FINAL CONTRACT REPORT

MITIGATING CONTAMINANT TRANSPORT IN UTILITY INSTALLATION

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TABLE OF CONTENTS

1. INTRODUCTION AND STUDY RATIONALE ---------- 1
   1.1 Regulatory Basis for Study ---------- 1
   1.2 Focus on Pipe Utilities ---------- 2
   1.3 Intended Use of Manual ---------- 2
   1.4 Contents of Manual ---------- 3
2. REVIEW OF FEDERAL AND STATE REGULATIONS ---------- 3
   2.1 Federal Regulations ---------- 4
   2.2 Commonwealth of Virginia Regulations ---------- 6
3. THE CONTAMINANT MIGRATION PROBLEM ---------- 8
   3.1 Types of Contaminants ---------- 8
   3.2 Contaminant Migration Concerns ---------- 10
   3.3 Types of Utility Corridors ---------- 11
   3.4 Existing and Proposed Site Characteristics ---------- 12
   3.5 Experience of State Transportation Agencies and Others ---------- 13
4. MITIGATION MEASURES FOR CONTAMINANT MIGRATION ---------- 13
   4.1 Pre-construction Site Investigations and Planning ---------- 14
   4.2 Temporary Engineering Controls During Construction ---------- 15
   4.3 Long-Term Engineering Controls ---------- 16
   4.4 Trenchless Technologies ---------- 23
   4.5 Planning/Design versus Constructed Controls ---------- 25
   4.6 Post-auditing of Engineering Controls ---------- 25
5. UTILITY MATERIALS AND CONTAMINANT RESISTANCE ---------- 26
   5.1 Pipe Materials ---------- 26
   5.2 Pipe Coatings and Liners ---------- 34
   5.3 Pipe Joints ---------- 40
   5.4 Trade Associations and Contact Information ---------- 42
6. CASE STUDIES ---------- 43
   6.1 Route 11, Greenville, Virginia: 10-inch Sanitary Sewer ---------- 43
   6.2 Abingdon, Virginia: 72-inch Storm Sewer ---------- 55
   6.3 North Main Street, Suffolk, Virginia: Various Utilities ---------- 66
7. SUMMARY AND CONCLUSIONS ---------- 73
REFERENCES ---------- 75

ABSTRACT

In recent years, the Virginia Department of Transportation (VDOT) has experienced problems with various forms of contamination (primarily from underground storage tanks, USTs) migrating into its right-of-way. In many cases VDOT has had to install culverts, pipes or other utilities through these contaminated areas. Utility installation in VDOT's construction projects includes laying telephone lines, power lines, and construction of sanitary and storm sewers. When installed through contaminated areas, these utilities or utility corridors may serve as conduits or preferential pathways for the migration of contaminants offsite, thereby introducing the possibility of liability for VDOT.

Because little information exists regarding ways of preventing such contamination from migrating along preferential pathways created by the installation of utilities, the primary objective of this project, and the resulting document, is to classify the typical types of contamination problems and outline mitigation measures to prevent or minimize them.

Emphasis is placed on presenting real-world and practical mitigation methods, guidelines, and procedures. Although the manual is intended for use by field operatives and designers primarily as a guide for obtaining additional, more detailed information, it also presents some methods that can be applied directly.

1.0 INTRODUCTION AND STUDY RATIONALE

In recent years, Virginia Department of Transportation (VDOT) has been experiencing problems with various forms of contamination (primarily from underground storage tanks, USTs) migrating into its right-of-way. In many cases VDOT has to install culverts, pipes or other utilities through these contaminated areas. Utility installation in VDOT's construction projects includes laying telephone lines, power lines, and construction of sanitary and storm sewers. When installed through contaminated areas, these utilities or utility corridors may serve as conduits or preferential pathways for the migration of contaminants offsite, thereby introducing the possibility of liability for VDOT. Soil and water contamination is VDOT's primary concern with utility installation through a contaminated area during and after construction. There exists a need to develop a means of preventing such contaminants from migrating along preferential pathways created by the installation of utilities. At the present time, information on assessing and mitigating these environmental problems are limited. The primary purpose of this manual is to address this need by classifying the contamination problems and outlining mitigating measures to prevent or minimize these problems. The emphasis is on presenting real-world and practical mitigation methods, guidelines, and procedures. Although the manual is intended for use by field operatives and designers primarily as a guide for outlining additional, more detailed information, it also presents some methods that can be applied directly.

1.1 Regulatory Basis for Study

The regulatory basis for re-deposition of contaminated soils in utility trenches and subsequent mitigation of contaminant transport stems from the interpretation of the requirements of the Resource Conservation and Recovery Act (RCRA) by certain federal and state agency officials. The interpretation is found in two letters, one from an official of the US Environmental Protection Agency (EPA) and one from an official of the Virginia Department of Environmental Quality (VDEQ). These letters provide the basis and the rationale for the preparation of this report. Other important regulations will be discussed in Section 2 of this document.

US Environmental Protection Agency (EPA)

The federal regulatory basis for redeposition of contaminated soils in utility trenches can be found in a letter written on June 11, 1992 from Sylvia Lowrance, Director, EPA Office of Solid Waste to Douglas Green of Piper and Marbury (Lowrance 1992). In this letter, Lowrance explains the EPA's "interpretation of the applicability of RCRA requirements to common excavation-type activities." The types of activities cited in the letter include "excavation of soils, such as trenching operations for pipeline installation, where the soils may be hazardous by characteristic, or may contain listed hazardous wastes." Where contaminated soils are temporarily removed from such an excavation and then redeposited, EPA states that this activity does not constitute treatment, storage or disposal of a hazardous waste under RCRA and thus does not trigger RCRA hazardous waste disposal requirements. Furthermore, the EPA states that the excavator is not considered to be a "generator" and thus is not subject to any generator requirements under RCRA.

Virginia Department of Environmental Quality (VDEQ)

The State regulatory basis for redeposition of contaminated soils in utility trenches can be found in a letter written on July 29, 1994 from Peter Schmidt of VDEQ to David Gehr, Commissioner of VDOT (Schmidt 1994). The letter deals directly with the disposal of contaminated soils within highway rights-of-way. In the letter, Schmidt cites and concurs with the letter by Lowrance stating that "excavation within the area of contamination and redeposition of contaminated soils from the excavation activities relating to trenching operations, such as pipeline installation and maintenance activities, into the same excavation area does not constitute treatment, storage or disposal under RCRA." The letter also states that these activities do not constitute generation of hazardous waste, as discussed in the Virginia Hazardous Waste Regulations, and do not trigger the requirements of a generator. Schmidt also specifically addresses petroleum contamination, stating "VDOT may return low level petroleum contaminated soils to the area of the excavation in those cases where no underground storage tanks (USTs) are known to be the source of contamination, groundwater is not known to be impacted, and no UST remediation project is to be impacted." Schmidt defines low-level contamination as that "amount (or less) of petroleum contamination that would not be expected to leach petroleum hydrocarbons to the environment." This definition is the basis for the implementation of mitigative methods to prevent contaminant migration. The VDEQ also further defines the situations where redeposition can be applied stating "this interpretation only applies to excavation activities where soil is excavated and stockpiled near the excavation and redeposited back into the same excavation within the contaminated area, after installation or maintenance activities are complete." Schmidt also recommends, "that the soil be stockpiled and redeposited in such a manner as to prevent further migration of contamination." This statement further supports the utilization of techniques to mitigate contaminant migration.

1.2 Focus on Pipe Utilities

As mentioned before, the concern for migration of contaminants extends to all types of utility installations. However, because of the inherent nature of pipe utilities, especially sanitary and storm sewers placed on grade, these utilities may have the greatest potential for migration of contaminants offsite. Furthermore, pipe utilities like storm sewer corridors may lead to potentially sensitive receptors like streams or other natural water resources. Also, drinking water force mains deliver water directly to users and therefore must be guarded vigorously against contamination. Because of the greater potential threat posed by pipe utilities, the focus of the information presented in this manual tends to favor these types of utilities. However, much of the information presented in this report can and should be applied to all types of utility installations.

1.3 Intended Use of Manual

The ultimate decision for when and how to mitigate the problem of contaminant migration is the responsibility of the regulating authority with input from VDOT, the contractor, and the local community. Thus, the information provided in this manual should be used as guidance or as a "springboard" in sound decision making, which should find the most economical solution while also safeguarding public health and protecting natural resources. Ideally, the manual is intended to be a starting point and a road map, where readers can get ideas for solutions to their problem and find gateways to more specific information. However, much of the information supplied by this manual can be directly applied without additional research. In any case, this manual does not provide an "off the shelf" or "one size fits all" solution to all problems concerning contaminant migration cause by utility installation. Each problem encountered may have a variety of suitable solutions and this manual is designed to provide assistance and guidance in finding those solutions.

1.4 Contents of Manual

The information in this manual is presented in five main sections. Section 2 presents Federal and State environmental regulations, which may be directly or indirectly related to soils and groundwater contamination. This section is by no means comprehensive, but lists and describes some important laws and regulations. Section 3 deals with identifying, defining, and categorizing the contaminant migration problem. Subjects discussed include different types of utility corridors, different types of contaminants, and major concerns of contaminant migration. Section 4 discusses different methods for mitigation of contaminant migration. Methods considered are separated into pre-construction studies, short-term engineering controls, long-term engineering controls, and trenchless technologies. Section 5 deals with utility materials and their contaminant resistance. Chemical compatibility or resistance of a utility is a very important consideration when specifying material for a utility construction project. The major discussion in this section focuses on contaminant resistance properties of pipe materials, pipe liners and coatings, and pipe joints. Finally, research for this project included several site visits or case studies that are presented in Section 6. Information collected and presented for these case studies includes informational contacts and site visits, environmental investigative history, groundwater conditions and hydrogeology, site topography, geotechnical and soils, contamination characterization, and design/construction procedures utilized to mitigate contaminant migration. The information and experience gathered from the case studies was invaluable and was deemed necessary to include in the manual to achieve the intended objectives.

2.0 REVIEW OF FEDERAL AND STATE REGULATIONS

The regulatory basis for redeposition of contaminated soils in utility trenches and subsequent mitigation of contaminant transport was explained in Section 1. As discussed, the basis stems from the interpretation of RCRA by certain federal and state agency officials with regard to excavation activities associated with utility installation. The purpose of this section is to present a brief historical summary of important environmental laws and regulations which are relevant to the subject matter of this report. Federal and State regulations are discussed separately.

2.1 Federal Regulations

Over the past four decades, the United States government has drafted and enacted many environmental laws, regulations and statutes. Public sentiment toward protection of the environment became strong in the 1960's and continues to the present. Cole (1994) suggests that future historians will designate the past four or five decades as the beginning of the environmental era. New rules and regulations are published or codified in the Code of Federal Regulations (CFR) and Title 40 of the CFR is earmarked for regulations enacted by the EPA for protection of the environment. The section lists and discusses some of the important federal environmental statues that are directly or indirectly related to soils and groundwater contamination. The federal regulations discussed in this section are not comprehensive and for more information the reader is referred to laws and regulations published by EPA on the web at http://www.epa.gov/epahome/laws.htm (EPA 2003).

National Environmental Protection Act

The National Environmental Protection Act (NEPA) was first enacted in 1969 and is primarily a statement of national policy and establishes the framework for the protection of the environment through federal regulation (Cole 1994). The policy of this act requires the federal government to consider potential impacts to the environment from activities like the construction of airports, buildings, military facilities, or highways or purchases of parklands (EPA 2003). The most evident requirements of NEPA are the preparation of Environmental Assessments (EAs) and Environmental Impact Statements (EIS) by Federal agencies, which assess the potential impacts from different courses of action. This Act has no direct impact on the mitigation of contaminant transport in utility trenches but may indirectly affect remediation or mitigation through its policy.

Solid Waste Disposal Act

The Solid Waste Disposal Act (SWDA), enacted in 1965, was the first waste disposal act and was originally designed to regulate waste disposal at landfills and the resource recovery or recycling of used motor oil (Cole 1994). The Act also establishes definitions for hazardous waste generators and operators of hazardous waste storage facilities. This Act was expanded and amended in 1970, 1973, 1976, and 1984 and provided the regulatory authority for the EPA when this agency was established by President Nixon in 1970 (Cole 1994).

Resource Conservation and Recovery Act

Originally enacted in 1976, the Resource Conservation and Recovery Act (RCRA) was designed to address concerns about the disposal and storage of hazardous wastes. The Act gives EPA "cradle to grave" control over hazardous wastes, which includes "generation, transportation, treatment, storage, and disposal of hazardous waste" (EPA 2003). RCRA also establishes other guidelines for management of non-hazardous wastes. Amendments to RCRA in 1984 were called the Federal Hazardous Solid Waste Amendments (HSWA). HSWA extended the enforcement and regulatory power of the EPA, established stricter standards for hazardous waste management, required the phasing out of land disposal, and established a program for underground storage tanks (USTs). Amendments to RCRA in 1986 further empowered EPA to address problems resulting from the storage of petroleum and other hazardous materials in USTs. It should be noted that RCRA only deals with existing or future facilities, not with abandoned or historical sites, which is the purpose of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). As discussed in Section 1, the regulatory basis for mitigation of contaminant migration in utility trenches involves the interpretation of RCRA by certain agency officials. Thus, RCRA has a direct influence on the subject matter presented in this report. It should be noted that RCRA specifically exempts petroleum as a hazardous waste, however, it does not exempt petroleum products that may be hazardous, like ethylene glycol found in antifreeze. Also, some states, which may enforce more stringent rules than EPA, do not exempt benzene as a hazardous waste, which is a component of gasoline (Cole 1994).

Comprehensive Environmental Response, Compensation, and Liability Act

Congress enacted CERCLA, also known as "The Superfund Law," in 1980 to establish responsibility for and to subsequently cleanup highly contaminated sites. These sites, which may have been abandoned or historical, are called Superfund sites and are placed on the National Priorities List (NPL). Typically, Superfund sites are extremely contaminated with hazardous materials and require a very high level of effort for remediation. CERCLA empowered the federal government to respond to releases or threatened releases of hazardous materials, created rules and requirements for closed and abandoned sites, and established liability guidelines for those parties responsible for the contamination (EPA 2003). The Act also created a tax on petroleum and chemical industries and a subsequent trust fund to be used when no responsible party could be identified. CERCLA provided for two types of response actions from the federal government: short-term removals, where prompt response to releases or potential releases is necessary, and long-term remediation actions, where sites require major clean up but do not immediately threaten life. As with RCRA, CERCLA also provides an exemption for petroleum as a hazardous substance.

The Superfund Amendments and Reauthorization Act (SARA) amended CERCLA in 1986. The amendments provided by SARA were based on the six years of EPA's experience with the Superfund program. The amendments encouraged the use of permanent remedies and innovative treatments, considered requirements of other State and Federal laws, increased State involvement, focused on potential health problems caused by hazardous waste contamination, encouraged citizen involvement, established additional enforcement authorities, and increased the size of the trust fund used for sites without a responsible party (EPA 2003). SARA also created a five-year Leaking Underground Storage Tank (LUST) trust fund intended to assist in remedial actions when necessary.

Clean Water Act

The Federal Water Pollution Control Act Amendments of 1972 were enacted in response to concern over the negative impacts caused by water pollution. This law was amended in 1977 and subsequently became known as the Clean Water Act (CWA). The Act deals solely with surface water quality issues and does not address groundwater or water quantity issues. CWA gave EPA the authority to regulate discharges into navigable waters by requiring a permit, establish water quality standards for discharges of wastewater, and fund construction of sewage treatment plants through a construction grants program (EPA 2003). CWA of 1977 distinguished between conventional pollutants like microorganisms and organic waste and toxic pollutants like hazardous chemicals. CWA also recognized non-point source pollution and the need to deal with this problem. Amendments in 1981 improved the construction grants program and changes in 1987 replaced the construction grants program with the State Pollution Control Revolving Fund. Additional amendments in 1987 established rules and requirements for toxic pollutants and non-point source pollution control. Section 303 of the CWA establishes water quality standards and requirements of the Total Maximum Daily Load (TMDL) program, which is designed to improve the water quality of impaired water bodies through a holistic watershed approach and stakeholder involvement.

Clean Air Act

The Clean Air Act (CAA) authorizes the EPA to regulate emissions from stationary and mobile sources (EPA 2003). Although based on previous regulation, the first Clean Air Act was enacted in 1963 and amended in 1970, 1977, and 1990. The amendments of 1970 require that EPA establish National Ambient Air Standards (NAAQSs) for pollutants. The CAA requires that States also develop state implementation plans, which would comply with or exceed the NAAQSs. The goal set by the Act was to establish NAAQSs in each State by 1975. The CAA was amended in 1977 to set new goals for establishing NAAQSs in each State because the goal had not yet been achieved. Amendments to the CAA in 1990 dealt with previously unaddressed problems including "acid rain, ground-level ozone, stratospheric ozone depletion, and air toxics" (EPA 2003).

Other Federal Laws

There are many other federal laws that may be indirectly related to the subject matter presented in this document. Some other important laws include the Oil Pollution Act (OPA), the Toxic Substances Control Act (TSCA), the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), the Safe Water Drinking Act (SDWA), and the Endangered Species Act (ESA).

2.2 Commonwealth of Virginia Regulations

In addition to the federal regulation provided by the EPA, the Commonwealth of Virginia provides regulation for protection of the environment with regards to air, water, and waste. These State environmental regulations are provided in the Virginia Administrative Code, Title 9 and are available for perusal on the web at http://leg1.state.va.us/000/reg/TOC.HTM. (VGA, LIS 2003). The Virginia Department of Environmental Quality (VDEQ) provides discussions, summaries, and technical guidance to the regulations on the web at http://www.deq.state.va.us/regulations/ (VDEQ 2003). This section will provide a brief discussion regarding environmental regulations promulgated by the Commonwealth. For more detailed information, the reader is referred to the websites listed.

Air Regulations

The State Air Pollution Control Board is responsible for State air regulations that are published in the Virginia Administrative Code under Title 9, Agency 5. These regulations deal with ambient air quality standards, fixed sources, mobile sources, hazardous air pollutant sources, and dispute resolution guidance. The regulations also provide rules to ensure that some projects adhere to federal requirements (VDEQ 2003).

Water Regulations

State water regulations are promulgated by the Virginia Water Control Board and published in the Virginia Administrative Code under Title 9, Agency 25. The CWA authorizes EPA to give States certain duties and responsibilities for the protection of water resources, including the issuance of National Pollutant Discharge Elimination System (NPDES) permits. The State regulations outline rules for the issuance of Virginia Pollutant Discharge Elimination System (VPDES) permits, dispute resolutions, state water quality standards, and petroleum storage tanks.

Waste Regulations

The Virginia Waste Management Board publishes waste regulations in the Virginia Administrative Code under Title 9, Agency 20. These regulations deal with solid waste, hazardous waste, medical waste, transport of hazardous materials, recycling certification requirements, yard waste composting, and dispute resolution requirements. The hazardous waste management regulations are published in Chapter 60 and closely follow the federal standards established under RCRA (VDEQ 2003).

Chesapeake Bay Regulations

State Regulations intended to protect and improve the water quality of the Chesapeake Bay and its tributaries are promulgated by the Chesapeake Bay Local Assistance Board and published in the Virginia Administrative Code under Title 9, Agency 10. These regulations discuss public participation and provide guidance for local governments to establish the Chesapeake Bay Preservation Areas within their jurisdictions. The regulations stipulate criteria "for use by local governments in granting, denying or modifying requests to rezone, subdivide, or to use and develop land in Chesapeake Bay Preservation Areas" (VAC, LIS 2003).

DEQ Regulations

Other regulations promulgated by the VDEQ are published as DEQ Regulations in the Virginia Administrative Code under Title 9, Agency 15. These additional regulations involve public participation guidelines, environmental impact assessment guidelines, and rules for recycling certification.

Other State Regulatory Guidance

The VDEQ also publishes many regulatory and technical guidance documents. Among the guidance publications provided by the VDEQ is the "Storage Tank Program Manual, DEQ Guidance Document No. 01-2024." Section 3.1.5.2 of the manual grants VDOT a liability exemption and is not deemed the responsible party on property acquired for transportation purposes (VDEQ 2001). However, this exemption does not apply to a property where VDOT is the owner or operator of an underground or above ground storage tank (UST or AST). Also notable is Section 6.2.4 of the manual entitled "Management of Petroleum Contaminated Soil at VDOT Road Construction Sites." This section explains an agreement between VDEQ and VDOT whereby VDOT is permitted to re-deposit contaminated "soil in the excavation from which it originally came without triggering the requirements of the Solid and Hazardous Waste Management Regulations" (VDEQ 2001). This manual is available in its entirety on the web at http://www.deq.state.va.us/tanks/pdf/techman.pdf (VDEQ 2001).

3.0 THE CONTAMINANT MIGRATION PROBLEM

The purpose of this section is to refine further the definition of the contaminant migration problem associated with underground utilities and when mitigation of the potential problem might be beneficial. As it applies to installation or repair of underground utilities, the problem pertains to the migration of contaminants through a preferential pathway resulting from installation of the utility or the disturbance and subsequent spreading of the contaminant during construction. The problem, as dealt with by this manual, is limited to scenarios where utilities are installed through or near a contaminated area that will not be remediated or will be only partially remediated. Therefore, methods presented in this manual have the general purpose of significantly reducing the chance of spreading or migration of the contaminant to another area. Some of the issues further defining the problem of contaminant migration through utility corridors and influencing the decision to mitigate contaminant migration will be discussed in this section.

3.1 Types of Contaminants

Contamination in the environment can be found in surface water, ground water, and the soil. Primarily, soil and groundwater contamination are of major concern when assessing the potential for migration of pollutants along utility corridors. There are many types of contaminants polluting the soil and groundwater that might be encountered during a utility installation. Boulding says that over 200 chemicals have been found in groundwater, of which many have negative impact on human health and have also been introduced into the environment by humans (1995). As presented by the National Research Council, Table 3-1 ranks the most common chemicals found at hazardous waste sites and list typical sources for these chemicals (1994).

During a survey conducted by the Texas Department of Transportation (TxDOT), state transportation agencies were asked about the major contaminants encountered during their construction activities. Of the 17 respondents to the survey, 16 states or 94% claimed petroleum hydrocarbons as the major contaminant. Solvents were listed as another major contaminant by 4 states (23%), industrial source waste was listed by 2 states (12%), coal tar was listed by 2 states, and agricultural pesticides were listed by 1 state as a contaminant encountered during construction (Crosby 2000). The same survey was also conducted within the State of Texas asking each of the Districts within the TxDOT the major contaminant encountered, and very similar percentages were noted. Another independent study, presented by the Transportation Research Board, concluded that 90% of petroleum contaminated sites encountered and remediated by state transportation agencies include gasoline and/or diesel fuel as a major contaminant in soils (Friend 1996). These studies would indicate that the majority of contaminated sites that are encountered by transportation agencies are petroleum-contaminated sites that are predominated by gasoline and/or diesel fuel.

TABLE 3-1
The 25 Most Frequently Detected Ground Water Contaminants at Hazardous Waste Sites
(National Research Council 1994)

Rank	Chemical	Common Sources
1	Trichloroethylene	Dry cleaning; metal degreasing
2	Lead	Gasoline (prior to 1975); mining; construction material (pipes); manufacturing
3	Tetrachloroethylene	Dry cleaning; metal degreasing
4	Benzene	Gasoline; manufacturing
5	Toluene	Gasoline; manufacturing
6	Chromium	Metal plating
7	Methylene Chloride	Degreasing; solvents; paint removal
8	Zinc	Manufacturing; mining
9	1,1,1-Trichloroethane	Metal and plastic cleaning
10	Arsenic	Mining; manufacturing
11	Chloroform	Solvents
12	1,1-Dichloroethane	Degreasing; solvents
13	1,2-Dichloroethene, trans-	Transformation product of 1,1,1-trichloroethane
14	Cadmium	Mining; plating
15	Manganese	Manufacturing; mining; occurs in nature as oxide
16	Copper	Manufacturing; mining.
17	1,1-Dichloroethene	Manufacturing
18	Vinyl Chloride	Plastic and record manufacturing
19	Barium	Manufacturing; energy production
20	1,2-Dichloroethane	Metal degreasing; paint removal
21	Ethylbenzene	Styrene and asphalt manufacturing; gasoline
22	Nickel	Manufacturing; mining
23	Di(2-ethylhexyl)phthalate	Plastics manufacturing
24	Xylenes	Solvents; gasoline
25	Phenol	Wood treating; medicines

"Note: This ranking was generated by the Agency for Toxic Substances and Disease Registry using ground water data from the National Priorities List of sites to be cleaned up under CERCLA. The ranking is based on the number of sites at which the substance was detected in ground water." (National Research Council 1994)

However, while gasoline and diesel fuel can be expected to be the contaminant that will be encountered most during utility installations, other types of contaminants may also be encountered. The type of contaminant and its subsurface behavioral characteristics should be considered when planning and implementing mitigation measures. For example, density and viscosity differences of contaminants can influence the direction and rate at which contaminants travel through a hydrogeologic system. Contaminants with a density less than water tend to concentrate near the top of the water table in an aquifer, while contaminants with a density greater than water usually accumulate along the bottom. Density and viscosity differences become significant when dealing with the transport characteristics of nonaqueous phase liquids (NAPLs) (Boulding 1995). When NAPLs move through the soil, a certain percentage of the contaminant will adhere to the soil particles in the vadose zone and additional movement of the contaminants can be attributed to volatilization or dissolution by groundwater. This percentage of remaining contaminant is called residual saturation. NAPLs that are lighter than water (LNAPLs) behave differently in the subsurface than NAPLs that are more dense than water (DNAPLs). Most of the components of gasoline are LNAPLs, including benzene, toluene, and xylene. LNAPLs tend to be volatile and may travel through the vadose zone through molecular diffusion or be dissolved by percolating groundwater. If a spill is large enough for it to reach the water table, some product may dissolve and move with the groundwater and some liquid product or "free product" may travel along the top of the capillary fringe and water table. If the source of the spill is stopped, the product will travel through the vadose zone until residual saturation is reached. Examples of DNAPLs include chlorinated solvents like trichloroethylene and other non-halogenated compounds like phenol and fluorene. Because of their low solubility, high density, and low viscosity, DNAPLs can be very mobile in a hydrogeologic system (Boulding 1995). DNAPLs can travel through the vadose zone as vapors, travel with groundwater flow in a dissolved phase, and travel along the bottom of an aquifer as liquid product. The contaminant transport possibilities become more complicated when both LNAPLs and DNAPLs exist in significant quantities on a project site. Under certain conditions, DNAPLs can dissolve LNAPLs and transport the contaminant well below the water table. Nonetheless, all subsurface migration characteristics of a contaminant, including density and viscosity, should be examined during planning and implementation of mitigation measures.

