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A COMPARATIVE COST ANALYSIS OF SOIL REMEDIATION TECHNOLOGIES

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Helen Rene Smith

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Helen R. Smith

ABSTRACT

A database of technical parameters and costs associated with 45 Underground Storage Tank (UST) sites in Tennessee was developed and analyzed. Soil remediation technologies were evaluated to provide a cost comparison of the technologies. A description of the soil technologies that are most commonly used for remediating petroleum contamination is given. The technologies were examined for advantages, disadvantages and limitations, as well as for typical published costs. Analyses included comparing technologies on a basis of average total cost of site cleanup and on a cost per volume basis. The effects of volume and concentration of contaminated soil were examined, and indicated that other site characteristics have more bearing on the total cost of site cleanup. The large differences in geology between eastern, middle, and western Tennessee did not seem to have an effect on total site cleanup costs either. Volatility of contaminant was shown to have a pronounced effect on cleanup costs. Despite a bias of engineers toward equipment intensive designs, it appears that ex-situ bioremediation may have slight cost advantages over soil venting, combinations of technologies, and in-situ bioremediation. This effect may be caused by the simplicity of the typical ex-situ bioremediation treatment. The effect of competition among consultants has caused a steadily decreasing total site cleanup cost since 1988.

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CHAPTER I

Introduction

Leaking underground storage tanks (USTs) are major sources of contaminated soil and groundwater throughout this country. The process of cleaning up this contamination has been going on since the early 1980s when the Environmental Protection Agency (EPA) first addressed the issue of potential environmental contamination caused by UST systems. The Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act of 1976 (RCRA) were passed in 1984. Subtitle I of these amendments created a comprehensive program of regulations for USTs. The program required that all facilities with petroleum-containing tank systems maintain records that demonstrate financial responsibility for any damage associated with a release from a UST. In abbreviated terms, the requirements were: that measures be taken to insure that future releases would be less in frequency and size, that existing contamination be remediated, and that financial resources be available for fixing any problems that arise in the future.

These regulations have been the inspiration for development of technologies which are capable of accomplishing this remediation effort. In the arena of technologies for groundwater contamination, several variations of the pump and treat philosophy have been developed. Almost all of the technologies for groundwater cleanup involve some form of the pump and treat method. The development of technologies for soil remediation, however, has seen much more diversity in types of remediation techniques. Some technologies that had been in use for years in

hazardous and solid waste treatment were adapted or converted to be suitable for disposing of contaminated soil from UST sites. Incineration and landfilling of excavated soils were instantly popular remediation techniques, however, various problems associated with these types of solutions attracted attention. Excavation and disposal of soils was not only expensive, but left large areas of gas station parking lots without any backfill material. The need for alternate technologies became apparent.

Since that time, many technologies have been implemented. Soil venting and technologies that remediate contaminated soil concurrently with contaminated groundwater have become viable options. Biological remediation techniques which engage either indigenous or genetically engineered microbes that break down contamination have seen greater use since Exxon proved it was a plausible alternative in Valdez, Alaska in 1989. The procedure of excavating contaminated soil and bioremediating it at the surface has become a popular solution to the contamination problem. In-situ techniques such as soil flushing or in-situ bioremediation have been tried on a limited basis.

Although the number of soil remediation alternatives has greatly increased, many engineers continue to use the same technologies again and again. Despite a belief by many scientists that bioremediation has many advantages over the non-biological techniques, including economic advantages, many engineers are unwilling to implement biological technologies at their sites. It is suspected that the primary reason engineers disregard biological technologies is because of a lack of information, both from a technical standpoint and from an economic standpoint. Also, engineers

tend to develop equipment intensive designs rather than depend upon the scaleup of laboratory biological processes. Although many scientists will state that bioremediation is a cheaper treatment technology to implement and that it will accomplish the same remedial goals in the long run, there has been little evidence that would prove such statements. Tennessee is one of few states that uses bioremediation with any regularity.

In 1992, Ouellette predicted that cleanup of leaking UST contamination could cost $ 30 billion. (Ouellette, 1992) "Simply assessing the extent of a contamination problem caused by a leaking underground storage tank can cost $10,000 or more. A leak caught early and still within the property boundary could cost between $3000 and $30,000 to clean up." (Cruver, 1991) Many sites have had tanks leaking for years and cost in the hundreds of thousands of dollars to remediate.

