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NIROP FRIDLEY
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# DRAFT

# OPTIMIZATION STUDY REPORT

# FOR

# REMEDIAL ACTION OPERATION OF THE GROUNDWATER REMEDIATION SYSTEM

# AT

# NAVAL INDUSTRIAL RESERVE ORDNANCE PLANT (NIROP), FRIDLEY, MINNESOTA

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ACP | Anoka County Riverfront Regional Park |
| AMR | Annual Monitoring Report |
| ATSDR | Agency for Toxic Substances and Disease Registry |
| bgs | below ground surface |
| CAH | chlorinated aliphatic hydrocarbon |
| CERCLA | Comprehensive Environmental Response, Compensation and Liability Act |
| CSM | conceptual site model |
| CVOC | chlorinated volatile organic compound |
| DCA | dichloroethane |
| DCE | dichloroethene |
| DNAPL | dense, nonaqueous-phase liquid |
| DO | dissolved oxygen |
| DoD | U.S. Department of Defense |
| gpm | gallons per minute |
| GWTS | groundwater treatment system |
| HRL | Health Risk Limit |
| IAS | Initial Assessment Study |
| LTM | long-term monitoring |
| MCES | Metropolitan Council for Environmental Services |
| MCL | maximum contaminant level |
| MDH | Minnesota Department of Health |
| MPCA | Minnesota Pollution Control Agency |
| MWW | Minneapolis Water Works |
| N/A | not applicable |
| NA | needs assessment |
| NAS | Naval Air Station |
| NAVFAC | naval Facilities Engineering Command |
| NIROP | Naval Industrial Reserve Ordnance Plant |
| NPDES | National Pollutant Discharge Elimination System |
| NPV | net present value |
| O&M | operation and maintenance |
| ORP | oxidation-reduction potential |
| OU | operable unit |
| PC | personal computer |
| PCE | tetrachloroethene |
| PLC | programmable logic controller |
| PRB | permeable reactive barrier |

| | |
|---|---|
| QA | quality assurance |
| QC | quality control |
| RA | remedial action |
| RAWP | remedial action work plan |
| ROD | Record of Decision |
| ROI | radius of influence |
| SDS | State Disposal System |
| TCA | trichloroethane |
| TCE | trichloroethene |
| TtNUS | Tetra Tech NUS, Inc. |
| UDLP | United Defense Limited Partnership |
| USACE | United States Army Corps of Engineers |
| U.S. EPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| VC | vinyl chloride |
| VFD | variable frequency drive |
| VOC | volatile organic compound |
| ZVI | zero-valent iron |

No. Sold to UDLP in June 2004.

# EXECUTIVE SUMMARY

The Naval Industrial Reserve Ordnance Plant (NIROP) Fridley, MN is an active facility that consists of about 80 acres of government-owned land and is bordered on the east by the Burlington Northern Rail Yard, on the south by property owned by the United Defense Limited Partnership (UDLP), various industrial facilities on the north, and East River Road on the west. Historical operations and disposal practices have resulted in the presence of trichloroethene (TCE) and other volatile organic compounds (VOCs) in groundwater beneath and downgradient of the site. A variety of assessments and investigations were performed, which confirmed and delineated the extent of contamination at the NIROP.

A CERCLA Record of Decision (ROD) for Operable Unit 1 (OU-1), plant-wide groundwater, was signed in September 1990. Groundwater extraction and treatment was selected as the remedial action, and the remedial action (RA) objectives specified in the ROD include hydraulic containment and recovery of all contaminated groundwater at the NIROP facility, and the recovery, to the extent feasible, of contaminated groundwater downgradient of the NIROP facility.

The objective of the optimization study is to assess the existing remedial actions for the groundwater extraction system and groundwater treatment system (GWTS) installed and operating at the NIROP, and provide recommendations to achieve site RA objectives and ultimate closure for optimal life-cycle costs. The basis for conducting the study includes a review of various site-related documents and data, meetings with the operator of the system, and a site tour.

On-site groundwater is not currently used as a potable water supply at the site, and it is not expected to be used as potable water in the future because a public water supply is available. However, groundwater from the site flows west/southwest entering the Mississippi River, and the City of Minneapolis draws its municipal water from the river approximately 2,000 ft downstream from the NIROP site (U.S. EPA, 1991). Therefore, the short-term RA objective is hydraulic containment of the contaminated groundwater at the NIROP, and the final RA objective is to achieve the federal MCLs or Minnesota Pollution Control Agency (MPCA) Health Risk Limits (HRLs). The effectiveness of the remedial action in meeting the RA objectives is evaluated based on the following factors: (1) hydraulic containment of the contaminated groundwater; (2) comparison of groundwater monitoring data to the MCLs or HRLs; and (3) contaminant mass removal by the groundwater treatment system.

Based on available data, the extraction well network appears to be containing a large percentage of the most highly contaminated groundwater with TCE concentrations exceeding 100 μg/L along the property boundary; however, monitoring well data indicate that elevated TCE concentrations also are present downgradient of the site, outside of the area of influence of the extraction wells. The TCE concentrations have not reached the MCL of 5 μg/L in any monitoring wells located either in the extraction well capture zone, or downgradient of the extraction wells. The persistent elevated TCE concentrations are to be expected, as pump-and-treat is not an effective technology for groundwater cleanup of chlorinated VOCs where a source area remains, as is suspected beneath the NIROP Fridley manufacturing plant building.

Given that TCE concentrations in many of the monitoring wells located in the extraction well capture zone have not decreased significantly, contaminant mass removal rates should still be high if the groundwater extraction system is continuing to remove and treat this water. The available data indicate that the groundwater extraction system has not yet reached asymptotic mass removal, as a significant mass of TCE (approximately 700 lb) was removed by the groundwater extraction system in 2003; therefore the existing system is continuing to operate effectively.

Three optimization approaches were considered for implementation at the NIROP to achieve the RA objectives in a shorter time frame and decrease life-cycle operating costs, if possible, including: (1) perform various modifications to the existing GWTS; (2) install a permeable reactive barrier (PRB); and (3) source zone treatment.

Installation of a PRB at this site is technically feasible; however, construction would be difficult and expensive given the depth and extent of contamination. The only PRB scenario evaluated that would cost less than the net present value (NPV) cost of continued pump-and-treat operation is installation of the PRB at the property boundary that would only capture the more highly contaminated (e.g., >1,000 μg/L) groundwater. This would be acceptable only if an alternate remedy is performed for the contaminated groundwater not intercepted by the PRB (e.g., biostimulation). Therefore, installation of a PRB is not recommended at this time, but may be revisited if the findings of ongoing biostimulation testing demonstrate that this technology can effectively address the moderate to lower levels of contamination.

Treatment of the DNAPL source zone would significantly reduce the time and cost to treat (or contain) the dissolved-phase plume downgradient of the source area. At sites such as Fridley where the geology is complex and the plume is very large, one option has been to inject zero-valent iron (ZVI) directly into the source. However, the locations of the source zones are not known at this time, and detailed characterization and remediation of the sources within the facility is limited due to the high-security mission of the facility, and also cost prohibitive due to the extensive building infrastructure and equipment present at the facility. Due to these challenges, source zone treatment is not feasible at the current time. This should be revisited if activities conducted in the building change and allow significant intrusive work to be conducted to investigate and remediate under the building.

Modifications to the existing GWTS which have been evaluated in this report include taking one air stripper off-line based on the current system design flowrate (approximately 650 gpm), replacing the existing air stripper feed pump motors with variable frequency drives (VFDs), and updating the control system to allow for data storage and easier data access and reporting. Capital costs for implementing these modifications are estimated to be approximately $37,000, and implementation of these modifications could result in a net present value (NPV) cost savings of approximately $300,000 over the next 30-year operating period. Based on this cost evaluation, the breakeven point for implementing all of these proposed modifications is approximately 2.4 years. Therefore, implementation of these modifications is recommended to optimize life-cycle operating costs of the GWTS.

## Section 1.0: BACKGROUND

### 1.1 Introduction

See page 1

The Naval Industrial Reserve Ordnance Plant (NIROP) is located on the southernmost tip of Anoka County, Minnesota, about one-quarter mile east of the Mississippi River, within the City of Fridley (Figure 1-1). The site is located on an active facility that is located in a very industrialized area and consists of about 80 acres of government-owned land, of which about 50 acres are covered with buildings and/or are paved. It is bordered ~~on the east by the~~ Burlington Northern Rail Yard, on the south by property owned by the United Defense Limited Partnership (UDLP), on the north by various industrial facilities, and on the west by East River Road.

The NIROP Fridley site has been divided into three operable units: OU-1, which addresses groundwater; OU-2, which addresses soil contamination outside the footprint of the manufacturing plant building; and OU-3, which originally addressed only soil contamination under the footprint of the manufacturing plant building. OU-2 and OU-3 later were combined and sources located in the saturated zone beneath the building were added. A Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Record of Decision (ROD) (U.S. EPA, 1990) was signed on September 28, 1990 for OU-1 for groundwater remediation at the NIROP, which is the focus of this study.

The remedial action in the ROD specified hydraulic containment and recovery of all contaminated groundwater at the NIROP facility, and the recovery, to the extent feasible, of contaminated groundwater downgradient of the NIROP facility. The selected remedy included the installation and operation of extraction wells with a two-phase plan for disposal of groundwater generated by the extraction system. Phase I involved discharging groundwater from the extraction system to an existing sanitary sewer with treatment provided at a local wastewater treatment facility. Phase II, which was initiated in December 1998, involved the construction and operation of a groundwater treatment facility to provide long-term groundwater treatment.

### 1.2 Project Objectives and Scope

The objective of the optimization study is to assess the existing remedial actions for the groundwater extraction system and groundwater treatment system (GWTS) installed and operating at NIROP Fridley and provide recommendations to achieve site remedial action objectives and ultimate closure for optimal life-cycle costs. Specific objectives for the site include:

- Evaluate methods to address fouling issues at the extraction wells and recovery pump;
- Review GWTS efficiencies;
- Evaluate alternative treatment technologies that would allow the pump-and-treat system to discontinue operation;
- Perform a cost analysis on any alternative treatment technologies identified;
- Develop options for system operational and design modifications to reduce operating costs and perform life-cycle cost analysis; and,
- Document optimization work performed to date.

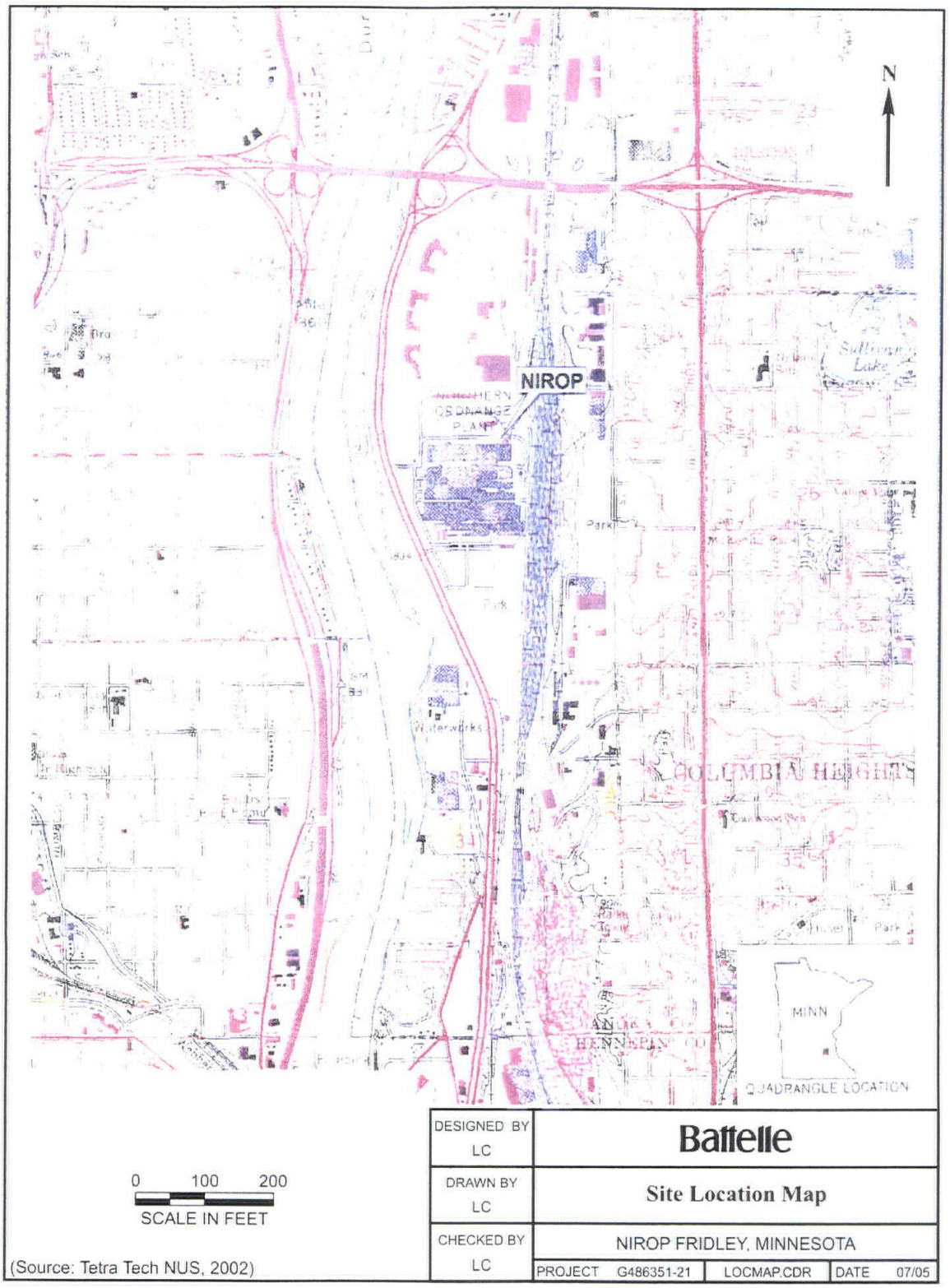


**Figure 1-1. Facility Location**

## 1.3 Site History

The NIROP Fridley facility was constructed in 1940 when Northern Pump negotiated a contract with the Navy to produce five-inch gun mounts. The existing manufacturing facility, located in Minneapolis, was inadequate to meet the contract needs, so the Fridley manufacturing plant was built. The plant was completed in 60 days and was in full production by January 1941. Initially the plant manufactured single gun mounts, followed by the production of the Mark 42, fully automated gun mount. During the 1950s, the facility began to produce advance missile launching systems and torpedo launching tubes, followed by the production of more advanced guided missile systems in the 1970s and 1980s. Plant operations consisted of plating, welding, heat treating welding, and foundry processes. The plant also is equipped with electronics and metallurgical laboratories and hydraulic testing facilities.

Trichloroethylene (TCE) was commonly used during day-to-day operations at the NIROP facility to degrease parts prior to welding, and in 1987 was replaced with trichoroethane (TCA). Spills of TCE were documented in the 1980s, and likely occurred throughout the operation of the facility.

Other sources of potential contamination include drums of waste and other debris, which were reported to be in excavated pits and trenches located in several areas of the facility that were disposed of in the 1960s and 1970s. The majority (maybe all) of this debris was excavated and removed in the 1980s and 1990s, including in a storage lot and scrap yard located at the north end of the facility; a metal shaving and milling waste loading area in the location of the existing hazardous materials storage building; the plating chemical storage, oil/solvent storage and cyanide storage areas, which were located on the west end of the plant; and five interim storage areas that were located in various parts of the plant.

## 1.4 Site Investigation Activities

An anonymous telephone call to the Minnesota Pollution Control Agency (MPCA) in March 1981 led to the discovery of led to the discovery of TCE in the three NIROP Fridley water supply wells. TCE also was detected in the City of Minneapolis Mississippi River water intake plant, located about 2,000 ft downgradient of the NIROP. A variety of assessments and investigations were performed, which confirmed and delineated the extent of contamination at the NIROP. A summary of these investigations is provided as Table 1-1. These activities are summarized in additional detail in the *Supplemental Remedial Investigation Information Report* (TtNUS, 2002a).

## 1.5 Site Remediation Activities

The ROD for groundwater remediation at NIROP Fridley was signed in September 1990. The remedial action in the ROD specified hydraulic containment and recovery of all contaminated groundwater at the NIROP facility, and the recovery, to the extent feasible, of contaminated groundwater downgradient of the NIROP facility. The selected remedy included the installation and operation of extraction wells with a two-phase plan for disposal of groundwater generated by the extraction system.

Phase I involved discharging groundwater from the extraction system to an existing sanitary sewer with treatment provided at a local wastewater treatment facility. The initial extraction system included four extraction wells. Operation of the system was begun in September 1992. As required by the ROD, an evaluation of the effectiveness of the groundwater treatment system was performed based on data collected during the initial 90 days of operation (RMT, 1992). Based on the results of this investigation, two additional extraction wells were constructed and placed into operation in June 1995.