3.2 Contaminant Migration Concerns

In general, the concerns of contaminant migration along utility corridors exist as vapor hazards or liquid hazards. The potential for either of these hazards may warrant the implementation of mitigative measures. The general concern for either hazard is that the backfill material or the utility itself is more permeable than the surrounding soils.

Certain types of contaminants vaporize under normal atmospheric conditions and may travel along a preferential pathway furnished by a utility corridor. Vapors can theoretically travel in either direction along a utility corridor. If the utility trench connects to a building, the vapors could travel along the utility corridor and into the building, potentially increasing the risk of an indoor explosion or decreasing the indoor air quality to an unacceptable level. Among the petroleum hydrocarbon contaminants, only those products with a high vapor pressure, like gasoline and some of the kerosene-derived middle distillates pose a significant hazard with regards to fire or explosion (Cole 1994). However, as previously mentioned, most of the petroleum contamination encountered is gasoline or diesel fuel. Concentrations of petroleum hydrocarbons which may pose an explosive hazard or which are considered to be toxic when inhaled can be fairly low. For example, benzene, a component of gasoline, exhibits a lower explosive limit of 13 mL of benzene per liter of air. Likewise, the concentration for acute inhalation toxicity of benzene is in the parts per million range (Cole 1994). Thus, a vapor migration concern might exist if the proposed utility corridor connects directly to a building, basement, or other receptor. Explosions caused from ignition of vaporized contaminants and detrimental health effects to workers due to inhalation should also be a concern during installation of the utility. Vapor extraction fans and respirators can be utilized during construction to reduce such hazards. Also, routine sampling should be conducted during construction in a contaminated area to detect and properly mitigate vapor hazards.

Migration of liquid contaminants along utility corridors as free product or as a dissolved phase product is also a concern. Liquid contaminants can travel along preferential pathways and pollute drinking water wells and other water resources. Generally, free product or dissolved phase product will travel in the down gradient direction of the utility corridor. According to Wade (unpublished information, 2000), a liquid migration concern may exist if the contaminant source intersects the utility corridor (especially free product), the water table intersects the utility corridor, or the trench backfill has a higher permeability than the surrounding soils. If only contaminated groundwater is present on a project site (free product and vapors are not present) and the utility corridor is above the water table, then migration of contaminants through the utility corridor is generally not a concern (Wisconsin Department of Natural Resources 2000). Care should be taken when establishing water table elevations to account for seasonal differences and perched aquifers. Some project sites, where the native soils have a low permeability, can exhibit a general concern for contaminant migration when the native materials are also used for backfill and bedding. Excavation and disruption of the native soils and re-use of those soils as backfill can lead to higher permeability in the trench than surrounding soils (Wisconsin Department of Natural Resources 2000).

3.3 Types of Utility Corridors

Many types of underground utilities are installed in the rights-of-way of proposed road construction or widening projects. These include but are not limited to storm sewers, gravity and force sanitary sewers, water supply pipelines, natural gas pipelines, electrical lines, and telecommunications (Wade, unpublished information 2000). Most of these utilities are installed using an open trench method; however, trenchless technologies have been shown to be very effective, especially in urban environments. The type of utility and installation method can influence decisions involving mitigation of contaminant migration. As stated before, the general concern for contaminant migration is that the backfill material is less permeable than the in situ material. Certain types of utilities, like gravity sanitary or storm sewers, are installed in a bed of gravelly material and are installed on a downsloping grade. Thus, gravity sewers are a prime example where the gravel bed material will most likely be more permeable than the surrounding soils and may provide a preferential pathway for contaminants. In addition, typical storm sewers are not designed with watertight joints, providing another potential pathway for contaminants along the inside of the pipe. Regardless of the surrounding soils, gravity sanitary and storm sewers and foundation drains, which are open to the atmosphere, have the potential to carry free or dissolved phase product downstream and vapor in either direction along the utility corridor. The potential paths for migration in a gravity sewer are exemplified on Figure 3-1.

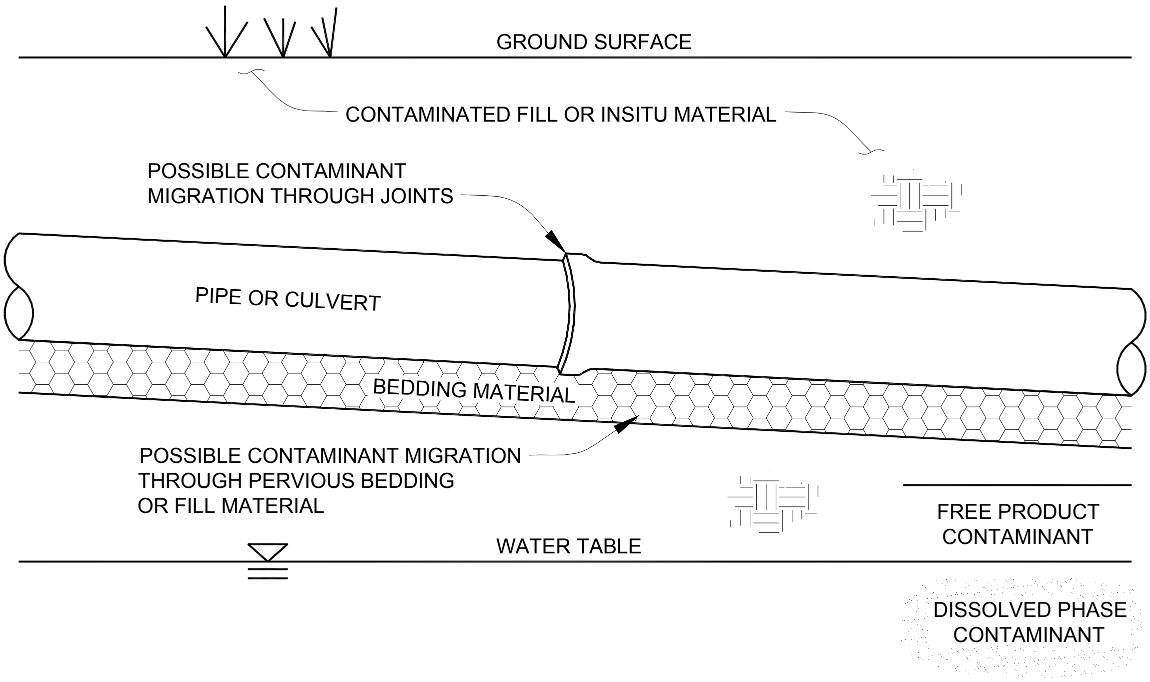

Figure 3-1. Contaminant Migration through Gravity Sewer Corridors

Water force mains can also be a concern when installed through a contaminated area. During negative pressure, which might occur in a water main when a pumping truck from the fire department draws water from a nearby hydrant, contaminants surrounding the pipe could be drawn in at a faulty joint (Wisconsin Department of Natural Resources 2000). Also, some materials used for these utilities can degrade or deteriorate when exposed to certain types of contaminants. Chemical resistance of pipe and gasket materials is discussed in Section 5 of this manual. The type of utility and the materials of its construction should be considered when installing utilities through a contaminated area and/or when implementing contaminant migration mitigative methods.

3.4 Existing and Proposed Site Characteristics

Characteristics of the project site can also influence the decision to mitigate contaminant migration, what type of mitigation control is used, and where the mitigation control is implemented. Understanding the project setting, including hydrogeology and contaminants of concern, and how the existing and proposed utility infrastructure fits into this environment, is vital for successful mitigation of contaminant migration (Pearson, unpublished information 2002). If the existing and proposed characteristics of the project site are not fully understood, engineering controls for mitigation of contaminant migration may be implemented when or where they are not effective. On the other hand, controls might not be implemented when they could have been effective. Also, certain types of mitigation techniques could lead to a change in the hydrogeology of the project site, such as redirection or blockage of groundwater flow, which could be an undesired environmental consequence. As a result, for these reasons, consideration and understanding of existing and proposed site characteristics is absolutely necessary during planning and design of mitigation measures.

3.5 Experience of State Transportation Agencies and Others

To further understand the problem and to benefit from other's experience, attempts were made to contact all of the state transportation agencies in the United States regarding the issue of contaminant migration during utility installation. Of the attempts, 25 contacts were established through either phone or email. The 25 potential informational contacts were assessed and subdivided into the following categories:

- Eight contacts were simply established but no additional information was obtained.
- Four contacts had no previous experience or policy regarding contaminant migration during utility installations.
- Nine contacts had some experience with the issue and provided informative responses but no relevant specifications, regulations, or design related material.
- Two contacts had some experience and provided some relevant specifications, regulations, or design related material.
- Two contacts had extensive experience and provided relevant reports and/or design specifications.

Some of the relevant information obtained from the contacts at the state transportation agencies is incorporated into this document.

Contacts were also established at Dominion Power, the U.S. Army Corps of Engineers, and VADEQ. The contact at Dominion Power provided no additional information and stated that they usually defer to the VADEQ when contamination is encountered. The contact at the U.S. Army Corps of Engineers did not provide any information relevant to contaminant migration during utility installations. Contacts at VADEQ suggested looking in the *Storage Tank Program Technical Manual,* DEQ Guidance Document No. 01-2024 for relevant information. Specifically, the contact at VADEQ suggested reviewing Section 3.1.5.2 Virginia Department of Transportation (VDOT) and Section 5.4.3.2.2 Endpoint Determination and Future Use. While these sections were useful in the understanding of the regulatory and liability requirements of VDOT with regards to contamination due to underground storage tanks, no specific information was provided regarding mitigation of contaminant migration due to utility installation.

4.0 MITIGATION MEASURES FOR CONTAMINANT MIGRATION

The purpose of this section is to describe some of the methods that have been used to mitigate contaminant migration and to also provide some additional insight into their application and design. During our research in this area, very little published information was discovered which specifically addressed the issue of mitigating contaminant migration during utility installation. Of the published information available, very little discussed the effectiveness of different mitigation measures. As a result, most of the mitigative measures discussed in this section are drawn from the experience of VDOT and other state transportation agencies. Some experience is taken from the case studies as presented in Section 6 of this manual and also from different specifications and reports supplied by the different state transportation agencies. Subjects discussed in this section include pre-construction mitigative activities, temporary engineering controls, permanent engineering controls, trenchless technologies, and post auditing.

4.1 Pre-construction Site Investigations and Planning

Once contamination is suspected in the right-of-way of a road construction or widening project, a more in-depth subsurface investigation should be conducted. A pre-construction site investigation is very important and can help ascertain whether mitigation of contaminant migration is a worthwhile pursuit and where and how the mitigation measures will be implemented. Subsurface site investigations can be a vital step in the planning process, and good planning is paramount to successful contaminant migration mitigation. An ideal subsurface site investigation for a potentially contaminated area where a utility installation is planned should exhibit the following:

- The investigation should identify the type and extent of contamination. Ideally, the entire contaminant plume should be delineated with concentration contours for all contaminants identified. At a minimum, the contamination should be identified along the alignment of the utility corridor to a depth slightly below the trench bottom. Concentrations of the contaminant should be compared to those levels established to be a concern by the regulating authority. Description of the contamination should include whether free product, dissolved phase product, residual soil contamination, or vapor content was observed and to what extent.

- Existing soils should be characterized in the area of contamination. Lithologic descriptions of the subsurface should be prepared, and physical properties of the soils should be determined, especially the hydraulic conductivity.

- Groundwater conditions and hydrogeology should be characterized in the area of contamination. Depth to groundwater, static groundwater elevations and hydraulic gradients should be determined. Differences in seasonal fluctuations and perched aquifers should be considered when establishing groundwater elevations. Subsurface hydrogeologic features like aquifers, perched aquifers, and aquicludes should be identified. If feasible, depth to bedrock and type of bedrock in the area should be determined. General direction of ground water flow direction and rate should be established.

- Existing utility infrastructure should be assessed, located and described. This type of information can be obtained from utility maps kept by the local Public Works, City or County Engineering Department, or from utility owners. Information obtained about existing utilities should include the alignment and depth of the utility and how the utility was constructed (trench bedding and materials).

- The site topography should be assessed and described. General slopes and direction of slopes should be established. Surrounding features should also be described. Some of this information can be determined using USGS maps or actual site surveys.

- Potential receptors in the vicinity of the utility should be identified. Receptors in the area may include groundwater wells, aquifers, surface water bodies, wetlands, buildings and any other natural resources or structures which should be safeguarded against potential contaminant migration.

If an environmental consultant, in addition to the components listed, conducts the subsurface site investigation VDOT may also desire that the consultant provide recommendations about the necessity of mitigation of contaminant transport and the subsequent methods of mitigation. A well-organized and comprehensive site investigative study, which contains the elements as described above, can save time and money during the course of the project. For example, careful planning using the results of a site investigation study could enable VDOT to avoid contamination altogether during utility installation, thus avoiding the additional cost of mitigation and monitoring. In some situations, contamination is discovered during construction. In these cases, cessation of work until an adequate site investigation can be performed is the most preferential plan of action. This will allow VDOT and its contractor to assess the situation and mitigate contaminant migration if necessary.

4.2 Temporary Engineering Controls During Construction

Spreading of contaminants discovered in soil and groundwater is always a concern during a construction project, especially those requiring excavation like most utility installations. Thus, adequate management of excavated soil and groundwater either removed from the excavation or entering the excavation during construction is the greatest concern during the installation of a subsurface utility. Most VDOT construction projects, which are located in contaminated areas, utilize special provisions that detail the management, treatment and/or disposal of contaminated groundwater and soil. An example of such a provision is included as Figure 6-10 in Section 6. The special provisions may require the implementation of temporary engineering controls designed to prevent the spreading or migration of contaminants from the construction site. Most temporary engineering controls are site specific and might include some of the following:

- Groundwater barrier walls can be constructed along the length of the trench on one side or both to prevent groundwater from entering the trench during construction. The barrier walls can be constructed using sheet piles, plastic liners, or by some other method.

- Groundwater recovery wells can be installed around the excavation to draw the groundwater down below the bottom of the trench.

- Small depressions or storage basins can be excavated just down gradient of the utility installation to capture and hold the contaminated groundwater so that it may be removed and properly treated or disposed.

- If the utility is a large diameter storm drain, small sand bag dams can be constructed inside the pipe at the downstream end to capture any contaminated water.

- Extra pumps and holding tanks can be kept on hand at all times during construction in the contaminated area in case groundwater must be removed quickly.

- Field sampling and screening of all soil excavated and groundwater encountered in the contaminated area could be conducted. Subsequent management, treatment, and disposal of all contaminated groundwater or soil should be performed.

- When contaminated soil is stockpiled, the soil should be placed on a plastic liner. A plastic liner should also be placed over the top of the stockpile to protect the soil from being washed away by rain. The stockpiles should be bermed and straw bales should be placed to prevent erosion or migration of the material.

- When adequate planning for the project is allowed, construction should occur in the dry season of the year when groundwater levels are lower and there is less chance of stormwater runoff, which could erode stockpiles and spread contamination.

If implemented, some of the temporary engineering controls listed above could prevent the spreading of contamination during a utility installation. Once again, good planning can help in the implementation of these controls and in the containment of contaminated soils and groundwater.

4.3 Long-Term Engineering Controls

Engineering controls or methods can be incorporated into the design of a utility installation to reduce the migration of contaminants on a long-term or permanent basis. While it is improbable to stop contaminant migration altogether, long-term mitigation methods are designed to slow down the migration of contaminants in the utility corridor to a level at or below the pre-construction rate found in existing soils. The effective purpose of the methods discussed here is to reduce the migration of contaminants in the utility corridor by either lowering the hydraulic conductivity of the backfill material or by lengthening the flow path for groundwater through the trench. This section will discuss some of these long-term engineering controls, their design and their application. It should be noted that much of the information presented in this section is taken from specifications or other design related material that was prepared for site-specific purposes. Therefore, when applying this information to a project, the sample specifications presented herein should be used as a starting point, not as the final product. Also, as discussed in Section 3, many factors should be considered while deciding when, where, and what type of mitigative measure is implemented.

Low Permeability Trench plugs

Low permeability trench plugs are sometimes specified to significantly reduce the flow of groundwater through a preferential pathway created by a utility corridor. Trench plugs have also been specified in the past when there is a concern about a change in natural groundwater flow due to the installation of a utility. According to Howard, trench plugs may be useful when the bedding or embedment for the pipe is constructed using cohesionless, free-draining material (1996). Howard adds “in areas where there is high groundwater, where the pipeline crosses streams or aquifers, or where the natural groundwater flow would be affected (or even diverted) by free-draining material, trench plugs of compacted, cohesive, impervious soils should be constructed at predetermined intervals along the pipeline." The same principals should be applied when specifying trench plugs for the purpose of reducing contaminant migration. When specifying locations and dimensions of the trench plugs, the existing hydrogeology and utility infrastructure of the project site should be considered carefully. In general, the trench plugs should be placed such that they surround the utility, extend slightly into the trench walls and bottom, and extend above the determined water table. Trench plugs can be placed up gradient of a contaminated area to prevent clean groundwater from entering the site and down gradient of the contamination to prevent contaminated groundwater from leaving the site. Extraction wells can be placed just up gradient of the downstream trench plug for remediation or monitoring of captured groundwater. A schematic showing an ideal configuration for the placement of trench plugs is shown on Figure 4-1. Once again, consideration of the existing hydrogeology and utility infrastructure of the project site is very important during placement of trench plugs. For example, an up gradient trench plug might be useless in preventing the influx of clean groundwater if another existing utility corridor passes through the area.

Material used for the construction of trench plugs should be less permeable than the bedding material, embedment material, and the backfill material and should be at least as permeable or less permeable than the in situ material. Howard (1996) recommends the use of cohesive soils classified with symbols SC, CL, or GC or a blend of soils beginning with these symbols. He also says these soils should be compacted to a minimum of 95% standard Proctor having a moisture content between 2% wet or 2% dry of optimum moisture content. In addition to having a low permeability, it is also desirable for the fill to have a similar or stronger compressive strength as the in situ material and be easily placed or constructed. However, the material should not have such a high strength that it is not easily excavated after placement. One such type of material that has been developed in recent years for use with utility installation is called flowable fill. The development and use of this material is discussed in the next section.

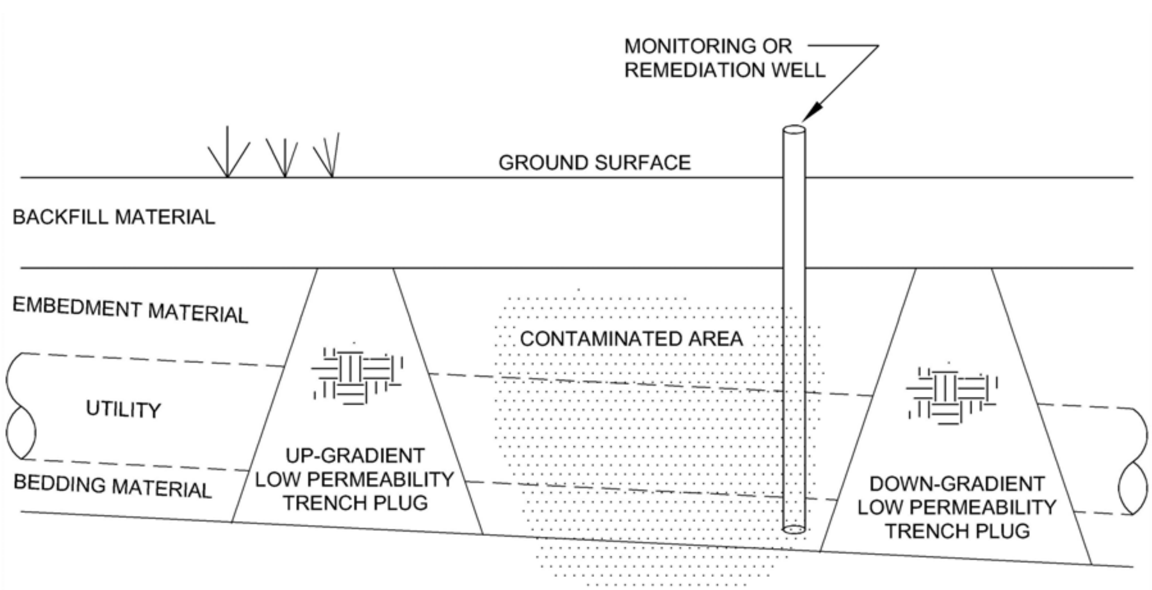

Figure 4-1: Typical Placement of Low Permeability Trench Plugs

Flowable Fill

According to the Turner-Fairbank Highway Research Center (TFHRC), flowable fill “refers to a cementitious slurry consisting of a mixture of fine aggregate or filler, water, and cementitious material(s), which is used primarily as a backfill in lieu of compacted earth” (2002). Other names for flowable fill include controlled low strength material (CLSM) and controlled density fill (CDF). Flowable fill materials are ideal for below grade applications like utility installations. During placement, flowable fill is self-leveling and will fill hard to reach places, like around pipes or other utilities. The American Concrete Institute (ACI) specifies that the compressive strength of flowable fill should not exceed 1,200 lb/in^2 (1994). The TFHRC says that most flowable fill materials used in current applications do not exceed a compressive strength of around 300 lb/in^2 (2002). Cementitious materials that are used in the composition of flowable fill include portland cement, pozzolanic materials, and other self-cementing materials like coal fly ash.

Mixture designs for flowable fill are influenced by the technical and economic requirements of the project. Properties that are considered when designing a flowable fill mixture include desired strength level, flowability, permeability, shrinkage or expansion after hardening, and compatibility with utility materials (Ramme 1999). For utility installation projects, lower compressive strength is typically desired for flowable fill mixtures because it will more closely match the strength characteristics of the surrounding soil while also being easier to excavate when necessary. Flowability and workability should be good to ensure that all voids in the trench and around the utility are totally filled. When mitigating contaminant migration is a concern, permeability of the hardened flowable fill should be lower than the surrounding soils. Shrinkage or expansion should be kept at a minimum for use with installation projects to ensure that no voids are created during hardening. Compatibility with the utility is also an important consideration when designing a mixture for flowable fill, and should be researched during design to ensure a long-term installation. Properties that may indicate compatibility include electric resistivity, thermal conductivity, and plastics compatibility (Ramme 1999). A sample specification for flowable fill prepared by VDOT is included as Figure 6-13 in Section 6. This specification is provided as an example only and all of the properties discussed above should be considered when designing a mixture for a specific project. The Wisconsin Electric Power Company has developed mixtures for flowable fill using coal combustion fly ash as the cementitious ingredient. Their research and products are thoroughly discussed in a book entitled *Coal Combustion Products Utilization Handbook* authored by Ramme and Tharaniyil. This book is an excellent resource for the topic of flowable fill and the reader is referred to this publication for more information.

When mitigating contaminant transport along utility corridors, flowable fill can be used as material for trench plugs, which are described in the previous section, or can be used to fill entire lengths of the utility corridor. Figure 4-2 shows flowable fill being placed during the installation of an underground steam pipe. In recent years, the Wisconsin Department of Transportation (WDOT) has specified the use of flowable fill for trench plugs to prevent contaminant transport (Pearson, unpublished information 2002). Because the purpose of the flowable fill material is to prevent migration of contaminants through the utility corridor, WDOT desired a mix that upon hardening would exhibit low hydraulic conductivity. In an effort to achieve low hydraulic conductivity characteristics, WDOT includes sodium bentonite clay as an ingredient in the flowable fill design mixture. A sample specification for flowable fill used by WDOT is shown on Figure 4-3. WDOT has measured hydraulic conductivity values for samples of hardened flowable fill in the 10^{-6} to 10^{-7} cm/s range (Pearson, unpublished information 2002). The sample specification shown in Figure 4-3 was prepared for a site-specific purpose and is provided as an example and not as a perfected design mixture. WDOT is currently refining design mixtures for flowable fill as well as developing other additional options to address contaminant migration issues.