The Division of the Tennessee Department of Environment and Conservation (TDEC) serves as a reliable source of information for comparing costs associated with the different soil remediation alternatives that are in use in the state. The remediation programs for Superfund, USTs, and for federal and state facilities "have fairly well defined institutional processes and legal precedents and are proceeding along a predictable path" therefore, now is the time to try to develop this cost comparison of remedial technologies. (Russell, Coglazier, and Tonn, 1992) The point of this study, then, has been to compare actual costs of Tennessee sites using bioremediation, soil venting, to more traditional treatment technologies.

Most of the analyses were conducted using total costs which are accurate to

within ± $1000 in most cases and to within ± $5000 in all cases. Both in-situ and ex-situ bioremediation were compared to the most popular soil treatment methods used for corrective action at sites with petroleum contamination from USTs. Costs were compared for the eastern, middle, and western Tennessee. It was suspected that differing geology from one region to another contributes to differences in costs for the same technologies. Karst topography, which is native to the eastern and middle Tennessee regions, often contributes to high costs of the environmental assessment of a UST site. Determining the extent and location of contamination is complicated by the geology associated with karst topography. The total costs of remediation associated with sites in regions of karst would be expected to be higher than total costs of UST sites in western Tennessee, which is characterized by more homogeneous sands and silts.

The distribution of types of fuel contaminating the sites in the study was determined, and the cost of remediating gasoline contamination was compared to the combined costs of remediating other fuel types. An attempt was made to estimate the volumes of contaminated soil at the sites included in the study. Analyses were conducted to determine if the volume of soil to be remediated had a large effect on the total cost of a site remediation. A similar analysis was done to determine the effect of the concentration of contamination of Total Petroleum Hydrocarbons (TPH). All of these analyses are presented in Chapter V.

Beyond the intended goals of this study, the presented analyses may contribute to the ongoing examination of cost data being conducted by the Tennessee Division of

USTs, to determine if the reimbursement program is being abused. Identifying true costs of remediation only was very difficult for most of the analyses in this study because each site was at a different stage of completing the remedial process. The percentage of work toward completion of remediation which had been done on the sites was unavailable to the author. However, detailed cost information is being filed as sites are completing the remedial process. When an extensive and complete set of costs are found to exist, a future study could have a direct effect of widening the choice of technologies for such remedial work.

Chapter II contains the detailed objectives of this study, while Chapter III is a review of the literature which was available for background information on the subject of comparing the technologies. Very few authors have presented actual field costs, as opposed to merely suggesting that one soil cleaning alternative is cheaper to use than the others. A short discussion of the general methodology and collection of data and following analyses is presented in Chapter IV.

Chapter V contains the actual analysis of the data and presents the results of the analyses. An attempt to explain the trends in the data correlations is made, and the results of the analysis of the total costs of the sites are presented. References and an appendix which contains the site parameters and the estimated final total costs of the projects is included after chapter V.

CHAPTER II

Objectives

An understanding of cost variations between soil remediation technologies, whether biological or conventional, is a critical link to developing remediation strategies and complying with regulatory policy on cleanup of contaminated sites. Reliable information on cleanup costs will allow both regulators and environmental professionals to determine which method of treatment will be the best choice for remediation of contaminated soil and groundwater. Unfortunately, a dearth of this information exists for biological treatment methodologies, which have recently become widely accepted as a means of remediating wastes under appropriate conditions.

The goal of this study was to develop and implement a methodology to compare remedial actions of sites with contamination of both hazardous and non-hazardous materials. The Tennessee Division of Underground Storage Tanks (TDUST) was used as the source of the database that was generated for analysis in this study. There were several reasons for using the Underground Storage Tank (UST) program as a prototype for this project. Because greater than ninety percent of UST's contain petroleum products, the need to vary model coefficients based on type of pollutant is diminished. Also, regulations demand that costs of remediation for UST's be held to a minimum. Tennessee requires and retains detailed cost information on UST remedial actions. Tank owners and operators who remain in compliance with state regulations are eligible for reimbursement of costs for site assessment and remediation. Therefore, the UST division could be used as the source of complete and

actual cost information for many sites with petroleum contamination under very similar conditions as those of sites with hazardous or non-hazardous contamination.

Factors to be considered in the analyses included type and extent of contamination, concentrations of contamination, volume of contamination plumes, geologic conditions, and remedial actions chosen. Technologies that have been implemented at the sites of petroleum contamination within the state of Tennessee provided an adequate database to allow these comparisons.

