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PROPOSED REMEDIAL ACTION CONCEPTUAL DESIGN REPORT

FORMER ROCKWELL INTERNATIONAL SITE
ALLEGAN, MICHIGAN

SEPTEMBER 2001
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LIST OF ACRONYMS/SHORT FORMS

ACL	-	Alternate Concentration Limit
AMSL	-	Above Mean Sea Level
bgs	-	Below Ground Surface
BTEX	-	Benzene, Toluene, Ethylbenzene, and Xylene
c.y.	-	Cubic Yards
C-B	-	Cement-Bentonite
CERCLA	-	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	-	Code of Federal Regulations
COIs	-	Chemicals of Interest
CQA	-	Construction Quality Assurance
CRA	-	Conestoga-Rovers & Associates
DCC	-	Direct Contact Criteria
ETI	-	EnviroMetal Technologies, Inc.
FS	-	Feasibility Study
GAC	-	Granular Activated Carbon
GSI	-	Groundwater/Surface Water Interface
HASP	-	Health and Safety Plan
KVCC	-	Kalamazoo Valley Community College
LNAPL	-	Light Non-Aqueous Phase Liquids
MDEQ	-	Michigan Department of Environmental Quality
NAAQS	-	Federal Natural Ambient Air Quality Standards
O&M	-	Operation and Maintenance
ORC	-	Oxygen Releasing Compound
OSHA	-	Occupational Safety and Health Administration
PAHs	-	Polynuclear Aromatic Hydrocarbons
PCBs	-	Polychlorinated Biphenyls
POTW	-	Publicly Owned Treatment Works
PRB	-	Permeable Reactive Barrier
QAPP	-	Quality Assurance Project Plan
RA	-	Remedial Action
RCRA	-	Resource Conservation and Recovery Act

LIST OF ACRONYMS/SHORT FORMS

RD	-	Remedial Design
RI	-	Remedial Investigation
ROW	-	Right-of-Way
S-A	-	Soil-Attapulgite
S-B	-	Soil-Bentonite
SCB	-	Soil-Cement-Bentonite
SOS	-	Soluble Oil Separation
SOW	-	Scope of Work
SVOCs	-	Semi-Volatile Organic Compounds
TSCA	-	Toxic Substances Control Act
U of W	-	University of Waterloo
U.S. EPA	-	United States Environmental Protection Agency
VOCs	-	Volatile Organic Compounds
WWTP	-	Wastewater Treatment Plant

1.0 INTRODUCTION

This Conceptual Design Report (Report) presents an overview of the overall design for the proposed remedy at the former Rockwell International Corporation Site (Site), located in the City of Allegan, Allegan County, Michigan. Conestoga-Rovers & Associates (CRA), EnviroMetal Technologies, Inc. (ETI), and Geo-Solutions, Inc. (Geo-Solutions) have prepared this Conceptual Design Report on behalf of ArvinMeritor, Inc. (ArvinMeritor). ETI and Geo-Solutions have been included as part of the Project Team to provide expertise in the design and construction of the slurry wall and permeable reactive barrier (PRB) funnel and gate system and have contributed to the relevant sections of the Report. This Conceptual Design Report also outlines the specific tasks required to complete the detailed Remedial Design (RD) and to implement the Remedial Action (RA).

The Site location is presented on Figure 1.1. An aerial photograph of the Site from 1986 is presented on Figure 1.2. A Site plan is presented on Figure 1.3.

A variety of investigations have been completed at the Site to address concerns related to residual contamination at the Site. A Remedial Investigation (RI)/Feasibility Study (FS) is currently being completed by the United States Environmental Protection Agency (U.S. EPA). A list of pertinent reference documents is provided in Appendix A.

The proposed remedy at the Site includes the following remedy components:

Source Areas

1. Hydraulic Control, Extraction, and Off-Site Disposal of Light Non-Aqueous Phase Liquids (LNAPL);
2. Excavation and Off-Site Disposal of Selected Polychlorinated Biphenyl (PCB) Soil Hotspots (i.e., PCBs $\geq$ 50 mg/kg);
3. Solidification of Wastewater Treatment Plant (WWTP) Pond Sediments, Consolidation, and Capping within WWTP Ponds Area;
4. Consolidation of Selected Site Soils and Building Demolition Debris within WWTP Ponds Area; and
5. Site Capping through Re-Development of the Property.

Groundwater

1. Construction of a Fully Encircling Slurry Wall Keyed to the Clay Till Layer to Provide Physical Containment; and
2. Construction of PRBs at Selected Locations Within the Slurry Wall to Address Aqueous Phase Contaminants.

Site-Wide Activities

1. Performance Monitoring Program to Monitor the Effectiveness of the Remedy; and
2. Institutional Controls.

The purpose of this Conceptual Design Report is to provide a description of the remedy components, a conceptual remedial approach for the remedy, and an outline of the design and implementation tasks required to successfully implement the remedial action. The Scope of Work (SOW) presented in this Conceptual Design Report will address the following:

i) development of performance standards;
ii) pre-design studies;
iii) detailed design activities;
iv) final design drawings and specifications; and
v) construction quality assurance.

The remainder of this Conceptual Design Report is organized as follows:

Section 2.0 – Site Description

This section presents a description of the Site history, the physical Site conditions, and the previous investigations performed at the Site.

Section 3.0 – Environmental Characterization

This section presents a review the Site environmental conditions and a summary of the environmental characterization that has formed the basis for the conceptual remedial approach presented in this Report.

Section 4.0 – Conceptual Design Approach

This section presents the basis and objectives of the conceptual design and provides a conceptual approach for the various remedial components that will meet the outlined objectives in a protective, environmentally sound, and cost-effective manner.

Section 5.0 – Components of Conceptual Design Approach

This section presents a detailed description of the various remedial components and how they will be implemented at the Site.

Section 6.0 – Design Scope of Work

This section presents a detailed description of the design, construction, and operational tasks required in order to implement the selected remedial components.

Section 7.0 – Project Schedule

This section discusses the schedule requirements to implement the remedy in a timely manner.

Section 8.0 – Project Cost Estimate

This section presents a preliminary project cost estimate.

Section 9.0 – Project Team

This section presents the Project Team selected to implement the design and construction of the remedy.

2.0 SITE DESCRIPTION

2.1 BACKGROUND

The purpose of this section is to present an overview of the Site background which provides the basis for the remedial approach and conceptual design presented in this Report.

2.2 SITE HISTORY

Manufacturing industries have occupied the Site since approximately 1908. A glass manufacturing facility was originally constructed on the Site by Allegan Mirror and Plate Glass Company. The Site was subsequently purchased by the Blood Brothers in 1914 for the manufacturing of drive-line assemblies for the trucking and automotive industries. The Site was then purchased by Standard Steel and Spring which became part of the automotive division of Rockwell International Corporation (Rockwell) through a number of mergers and acquisitions in 1953. The eastern portion of the Site was sold to Allegan Metal Finishing in 1995. Meritor was divested from Rockwell in 1997. A more detailed outline of the Site history and operations is provided in the RI Report being developed by U.S. EPA.

2.3 SITE DESCRIPTION

The Site is located in the City of Allegan, Allegan County, Michigan at 1 Glass Street on an approximately 30.4-acre parcel of land. The Site location is presented on Figure 1.1. An aerial photograph of the Site from 1986 is presented on Figure 1.2. The Site is bounded to the north by the Kalamazoo River and to the east by residential dwellings including the North Ward Elementary School. The City of Allegan Publicly Owned Treatment Works (POTW) is located immediately west of the Site. The Site is bordered to the south by North Street. A mixture of buildings including a newspaper office, a union hall, and residential dwellings are located on North Street. The undeveloped area southwest of the Site is largely owned by the Consumers Power Company. The Site and all adjacent areas west of River Street are located on the inside of a meander of the Kalamazoo River.

The Site layout is presented on Figure 1.3. The current Site configuration consists of approximately 330,000 square feet of buildings including the former manufacturing complex, former drive-line assembly building, the former heat treat building, and the former WWTP building. The former drive-line assembly building and former heat treat building, located in the eastern portion of the Site, are currently utilized for warehousing by the current owner and are separated from the remainder of the Site by a fence. Additional areas and features of the Site include of an undeveloped grassy area, an aboveground fire protection tank and shed, pump house, parking lots, and three former WWTP ponds. Historical conditions at the Site included a former railroad right-of-way (ROW) extending in a north-south direction through the center of the Site, a former chip loading area, and a former oil flotation house.

2.4 FUTURE LAND USE

Ownership of the western portion of the property has been transferred to the City of Allegan. The eastern portion of the Site, which includes the former heat treat building and the former drive-line assembly building, was sold to the Allegan Metal Finishing Company in 1995. It is expected that the Site will be re-developed for possible future industrial or commercial activities.

This conceptual design has been prepared to present a remedial approach which can be rapidly and successfully implemented to support the City of Allegan and its proposal that Kalamazoo Valley Community College (KVCC) develop a new college campus on the Site. The City of Allegan proposal provides a future land use that can be successfully integrated with the proposed remedy. There are some obvious synergies with the City of Allegan proposal that provide for the beneficial re-use of the Site, particularly re-use of the existing concrete slabs to support building construction, and the use of potential capped areas for parking lots, recreational areas, and green space. In addition, the City of Allegan proposal facilitates the early completion of a remedy at the Site.

2.5 ENVIRONMENTAL SETTING

The purpose of this section is to provide an overview of the Site-specific description of the geology, hydrogeology, and hydrology identified at the Site.

2.5.1 SITE GEOLOGY

Allegan County, which encompasses approximately 837 square miles, lies adjacent to the eastern shore of Lake Michigan in southwestern Michigan. Topographic features of Allegan County are associated with the Lake Michigan Lobe of the Wisconsin Ice Sheet. Glacial drift deposited during glacial retreat ranges in thickness in Allegan County from 50 feet to 400 feet. Bedrock beneath Allegan County consists of Mississippian sandstones and shale.

The available subsurface data identifies the presence of four major geologic units: fill; alluvial and glaciofluvial sediments; till layer; and shale. The four major geologic units are further described as follows:

- The fill is extremely variable in nature, predominantly comprised of sand and gravel, ranging in thickness from approximately 3 feet below ground surface (bgs) in the vicinity of the former railroad ROW, to approximately 34 feet bgs in the vicinity of the former Soluble Oil Separation (SOS) Pond.
- Alluvial and glaciofluvial sediments are characteristic of recent deposition by a mature river system and an outwash depositional environment, with the thickness of these unconsolidated deposits ranging from 20 feet in the vicinity of the former SOS Pond to 63 feet in the area northeast of the manufacturing complex.
- The till layer consists of a dry, dense, dark gray clayey silt with trace fine gravel, undulating beneath the Site in a pattern which does not conform to the local topography, ranging in thickness from 113 feet at the south boundary of the Site to 30 feet north of the manufacturing complex.
- The first bedrock unit encountered underlying the till at the Site is a light blue-gray shale of the Coldwater Formation at depths ranging from 85 feet to 151 feet bgs.

2.5.2 SITE HYDROGEOLOGY

In general, two hydrostratigraphic units have been identified on Site and are commonly referred to as the shallow and the deep groundwater systems. Previous investigations identified that in the vicinity of the Site shallow groundwater discharges radially to the Kalamazoo River, while the predominant flow direction in the deep groundwater system is north. The two groundwater systems are further described as follows:

- The shallow groundwater system is comprised of two zones largely within unconsolidated alluvial and glaciofluvial deposits and saturated sandy fill material, consisting of an upper shallow unconfined water-bearing horizon underlain by a basal water-bearing zone. The two groundwater zones are hydraulically separated by a clayey silt layer in some areas of the Site and hydraulically connected in areas where the clayey silt is not present.
- The deep groundwater system is comprised of discontinuous lenses of sand and gravel within the lower permeability till. The till, which is comprised of silt and clay, isolates the shallow groundwater system from the deep groundwater system.

2.5.3 SITE HYDROLOGY

The Site consists of a relatively flat topography with some low rolling hills. The underlying geology of the Site is the result of glacial deposition that has been extensively reworked by the Kalamazoo River. Development in the area of the Site has resulted in extensive filling of the area to current Site grades. The average elevation of the Site is 630 feet above mean sea level (AMSL). The mean pool elevation of the Kalamazoo River in the vicinity of the Site is 615 feet AMSL.

The 100-year flood elevation of the Kalamazoo River in the vicinity of the Site ranges from 619 feet AMSL downstream of the Site to 621 feet AMSL upstream of the Site. Limited portions of the Site, primarily in the vicinity of the former WWTP ponds, are located in the 100-year floodplain of the Kalamazoo River.

2.5.4 CLIMATOLOGY

The climate of Allegan County is directly influenced by its proximity to Lake Michigan. Average temperatures vary from 25.7°F in winter to 69.5°F during the summer months. The total average annual precipitation is 35.7 inches with an average of 20.0 inches falling from April through September. The average seasonal snowfall is 79.7 inches. Prevailing westerly winds have the highest wind speed in January, averaging 11.5 miles per hour.

3.0 ENVIRONMENTAL CHARACTERIZATION

3.1 BACKGROUND

Previous investigations have identified several environmental issues including:

- surface soil staining in the vicinity of the former SOS Pond;
- LNAPL in the former SOS Pond;
- LNAPL adjacent to the former Interim Pond area (RW-2 and RW-3);
- LNAPL in the former Rockwell WWTP ponds (MW-1);
- LNAPL in the former railroad ROW (MW-10);
- surface water and sediments in the former Rockwell WWTP ponds; and
- Site groundwater contamination.

These issues are reviewed in this Report under the general categories of source areas (i.e., LNAPL, soil, surface water, sediments, and LNAPL) and groundwater.

3.2 SOURCE AREAS

The source areas include the former SOS and Interim Ponds, the former Rockwell WWTP Ponds, and the former Railroad ROW. Previous investigations evaluated the impact of historical operations in terms of the impacts to surface soil, subsurface soil, and groundwater, as well as surface water and pond sediments in the former Rockwell WWTP Ponds. Chemicals of Interest (COIs) in the source areas are summarized on a media basis as follows:

A.	Soil:	Volatile Organic Compounds (VOCs); Polynuclear Aromatic Hydrocarbons (PAHs); non-PAH Semi-Volatile Organic Compounds (SVOCs); pesticides; PCBs (Aroclor 1254); and various inorganics.
B.	Surface Water:	non-PAH SVOCs; and aluminum, iron, lead, and manganese.

C. Pond Sediments: non-PAH SVOCs;
pesticides;
PCBs (Aroclor 1254); and
aluminum, arsenic, calcium, cobalt, and iron.

D. LNAPL: VOCs;
PAHs;
non-PAH SVOCs;
PCBs (Aroclor 1254); and
various inorganics.

3.3 GROUNDWATER

The shallow groundwater was identified to have the following COIs:

A. Groundwater: VOCs;
PAHs;
non-PAH SVOCs;
pesticides;
PCBs (Aroclor 1254); and
various inorganics.

4.0 CONCEPTUAL DESIGN APPROACH

4.1 DESIGN OBJECTIVES

The conceptual design objectives (i.e., RA objectives) are summarized as follows:

- prevent direct contact with or ingestion of contaminated soil, sediment, and groundwater above applicable risk-based criteria;
- address the presence of LNAPL;
- reduce leaching of COIs from soil and sediment to groundwater;
- control groundwater discharges to surface water (i.e., the Kalamazoo River);
- control infiltration and therefore the transport of COIs towards the Kalamazoo River;
- prevent erosion and runoff of contaminated soil to off Site areas;
- reduce mobility, toxicity, or volume of contaminants;
- support the beneficial re-use of the property;
- conduct remedial action on Site to the extent possible; and
- be cost-effective.

The proposed remedy for the Site will address potential risks to public health and the environment. The conceptual design approach for the Site is summarized in two general categories, as follows:

- source areas (soil, surface water, sediments, and LNAPL); and
- groundwater.

4.2 SITE-SPECIFIC DESIGN CONSIDERATIONS

A conceptual design for the proposed remedy has been developed for the Site that addresses issues at the source areas (e.g., former SOS and Interim Ponds, the former Rockwell WWTP Ponds, and the former Railroad ROW) and Site groundwater. The issues will be addressed under one integrated remedial approach for source areas and groundwater.

The following sections discuss the various areas included in the conceptual design, issues associated with selecting individual remedial technologies for these areas, and the remedial requirements within each area such that the individual components will be effective as a Site-wide remedy.

4.2.1 SOURCE AREAS

4.2.1.1 FORMER SOS AND INTERIM PONDS

The principal issues within the former SOS and Interim Ponds are direct contact with surface soil and the presence of LNAPL. The conceptual design considerations specific to the former SOS and Interim Ponds area will focus on the removal or capping of impacted soils and the hydraulic containment and extraction of LNAPL.

4.2.1.2 FORMER ROCKWELL WWTP PONDS AREA

The principal issues within the former Rockwell WWTP Ponds area are direct contact with surface water and sediments and the presence of LNAPL. The conceptual design includes a mechanism to prevent direct contact with surface water and sediments and the hydraulic containment and extraction of LNAPL. The conceptual design for this area includes LNAPL collection; solidification/stabilization, consolidation, and capping of affected sediments.

The quantity of soil and sediment that may require remediation in the former Rockwell WWTP Ponds is estimated to be at least 11,200 cubic yards (c.y.). This volume includes the pond sediments (~7,200 c.y.) and approximately 1.5 feet of the underlying soil (~4,000 c.y.).

The conceptual design for the former Rockwell WWTP Ponds will include the management of surface water and groundwater which will be required to implement the remedy components.

4.2.1.3 FORMER RAILROAD ROW

The principal issue associated with the former Railroad ROW is the presence of impacted soil and LNAPL. The conceptual design includes a mechanism to prevent direct contact with LNAPL and the hydraulic containment and extraction of LNAPL.

4.2.2 GROUNDWATER

The principal issues with groundwater are the potential future risks associated with groundwater use and the discharge of groundwater to the Kalamazoo River. The conceptual design includes the use of institutional controls and hydraulic containment/passive treatment to address these concerns.

5.0 COMPONENTS OF CONCEPTUAL DESIGN APPROACH

The following sections present the conceptual design approach for the source areas and Site-wide groundwater that will meet the objectives outlined in Section 4.1 and that is complementary to the future Brownfields re-development of the Site by the City of Allegan. The major components of the conceptual design are presented on Figure 5.1, and include:

1. excavation and off-Site disposal of soils with PCBs ≥ 50 mg/kg,
2. solidification of pond sediments,
3. excavation and consolidation of contaminated selected surficial soils and sediments within the former Rockwell WWTP pond area,
4. placement of other materials within the former Rockwell WWTP pond area to cover and raise the top surface elevation above the 100-year flood elevation and contouring into the adjacent areas to provide scour protection,
5. scour protection to protect capped areas outside the slurry wall that could potentially be subject to erosion by the Kalamazoo River,
6. capping of the Site through re-development,
7. LNAPL collection and off-Site disposal,
8. groundwater hydraulic containment wall (slurry wall),
9. PRB gates to passively treat groundwater prior to discharge,
10. institutional controls, and
11. performance monitoring plan.

5.1 SOURCE AREAS

The primary objective of the conceptual design for the former Rockwell WWTP Ponds and former SOS Pond is to address the issues associated with direct contact of the surface soils within and adjacent to these areas. Direct contact could take the form of dermal, ingestion, or inhalation.

To avoid any direct contact, soil and sediment within the former Rockwell WWTP Ponds will be solidified in situ (as necessary to meet appropriate strength requirements) and consolidated into Pond No. 2 and the southern quarter of Pond No. 3, as presented on

Figure 5.1. The selected consolidation area will provide additional separation from the Kalamazoo River (i.e., the sediments from Pond No. 1 and No. 3 will be consolidated to the east). The solidification process will mechanically lock contaminants (both organic and inorganic) within the solidified matrix. Contaminant loss (through leachability) and mobility would be minimized through reduction of surface area in contact with the environment and by physically binding the sediments into a solidified mass. It should be noted that the components of the remedy which address groundwater (see Section 5.2) include the use of a funnel and gate alternative that will further isolate this area from the Kalamazoo River. In addition, utilization of Portland cement (or similar reagents) as a solidifying agent would serve to increase the pH of infiltrating water to a level at which metals are not significantly soluble in water. The solidified material will have an increased strength and lower hydraulic conductivity. Treatability studies to further design the solidification approach will be required as part of the pre-design investigations.

Additional selected soil material from the former SOS Pond surface soil staining area will be excavated and consolidated into Pond No. 2 and the southern quarter of Pond No. 3 as well. During the consolidation of the pond sediments and surface soils, demolition of remaining structures associated with the former Rockwell WWTP Ponds, including but not limited to inlet/outfall structures, will be placed within the consolidation area as well.

It should be noted that the area of the former Rockwell WWTP Ponds is currently located below the 100-year flood elevation. Consolidation of solidified sediments and surface soils would bring the elevation of Pond No. 2 and the southern quarter of Pond No. 3 to approximately 615 feet AMSL. A variety of design components exist to protect this area from erosion due to flooding in the future. These include some or any of the following:

- provide berming around the consolidation area to protect against flooding;
- backfilling additional soil, or inert building rubble, in the former Rockwell WWTP Ponds area to raise the overall elevation to a level above the 100-year flood elevation; and/or
- utilizing a flood scour protective cover system.

Outside the proposed groundwater containment/treatment wall (see Section 5.2), there are some stained soils and localized detections of PCBs in groundwater which resulted from the in-place deposition of stained, PCB-bearing soils as part of fill relocation along the riverbank. Although the proposed containment/treatment wall will be placed as close as practicable to the riverbank to allow for containment and treatment of impacted groundwater in this area, there is material located close to the riverbank which will not be isolated by the containment/treatment wall. Wherever practicable, impacted materials outside of the alignment of the containment/treatment wall will be excavated and consolidated within the WWTP consolidation area. Remaining impacted soils outside the containment/treatment wall (if any) will be covered with a layer of organic-rich material to absorb any organic constituents in the groundwater beyond the containment/treatment wall. A scour protective cover will also be placed over this area to prevent against direct contact with localized contaminated material and prevent erosion due to river action.

Upon completion of the solidification process and backfilling, the consolidation area will be covered with a soil cover and vegetated to protect the cover from erosion. The soil cover system would be likely be an engineered semi-permeable cap, appropriate for the planned re-use of this portion of the Site. It should be noted that the design (e.g., solidified material strength, cover, etc.) will be modified, as required, to support the City of Allegan's proposed re-use of the area (e.g., parking lot, building, etc.). An evaluation of the most appropriate cover system for each type of area use by the City of Allegan, as well as methods to protect the shoreline from erosion due to the Kalamazoo River, will be conducted as part of the pre-design and design activities.

This portion of the conceptual design will also involve the collection and treatment of the existing surface water currently stored within the three former Rockwell WWTP ponds. During excavation of the residual sediments, employed methodologies will likely involve dewatering of the excavations and treatment of collected water.

In addition to the identified surface soils and pond sediments that must be removed and consolidated within the former Rockwell WWTP Ponds, there are limited areas within the former SOS and Interim Ponds and the former Railroad ROW where LNAPL has been observed. The presence of LNAPL will be addressed separately in light of the planned slurry wall/PRB technology incorporated within the groundwater containment/treatment wall, as discussed further in Section 5.2.

LNAPL recovery systems will be installed at each primary area identified to contain LNAPL. The conceptual design for each recovery system will consist of two intersecting gravel collection trenches, although alternative recovery systems will be evaluated during the preliminary (30%) design. An extraction sump will be constructed at the intersection point. Figure 5.2 presents a typical detail of an LNAPL extraction system. Figure 5.3 presents a typical cross section of the trench and extraction sump. Floating skimmer pumps or well drawdown pumps will be installed in the extraction sumps to create a slight inward gradient causing LNAPL to flow to the extraction sump and be collected. The LNAPL/water mixture removed from the extraction sump will be directed to an oil/water separator, with collected LNAPL being containerized for proper off-Site disposal. Following LNAPL separation, collected groundwater will be returned to the groundwater system. The addition of oxygen releasing compounds (ORC) to the groundwater prior to re-injection will be evaluated to determine its effect on the further degradation of Site contaminants within groundwater.

The LNAPL recovery systems will provide hydraulic containment during collection activities and remove collectable LNAPL. The LNAPL recovery systems would be operated until collectable LNAPL has been removed. Following LNAPL recovery system shutdown, any residual uncollectable LNAPL would no longer be mobile.

The LNAPL area located between Pond No. 2 and Pond No. 3 may be removed if it is determined the LNAPL collection system is not practical, or is not consistent with the containment remedy for the ponds. Should excavation of this LNAPL area occur, unsaturated surface and subsurface soils would be excavated and stockpiled to expose the LNAPL layer. Thereafter, the impacted soils within the LNAPL layer would be removed along with all available LNAPL. The LNAPL product would be separated from the excavated soils allowing the excavated soils to then be consolidated within Pond No. 2 and the remaining portions of Pond No. 1 and 3. Following removal of the LNAPL and impacted subsurface soils, the stockpiled unsaturated soils could be placed back within the excavations prior to capping. Collected LNAPL would be containerized and properly disposed off Site.

Figures 5.4 and 5.5 present the existing contours/cross section in the area of the former Rockwell WWTP Ponds, while Figures 5.6 and 5.7 present a conceptual final contour configuration/cross section which would raise the elevation to approximately 625 feet AMSL (i.e., above the 100-year flood elevation). This conceptual configuration would require approximately 45,000 to 50,000 c.y. of additional fill material (soil from Site-wide cleanup, clean fill, building rubble, etc.), beyond the amount of pond sediments and surface soils to be solidified/consolidated within Pond No. 2.

5.2 SITE-WIDE GROUNDWATER

Although LNAPL presence is directly related to groundwater (i.e., LNAPL floats on the groundwater table) and impacts the groundwater quality, LNAPL is addressed on a localized area basis so as to prevent any further migration of LNAPL beneath the Site and beyond. The localized containment or removal of LNAPL is important to the proposed conceptual design for the overall Site-wide groundwater regime as LNAPL could be adverse to the passive PRB system being proposed.

The primary objective of the conceptual design for the Site-wide groundwater is to reduce the potential migration of impacted groundwater beyond the Site boundaries and into the Kalamazoo River. To achieve this objective, the conceptual design includes the construction of a subsurface slurry wall completely around the Site which will be keyed to the clay till. However, this subsurface wall would not solely provide physical and hydraulic containment but will also include several areas where the groundwater will be allowed to pass through an engineered "gate" in the wall where passive treatment will take place. Further discussion is provided in the following sub-sections regarding the two components of the proposed groundwater containment/treatment wall.

5.2.1 CONTAINMENT WALL TECHNOLOGY

There are several available technologies that will be considered for constructing a containment wall, but the most common method utilized within overburden soils below the groundwater table is the slurry trenching technique. The advantages of the slurry trenching technique include excavation of a narrow trench without construction dewatering, and subsequent re-use of the excavated material within the installed containment wall. In ideal situations, little excavated material requires disposal and no water handling is required.

Soil-bentonite slurry trenching utilizes bentonite slurry (cement and attapulgite will also be considered, as required) to maintain vertical trench walls during excavation and until backfilling is complete. The bentonite slurry forms a filter cake on the trench walls providing an impermeable barrier against incoming groundwater flow. The excavated soils are typically placed beside the trench as trenching progresses and these excavated soils are mixed with more bentonite slurry as well as dry bentonite powder to the appropriate consistency based on treatability testing (typically 3 to 5 percent total bentonite by weight). The soil-bentonite (S-B) mixture is then placed back into the slurry-filled trench at the opposite end from the excavation face. Excavation and backfilling then progresses concurrently such that the bentonite slurry within the trench is moved along as a slug (and replenished as needed). Figure 5.8 illustrates the general slurry wall installation procedure.

Upon completion, the backfilled S-B wall forms a continuous, non-structural, low-permeability barrier to groundwater movement. Typically, the hydraulic conductivity for a completed S-B wall will be on the order of 1×10^{-7} cm/sec to 1×10^{-8} cm/sec.

Cement-bentonite (C-B) slurry walls provide an alternative to S-B, where more structural strength is required. In these cases, cement is typically added to either the backfill (soil-cement-bentonite) or the slurry (cement-bentonite) to create a low permeability backfill for the slurry trench with some structural strength. C-B is a self-hardening grout that can be highly advantageous when working room is restricted or when traversing sudden changes in terrain. With C-B, the grout (trench slurry) hardens within the excavation, so there is no separate backfilling operation, and the excavated soils are not reused. Soil-cement-bentonite (SCB) is much like S-B but produces a denser and less costly backfill that is often used in earthen dams and dikes where moderate structural capability of the completed structure is required. SCB and C-B are also commonly used at the intersection of a slurry wall with a PRB gate, so that the treatment media is adequately supported and not mixed with S-B or bentonite slurry.

Chemical compatibility is an important consideration in designing any type of slurry wall backfill. To ensure that the chemicals present at this Site are not detrimental to the performance of the slurry or the backfill, laboratory compatibility testing will be performed. This testing will evaluate obvious physical effects on the slurry mixture used to maintain trench stability (i.e., flocculation and loss of swelling capacity) and the visual effects on the slurry mixture (i.e., cracking, shrinkage, lack of hardening, etc.). This phase of testing is important for this application, as it is expected that the contaminated groundwater will likely come in contact with the wall backfill.

The permeability of the completed wall is also critical in designing a containment wall. The testing program is a two-step process, in that a mixture must first be developed which achieves the desired hydraulic conductivity, and then the impacts of chemical exposure can be measured in terms of the effects on the resultant hydraulic conductivity. For S-B or soil-attapulgite (S-A) slurry walls, prepared slurry as well as dry powder will be mixed with Site soils to the desired consistency and the resultant hydraulic conductivity will be measured by placing the S-B or S-A mixture in a permeameter and passing through water. For C-B slurry walls, the cement and bentonite slurry is allowed to harden prior to testing. The hardened C-B is tested in a permeameter, following the same methodology as described for S-B. For SCB slurry walls, cement (grout or dry powder), bentonite slurry, and dry bentonite powder are mixed with Site soils to the desired consistency. The hydraulic conductivity of the SCB is measured after the mixture hardens using the same methodology. If the resultant hydraulic conductivity is not low enough, the mixture may be adjusted. For S-B and SCB walls, additional fines may be added to the Site soils to lower the hydraulic conductivity of the soils prior to mixing with bentonite. In some cases, imported soils may completely replace the Site soils. For C-B and SCB walls, different types of cement or other adjustments in the mixture can be made to lower the hydraulic conductivity of the mixture.

Once the hydraulic conductivity of the designed slurry wall mixture is determined in a "clean" environment (i.e., potable water is used as the permeant to determine a baseline hydraulic conductivity), then the impacts of the chemicals present at the Site can be assessed. A representative sample of Site groundwater is passed through the slurry wall mixture and the resultant hydraulic conductivity is compared to the results for potable water. If the hydraulic conductivity is severely affected, it could be that a different slurry wall mixture is required. Therefore, the testing program will use a range of slurry wall mixtures to determine the most appropriate ratio of soil and bentonite. The use of high carbon fly ash will also be tested in the laboratory as an additive to further reduce the hydraulic conductivity. A final step in the hydraulic conductivity testing program is measuring the long-term affects on hydraulic conductivity by passing through several pore volumes of Site groundwater. CRA has implemented several of these testing programs at other sites, and the previous results can be utilized to draw conclusions on how the selected slurry wall mixture will respond over the long term.

The two most important field considerations in designing a slurry wall are the alignment and the depth. Figure 5.9 presents the proposed fully encircling alignment of the slurry wall.

Although the alignment of the slurry wall is important, an even more important design consideration is the depth of the installed containment wall. Typically, the wall will be "keyed" in some underlying strata that will provide hydraulic containment in the vertical direction. At the Site, there is a continuous till layer present beneath the Site. This native till layer ranges in depth from between 30 feet and 70 feet bgs. The slurry wall will be keyed a minimum of two feet into the underlying clay till aquitard.

5.2.2 TREATMENT WALL TECHNOLOGY

PRBs involve the placement of treatment media in a subsurface trench/excavation or other engineered structure to intercept a plume of contaminated groundwater which must flow through the PRB, typically under a natural gradient, thereby creating a passive treatment system. As the aqueous phase contaminants move through the treatment media, physical, chemical or biological reactions occur that transform them to a less harmful (non-toxic) or immobile species. The first pilot-scale PRB was installed in 1991. The first full-scale installation of a PRB occurred in December 1994.

PRB technologies potentially have several advantages over conventional pump-and-treat methods for groundwater control. PRBs can degrade or immobilize contaminants in situ. There typically is no need to handle the contaminants, bring the contaminants to the surface, or expose workers and the public to contaminants during operation. In addition, PRBs do not require continuous input of energy because a natural gradient of groundwater flow is used to carry contaminants through the reactive zone. Only periodic replacement or rejuvenation of the reaction medium may be required after its capacity is exhausted or it is clogged by precipitants and/or microorganisms. PRBs are particularly amenable to Brownfields redevelopment, as they can be installed completely below ground surface thereby eliminating the need for surface infrastructure and providing more area to redevelop the Site for a beneficial use.

In contrast, pump-and-treat systems require that the contaminants are pumped to the ground surface, potentially exposing workers and the public to the contaminants and by products including air discharges that are of particular importance in the context of a Brownfield redevelopment. Pump-and-treat systems require significant infrastructure which may impair the future use of the Site. Pump-and-treat systems must pump and treat significantly more groundwater than the original size of the plume. This is especially pertinent in hydrogeological systems close to significant bodies of surface water where extremely large volumes of water would require pumping to establish hydraulic control.

The remedy that is being proposed is to utilize a combination of containment wall technology and PRB treatment technology to effectively control and passively treat the groundwater at the Site.

To ensure a comprehensive and technically complete design is developed, CRA has retained experts in containment wall and PRB treatment technology. The University of Waterloo (U of W), and its affiliated company ETI, are leaders in research and application of PRB technology and hold several patents relating to treatment of groundwater with PRBs. ETI has been involved in over 75 installations of PRBs to treat a variety of organic and inorganic compounds and has completed over 200 laboratory treatability tests on the technology. Senior staff at ETI have been involved with the technology from the initial development and are amongst the most experienced professionals worldwide in the application of PRBs.

Dr. Robert Gillham, the developer and foremost expert of iron PRBs for treatment of chlorinated organics and co-founder of ETI, and Dr. David Blowes, the developer and foremost expert of treatment of metals in PRBs are part of the Project Team and will provide additional technical advice on the PRB design and to provide outside peer review.

Geo-Solutions is a construction consulting firm with offices in Pennsylvania and Colorado that specializes geotechnical construction, in particular vertical containment technologies such as slurry walls and PRBs. In addition, Geo-Solutions has installed several PRBs, in conjunction with ETI and U of W.

These experts, together with CRA's design staff, will focus on selection of the most effective PRB design and the appropriate construction technique for installation of the combined slurry wall and PRB system.

5.2.2.1 EVALUATION OF POTENTIAL PRB TREATMENT MATERIALS

As groundwater moves through the PRB, the contaminants are removed by physical, chemical, and/or biological processes, including precipitation, oxidation/reduction, sorption, fixation, biodegradation, or chemical degradation. A review of the groundwater chemistry at the Site is presented in Table 5.1. The following table summarizes the COIs that had significant detections and the possible treatment media for each COI:

Contaminant of Interest (COI)	*Possible Treatment Media*	*Treatment Mechanism*
VOCs 1,1,1-Trichloroethane 1,1-Dichloroethane 1,2-Dichloroethene Chloroform cis-1,2-Dichloroethene Tetrachloroethene trans-1,2-Dichloroethene Trichloroethene Vinyl chloride	1. Zero-Valent Iron 2. Biological 3. Granular Activated Carbon (GAC)	1. Degradation 2. Degradation 3. Sorption
VOCs 1,2-Dichlorobenzene 1,4-Dichlorobenzene 2-Butanone Acetone Benzene Carbon Disulfide Chlorobenzene Chloroethane Ethylbenzene Methylene Chloride Styrene Toluene Xylenes (total)	1. Biological 2. GAC	1. Degradation 2. Sorption
PAHs	GAC	Sorption
Non-PAH SVOCs	GAC	Sorption
Pesticides	1. GAC 2. Zero-Valent Iron	1. Sorption 2. Degradation
PCBs (Aroclor 1254)	GAC	Sorption

Contaminant of Interest (COI)	*Possible Treatment Media*	*Treatment Mechanism*
Major Metals Arsenic Cadmium Chromium Copper Iron Lead Mercury Nickel Selenium Zinc	1. Zero-Valent Iron 2. Organic Carbon 3. Limestone	1. Precipitation 2. Sulfate Reduction /Precipitation 3. Precipitation

The treatment media listed above have all been demonstrated in a PRB configuration for treatment of the contaminants identified. These include:

- over 60 PRB applications of zero-valent iron for treatment of chlorinated organic compounds;
- over 10 PRB applications for treatment of trace metals. Treatment materials utilized in field applications include zero valent iron for chromium, arsenic and manganese removal, compost for arsenic, cadmium, copper, iron, lead, nickel, and zinc removal, and limestone for lead, zinc and copper removal; and
- The use of GAC for petroleum hydrocarbons and benzene, toluene, ethylbenzene, and xylene (BTEX) compounds, PAHs, VOCs and pesticides. GAC is effective in removing any PCBs from groundwater as well.

5.2.2.2 PRB CONFIGURATION

There are two basic designs for a PRB, a continuous PRB or a "funnel and gate". In the continuous PRB configuration, the treatment media is distributed across the entire path of the contaminated groundwater. The treatment media must have a hydraulic conductivity that is equal or greater than the aquifer to prevent the natural groundwater flow path or velocity from being significantly altered.

A funnel and gate configuration uses low permeability materials (funnel) to direct groundwater towards a permeable treatment zone (gate). By directing or funneling the groundwater through a treatment gate, the natural groundwater flow velocity may be increased several times in the gate. To ensure that flow beneath the system does not occur, funnel and gate systems must be keyed into a competent underlying low permeability zone.

The funnel and gate configuration lends itself to designs incorporating media which may require periodic replacement (e.g. GAC) and to designs which may require a higher degree of hydraulic control.

A more recent development in the application of "funnel and gate" PRBs is the use of constructed vessels in place of the excavated/backfilled trench. This application allows the flexibility of installing separate treatment vessels as well as easing the process of replacing the reactive media in the future, should fouling, precipitation, or consumption negate the effectiveness of this treatment process. In situ treatment vessels operating passively as treatment gates have been installed at sites in Colorado, Georgia, and the United Kingdom, where easier access to replace the treatment media was desired. Figure 5.10 illustrates the two "funnel and gate" techniques discussed.

5.3 CONCEPTUAL CONTAINMENT WALL/PRB DESIGN

Figure 5.9 shows the approximate location of the proposed containment wall/PRB as part of the conceptual design for the Site. The length of the containment/treatment wall indicates that approximately five PRB gates will be required depending on hydraulic modeling results. The type and quantity of treatment media, and the appropriate sequencing of treatment media within each PRB may potentially be varied across the Site based on the type and flux of COIs expected at each gate. The containment wall would act as an effective barrier to off-Site migration of groundwater, with the contained groundwater directed toward the gates for treatment via the reactive media.

Hydraulic modeling will be used to determine the most appropriate configuration for the gate(s) and number of gates. GAC sorption models and geochemical modeling will be used to determine the anticipated life-span of the PRB gates (dependent upon the estimated groundwater flow).

LNAPL observed during the previous investigations is suspected to be residual and not significantly mobile in its present state. The groundwater will not be pumped and therefore it is not expected that the LNAPL will be mobilized. However, the migration of LNAPL into and through the PRB gates would not be desirable as LNAPL would likely clog the reactive media and render the passive treatment system less effective. Therefore, engineering controls at the PRB gates have been included in the conceptual design to prevent LNAPL from reaching the PRB gates. The preliminary (30%) design will evaluate alternative designs to eliminate the potential for LNAPL to enter the PRB. As stated previously, LNAPL collection trenches are proposed to be installed at each LNAPL source area, as well as selected excavation of subsurface soils contaminated with LNAPL (or in situ solidification), to prevent continued LNAPL movement. Figure 5.11 presents a conceptual design to address potential LNAPL accumulation at the PRB gate.

A hydrogeologic evaluation will be conducted as part of the preliminary (30%) design phase using modeling to determine the most appropriate configuration for the PRB and slurry wall funnel. Preliminary review of the Site hydrogeology and extent of impacted groundwater indicates that the shallow groundwater tends to migrate in an upward direction with subsequent discharge to the Kalamazoo River. Four cross-sections of the preliminary proposed alignment of the containment wall/PRBs are presented on Figures 5.12 through 5.15, illustrating the depth to the existing and continuous confining clay till.

Several PRB media may be applicable for treatment of the Site groundwater. A treatability study will be required to determine the most effective media for remediating Site groundwater.

Following installation, and as part of the quality assurance program, measures will be taken to verify the construction of the slurry wall and PRB gates as designed. Drilling and geophysical methods, in combination with standard hydrologic characterization methods, such as dye testing, have been successfully used to achieve design verification. In addition, a series of monitoring wells will be installed in the vicinity of the gates to monitor the treatment process and performance.

6.0 DESIGN SCOPE OF WORK

This section presents the scope of work to complete the pre-design, design, and implementation of the proposed remedy at the Site. The scope of work includes the following tasks:

Task 1: Performance Standards Review Program;

Task 2: Pre-Design Studies Program;

Task 3: Detailed Design Program;

Task 4: Construction Quality Assurance Program;

Task 5: Operation and Maintenance Program; and

Task 6: Community Relations.

6.1 TASK 1: PERFORMANCE STANDARDS REVIEW PROGRAM

Prior to initiating the preliminary (30%) design process, it is important to review and define the performance standards applicable to the proposed remedial action. Critical to the performance standards selection process is the determination of the most reasonably foreseeable future land use, which at this time consists of an expression of interest by the City of Allegan to support the KVCC re-use of the Site. Significant regulations which will be considered as part of the design include, but may not be limited to, the following:

- Toxic Substance Control Act (TSCA) sets forth standards applicable to material containing PCBs;
- Resource Conservation and Recovery Act (RCRA) generator standards in 40 CFR 262 and Michigan Act 451, Part 111, which set forth standards applicable to generators of hazardous waste;
- RCRA transporter standards in 40 CFR 263 and Michigan Act 451, Part 111, set forth standards applicable to transporters of hazardous waste;
- RCRA land disposal restrictions in 40 CFR 268 which set forth prohibition and restrictions on land disposal, including treatment standards for certain waste;
- Michigan Environmental Remediation Regulations (Act 451, Part 201) regulates management of contaminated facilities to protect human heath and the environment;

- Michigan Solid Waste Management Regulations (Act 451, Part 115) regulates the storage, treatment, transportation and disposal of solid waste;
- Clean Water Act (40 CFR 131) provides guidelines for water quality standards for the protection of human health and aquatic life;
- Michigan Water Resources Commission Act (Act 451, Part 31) regulates construction activities within the floodplain;
- Federal National Ambient Air Quality Standards (NAAQS);
- State Air Regulations incorporated in the Michigan Air Pollution Act; and
- Occupational Safety and Health Administration (OSHA) recordkeeping and reporting in 29 CFR 1904 set forth recordkeeping and reporting for employers.

The following components of the remedy will be evaluated in terms of performance standards as part of Task 1. The applicable performance standard for each component will be summarized in the Pre-Design Work Plan, as discussed in Task 2, and will form the basis for the pre-design studies and detailed design.

Remedial Action Component	*Potential Basis for Performance Standard*
Surface Soil Cleanup Criteria	• Visual observation of stained areas • Michigan Act 451, Part 201 Generic Soil Direct Contact Criteria (DCC)
Solidification of Sediments	• minimum strength to support cover system and possible re-development (unconfined compressive strength) • workability • elimination of free water
Backfill Materials	• applicability of demolition debris for use as backfill • other soil requiring remediation • inert on/off-Site backfill material • construction within the floodplain
Soil Cover Requirements	• semi-permeable vs. non-permeable • infiltration rate to maintain Site hydraulics • slopes

	• vegetation type • alternate covers (asphalt, buildings)
Slurry Wall Performance	• hydraulic conductivity through wall • hydraulic gradient requirements • alignment and depth of wall system • structural compatibility with the PRBs • structural stability near rivers/along slopes
PRB Performance	• Michigan Act 451, Part 201 Groundwater/Surface Water Interface (GSI) with Site-specific mixing zone • Alternative Concentration Limit (ACL) with mixing zone concept

6.2 TASK 2: PRE-DESIGN STUDIES PROGRAM

Pre-design activities are necessary to confirm Site conditions, conduct appropriate testing, and provide sufficient information to complete the detailed remedial design. The detailed scope of work for specific pre-design activities will be presented in a Pre-Design Work Plan. The Pre-Design Work Plan will also provide a presentation of the performance standards review program completed during Task 1 and present the applicable performance standard for each remedial component. The following sections provide brief overviews of the scope of the pre-design activities that may be required.

6.2.1 SITE-SPECIFIC HEALTH AND SAFETY PLAN/ QUALITY ASSURANCE PROJECT PLAN (QAPP)

A Site-specific Health and Safety Plan (HASP) will be developed that will be applicable to all pre-design activities. The HASP will describe the procedures that will be used to protect on-Site personnel and area residents from hazards posed by Site activities during the pre-design study program. All pre-design studies will be completed following the analytical chemistry requirements of existing Quality Assurance Project Plans (QAPPs) developed for the RI to the extent the requirements apply to the type of activity being performed. Specific methods required to complete the geotechnical and chemical compatibility testing requirements will be presented in the Pre-Design Work Plan.

6.2.2 SITE RECONNAISSANCE AND TOPOGRAPHIC SURVEY

A Site reconnaissance will be conducted to confirm existing conditions at the Site. A detailed topographic survey will be required along the proposed alignment of the containment/treatment wall. Additional borings may be required to confirm the presence and depth of till in areas where little stratigraphic data is available, as well as collecting representative soil samples to be used during compatibility testing.

6.2.3 LNAPL DELINEATION STUDY

Additional LNAPL delineation will be completed, as necessary, to more fully define the extent of identified LNAPL areas. The study will include the installation and monitoring of temporary or permanent monitoring wells to confirm the extent of LNAPL in each area.