Figure 4-2. Placement of Flowable Fill (Ramme 1999)

Figure 4-3
SAMPLE SPECIFICATION FOR FLOWABLE FILL
WISCONSIN DEPARTMENT OF TRANSPORTATION
LOW PERMEABILITY TRENCH PLUG

A. Description: This work consists of constructing two low permeability trench plugs within the storm water trench bordering Parcel 105, including the associated form work and quality assurance testing.

A. Materials: The Contractor shall furnish the materials required to mix and construct the low permeability trench plug. The materials to be used to make the low permeability mixture shall be acquired from the same source for all Work and are:

1. #1 Stone: Gradation in accordance with WDOT Concrete Coarse Aggregate, Section 501.3.6.4.5, No. 1.

Sieve Size	Percent Passing
1 inch	100
3/4 inch	90 - 100
3/8 inch	20 - 55
No. 4	0 - 10
No. 8	0 - 5

2. Sand: Natural river of bank sand; free of silt, clay, loam, friable or soluble materials, or organic matter; graded in accordance with WDOT Concrete Fine Aggregate Section 501.3.6.3.6, within the following limits:

3. Cement: ASTM C 150, Type I - Normal

4. Bentonite: A high yield 200 mesh sodium bentonite clay.

5. Water: Use pre-approved WDOT source. Water shall be clean and not detrimental to concrete.

The low permeability trench plug mixture shall consist of the following (per one cubic yard of mix); one 50-pound bag of cement, two 50-pound bags of sodium bentonite, 1,280 pounds of sand, and 1,939 pounds of #1 stone. The mixture shall have sufficient water to be free-flowing and self healing with a slump of 8 to 10 inches.

Form material to be used shall be at the discretion of the Contractor. If lumber is used, use SPF species; construction grade; or better.

The Contractor shall submit the following:

1. Submit Construction Sequence Plan to Engineer one week prior to low permeability trench plug construction. Construction Sequence Plan shall include the following: sequencing of form work construction, material mixing, material and placement; and staging plan including where mixing will occur.
2. Notify Engineer a minimum of 2 working days prior to commencement of low permeability trench plug construction.
3. Product Data: Provide data on bentonite, cement, and aggregate. Submit to Engineer one week upon low permeability trench plug construction completion.

C. <u>Construction Methods:</u> The Contractor shall examine the following items prior to the low permeability trench plug construction to verify materials to be used are acceptable; confirm trench subgrade and walls meet specifications; and confirm trench subgrade is free of water ponding.

Contractor shall erect formwork, shoring and bracing to achieve design requirements, in accordance with requirements of ACI 301. The Contractor shall provide bracing to ensure stability of formwork. Shore or strengthen formwork subject to overstressing by construction loads. The trench backfill placed at the angle of repose in completed sections of the storm sewer trench will serve as containment for one face of the low permeability trench plug.

The Contractor shall construct the low permeability trench plug at both the west (Station 377+47) and south (Station 57+50S) ends of the trench located along the north and east boundaries of Parcel 105, respectively. Each trench plug shall extend three feet along the trench length. The height of each trench plug shall extend from the bottom of the design utility trench to one foot below the design surface grade. The low permeability trench plug shall completely encase the storm sewer pipe and extend from the trench sidewall to sidewall. The materials shall be placed such that materials do not segregate. The Contractor shall maintain records of material placement (e.g. record data, location, quantity, air temperature, and test samples taken).

The Contractor shall remove the formwork in accordance with requirements of ACI 301. The forms shall be removed after the low permeability trench material has achieved a strength of at least 50 psi as measured by unconfined compressive strength tests on test specimens. If low permeability trench plug material does not have the strength to maintain its shape without the assistance of forms, the forms shall not be removed but shall stay in place.

Field inspection and testing will be performed by Engineer or Engineer's representative. The Contractor shall assist Engineer or Engineer's representative with obtaining material samples. The Engineer or Engineer's Representative may perform tests of bentonite, cement and aggregates to ensure conformance with specified requirements. The Engineer or Engineer's Representative shall obtain eight 2" by 4" test cylinders and perform one slump test for every 50 cubic yards or less of trench plug material placed. Six of the test cylinders will be used to determine unconfined compressive strength at the following schedule: one at 1 day, one at 2 days, one at 3 days, one at 7 days and two at 20 days. The remaining two test cylinders will be used to determine the permeability of the material. If field inspections indicate Work does not meet specified requirements, remove Work and replace at no cost to WDOT or Engineer.

D. Method of Measurement: This item shall be measured by the cubic yard of material placed and accepted. Such volume shall be computed from the actual measurements of the dimensions of the low permeability trench plug.

E. Basis of Payment: This item, measured as provided above, will be paid for on a unit price per cubic yard. That price shall be full compensation for supplying all materials and formwork, preparing the low permeability trench plug, hauling it to the construction site, placing the material, removing formwork (if performed as specified above), and for furnishing all equipment, labor, tools, and incidentals necessary to complete the work.

Trench Liners

To prevent the migration of contaminants through a utility corridor, a plastic liner can be placed along the trench wall and trench bottom separating the embedment and backfill from the surrounding soils. A schematic showing an idealized application of a plastic trench liner is shown on Figure 4-4. WDOT recommends using a polyvinyl chloride (PVC) or high-density polyethylene plastic liner of thickness ranging from 10 to 30 millimeters (Wade, unpublished information 2000). A plastic trench liner could be used in the construction of a trench plug or could be used to line the entire length of the trench in the contaminated area. Geocomposite or geosynthetic clay liners (GCL) might also be used as trench liners to mitigate contaminant migration. In any case, the manufacturer of plastic liners and GCLs should be consulted prior to application.

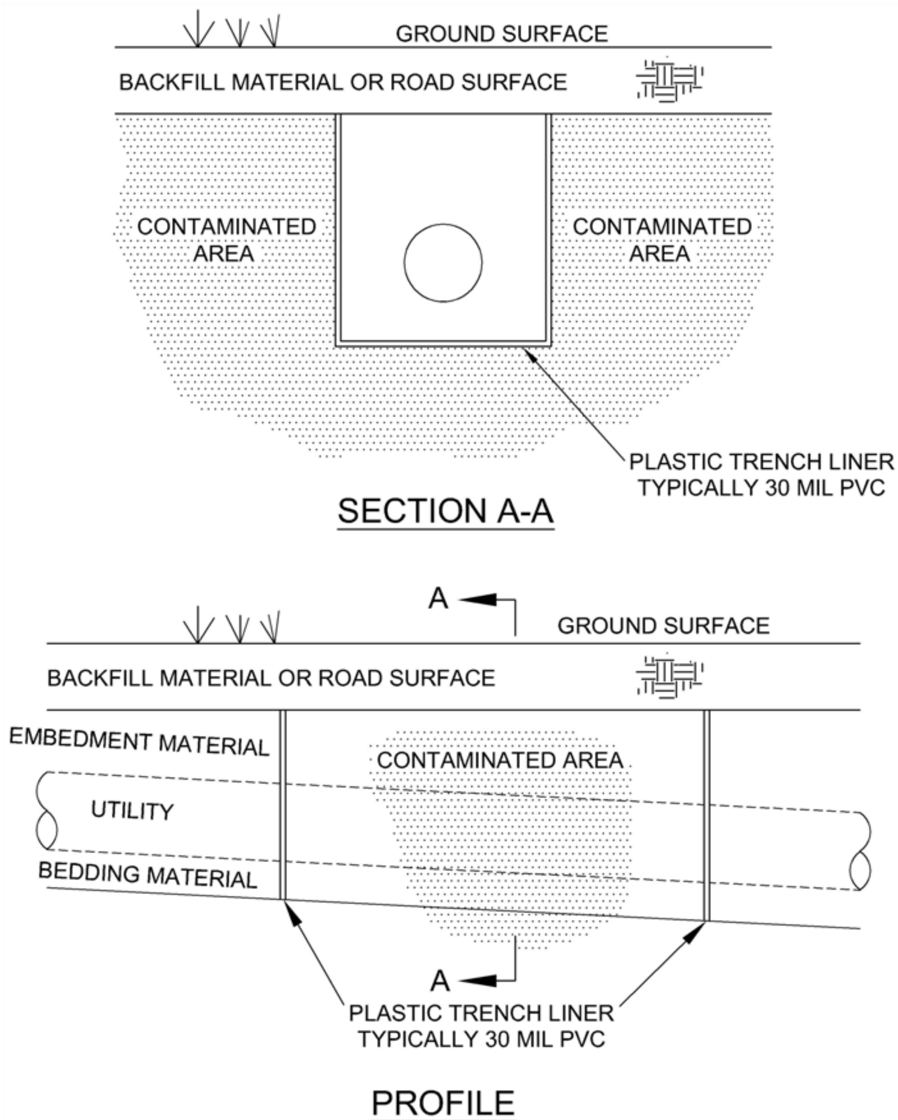

Figure 4-4. Typical Placement of Trench Liners

Anti-seep Collars

Anti-seep collars have also been used around pipes to prevent the migration of contaminants through a utility corridor. The case study presented in Section 6.2 describes such an application. Traditionally, anti-seep collars were used to increase the flow path of water through a dam embankment, which could reduce seepage along the pipe and the chance for piping and subsequent failure of the embankment. A picture of an antiseep collar used in a dam embankment is shown on Figure 4-5. To prevent or intercept seepage along the outlet pipe, the NRCS (1997) recommends the installation of an anti-seep collar or a filter diaphragm along the outlet pipe within an embankment. They also note that more fabricated materials are required for installation of anti-seep collars than filter diaphragms. The Bureau of Reclamation (1987) at one time recommended the installation of antiseep or "cutoff" collars, but has since changed their policy and now recommends other methods to mitigate problems caused by seepage. One of the concerns associated with the installation of anti-seep collars in embankments is that compaction requirements are sometimes more difficult to obtain around the collars. Different levels of compaction along the length of the pipe can lead to differential settlement and subsequent seepage paths or pipe joint leakage. Thus, if anti-seep collars are specified for a utility project and especially if compaction is very important, proper installation of anti-seep collars is essential for adequate contaminant migration control.

The purpose of anti-seep collars is similar to that of trench plugs, therefore, their vertical and horizontal dimensions and location of placement should be similar. The anti-seep collar should extend slightly into the trench walls and bottom and also slightly above the established water table or permeable embedment. Hydrogeology and existing and proposed utility infrastructure should always be considered during location and placement of the collars. Anti-seep collars can be constructed using any rigid impermeable material. For concrete pipes, anti-seep collars are typically constructed with cast-in-place or prefabricated concrete. For steel or corrugated metal pipes, anti-seep collars usually consist of prefabricated steel or corrugated metal that is fixed to the pipe using bolts or bands.

4.4 Trenchless Technologies

The disturbance of contaminated areas and subsequent migration of contaminants on a utility project can be potentially reduced through the use of trenchless technologies. Trenchless technology is a term that describes "the collection of technologies and methods that can be used to repair, upgrade, replace or install underground infrastructure systems with minimum surface disruption" (McKim 1998). The growing complexity of utility infrastructure coupled with the advancement and growing experience of the various technologies has made the use of trenchless technologies a viable option for many projects.

The technologies can be subdivided into two general categories: pipe and manhole rehabilitation and trenchless utility installation. Pipe rehabilitation includes practices like slip lining, modified slip lining, cured in place (CIP) lining, coatings, on-line replacement, segmental linings, and point repair techniques (Kramer 1998). The case study discussed in Section 6.3 describes the use of slip lining techniques and coating techniques to rehabilitate a gravity sewer and associated manholes. Slip lining involves inserting a new pipe within an existing pipe and modified slip lining involves installation of a deformed pipe within an existing pipe. Another technique for rehabilitation of sewer pipes is called pipe bursting, where the old, deteriorating pipe is either broken out and enlarged using radial pressures and then replaced with a new pipe. Support technologies for pipe rehabilitation also continue to become more advanced, thus increasing ease of application for rehabilitation techniques. With an aging utility infrastructure, the growing environmental and economic pressures, and greater use and experience, the demand for pipe rehabilitation continues to increase.

There are a wide variety of techniques used for trenchless utility or conduit installation. These methods include auger boring, slurry boring, microtunneling, horizontal directional drilling, pipe ramming, soil compaction, pipe jacking, and utility tunneling. For a full description of these methods, including cost information and applicability, the reader is referred to *NCHRP Synthesis*

Figure 4-5. Anti-seep Collar in a Pond Embankment
(Natural Resources Conservation Service (NRCS) 1997)

242, Trenchless Installation of Conduits Beneath Roadways (Iseley 1997). Horizontal directional drilling is a technique that has been used to install all types of utilities including pressure pipes, conduits, and cables. This method involves a two step process where a surface launched, steerable drilling system is used to first establish a small diameter pilot hole along a predetermined path, then the hole is enlarged using a backreamer to accommodate the size required by the desired utility. During the backreaming step, the utility is pulled into place. The horizontal boring and backreaming process is controlled from a surface mounted drill rig and is typically fluid assisted. Horizontal directional drilling systems have gained popularity for installation of utilities through environmentally sensitive areas, where disturbance must be kept to a minimum. For the same reason, guided drilling systems may be useful for installation of utilities through contaminated areas

Microtunneling is another trenchless technology that is beginning to gain acceptance for the installation of utilities. For all practical purposes, microtunneling is a remote controlled, miniaturized version of pipe jacking which is used to install utilities along a predetermined path (Kramer 1998). Both microtunneling and pipe jacking utilize a jacking force to push a shield and/or tunnel boring machine through the ground to develop a horizontal boring for placement of a conduit or utility. Oftentimes, the remote guidance system for microtunneling utilizes a laser mounted in the drive shaft, which establishes a reference line for the steering head. Microtunneling machines are typically fluid assisted. Like horizontal directional drilling, microtunneling techniques could be used to reduce disturbance of a contaminated area, thus reducing the chance for contamination migration.

4.5 Planning/Design versus Constructed Controls

As previously discussed, good planning and design, including comprehensive pre-construction site investigations, is very important during the implementation of the engineering controls discussed in this section. However, unforeseen complications can always crop up during the course of the project. Certain geologic features or existing utilities may not have been revealed during pre-construction investigations and were not anticipated during the planning process. In these cases, which oftentimes seem to be the norm rather than atypical, VDOT and its contractor must reevaluate the effectiveness of the controls used for contaminant migration and re-design the plan if necessary. During re-designing of the plan for contaminant migration control, consideration should be made for the project setting and the existing and proposed infrastructure.

Situations may also arise where contamination is encountered on a project but is not expected. In some of these cases, proper planning and pre-construction site investigations may not be feasible, and emergency engineering controls may be implemented which are not effective. To avoid such situations, if there is a remote chance that contamination may be encountered on a utility installation project, language should be included in the contract documents to allow for a course of action. Such language could include the requirement of a thorough site investigation if contamination is encountered so that the situation may be properly addressed. Good contract documents, which address the issue of mitigation of contaminant migration, can save time and money for VDOT if contamination is encountered on a project.

4.6 Post-auditing of Engineering Controls

While usually prohibited by time and cost, post-auditing the performance of implemented engineering controls for contaminant migration could be very useful for design and implementation of controls in the future. If possible, engineering controls should be monitored for a period of time after their installation to measure their effectiveness. As an example, monitoring or extraction wells could be installed up gradient and down gradient of a trench plug and samples can be collected to measure and compare the groundwater quality in both areas. Such post-auditing research activities can not only measure the effectiveness of engineering controls, but can also reveal any negative or positive changes in hydrogeology. Also, post-auditing may show that a very costly type of engineering control is not very effective in the mitigation of contaminant migration and should not be implemented on future projects. Thus, post-auditing activities could save money on future projects by not implementing controls that have been shown to be ineffective. Consequently, post-auditing research should be conducted for utility projects if time and money allow.

5.0 UTILITY MATERIALS AND CONTAMINANT RESISTANCE

During utility installation through a contaminated area, the potential degradation of utility materials by the surrounding contaminants may be a concern. Especially with pipe utilities, the contaminants may degrade or permeate the pipe wall or the joint materials and migrate through the inside of the pipe. In the case of storm sewers, after degradation of the pipe and/or joints, the pollutant could infiltrate the pipe and contaminant water resources downstream. With regard to water mains, the pollutant could enter the pipe during negative pressure and contaminate drinking water that is piped directly to users. For sanitary sewers, exfiltration of sewage into the environment after degradation of the pipe is of greatest concern. It is also foreseeable that contaminants may soften pipe materials like plastic, possibly causing deformation and subsequently lowering the performance of the pipe. Thus, these concerns warrant the use of utility materials that may reduce the potential harmful effects of exposure to subsurface contamination. The purpose of this section is to provide some guidance about the chemical compatibility of contaminants and utility materials and where to find more specific compatibility information. Information discussed in this section was obtained from publications dealing with corrosion resistance of materials and from manufacturers or their respective trade associations. Unfortunately, most of the information available focuses on conveyance of corrosive materials rather than protection from subsurface contaminants. As a result, information about conveyance of corrosive materials was extrapolated to apply to the chemical compatibility of utility materials with the subsurface environment. This section then, is intended to serve as general guidance only and the manufacturer should always be consulted prior to specification of utility materials for a project. Topics discussed in this section include pipe materials, coatings and liners, and joint and gasket materials.

5.1 Pipe Materials

There are many materials used in the construction of pipe for utility applications. For design or installation purposes, the type of pipe is usually referred to as rigid or flexible. Examples of material used for rigid pipes include concrete (unreinforced, reinforced and prestressed), vitrified clay, and asbestos-cement. Examples of materials used for flexible pipes include steel, pretensioned concrete, corrugated metal (steel or aluminum), ductile iron, fiberglass, polyvinyl chloride (PVC), polyethylene (PE), acrylonitrile-butadiene styrene (ABS), and polybutylene (PB) (Howard 1996). Excellent resources for the discussion of pipe materials and associated chemical resistance are presented by Nayyar (2000) and Schweitzer (1994, 2001). For the purposes of this manual, the materials used for pipe construction will be addressed in the following categories: plastic, metallic, concrete, fiberglass and vitrified clay.

Plastic

Development of plastic materials for pipe construction has been extensive in the last several decades and plastic pipe materials have been used for a variety of utility installations. Plastic materials used for pipe construction can be generally subdivided into two types: thermoplastic and thermosetting. Thermoplastic resins have the capability of being heated and then reformed, whereas thermosetting resins, once cured, cannot be changed again in shape when heated.

Examples of thermoplastic resins include acrylonitrile-butadiene styrene (ABS), polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), polyethylene (PE or HDPE), polybutylene (PB), polypropylene (PP), polyvinylidene fluoride (PVDF), and ethylene chlorotrifluorethylene (ECTFE). (Schweitzer 1994). Thermoplastics account for the vast majority of plastics used for piping projects. In 1989, 95 percent of the plastics used for piping consisted of thermoplastics, with three-quarters of that amount being PVC, 15% being PE, 4%t being ABS, and the remaining 6% being fabricated using the other resins (Nayyar 2000). The four main resins used in thermosetting plastics include vinyl esters, unsaturated polyesters, epoxies, and furans. Cross-linked polyethylene (PEX) is an example of a thermoset material that is made from a thermoplastic material, polyethylene (PE). PEX is fabricated by crosslinking of the polymer during or soon after extrusion. The result is a pipe material that can withstand higher operating temperatures than the original PE material.

The corrosion of plastic materials is different than that of metal or other materials. Metals exhibit a corrosion rate, thus it is possible to predict the serviceable life of a metallic material when in contact with a certain corrodent. However, plastics do not exhibit a corrosion rate and they either are completely resistant to a chemical or degrade quickly after exposure (Schweitzer 1994). It should be noted that plastic pipe materials usually carry the name of the base resin used in the manufacturing process. Manufacturers may change the composition of a plastic material with the addition of ingredients to the base resin, which may change certain properties, including chemical resistance. Consequently, different manufacturers may fabricate a plastic pipe material that bears the same name but exhibits slightly different properties. Thus, the manufacturer of the pipe should always be consulted when a pipe material is specified for a chemical resistance purpose. Nayyar (2000) presents a chemical resistance guide for thermoplastic materials (Table 5-1). For a more detailed discussion of chemical and corrosion resistance of thermoplastic and thermosetting materials, the reader is referred to a book entitled *Corrosion Resistant Piping Systems* by Schweitzer (1994). This book contains tables for different plastic materials and their associated resistance to a large list of chemicals and also contains other useful information like design concerns and joining methods for plastic pipe. Of additional note, extensive chemical resistance tables for polyvinyl chloride can be obtained from National Pipe and Plastics, Inc. (www.nationalpipe.com). Also, chemical resistance tables for polyethylene can be obtained from The Plastics Pipe Institute, Inc. (www.plasticpipe.org). Chemical resistance tables supplied by these sources are very extensive and will not be reproduced in this manual. Contact information for these two trade associations are provided in Section 5.4 of this manual.

Metallic

There are many types of metallic materials used for pipes on utility installation projects. Different alloys have been developed over many years to serve different purposes. Popular types of metal pipe used for subsurface utility installations include ductile iron pipe and corrugated metal pipe (usually steel or aluminum). Ductile iron pipe is typically used for force water and sewer mains while corrugated metal pipe is typically used for drainage purposes. Most metals are not stable in the natural environment. Metals that are manufactured by artificially reducing ores have a tendency to return to the original ores or related compounds when exposed to the natural environment (Schweitzer 2001). For example, iron will be oxidized to ferric oxides when

TABLE 5-1
Plastic Piping Materials: Chemical Resistance Guide[1]
For Ambient Temperatures (Nayyar 2000)

Chemical	ABS	PVC Type I	PVC Type II	CPVC	PE	PEX	PB	PP	PVDF
Inorganic Materials									
Acids, dilute	G	G	L	G	G	G	G	G	G
Acids, concentrated (<80%)	L	L	L	G	L	L	L	L	G
Acids, oxidizing	L	P	P	L	P	L	P	P	G
Alkalines, dilute	G	G	G	G	G	G	G	G	G
Alkalines, concentrated (<80%)	L	G	L	G	G	G	G	G	G
Gases, HCl & HF, dry	L	L	L	L	L	L	L	L	G
Gases, HCl & HF, wet	L	G	L	G	L	L	L	L	G
Gases, ammonia, dry	L	G	L	G	G	G	G	G	G
Gases, halogen, dry	L	L	L	L	L	L	L	P	G
Gases, sulfur containing, dry	P	G	L	G	G	G	L	P	G
Salts, acidic	G	G	G	G	G	G	G	G	G
Salts, basic	G	G	G	G	G	G	G	G	G
Salts, neutral	G	G	G	G	G	G	G	G	G
Salts, oxidizing	L	L	L	L	G	G	G	G	G
Organic Chemicals									
Acids	G	G	G	L	G	G	G	G	G
Acid anhydrides	L	L	L	P	L	L	L	L	L
Alcohols, glycols	L	G	L	G	L(2)	G	G	G	G
Esters, ethers, ketones	P	P	P	P	L	L	L	L	L
Hydrocarbons, aliphatic	L	L	L	G	L	L	L	L	G
Hydrocarbons, aromatic	P	P	P	L	P	L	P	P	G
Hydrocarbons, halogenated	L	L	L	L	P	L	P	P	L
Natural gas (fuel)	G	G	G	G	G	G	G	G	G
Mineral oil	G(2)	G	G	G	L(2)	G	G	G	G
Oils, animal & vegetable	G(2)	G	G	G	L(2)	G	G	G	G
Synthetic gas (fuel)	L	L	L	L	L	L	L	L	G

"Notes:

1. G denotes good; L limited resistance; and P poor. These ratings are only for general guidance. For determination of suitability of chemical resistance under actual anticipated end use conditions more detailed information should be consulted.
2. Stress crack resistant grade of plastic material should be used." (Nayyar 2000)

exposed to the natural environment. When exposed to a corrodent (or the environment), metal can degrade or corrode at a specific rate that can be predicted based on certain variables. Ductile iron and corrugated steel pipe are typically resistant and impermeable to most contaminants associated with groundwater contamination, but their rate of corrosion can be accelerated under acidic or oxidizing soil conditions or when exposed to acidic sewage. Aggressive or corrosive conditions for metallic materials can occur naturally in soil or can be induced by contamination. Corrosion of metal pipes can be greatly reduced through the application of special coatings to the outside of the pipe or by cathodic protection. Coatings will be discussed in Section 5.2. General resistance of a specific metal to a specific chemical is extensively tabulated by Schweitzer (1999) in *Corrosion Resistance Tables*. Another comprehensive but older source for chemical resistance information is the *Corrosion Resistant Materials Handbook* by De Renzo (1985). For additional information about ductile iron pipe, the reader is referred to the Ductile Iron Pipe

Research Association (www.dipra.com). For more information about corrugated metal pipe, the reader is referred to the National Corrugated Steel Pipe Association (www.ncspa.org). Contact information for these trade associations is provided in Section 5.4.

