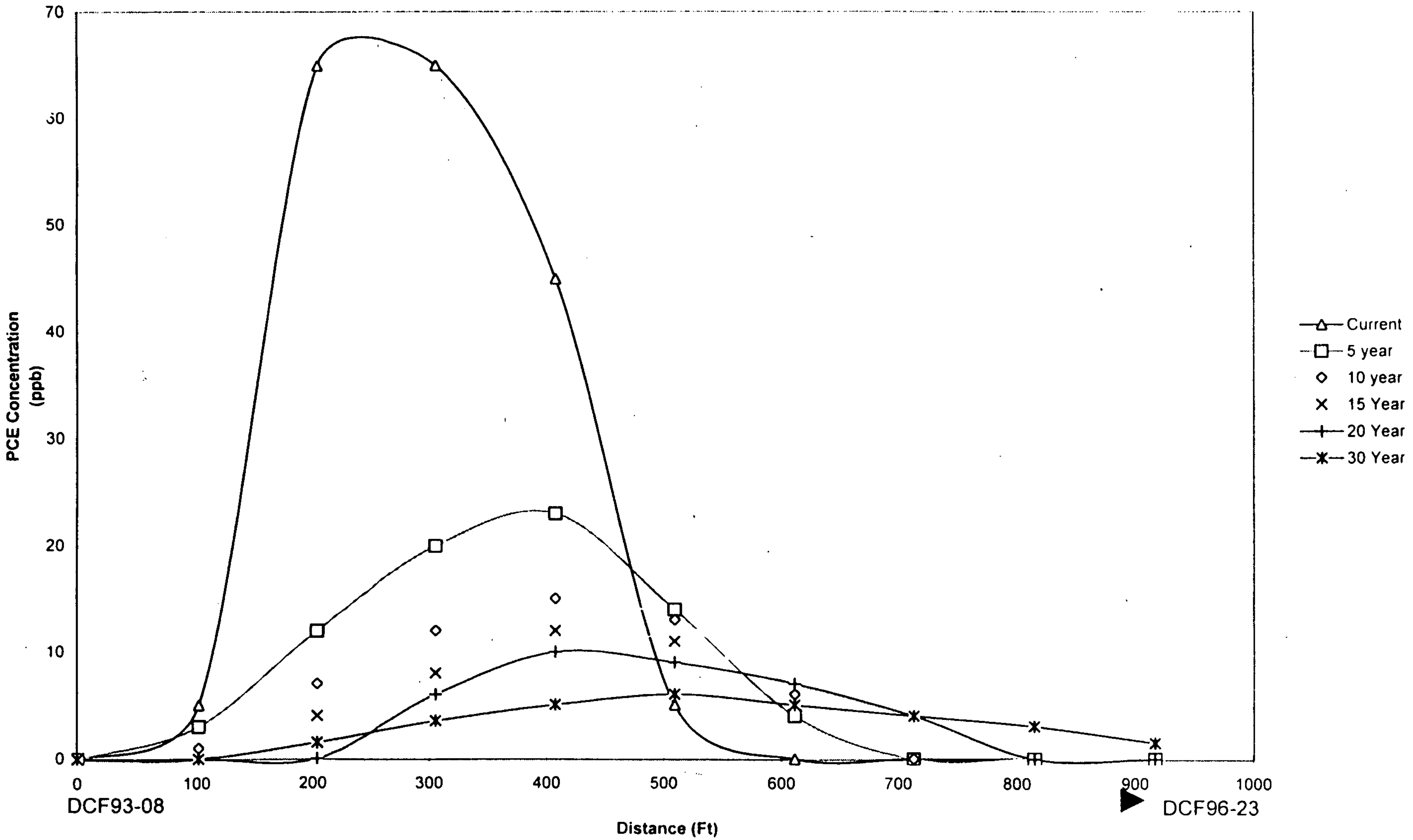
Analytical Solution

$$C\,(X,\,Y,\,t) \cdot \frac{C_0 x}{4\sqrt{\pi D_x}}\; e^{\frac{v_x x}{2D_x}}\; \gamma' \cdot \int_{t_0}^{t} \frac{e^{\cdot(K \cdot \gamma \cdot \frac{v^2_x}{4D_x}\tau \cdot \frac{x^2}{4D_x\tau})}}{\tau^{3/2}} \left\{ \cdot\, erfc\,\left(\frac{(y_2 \cdot Y)}{2\sqrt{D_y \tau}} \cdot \frac{V_y}{2}\sqrt{\frac{\tau}{D_y}}\right) \cdot \cdot\, erfc\,\left(\frac{(y_1 \cdot Y)}{2\sqrt{D_y \tau}} \cdot \frac{V_y}{2}\sqrt{\frac{\tau}{D_y}}\right)\right\} \cdot d\tau$$

Concentration Vs Distance Profiles Over Time
Fast Flush Senario



Concentration Vs Distance Profiles Over Time
Slow Flush Senario



APPENDIX C
GEOTECHNICAL TESTING RESULTS

SUMMARY OF LABORATORY 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)	[illegible]
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

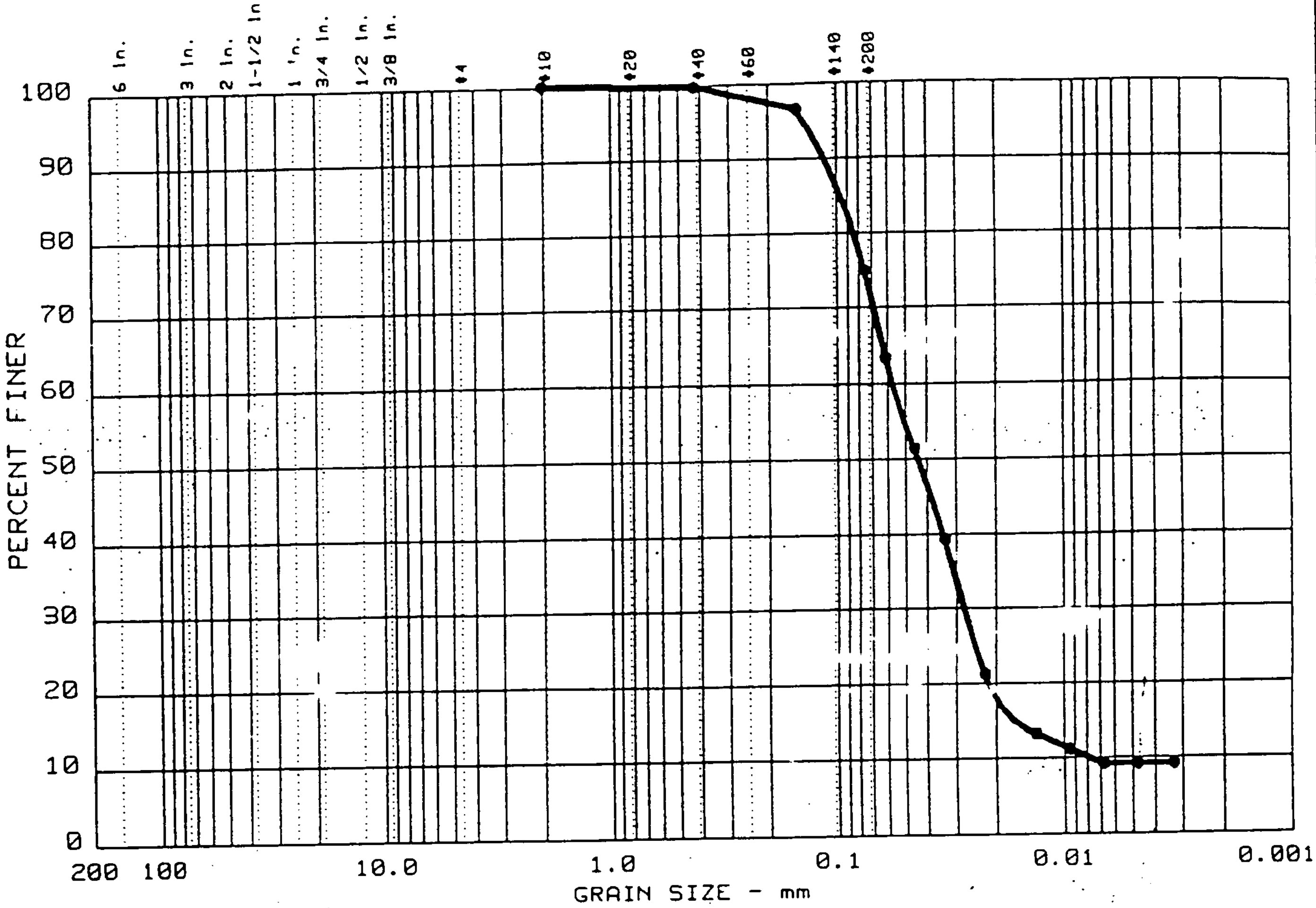
CHE... D.

LABORATORY TESTING SERVICES

A F... ECH... ING

FILE NO. 8955-01

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

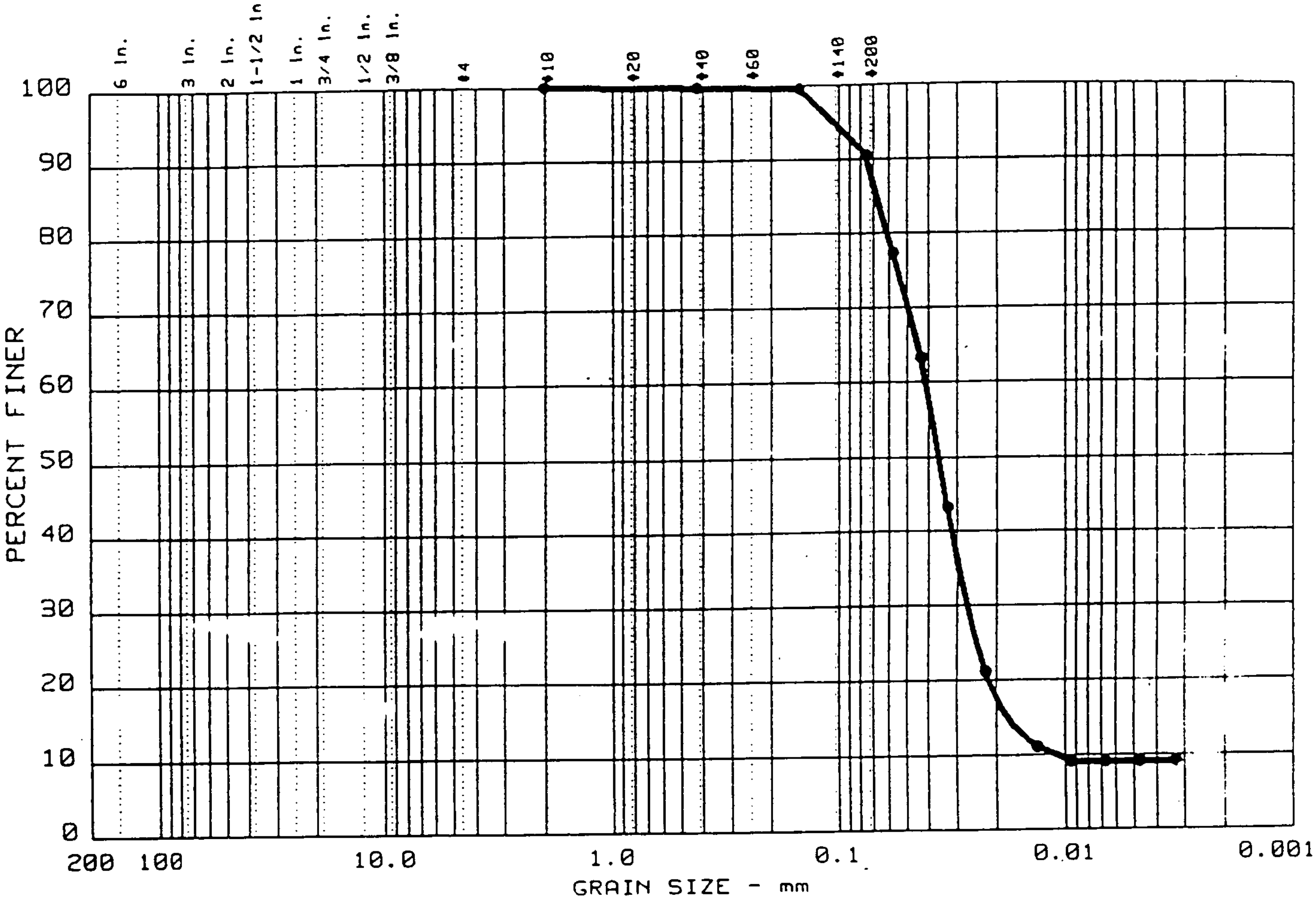
GRAIN SIZE DISTRIBUTION TEST REPORT

SITE-Blauvelt Engineers, Inc.

Remarks:
"PROJECT NO. JG1199"

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

APPENDIX D
ALTERNATIVE 4 COST ESTIMATE SUPPORT DOCUMENTATION

Appendix D

Dry Cleaning Facility Area, Fort Riley, Kansas

Table D-1

Assumed Parameters, Variables and Inputs for Modeling and Costing

Parameter	Parameters Used to Generate Slowest Estimated Time to Meet MCLs	Parameters Used to Generate Fastest Estimated Time to Meet MCLs
Hydraulic Gradient (ft/ft)[1]	0.007	0.014
Hydraulic Conductivity (ft/day)[2]	0.028	100
Soil Porosity[3]	0.35	0.35
Depth of Contamination (ft-bgs)[4]	60	60
Depth of Groundwater Table (ft-bgs)[5]	20	20
Saturated Thickness Groundwater (ft)	40	40
Area of Contaminant Impact (sf)[6]	432,000	432,000
Volume of Contaminant Impact (cf)[7]	17,280,000	17,280,000
Volume of Impacted Groundwater (cf)[8]	6,048,000	6,048,000
Volume of Impacted Groundwater (gal)	45,239,040	45,239,040
Downgradient edge of Contaminant Plume (ft)[6]	1,300	1,300
Transmissivity (ft^2/day)[9]	1.12	4,000
Velocity (ft/day)[10]	1.96E-04	1.4
Seepage Velocity (ft/day)[11]	5.60E-04	4
Assumed Pumping Rate per Well (gpm)[12]	3	6
Number of Wells	12	20
Approximate Total Pumping Rate (gpm)	36	120
Assumed Radius of Influence (ft)[13]	100	65

Notes:

1 From field data.

2 From data published in Principles of Geotechnical Engineering (Das) and values published for production wells elsewhere in alluvium adjacent to the Kansas River.