Reliable information on environmental cleanup costs and projections of future costs is critical to making decisions on the most effective way to manage a remediation project. Therefore, the main objective of this study is to provide an engineering cost analysis that permits determination of the cost-effectiveness of conventional and innovative means of petroleum remediation. Actual total costs of sites were analyzed and are presented in this study.

The hypothesis of this thesis is that remediation of contamination by biological means, or bioremediation, is a more economical method of treatment than treatment by the more conventional methods (such as landfilling, incineration, and soil venting). This hypothesis was tested in situations where low amounts of contamination or low volumes of contamination are present. Petroleum products are especially amenable to bioremediation techniques, which is another reason that the Tennessee Division of USTs was selected as a source of information for this study.

In short, the objectives of this project were:

(1) to generate new cost information by compiling and analyzing UST bioremediation

cost data recorded by the state of Tennessee,

(2) to develop a cost comparative analysis between conventional UST treatment methods to bioremediation, and

(3) to determine cost trends and average cost information based on site characteristics and type of remedial action.

CHAPTER III

Literature Review

Cleaning up land and water resources that are contaminated with materials that pose a health risk has become a major priority in the United States during the past two decades. Remediation of contamination caused by various sources has provided a market for many different technologies. Various technologies are used for remediating contamination that is either hazardous, non-hazardous, or radioactive. Petroleum contamination from leaking underground storage tanks (USTs) is excluded from being a hazardous waste in the Code of Federal Regulations, but provides a large market for several of the same remedial technologies that are used for remediation of hazardous waste contamination.

Across the entire United States, petroleum contamination from leaking underground storage tanks (USTs) provides one of the largest sectors of the remediation market. The U.S. Environmental Protection Agency (EPA) has reported that there are currently 1.5 million registered underground storage tanks (USTs) at 750,000 facilities across the country, with 15 to 16 percent of those tanks leaking. (Ouellette, 1990) Petroleum products are contained in about 1.4 million of the registered tanks and the remainder contain hazardous chemicals. With millions more USTs which are currently exempt from federal requirements, it has been estimated that there is a total of 5 to 7 million USTs that contain either petroleum products or hazardous substances in the United States. (Cruver, 1991)

Eight technologies are popularly used in one form or another for remediating

soil contamination by hydrocarbons and other petroleum constituents. These technologies include landfilling, incineration, in-situ bioremediation, ex-situ bioremediation, soil venting, soil flushing, low temperature thermal desorption, and asphalt incorporation. Table 3.1 gives a brief description of each of these technologies with their advantages and disadvantages. The technologies are sometimes used singly, but are often used in combination with one another.

Thermal incineration and landfilling are popular remediation methods that have been used for years. These traditional technologies are widely used and have been exploited to nearly their highest potentials. EPA has encouraged the development of innovative technologies which will be technically and economically better than the old technologies, by providing funding for their development. (Vervalin, 1989) In recent years, innovative technologies have been developed that many scientists believe meet the technical and economical standards which will allow them to be used on a regular basis as alternatives to the more traditional technologies. For instance, low temperature thermal desorption is a spinoff technology from high temperature thermal incineration that is receiving much attention in the remediation arena in some states. Bioremediation is also emerging as one of the most promising new technologies, partially because of its adaptability to be either an in-situ process or an ex-situ process. A considerable amount of federal money delegated to the development of innovative technology has been spent on the development of biological processes in particular, because they meet several of the criteria set for innovative technologies. (Vervalin, 1989) The EPA encourages development of technologies

TABLE 3.1 OPTIONS FOR TREATMENT OF PETROLEUM CONTAMINATED SOILS

TECHNOLOGY/ COMMON NAMES	DESCRIPTION AND SPECIFICATIONS	ADVANTAGES	DISADVANTAGES AND LIMITATIONS
Landfilling	Excavated soils are hauled to a Class I or Class III landfill. Applicable for all contaminants.	Offsite disposal, quick procedure that removes 100% of the contamination[4].	Does not eliminate the source of contamination or future liablilty, backfill material required, difficult to use below groundwater table, takes up valueable landfill space[4].
High Temperature Thermal Treatment/ Rotary Kiln Incineration	A rotary kiln incinerator is a cylindrical, refractory-lined shell that is fueled externally. Combustion temperatures range from 1200°F to 3000°F. Applicable for organic contaminants.	Quick solution, eliminates future liability, costs decrease as volume of soil increases, contaminants 99.99% destroyed, destroys multiple contaminants, mobile systems available	Excavation and transportation of soil required, backfill material required, much air pollution control equipment and many permits are required.
Enhanced In-Situ Bioremediation	Microbial population growth is stimulated by nutrients and oxygen, or commercial blends of fertilizer. The microbes use the contaminants as a source of food and energy during the degradation process. Applicable for organic contaminants.	No excavation required, contaminant source elimination alleviates future liability, human exposure reduced[7], may be used in combination with other treatments[2], may remediate large volumes of soil with low contamination[11].	May be slower alternative than other treatments[1], will not work on extremely strongly sorbed components[6], may need a polishing step to acheive the low concentrations that some other technologies acheive, will not work in tight clays.