6.2.4 SEDIMENT DELINEATION STUDY

A sediment delineation study within the former Rockwell WWTP Ponds will be conducted to fully define the extent that sediment and soil materials have been impacted by historical operations. The study will include borehole installation and sampling to fully define the volume and existing strength of material that will require management as part of the sediment solidification and consolidation portion of the proposed conceptual design.

6.2.5 SEDIMENT/SOIL TREATABILITY STUDY

A sediment/soil treatability study will be performed to evaluate the effectiveness of treatment technologies such as dewatering and solidifying the sediment/soil material. Representative samples will be collected during the above sediment delineation study.

6.2.6 GROUNDWATER INVESTIGATION

Additional groundwater sampling may be conducted to provide current general chemistry data for the design of the PRB wall system. The groundwater investigation will focus, in particular, on wells in the vicinity of the former SOS and Interim Ponds area and the former Rockwell WWTP Ponds area. Compatibility testing of the trench slurry and potential backfill materials will also require the collection of representative groundwater samples.

6.2.7 SLURRY WALL BACKFILL COMPATIBILITY STUDIES

A chemical compatibility study will be performed to ensure that contact of the Site chemistry with the proposed slurry wall will not adversely affect this remedial component, both during installation to maintain the required open trench and following completion to maintain the desired hydraulic conductivity. The primary purpose of conducting these compatibility and hydraulic conductivity tests will be to ensure the long-term applicability of the selected technology.

It should be noted that the compatibility testing results would also assist in providing pertinent design data for selection of the design mixtures to be implemented during implementation. The appropriate re-use of Site soils will also be determined during the compatibility testing, and any future need to incorporate alternative clays or cement, fines addition, or the complete replacement of Site soils with imported fill will be evaluated.

6.2.8 GROUNDWATER TREATABILITY STUDIES

A groundwater treatability study will be required to fully evaluate the most suitable treatment media for the COIs. Bench-scale treatability studies will be completed with representative Site groundwater and PRB treatment media. The selection of appropriate groundwater sample locations and PRB treatment media will be based on a more thorough review of the spatial characteristics of the contaminant plume. This might include simulations of sequenced treatment configurations (e.g. zero-valent iron followed by GAC). The bench-scale treatability study will be designed to obtain the necessary parameters for full-scale design and allow the design to be optimized in terms of amount of treatment media required, and rejuvenation/replacement schedules for the treatment media.

It should be noted that the treatability studies would also be utilized to provide the necessary data to design any treatment systems that may be required as a contingency in the event that a treatment wall system is not feasible.

6.2.9 GROUNDWATER MODELING STUDIES

Groundwater modeling studies will be completed to evaluate the most appropriate funnel and gate configuration based on the expected flux through the PRB gates and/or treatment vessels. The modeling study will be used to optimize the overall design including the required permeability of the containment wall, the required permeability of the treatment media, and the size and location of the treatment gates/vessels.

6.2.10 COVER SYSTEM MATERIALS EVALUATION

A cover system material evaluation will be conducted to determine the most appropriate cover system for the proposed capped areas of the Site. At this time it is expected that Site re-development will constitute a major portion of the future Site capping. The evaluation will consider the interrelationship between the permeability of the cover with the hydraulic requirements of the treatment wall. The evaluation will also address the erosion protection required along the Kalamazoo River.

6.2.11 PRE-DESIGN REPORTING

A Pre-Design Study Report will be assembled subsequent to completing all pre-design activities for submittal to U.S. EPA. The Pre-Design Study Report will include the results of the pre-design studies and any conceptual design changes that develop as a result of these studies.

6.3 TASK 3: DETAILED DESIGN PROGRAM

The Detailed Design will include the following:

- a detailed description of the design objectives and the means by which each element of the selected remedy will be implemented to achieve those objectives;
- documents for construction including, but not limited to, documents, plans, and specifications prepared, signed, and sealed by a professional engineer. These documents will be consistent with all applicable local, state, and federal laws, rules, and regulations, as required, and will contain sufficient information to document the work to be performed;
- quality control and quality assurance procedures and protocols to be applied during implementation of the remedial action;
- a time schedule for completing construction;
- the parameters, conditions, procedures and protocols to determine the effectiveness of the implemented remedy, including a schedule for periodic sampling and monitoring of Site conditions;
- a description of operation, maintenance, and monitoring activities to be undertaken after the U.S. EPA has approved construction of the remedy;
- a contingency plan to be implemented if any element of the remedy fails to achieve any of its objectives or otherwise fails to protect human health or the environment; and
- a community construction health and safety plan for the protection of persons at, and in the vicinity of, the Site during construction and after completion of construction. This plan shall be prepared in accordance with 29 CFR Part 1910 by a certified health and safety professional and allow an opportunity for public input.

Clear and comprehensive design documents, drawings and project specifications will be developed, which include but are not limited to the following:

1. Discussion of the design strategy and the design basis, including:
    - compliance with all relevant, applicable, and appropriate environmental and public health laws, rules, regulations, and standards, and
    - minimization of environmental and public impacts;

2. Discussion of the technical factors of importance to the design and construction including:
   - use of currently accepted environmental control measures and technology,
   - the constructability of the design, and
   - use of currently acceptable construction practices and techniques;
3. Description of assumptions made and detailed justification of these assumptions;
4. Discussion of the possible sources of error and references to possible operation and maintenance problems;
5. Detailed drawings of the proposed design including:
   - qualitative flow sheets, and
   - quantitative flow sheets;
6. Detailed specifications;
7. Implementation schedule;
8. Tables listing equipment and specifications;
9. Tables giving material and energy balances; and
10. Appendices including:
    - sample calculations (one example presented and explained clearly for significant or unique design calculations),
    - derivation of equations essential to understanding the report, and
    - results of other laboratory or field tests.

The detailed Design Report and associated drawings will be submitted to U.S. EPA.

6.4 TASK 4: CONSTRUCTION QUALITY ASSURANCE PROGRAM

A construction quality assurance (CQA) program will be developed to ensure, with a reasonable degree of certainty, that the completed remedy meets or exceeds all design criteria, drawings, and specifications. The CQA Plan will be prepared specifically for the Site and submitted for review by U.S. EPA along with the Detailed Design submittal. At a minimum, the CQA Plan will include the elements summarized below. Upon U.S. EPA approval of the CQA Plan, the remedy will be implemented in accordance with the approved design, schedule, and the CQA Plan.

6.4.1 RESPONSIBILITY AND AUTHORITY

The CQA Plan will describe fully the responsibility and authority of all organizations (i.e., technical consultants, subcontractors, etc.) and key personnel involved in the construction of the remedy. The CQA Plan will also identify a CQA officer and the necessary supporting inspection staff.

6.4.2 CONSTRUCTION QUALITY ASSURANCE PERSONNEL QUALIFICATIONS

The qualifications of the CQA officer and supporting inspection personnel will be presented in the CQA Plan in order to demonstrate that they possess the training and experience necessary to fulfill their identified responsibilities.

6.4.3 INSPECTION ACTIVITIES

The CQA Plan will summarize the observations, inspections, and tests that will be used to monitor the construction and/or installation of the remedial components. The CQA plan will include the scope and frequency of each type of inspection and test. Inspections will verify compliance with the environmental requirements and include, but not be limited to, air quality and emissions monitoring records, and waste disposal records. The inspections will also ensure compliance with all health and safety procedures. In addition to construction oversight inspections, the activities described in the following sub-sections will be conducted.

6.4.3.1 PRE-CONSTRUCTION INSPECTION AND MEETING

Prior to initiating or commencing construction, a construction inspection and meeting will be conducted to:

- review methods for documenting and reporting inspection data;
- review methods for distributing and storing documents and reports;
- review work area security and safety protocol;

- discuss any appropriate modifications of the CQA plan to ensure that Site-specific considerations are addressed; and
- conduct a Site walk-around to verify that the design criteria, plans, and specifications are understood, and to review material and equipment storage locations.

The pre-construction inspection and meeting will be documented by a designated person and minutes will be transmitted to U.S. EPA.

6.4.3.2 PRE-FINAL INSPECTION

Prior to substantial completion of the Project, the U.S. EPA will be notified for the purpose of conducting a pre-final inspection. The pre-final inspection will consist of a walk-through inspection of the entire Project Site. The inspection is to determine whether the Project is complete and consistent with the Contract Documents and the approved design. Any outstanding construction items discovered during the inspection will be identified and noted. Additionally, treatment equipment, if any, will be operationally tested. The equipment will be certified that it has performed to meet the purpose and intent of the specifications. Retesting will be completed where deficiencies are revealed. The Pre-Final inspection report will outline the outstanding construction items, actions required to resolve items, completion date for these items, and date for final inspection.

6.4.3.3 FINAL INSPECTION

Upon completion of any and all outstanding construction items, the U.S. EPA will be notified for the purposes of conducting a final inspection. The final inspection will consist of a walk-through inspection of the Project Site. The Pre-Final inspection report will be used as a checklist with the Final inspection focusing on the outstanding construction items identified in the Pre-Final inspection. Confirmation shall be made that outstanding items have been resolved.

6.4.4 SAMPLING REQUIREMENTS

The sampling activities, sample size, sample locations, frequency of testing, acceptance and rejection criteria, and plans for correcting problems as addressed in the Project Specifications will be presented in the CQA Plan.

6.4.5 DOCUMENTATION

Reporting requirements for CQA activities will be described in detail in the CQA Plan. This will include such items as daily summary reports, inspection data sheets, problem identification and corrective measures reports, design acceptance reports, and final documentation. Provisions for the final storage of all records will be presented in the CQA Plan.

6.5 TASK 5: OPERATION AND MAINTENANCE PROGRAM

An Operation and Maintenance (O&M) Plan will be prepared and submitted to U.S. EPA for approval to cover both implementation and long-term maintenance of the conceptual design. The O&M Plan shall consist of the following elements:

1. Description of normal O&M, including:
    - description of tasks for operation,
    - description of tasks for maintenance,
    - description of prescribed treatment or operation conditions, and
    - schedule showing frequency of each O&M task;
2. Description of potential operating problems, including:
    - description and analysis of potential operation problems,
    - sources of information regarding problems, and
    - common and/or anticipated remedies;
3. Description of routine monitoring and laboratory testing, including:
    - description of monitoring tasks,
    - description of required laboratory tests and their interpretation,
    - required data collection,

- schedule of monitoring frequency and date, if appropriate, when monitoring may cease, and
- description of triggering mechanisms for soil and groundwater monitoring results;

4. Description of alternate O&M, including:
   - should systems fail, alternate procedures to prevent releases or threatened releases of hazardous substances, pollutants, and contaminants in order to protect public health and the environment, and prevent exceedance of any applicable, relevant, and appropriate standard, and
   - analysis of vulnerability and additional resource requirement should a failure occur;
5. Corrective Action, including:
   - description of corrective action to be implemented, and
   - schedule for implementing these corrective actions;
6. Safety plan, including:
   - description of precautions and necessary equipment, for safety of Site personnel, and
   - safety tasks required in event of systems failure;
7. Description of equipment, including:
   - equipment identification,
   - installation of monitoring components,
   - maintenance of Site equipment, and
   - replacement schedule for equipment and installed components; and
8. Records and reporting mechanisms, including:
   - daily operating logs,
   - laboratory records,
   - records for operating costs,
   - mechanism for reporting emergencies,
   - personnel and maintenance records, and
   - monthly/annual reports to State agencies.

A Draft O&M Plan will be submitted simultaneously with the submittal of the Final Design Report. The Final O&M Plan will be submitted with the draft Construction Report.

6.6 TASK 6: COMMUNITY RELATIONS SUPPORT

It is anticipated that a community relations program will be implemented during design and implementation to keep the community informed as to the status of activities at the Site. ArvinMeritor and CRA will coordinate community relations with the U.S. EPA during both the design and implementation. Implementation of the community relations program will involve preparation of all appropriate information disseminated to the public and in public meetings that may be held or sponsored by the U.S. EPA to explain activities at or concerning the Site.

7.0 PROJECT SCHEDULE

The schedule for implementation of pre-design and design tasks will be established to be consistent with re-development opportunities for the property, as well as U.S. EPA and Michigan Department of Environmental Quality (MDEQ) schedules for necessary reviews and approvals.

A detailed implementation schedule will be submitted with the Preliminary (30%) Design submittal, at which time the scheduling requirements will be able to be fully determined.

8.0 PROJECT COST ESTIMATE

A preliminary project cost estimate is presented in Table 8.1.

9.0 PROJECT TEAM

9.1 OVERALL PROJECT TEAM STRUCTURE

The overall project team structure is presented on Figure 9.1. ArvinMeritor and its counsel, will provide overall direction to the project team and liaison with the U.S. EPA. CRA, as project engineer, will be responsible for the design and implementation. CRA will procure subcontractors acceptable to ArvinMeritor to complete field studies, assist with design elements, and coordinate the implementation on behalf of ArvinMeritor.

9.2 CRA PROJECT MANAGEMENT TEAM

CRA has assembled a project management team comprised of personnel who have effectively completed numerous similar projects. The work will be completed primarily utilizing personnel from CRA's Romulus, Michigan office. Additional support will be gained from CRA Services' Kalamazoo, Michigan and CRA's Waterloo, Ontario offices. Descriptions of the responsibilities of the key project personnel are presented in the following sections. Please note that the actual field personnel to be utilized to oversee the implementation of the conceptual design in the field will be determined as the design progresses in order to ensure that the appropriate oversight personnel are utilized.

9.2.1 RESPONSIBILITIES OF PROJECT MANAGEMENT TEAM

The project management personnel assembled for this project consist of individuals who have the necessary experience and capabilities required to conduct the design and construction oversight activities at the Site. Curricula vitae for key personnel are included in Appendix A. The functional responsibilities of the project management personnel are discussed below:

Mr. Glenn Turchan, M.A.Sc. P. Eng. - Project Director

Mr. Glenn Turchan will serve as the Project Director. Mr. Turchan will participate in meetings with U.S. EPA, as required. Mr. Turchan has over 15 years of related environmental experience including extensive experience in projects of this nature, and on numerous other Comprehensive Environmental Response, Compensation, and

Liability Act (CERCLA) projects. In addition, Mr. Turchan is the corporate manager of CRA's Romulus office, which has a staff of approximately 50 professionals.

Mr. Greg Carli, P. Eng./P.E. - Project Manager

The Project Manager's role is to provide overall direction of the project and to ensure that the services of CRA are of the highest quality. Mr. Carli is a Professional Engineer with approximately 5 years of related experience. Mr. Carli will provide day to day project management activities. Mr. Carli will ensure that all Site remedial activities are coordinated.

Mr. Jeff Daniel, P. Eng./P.E. - Project Coordinator

Mr. Jeff Daniel, P.Eng./P.E. will act as CRA's Project Coordinator. Mr. Daniel has over 8 years of environmental engineering experience. Mr. Daniel will coordinate the completion of the pre-design, design, and remedial action tasks on a day-to-day basis to ensure project schedules and budgets are not.

Mr. Rick Hoekstra, P. Eng. - Design Coordinator

Mr. Rick Hoekstra, P. Eng. will act as CRA's Design Coordinator. Mr. Hoekstra will provide overall coordination of the design team of the project from a technical perspective, will be responsible for maintaining budgets and schedules, and will participate in technical discussions and negotiations with the agencies. Mr. Hoekstra has over 17 years of related environmental experience and has been a project manager/design engineer for a number of remediation projects involving slurry walls. Mr. Hoekstra is currently a project design manager within CRA's Design and Construction Services Group with responsibilities for landfill cap/covers and perimeter containment systems. Mr. Hoekstra has considerable experience and the necessary administrative and technical capabilities in regards to project management, design, construction administration, liaison and negotiation with regulatory agencies, and public interaction.

Mr. Wayne Bauman/Mr. Peter Maltese - Construction Manager

Mr. Wayne Bauman is the general manager of the CRA Services office located in Kalamazoo, Michigan and Mr. Peter Maltese is a project manager for CRA Services out of Pittsburgh, Pennsylvania. Mr. Maltese has been involved in slurry wall construction for over 13 years (responsibilities covering field engineer, project superintendent, construction manager, and site manager) and has supervised over 25 slurry wall projects. CRA Services specializes in the design, construction, and operation of advanced biological, physical, and chemical treatment systems for industrial effluents and contaminated groundwater and soil. In addition, CRA Services provides a full range of construction services to the environmental, chemical, industrial, and wastewater industries. CRA Services will be incorporated into the Project Team to assist with field activities on an as-needed basis.

Project Advisors

- Mr. Frank A. Rovers, M.A.Sc, P. Eng. - Project Advisor; and
- Dr. Edward A. McBean, Ph.D., P. Eng. - Project Advisor.

The Project Advisors will be utilized on an as required basis.

Curricula vitae for CRA's engineering team are provided in Appendix B.

9.2.2 ADDITIONAL OUTSIDE EXPERTISE

CRA has considerable experience related to design and construction projects in the environmental remediation field and has key personnel throughout the organization that can be utilized as required. One component of the conceptual design involves the implementation of a containment wall (installed using the slurry wall approach) to "funnel" migrating groundwater toward PRB "gates" for passive treatment as the groundwater passes through the treatment wall (often referred to as funnel-and-gate). The PRB technology is considered innovative and CRA will utilize several outside experts to provide assistance with the PRB design and construction.

Dr. Robert Gillham from U of W, developer of the iron PRB technology for treatment of chlorinated organics, and Dr. David Blowes from U of W, developer of the PRB technology for treatment of metals will be utilized throughout the design and implementation of this project. ETI, the commercial venue for implementing this technology for using zero-valent metal (in particular, iron) to degrade volatile organics

(VOCs), will be part of the Project Team. A copy of ETIs Professional Qualifications is presented in Appendix C.

Geo-Solutions is a consulting firm out of Pennsylvania and Colorado that specializes in technologies such as slurry walls and PRBs and CRA has worked with Geo-Solutions in a number of previous slurry wall applications. In particular, Mr. Steve Day has been actively involved PRB projects where bio-polymer degradable slurry is used for trench construction in order to facilitate installation of the reactive media. Geo-Solutions has installed several PRB walls, in conjunction with both ETI and the U of W. A copy of Geo-Solutions Professional Qualifications is presented in Appendix D.

These experts, together with CRA's design staff, will focus on selection of the most effective reactive media system configuration and the appropriate construction technique for installation of the combined S-B and PRB wall to create the "funnel-and-gate" required for containment and treatment. Additional documentation on the use of PRBs is presented in Appendix E.

FIGURES

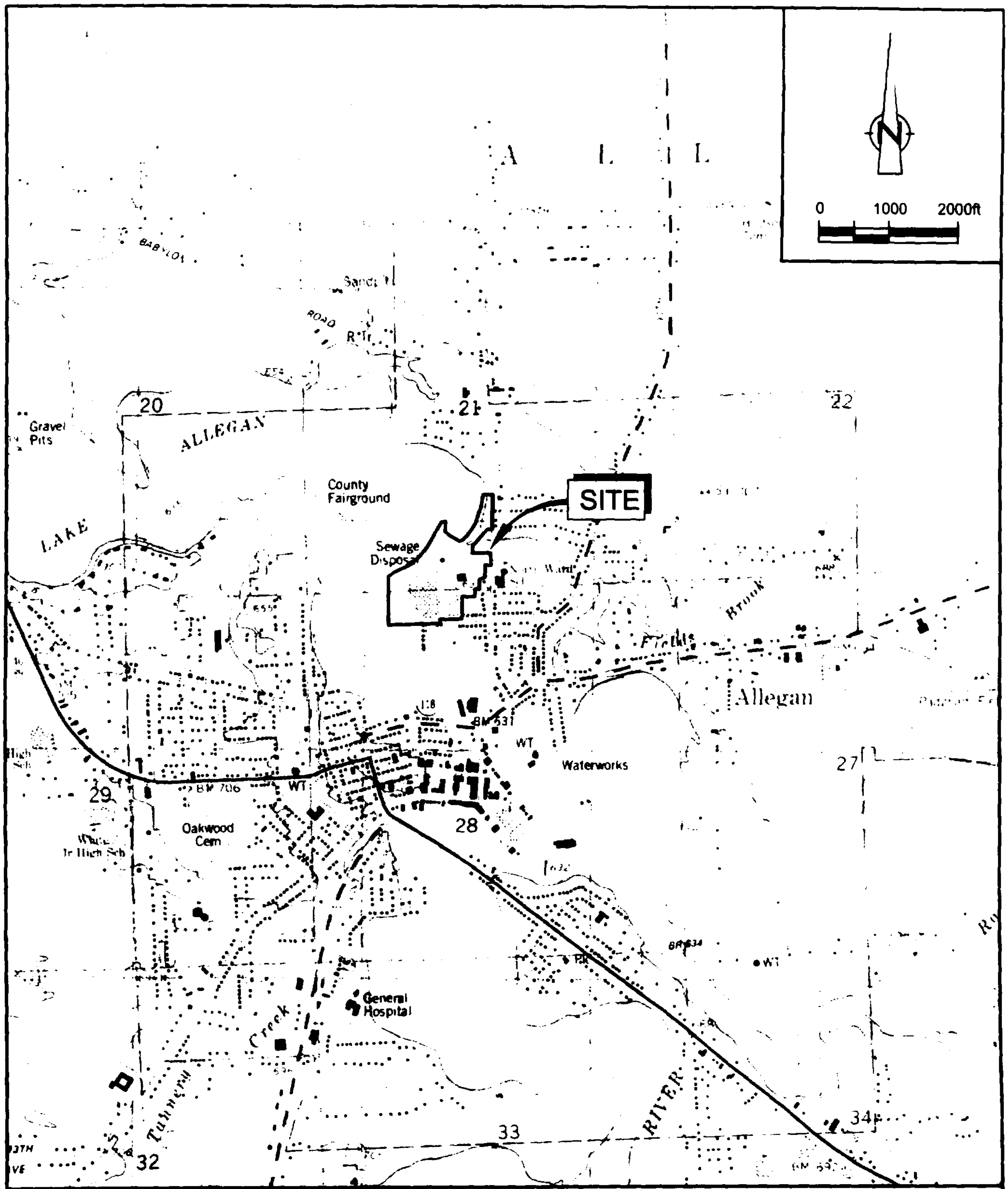


figure 1.1

SITE LOCATION
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA004 SEP 14/2001

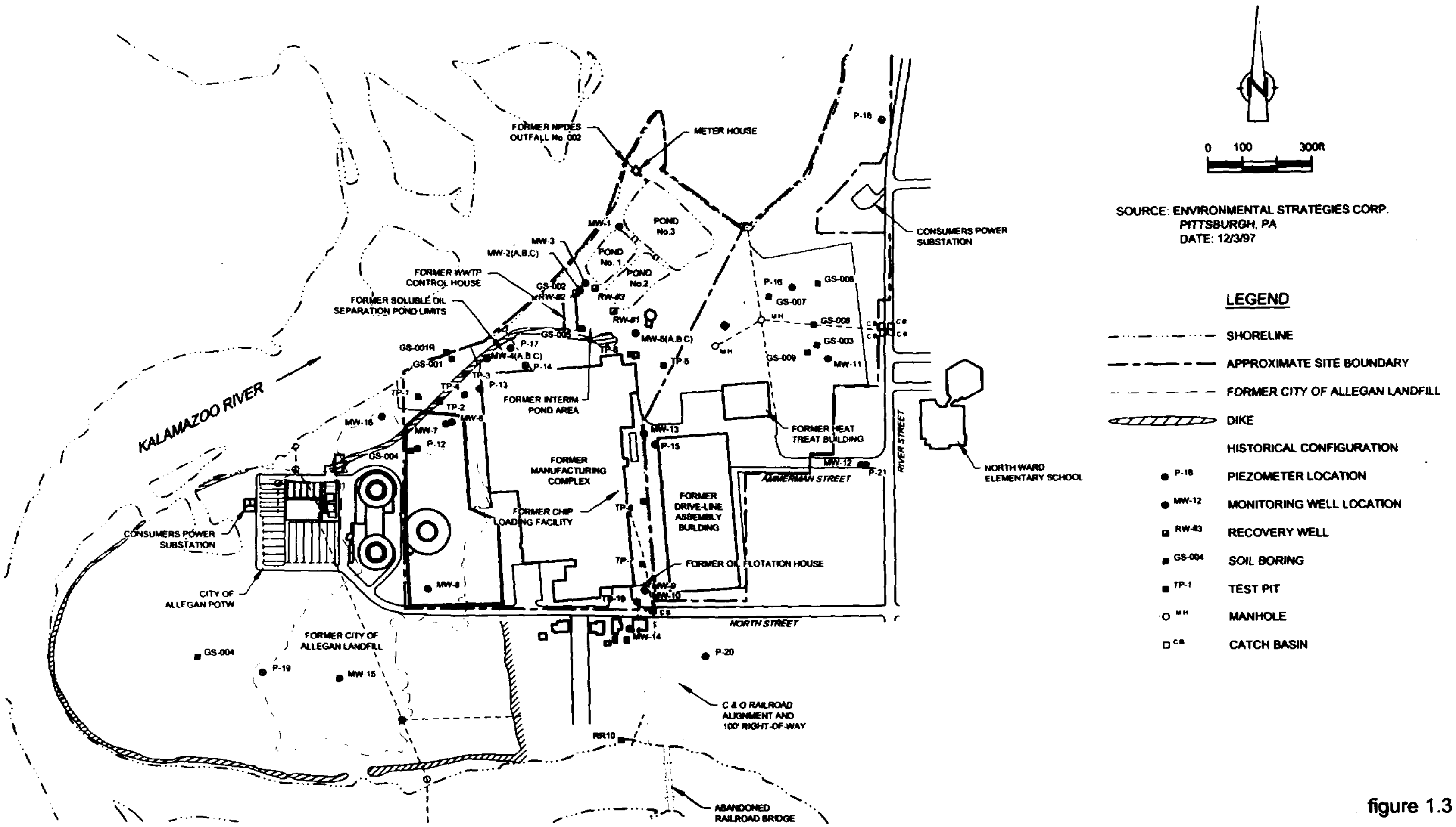


figure 1.3

SITE PLAN
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA005 SEP 25/2001

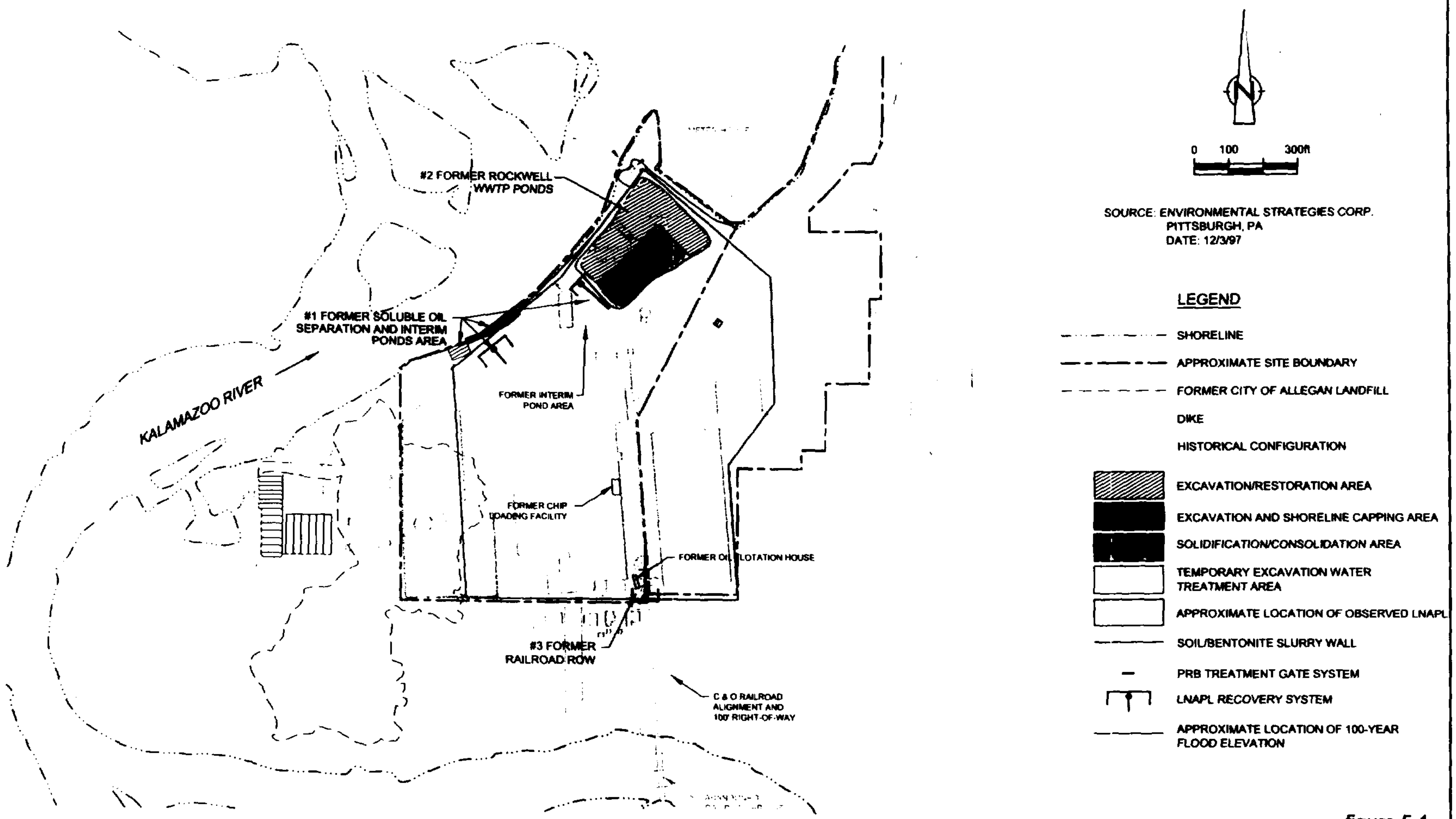


figure 5.1

OVERALL CONCEPTUAL DESIGN
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA007 SEP 26/2001

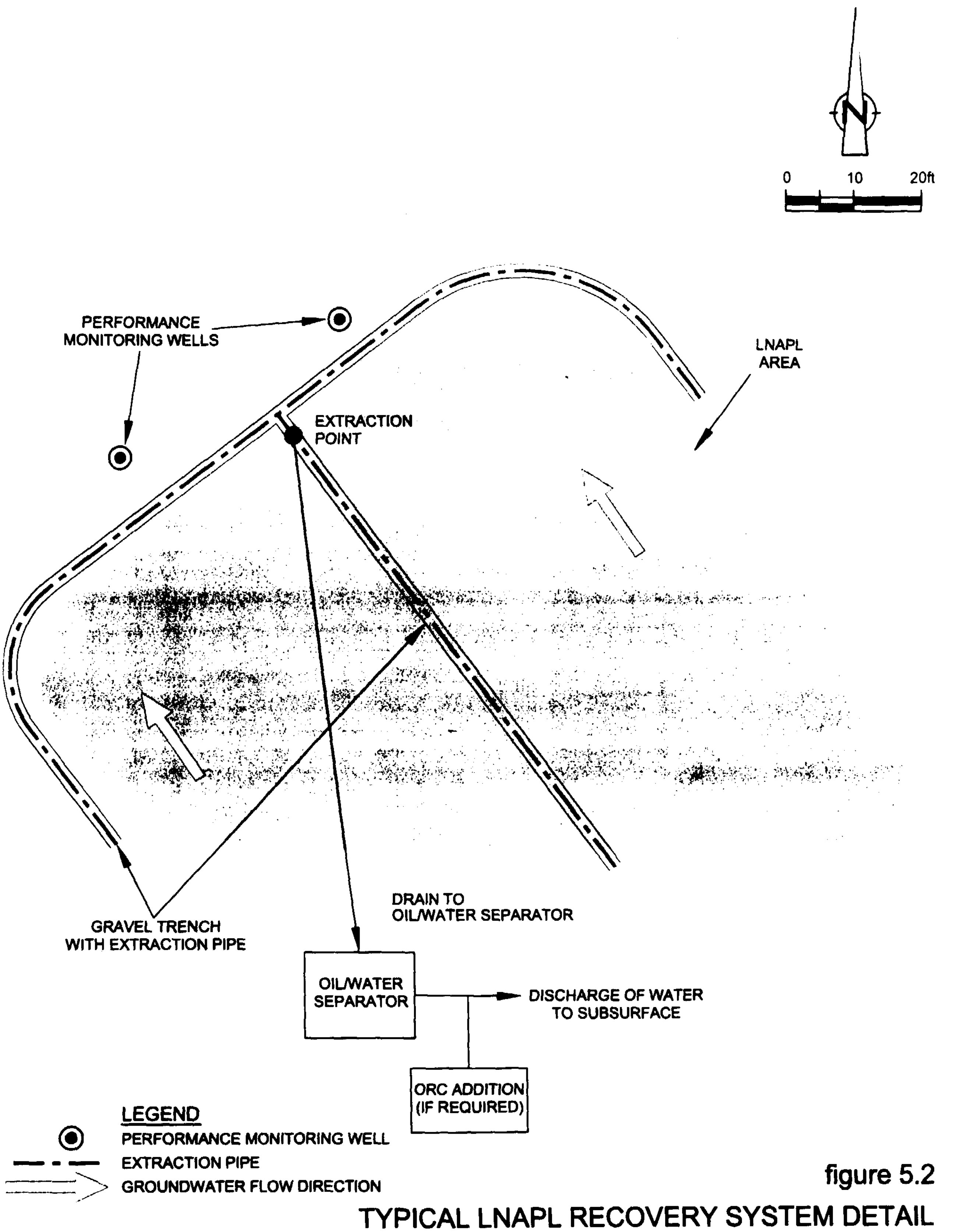


figure 5.2

TYPICAL LNAPL RECOVERY SYSTEM DETAIL
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA016 SEP 24/2001

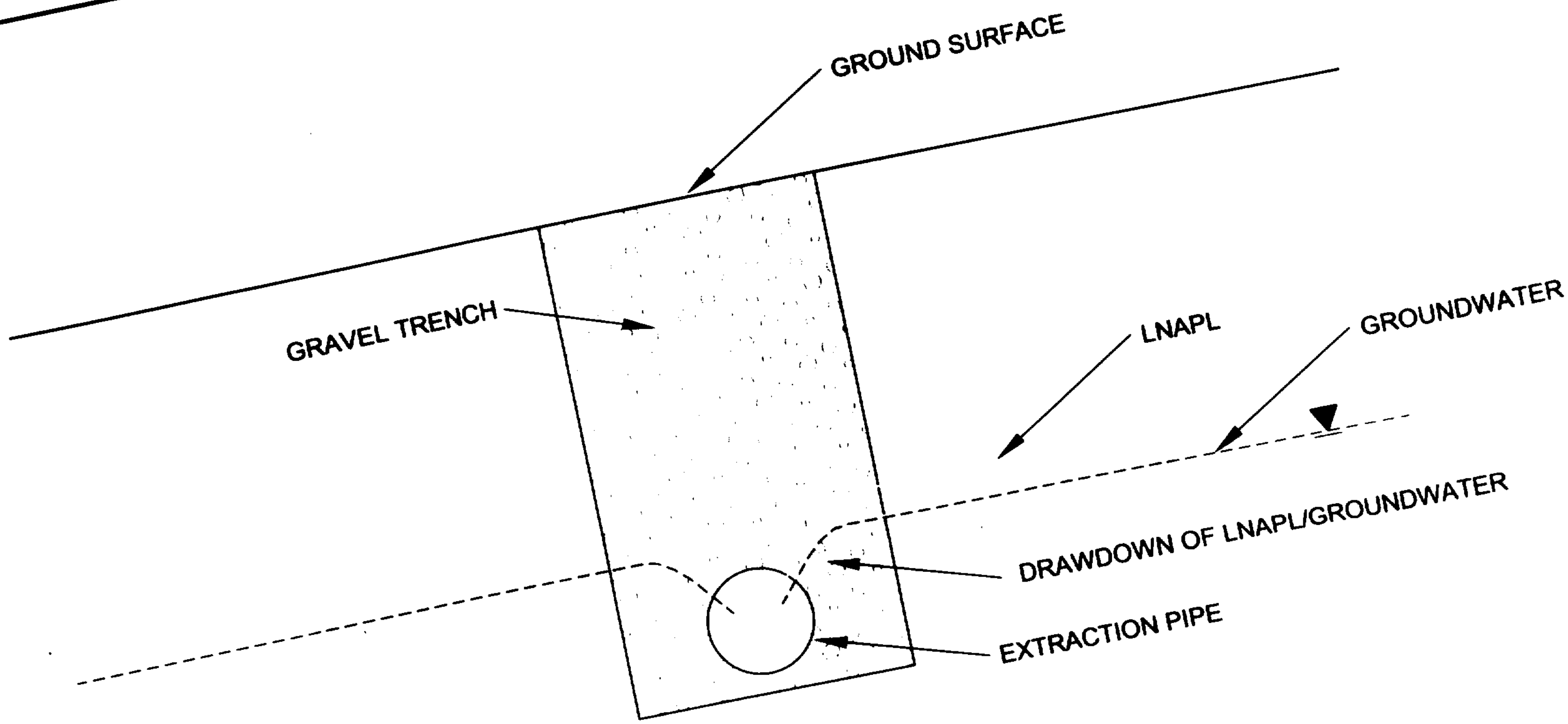


figure 5.3

TYPICAL CROSS-SECTION OF LNAPL RECOVERY SYSTEM
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA017 SEP 24/2001

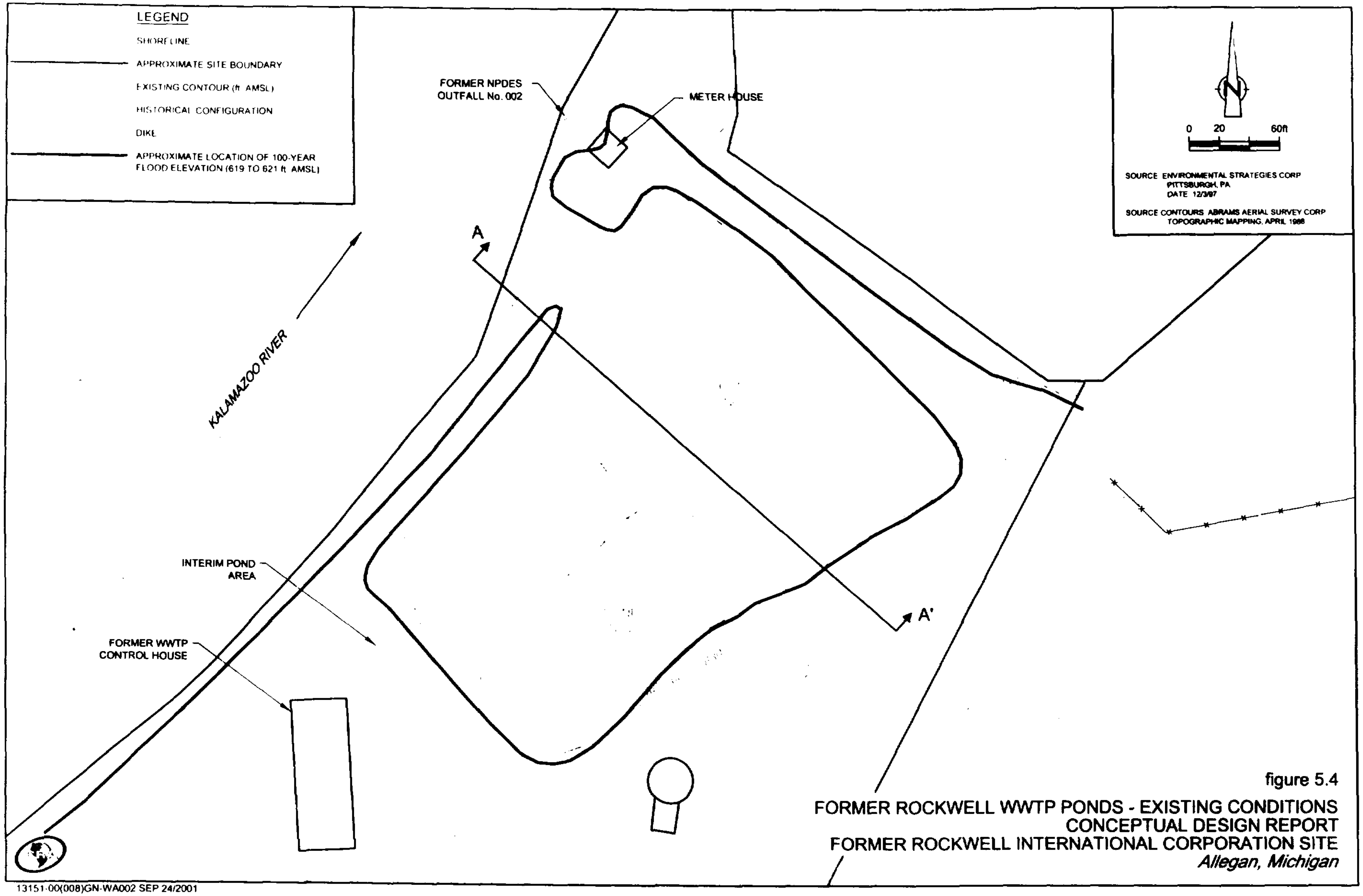


figure 5.4

FORMER ROCKWELL WWTP PONDS - EXISTING CONDITIONS
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA002 SEP 24/2001

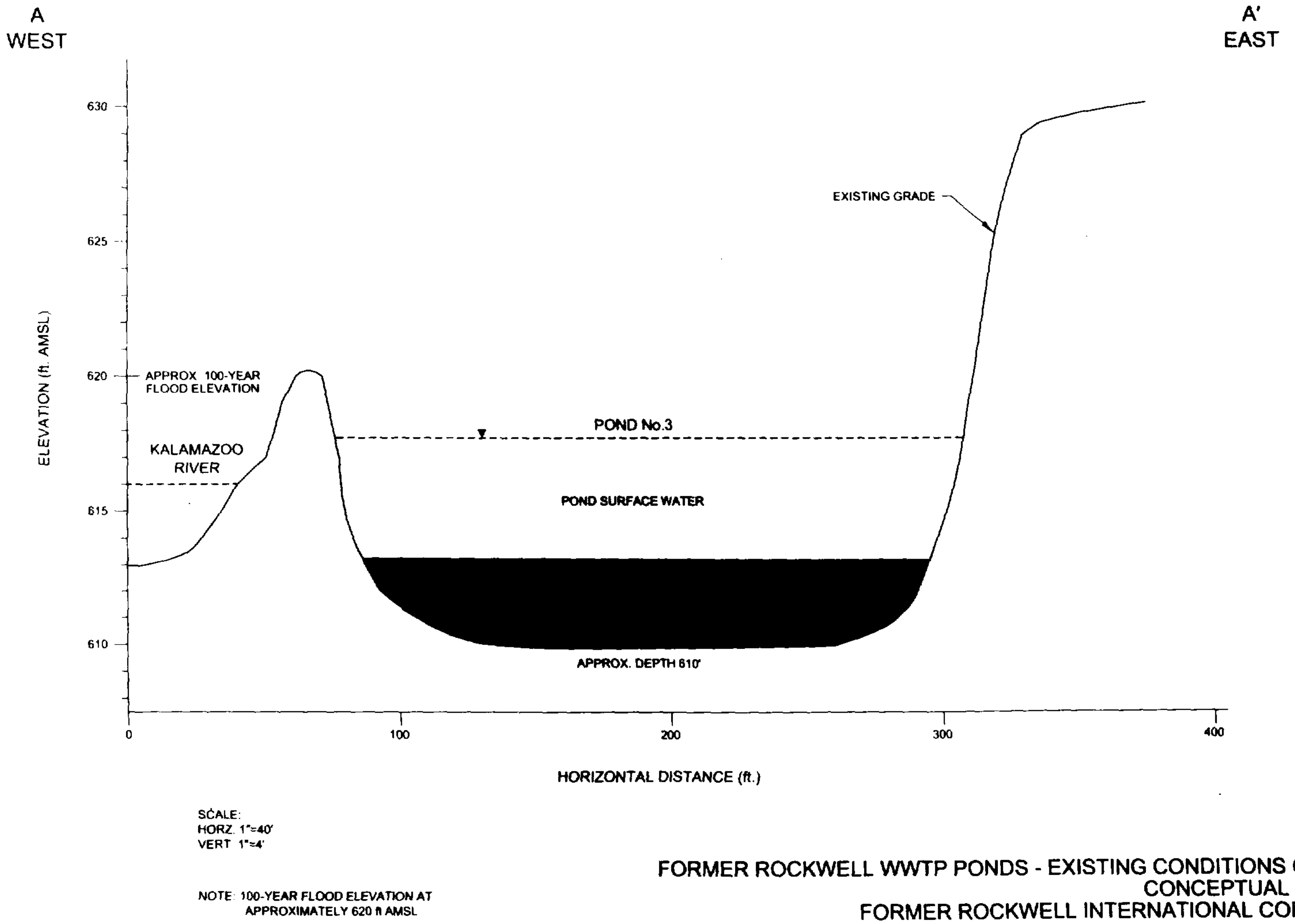


figure 5.5

FORMER ROCKWELL WWTP PONDS - EXISTING CONDITIONS CROSS-SECTION
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA001 SEP 18/2001