3 From data published in Principles of Geotechnical Engineering (Das, 1990)

4 Based on assumption that confining bedrock layer is 60 bgs

5 Based on historical groundwater monitoring

6 Based on historical isoconcentration contours

7 Based on impacted area and saturated thickness of groundwater

8 Based on total volume and soil porosity groundwater

9 Equals hydraulic conductivity times saturated thickness

10 Equals hydraulic conductivity times hydraulic gradient

11 Equals velocity divided by porosity

12 Based on engineering judgement

13 Based on engineering judgement

Time 9:05

DETAIL COST REPORT

Project:
DCFFS-ALT 4-5.97
Fort Riley KS
Revised Draft Feasibility Study
JVV
05/04/97

ALTERNATIVE 4 - INSTALLATION OF EXTRACTION WELLS (12), GROUND WATER TREATMENT SYSTEM, AND ACCESS (INCLUDES O+M)

Project Comments:

Site:
DCFFS-ALT 4A-5.97
Dry Cleaning Facility
JVV
05/04/97

Site Comments:

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.03	Site Work			
33.03.78	Access Roads			
33.03.78.01	Access Roads - Capital Costs			
	Light Brush, Heavy Trees, Clear, Grub, Haul	1.38 ACRE	6,537.21	9,021.35
	Rough Grading, 14G, 1 Pass	13,334.00 SY	0.54	7,240.61
	Fine Grading, 130G, 2 Passes	6,667.00 SY	0.14	989.62
	Compact Sand Subgrade (Wet & 2 Passes)	6,667.00 SY	0.36	2,405.21
	Total Capital Costs			19,656.79
	Total Access Roads			19,656.79
33.06	Groundwater Collection and Control			
33.06.98	Extraction Wells			
33.06.98.01	Extraction Wells - Capital Costs			
	6" Well, Portland Cement Grout	192.00 LF	6.80	1,307.23
	6" Screen, Filter Pack	504.00 LF	21.24	10,705.47

Time 9:05

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.06.98	Extraction Wells			
33.06.98.01	Extraction Wells - Capital Costs			
	6" Well, Bentonite Seal	12.00 EA	100.53	1,206.40
	Mud Drilling, 10" Dia Borehole	720.00 LF	22.11	15,925.45
	6" PVC, Sch 40, Well Casing	216.00 LF	10.25	2,214.40
	6" PVC, Sch 40, Well Screen	504.00 LF	20.95	10,562.06
	6" PVC, Well Plug	12.00 EA	74.10	889.30
	Well Developme[illegible]ipment Rental	12.00 WK	365.30	4,383.61
	Standby For Drilling	12.00 EA	135.95	1,631.44
	Mob/Demob Drilling Rig & Crew	1.00 LS	1,087.62	1,087.62
	Move Rig/Equipment Around Site	11.00 EA	33.98	373.87
	Decontaminate Rig, Augers, Screen (Rental Equipment)	7.00 DAY	121.04	847.28
	Furnish 55 Gal Drum For Drilling Cuttings & Devel Water	91.00 EA	38.13	3,470.42
	OVA Rental, Per Day	9.00 DAY	89.00	801.01
	Split Spoon Sample, 2" x 24", During Drilling	144.00 EA	22.25	3,204.00
	(1-1/2",3") PVC Double Wall Piping, w/Fittings	3,000.00 LF	13.09	39,275.06
	GW Pump, 1/3 HP, 230V, Controls, Probe	12.00 EA	4,319.77	51,837.27
	Electrical Charge (KWH)	5,318.00 KWH	0.04	236.65
	Restricted Area, Well Prot (W/4 Posts & Ep Receptacle)	12.00 EA	660.88	7,930.57
	5' Galvanized Chain Link Fence	300.00 LF	8.68	2,606.47
	5' Swing Gate, 12' Double	12.00 EA	291.37	3,496.47
	Total Capital Costs			163,992.05
33.06.98.99	Extraction Wells - O&M Costs			

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.06.98	Extraction Wells			
33.06.98.99	Extraction Wells - O&M Costs			
	Electrical Charge (KWH)	1,034,722.00 KWH	0.04	46,045.13
	Pump & Motor Maintenance/Repair	240.00 EA	275.01	66,003.65
	Total O&M Costs			112,048.78
	Total Extraction Wells			276,040.83
33.13	Physical Treatment			
33.13.07	Air Stripping			
33.13.07.01	Air Stripping - Capital Costs			
	Install Air Strip Tower, 1'-3' Dia, 13'-20' High	1.00 EA	2,757.21	2,757.21
	1.5' Dia x Ht, Pre-Fab, FRP Air Strip Column/Shell Only	25.00 FT	205.10	5,127.74
	1" - 3.5" Packing for Air Strip Tower	32.00 CF	6.67	213.60
	Internal Parts for Air Stripper, < 20' High	2.00 SF	44.50	89.00
	250 CFM, 6" Pressure, 3/4 HP, Blower	1.00 EA	570.52	570.52
	Electrical Controls For Air Stripper	1.00 EA	5,009.21	5,009.21
	550 Gal Horiz Plastic Sump W/4" NPT Connect	1.00 EA	1,822.43	1,822.43
	High Sump Level Switch For Avoiding Overflow	1.00 EA	471.70	471.70
	75 GPM, 2" Discharge, CI Sump Pump	1.00 EA	2,140.37	2,140.37
	5 Gal Bypass Chem Shot Feeder, Floor Mnt, 175 PSIG	1.00 EA	538.02	538.02
	6" Structural Slab On Grade	150.00 SF	3.17	476.04
	2", Class 200, PVC Piping	400.00 LF	2.90	1,161.18
	Electrical Charge (KWH)	3,018.00 KWH	0.04	134.30

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.13.07	Air Stripping			
33.13.07.01	Air Stripping - Capital Costs			
	Total Capital Costs			20,511.32
33.13.07.99	Air Stripping - O&M Costs			
	Electrical Charge (KWH)	195,970.00 KWH	0.04	8,720.67
	Packing Reconditioning	20.00 EA	1,660.44	33,208.80
	Blower And Motor Maintenance And Repair	6.00 EA	275.01	1,650.09
	Total O&M Costs			43,579.56
	Total Air Stripping			64,090.88
33.13.20	Carbon Adsorption (Liquid)			
33.13.20.01	Carbon Adsorption (Liquid)-Capital Costs			
	35 GPM, 1050 Lb Fill, Disposable	1.00 EA	3,033.04	3,033.04
	Saturation Indicator	1.00 EA	66.75	66.75
	8" Structural Slab On Grade	35.00 SF	4.52	158.28
	35 GPM, 1 HP, Transfer Pump W/Motor, Valves, Piping	1.00 EA	1,222.01	1,222.01
	Electrical Charge (KWH)	1,336.00 KWH	0.04	59.45
	Total Capital Costs			4,539.53
33.13.20.99	Carbon Adsorption (Liquid)-O&M Costs			
	35 GPM, 1050 Lb Fill, Disposable	120.00 EA	3,033.04	363,965.37
	Remove/Reinstall Carbon Adsorber Unit	120.00 EA	158.78	19,053.66
	Electrical Charge (KWH)	261,294.00 KWH	0.04	11,627.58
	Pump & Motor Maintenance/Repair	20.00 EA	275.01	5,500.31

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.13.20	Carbon Adsorption (Liquid)			
33.13.20.99	Carbon Adsorption (Liquid)-O&M Costs			
	Total O&M Costs			400,146.92
	Total Carbon Adsorption (Liquid)			404,686.45
	TOTAL DIRECT COSTS REMEDIAL ACTION			764,474.95

DETAIL COST REPORT

ALt 4
CAT OX
SLOW FLUSH
25 YEARS

Project:
ALTERNATIVE 4
Fort Riley KS
CAt OX for Alt 4
JVV
06/26/97

Project Comments:

Site:
DCFA
DCFA Alt 4
JVV
06/26/97

Site Comments:

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.14	Thermal Treatment			
33.14.92	Thermal and Catalytic Oxidation			
33.14.92.01	Thermal & Catalytic Oxidation - Cap Csts			
	100 scfm Fixed Bed Catalytic Unit	1.00 EA	27,667.27	27,667.27
	Electrical Charge (KWH)	48.00 KWH	0.04	2.14
	Natural Gas Usage, per 1000 cf	25.00 MCF	4.45	111.25
	4" PVC, Sch 40, Well Casing	30.00 LF	7.63	228.95
	4" PVC, 90 Degree, Elbow	2.00 EA	31.56	63.12
	Operational Labor Cost	1.00 DAY	618.49	618.49
	8" Structural Slab On Grade	50.00 SF	4.52	226.12
	Total Capital Costs			28,917.34
33.14.92.99	Thermal & Catalytic Oxidation - O&M Csts			
	Electrical Charge (KWH)	15,571.00 KWH	0.04	692.91
	Natural Gas Usage, per 1000 cf	7,867.00 MCF	4.45	35,008.15

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.14.92	Thermal and Catalytic Oxidation			
33.14.92.99	Thermal & Catalytic Oxidation - O&M Csts			
	Precious Metal Catalyst			
		0.90 SCF	2,848.00	2,563.20
	Operational Labor Cost			
		300.00 DAY	618.49	185,547.30
	Total O&M Costs			223,811.56
	Total Thermal and Catalytic Oxidation			252,728.90
	TOTAL DIRECT COSTS REMEDIAL ACTION			
				252,728.90

DETAIL COST REPORT

Project:
DCFFS-ALT 4-5.97
Fort Riley KS
Revised Draft Feasibility Study
JVV
05/04/97

ALTERNATIVE 4- INSTALLATION O EXTRACTION WELLS (20), GROU. WATER TREATMENT SYSTEM, AND ACCESS ROAD (INCLUDES O+M)

Project Comments:

Site:
DCFFS-AL 4B-5.97
Dry Cleaning Facility
jvv
05/04/97

Site Comments:

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.03	Site Work			
33.03.78	Access Roads			
33.03.78.01	Access Roads - Capital Costs			
	Light Brush, Heavy Trees, Clear, Grub, Haul	1.38 ACRE	6,537.21	9,021.35
	Rough Grading, 14G, 1 Pass	15,334.00 SY	0.54	8,326.64
	Fine Grading, 130G, 2 Passes	6,667.00 SY	0.14	989.62
	Compact Sand Subgrade (Wet & 2 Passes)	7,667.00 SY	0.36	2,765.97
	Total Capital Costs			21,103.58
	Total Access Roads			21,103.58
33.06	Groundwater Collection and Control			
33.06.98	Extraction Wells			
33.06.98.01	Extraction Wells - Capital Costs			
	6" Well, Portland Cement Grout	320.00 LF	6.80	2,178.72
	6" Screen, Filter Pack	840.00 LF	21.24	17,842.44

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.06.98	Extraction Wells			
33.06.98.01	Extraction Wells - Capital Costs			
	6" Well, Bentonite Seal	20.00 EA	100.53	2,010.66
	Mud Drilling, 10" Dia Borehole	1,200.00 LF	22.11	26,542.43
	6" PVC, Sch 40, Well Casing	360.00 LF	10.25	3,690.67
	6" PVC, Sch 40, Well Screen	840.00 LF	20.95	17,603.43
	6" PVC, Well Plug	20.00 EA	74.10	1,482.16
	Well Development Equipment Rental	20 00 WK	365.30	7,306.01
	Standby For Drilling	20.00 EA	135.95	2,719.07
	Mob/Demob Drilling Rig & Crew	1.00 LS	1,087.62	1,087.62
	Move Rig/Equipment Around Site	19.00 EA	33.98	645.78
	Decontaminate Rig, Augers, Screen (Rental Equipment)	12.00 DAY	121.04	1,452.48
	Furnish 55 Gal Drum For Drilling Cuttings & Devel Water	152.00 EA	38.13	5,796.75
	OVA Rental, Per Day	14.00 DAY	89.00	1,246.01
	Split Spoon Sample, 2" x 24", During Drilling	240.00 EA	22.25	5,340.00
	(1-1/2",3") PVC Double Wall Piping, w/Fittings	5,000.00 LF	13.09	65,458.44
	GW Pump, 1/3 HP, 230V, Controls, Probe	20.00 EA	4,319.77	86,395.44
	Electrical Charge (KWH)	8,863.00 KWH	0.04	394.40
	Restricted Area, Well Prot (W/4 Posts & Ep Receptacle)	20.00 EA	660.88	13,217.63
	5' Galvanized Chain Link Fence	500.00 LF	8.68	4,344.11
	5' Swing Gate, 12' Double	20.00 EA	291.37	5,827.45
	Total Capital Costs			272,581.70
33.06.98.99	Extraction Wells - O&M Costs			

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.06.98	Extraction Wells			
33.06.98.99	Extraction Wells - O&M Costs			
	Electrical Charge (KWH)			
		574,846.00 KWH	0.04	25,580.65
	Pump & Motor Maintenance/Repair			
		120.00 EA	275.01	33,001.83
	Total O&M Costs			58,582.48
	Total Extraction Wells			331,164.18
33.13	Physical Treatment			
33.13.07	Air Stripping			
33.13.07.01	Air Stripping - Capital Costs			
	Install Air Strip Tower, 1'-3' Dia, 13'-20' High			
		1.00 EA	2,757.21	2,757.21
	3' Dia x Ht, Pre-Fab, FRP, Air Strip Column/Shell Only			
		25.00 FT	468.44	11,711.07
	1" - 3.5" Packing for Air Strip Tower			
		128.00 CF	6.67	854.40
	Internal Parts for Air Stripper, < 20' High			
		8.00 SF	44.50	356.00
	750 CFM, 8" Pressure, 1.5 HP, Blower			
		1.00 EA	868.96	868.96
	Electrical Controls For Air Stripper			
		1.00 EA	5,009.21	5,009.21
	1,000 Gal Horiz Plastic Sump W/4" NPT Connect			
		1.00 EA	2,328.39	2,328.39
	High Sump Level Switch For Avoiding Overflow			
		1.00 EA	471.70	471.70
	100 GPM, 2-1/2" Discharge, CI Sump Pump			
		1.00 EA	2,440.64	2,440.64
	5 Gal Bypass Chem Shot Feeder, Floor Mnt, 175 PSIG			
		1.00 EA	538.02	538.02
	6" Structural Slab On Grade			
		150.00 SF	3.17	476.04
	2", Class 200, PVC Piping			
		200.00 LF	2.90	580.59
	Electrical Charge (KWH)			
		4,694.00 KWH	0.04	208.88

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.13.07	Air Stripping			
33.13.07.01	Air Stripping - Capital Costs			
	Total Capital Costs			28,601.11
33.13.07.99	Air Stripping - O&M Costs			
	Electrical Charge (KWH)	304,840.00 KWH	0.04	13,565.38
	Packing Reconditioning	20.00 EA	1,660.44	33,208.80
	Blower And Motor Maintenance And Repair	6.00 EA	275.01	1,650.09
	Total O&M Costs			48,424.27
	Total Air Stripping			77,025.38
33.13.20	Carbon Adsorption (Liquid)			
33.13.20.01	Carbon Adsorption (Liquid)-Capital Costs			
	Dual Bed,50 GPM Ser,100 GPM Para,1760 Lb Fill Ea	1.00 EA	12,488.18	12,488.18
	Saturation Indicator	2.00 EA	66.75	133.50
	8" Structural Slab On Grade	77.00 SF	4.52	348.22
	Electrical Charge (KWH)	6,678.00 KWH	0.04	297.17
	Total Capital Costs			13,267.07
33.13.20.99	Carbon Adsorption (Liquid)-O&M Costs			
	Coal Based Gen Purpose, 8X30 Sieve, 900 Iodine, <2K Lb	140,800.00 lb	1.29	181,702.40
	Remove/Reinstall Carbon Adsorber Unit	80.00 EA	158.78	12,702.44
	Electrical Charge (KWH)	435,489.00 KWH	0.04	19,379.26
	Pump & Motor Maintenance/Repair	6.00 EA	275.01	1,650.09
	Total O&M Costs			215,434.19
	Total Carbon Adsorption (Liquid)			228,701.26
	TOTAL DIRECT COSTS REMEDIAL ACTION			657,994.40

ALT 4
CAT OX
FAST FLUSH 8yrs

DETAIL COST REPORT

Project:
ALTERNATIVE 4B
Fort Riley KS
Catalytic Oxidizer
JVV
06/26/97

Project Comments:

Site:
DCFA
CAt Ox @ DCFA
JVV
06/26/97

Site Comments:

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.14	Thermal Treatment			
33.14.92	Thermal and Catalytic Oxidation			
33.14.92.01	Thermal & Catalytic Oxidation - Cap Csts			
	250 scfm Fixed Bed Catalytic Unit	1.00 EA	30,248.27	30,248.27
	Electrical Charge (KWH)	192.00 KWH	0.04	8.54
	Natural Gas Usage, per 1000 cf	98.00 MCF	4.45	436.10
	4" PVC, Sch 40, Well Casing	30.00 LF	7.63	228.95
	4" PVC, 90 Degree, Elbow	2.00 EA	31.56	63.12
	Operational Labor Cost	1.00 DAY	618.49	618.49
	8" Structural Slab On Grade	100.00 SF	4.52	452.24
	Total Capital Costs			32,055.71
33.14.92.99	Thermal & Catalytic Oxidation - O&M Csts			
	Electrical Charge (KWH)	19,931.00 KWH	0.04	886.93
	Natural Gas Usage, per 1000 cf	10,070.00 MCF	4.45	44,811.50

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.14.92	Thermal and Catalytic Oxidation			
33.14.92.99	Thermal & Catalytic Oxidation - O&M Csts			
	Precious Metal Catalyst	1.10 SCF	2,848.00	3,132.80
	Operational Labor Cost	96.00 DAY	618.49	59,375.13
	Total O&M Costs			108,206.36
	Total Thermal and Catalytic Oxidation			140,262.07
	TOTAL DIRECT COSTS REMEDIAL ACTION			140,262.07

APPENDIX E
ALTERNATIVE 6 COST ESTIMATE SUPPORT DOCUMENTATION

DETAIL COST REPORT

Project:
DCFFS-ALT 6-5.97
Fort Riley KS
Revised Feasibility Study
JVV
05/05/97

ALTERNATIVE 6. INSTALLATION OF SLURRY WALL INCLUDING CLEARING AND ACCESS ROAD

Project Comments:

Site:
DCFFS-ALT 6A-5.97
Dry Cleaning Facility
JVV
05/05/97

Site Comments:

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.03	Site Work			
33.03.02	Clear and Grub			
33.03.02.01	Clear and Grub - Capital Costs			
	Medium Brush W/O Grub, Clearing	1.50 ACRE	134.34	201.52
	Clear Trees To 6" Dia W/D8 Cat	120.00 EA	5.13	616.76
	Clear Trees To 12" Dia W/D8 Cat	38.00 EA	9.59	364.57
	> 6" and <= 12" Stump Removal, W/D8	150.00 EA	5.75	863.46
	Total Capital Costs			2,046.31
	Total Clear and Grub			2,046.31
33.03.78	Access Roads			
	Light Brush, Heavy Trees, Clear, Grub, Haul	0.23 ACRE	6,537.21	1,503.56
	Rough Grading, 14G, 1 Pass	2,556.00 SY	0.54	1,387.96
	Fine Grading, 130G, 2 Passes	1,112.00 SY	0.14	165.06
	Compact Sand Subgrade (Wet & 2 Passes)	1,278.00 SY	0.36	461.06

DETAIL COST REPORT

		Quantity	$/UM	Totals
33	REMEDIAL ACTION			
33.03.78	Access Roads			
33.03.78.01	Access Roads - Capital Costs			
	Total Capital Costs			3,517.64
	Total Access Roads			3,517.64
33.06	Groundwater Collection and Control			
33.06.03	Slurry Walls			
33.06.03.01	Slurry Walls - Capital Costs			
	Level and Compact Working Surface	1,889.00 CY	3.07	5,804.15
	Construct Dike for Mixing Basin	189.00 CY	3.07	580.72
	Normal Soil, 26'-75', Slurry Wall Excavation	10,862.00 CY	3.51	38,208.99
	Cat 235, 2 CY, Rock, No Hauloff Or Borrow, Trenching	662.00 BCY	49.63	32,855.38
	Bentonite, Material Purchase Price Per Ton	3,332.00 TN	133.50	444,822.00
	Slurry Mixing, Hydration, and Placement, Per Gallon	927,670.00 GAL	0.02	24,423.67
	Soil-Bentonite Backfill Mixing, Per Cubic Yard	12,467.00 CY	1.78	22,230.33
	Backfill Slurry Wall Trench, 1000' Avg Haul Distance	12,467.00 CY	1.40	17,503.16
	Backfill Trench, Borrow Mat'l, Delivered & Dumped Only	4,364.00 CY	5.29	23,104.18
	Demolish Mixing Basins and Re-grade Working Surface	51,000.00 SF	0.04	2,155.29
	Topsoil, 6" Lifts, On-Site	119.00 CY	3.67	437.63
	Seeding, Vegetative Cover	0.11 ACRE	1,321.36	145.35
	Watering With 3,000 Gal Tank Truck, Per Pass, 1kgal/AC	0.11 ACRE	34.09	3.75
	Total Capital Costs			612,274.60
	Total Slurry Walls			612,274.60
	TOTAL DIRECT COSTS REMEDIAL ACTION			617,[illegible].55

WHEN TOXICS MEET METAL

Virginia Fairweather

A new technology, zero-valent iron, reduces subsurface chlorinated solvents to harmless substances, has low operation and maintenance costs, and involves no surface paraphernalia that restrict property use. The method works as deep as 75 ft beneath the surface and renders ground water free of these difficult-to-treat contaminants.

Zero-valent iron is a technology "poised to take off," says Steven McCutcheon, EPA National Research Laboratory, Athens, Ga. He wants to see 10 reactive iron walls in place in five years, and 100 in the next 10 years. At a savings he estimates to be about 50% over the average costs of cleanup, the taxpayer should be ahead $750 million. But there is more work to be done. Zero-valent iron is "the most intriguing idea that has emerged in the remediation field," according to Lynn Roberts of the department of geography and environmental engineering at Johns Hopkins University, one of many researchers currently probing the remaining unknowns in the process.

Using iron to transform chlorinated solvents into innocuous components is a relatively new technology. Robert Gillham, professor of earth sciences at the University of Waterloo, Waterloo, Ontario, is generally regarded as the man who had the inspiration to apply research done back in the 1970s, and even patented, to the knotty problem of remediating chlorinated solvents in ground water. Research in the last four or five years has shown that granular iron can degrade harmful compounds such as trichloroethylene (TCE), perchloroethylene and vinyl chloride fairly swiftly and safely.

Paul Tratnyek, assistant professor at the Oregon Graduate Institute, is an environmental chemist working since 1991 on "how the treatment works." He describes the process as taking advantage of the chemical reaction taking place when iron in zero-valent form is oxidized. The chlorinated solvent is the agent that does the oxidizing, and the result is dechlorination, ultimately producing chloride and hydrocarbons. It's basically the same process that goes on during metal corrosion, put to use in "a beneficial way," he says.

Gillham, the University of Waterloo, and Beak Consultants, Ltd., Guelph, Ontario, formed EnviroMetal, Inc., or ETI, in 1992 to "market and implement" the technology. The method works by placing a porous wall of iron in the path of a contaminated groundwater plume. As the water passes through the permeable barrier, the chlorinated solvents are transformed into harmless substances. At some sites, a funnel and gate installation directs the contaminants to the wall, by means of slurry walls or sheet piling. So far installations have been limited to 45 or 50 ft below the surface, but Gillham says that geotechnical engineers have assured him that 100 ft should be "no problem." However, cost effectiveness at that depth is uncertain. ETI is currently involved in several pilot studies and in three small full-scale applications, two in California, one in Belfast, Ireland. Pending applications are a Superfund site in Somersworth, N.H. and another project in Elizabeth City, N.C.

In addition, McCutcheon points that a definitive proof of concept demonstration on a 300 ft plume has been proposed by the Department of Defense Strategic Environmental Research and Development Program. So performance data on the method will surely proliferate in the next several years.

Gillham lists the advantages of zero-valent iron as he sees them. The fact that there are no aboveground structures, and "no evidence that remediation is proceeding" means sites can be used for other things, such as parking lots. The contaminants are degraded instead of being transported elsewhere, which he says is desirable in the eyes of EPA. Finally, in the long term, the method should be economic. There are no or low operation and maintenance costs.

There are unknowns, Gillham is quick to point out. Long-term performance data are scarce, although a site at a Canadian Air Force base in Ontario has been operating for almost five years. University of Waterloo researchers have done core tests on that reactive wall, which "hasn't changed

Bentonite and filter rock are used to direct groundwater flow to the reactive iron wall.

0885-7024/96-0005-0044/$04.00+.50c per page

A reactive cell with top whaler support.

so far." But he is loath to extrapolate these data to other sites and agrees that more data are needed. Some researchers are concerned about precipitates clogging the reaction wall, slowing the process. As the pH goes up from the reaction of the iron and the water, inorganic constituents will precipitate, he says. Gillham and others are looking at chemical ways to rejuvenate the walls. "Replacing the walls would be expensive if you had to do it every year, but if you have to do this every 10 years, the method is cost-competitive," he thinks. Most researchers have seen more precipitation in the lab than in the field, and as more data accumulates, "we are becoming more confident" about the durability of the walls, he suggests.

SUNNYVALE SUCCESS STORY

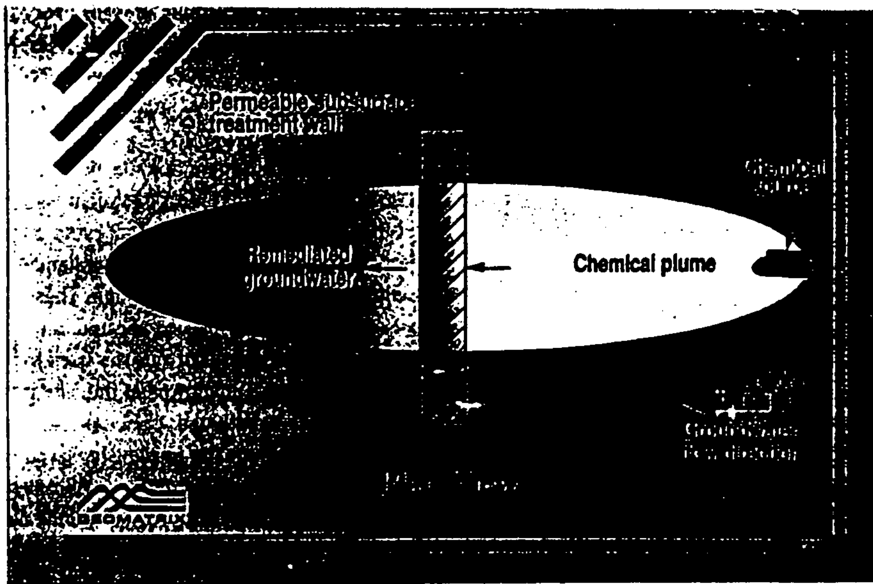
Deborah Hankins is a professional engineer who oversees several remediation sites for the General Electric Corp. (GE), including a former semiconductor manufacturing site at Sunnyvale, Calif. Hankins heard about the zero-valent technology through the University Consortium on Solvents in Ground Water Research Program, Remediation of Chlorinated Solvents, a group that combines EPA, Department of Energy, private-sector corporations, including GE, and several universities, including the University of Waterloo and Oregon Graduate Institute. She decided to give the process a try and put GE's consultant, Geomatrix, a San Francisco–based consulting firm, in touch with ETI's. A pump-and-treat system had been installed in 1986 at the site, leased by a GE subsidiary, Intersil.

Geomatrix assembled a team of hydrogeologists, microbiologists, geochemists and civil and structural engineers, including Scott Warner, a senior hydrogeologist. Working with ETI, they designed and installed the zero-valent iron system in December 1994. Subsequently, the aboveground pumping equipment was removed, and the site leased to another company that used it for a parking lot. The installation includes a 300 ft slurry wall on one side of the containment area, a 235 ft wall on the other and a reactive gate 40 ft wide, 4 ft thick and 13 ft deep. So far, Warner says, the system "works like a charm," removing the contaminants. The site is monitored to ensure compliance with regulatory requirements set forth by the regional Water Quality Control Board.

The prior pump-and-treat system had cost $300,000 per year to operate, maintain and manage. So Hankins sees the new system as having a three-year payoff. She adds that the landlord at the site refused to let GE out of their lease until the zero-valent system began operating. Now the landlord has released the firm and rented the site to a new tenant. GE will continue, however, to monitor the site, she says.

Warner is enthusiastic about zero-valent–iron remediation and says Geomatrix would like to use the method elsewhere. He believes the problem with mineral precipitation clogging has been observed mainly in lab studies and that it might be due in part to excess oxygen. Underground "you are in an anaerobic situation," and this process might be less of a concern. He does note that the method might not work everywhere. Depth is an issue, and he thinks 50–75 ft depth might be the limit at which one can maintain the wall's integrity using traditional methods. The bottom of the containment area is important, too. At the Intersil site, he says, there is a 65 ft thick clay layer that acts as an aquitard.

The other full-scale application is also Sunnyvale, where consulting firm Secor



tive iron wall

Robert Puls, with EPA's National Risk Management Laboratory in Ada, Okla., worked on a field pilot project installed at Elizabeth City, N.C. in September 1994. This project will go full scale this June, funded by EPA and the U.S. Coast Guard. The site is a chrome-plating facility used by both the Navy and Coast Guard for plating aircraft engine parts. The zero-valent method changed several parts per million of dissolved chromate to nondetectable levels through reduction and subsequent precipitation as an insoluble nontoxic iron-chromium hydroxide mineral phase. During the pilot, Puls and his coworkers also studied two different kinds of iron. One proved to be more effective in reducing the chromate in the ground water, and the other iron was more effective on the chlorinated organic compounds.

Yet a third kind of iron (manufactured by Peerless Metal Powders and Abrasives, Detroit) will be used in the first full-scale application of zero-valent–iron treatment at a mixed-waste site (organic and inorganic), says Puls. The pilot test treated a 12 ft section of the plume, 24 ft deep, and the full-scale project will treat all 150 ft of the mixed waste plume to a 24 ft depth. One objective of the project is to provide guidance on monitoring sites, says Puls, and another is to give guidance on the optimum amount of site characterization needed for an economic and effective design. He expects there will be detailed long-term monitoring for the installation for at least five years.

San Francisco office installed a system with ETI for another private sector electronics firm. At that site, Secor's Brent Brelje says the schedule drove the design. The site had to be remediated and construction completed between July and September 1995. Contaminants from a former owner had migrated horizontally under a building, which meant that about 4,000 sq ft of that building had to be demolished. During excavation, Secor and ETI decided that the permeable backfill and the site's "very tight" soils could work as a funnel and gate directing the plume through a reactive iron wall. The remediation area is 60 by 40 ft and 25 ft deep, says Brelje, and because of the tight schedule, they "used a safety factor of about five, and placed about 90 tons of iron in the wall." The entire system cost between $80,000 and $100,000, Brelje estimates. However, they predict the system should work for 30 years, and the previously installed pump-and-treat system is now sitting idle.

PILOTS POISED FOR FULL SCALE

Gregg Somermeyer, with Secor's Fort Collins, Colo., office, applied reactive iron technology at a private sector industrial site in Kansas with "a complex history of owners and site use." His firm, he says, had "confidence in the zero-valent–iron method" as an interim measure, and is compiling "actual" field data on the technology and on construction costs. Somermeyer, like others, worked closely with ETI at the site. Up-front capital costs for this particular site might be greater than for a "simple" pump-and-treat, but in the long run, Somermeyer points out, operation and maintenance costs should be significantly less. At this site Secor and ETI jointly designed and constructed a funnel and gate installation that has 1,000 ft of slurry wall, a ... ft long, 3 ft thick wall. The system is designed for a capture zone 500 ft wide and 30 ft deep. If the resulting data match predicted performance, the existing system could be expanded to treat the entire dissolved plume.