A second modification to the extraction system was initiated June 2001, and was based on recommendations made in the 1999 Annual Monitoring Report (AMR) (TtNUS, 2000) for increasing

system performance. Four new extraction wells were installed and operated at this time, and the operation of three of the existing wells was discontinued.

Phase II, which was initiated in December 1998, involved the construction and operation of a groundwater treatment facility to provide long-term groundwater treatment. Groundwater treated by the Phase II treatment system is being discharged to the Mississippi River via National Pollutant Discharge Elimination System (NPDES)/Metropolitan Council for Environmental Services (MCES) State Disposal System (SDS) storm sewer discharge permit. Under Phase II, the combined discharge from the extraction system is fed through a feed system and air-stripping units for treatment before the effluent is discharged to the Mississippi River through outfall 020 (NPDES/S:JS Permit MNOOO0710).

This two-phase approach originally specified that contaminated groundwater located offsite and downgradient of the NIROP Fridley facility in the Anoka County Riverfront Regional Park (ACP) would be allowed to naturally dissipate. However, in a five-year review completed in October 1998, the United States Environmental Protection Agency recommended that the Navy determine what could be done to reduce the residual concentrations of chlorinated aliphatic hydrocarbons (CAHs) (U.S. EPA, 1998). Subsequent discussions between the partnering team led to the decision to perform a pilot-scale test in December 2001 to determine if the organic substrate addition technology was a viable treatment option to accelerate the biodegradation of hydrocarbon mass located beneath ACP.

## 1.6 Optimization Review Outline

Section 2.0 of this report presents a summary of the existing conceptual site model (CSM) and identifies data gaps and the potential benefits of gathering this additional data. Section 3.0 presents the findings during the site visit, including a summary of meeting notes and a discussion of visual observations. Section 3.0 also presents a description of the current groundwater extraction and treatment system.

The results of the optimization evaluation are presented in Section 4.0. The remedial action objectives are discussed in Section 4.1, and the effectiveness of the remedial action in meeting the objectives is discussed in Section 4.2. The cost-efficiency evaluation is presented in Section 4.3. This includes a summary of projected O&M costs in terms of cost per year, cost per pound of perchlorate removed and cost to completion. Alternative approaches are then evaluated in Section 4.4, where the alternatives are compared to one another and to the status quo alternative based on a net present value (NPV) cost analysis as well as a discussion of the probability of obtaining success in implementing the proposed approach. The installation of a permeable reactive barrier (PRB) was considered as an alternative to pump-and-treat. Several potential configurations of the PRB were evaluated. Conclusions and the recommended optimization strategy are presented in Section 5.0, and references cited in text are listed in Section 6.0.

## Table 1-1. Previous Assessments and Investigations

| Environmental Activity | Conducted By | Date | Description |
|---|---|---|---|
| Three production wells at the site were sampled | MPCA | 1981 | Analysis results showed 0.035 to 0.200 mg/L of TCE detected. |
| Initial Assessment Study (IAS) | Envirodyne | 1983 | IAS for the NIROP site was completed by Envirodyne Engineers (June 1983). As a result of the IAS, the U.S. Army Corps of Engineers (USACE) was assigned to manage site remediation. The Corps installed 33 monitoring wells on and around the site over the next 3 years. |
| Groundwater sampling | RMT | 1983-1986 | Eight rounds of groundwater sampling were completed. The last round was conducted in November 1986. |
| Remedial investigation | RMT | 1986-1987 | RMT, Inc. was retained by the USACE to complete the Remedial Investigation/Feasibility Study for OU-1 (groundwater). |
| Soil pore gas survey included in the A-E Quality Control Summary Report | RMT | 1987 | Issued for OU-1. |
| Fifty-five soil borings were advanced to assess the extent of soil contamination | RMT | 1990 | Soil borings were advanced in four specific areas (background area, North 40 area, Hazardous Waste Storage Area C, and the southeast area near Well 9-S). |
| Aerial photographic review | RMT | 1991 | Initial aerial photographic review included photographs spanning the period from 1945 to 1977. |
| Installation of additional wells | RMT | 1991 | Installation of four groundwater recovery and containment wells, as well as additional groundwater monitoring wells. Completed in late 1991 for OU-1. |
| Second review of the aerial photographs | Navy, U.S. EPA, MPCA, RMT, FMC Corp. | 1991 | As a result of the review and subsequent discussions, additional areas of investigation were included as part of the OU-2 Remedial Investigation |
| Remedial Investigation report | RMT | 1993 | Issued for OU-2. |
| Results of East Plating Shop soil sampling | Bay West | 1994 | Two soil borings were completed, and several metals and cyanide were identified at concentrations greater than background levels during the OU-2 RI. |
| Results of East Plating Shop soil and groundwater investigation | Halliburton NUS | 1995 | The report identified soil and groundwater contamination under the East Plating Shop determined during the OU-2 RI. |
| OU-3 investigation | TtNUS | 1997-1998 | Characterized contamination under the NRIOP building via soil and groundwater sampling. In addition, six new permanent well clusters were installed. |
| Needs assessment | SAIC | 1998 | Needs Assessment (NA) was performed for the groundwater remediation to evaluate opportunities to optimize performance and cost prior to Phase II implementation. |
| Extraction system performance and groundwater monitoring | TtNUS | 1992-2000 | Monitor via an extensive well network, according to the procedures described in RAWP and RAWP revisions. |
| RAWP supplemented | TtNUS | 2001 | Supplemented with the 2001 Annual Monitoring Report Work Plan. |

## Section 2.0: CONCEPTUAL SITE MODEL

### 2.1 Setting

no!

The NIROP facility is located in the Township of Fridley, in the southern-most tip of Anoka County, MN. The site is currently active and consists of 82.6 acres of government-owned land, of which approximately 50 acres are paved or covered with buildings. The plant is bordered on the east by the Burlington Northern rail yard, on the north by various industrial facilities, on the south by UDLP, and on the west by East River Road and the Mississippi River. Located between East River Road, a four-lane highway, and the Mississippi River (west of the site) is the Anoka County Riverfront Regional Park. The 60-acre park is a day use recreational facility on the river's edge.

### 2.2 Geology and Hydrogeology

The hydrogeology within the vicinity of the NIROP consists of four aquifers or aquifer zones that govern groundwater movement through the shallow subsurface. These aquifers are, from shallow to deep, the unconsolidated Quaternary aquifer zone, the Lower Ordovician Prairie du Chien/Jordan aquifer (PC), the Franconia/Ironton/Galesville (FIG) aquifer, and the Mount Simon/Hinckley/Fond du Lac (MHF) aquifer. A brief discussion of the geology and hydrogeology of the unconsolidated Quaternary aquifer zone, which is the focus of remedial efforts, follows.

The unconsolidated Quaternary Aquifer Zone consists of glacial drift overlain by glacial-fluvial deposits. It is comprised of an unconfined aquifer (shallow and intermediate glacial drift) overlying a confined/semi-confined aquifer (deep glacial drift). These two aquifers vary significantly in thickness and hydraulic connection throughout the site. The shallow unconfined aquifer ranges in thickness from 41 to 93 ft, and the deep confined/semi-confined aquifer ranges in thickness from 19 to 55 ft across the site. A low-permeability layer, which acts as a leaky aquitard, separates the two aquifers. This layer varies greatly in thickness and horizontal extent across the site. It consists of silt and clay and ranges in thickness from 0 to 47 ft. It is rather thick and laterally continuous in the central, western and southwestern portions of the site. Thus, the aquitard acts to impede or redirect contaminant migrations through the groundwater flow system. However, at other portions of the site, the aquitard is very thin or nonexistent. In these areas, the deep aquifer may have direct hydraulic connection with the overlying shallow unconfined aquifer.

The St. Peter Formation, which consists of Lower Ordovician age sandstone, with beds of siltstone and shale in the lower formation, underlies the unconsolidated Quaternary-age deposits for most of the NIROP facility. Where present, it is considered locally to be an extremely leaky aquitard. The top of the St. Peter Sandstone is typically moderately to highly weathered. Within the project area, the St. Peter Sandstone ranges in thickness from 17 to 62 ft. The St. Peter Sandstone unconformably overlies the Prairie du Chien Group, which consists mostly of dolomite. In the extreme southwestern portion of the NIROP and ACP, the St. Peter Formation has been completely eroded, exposing the underlying Prairie du Chien Formation to the unconsolidated aquifer.

Under both non-pumping and pumping conditions, the general horizontal groundwater flow direction across the site in the Quaternary aquifer zone is generally toward the southwest and west. Groundwater from the Quaternary aquifer zone discharges directly into the Mississippi River (and into the extraction wells when in operation).

The natural groundwater flow direction at the site is altered significantly by the remedial wells actively pumping in the Quaternary aquifer zone. Due to the cones of depression created by these

actively pumping remedial wells, the horizontal hydraulic gradient is greater in the south and southwest portions of the site than in the north and northeast where few pumping wells are active. Average gradients for the entire site based on July 7, 1998 measurements were 0.00503 and 0.00689 for the shallow unconfined and the deep confined aquifers, respectively. Averages velocities for the entire site were 1.139 ft/day and 0.8 ft/day for the shallow unconfined and the deep confined aquifers, respectively (TtNUS, 2002b). Table 2-1 provides a summary of hydraulic gradients and groundwater velocity measured at different locations at the site.

**Table 2-1. Summary of Horizontal Hydraulic Gradients and Groundwater Velocity (Source, TtNUS, 2002b)**

| Aquifer Zone | Portion of Site | Average Horizontal Hydraulic Gradient | Average Horizontal Groundwater Velocity |
|---|---|---|---|
| Shallow Unconfined Aquifer Zone [(a)] | North and Northeast | 0.00123 | 0.277 |
| | South and Southwest | 0.00884 | 2.000 |
| | Average for entire site | 0.00503 | 1.139 |
| Deep Confined (or Semi-confined) Aquifer Zone [(b)] | North and Northeast | 0.00298 | 0.345 |
| | South and Southwest | 0.01080 | 1.253 |
| | Average for entire site | 0.00689 | 0.800 |

(a) Monitoring wells included in the shallow unconfined aquifer zone include shallow wells (S) and intermediate wells.
(b) Monitoring wells included in the confined (or semi-confined) aquifer zone include deep wells (D).

Extensive data on groundwater flow during non-pumping conditions were not available for review. The 2003 AMR (TtNUS, 2004) report provides one set of groundwater contour maps measured March 2003 for the various aquifer depths after the system was turned off for approximately two months. The groundwater flow direction appears to be overall similar to the groundwater flow direction under pumping conditions. The average horizontal gradient across the site in the shallow glacial drift of the unconfined aquifer was 0.0125, with significantly larger gradients in the vicinity of the pump-and-treat wells. The average gradients across the site in the intermediate glacial drift (located below the shallow zone within the unconfined aquifer) and in the deep glacial drift of the confined/semiconfined aquifer were slightly lower, with an average of 0.0083 and 0.0067, respectively. Assuming the same conductivity and porosity as provided in Appendix C of the OU-3 remedial site investigation report (TtNUS, 2002b), the average groundwater velocity across the site in the shallow, intermediate, and deep aquifers, are approximately 2.8 ft/day, 1.9 ft/day, and 0.78 ft/day, respectively.

## 2.3 Exposure Pathways

TCE continues to be the most widespread contaminant in site groundwater and is present at the highest overall concentrations. The TCE plume(s) cover an area of approximately 100-acres and occur in the shallow, intermediate, and deep aquifer zones. *cis*-1,2-dichloroethene (*cis*-1,2-DCE) is the second most extensive contaminant encountered, followed by tetrachloroethene (PCE). The remaining volatile organic compounds (VOCs) detected are *trans*-1,2-DCE, 1,1-dichloroethane (1,1-DCA), vinyl chloride, and 1,1-DCE (TtNUS, 2005). Multiple potential source areas have contributed to the contamination present at the NIROP, including some sources located off-site of the NIROP (TtNUS, 2002a). TCE is the primary chlorinated volatile organic compound (CVOC) in the plume. Results from

the most recent groundwater monitoring event for TCE, which is used as an indicator parameter for measuring NIROP contamination and monitoring the progress of the remedial system, are presented in Section 4.2. The maximum TCE concentration detected is 6,800 ppb, although the bulk of the plume is defined by 100-ppb and 1,000-ppb contours. Lesser levels of *cis*-1,2 DCE (865 ppb maximum), PCE (38 ppb maximum), and vinyl chloride (VC, 11 ppb maximum) also have been detected.

An evaluation of contamination and exposure of OU-1 at NIROP Fridley was performed by the Minnesota Department of Health (MDH) and the Agency for Toxic Substances and Disease Registry (ATSDR) in 1999 (MDH, 1999). The following is a summary of their findings:

***Current Pathways***

**Air (outdoor):** Air is not likely to be an exposure pathway because most of the site is covered with pavement or buildings. To date, no outdoor air quality impact studies from contaminated groundwater vapor migration have been conducted. Should soil vapor gas reach the surface, it would likely be diluted with ambient air to levels below health concern. A study may not be warranted based on ambient air dilution factors and the lack of long-term exposure to receptors.

**Air (indoor):** Under current conditions indoor exposure via soil vapor migration is not known to be occurring. In the case of indoor construction, the foundation may be opened potentially allowing soil vapor to infiltrate the building. In such cases, the Navy must first grant written consent to a contractor to open the foundation. Before permission is granted, a work plan which should include worker safety procedures, should be drafted and approved by the Navy and regulatory agency. To date no soil vapor gas migration studies have been conducted.

**Soil:** Soil is not likely to be an exposure pathway because most of the site is covered with pavement or buildings and small grassy areas. Dermal contact is not likely to occur on site under present conditions except when the foundation is opened for construction and excavations. In such cases, the soil is not likely to be contaminated from groundwater unless a free product is present directly below soil of concern.

**Groundwater:** NIROP and UDLP properties are the closest known sources of TCE contamination up stream from the Minneapolis Water Works (MWW) raw water intakes. TCE concentrations are monitored along with 125 other analytes at MWW as part of their water quality monitoring program. After the raw water (river water) is treated to meet all the federal Safe Drinking Water Act requirements, it is distributed to approximately 500,000 people in the greater Minneapolis-St. Paul metropolitan area (MDH, 1999). This treated water is called finished water.

MDH records show low levels of TCE in the MWW finished water 27 times ranging from 0.1 to 1.3 μg/L in the past 16 years. The highest TCE concentration detected in finished water (1.3 μg/L) is lower than the MCL of 5μg/L and below the MDH HRL of 30 μg/L. Any concentration of TCE below the MCL is considered acceptable for a lifetime of exposure. No other site related contaminants have been detected in the finished water (MDH, 1999).

Although a completed pathway exists via groundwater to surface water to drinking water, it is not a human health risk under current conditions, based on the limited raw water and more thorough finished water data collected at the MWW. A more comprehensive sampling plan is needed to assess the impact of site-related contamination on the MWW intakes. There are no drinking water wells on site or down gradient before groundwater discharges to the river.

***Potential Future Pathways***

If future activities at NIROP include excavation within the contaminant plume (saturated and unsaturated zones), exposures may occur via inhalation of soil gases and/or dermal contact. A future exposure scenario could occur from the volatilization of soil gases into nearby buildings and sewer system. Use of contaminated groundwater prior to treatment may result in ingestion, inhalation, and/or dermal exposure that could pose a public health hazard. It is possible that higher levels of TCE could impact MWW.

who?

## Section 3.0: SITE VISIT

The site visit took place on November 29, 2004. Participants included Mr. Clifford Casey and Mr. David Owens from Naval Facilities Engineering Command Southern Division, Ms. Megan Larson from Bay West, and Mr. Stephen Rosansky and Mr. Russell Sirabian from the Battelle optimization team. Bay West has been responsible for operating the system since April 2000.

### 3.1 Meeting Notes

The following information was provided by Navy personnel:

- The objective of the pump-and-treat system is to obtain hydraulic control of the dissolved-phase TCE plume.
- Under natural conditions the groundwater in the impacted area migrates towards and into the Mississippi River at a point upgradient of an intake to a public water supply system.
- The source of the dissolved-phase TCE groundwater plume has not been delineated.
- The source of the contamination is suspected of being under the building; there could be several source areas under the building.
- Because of the high level of complexity of the hydrogeology in the area, there has been difficulty demonstrating to stakeholders that hydraulic control has been achieved.
- A groundwater flow model does not exist for the site; however, the results of groundwater flow data and the effects on the piezometric surface have been evaluated to determine flowrates necessary to obtain hydraulic control. This work was performed by Hal Davis of the United States Geological Survey (USGS).
- In is unclear what entity is paying for power for the system. There is a separate electric meter but the disposition of the electric bills for that meter is not known by the personnel involved with system operation.

why important?

The following information was provided by Bay West personnel.