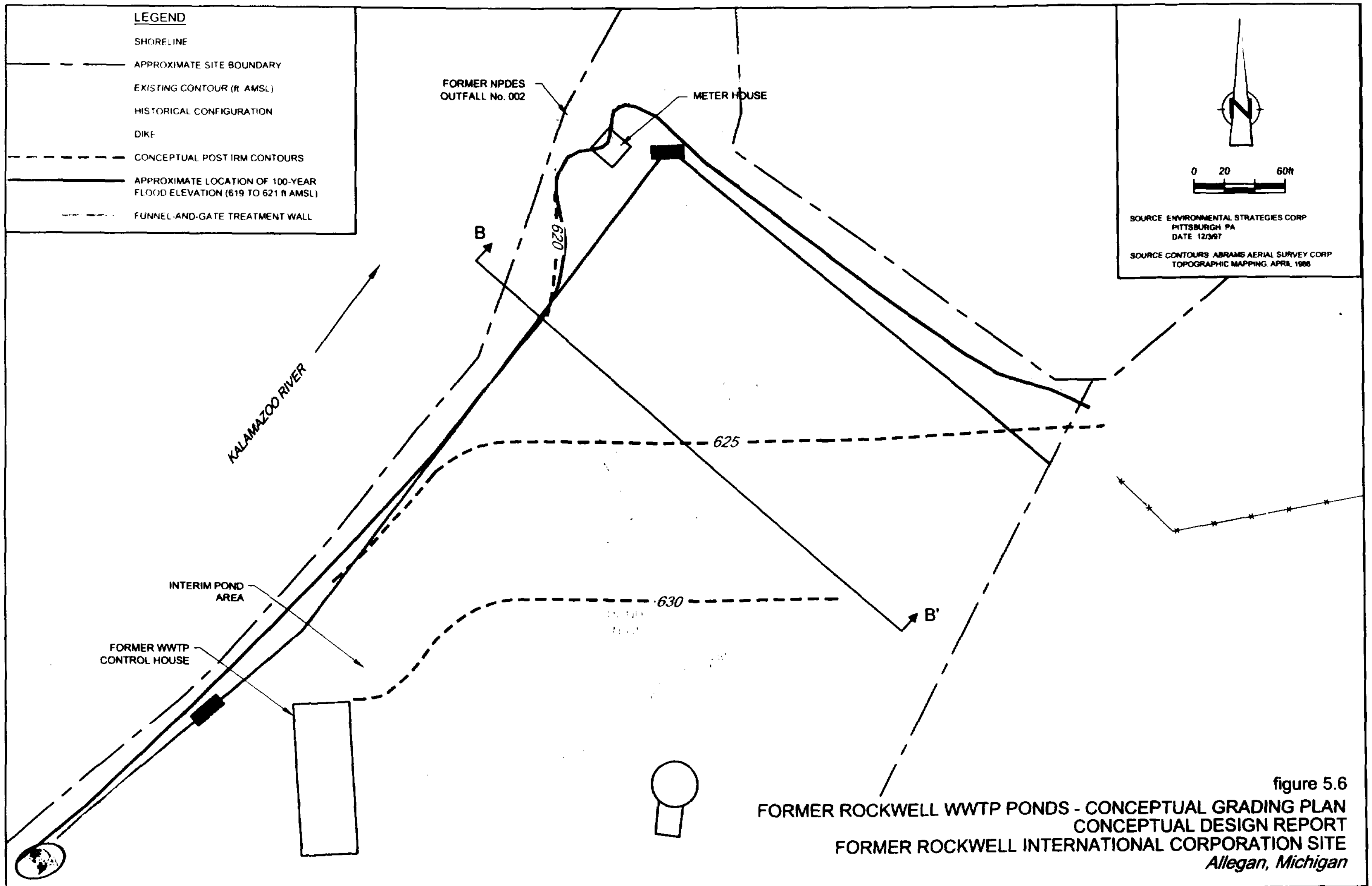
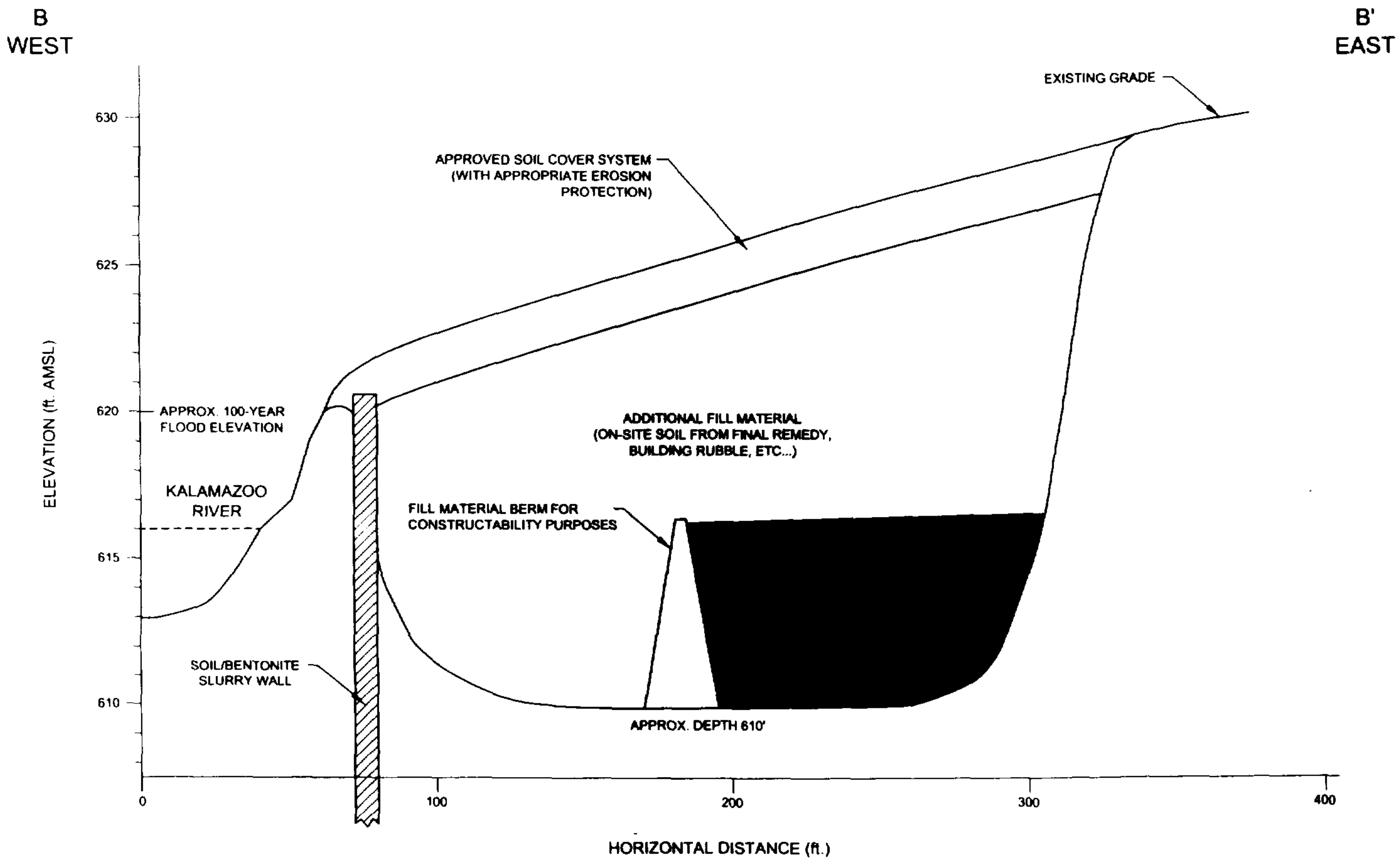


figure 5.6
FORMER ROCKWELL WWTP PONDS - CONCEPTUAL GRADING PLAN
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA003 SEP 18/2001



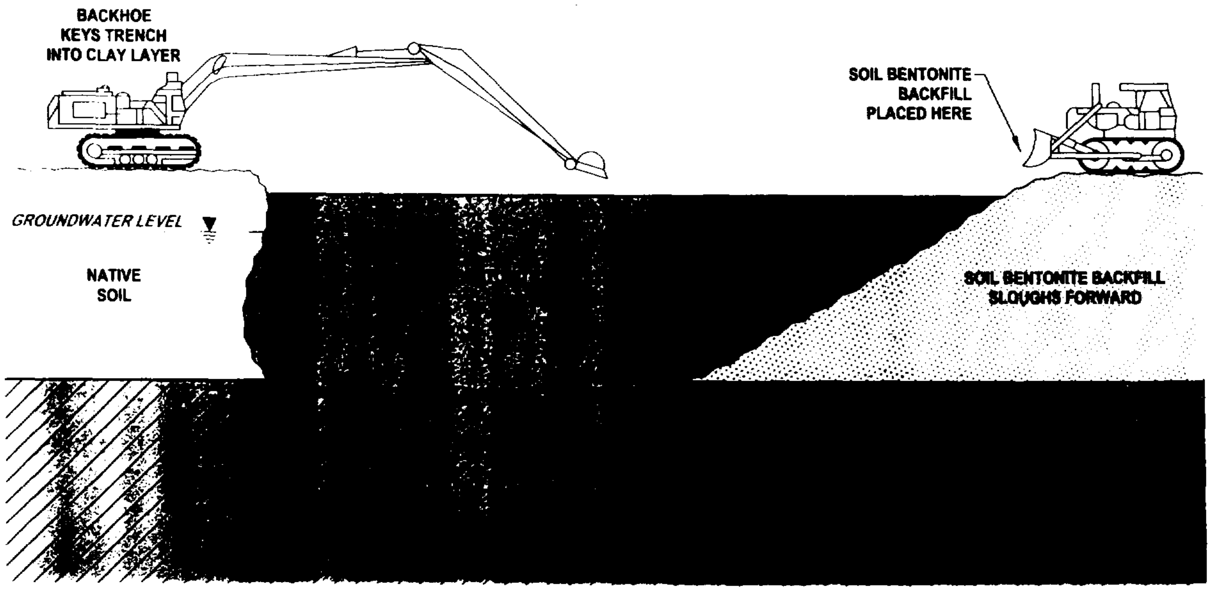
SCALE:
HORZ. 1"=40'
VERT. 1"=4'

NOTE: 100-YEAR FLOOD ELEVATION AT APPROXIMATELY 620 ft AMSL

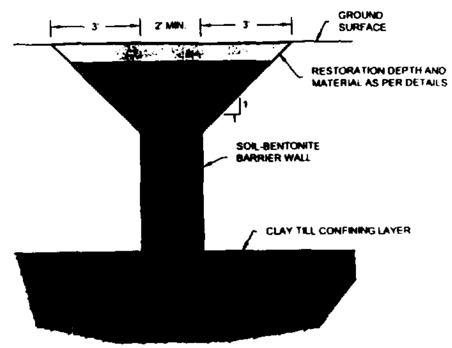
figure 5.7

FORMER ROCKWELL WWTP PONDS - CONCEPTUAL GRADING PLAN CROSS-SECTION
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA006 SEP 18/2001



TYPICAL PROFILE
NTS



TYPICAL SECTION
NTS

figure 5.8

SCHEMATIC OF SOIL-BENTONITE SLURRY WALL
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

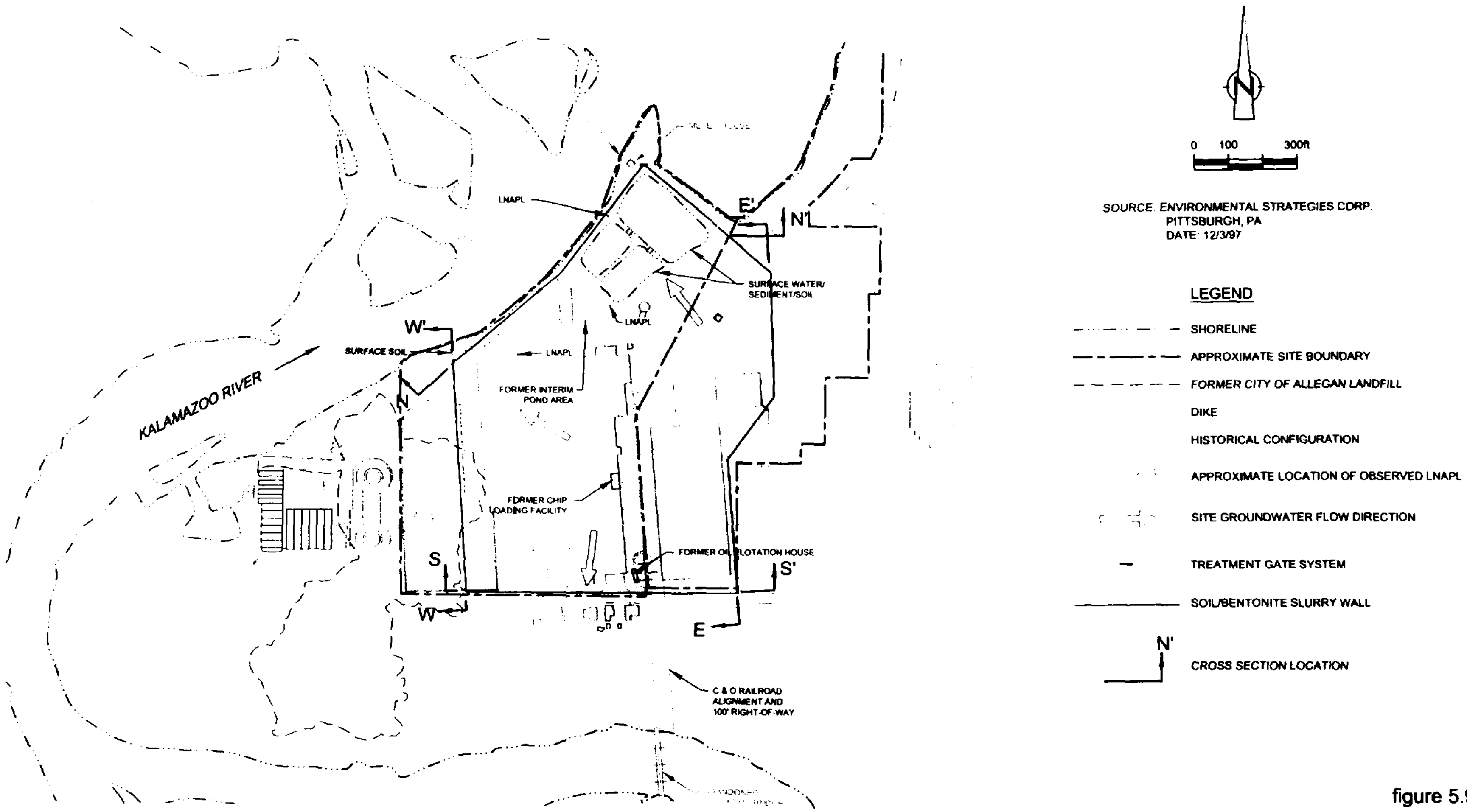
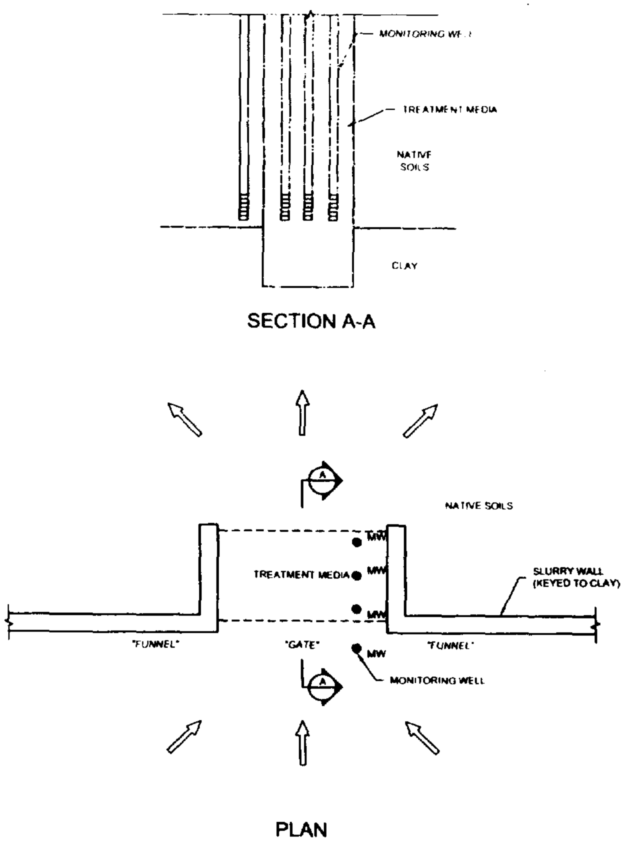


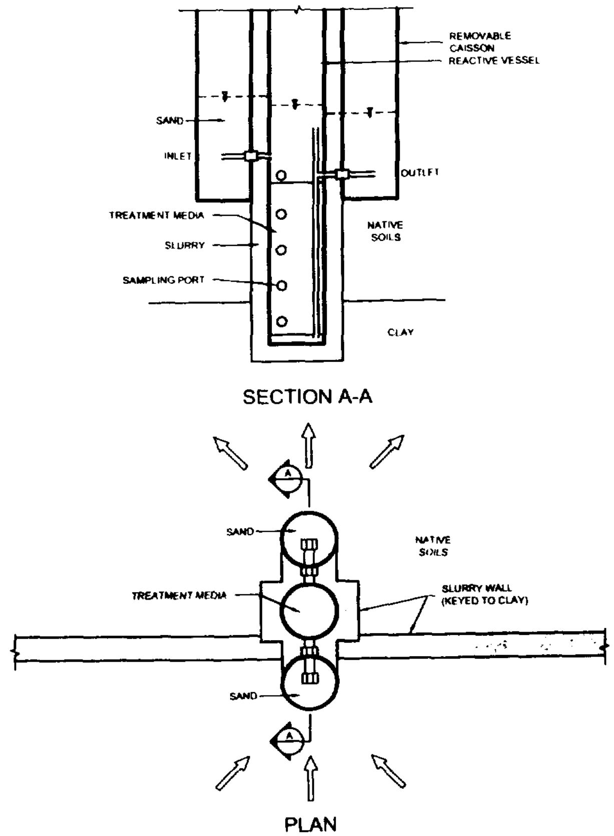
figure 5.9

CONCEPTUAL LAYOUT - CONTAINMENT/TREATMENT WALL
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA008 SEP 26/2001



FUNNEL AND GATE CONFIGURATION
N.T.S.

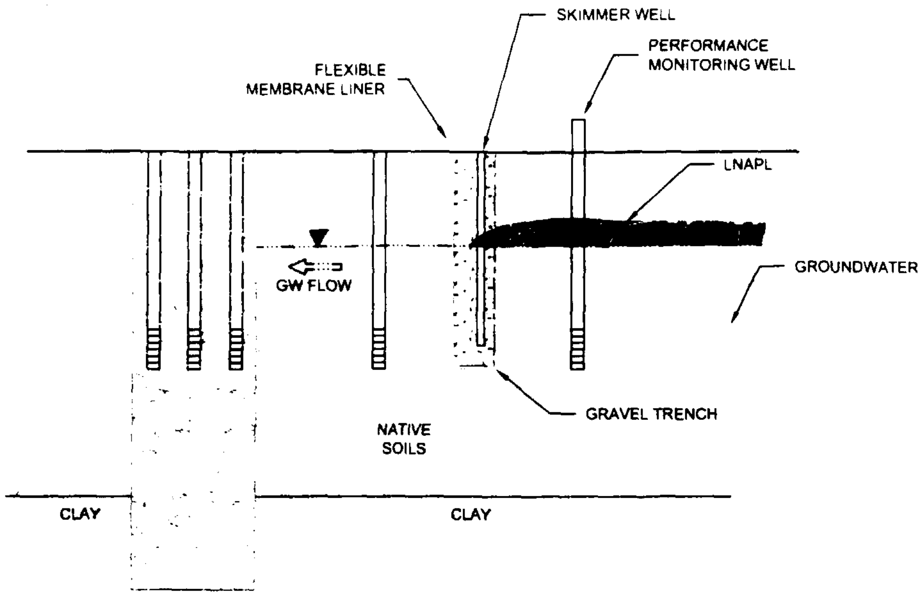


REACTIVE VESSEL CONFIGURATION
N.T.S.

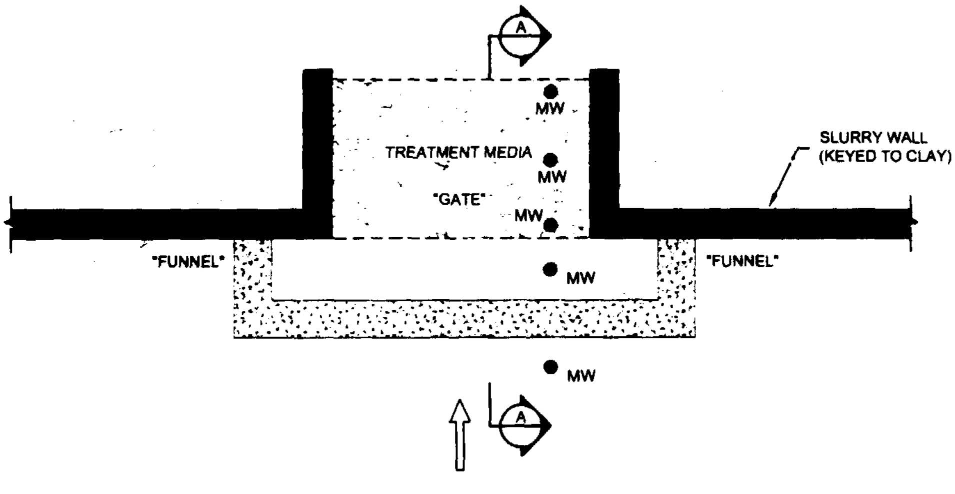
figure 5.10

TYPICAL PERMEABLE REACTIVE BARRIER DETAILS
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA018 SEP 25/2001



SECTION A-A



PLAN

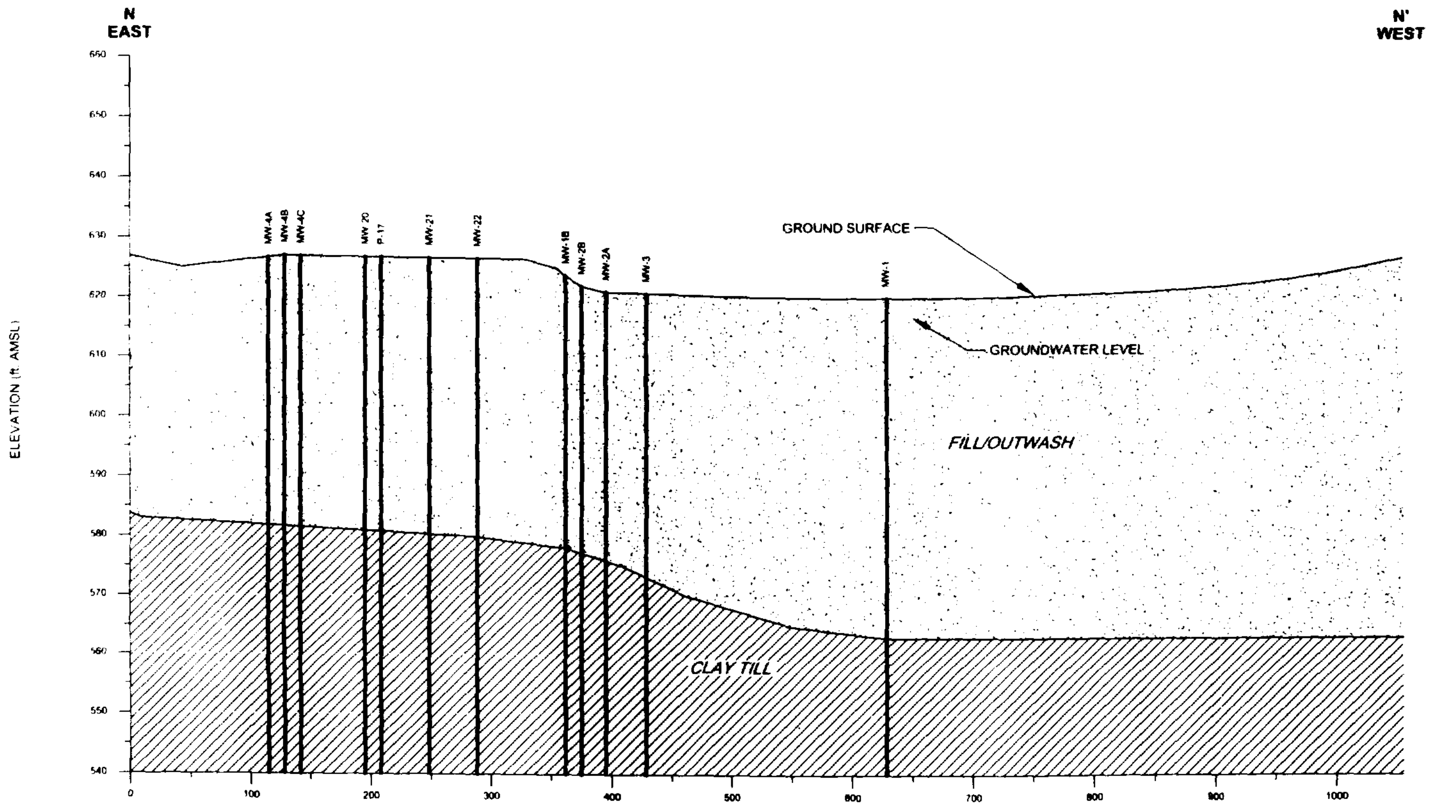
PRB LNAPL COLLECTION SYSTEM CONFIGURATION

N.T.S.

figure 5.11

PRB LNAPL COLLECTION SYSTEM
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA019 SEP 25/2001

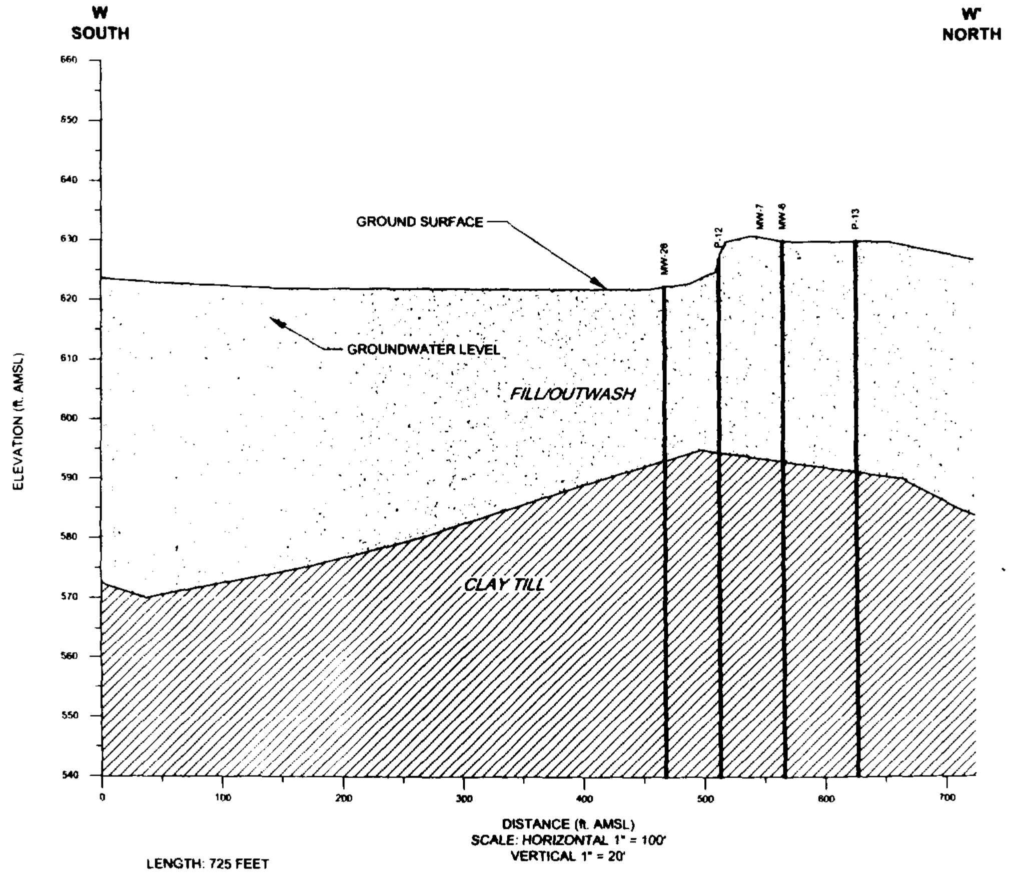


LENGTH: 1100 FEET
DEPTH: MINIMUM 43 FEET
MAXIMUM 54 FEET
AVERAGE 53 FEET

figure 5.12

NORTH CROSS SECTION
CONCEPTUAL LAYOUT - CONTAINMENT/TREATMENT WALL
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

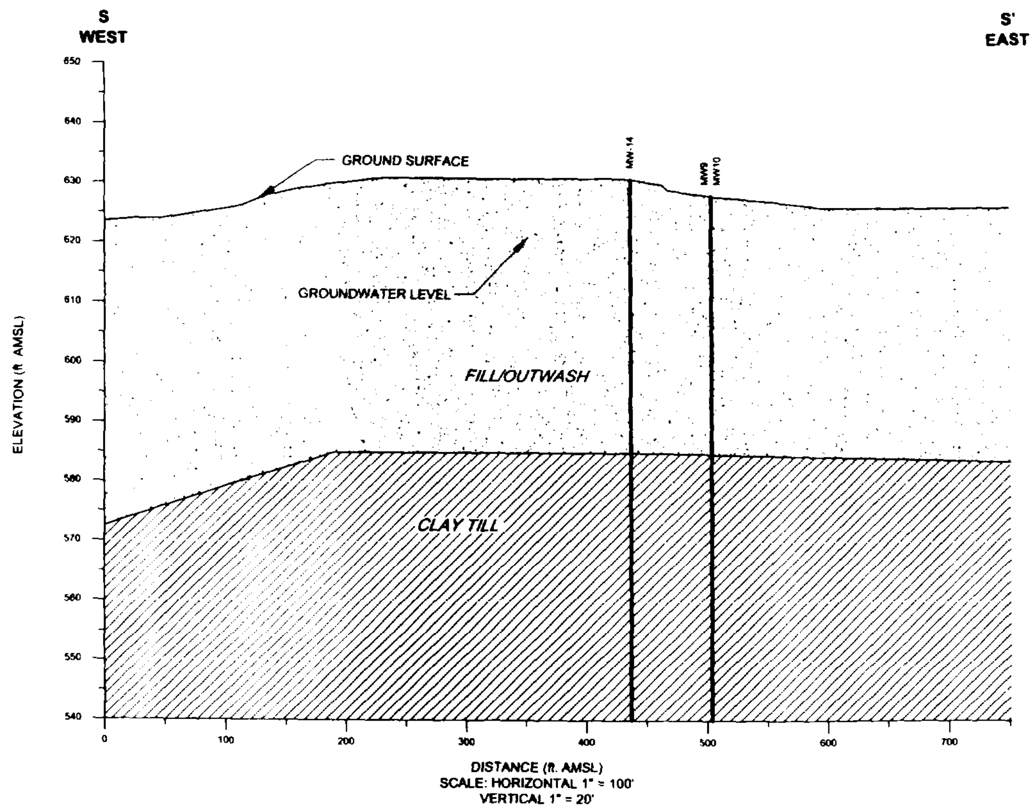
13151-00(008)GN-WA009 SEP 24/2001



LENGTH: 725 FEET
DEPTH: MINIMUM 28 FEET
MAXIMUM 55 FEET
AVERAGE 41.4 FEET

figure 5.13

WEST CROSS SECTION
CONCEPTUAL LAYOUT - CONTAINMENT/TREATMENT WALL
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

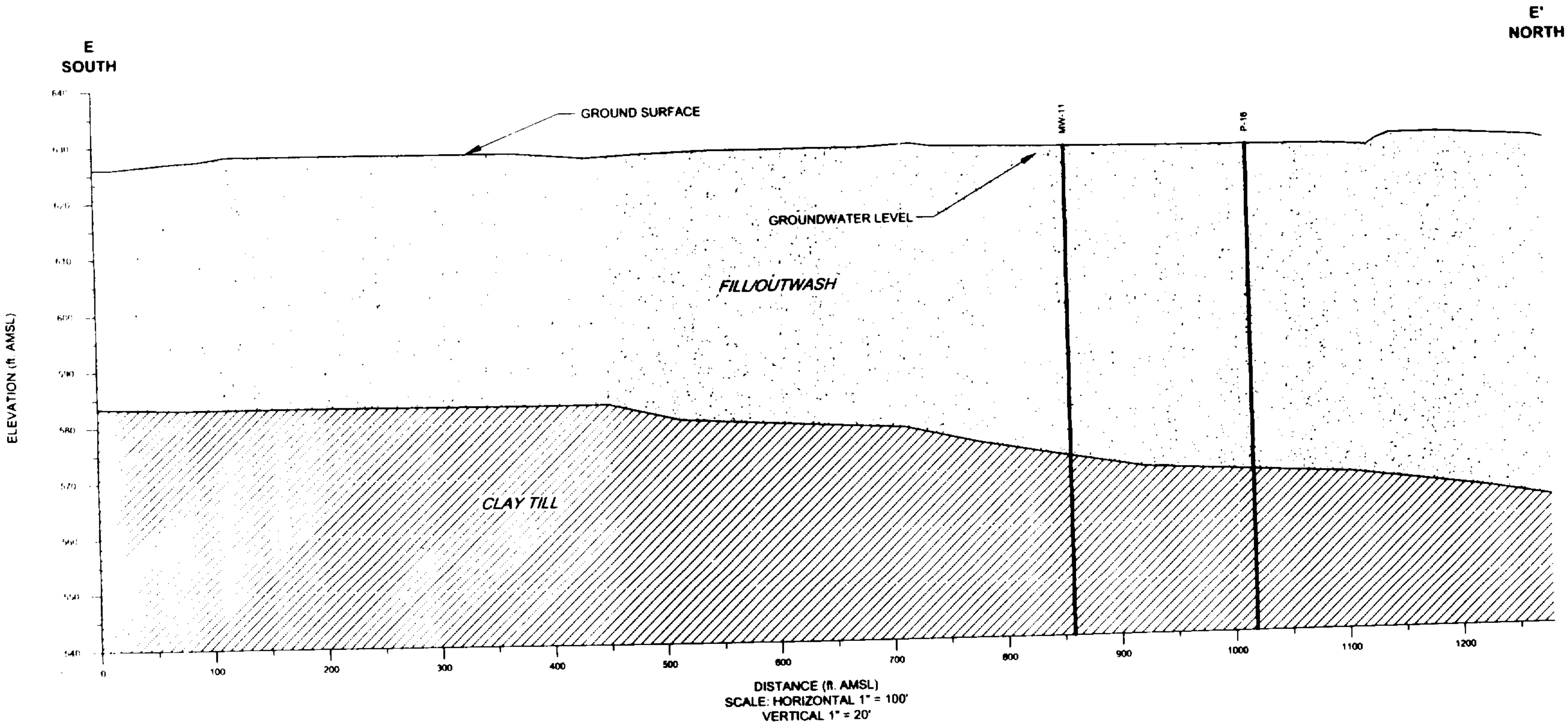


LENGTH: 750 FEET
DEPTH: MINIMUM 42 FEET
MAXIMUM 51 FEET
AVERAGE 46.6 FEET

figure 5.14

SOUTH CROSS SECTION
CONCEPTUAL LAYOUT - CONTAINMENT/TREATMENT WALL
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA011 SEP 24/2001



LENGTH: 1275 FEET
DEPTH: MINIMUM 43 FEET
MAXIMUM 64 FEET
AVERAGE 56.6 FEET

figure 5.15

EAST CROSS SECTION
CONCEPTUAL LAYOUT - CONTAINMENT/TREATMENT WALL
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA012 SEP 24/2001

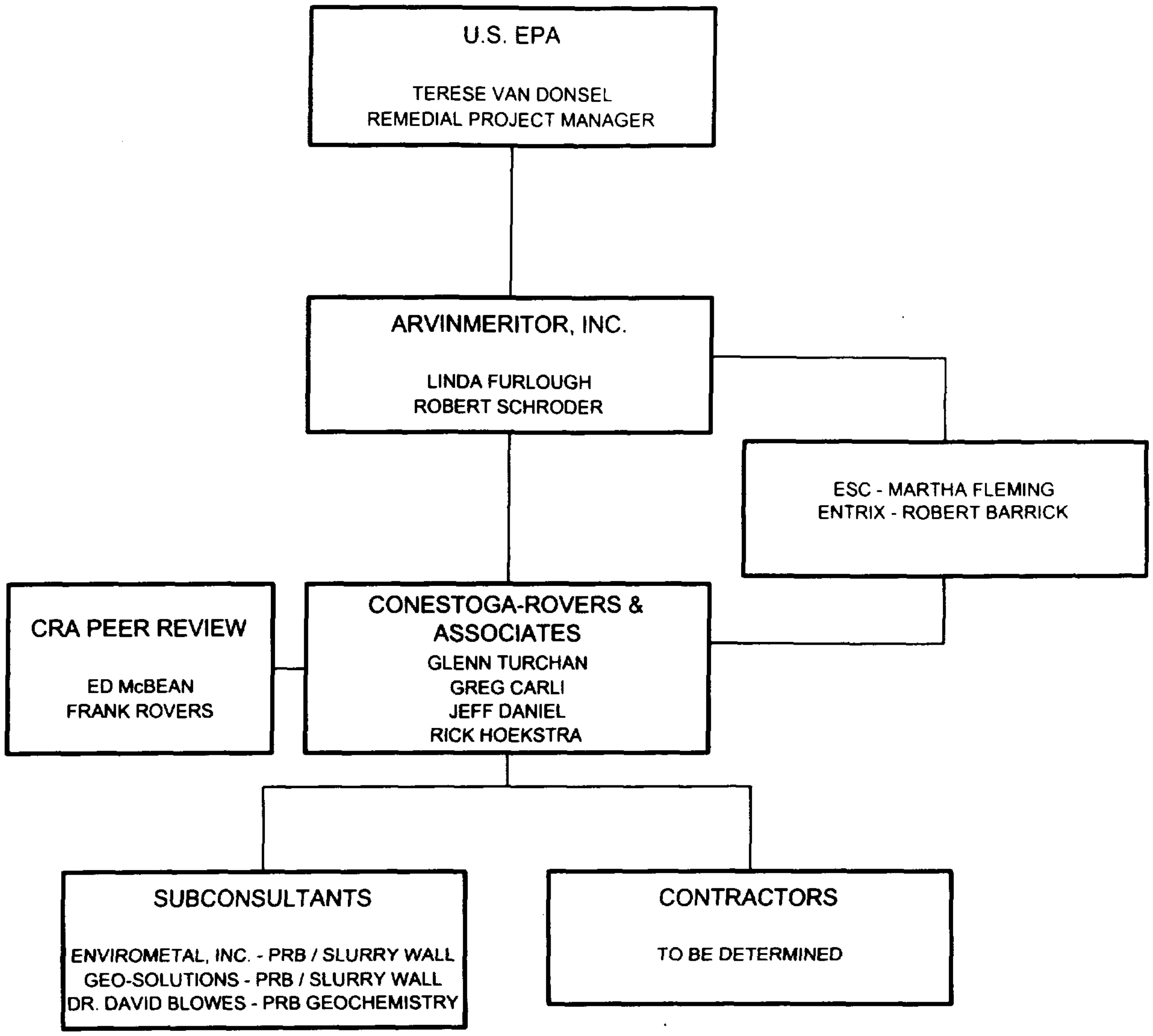


figure 9.1

PROJECT TEAM
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
Allegan, Michigan

13151-00(008)GN-WA014 SEP 24/2001

TABLES

TABLE 5.1

SUMMARY OF GROUNDWATER DATA
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
ALLEGAN, MICHIGAN

Parameter	*Number of Detections*	*Minimum Concentration (ug/l)*	*Maximum Concentration (ug/l)*	*Mean[1] Concentration (ug/l)*	*Median[1] Concentration (ug/l)*
VOCs					
Acetone	51	1.0 U	80	12.13	2.5
Benzene	44	1.0 U	4	0.64	0.5
Bromodichloromethane	41	1.0 U	1.0 U	0.5	0.5
Bromoform	41	1.0 U	1.0 U	0.5	0.5
Bromomethane	41	1.0 U	1.0 U	0.5	0.5
2-Butanone	41	5.0 U	9	2.66	2.5
Carbon disulfide	41	1.0 U	1.0 U	0.50	0.5
Carbon tetrachloride	41	1.0 U	1.0 U	0.50	0.5
Chlorobenzene	50	0.4 J	9	1.29	0.5
Chloroethane	41	0.6 U	0.4 J	0.49	0.5
Chloroform	41	1.0 U	0.3 J	0.50	0.5
Chloromethane	41	1.0 U	1.0 U	0.50	0.5
cis-1, 2- Dichloroethene	41	1.0 U	500 J	18.81	0.5
cis-1,3- Dichloropropene	41	1.0 U	1.0 U	0.50	0.5
1,2-Dibromo-3-chloropropan	41	1.0 U	1.0 U	0.50	0.5
Dibromochloromethane	41	1.0 U	1.0 U	0.50	0.5
1,2-Dibromoethane	41	1.0 U	1.0 U	0.50	0.5
1,2-dichlorobenzene	48	1.0 U	15	1.29	0.5
1,3-Dichlorobenzene	41	1.0 U	1.0 U	0.50	0.5
1,4-dichlorobenzene	43	1.0 U	6.0 J	0.76	0.5
1, 1-Dichloroethene	41	1.0 U	1.0 U	0.50	0.5
1,1-Dichloroethane	44	1.0 U	14	1.16	0.5
1,2-Dichloroethene (total)	47	1.0 U	58	3.45	0.5
1,2- Dichloropropane	41	1.0 U	1.0 U	0.50	0.5
Ethylbenzene	45	1.0 U	38	1.46	0.5
2-Hexanone	41	5.0 U	5.0 U	2.50	2.5
Methylene chloride	48	1.0 U	43	2.31	1
4-Methyl-2-pentanone	41	4.0 U	5.0 U	2.49	2.5
Styrene	41	1.0 U	0.4 J	0.50	0.5
Tetachloroethene	45	1.0 U	14	1.28	0.5
Toluene	47	1.0 U	39	5.50	1
trans-1, 2-Dichloroethene	41	1.0 U	7	0.72	0.5
trans-1,3-Dichloropropene	41	1.0 U	1.0 U	0.50	0.5
1,1,2,2-Tetrachloroethane	41	1.0 U	1.0 U	0.50	0.5
1,2,4-Trichlorobenzene	41	1.0 U	1.0 U	0.50	0.5
Trichloroethene	48	1.0 U	59 J	2.79	0.5
1,1,2-Trichloroethane	41	1.0 U	1.0 U	0.50	0.5
1,1,1-Trichloroethane	43	1.0 U	11	0.95	0.5
Vinyl Chloride	46	1.0 U	31 J	1.76	0.5
Total xylenes	43	1.0 U	14	0.88	0.5
SVOCs					
Acenaphthylene	44	5.0 U	50 U	5.74	2.5
Anthracene	44	5.0 U	50 U	5.74	2.5
Benzo (a) anthracene	44	5.0 U	50 U	5.74	2.5
Benzo (a) pyrene	44	5.0 U	50 U	5.74	2.5
Benzo (b) fluoranthene	44	5.0 U	50 U	5.74	2.5
Benzo (g,h,I) perylene	44	5.0 U	50 U	5.74	2.5
Benzo (k) fluoranthene	44	5.0 U	50 U	5.74	2.5
Benzoic acid	8	2.0 J	38.0 J	9.13	6
bis(2-Chloroethoxy)methane	44	5.0 U	50 U	5.74	2.5
bis(2-Chloroethyl) Ether	44	5.0 U	50 U	5.74	2.5
bis(2-ethylhexyl)phthalate	60	2.0 BJ	35	6.96	2.5

SUMMARY OF GROUNDWATER DATA
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
ALLEGAN, MICHIGAN

Parameter	*Number of Detections*	*Minimum Concentration (ug/l)*	*Maximum Concentration (ug/l)*	*Mean [1] Concentration (ug/l)*	*Median [1] Concentration (ug/l)*
SVOCs					
4-Bromophenyl-phenyl ether	44	5.0 U	50 U	5.74	2.5
Butylbenzylphthalate	47	1.0 J	45	6.41	2.5
4-Chloroaniline	44	5.0 U	50 U	5.74	2.5
4-Chloro-3-Methylphenol	44	5.0 U	50 U	5.74	2.5
2-Chloronaphthalene	44	5.0 U	50 U	5.74	2.5
2-Chorophenol	44	5.0 U	50 U	5.74	2.5
4-Chlorophenyl-phenyl ether	44	5.0 U	50 U	5.74	2.5
Chrysene	47	5.0 U	17	5.88	2.5
Dibenzo (a,h) anthracene	44	5.0 U	50 U	5.74	2.5
Dibenzofuran	44	5.0 U	50 U	5.74	2.5
3,3'-Dichlorobenzidine	44	5.0 U	50 U	5.74	2.5
2,4-Dichlorophenol	44	5.0 U	50 U	5.74	2.5
Diethylphthalate	45	5.0 U	4.0 J	5.70	2.5
2,4-Dimethylphenol	44	5.0 U	50 U	5.74	2.5
Dimethylphthalate	44	5.0 U	50 U	5.74	2.5
4,6-Dinitro-2-methylphenol	44	20 U	200 U	22.27	10
2,4-Dinitrophenol	44	20 U	200 U	22.27	10
2,4-Dinitrotoluene	44	5.0 U	50 U	7.73	5
2,6-Dinitrotoluene	44	5.0 U	50 U	7.73	5
Di-n-butylphthalate	49	2.0 J	7.0 J	7.33	5
Di-n-ethylphthalate	5	2.0 J	14	6.00	4
Di-n-octylphthalate	44	5.0 U	50 U	7.73	5
Fluoranthene	47	5.0 U	10.0 J	7.64	5
Fluorene	44	5.0 U	50 U	7.73	5
Hexachlorobutadiene	44	5.0 U	50 U	7.73	5
Hexachlorocyclopentadiene	44	5.0 U	50 U	7.73	5
Hexachloroethane	44	5.0 U	50 U	7.73	5
Hexachlorophenol	44	5.0 U	50 U	7.73	5
Indeno (1,2,3-cd)pyrene	44	5.0 U	50 U	7.73	5
Isophorone	44	5.0 U	50 U	7.73	5
2-Methylnaphthalene	46	5.0 U	4.0 J	7.52	5
2-Methylphenol	44	5.0 U	50 U	7.73	5
4-Methylphenol	44	5.0 U	50 U	7.73	5
Naphthalene	49	5.0 U	23	7.80	5
2-Nitroaniline	44	20 U	200 U	22.95	10
3-Nitroaniline	44	20 U	200 U	22.95	10
4-Nitroaniline	44	20 U	200 U	22.95	10
Nitrobenzene	44	5.0 U	50 U	5.74	2.5
2-Nitrophenol	44	5.0 U	50 U	5.74	2.5
4-Nitrophenol	44	20 U	200 U	22.95	10
N-Nitroso-di-n-propylamine	44	5.0 U	50 U	5.74	2.5
N-nitrosodiphenylamine (1)	44	5.0 U	50 U	5.74	2.5
2,2'-oxybis (1-Chloropropane	44	5.0 U	50 U	5.74	2.5
Pentachlorophenol	46	20 U	6.0 J	22.13	10
Phenanthrene	48	5.0 U	16	5.95	2.5
Phenol	47	5.0 U	18	5.88	2.5
Pyrene	47	5.0 U	7.0 J	5.67	2.5
2,4,5-Trichlorophenol	44	20 U	200 U	22.95	10
2,4,6-Trichlorophenol	44	5.0 U	50 U	5.74	2.5

TABLE 5.1

SUMMARY OF GROUNDWATER DATA
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
ALLEGAN, MICHIGAN

Parameter	Number of Detections	Minimum Concentration (ug/l)	Maximum Concentration (ug/l)	Mean [1] Concentration (ug/l)	Median [1] Concentration (ug/l)
Pesticides					
Aldrin	46	0.01 U	0.052 J	0.020	0.02
Alpha-chlordance	49	0.0018 JP	0.31	0.024	0.02
Gamma-Chlordance	47	0.0018 NJ	0.043 J	0.018	0.02
Alpha-BHC	46	0.04 U	0.00097 J	0.019	0.02
Beta-BHC	49	0.01 U	0.047 NJ	0.019	0.02
Delta-BHC	49	0.01 U	0.014 J	0.018	0.02
Gamma-BHC	45	0.01 U	0.014 J	0.019	0.02
4,4'-DDD	50	0.02 U	0.5	0.065	0.04
4,4'-DDE	54	0.0022 NJ	0.43 J	0.048	0.04
4,4'-DDT	50	0.02 U	0.14 J	0.038	0.04
Dieldrin	49	0.02 U	1.6 J	0.078	0.04
Endosulfan I	47	0.01 U	0.0088 J	0.019	0.02
Endosulfan II	49	0.02 U	0.26	0.045	0.04
Endosulfan sulfate	45	0.02 U	0.084 U	0.038	0.04
Endrin	47	0.0023 NJ	0.084 U	0.037	0.04
Endrin aldehyde	46	0.0030 NJ	0.084 U	0.037	0.04
Endrin ketone	46	0.02 U	0.0024 J	0.037	0.04
Epoxide	1	0.0054 NJ	0.0054 NJ	0.003	0.0027
Heptachlor	45	0.01 U	0.06	0.022	0.02
Heptachlor epoxide	45	0.01 U	0.2 J	0.023	0.02
Methoxychlor	45	0.01 U	0.06 J	0.175	0.19
Toxaphene	45	0.5	2.6 U	1.203	1.25
PCBs					
Arochlor-1016	47	0.04 U	5 U	0.53	0.5
Arochlor-1221	47	0.06 U	5 U	0.52	0.5
Arochlor-1232	47	0.04 U	5 U	0.53	0.5
Arochlor-1242	47	0.02 U	5 U	0.53	0.5
Arochlor-1248	47	0.04 U	5 U	0.54	0.5
Arochlor-1254	53	0.04 U	34	1.48	0.5
Arochlor-1260	47	0.04 U	5 U	0.53	0.5
Dioxin-Furan					
2,3,7,8-TCDD	1	3.375 U	3.375 U	1.69	1.69
1,2,3,7,8-PeCDD	1	5.457 U	5.457 U	2.73	2.73
1,2,3,4,7,8-HxCDD	2	4.12 U	8911.7 U	2,229	2,229
1,2,3,6,7,8-HxCDD	2	3.942 U	8527.7 U	2,133	2,133
1,2,3,7,8,9-HxCDD	2	3.875 U	147,849	73,925	73,925
1,2,3,4,6,7,8,-HpCDD	2	5.174 U	128.1	65.35	65.35
OCDD	1	11.3	11.3	11.27	11.27
2,3,7,8-TCDF	1	1.743 U	1.743 U	0.87	0.87
1,2,3,7,8-PeCDF	1	3.757 U	3.757 U	1.88	1.88
2,3,4,7,8-PeCDF	1	3.684 U	3.684 U	1.84	1.84
1,2,3,4,7,8-HxCDF	1	2.661 U	2.661 U	1.33	1.33
1,2,3,6,7,8-HxCDF	1	2.673 U	2.673 U	1.34	1.34
1,2,3,7,8,9-HxCDF	1	3.419 U	3.419 U	1.71	1.71
2,3,4,6,7,8-HxCDF	1	2.677 U	2.677 U	1.34	1.34
1,2,3,4,6,7,8-HpCDF	1	2.661 U	2.661 U	1.33	1.33
1,2,3,4,7,8,9-HpCDF	1	3.681 U	3.681 U	1.84	1.84
OCDF	1	2.434 U	2.434 U	1.22	1.22

TABLE 5.1

SUMMARY OF GROUNDWATER DATA
CONCEPTUAL DESIGN REPORT
FORMER ROCKWELL INTERNATIONAL CORPORATION SITE
ALLEGAN, MICHIGAN

Parameter	*Number of Detections*	*Minimum Concentration (ug/l)*	*Maximum Concentration (ug/l)*	*Mean [1] Concentration (ug/l)*	*Median [1] Concentration (ug/l)*
Inorganics					
Aluminum	94	16 U	210,000 J	7,839	114.5
Antimonty	94	4.3 U	43.3 J	10.3	10.5
Arsenic	94	2 U	208	25.7	13.4
Barium	94	21.4 J	6,320	480.9	230.0
Beryllium	94	1.0 U	9.9 J	1.4	0.7
Cadmium	94	0.6 U	4.6	1.7	2.5
Calcium	94	10100	3,100,000	241,291	99,650
Chromium	94	0.7 U	347 J	19.9	3.0
Cobalt	94	1.2 U	269	12.9	5.8
Copper	94	4.0 U	427 J	41.0	12.5
Iron	94	12.9 U	521,000 J	26,536	4,610
Lead	94	2.0 U	589 J	26.4	2.2
Mangesium	94	9,320	1,230,000	85,000	32,150
Manganese	94	1.0 U	11,000 J	1,583	821.5
Mercury	94	0.1 U	1.4	0.2	0.1
Nickel	94	0.70 U	619 J	34.1	19.3
Potassium	94	1260 U	50,900 J	8,585	7,330
Selenium	94	2.0 U	10	3.1	2.0
Silver	94	0.4 U	11.5	2.8	2.1
Sodium	94	3,700	2,980,000	111,111	40,850
Thallium	91	2.0 U	22.7 J	6.3	4.0
Vanadium	94	0.8 U	437	22.1	6.8
Zinc	94	1.0 U	1,600 J	108.8	23.3
Cyanide	94	4.3 U	294	17.0	5.0

Notes:

1 Half the detection limit was used for calculation of mean and median for non-detected parameters.
µg/L Microgram per liter.
J Estimated value.
U Analyte was not detected at the detection limit noted.
NJ Presumptive evidence of the presence of the material at an estimated concentration.
B Analyte was found in an associated blank.
ND ( ) Not detected at the method detection limit in brackets.