TECHNOLOGY/ COMMON NAMES	DESCRIPTION AND SPECIFICATIONS	ADVANTAGES	DISADVANTAGES AND LIMITATIONS
Soil Farming/ Ex-Situ Bioremediation Aerated Static Piles	Contaminated soils are removed and spread over a lined treatment staging area in 6 in. to 2 ft. layers or in a bioreactor to enhance biodegradation and volatilization, periodic application of nutrients, maintainance of soil moisture, water runoff control, and tilling or discing for oxygen exposure. In aerated static piles, 2 ft. lifts are separated by perforated plastic piping. Applicable for both organic and inorganic contaminants.[11]	Low equipment costs, low O&M costs[8], eliminates future liability and is applicable to both solids and sludges, can separate hazardous from non hazardous constituents[11].	Excavation required, may need off-gas treatment equipment, may need a polishing step to acheive the low concentrations of some other technologies achieve[4], large areas are required for soil pile treatments, treatment not allowed in all states because of air emissions from volatilization of contaminants, biodegradation may be a slower alternative[1].
Vapor Extraction/ Soil Venting Soil Vacuum Extraction	Soil vapor extraction operates by applying a vacuum (using a blower system) through extraction wells in the vadose zone (above the groundwater table). The resultant pressure gradient causes air to migrate through the soil pores to the extraction wells. Extracted air containing VOCs is either treated above ground or emitted to the air. Applicable for Volatile Organic Compounds.	Biodegradation is naturally enhanced, no need for excavation, human exposure reduced, good for treating volumes of soil >15,000 tons, cleanup may coour within as little as a few months[4].	High equipment costs, contamination transferred from soil to air, procedure may be lengthy, large capital investment for equipment[4], above ground treatment system required.

TECHNOLOGY/ COMMON NAMES	DESCRIPTION AND SPECIFICATIONS	ADVANTAGES	DISADVANTAGES AND LIMITATIONS
Soil Flushing/ Soil Leaching	Water or a surfactant is injected upstream while groundwater is extracted downstream and treated in an above ground system. Ex-Situ soil flushing is similar to the in-situ process, except that more powerful extracting agents may be used since the leachate can be captured without harm to the environment. Soil flushing encourages growth of microbes which biodegrade soil contamination. Applicable for hydrocarbon contamination.	In-situ process offers lower O&M costs, lower excavation costs, process is adaptable to in-situ or ex-situ needs, can remove 99% of contaminants in homogenous sands[4].	Process may be lengthy, contamination is transferred from soil to water then possibly to air, special requirements to address unsaturated zone soil contamination problem[3], works best in sandy soils than clays and silts[4].
Low Temperature Thermal Desorption	Soils are indirectly heated in a rotary kiln which allows multiple temperature controls, variations in solids residence times, and control of the rate and composition of the purge gas. Operating temperatures range from 200° to 600° F. Applicable for organic contaminants that will volatilize at relatively low temperatures.	Soil is returned to its original contamination free condition, backfill material is unnecessary, operation conducted on site.	Specialized mobile equipment is necessary, an afterburner or product recovery equipment is required, pyrolysis products may be formed which could be worse than the original contamination.
Asphalt Incorporation	Asphalt incorporation utilizes the petroleum contaminated soil as a partial substitute for stone aggregate. Applicable to petroleum contaminated soils.	Makes use of petroleum contaminated soils without remediation.	