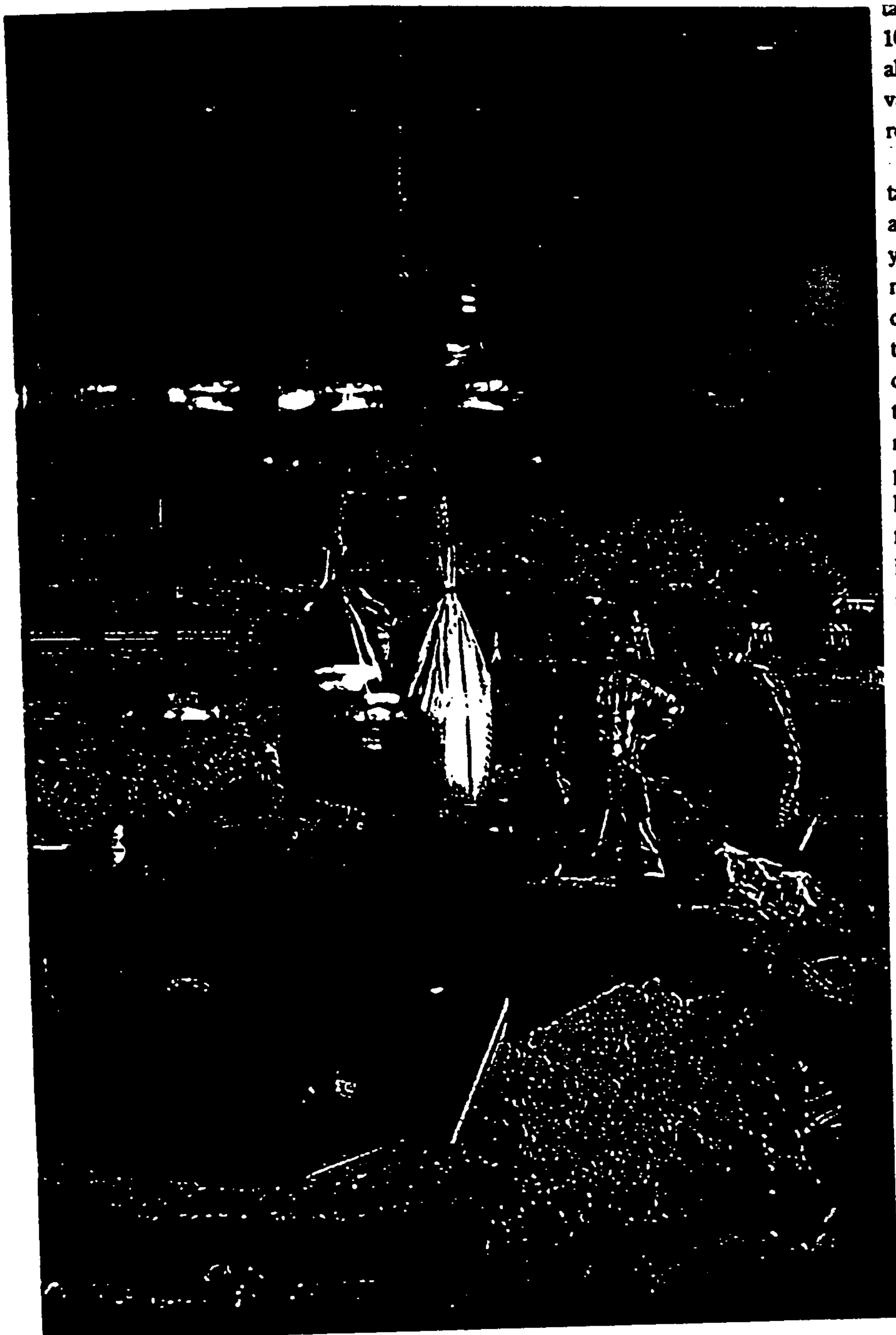
Dames & Moore is also looking at zero-valent iron along with other innovative ground-water treatment methods, according to Brian Myller of the firm's Denver office. Myller managed a pilot installation at Lowry Air Force Base near Denver on a project funded through the Air Force Center for Environmental Excellence. Myller heard about zero-valent technology via previous collaborative research with the University of Waterloo, and thought Gillham's idea had "significant promise."

At Lowry, TCE had been migrating through sediments to bedrock and dissolving to form a ground-water plume, says Myller. Dames & Moore and ETI built a reactive wall system, finished in December 1995. "So far it's working well," he says, "destroying the TCE." Dames & Moore has several other proposals with ETI "out there" to design and install zero-valent–iron systems, and hope to do more work using the technology.

> According to Air Force numbers, zero-valent iron technology should reduce remediation costs by about 50% for chlorinated solvents.

COST COMPARISONS

EPA's Steve McCutcheon agrees with the general assessment of the advantages of zero-valent–iron technology: The method is passive, you don't have operation costs, it can be used at remote sites, and the surface of a contaminated site can be used for other purposes. However, he believes a "definitive demonstration on a larger scale and a good disinterested design manual" are essential.



Lowering bags of iron reactant into a cell.

McCutcheon hopes to collect data from a project with ETI at one of several U.S. Air Force bases. The installation would have "rigorous monitoring," using tracers and taking sample cores. The goal would be to estimate the life of a reactive wall. McCutcheon is negotiating with the U.S. Army Corps of Engineers to publish the design manual, based on this project and others.

McCutcheon, who has been working since 1992 on the technology thinks degradation is still a "black box" to many. He wants to see it explained clearly, and wants more data on clogging and on types of iron used to reduce the chlorinates. He and other EPA scientists think there are still some mysteries. Pure iron does not react with chlorinated solvents, for example, and hydrogen alone does not react. Some chlorinated solvents do not react with iron. He would like to see clearer explanations of degradation processes and the ultimate geochemical state of the iron as it relates to precipitation and biofouling.

Costs are another important issue. McCutcheon says, as a rule of thumb, the Air Force estimates operation and maintenance costs are "zero" compared to pump and treat. He thinks this is optimistic and that clogging and biofouling will necessitate replacement or cleaning [illegible] 10 years. Those costs are unknown. Overall, according to Air Force numbers, zero-valent-iron technology should reduce remediation costs by about 50%.

At the Intersil site in Sunnyvale, the capital costs were $770,000 for a treatment wall and the costs of replacing the wall every 10 years and conducting simple compliance monitoring could be about $2 million. These costs are higher than will be expected in future walls. A safety factor of four was used to compensate for the unknowns at the site at that time. The estimated operation and maintenance costs for the previously placed pump-and-treat system were almost $8 million over the 30-year estimated operation, a fourfold increase. Finally, these costs do not include the value of being able to reuse the site, says McCutcheon

ETI's Gillham says the cost of the iron itself, a by-product of manufacturing operations, ranges from $400 to $450 per ton. This is down from the early stages of the technology when researchers paid up to $700 per ton, he says. Now there are more suppliers available.

INTRIGUING RESEARCH

Lynn Roberts, of the Department of Geography and Environmental Engineering at Johns Hopkins, says the zero-valent-iron technology has "gripped the research and consulting communities." One of dozens of scientists working in this field, her research focuses on the chemical pathways through which metals react with halogenated solvents, in particular on any possibility of creating harmful by-products. "You need to know all the reaction products that might result," she says, "because this may influence the design and thus the cost of a successful treatment wall."

David Burris is doing his research at the Armstrong Laboratory at Tyndall Air Force Base. His group is working on chlorinated solvent transformations and zero-valent iron is one of the "biggest parts" of their effort. They are focusing on the reaction pathways and the effect of sorption on the iron. They've looked at different sizes of grains and at different and cheaper kinds of iron, he says. The latter was less reactive and therefore slower. The group might also look at some other metals. In the end, Burris says, "the economics might be what drives the technology." He describes the research efforts as "fine-tuning" a technology moving in a positive direction. ◻

Field Application of Reactive Iron Walls for In-Situ Degradation of Volatile Organic Compounds in Groundwater

Robert Focht • John Vogan • Stephanie O'Hannesin

Robert Focht is a project manager with EnviroMetal Technologies Inc. (ETI). He joined ETI in 1995 and has served as ETI's field engineer on several of the installations completed to date. John Vogan is Manager of ETI and has been involved in the planning and design of all of the commercial installations implemented by the firm. Mr. Vogan joined the firm in 1993 after several years of consulting in Ontario. Stephanie O'Hannesin is a research project manager at the University of Waterloo. In 1991 she undertook the initial in-situ field trial of the granular iron reactive wall technology. She has assisted ETI with various stages of technology application at commercial sites since the company was founded in 1992.

Reactive walls containing metallic iron have been installed at several commercial sites in the United States to degrade chlorinated organic compounds in groundwater. Although the results of laboratory studies conducted to determine reaction mechanisms have been widely disseminated, little information has been published on the full-scale application of this technology. This article describes the construction, implementation, and cost of in-situ reactive walls at three commercial sites.

In-situ permeable treatment zones containing granular iron are currently in use to remediate groundwater contaminated with dissolved chlorinated solvents at many private and government facilities in the United States. This method of treatment, developed from research initiated at the Institute for Groundwater Research, University of Waterloo, involves placing granular iron in in-situ permeable zones, across the path of groundwater containing VOCs. As the contaminated groundwater flows through the permeable zones, the chlorinated solvent reacts with the granular iron. Although the iron does not have to be replaced because of the reaction rate, it may have to be replaced because of hydraulics.

This passive treatment system offers many advantages over conventional pump-and-treat systems. In particular, the contaminants degrade to nontoxic chemicals, and with proper placement, only contaminated water is treated. Because the process is fully passive, substantial reductions in operation and maintenance costs are anticipated.

EnviroMetal Technologies Inc. (ETI) was founded in 1992 to implement this patented technology on a commercial scale. More than 40 treatability studies of the technology have been initiated in the past two years at private and government sites in the United States and Canada. Many of these have now reached various stages of field implementation. Full-scale in-situ treatment zones have been installed at two private industrial facilities in California and one in Belfast, Northern Ireland. Three

CCC 1051-5658/96/060381-14

pilot-scale in-situ treatment zones were installed in 1995 and 1996, and several others are planned over the next 12 months. These three case studies applying the technology in the past 18 months illustrate the technical and economic considerations involved in construction of these in-situ treatment systems.

REACTION CHEMISTRY

Considerable research during the past five years has focused on the degradation of chlorinated solvents, such as trichloroethylene and perchloroethylene, by reactions with granular iron. Although faced with considerable initial skepticism, it is now widely accepted that the process is an abiotic reductive dehalogenation with psuedo-first order kinetics. Although details of the reaction chemistry remain unknown, the process involves the simultaneous oxidative corrosion of the reactive iron metal by both water and the chlorinated organic compounds (Matheson and Tratnyek, 1994; Orth and Gillham, 1996). The two half-reactions involving iron and TCE can be shown as:

$$Fe^{o} \rightarrow Fe^{+2} + 2e^{-} \quad (1)$$

$$C_2HCl_3 + 3H^{+} + 6_e^{-} \rightarrow C_2H_4 + 3Cl^{-} \quad (2)$$

These are accompanied by the hydrolysis of water and subsequent formation of hydrogen gas:

The process involves the simultaneous oxidative corrosion of the reactive iron metal by both water and the chlorinated organic compounds.

$$2H_2O + 2_e^{-} \rightarrow H_{2(g)} + 2OH^{-} \quad (3)$$

As suggested by equation (2), TCE degrades spontaneously in the presence of iron, requiring no additives or application of energy, and the products are chloride and nontoxic hydrocarbons.

In bench-scale studies using contaminated water from commercial sites, 10 to 20 percent of the original TCE appears as cis-1,2-dichloroethene (cDCE) and less than 1 percent as vinyl chloride (VC). However, these breakdown products also degrade in the presence of granular iron given sufficient contact time. For chlorinated methanes and ethanes such as carbon tetrachloride and 1,1,1-trichloroethane (1,1,1-TCA), the percentage of chlorinated breakdown products (e.g., trichloromethane from carbon tetrachloride and 1,1-dichloroethane from 1,1,1-TCA) is higher. **Exhibit 1** lists the chlorinated volatile organic compounds (VOCs) that have been successfully degraded by the process in commercial applications, as well as those that do not appear to degrade.

The dissociation of water, as shown in equation (3), has important consequences with respect to the potential operation and maintenance (O&M) associated with the technology. As a result of the increase in pH, carbonate minerals, including calcium carbonate ($CaCO_3$) and siderite (Fe_3CO), may precipitate in the reactive material. With exhaustion of the carbonate buffering capacity, further pH increases can result in the precipitation of ferrous hydroxides ($Fe(OH)_2$). This precipitation process

Exhibit 1. Compounds Evaluated during Treatability Studies

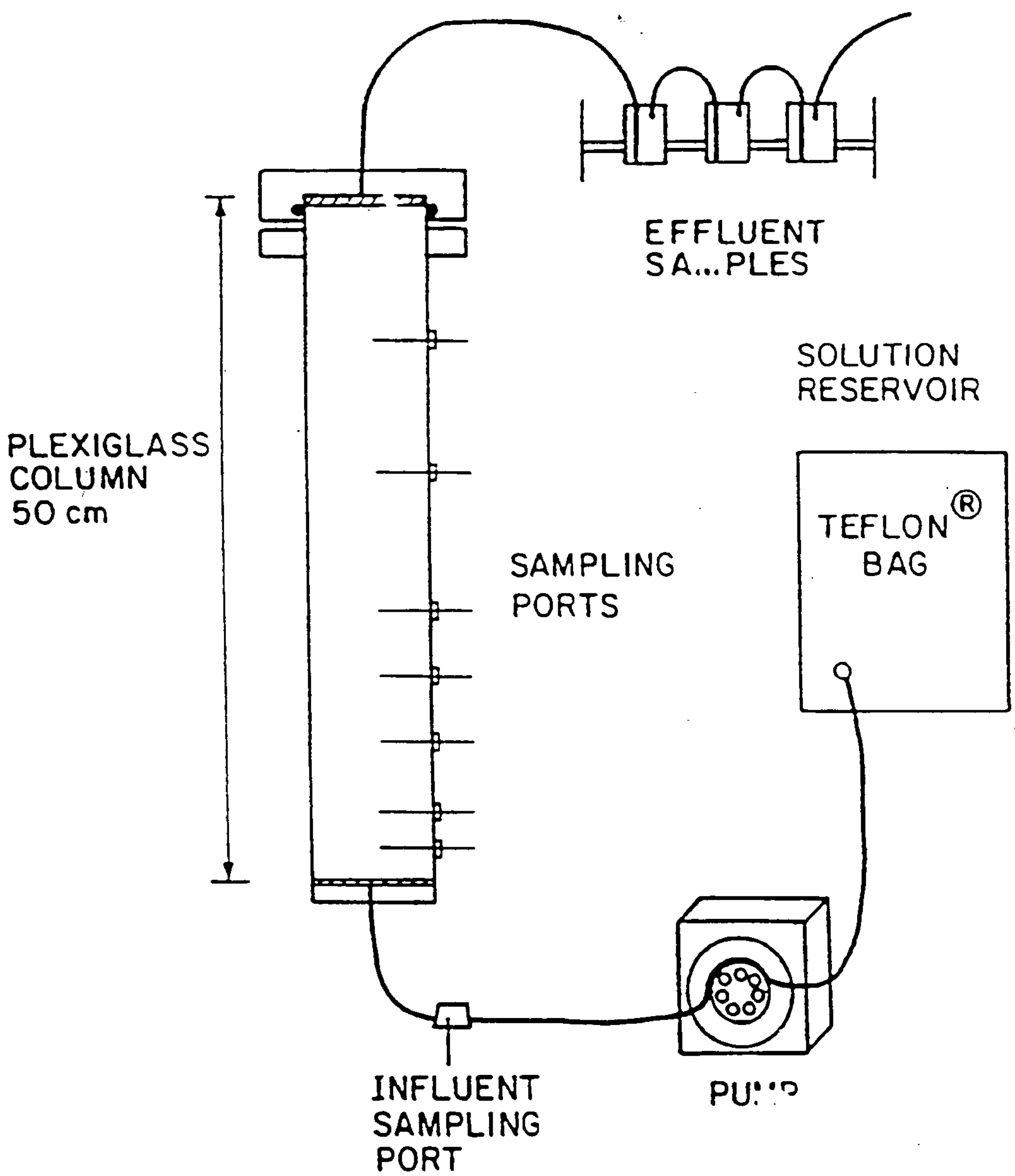
Compound	Successfully Degraded Yes	No
Methanes		
tetrachloromethane	✓	
trichloromethane	✓	
dichloromethane		✓
Ethanes		
hexachloroethane	✓	
1,1,1-trichloroethane	✓	
1,1,2-trichloroethane	✓	
1,1-dichloroethane	✓	
1,2-dichloroethane		✓
chloroethane		✓
Ethenes		
tetrachloroethene	✓	
trichloroethene	✓	
cis-1,2-dichloroethene	✓	
trans-1,2-dichloroethene	✓	
1,1-dichloroethene	✓	
vinyl chloride	✓	
Propanes		
1,2,3-trichloropropane	✓	
1,2-dichloropropane	✓	
Other		
hexachlorobutadiene	✓	
1,2-dibromoethane	✓	
freon 113	✓	

results in clogging of the system and, possibly, coating of the granular iron surface. Clogging or coating inhibits the performance of the system, necessitating replacement or flushing of the granular iron every few years in areas where groundwater may have a high mineral content.