TABLE 8.1

PRELIMINARY PROJECT COST ESTIMATE
FORMER ROCKWELL INTERNATIONAL SITE
ALLEGAN, MICHIGAN

Description	*Units*	*Unit Price*	*Quantity*	*Total Costs*
A. CAPITAL COSTS				
EXCAVATION OF PCB SOILS [1]				
Soil borings/analytical for PCB delineation within former Interim Ponds	Ea.	$1,000	25	$25,000
Excavate subsurface soils with PCBs < 50 mg/kg (assume 0-10')	C.Y.	$15	3,000	$45,000
Excavate subsurface soils with PCBs ≥ 50 mg/kg (assume 10-20')	C.Y.	$15	2,000	$30,000
Confirmatory sampling to define extent of PCB contamination	Ea.	$125	40	$5,000
Off-Site transportation of TSCA regulated soils	ton	$50	3,000	$150,000
Disposal of TSCA regulated soils at TSCA landfill	ton	$100	3,000	$300,000
Backfill bottom of excavation with soils less than 50 mg/kg	C.Y.	$5	3,000	$15,000
Backfill remainder of excavation with imported clean fill	C.Y.	$12	2,000	$24,000
				$594,000
LNAPL COLLECTION SYSTEM [2]				
Excavate collection trenches using biopolymer slurry (15' depth)	S.F.	$10	9,000	$90,000
Backfill collection trenches with engineered sand or gravel	C.Y.	$15	1,000	$15,000
Install collection wells/pumps at intersection of trenches	Ea.	$7,500	3	$22,500
Temporary oil/water separator units and LNAPL storage tanks	Ea.	$7,500	2	$15,000
Install re-injection wells to discharge treated water back into ground	Ea.	$2,500	3	$7,500
Oxygen Release Compound (ORC) addition system	Ea.	$2,500	2	$5,000
Miscellaneous piping between wells and oil/water separator	L.S.	$20,000	1	$20,000
Electrical service and electrical/instrumentation controls	L.S.	$20,000	1	$20,000
				$195,000
SOIL/SEDIMENT CONSOLIDATION				
Removal and treatment of water within three WWTP ponds	Kgal.	$50	2,000	$100,000
Solidification and consolidation of WWTP pond sediments	C.Y.	$25	11,200	$280,000
Interim berm within Pond No. 3 for solidified sediment	L.F.	$20	500	$10,000
Surface soil removal - along riverbank (assume 24" depth) [3]	C.Y.	$10	280	$2,800
Surface soil removal - former SOS pond (assume 24" depth) [4]	C.Y.	$10	560	$5,600
Surface soil removal - former Interim pond (assume 24" depth) [5]	C.Y.	$10	460	$4,600
Surface soil removal - former Railroad ROW (assume 24" depth) [6]	C.Y.	$10	740	$7,400
Placement of demolition materials to raise WWTP ponds [7]	C.Y.	$0	--	$0
				$410,400
WWTP PONDS CAPPING PROGRAM [8]				
WWTP Pond Cover - Grading layer over debris (24" thick)	C.Y.	$12	6,500	$78,000
WWTP Pond Cover - Supply and place 40-mil VFPE liner	S.Y.	$4	9,700	$38,800
WWTP Pond Cover - Sand drainage layer (12" thick)	C.Y.	$20	3,200	$64,000
WWTP Pond Cover - Barrier protection layer (18" thick)	C.Y.	$12	4,900	$58,800
WWTP Pond Cover - Topsoil material (6" thick)	C.Y.	$15	1,600	$24,000
WWTP Pond Cover - Seed and mulch	S.Y.	$2	9,700	$19,400
WWTP Pond Cover - Erosion protection stone along riverbank	S.Y.	$20	1,800	$36,000
				$319,000
MISCELLANEOUS CAPPING PROGRAMS				
Riverbank Restoration Area - Erosion protective stone [9]	S.Y.	$20	560	$11,200
Riverbank Excavation Area - Fill (18" thick)/topsoil material (6" thick) [3]	C.Y.	$15	280	$4,200
Former SOS Pond - Fill (18" thick)/topsoil material (6" thick) [4]	C.Y.	$15	10	$150
Former Interim Pond - Fill (18" thick)/topsoil material (6" thick) [5]	C.Y.	$15	460	$6,900
Riverbank and SOS & Interim Ponds - Seed and mulch [3][4][5]	S.Y.	$2	1,900	$3,800
Former Railroad ROW - Fill (12" thick) [6]	C.Y.	$12	370	$4,440
Former Railroad ROW - Stone sub-base (9" thick) [6]	C.Y.	$20	280	$5,600
Former Railroad ROW - Asphalt cover (3" thick) [6]	S.Y.	$5	1,110	$5,550
Capping over remainder of Site (landscaping/pavement) [10]	S.Y.	$0	0	$0
				$41,840

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TABLE 8.1

PRELIMINARY PROJECT COST ESTIMATE
FORMER ROCKWELL INTERNATIONAL SITE
ALLEGAN, MICHIGAN

Description	*Units*	*Unit Price*	*Quantity*	*Total Costs*
A. CAPITAL COSTS (cont'd)				
PHYSICAL CONTAINMENT WALL [11]				
Soil borings to determine depth to clay till along wall alignment	Ea.	$1,000	200	$200,000
Slurry compatibility and hydraulic conductivity testing	L.S.	$50,000	1	$50,000
Soil-bentonite slurry wall (assume 60' average depth)	S.F.	$6	210,000	$1,260,000
Cement-bentonite gates (assume 25' each side of 5 PRB gates)	S.F.	$15	15,000	$225,000
				$1,735,000
PERMEABLE REACTIVE GATES [11]				
Excavate 5 PRB gates using biopolymer slurry (60' depth)	S.F.	$15	9,000	$135,000
Supply reactive media (assume 20% iron / 80% sand)	tons	$100	2,500	$250,000
Install reactive media (assume 5' width and 60' depth)	tons	$30	2,500	$75,000
LNAPL interceptor trench in front of PRB gates (20' depth)	S.F.	$10	5,000	$50,000
Install collection wells/sumps (for potential future use)	Ea.	$5,000	5	$25,000
Backfill interceptor trenches with engineered sand or gravel	C.Y.	$15	600	$9,000
				$544,000
GROUNDWATER MONITORING WELLS				
Monitoring wells to evaluate effectiveness of PRB gates	Ea.	$2,000	20	$40,000
Monitoring wells to evaluate effectiveness of LNAPL collection systems	Ea.	$2,000	11	$22,000
Gradient piezometers straddling slurry wall alignment to monitor effectiveness	Ea.	$1,200	20	$24,000
				$86,000
INSTITUTIONAL CONTROLS				
Place deed restrictions to ensure no excavation	L.S.	$25,000	1	$25,000
				$25,000
TOTAL REMEDIATION CAPITAL COSTS				$3,950,240
ASSOCIATED IMPLEMENTATION SUPPORT COSTS				
Mobilization (5% of remediation costs)	L.S.	$197,500	1	$197,500
Bonds (2% of remediation costs)	L.S.	$79,000	1	$79,000
Insurance (3% of remediation costs)	L.S.	$118,500	1	$118,500
Temporary Facilities and Controls (8% of remediation costs)	L.S.	$316,000	1	$316,000
Health and Safety (5% of remediation costs)	L.S.	$197,500	1	$197,500
Demobilize (3% of remediation costs)	L.S.	$118,500	1	$118,500
TOTAL SUPPORT CAPITAL COSTS				$1,027,000
SUB-TOTAL CAPITAL COSTS				$4,977,240
ENGINEERING DESIGN AND OVERSIGHT (10% of Construction Costs)				$497,700
SUBTOTAL ENGINEERING AND CAPITAL COSTS				$5,474,940

TABLE 8.1

PRELIMINARY PROJECT COST ESTIMATE
FORMER ROCKWELL INTERNATIONAL SITE
ALLEGAN, MICHIGAN

Description	*Units*	*Unit Price*	*Quantity*	*Total Costs*
B. OPERATION & MAINTENANCE COSTS				
LNAPL COLLECTION AND TREATMENT SYSTEM				
Power to operate LNAPL collection wells/sumps	Kwh	$0.10	5,000	$500
Oxygen Release Compound (ORC) addition system	L.S.	$2,500	2	$5,000
Capital replacement of LNAPL system (assume 5% of capital)	L.S.	$1,500	1	$1,500
Collected LNAPL storage and disposal cost	gal.	$10	1,000	$10,000
Replenish reactive media (assume every 10 years)	tons	$130	250	$32,500
Cap inspection and maintenance (assume 3% of capital)	L.S.	$11,000	1	$11,000
Groundwater gradient and LNAPL migration monitoring	L.S.	$15,000	1	$15,000
Monitoring well repairs/replacement (assume 1/year)	L.S.	$2,000	1	$2,000
Groundwater sampling and reporting (assume 20 wells) (12)	L.S.	$20,000	1	$20,000
ANNUAL O&M COSTS				**$97,500**
PRESENT WORTH - O&M COSTS (30 years @ 7%) (13)				**$1,209,900**
SUBTOTAL - CAPITAL AND O&M				**$6,684,840**
CONTINGENCY (25%)				**$1,671,000**
TOTAL - ALL ITEMS				**$8,355,840**

Assumptions:

A conversion factor of 1 cubic yard = 1.5 tons was utilized for soil materials.

(1) Area of PCBs ≥ 50 ppm encompasses SB-16 & SB-75, with interpolated excavation limits halfway to SB-15, SB-76, & SB-77 (base area: 40 ft. x 85 ft. = 3400 S.F. and top area: 60 ft. x 110 ft. = 10,800 S.F. for a total volume of 5,000 C.Y.).

(2) Length of each LNAPL collection system trench = 200 L.F. (with combined treatment for the SOS & Interim pond areas).

(3) Area of surface soil removal along Kalamazoo Riverbank: 50 ft. x 75. ft. = 3,750 S.F.

(4) Area of surface soil removal within former SOS pond: 1/2 (100 ft. x 150 ft.) = 7,500 S.F.

(5) Area of surface soil removal within former Interim pond: 50 ft. x 125 ft. = 6,250 S.F.

(6) Area of surface soil removal within former railroad ROW: 100 ft. x 100 ft. = 10,000 S.F.

(7) Placement of demolition materials in former WWTP ponds assumed to be completed as part of Site redevelopment.

(8) Area of multi-layer capping over WWTP ponds consolidation: 360 ft. x 250 ft. = 87500 S.F.

(9) Area of erosion protection stone along Kalamazoo River shoreline: 200 ft. x 25 ft. = 5000 S.F.

(10) Construction of buildings, pavement, and landscaping assumed to be completed as part of Site redevelopment.

(11) Overall length of physical containment wall = 3900 L.F. (with 30' PRB gates and 25' C-B wing walls on each side).

(12) Assumes annual sampling & analysis for VOCs, SVOCs, PCBs, and metals at $800/sample including reporting.

(13) A discount rate of 7% was utilized to calculate the Present Worth of Operation and Maintenance costs to be consistent with the discount rate utilized by U.S. EPA in the draft Feasibility Study.

APPENDICES

APPENDIX A

REFERENCE DOCUMENTS

APPENDIX A

REFERENCE DOCUMENTS

"Remedial Investigation Report", Former Rockwell International Corporation Allegan, Michigan Site, Environmental Strategies Corporation, Reston, Virginia, McLaren/Hart, Inc. PTI Environmental Services, Boulder, Colorado, February 1998.

"Historical Activities Reconstruction Report", Former Rockwell International Corporation Allegan, Michigan Site, Environmental Strategies Corporation, Reston, Virginia, March 1998.

"Aerial Photographic Interpretation: Allegan, Michigan", Technical Memorandum, PTI Environmental Services, Boulder, Colorado, March 1998.

"1997 Reconnaissance of Subsurface Soils and Groundwater Conditions in the Vicinity of the Former Soluble Oil Separation Pond", Meritor Automotive Allegan Michigan Site, PTI Environmental Services, Boulder, Colorado, March 1998.

"Aerial Photographic Analysis of Rockwell International Site, Allegan, Michigan" TS-AMD-86710-12, U.S. EPA, 1986.

"Permeable Reactive Barrier Technologies for Contaminant Remediation", U.S. EPA Office of Research and Development and Office of Solid Waste and Emergency Response, Washington DC, EPA/600/R-98/125, September 1998.

"Revised Remedial Investigation Report" Rockwell International Corporation Site, Allegan, Michigan, TetraTech EM Inc.

"Revised Remedial Investigation Report" Rockwell International Corporation Site, Allegan, Michigan, TetraTech EM Inc.

APPENDIX B

CURRICULA VITAE FOR KEY CRA PROJECT PERSONNEL

GLENN T. TURCHAN, M.A.Sc., P. Eng.

EDUCATION

B.A.Sc.	University of Waterloo, Geological Engineering
M.A.Sc.	University of Waterloo, Civil Engineering
Other Courses:	Organic Contaminants in Groundwater, June 1988 (sponsored by MOE and WCGR)
	40-Hour OSHA Personal Protection and Safety Training (as per CFR 1910-120), September 1988 (hazardous waste site safety training)
	8-Hour OSHA Site Supervisors and Managers Course Training (as per 29 CFR 1910-120), March 1989 (hazardous waste site managers health and safety training)
	8-Hour Refresher in Personal Protection and Safety (as per 29 CFR 1910-120) (yearly update as required)

EMPLOYMENT

1995-Present	Project Manager/Principal/Principal-In-Charge (Detroit Office) Conestoga-Rovers & Associates
1994-95	Associate, Project Manager/Coordinator, Conestoga-Rovers & Associates
1989-93	Project Manager/Coordinator, Conestoga-Rovers & Associates
1987-89	Project Engineer, Conestoga-Rovers & Associates
1985-86	Engineering Assistant, Conestoga-Rovers & Associates
1984	Engineering Assistant, Atomic Energy of Canada Limited
1984	Engineering Assistant, Acres Consulting Services Limited

AFFILIATIONS

Professional Engineers Ontario (PEO #90212960)

PROFILE OF PROFESSIONAL ACTIVITIES

- Professional Engineer/Hydrogeologist
- Project Engineer/Coordinator or Project Manager responsible for environmental due diligence/environmental site assessments/environmental compliance audits/investigations/site characterizations/remedial investigations (RI)/feasibility studies (FS)/remedial design (RD)/remedial action (RA)/LUST closures/permitting/contract documents/supervision and contractor oversight
- Remedial Investigation/Feasibility Studies (RI/FS) at the following sites:
  - Willow Run Sludge Lagoon, Washtenaw County, Michigan
  - Willow Run Creek Site, Washtenaw County, Michigan
  - WDE Sanitary Landfill, Andover, Minnesota

- Nepera Inc. Plant Site, Harriman, New York
- Nepera Inc. Former Lagoon NPL Site, Maybrook, New York
- Fons Landfill Site, Washtenaw County, Michigan
- Old Wayne Landfill Site, Washtenaw County, Michigan
- Textile Road Site, Rawsonville, Michigan
- RCRA RFI/CMS at GM Pontiac facility, Pontiac, Michigan
- Metamora Landfill Site, Lapeer County, Michigan
- Highway 48 Site, Stouffville, Ontario
- Sterling Drug Site, Cincinnati, Ohio
- National Airport Site, Westland, Michigan

• Overview and Critique of U. S. EPA or State Lead RI/FS or RD/RA programs at the following Superfund sites:
  - Pristine Site, Cincinnati, Ohio
  - G & H Landfill Site, Utica, Michigan
  - Metamora Landfill Site, Lapeer County, Michigan
  - MIG/Dewane Landfill Site, Belvidere, Illinois
  - Michigan Chrome and Chemical, Detroit, Michigan

• Remedial Design/Remedial Action (RD/RA) at the following sites:
  - Metamora Landfill Site, Lapeer County, Michigan
  - G&H Landfill Site, Utica, Michigan
  - Willow Run Creek Site, Washtenaw County, Michigan
  - Fons Landfill Site, Washtenaw County, Michigan
  - Old Wayne Landfill Site, Washtenaw County, Michigan
  - SMDA Sites 9/9A Macomb Township, Michigan
  - Pontiac Sites (various), Pontiac, Michigan
  - Meritor Automotive Site, Allegan, Michigan
  - Middleground Landfill, Bay City, Michigan

• Environmental Site Assessments/Environmental Compliance Audits
  - Completed over 250 ESA and ECA projects in Canada and the United States involving industrial and commercial facilities

• Acquisition/Divestiture Due Diligence
  - Environmental due diligence support related to purchase of five commercial laundry plants
  - Environmental due diligence support related to acquisition of 14 gravel pit operations
  - Environmental due diligence support on purchase of 2 radio stations
  - Environmental due diligence support in divestiture of a shopping mall located in Bloomfield Township
  - Environmental due diligence support to GM related to various properties at the Centerpoint Business Campus and Clark Street Technology Park

- Environmental due diligence support to GM in divestiture of two Delphi plants in Livonia and Flint to Peregrine Inc.
- Environmental due diligence support related to purchase of 11 cemeteries
- Environmental due diligence support to GM in divestiture of five plants in Grand Rapids, Auburn Hills and Warren to Lear Corporation
- Environmental due diligence support to GM in divestiture of three Delphi plants in Oshawa, St. Catherine's and New Brunswick, New Jersey
- Environmental due diligence support to Oxford Automotive in acquisition of two plants in Ohio and two plants in Michigan from Howell Industries Inc.
- Environmental due diligence support to Oxford Automotive in acquisition of one plant in Indiana and two plants in Ontario from Eaton-Yale
- Environmental due diligence support to Delphi Automotive Systems in leasing facilities in Rochester Hills, Michigan and Duncan, South Carolina
- Environmental due diligence support to Ferrous Processing and Trading in acquisition of scrap yard facilities in Windsor, Ontario (3), Detroit (2), Warren, and Flint
- Environmental due diligence support to Trident Properties on acquisitions of properties throughout Michigan

- Baseline Environmental Assessments
  - Northline L.L.C., Romulus, Michigan
  - Equipment Supply, Romulus, Michigan
  - Schlafer Iron and Steel Company, Detroit Michigan
  - TBS Industrial Recycling, Inc., Pontiac, Michigan
  - Mason Iron and Metal, Detroit, Michigan
  - Grand Traverse Overall Supply, NPL Site, Traverse City, Michigan
  - Ferrous Processing Inc., Detroit, Michigan
  - Former New Holland Site, Troy, Michigan
  - St. Marys Cement Plant, Detroit, Michigan
- Brownfield Redevelopment Projects
  - Clark Street Technology Park, Detroit, Michigan
  - Centerpoint Business Campus, Pontiac, Michigan
  - Northline L.L.C., Romulus, Michigan
  - Former New Holland Site, Troy, Michigan
  - Textile Road Site, Ypsilanti Township, Michigan
- Environmental Decommissioning
  - Removal action at Chrysan Industries in Detroit, Michigan
  - Support to GM in development of standard guidelines and specifications for plant decommissioning
  - Building decommissioning assessments at the following sites:
    - GM Brea, California
    - GM Moraine facility, Moraine, Ohio

- Oldsmobile Site, Lansing, Michigan
  - 500,000 square feet
- Oldsmobile Site, Lansing, Michigan
  - 1,000,000 square feet
- GM Desert Proving Grounds, Mesa, Arizona
  - 500,000 square feet on 7500 acres
- GM Metal Fabrication Division, Kalamazoo, Michigan
  - 1,500,000 square feet on 350 acres
- Delco Electronics, Kokoma, Indiana
  - 750,000 square feet
- GM Metal Fabrication Buildings 2, 5, 12, Pontiac, Michigan
  - 750,000 square feet
- Delphi, Rochester, New York
  - 350,000 square feet

- Risk Assessment Evaluations
- Landfill Gas Management/Recovery/Utilization Projects
  - Brock West Site, Pickering, Ontario
  - Keele Valley Site, Maple, Ontario
- Supervision of drilling and groundwater monitoring well installation
- Preparation and representation of technical information to representatives of State and Federal Governments
- Litigation Support
- Support to various clients on a variety of litigation matters

PUBLICATIONS

- "Landfill Gas Collection and Utilization", paper presented at *Canadian Geotechnical Society, Southern Ontario Section, Solid Waste Symposium*. Toronto, Ontario, March 9, 1988 (with A.J. Crutcher, A.W. Van Norman)
- "Overview on Problems of Pond Construction", paper presented at *Prevention & Treatment of Groundwater and Soil Contamination in Petroleum Exploration and Production* Calgary, Alberta, May 10, 1989 (with D.H. Haycock, S.T. Ruminsky)
- "Soil Remediation Issues", presented at *Third Annual National Meeting and Conference of the Academy of Certified Hazardous Materials Managers*, July 25 - 28, 1989, Indianapolis, Indiana (with A.W. Van Norman)
- "Groundwater Cutoff Walls: Application at Hazardous Waste Sites", paper presented at *Focus Conference on Eastern Regional Groundwater Issues*, National Water Well Associations, Kitchener, Ontario, October 18, 1989 (with A.W. Van Norman, I.K. Richardson)
- "Remediation Approaches and Technologies for Potential Application to PCB Contaminated Sludge Sites", paper presented at *SUPERFUND XIV*, December 1993, Washington, D.C., (with J. Daniel, E. Peterson, K. Waskiewicz, A.W. Van Norman)

- Carey, G.R., M.G. Mateyk, G.T. Turchan, E.A. McBean, and J.R. Murphy, 1996, "Intrinsic Remediation as an Effective Alternative to Groundwater Pump-and-Treat: A Case Study", submitted for publication in NWWA/API Conference on Proceedings of Petroleum Hydrocarbons & Organic Chemicals in Ground Water, Houston, Texas.
- Carey, G.R., M.G. Mateyk, E.A. McBean, G.T. Turchan, and F.A. Rovers, 1996, "Application of a Technical Protocol for Evaluating Intrinsic Remediation at Landfill Sites", submitted for publication in Proceedings of the Madison Waste Conference, Madison, Wisconsin.
- Carey, G., M. Mateyk, E. McBean, G. Turchan, J. Campbell and F. Rovers (1996): "Multiple Lines of Evidence for Evaluating Intrinsic Remediation at a Landfill Site", presented at the 19th Annual Madison Waste Conference, Madison, Wisconsin, September 1996
- Carey, G., Michael Mateyk, Glenn Turchan, Edward McBean, Frank Rovers and Richard Murphy (1996): "Application of an Innovative Visualization Method for Demonstrating Intrinsic Remediation at a Landfill Site", presented at the 1996 Petroleum Hydrocarbons Exposition, Houston, Texas, November 1996
- "Modelling Landfill Cap Influence on Natural Attenuation", presented at Sixth International Landfill Symposium, Cagliari, Sardinia, Italy, October 13-17, 1997 (with G. Carey, P. Van Geel, E. McBean, G. Turchan)
- "Site Reuse/Brownfield Redevelopment in the Detroit Empowerment Zone" technical paper presented (by K. West) at Superfund XVIII Conference, Washington, D.C., December 4, 1997 (co-authors(K. West, B. Pitlock, K. Richards, G. Turchan, S. Anderson)

Reports:

- "Groundwater Cutoff Walls: Applicability, Design and Implementation at Hazardous Waste Sites", *in partial fulfillment of the requirements for the degree of M.A.Sc.*, Department of Civil Engineering, University of Waterloo, March 1, 1990

Presentations:

- "Environmental Engineering in the 90's", presentation at Professional Engineers Ontario - Undergraduate Engineering Students Conference 1994, January 28, 1994 (with J. Daniel, G. O'Neill)
- "Center Point Business Campus Redevelopment", presentation at Industrial Site Recycling Conference – Phoenix Award Finalist, Pittsburgh, Pennsylvania, April 14, 1998 (presented by K. West)

C. RICHARD HOEKSTRA, B.A.Sc., P. Eng.

EDUCATION

B.A.Sc.	Civil Engineering, University of Waterloo, 1982
Other Courses	40-Hour OSHA Personal Protection and Safety Training (as per 29 CFR 1910-120), November 1987
	8-Hour OSHA Site Supervisors and Managers Course Training (as per 29 CFR 1910-120), March 1989
	8-Hour Refresher in Personal Protection and Safety (as per 29 CFR 1910-120), 1989, 1990, 1991, 1992, 1993,1994, 1995, 1996, 1997, 1998, and 1999
	Emergency First Aid and CPR Certification, Emergency Care Instruction Services, January 1993 and 1996
	8-Hour OSHA Confined Space Safety Training (as per 29 CFR 1910-146 (g)1 – (g)3), Entrant, Attendant, & Supervisor, (29 CFR 1926.21 (b)(6)(i)), February 1999

EMPLOYMENT

1994-Present	Project Manager/Design Engineer Conestoga-Rovers & Associates
1992-94	Senior Engineer, Conestoga-Rovers & Associates
1988-92	Intermediate Engineer/Project Coordinator, Conestoga-Rovers & Associates
1983-88	Junior Engineer, Conestoga-Rovers & Associates
1981	Student Engineer (work term), Waterloo Centre for Process Development
1981	Student Engineer (work term), City of Cambridge
1980	Student Engineer (work term), Conestoga-Rovers & Associates
1979	Project Officer/Student Engineer (two work terms), Government of the N.W.T.

AFFILIATIONS

Association of Professional Engineers of Ontario

PROFILE OF PROFESSIONAL ACTIVITIES

- Project Manager of remedial program involving design and implementation of a landfill source control (NAPL recovery) system, an overburden drain tile system, a bedrock purge/recirculation well (APL/NAPL) system, off-site excavation and capping, and final landfill capping (all construction completed) at a Superfund hazardous waste site (New York)
- Project Manager of remedial program involving design and implementation of an overburden soil-bentonite slurry wall, an overburden drain tile collection system (constructed using biopolymer slurry trenching), a bedrock NAPL recovery system, an overburden (APL/NAPL) and bedrock (APL)

groundwater pumping system, landfill disposal activities, and final landfill capping (to be completed) of a Superfund hazardous waste site (New York)

- Project Manager of remedial program involving design and implementation of landfill closure project involving the importation of 200,000 cubic yards of clean fill, construction of 10,000 feet of a perimeter barrier wall in combination with an overburden drain tile collection system, installation of 5,000 feet of forcemain for discharge to the local POTW, remediation and restoration of adjacent EPA and State regulated wetlands, construction of 3,500 feet of storm sewer piping, and final landfill capping of a 60+ acre co-mingled municipal/hazardous waste site (New York)
- Project Coordinator for divisibility of harm report in support of expected litigation involving a complete review of the Administrative Record for a remediated NPL site and conducting a critique of the numerous supporting documents including remedial investigation reports, feasibility studies, remedial designs, record of decision documents, etc. (New Jersey)
- Project Coordinator of video presentation regarding completion of a remedial construction project in Michigan involving the solidification and removal of approximately 350,000 cubic yards of impacted sediments from almost 3 miles of creek bed, as well as two ponds and a former sludge lagoon (Michigan)
- Design Coordinator of remedial program involving design and implementation of an overburden groundwater collection system, a partial soil-bentonite slurry wall, and final landfill grading and capping at a State hazardous waste site (New York)
- Design Coordinator of closure plans for former electrical substations beneath operating powertrain facility involving decommissioning of PCB-contaminated surfaces, treatment of removed water and cleaning fluids, and complete filling of cleaned subsurface vaults (Michigan)
- Coordinator of remedial design for an overburden barrier wall consisting of soil-bentonite slurry wall and jet grout wall in conjunction with an adjacent groundwater collection trench (Michigan)
- Project Coordinator of several laboratory studies regarding accelerated testing of slurry wall and grouting materials in contact with site contaminants (APL/NAPL) from Superfund and State hazardous waste sites (New York and Michigan)
- Project Coordinator of laboratory study regarding compatibility testing of biopolymer slurry materials in contact with site contaminants (APL/NAPL) from Superfund hazardous waste site (New York)
- Coordinator of a three-phase assessment of state-of-the-art in situ bedrock groundwater containment technologies including ground freezing, hydromilling, pressure grouting, megadrilling, and pump-and-treat remedies (Ontario)
- Project Coordinator of hydrogeologic investigation and subsequent Remedial Investigation/Feasibility Study at a large industrial facility (New York)
- Project Coordinator of hydrogeologic investigation at former phosphorus/phosphate production facility (Tennessee)
- Project Coordinator of various site investigations at smaller facilities throughout New York State
- Construction supervisor for installation of an overburden drain tile system and associated forcemains and final landfill cap at a Superfund hazardous waste site (New York)
- Construction manager for installation of an overburden slurry wall and biopolymer drain collection trench at a Superfund hazardous waste site (New York)
- Supervision of field investigations including drilling and sampling programs at various manufacturing plants and hazardous waste sites in New York, Iowa, Tennessee, and South Carolina, as well as a specific assignment in Belgium

- Involvement in technical group preparing requisite remedial technology studies and remedial action plans for identified hydrogeologic problems including hazardous waste facilities
- Involvement in internal design group for consultation with regard to construction of drain tile systems, slurry walls, NAPL recovery systems, and final landfill caps for various company projects
- Hydrogeologic investigations of hazardous waste sites including groundwater monitoring and sampling studies
- Contaminant migration studies at hazardous waste disposal sites and other industrial facilities
- Technical evaluations of potential remedial alternatives to address groundwater contamination at several industrial landfill sites
- Design and maintenance of project scheduling for time periods of 6 months to a projected 7 years
- Preparation of contract documents and specifications for drilling, excavation, slurry walls, grouting, capping, piping, waste disposal, and other remedial action programs
- Cost estimations for remedial action and investigative programs
- Preparation of proposals for RI/FS and RD/RA programs with accompanying scheduling and cost estimating for potential clients
- Preparation of landfill and hazardous waste site closure plans
- Preparation of historical databases of past investigations and studies completed at various sites
- Participation in conceptual landfill design and waste placement planning

JEFF DANIEL, P.ENG.

EDUCATION

B.A.Sc. Civil Engineering, Water Resources Option, University of Waterloo, 1993

EMPLOYMENT

1998 - Present	Project Manager/Coordinator Conestoga-Rovers & Associates
1995-98	Project Coordinator/Engineer Conestoga-Rovers & Associates
1993-95	Environmental Engineer, Conestoga-Rovers & Associates
1992	Student Engineer, Conestoga-Rovers & Associates
1991	Construction Inspector, Regional Municipality of Waterloo
1990	Student Engineer, M.M. Dillon Ltd.
1988-89	Student Engineer, Wiebe Engineering Group
1987-88	Construction Inspector/Surveyor, Corporation of the City of Chatham

AFFILIATIONS

Board of Professional Engineers - State of Michigan (License No. 44981)
Professional Engineers of Ontario (Registration No. 90436692)

PROFILE OF PROFESSIONAL ACTIVITIES

- Coordination of pre-design investigations for the Willow Run Creek (WRC) Site sediment cleanup (approximately 350,000 cubic yards). Investigations included, hydrogeologic/geotechnical landfill siting, sediment treatability studies, delineation of the extent of contamination, wetlands delineation, and synthetic liner compatibility study
- Project coordinator for implementation of the WRC Site Remedial Action (RA)
  - Remedy included construction of a containment cell on-Site, in-situ solidification of sediments, excavation, transportation, wastewater/leachate treatment, landfilling, wetlands mitigation, and restoration
  - Development of Contract Documents and contractor procurement
  - General project coordination, submittals review, Contract administration
  - Documentation of the progress of construction
  - Dispute resolution with RA Contractor
- Preparation of technical reports including; Feasibility Study Report, Proposals for Professional Services, Sampling and Analysis Plans, Site Evaluation Reports, Site Investigation Plans, and Health and Safety Plans
- Project/Design Coordinator for the Fields Brook Superfund Site located in Ohio. The project includes construction of an on-Site landfill, water diversion, sediment removal from a creek system,

dewatering, and restoration of wetland areas. Investigation of areas of radium and dense non-aqueous phase liquid (DNAPL) contamination and subsequent assistance to the Group in negotiation of remedy changes to address these issues was added to CRA's scope of activities

- Environmental Site Assessments
- Supervision of soil sampling activities
- Preparation of contract documents
- Supervision of soil boring activities
- Critical path scheduling
- Cost estimation
- Contractor supervision
- Survey experience

PAPERS AND PRESENTATIONS

- "Remediation Approaches and Technologies for Potential Application to PCB Contaminated Sludge Sites", technical paper presented (by G. Turchan) at Superfund XIV Conference, Washington, D.C., December 2, 1993 (co-authors G. Turchan, A. Van Norman, K. Waskiewicz, E. Peterson)
- "Environmental Engineering in the 90's", presentation at Professional Engineers Ontario - Undergraduate Engineering Students Conference 1994, January 28, 1994 (with G. Turchan, G. O'Neill)

GREGORY A. CARLI, P. Eng.

EDUCATION

B.A.Sc. Civil Engineering, Water Resources Option, University of Waterloo, 1996

Other Courses: 40-Hour OSHA Health and Safety Training (as per 29 CFR 1910.120), November 1996

8-Hour OSHA Health and Safety Training Refresher (as per 29 CFR 1910.120), February 1997, February 1998, February 1999

EMPLOYMENT

1998-Present	Project Coordinator Conestoga-Rovers & Associates
1996-98	Engineering Assistant, Conestoga-Rovers & Associates
1995	Student Environmental Engineer, Conestoga-Rovers & Associates (one work term)
1995	Teaching Assistant, University of Waterloo (first year engineering tutor)
1994	Student Design Engineer, Union Gas Limited (two work terms)
1993	Student Engineer, Municipality of Metropolitan Toronto, Transportation Department (two work terms)
1992	Research Assistant, University of Waterloo, Department of Civil Engineering (one work term)

AFFILIATION

Association of Professional Engineers of Ontario

PROFILE OF PROFESSIONAL ACTIVITIES

- Preparation of various documents and technical reports including: Site Investigation Work Plans, Site Investigation Reports, Remedial Action Plans, Baseline Environmental Assessments, Environmental Compliance Analysis, Health and Safety Plans and Progress Reports, Subcontract and Contract Specifications, and Cost Estimates
- Coordination of investigative/remedial site activities for several environmental projects
- Performance of various field activities including groundwater sampling and hydrogeologic investigations
- Preparation and expedition of contract documents
- Preparation of cost estimates and budgeting
- Compliance evaluations with regulatory criteria
- Data management and analysis, including statistical analysis
- Project management and invoicing

PROJECT EXPERIENCE

- Project Coordinator for the design and implementation of a PCB contaminated soil cleanup for a former gravel extraction and disposal site, including the following:
  - Assistance in the derivation of an excavation plan. The plan included the analysis of cleanup goals to delineate areas requiring remediation and the preparation of detailed soil volume calculations for soils requiring disposal and/or regrading
  - Preparation of a contaminated soil cleanup plan that included the formulation and examination of a soil remediation work plan and design, public notification, permitting, air monitoring tasks, access issues, fugitive dust control procedures, and confirmation sampling tasks
  - Assisted in producing design project specifications for contract procurement complete with general conditions and material/product specifications
  - Conducted detailed assessment of the risks to human health and the environment associated with the proposed removal action with specific focus on the exposure of future children living on the property and the protection of groundwater from low level contamination remaining on a portion of the property
  - Assisted in the evaluation of design drawings complete with grading plans, road, excavation area and path plans, soil staging plans and profiles, and related details
  - Preparation of detailed cost estimates and a detailed construction schedule for completion of the work
  - Participation in the conceptual design and negotiation with municipal officials for the redevelopment of the property following remedial activities
- Assisted in the engineering oversight and implementation of contaminated sediment remediation project of former sludge lagoon, creek and two stormwater retention/fire ponds. Activities included:
  - Evaluation of slope stability associated with the design and construction of a chemical waste landfill for disposal of contaminated material
  - Review of air monitoring data and assessment of the risks to workers associated with air emissions from the placement and disposal of PCB waste, including technical review of exposure pathways and mechanisms and development of technical documents in support of air emission levels submitted to regulatory agencies
  - Technical review of contract and design submittals my remedial construction contractor
- Coordinated Phase I and II Environmental Assessments and Baseline Environmental Assessment (Michigan) for acquisition at the following:
  - Scrap Metal Recycling Facilities – Detroit, Warren, and Flint, Michigan and Windsor, Ontario
  - Automotive Parts Manufacturer – Chatham and Wallaceburg, Ontario
- Conducted an air emissions inspection and associated reporting for two automotive manufacturing facilities. Activities included identification of all air emissions sources, field measurements of air emissions sources, detailed review of historic air evaluation data, and technical review of processes contributing to air contamination
- Participated in a water level monitoring program to evaluate the effect of a recently installed extraction well on the surrounding groundwater and surface elevations
- Participated in site reconnaissance visits in conjunction with remedial design efforts at various facilities

- Conducted groundwater monitoring well sampling activities at various sites to evaluate groundwater quality. Conducted field testing of water to measure field parameters. Responsible for sample collection and analysis quality control activities including the collection of sample blanks, duplicate samples, and rinsate samples
- Conducted oversight activities of drum removal contractor, activities included: documentation of project progress, inspection of completed works, liaison with regulatory oversight personnel, and insuring health and safety procedures and protocols were followed by site personnel

PAPERS AND PRESENTATIONS

- "Site Reuse/Brownfield Redevelopment in the Detroit Empowerment Zone" technical paper presented (by K. West) at Superfund XVIII Conference, Washington, D.C., December 4, 1997 (co-authors(K. West, B. Pitlock, K. Richards, G. Turchan, S. Anderson)
- "Center Point Business Campus Redevelopment", presentation at Industrial Site Recycling Conference – Phoenix Award Finalist, Pittsburgh, Pennsylvania, April 14, 1998 (presented by K. West)

ROBERT E. SCHLOESSER, B.S., M.S., C.H.M.M.