Concrete

Concrete materials are used in pipe construction for many different types of utility projects. These include storm sewer, gravity sanitary sewer, drinking or irrigation water force mains and force sanitary sewer force mains. Concrete pipe can be cast-in-place or pre-fabricated and can be reinforced or not reinforced. Deterioration of concrete in the environment can be due to degradation of one of three components: cement paste, aggregates, or reinforcement (Mindless 2002). Furthermore, degradation of one of the components may lead to or aid in the degradation of another component. For the purposes of this manual, further discussion is focused on the degradation of the cement paste.

Portland cement mixed with water is usually used as the cement paste in concrete construction. When Portland cement and water are mixed, chemical reactions take place during hardening where calcium hydroxide and tricalcium silicate hydrate are generated. Any chemical, when exposed to the hardened cement paste, that removes calcium oxide or hydroxide, thus lowering the pH of the mixture, can cause degradation of the cement paste. The cement paste is an alkaline material, thus attack and degradation of concrete by basic chemicals is not expected. The most common chemicals causing degradation of concrete are inorganic and organic acids, especially those that form soluble salts using calcium oxide or calcium hydroxide (Schweitzer 2001). Acidic groundwaters are not typical of natural systems except in marshy areas, but acidic groundwaters or surface waters can be found near landfills or stockpiles or near tailings from mining operations (Mindless 2002). Acidic wastes are produced from agricultural and industrial processes, especially the food and animal processing. Schweitzer provides information about the effect of chemicals from different industries on concrete that is reproduced in Table 5-2 (2001). For a more comprehensive list of chemicals and their effect on concrete, the reader is referred to *Effects of Substances on Concrete and Guide to Protective Treatments* published by the Portland Cement Association (2001).

According to Mindless (2002), the durability of concrete in the environment is largely influenced by its permeability. From a chemical compatibility standpoint, permeability can control the rate at which moisture and aggressive chemicals enter the concrete. In general, as the water to cement ratio becomes lower, the permeability of a concrete also decreases. Permeability values for concrete are typically very low, but should be considered when mitigating the transport of contaminants through a utility corridor. Theoretically, contaminants could migrate through the pipe wall and be transported downstream through the inside of the pipe. Some contaminants will have a higher penetration rate than others.

Possibly the most common form of chemical attack and subsequent deterioration of concrete is caused by sulfates (Mindless 2002). Natural groundwater can contain levels of sulfates that may cause deterioration of concrete, especially when the soil contains large amounts of clay.

TABLE 5-2 **Effect of Chemicals on Concrete** **(Schweitzer 2001)**	
Chemical	**Effect on Concrete**
Chemical Plants	
Acid waters pH 6.5 of less	Disintegrates slowly
Ammonium nitrate	Disintegrates
Benzene	Liquid loss by penetration
Sodium hypochlorite	Disintegrates slowly
Ethylene	Disintegrates slowly
Phosphoric acid	Disintegrates slowly
Sodium hydroxide 20% and above	Disintegrates slowly
Food and beverage plants	
Almond oil	Disintegrates slowly
Beef fat	Solid fat disintegrates slowly, melted fat more readily
Beer	May contain, as fermentation products, acetic, carbonic, lactic, or tannic acids which disintegrate slowly
Buttermilk	Disintegrates slowly
Carbonic acid (soda water)	Disintegrates slowly
Cider	Disintegrates slowly
Coconut oil	Disintegrates slowly
Corn syrup	Disintegrates slowly
Fish oil	Disintegrates slowly
Fruit juices	Disintegrates
Lard or lard oil	Lard disintegrates slowly, lard oil more quickly.
Milk	No effect
Molasses	Disintegrates slowly above 120°F/49°C
Peanut oil	Disintegrates slowly
Poppyseed oil	Disintegrates slowly
Soybean oil	Disintegrates slowly
Sugar	Disintegrates slowly
Electric generating utilities	
Ammonium salts	Disintegrates
Coal	Sulfides leaching from damp coal may oxidize to sulfurous or sulfuric acid, disintegrates
Hydrogen Sulfide	Dry; no effect. In moist oxidizing environments converts to sulfurous acid and disintegrates slowly
Sulfuric acid (10 – 80%)	Disintegrates rapidly
Sulfur dioxide	With moisture forms sulfurous acid which disintegrates rapidly
Pulp and paper mills	
Chlorine gas	Slowly disintegrates moist concrete
Sodium hypochlorite	Disintegrates slowly
Sodium hydroxide	Disintegrates slowly
Sodium sulfide	Disintegrates slowly
Sodium sulfate	Disintegrates concrete of inadequate sulfate resistance
Tanning liquor	Disintegrates if acid

Sulfates can also be found in groundwaters located near industrial wastes associated with mine tailings and slag heaps. The mechanisms of sulfate attack will not be further discussed in this manual and for more information, the reader is referred to the discussion presented by Mindless (2002).

Concrete degradation due to exposure to certain chemicals and migration of chemicals through concrete pipe walls can be mitigated through the application of a protective coating. Coatings and liners for pipes will be discussed further in Section 5.2. More information about concrete pipes and concrete materials can be obtained from the American Concrete Pipe Association (www.concrete-pipe.org) and the Portland Cement Association (www.portcement.org). Contact information for these trade associations is provided in Section 5.4.

Fiberglass

Fiberglass or reinforced fiberglass pipe is sometimes used in utility applications. In general, fiberglass exhibits very good corrosion and chemical resistance. The chemical resistance of a fiberglass piping system is largely dependant upon the type of resin used in pipe manufacture and other factors including curing agent, liner material, liner thickness, and cure profiles (Nayyar 2000). Larger pipe sizes are usually fabricated from polyester or vinyl ester resins because these types of resins are easier to handle in large quantities. Smaller pipe sizes are typically manufactured using epoxy resins that are more suited for mass-production. Pipes made using furan or phenolic resins are also available for special purposes, specifically corrosion or flame resistance.

Properties exhibited by epoxy resins depend on the base resin and the curing or cross-linking agent. Two common epoxy resins are bisphenol-A epoxies and epoxy novolacs which can both be cured with a variety of curing agents, which in turn affects the properties of the final product. One common resin system for fiberglass pipe is bisphenol epoxy cured with aromatic amines, which are generally resistant to salt solutions, alkalines, solvents and dilute acids (Nayyar 2000). Another common resin system is bisphenol epoxy cured with aromatic anhydrides, which are generally less resistant than the previous system, having no resistance to alkaline solutions. Neither system is resistant to strong mineral acids or oxidizers.

Properties of fiberglass pipes manufactured using polyester resins depend on the type of resin only and not the curing agent because all polyester resins are cured using styrene. Types of polyester resins include vinyl ester, bisphenol-A fumarate polyester, isophthalic and chlorendic. Fiberglass pipe fabricated using vinyl ester polyester and bisphenol-A fumarate resins are resistant to oxidizers, strong mineral acids, and alkaline environments. Chlorendic polyester resins are very resistant to strong mineral acids and oxidizing environments, and more resistant to solvents than other polyester resins, but not resistant to alkaline solutions. Isophthalic resins are the least expensive and least chemically resistant of the polyester resins, having good resistance to water, dilute acids, very weak alkaline solutions and petroleum solvents.

Fiberglass pipes made with furan and phenolic resins require special fabrication processes and thus are typically used only for special temperature and chemical resistance applications. Furan resins exhibit excellent resistance to acids, alkaline solutions, and solvents at very high temperatures, but should not be used in oxidizing environments. Phenolic resins provide excellent resistance to acids and solvents at very high temperatures.

Nayyar (2000) presents a preliminary guide for the resistance of different fiberglass resins to an extensive list of chemicals. More information about fiberglass pipe can be obtained from the Fiberglass Tank and Pipe Institute (www.fiberglasstankandpipe.com). Additional contact information for this institute is provided in Section 5.4.

Vitrified Clay

Pipes constructed using vitrified clay have traditionally been specified for domestic sanitary sewer systems because of the material's excellent resistance to chemicals associated with sewage. Other applications for clay pipe have arisen in recent years associated with the cleanup of hazardous waste dumps and landfills. Clay pipe exhibits excellent resistance and impermeability to most chemicals with the exception of hydrofluoric acid. Clay pipe is chemically inert, resistant to gases and acids generated by sewage and buried garbage, cleaning compounds and solvents, and is rustproof (Schweitzer 1994). Schweitzer (1994) lists the compatibility of vitrified clay pipe with some chemicals that is reproduced here as Table 5-3.

Bell and spigot type joints sealed by an O-ring are typically used for joining sections of clay pipe. When the joint might be exposed to corrosive acids or solvents, a bead of chemical resistant furathane mortar can be placed around the O-ring joint. Furathane mortar is a thermosetting material constructed with a furane resin, and is generally resistant to most chlorinated solvents, non-oxidizing acids, and detergents.

Despite its excellent chemical resistance, the use of clay pipe does have some disadvantages. Clay pipe is very brittle, and installation must be performed properly, especially when a water-tight joint is desired (Schweitzer 1994). To provide adequate support, the installation of concrete pads and saddles underneath the pipe are recommended. Large stones must be removed from backfill material within 1 foot of the pipe to avoid damage. Good compaction by tamping around the pipe must be performed to prevent movement of the pipe joints.

Additional information about vitrified clay pipes can be obtained from the National Clay Pipe Institute (www.ncpi.org) for which contact information is provided in Section 5.4.

Double Containment Piping Systems

Double containment piping systems consist of an interior carrier pipe, designed to contain the conveyed liquid, and an exterior pipe, designed to protect the interior pipe and also to contain leakage if necessary. From a chemical resistance perspective, the interior pipe is designed to resist degradation by the liquid conveyed and the exterior pipe is designed to resist degradation or corrosion by chemicals in its environment. Double containment systems were originally designed for use in industries that transport hazardous liquids through pipelines where the leakage of the liquid is a great concern. Some of these systems are equipped with leak detection systems that inform operators of leaks from the interior pipe. Double containment systems might be overkill when dealing with mitigation of contaminant transport in utility trenches, but designers should be aware that these types of systems are an option. Single pipes and joints that are compatible with subsurface contaminants will more likely be a less expensive option than double containment piping systems. For more information about the design and use of double containment piping systems, the reader is referred to *Corrosion-Resistant Piping Systems* by Schweitzer (1994).

TABLE 5-3
Chemical Compatibility of Vitrified Clay Pipe
(Schweitzer 1994)

Chemical	Maximum Temperature (F°/C°)*
Acetic Acid 5%	**150/66**
Acetone	73/23
Aluminum chloride	X
Aluminum sulfate 5%	150/66
Ammonium chloride 5%	150/66
Ammonium chloride 10%	X
Ammonium chloride 25%	X
Ammonium hydroxide 5%	73/23
Ammonium hydroxide 10%	73/23
Aniline	73/23
Benzene	73/23
Borax	150/66
Carbon tetrachloride	73/23
Chromic acid 10%	150/66
Citric acid 10%	150/66
Copper sulfate 3%	150/66
Ferric chloride 1%	150/66
Hydrochloric acid 10%	120/49
Hydrofluoric acid 30%	X
Hydrofluoric acid 70%	X
Hydrofluoric acid 100%	X
Nitric acid 1%	150/66
Nitric acid 10%	150/66
Nitric acid 20%	150/66
Sodium carbonate 20%	150/66
Sodium chloride 30%	150/66
Sodium hydroxide 10%	150/66
Sulfuric acid 20%	150/66
Sulfuric acid 30%	150/66
Toluene	120/49

*Maximum allowable temperature shown for data available. X means incompatibility.

5.2 Pipe Coatings and Liners

As previously mentioned, coatings and liners are sometimes applied to pipes used for utility construction. For the purposes of this manual, coatings are referred to as materials applied to the exterior of the pipe and liners are referred to as materials applied to the interior of the pipe. Coatings that are used with concrete pipes, ductile iron pipes, and corrugated metal pipes are discussed in this section. In general, for concrete pipes, coatings are used to prevent the degradation of the cement paste by contaminants and to prevent the permeation of contaminants through the pipe wall. For iron pipes and corrugated metal pipes, coatings are generally used to slow down corrosion of the metallic material when exposed to aggressive or corrosive environmental conditions.

Pipe liners have been traditionally installed to prevent the degradation of the interior of the pipe by harsh liquids conveyed. In recent years, liners have been utilized to rehabilitate old, deteriorating utility pipes. Because pipe rehabilitation does not require excavation to replace a failing utility, this practice can be used to mitigate contaminant transport during utility installation by reducing the potential for spreading contamination. Pipe rehabilitation through the installation of liners is also discussed in this section.

Based on the variety of options available for coatings and liners and the variety of pipe materials to which they can be applied, the discussion presented in this manual is very limited. The discussion is focused on the use of coatings and liners for the mitigation of contaminant transport in utility trenches and is intended to be useful in this regard only. An excellent source for in-depth information about liners and coatings is *Corrosion-Resistant Linings and Coatin*gs by Schweitzer (2001).

Coatings for Concrete Pipe

Coatings are applied to concrete and concrete pipe for one of two purposes: to prevent degradation of the cement paste by a surrounding contaminant or to prevent permeation of the concrete by the contaminant. There are many different types of coatings available for concrete surfaces and the most popular surfacings include: 1) epoxy and epoxy novolac, 2) polyester, 3) vinyl ester and vinyl ester novolac, 4) acrylic, 5) urethane, 6) and phenolic novolacs (Schweitzer 2001). Table 5-4 shows some of these concrete surfacings and their comparative chemical resistance as presented by Schweitzer (2001).

Coatings are applied at different thicknesses depending on the aggressiveness of the environment and the contaminants. Thin film coatings are those that are approximately 20 mils thick and are usually composed of epoxies. These coatings can resist hydrocarbon fuels, weak acids and bases, agricultural chemicals, and some aromatic solvents. Medium film coatings are approximately 20-40 mils thick and often consist of flake-filled epoxies and vinyl esters. Vinyl esters may provide resistance to acids, bases, hypochlorites and solvents (Schweitzer 2001). Thick film coatings, which are approximately greater than 40 mils thick, are used for the most aggressive conditions. Epoxy materials used for thick film coatings are trowel applied with inorganic aggregate and polyesters and vinyl esters are applied with fiberglass matting.

Schweitzer recommends different film thickness for different types of contaminants that are shown in Table 5-5 (2001).

TABLE 5-4
Chemical Resistance of Concrete Surfacings
(Schweitzer 2001)

Medium, Room Temperature	1			2		3	
	A	**B**	**C**	**D**	**E**	**F**	**G**
Acetic Acid, to 10%	R	R	R	R	R	R	R
Acetic Acid, 10-15%	C	R	C	R	R	C	R
Benzene	C	R	R	R	N	R	R
Butyl Alcohol	R	C	R	R	R	N	R
Chlorine, wet, dry	C	C	C	R	R	R	R
Ethyl alcohol	R	C	R	R	R	R	R
Fatty acids	C	R	C	R	R	R	R
Formaldehyde, to 37%	R	R	R	R	R	R	R
Hydrochloric acid, to 36%	C	R	R	R	R	R	R
Kerosene	R	R	R	R	R	R	R
Methyl ethyl ketone, 100%	N	N	N	N	N	N	N
Nitric acid, to 20%	N	N	R	R	R	R	R
Nitric acid, 20-40%	N	N	R	R	N	N	C
Phosphoric acid	R	R	R	R	R	R	R
Sodium hydroxide, to 25%	R	R	R	N	R	R	R
Sodium hydroxide, 25-50%	R	C	R	N	R	C	R
Sodium hypochlorite, to 6%	C	R	R	R	R	R	R
Sulfuric acid, to 50%	R	R	R	R	R	R	R
Sulfuric acid, 50-75%	C	R	R	R	C	R	R
Xylene	N	R	R	R	R	N	R

R, recommended; N, not recommended; C, conditional.
1-A = bisphenol A epoxy – aliphatic amine hardener
1-B = bisphenol A epoxy – aromatic amine hardener
1-C = bisphenol F epoxy (epoxy novolac)
2-D = polyester resin – chlorendic acid type
2-E = polyester resin – bisphenol A fumarate type
3-F = vinyl ester resin
3-G = vinyl ester novolac resin

Coatings for Ductile Iron Pipe

As discussed, ductile iron pipe is resistant to rapid breakdown or permeation to most chemicals, however, the rate of corrosion of the pipe can be accelerated through exposure to corrosive conditions. Coatings for ductile iron pipe are typically applied when the pipe is installed in aggressive conditions to slow down the corrosion rate, thus extending the service life of the pipe. According to Schweitzer (1994), "soils contaminated by coal mine waters, cinders, refuse, or salts are also generally considered to be corrosive" to ductile iron pipe, "as are certain naturally occurring environments such as swamps, peat bogs, expansive clays, and alkali soils." Corrosion of ductile iron pipes can be slowed or stopped by utilizing different methods, including bonded coatings, polyethylene encasement, or cathodic protection.

TABLE 5-5 Guidelines for Film Thickness (Schweitzer 2001)			
	Film Thickness		
Contaminant	**Thin**	**Medium**	**Thick**
Aliphatic hydrocarbons	X	X	X
Aromatic hydrocarbons	**X**	**X**	
Organic Acids:			
Weak	X		
Moderate	X	X	
Strong			X
Inorganic Acids:			
Weak	X		
Moderate		X	
Strong			X
Alkalies:			
Weak	X		
Moderate		X	X
Strong			X
Bleach liquors	X		
Oxygenated fuels	X	X	
Fuel additives	X	X	
Deionized water			X
Methyl ethyl ketone	X	X	
Fermented beverages	X	X	
Seawater	X		
Hydraulic/brake fluids	X	X	X

The American Ductile Iron Pipe Company (ACIPCO) supplies ductile iron pipe with a standard asphalt coating of 1 mil thick (American Ductile Iron Pipe Company 2002). ACIPCO also supplies ductile iron pipe furnished with other primers and coatings. For mild exposure, phenolic primer can be provided which can accept a variety of topcoats including “alkyds, aluminums, epoxies (polyamide, poly-amidoamine, water-borne, and coal-tar), and urethanes” (ACIPCO 2002). For more aggressive exposure, a high solids epoxy primer can be used for typical topcoats that include “epoxies (amine, polyamide, polyamidoamine, water-borne, coal-tar) and urethanes” (ACIPCO 2002). A fusion bonded epoxy coated and lined ductile iron pipe is also available from ACIPCO. Other special coatings are available from ACIPCO and other suppliers. In any case, the manufacturer of the coating and pipe should be consulted prior to installation to ensure that the coating materials are compatible with the subsurface environment.

Polyethylene encasement of ductile iron pipe in the field just prior to installation has been very effective and economical for corrosion protection (Schweitzer 1994). The polyethylene tube or sheet utilized is typically 8 mils thick and serves as an unbonded film, preventing soil to pipe contact. Some water may seep inside the encasement and instigate corrosion, but the oxygen supply inside the encasement is quickly depleted and corrosion ceases before significant degradation occurs.

Coatings for Corrugated Steel Pipe

As with ductile iron pipe, coatings are usually applied to corrugated steel pipe to slow down the rate of corrosion, thus extending the service life of the pipe. These coatings are generally specified for corrugated steel pipe when environmental conditions are considered to be "corrosive." The term "corrosive" usually means the subsurface environment or conveyed liquid exhibits a low pH value and/or the soil has a low resistivity. There are many coating options for corrugated steel pipe and decisions to specify certain coatings over others may be driven by required protection and cost of the coating process. Figure 5-1 shows environmental guidelines and Figure 5-2 shows product usage guidelines for corrugated steel pipe as provided by the National Corrugated Steel Pipe Association (2000).

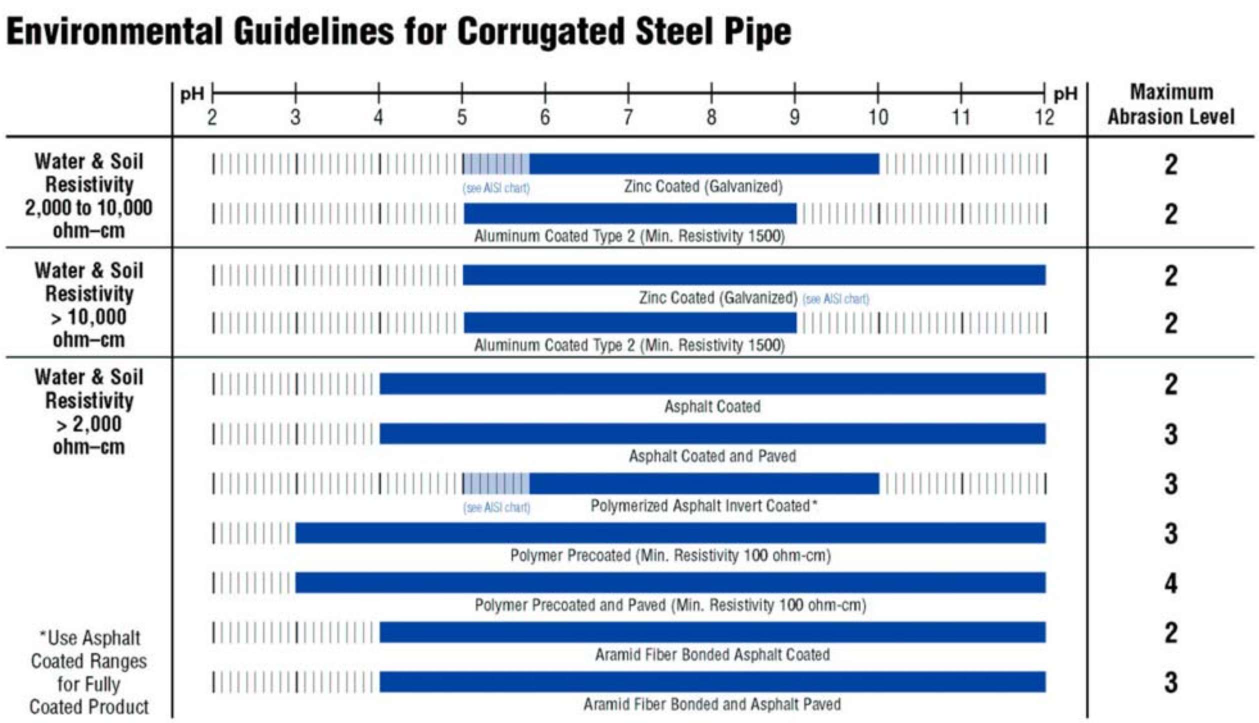

Figure 5-1: Environmental Guidelines for Corrugated Steel Pipe
National Corrugated Steel Pipe Association 2000. Reprinted with permission.

Product Usage Guidelines for Corrugated Steel Pipe

● Shaded Circles Indicate Applicable Coatings
* See AISI Chart

COATING	WATERSIDE: Normal Conditions	Mildly Corrosive	Corrosive	Non-Abrasive/Low Abrasion (Lvl. 1 & 2)	Moderate Abrasion (Level 3)	High Abrasion (Level 4)	Provides Additional Soil Side Protection
Zinc Coated (Galvanized)	●*	●*	○	●	○	○	○
Aluminum Coated Type 2	●	●	○	●	○	○	○
Asphalt Coated	●	●	●	●	○	○	●
Asphalt Coated and Paved	●	●	●	●	●	○	●
Polymerized Asphalt Invert Coated*	●	●	○	●	●	○	○
Polymer Precoated	●	●	●	●	●	○	●
Polymer Precoated and Paved	●	●	●	●	●	●	●
Polymer Precoated w/ Polymerized Asphalt	●	●	●	●	●	●	●
Aramid Fiber Bonded Asphalt Coated	●	●	●	●	○	○	●
Aramid Fiber Bonded and Asphalt Paved	●	●	●	●	●	○	●
High Strength Concrete Lined	●	●	○	●	●	○	○
Concrete Paved Invert (75mm (3") Cover)	●	●	○	●	●	●	○

* Use Asphalt Coated Environmental Ranges for Fully Coated Product

Note: Coatings listed under additional soil side protection are generally considered to provide 100 years service life from a soil side perspective within appropriate environmental conditions.[1]

ENVIRONMENTAL RANGES:

- **Normal Conditions:** pH = 5.8 – 8.0 (for R > 2000 ohm-cm)
- **Mildly Corrosive:** pH = 5.0 – 5.8 and/or for R = 1500 to 2000 ohm-cm
- **Corrosive:** pH < 5.0 (for R < 1500 ohm-cm)

ABRASION

Invert Protection/Protective Coatings can be applied in accordance with the following abrasion criteria. Abrasion velocities should be evaluated on the basis of frequency and duration. Consideration should be given to a frequent storm such as a two year event (Q_2) or mean annual discharge ($Q_{2.33}$) or less when velocity determination is necessary.