IMPLEMENTATION PROCEDURE

The initial phase in applying the technology at a site involves bench-scale tests, where groundwater from the site is pumped through a column containing granular iron (**Exhibit 2**). These tests determine the degradation rate of the VOCs in the site groundwater under flowing conditions. Data on the initial VOC concentrations and the degradation rate can be used to calculate the amount of time the contaminated groundwater must

Exhibit 2. Schematic of the Apparatus Used in the Bench-Scale Testing



remain in contact with the granular iron (residence time) to enable sufficient degradation to meet treatment objectives. Degradation rates are typically expressed in terms of half-life, or the time needed to lower the concentration by 50 percent.

With this information, and knowing the groundwater velocity, the thickness of the reactive zone (the flow-through distance) can be calculated. For example, **Exhibits 3, 4, and 5** present results of column tests conducted on groundwater from an industrial facility in New Jersey. **Exhibit 6** shows how the degradation rates were used to calculate the residence times required to meet the objectives for each compound. In this case, though cDCE had a much lower initial concentration than PCE, cDCE was the limiting parameter in the design of the reactor because of its larger half-life and because degradation of PCE resulted in an increase in the cDCE concentration. A small aboveground reactor designed from these data has been operating since November 1994.

Exhibit 3. Degradation of PCE, 100-Percent Iron

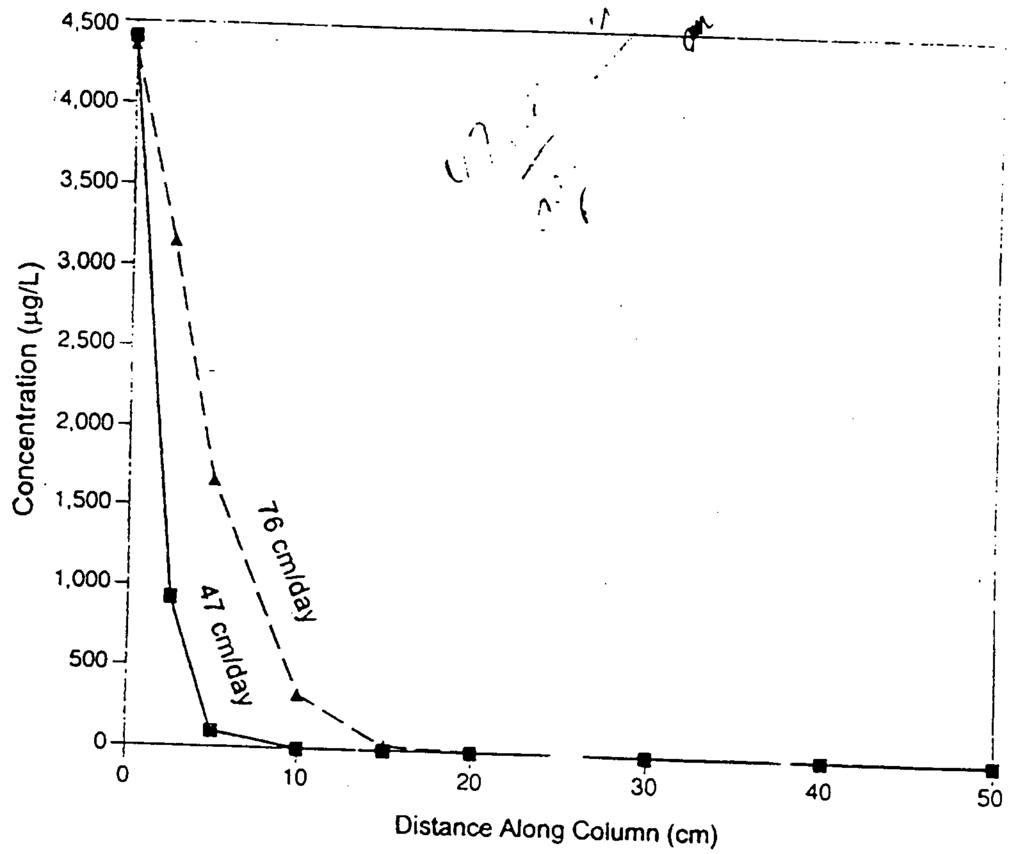
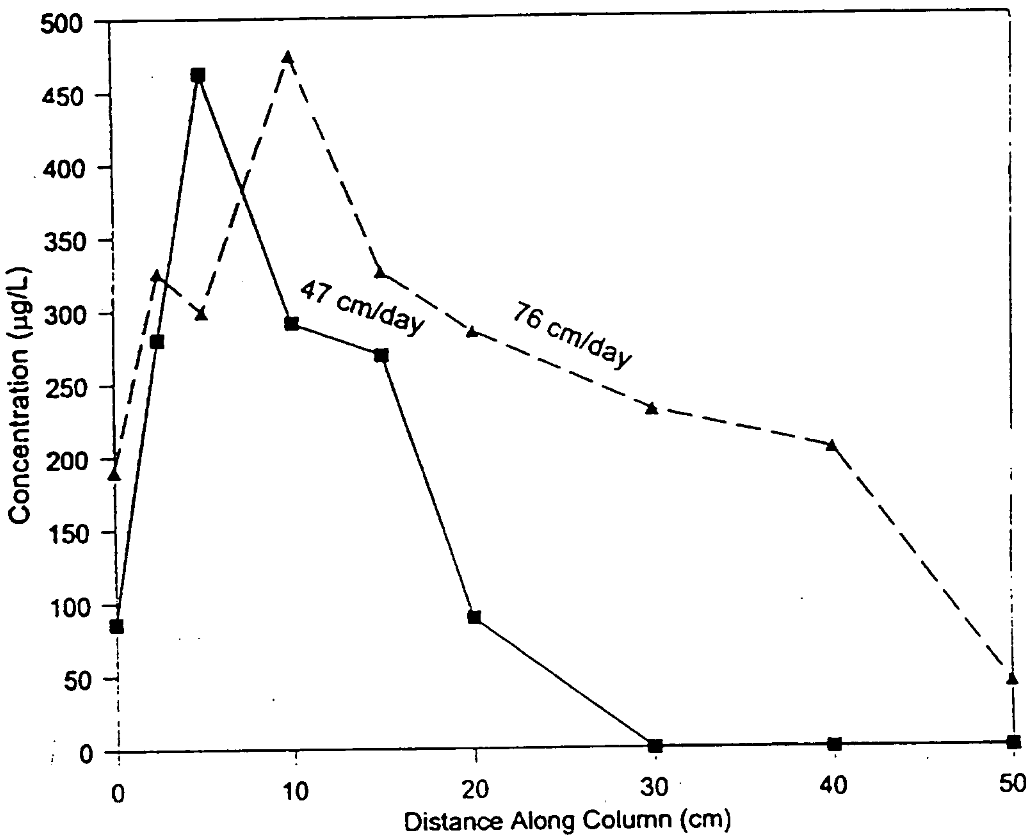


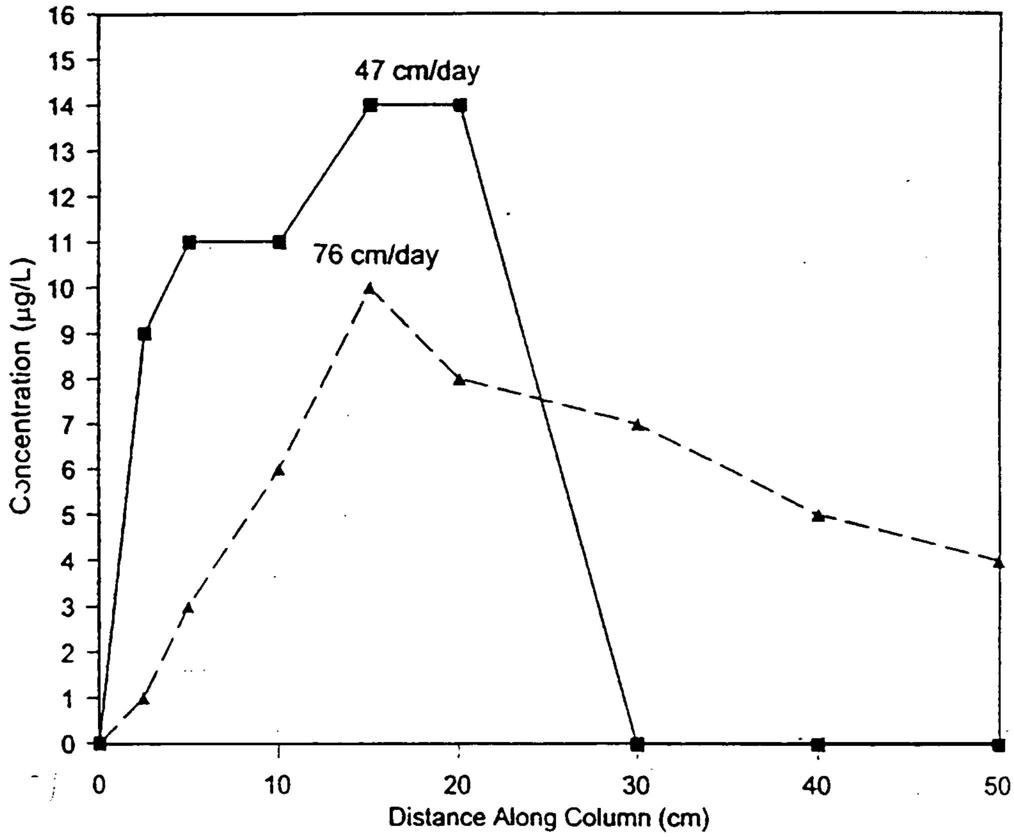
Exhibit 4. Degradation of cDCE, 100-Percent Iron



Inorganic parameters measured in the column influent and effluent during bench-scale tests are used to evaluate the potential for mineral precipitation in the reactive material. The measured parameters include calcium, magnesium, iron, and alkalinity. Another factor that affects the rate at which the degradation of chlorinated VOCs occurs in the presence of granular iron is temperature (the reaction increases with increasing temperature). In the design of a full-scale system, the degradation rates determined by bench-scale tests conducted in the laboratory are often adjusted to take into account groundwater temperature and possible effects of field variations in inorganic geochemistry.

Concurrently or following bench-scale testing, groundwater modeling of the in-situ treatment system is performed to determine the permeable treatment zone dimensions required to create the desired residence time, and the size system required to capture the plume. Two-dimensional or

Exhibit 5. Degradation of VC, 100-Percent Iron



three-dimensional models are used, depending on aquifer characteristics and the configuration of the proposed system (Shikaze et al., 1995). Particle tracking routines in the groundwater model are used to determine residence times in a treatment zone (**Exhibit 7**) and the width of the upgradient aquifer captured by a treatment zone of given dimensions (**Exhibit 8**). Configurations of treatment systems containing granular iron may consist of a continuous permeable wall placed across the contaminant plume, or a "funnel and gate" system where impermeable funnel sections are used to direct groundwater toward permeable treatment zones. The choice of system configuration is based on several factors, including plume configuration and depth, construction costs and the potential for underflow of contaminated groundwater. Because the residence time determined in these models is highly sensitive to the groundwater velocity, the reliability of the modeling results depends on the accuracy of the measurements used to determine the hydrogeologic parameters. Thus, a thorough understand-

Exhibit 6. Design Calculations

Compound	Assumed Initial Concentration (μg/L)	MCL (μg/L)	Laboratory Half-Life (hrs)	Required Residence Time (hrs)
PCE	30,000	1	0.6	8.9
cDCE	3,000	10	1.5	12.3
VC	300	5	1.0	5.9

- cDCE and VC result from PCE degradation
- Required residence time: 8.9 + 12.3 + 5.9 = 27.1 hrs
- Conservative approach
- Adjustments for field conditions

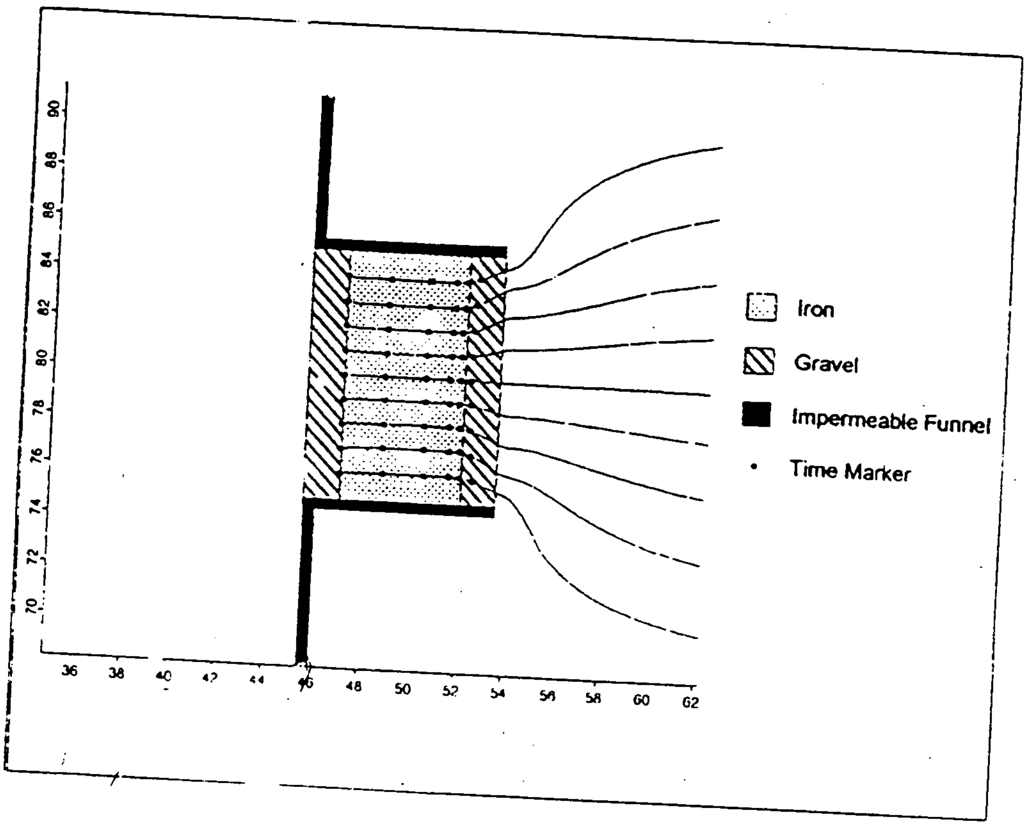
ing of the hydrogeology of the site is essential in developing a treatment system design.