EDUCATION

B.S.	University of Wisconsin, 1974
M.S	University of Wisconsin, Botany, 1977

EMPLOYMENT

1995-Present	Senior Construction Supervisor Conestoga-Rovers & Associates
1989-95	Vice President - Environmental Services, Bierlein Demolition Contractors
1987-89	Environmental Consultant, Trans-Tech, Inc.
1979-87	Vice President, Enviro-Analysts, Inc.
1978-79	Research Associate, Savannah River Ecology Lab

AFFILIATIONS

Academy of Certified Hazardous Materials Managers (#1515)
Sigma Xi, Scientific Research Society
National Association of Environmental Professionals
Michigan Association of Environmental Professionals

PROFILE OF PROFESSIONAL ACTIVITIES

- Certified Hazardous Materials Manager, Master Level
- Twenty years of professional environmental experience including ten years of remediation/demolition contracting experience
- Experience in senior level construction management on landfill remedial design and build projects
- Industrial dismantlement, demolition and remediation experience includes
  - requirements for Health and Safety compliance
  - experience with union/non-union labor forces
  - knowledge of equipment and demolition techniques
  - ability to estimate material volumes
  - experience in salvage material recycling and debris disposal requirements
- Experienced in remediation and demolition estimating and evaluation of contractor specifications. Extensive knowledge of dismantlement and demolition techniques in automotive, petrochemical and utility industries

PROFILE OF PROJECT EXPERIENCE - OTHER INDUSTRIES

- Project Manager
  - remedial action cap construction at a 15-acre RCRA Site, Rochester Hills, Michigan, 1996
  - remedial construction project at the G&H Superfund site in Shelby Township, Michigan, 1977-98. Project included construction of a 90-acre cap, leachate collection system, 40 acres of wetlands, and permanent wastewater treatment plant, total cost $20M
- Project Co-ordinator/Project Manager
  - remediation and demolition of downtown facilities, General Motors Corporation, Seattle, Washington
  - removal and remediation of underground storage tanks, GM Technical Center, General Motors Corporation, Warren, Michigan
  - removal and remediation underground storage tanks, GM dealership at sites within nine states, General Motors Corporation
  - removal and remediation of in-ground treatment tanks, General Motors Corporation, Mansfield, Ohio
  - waste removal and remediation of multiple contaminated sites, General Motors Corporation, Bay City, Michigan
  - hazardous waste consolidation and remediation former Allis-Chalmer's manufacturing facility, West Allis, Wisconsin
  - hazardous waste remediation, Johnson Controls corporation, Milwaukee, Wisconsin
  - hazardous waste consolidation and TSDF site management, PPG Industries, Oak Creek, Wisconsin
  - hazardous waste consolidation and management, Saint Luke's Hospital, Racine, Wisconsin
  - hazardous waste consolidation and management, Delco Electronics, Milwaukee, Wisconsin
  - remediation and demolition of the former wastewater treatment plant, City of Houston, Houston, Texas
  - hazardous waste remediation and facility dismantlement, Chrysler Corporation, Milwaukee Stamping Plant, Milwaukee, Wisconsin
  - hazardous waste remediation, Chrysler Corporation, Lakefront Plant, Kenosha, Wisconsin
  - facility remediation and demolition, Chrysler Corporation, Old Mack Stamping Plant, Detroit, Michigan
  - removal of underground storage tanks and soils remediation, Chrysler Corporation, Kenosha Main Plant, Kenosha, Wisconsin
  - removal of underground storage tanks, Chrysler Corporation, Jeep Manufacturing Facility, Toledo, Ohio
  - remediation and dismantlement of manufacturing processes, Chrysler Corporation, Kenosha Main Plant, Kenosha, Wisconsin
  - remediation and demolition of former BASF resin manufacturing plant, Cincinnati, Ohio
  - remediation and demolition of Freedom, Pennsylvania refinery site, Ashland Petroleum Company
  - hazardous waste management and regulatory compliance, McGraw-Edison Company, South Milwaukee, Wisconsin

- emergency response action and remediation of pesticide spill for U.S. EPA, St. Louis, Michigan
- On-Site/Oversight Engineer
  - G&H remedial action Superfund project, 1996-1998

WILLIAM H. BAKER, R.P.G.

EDUCATION

University of Illinois, Civil Engineering

Illinois State Water Survey (Two year groundwater hydrology course designed and conducted by William C. Walton)

EMPLOYMENT

1995-Present	Resident Site Engineer Conestoga-Rovers & Associates
1990-95	Supervising Geoscientist, McLaren/Hart Environmental Eng., Corp.
1988-90	Associate Hydrologist and Regional Manager, Illinois State Water Survey
1979-88	Applied Science Manager/Hydrogeology, Morrison Knudsen Corporation
1978-79	Senior Hydrologist & Water Resource Manager, ERT/Ecology Consultants, Inc.
1976-78	Hydrologist, Amax Coal Company, Inc.
1959-76	Assistant Hydrologist, Illinois State Water Survey
1956-59	Hydraulic Engineering Aid, United States Geological Survey

AFFILIATIONS

National Academy of Science, Research Council Committee Member

PROFESSIONAL REGISTRATION

Registered Professional Geologist, State of Arkansas, No. 1716

PROFESSIONAL LICENSES

Licensed Water Well Driller - Texas No. 2399

Licensed Water Well Driller - Colorado No. 1187

Operator, Storm Water Runoff Control in the State of Michigan- No. 01650

Underground Storage Tank Professional in the State of Michigan- No. 295

PROFILE OF PROFESSIONAL ACTIVITIES:

- Construction Oversight
  - Demolition of Chrysler Old Mac Stamping Plant, Detroit, MI

- Elf Atochem Site, Riverview, MI
  - dewatering of one-third a mile of stream bed
  - in situ stabilization of stream sediments
  - excavation of stabilized sediments to landfill
- Willow Run Creek TSCA Site, Ypsilanti, MI, Project Value: $35 Million
  - 10-acre landfill excavation and construction
  - remediation of 2 ponds, 1 lagoon and several creek area locations
  - in situ stabilization and excavation of sediments
  - placement and compaction in landfill
  - leachate and leakage central system installations
  - waste treatment plant operations
  - capping and completion of landfill
  - post construction monitoring
- Commercial Oil Services Site, Oregon, OH, Project Value: $15 Million
  - remediation of wastes oil recycling facility consisting of seven sludge ponds
  - construction of 5-acre landfill
  - removal and treatment of on-site water
  - in situ blending of sludges with partially treated material
  - construction of stabilization equipment including pug mill
  - construction of CATOX Air Pollution Control System
  - placement and compaction in landfill
  - capping and completion of landfill
  - backfilling emptied sludge lagoons
  - leachate collection and treatment systems
  - post construction monitoring

- Manager of regional field services
- Design and implementation of major remedial investigations
- Design and implementation of remedial actions:
  - groundwater interceptor trenches
  - slurry walls
  - groundwater extraction systems
  - sheet pile isolation walls
  - bank stabilization
  - in situ solidification
  - low temperature thermal extraction
  - dig and haul
  - vapor extraction
  - hydraulic groundwater barrier

  - leaching-capture system
  - pump and treat
- Underground storage tank investigations and removal
- Relocation of municipal groundwater source
- Exploration drilling, monitor well construction, and testing
- Dewatering system design
- Demolition of contaminated industrial plant process areas
- Design and construction of large diameter collector well to capture chemicals in low permeability aquifers
- Wrote standard operating procedures (SOPs) and quality assurance/quality control (QA/QC) documents for field and laboratory activities
- Conduct baseline studies in ground and surface water to permit and design water handling for lignite, coal, gold, copper, molybdenum, and oil shale mines in several midwest and western states
- Conducted ground and surface water research and service activities throughout the state of Illinois
- Conducted field investigations in preparation for design of federal interstate highway bridges in the state of Illinois

PUBLICATIONS:

- Baker, W.H., Jr., 1972. Groundwater levels and pumpage in East St. Louis area, Illinois.
- 1967 - 1971. Illinois State Water Survey Circular 112.
- Sasman, R.T., W.H. Baker, Jr., and W.P. Patzer. Water level decline and pumpage during 1961 in deep wells in the Chicago region, Illinois. Illinois State Water Survey Circular 85.
- Sasman, R.T., W.H. Baker, Jr. 1966. Groundwater pumpage in Northwestern Illinois through 1963. Illinois State Water Survey Report of Investigation 52.

Note:

Familiar with Butterworth Landfill Site, Grand Rapids, MI from a previous association

WAYNE G. BAUMAN

EDUCATION

B.Sc.	Industrial Engineering, Minor Mathematics, Western Michigan University, 1986
Other Courses	Completing course work in the Engineering Management Masters program at Western Michigan University

EMPLOYMENT

2000-Present	Project Manager CRA Services, a Construction Division of Conestoga-Rovers & Associates, Kalamazoo, MI
1998-00	Project Manager CRA Services, Kalamazoo, MI
1996-98	General Manager, Business Development, BK Environmental, division of TreaTek-CRA Company, Kalamazoo, MI
1992-96	President, Bauman-Krueger Contractors, Inc., Kalamazoo, MI
1990-92	Project Manager, ETG Environmental, (formerly MWR, Inc.), Lansing, MI
1990-92	Owner, Bauman Builders (residential/commercial building), Delton, MI
1987-90	Industrial Engineer, Viking Corporation, Hastings, MI

AFFILIATIONS

Past Board Member for the Michigan Environmental Consultants and Contractors Association

Delivered a presentation to the Michigan Chapter of the National Groundwater Association on the topic of "Soil Vapor Extraction and Groundwater Sparging, Techniques, Applications and Management"

Delivered numerous presentations to Western Michigan University Senior Hydrogeology Classes regarding remediation technologies and applications

LICENSES AND CERTIFICATIONS

- Michigan licensed builder
- 40-hour hazardous waste operations and emergency response training
- OSHA certified competent construction supervisor

PROFILE OF PROFESSIONAL ACTIVITIES

- Project Manager for remedial activities at an active automotive manufacturing facility. Tasks include sheet piling, lagoon sediment stabilization for PCBs, multi-layer cap, groundwater extraction, lagoon liner installation, and miscellaneous concrete work. Value $8 million. Bay City, MI

- Project Manager for remedial activities to isolate and immobilize PCB contaminated DNAPL within a closed landfill. Tasks included watertight sheet piling, permeation grouting, and capping. Value $1.3 million. Bay City, MI
- Project Manager for Health and Safety activities related to remedial activities and Brownfield Redevelopment of a Superfund site. The project involved excavating, consolidating, and capping lead contaminated soil.
- Project Manager for plant decommissioning activities including UST removal, sewer cleaning, fluids disposal, and demolition. Dayton, OH
- Project Manager for the construction of a 1,000 lf slurry wall. The slurry wall was used to isolate the basement of a new hotel and eliminate contaminated groundwater from entering the basement. Site was the largest State of Michigan funded Brownfield project. Owosso, MI
- Project Manager for UST removals and upgrades in Michigan and Ohio
- Project Manager for landfill cap inspection and maintenance for a 40-acre landfill. Activities include semi-annual inspection of all vents, cap, stormwater controls; annual cutting; preparation of scope and administration of cap repairs. Plainwell, MI
- Project Manager for the design, construction, operation, and decommissioning of a soil and groundwater remediation system. Technologies consisted of soil vapor extraction and groundwater pumping. Treatment technologies consisted of air stripping with a packed tower, ozone, carbon adsorption. El Paso, TX
- Project manager for the design, construction, and operation of a soil and groundwater remediation system. Technologies consisted of soil vapor extraction using stratified wells to a depth of 80 feet, sparging using a combination of nitrogen and oxygen and groundwater removal with packed tower air stripping. Albuquerque, NM
- Project Manager for the design, construction, operation, and reporting for a pilot-scale soil vapor extraction and site capping system. System was designed to remove both volatile and semi-volatile organic compounds. Application was in clay soils and within a series of abandoned building foundations. Elizabeth, NJ
- Project Manager for the design, construction and operation of a groundwater sparging system. The system was designed to act as barrier and reduce the level of DCE and DCA migrating from an existing landfill to an adjacent Superfund site. Lansing, MI
- Project Manager/Construction Supervisor for numerous remediation projects ranging in size from $50,000 to $1 Million throughout the United States
- Project Manager for $2 Million expansion of an existing manufacturing facility. Included was the demolition of an asbestos lined fire test building; removal and disposal of soil mixed with foundry sand and scraps; stormwater management and permitting; and general commercial construction
- Managed an in-plant metal working fluid system. Analyzed for aerobic/biological content; sampled and analyzed waste prior to disposal; investigated, purchased and used additives to extend the life and quality of fluids

PETER C. MALTESE, B.Sc.

EDUCATION

B.S.	Civil Engineering, Pennsylvania State University, 1987
Other Courses:	OSHA 40-Hour Hazardous Waste Operations with Annual 8-Hour Refresher Training
	OSHA 8-Hour Supervisory Training
	FEMA Certificate for Hazardous Response

EMPLOYMENT

2000-Present	Project Manager CRA Services, a Construction Division of Conestoga-Rovers & Associates
1998-2000	Project Manager, Geo-Con, Inc.
1997-1998	Site Manager, Geo-Con, Inc.
1996-1997	Resource Manager, Geo-Con, Inc.
1995-1996	Construction Manager, Geo-Con, Inc.
1990-1995	Project Superintendent, Geo-Con, Inc.
1988-1990	Field Engineer, Geo-Con, Inc.

AFFILIATIONS

Associate Member of American Society of Civil Engineers (ASCE)

PROFILE OF PROFESSIONAL ACTIVITIES AND EXPERIENCE

Project Manager:

- Project Manager for a design-build project, which included the remediation and closure of an inactive 11-acre industrial and municipal waste landfill. The main components of the remedial action included removal of existing residential/commercial structures, capping the landfill, installing a gas collection system, and a long-term monitoring plan. Specific industrial wastes, within the landfill limits, were excavated and relocated to an onsite containment cell prior to final capping. The landfill cap consisted of GCL, HDPE liner, geocomposite, cover soil and low-permeability clay in some areas, and vegetative cover soil.
- Project Manager for the construction of a permanent excavation support system. The system was constructed using deep soil mixing (DSM) to allow for excavation of a cut and cover highway tunnel underpass through a historic district. The soil mixing blended the in situ soils with a cement grout to form a continuous soil-cement wall. Steel beams were placed into the soilcrete, prior to the initial set, to provide added reinforcement. The walls were constructed so that the minimum effective wall width was 24 inches. The project consisted of 1,220 lineal feet of soil-mixed wall to depths of 40 feet. Average 28-day strengths of the soilcrete were 614 psi.

- Project Manager for installation of an interception/extraction trench using the Bio-Polymer slurry method. The trench included a flexible HDPE barrier to limit infiltration from one side of the trench. Collection sumps, along with associated piping, were installed in the trench to transfer contaminated groundwater to an onsite treatment facility. The trench was constructed to a depth of 24 feet and was backfilled with a porous, pea gravel.
- Project Manager for the underpinning of a historic landmark. The project owner designed an addition to the existing building, which required a deep foundation to support the new structure. The project team worked with the designers and developed the specifications for a shallow soil mixing (SSM) process that used cement grout in conjunction with high pressure to treat the site soils and create a soilcrete block partially under and adjacent to the existing structure. The site soils were excavated alongside the soilcrete walls and the new building was built without disturbance to the existing structure.
- Project Manager for construction of an excavation support system for a tunnel pump station. The project used a large diameter auger in combination with high pressure grout to form a continuous ring of soil-cement to allow for future excavation to a depth of 45 feet. A bottom plug was also mixed to prevent upward soil movement during excavation.
- Project Manager for remedial activities to immobilize PCB contaminated DNAPL within a closed landfill. Permeation grouting was used to treat a zone within an area isolated by sheet piling. A cement grout was injected under pressure to fill voids within the area and prevent migration of contaminated groundwater.
- Project Manager for the construction of a drainage trench using the Bio-Polymer slurry method. This project consisted of 250 lf of trench, which contained a central sump along with cleanouts and collection piping. The porous backfill was surrounded by a filter fabric envelope. The drainage trench was used to recover a plume of contaminated groundwater, which had migrated off the property.
- Construction Manager for installation of approximately 8 miles of slurry cutoff wall around the perimeter of two active sanitary landfills within the Fresh Kills Landfill Complex in Staten Island, New York. The cutoff walls consisted of approximately 776,000 vsf of soil-bentonite and 529,000 vsf of cement-bentonite to control the leaching of contaminated groundwater into nearby waterways. The cutoff walls were installed at depths ranging from 20 to 62 feet.
- Project Manager for a project using a cement grout mix to stabilize dredge spoils. The grout was mixed using a small diameter auger to create a homogeneous mixture. After the material cured, a clay cap was installed over the stabilized material.
- Project Superintendent for closure of a 6-acre sludge pond. This project included a jet grout wall, a cement-bentonite slurry cutoff wall, sludge solidification using soil mixing techniques, HDPE liner, and final cap.
- Project Superintendent for a project using Thermally Enhanced Vapor Extraction (TEVE) in conjunction with soil mixing to remove VOCs from the soil. The project was successfully performed at a DOE facility with stringent removal guidelines.
- Mr. Maltese has been involved with over 50 slurry wall projects. His various roles on these projects has given him experience with several types of cutoff walls and drainage trenches, including soil-bentonite, cement-bentonite, cement-attapulgate, plastic concrete, and soil-cement-bentonite cutoff walls, as well as Bio-Polymer drainage trenches.

PUBLICATIONS

- Kenneth B. Andromalos, P.E., Kenneth L. Fishman, Ph.D., P.E., Peter C. Maltese, Donald R. McMahon, "A DSM Wall for Excavation Support", *Proceedings for a Geo-Institute Conference, Foundations and Ground Improvement,* Virginia Tech, Virginia, June 2001.
- Peter C. Maltese, Robert M. Schindler, "HDPE Curtain Wall with Sheetpile Tie-in on Both Ends", *Proceedings of the International Containment Conference,* St. Petersburg, FL, February 1997.

FRANK A. ROVERS, M.A.Sc., P. Eng.

EDUCATION

B.A.Sc.	University of Waterloo, 1970
M.A.Sc.	University of Waterloo, 1972

EMPLOYMENT

2000-Present	Conestoga-Rovers & Associates Chairman of Board
1981-00	Conestoga-Rovers & Associates Limited (President)
1984-00	Conestoga-Rovers & Associates, Inc. (President)
1976-81	Conestoga-Rovers & Associates Limited (Senior Partner)
1976-86	President, Frank A. Rovers & Associates Limited (President)
1975-76	Lecturer, University of Ottawa
1973-75	Senior Consulting Engineer, Hydrology Consultants Limited
1970-75	Lecturer and Teaching Assistant, University of Waterloo
1970	Waterloo Research Institute

HONOURS & AWARDS

Award of Excellence Engineering Medal - Management Category, from Professional Engineers of Ontario, 1999

Faculty of Engineering Alumni Achievement Medal, University of Waterloo, 1994

AFFILIATIONS

Association of Professional Engineers of Ontario

Canadian Society of Civil Engineers

Pollution Control Association of Ontario (WPCF)

American Water Works Association

Ontario Waste Management Association (National Solid Wastes Management Association)

PROFILE OF PROFESSIONAL ACTIVITIES

- Planning and design of regional waste management systems
- Design of solid waste disposal sites

- Design of hazardous waste disposal sites
- Design of liquid waste disposal systems
- Design and supervision of remedial programs at existing and former waste disposal sites
- Groundwater availability studies
- Design of water supply systems
- Engineering management of waste disposal operations
- Environmental impact statements
- Expert testimony at Environmental Assessment Board Hearings and Ontario Municipal Board Hearings
- Principal investigator on numerous research studies
- Numerous lectures and papers presented across Canada and the U.S.A.
- Chairman of International seminars to formulate guidelines for waste disposal on land practices

PUBLICATIONS

Books Published:

- Statistical Procedures for Analysis of Environmental Monitoring Data and Risk Assessment, Prentice-Hall Publishing Co. Inc., Englewood Cliffs, New Jersey (with E. McBean)
- Solid Waste Landfill Engineering and Design, Prentice-Hall Publishing Co. Inc., Englewood Cliffs, New Jersey (with E. McBean)
- Constructed Wetlands for Treating Landfill Leachate, Lewis Publishers, Ann Arbor, Michigan, 1998

Published Refereed Papers:

- "Gas Production During Refuse Decomposition", *Water, Air and Soil Pollution*, Vol. 2, No. 4, D. Reidel Publishing Company, Dordrecht, Holland, October 1973 (with G.J. Farquhar), pp. 483-495
- "Infiltration and Landfill Behaviour", *Journal of the Environmental Engineering Division, ASCE* 99 EE5, October 1973 (with G.J. Farquhar)
- "Average pH", Communication, *Journal Water Pollution Control Federation*, 49, February 1976 (with A.C. Middleton)
- "Methane Gas Utilization from a Landfill Site", *Journal of the Energy Division, ASCE*, Vol. 107, May 1981 (with A.J. Crutcher and E.A. McBean), pp. 95-102
- "The Impact of Gas Extraction on Landfill-Generated Methane Gas Levels", *Water, Air and Soil Pollution*, Vol. 16, 1981, pg. 55-66 (with A.J. Crutcher and E.A. McBean)
- "Significance Testing for Impact Evaluation", *Ground Water Monitoring Review*, July 1981 (with E.A. McBean), pp. 39-43
- "Leachate Collection Design for Containment Landfills", *Journal of the Environmental Engineering Division, ASCE*, Vol. 108, No. EE1, February 1982 (with E.A. McBean, R. Poland and A.J. Crutcher), pp. 204-209
- "Temperature as an Indicator of Landfill Behavior", *Water, Air and Soil Pollution*, Vol. 17, 1982, (with E.A. McBean and A.J. Crutcher), pp. 213-223
- "Influence Assessment of Landfill Gas Pumping", *Water, Air and Soil Pollution*, Vol. 22, 1984, pg. 227-239, (with E.A. McBean and A.J. Crutcher)

- "Alternatives for Handling Detection Limit Data in Impact Assessments", *Ground Water Monitoring Review*, Spring 1984, (with E.A. McBean), pp. 42-44
- "Alternatives for Assessing Significance of Changes in Concentration Levels", *Ground Water Monitoring Review*, Summer 1984, pg. 39-41 (with E.A. McBean)
- "Analysis of Variances as Determined from Replicates Versus Successive Sampling", *Ground Water Monitoring Review*, Summer 1985 pg. 61-64 (with E.A. McBean)
- "Statistical Evaluation of Performance Monitoring to Ensure Acceptable Risk Exposure of Remediated Landfills", in *Environmental Health Risks: Assessment and Management*, R.S. McColl, University of Waterloo Press, Waterloo, Ontario, 1987 (with E.A. McBean)
- "A Critical Examination of Approximations Implicit in Cochran's Procedure" *Groundwater Monitoring Review*, Winter 1988 (with E.A. McBean and M. Kompter)
- "Flexible Selection of Statistical Discrimination Tests for Field-Monitored Data" *Groundwater and Vadose Zone Monitoring, ASTM STP 1053*, 1990, pp. 256-265 (with E.A. McBean)
- "Evaluation of Collection Well Parameters for DNAPL", *ASCE - Journal of the Environmental Engineering Division*, Vol. 118, No. 2, Mar/Apr 1992, pp. 183-195 (with K. Schmidtke and E. McBean)
- "Risk Assessment Using Relatively Simple Mathematical Models" in *Risk Assessment for Groundwater Pollution Control* ed. by W. McTernan and E. Kaplan, ASCE Monograph, (with K. Schmidtke and E. McBean), 1990
- "Estimation of the Probability of Exceedance of Contaminant Concentrations", *Groundwater Monitoring Review*, Winter 1992, pp. 115-119 (with E. McBean)
- "Utility of Risk-Time Curves in Selecting Remediation Alternatives", *Journal of Waste Management & Research*, Vol. 13, 1995, pp. 167-174 (with E. McBean)
- "Comparison of Alternative Remediation Approaches Utilizing Time-Risk curves", *Remediation of Soil and Groundwater Opportunities in Eastern Europe*, NATO ASI Series 2 - Environment - Vol. 17, edited by E.A. McBean, J. Balek and B. Clegg, pp. 323-328 (with E.A. McBean), 1996
- "Landfill Leachate Characteristics as Inputs for the Design of Wetlands Used as Treatment Systems", *Constructed Wetlands for the Treatment of Landfill Leachate"*, edited by , George Mulamoottil, E.A. McBean, Frank Rovers, 1998
- "Sequence Visualization of Natural Attenuation Trends at Hill Air Force Base, Utah", *Battelle Memorial Institute Bioremediation Journal*, 4(3), pp. 379-393, (with G. Carey, T. Wiedemeir, P. Van Geel, E. McBean, R. Murphy), 1999
- "Monitoring of Contaminants & Risk-Based Corrective Action", Chapter 28, *Geotechnical and Geoenvironmental Engineering Handbook* (ed. Kerry Rowe), McGraw-Hill, (with E. McBean, K. Schmidtke, W. Dyck), 2001

Papers Presented and Published in Conference Proceedings:

- "Evaluating Contaminant Attenuation in the Soil to Improve Landfill Selection and Design", *Proceedings of the International Conference on Land for Waste Management*, National Research Council of Canada, Ottawa, October 1-3, 1973 (with G.J. Farquhar)
- "Landfill Contaminant Flux - Surface and Subsurface Behaviour" presented at the *21st Ontario Industrial Waste Conference, June 23-26, 1974*, Toronto (with G.J. Farquhar and J.P. Nunan).
- "Some Implications of Lining Landfill Sites" presented at *3rd Annual Conference of Environmental Earth Sciences and Engineering, November 1974*, St. Catharines, Ontario (with B.W. Beatty and J.P. Nunan)
- "Contaminant Movement from the St. Agatha Sanitary Landfill" in *Field Excursion Guidebook, Part C, Environmental Geology - Geological Association of Canada, 1975*

- "Leachate Attenuation in Undisturbed and Remoulded Soils" presented at EPA sponsored Conference entitled "*Gas and Leachate from Landfills - Formation, Collection and Treatment*" at the State University of New Jersey, March 25 and 26, 1975 (with G.J. Farquhar)
- "Contaminant Attenuation - Dispersed Soil Studies" presented at *Hazardous Research Symposium: Residual Movement by Land Disposal, February 2 and 3, 1976*, Tucson, Arizona (with H. Mooij and G.J. Farquhar)
- "Preliminary Investigations - Pesticide Migration from Waste Disposal Sites" presented at the *1976 Research Seminar January 14-15 1976* sponsored by the Ontario Pesticides Advisory Committee, January 14 and 15, 1976, Toronto, Ontario (with A. Twefik)
- "Landfill Site Selection", presented at the *16th Annual International Seminar and Equipment Show, Governmental Refuse Collection and Disposal Association*, Calgary, Alberta, August 1978 (with H. Mooij and A.J. Crutcher)
- "The Design of a Natural Leachate Attenuation System", presented at *1st Annual Conference of Applied Research and Practice on Municipal and Industrial Waste*, Madison Wisconsin, September 1978 (with A.J. Crutcher)
- "Hazardous Waste Leachate Treatment - State of the Art Review", presented at the *Engineering Summer Conferences - Hazardous Waste Management*, July 28 - 30, 1980, The University of Michigan (with A. Van Norman)
- "Safety Procedures for Hazardous Waste Remedial Works", presented at *2nd Annual Conference of Applied Research and Practice on Municipal and Industrial Waste*, Madison Wisconsin, September 1979 (with J. Slack, D.H. Haycock, A.J. Crutcher, W.J. McDougall)
- "Landfilling of Hazardous Wastes", presented at the *Hazardous Waste Management Seminar*, October 25 - 28, 1978, Toronto, Ontario
- "Hazardous Waste Disposal: Love Canal", presented at *Hazardous Waste Management and Disposal Seminar*, State University of New York at Buffalo, February 23, 1979
- "Extraction and Utilization of Unprocessed Landfill Generated Methane Gas", presented at *AGU Spring Annual Meeting*, May 1980, Toronto, Ontario, (with A.J. Crutcher)
- "Remedial Site Containment", presented at *Society for Occupational and Environmental Health Conference on Hazardous Waste*, December 1980, Washington, D.C. (with M. Jones)
- "Remedial Actions at Problem Landfill Sites", paper presented at *Pollution Control Association of Ontario Seminar "Solutions for Industrial Waste Disposal"* at Hamilton, Ontario, March 1981, (with D.H. Haycock)
- "An Assessment of Alternatives for Analysis of Monitoring Program Data for Solid and Hazardous Waste Disposal Sites", presented at *Groundwater Monitoring*, Columbus, Ohio, May 29-30, 1981, (with E.A. McBean)
- "Groundwater Data Analysis and Interpretation", presented at *Central Lakes States Regional Meeting, National Council for Air and Stream Improvement Inc.*, Chicago, Illinois, September 23, 1981, (with E.A. McBean)
- "Liners for Leachate Control", presented at *Sanitary Landfill Gas and Leachate Management Seminar*, University of Wisconsin-Extension, Madison, Wisconsin, November 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990
- "Monitoring an Implemented Remedial Action", presented at the *7th Annual Madison Waste Conference*, University of Wisconsin, Extension, Madison, Wisconsin, September 11-12, 1984, (with E.A. McBean)
- "Statistical Evaluation of Performance Monitoring to Ensure Acceptable Risk Exposure of Remediated Landfills", presented at the *Symposium of Environmental Health Risks: Assessment and Management*, Waterloo, Ontario, May 29-31, 1985 (with E.A. McBean)

- "Safety and Health Programs for Remediation of Past Disposal Practices", presented at the *Symposium on Environmental Health Risks: Assessment and Management*, Waterloo, Ontario, May 29-31, 1985, (with E.A. McBean)
- "Flow and Sensitivity Analyses at a Hazardous Waste Landfill", presented at *Practical Applications of Groundwater Models*, Columbus, Ohio, August 19-20, 1985 (with J. Sykes, K. Schmidtke and E. McBean)
- "Uses and Pitfalls of Statistical Discrimination Techniques in Assessment of Remediation Effectiveness at Landfills", presented at the *7th National Conference on Waste Management in Canada*, Ottawa, November 4-6, 1985, (with E.A. McBean)
- "Drawdown Impacts in Dense Non-Aqueous Phase Liquids", presented at *First National Outdoor Action Conference on Aquifer Restoration, Groundwater Monitoring*, Las Vegas, May 14-17, 1987 (with K. Schmidtke and E. McBean)
- "Statistical Discrimination Testing of Field-Monitored Data", presented at *Symposium on Standards Development for Ground Water and Vadose Zone Monitoring Investigations*, American Society for Testing Materials, Albuquerque, New Mexico, January 1988 (with E. McBean)
- "Determining Aquifer Characteristics from Tidal Fluctuation Data", presented at *International Conference on Groundwater Resources Management*, Asian Institute of Technology, Bangkok, Thailand, November 1990 (with E. McBean, K. Schmidtke and M. Mateyk)
- "Reliability-Based Design for Leachate Collection Systems", presented at *Sardinia '93, Fourth International Landfill Symposium*, Sardinia, Italy, October 1993 (with E. McBean and F. Mosher)
- "Examining Tradeoffs Between Expenditures and Exposure Point Risks", presented at *University Consortium Solvents-in-Groundwater Meeting*, Queen's University, Kingston, Ontario, October 1-3, 1996 (with E.A. McBean)
- "Multiple Lines of Evidence for Evaluating Intrinsic Remediation at a Landfill Site", presented at *Nineteenth International Madison Waste Conference*, University of Wisconsin-Madison, September 25-26, 1996 (with G. Cary, M. Mateyk, E. McBean, G. Turchan, J. Campbell)
- "Application of an Innovative Visualization Method for Demonstrating Intrinsic Remediation at a Landfill Superfund Site", presented at *Petroleum Hydrocarbons & Organic Chemicals in Ground Water: Prevention, Detection, and Remediation Conference and Exposition*, Houston, Texas, Nov. 13-15, 1996 (with G. Carey, M. Mateyk, E. McBean, G. Turchan, J. Campbell)
- "Modeling Landfill Cap Influence on Natural Attenuation", presented at *Sixth International Landfill Symposium*, Cagliari, Sardinia, Italy, October 13-17, 1997.(with G. Carey, P. Van Geel, E. McBean, G. Turchan)
- "Chapter 13, Time-Risk Methodologies for Examining Remediation Technologies for Waste Contamination Sites", presented at the *NATO Advanced Research Workshop entitled "Decommissioned Submarines in the Russian Northwest, Assessing and Eliminating Risks", Kirkenes, Norway, June 24-28, 1996* (with E.A. McBean and Darrell E. O'Donnell)
- "Statistical Evaluation of Performance Monitoring to Ensure Acceptable Risk Exposure of Remediated Landfills", (with E.A. McBean) Chapter in Book "*Environmental Health Risks: Assessment and Management*, 1987 (editor, R. Stephen McColl)
- "Coupled Biodegradation - Redox Modeling to Simulate Natural Attenuation Processes at the Plattsburgh Air Force Base (New York)", presented at *MODFLOW'98, Golden, Colorado, October 5-7, 1998* (with Grant R. Carey, Paul J. VanGeel, J. Richard Murphy, and Edward A. McBean)
- "An Integrated Landfill Modeling System for Evaluating Remediation Alternatives", presented at the *First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 18-21, 1998* (with Grant R. Carey, Paul J. VanGeel, and Edward A. McBean)

- "Full-Scale Field Application of a Coupled Biodegradation-Redox Model (BioRedox)", presented at the *First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 18-21, 1998* (with Grant R. Carey, Paul J. VanGeel, and Edward A. McBean)

Published Reports:

- "Final Report - Sanitary Landfill Study, Vol. I - Field Studies on Groundwater Contamination from Sanitary Landfills, 1972", prepared for the Ontario Department of Health and the Grand River Conservation Authority, WR1 Project No. 8083-4 (with G.J. Farquhar, R.N. Farvolden, H.M. Hill)
- "Final Report - Sanitary Landfill Study, Vol. II - Effect of Season on Landfill Leachate and Gas Production, 1972", prepared for the Ontario Department of Health and the Grand River Conservation Authority, WR1 Project No. 8083-4 (with G.J. Farquhar)
- "Final Report - Sanitary Landfill Study, Vol. IV - Guidelines to Landfill Location and Management for Water Pollution Control, 1975", prepared for the Ontario Department of Health and the Grand River Conservation Authority, WR1 Project No. 8083-4 (with G.J. Farquhar)
- "Liquid Industrial Waste Attenuation in Soil, 1975", prepared for Environment Canada, Contract #0SS4-0288 (with G.J. Farquhar)
- "Recommended Groundwater and Soil Sampling Procedures" - Proceedings of an International Seminar: Solid Waste Management Branch Report EPS-4EC-76-7, Environmental Conservation Directorate, June 1976 (with H. Mooij)
- "Recommended Procedures for Landfill Monitoring Program Design and Implementation", Waste Management Branch EPS 4 EC-77-3, Environmental Conservation Directorate, May 1977 (with H. Mooij, A. Sobanski)
- "Procedures for Landfill Gas Monitoring and Control", Waste Management Branch EPS 4-EC-77-4 Environmental Impact Control Directorate, October 1977 (with H. Mooij and J.J. Tremblay)
- "Contaminant Migration in Three Great Lakes Drainage Basins - Mississauga Landfill Site", Ecological Protection Branch, Department of the Environment, DSS#0Z22.KE204-6-EP01, 1977 (with J.F. Sykes, G.J. Farquhar and A.J. Crutcher)
- "Contaminant Migration in Three Great Lakes Drainage Basins" Ecological Protection Branch, Department of the Environment, DSS# 0255.KE204-6-EP01 1977. (with J.F. Sykes, G.J. Farquhar, and A.J. Crutcher)
- "Small Municipal Waste Disposal Site Selection", Fisheries & Environment Canada DSS File No. 02SS-KE 204-6-EP 45, 1978. (with A.J. Crutcher)
- "Groundwater Contaminant Migration Modeling" Waste Management Branch, Environmental Impact Control Directorate, EPS3-EC-79-10, November 1979 (with J.F. Sykes, G.J. Farquhar, and A.J. Crutcher)
- "Gas Recovery and Utilization from a Municipal Waste Disposal Site - Vol. 1 - Final Report", Environment Canada, Technical Development Report EPS 4-EC-81-2, November 1981 (with A.J. Crutcher)

EDWARD A. MCBEAN, Ph.D., P. Eng., P.E.

EDUCATION

Ph.D.	Massachusetts Institute of Technology (1973)
C.E.	Civil Engineer's Degree, Massachusetts Institute of Technology (1972)
S. M.	Massachusetts Institute of Technology (1970)
B.A.Sc.	University of British Columbia (1968)

EMPLOYMENT

- Conestoga-Rovers & Associates
  - Vice-President, 1999 - present
  - Associate, 1995-1999
- CRA Engineering Inc., President, 1996 - present
- Conestoga-Rovers & Associates, Senior Technical Advisor, 1977 - 1995
- University of Waterloo, Department of Civil Engineering
  - Professor, Department of Civil Engineering, 1981 - 1991, 1992 - 1995
  - Acting Director, Institute for Risk Research, 1993
  - Associate Professor, Department of Civil Engineering, July 1977 - 1981
  - Assistant Professor, Department of Civil Engineering and School of Urban and Regional Planning, July 1974 - July 1977
- University of California at Davis
  - Professor of Water Resources, Land, Air and Water Resources, 1991 - 1992
- Cornell University
  - Water Resources and Marine Sciences Centre, Research Associate, February 1973 - June 1974
- Meta Systems, Inc., Cambridge, Massachusetts, Project Engineer, June 1972 - June 1974
- Acres Consulting Services, Niagara Falls, Canada, Engineer, June 1970 - September 1971
- Massachusetts Institute of Technology, Department of Civil Engineering
  - Research Assistant, September 1968 - June 1970 and September 1971 - June 1972
  - Graduate Assistant, June 1972 - September 1972
  - Visiting Engineer, June 1973 - June 1974

PROFESSIONAL ENGINEERING MEMBERSHIPS

Location	*Number*	*Location*	*Number*
Alabama	Member 23853	Minnesota	Member 24650
Alberta	Member M60957	Mississippi	Member 12994
Arizona	Member 30613	Missouri	Member EN028155
British Columbia	Member 22894	Montana	Member 13713PE
California	Member C053443	Nebraska	Member E-8563

Location	*Number*	*Location*	*Number*
Colorado	Member 34874	Nevada	Member 013788
Connecticut	Member 19686	New Hampshire	Member 10292
Delaware	Member 10873	New Jersey	Member GE40243
Florida	Member PE-0050906	North Carolina	Member 022262
Georgia	Member 23119	Ontario	Member 2987 3015
Hawaii	Member PE9663 (CE)	Ohio	Member E-60567
Illinois	Member O62-050693	Oregon	Member 18775PE
Indiana	Member PE19600326	Pennsylvania	Member PE-051217-E
Iowa	Member 13715	South Carolina	Member 18539
Maine	Member 9577	Tennessee	Member 103517
Kansas	Member 14269	Utah	Member 3098848-2202
Kentucky	Member 19379	Vermont	Member 7500
Louisiana	Member 26904	Virginia	Member 0402 032964
Maine	Member 9577	Washington	Member 33522
Maryland	Member 23314	West Virginia	Member 13921
Massachusetts	Member 39610	Wisconsin	Member 31739
Michigan	Member 42260		

AFFILIATIONS

Member, Landfill Gas Industry Alliance, an assembly of Canadian Industry Stakeholders in Landfill Gas Industry

Associate Editor, American Society of Civil Engineers, Journal of the Environmental Engineering Division, 1996 - 1998

Associate Editor, Canadian Journal of Civil Engineering, 1989 - 1997

Member, American Geophysical Union

Life Member, Indian Association of Hydrologists

Editorial Board Member, Journal of Advances in Environmental Research, 1996 - present

Member, Board of Directors, Waterloo Centre for Groundwater Research, 1993 - 1996

Member, Institute for Risk Research, University of Waterloo, 1983 - present

Associate Editor, Water Resources Research, 1979 - 1987

UNESCO/UNDP consultant in water quality modeling in India, 1984 and 1993

Director, NATO Advanced Research Workshop on "Remediation of Soil and Groundwater as a Technical, Institutional and Socio-Economic Problem: Opportunities in Eastern Europe; Czech Republic, November 1995

Visiting Erskine Fellow, University of Canterbury, New Zealand, 2001

International Editorial Committee, Encyclopedia of Life Support Systems, 1995 - present

INTERNATIONAL EXPERIENCE

United Kingdom	Russia & USSR	Hungary
Germany	Hong Kong	Denmark
India	Italy	Netherlands
China	Sweden	Japan
Czech Republic	Switzerland	Thailand
Bahamas	France	Slovakia
Qatar	Colombia	St. Kitts-Nevis
Dubai	Barbados	Norway
Grenada	St. Lucia	Abu Dhabi
Malaysia	Nigeria	Saudi Arabia
Argentina	Pakistan	Ecuador
Indonesia	Austria	Mexico
Spain	Portugal	Egypt
Latvia	Uruguay	Greece
New Zealand	Australia	

AWARDS

Recipient, Gold Medal from the Institution of Engineers (India), The Nawab Zain Yar Jung Bahadur Memorial Gold Medal for 1986-87

EXPERIENCE

Examples of Experience in Environmental Assessment and Hazardous Waste Management

- Examples of Design Aspects Associated with Landfills:
  - design of leachate collection system and surface runoff modeling for the Keele Valley Landfill, Vaughan, Ontario. Assessment of "piggybacking" of landfill to gain additional disposal space
  - examination of leachate mounding at Brock West (Ontario) and characterized the efficiency of the leachate collection system and degree of hydraulic containment. Examined implications on landfill gas generation rates and potentials for gas recovery
  - examination of landfill gas generation and landfill gas pumping assessments for Erb St. Landfill (Ontario). Modeling of water balance and groundwater plume migration, and involved in the design of the gas utilization system
  - project manager for Azusa Landfill (California) assessment including water balance modeling (including influence of gas extraction system), potential for gas migration to have caused groundwater contamination, and assessment of leachate quantities impacting groundwater aquifer. Review of upgradient/downgradient monitoring data and potential remediation alternatives. Seismic assessments completed. Presentations at Regional Water Quality Control Board
  - statistical analyses of on-site and off-site groundwater monitoring at the Operating Industries Landfill in Monterey Park, California. Modeling of off-site groundwater migration
  - computer modeling and assessment of off-site monitoring data for LaBounty Landfill (Iowa). Development of site remediation plans for containment of leachate

- water balance modeling and design of surface cap for Peterborough Landfill (Ontario). Assessment of implications of "piggybacking" of landfill
- gas migration modeling for hazard characterization at Port Mann Landfill (B.C.)
- assessment of input quantities from PRPs for Fresh Kills Landfill (New York)
- assessment of liner constructability and resulting integrity for Willow Run Landfill (Michigan)
- examined solidification issues for specific wastes for G&H Landfill (Michigan)
- design of monitoring system and preparation of technical analyses for quantifying nonpoint source contributions for County Line Landfill (Ohio)
- water balance modeling for Helen Kramer Landfill including implications of 100-year rainfall event
- technical design of landfill cap for Hardemann County (Tennessee) and constructability/staging issues
- design of surface cap for Laurel Park Landfill (Connecticut). Erosion controls and assessment of number of berms for very long slopes were particular issues
- assessment of leachate and gas migration pathways for off-site migration of VOCs at Puente Hills Landfill (California). Presentation to State Water Quality Control Board in California
- technical assessment of disposal volumes, leachate implications and economic implications of early closure of Lee County Landfill and accelerated opening of Hendry County Landfill, Florida
- computer modeling, design of monitoring system and statistical evaluation program for Metamora Landfill, Michigan for intrinsic remediation
- examination of leachate quantities and qualities and implications for leachate recycle for Green Lane Landfill (Ontario)
- assessment of off-site migration opportunities for Hyde Park Landfill, New York
- statistical analyses of off-site monitoring data and design/execution of biological indicator procedures for North Hollywood Dump (Tennessee)
- computer modeling and statistical interpretation of gas migration data for Ottawa Street Landfill (Ontario). Execution of pumping tests for gas extraction and design of gas utilization system
- landfill gas pumping and utilization project for purposes of energy recovery for St. Thomas Landfill (Ontario)
- water balance modeling and groundwater contamination migration modeling for Owens-Illinois Landfill (Wisconsin)
- landfill closure and post-closure cost estimates, John Sexton Sand & Gravel Corp., Illinois, Wisconsin, Pennsylvania, Louisiana and Mississippi
- water balance modeling, slope stability considerations, nonpoint source loading assessments, and assessment of remediation options for Defiance Landfill (Ohio)
- assessment of landfill gas migration (including VOCs) opportunities at Hassayampa Landfill (Arizona). Implications of poor monitoring well construction
- involved in characterization of off-site migration opportunities for 102nd Street Landfill (New York). Statistical interpretation of off-site data and development of dilution calculation scenarios
- water balance characterizations and involved in the treatability effectiveness for Love Canal Landfill (New York)
- assessment of seismic implications and water balance concerns at ECDC Landfill (Utah)

  - statistical interpretation of groundwater monitoring data, potential for gas migration to have caused off-site migration, and development of air permits for Deans Bridge Landfill (Georgia)
  - development of risk assessment for off-site concerns associated with Mig/deWane Landfill (Illinois)
  - assessment of trade offs between transfer station and Chaumox Landfill, B.C.
  - development of closure plan for Pemberton Landfill (B.C.)
- design of cleanup strategy for PCB contamination for Bridgeport, Connecticut for Duracell facility and Mack Plant (Michigan)
- mathematical modeling of vapor phase contamination of groundwater as a result of monitoring well construction at Hassayampa, Arizona
- design of storm sewer interceptor for Case Industries facility in Chicago, to prevent oil slick formation
- design of a passive methane gas abatement system for centralized estimation facility, Coquitlam, B.C.
- use of environmental impact ranking procedures in a series of studies including site selection for locating the regional landfill for the cities of Oakville, Burlington, and Milton. This study involved use of both fuzzy-set procedures and matrix-weighting procedures
- development of a selection procedure for the Ontario Ministry of the Environment for identifying remedial technologies for abatement of pollutants to surface water bodies. Of particular interest in this study was to account for the noncommensurate nature of the remedial technologies including the cost, reliability and effectiveness
- the use of multiple objective weighting procedures for selection between alternative wastewater treatment components for northern components
- extensive involvement in studies involving hazardous waste management including those for:
  - coal tar residuals management in the City of Waterloo and the Region of Ottawa-Carleton
  - arsenic, ONA and 1,1-TCE for Salsbury Laboratories
  - nonaqueous phase liquid movements in Taft, Louisiana for Occidental Chemical Corporation
  - contaminant migration in groundwater of organics from the Twin Cities Army Ammunition Plant in Minneapolis, Minnesota
  - inventory assessment for cost-allocation for remediation cost-sharing in Tybouts Landfill, New York
  - assessment of surface and subsurface migration concerns for Lafarge Cement, S-Area Landfill, Owens-Illinois Landfill, Keele Valley landfill
- risk assessment associated with remediation of hazardous waste landfills at Sheffield, Illinois
- human health and risk assessment associated with contaminated bank soils and river sediments for Crompton facility in Elmira, Ontario
- peer review of risk assessment associated with Oak Street property in Vancouver dealing iwth napthalenes and PAHs in general
- risk assessment associated with chemical unloading facilities at Benson Chemicals, Hamilton, Ontario
- design of sampling strategy and remediation effectiveness of alternatives for DDT contamination at former manufacturing facility in Alabama
- groundwater quantity modeling for Hooker Chemical facility in Oregon
- review of aquifer performance test data analyses and recommendation on lakefront purge well operation and performance monitoring, Montague, Michigan
- refuse volume forecast for the Region of Waterloo, Waterloo, Ontario

Examples of Experience in Water Quality Assessments and Wastewater Treatment

- water quality management study for Saint John River, New Brunswick undertaken for Environment Canada. Specific attention was focussed on details of treatment sequences for several existing and several potential pulp and paper facilities in the basin
- water quality management study for Aroostook, Presquile, and Meduxnekeag Rivers in the State of Maine for US EPA
- analysis of water quantity and quality impacts arising from urbanization in Barrie, Ancaster, Hamilton, Waterloo, Kitchener, Ottawa, Windsor
- impact assessments on receiving water body quality arising from industrial and municipal discharges. Such assessments have been carried out for numerous locations including the South Nations, Saskatchewan River, Grand River, Ottawa River, Humber River, Lake of the Woods, etc.
- impact assessment on English River and Spanish Rivers because of industrial spills
- design of diffusers for wastewater treatment plant outfalls for numerous communities including Thornbury, and several towns in Muskoka
- development of a computer model for spill propagation assessment of hazardous chemicals for Environment Canada
- examination of operating policies for a series of small reservoirs used for water supply in Ecuador
- examination of migration pathways and remediation alternatives for urban runoff controls for PAHs in Sault Ste. Marie
- salinity drainage modeling for the San Joaquin River valley, California

Examples of Experience in Floodplain Delineation and Stormwater Management

- participation in development of floodplain criteria and management evaluation study for the Ontario Ministry of Natural Resources and Ontario Ministry of Housing
- expert witness testimony in appeal by Brewers Retail for facility expansion in Dunneville, Ontario
- participation in study of uncertainties in water surface profile computations for Alberta Environment
- study of flood forecasting opportunities for Lake Nipissing/French River, Ontario
- analyses of flood damage data to develop flood damage curves used in the Province of Ontario
- floodplain delineation in numerous communities including those of Southampton, Ontario and the Raisin River, Ontario
- environmental impact assessment associated with potential construction of Dickey-Lincoln Reservoir, for the U.S. Army Corps of Engineers
- determination of impacts of urbanization in the Town of Vaughan on runoff into the Town of Markham
- determination of impacts of urbanization in the Towns of Ancaster and Georgetown, Ontario
- analysis of water quantity and quality impacts arising from urbanization in Barrie, Ontario
- analysis of merits of realtime control of stormwater runoff from the City of Edmonton
- design of stormwater management facility for St. John's airport, Newfoundland
- assessment of impact of alternative reservoir operating policies for the Rafferty/Alameda Reservoirs, Province of Saskatchewan
- calculation of sediment losses from rural farmlands flowing in the City of Hamilton, Ontario

- examination of operations policies and sediment control facilities for the Indus River, Pakistan and specifically for the Basha, Tarbella, and Kalabash Reservoirs
- design of floodwall for St. Marys, Ontario

Examples of Experience in Air Pollution Management

- development of a computer model to examine alternative control strategies for abatement of air pollutant emissions. This study involved modeling 235 controllable sources and 83 area sources to determine cost-effective control strategies to improve acid rain depositions in eastern North America
- development of a strategy for rationalization of acid rain deposition monitoring network
- utilization of a number of air pollution computer models to determine linkages between sources and downwind air quality
- modeling of exposure concentrations and comprehensive risk assessment associated with incineration of industrial wastes at Sheffield site, Illinois
- modeling of depositional patterns arising from air emissions from the Feed Materials Production Center, Fernald, Ohio
- modeling of airborne exposure levels for disposal of incinerated wastes for T-area, Niagara Falls, New York
- Waste composition and air emissions impact for Burnaby Incinerator, Burnaby, B.C.