ABRASION LEVELS

The following qualitative definitions are provided as guidance to evaluate abrasion conditions when necessary.

Non-Abrasive (Level 1): No bedload regardless of velocity; or storm sewer applications.

Low Abrasion (Level 2): Minor bedloads of sand and gravel and velocities of 5 ft./sec. or less.

Moderate Abrasion (Level 3): Bedloads of sand and small stone or gravel with velocities between 5 and 15 ft./sec.

Severe Abrasion (Level 4): Heavy bedloads of gravel and rock with velocities exceeding approximately 15 ft./sec.

Figure 5-2: Product Usage Guidelines for Corrugated Steel Pipe
National Corrugated Steel Pipe Association 2000. Reprinted with permission.

Liners for Pipe Rehabilitation

With the advancement of technology, the installation of liners within old and failing pipe utilities is becoming a viable option for pipe rehabilitation. The variety of methods available for the installation of liners can be generally divided into three categories: nonstructural, semistructural, and structural (Smith 2000). In each of the methods, the result is a liquid tight barrier placed inside the existing pipe without the need for excavation or removal of the existing pipe. In all cases, the host pipe must be thoroughly cleaned prior to placement of a liner to ensure its effectiveness.

Nonstructural liners simply increase the corrosion and chemical resistance of a pipe and do not improve the structural integrity of the pipe by bridging holes or gaps. These type of liners are typically applied to extend the life of existing pipes and prevent leaks. Epoxy and cement mortar are the most common types of materials used for non-structural liners in drinking water pipes (Smith 2000).

Semistructural liners are designed to fit tightly against the inside of the pipe, providing limited structural support across pipe joints and small defects or holes in the pipe, while still relying on the existing pipe for resistance against internal pressure and external loads. These types of liners are typically used where the existing pipe is structurally sound and some loss of flow capacity is tolerable. Types of semistructural liners include close-fit pipe lining, woven hose lining, cured-in-place pipe lining, and spirally wound lining. The close-fit pipe lining method, sometimes called the modified slip lining method, involves pulling a temporarily deformed pipe through an existing pipe. The deformed pipe rebounds to its original shape, sometimes catalyzed by circulating hot water or low pressure steam, and should press tightly against the interior of the existing pipe. Polyethylene is the typical material used in close-fit pipe lining methods (Smith 2000). The woven hose lining method, involves the installation of a woven hose coated with an elastomer and adhesive. The woven hose provides resistance against pressure, the elastomer acts as a liquid barrier, and the adhesive attaches the lining to the interior of the pipe. The woven hose is installed by an inversion process where the adhesive is originally on the interior wall of the woven hose and during installation the hose is turned inside out causing the adhesive to stick to the inside of the existing pipe. The cured-in-place lining method involves the installation of a flexible tube saturated with a thermosetting resin using an inversion process similar to the woven hose method. The tubing usually is composed of glass or polymer fiber and is placed into the existing pipe using water pressure. The resin is cured using hot water or low pressure steam and stiffens, forming a semistructural lining along the inside of the existing pipe. The spirally wound pipe lining method involves the placement of a long strip of plastic in a spiral formation along the inside of the existing pipe. The edges of the strip are designed to interlock, creating a tight joint on both sides of the strip.

Structural liners are designed to replace the full functionality of the host pipe and should be able to withstand operating pressures of the original system. These liners are self-supporting and water tight. While the replacement liner may not exhibit the same strength characteristics as the original pipe with regard to external loads and vacuum, it should be designed to serve the intended purpose. Structural liners are used when the structural condition of the existing pipe is not adequate and loss of flow capacity is tolerable. Two methods used for placement of structural liners include continuous pipe lining and segmented pipe lining. Continuous pipe lining, also called slip lining, refers to pulling a long, flexible piece of pipe into an existing pipe. Plastic or steel pipe is typically used for this method of lining. Segmented lining involves the installation of split sections of pipe liner inside the host pipe to form a new pipe section. Sound longitudinal and circumferential joints are required for effectiveness of the new pipe liner. Fiber reinforced plastic or concrete are the materials typically used for segmented liners. Structural liners may require a significant reduction of flow area from that available from the original pipe (Smith 2000).

Regardless of what type of lining method is used for pipe rehabilitation, when installing the liner in a contaminated area, the manufacturer should be consulted to determine if the liner material is resistant to subsurface contaminants.

5.3 Pipe Joints

Many methods are available for joining pipe sections. Types of pipe joints include, but are not limited to, gasketed, welded, solvent cemented, heat fused, adhesive bonded, flanged, mechanical couplings, fiberglass overlays, and mastic (Howard 1996). When installing pipe utilities in contaminated areas, chemical resistance of the pipe joint material to subsurface contaminants presents some concerns, primarily involving the potential for the contaminant to degrade or to penetrate the pipe joint material. These types of concerns mainly exist for gasketed joints or joints sealed with mastic or some other type of sealant. The chemical resistance of gaskets and joint sealants will be discussed in this section.

Gaskets

Gaskets are used with all types of pipe materials and typically used for bell and spigot type joints and flanged type joints. Gasket material used for these joints ranges from soft metals to a full assortment of elastomeric materials (Schweitzer 1994). When specifying gaskets for a pipe utility project that traverses a contaminated area, the type of material used for gaskets should be resistant to degradation or penetration by the contaminant to prevent further contaminant migration inside the pipe. Table 5-6 shows the general chemical resistance of elastomerics used for gasket materials as described by National Pipe and Plastics, Inc. (Paugh, unpublished information 2002). A more comprehensive list of the resistance of elastomeric materials to specific chemicals is provided by Schweitzer in *Corrosion Resistant Piping Systems* (1994). Another comprehensive source of elastomeric chemical resistance information is published on the world wide web by Dupont Dow at www.dupont-dow.com/Tech_Info/chemical.asp. The chemical resistance guide published by Dupont Dow provides information for 19 different elastomers.

TABLE 5-6 **Properties of Selected Gasket Materials** **(Paugh, unpublished information 2002)**					
Property	**SBR**	**FKM**	**IR**	**EPDM**	**NBR**
Physical Properties					
Hardness Range	35-90	60-95	35-90	35-90	45-90
Resilience	Good	Fair	Excellent	Good	Good
Compression Set	Good	Good to Excellent	Good to Excellent	Good	Good
Cut Growth Resistance	Good	Fair	Fair	Good	Good
Environmental Properties					
Oxidation Resistance	Good	Excellent	Good	Good to Excellent	Good
Ozone Resistance	Good	Excellent	Fair to Good	Excellent	Good
Weathering Resistance	Good	Excellent	Fair to Good	Excellent	Good
Sunlight Resistance	Fair	Excellent	Fair to Good	Excellent	Fair
Water Resistance	Good to Excellent	Good to Excellent	Excellent	Excellent	Good to Excellent
Heat Resistance	Fair to Good	Excellent	Poor to Fair	Good to Excellent	Good
Low Temperature Flexibility	Good	Good	Good to Excellent	Good to Excellent	Good
Chemical Resistance Properties					
Oil and Gasoline Resistance	Poor	Excellent	Poor	Poor	Good to Excellent
Animal and Vegetable Oils	Fair	Excellent	Fair	Good	Good to Excellent
Alcohols	Good	Good	Good	Fair to Good	Good
Alkalis	Fair	Good	Fair	Good to Excellent	Good to Excellent
Acids	Good	Good	Fair to Good	Good to Excellent	Good to Excellent
Aliphatic Hydrocarbon Solvents	Poor	Excellent	Poor	Poor	Excellent
Aromatic Hydrocarbon Solvents	Poor	Excellent	Poor	Poor	Fair to Good
Oxygenated Solvents	Good	Poor	Good	Good to Excellent	Poor

SBR = Styrene Butadiene Rubber Compounds
FKM / Viton = Fluorocarbon Rubber
IR = Poly-isoprene
EPDM = Ethylene-Propylene DIene Compounds
NBR = Acrylonitrile-Butadiene Rubber Compounds

Joint Sealants

To prevent migration of contaminants through concrete pipe joints, especially tongue and groove, joints can be sealed using chemical resistant sealants or mastics. This practice is exemplified by the second case study discussed in Section 6.2. Different types of chemical resistant joint sealants can be procured from different suppliers. Concrete Sealants, Inc. supplied the petroleum resistant mastic joint sealant used in the case study discussed in Section 6.2. This joint sealant product, called CS-440, is a butyl sealant and is intended to be utilized on precast structures which are expected to be exposed to gasoline, diesel fuel, or jet fuel (Concrete Sealants, Inc. 2002). Other types of joint sealants are available from Concrete Sealants, Inc and other suppliers. Another supplier, Press-Seal Gasket Corporation, also provides butyl type mastic joint sealants as well as cellular joint filler composed of neoprene/EDPM rubber material. In any case, the manufacturer of the joint sealant should be consulted to ensure that the product can resist degradation or permeation from the contaminants of concern.

5.4 Trade Associations and Contact Information

Trade associations can be an excellent source of information about pipe materials and their installation. These associations conduct research and provide design information that can be used when specifying a chemically resistant piping system. Below is a partial list of trade associations for certain pipe materials.

American Concrete Pipe Association
222 W. Las Colinas Blvd., Suite 641
Irving, TX 75039-5423
Phone: (972) 506-7216
Fax: (972) 506-7682
E-mail: info@concrete-pipe.org
Website: www.concrete-pipe.org)

Ductile Iron Pipe Research Association
245 Riverchase Parkway East, Suite O
Birmingham, AL 35244
Phone: (205) 402-8700
Fax: (205) 402-8730
Website: (www.dipra.com)

Fiberglass Tank and Pipe Institute
11150 South Wilcrest Dr., Suite 101
Houston, TX 77099-4343
Telephone: (281) 568-4100
Fax: (281) 568-4500
E-mail: sullycurra@aol.com
Website: www.fiberglasstankandpipe.com

National Clay Pipe Institute
PO BOX 759
Lake Geneva, WI 53147
Phone: (262)248-9094
Fax: (262)248-1564
E-mail: info@ncpi.org
Website: www.ncpi.org

National Corrugated Steel Pipe Association
1255 Twenty-Third Street, NW
Washington, DC 20037-1174
Phone: (202) 452-1700
Fax: (202) 833-3636
E-mail: csp@ncspa.org
Website: (www.ncspa.org)

National Pipe and Plastics, Inc.
3421 Old Vestal Road
Vestal, NY 13850
Phone: (800)836-4350
Fax: (607)729-6130
E-mail: info@nationalpipe.com
Website: www.nationalpipe.com

The Plastics Pipe Institute, Inc.
1825 Connecticut Ave., NW, Suite 680
Washington, DC 20009
Phone: (202) 462-9607, Toll Free: (888) 314-6774
Fax: (202) 462-9779
Website: (www.plasticpipe.org)

Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077
Phone: (847) 966-6200
Fax: (847) 966-8389
E-mail: info@cement.org
Website: (www.portcement.org)

6.0 CASE STUDIES

To better understand the construction practices used on typical projects contracted by VDOT and to gain information about techniques currently being employed to mitigate contaminant migration, three case studies were selected and researched for presentation in this manual. The intention of this section is to present real-world scenarios where mitigative techniques were utilized or could have been utilized to prevent the migration of contaminants. In an effort to find suitable project sites, VDOT HazMat managers for each District in Virginia and several VDOT Resident Engineers were contacted. To be more representative of the entire Commonwealth, the three case studies were selected such that each is located in a different part of Virginia; Central Virginia, Southwestern Virginia, and Tidewater Virginia. Information was collected for each of the case studies to characterize the project site with regard to soil and geotechnical conditions, groundwater conditions, and the extent and type of contamination. Information was also collected regarding any techniques or methods used to mitigate contaminant migration during and after construction. It should be noted that the case studies discussed in this section are presented using information gathered from many sources, including letters, notes, personal communication, and site assessment reports.

6.1 Route 11, Greenville, Virginia: 10-inch Sanitary Sewer

The scope of work for this project involves the installation of a 10-inch gravity sanitary sewer pipe underneath and along the right-of-way of Route 11, close to its junction with Interstate Highway 81, approximately one mile north of Greenville, Virginia. This project is located in the Shenandoah Valley area of Virginia. Roberts furthered classifies the area around Greenville as being within the Valley and Ridge province and more specifically in the Great Valley subprovince, which is characterized by low to moderate slopes underlain by carbonate rocks, ranging in elevation from 500 to1500 feet-msl (2002). The installation of the sewer pipe will enable the Augusta County Service Authority to provide wastewater collection and treatment services for the local high school and several small businesses (Waller 2002), including three service stations as depicted on Figure 6-1. As shown, the northernmost service station is a Shell Station (Stop-In No. 77), the middle is an Amoco Station (Deno's No. 6) and the southernmost is a Pilot Truck Stop (former Pink Cadillac Restaurant). Petroleum contamination was discovered in the vicinity of the three service stations and site investigations indicate that the source of contamination was underground storage tanks (UST) leaking gasoline and diesel fuel (GES 2000). Christians Creek is located just to the south of the project site and was identified as a potential receptor of contaminants by migration through the proposed sanitary sewer corridor. To prevent migration of contaminants into Christian's Creek, engineering controls were implemented, including the installation of two in-trench barriers and the use of petroleum resistant pipe and gaskets.

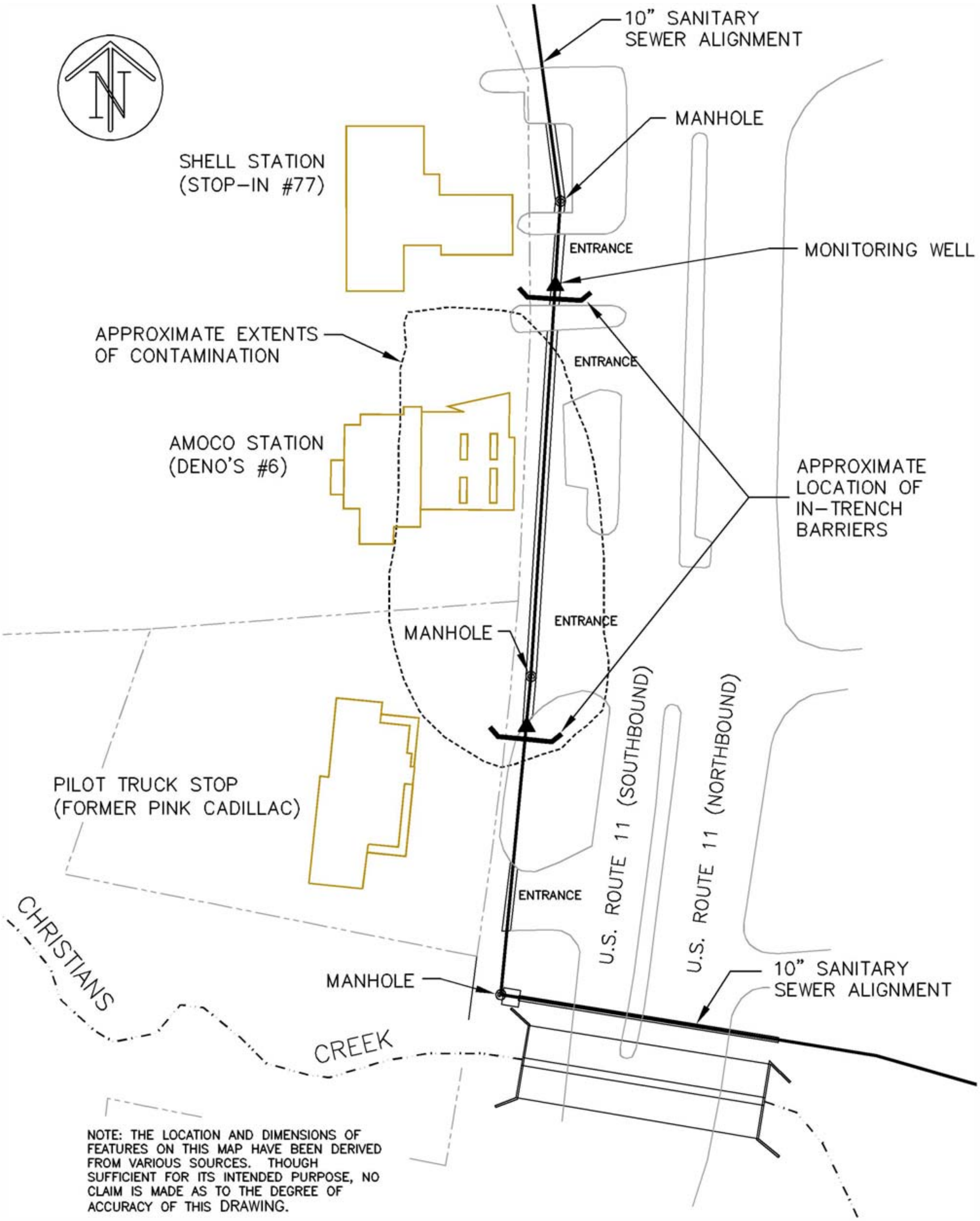

Figure 6-1. Rt. 11, Greenville Site Map (not to scale)

Site Visits and Informational Contacts

Four visits to the project site were conducted in June 2002. The site visits were conducted to observe construction methods and to meet with the involved parties, including the VDOT Hazardous Materials Manager for the Staunton District (Waller 2002), the environmental consultant, Geotechnical and Environmental Services, Inc., (Fansler 2002), and the contractor, M&W Construction (Saenz 2002). Informational contacts with the design engineer (Houston 2002) and the pipe supplier (Stone 2002) were made by phone and email.

Environmental Investigative History

In October 1999, a Phase II Environmental Site Assessment conducted for the former Pink Cadillac Restaurant site (presently the Pilot Truck Stop) revealed the presence of petroleum hydrocarbons in the soil and groundwater. VADEQ was notified of the release and subsequently determined, using this and information gathered at the Shell Station site, that Dixie Gas and Oil Corporation (owner of the Amoco Station) was the responsible party for the release. Subsequently, VADEQ required that a Release Investigation Report be prepared for the Amoco Station site. In June 2000, Geotechnical and Environmental Services, Inc. (GES) reported to VADEQ that petroleum contamination was encountered in the soils and groundwater on the project site. VADEQ then requested that a Site Characterization Report (SCR) be prepared for the project site (GES 2000). The SCR was prepared by GES in June 2000 at the request of Dixie Gas and Oil Corporation to comply with VADEQ's Underground Storage Tank regulations for petroleum releases. The SCR documented the characteristics of the project site including soil conditions, bedrock conditions, groundwater conditions and the extent and location of contamination. The report also discusses the installation and sampling of eight monitoring wells, with locations as shown on Figure 6-2. Another round of sampling was conducted in April 2002 for five of the monitoring wells (three were destroyed during the construction of the Pilot Truck Stop). Site characterization information discussed in this case study was taken from the original SCR prepared by GES. Other environmental investigative reports may have been prepared for the area, but none were obtained.

Groundwater Conditions

The SCR indicates that a shallow unconfined aquifer and a deeper confined aquifer are located below the project site. In the upper unconfined aquifer, groundwater was encountered at a depth ranging from 12.6 feet to 16.1 feet. Groundwater in the lower confined aquifer was measured at a depth of 39.3 and 43.4 feet, at monitoring wells MW-8 and MW-4, respectively. Static groundwater elevations were also determined for the unconfined aquifer to determine the direction of groundwater flow. An arbitrary benchmark elevation of 100 feet was placed on the southeast corner of the pump island concrete pad at the Amoco Station. Figure 6-2 shows the monitoring wells and groundwater elevations in relation to the benchmark elevation and apparent direction of flow in the upper unconfined aquifer. Hydraulic gradients between monitoring wells

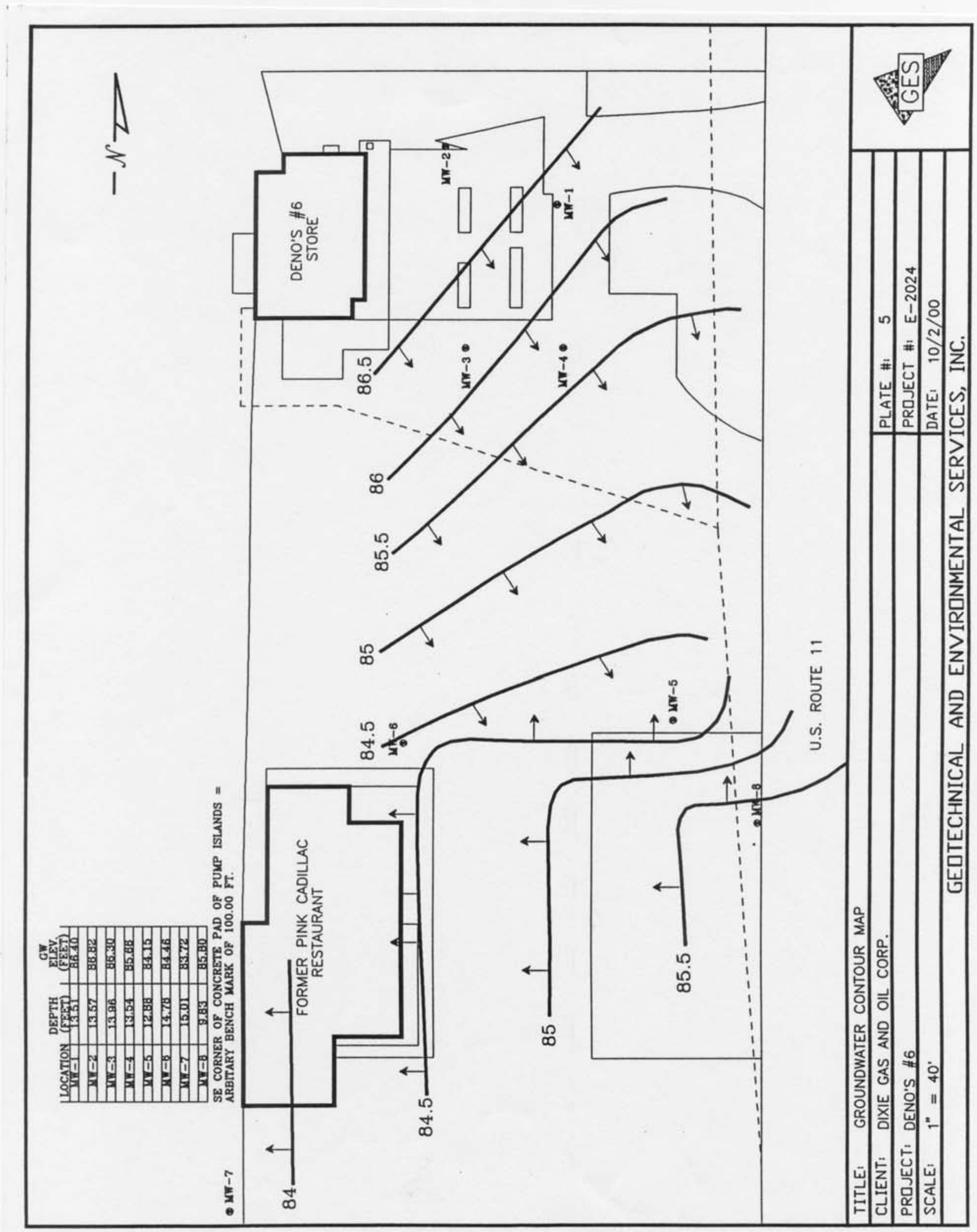

Figure 6-2. Monitoring Wells and Groundwater Elevations (Geotechnical and Environmental Services, Inc. 2000)

range from 0.027 to 0.044 ft/ft and as shown in the figure, groundwater in the unconfined aquifer moves in a southeast direction. Based on slug testing, the hydraulic conductivity of the upper unconfined aquifer was estimated to be 0.0125 ft/day, while the hydraulic conductivity of the lower confined aquifer was estimated to be 0.1872 ft/day. There are no known potable drinking wells in service within 0.25 miles of the project site. Potable water users in the area use the County of Augusta's water supply system.

Site Topography and Soils

According to the SCR, the Amoco Station site is located on a slight rise and is approximately 400 feet north of Christians Creek. The site slopes gently south and southeast toward Christians Creek. To understand the soil conditions at the site, borehole logs were recorded during the drilling of the eight monitoring wells. Natural residual soils found at the monitoring well locations were primarily orange-brown, low-plastic clay, which were formed from the weathering of the underlying limestone bedrock. Fill soils were encountered at MW-7 and MW-8, consisting of gray-brown, low plastic silt. Depth to bedrock varies from 3 feet at MW-4 to a depth of 19 feet at MW-5 and MW-8 and was not encountered at some borehole locations. The bedrock is described by the boring logs as light to dark gray, hard, with minor to highly weathered zones.

Contamination Characterization

During the investigations conducted for the SCR, soils and groundwater sampled from the monitoring wells were analyzed using EPA Test Method 8015 V for gasoline and 8021 to determine the extent of petroleum contamination. Headspace vapor measurements were also conducted using a photo ionization detector (PID). Testing results for soil contamination are summarized on Table 6-1. Testing results for dissolved phase groundwater contamination are summarized in Table 6-2. There was no free product observed at the monitoring wells during the original investigation. Testing results for the headspace vapor measurements are summarized on Table 6-3.