- Typical labor for operating the system is 20 hours per week unless there are problems.
- The system is fairly reliable although the past year there have been several unplanned shutdowns caused by a variety of issues, including the programmable logic controller (PLC) being damaged by a lightning strike. The system currently is operating well.
- Groundwater pumping rates are set based on the target flowrate that is listed in the system operations and maintenance (O&M) manual.
- Fouling of the wells and process equipment is a concern, but because the system was designed with this in mind, this is addressed through compliance with maintenance procedures, such as acid washing of air strippers and redevelopment of recovery wells.

- To allow acid washing of air strippers to address fouling concerns, each stripper is equipped with an acid recirculation pump. In addition, the following equipment is used for all strippers: an acid mix tank, a spent acid solution treatment tank to neutralize and condition the solution for dewatering, and a filter press for dewatering the solution.

- The sludge from the acid cleaning process is disposed of off-site as a non-hazardous waste.

- The strippers are acid washed every six months. This is done as a routine operating requirement. Typically there are no indications that the strippers are fouled when this cleaning in performed.

- The process of cleaning the strippers takes approximately two days to perform. All strippers are typically done at the same time, which requires the system to be shutdown during the cleaning event. The strippers can be cleaned one or two at a time which would allow the system to continue to operate at a reduced flow but this would require more labor to perform. This cleaning system allows the strippers to be cleaned without the need to remove the trays. However, if tray removal is necessary, an overhead crane that is part of the manufacturing operation can be used. The crane is located in the same building that the air strippers are housed.

- The telemetry alerts the operator of a plant shutdown and the unit works reliably.

- The control system does not store data or generate reports.

- The distribution of flow among the four air strippers is controlled by manual adjustment of flow control valves based on maintaining the same level of water in the discharge sumps. This is the control parameter because it is presumed that the draining of water out of the stripper sumps and into the common sump is the rate limiting factor, although the operator was not sure if this is indeed the case.

- The sequestering agent is added at the influent equalization tank and at no other location.

- Sampling is not routinely done for inorganic parameters such as metals, ions, dissolved oxygen (DO) or oxidation-reduction potential (ORP). Metals analysis has been done in the past.

## 3.2 Visual Observations

The five meeting participants walked the site. The following is a discussion of visual observations during the site tour. The photos presented in this section were all taken on the day of the site visit (November 29, 2004).

***Extraction Well Piping***

Photographs of the piping are presented in Figures 3-1 through 3-3. Piping from each well enters the influent building directly from underground as shown in Figure 3-1. This photograph also shows a sample valve on the piping from each extraction well as it comes into the building. For each of the extraction wells there is a flowmeter (shown in Figure 3-2), a flow control valve, and a pressure switch, allowing the flowrate to be monitoring and controlled from this central location. It is not clear

what the pressure switch is used for and the operator was not aware of its function. Groundwater from each well is piped into the top of the flow equalization tank as shown in Figure 3-3. With this piping arrangement, the flow from each extraction well is kept separated until being combined in the equalization tank. This is advantageous in preventing backflow from one well into another, without relying on check valves which sometimes fail, and also prevents changes in backpressure due to changing flow from a extraction well from affecting the other wells.

### *Equalization Tank*

The flow from all extraction wells is combined in the equalization tank. The sequestering agent tank (Figure 3-4) and pump system (Figure 3-5) is located in this building, where the agent is added to the combined groundwater flow. A duplex pump system (Figure 3-6) is used to pump groundwater from this tank into the treatment area. The flow from the equalization tank is controlled by a level transmitter in the equalization tank and an automatic flow control valve (Figure 3-7). The pump motors are single speed devices and the only means to reduce flow is by the throttling of the flow control valve. The tank and pump system appears to be in good condition.

### *Treatment System*

The treatment system is located inside a fenced-in area of a building that is used for manufacturing operations. Active operations within the building were apparent. Equipment within this area included, four low profile tray-type air stripers, an acid mixing tank, a spent acid treatment tank, a filter press, an effluent pump station and a control room.

### *Air Strippers*

Treatment for VOC removal is achieved through the use of four air strippers connected in parallel as shown in Figure 3-8. The combined flow from the discharge from the equalization tank pump system is divided into the air strippers and the distribution is controlled by a manual flow control valve. A flowmeter monitors the flow into each stripper. Figure 3-9 shows the piping from the manifold entering the top of one of the air strippers, and also shows the manual flow control valve and the flowmeter. At the time of the visit, the flowrate into each stripper was in the range of approximately 120 to 180 gallons per minute (gpm), which is below the design flow of 250 gpm. Each stripper includes the following: seven trays, an effluent drain pipe, a recirculation pump for acid washing (Figure 3-10), and a belt-driven air blower (Figure 3-10), which takes air in from outside the building. The off-gas from each stripper is manifolded together and emitted to the atmosphere via a stack. The strippers are elevated relative to the floor of the building which allows treated groundwater to gravity drain from each stripper into an effluent holding sump that is at an elevation lower than the strippers. From visual observations it was not apparent why it would be necessary to control the flow to each stripper in order to maintain a similar water level in each stripper sump. Each air stripper appears to have an identical design and the piping arrangement on the influent and effluent also appears to be designed such that the flow into each on-line stripper should be the same. As shown in Figures 3-8 and 3-10, iron staining is apparent on the outside of an air stripper indicating that a leak had occurred at one time. The operator confirmed that leaks occasionally develop at the gasket between the stripper trays. This is usually caused by grit deposits at the gasket. In the past, the operator has been able to stop the leak and overall this has not been a significant issue.

### *Stripper Cleaning Equipment*

Stripper cleaning equipment includes an acid solution holding tank, a spent acid treatment tank and a filter press. Figure 3-11 shows the acid solution holding tank (on the right side) and the spent

acid treatment tank (on the left side). Figure 3-12 shows the filter press. This equipment is only needed for stripper cleaning which is performed twice per year. These components were not in use at the time of the visit.

### *Effluent Holding Sump*

The effluent holding sump and piping are shown in Figure 3-13. The effluent pumps are located inside this sump and thus were not visible. The discharge flow is controlled by an automatic flow control valve. A recirculation pipe with a manual flow control valve is used to recycle a portion of the effluent back into the sump. This is done to allow the pump to maintain a flowrate that is higher than the total groundwater flow through the treatment system so the pump can operate at a more optimum point on the pump curve. The pump motors are single speed devices and the only means to reduce flow is by the throttling of the flow control valve. Valves are available to pump effluent to either the sanitary sewer which would convey the effluent to a publicly owned treatment works or to a storm sewer which would convey the effluent to the Mississippi River. The effluent is typically routed to the storm sewer which was the case at the time of the visit.

### *Control System*

The control system is located in a control room located in the vicinity of the treatment system. The system is controlled by an Allan Bradley PLC, which communicates with a personal computer (PC) also located in the control room. Various customized screens are available at the PC which allow the operator to easily monitor operations of the system. From the PC, the operator can monitor various parameters such as: flowrate from each extraction well, total flow, flow into each air stripper, air flowrate and pressure into each air stripper, and water level in the equalization tank and effluent sump. According to the operator, this information cannot be viewed at a remote location and the software does not store the data or generate reports.