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FREDERICK (RICK) A. MOSHER, P. Eng.

EDUCATION

1982-86	B.A.Sc. (Civil Engineering), University of Waterloo
1975	Construction Law (post grad course), University of Waterloo
1975	Project Management (post grad course), University of Waterloo
1972-74	Carpentry Apprenticeship, George Brown College (Completed with interprovincial trade certification)

EMPLOYMENT

1992-Present	Associate Conestoga-Rovers & Associates
1989-Present	Project Manager, Canadian Engineering Group Conestoga-Rovers & Associates
1998-99	Engineering Group, Conestoga-Rovers & Associates
1989-95	Branch Manager - Mississauga Office, Canadian Environmental
1988-89	Project Co-ordinator, Canadian Environmental Engineering Group, Conestoga-Rovers & Associates
1986-88	Project Engineer, Canadian Environmental Engineering Group, Conestoga-Rovers & Associates
1985	Field Engineer, Dufferin Construction Limited (Oakville)
1984	Research Assistant, University of Waterloo
1983	Construction Supervisor, Fletcher Contracting Limited (Kitchener)
1980-82	Construction Manager, Westmount Engineering (Peterborough)
1977-80	Partner, Manager, Estimator, Jaric General Contracting (Midland)
1972-77	Carpenter, Surveyor, Foreman, Construction Superintendent, Whitman Contracting Limited (Kitchener)
1970-72	Tradesman, Pernfuss Roofing Limited (Kitchener)

AFFILIATIONS

Professional Engineers Ontario (PEO)

Member of the Rotary Club (Kitchener Grand River)

Solid Waste Management Association of North America (SWANA)

PROFILE OF PROFESSIONAL ACTIVITIES

Management Activities

- Director of Donson Engineering Ltd., an engineering and specialty construction services firm working in cooperation with CRA to develop wastewater treatment projects in North America (1999-)

- Corporate Account Manager for the Suncor Energy Inc. Alliance Agreement with CRA to develop LFG to Energy Facilities in North America and internationally (1999-)
- Director of CRA Contracting Ltd., a fully owned subsidiary of Conestoga-Rovers & Associates (1995-2000)
- Co-ordinator for organization of corporate design services and standardization of technical drawings and specifications (1995-present)
- Corporate responsibility for Conestoga-Rovers & Associates branch office in Mississauga, Ontario. Responsibilities include all administrative, staffing and financial management of the office (1989-1995 and 1998-2000)
- Principal in Jaric General Contracting responsible for business management, bid and cost estimating, and contract administration for numerous construction projects, primarily for Ontario's Ministry of Government Services and the Federal Department of Supply and Services (DSS) (1977-1980)
- Senior project manager and cost estimator for bid preparation and cost control for Whitman Contracting Ltd. (1976-1977)

Solid Waste Management

- Peer Reviewer/Technical Advisor for the Tomah Landfill in Wisconsin (1999-)
- Project Manager and Senior Design Engineer for the Leachate reinjection systems at the Trail Road Landfill in Ottawa (1999-)
- Peer Reviewer/Technical Advisor for the design of the Woodstock Landfill in Wisconsin (1997-)
- Project Manager and Senior Design Engineer for the Holly Disposal Landfill in Michigan (1998-)
- Project Manager/Senior Design Engineer for the leachate management systems at the Pine Tree Acres Landfill in Michigan (1997-)
- Senior Design Engineer for the assessment and design of a remedial program for the Rhinelander Landfill Site in Wisconsin (1997)
- Senior Technical Advisor for landfill design at various USA Waste landfills in the southern United States (1997-)
- Technical Reviewer and senior design engineer for new TSCA Landfill Site at the Willow Run Creek Remediation Site in Michigan (1995-1996)
- Technical Reviewer, senior engineer for preparation of Remedial Design for G&H Landfill, Michigan (1994-1995)
- Project Manager for the multi-disciplinary consulting team to undertake all hydrogeological and technical studies necessary to support the design of an expansion to the Keele Valley Landfill Site (1991-1995)
- Senior Engineer and technical peer reviewer acting for the PRP group for the Helen Kramer Landfill Site in New Jersey (1994)
- Project Manager and senior engineer for development and implementation of a stormwater management plan for the Keele Valley Landfill Site (1989-1994)
- Project Manager for hydrogeological site assessment and development of a remediation program at the Morningside Landfill Site for the City of Scarborough (1994-1996)
- Project Manager for the site design, development, operations, maintenance, and monitoring programs of the Bensfort Road Landfill Site of the City of Peterborough (1990-1997)
- Project Manager for the design and construction of a leachate forcemain from the Bensfort Road Landfill Site for the City of Peterborough (1992)

- Project Manager for the site investigation, design and operations plan for a waste disposal site for the cement kiln dust at the Brookfield Facility for Lafarge Canada Inc. (1989-1990)
- Project Co-ordinator for the conceptual site design, stormwater management leachate control/disposal, and gas control/utilization at a proposed landfill site for Waste Management of Canada Incorporated (1989-1990)
- Project Engineer for the preliminary design of the leachate collection and pumping system at the Waterloo Landfill for the Regional Municipality of Waterloo (1987)

Landfill/Soil Gas Management

- Project Manager for the Inventory of Landfill Sites in Canada with the potential for future development for both landfill gas control and utilization for Environment Canada (1999)
- Senior Design Engineer for Air Sparge/SVE system for Mercury Marine Ltd. site in Toronto (1998)
- Peer Reviewer/Technical Advisor for the gas control systems at the Yeomen Creek Landfill in Illinois (1998-)
- Peer Reviewer/Technical Advisor for the soil gas migration issues associated with a former Ford Motor Company facility in Michigan (1998-)
- Peer Reviewer/Technical Advisor for the landfill gas issues at the Eau Claire Landfill in Wisconsin (1997-)
- Peer Reviewer for soil gas migration issue at Valleycrest Landfill in Ohio (1998)
- Project Manager for assessment and design of a landfill gas migration control system at the Tybouts Corner Landfill in Delaware (1997-)
- Project Manager for the preparation of Landfill Gas Collection and Control Design Plans for City Management Corporation for four large landfill sites in Michigan (1997)
- Project Manager for design and construction of SVE system at VacAir facility in New York (1996-1997)
- Project Manager for the design and construction of a landfill gas control system for the Morningside Landfill in the City of Scarborough (1995-1996)
- Project Manager for the design and implementation of an active landfill gas control systems at the Regional Municipality of Waterloo Landfill Sites (1993-1997)
- Project Manager for the assessment of the landfill gas generated at the Waterloo Landfill Site as a potential fuel source for recovery and utilization (1994-1996)
- Project Manager for the design and implementation of a landfill gas collection/disposal system at the Nepean Landfill for the Regional Municipality of Ottawa-Carleton (1992-1994)
- Project Manager for the conceptual design detail design, and construction of a landfill gas collection, control, and disposal system at the Trail Road Landfill Site of the Regional Municipality of Ottawa-Carleton (1990-1992)
- Project Manager for construction of a landfill gas control system for Waste Management of Canada Inc. in Aurora, Ontario (1990-1991)
- Project Co-ordinator for the development of a landfill gas utilization program at the Keele Valley Landfill Site for the Municipality of Metropolitan Toronto (1988-1989)
- Project Co-ordinator for the site evaluation, preliminary design and detail design of the landfill gas control system at the Upper Ottawa Street Landfill for the Regional Municipality of Hamilton-Wentworth (1988)
- Project Co-ordinator for the site evaluation, preliminary design, and detail design of the landfill gas control system at the Port Mann Landfill for the District of Surrey (1988)

- Project Co-ordinator for the design of the Stage 2 and Stage 4 Header System at the Keele Valley Landfill for the Municipality of Metropolitan Toronto (1988-1991)
- Project Engineer for the preliminary and detail design of the landfill gas control system at the Marathon County Landfill in Wisconsin (1987-1988)
- Project Engineer for the construction of the landfill gas control plant at the Keele Valley Landfill for the Municipality of Metropolitan Toronto (1987-1988)

Site Remediation and Groundwater/Wastewater Treatment

- Technical Reviewer, senior engineer for site assessment and remedial design of the VacAir Alloys Site for Keywell Corporation in Frewsburg, New York (1996-1997)
- Technical Reviewer, senior engineer for preparation of Remedial Design for Willow Run Creek, Michigan (1995-1997)
- Project Manager for the site investigation and design of a site remediation program for Nacan Ltd. at the Hart Chemical Site in Guelph, Ontario (1991-1994)
- Project Manager for the assessment, all design phases and construction of a wastewater treatment system at Hart Chemical Company in Guelph, Ontario (1991-1994)
- Project Co-ordinator for site evaluation, preliminary design and detail design of a coal tar collection and treatment system for Algoma Steel Corporation Ltd. and Domtar Chemicals Ltd. at their facilities in Sault Ste. Marie, Ontario (1990-1991)
- Project Engineer for the design and construction of a PCB groundwater collection and treatment system for the T.T.I. transformer plant in Guelph, Ontario (1988)
- Project Engineer for the preliminary design of a PCB treatment plant for Westinghouse, London (1987)
- Project Engineer for the design and construction of the leachate collection system at the Lees Avenue Bus Transit Station for the Regional Municipality of Ottawa-Carleton (1986-1987)
- Project Engineer for the design and construction of the treatment plant and pumping station at the Lees Avenue Bust Transit Station (1986-1987)

Site Assessment

- Project Manager for a hydrogeological assessment and the site and development and implementation of an environmental management plan at Federal Industries, NEO-Mead Ave. facility in Hamilton (1991-1994)
- Project Manager for the development and implementation of an environmental management plan at CCL Industries former Conn-Chem Plant in East York (1991-1995)
- Project Manager for hydrogeological and geotechnical investigations of various TTC sites in Metropolitan Toronto (1990-1991)
- Project Manager for the design and development of a Waste Management Plan for Pan Abrasive Inc. (1990-1991)
- Project Manager for the Site Investigation for Lafarge Canada Inc. at the Francon Quarry in Montreal, Quebec (1990)
- Project Manager for the review and assessment of the wastewater treatment alternatives for Moore Business Forms production facility in Fergus, Ontario (1990)
- Project Manager for various plant and site audit services including Genstar, Federal Industries, Westinghouse, CCL Industries and Triple M Metals Ltd. (1989)

Construction and Other

- Project Co-ordinator for the stormwater management, site operations and report preparation for the Avondale North Clay Borrow Expansion Area for the Municipality of Metropolitan Toronto (1988-1989)
- Field Engineer responsible for the management and site supervision of heavy equipment operations for the site services and land development for Dufferin Construction (1985)
- Research and produced a report examining the potential damage to forests due to acidification as a research assistant at the University of Waterloo (1984)
- Construction Manager responsible for scheduling, site supervision, and cost control on the following projects:
  - Scott Medical Clinic, Peterborough (Westmount Engineering), 1982
  - Chemong Plaza, Peterborough (Westmount Engineering), 1980/1981
  - Bank of Commerce, Peterborough (Westmount Engineering), 1981
  - City of Peterborough - Water Pumping Station (Westmount Engineering), 1981/1982
  - Royal Bank, Kincardine (Whitman Contracting), 1976/1977
  - NCR Phase III, Waterloo (Whitman Contracting), 1975
  - Mohawk Race Track, Milton (Whitman Contracting), 1976
  - Walker Muffler Factory, Cambridge (Whitman Contracting), 1974/1975
- Extensive field experience in most areas of light and heavy construction in various capacities, including construction superintendent, foreman, surveyor, carpenter, and apprentice

Expert Witness Services and Litigation Support

- Litigation support in case preparation for a personal injury lawsuit for Ford Motor Company related to a gas explosion (1998-)
- Expert witness on landfill design acting for the City of Oshawa in a hearing for a development proposal adjacent to a closed landfill site (1994-1995)
- Expert witness on landfill design acting for the Regional Municipality of Hamilton-Wentworth at the Steetley Landfill Hearing (1993-1994)
- Expert witness on lawsuit regarding the design and construction of the Coal Tar Collection System at the Lees Avenue Bus Transit Station for the Regional Municipality of Ottawa-Carleton (1986)
- Expert witness on landfill design and borrow pit operations for the Municipality of Metropolitan Toronto in its undertaking before the Consolidated Hearing Board to expropriate part Lots 29 and 30 in the Town of Vaughan for the clay resources on these properties (1988-1990)
- Expert witness on a lawsuit related to pipe supply for use in a landfill gas control system at the Keele Valley Landfill on behalf of the Municipality of Metropolitan Toronto (1994)
- Expert witness on stormwater management and landfill design in a lawsuit regarding use of lands adjacent to the Keele Valley Landfill on behalf of the Municipality of Metropolitan Toronto (1994)
- Expert witness on landfill design in a hearing for expansion of the Mountain Road Landfill in Niagara Falls (1993)

PAPERS

- "A Case History of Leachate Collection and Moisture Recirculation, Keele Valley Landfill Site, Municipality of Metropolitan Toronto" paper presented at *Clayey Barriers for Mitigation of Contaminant Impact*, University of Western Ontario, Faculty of Engineering Science, London, Ontario, December 1990 (with A.J. Crutcher)
- "Leachate Collection and Moisture Recirculation at the Keele Valley Landfill Site" paper presented at *First Canadian Conference on Environmental Geotechnics*, The Canadian Geotechnical Society, Montreal, Quebec, May 1991 (with A.J. Crutcher)
- "Reliability-Based Design for Leachate Collection Systems", presented at *Sardinia '93, Fourth International Landfill Symposium*, Sardinia, Italy, October 1993 (with E. McBean and F. Rovers)
- "Applications and Supporting Documentation Requirements for Industrial/Commercial Environmental Approvals" paper presented at *Industrial and Commercial Environmental Approvals* conference, Insight Information Inc., Toronto, Ontario, April 1994 (with A.J. Crutcher and J.R. Yardley)
- "Disposal and Utilization Technologies for Landfill Gas" paper presented at *Sanitary Landfill Leachate and Gas Management* seminar/workshop held jointly by EPIC Educational Program Innovations Center and University of Toronto, Toronto, Ontario, April 1994 (with M.L. Duchene)
- "Performance and Design Criteria for Landfill Gas Management", presented at Landfill Design for Long Term Performance seminar/workshop held jointly by EPIC Educational Program Innovations Centre and the University of Toronto, February 1995
- "Guidance Document for Landfill Gas Management" published by Environment Canada, Ottawa, Ontario, January 1996 (with N. MacDonald)
- "Landfill Gas Collection System Efficiencies - Facts and Fallacies", presented at the 19th Annual Landfill Gas Symposium of the Solid Waste Association of North America (SWANA), Research Triangle Park, North Carolina, March 1996 (with J. Yardley)
- "Landfill Cover System Design", presented at the Elements of Landfill Design Course for the Ministry of Environment and Energy, Toronto, Ontario, August 1996
- "Leachate Recirculation to Achieve Rapid Stabilization of Landfills - Theory and Practice", presented at the 2nd Annual Landfill Symposium of the Solid Waste Association of North America (SWANA), August 1997 (with E. McBean et al.)
- "Innovations In Landfill Cover System Design", presented at the Elements of Landfill Design Course for the Ministry of Environment and Energy, Toronto, Ontario, September 1998
- "Optimizing Landfills for Energy Recovery and Greenhouse Gas Reduction", presented at the 20th Canadian Solid Waste Management Congress Hamilton, Ontario September 1998

APPENDIX C

PROFESSIONAL QUALIFICATIONS FOR ENVIRONMETAL TECHNOLOGIES, INC.

enviro**metal**
technologies
inc.

12 September 2001

Mr. Rick Hoekstra
Conestoga Rovers and Associates
651 Colby Drive
Waterloo, Ontario
N2V 1C2

Re: EnviroMetal Technologies Inc. Letter of Support for Reactive Barrier Design and Installation, Michigan Project – 31877.88

Dear Mr. Hoekstra:

This letter confirms EnviroMetal Technologies Inc.'s (ETI's) interest in supporting Conestoga Rovers and Associates (CRA) in the design and implementation of a proposed reactive barrier remediation of a mixed plume at a site in Michigan.

As you are aware, ETI is the worldwide leader in applications of permeable reactive barrier technology for the remediation of contaminated groundwater, with the experience of over sixty applications in United States, Europe and Australia. ETI was founded to implement a remedial technology based on the ability of zero valent metals to degrade volatile organic (VOC) compounds in groundwater. The technology is supported by a number of US patents granted to the University of Waterloo, Waterloo, Ontario, Canada. The University of Waterloo has granted an exclusive license for implementing the technology to ETI.

ETI's staff of hydrogeologists and engineers represents the group with the most experience with PRB technology worldwide. The ETI project team has successfully worked on all field applications of the technology to date. Key staff members include Dr. Robert Gillham, the inventor of the metal-based technology for remediation of groundwater containing VOCs, who serves as the senior technical reviewer for ETI's projects. John Vogan and Stephanie O'Hannesin have been involved in all ETI's commercial installations of this technology to date. Ms. O'Hannesin was responsible for the pioneering field trial of the technology at the University of Waterloo Borden test site that began in 1991. In addition to their technical responsibilities, Mr. Vogan and Ms. O'Hannesin are involved in various aspects of site license agreement negotiation, partnering and teaming arrangements, and international market development. Robert Focht completed his Master's thesis on this technology in 1995 prior to joining ETI, and together with Michael Duchene, lead ETI's engineering design efforts to support construction of large-scale systems. Andrzej Przepiora provides additional technical expertise during all phases of project completion.

745 Bridge St. W., Suite 7
Waterloo, Ontario
Canada N2V 2G6
Tel: (519) 746-2204
Fax: (519) 746-2209

ETI acts as a subconsultant/subcontractor to site owners, operators, consultants, or government agencies when applying the technology. We provide a variety of services, including the following:

- evaluation of required treatment zone dimensions and configurations for both organic and inorganic plume constituents;
- selection of appropriate construction methods;
- bench-scale testing (if required); and
- on-site installation support.

As mentioned previously, field installations have occurred at over 60 sites in the U.S. and Europe. These include 40 full-scale installations and several smaller pilot-scale trials. Of particular relevance to your project may be the following mixed plume applications:

(i) a PRB to treat a combined BTEX and chlorinated VOC plume in California;
(ii) PRBs to treat mixed chromium and chlorinated VOC plumes in North Carolina and Denmark; and
(iii) a PRB to treat a mixed nitrate and VOC plume in Belgium.

For those mixed plume projects, ETI involves the academic experts at the University of Waterloo (e.g., Dr. Dave Blowes' group) and elsewhere as appropriate. As I mentioned on the phone, we have also worked with Mr. Steve Day of Geosolutions Inc. on several projects.

ETI can make a significant contribution to the design and construction of a cost effective and efficient remediation system at the site that will satisfy regulatory requirements. ETI looks forward to working with CRA on this project.

Sincerely,

EnviroMetal Technologies Inc.

John Vogan, M.Sc.
President

(buck/project related/31000/31800/31877.88 Conestoga Rovers Sept 12.doc)

BioSketch 2001

John Vogan

John Vogan joined ETI in February 1993 as a hydrogeologist and project manager, and has been ETI's President since October 1997. He provides technical and administrative oversight in all aspects of the technology application. His specific responsibilities include contract negotiation and administration, review of hydrogeologic data from potential sites, and design of field applications of the technology. He has provided technical input into all commercial applications of the EnviroMetal Process to date. John is also involved in international sublicensing arrangements with a number of firms in Europe and the Pacific Rim. He has co-authored several technical publications concerning permeable barrier installations.

Employment

1997 - present	President, EnviroMetal Technologies Inc.
1994 - 1997	Manager, EnviroMetal Technologies Inc.
1993 - 1994	Hydrogeologist, EnviroMetal Technologies Inc.
1988 - 1990	Manager, Dames & Moore, Cambridge, Ontario. Supervised 10 staff members, involved in the completion of a variety of groundwater contamination and groundwater supply investigations. Responsibilities included technical and project management, budget, direction of field programs, preparation and review of technical reports, public meeting attendance and presentations.
1986-1988	Hydrogeologist, Dames & Moore, Brampton, Ontario. John was responsible for field programs and reports of hydrogeologic investigations of small landfill sites. He also completed data reviews, field programs and reports for several municipal groundwater supply studies. Mr. Vogan also has past experience in petroleum research and mineral exploration.

University Education and Professional Memberships

1993	M.Sc.: University of Waterloo, Earth Sciences – Hydrogeology. Thesis work involved the use of permeable barriers for nitrate removal. John received the Distinguished Graduate Studies Award from the University of Waterloo in recognition of his research.
1986	B.Sc.: University of Waterloo, Earth Sciences – Honours Applied Earth Sciences
OSHA	Occupational Health and Safety Administration and 8 Hr. Annual Refresher Association of Professional Geoscientists of Ontario AGWSE Division, National Ground Water Association

Stephanie O'Hannesin

Stephanie O'Hannesin received her MSc in Hydrogeology from the Department of Earth Sciences at the University of Waterloo, Waterloo, Ontario, Canada. In the late 1980's, Stephanie assisted in the development of the iron technology and in 1991 she undertook the initial *in-situ* field trial of the granular iron reactive wall technology. She assisted EnviroMetal Technologies Inc. (ETI), with various stages of technology application at commercial sites since the company was founded in 1992, and joined ETI full-time in 1997 as a Senior Project Director. Her responsibilities include client liaison and international marketing, as well as various technical activities. She also coordinates the ETI bench scale treatability tests performed under contract to the University of Waterloo. Stephanie joined ETI with sixteen years of experience from the Institute for Groundwater Research at the University of Waterloo, where her work focused on the fate and transport of dissolved contaminants in groundwater and groundwater remediation.

Stephanie has 12 refereed publications, 38 non-refereed publications along with numerous abstracts and technical reports. She received a 1998 Award of Excellence from the Ontario Ministry of the Environment for her principal lead in developing "Long-term performance of an in-situ "Iron Wall" for remediation of VOCs in groundwater". She also is co-holder of a patent related to an enhancement to the iron technology.

Employment

1997 - present	Senior Project Director, EnviroMetal Technologies Inc., Waterloo, Ontario
1992 - 1997	Senior Consultant, EnviroMetal Technologies Inc., Waterloo, Ontario
1993 - 1997	Research Project Manager, Institute for Groundwater Research, University of Waterloo
1988 - 1997	Research Co-ordinator, Institute for Groundwater Research, University of Waterloo
1985 - 1988	Senior Research Technician, Institute for Groundwater Research, University of Waterloo
1981 - 1985	Hydrogeology Technician, Institute for Groundwater Research, University of Waterloo

University Education

1993	M.Sc.:	University of Waterloo, Earth Sciences – Hydrogeology
	Thesis:	*A field demonstration of a permeable reaction wall for the in situ abiotic degradation of halogenated aliphatic organic compounds.*
1981	B.E.S.:	University of Waterloo, Environmental Studies – Honours Geography
	Thesis:	*Spatial variability of grain-size parameters and hydraulic conductivity at a dispersion test site.*
OSHA	Occupational Health and Safety Administration Training and Annual Refresher	

Robert Gillham

Dr. Gillham was educated as a Physicist and Soil Physicist and since 1973 has held academic positions as a hydrogeologist in the Department of Earth Sciences at the University of Waterloo, Waterloo, Ontario, Canada. Dr. Gillham was Director of the Waterloo Center for Groundwater Research for the period of 1987 to 1992, was Chair of the Earth Science Department from 1993 to 1997 and currently holds the NSERC / Motorola / EnviroMetal Technologies Inc. Industrial Research Chair in groundwater remediation.

Dr. Gillham's primary research area concerns the migration of contaminants in saturated and unsaturated geologic materials and over the past twelve years he has focused on the evaluation and improvement of groundwater cleanup technologies. In 1989, Dr. Gillham recognized that metallic iron was effective in degrading a wide rage of chlorinated organic compounds and further recognized the potential for using granular iron for the in situ remediation of groundwater containing these chemicals. He is the holder or co-holder of several international patents related to the technology, and is co-founder of EnviroMetal Technologies Inc. (ETI). Dr. Gillham is a technical advisor to ETI.

Dr. Gillham has over 100 refereed publications, a similar number of non-refereed contributions, and 48 M.Sc. and 16 Ph.D. students have graduated under his supervision. In 1988 he received the Thomas Roy Award of the Canadian Geotechnical Society, in 1996 he was co-recipient of the Miroslaw Romanowski medal of the Royal Society of Canada and in 1997 was elected a Fellow of the Royal Society of Canada (FRSC). In 1999 he was awarded an Honourary Doctor of Science by the University of Guelph.

Employment

1997 - present	NSERC / Motorola / EnviroMetal Technologies Inc. Industrial Research Chair
1993 - 1997	Department Chair, Dept of Earth Sciences, University of Waterloo, Waterloo, ON
1992 - 1997	President of EnviroMetal Technologies Inc., Waterloo, ON
1986 - 1998	Director, Waterloo Center for Groundwater Research, Waterloo, ON
1986 - present	Professor, Dept of Earth Sciences, University of Waterloo, Waterloo, ON
1980 - 1986	Associate Professor, Dept of Earth Sciences, University of Waterloo, Waterloo, ON
1977 - 1980	Assistant Professor, Dept of Earth Sciences, University of Waterloo, Waterloo, ON
1974 - 1977	Research Assistant, Dept of Earth Sciences, University of Waterloo, Waterloo, ON

University Education

1973	Ph.D.:	University of Illinois
1968	M.Sc.:	University of Guelph
1963	B.S.A.:	University of Toronto

Michael Duchene

Michael Duchene received both his Bachelors of Applied Science and Masters of Applied Science in Civil Engineering from the University of Waterloo. Prior to joining ETI, Mike worked primarily as a design engineer and designed and operated several groundwater remediation systems. He joined ETI in October 1999 and has more than 10 years consulting engineering experience in the environmental field. As Senior Engineer, his responsibilities include managing various engineering aspects of the design, installation of PRBs and long-term operation of PRBs. Mike is primarily involved in assisting clients in the detailed design of PRBs including detailed assessments of groundwater hydraulics, assessment and specification of potential construction techniques, and construction QA/QC protocols. He is also involved in the development and evaluation of innovative construction methods and the interpretation of chemical and hydrogeological performance data for completed PRBs.

Employment

1999 - present	Senior Engineer, EnviroMetal Technologies Inc, Waterloo, ON.
1998 - 1999	Project Manager, Conor Pacific Environmental Technologies Inc., Vancouver, BC. Project Manager responsible for the design, installation and operation of soil and groundwater remediation systems.
1996 - 1998	Environmental Engineer, Morrow Environmental Consultants Inc., Burnaby, BC. Engineer in the remediation group responsible for all aspects of in-situ remediation including hydrogeological modeling and assessment, remedial alternative evaluation, pilot-scale testing, cost estimating, detail design, preparation of specifications, obtaining permits and approvals, system installation and commissioning, and long-term operation, maintenance and evaluation.
1992 - 1996	Environmental Engineer, Conestoga-Rovers & Associates, Waterloo, ON and Vancouver, BC. Environmental engineer involved in the evaluation, design and remediation of landfills and industrial sites.

University Education and Professional Memberships

1992	Master of Applied Science, Civil Engineering, University of Waterloo.
1989	Bachelor of Applied Science, Civil Engineering, University of Waterloo. First Class Honours, Water Resources and Management Sciences Options.
	Association of Professional Engineers of Ontario
OSHA	Occupational Health and Safety Administration Training and Annul Refresh

Robert Focht

Robert Focht received both his B.A.Sc. in Chemical Engineer and M.Sc. in Hydrogeology from the University of Waterloo, Waterloo, Ontario, Canada. Robert has been involved with the granular iron technology since he started his M.Sc. in 1992. After completion of his M.Sc. he continued to be involved in research and development efforts with the University of Waterloo focusing on enhancements to the technology. During this time, he became involved with EnviroMetal Technologies Inc., joining the company in 1995. Robert has been mainly involved in reviewing data from potential sites, interpretation of bench-scale tests, chemical and groundwater modeling, development of field designs, installation oversight and evaluation of performance monitoring data on many of the installations to date. He has also been involved in evaluating innovative construction methods for permeable reactive barrier installation. This work includes research on the interaction between biopolymers and the iron technology.

Robert has 5 refereed publications and 7 non-refereed publications related to the technology. He is also co-holder of a patent on an enhancement to the iron technology.

Employment

1995 - present	Remediation Engineer, EnviroMetal Technologies Inc., Waterloo, Ontario
1994 - 1995	Research Technician, Department of Earth Sciences, University of Waterloo

University Education

1994	M.Sc., University of Waterloo, Earth Sciences – Hydrogeology Thesis: *Bench-scale treatability testing to evaluate the applicability of metallic iron for above-ground remediation of 1,2,3-trichloropropane contaminated groundwater.*
1991	B.A.Sc., University of Waterloo, Chemical Engineering
P.Eng.	Professional Engineers Ontario
OSHA	Occupational Health and Safety Administration

Andrzej Przepiora

Andrzej Przepiora received his M.Sc. in Geology from the Department of Geology and Geophysics at Texas A&M University, College Station, Texas, USA. His graduate work involved research on fate of metals in the presence of mobile colloidal matter. Andrzej worked for 4 years as a research associate at North Carolina State University in the area of pesticide and suspended sediment transport in surface waters and groundwater. In August 1999, he joined EnviroMetal Technologies Inc. as a hydrogeologist. Andrzej's main responsibilities include initial data evaluation from potential sites, development of field designs, chemical and groundwater modeling, on-site field installation support and performance monitoring data review.

Employment

1999 - present	Hydrogeologist, EnviroMetal Technologies Inc., Waterloo, Ontario
1995 - 1999	Research Associate, Department of Soil Science, North Carolina State University, Raleigh, North Carolina

University Education

1995	M.Sc. Texas A&M University, Department of Geology and Geophysics - Geochemistry and Hydrogeology. *Thesis: The role of soil-borne colloids in the transport of Cu and Zn; evaluation of the Rio Grande flood plain soils.*
1990	B.Sc. University of Warsaw, Department of Geology - Engineering Geology
OSHA	Occupational Health and Safety Administration Training

STATEMENT OF QUALIFICATIONS
EnviroMetal Technologies Inc.

EnviroMetal Technologies Inc. (ETI) is the worldwide leader in applications of permeable reactive barrier (PRB) technology for the remediation of contaminated groundwater, with experience in North America, Europe and Australia. ETI provides a range of advisory and support services to site owners, remediation consultants and contractors to assist them with the design and installation of our patented PRB systems and other passive remediation technologies.

ETI was founded to implement a remedial technology based on the ability of zero valent metals to degrade organic compounds in groundwater. The technology is supported by intellectual property filed in numerous countries including U.S. Patent No. 5,266,213 ('213), which was issued on November 1993 and is held by the University of Waterloo. The University of Waterloo (U of W) subsequently granted an exclusive license for implementing the technology to EnviroMetal Technologies Inc. The '213 patent discloses and claims a procedure for in-situ removal of a halogenated organic contaminant from groundwater in an aquifer. The procedure comprises passing the groundwater through a body of particulate metal which is permeable to the groundwater. ETI and the U of W have several additional patents on related PRB technology. ETI has access on a contract basis to the expertise and resources of the U of W and sponsor a research industrial chair on this technology. ETI acts as a subconsultant to site owners, operators, consultants, or government agencies when applying the technology.

ETI staff of hydrogeologists and engineers represent the group with the most experience with PRB technology worldwide. The ETI project team has successfully worked on all field applications of the technology to date. Key staff members include Dr. Robert Gillham, the inventor of the metal-based technology for remediation of groundwater containing VOCs, who serves as the senior technical reviewer for ETI's projects. John Vogan and Stephanie O'Hannesin have been involved in every one of the sixty commercial installations of this technology to date. Ms. O'Hannesin was responsible for the pioneering field trial of the technology at the University of Waterloo Borden test site which began in 1991. In addition to their technical responsibilities, Mr. Vogan and Ms. O'Hannesin are involved in various aspects of site license agreement negotiation, partnering and teaming arrangements, and international market development. Robert Focht completed his Master's thesis on this technology in 1995 prior to joining ETI, and together with Mike Duchene, lead ETI's engineering design efforts to support construction of several large scale systems. Andrzej Przepiora provides additional technical expertise during all phases of project completion.

Full-Scale *In Situ* Field Remediation Projects

39 Industrial facility, California - biopolymer continuous wall - *Dec 2000*
38 Industrial facility, California - vertical hydrofracturing - *Dec 2000*
37 Industrial facility, Edenkoben, Germany - multiple gates and sheet piling funnel - *Dec 2000*
36 Former Dry Cleaning Site, Finger Lakes, New York - continuous wall - *Sept 2000*
35 Industrial facility, Ohio - open trench excavation continuous wall - *Sept 2000*
34 Somersworth Landfill Superfund Site, New Hampshire – biopolymer continuous wall - *Aug 2000*
33 U.S. DOD facility, Lake City AAP, Missouri – biopolymer continuous wall - *Aug 2000*
32 U.S. DOD facility, Pease AFB, Site 49, New Hampshire - biopolymer continuous wall - *Jun 2000*
31 Industrial facility, Iowa - vertical hydrofracturing continuous wall - *Nov 1999*
30 Industrial facility, Ohio – open trench excavation continuous wall - *Nov 1999*
29* Industrial facility, Seattle, Washington – slurry wall and gates (2) - *Oct 1999*
28* U.S. DOE facility, RFETS, Colorado – in-situ collection system and reactive vessel - *Aug 1999*
27 Industrial facility, North Carolina - jetting continuous wall - *Aug 1999*
26* Industrial facility, Denmark - sheet pile funnel and gate (1) - *Aug 1999*
25 Industrial facility, Sudbury, MA - continuous wall - *Aug 1999*
24 U.S. DOD facility, Pease AFB, Site 73, New Hampshire - biopolymer continuous wall - *Aug 1999*
23* U.S. DOD facility, Warren AFB, Cheyenne, WY - continuous wall - *Aug 1999*
22* U.S. DOD facility, New York - continuous wall- *Dec 1998*
21 Industrial facility, Louisiana - continuous wall - *Nov 1998*
20* Industrial facility, Denmark - continuous wall and recirculation system- *Nov 1998*
19* U.S. DOD facility, Shaw AFB, South Carolina - continuous walls (4) - *Nov 1998*
18* U.S. DOD facility, Watervliet Arsenal, New York - continuous walls (2) - *Oct 1998*
17 Industrial facility, Germany - gates (3) and slurry funnel - *Oct 1998*
16 Industrial facility, Vermont - gates (4) and HDPE funnel - *August 1998*
15* Former Manufacturing Site, New Jersey - continuous wall - *Sept 1998*
14* U.S. DOE facility, RFETS, Colorado – in-situ collection system and reactive vessel - *July 1998*
13* Industrial facility, Copenhagen, Denmark - continuous wall - *June 1998*
12* U.S. DOE facility, Kansas City, Missouri - continuous wall - *April 1998*
11* Caldwell Trucking Superfund Site, New Jersey - continuous wall – hydrofracturing - *Apr 1998*
10* Aircraft Maintenance Facility, Oregon - gates (2) and slurry funnel - *Mar 1998*
9 Industrial Facility, Upstate New York - continuous wall - *Dec 1997*
8 Industrial Facility, Colorado - gate and slurry funnel - *Nov 1997*
7* Industrial Facility, South Carolina - continuous iron/sand wall - *Nov 1997*
6* *Federal Highway Admin. Facility, Lakewood, CO - Sheet pile funnel(s)/multiple gates (4)* - Oct 1996
5* USCG Facility, Elizabeth City, North Carolina - continuous wall - *Jun 1996*
4* Industrial Facility, Coffeyville, Kansas - slurry wall and gates (3) - *Jan 1996 & Nov 1999*
3* Industrial Facility, Belfast, Northern Ireland - In-situ vessel and slurry wall - *Dec 1995*
2 Industrial Facility, Sunnyvale, California - continuous wall - *Sept 1995*
1* Intersil Semiconductor Site, Sunnyvale, California - continuous wall - *Feb 1995*

*For detailed descriptions of field applications, please refer to: www.rtdf.org/public/permbarr/PRBSUMMS
(see attached)

June 2001

In Situ Pilot Demonstrations of the EnviroMetal Process

21 Former Industrial facility, California – pneumatic fracturing – *Dec 2000*
20 Industrial facility, Upstate New York – iron injection – *July 2000*
19 Former Dry Cleaning Site, Sweden - *June 2000*
18 Industrial facility, Upstate New York - iron injection - *Feb 2000*
17 NASA facility, Louisiana - Passive Drain - *Sept 1999*
16 U.S. DOD, Travis AFB, Fairfield, CA - Jetting (Iron & Guar), continuous wall - *July 1999*
15 Industrial facility, Sydney, Australia - funnel and gate - F*eb 1999*
14* Former Dry Cleaning Site, Rheine, Westphalia, Germany - *June 1998*
13 Industrial facility, Edenkoben, Germany - *July 1998-*
12 U.S. ACE, Maxwell AFB, AL - hydrofracturing - *July 1998*
11* ANG Demonstration, Otis AFB, Cape Cod, Massachusetts - hydrofracturing - *June 1998*
10 NASA Demonstration, CCAS, Florida - Soil Mixing - *Feb 1998*
9* U.S. AFRL Dover AFB, Delaware - funnel and caisson gates - *Jan 1998*
8 U.S. DOE Argonne National Laboratory, Illinois - Iron/Soil Mixing - *Nov 1997*
7* AFCEE Demonstration, CCAS, Florida - Mandrel & Vibrated Beam (Iron & Guar) - *Nov 1997*
6* U.S. DOE Savannah River Site, South Carolina - GeoSiphon - *Jul 1997*
5* U.S. Naval Air Station Alameda, California - funnel and sequence gate - *Dec 1996*
4* Somersworth Landfill Superfund Site, NH - funnel and gate - *Nov 1996; Bioslurry - Nov 1999*
3* U.S. Naval Air Station Moffet Field, California - funnel and gate - *Apr 1996*
2* U.S. DOD facility, Lowry AFB, Denver, Colorado - funnel and gate - *Dec 1995*
1* Industrial facility, Upstate New York - funnel and gate - *May 1995*

*** For detailed descriptions of pilot applications, please refer to:**
United States Environmental Protection Agency, 1999. Field Applications of *In Situ* Remediation Technologies: Permeable Reactive Barriers, April. EPA-542-R-99-002.

Semi-annual Updates: www.rtdf.org/public/permbarr/PRBSUMMS

Jan 2001

APPENDIX D

PROFESSIONAL QUALIFICATIONS FOR GEO-SOLUTIONS, INC.

Reactive Barrier Wall (Funnel and Gate) Contract References

All of the following contracts have been executed by Geo-Solutions on a technical assistance basis, i.e. provisions of specialized personnel and equipment to assist a general contractor in completing the work.

Reactive Barrier Wall for confidential client at North Vancouver, BC

- Project included of 3 trenches 8.2 ft (2.5 m) wide and 6.5 ft wide (2 m), a total of 1750 ft long and up to 59 ft (18 m) deep all constructed by the bio-polymer slurry technique. The trenches were backfilled with a patented mixture intended to promote sulfate-eating bacteria to treat metal contamination in the groundwater.
- Due to use of bacteria in the media, no preservatives were allowed in the slurry.
- Largest permeable reactive barrier constructed to date.
- Dates of Performance: November 2000 to March 2001

Client and Contact: Michael Mattson	Client:
Matcon Excavating	Confidential
4481 – 232nd Street	
Langley, B.C Canada V2Z 2S2	
604-530-1402	

Zero-Valent Iron Wall for A&B Jacobson, LLC at Seattle, WA

- Two - zero valent iron gates constructed with BP slurry up to 35 ft deep and cement-bentonite funnel 320 ft long
- Project was completed to replace pump & treat system and permit commercial development
- Dates of Performance: October 1999

Owner: Al Jacobson	Client:
A&B Jacobson, LLC	Remtech Inc.
300 Admiral Way, Suite 209	1803 99th Street East
Edmonds, WA 98020	Tacoma, WA 98445
425-744-9765	

Phase II Funnel and Gate at former Aptus Site for CBS at Coffeyville, KS

- 100,000 sf of soil-bentonite slurry wall up to 35 ft deep constructed for groundwater funnel
- Two – zero valent iron gates constructed with sheet piles by client
- Dates of Performance: Sept. to Nov. 1999

Client and Contact: Dennis Metz	Owner: Leo Brauch
ThermoRetec Corporation	CBS Corporation
1726 Cole Blvd, Bldg 22	11 Stanwix Street
Golden, CO 80401	Pittsburgh, PA 15227
303-271-2100	412-642-3922

Proof of Concept Project at P.E.C Site for confidential client, Vancouver, BC, Canada

- Permeable reactive barrier (PRB) pilot project, 50 ft deep, 50 ft long and 8 ft wide
- Engineered biological media installed by the bio-polymer trenching method
- Dates of Performance: December 1999.

Client and Contact: Michael Mattson Owner: Confidential
Matcon Excavating
4481 – 232nd Street
Langley, B.C Canada V2Z 2S2
604-530-1402

Peer-Review of Permeable Reactive Barriers for US Department of Energy

- Review and Recommendations for two PRBs installed at Oak Ridge, May 1999.
- Review and Recommendations for PRB Technology Improvements at five DoE facilities, May 2000.
- Review and Recommendations are published and provided for Congressional Oversight of DoE.

Client and Contact: Dr. Alan Moghissi
Institute for Regulatory Science
5457 Twin Knolls Road
Columbia, MD 21045
301-596-1700

The following projects were completed under the supervision of Steve Day, Vice President of Geo-Solutions, while he was employed by Geo-Con. Mr. Day was directly responsible for the construction of these projects and instrumental in introducing geotechnical construction techniques for reactive media installations.

Soil Treatment in 317 French Drain Area for Department of Energy at Argonne, IL.

- 20,000 cy treated up to 25 ft deep
- Treatments used granular iron, hot air, steam, potassium permanganate, engineered bacteria, humic acid, soil vapor extraction, guar gum slurry and proprietary additives.
- Dates of Performance: November 1996 to May 1997.

Client and Contact: Larry Moos
Argonne National Laboratory
9700 S. Cass Ave.
Argonne, IL 60439
630-252-3455

The project included parts of the design and construction for the remediation of a former disposal site. The site is located at the radioactive waste storage yard at Argonne National Laboratory. The site was formerly used to dispose of wastes by dumping into a french drain. Contaminates known to be present included volatile organic compounds. The treatment consisted of injecting granular iron, hot air, bio-polymer slurry and steam into soil mixed columns while simultaneously extracting gas vapors through a shroud which covered the mixing area. The french drain pipe and trench was also located and grouted with a special low permeability grout.

Mr. Day served as the Senior Vice President of Engineering/Technical Director and quality assurance supervisor during the grouting phase of the project. He also worked under a separate contract as the project manager on a laboratory study with Argonne National Laboratory prior to construction to develop and test the reactive media and the means for their application. This effort included extensive testing of workability, application rates, and comparisons of different reactive media, which recommended granular iron filings applied with a bio-polymer slurry.

This project has been summarized in a technical paper published as:
Day, S.R. and L. Moos, "A Comparison of In-Situ Soil Mixing Treatments", **Remediation of Chlorinated and Recalcitrant Compounds,** edited by G. B. Wickramanayake and R.E. Hichee, Battelle Press, Monterey, California, 1998.