TABLE 6-1
Route 11, Greenville, Virginia - 10-inch Sanitary Sewer
Analytical Results for Soil Contamination
(Geotechnical and Environmental Services, Inc. 2000)

Sample Location	Depth (feet)	8015 V TPH (ppm)	Total BTEX (ppb)	MTBE (ppb)
MW-1	14.0-16.0	551.5	138,240	8,694
MW-2	14.0-16.0	885.4	149,050	3,433
MW-3	14.0-16.0	223.7	39,957	3,082
MW-5	14.0-16.0	2091.1	293,252	14,908
MW-6	4.0-5.5	BDL	BDL	BDL
MW-7	14.0-16.0	BDL	BDL	BDL
MW-8	8.0	BDL	BDL	BDL

BDL= below detection limit

TABLE 6-2 Route 11, Greenville, Virginia - 10-inch Sanitary Sewer Analytical Results for Groundwater Contamination (Geotechnical and Environmental Services, Inc. 2000)				
Sample Location	**Depth (feet)**	**8015 V TPH (ppm)**	**Total BTEX (ppb)**	**MTBE (ppb)**
MW-1	12.60	298.1	93,050	95,612
MW-2	14.60	225.7	58,081	48,330
MW-3	16.08	172.1	60,915	17,439
MW-4	43.40	0.7	180.9	237
MW-5	13.10	45.5	10,319	3,359
MW-6	15.30	BDL	BDL	45.6
MW-7	15.50	BDL	BDL	BDL
MW-8	38.50	BDL	BDL	BDL

BDL = Below detection limit.

TABLE 6-3 Route 11, Greenville, Virginia - 10-inch Sanitary Sewer Headspace Vapor Measurements (Geotechnical and Environmental Services, Inc. 2000)		
Sample Location	**Depth (feet)**	**Headspace Readings TPH (ppm)**
MW-1	4.0-6.0 9.0-11.0 14.0-16.0	97 492 1,205
MW-2	4.0-6.0 9.0-11.0 14.0-16.0	2,812 336 1,328
MW-3	4.0-6.0 9.0-11.0 14.0-16.0 19.0	18.9 1,136 936 516
MW-5	4.0-6.0 9.0-11.0 14.0-16.0	13 414 1,129
MW-6	4.0-5.5	0
MW-7	4.0-6.0 9.0-11.0 14.0-16.0	0 0 0
MW-8	8.0	0

For additional definition of the extent of contamination, concentration contours for Total Petroleum Hydrocarbon (TPH) in the soil are shown on Figure 6-3 and for TPH in the groundwater are shown on Figure 6-4.

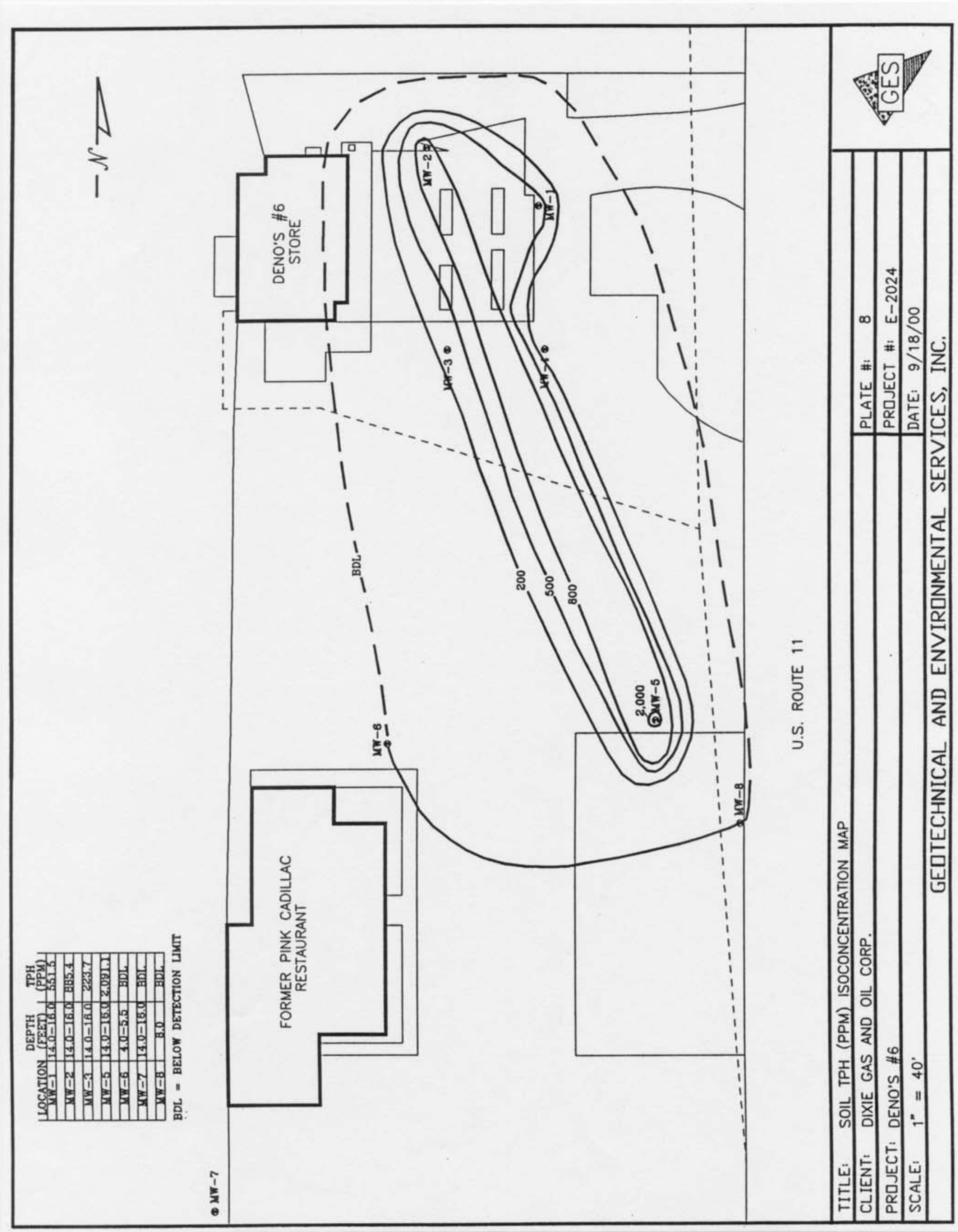

Figure 6-3. TPH Contours for Soil
(Geotechnical and Environmental Services, Inc. 2000)

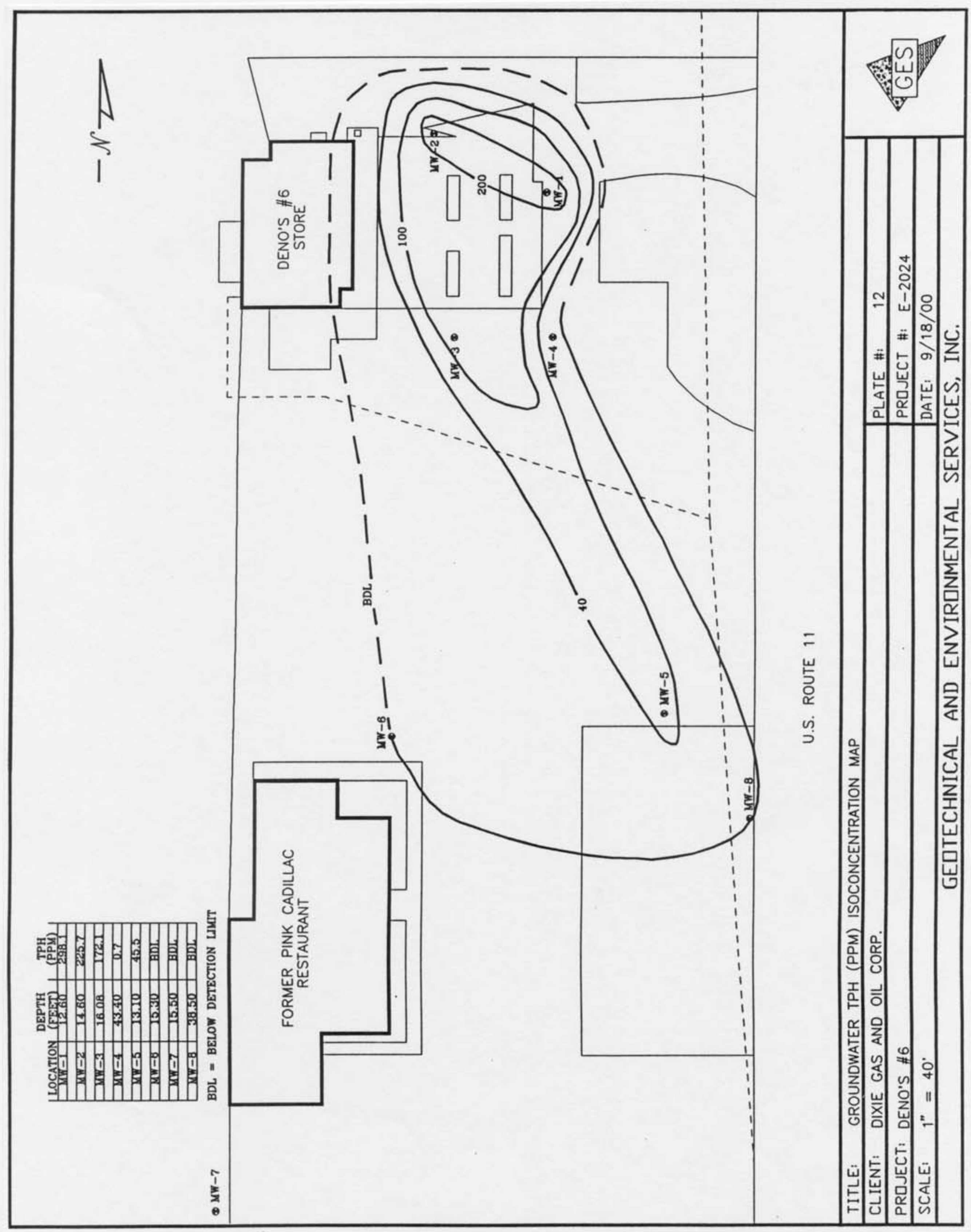

Figure 6-4. TPH Contours for Groundwater (Geotechnical and Environmental Services, Inc. 2000)

Design/Construction and Procedures to Mitigate Contaminant Migration

As shown on Figure 6-1, the sanitary sewer was installed through the contaminated area. In some areas, the sewer pipe was installed as low as 19 feet beneath the ground surface. A picture of the trench with a wall support box is shown on Figure 6-5. Consequently, based on measurements conducted by GES, the sewer pipe and corridor would be at or below the groundwater level in some areas. Prior to construction, VADEQ was concerned that migration of contaminants might occur along the pipe corridor into the tributary of Christians Creek. This is a viable concern because the pipe bedding, consisting of gravel, is much more permeable than the in-situ material, thus providing a potential migratory pathway for the contaminant into the stream. It should be noted that if the utility corridor did not intersect the stream, the stream would not be considered a potential receptor and the migration of contaminants would likely not be a large concern.

Working with the design engineer for the project, VADEQ recommended the installation of impervious barriers or plugs in the utility corridor to prevent the migration of contaminants. A detail of the specified barrier or clay dam is shown on Figure 6-6. This type of in-trench barrier was previously specified by the design engineer in areas where the U.S. Army Corps of Engineers is concerned about draining wetlands along a sewer alignment (Houston 2002). Two in-trench barriers were used on the project and their approximate locations are shown in plan view on Figure 6-1. As shown, each barrier is equipped with a monitoring well located just up gradient of the barrier. The purpose of the monitoring well is to sample the groundwater in front of the barrier and to extract free product if necessary. Upon construction of the barrier, instead of using clay or bentonite for the barriers, the contractor used a weak grout mixture, consisting of portland cement and sand (Saenz 2002). The exact quantities used in the mixture were not obtained. A picture showing one of the barriers prior to backfill of the trench is shown on Figure 6-7. See Section 4.4 for more information about in-trench barriers.

Of additional concern was the chemical resistance of the pipe materials and gaskets to the in-situ contaminants. The concern is that the contaminants may degrade the gaskets or pipe materials, thus causing exfiltration of sewage and requiring the replacement of the sewer pipe. Considering the depth of the sewer pipe and other difficulties encountered during installation, extending the service life of the sewer was in the best interest of the Service Authority. As a result, acrylonitrile-butadiene rubber gaskets (NBR) and polyvinyl chloride plastic (PVC) pipe (SDR 35) were specified for the project (Stone 2002). Both of these materials provide excellent chemical resistance to oil and gasoline. See Section 5 for more information about pipe materials and gaskets.

Because of high headspace vapor measurements in the monitoring wells, there was also concern for the exposure of workers and the potential for combustion. During a site visit, gasoline vapor was easily detectible by smell from a significant distance from the open trench. Consequently, a vapor extraction fan was utilized to remove vapor from the trench as contaminated soil and groundwater were encountered (Fansler 2002). A picture of the vapor extraction fan used on the project is shown on Figure 6-8.

Figure 6-5. Open Trench with Safety Box and Monitoring Well

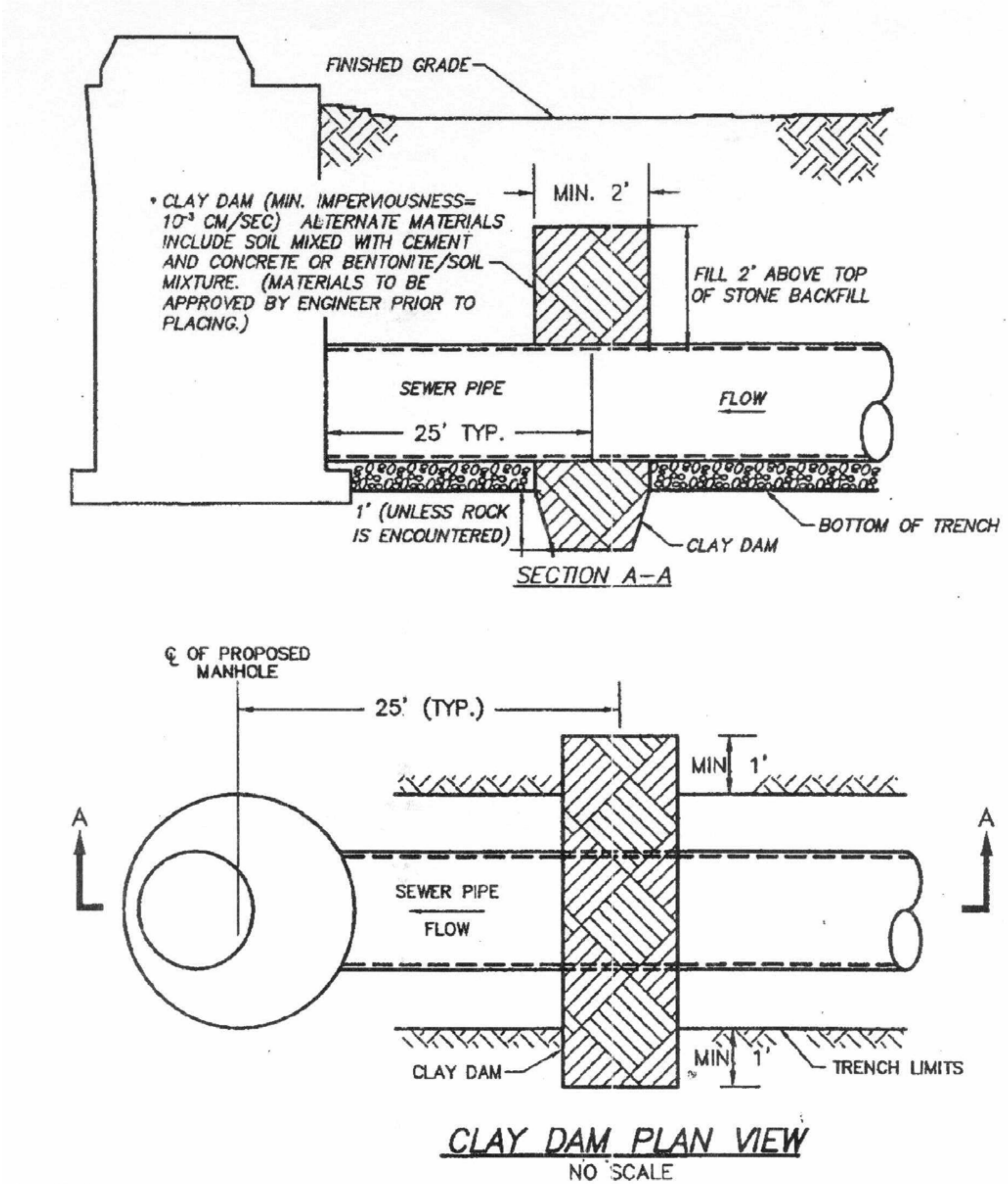

Figure 6-6. Design Details for In-Trench Barrier (Houston 2002)

Figure 6-7. In-Trench Barrier (Saenz 2002)

Figure 6-8. Vapor Extraction Fan

Concluding Remarks

Excavated soil was analyzed as necessary during installation of the sanitary sewer pipe. No impacted soil or groundwater was required to be removed or remediated during the project. The monitoring wells installed up gradient of the in-trench barriers will be used to observe the integrity of the groundwater that may collect in front of the barriers.

6.2 Abingdon, Virginia: 72-inch Storm Sewer

The scope of work for this project consists of the installation of a 72-inch concrete storm sewer pipe on the C.R. Quesenberry, Inc. Property on Deadmore Street in Abingdon, Virginia. Installation of the storm sewer pipe, which eventually empties into Town Creek, was part of a road and bridge construction project on the east end of Abingdon. Abingdon is located in the Shenandoah Valley area of Virginia. Roberts classifies the area around Abingdon as being within the Valley and Ridge province and more specifically in the Great Valley subprovince, which is characterized as a broad valley underlain with carbonate rocks with low to moderate slopes and elevations ranging from 1200 to 2300 feet (2002). Figure 6-9 shows the location of the storm sewer alignment in the vicinity of the C.R. Quesenberry, Inc. Property. The alignment of the storm sewer crosses the southern portion of the property, parallels the NS Railroad line, and ranges in depth from ten to twelve feet. Investigative studies conducted by Marshall Miller & Associates (MM&A) revealed the presence of petroleum contaminated soil and groundwater on the C.R. Quesenberry property. Because of the petroleum contamination, VDOT was concerned that installation of the storm sewer pipe might spread the contamination during construction activities or by migration of contaminants along the trench corridor or along the inside of the pipe after installation. To mitigate the potential migration of contaminants, engineering controls were implemented including coating the exterior of 300 feet of pipe with petroleum resistant paint, installation of two anti-seep collars on either side of the designated contamination, and installation of flowable fill around the bottom portion of the pipe. Pipe installation within the contaminated area began on July 11, 2000 and finished on July 20, 2000 (Davis 2002B)

Site Visits and Informational Contacts

All informational contacts were developed by phone and email. The Assistant Hazardous Materials Manager for the Bristol District was the major source of information and was instrumental in gathering information from other minor sources (Davis 2002A). This project was completed well before the initiation of this investigative case study. Therefore, visits to the project site were not considered to be beneficial to the study and were not conducted.

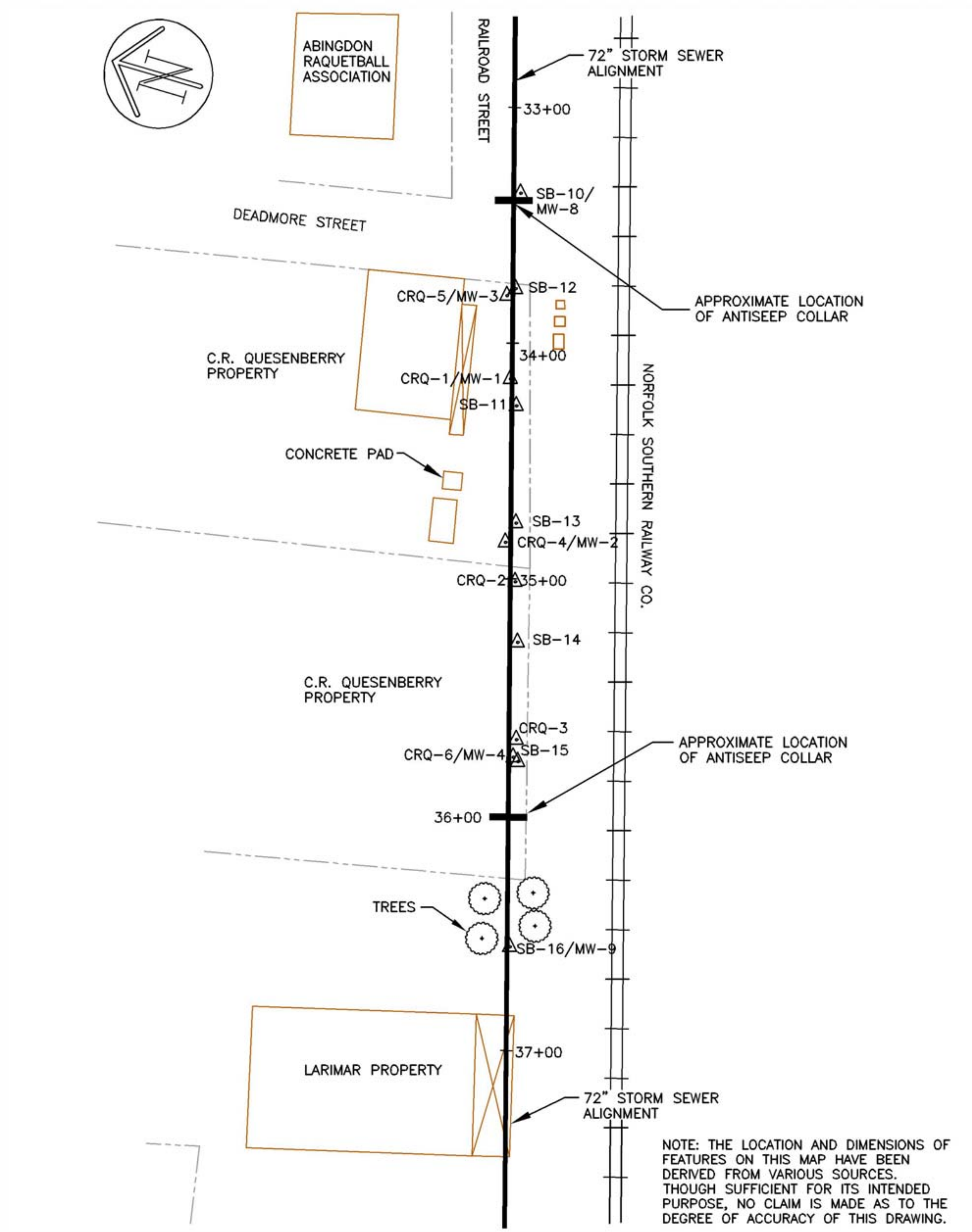

Figure 6-9. Site Map (not to scale)

Environmental Investigative History

A limited subsurface investigation was prepared for VDOT and submitted by MM&A in June 1998 (MM&A 1998). During this investigation, six soil borings were installed, of which four of the boreholes were maintained as monitoring wells. Figure 6-9 shows the locations of the borings, labeled as CRQ-1 through CRQ-6, and the locations of the monitoring wells, labeled as MW-1 through MW-4. During this study, ten soil samples and four groundwater samples were submitted for analysis. Slug tests were performed on MW-1, MW-2 and MW-3. Soil and groundwater were analyzed for concentrations of TPH-Gasoline Range Organics (TPH-GRO), TPH-Diesel Range Organics (TPH-DRO), Benzene, Toulene, Ethylbenzene, and Total Xylenes. Vapor phase readings, determined using a PID, were also measured for each borehole.

To further characterize the site, another investigative report was prepared and submitted by MM&A in June 1999 entitled "C.R. Quesenberry Special Provision Detail, Deadmore Street, Abingdon, Virginia" (MM&A 1999A). For this report, seven additional soil borings were installed (SB-10 through SB-16) and both of the boreholes were converted to permanent monitoring wells (MW-8 and MW-9). Locations of the boreholes and monitoring wells are shown on Figure 6-9. Lithologic descriptions were prepared using split spoon samples from the additional boreholes. Soil and groundwater at MW-8/SB-10 and MW-9/SB-16 were analyzed for TPH-GRO, TPH-DRO, Benzene, Toulene, Ethylbenzene, Total Xylenes, and Polynuclear Aromatic Hydrocarbons (PAH). Slug tests were performed using the two additional monitoring wells.

Additional sampling and testing was performed by MM&A and submitted in January 2000 in a report entitled "Ground Water Assessment Report C.R. Quesenberry Bulk Plant" (MM&A 2000). Each of the monitoring wells were sampled on several dates and tested for TPH-GRO, TPH-DRO, Benzene, Toulene, Ethylbenzene, Total Xylenes, and PAH.