FIELD APPLICATION

The primary factors affecting the installation cost of a reactive iron wall are plume dimensions, upgradient VOC concentrations, and groundwater velocity. These parameters affect the size of the system and treatment zone dimensions, particularly the "flow-through" thickness of the reactive zone required for the necessary residence time. Reactive iron represents a significant component of the installation costs. The unit cost of the original iron source used in the first field applications (in 1994) was approximately $650/ton. This cost has since dropped to between $400 and $450/ton as additional sources of granular iron have been identified and tested.

As mentioned above, either a continuous permeable wall or a funnel-and-gate-system may be employed, based on site-specific characteristics. In either case, the iron is placed deep enough to intercept the saturated thickness of the plume in a treatment zone. Treatment zones to date have been constructed using the following procedure. A rectangular box is built by driving sheet piling. Native material is excavated and replaced with granular iron. The piling on the long axis of the box is then removed to create a flow through the reactive section (Exhibit 7). A layer of pea gravel is placed on either side of the iron, which serves several purposes: (1) to minimize the effects of high velocity layers in the aquifer by spreading flow vertically across the reactive zone; (2) to serve as locations for monitoring well placement; and (3) to facilitate "closed-loop" flushing of the iron

Exhibit 7. Groundwater Model Particle Tracking Routines Used To Determine Residence Time in the Treatment Zone

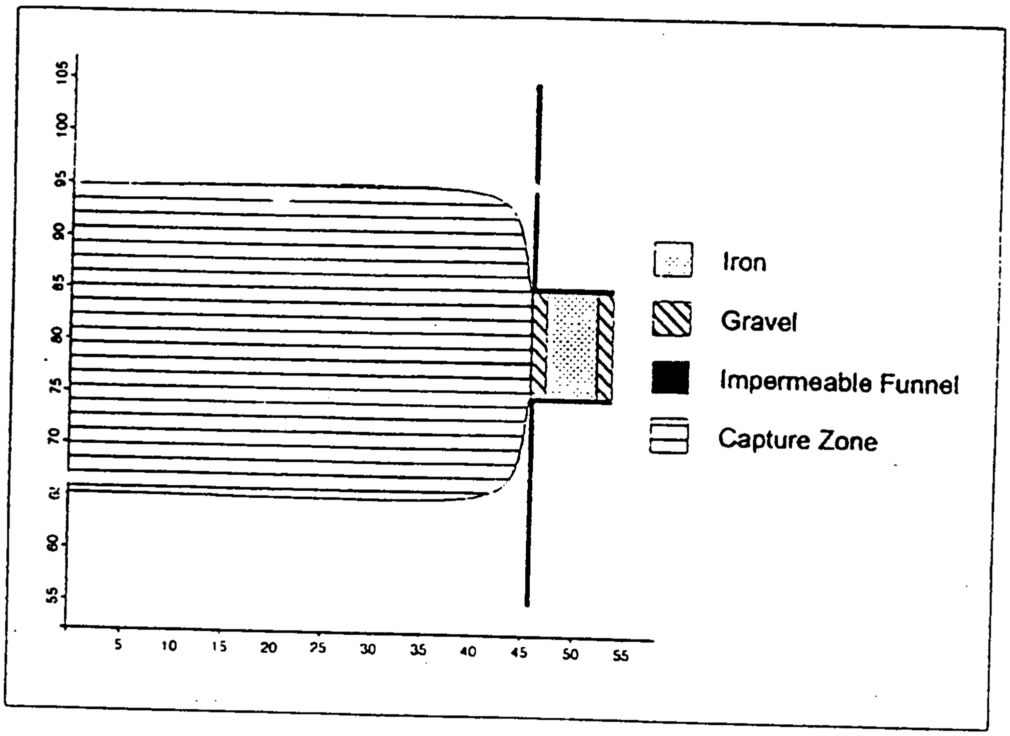


material to remove precipitate build-up, should the need arise. Continuous permeable wall systems involve placing the treatment zone perpendicular to the groundwater flow in a location that intercepts the downgradient edge of the plume. In funnel-and-gate systems, slurry walls or sheet piling is installed to direct groundwater flow through the treatment zone.

Five funnel-and-gate systems have been constructed and are currently operating in the United States. Although no full-scale continuous permeable wall systems have been constructed, one is planned at a site in North Carolina in 1996.

A system to monitor the performance of the system generally consists of long-screened wells placed across the vertical thickness of the iron on the downgradient side of the treatment zone gate. In addition, wells may be placed at various locations within the iron itself. VOC results from these wells, combined with the groundwater velocity, can be used to determine VOC degradation rates in the field. These data are extremely useful when r[illegible] from a pilot-scale system, placed in a small part of the plume, are

Exhibit 8. Capture Zone Upgradient of a Funnel and Gate



used to "scale up" during the design of a full-scale system.

The three field installations described below include one full-scale installation and two recent pilot-scale installations. It is of some importance to note that health and safety issues played a significant role during these field-scale applications. The iron itself is nonhazardous, with only nuisance dust concerns, but preparing the excavation and placing the reactive material represent a variety of confined-space health and safety requirements.

CASE STUDIES

Industrial Facility, Sunnyvale, California

The first full-scale in-situ treatment wall was installed at a former semiconductor manufacturing facility in Sunnyvale, California, to replace an existing pump-and-treat system. VOCs in the groundwater beneath this facility, including TCE, cDCE, and VC, were degraded rapidly in bench-scale tests. Degradation rates were further evaluated in a field-test reactor (a large fibreglass canister) containing 50-percent iron and 50-percent sand by weight at a flow velocity of 4 ft/day for nine months. Influent concentrations, half-lives, and required residence times are presented in **Exhibit 9**. Measured degradation rates in Exhibit 9 are expressed in terms of half-life.

Following regulatory approval, a full-scale in-situ wall was installed in December 1994. The reactive zone is four feet wide, 40 feet long, and about 20 feet deep, and contains 100-percent granular iron. The permeable wall is flanked by slurry walls on either side, one 225 feet long and one 250 feet long, to direct groundwater flow toward the permeable section. Approximately 220 tons of iron were placed in the reactive zone. The total capital costs for the system, including the slurry walls, were about $720,000. Since the system was installed, no VOC concentrations exceeding maximum contaminant levels (MCLs) have been detected from downgradient monitoring wells.

As part of this design, hydrogen gas generation rates measured in the laboratory (Reardon, 1995) were used to evaluate the need for a hydrogen gas collection system. Based on an evaluation of microbial hydrogen gas consumption rates, no need for a gas collection system was indicated. Groundwater from within the field test canister was sampled for phospholipid fatty acid (PLFA) analysis to evaluate the potential for microbial growth in the reactive material. These results indicated that the reactive material did not encourage the development of a microbial population beyond the population observed in "background" groundwater. This has also been observed in groundwater samples taken from other in-situ installations.

Industrial Facility, New York

Following successful bench-scale studies, a pilot-scale in-situ funnel and gate was installed in May 1995 to treat up to 300 ppb of TCE, up to 500 ppb of cDCE, and up to 80 ppb of VC present in a shallow aquifer at an industrial facility in New York. A 12-foot-wide, 3.5-foot-thick central

Exhibit 9. Field Canister Test Results Using 50-Percent Iron and 50-Percent Sand by Weight

VOC	Influent Concentration (ppb)	Half-Life (hrs)	Time to Reach MCLs (hrs)
TCE	210	1.7	10
cDCE	1,415	0.9	7
VC	540	4.0	43

reactive section is flanked by 15 feet of sheet piling extending laterally on either side. The installation, which was keyed into a clay layer located approximately 14 to 15 feet below the ground surface, took about ten days to complete. This trial was monitored through the EPA Superfund Innovative Technology Evaluation (SITE) Program for six months, through the summer and fall of 1995. VOC concentrations have been reduced to MCLs within 1.5 feet of travel through the reactive media (**Exhibit 10**). Based on water level data, the velocity through the zone is about 1 foot/day, and a portion of the plume about 24 feet wide is being captured and treated. Costs for the installation of this system, about $250,000, included $30,000 for approximately 45 tons of iron. Preliminary microbial analyses on groundwater samples from the site show a significant decrease in microbial population in the iron relative to the population present in the aquifer, either upgradient or downgradient of the reactive zone. This indicates that the sysem operation should not be significantly inhibited by biofouling.

Industrial Facility, Kansas

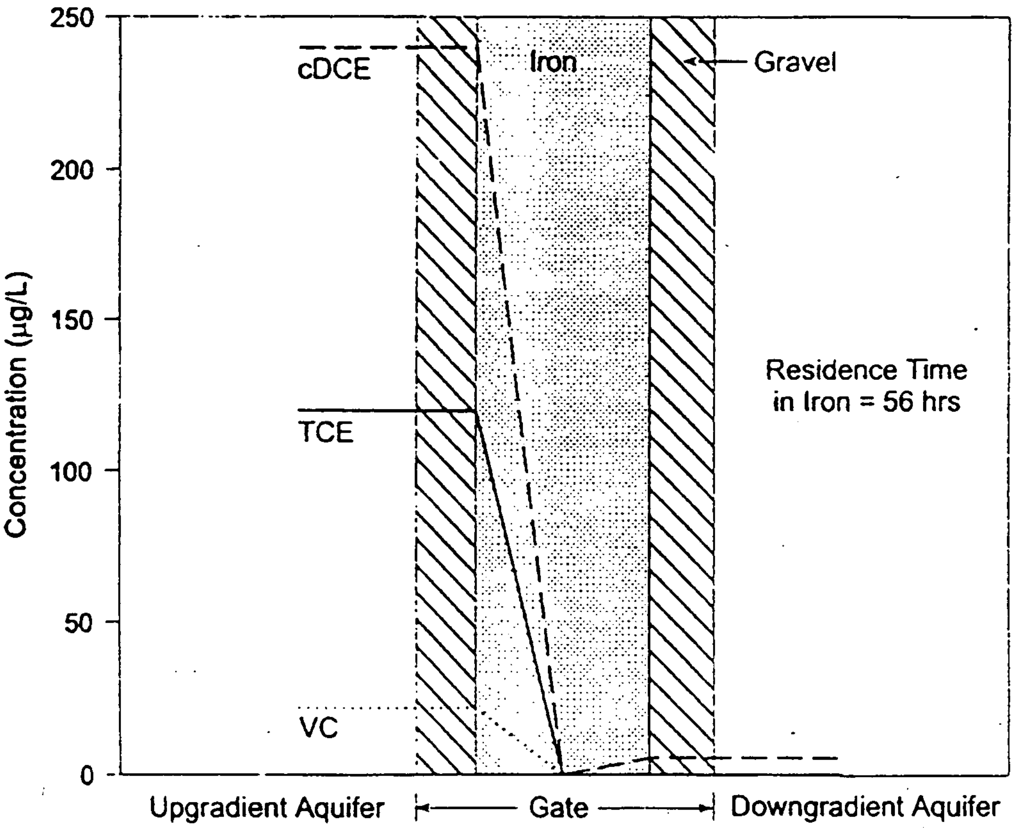
A 1,000-foot-long funnel-and-gate system was installed at the property boundary of an industrial facility in Kansas in January 1996 to treat about 100 to 400 ppb of TCE in groundwater migrating across the property boundary. The TCE occurs in a basal alluvial sand and gravel zone overlying the local bedrock, at a depth of about 30 feet. Low natural groundwater velocity permitted the use of a high funnel-to-gate ratio (490 feet of funnel on either side of a 20-foot-long gate). That is, the velocity increase due to the funneling action still permitted a reasonably sized treatment zone to be built. The reactive zone was placed from about 30 feet to 17 feet below ground surface and had a flow-through thickness of three feet. Excavated soil was placed from the top of the zone to the ground surface. The "funnel" sections of this system consisted of a soil-bentonite slurry wall. The gate section was excavated in the center of the slurry wall after the slurry was allowed to set. Inclement weather and the Christmas holiday season extended the construction period; however, the contractor estimated that under optimum conditions, the soil-bentonite slurry wall could have been built in one to two weeks, and the gate section in one week. The installation costs, including slurry walls and gate, and 70 tons of granular iron, were about $400,000.

The major factor affecting operation and maintenance costs is the possibility of periodic removal of precipitates from the reactive material.

OPERATION AND MAINTENANCE REQUIREMENTS

Other than groundwater monitoring, the major factor affecting operation and maintenance costs is the possibility of periodic removal of precipitates from the reactive material, perhaps by "closed-loop" flushing, or periodic replacement of the affected sections of the material if the precipitates cannot otherwise be removed. Before implementation it is difficult to judge the extent to which inorganic precipitates may occur; however, porosity losses due to inorganic mineral precipitates from 2 to 15 percent per year have been predicted based on laboratory column results. It has been suggested that the amount of precipitation that will

Exhibit 10. Field VOC Concentrations Through 100-Percent Iron



occur in-situ will be significantly less than predicted from laboratory studies, due to the condition of groundwater used in the laboratory. Groundwater sampling and transport can shift the carbonate equilibrium, causing groundwater used in the laboratory tests to be supersaturated with calcium carbonate before it enters the reactive iron column. No significant precipitates were observed in the in-situ reactive wall at the University of Waterloo Borden test site almost four years after it was installed. This wall has now been performing consistently for 4.5 years. Data from in-situ systems installed in California and from other in-situ field trials will generate further inorganic data to better evaluate this issue.

Although the need for rehabilitation or replacement has yet to be demonstrated, the possibility should be recognized when evaluating the economic viability of a treatment system. Rehabilitation or replacement costs can be calculated by assuming that a percentage of the original iron costs will need to be spent every five to ten years. The percentage and frequency are site-specific; for example, for very high TDS (carbonate) groundwaters, 75 percent of the iron costs might be expended at five-year intervals; for lower TDS groundwater, one might assume expenditures of only 25 percent of the iron costs every ten years.

TECHNOLOGY ADVANCEMENT

There are several areas where the commercial application of reactive iron walls can possibly be enhanced. One is to extend the depth of the treatment zone. Contractors indicate that the "sheet pile box" method for constructing permeable treatment zones is most cost-effective with depths up to 45 feet. A number of techniques for deeper placement of reactive material are being evaluated. Another significant area of potential improvement is the integration of this technology with others to treat groundwater plumes containing a mixture of contaminants. ETI is providing technical review and design support to the Advanced Applied Technology Demonstration Facility for Environmental Technology (AATDF), a Rice University/Department of Defense project at the University of Waterloo Borden test site, where granular iron will be used in combination with other in-situ technologies to treat mixed plumes of chlorinated and nonchlorinated VOCs. In addition, a permeable wall containing granular iron will be installed in 1996 to treat a combined TCE and chromium plume emanating from a source area beneath a former machine shop at a facility in North Carolina. Also, considerable interest has been expressed at DOE sites where the technology may be used to treat combined plumes of chlorinated VOCs and trace radionuclides. A variety of methods of enhancing the iron degradation rates are being investigated. Should these be successful, the technology may be more applicable to aboveground treatment systems. Field trials of these enhancements will be initiated in mid-1996.