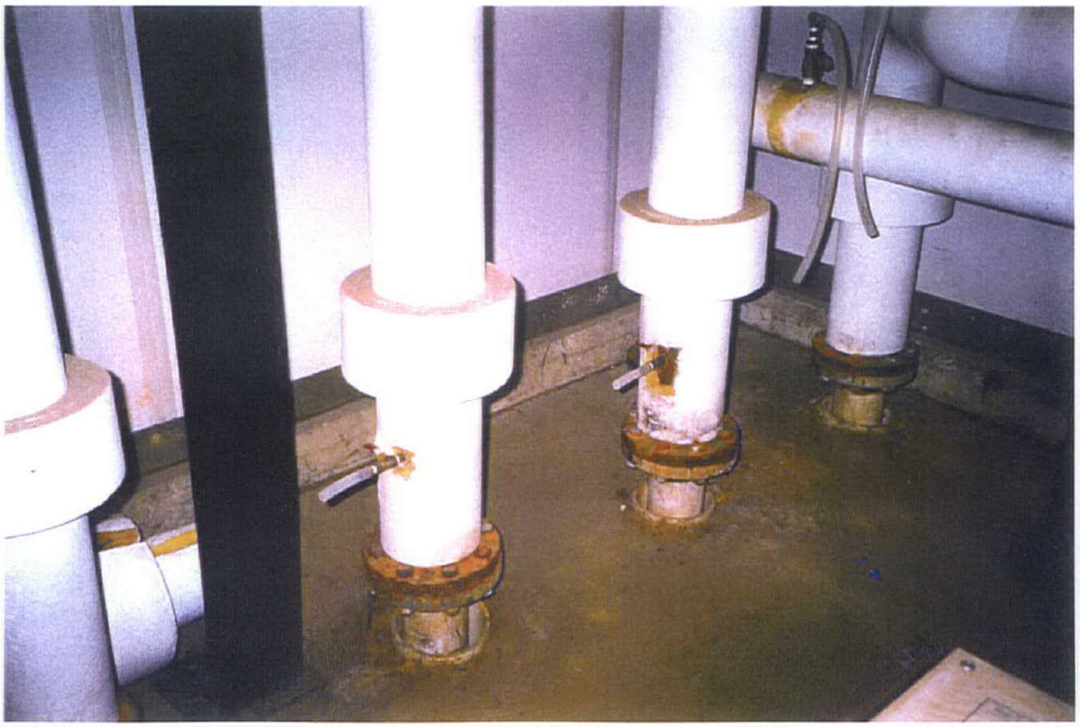

**Figure 3-1. Influent Piping from Extraction Wells**

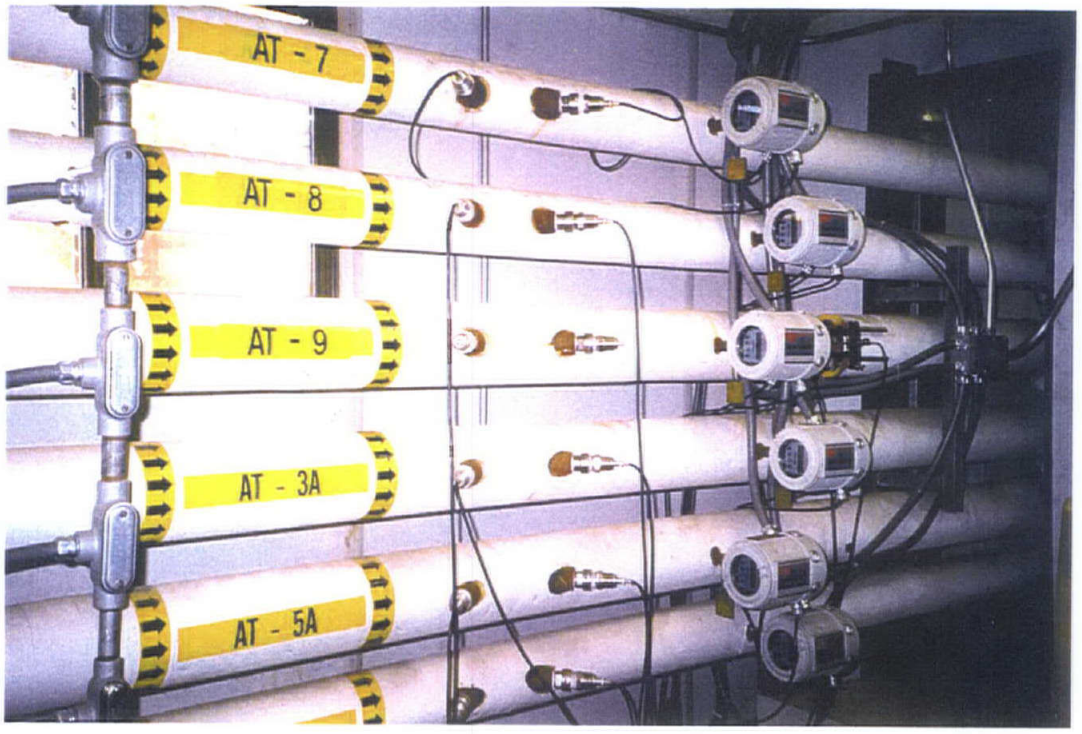


**Figure 3-2. Influent Flow Measurements**

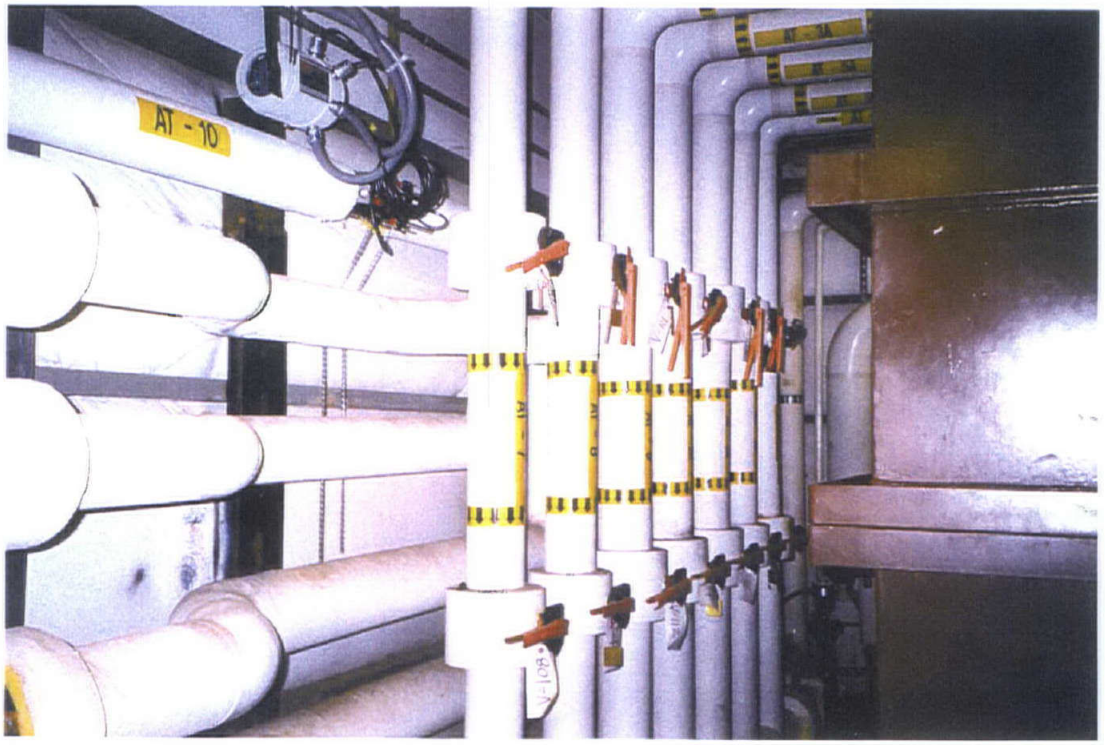


**Figure 3-3. Influent to Equalization Tank**

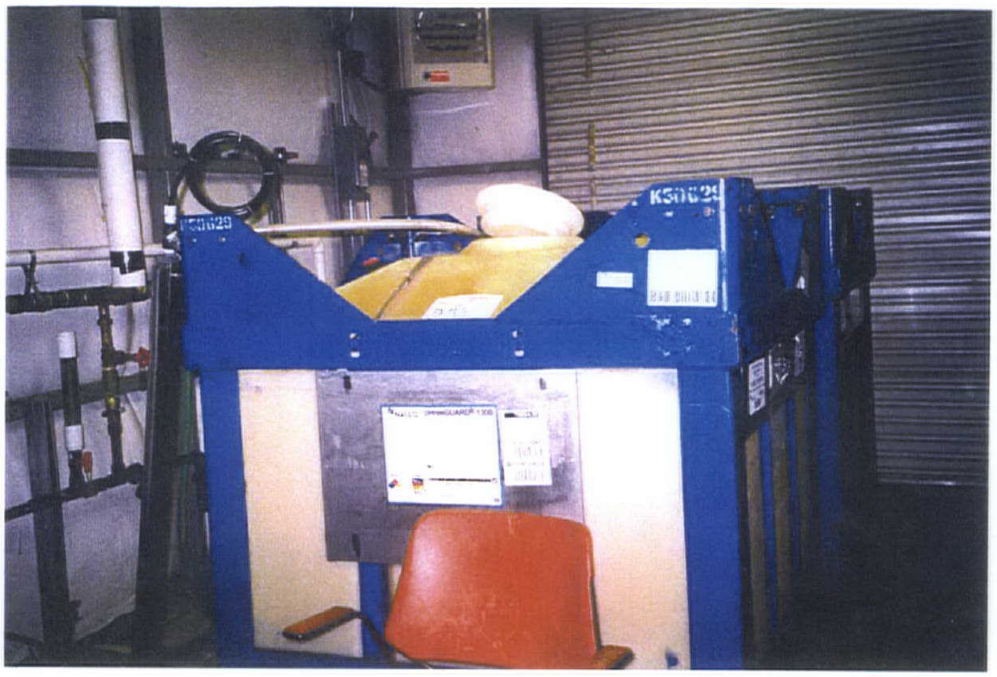

Figure 3-4. Sequestering Tank

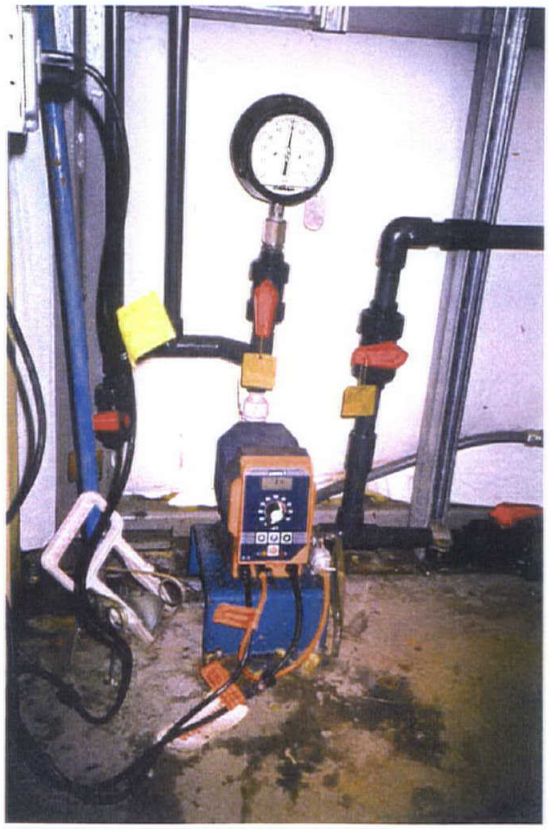

Figure 3-5. Sequestering Pump

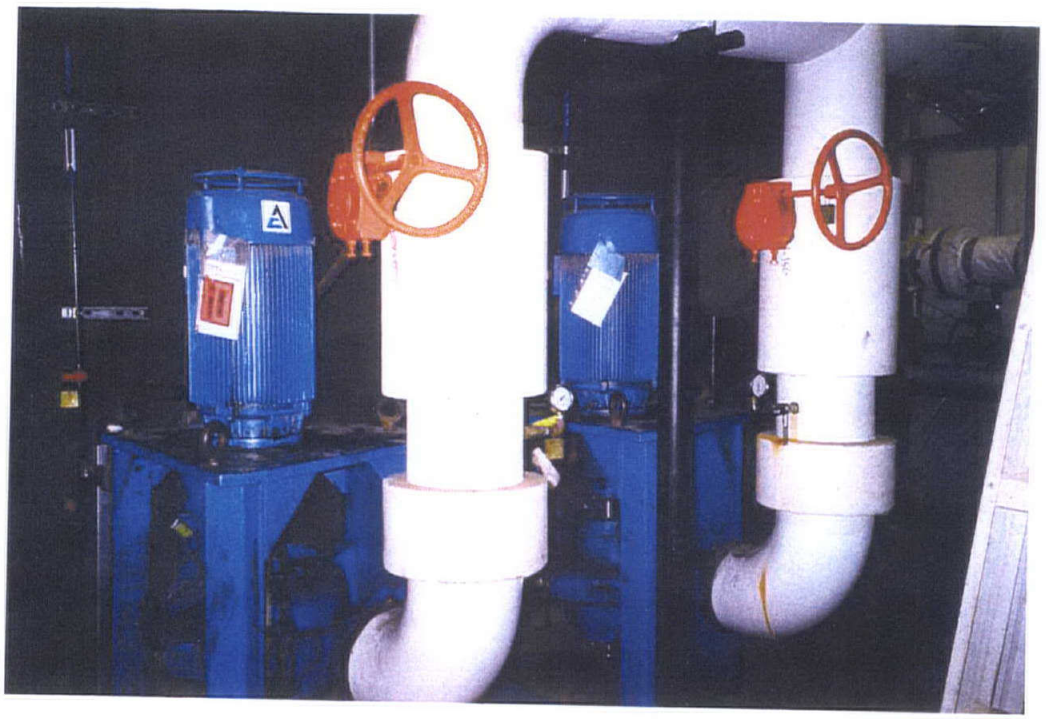

Figure 3-6. Effluent Equalization Tank Pumps

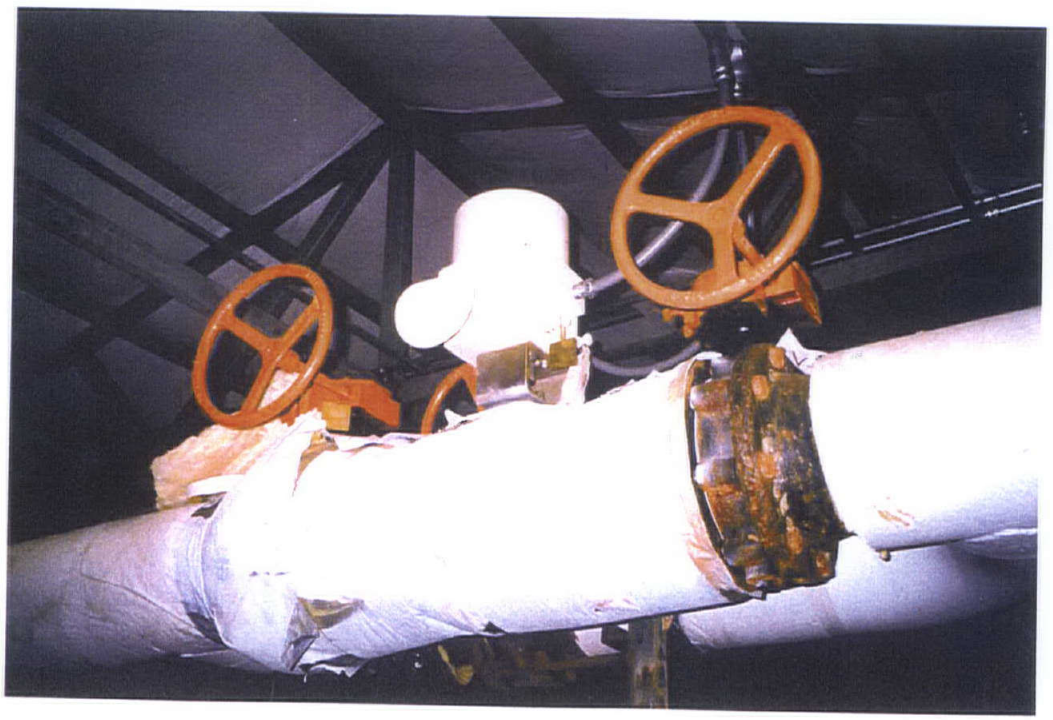

Figure 3-7. Equalization Tank Flow Control Valve

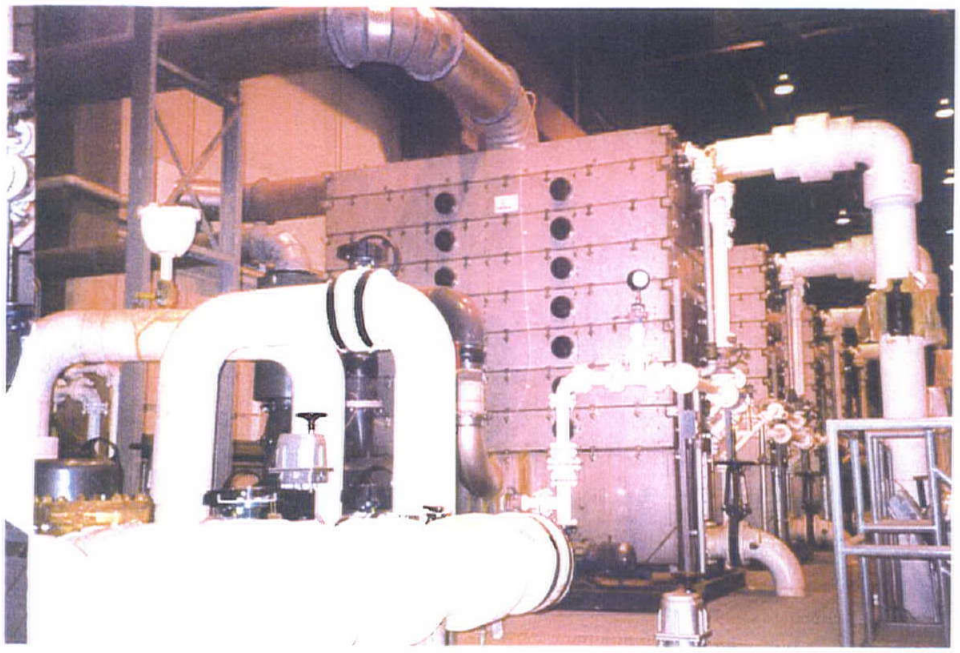

Figure 3-8. Air Strippers

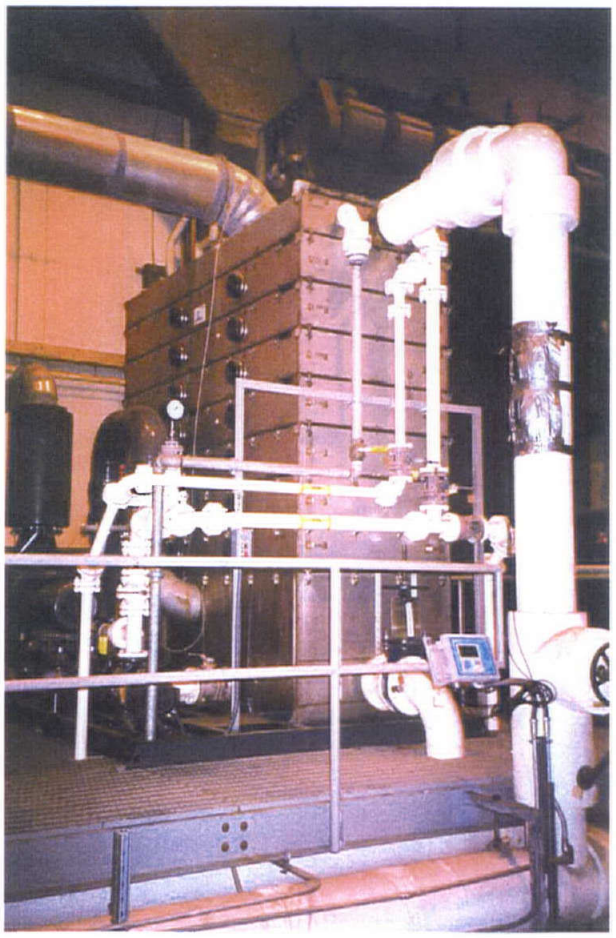

Figure 3-9. Air Stripper Influent

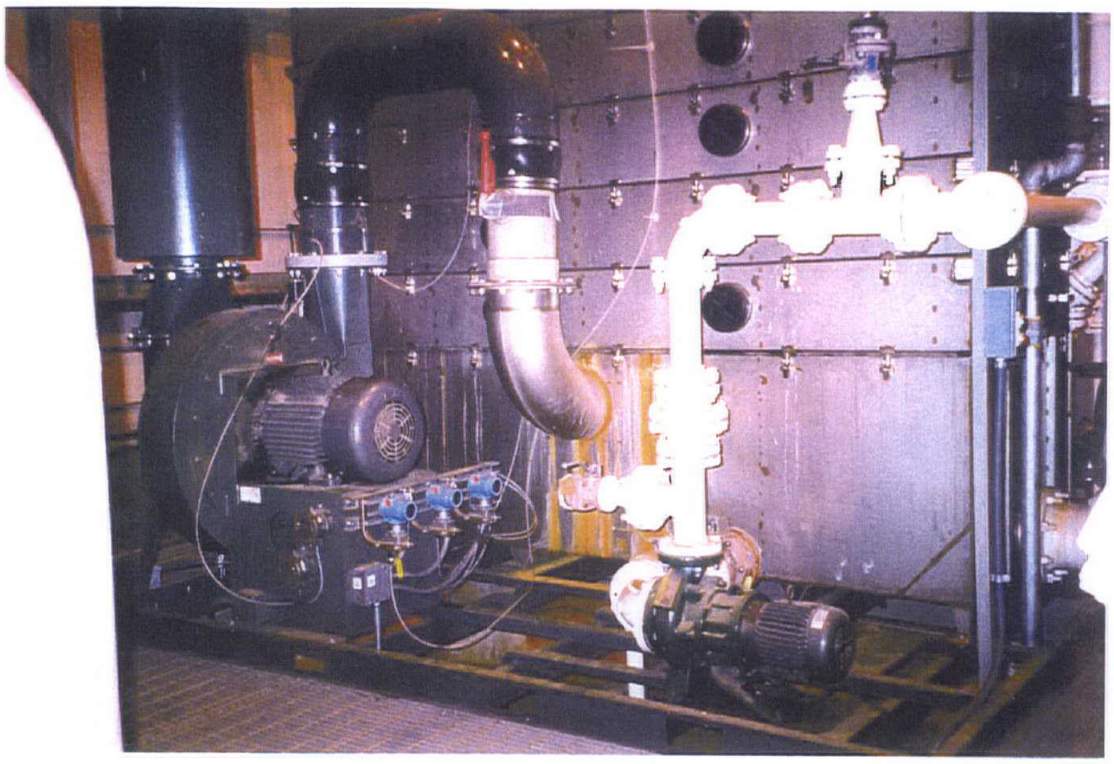

**Figure 3-10. Acid Washing Recirculation Pump and Belt Driven Air Blower**

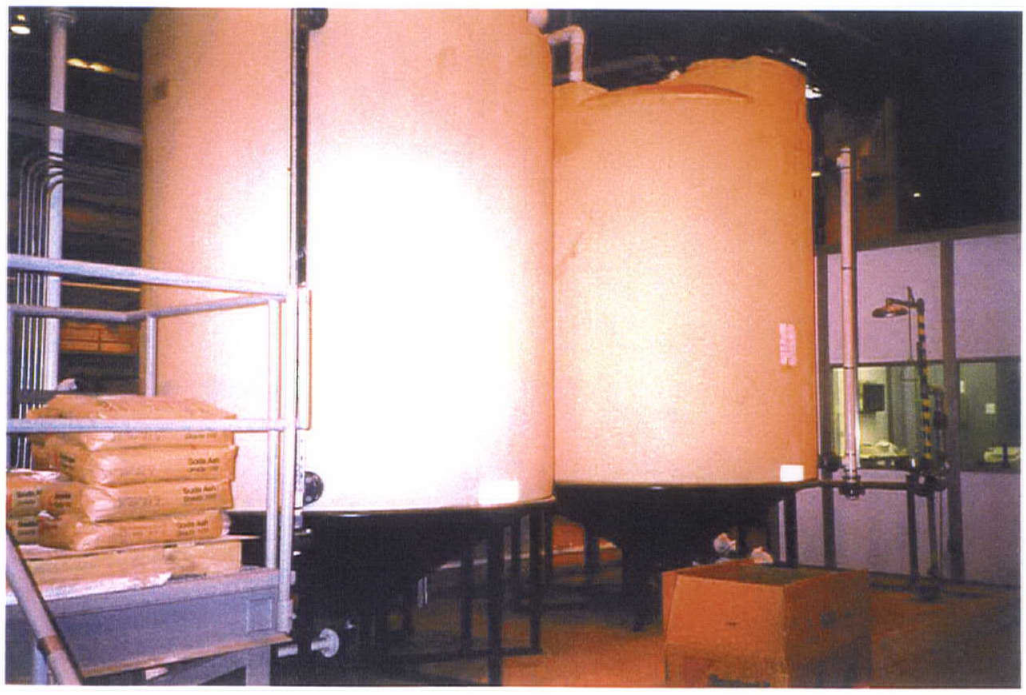

**Figure 3-11. Acid Solution Holding Tank**

**Figure 3-12. Filter Press**

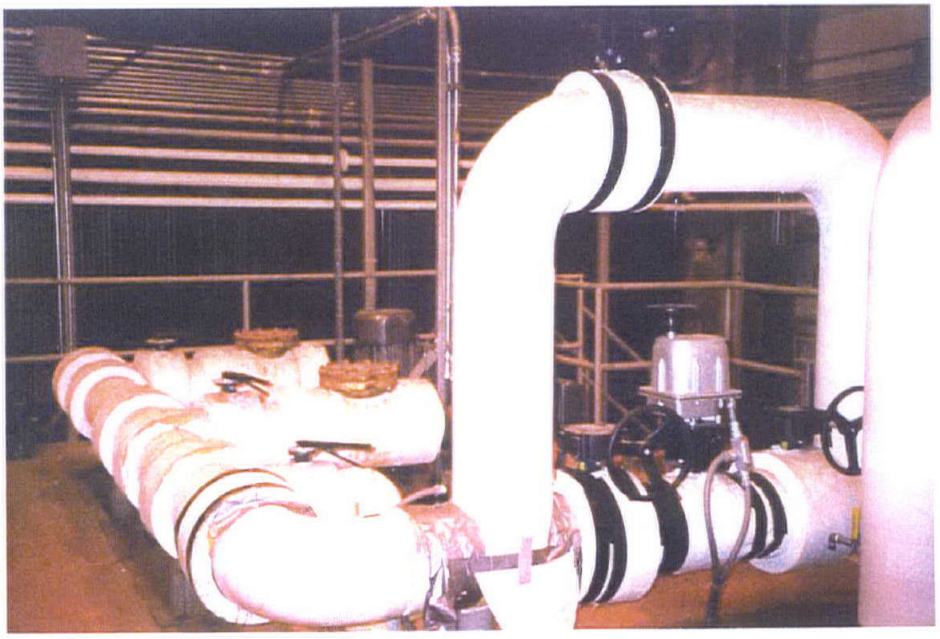

**Figure 3-13. Effluent Sump and Piping**

## Section 4.0: OPTIMIZATION STRATEGY

### 4.1 Review and Evaluate Remedial Action Objectives

It is important to identify the target treatment zones for the NIROP site and to establish the remedial action (RA) objectives for each target treatment zone. Once this is done, the remedial approach can be more efficiently evaluated. The following target treatment zones have been identified: surface soil, subsurface soil, dense-nonaqueous-phase liquid (DNAPL), and VOCs in groundwater. Table 4-1 presents a summary of target treatment zones, current RA objectives, current status, and potential modifications to the RA objectives and remedies. Table 4-1 also includes potential alternate remedies. These remedies are discussed in more detail in Section 4.4.