Groundwater Conditions

Depth to groundwater was recorded on April 30, 1998 by MM&A to be 1.89 feet at MW-1, 2.65 feet at MW-2, 2.71 feet at MW-3, and 14.25 feet at MW-4 (MM&A 1998). Corresponding groundwater elevations were 2048.96, 2048.09, 2048.49 and 2037.55 feet, respectively (MM&A 1998). Based on these measurements, the storm sewer pipe would be installed well below groundwater levels in some places. Slug tests were performed for MW-1, MW-2 and MW-3, yielding hydraulic conductivity values of 0.235, 0.021 and 0.071 feet/day, respectively (MM&A 1998). Later slug testing revealed hydraulic conductivity values for MW-8 and MW-9 of 3.397 feet/day and 0.235 feet/day (MM&A 1999A). MM&A noted in their report that the value calculated at MW-8 appears to be abnormally high. Based on these groundwater measurements, direction of groundwater flow appears to be from northwest to southeast, almost perpendicular to the storm sewer alignment. Using a value for hydraulic conductivity of 0.109 feet/day, MM&A estimates that after the initial water is removed, that 1,200 to 2,450 gallons could enter the trench daily if the entire length of the trench in the impacted area (210 feet) were open (MM&A 1999A).

Geotechnical and Soils

The subsurface investigations performed by MM&A in February 1999 revealed depths to bedrock (auger refusal) ranging from 19.5 feet at SB-12 to 37.0 feet at SB-16 (MM&A 1999A). Although samples were not taken, the type of bedrock encountered is assumed by MM&W to be limestone. The investigations revealed soils that were 80 to 98% clay with some sand and gravel. An average permeability was determined to be 1 x 10^{-7} cm/sec, which is within the range of soils considered to have low permeability. Tests also revealed that the in-situ soils are capable of 95% standard proctor compaction at an optimum moisture of plus 2%, which indicates that the soils are suitable for backfill around the pipe (MM&A 1999A).

Contamination Characterization

In general, the extent of contamination was identified to exist approximately between the stations 33+50 and 36+00 along the storm sewer alignment (MM&A 1999A). Station numbers are shown on Figure 6-9. Soil samples were tested for contaminants and the results are summarized on Table 6-4. Ground water was also tested and the results are summarized on Table 6-5. As shown, contaminants were not found at SB-10/MW-8 and SB-16/MW-9, thus defining the limits of contamination along the storm sewer alignment. Additional groundwater sampling results are presented in the report by MM&A, submitted in January 2000 and entitled “Ground Water Assessment Report C.R. Quesenberry Bulk Plant,” but are not reproduced here.

TABLE 6-4
Abingdon, Virginia – 72-inch Storm Sewer
Analytical Results for Soil Contamination (mg/kg)

Sample Location	Depth (feet)	TPH GRO	TPH DRO	B	T	E	X	PID (ppm)	PAH
Sampled February 24 and 26, 1998 and April 29, 1998 (MM&A 1998)									
CRQ-1	3.0-5.0	16	BDL	---	---	---	---	367	---
	7.0-9.0	BDL	BDL	---	---	---	---	253	---
	10.0-12.0	310	100	0.037	0.10	0.18	0.42	483	---
CRQ-2	10.0-12.0	BDL	BDL	---	---	---	---	0	---
CRQ-3	5.0-7.0	BDL	BDL	---	---	---	---	0	---
CRQ-4	3.0-5.0	1.3	BDL	---	---	---	---	248	---
	10.0-12.0	16	22	---	---	---	---	63	---
CRQ-5	10.0-12.0	BDL	BDL	---	---	---	---	0	---
CRQ-6	10.0-12.0	BDL	130	---	---	---	---	12	---
	15.0-17.0	0.72	58	---	---	---	---	0	---
Sampled February 8 and 9, 1999 (MM&A 1999A)									
SB-10	10.0-12.0	BDL	BDL	BDL				---	BDL
SB-16	15.0-17.0	BDL	BDL	BDL				---	BDL

--- - Not analyzed
BDL - below detection limit
TPH -Total Petroleum Hydrocarbons
PAH - Polynuclear Aromatic Hydrocarbons
BTEX - Benzene, Toluene, Ethylbenzene, Total Xylenes
DRO - Diesel Range Organics
GRO - Gasoline Range Organics
PID - Photoionization Detector

TABLE 6-5
Abingdon, Virginia – 72-inch Storm Sewer
Analytical Results for Groundwater Contamination (mg/L)

<table>
<tr><th>Sample Location</th><th>TPH GRO</th><th>TPH DRO</th><th>B</th><th>T</th><th>E</th><th>X</th><th>PAH</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Sampled March 3, 1998 (MM&A 1998)</td></tr>
<tr><td>CRQ-1/MW-1</td><td>7.2</td><td>10.8</td><td>0.16</td><td>0.016</td><td>0.15</td><td>0.038</td><td>0.364</td></tr>
<tr><td>CRQ-4/MW-2</td><td>58</td><td>83</td><td>7.5</td><td>0.16</td><td>1.6</td><td>3.5</td><td>12.76</td></tr>
<tr><td>CRQ-5/MW-3</td><td>22</td><td>22.63</td><td>BDL</td><td>0.002</td><td>0.010</td><td>0.053</td><td>0.065</td></tr>
<tr><td>CRQ-6/MW-4</td><td>BDL</td><td>0.50</td><td>0.031</td><td>0.029</td><td>0.013</td><td>0.063</td><td>0.136</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Sampled February 15, 1999 (MM&A 1999A)</td></tr>
<tr><td>SB-10/MW-8</td><td>BDL</td><td>BDL</td><td colspan="4">BDL</td><td>BDL</td></tr>
<tr><td>SB-16/MW-9</td><td>BDL</td><td>BDL</td><td colspan="4">BDL</td><td>BDL</td></tr>
</table>

--- - Not analyzed
BDL - below detection limit
TPH -Total Petroleum Hydrocarbons
PAH - Polynuclear Aromatic Hydrocarbons
BTEX - Benzene, Toluene, Ethylbenzene, Total Xylenes
DRO - Diesel Range Organics
GRO - Gasoline Range Organics
PID - Photoionization Detector

Design/Construction and Procedures to Mitigate Contaminant Migration

As shown on Figure 6-9, the storm sewer was installed through the contaminated area. Residual contamination of the soil was identified from approximately station 34+00 to 34+90 along the sewer alignment. In these areas, it was estimated that the contractor would be required to remove approximately 150 tons of petroleum contaminated soils and either clean or dispose of the material. Also, the contractor was advised that special handling of groundwater may be necessary from station 33+50 to 35+60. The contractor was required to prevent the release of contaminated water through the use of engineering controls, like underflow dams, absorbent booms, absorbent pads, and pneumatic bladders (Davis 2002A). Special provisions for site remediation of contaminated soil and groundwater are reproduced in part as Figure 6-10. A photograph of an underflow dam used to contain impacted groundwater is shown on Figure 6-11.

Figure 6-10
VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
SITE REMEDIATION OF CONTAMINATED SOIL
(DAVIS 2002A)

I. DESCRIPTION

This work shall consist of the removal and disposal of petroleum contaminated soil at locations shown on the plans or listed herein in accordance with applicable federal, state, and local regulations and the provisions herein. The work shall be performed in preparation to the installation of a 72" drainpipe across the Quesenberry property, Parcel No. 032. Work shall be performed by a licensed environmental contractor capable of performing the work, complying with all applicable regulations, and holding all necessary licenses and certifications for both removal and disposal of petroleum contaminated soil and water.

II. PROCEDURES FOR CONTAMINATED SOILS

The Contractor is advised that residual contamination of soil exist from approximately Sta. 34+00 to Sta. 34+90. Based upon soil boring available to the Department, it is anticipated residual contamination levels encountered during trenching operations will range from >50 mg/kg TPH to 410 mg/kg. It is estimated approximately 150 tons of petroleum contaminated soil will exceed clean fill standards and will have to be properly managed. The contaminated soil ranges from approximately elevation 2042 to elevation 2045 for the uppermost portion of impact. Elevated vapor readings measured with a photoionization detector (PID) exceed 100 ppm in the soil from Sta. 34+00 to 35+00. The Contractor shall provide a qualified professional to screen soils during trench excavation and direct segregation of the clean and contaminated material. The Contractor shall make a reasonable effort to separate contaminated soils from clean soil during the excavation process. The excavated soil shall be placed on polyethylene sheeting of no less than 6-mil thick ness and the stockpiled soil are shall be bermed with baled straw to prevent migration of the soils. The stockpile shall be covered with polyethylene sheeting of no less than 6-mil thickness. The cover sheeting shall extend to the outside of the berm and be installed and secured in such a manner as to prevent ponding from precipitation of damage from winds.

The Contractor shall provide proper characterization of the soil stockpile, which shall include laboratory analyses for TPH and BTEX at a frequency of one composite sample per 100 cubic yards of material. The Contractor shall dispose of all soils exceeding the Virginia Department of Environmental Quality Solid Waste Division's Special Waste criteria for clean fill.

III. PROCEDURES FOR CONTAMINATED GROUNDWATER

The Contractor is advised that the Department anticipates the encountering of contaminated groundwater during trench excavation from approximately Sta. 33+50 to 35+60. To minimize the volume of contaminated water requiring disposal the Contractor shall endeavor to perform excavation activities during periods of dry weather. The Contractor is also encourages to excavate small pits in advancement of pipe installation and placement activities so that water will migrate to these areas in order that installation will occur as much as possible "in the dry". As the piping trench approaches Deadmore Street from the west, contaminated water in the pit will have to be pumped from the excavation, containerized, tested, and transported offsite for disposal. Water that contains more than 1 ppm TPH or BTEX will considered as contaminated and subject to disposal offsite. The Department estimates total contaminated water in the trench, which may require disposal, to be approximately 39,475 gallons.

The Contractor shall install engineering controls to prevent the release of contaminated water through the drainpipe into surface waters during installation procedures. Engineering controls shall be approved by the district Environmental Quality Division prior to use, and may include such items as underflow dams, absorbent pads, and pneumatic bladders.

The Contractor shall obtain all necessary permits and inspections as required by local, state, and federal laws, rules and regulations.

Figure 6-11. Underflow Dam at final End Section (Davis 2002A)

Permanent engineering controls designed to prevent and mitigate the transport of contaminants along the trench corridor were also implemented. These include the following (Davis 2002B):

- The exterior of 300 linear feet of the 72-inch concrete pipe was double-coated with petroleum resistant paint called CONSEAL CS-90. The joints of the pipe were sealed with a compound called CONSEAL CS-440. (See Section 5 for more discussion about coatings and joint sealants).

- Concrete anti-seep collars were installed on each side of the contaminated Quesenberry property. (See Section 4.4 for more discussion about anti-seep collars).

- Flowable backfill was installed from station 33+75 to 36+00 along bottom portion of the pipe from the bedding to the center of the pipe. (See Section 4.4 for additional discussion about flowable backfill).

Specifications for the project outlining the permanent engineering controls and stating the requirements for the installation of the 72-inch pipe are reproduced in part on Figure 6-12. Special provisions discussing the requirements for flowable fill used on the project are reproduced in part on Figure 6-13. A detail of the anti-seep collar used on the project is shown on Figure 6-14. Photographs showing the installation of flowable fill are shown on Figure 6-15 and a photograph showing the installation of the pre-cast anti-seep collars are shown on Figure 6-16.

Figure 6-12
VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIFICATIONS FOR
INSTALLATION OF 72" DRAIN (QUESENBERRY PROPERTY)
(DAVIS 2002)

The Contractor shall install the 72" drainage pipe within the limits of this property (Parcel NO. 032) in accordance with Section 302 of the Specifications, plan details and the following conditions:

The Contractor shall endeavor to minimize the size of the trench from Sta. 33+50 to Sta. 36+50.

The manufacturer of the pipe shall double coat the exterior of the pipe with a petroleum resistant mastic/paint from Sta. 33+00 to Sta. 36+00.

Pipe joints shall be sealed with petroleum resistant mastic from Sta. 33+00 to Sta. 36+00.

After the pipe has been bedded and set to line and grade, flowable fill shall be placed in the trench around the pipe and to a depth of three (3) feet. Flowable fill shall be used from Sta. 33+75 to Sta. 36+00. Flowable fill shall conform to the requirements listed in the VDOT Special Provision for Flowable Fill dated July 17, 1998c and include at a minimum be 150 kg/m^3 Class F fly ash conforming to ASTM C618 and a minimum 25 kg/m^3 of hydraulic cement. Air-entraining admixtures will not be permitted. After proper curing of the flowable fill, "clean" fill shall be used to backfill the remaining trench and compacted to finished grade.

Two seep collars shall be installed at Sta. 35+35 and Sta. 36+00. Design of seep collars is attached. Precast seep collars area available from the manufacturer of the Contractor may cast-in-place the design at his option.

The cost for installation measures outlined herein shall not be measured separately but shall be included in the price bid for the 72" pipe.

Figure 6-13
VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISIONS FOR
302E - FLOWABLE BACKFILL
(DAVIS 2002A)

DESCRIPTION

This work shall consist of furnishing and placing flowable backfill in lieu of compacted soil or aggregate backfill in pipe installations or at other locations designated on the plans and as backfill material for plugging designated abandoned pipe and box culverts.

I. MATERIALS

Hydraulic Cement shall conform to the requirements of Section 214 of the Specifications.
Fly Ash shall have no specific requirement for fineness, loss of ignition, or reactivity.
Water shall conform to the requirements of Section 216 of the Specifications
Aggregates shall conform to the requirements of Sections 202 and 203 of the Specifications with a combined gradation as determined by the Contractor.
Admixtures shall conform to the requirements of Section 215 of the Specifications.
Granulated Iron Blast Furnace Slag shall conform to the requirements of Section 215 of the Specifications.

II. MIX DESIGN

Mix design for flowable backfill shall be provided by the Contractor. Flowable backfill shall have a design compressive strength of 30 to 200 psi at 28 days when tested in accordance with AASHTO T-23. Mix design shall result in a fluid product having no less than an 8 inch slump at time of placement. The Contractor shall submit a mix design for approval supported by laboratory test data verifying compliance with 28 days compressive strength requirements. Mix design shall be approved by the Engineer prior to placement.

III. PROCEDURES

Mixing and transporting shall be in accordance with Section 217 of the Specifications or by other methods approved by the Engineer.

Temperature of flowable backfill shall be at least 50 degrees Fahrenheit at time of placement. Material shall be protected from freezing for 24 hours after placement.

When used as backfill for pipe and floatation or misalignment occurs, correct alignment of the pipe culvert shall be assured by means of straps, soil anchors or other approved means of restraint.

When used to fill the voids in abandoned pipes and box culverts, they shall be plugged and backfilled in accordance with the plan details or as directed by the Engineer. The plugs shall be in accordance with the plan details. The backfill material shall be flowable backfill or fine aggregate placed into the abandoned pipe culvert or box culvert without voids. The opening for culvert backfill installation shall be sealed with masonry or Class A-3 concrete at completion of backfilling.

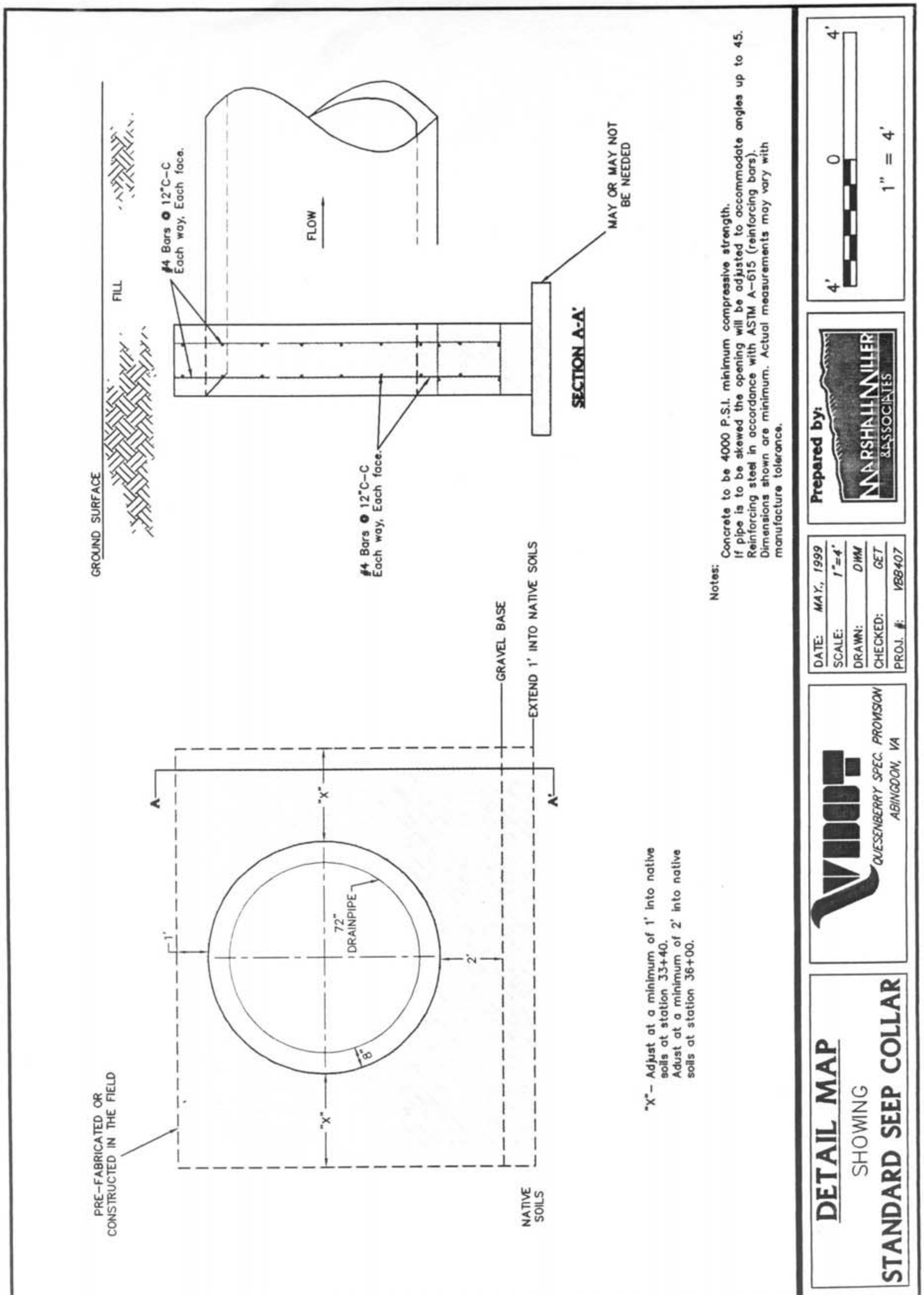

Figure 6-15. Anti-seep Collar Detail (MM&A 1999A)

Figure 6-15. Pre-cast Anti-seep Collars (Davis 2002A)

Figure 6-16. Flowable Backfill installed around bottom portion of pipe (Davis 2002A).

Concluding Remarks

During the installation of the storm drain through the contaminated area, approximately 714 tons of impacted soil were removed, staged and tested (Davis 2002B). Contaminated soil was remediated by way of incineration. Also, approximately 740 gallons of contaminated groundwater was removed, tested, and properly disposed (Davis 2002B). No known contaminants were known to migrate into Town Creek as a consequence of this construction project (Davis 2002B). Thus, the permanent and temporary engineering controls used to prevent contaminant migration have been effective and from an environmental perspective, VDOT has considered this project a success.

6.3 North Main Street, Suffolk, Virginia – Various Utilities

The scope of work for this project consists of widening the pavement section for the North Main Street in downtown Suffolk, Virginia. This project is located in the Coastal Plain portion of Virginia, characterized by a somewhat flat landscape ranging in elevation from 0 to 60 feet-msl (Roberts 2002). The portion of the road requiring widening is located just north of its crossing of the Nansemond River. The scope of work also included relocation or replacement of existing utilities along the right-of-way of the widened road (Sarros 2002), which are shown in relation to the road alignment on Figure 6-17. Major utilities on the east side of the road include a sanitary sewer force main, a water force main, and a storm sewer (Gaskins 2002). Major utilities on the west side of the road include a gravity sanitary sewer and a storm sewer (Gaskins 2002). Other utilities including power, natural gas and cable were present in the area, but will not be discussed in this case study. During investigative studies, high levels of petroleum contamination were discovered in the right of way of the road-widening project. During the road widening project, much of the soil and groundwater in the area of contamination was removed and either treated or properly disposed. Also, to avoid the high level of contamination on the west side of the road, the gravity sanitary sewer and associated manholes were rehabilitated using slip-lining techniques.

Site Visits and Informational Contacts

A site visit to the VADEQ office in Virginia Beach, Virginia was conducted to gather information regarding the history and extent of contamination in the vicinity of the project. A meeting was also held with the VDOT HazMat Manager for the Hampton Roads District to gather additional information (Sarros 2002). While the work had already been completed by the time of the meetings, a visit was also conducted to the project site and the area of contamination to assess site characteristics.

Environmental Investigative History

In preparation for the road widening project, a limited subsurface investigation was conducted in the Fall of 1999 by MM&A (MM&A 1999B). The investigation revealed that substantial petroleum contamination was present in the right-of-way on both sides of the proposed widened road section. However, this discovery was not a surprise, as VADEQ has several documented cases of petroleum spills and contamination along North Main Street, dating back to 1989. In the past, the area along North Main Street was occupied by several bulk petroleum storage and loading facilities. The project site and surrounding area has a long history of other commercial activity as well, including agricultural warehousing and processing, lime/fertilizer manufacturing, oyster processing, automobile repair and automobile storing (New Millennium Environmental, Inc. 2001). Presently, this area is occupied by a mixture of gas stations, restaurants and other small businesses. Multiple sources of contamination have been identified with two sources being the major contributors. Former Kimberly Supreme Gas Station and the former Supreme Bulk Plant is believed by VADEQ to be one of the sources responsible for gasoline contamination in the right-of-way (Sarros 2002). An auto repair shop called Dr. Beeper's is currently located on this site owned by Supreme Petroleum. Another documented release of petroleum occurred from a Texaco Gas Station owned by Suffolk Oil during the flooding cause by Hurricane Floyd in September 1999. Thus, VADEQ believes that Suffolk Oil is the other major source responsible for the petroleum contamination in the right-of-way.

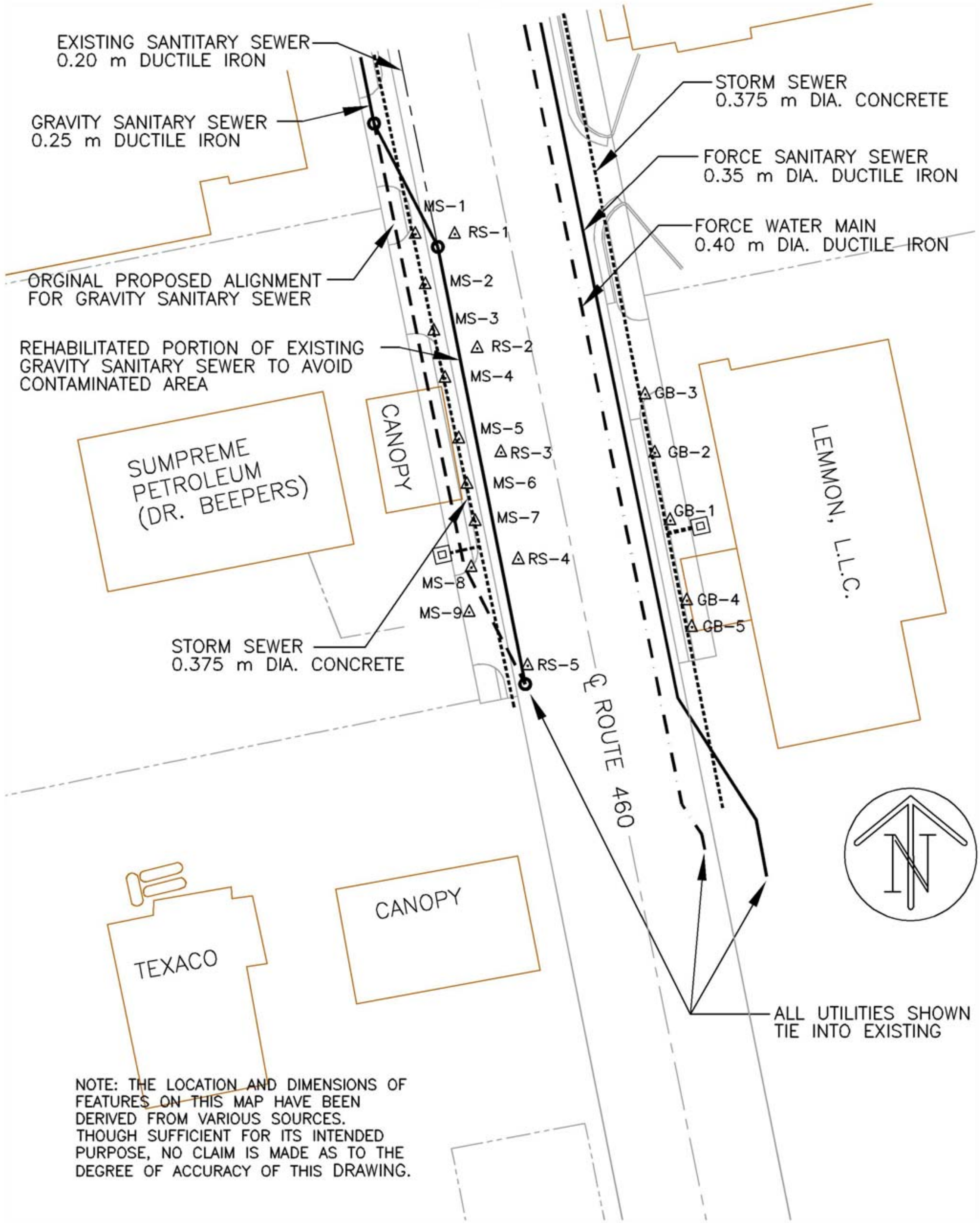

Figure 6-17. Site Map (not to scale)

The subsurface investigation conducted by MM&A in 1999 was limited to the first 50 to 60 meters of the road-widening project (MM&A 1999B). The investigation included 19 borings that are shown in plan view on Figure 6-17. Borehole locations were separated into three categories; boreholes located in the roadway (RS), boreholes located east of Main Street (GB), and boreholes located west of Main Street (MS). All boreholes were screened using an Organic Vapor Analyzer (OVA). Soil samples collected from the west and east side of Main Street were analyzed for TPH-DRO and TPH-GRO. Samples taken from the roadway were subjected to the OVA screening analysis but were not submitted to the laboratory for further analysis. Groundwater samples were collected from four borings (MS-7, GB-1, RS-3 and RS-4) and were analyzed for benzene, toluene, ethylbenzene and xylene, TPH-GRO, and TPH-DRO.