In-Situ Soil Mixing & Treatment for the Department of Energy at Kansas City, Mo

- 18 columns 25 and 47 ft deep with 8 and 10 ft diameters
- Treatment used heated air, potassium permanganate, engineered bacteria, lime and water
- Dates of Construction: May to July 1996

Client: Joe Baker
Allied Signal
PO Box 419159
Kansas City, MO 64114

Contact: Steve Cline
Oak Ridge National Laboratory
PO Box
Oak Ridge, TN
423-241-3957

This project was a pilot project to test different reactive media and the limits of SSM technology. The site was situated on the edge of a former sludge lagoon, some of which was filled with debris. The contaminates known to be present were primarily volatile organic compounds. Eighteen test columns were constructed at different depths, using different mixer sizes, and using different reactive media. A record depth of 47 ft was achieved with an 8 ft diameter auger and a depth of 35 ft with a 10 ft diameter auger.

Mr. Day was the District Manager, project engineer, and Senior Vice President of Operations for this project. He wrote the work plans, aided the Department of Energy in planning the experiments and was responsible for the profitability of the project.

The results of this test program were published by Oak Ridge National Laboratories in:
Cline, S.R., O.R. West, R.L. Siegrist, and W.L. Holden, "Performance of In-Situ Chemical Oxidation Field Demonstration at DOE Sites", **In-Situ Remediation of the Geoenvironment,** edited by J. Evans, ASCE, Minneapolis, MN, 1997.

X-231B Soil Remediation for the Department of Energy at Piketon, Ohio

- 28,000 cy treated to a depth of 22 ft.
- Treatment used heated air, soil vapor extraction and hydrogen peroxide
- Dates of Construction: November 1993 to May 1994

Client: Theran Muggleston
(formerly with MK)
MK Ferguson of Oak Ridge
PO Box 2011
Oak Ridge, TN 37831

Contact: Douglas Davenport (formerly with Oak Ridge National Laboratory)
MSA Professional Services
1230 S. Boulevard
Barboo, WI 53913
608-356-2770

This project was the first ever full-scale use of Shallow Soil Mixing to treat and remove contaminates from the ground. Two plots (about 0.8 acres) of a former landfarm were treated. The site was contaminated with waste oils and degreasing solvents, primarily trichloroethylene, and radioactive wastes. A full-scale testing program was also enacted using hydrogen peroxide as a chemical reagent. Auger mixing was performed using 8, 10, and 12 ft diameter augers with 8 ft being selected as the optimum size. The treatment involved injecting heated air and mixing the soils with Shallow Soil Mixing (SSM). A shroud was used to cover the mixing zoning which was connected to an off gas treatment unit.

Mr. Day served as the estimator, District Manager, chief engineer, and quality assurance supervisor for the contractor. He wrote or was responsible for all work plans, was responsible for the profitability of the project, and oversaw the staffing and equipment employed on the project.

This project was summarized in a report published by the Department of Energy in an Innovative Technology Report prepared by Colorado Center for Environmental Management and Oak Ridge National Laboratory. Mr. Day assisted in preparing the report.

Additional Reactive Barrier projects completed under the direction or with the assistance of Mr. Day include:

Permeable Reactive Barrier Wall at Bear Creek Valley, Oak Ridge, TN for DoE
1997: First-ever Reactive Barrier constructed by the Bio-Polymer trench method.
Contact: Bill Zaist, Avisco, Knoxville, TN, 423-689-6383

Removal of Source Materials from North Gas Holder for Georgia Power
1997: Pilot project using heated air and pozzolans injected by SSM to remove toxic vapors from buried MGP waste.
Contact: Mark McCade, ThermoRetec, Concord, MA, 508-371-1422

The following person and firm may also be contacted as a reference:

Stephanie O'Hannesin
EnviroMetals Technologies
745 Bridge Street, Suite 7
Waterloo, Ontario, Canada N2V 2G6
519-746-2204

Staff Resume – Permeable Treatment Walls

Steven R. Day
Vice President/Slurry Specialist

INTRODUCTION

Mr. Day manages the Colorado office of Geo-Solutions concentrating on projects in the American west. Mr. Day has over 25 years of engineered construction experience. He has special expertise in permeable reactive barriers, trenching, slurry walls, grouting, and soil mixing. Mr. Day has participated in a number of innovative projects including first of a kind projects for permeable reactive barrier constructed with bio-polymer slurry, insitu soil mixing to treat contaminated soils, bio-polymer slurry trench drains, attapulgite slurry walls, and others. He has also participated in a number of research studies for the implementation of geotechnical solutions on special projects including funded research for US EPA, DoE, DoD, EPRI, and a number of private industry and consulting clients.

CREDENTIALS

Education

BS Sociology & Economics	So Dak. State University	1973
BSCE Civil Engineering	University of Utah	1982
MSc Geotechnical Engineering	University of Texas	1984

Hazwoper 40 hr. training plus annual updates

Professional Licenses

Licensed Contractor in several states including: Utah, Arizona, California, North Carolina, South Dakota and Mississippi.

Professional Societies/Affiliations

American Society of Civil Engineers (served on Environmental Geotechnics committee)
American Society for Testing and Materials (served on Hydrologic Properties (standard D-5084) and Hydraulic Barriers subcommittees)
Association of State Dam Safety Officials
Geo-Institute
International Containment Technology (served on workshop committee, co-authored Assessment of Barriers, and lead trainer for Quality Control of Vertical Barriers)
Technical Information Exchange of DOE (served as technology vendor representative)

Experience Synopsis

Mr. Day has had a long and distinguished career in geotechnical engineering and construction. He has managed, supervised, and built nearly every kind of slurry trench, biopolymer trench, and soil mixing project. In addition, he has significant experience in grouting and soil improvement. His roles have ranged from superintendent to project engineer, to project manager and Vice President. His background includes multiple projects in each of the following areas:

Slurry cut-off walls	Bio-Polymer Trench Drains	Pressure Grouting
CB cut-off walls	Permeable Reactive Barriers	Insitu Soil Treatments
SCB slurry walls	Jet Grouting	Composite Barriers
Deep Soil Mixing	Utility Construction	Earthwork
Shallow Soil Mixing	Landfill Construction	Synthetic Liner Installation

PROJECT EXPEREIENCE (Selected Examples)

Reactive Barrier Wall for confidential client at North Vancouver, BC

- Project included of 3 trenches 8.2 ft (2.5 m) wide and 6.5 ft wide (2 m), a total of 1750 ft long and up to 59 ft (18 m) deep all constructed by the bio-polymer slurry technique. The trenches were backfilled with a patented mixture intended to promote sulfate-eating bacteria to treat metal contamination in the groundwater.
- Due to use of bacteria in the media, no preservatives were allowed in the slurry.
- Largest permeable reactive barrier constructed to date.
- Dates of Performance: November 2000 to March 2001

Client and Contact: Michael Mattson
Matcon Excavating
4481 – 232nd Street
Langley, B.C Canada V2Z 2S2
604-530-1402

Client:
Confidential

Zero-Valent Iron Wall for A&B Jacobson, LLC at Seattle, WA

- Two - zero valent iron gates constructed with BP slurry up to 35 ft deep and cement-bentonite funnel 320 ft long
- Project was completed to replace pump & treat system and permit commercial development
- Dates of Performance: October 1999

Owner: Al Jacobson
A&B Jacobson, LLC
300 Admiral Way, Suite 209
Edmonds, WA 98020
425-744-9765

Client:
Remtech Inc.
1803 99th Street East
Tacoma, WA 98445

Phase II Funnel and Gate at former Aptus Site for CBS at Coffeyville, KS

- 100,000 sf of soil-bentonite slurry wall up to 35 ft deep constructed for groundwater funnel
- Two – zero valent iron gates constructed with sheet piles by client
- Dates of Performance: Sept. to Nov. 1999

Client and Contact: Dennis Metz
ThermoRetec Corporation
1726 Cole Blvd, Bldg 22
Golden, CO 80401
303-271-2100

Owner: Leo Brauch
CBS Corporation
11 Stanwix Street
Pittsburgh, PA 15227
412-642-3922

Proof of Concept Project at P.E.C Site for confidential client, Vancouver, BC, Canada

- Permeable reactive barrier (PRB) pilot project, 50 ft deep, 50 ft long and 8 ft wide
- Engineered biological media installed by the bio-polymer trenching method

- Dates of Performance: December 1999.
  Client and Contact: Michael Mattson   Owner: Confidential
  Matcon Excavating
  4481 – 232nd Street
  Langley, B.C Canada V2Z 2S2
  604-530-1402

Peer-Review of Permeable Reactive Barriers for US Department of Energy

- Review and Recommendations for two PRBs installed at Oak Ridge, May 1999.
- Review and Recommendations for PRB Technology Improvements at five DoE facilities, May 2000.
- Review and Recommendations are published and provided for Congressional Oversight of DoE.

Client and Contact: Dr. Alan Moghissi
Institute for Regulatory Science
5457 Twin Knolls Road
Columbia, MD 21045
301-596-1700

The following projects were completed under the supervision of Steve Day, Vice President of Geo-Solutions, while he was employed by Geo-Con. Mr. Day was directly responsible for the construction of these projects and instrumental in introducing geotechnical construction techniques for reactive media installations.

Soil Treatment in 317 French Drain Area for Department of Energy at Argonne, IL.

- 20,000 cy treated up to 25 ft deep
- Treatments used granular iron, hot air, steam, potassium permanganate, engineered bacteria, humic acid, soil vapor extraction, guar gum slurry and proprietary additives.
- Dates of Performance: November 1996 to May 1997.

In-Situ Soil Mixing & Treatment for the Department of Energy at Kansas City, Mo

- 18 columns 25 and 47 ft deep with 8 and 10 ft diameters
- Treatment used heated air, potassium permanganate, engineered bacteria, lime and water
- Dates of Construction: May to July 1996

X-231B Soil Remediation for the Department of Energy at Piketon, Ohio

- 28,000 cy treated to a depth of 22 ft.
- Treatment used heated air, soil vapor extraction and hydrogen peroxide
- Dates of Construction: November 1993 to May 1994

Permeable Reactive Barrier Wall at Bear Creek Valley, Oak Ridge, TN for DoE

- First-ever Reactive Barrier constructed by the Bio-Polymer trench method.
- 225 ft long, 3 ft wide, and up to 20 ft deep
- Dates of Construction: Winter 1997

The following person and firm may also be contacted as a reference:

Stephanie O'Hannesin
EnviroMetals Technologies
745 Bridge Street, Suite 7
Waterloo, Ontario, Canada N2V 2G6
519-746-2204

APPENDIX E

TECHNICAL INFORMATION ON PERMEABLE REACTIVE BARRIERS

Successful Remediation of Solvent-Contaminated Groundwater Using a Funnel and Gate Constructed by Slurry Trench Methods

Steven R. Day[1], Jeremy Porter[2], Barry Kellems, P.E.[2], and Doug Hillman, P.G.[2]

ABSTRACT: One of the more difficult problems facing our cities is the reuse of former manufacturing facilities. In Seattle, WA, a former manufacturing site was contaminated with chlorinated solvents. Previous attempts to cleanup the site using pump and treat systems failed because the soils were heterogeneous, making it difficult to control the contamination. The owner and his consulting engineer decided that the technology with the highest probability of success for the site was a funnel and gate system using zero-valent iron to treat the groundwater. In 1999, reactive iron treatment was generally well accepted, but construction methods for its installation in deep trenches were still developing. As a result the owner, the engineer, and a slurry trench engineer developed and implemented an innovative plan to install a funnel and gate system up to 35 ft deep, using cement-bentonite (CB) slurry walls for the funnels and bio-polymer degradable slurry to install the iron-filled gates. One year after installation measured chlorinated solvent destruction efficiencies are greater than 95%. Downgradient from the gates, natural attenuation processes, including intrinsic biodegradation, are further reducing solvent concentrations to below surface water cleanup standards before reaching a public waterway less than 200 ft from the site.

INTRODUCTION: In the Ballard district of Seattle, WA, the previous operations of a defunct window manufacturer resulted in chlorinated solvents in the groundwater on a site that is now desirable for commercial and residential development. The site was used for metal anodizing, painting, and light manufacturing from the 1940's until 1989. Furthermore, the site is within 200 ft of the Lake Washington Ship Canal and adjacent to a public area that is the third most popular tourist destination in the city. Existing buildings on the site, railroad tracks, public walkways, and nearby properties preclude large excavations for the remediation. The site was also used as a path for joggers and tourists.

The groundwater plume consisted of tetrachloroethylene (PCE) and its degradation products trichloroethylene (TCE), cis-1,2-dichloroethene (cis-DCE), and vinyl chloride (VC). Two potential source areas were identified with maximum detected constituent concentrations in groundwater of 50 mg/L PCE, 23 mg/L TCE, 8 mg/L cis-DCE, and 0.8 mg/L VC. Areas of high pH (up to pH 12) were also found in the groundwater. Upper soil layers consisted of heterogeneous fill material overlying stratified estuarine deposits, forming two distinct water-bearing zones. Chlorinated solvents were found up to 32 ft deep beneath the surface where a dense, relatively impermeable till tends to prevent vertical migration of contaminants.

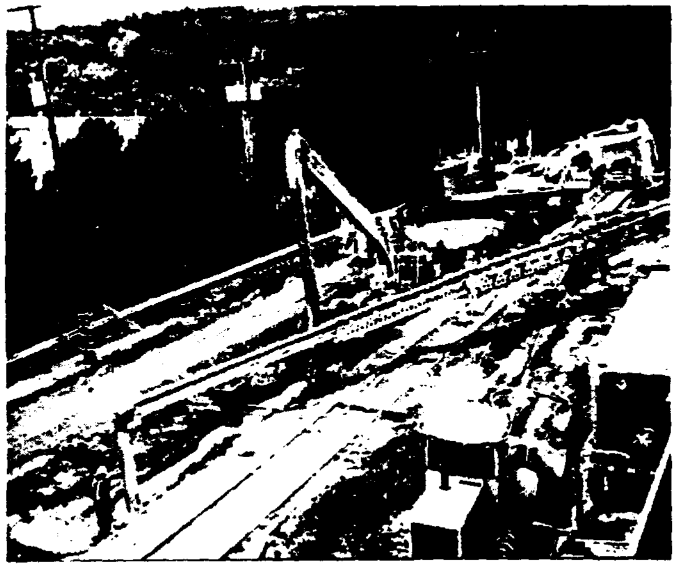
Prior to construction, the site was a narrow, paved parking lot and gravel alley separated by an active railroad track. From fence line to building line the site was only about 70 ft wide, including the railroad track. The alley provided access to an unloading dock with a 4 ft depressed passageway between the railroad tracks and the loading

1. Geo-Solutions, Littleton, CO
2. Hart Crowser, Seattle, WA

docks. A domestic water pipe, storm and sanitary sewers, monitoring wells, bollards, overhead wires, and underground vaults all were located on the site.

DESIGN: The combination of chlorinated solvents in the groundwater and the heterogeneous soils presented the primary challenges to the remedial design. The potential depth of DNAPL occurrences would have made excavation prohibitively difficult and expensive, while soil heterogeneities limit the effectiveness of many in-situ treatment technologies. A permeable reactive barrier (PRB) is an in-situ technology that treats chlorinated solvents in groundwater and is not limited by soil heterogeneities. This technology uses zero-valent iron, which can destroy PCE and TCE dissolved in groundwater with reductive dehalogenation. In order to determine the amount of zero-valent iron required, a bench scale test was conducted. The testing program considered the site contaminants, use of bio-polymer slurry and type of iron. The results of the test provided the recommended residence time and wall thickness.

Using the results of the bench test, the designers devised a layout for the funnel and gate. The design had to recognize the constraints of the site and the effect on construction, as well as on the final development of the site. A 330-foot-long funnel and gate, consisting of three CB cutoff walls (funnels) and two 45-foot-long permeable reactive gates, was designed to capture and treat the chlorinated solvent plume. The 3-foot wide gates were designed with a 50/50 mixture of iron filings and sand. The gates were designed to be constructed using biodegradable, guar-based slurry, which avoided the need to drive sheet piling saving significant cost. The barrier was imbedded three feet into the dense, impermeable till layer to prevent underflow.



In addition to the funnel and gate, the design considered natural attenuation and methods to enhance attenuation. In developing the final wall thickness, natural attenuation of the solvents between the wall and the ship canal was considered. The model was a numerical description of the advective/dispersion equation, using empirically derived decay rates. As a contingency, a system of wells was designed to inject oxygenating compounds downgradient of the funnel and gate, in case the funnel and gate failed to perform as expected. Finally, disposal of excess soils resulting from construction was considered. After testing and meeting acceptance criteria, excess soils could be reused as fill to level the loading dock area.

CONSTRUCTION: Construction of the funnel and gate began with a number of site preparation activities including removing asphalt, removing a guard shack, installing security fencing, setting up a slurry mixing and pumping plant, and designating soil staging areas. Due to the close proximity of the public, the owner made personal visits to many of the nearby business and carried out a concerted effort to make the public aware of the construction activities planned for the site. Once these measures were in place excavation of the slurry trench began to form the funnels. Each of the funnels was constructed by excavating under CB slurry. Within a few days the CB hardened to a clay-like material that is relatively impermeable. During the construction of the funnel various obstruction including sewer pipes, a water line, and the railroad track were crossed. Still, unexpected events kept the construction team from becoming complacent. Shortly after the railroad was crossed and the tracks replaced, the funnel was being constructed around a deep sewer that caused the trench to be nearly 10 ft wide at the surface. While the trench was being filled with CB slurry a fully loaded and unscheduled train came down the tracks and passed within 10 ft of a 30 ft deep trench supported only by slurry. Although this caused concern, the train caused no damage.

The gate sections were constructed by excavating under a bio-polymer slurry composed of guar gum, additives, and water. After excavation, two temporary wells were installed in each gate prior to backfilling with the iron/sand mixture. The iron/sand mixture was made by adding 3000# bags of granular iron into readymix trucks on site, and turning the drum to mix the sand and iron. After mixing, the iron/sand was conveyed to the trench using a truck-mounted ladder conveyor. The conveyor was equipped with a tremie pipe that deposited the iron/sand directly into the trench under the slurry. After backfilling, the temporary wells were pumped while adding breaker enzymes, and recirculating the slurry over the top of the iron/sand. This caused the slurry to degrade without the need for disposal. After a few days of recirculating, the viscosity of the bio-polymer was reduced and the trench was ready for a final cap of compacted clay.

RESULTS OF MONITORING: Monitoring wells were installed up and down gradient of the funnel and gates. In addition, there were existing wells both up- and down gradient that were used for monitoring the changes in the groundwater resulting from the remediation. The results of the monitoring are summarized in the following table.

Compound	Upgradient	Within	Downgradient
PCE (ug/L)	36,000	32	<1
TCE (ug/L)	11,000	8.9	3.4
cis-DCE (ug/L)	8,000	60	470
VC (ug/L)	610	16	110

Contamination downstream of the funnel and gate continues to improve as the plume that formerly existed in this area dissipates. Groundwater elevation data indicate that the funnel and gate system is effectively controlling the plume and contamination is not migrating above, below or around the wall.

CONCLUSIONS: The use of an innovative funnel and gate remedial technology has allowed a contaminated site to be redeveloped into a useful property. The innovative construction method was the low cost solution for barrier installation; avoided the need for shoring; eliminated dewatering and residual water management; and minimized impact to utilities.

Examples of PRB Treatment Materials

1. **Iron PRBs for VOCs** – R.W. Gillham, 1999. In-situ remediation of VOC-contaminated groundwater using zero-valent iron: Long-term performance. Presented at the 1999 Contaminated Site Remediation Conference "Challenges Posed by Urban & Industrial Contaminants" organized by The Centre for Groundwater Studies, Fremantle, Western Australia, March 21-25, pp. 11.

2. **Activated Carbon for PAHs** - Hermann Schad, Raindre Klein, Brigitte Haist-Gulde and Bertram Schulze, 2000 – Funnel-and-Gate at the Former Manufactured Gas Plant Site in Karlsruhe: (1) Hydraulic Design and Sorption Test Results. Consoil2000 in Leipzig, September 18- 22, 200 – Remediation Strategies and Technologies.

3. **Activated Carbon for Pesticides** – Dean Williamson, Karl Hoenke, Jeff Wyatt, Andy Davis and Jeff Anderson, 2000. Construction of a Funnel-and-Gate Treatment System for Pesticide-Contaminated Groundwater. Chemical Oxidation and Reactive Barriers Remediation of Chlorinated and Recalcitrant Compounds. Presented at the Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 22-25, 2000.

4. **Organic Carbon Barriers for Trace Metals** – D.J.A. Smyth, D.W. Blowes, S.G. Benner, A.H.M. Hulshof, 2001. In Situ Treatment of Acid Mine Drainage in Groundwater Using Permeable Reactive Materials. and The Removal of Arsenic from Groundwater Using Permeable Reactive Barriers (PRBs). Abstracts 2001 International Containment and Remediation Technology Conference and Exhibition, June 10-13, Orlando, Florida.

5. **Granular Activated Carbon for Petroleum Derivatives** – Kent O'Brien, Gary Keyes and Neil Sherman, 1997. Implementation of a Funnel-and-Gate Remediation System. Presented at the 1997 International Containment Technology Conference and Exhibition, St. Petersburgh, Florida, Feb. 9 – 12.

In Situ Remediation of VOC-Contaminated Groundwater Using Zero-Valent Iron: Long-Term Performance

R.W. Gillham
Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada, N2L 3G1

ABSTRACT: Since introduced in 1992, the use of granular iron for in situ cleanup of groundwater containing chlorinated organic chemicals has gained substantial recognition as a cost-effective remediation alternative. Implementation generally involves the emplacement of a permeable granular iron wall across the path of a contaminant plume. Because capital costs can be high, the cost advantage relies on the expectation of low operating and maintenance costs over long periods of time. It can readily be shown that consumption of the iron by chemical processes is not a significant factor. However, long-term performance may be influenced by precipitates that form as a consequence of the dechlorination reactions or as a consequence of pH changes in the reactive material. This paper reviews the processes that have been identified as potential sources of precipitates and the evidence concerning the effect that these may have on long-term performance.

KEYWORDS: chlorinated solvents, groundwater, remediation, reductive dechlorination, granular iron

INTRODUCTION

The potential for using granular iron for the in situ remediation of groundwater containing chlorinated organic contaminants was recognized in 1989. In the intervening decade, the technology has become a major topic of environmental research, leading to a much improved understanding of processes, pathways and potential limitations. In addition, the technology was commercialized in 1992 through an Ontario company, EnviroMetal Technologies Inc. (ETI), and is rapidly gaining acceptance as a cost-effective groundwater cleanup technology. ETI currently lists 36 installations; 22 of which are full-scale applications at commercial sites, while the remainder are demonstration facilities. Of particular note, 18 of the 22 full-scale systems have been installed within the past two years, indicating the growing commercial acceptance of the technology. Though the greatest activity is in the United States, the technology has also gained international scope, with installations in Australia, Denmark, Germany and Great Britain.

Implementation generally involves the excavation of a trench across the path of a contaminant plume. The trench is then filled with granular iron forming a permeable treatment wall. As contaminated water passes through the "wall", passively under natural hydraulic gradients, the contaminants are degraded, allowing uncontaminated water to emerge on the down-gradient side. Alternatively the technology can be applied in a "funnel and gate" configuration, where impermeable funnel sections direct the groundwater through permeable reactive zones (gates).

Numerous factors affect the cost of installation, with cross-sectional dimensions of the plume,

Gillham, R.W., 1999. In-situ remediation of VOC-contaminated groundwater using zero-valent iron: Long-term performance. Presented at the 1999 Contaminated Site Remediation Conference "Challenges Posed By Urban & Industrial Contaminants" organized by The Centre for Groundwater Studies, Fremantle, Western Australia, March 21- 25, pp. 11.

Though a step-wise dechlorination process was proposed initially, low concentrations of intermediate degradation products (Orth and Gillham, 1995, for example) argued otherwise. In the degradation of chlorinated ethenes such as trichloroethene (TCE) or tetrachloroethene (PCE), degradation products, including the dichloroethene (DCE) isomers and vinyl chloride (VC), generally accumulates to only a few percent of the concentration of the initial compound. Roberts et al. (1996), using Zn as the metal reductant, showed chloroacetylene to be an intermediate, which, being highly unstable, rapidly degrades to chloride and ethene. While significant with respect to the degradation of chlorinated ethenes, the work of Roberts et al. is equally important in demonstrating that compounds can degrade following multiple and simultaneous pathways.

The work of Sivavec and Horney (1995) is significant in showing that iron surfaces are seldom clean, and particularly in the case of granular iron materials that are used for commercial installations, the iron is coated with a thick layer of iron oxyhydroxides. It is recognized that the electron transfer for dechlorination must occur at the surface of the oxide coating rather than at the metallic iron surface. Thus, to be effective, the materials coating the iron must be conducting with respect to electron transfer.

First-order degradation rates have been reported by numerous investigators and for several compounds. To provide a basis for comparison, it is common to normalize the rates to 1 m^2 of iron surface area per millilitre of solution. Summary tables of reported rates for common groundwater contaminants are included in Gillham (1996), Johnson et al. (1996) and Tratnyek et al. (1997). Half-lives range from a few minutes to several hours, depending upon the compound, the source of iron and geochemical characteristics of the groundwater. Considering the chlorinated ethenes for example, as representative numbers, Tratnyek et al. (1997) suggest:

PCE - 20 min	t12DCE - 350 min
TCE - 110 min	c12DCE - 1000 min
11DCE - 650 min	VC - 830 min

Because iron materials used in commercial installations commonly have specific surface areas greater than 1 $m^2\ ml^{-1}$, design half-lives are frequently lower than those indicated above. Nevertheless, because of the variability that has been encountered, for design purposes it is normally recommended that half-lives be measured in the laboratory using the iron material that is likely to be used in the installation and contaminated groundwater from the site.

Because the degradation process is first-order, the half-life provides a convenient basis for design. As a useful "rule of thumb", a decrease in concentration of three orders of magnitude requires ten half-lives. For example, to reduce the concentration of PCE from 1,000 $\mu g\ L^{-1}$ to 1 $\mu g\ L^{-1}$ would require a residence time, using the half-life of Tratnyek et al. (1997), on the order of 200 min. Thus, if the groundwater velocity is 30 cm day^{-1}, a wall thickness of about 4 cm would be required. Though instructive, the above calculation is misleadingly simple. In practice the potential formation of chlorinated degradation products and the time required for these to degrade must be incorporated into the design, as should the lower degradation rates associated with normal groundwater temperatures. The above calculation also assumes that the porosity (and thus the velocity) in the granular iron is the same as the porosity of the geologic material. Also, the uncertainty in the estimated groundwater velocity will have a major influence on safety factors incorporated into the design.

1998) that the iron hydroxide formed initially is converted over a short period of time to magnetite (Fe_3O_4). The 7.2 x 10^{-5} moles of Fe^{2+} released to solution would produce 2.4 x 10^{-5} moles of magnetite, having a molar volume of 44.6 cm^3. Thus the volume of iron precipitate formed would be 1.1 x 10^{-3} cm^3 day^{-1}. Subtracting the volume of iron consumed (3.9 x 10^{-3}/7.8 = 5 x 10^{-4} cm^3) gives a net loss of pore space of 6 x 10^{-4} cm^3 in the 30 cm^3 element. Assuming a porosity of 50%, this represents a loss of 0.004% of the initial porosity per day. Further, considering a specific surface area of 1.4 m^2 g^{-1}, the precipitate produced in one day, if distributed evenly, would result in a coating 3.6 x 10^{-10} cm thick over the entire surface area.

In addition to iron precipitates, the increase in pH as a consequence of equation (1) causes a shift in the carbonate equilibrium, from bicarbonate to carbonate with a consequent precipitation of carbonate minerals, particularly calcium carbonate. Though highly variable in concentration, most groundwaters contain significant amounts of calcium and bicarbonate and thus the formation of calcium carbonate precipitates must be anticipated.

For each mole of Ca^{2+} removed from solution, one mole of $CaCO_3$ will be produced, and using an average molar volume (35.5 cm^3 $mole^{-1}$), 35.5 cm^3 of precipitate would be formed. Thus, for each 10 mg of Ca^{2+} removed from solution 9 x 10^{-3} cm^3 of precipitate would form. Because the pH increase is generally observed very near the influent end of laboratory columns, it is reasonable to expect that carbonate precipitates would form in this region. Thus, assuming most precipitation to occur in the up-gradient 10 cm of a reactive wall, a groundwater velocity of 30 cm day^{-1}, an aquifer porosity of 30%, and a granular iron porosity of 50%, removal of 10 mg/L Ca^{2+} would form 7 x 10^{-5} cm^3 day^{-1} of precipitate, which, if deposited uniformly over the up-gradient 10 cm of the wall, would result in a reduction of the initial porosity at a rate of 1.4 x 10^{-3}% per day or about 0.5% per year. Adding porosity losses due to the precipitation of Fe^{2+}, as calculated previously, the total porosity loss in the up-gradient portion of the wall would be approximately 2% per year.

Clearly the rate of precipitate formation is strongly dependent upon the rate at which water is entering the reactive zone and the inorganic chemistry of the influent water. For water high in Ca^{2+} and with high alkalinity, losses of initial porosity of 2 to 5% per year could be anticipated. Nevertheless, even at these rates, reactive walls should maintain substantial porosity (and thus permeability) over periods of at least 5 to 10 years.

Evidence from Laboratory Tests

Early tests of precipitate formation in laboratory columns are reported in Mackenzie et al. (1995). Columns were packed with coarse granular iron, and in order to accelerate aging, high flow rates of a highly mineralized water were used. White precipitate, identified as calcium carbonate appeared initially at the influent end of the column, and the precipitate front migrated along the column with the passage of time. There was a significant decline in permeability over time; however, no attempt was made to quantitatively relate the decline in permeability to the amount of precipitate formed. Of particular note, the reactivity of the column with respect to the degradation of TCE did not decline substantially. Thus it appears that the structure of the carbonate precipitate was sufficiently open to allow access of the TCE to the iron surfaces. Mackenzie et al. (1995) also noted iron oxide precipitate at the influent end of the column as a consequence of oxygen removal from the influent water.

Schuhmacher (1995) studied precipitate formation in laboratory columns containing high-

Field Demonstration at CFB Borden

The first field demonstration of the technology was initiated at a test site at Canadian Forces Base Borden in Ontario in 1991, and was terminated in 1996. Details of the test are given in O'Hannesin (1993) and O'Hannesin and Gillham (1998).

A reactive wall consisting of 22% granular iron by weight mixed with 78% coarse sand was constructed across the path of a contaminant plume containing approximately 268 mg L^{-1} TCE and 58 mg L^{-1} PCE. Groundwater velocity was approximately 9 cm day^{-1} and the wall was 1.5 m thick in the direction of flow. About 90% of the TCE and 86% of the PCE was removed as the groundwater passed through the wall, with no apparent change in performance over the five-year duration of the study. As expected on the basis of first-order kinetics, the concentrations of TCE and PCE declined exponentially with distance travelled through the wall, with most of the mass removal occurring within the first 50 cm of travel distance. Using laboratory tests of rates of hydrogen evolution as a measure of reactivity, the granular iron used in the demonstration was shown to be less active than materials currently used in commercial applications. O'Hannesin and Gillham (1998) suggest that had a more reactive iron been used, or had a greater proportion of iron been used in the iron-sand mixture, complete removal of TCE and PCE could have been achieved.

Of particular relevance to this paper, the total dissolved iron concentration was < 0.5 mg L^{-1} in up-gradient sampling points, and ranged between 1 and 7 mg L^{-1} down-gradient. In addition, the Ca^{2+} concentration declined by over 150 mg L^{-1} as the groundwater passed through the iron material. Possibly because of the buffering effect of the sand included in the reactive mixture, the pH increased from 7.9 to a maximum of 8.7, rather than the 9 to 10 range commonly observed in reactors containing only iron. The results suggest significant precipitation of both iron and calcium, and at the measured pH values, the iron would be expected to precipitate as siderite rather than iron hydroxide.

Core samples of the iron-sand mixture were collected on three occasions, 1, 2 and 3.8 years after installation. These were taken on an angle such that both the up-gradient and down-gradient interfaces between the aquifer and the reactive zone were intersected. There was no visual alteration of the materials in cores collected one and two years after installation. In addition, using scanning electron microscopy (SEM), no precipitates were identified in the samples collected two years after installation. After 3.8 years, there was no cementation and no visual alteration of the material with the exception of traces of orange coloured material, assumed to be iron oxide, in the first few millimetres of the up-gradient interface. SEM also revealed traces of $CaCO_3$ and $FeCO_3$ within this same zone. As reported in Matheson (1994), very low levels of biological activity were found in the core samples collected one and two years after installation. (Biological tests were not performed on the samples collected after 3.8 years.)

Though precipitates were undoubtedly forming, with the exception of minor changes in the up-gradient few millimetres of the reactive zone, there were no visual or mechanical alterations of the reactive material after 3.8 years of operation and no evidence of significant biological activity. Based on these observations and the consistent performance with respect to dechlorination, O'Hannesin and Gillham (1998) concluded that adequate performance should persist for at least an additional five years.

with this reduction, the permeability of the wall should remain higher than that of the aquifer. The study is also important in that it provides the first field evidence that should maintenance of the wall ultimately be required, mechanical or chemical treatment of the up-gradient portion of the wall could be sufficient, rather than complete replacement.

CONCLUSIONS

The use of granular iron for in situ treatment of groundwater is rapidly gaining acceptance, supported in part by the expectation of low operating and maintenance costs. These costs are highly dependent upon the period over which a facility will maintain performance without significant intervention.

Based on knowledge of the chemical reactions and the results of early laboratory tests, it is recognized that precipitates will form within treatment zones consisting of granular iron. Though not conclusive, the evidence also suggests that these precipitates will not have a major detrimental effect on reaction rates, but could, over time, reduce the permeability such that the contaminated water would be diverted around the treatment zone.

The primary precipitates that have been identified are those of iron and calcium. The precipitation of iron is a consequence of corrosion of the iron by both water and the chlorinated compounds, while the precipitation of calcium (as calcium carbonate) is influenced primarily by the calcium and bicarbonate concentrations of the groundwater and the flux of groundwater into the treatment zone. Thus the rate of precipitate formation is certain to be highly variable and site specific.

Though there is no doubt that precipitates form, the rate of formation and the practical consequences remain uncertain. Based on the limited field evidence that is available, it would appear that even in quite unfavourable conditions, in situ treatment walls should perform effectively for a minimum of five years or more. Under favourable conditions, it is not unreasonable to expect maintenance-free performance for periods of up to twenty years or more.

To this point there is no evidence that performance of field installations has been adversely affected by precipitate formation, and therefore there has been no experience in rejuvenating walls that have become clogged. The fact that the region of greatest precipitate formation is in a narrow zone at the upgradient face should be advantageous. In particular, it should be possible to apply mechanical or chemical treatments only to this zone, rather than replacing the entire wall.

The recent increase in the number of applications of the technology is evidence of the growing confidence in the long-term performance. Nevertheless, more research is required to evaluate the effect of various types of precipitate on the reactivity of the iron surfaces, and to determine rates of precipitate formation in groundwater covering a range in chemical characteristics.

ACKNOWLEDGEMENTS

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FUNNEL-AND-GATE AT THE FORMER MANUFACTURED GAS PLANT SITE IN KARLSRUHE: (1) HYDRAULIC DESIGN AND SORPTION TEST RESULTS

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(oral presentation under topic F: Remediation Strategies and Technologies)

Abstract

Groundwater contamination by polycyclic aromatic hydrocarbons (PAH) is typical for many former manufactured gas plant sites. Most of the PAHs are very persistent in the subsurface, i.e. they are still present in high concentrations many decades after the contamination occurred and cannot be removed from the subsurface within a reasonable period of time by pump-and-treat. This persistence above all is caused by slow dissolution kinetics of the compounds from non-aqueous phase liquids, slow diffusion of the contaminants from low permeability zones (in which the pollutants have accumulated over decades) or resistant adsorption of the contaminants by the aquifer material. Fast remediation of such contaminations is only possible by excavating the contaminated soil. This, however, can only be applied at shallow sites and is still expensive. Since the remediation goal is the protection of groundwater resources downgradient from the contaminated area, in-situ treatment may be focused on the plume rather than on the source. This can be achieved using the concept of permeable reactive barriers. Within the reactive zone the pollutants can either be degraded, sorbed or precipitated through biotic or abiotic processes.

In this paper we present results of an intensive investigation program carried out for the design of a funnel-and-gate system which will be constructed in 2000 for longterm remediation of the former manufactured gas plant site of the city of Karlsruhe. The site is located within the municipal area of the city and covers approximately 100.000 m². Site investigation programs were completed in 1996 with the recommendation of funnel-and-gate as the most favourable remediation technique for that site.

The geological and hydrogeological situation at the site may be classified as typical for the upper Rhine valley. The aquifer has a thickness of about 12 m and consists of mostly sandy gravel which is underlain by a clay layer at a depth of 16 m below surface. Groundwater flow is directed towards the Rhine river northwest of the site. The contamination of the site is dominated by PAHs with Acenaphthene being the highest concentrated compound of the plume extending about 400 m downgradient from the site. Several infiltration hot spots of non-aqueous phase (NAPLs) liquids were located within the saturated zone at the site. The hydraulic conductivity of the aquifer was estimated to 4×10^{-3} m/s, the hydraulic gradient amounts to approximately 0,1 %. The groundwater flow rate from the contaminated site amounts to about 10 l/s under natural conditions.

The investigation program was set up specifically to design a funnel-and-gate system at the site and focused on two main topics:

(a) Characterization of the hydraulic properties of the aquifer and numerical modelling of the groundwater flow after installation of a funnel-and-gate system at the site
(b) Identification of processes to be considered with regard to in-situ sorption of PAHs as well as laboratory and field testing of different types of activated carbon towards a comparative evaluation of the different products

The characterization of the hydraulic properties of the aquifers included the performance of several pump tests in order to determine the spatial variability of the transmisivity of the aquifer and the measurement of flowmeter profiles at several borehole locations in order to determine to variability of the hydraulic conductivity in vertical direction. Seismic tomography was performed along two perpendicular profiles to characterize spatial heterogeneity structures of the aquifer between boreholes. Based on a statistical and geostatistical analysis of the data obtained a stochastic flow modelling approach was applied, i.e. the spatial variability of the hydraulic conductivity field is explicitly considered in the flow model. With the flow model itself different funnel-and-gate configurations (e.g. length and location of the funnel, number, size and location

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of the gates, vertical or horizontal flow within the gates) were simulated. The hydraulics of the funnel-and-gate system was determined for different regional flow situations. The overall modelling goal was to find an appropriate configuration for the funnel-and-gate system taking the site conditions into account. The field tests and modelling results show that spatial variability of the hydraulic properties may play an important role with regard to the design of funnel-and-gate systems. Multi gate systems are generally favourable; the funnel length must exceed the width of the plume in order to account for varying groundwater flow directions. A system with altogether eight gates was determined to be most appropriate for the site in Karlsruhe. Due to the overall hydraulic resistance of the funnel-and-gate system the flow rate from the site is reduced by about 15%. At each gate a flow rate of approximately 1 l/s has to be expected. The distribution of the flow rate over the vertical extension of the gates is non-uniform, which needs to be considered in the calculation of regeneration cycles of the sorption materials.

Sorption of the PAHs in the gates is intended to be achieved with activated carbon. Each gate will have a capacity of approximately 40 m^3. The sorption behaviour was investigated at the site for two different materials under quasi in-situ conditions through column tests over a period of six months. These tests showed that the anaerobic conditions present in the aquifer are maintained in the activated carbon filters and iron precipitation can be avoided. Hardly any changes of the inorganic constituents of the groundwater could be observed. It was also found that only minor microbiological activity has to be expected in the gates. From the sorption capacity of the tested activated carbon materials for the PAHs present at the site a regeneration cycle of approximately 6 years was calculated for the area with the highest acenaphthene concentrations. Towards both sides of the plume the regeneration cycles will be considerably longer. The comparison of different activated carbon materials in the laboratory showed that there is a distinct dependence of the price-performance ratio on the PAH concentration. This dependence is different for different materials.

The methodology and the results of the investigation program applied at the gas works site in Karlsruhe can be regarded to be exemplary for many other contaminated sites in alluvial aquifers. It is evident that funnel-and-gate systems require careful investigation of the aquifer hydraulics. Activated carbon proved to be suitable for in-situ filtration of PAH-contaminated groundwater under anaerobic conditions.

Furthermore, methods for the removal of vinylchloride as an additional contaminant which was detected in the groundwater flowing into the remediation site are investigated for its application in this project. Preliminary experiments have shown that the degradation of these constituents is possible by UV-radiation. The application of this method in the funnel-and-gate-system will be investigated in a pilot-scale equipment using groundwater from the contaminated site. Moreover, the possibility of the degradation of vinylchloride in a combination of reactive materials with the activated carbon will be examined in the pilot-scale equipment.

The implications of the investigation results for the technical design of the funnel-and-gate system are described in the second part of this paper (Schulze and Schad, this issue).

FUNNEL-AND-GATE AT THE FORMER MANUFACTURED GAS PLANT SITE IN KARLSRUHE: (2) TECHNICAL DESIGN AND CONSTRUCTION

Bertram Schulze[1] and Hermann Schad[2]

(oral presentation under topic F: remediation strategies and technologies)

Abstract

Unterhalb des ehemaligen Gaswerks Karlsruhe-Ost liegt eine Boden- und Grundwasserkontamination insbesondere mit polyzyklischen aromatischen Kohlenwasserstoffen (PAK), Benzol und, aus einem anderen, oberstromig gelegenen Schadensherd, Vinylchlorid vor. Most of the PAHs are very persistent in the subsurface, i.e. they are still present in high concentrations many decades after the contamination occurred and cannot be removed from the subsurface within a reasonable period of time by pump-and-treat. Fast remediation of such contaminations is only possible by excavating the contaminated soil. This, however, can only be applied at shallow sites, if the contamination zones can be located exactly and is still expensive. Since the remediation goal is the protection of groundwater resources downgradient from the contaminated area, in-situ treatment may be focused on the plume rather than on the source. This can be achieved using the concept of funnel-and-gate.

Bei funnel-and-gate wird das Grundwasser durch eine entsprechend bemessene Anordnung von Dichtwänden (funnel) passiv auf einen oder mehrere entsprechend gestaltete Reaktionsbereiche (gates) im Untergrund hingeleitet und in den gates mit einer dem Schadstoffspektrum angepaßten Technik, z.B. adsorptiv mit Aktivkohle, reaktiv mit Eisenspänen oder durch UV-Bestrahlung gereinigt.

Im vorliegenden Falle wurde ein funnel-and-gate-System entworfen, das die Ergebnisse der Sanierungsvoruntersuchungen (Schad et. al, first part of this paper) und insbesondere den Gebäude-, den Baum und den Leitungsbestand berücksichtigt. Für die Herstellung des funnels ist vorgesehen, daß eine ca. 240 m lange Spundwand unter teilweise beengten Platzverhältnissen bis zu 17 m tief in den Untergrund gepreßt wird. Dabei werden zunächst mitteldicht bis dicht gelagerte sandige Kiese, z.T. mit Steinen, durchfahren; der Aquifer wird nach unten von einem tonig-schluffigen Stauhorizont abgeschlossen. Eine erschütterungsarme Einbringtechnik ist wegen der Nähe der funnel-Trasse zu einigen denkmalgeschützen Gebäuden erforderlich. Die Eignung von Preßverfahren wurde im Sommer 1999 in einem Testfeld auf dem Gelände nachgewiesen.

Wegen der beengten Platzverhältnisse und wegen städtebaulicher Neuplanung in Teilen der funnel-Trasse kam die Herstellung großer Baugruben für den Einbau der gates nicht in Frage. Deshalb werden nun insgesamt 8 "kleine" gates im Großloch-Bohrverfahren (d = 2.50 m) hergestellt und mit einer neu entwickelten Technik an die Spundwand dicht angeschlossen.

Die Ausmaße der baulichen Maßnahmen und die Tatsache, daß der planmäßige Betrieb der unterirdischen Reaktoren durch eine geeignete Bautechnik sichergestellt sein muß, machen das vorliegende Vorhaben zum weltweit größten Anwendungsfall für die funnel-and-gate-Technik.

Die wasserrechtliche Erlaubnis für dieses Verfahren liegt zwischenzeitlich vor. Planmäßiger Baubeginn ist Juni 2000. Die Baumaßnahme ist voraussichtlich im November 2000 abgeschlossen.

Der vorliegende Beitrag beschreibt die Planung des neuartigen "multi-gate"-Systems und die Erfahrungen, die bei der Spundwand-Probepressung im Sommer 1999 gemacht wurden.

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FUNNEL-AND-GATE AT THE FORMER MANUFACTURED GAS PLANT SITE IN KARLSRUHE, GERMANY: DESIGN AND CONSTRUCTION

Dr. Hermann Schad[1] and Dr.-Ing. Bertram Schulze[2]

Abstract

In this paper we present the current status of the design of a funnel-and-gate system which will be constructed in 2000 for long-term remediation of the former manufactured gas plant site of the city of Karlsruhe. The site is located within the municipal area of the city and covers approximately 100.000 m². Site investigation programs were completed in 1996 with the recommendation for funnel-and-gate as the most favourable remediation technique for that site. The design of the system is based on a specific investigation program which was carried out during the last two years including hydraulic studies as well as laboratory and field testing of different sorption materials.

The aquifer has a thickness of about 12 m and consists of mostly sandy gravel which is underlain by a clay layer at a depth of 16 m below surface. The contamination of the site is dominated by PAHs with Acenaphthene being the highest concentrated compound of the plume extending about 400 m downgradient from the site. Several infiltration hot spots of non-aqueous phase (NAPLs) liquids were located within the saturated zone at the site. The groundwater flow rate from the contaminated site amounts to about 10 l/s under natural conditions.

An investigation program was set up specifically to design a funnel-and-gate system at the site and focused on the following topics:

(a) Characterization of the hydraulic properties of the aquifer including several pump tests in order to determine the spatial variability of the transmissivity of the aquifer. Seismic tomography was performed along two perpendicular profiles to characterize spatial heterogeneity structures of the aquifer between boreholes.