No further action is required for surface soil at the NIROP Fridley. Future site use is expected to be limited to industrial; therefore, the risk evaluation for the industrial worker indicates that there is not a need for controls to limit exposure of workers to surface soil (0 to 4 ft). However, the industrial risk evaluations for activities that involve contact with soils beyond 4 ft suggest that the need for exposure controls should be evaluated (e.g., zoning restriction, deed notifications) to limit future property uses or activities that may result in higher exposures or exposures to different receptors (TtNUS, 2002b).

For DNAPL, the remedial action objective is to remove product if possible. Although the present CSM does not identify the precise location of the DNAPL, it is possible that DNAPL is present beneath the NIROP Fridley manufacturing plant building. If so, it is unlikely that any effective DNAPL removal can be conducted while the building is in place. Thus, delineation and removal of DNAPL that may be present beneath the building is not considered to be feasible at this time. No potential alternative RA objective is recommended.

The ROD for groundwater remediation at the NIROP Fridley was signed in September 1990. The remedial action in the ROD specifies hydraulic containment and recovery of all contaminated groundwater at the NIROP facility, and the recovery, to the extent feasible, of contaminated groundwater downgradient of the NIROP facility (TtNUS, 2004). On-site groundwater is not currently used as a potable water supply at the site, and it is not expected to be used as potable water in the future because a public water supply is available. However, groundwater from the site flows west/southwest entering the Mississippi River, and the City of Minneapolis draws its municipal water from the river approximately 2,000 ft downstream from the NIROP site (U.S. EPA, 1991). Therefore, the final remedial goal for groundwater at the NIROP Fridley is to achieve the federal maximum contaminant levels (MCLs) or the MPCA Health Risk Limits (HRLs) if no MCL is established for a constituent.

It may be possible to negotiate less-stringent goals with the regulatory agency that are developed using risk-based criteria; however, given the elevated concentrations down gradient of NIROP Fridley, and the nearby location of the MWW raw water intake, it may be difficult to obtain regulatory approval. These cleanup goals are summarized in Table 4-1.

### 4.2 Evaluate Remedial Action Effectiveness

As discussed in Section 4.1, the short-term RA objective for groundwater treatment is containment of the contaminated groundwater, and the long-term RA objective is to achieve the MCLs or HRLs in groundwater. The selected groundwater remedy includes the installation and operation of extraction wells with a two-phase plan for disposal of groundwater generated by the extraction system. Under Phase I, the extracted groundwater was discharged directly to the existing sanitary sewer system

wrong! LUC RD + deed restrictions.

**Table 4-1. Summary of Target Zones and RA Objectives and Actions**

| Target Treatment Zone | RA Objective/ Cleanup Goals | Current Remedy | Status | Potential Alternative RA Objective | Alternate Remedy or Treatment Train |
|---|---|---|---|---|---|
| Surface soil | Meet MDH Soil Criteria | None required under the industrial use scenario | Completed | None | None |
| Subsurface soil | Meet MDH Soil Criteria | Informal institutional controls (e.g., fencing and restricted site access) | Completed | None | Formal institutional controls (e.g., zoning restrictions, deed notifications) |
| DNAPL | Remove if possible | None | N/A | None | None |
| VOCs in groundwater | Interim objective to contain and recover contamination groundwater | Pump and treat | Ongoing | None | None, groundwater containment is effective |
| VOCs in groundwater | Meet MCL or HRL Criteria | Pump and treat | Ongoing | None | In situ permeable reactive barrier |

N/A = not applicable.

for treatment at the local wastewater treatment facility. Under Phase II, extracted groundwater is now treated in an on-site treatment system, and the treated water is discharged to the Mississippi River via a NPDES permit. The effectiveness of this remedial action in meeting the RA objectives will be evaluated based on the following factors:

(1) Hydraulic containment of the contaminated groundwater with total VOC concentrations greater than 100 µg/L (Casey, 2005);
(2) Comparison of groundwater monitoring data to the MCLs or HRLs; and,
(3) Contaminant mass removal by the groundwater treatment system.

***Hydraulic Containment***

The goal of the pump and treat system is to maintain hydraulic containment of VOC-contaminated groundwater (U.S. EPA, 1990). Because TCE is the primary contaminant of concern, it is used as an indicator of total VOC concentrations when evaluating hydraulic containment. A value of 100 µg/L was negotiated with the MPCA as a target for evaluating the effectiveness of hydraulic containment (Casey, 2005). An evaluation of the extraction well capture zones was performed for the 2001 AMR using a combination of approaches, including analytical equations, a flow net evaluation, and numerical groundwater flow/particle track modeling. In addition, the USGS performed an independent evaluation of the site hydrogeology and extraction well capture zones in 2002 (USGS, 2002). In general, good agreement was found between the calculated and flow-net type approaches presented in the AMRs and the USGS 2002 report (TtNUS, 2004). Figures 4-1, 4-2, and 4-3, which were taken from the 2004 AMR (TtNUS, 2005), were used to evaluate the effectiveness of hydraulic containment achieved by the pump-and-treat system. These figures present the approximate aerial capture zone extents for shallow, intermediate, and deep groundwater based on a flow-net approach.

In the shallow zone, extraction wells AT-5A, AT-7, AT-8, and AT-9 appear to be capturing all of the groundwater with TCE concentrations greater than 100 µg/L along the property boundary (Figure 4-1). However, groundwater flow contours immediately down gradient of AT-7 and AT-8 indicate that some potential bypass could occur in this area (TtNUS, 2005).

Extraction wells AT-3A and AT-10 pump from the intermediate zone, and it appears that nearly all of the groundwater along the property boundary with TCE concentrations exceeding 100 µg/L is being captured by these two extraction wells (Figure 4-2). An area of potential concern is near wells located north of AT-3A (i.e., MS-34I and MS-35I), which have relatively high concentrations of TCE. Also, another area of uncertainty is at the hydraulic unconformity located between the intermediate capture zones of AT-3A and AT-10, where hydraulic head data indicate the potential for bypass of some contaminated groundwater to occur in this area (TtNUS, 2005). In the deep zone, 2004 groundwater monitoring data indicate that only two wells have TCE concentrations greater than 100 µg/L: 17-D and AT-5B. Field data indicates that AT-3A draws from both the intermediate and deep zones (TtNUS, 2005), so it has been included in both capture zone evaluations. The estimated capture zones around AT-3A and AT-5B indicate that there may be some groundwater bypass along the property boundary between these two extraction wells (Figure 4-3).

The extraction well network appears to be containing the majority of the groundwater with TCE concentrations exceeding 100 µg/L along the property boundary. Contaminant concentrations in the central portion of the ACP have decreased in 2004 compared to those observed in previous years. Figures 4-4 through 4-9 show TCE concentration trends for the shallow, intermediate, and deep zones for monitoring wells located within the area of influence of the extraction wells and for monitoring wells located downgradient of the site and outside the area of influence of the extraction wells. The data indicate that TCE concentrations at most wells are decreasing over time, particularly the monitoring wells outside the capture zone. The downward trend in CVOC concentrations indicates that the pump-and-treat system is effective at containing the plume. Thus, additional pumping at greater flowrates and/or from additional extraction wells is not warranted at this time. Also, some decrease in concentrations within the ACP pilot study area has been documented due to the vegetable oil injection pilot test that was recently conducted at ACP. There is evidence that some natural attenuation is occurring; however, the rates are not adequate to prevent the downgradient contaminated groundwater from exceeding surface water standards for the Mississippi River (TtNUS, 2004). Additional field application to enhance in situ bioremediation via vegetable oil injection is planned to address the downgradient contaminated groundwater (Parsons, 2005).

***Comparison of Groundwater Data to MCLs***

TCE concentrations have not reached the MCL of 5 µg/L in any monitoring wells located either in the extraction well capture zone, or downgradient of the extraction wells. This is to be expected, as pump-and-treat is not an effective technology for groundwater cleanup of CVOCs where a source area remains, as suspected beneath the NIROP Fridley building.

***Contaminant Mass Removal by the Groundwater Treatment System***

Another way to evaluate hydraulic containment by the groundwater extraction system is to monitor the contaminant mass removal. Because TCE concentrations in many of the monitoring wells located in the extraction well capture zone have not decreased significantly, contaminant mass removal rates should still be high if the groundwater extraction system is continuing to remove and treat this water. Figure 4-10 shows the cumulative TCE mass removed over time. This figure indicates that the groundwater extraction system has not yet reached asymptotic mass removal; therefore, the system is continuing to operate effectively. Recent data indicate that approximately 700 lb of TCE was removed by the groundwater extraction system in 2003. This is a significant amount of contaminant mass given that operational efficiencies of the extraction wells were low in 2003, in the range of 45% to 61%, which is approximately 20% to 30% lower than in 2002 (TtNUS, 2004). In 2004, approximately 896 to 1,096 lb of TCE were removed, and the operational efficiencies of the extraction wells were higher, ranging from 55% to 85% (TtNUS, 2005).