There are several areas where the commercial application of reactive iron walls can possibly be enhanced.

ACKNOWLEDGMENTS

We wish to thank the firms of Geomatrix Consultants (California site), Stearns and Wheler (New York site) and SECOR (Kansas site) for provision of construction information and cost data on these projects. The support of the owners of these installations is also appreciated. ■

REFERENCES

Matheson, L.J., and P.G. Tratnyek. 1994. "Reductive Dehalogenation of Chlorinated Methanes by Iron Metal." *Environ. Sci. Technol.* 28:2045-2053

Orth, W.S., and R.W. Gillham. 1996. "Dechlorination of Trichloroethene in Aqueous Solution Using Fe°." *Environ. Sci. Technol.* 30:66-71.

Reardon, E.J. 1995. "Anaerobic Corrosion of Granular Iron: Measurement and Interpretation of Hydrogen Evolution Rates." *Environ. Sci. Technol.* 29:2938-2945.

Shikaze, S.G., C.D. Austrins, D.J.A. Smyth, J.A. Cherry, J.F. Barker, and E.A. Sudicky. 1995. *The Hydraulics of a Funnel and Gate System: Three-Dimensional Numerical Analysis.* Presented at I.A.H. Conference. Edmonton, Alberta

APPENDIX F
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

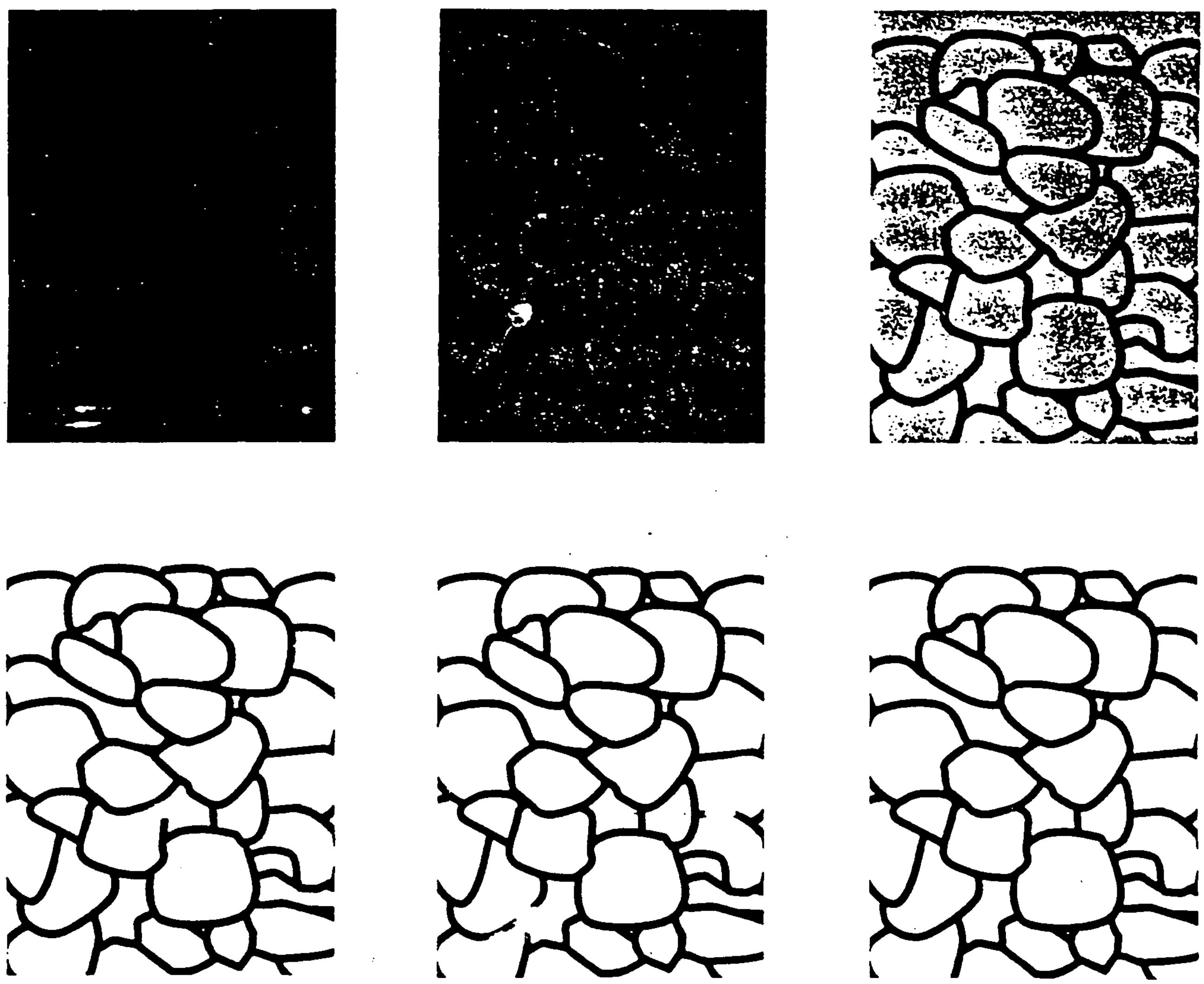
Office of Research and Development
Washington, DC 20460

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



Printed on paper that contains at least 20 percent postconsumer fiber

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 the moving ground water to generate a plume of dissolved 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:

$$\text{Perchloroethene} \rightarrow \text{Trichloroethene} \rightarrow \text{Dichloroethene} \rightarrow \text{Vinyl chloride} \rightarrow \text{Carbon dioxide}$$

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:

$$\text{Perchloroethene} \rightarrow \text{Trichloroethene} \rightarrow \text{Dichloroethene} \rightarrow \text{Vinyl chloride} \rightarrow \text{Ethene} \rightarrow \text{Ethane}$$

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.

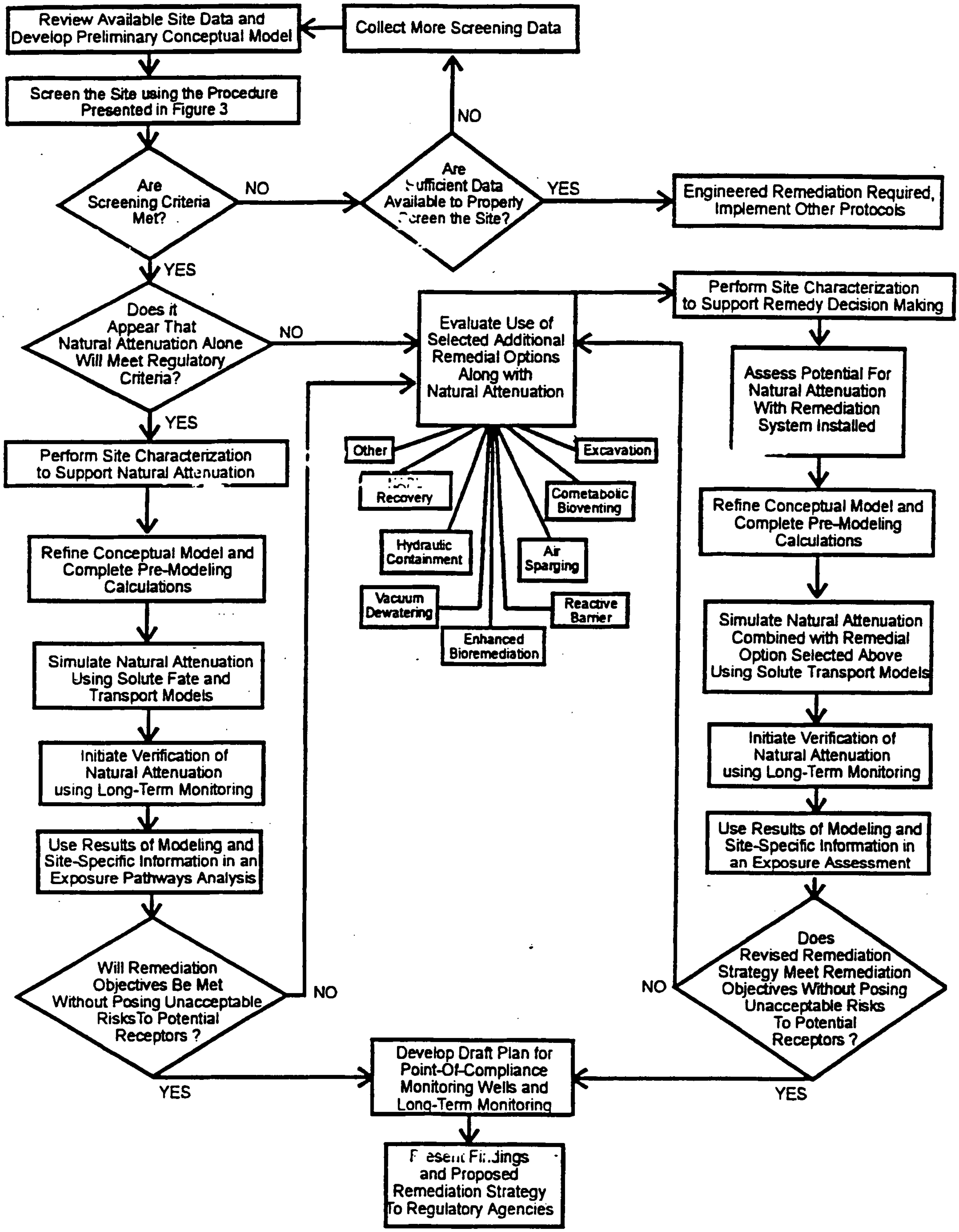


Figure 1. Natural attenuation of chlorinated solvents flow chart.

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 an 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.

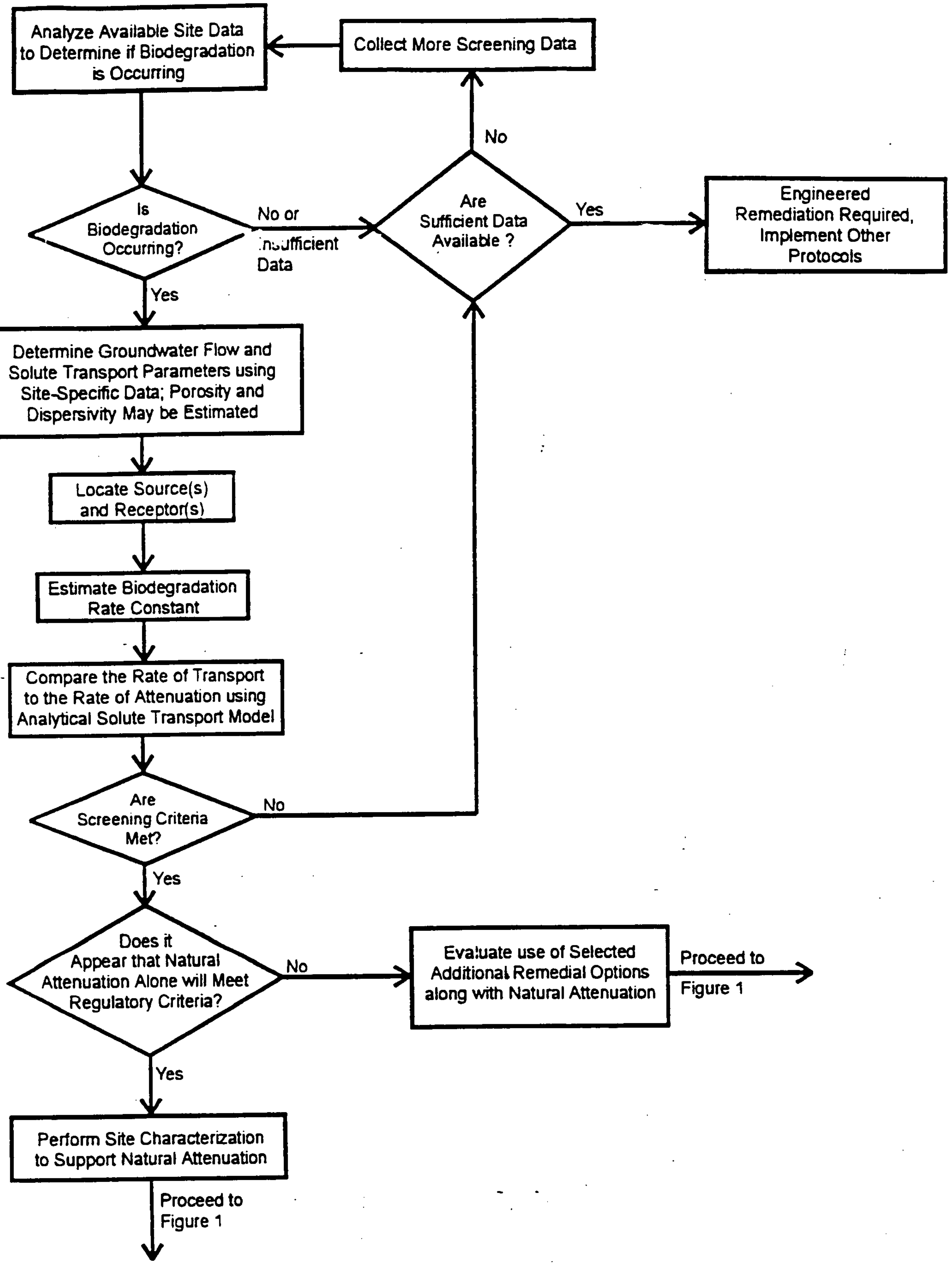


Figure 2. Initial screening process flow chart.

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 > 20ĒC, 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	

[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).

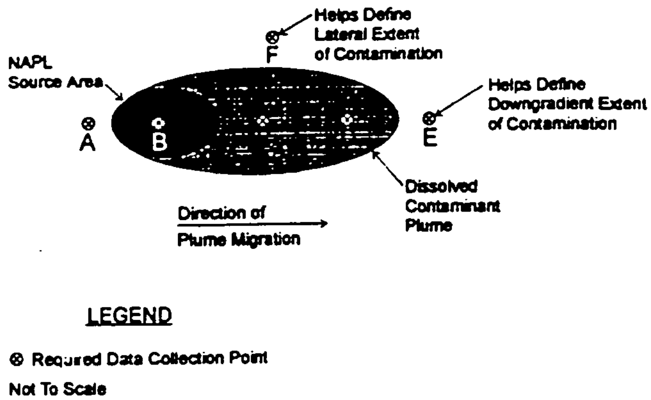


Figure 3. Data collection points required for screening.

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.[illegible] 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.