An Environmental Site Assessment of the former Kimberly Supreme Gas Station and the former Supreme Bulk Plant was prepared in 2001 by New Millennium Environmental, Inc. at the request of Suffolk Oil Company (New Millennium Environmental, Inc. 2001). This investigation included the installation of boreholes and monitoring wells and the sampling and testing of soil and groundwater for petroleum hydrocarbons. While this information is useful for characterization of the Supreme Petroleum property, it will not be presented in this case study. Other environmental investigative reports may have been prepared for the area, but no other reports were obtained.

Groundwater and Soils

The limited subsurface investigation performed by MM&A revealed that groundwater was found at all 19 borehole locations. The depth to groundwater ranged from 0.7 to 1.3 feet. Sampling indicated that soils in the right-of-way of the road widening project consist of black/dark gray to brown sandy clay (MM&A 1999B). Direction of groundwater flow and the hydraulic conductivity of the soils were not determined.

Contamination Characterization

During the field OVA screening, maximum concentrations of >10,000 ppm were measured in 10 samples. Field screening results are shown on Table 6-6. TPH-DRO concentrations measured in the collected soil samples ranged from below the detection limit to 1970.3 mg/l and TPH-GRO concentrations in the soils ranged from below the detection limit to 4895.0 mg/l. Table 6-7 and 6-8 show the analytical results for soil contamination. TPH-DRO concentrations measured in the groundwater samples ranged from 2.3 to 37.6 mg/l and TPH-GRO in the groundwater ranged from 1.8 to 136.4 mg/l. Benzene was found to be present in the water samples ranging from 0.043 to 15.882 mg/l. Toulene was measured in the water samples and ranges from 0.025 to 13.654 mg/l. Ethylbenzene was detected at levels ranging from 0.046 to 4.384 mg/l and xylene was measured at concentrations from 0.043 to 14.522 mg/l. Analytical results for groundwater contamination are shown on Table 6-9. Based on their investigation, MM&A concluded that special handling and/or disposal of petroleum affected soils and groundwater will be necessary if excavated during road construction (MM&A 1999B).

TABLE 6-6
North Main Street, Suffolk, VA
Field Screening Results for Route 460 Roadway
(MM&A 1999B)

Borehole ID	Sample Depth (feet)	OVA (ppm)
RS-1	1-4	900
RS-1	4-8	1,500
RS-2	1-4	900
RS-2	4-8	1,400
RS-3	1-4	900
RS-4	4-8	2,000
RS-4	1-4	700
RS-5	4-8	700
RS-5	1-4	500
RS-5	4-8	500

TABLE 6-7
North Main Street, Suffolk, VA
Analytical Results for Soil Contamination - East Side of Route 460
(MM&A 1999B)

Borehole ID	Sample Depth (feet)	TPH-DRO (mg/L)	TPH-GRO (mg/L)	PID (ppm)
GB-1	0.5-4.5	1092.2	448.0	3,500
GB-1	4.5-6	131.7	4.5	1,750
GB-2	0.5-2.5	100.7	BDL	1,250
GB-2	4.5-8.5	34.4	BDL	700
GB-3	0.5-4.5	164.7	7.7	1,500
GB-3	4.5-8.5	14.5	BDL	2,500
GB-4	0.5-4	136.7	70.6	600
GB-4	4-8	267.6	64.7	300
GB-5	0.5-4	1726.7	515.6	>10,000
GB-5	5-8	169.9	34.4	1,750

BDL-below detection limit.

TABLE 6-8 North Main Street, Suffolk, VA Analytical Results for Soil Contamination - West Side of Route 460 (MM&A 1999B)				
Borehole ID	**Sample Depth (feet)**	**TPH-DRO (mg/L)**	**TPH-GRO (mg/L)**	**PID (ppm)**
MS-1	0.5-4.5	BDL	BDL	500
MS-1	4.5-8.5	25.1	BDL	1,500
MS-2	0.5-2.5	186.0	280.6	>10,000 (.5'-2.5') 1,250 (2.5'-4.5')
MS-2	4.5-8.5	41.5	12.8	1,500 (4.5'-6.5') 1,500 (6.5'-8.5')
MS-3	0.5-4.5	1970.3	4895.0	>10,000
MS-3	4.5-8.5	27.0	19.5	8,000 (4.5'-6.5') 2,000 (6.5'-8.5')
MS-4	0.5-4.5	1495.6	1505.1	>10,000
MS-4	4.5-6.5	13.8	8.4	6,000 (4.5'-6.5') 3,500 (6.5'-8.5')
MS-5	0.5-4.5	1510.7	2887.7	>10,000
MS-5	4.5-8.5	89.5	0.5	3,000 (4.5'-6.5') 1,750 (6.5'-8.5')
MS-6	0.5-4.5	369.6	232.7	>10,000
MS-6	4.5-8.5	44.1	27.8	1,500
MS-7	0.5-4.5	433.7	528.6	>10,000
MS-7	4.5-8.5	184.6	79.1	1,500
MS-8	0.5-4.5	115.7	1120.2	>10,000
MS-8	4.5-8.5	101.4	8.1	4,000
MS-9	0.5-4.5	1038.6	2100.8	>10,000
MS-9	4.5-8.5	620.9	450.0	>10,000

BDL-below detection limit.

TABLE 6-9 North Main Street, Suffolk, VA Analytical Results for Groundwater Contamination (MM&A 1999B)							
Borehole ID	**Depth to Water (feet)**	**TPH-DRO (mg/L)**	**TPH-GRO (mg/L)**	**Benzene (mg/L)**	**Toulene (mg/L)**	**Ethyl Benzene (mg/L)**	**Xylenes (mg/L)**
MS-7	1.3	37.6	133.8	15.882	13.654	4.384	14.522
GB-1	0.7	31.7	1.9	0.043	0.030	0.046	0.043
RS-3	0.9	---	136.4	12.177	1.030	3.038	7.860
RS-4	1.0	2.3	1.8	0.068	0.025	0.074	0.056

---Not analyzed.

Design/Construction and Procedures to Mitigate Contaminant Migration

As a consequence of the subsurface investigation, during the installation, relocation and/or replacement of utilities, VDOT's contractor was required to remove contaminated soil and groundwater and properly dispose or treat before discharge or reuse. On the east side of the road, VDOT decided to replace the force main sanitary sewer and the force main water line as originally planned, only contaminated soil and groundwater would be removed and disposed of during construction. Subsequently, suitable material was hauled in and used during installation of the utilities on the east side of the road. The total volume of contaminated soil that should have been removed for subgrade and utility cuts was estimated to be 2,124 cubic meters (Lomax 2002).

Because of the level of contamination on the west side of the road and the potential risk of the further spreading of contamination during construction, VDOT decided that the gravity sanitary sewer and associated manholes located on the west side of the road would be rehabilitated in this area instead of replaced. The sanitary sewer was lined and the manholes were rehabilitated using technology provided by Tri-State, Inc. and its associates (Gaskins 2002). Once it was decided that this portion of the sanitary sewer would be rehabilitated instead of replaced, the construction work was conducted in the following sequence: 1) replace existing manholes and reconnect existing sanitary sewer pipes, 2) rehabilitate existing manholes, 3) rehabilitate existing sanitary sewer pipe, 4) replace service connections (VDOT 2000).

Existing manhole rehabilitation began with bench and channel reconstruction (Kurz 2002). Reformed benches and channels were coated with a trowelable mortar at a minimum thickness of 1/8 inch. Following bench reconstruction, voids greater than 1/16 inch found on interior manhole walls that did not exhibit excessive seepage were sealed with a waterproof hydraulic cement called ThoRoc Patch manufactured by Harris Specialty Chemicals, Inc. Voids on interior walls that exhibited excessive seepage were sealed using a rapid setting cement-based mortar called ThoRoc Plug, also manufactured by Harris Specialty Chemicals, Inc. To prevent groundwater from entering the manhole, chemical grout was injected directly into soil surrounding all exterior wall surfaces, pipe connections and frame adjustments. Finally, interior manhole walls were spray coated with a polymer modified cement compound called ThoRoc SP-15. This product is waterproof and resistant to attack by hydrogen sulfide and was applied at a minimum thickness of ½ inch (Harris Specialty Chemicals, Inc. 1998).

Cured in place pipe (CIPP) lining was installed in a portion of the existing sanitary sewer located on the west side of the road. Television inspection of the sanitary sewer was performed before installation of the liner, after installation of the liner, and after the highway surface paving. Inspection was conducted using closed circuit television and a radial eye camera (VDOT 2000). Prior to removing the sanitary sewer from service, flow was bypassed by intercepting the flow at an upstream manhole and pumping the sewage to a downstream manhole. Before placement of the liner, the receiving pipe was cleaned using standard hydraulic jet cleaning equipment. The equipment was required to remove all sludge, dirt, grease, rock, concrete, roots, and foreign objects from the sewer pipe and manholes. Additionally, all service laterals and other obstructions were removed prior to placement of the liner (VDOT 2000).

The liner tubing consisted of flexible needled felt or equivalent woven or non-woven material, coated on one or both sides with a geomembrane with a minimum thickness of 12 mils (VDOT 2000). The resin used with the liner was a premium resistant isophthalic, thixotropic, unsaturated polyester resin. Both the liner and resin used were designed to be resistant to long term exposure to hydrocarbons, which are found in the surrounding soil and groundwater. A catalyst was also used during liner installation that was compatible with the liner and resin. Seven lengths of sanitary sewer were rehabilitated, one with a host pipe size of 250 mm diameter and the other six lengths with host pipe sizes of 200 mm diameter. Liner thicknesses for all lengths were 4 mm with the exception of one length of 200-mm-diameter pipe, which required a liner thickness of 13.5 mm. The liners were installed in each length of existing pipe by attaching a cable to one end of the liner and pulling the liner into place using a winch assembly. Prior to pulling the liner into place, the liner was impregnated with the resin, filling all voids in the tube. The resin impregnating process is also called the "wet-out" process. The liner was expanded against the inner walls of the existing pipe by means of compressed air or water. Finally, the resin was cured by passing heated water through the pipe for an adequate amount of time. Initial cure of the liner and resin is accomplished at a certain temperature and post-cure is accomplished at a higher temperature. After the liner was cured in place, service connections were re-established and the rehabilitated pipe was re-inspected for proper installation using the radial eye camera (VDOT 2000). Additional information about the use of liners for pipe rehabilitation is discussed in Section 5.2.4 of this document.

Concluding Remarks

Rehabilitation of the sanitary sewer and manholes in the location of the most contaminated areas of the construction project was completed successfully. The rehabilitation process avoided the use of an open cut trench and subsequent replacement of the sanitary sewer, thus reducing the potential for spreading of the contaminants found in the surrounding soil. Furthermore, the liner and resin material used in rehabilitation were designed to resist any degradation by the existing contamination.

7.0 SUMMARY AND CONCLUSIONS

The purpose of this document is to identify and classify problems associated with contaminant migration during utility installation and to present mitigating measures that may prevent or minimize these problems. The document is intended to be used as a starting point to the solution or mitigation of a contamination migration problem. The document presents general definitions and concepts and also provides gateways to more detailed information. The information in this manual is presented in five main sections. Section 2 presents Federal and State environmental regulations, which may be directly or indirectly related to soils and groundwater contamination. Section 3 deals with identifying, defining, and categorizing the contaminant migration problem. Section 4 discusses different methods for mitigation of contaminant migration. Section 5 deals with utility materials and their contaminant resistance. Finally, research for this project included several site visits or case studies that are presented in Section 6.

During our research and subsequent preparation of the report, distinct main concepts or ideas concerning the contaminant migration problem became apparent. When working on utility installation projects and using this document, it is recommended that the following conclusions, recommendations, and ideas be considered:

- Consider existing hydrogeology and utility infrastructure during design and construction. Successful mitigation of contaminant migration requires an understanding of the project setting, including hydrogeology and contaminants of concern, and how the existing and proposed utility infrastructure fits into the environment (Pearson, unpublished information 2002). Spending the time and effort to understand the project setting and environment will enhance confidence in the decision making process and will most likely save time and money over the long term.

- Closely related to the previous recommendation, planning is paramount to successful mitigation of contaminant transport and pre-construction site investigations are a vital step in the planning process. Sub-surface site investigations should always be conducted when possible and can help ascertain whether mitigation of contaminant migration is a worthwhile pursuit and where and how the mitigation measures will be implemented. Desired components of a subsurface site investigation for a potentially contaminated area where a utility installation is planned are discussed in the report.

- Consult manufacturers of utility products when there is a question about chemical compatibility. Chemical resistance of a utility material to a subsurface contaminant is an important consideration. The information provided in this report and other references can be used as a general guide to chemical compatibility between a material and contaminants. However, to be absolutely confident about chemical compatibility, the manufacturer or vendor of a utility product should be asked to provide information about contaminant resistance. For instance, two manufacturers could produce a product with the same name, but which may have slightly different chemical compatibility characteristics.

- There is not always an “off the shelf” or “one size fits all” solution to contaminant migration problems. Many techniques and many avenues to find new techniques have been presented in this manual. However, a single technique or method may not provide a total solution. The total solution might include a combination or modification of techniques provided in this manual or may include techniques provided by other sources. Few standards have been established with regard to mitigation of contaminant migration during utility installation, thus, solutions must primarily be based on the prudent engineering judgment of the designer.

- Consider post-auditing a project to evaluate the effectiveness of engineering controls that were implemented. While usually prohibited by time and cost, post-auditing the performance of implemented engineering controls could be very useful for design and implementation of controls in the future. Post-auditing could reduce costs in the long term by revealing that certain expensive procedures are not as effective as simpler, less costly techniques. This type of research may be necessary to identify and develop standards.

- Remain informed and learn from experiences of other State transportation agencies. Some of the most valuable information obtained for this report originated from other State transportation agencies. Our research has shown that the two agencies that are most active in research and/or consideration of contaminant migration during utility installation are the Wisconsin Department of Transportation (WisDOT) and the Texas Department of Transportation (TxDOT).

The information presented in this report is by no means exhaustive and many opportunities exist to refine or expand research in this area. Additional research concerning mitigation of contaminant migration during utility installation might include the following:

- Perform additional case studies on new projects where utilities must be installed in contaminated areas. Information and knowledge gained from the case studies for this report was invaluable and accounted for a good portion of the information presented in the report. Also, observation of construction activities and discussion with those who work in the field can help to understand the contamination migration problem and how best to apply a solution which is practical and which fits in with current construction practices used by VDOT.

- Monitoring or post-auditing of engineering controls implemented on utility installation projects. Research could focus on one type of engineering control, like in-trench plugs, or could attempt to assess the effectiveness of many types of controls. As previously mentioned, post-auditing of engineering controls can reveal which controls are effective and which are ineffective.

REFERENCES

American Concrete Institute. (1994). *Controlled Low Strength Materials (CLSM)*, *Report No. 229R-94*, ACI Committee 229, Detroit, Michigan.

American Ductile Iron Pipe Company. (2002). *American Coatings and Primers for Pipe and Fittings*. http://www.acipco/adip/linings/coatings.cfm. Accessed August 2002.

Boulding, J. Russell. (1995). *Soil, Vadose Zone and Ground-Water Contamination*. CRC Press, Inc., Boca Raton, Florida.

Bureau of Reclamation. (1987). *Design of Small Dams*. United States Government Printing Office, Denver, Colorado.

Cole, G. Mattney. (1994). *Assessment and Remediation of Petroleum Contaminated Sites*, CRC Press, Inc., Boca Raton, Florida.

Concrete Sealants, Inc. (2002). *Product List*. http://www.conseal.com/html/product_list.html. Accessed November 2002.

Crosby, Ernest, M. Spindler, A. Puppala, J. Overman. (2000). *Draft Final Report, TxDOT Project 7-3998, Design Construction and Maintenance for Storm Sewers in Contaminated Environments*. University of Texas at Arlington, Arlington, Texas.

Davis, Ralph. (2002A). *Personal Communication*. Virginia Department of Transportation, Environmental Section, Bristol District.

Davis, Ralph. (2002B). *Letter to Dan Manweiler, Groundwater Program Manager, Department of Environmental Quality*. Virginia Department of Transportation. June 21, 2002.

De Renzo, D.J. (1985). *Corrosion Resistant Materials Handbook.* Noyes Data Corporation, New Jersey.

Fansler, W. Wilton, III. (2002). *Personal Communication*. Geotechnical and Environmental Services, Inc.

Fetter, C.W. (2001). *Applied Hydrogeology*. Prentice Hall. New Jersey.

Friend, David J. (1996). *NCHRP Synthesis 226: Remediation of Petroleum-Contaminated Soils*. Transportation Research Board, National Academy Press, Washington, D.C.

Gaskins, Cliff. (2002). *Personal Communication*. Virginia Department of Transportation. Geotechnical and Environmental Services, Inc. (GES). (2000). *Site Characterization Report for Underground Storage Tank Systems, Deno's #6 Greenville, Virginia*.

Harris Specialty Chemicals, Inc. (1998). *Thoroc SP15 Spray Mortar, Thoroc Patch, Thoroc Plug.* Specifications.

Houston, Brian R. (2002). *Personal Communication*. Timmons, Inc.

Howard, Amster K. (1996). *Pipeline Installation*. Relativity Publishing, Lakewood, Colorado.

Iseley, Tom, S. Gokhale. (1997). *NCHRP Synthesis 242: Trenchless Installation of Conduits Beneath Roadways*. Transportation Research Board, National Academy Press, Washington, D.C.

Kramer, Steven R. (1998). The Invisible Infrastructure. *Civil Engineering*. October 1998, 48-51.

Kurz, Peter E. (2002). *Personal Communication*. Utility Rehabilitation Specialists. Chesapeake, Virginia.

Lomax, J.E. (2000). *Letter to Taylor Wyant, Wolf Contractors, Inc*. Virginia Department of Transportation, Suffolk Residency. October 18, 2000.

Lowrance, Sylvia K. (1992). *Letter to Mr. Douglas Green, Piper & Marbury.* Office of Solid Waste, United States Environmental Protection Agency. June 11, 1992.

Marshall Miller & Associates. (1998). *Limited Subsurface Investigation Route 11 Main Street Stormwater Drain Improvements Abingdon, Virginia 24212 Within VDOT Project No. 0011-140-104, C502*.

Marshall Miller & Associates. (1999A). *C.R. Quesenberry Special Provision Detail within VDOT Project No. 0011-140-104, C502, Route 11 Stormwater Drain Project Abingdon, Virginia.*

Marshall Miller & Associates. (1999B). *C.R. Quesenberry Special Provision Detail within VDOT Project No. 0011-140-104, C502, Route 11 Stormwater Drain Project Abingdon, Virginia.*

Marshall Miller & Associates. (2000). *Ground Water Assessment Report C.R. Quesenberry Bulk Plant Route 11 Stormwater Drain Improvements within VDOT Project No. 0011-140-104 Abingdon, Washington County, Virginia*.

McKim, Robert A. (1997). Selection Method for Trenchless Technologies. *Journal of Infrastructure Systems*. Vol. 3, No. 3, 119-125.

Mindless, Sidney, J. Young, D. Darwin. (2002). *Concrete*. Prentice Hall, Pearson Education, Inc. New Jersey.

National Corrugated Steel Pipe Association. (2000). *Corrugated Steel Pipe Durability Guide*. http://www.ncspa.org. Accessed October 2002.

National Research Council. (1994). *Alternatives for Groundwater Cleanup, Committee on Groundwater Cleanup Alternatives*, National Academy Press, Washington D.C.

Natural Resources Conservation Service, U. S. Department of Agriculture. (1997). *Ponds: Planning, Design, Construction, Agricultural Handbook Number 590*.

Nayyar, Mohinder L. (2000). *Piping Handbook*. McGraw-Hill. United States.

New Millennium Environmental, Inc. (2001). *Environmental Site Assessment, Former Suffolk Oil Company Bulk Plant, 724 N. Main Street Suffolk, Virginia 23434, PC 01-090*.

Paugh, Eric W. (2002). *Personal Communication*. National Pipes and Plastics, Inc.

Pearson, Robert E. (2002). *Personal Communication*. Wisconsin Department of Transportation.

Portland Cement Association. (2001). *Effects of Substances on Concrete and Guide to Protective Treatments.* Skokie, Illinois.

Ramme, Bruce W. M. Tharaniyil. (2000). *Coal Combustion Products Utilization Handbook, Wisconsin Electric Power Company*. TekDoc – Technical Documentation, Inc. Greendale, Wisconsin.

Roberts, Chad. (2002). *The Geology of Virginia*, An Electronic Resource, College of William and Mary, Williamsburg, Virginia.

Saenz, R.E. (2002). *Personal Communication*. M & W Construction.

Sarros, Mike. (2002). *Personal Communication*. Virginia Department of Transportation, Environmental Section, Hampton Roads District.

Schmidt, Peter W. (1994). *Letter to Mr. David R. Gehr, Commissioner, Commonwealth of Virginia, Department of Transportation.* Virginia Department of Environmental Quality. July 29, 1994.

Schweitzer, Philip A. (2001). *Corrosion-Resistant Linings and Coatings*. Marcel Dekker, Inc., New York.

Schweitzer, Philip A. (1995). *Corrosion-Resistance Tables*. Marcel Dekker, Inc., New York.

Schweitzer, Philip A. (1994). *Corrosion-Resistant Piping Systems*. Marcel Dekker, Inc., New York.

Stone, Rick. (2002). *Personal Communication*. CMC Supply, Inc.

Smith, Lawrence A., K. Fields, A. Chen, A. Tafuri. (2000). *Options for Leak and Break Detection and Repair for Drinking Water Systems*. Battelle Press. Columbus, Ohio.

Turner-Fairbank Highway Research Center. (2002). *Application Description – Flowable Fill*. http://www.tfhrc.gov////hnr20/recycle/waste/app6. Accessed September 2002.

United States Environmental Protection Agency (EPA). (2003). *Laws and Regulations*, Major Environmental Laws. http://www.epa.gov/epahome/laws.htm. Accessed June 2003.

Virginia Department of Environmental Quality (VDEQ). (2003). *Laws and Regulations*. http://www.deq.state.va.us/regulations/homepage.html. Accessed June 2003.

Virginia Department of Environmental Quality (VDEQ). (2001). *Storage Tank Program Technical Manual, DEQ Guidance Document #01-2024*. VDEQ. Third Edition, October 4, 2001. http://www.deq.state.va.us/tanks/pdf/techman.pdf. Accessed June 2003.

Virginia Department of Transportation. (2000). *Virginia Department of Transportation Special Provisions For Utility Facilities Owned by the City of Suffolk, Project: 0460-133-F01, RW-201, C-501*. May 17, 2000.

Virginia General Assembly, Legislative Information System (VGA, LIS). (2003). V*irginia Administrative Code, Table of Contents*. http://leg1.state.va.us/000/reg/TOC.HTM. Accessed June 2003.

Wade, Ken. (2000). *Contaminant Migration In Utility Corridors*. Training Presentation by the Wisconsin Department of Transportation.

Waller, Brett. (2002). *Personal Communication*. Virginia Department of Transportation, Environmental Section, Staunton District.

Wisconsin Department of Natural Resources. (2000). *Guidance for Documenting the Investigation of Utility Corridors, PUBL-RR-649*. Bureau of Remediation and Redevelopment, Wisconsin.