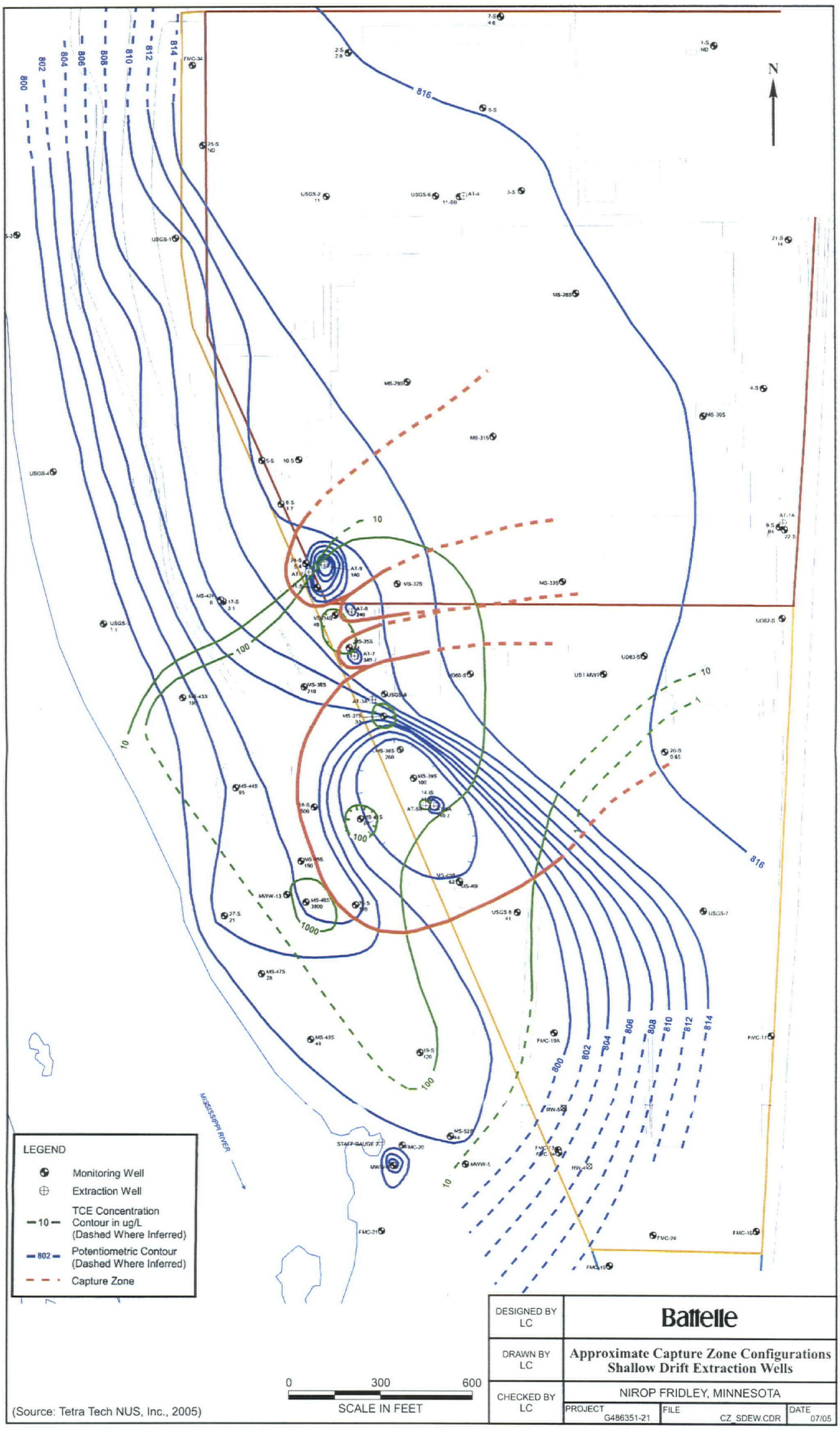


**Figure 4-1. Approximate Capture Zone Configurations for Shallow Drift Extraction Wells a NIROP Fridley, MN**

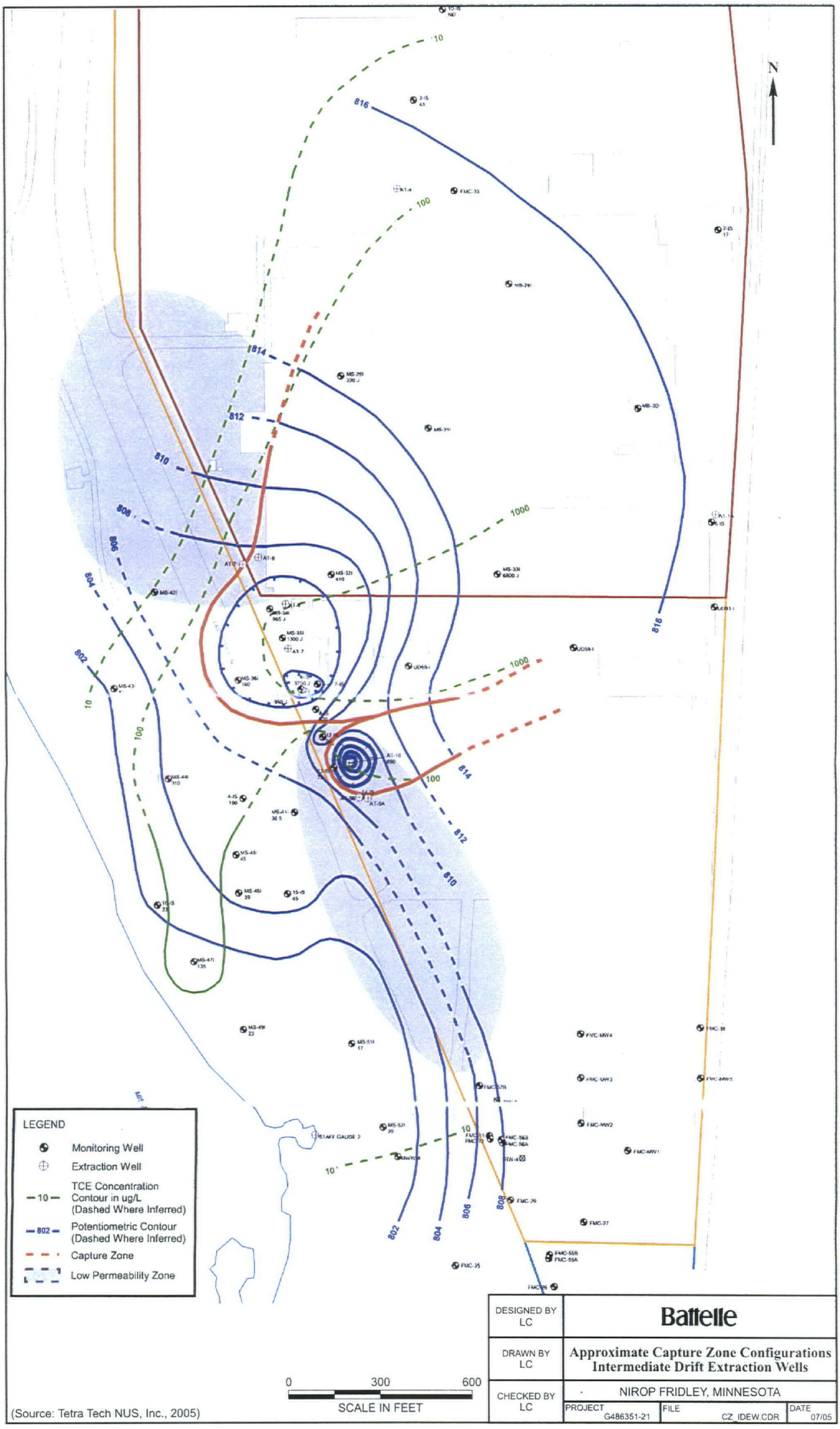


**Figure 4-2. Approximate Capture Z one Configurations for Intermediate Drift Extraction Wells at NIROP Fridley, MN**

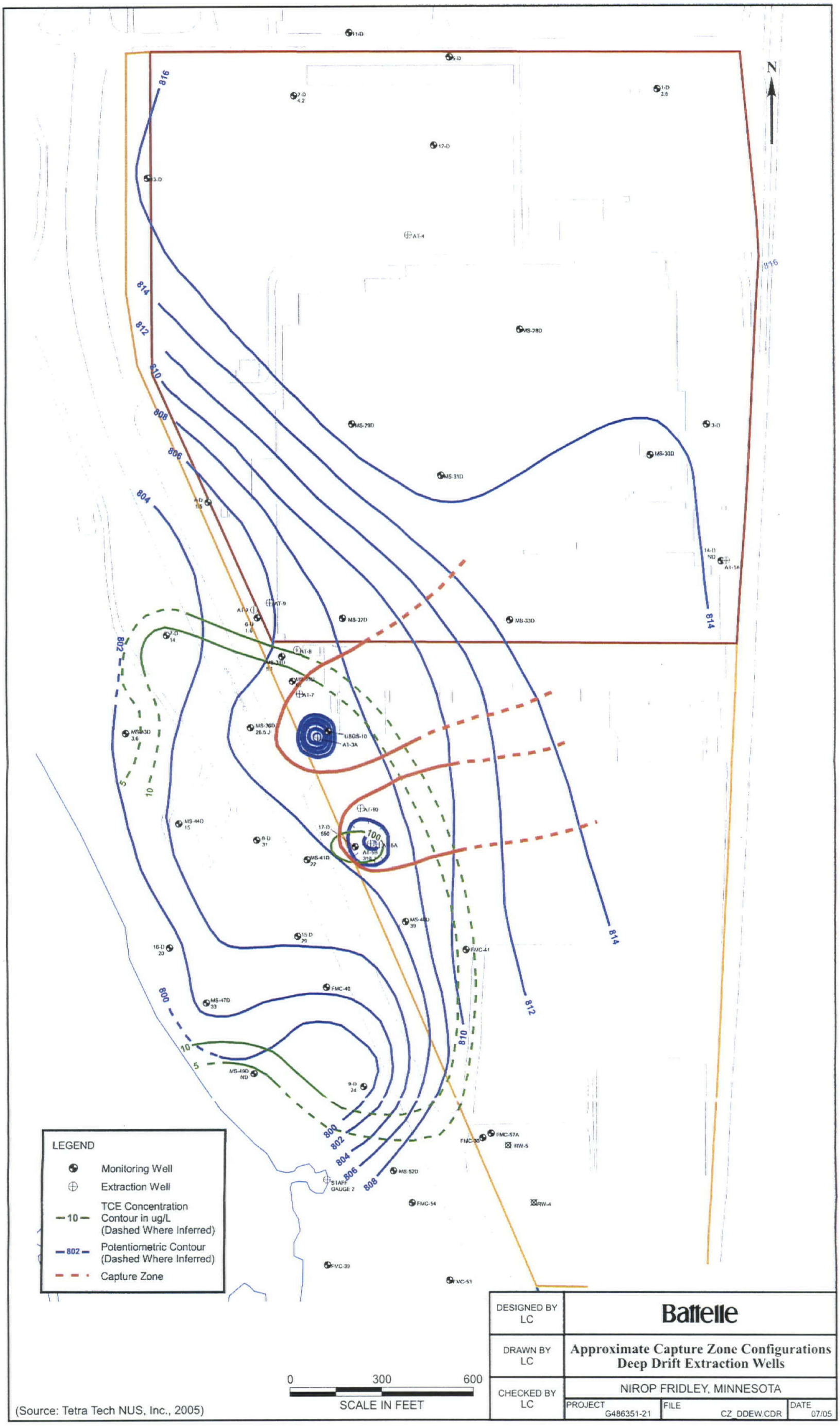


**Figure 4-3. Approximate Capture Zone Configurations for Deep Drift Extraction Wells at NIROP Fridley, MN**

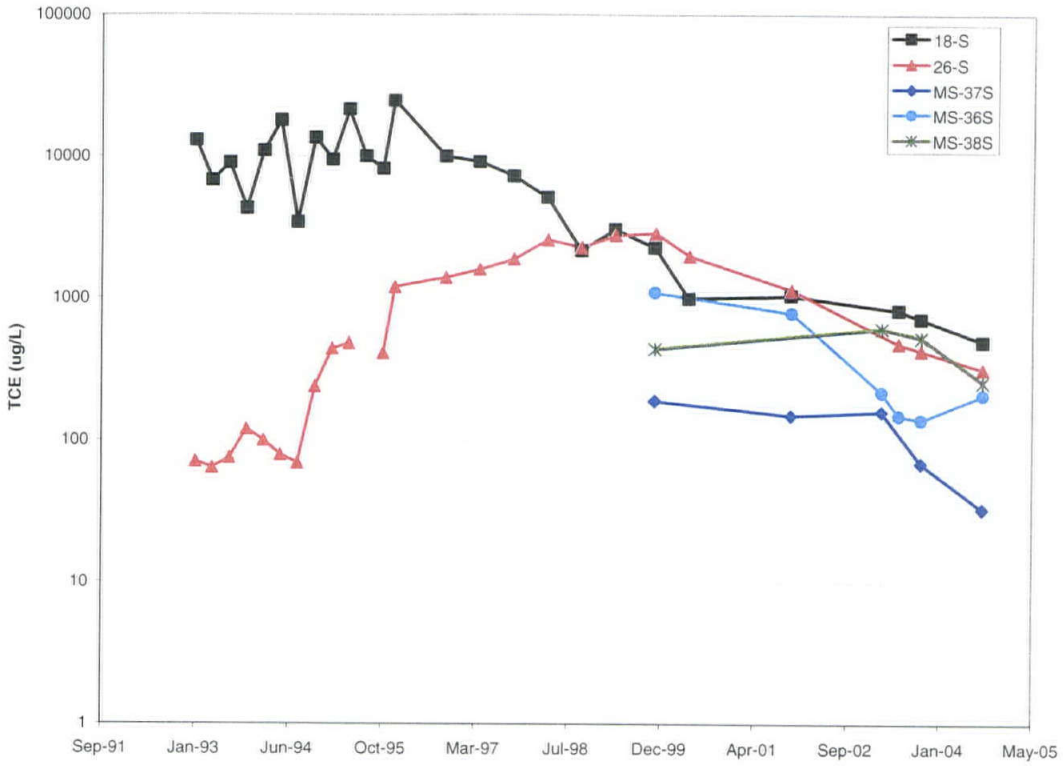


**Figure 4-4. TCE Concentrations in Shallow Wells Inside the Capture Zone**

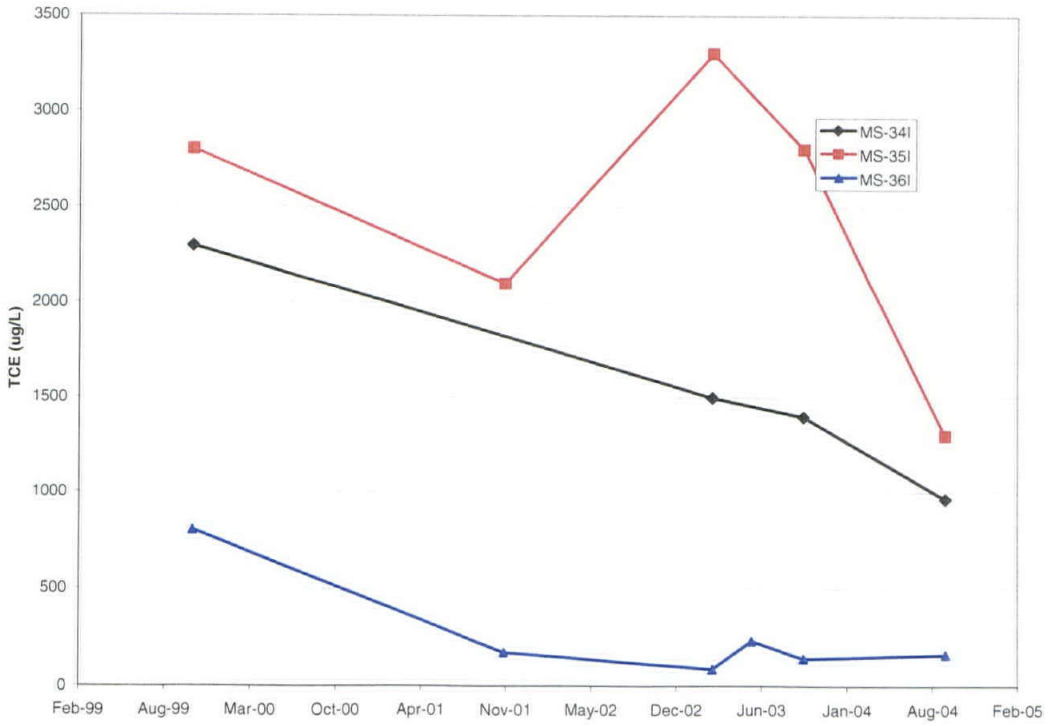


**Figure 4-5. TCE Concentrations in Intermediate Wells Inside the Capture Zone**

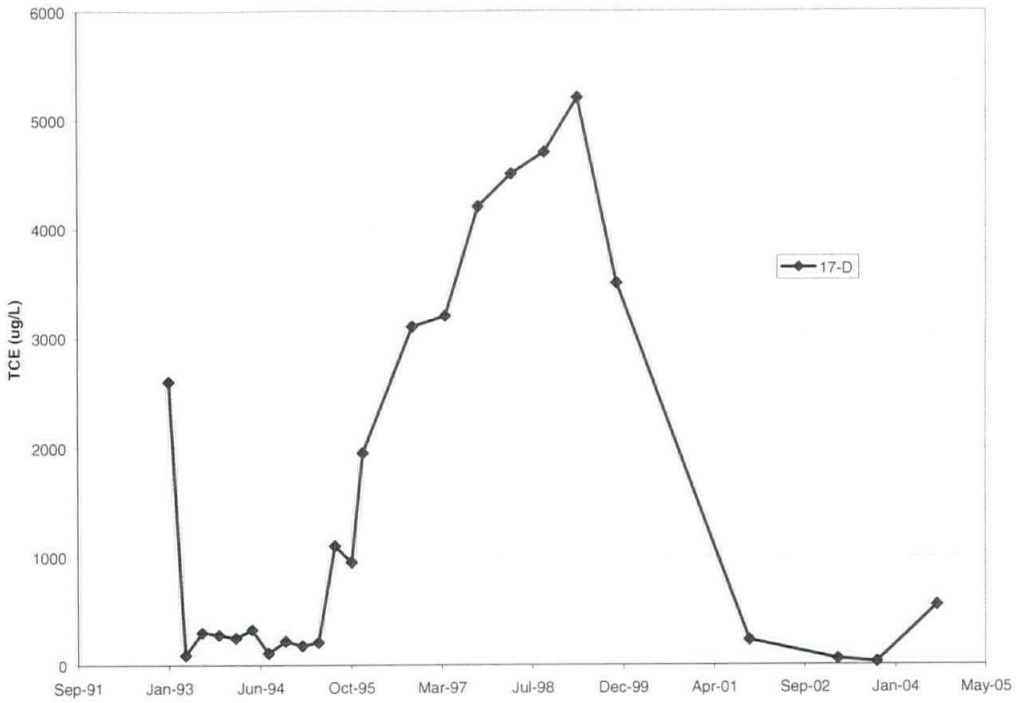


**Figure 4-6. TCE Concentrations in Deep Wells Inside the Capture Zone**

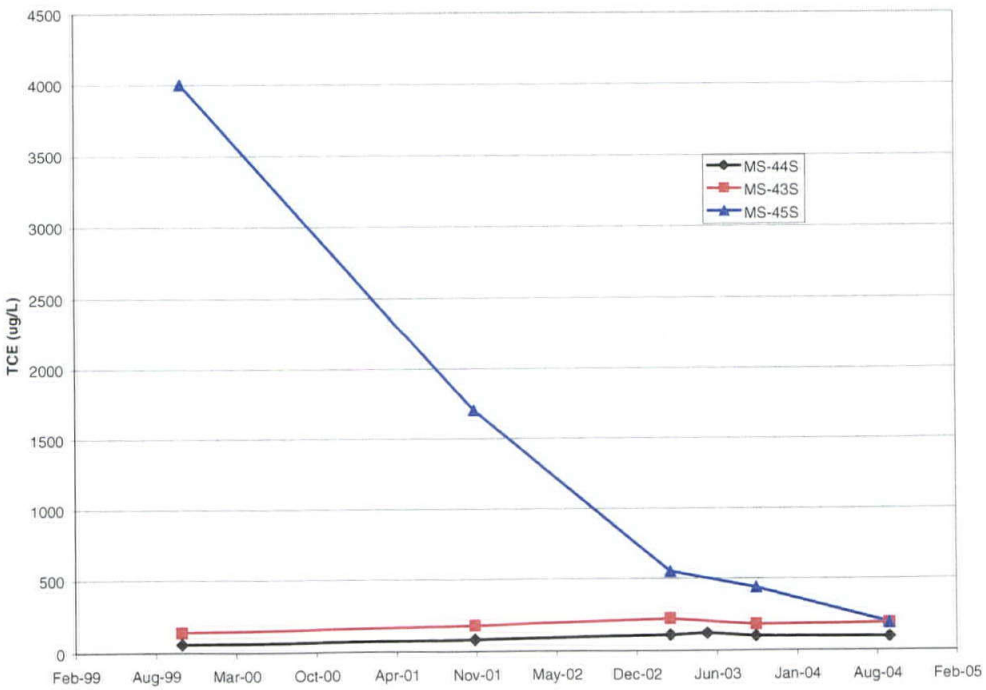


**Figure 4-7. TCE Concentrations in Shallow Wells Outside the Capture Zone**

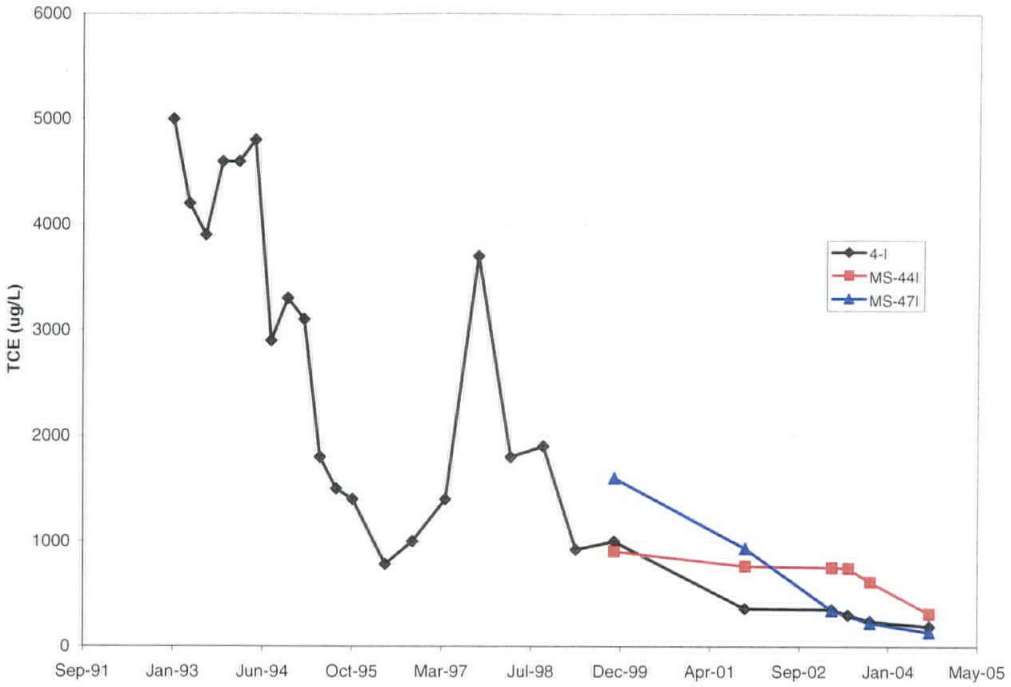


**Figure 4-8. TCE Concentrations in Intermediate Wells Outside the Capture Zone**

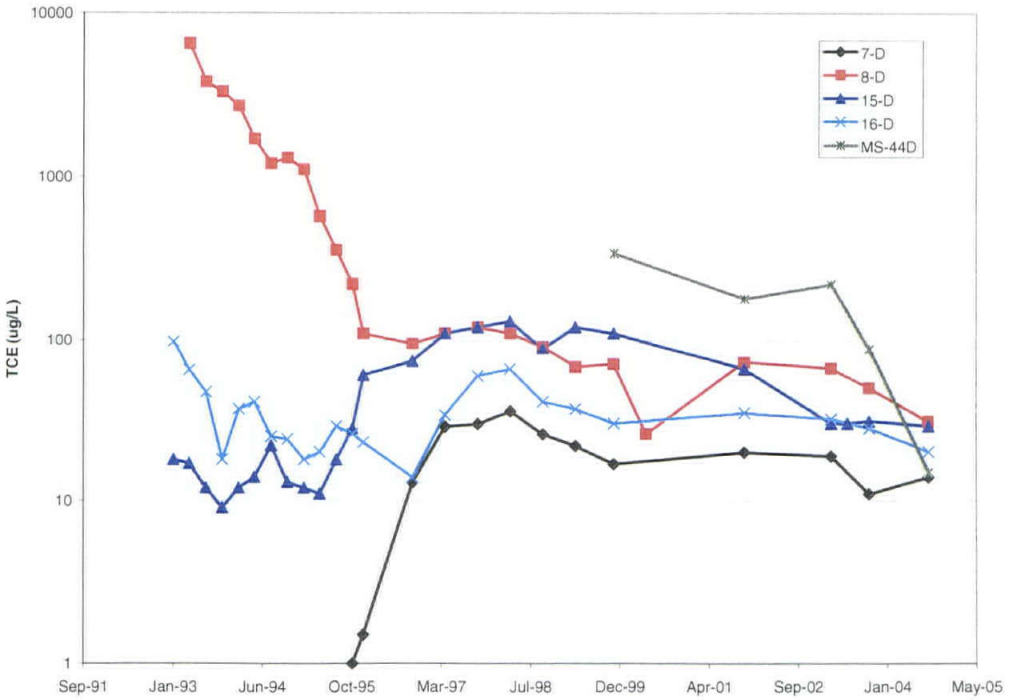


**Figure 4-9. TCE Concentrations in Deep Wells Outside the Capture Zone**

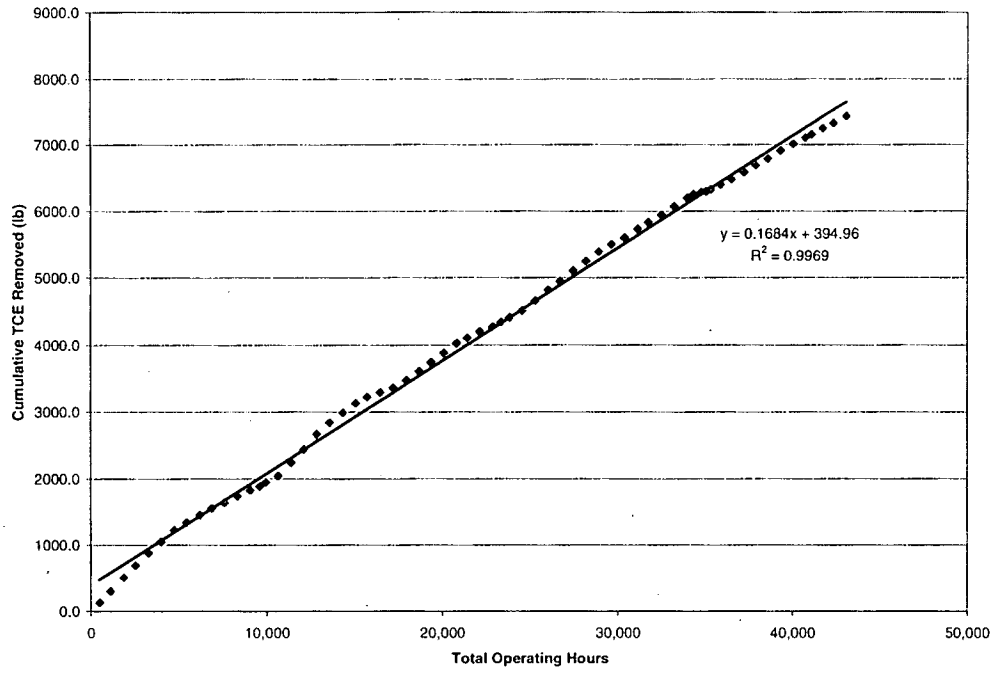


**Figure 4-10. Cumulative TCE Recovery**

## 4.3 Evaluate Cost-Efficiency

The cost-efficiency evaluation presented in this section includes a summary of projected O&M costs in terms of cost per year, cost per pound of VOCs removed and cost to completion. Table 4-2 summarizes the current annual O&M costs for the groundwater extraction system. The table is based on the following information provided by Bay West, the current plant operator:

- O&M costs and equipment repair costs include management, office support, and on-site labor; equipment and supplies; and purchased goods and services.

- Groundwater sampling costs include labor, equipment, supplies and laboratory fees for the semi-annual groundwater sampling events. Groundwater gauging, groundwater sampling, project management and laboratory management costs are included in the labor costs. Groundwater samples are submitted for VOC analyses in accordance with U.S. EPA SW-846 Method 8260B.

- There are two discharge permits for the site. One permit is a NPDES permit, the second permit is a sanitary sewer permit from the Metropolitan Council for Environmental Services. All fees (application, annual, use, etc.) are paid directly by the Navy or UDLP (holder of the NPDES permit for the site). Information is not readily available regarding the fees paid, but based on discussions with Navy personnel, it is believed that this is not a significant expense.

Navy is co-permittee

**Table 4-2. O&M Costs**

| Year | Annual O&M Fixed Fee | Annual Groundwater Sampling Fixed Fee | Additional Annual Equipment Repair Costs | Total Costs During Contract Year |
|---|---|---|---|---|
| Base Year | $179,954 | $70,042 | $19,291 | $269,287 |
| First Option Year | $158,664 | $82,519 | $45,790 | $286,973 |
| Second Option Year | $160,900 | $85,820 | $71,282 | $318,002 |
| Third Option Year | $167,799 | $89,253 | $78,629 | $335,681 |
| Fourth Option Year | $183,199 | $92,789 | $3,971 | $279,959 |

Source: Bay West (2005).

As shown in Table 4-2, the total costs are largely attributed to project management, office support, and on-site labor; equipment and supplies; purchased goods and services; and additional equipment repair (including redevelopment of recovery wells). Additional equipment repair (including redevelopment) can be quite significant cost (up to 32% of O&M costs excluding groundwater monitoring costs).

The annual O&M cost is approximately $300,000 per year, and the average cost per pound of TCE removed in 2003 was calculated to be between $175 and $200 (TtNUS, 2004). The average cost per pound of TCE removed in 2004 ranged from $201 to $215 (TtNUS, 2005). Prior to 2003, the average cost per pound of TCE was between approximately $60 and $350. The average cost per pound of TCE removed reported in the AMR is calculated based on cumulative TCE removed divided by the cumulative cost.

Figure 4-11 shows the average cost per pound of VOCs removed, as well as the cumulative costs incurred since November 1998. The average cost per pound removed was calculated based on monthly recovery and monthly cost, as reported in the 2004 AMR (TtNUS, 2005). Thus, in 2003 and 2004 in some months the costs per pound removed were high, in the range of $1,000 to $4,000. This occurs in times of unusually high number of operational problems, system maintenance, and system shutdown periods, when costs are high and recovery is low because of long shutdown periods. In months when normal flowrates were achieved, the cost per pound removed remained in the range of $175 to $350.

It is important to note that these costs do not include utilities. At present, the Navy is not paying for the electricity required to operate the system. According to the meter readings reported in the AMR, the electricity usage for the groundwater treatment system was approximately 432,000 kWh in 2003 (TtNUS, 2004), during which the system only was operational for about 60% of the year. Assuming a cost of $0.062/kWh, the total electricity costs for 2003 would be approximately $27,000. In a year during which the system is operational at least 90% of the time, at the same cost of electricity, the cost for electricity would be greater than $40,000, which represents about 15% of the annual O&M costs.

Assuming that no system modifications are made, and that the system will operate for an additional 30 years, the total present worth cost for O&M of the treatment system is approximately $6.9 million. This present worth cost is based on an annual O&M cost of $300,000, an annual electricity cost of $50,000, and a rate of return of 3%. Some system and operational modification can be made to reduce the lifetime costs of the system, including improvements to reduce electricity requirements and increase automation of the system which would result in a reduction of labor required. These system modifications are discussed further in Section 4.4.

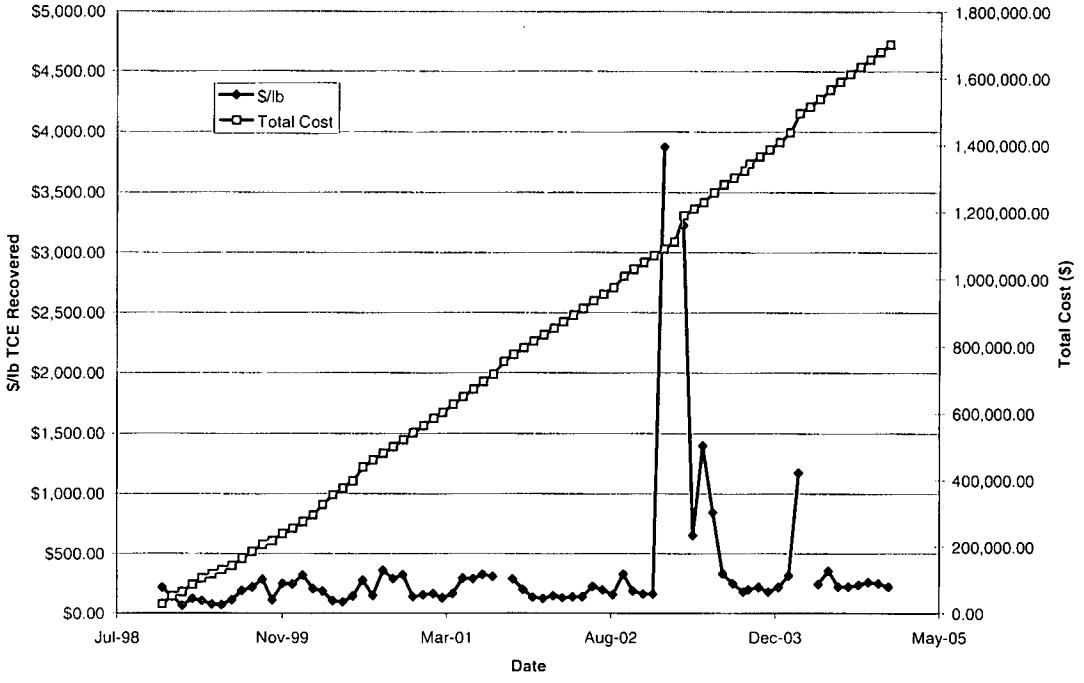