(b) Numerical modelling of the groundwater flow after installation of a funnel-and-gate system at the site in order to design the system (e.g. length and location of the funnel, number, size and location of the gates, vertical or horizontal flow within the gates).

(c) Identification of processes to be considered with regard to in-situ sorption of PAHs as well as laboratory and field testing of different types of activated carbon towards a comparative evaluation of the different products.

The modelling results show that multi gate systems are generally favourable. A system with altogether eight gates was determined to be most appropriate for the site. At each gate a flow rate of approximately 1 l/s has to be expected. The distribution of the flow rate over the vertical extension of the gates is non-uniform, which needs to be considered in the calculation of regeneration cycles of the sorption materials.

Sorption of the PAHs in the gates (40 m³ each) is intended to be achieved with activated carbon. The sorption behaviour was investigated at the site under quasi in-situ conditions through column tests over a period of six months. These tests showed that the anaerobic conditions present in the aquifer are maintained in the activated carbon filters and iron precipitation can be avoided. From the sorption capacity a regeneration cycle of approximately 6 years was calculated for the area with the highest acenaphthene concentrations.

The funnel-and-gate system will consist of approximately 240 m funnel and eight gates. The funnel will be constructed using sheet piling down to a maximum depth of 17 m and will be keyed into the clay layer. The gates will be constructed via cased large diameter (d=2,5 m) borings into which perforated steel or HDPE-tubings (d=2,0 m) will be introduced. After completing the gates the casing has to be removed in order to connect the funnel segments with the gates.

The design of the entire funnel-and-gate system has been already approved by the regulatory agencies. It is planned to install the system, which will be one of the largest funnel-and-gates worldwide, between June and November 2000.

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CONSTRUCTION OF A FUNNEL-AND-GATE TREATMENT SYSTEM FOR PESTICIDE-CONTAMINATED GROUNDWATER

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ABSTRACT: Over thirty years of handling and blending pesticides at the Marzone Superfund site, Tifton, Georgia, resulted in soil and groundwater contamination. Contaminants detected at the site include DDT, Toxaphene, Atrazine, Dieldrin, Chlordane, Lindane, alpha-BHC, Endosulfan, methyl parathion, xylene, and ethyl benzene. Faced with implementing a Superfund Record of Decision (ROD) specifying a pump-and-treat remedy for contaminated groundwater, Chevron Chemical Company worked with CH2M HILL to evaluate passive, in-situ groundwater treatment alternatives. A Funnel-and-Gate (F&G)-type passive system was selected as a viable alternative to pump-and-treat.

The Marzone project team successfully designed, built, and started-up a full-scale F&G groundwater treatment system at the Marzone Superfund site to test its efficacy as a permanent groundwater remedy. Results from the first 1.5 years of operations indicate the system is successfully operating as intended.

The F&G system has operated since August 1998, treating approximately 1 to 2 gallons of hydrocarbon- and pesticide-contaminated groundwater per minute. Total xylene concentrations are reduced from approximately 12,000 to 20,000 ug/L in the influent to less than 1 ug/L in the effluent. Total BHC concentrations are reduced from approximately 1 to 4 ug/L to less than 0.05 ug/L in the effluent. Other contaminants are similarly removed. EPA has developed a ROD Amendment to make this system the permanent groundwater remedy.

The reactive media in the treatment gates is granular activated carbon (GAC). The gates are constructed of three subsurface, precast-concrete vessels which provide significant process flexibility. The system can operate in series, parallel, upflow, or downflow mode. The system is designed to operate in a low-flow, low-head aquifer. A process modification of the standard F&G approach, using a trench for contaminated groundwater collection, was selected to maximize hydraulic efficiency. A similar trench was used to distribute the treated groundwater downgradient of the cut-off wall.

The "funnel" portion of the system was constructed using the vibrated beam method. A proprietary technology was used to install an impermeable 4-inch-thick cut-off wall similar to a conventional soil-bentonite (SB) slurry wall, but without the excessive site disturbance associated with SB wall construction.

The biopolymer slurry method was used for construction of the collection and distribution trenches. After startup, gas accumulation within the system piping resulted in periodic flow stoppages. Vents were installed in the piping to allow the gas to escape. This enabled the system to operate more effectively and significantly decreased the frequency of flow stoppage incidents. The source of

the gas was believed to be generated by microbiological activity in the groundwater system. The amount of gas accumulating in the system decreased significantly over the first 6 to 9 months. A significant excess of TOC (on the order of 100 mg/L), above that attributable to known contamination, was also noted initially and decreased with time. The large amount of biogas in the system and initial presence of high TOC were both eventually attributed to the use of guar as part of the biopolymer slurry construction method.

INTRODUCTION

The Marzone site in Tifton, GA was formerly a regional pesticide formulation plant that operated from 1950 through 1983. Chevron Chemical Company (Chevron) owned and operated the site through 1970 followed by a succession of smaller companies including Tifton Chemical Company, Tifchem Products, Inc., Marzone Chemical Company, and Kova Fertilizer.

The 1.5 acre site is located on the edge of the city of Tifton, a sm agricultural community in southern Georgia. The facility formulated chlorinated and organophosphate pesticides (e.g., DDT and toxaphene) used to control pests on peanuts and cotton as well as the herbicide atrazine and provided large quantities of DDT to U.S. Department of Agriculture to control fire ants during the 1950's and 1960's.. During the early 1960's liquid blending equipment was added. Xylene was received, stored in bulk containers and used as the liquid carrier solvent. The pesticide formulation slate expanded over the years to include chlordane, parathion, methyl parathion, lindane, and endosulfan.

Chevron sold the facility in 1970. A series of owners continued pesticide formulating operations. Over the course of thirty three years of operation, incidental leaks, spills and actual waste disposal resulted in significant pesticide and solvent contamination of soils and groundwater at the site. In 1989, the site was placed on the National Priorities List (NPL). Chevron and two other Potentially Responsible Parties (PRPs) entered into a Consent Decree with EPA Region IV in 1990 to perform a Remedial Investigation/ Feasibility Study (RI/FS) for the site. The RI and FS were completed in 1992 and 1993 respectively. EPA issued a Record of Decision (ROD) for the Marzone Superfund Site in 199[illegible] specifying low temperature thermal desorption (LTTD) as the remedy [illegible] contaminated soil and a pump-and-treat (P&T) approach for contaminated groundwater.

In mid 1995, Chevron, EPA, the State of Georgia and other key stakeholders formed an innovative High Performance Team(HPT) to accelerate remediation activities. The HPT successfully completed the soil remediation at the Marzone site in early 1999.

GROUNDWATER CONTAMINATION AND SITE HYDROGEOLOGY

A general site plan, showing the original source area and general hydraulic gradients, is presented in Figure 1. Only the shallow surficial aquifer (to a depth of approximately 25 to 30 feet below land surface) has been affected by releases of contamination at the site. The shallow aquifer is comprised of primarily of interbedded silts and clays, with some sand lenses that may not be continuous.

Groundwater flow velocities in this aquifer unit are typically on the order of 10 to 20 feet per year, although within some thin sand layers the flow velocity could be somewhat higher than this.

The primary groundwater contaminants include xylene and several OCl pesticides, particularly alpha BHC, beta BHC and gamma BHC (lindane). Ethylbenzene and ethoprop are also present at elevated levels. The groundwater source area has an anaerobic core zone, characterized by low ORP, low dissolved oxygen, and high dissolved iron. Groundwater becomes more oxic downgradient of the former source area.

The Marzone team was concerned that the P&T approach specified in the ROD would be ineffective based on site hydrogeologic conditions. In 1997, the team prepared a FS addendum to evaluate in-situ technologies including permeable reactive barriers. As a result of the FS Addendum, the team selected a Funnel-and-Gate approach as an effective alternative to P&T. EPA agreed to allow Chevron to construct a field-scale system as a pilot test to assess its efficacy.

F&G HYDRAULIC DESIGN

Groundwater flow modeling was used to identify the optimal configuration of the F&G system. The well-known groundwater flow model MODFLOW was used to simulate the groundwater flow regime. Potential gate configurations, including one and two gate systems, were modeled to assess the number of gates required and potential size. A single gate system was predicted to be adequate by the model.

The aquifer unit of interest is a relatively low productivity aquifer, comprised of various interbedded clay, silt and sand layers. The total groundwater flow through the target treatment area was estimated by the model to be approximately 1 gallon per minute (gpm). Because of the heterogeneous nature of the aquifer, a process modification of the F&G system involving a collection trench for collecting groundwater was developed. The purpose of the collection trench was to ensure uniform collection of groundwater flowing through the system. The collection trench was designed to fully penetrate the target aquifer recovery zone. The trench was designed to be backfilled with an inert gravel media (granite) to ensure that undesirable geochemical reactions did not occur.

Similarly, a discharge trench was selected for reinfiltration of treated groundwater into the shallow aquifer downgradient of the F&G system. The location of the discharge trench was placed as far downgradient as feasible to obtain as much hydraulic driving force (system head) as possible.

Various potential locations for the F&G system were evaluated by the project team. The decision regarding where to locate the system required balancing two issues. One the one hand, the system needed to be located hydraulically downgradient of the source area far enough to capture as much of the plume as practicable. One the other hand, the further the system was placed downgradient of the source area, the longer it would take contaminated groundwater to flow though the system for treatment. Because the groundwater flow velocity at the site is on the order of 10 to 20 ft per year, placing the system

100 feet downgradient of a particular source area location would require the groundwater to flow towards it for 5 to 10 years before the groundwater received treatment. Based on a review of potential system locations, the team selected a location relatively near the downgradient edge of the most contaminated groundwater locations, but sufficiently downgradient of the source area to capture an estimated 93% of the contaminant plume mass.

F&G SYSTEM DESIGN

Several reactive media were considered for use in the treatment gate. A medium was required that was capable of removing or degrading hydrocarbons, such as xylene and ethylbenzene, as well as the OCl pesticides present in the groundwater. Granular activated carbon (GAC) was one obvious choice. Dy ic (flowthrough) bench-scale testing of GAC using contaminated site groundwater was performed by Calgon Corporation to assess GAC loading rates performance and breakthough curves. Xylene was found to be the contaminant that broke through first, prior to other hydrocarbons and pesticides.

In addition, bench-scale testing of zero valent iron (ZVI) was conducted by EnviroMetals Technologies, Inc. (ETI) on site groundwater spiked with lindane to assess the potential effectiveness of this media. Although effective for lindane degradation, the use of ZVI was concluded to be not well suited for application because of its inability to degrade xylene and ethyl benzene. GAC . selected as the reactive medium for this system.

Having decided on a reactive medium, the next task was to design the appropriate gate system. Key design criteria for GAC systems include residence time within the GAC (typically expressed as Empty Bed Contact Time [EBCT]) and surface loading rate. Additional design criteria related to issues such as constructability, accessibility, carbon change-out requirements, life cycle costs, corrosion resistance, and safety. Based on these considerations, a gate design based on the use of pre-cast concrete vaults was selected.

The number of vaults and configuration of the interconnecting piping developed based on desired process operational flexibility. Because the system was intended to be in place and operating for up to several decades, it was considered likely that the operational modes could change over time and that a different reactive medium or combination of media might be used at some future time. For these reasons, three vessels were included in the gate system with interconnecting piping that would allow operation of two vessels in series or two vessels in parallel, and both upflow and downflow modes. Thus, the system had nearly the same process flexibility that an above-grade two-vessel GAC system would have.

The selection of the design and construction approach for the cutoff wall (typically the funnel portion of a F&G system) considered various available methods, including a soil-bentonite (SB) slurry wall, use of driven sheets of various synthetic materials (e.g., Waterloo barrier) and the vibrated beam (VB) method. Each of these methods produces a cutoff wall of different thickness. Other factors considered in selecting a method for cutoff wall installation included the need to construct a portion of the cutoff wall adjacent to an activ railroad, community concern about the visual condition of the site, and the nature of subsurface conditions. The VB method was chosen based on its ability to install a cutoff wall of suitably-low permeability quickly, adjacent to railroad tracks, and without the typical surface disturbance associated with SB slurry walls. In the United States, the VB method is implemented using proprietary technology owned by Slurry Systems, Inc. (SSI).

For construction of the collection and discharge trenches, conventional excavation methods were evaluated and compared to other methods such as the biopolymer (BP) slurry method. The BP slurry method employs a gum derived from the guar bean to increase the viscosity of the water inside the trench, which holds up the trench side walls during excavation. This construction method eliminates the need for trench boxes and ensures that no personnel have to enter down into an earthen trench during construction, thus eliminating a significant safety hazard in trench construction. The BP slurry method was selected for construction of the collection and distribution trenches.

A schematic, 3-D diagram of the Marzone F&G system design is presented in Figure 3. The general locations of the system components at the site are shown in Figure 1.

F&G CONSTRUCTION AND STARTUP

Construction of the system began in July 1998 and was completed in August 1998. The construction was implemented largely as anticipated with no major system changes. The trenches were installed using the biopolymer slurry method, the cutoff wall was installed with the vibrated beam method and the GAC reactor vaults were install using a trench box.

Functional startup testing was initiated in August and September 1998. During the initial start of the system, it was observed that although a significant head difference (approximately 4 feet) was present across the system (as measured from the water elevations in GAC reactors and a piezometer in the discharge trench), no flow was observed to be occurring. Various activities were implemented to assess the cause of the lack of flow, including evaluating the settings on the valves (on/off), purging the lines to eliminate potential blockages, and backflushing the lines to the GAC reactors.

By the process of elimination and evaluation of monitoring and hydraulic data, it was concluded that the presence of gases and vapors in some of the interconnecting piping was inducing a "vapor lock" in some of the piping such that flow was being blocked. In particular, the piping leading from the GAC vaults to the discharge trench was found to be susceptible to build up of gases and vapor lock. By purging this line, it was possible to induce system flow.

The next task was to identify the source of the gases in the lines. After reviewing the data, it was concluded that the most likely source was biodegradation of guar used in the construction of the trenches, which were constructed using the biopolymer slurry method. During the construction of the trenches, significant amounts of guar were added to the water in the trench because the relatively high ambient temperatures at the site during construction made the guar biodegrade quickly, with a resultant loss of viscosity of the slurry.

Guar is a polysaccharide comprised primarily of D-mannose and D-galactose. These sugars are readily biodegradable. The influent TOC data indicated that a significant amount of TOC (over 100 mg/L), other than was attributable to site COCs, was present initially in the influent but dropped off exponentially over the ensuing months. The source of much of this TOC was considered likely attributable to the guar used during construction. Some biogas may also have been produced by biodegradation of xylenes and other site COCs.

In order to eliminate the accumulation of gases in the pipes, vents were installed at strategic locations to allow gases to vent to the atmosphere. The installation of the vents significantly reduced the problems of flow stoppage caused by vapor accumulation.

Performance of the GAC for COC Removal. Performance of the treatment system for removal of COCs from groundwater was assessed by analyzing influent and effluent groundwater samples. The system was found to remove target COCs to below the applicable cleanup standard and typically to below the applicable method detection limit.

Water Quality Observations. Generally, influent water quality entering the GAC reactors was not considered optimal for most treatment systems. Total suspended solids were in the range of 12 to 50 mg/L. Dissolved iron concentrations of up to 60 mg/L were also measured in the influent. The iron was found to generally pass through the GAC system, presumably as ferrous iron, and has not noticeably interfered with system effectiveness. Over time, however, the concentrations of several parameters, such as TSS, have decreased. Plugging of the GAC beds due to the presence of TSS has not yet been a problem in this system.

Hydraulic Performance. Groundwater elevations collected after startup of the system were compared to groundwater contours predicted by the modeling during the design stage. Generally, the actual contours were found to compare well with the modeled contours. From a hydrogeologic perspective, the data indicate the system is working as intended.

SUMMARY

Overall, the Marzone site F&G system has performed largely as intended. The system is monitored for hydraulic performance on a monthly basis to ensure it is operating. If necessary, lines are purged to eliminate trapped gases within the piping. Samples are collected on a quarterly basis to assess the performance of the GAC.

Based on the effectiveness of the system, EPA has developed a ROD Amendment that changed the recommended groundwater remedy for the site from a pump-and-treat system to the funnel and gate system.

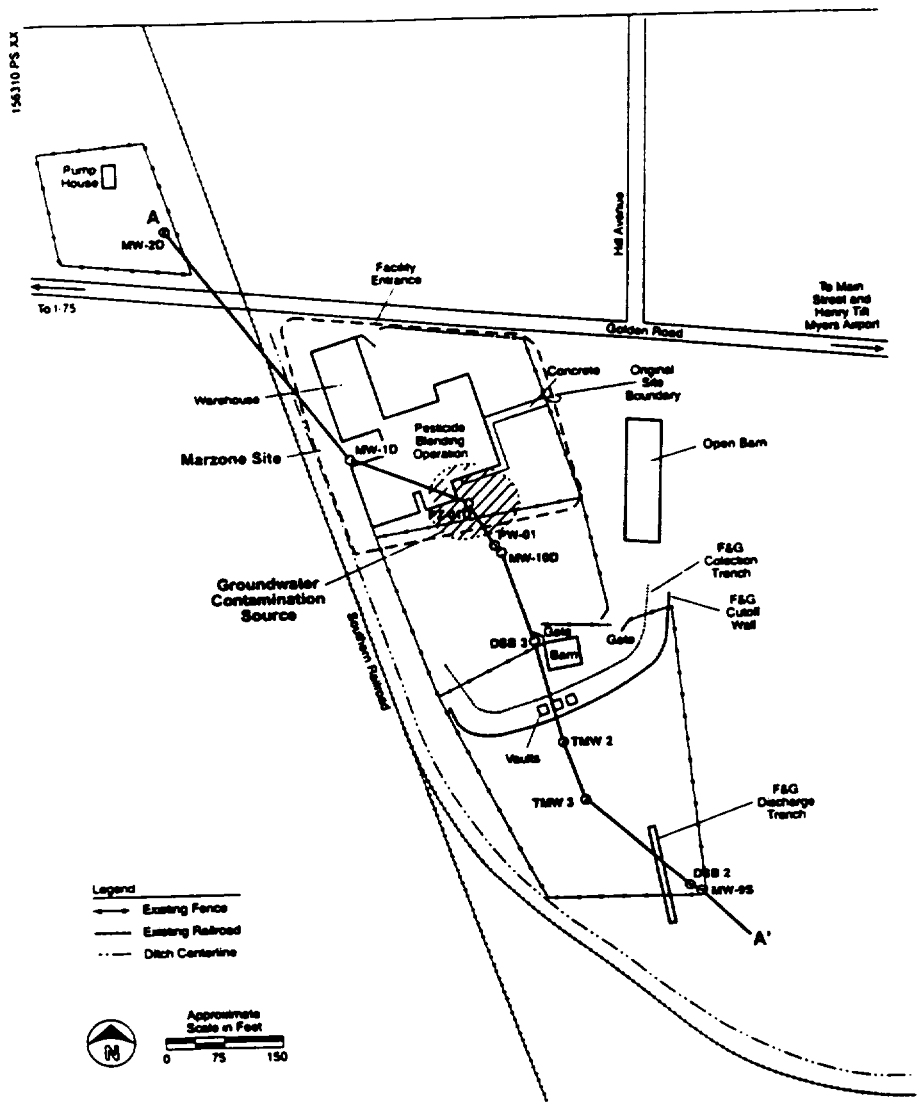

FIGURE 1
Marzone Site Layout and Cross-Section Location

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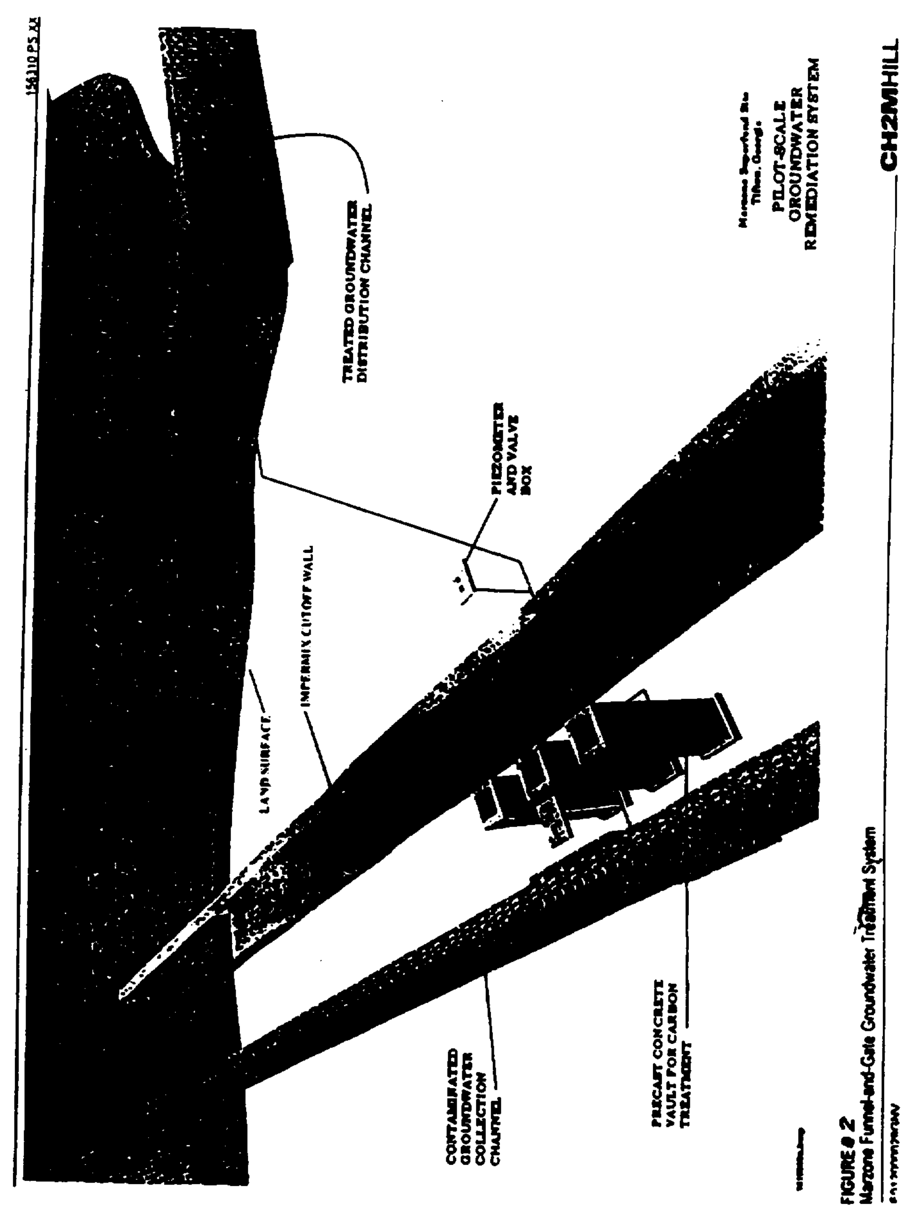
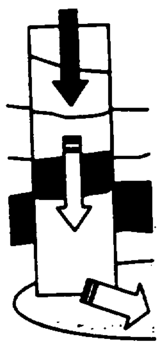


FIGURE # 2
Marzone Funnel-and-Gate Groundwater Treatment System

Chemical Oxidation and Reactive Barriers



Remediation of Chlorinated and Recalcitrant Compounds

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In Situ Treatment of Acid Mine Drainage in Groundwater Using Permeable Reactive Materials

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Acid-mine drainage (AMD) can introduce elevated concentrations of sulfate, ferrous iron and other dissolved metals to groundwater and receiving surface water. Permeable reactive barriers (PRBs) offer an approach for the passive interception and *in situ* treatment of AMD-impacted groundwater. Three field-scale applications and supporting laboratory columns in the past six years have shown that several thousands of mg/L sulfate, more than 1,000 mg/L iron, and several tens of mg/L of other metals can be removed from plume or tailings groundwater. The reactive materials, which incorporate various forms of organic carbon, promote microbially mediated sulfate reduction, the generation of hydrogen sulfide, and the subsequent precipitation of sparingly soluble iron and other metal sulfide minerals. The applications include two permeable wall PRBs for the treatment of a plume at full scale from a mine-tailings impoundment (Sudbury, Ontario) and at demonstration-scale at a former metal processing facility (Vancouver, British Columbia). These PRBs have removed iron and other metals from groundwater. Similar materials were also used to create reactive layers within control cells directly in a tailings impoundment (Timmins, Ontario) with the objective of removing iron and sulfate from the pore water before it migrates from the tailings impoundment.

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The Removal of Arsenic from Groundwater using Permeable Reactive Barriers (PRBs)

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PRBs are engineered systems that provide passive interception and *in situ* treatment of contaminated groundwater. Within the past decade, PRBs have been applied for the control and remediation of a range of organic and inorganic contaminants in groundwater. In recent laboratory batch and dynamic column tests, a selection of reactive materials that effectively attenuate dissolved arsenic in groundwater to low levels (<0.01 mg/L) have been identified. Basic oxygen furnace (BOF) slag promotes the oxidation of As(III) to As(V), which is subsequently sorbed to the BOF surface. Activated alumina also removes arsenic by the sorption of both As(III) and As(V). Zero-valent iron (ZVI) reduces As(V) to As(III), which is subsequently removed from solution by co-precipitation. In groundwater containing sulfate, ZVI and mixtures containing organic carbon can promote sulfate reduction and the subsequent precipitation of sparingly soluble arsenic and other metal sulfides. The laboratory tests have been conducted using neutral and low pH groundwater, with arsenic concentrations of as much as 4 mg/L. Groundwater chemistry, contaminant flux, the required duration for treatment, and costs for materials and installation will influence the selection of specific media for field-scale PRBs.

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Implementation of a Funnel-and-Gate Remediation System

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Abstract

A funnel-and-gate™ system incorporating activated carbon was deemed the most attractive remediation method for an active lumber mill in the western United States. Petroleum hydrocarbons, chlorinated solvents, pentachlorophenol, and tetrachlorophenol were detected in on-site groundwater samples. The shallow aquifer consists of a heterogeneous mixture of marine deposits and artificial fill, underlain by low-permeability siltstones and mudstone.

In the funnel-and-gate™ system, a low-permeability cutoff wall was installed to funnel groundwater flow to a smaller area (a "gate") where a passive below-grade treatment system treats the plume as it flows through the gate. Groundwater flow modeling focused on the inhomogeneities of the aquifer and the spatial relationship between gate(s) and barrier walls.

The gate design incorporates several factors, including contaminant concentration, flow rate, and time between carbon changeouts. To minimize back pressure and maximize residence time, each gate was designed using 1.25-meter (4-foot) diameter corrugated metal pipe filled with a 1.25-meter (4-foot) thick bed of activated carbon. The configuration will allow water to flow through the treatment gates without pumps. The installed system is 190 meters (625 feet) long and treats approximately 76 L/min (20 gpm) during the winter months.

* * *

Introduction

Funnel-and-gate™ systems are gaining attention because they minimize the lifetime costs of implementing remedial actions in situation where containment of contaminated groundwater is required. The term "funnel-and-gate" refers to the installation of low-permeability barriers downgradient of impacted groundwater which are arranged so as to direct the flow of groundwater through treatment gates (Starr and Cherry, 1994). The flow through treatment gates is driven by natural groundwater gradients, eliminating costly extraction pumps and above-ground treatment systems. The treatment gates are designed specifically to treat the groundwater contamination flowing through the gates. In addition, groundwater monitoring and system compliance issues can generally be streamlined for even greater cost savings. It is a developing technology which is currently operating successfully at a site in Mendocino County, California.

Background

Louisiana-Pacific Corporation owns and operates a studmill south of Fort Bragg in Mendocino County, California. The studmill occupies approximately 16 hectares (40 acres) of land. The mill building is located adjacent to a creek, segments of which have been filled to increase log deck capacity. The creek has also been dammed to provide the mill with fire-suppression water.

The area surrounding the mill has been developed as a residential area. Domestic water for the residences is primarily provided through shallow groundwater wells. Groundwater in the area occurs at a depth of approximately 3 meters (10 feet) below ground surface (bgs) from an aquifer consisting of sands and silty sands which extends to a total depth of approximately 4 to 6 meters (12 to 18 feet) bgs. Below this aquifer, a low-permeability weathered bedrock is encountered consisting of clayey siltstones. The underlying bedrock consists of very low-permeability siltstone and sandstone.

Since the early 1980s, soil and groundwater investigations have identified petroleum hydrocarbons, chlorinated solvents (wood-treating compounds), and pentachlorophenol (PCP) (a wood-treating compound) beneath the site.

Development of Final Remediation Strategy

A strategy for final remediation at the site was developed consisting of a combination of source removal by excavation, isolation of the residual impacted soils, in-situ natural degradation of these residuals, and institutional controls for on-site groundwater usage. While institutional controls effectively prevent on-site exposure, preventing off-site migration required the installation of engineered controls. Although the ultimate success of the on-site groundwater remediation program will be determined by natural attenuation processes, protection of the off-site groundwater resource is being achieved using the emerging technology of the funnel-and-gate™ groundwater treatment system.

The funnel-and-gate™ approach consists of the combined application of two proven technologies: slurry-wall hydraulic barriers and activated carbon adsorption. The treatment technologies considered for the gates included native iron reactive zones for dechlorination and treatment of such chlorinated hydrocarbons as trichloroethene (TCE), air sparging for removal of dissolved volatile or aerobically biodegradable compounds, and activated carbon for adsorption of both chlorinated and nonchlorinated hydrocarbons. Granular activated carbon was selected as the most appropriate for this application because the native iron reactive zones would not be effective on the diesel and BTEX, and air sparging would not be reliable at either stripping or biodegrading the TCE and PCP.

Application of the funnel-and-gate™ technology to the site involved installing multiple permeable treatment gates along a downgradient slurry wall. The gates were spaced along the hydraulic barrier at intervals designed to minimize impacts to the natural groundwater flow regime. The effectiveness of the system is monitored using monitoring wells placed up- and downgradient of the treatment gates to provide verification that water leaving the gates meets water-quality objectives.

Groundwater Flow Patterns

A key site condition which made the funnel-and-gate™ approach feasible was the high contrast between permeabilities in the water-bearing shallow aquifer and in the bedrock. In order to minimize the disruption of the natural groundwater flow patterns, there were three key concerns that needed to be addressed.

The first was the effect on water levels both up- and downgradient of the wall. Modeling showed that pressure required to move water through the gate was slightly greater than the natural gradient and was a function of the gate configuration and permeability of the gate.

The "analytic element method" groundwater modeling technique was used to optimize the total number of gates and their locations. This method was developed at the University

Minnesota Department of Civil and Mineral Engineering by Dr. Otto D. L. Strack. The analytic element approach and its application to groundwater flow is described in the book *Groundwater Mechanics* (Strack, 1989a) and in various conference proceedings (Strack et al., 1987 and 1989, and Strack, 1987 and 1989b).

The computer code selected for the modeling study at the Louisiana-Pacific Corporation site is the two-dimensional groundwater flow code SLAEM (the Single-Layer Analytic Element Model). This code implements the analytic element method for simulation of single-layer, steady-state groundwater flow systems. Streamlines are calculated from the velocity vector using a standard numerical integration technique (second-order Runga-Kutta algorithm).

Transmissivities were determined by aquifer testing and model calibration. The model was calibrated by matching the groundwater contour maps for the site with contour maps generated by the model. The global transmissivity value assigned to the model, 19.5 m^2/day (210 ft^2/day), was based on aquifer testing. Embedded in this background transmissivity were two permeability inhomogeneities. These are identified in Figure 1. The first was assigned a transmissivity of 2.6 m^2/day (28 ft^2/day), and forms a lower transmissivity band curving south to northeast. The second inhomogeneity has a transmissivity of 0.33 m^2/day (3.5 ft^2/day) and runs along the position of the creek and pond downcut through the full thickness of the shallow, saturated sediments. Head-specified line sinks were used to represent the pond and that portion of the creek upstream from the pond. The gradient across the site was assumed to be 0.046 m/m (0.046 ft/ft).

Groundwater streamlines were generated for several combinations of gate lengths and spacings. Successful designs were obtained for a broad range of combinations. One example of a workable system is shown in Figure 1, incorporating four gates and an L-shaped barrier arrangement. The calculated streamlines shown on the top drawing of Figure 1 demonstrated that all groundwater flowing beneath the studmill will pass through the treatment gates.

The second concern was ensuring that groundwater could readily access a treatment gate. Because of the nonuniform distribution of hydraulic transmissivities across the site, water could be impeded in its lateral movement toward and away from the gates, which could have resulted in undesirable hydraulic mounding behind the portion of the wall midway between gates. To minimize this effect, gravel-filled collection and distribution galleries are installed at each gate to collect water from the upgradient side of the gate, guide it through the gate, and then redistribute it uniformly after treatment (bottom drawing of Figure 1).

The third concern was that of inadvertently inducing untreated groundwater to flow around the ends of the barrier. This potential effect was evaluated using computer modeling. Use of the model resulted in designing a curved hydraulic barrier that routed the water from underneath the mill through the gates and avoided flow of contaminated water around the ends of the barrier (Figure 1).

Underflow of Barrier

A comparison of the transmissivity of the shallow drinking-water aquifer with that of the underlying bedrock indicated that the hydraulic conductivity of the bedrock is approximately one-thousandth of that of the overlying shallow aquifer. This resulted in a conservatively calculated underflow equal to less than 1% of the total flow through the combined aquifers.

Number and Location of Gates

Due to the complex geology and the influence of the funnel-and-gate™ arrangement on the flow lines across the site, the total flux of water at the barrier cannot be easily calculated. However, the flow can be approximated by taking the cross-sectional flow of a region where the particle traces generated by the computer model are relatively straight. In the area under the mill, the flow lines are relatively unaffected by the presence of the funnel-and-gate™ system. This length is approximately 122 meters (400 feet) of potentially impacted aquifer.

The combined flow rate through all four treatment gates is the product of the transmissivity, the length of the cross-sectional area, and the hydraulic gradient. This results in a total flow of approximately 76 liters per minute (L/min) (20 gallons per minute [gpm]). The flow through each gate is therefore estimated as one-fourth of the total flow, or 19 L/min (5 gpm) per gate.

Gradient Control

Figure 2 shows the plan and cross-section views of the treatment gate with collection and distribution galleries installed to guide water through the gates. Because the aquifer will tend to have higher horizontal than vertical permeability, the collection and distribution galleries are downcut into the aquifer to expose a large cross-sectional area to groundwater flow. This design minimizes the pressure required to move water from the aquifer into the gallery and then to the carbon treatment gate. This is also important on the downgradient side of the wall, where infiltration of water will be limited by the infiltration rate of the aquifer. The installation of these collection and distribution galleries further ensures that the pressure drops across the wall will minimally affect the natural groundwater gradients and flow patterns.

Gate Design

For the purpose of designing the carbon gates, a very large margin of safety was factored into the mass of carbon installed in each gate. The estimated gate flow rate is 19 L/min (5 gpm). The time between changeouts has been selected to be 4 years, although more frequent changeouts could easily be accommodated. In the vicinity where the gates are installed, concentrations of compounds of concern have ranged from nondetect to the low parts per billion. A concentration of 200 micrograms per liter (μg/L) was used in this design to account for the loading due to natural occurring wood-degradation compounds. Using the average carbon loading efficiency of 1% and the constraint of a relatively thin aquifer results in a carbon bed 1.25 meters (4 feet) tall placed within a cylinder 1.25 meters (4 feet) in diameter.

The selection of a moderate carbon grain size and the design of the treatment gates shown in Figure 2 minimizes the pressure loss across the treatment gate by presenting a large cross-sectional flow area through the carbon. This prevents water from backing up behind the gate and increasing the hydraulic head on the upgradient side of the barrier. The pressure required to move the water through the gates corresponds to an increase in water differential of approximately 5 centimeters (2 inches). The treatment gates themselves therefore have a negligible effect on groundwater elevation.

Monitoring points are located upgradient, within the carbon bed, and downgradient of the treatment gate (Figure 2). Samples are collected from the monitoring points to verify that the treatment gate is being effective in removing contaminants. Upon detection of a compound of concern at a concentration above water-quality objectives at the midgate measuring point, the carbon will be removed and replaced.

Carbon replenishment is a relatively easy procedure. Wet spent carbon will be vacuumed out as a slurry, using above-ground slurry pumps. Fresh carbon will be emplaced after dewatering the gate using the upgradient monitoring well which is completed in the gravel packing adjacent to the gate. While water is being evacuated and the gate is dry, fresh carbon will be poured into the gate to the desired thickness.

Conclusion

Funnel-and-gate™ systems will become increasingly popular as alternatives to long-term conventional pump-and-treat systems. Funnel-and-gate™ systems provide a reliable means of controlling groundwater flow to prevent contaminant migration and facilitate cost-effective, in-situ treatment of a limited number of gates.

Creative design and implementation can result in very reasonable capital costs. The design, permitting, and installation of the complete system at the Mendocino County site cost less than $500,000 US. System startup occurred in September 1995. Subsequent monitoring of groundwater elevations and groundwater quality indicates that the system is working effectively.

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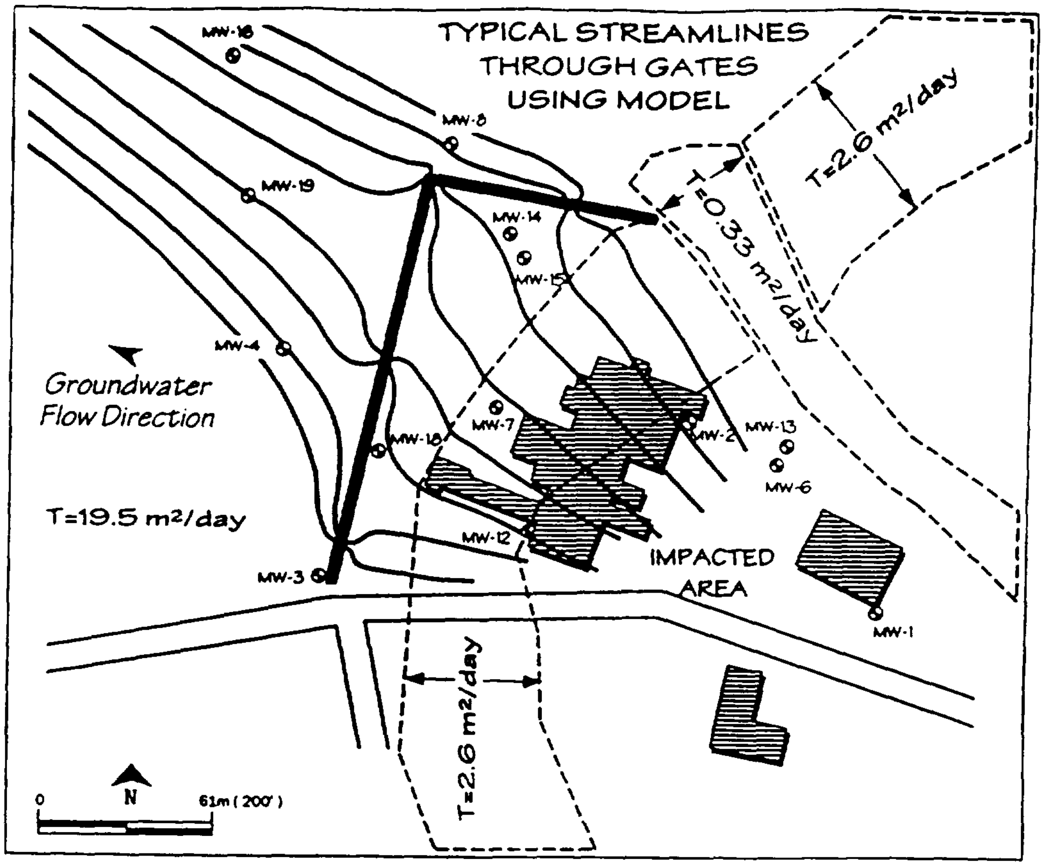

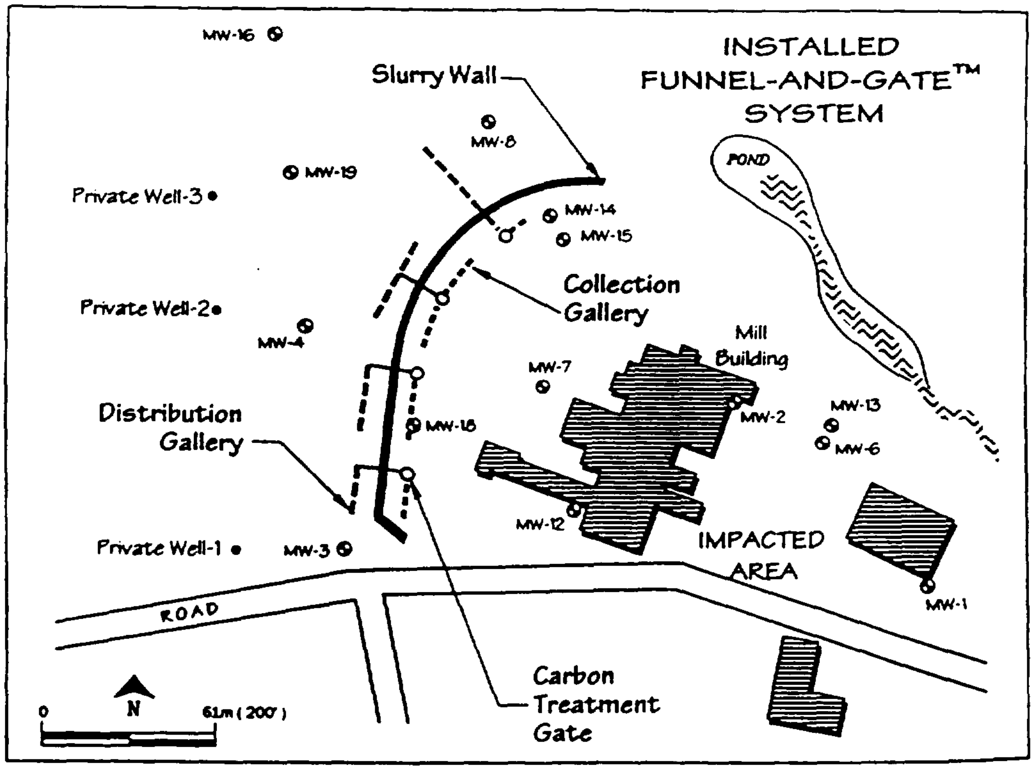

Figure 1 - Streamlines through gates (top drawing) with configuration of funnel-and-gate™ system (bottom drawing).

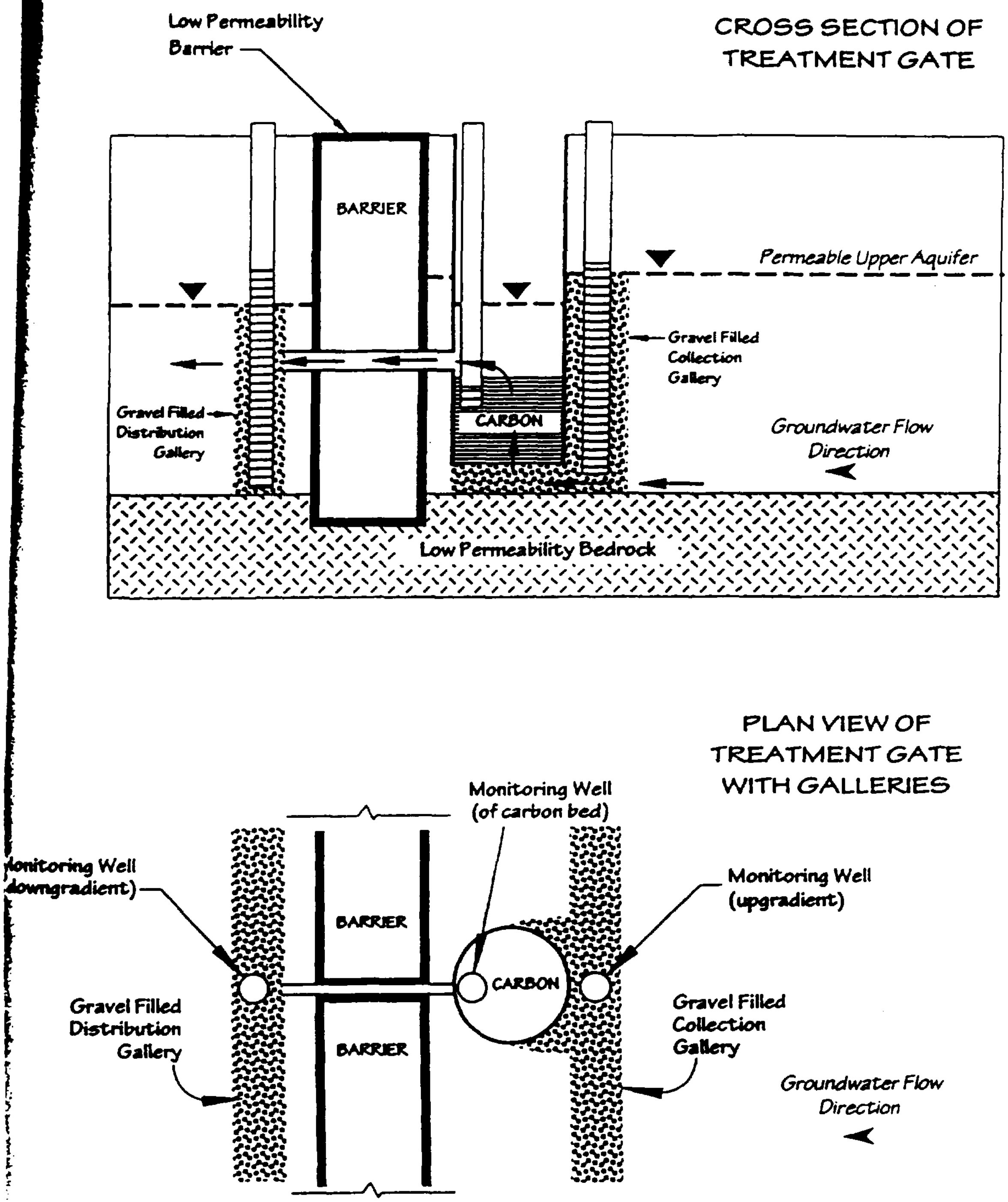

Figure 2 - Cross Section (top drawing) and Plan View (bottom drawing) of Treatment Gate