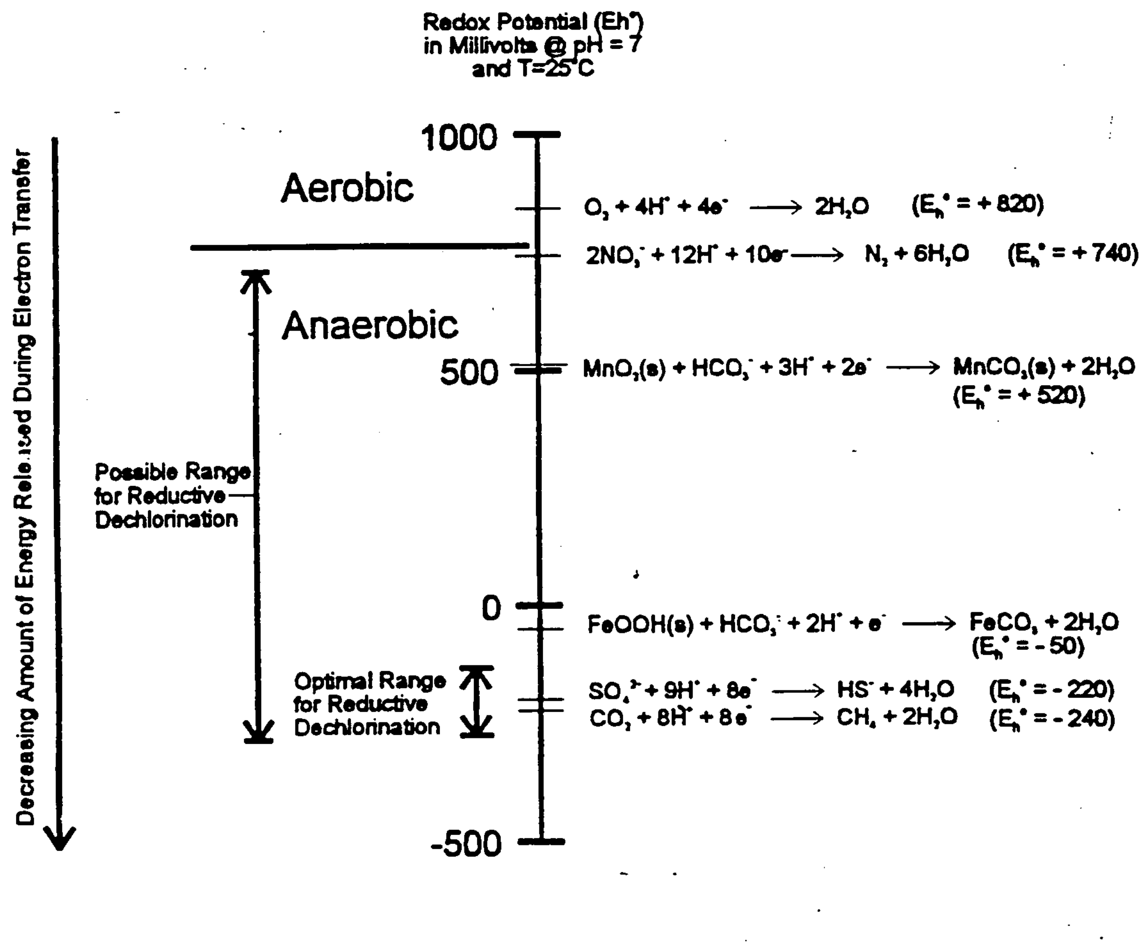
After DO has been depleted in the microbiological treatment zone, nitrate may be used as an electron acceptor for anaerobic biodegradation via denitrification. In some cases iron(III) is used as an electron acceptor during anaerobic biodegradation of electron donors. During this process, iron(III) is 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 tne 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 tempera‹ :so affects the metabolic activity of bacteria. Rates oı nydrocarbon 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. Durinu 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 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.

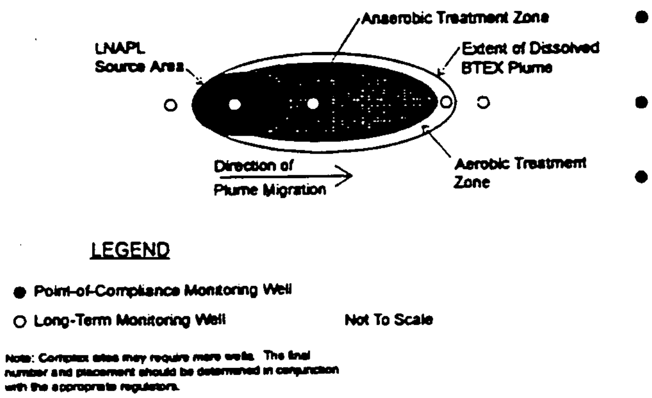


Figure 5. Hypothetical long-t... ıonitoring strategv.

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.

References

1. Wiedemeier, T.H., J.T. Wilson, D.H. Kampbell, R.N. Miller, and J.E. Hansen. 1995. Technical protocol for implementing intrinsic remediation with long-term monitoring for natural attenuation of fuel contamination dissolved in groundwater. San Antonio, TX: U.S. Air Force Center for Environmental Excellence.

2. National Research Council. 1993. In-situ bioremediation: When does it work? Washington, DC: National Academy Press.

3. Bouwer, E.J., B.E. Rittman, and P.L. McCarty. 1981. Anaerobic degradation of halogenated 1- and 2-carbon organic compounds. Environ. Sci. Technol. 15 (5):596-599.

4. Wilson, J.T., and B.H. Wilson. 1985. Biotransformation of trichloroethylene in soil. Appl. Environ. Microbiol. 49(1):242-243.

5. Miller, R.E., and F.P. Guengerich. 1982. Oxidation of trichloroethylene by liver microsomal cytochrome P-450: Evidence for chlorine migration in a transition state not involving trichloroethylene oxide. Biochemistry 21:1090-1097.

6. Nelson, M.J.K., S.O. Montgomery, E.J. O'Neille, and P.H. Pritchard. 1986. Aerobic metabolism of trichloroethylene by a bacterial isolate. Appl. Environ. Microbiol. 52 (2):949-954.

7. Bouwer, E.J., and J.P. Wright. 1988. Transformations of trace halogenated aliphatics in anoxic biofilm columns. J. Contam. Hydrol. 2:155-169.

8. Lee, M.D. 1988. Biorestoration of aquifers contaminated with organic compounds. CRC Crit. Rev. Environ. Control 18:29-89.

9. Little, C.D., A.V. Palumbo, S.E. Herbes, M.E. Lidstrom, R.L. Tyndall, and P.J. Gilmer. 1988. Trichloroethylene biodegradation by a methane-oxidizing bacterium. Appl. Environ. Microbiol. 54(4):951-956.

10. Mayer, K.P., D. Grbi-Gali, L. Semprini, and P.L. McCarty. 1988. Degradation of trichloroethylene by methanotrophic bacteria in a laboratory column of saturated aquifer material. Water Sci. Tech. 20(11/12):175-178.

11. Arciero, D., T. Vannelli, M. Logan, and A.B. Hooper. 1989. Degradation of trichloroethylene by the ammonia-oxidizing bacterium *Nitrosomonas europaea*. Biochem. Biophys. Res. Commun. 159:640-643.

12. Cline, P.V., and J.J. Delfino. 1989. Transformation kinetics of 1,1,1-trichloroethane to the stable product 1,1-dichloroethene. In: Biohazards of drinking water treatment. Chelsea, MI: Lewis Publishers.

13. Freedman, D.L., and J.M. Gossett. 1989. Biological reductive dechlorination of tetrachloethylene and trichloroethylene to ethylene under methanogenic conditions. Appl. Environ. Microbiol. 55:2144-2151.

14. Folsom, B.R., P.J. Chapman, and P.H. Pritchard. 1990. Phenol and trichloroethylene degradation by *Pseudomonas cepacia* G4: Kinetics and interactions between substrates. Appl. Environ. Microbiol. 56(5):1279-1285.

15. Harker, A.R., and Y. Kim 1990. Trichloroethylene degradation by two independent aromatic-degrading pathways in *Alcaligenes eutrophus* JMP134. Appl. Environ. Microbiol. 56(4):1179-1181.

16. Alvarez-Cohen, L.M., and P.L. McCarty. 1991. Effects of toxicity, aeration, and reductant supply on trichloroethylene transformation by a mixed methanotrophic culture. Appl. Environ. Microbiol. 57(1):228-235.

17. Alvarez-Cohen, L.M., and P.L. McCarty. 1991. Product toxicity and cometabolic competitive inhibition modeling of chloroform and trichloroethylene transformation by methanotrophic resting cells. Appl. Environ. Microbiol. 57(4):1031-1037.

18. DeStefano, T.D., J.M. Gossett, and S.H. Zinder. 1991. Reductive dehalogenation of high concentrations of tetrachloroethene to ethene by an anaerobic enrichment culture in the absence of methanogenesis. Appl. Environ. Microbiol. 57(8):2287-2292.

19. Henry, S.M. 1991. Transformation of trichloroethylene by methanotrophs from a groundwater aquifer. Ph.D. thesis. Stanford University, Palo Alto, CA.

20. McCarty, P.L., P.V. Roberts, M. Reinhard, and G. Hopkins. 1992. Movement and transformations of halogenated aliphatic compounds in natural systems. In: Schnoor, J.L., ed. Fate of pesticides and chemicals in the environment. New York, NY: John Wiley & Sons.

21. Hartmans, S., and J.A.M. de Bont 1992. Aerobic vinyl chloride metabolism in *Mycobacterium aurum* Li. Appl. Environ. Microbiol. 58(4):1220-1226.

22. McCarty, P.L., and L. Semprini. 1994. Ground-water treatment for chlorinated solvents, In: Norris, R.D., R.E. Hinchee, R. Brown, P.L. McCarty, L. Semprini, J.T. Wilson, D.H. Kampbell, M. Reinhard, E.J. Bouwer, R.C. Borden, T.M. Vogel, J.M. Thomas and C.H. Ward, eds. Handbook of bioremediation. Boca Raton, FL: Lewis Publishers.

23. Vogel, T.M. 1994. Natural bioremediation of chlorinated solvents. In: Norris, R.D., R.E. Hinchee, R. Brown, P.L. McCarty, L. Semprini, J.T. Wilson, D.H. Kampbell, M. Reinhard, E.J. Bouwer, R.C. Borden, T.M. Vogel, J.M. Thomas, and C.H. Ward, eds. Handbook of bioremediation. Boca Raton, FL: Lewis Publishers.

24. Bouwer, E.J. 1994. Bioremediation of chlorinated solvents using alternate electron acceptors. In: Norris, R.D., R.E. Hinchee, R. Brown, P.L. McCarty, L. Semprini, J.T. Wilson, D.H. Kampbell, M. Reinhard, E.J. Bouwer, R.C. Borden, T.M. Vogel, J.M. Thomas, and C.H. Ward, eds. Handbook of bioremediation. Boca Raton, FL: Lewis Publishers.

25. Vogel, T.M., and P.L. McCarty. 1985. Biotransformation of tetrachloroethylene to trichloroethylene, dichloroethylene, vinyl chloride, and carbon dioxide under methanogenic conditions. Appl. Environ. Microbiol. 49(5):1080-1083.

26. Murray, W.D., and M. Richardson. 1993. Progress toward the biological treatment of C1 and C2 halogenated hydrocarbons. Crit. Rev. Environ. Sci. Technol. 23(3):195-217.

27. Bradley, P.M., and F.H. Chapelle. 1996. Anaerobic mineralization of vinyl chloride in Fe(III)-reducing aquifer sediments. Environ. Sci. Technol. 40:2084-2086.

28. Wiedemeier, T.H., L.A. Benson, J.T. Wilson, D.H. Kampbell, J.E. Hansen, and R. Miknis. 1996. Patterns of natural attenuation of chlorinated aliphatic hydrocarbons at Plattsburgh Air Force Base, New York. Platform abstracts presented at the Conference on Intrinsic Remediation of Chlorinated Solvents, Salt Lake City, UT, April 2.

29. U.S. EPA. 1986. Test methods for evaluating solid waste, physical and chemical methods, 3rd ed. SW-846. Washington, DC.

30. U.S. EPA. 1983. Methods for chemical analysis of water and wastes. EPA/16020-07-71. Cincinnati, OH.

31. Hach Co. 1990. Hach Company Catalog: Products for Analysis. Ames, IA.

32. American Public Health Association. 1992. Standard methods for the examination of water and wastewater, 18th ed. Washington, DC.

33. AFCEE. 1993. Handbook to support the Installation Restoration Program (IRP) remedial investigations and feasibility studies (RI/FS). U.S. Air Force Center for Environmental Excellence. September. Brooks Air Force Base, TX.

34. AFCEE. 1992. Environmental chemistry function Installation Restoration Program analytical protocols. June.

35. Kampbell, D.H., J.T. Wilson, and S.A. Vandegrift. 1989. Dissolved oxygen and methane in water by a GC headspace equilibrium technique. Int. J. Environ. Anal. Chem. 36:249-257.

36. Wiedemeier, T.H., M.A. Swanson, J.T. Wilson, D.H. Kampbell, R.N. Miller, and J.E. Hansen. 1996. Approximation of biodegradation rate constants for monoaromatic hydrocarbons (BTEX) in groundwater. Ground Water Monitoring and Remediation. In press.

37. Wiedemeier, T.H., M.A. Swanson, D.E. Moutoux, J.T. Wilson, D.H. Kampbell, J.E. Hansen, P. Haas, and F.H. Chapelle. 1996. Technical protocol for natural attenuation of chlorinated solvents in groundwater. San Antonio, TX: U.S. Air Force Center for Environmental Excellence. In preparation.

38. Domenico, P.A. 1987. An analytical model for multidimensional transport of a decaying contaminant species. J. Hydrol. 91:49-58.

39. Domenico, P.A., and F.W. Schwartz. 1990. Physical and chemical hydrogeology. New York, NY: John Wiley and Sons.

40. Morel, F.M.M., and J.G. Hering. 1993. Principles and applications of aquatic chemistry. New York, NY: John Wiley & Sons.

41. Willey, L.M., Y.K. Kharaka, T.S. Presser, J.B. Rapp, and I. Barnes. 1975. Short chain aliphatic acid anions in oil field waters and their contribution to the measured alkalinity. Geochim. Cosmochim. Acta 39:1707-1711.

42. Lovley, D.R., and S. Goodwin. 1988. Hydrogen concentrations as an indicator of the predominant terminal electron-accepting reaction in aquatic sediments. Geochim. Cosmochim. Acta 52:2993-3003.

43. Lovley, D.R., F.H. Chapelle, and J.C. Woodward. 1994. Use of dissolved H_2 concentrations to determine distribution of microbially catalyzed redox reactions in anoxic groundwater. Environ. Sci. Technol. 28(7):1205-1210.

44. Chapelle, F.H., P.B. McMahon, N.M. Dubrovsky, R.F. Fujii, E.T. Oaksford, and D.A. Vroblesky. 1995. Deducing the distribution of terminal electron-accepting processes in hydrologically diverse groundwater systems. Water Resour. Res. 31:359-371.

45. Hem, J.D. 1985. Study and interpretation of the chemical characteristics of natural water. U.S. Geological Survey Water Supply Paper 2254.

46. Kaufman, W I., and G.T. Orlob. 1956. Measuring ground water movement with radioactive and chemical tracers. Am. Water Works Assn. J. 48:559-572.

47. Buscheck, T.E., and C.M. Alcantar. 1995. Regression techniques and analytical solutions to demonstrate intrinsic bioremediation. In: Proceedings of the 1995 Battelle International Conference on In-Situ and On Site Bioreclamation. April.

48. Bear, J. 1979. Hydraulics of groundwater. New York, NY: McGraw-Hill.

49. Rice, D.W., R.D. Grose, J.C. Michaelsen, B.P. Dooher, D.H. MacQueen, S.J. Cullen, W.E. Kastenberg, L.G. Everett, and M.A. Marino. 1995. California leaking underground fuel tank (LUFT) historical case analyses. California State Water Resources Control Board.