**Figure 4-11. Cost Evaluation of the Groundwater Treatment System**

## 4.4 System Modifications and Remedial Alternatives

Three remedial approaches were considered for implementation at the NIROP, and each is discussed in detail in this section:

- Perform various modifications to the existing pump-and-treat system to either improve efficiency or reduce operating costs;
- Install a PRB; and,
- Perform source zone treatment.

**4.4.1 Modifications to Existing System.** A review of the O&M cost of the existing pump-and-treat system indicates that most of the operating cost is attributed to electricity, labor costs, and additional equipment repair. Additional cost analysis is presented based on making the following system modifications:

(1) At the current flow and mass loading conditions, one air stripper can be taken off-line to save energy costs associated with pumps and blowers;

(2) Replace existing air stripper feed pump motors with variable frequency drives (VFDs); and,

(3) Update the PLC to allow for data storage and easier data access and reporting.

*Remove One Air Stripper from Operation*

According to the O&M Manual (Morrison Knudsen, 1999), each air stripper is designed to treat 250 gpm at the maximum VOC concentrations, while producing treated groundwater that meets the required effluent criteria. Four air strippers were installed to accommodate the 815 gpm from the original extraction wells; however, the combined target flowrate after optimizing the well field is now only 674 gpm (TtNUS, 2004). Therefore, because the target flowrate is now below 750 gpm, groundwater can be treated effectively using only three of the four air strippers. Each stripper blower is equipped with a 25 hp motor, which draws an estimated of 204,000 kWh of power annually (assuming 80% of the name plate hp, 90% motor efficiency, and 100% operational time). Assuming an electric cost of $0.062/kWh, an annual cost savings of $9,000 would be realized if one of the air strippers is not operated.

An extra tower will be available to use when routine maintenance (such as acid cleaning) or other unanticipated maintenance activities are being performed on one of the three towers, so it may be possible to improve operating time and/or reduce O&M costs by using the "spare tower" instead of shutting the system down to perform the maintenance. However, at the time this report was prepared, detailed cost data were not available to determine if there would be a definitive cost savings with respect to maintenance activities associated with eliminating the operation of one of the towers. As there is essentially no capital cost associated with this modification and the annual cost savings is estimated to be up to $9,000 per year, this modification is recommended.

*Replace Air Stripper Feed Pump Motors with VFDs*

Groundwater is pumped from the equalization tank to the air strippers by a 30-hp feed pump designed to pump up to 1,000 gpm. Because the target flowrate is now only approximately 650 gpm, the pump is continually working against extra pressure caused by the partially closed flow valves which maintain this reduced flowrate. This extra pressure causes more electricity to be consumed than under normal operating conditions. The use of a VFD in place of the existing soft-start motor starters may significantly reduce electricity costs associated with operating these pumps. The capital cost associated with this upgrade for the two air stripper feed pumps is approximately $30,000 (SAIC, 1998).

Operation of the existing 30-hp pumps is estimated to cost approximately $10,800 per year. This assumes 80% of the name plate hp, 90% motor efficiency, 100% operational time, and $0.062/kWh. Replacement with a VFD motor would require a 18.7 brake horse power (BHP) motor to pump approximately 80 ft of discharge head, assuming 70% pump efficiency. The estimated cost to operate this VFD would be $8,400 per year, assuming 90% motor efficiency, 100% operational time, and $0.062/kWh. Therefore, a potential savings in electricity costs of approximately $2,400 per pump, per year (or a total savings of $4,800 per year) may be realized by upgrading the pumps with VFDs. Based on a 3% rate of return, the breakeven point for this modification is 7 years. As it is anticipated that the pump-and-treat system will operate for longer than this period of time, this modification also is recommended.

*Update PLC*

Upgrading the PLC with the capability to log the total daily flow from each extraction well and other pumping stages in the treatment system, as well as instantaneous flow from each air stripper blower, may result in a decrease in labor associated with system monitoring and reporting. Such data trending also can assist the O&M contractor in troubleshooting. For instance, if an air stripper blower shuts down, it may be useful to review the air flowrates leading up to the shutdown condition. The capital cost associated with upgrading the PLC programming is approximately $7,000. Implementation of these

upgrades may reduce labor associated with system monitoring and reporting by approximately 4 hours per month, resulting in an annual savings of approximately $2,500.

Based on a 3% rate of return, the breakeven point for this modification is approximately 3 years. As it is anticipated that the pump-and-treat system will operate for longer than this period of time, this modification also is recommended.

*Cost/Benefit Analysis of Modifications*

The cost for implementing the above recommendations is approximately $37,000. This includes $30,000 for the VFD upgrade, and $7,000 for the PLC upgrade. As discussed above, it is estimated that these upgrades will result in a total annual savings of $13,800 in power costs, and $2,500 in labor costs. Additional savings in maintenance costs also may be realized by not operating one of the four air strippers.

**4.4.2 In Situ Permeable Reactive Barrier.** The PRB technology was first developed in the 1990s as a passive method for addressing long-lived contamination, such as that created by DNAPLs or CVOC contamination. A typical PRB consists of a trench filled with granular (-8+50 mesh size) zero-valent iron (ZVI), which is installed in the path of a groundwater plume. As the groundwater flows through the PRB, the CVOCs react with the ZVI and are degraded by relatively fast abiotic reactions to ethene and chloride.

The contaminants of concern (COCs) present at NIROP Fridley, primarily TCE, DCE, and PCE, have been treated effectively at more than 50 sites, including U.S. Department of Defense (DoD) sites such as Naval Air Station (NAS) Moffett Field, in the last 10 years. Therefore, the issue of feasibility is based on an assessment of the constructability of the PRB and the economics of the application.

*Constructability of the PRB*

The biggest challenge at this site is the depth of the contamination. Typically trench-type PRBs can be installed cost-effectively with standard construction equipment at depths of approximately 40 to 60 ft below ground surface (bgs). Below this depth, innovative methods of construction must be used. The first part of the analysis, therefore, consisted of an evaluation of the plume to see if there was any location near the source, property boundary or close to the river where the plume could be intercepted with a PRB that is approximately 60 ft bgs or less. There does not appear to be such a location at this site. Even near the former East Plating Shop, the most significant known potential source location, the plume (and perhaps the DNAPL itself) has migrated downwards through a gap in the silty clay layer and is present at depths closer to the bedrock, which is more than 100 ft bgs. Therefore, innovative methods of construction have to be explored. Two methods that have undergone serious testing to install deeper PRBs include pneumatic fracturing and hydraulic fracturing.

Of the two methods, pneumatic fracturing appears to have advanced more towards source treatment using nanoscale ZVI. Hydraulic fracturing has been oriented more towards PRB applications using granular or similarly-sized ZVI and there is a history of a few applications of this technology. For hydraulic fracturing applications, water is injected at high pressures to create a series of overlapping hydraulic fractures through a row of boreholes. The fractures then are filled with ZVI. Only one vendor offers this method, so commercial availability is limited. However, this vendor has demonstrated a fair amount of competence over the technology, which has been presented widely in various scientific forums.

Two primary limitations of the hydraulic fracturing technology constrain the applicability of this technology at this site: (1) uniformity and continuity of the injected PRB, and (2) achievable flow-through thickness of the PRB.

Uniformity and continuity are not a concern for a trench-type PRB. Careful excavation of soil and creation of a void that is then filled with ZVI virtually ensures that a trench-type PRB will not have any significant gaps through which the plume could escape downgradient. In an injected PRB, ZVI fills up fractures that have to be created and overlapped in such a way that continuity of the resulting PRB is obtained. The vendor claims that advances in construction methods, in quality control (QC), and in measurement techniques in the last one or two years have led to the type of uniformity and continuity that creates virtually a "trench-type" PRB. These advances include injection through a split-wing (directional) aluminum casing, sequencing and pore-pressure release in boreholes to "draw ZVI in desired directions," and the use of a proprietary additive to the ZVI. Although each step of the construction process is carefully monitored and the consequent quality assurance (QA) information has been widely disseminated by the vendor, it may be several years before the field performance (downgradient water quality improvement) of these injected PRBs is verified (after ten years of installation of the more conventional trench-type PRBs, the ability of these PRBs to improve downgradient water quality is just beginning to be verified). However, the vendor is confident about this aspect and has communicated their willingness to guarantee the thickness, continuity, and permeability of the PRB.

The bigger constraint is the achievable flow-through thickness of the PRB. Trench-type PRBs have been installed with a thickness of 1 to 6 ft, with the majority of the recent ones ranging from 1 to 3 ft thick. Most of these are sites with groundwater velocity of 1 ft/day or less. In an injected PRB, on the other hand, the thickness typically ranges between 1.5 and 4.5 inches. The vendor believes that they could potentially increase the thickness of the PRB to 1 foot with successive series of injections, but with each successive series the cost goes up considerably. A limited thickness means limited contact time between the naturally flowing groundwater and the stationary ZVI in this passive technology. Based on the March 2003 groundwater monitoring event (TtNUS, 2004), the average groundwater velocity for this site under non-pumping conditions appears to be approximately to 1.9 to 2.8 ft/day in the shallow and intermediate aquifer zones. Based on the estimated groundwater velocity at this site, a relatively thin PRB (3 to 4.5 inches) may not be sufficient. However, a more detailed hydrologic investigation at this site under non-pumping conditions may reveal that the groundwater velocity is lower than estimated.

Similar to the pump-and-treat system currently implemented, regulatory cooperation would be required to allow the off-site plume to attenuate naturally. Alternatively, additional remediation measures, such as biostimulation as is being tested in the ACP, should be considered for the off-site portion of the plume (Parsons, 2004).

### *Conceptual Design and Economics of Application*

A PRB would need to be constructed approximately 900 ft long and 75 ft high in order to capture the majority of the groundwater plume (i.e., the 100 ppb contour). It is estimated that such a barrier would cost $9 million. This estimate includes the cost of proprietary materials and processes involved. The barrier would be installed with the understanding that operation of the pump-and-treat system would be discontinued. The regulators would need to cooperate with a strategy in which there is a probability (however small) that after installation of the PRB, a small part of the contamination could migrate downgradient and would be allowed to attenuate naturally. Additional analysis would be required to evaluate the feasibility and acceptability of this scenario; however, this is not warranted at this

time because the implementation cost exceeds the $6.9 million 30-year NPV cost of continuing to operate the pump-and-treat system.

An alternate, potentially less costly approach would be to design the PRB with the objective of addressing only the more highly-concentrated portions of the plume located in the intermediate interval along the property boundary. The resulting PRB would be 500 ft long and 20 ft high and would cost $2 million. However, this alternative likely would not be acceptable without additional remedial measures as it would allow a much greater mass of contamination to be uncontrolled compared to the existing condition.

Any strategy that seeks to reduce PRB costs by focusing ZVI injections only in certain sections of the plume and by keeping the thickness of the PRB as small as possible should be conducted in conjunction with a risk reduction evaluation. The design of the PRB should be optimized using probabilistic, rather than deterministic, models, to determine the minimal thickness required to bring CVOC concentrations down to below MCLs. The probabilistic design model allows for variability of site formation hydraulic conductivities, groundwater flow gradients, CVOC concentrations levels, CVOC degradation half-lives, etc. The viability of biodegradation mechanisms at the site should be evaluated to verify the prospects of downgradient CVOC attenuation.

**4.4.3 Source Zone Treatment.** The most cost-effective remedy at a majority of chlorinated solvent contaminated sites where a DNAPL is present is to identify and treat the DNAPL source area. Elimination of the DNAPL source will significantly reduce the time and cost to treat (or contain) the dissolved-phase plume downgradient of the source area. At sites such as NIROP Fridley where the geology is complex and the plume is very large, one option has been to inject ZVI directly into the source.

Although elimination of the DNAPL source at the NIROP could significantly reduce the time which the existing pump-and-treat system would need to operate, source reduction may not be a viable option for this site. Several challenges present themselves:

- The locations of the source zones that need to be treated are not known. Multiple source locations are present. Substantial additional data to adequately characterize the 40-acre area beneath the main industrial plant building is required.

- Access to the facility is limited as a result of the high-security mission of the facility to produce a variety of missiles for the U.S. government. Characterization and treatment activities could be limited.

- Detailed characterization and remediation within the facility may be cost-prohibitive due to the building infrastructure (i.e., thick reinforced concrete slabs, utilities, limited space) and equipment associated with the mission of the facility.

Due to the challenges presented above, source zone treatment is not feasible at the current time. This should be revisited if activities conducted in the building change and allow significant intrusive work to be conducted to investigate and remediate under the building.

**4.4.4 Comparison of Alternatives.** The only alternative evaluated that is technically feasible and results in a lower NPV cost than the status quo alternative is modifications to the existing pump-and-treat system. The capital cost of these modifications is $37,000 and it is projected that these will result in an annual cost savings of approximately $16,300. This would result in a 2.4-year payback period if all of the upgrades are implemented. The 30-year net present value would be reduced from $6.9 million to $6.6 million, resulting in approximately $300,000 cost avoidance.

## 4.5 Previous Optimization Efforts

Several optimization measures have been performed thus far aimed at reducing overall project cost while maintaining protectiveness to humans and the environment. These previous efforts are identified in this section.

*LTM Network*

The original monitoring well network included 31 monitoring wells. Beginning with the November 1995 sampling round, 17 additional existing monitoring wells were included in the monitoring well network, in accordance with the approved work plan (RMT, 1995). With these additional wells, a total of 49 monitoring wells were sampled as part of the long-term monitoring (LTM) network from November 1995 through the fourth quarter of 1999 (TtNUS, 2000). The 44 to 49 wells were sampled twice per year. In response to the first system five-year review, completed in October 1998 (U.S. EPA, 1998), a total of 43 groundwater monitoring wells were installed to address an apparent data gap in the monitoring well network (TtNUS, 2000b). Wells that were installed and sampled as part of the field investigation at NIROP and ACP also were sampled in the fourth quarter of 1999 (TtNUS, 2000). Since 1999, one comprehensive sampling round (73 to 94 wells) and one limited sampling round (7 to 20 wells) in the vicinity of the pump-and-treat system has been conducted on an annual basis.

*Capture Analysis (Hydraulic Containment)*

The Navy is in the process of providing U.S. EPA and MPCA with a highly technical groundwater capture evaluation prepared by USGS. The final report was not available for review. According to the 2004 AMR (TtNUS, 2005), preliminary conclusions from the capture analysis include consensus the that evaluation did not warrant additional pumping at this time: that the annual monitoring performed at the site would be reviewed on a yearly basis and that trends in down gradient contaminant levels would be used as another evaluation tool to monitor the effectiveness of capture (as decided in the DQO process). The groundwater in ACP is being monitored on a more frequent basis (semiannually) to determine if the improved capture scenario implemented in 2001 will result in the decline in contaminant levels. The Navy plans to install a nest of monitoring wells, including a shallow and intermediate well, downgradient of AT-3A to serve as "sentinel" wells to monitor the down gradient impact of AT-3A. The Navy will ultimately incorporate the USGS work in future annual groundwater monitoring reports (TtNUS, 2005).

*Biostimulation – Anoka County Riverfront Regional Park (ACP)*

The ACP is a recreational facility consisting of approximately 60 acres located to the southwest of the NIROP facility and bordering the Mississippi river. The park is located immediately downgradient of the extraction system. It has been found to be contaminated with CAHs. The 5-year review of the selected remedy for groundwater (U.S. EPA, 1998) recommended that the Navy determine what could be done to reduce groundwater contamination at the park. In response, the Navy initiated an in situ bioremediation pilot test using vegetable oil to demonstrate the efficacy of enhancing CAH biodegradation in December 2001. Approximately 3,600 gallons of food-grade soybean oil was emulsified with approximately 7,200 gallons of groundwater and injected into the aquifer.

Subsequent groundwater monitoring indicated that the test was somewhat successful in accelerating reductive dechlorination of the chlorinated ethenes (Parsons, 2004). However, it also was determined that the vegetable-oil-derived organic carbon was not effectively distributed within the pilot test area and that complete reductive dechlorination was only induced in a relatively small area. An addendum to the original pilot test work plan has been prepared to address information gaps (Parsons,

2005) and to gather the information necessary to determine if the technology has promise for full-scale implementation (TtNUS, 2005).

*SAIC Needs Assessment*

In 1998, a Needs Assessment (NA) was performed for the groundwater remediation program at the NIROP (SAIC, 1998). The objective of the assessment was to ensure that the remediation program was optimized with respect to performance and cost. Specific objectives included:

- An evaluation of the remediation strategy, the remedial system design, and the system O&M program with respect to performance and cost.
- An evaluation of modifications to the groundwater remediation program and upgrades to the remediation system hardware and software components that likely would improve performance and/or reduce remediation program costs.
- Providing recommendations for change when potential modifications were believed to offer a significant financial return on investment (ROI) or provide other significant non-monetary benefits.

The NA evaluated two distinct phases of the groundwater remediation program: Phase I, which has been ongoing since September 1992, consisting of groundwater extraction and discharge of untreated water to the municipal sanitary sewer; and Phase II, which included the construction and operation of a GWTS. At the time that this NA was performed, the construction of the GWTS had not been completed. The rationale for performing the NA prior to completing construction of the GWTS was to identify cost savings and/or performance enhancement measures that could be easily incorporated into the remedial program during the final phases of construction and/or during the early phases of operation.

The NA consisted of a number of tasks including a review of background information, an on-site evaluation of the remedial system and strategy, and an analysis of the major program elements and potential cost-saving alternatives. Cost savings approaches were screened against criteria that included technical feasibility; public and regulatory considerations; advantages and disadvantages with respect to performance, O&M, and program administration; and effect on direct and indirect program costs. A detailed financial analysis then was performed on those cost-saving alternatives that were believed to provide the most significant savings, resulting in the implementation of the following recommendations:

- Modification of the well field and pumping program to increase VOC mass recovery efficiency and to decrease O&M costs associated with fouling of the extraction wells;
- Introduction of a bypass for captured water to the sanitary sewer during stripper system downtime to save costs associated with operation of the influent pumps;
- Implementation of a preventative and predictive O&M program to optimize system maintenance costs; and,
- Upgrade of the automated control and monitoring system to allow for remote monitoring and less frequent site visits by system operators.

The NA also recommended a reduction of the number and frequency of monitoring well samples collected to eliminate wells producing redundant or unreliable data, and to reduce data obtained

from wells which have consistently exhibited very low or non-detectable concentrations of chemicals. In addition, the NA recommended a modification of the sample analysis analytical method from U.S. EPA Method 624 to Method 601/602 based on the list of target VOCs in the groundwater and treated water samples. The LTM network has been modified since the NA was prepared, but the exact changes to the sampling regime are not made clear in the annual monitoring reports provided for review.

## Section 5.0: CONCLUSIONS AND RECOMMENDATIONS

The remedial action in the ROD for OU-1 at NIROP Fridley specifies hydraulic containment and recovery of all contaminated groundwater at the NIROP facility, and the recovery, to the extent feasible, of contaminated groundwater downgradient of the NIROP facility (TtNUS, 2004). On-site groundwater currently is not used as a potable water supply at the site, and it is not expected to be used as potable water in the future because a public water supply is available. However, groundwater from the site flows west/southwest entering the Mississippi River, and the City of Minneapolis draws its municipal water from the river approximately 2,000 ft downstream from the NIROP site (U.S. EPA, 1991). Therefore, the final remedial goal for groundwater at the NIROP Fridley is to achieve the federal MCLs or MPCA HRLs. It may be possible to negotiate less-stringent goals with the regulatory agency that are developed using risk-based criteria; however, given the elevated concentrations down gradient of NIROP Fridley, and the nearby location of the MWW raw water intake, it may be difficult to obtain regulatory approval.

Based on available data, the extraction well network appears to be effective in containing a large percentage of the most highly contaminated groundwater with TCE concentrations exceeding 100 μg/L along the property boundary; however, monitoring well data indicate that elevated TCE concentrations also are present downgradient of the site, outside of the area of influence of the extraction wells. The TCE concentrations have not reached the MCL of 5 μg/L in any monitoring wells located either in the extraction well capture zone, or downgradient of the extraction wells. The persistent elevated TCE concentrations are to be expected, as pump-and-treat has not been proven to be an effective technology for groundwater cleanup of CVOCs where a source area remains, as is suspected beneath the NIROP Fridley building. However, given that TCE concentrations in many of the monitoring wells located in the extraction well capture zone have not decreased significantly, contaminant mass removal rates should still be high if the groundwater extraction system is continuing to effectively remove and treat this water. The available data indicate that contaminant mass removal rates from the groundwater extraction system have not yet reached an asymptotic level, and that the existing system is continuing to operate effectively.

Three optimization approaches were considered for implementation at the NIROP to achieve the RA objectives in a shorter time frame and decrease life-cycle operating costs, if possible, including: (1) perform various modifications to the existing GWTS; (2) install a PRB; and (3) source zone treatment.

Based on the technical and cost evaluations presented in this report, three modifications to the existing GWTS are recommended, including: taking one air stripper off-line, replacing the existing air stripper feed pump motors with VFDs, and updating the PLC to allow for data storage and easier data access and reporting. Further engineering design should be conducted to determine specific equipment requirements for VFD replacements and PLC upgrades. Once specific equipment requirements have been identified, then more precise cost quotes can be obtained for completing these upgrades. Based on the data reviewed and the subsequent preliminary cost evaluation, the capital costs for implementing these modifications are estimated to be approximately $37,000, and implementation of these modifications could result in a NPV cost savings of approximately $300,000 over the next 30-year operating period. The breakeven point for implementing all of these proposed modifications is approximately 2.4 years; therefore, implementation of these modifications is recommended to optimize life-cycle operating costs of the GWTS.

Installation of a PRB at this site is technically feasible, but cost-prohibitive at this time based on the depth and extent of groundwater contamination. Treatment of the DNAPL source zone would significantly reduce the time and cost to treat (or contain) the dissolved-phase plume downgradient of the

source area. However, source zone treatment is not feasible at this time because the locations of all source zones are not known and detailed characterization and remediation of the sources within the facility is limited due to the high-security mission of the facility, as well as cost prohibitive due to the extensive building infrastructure and equipment present at the facility.

## Section 6.0: REFERENCES


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