[1]Block and Clark, 1989
[2]Chermisinoff and Goessman, 1992
[3]Cooley, 1992
[4]Fiorenza, Duston, and Ward, 1991
[5]MacDonald and Rittman, 1993
[6]McCarty, 1991
[7]Newton, 1990
[8]Ryan, Lowhr, and Rucker, 1991
[9]Sudnick, 1993
[10]Shook, 1992
[11]Vervalin, 1989

that will provide alternatives to the conventional technologies which simply transfer the contamination from one medium to another, sometimes creating more concentrated pollutants than they start with. (Thayer, 1991) Eliminating the disadvantages that are associated with ex-situ operations has been a major advantage for the in-situ operations. There is no need for fill material to be hauled in to replace the excavated soil, and the in-situ technologies can be used on small sites where there is no room for storage of excavated soil and heavy equipment. In the past, states have shown favoritism toward the traditional technologies for cleanup, particularly ex-situ processes. In the general cleanup effort, states report that approximately 68% of all sites have traditional offsite disposal treatment methods in use. The primary reason for the reluctance of scientists and engineers to recommend alternative technologies such as biological treatment technologies is the lack of information available concerning the specifics of the technologies and proof that the alternatives work cost effectively in the field. (Tremblay and Evans, 1993) Other reasons include the natural comfort associated with the "tried and true methods", and the fact that results are more easily predicted. Particularly for bioremediation, the statement has been made that "...the further you get from the laboratory, the more variable the results." (Thayer, 1991) Although laboratory data is abundant, the lack of published field data associated with bioremediation, soil flushing, and other newer technologies has contributed to the delay in their widespread use. Field data associated with bioremediation costs is almost not available, and its scarcity does nothing to help the credibility of the technique. Even with methods for which there is an abundance of

field data, "...most of the cleanup efforts [are] begun with good intentions but with only the haziest notion of the money and resources that ultimately [are] required." (Russell, Coglazier, and Tonn, 1992)

Asphalt incorporation is not widely used in Tennessee. Incineration is sometimes used in Tennessee, however it is not used to the extent that landfilling, soil venting, and the in-situ and ex-situ methods of bioremediation are used. Soil flushing and low temperature thermal desorption are other technologies which have seen only limited field use in Tennessee.

Despite the lack of published field data, ex-situ bioremediation has become a fairly popular technique in the state of Tennessee. Work done over the last decade has decreased the paucity of information which existed due to the fact that the data to estimate the extent of contamination, its environmental consequences, and social costs were not available. However, even with this expansion of available information, a clear comparison of remediation technologies still does not exist. This is due to some disturbing tradeoffs between environmental endpoints, tradeoffs across media, and differences among populations.

Many biological treatment technologies have been applied to both soils and groundwater that were contaminated with organic compounds over the past several years. Bioremediation is not a novel technology; it has been used to treat petroleum contaminated soils and degrade oily wastes for more than 30 years. "The growing understanding of microbiology has allowed bioremediation to advance from the early days of back lot landfarms to today's sophisticated remediation technology."

(Hildebrandt and Wilson, 1991) "Applications of the technology are becoming increasingly important in the field of hazardous waste due to its effectiveness and low cost as compared to other treatment alternatives." (Ryan, Lowhr, and Rucker, 1991) "This technology has been proved cost-effective for treatment of soils contaminated with petroleum hydrocarbons. Biological treatment processes have received increased attention over the past several years as a safe and cost-effective means of treating a variety of hazardous and nonhazardous sites." (Block and Clark, 1989)

Many authors claim that bioremediation of petroleum contaminated soils is less expensive than remediation by conventional techniques, but never offer any explanation of how much cheaper the bioremediation is. The cost of a bioremediation project will vary with the location, volume and characteristics of the wastes, as well as the methodologies employed. (Fiorenza, Duston, and Ward, 1991) Also, answering the question of how to speed the natural process in the few cases where it is too slow to meet the demands of society and regulators has proven to be a difficult matter. (McCarty, 1991)

Biological treatments are not always able to achieve the low concentrations that air stripping systems can. (Cheremisinoff and Goessman, 1992) Although groundwater pump and treat systems such as air stripping are more easily directly controlled than in situ approaches, they have been scrutinized recently because after the cleanup goals have been met and the groundwater systems stopped, the contamination sometimes appears at high levels again. (McFarland, 1989) Wilson and Brown (1989) determined that in-situ bioremediation saved approximately 50% of

the costs that would have been associated with pump and treat technology of a specific site. This cost savings was primarily attributed to the fact that the microorganisms degraded the source of contamination, allowing the groundwater to be cleaned along with the soil cleaning and also to the fact that biological processes took a significantly less amount of time to finish the cleaning process than pump and treat technology would have allowed. (Wilson and Brown, 1989)

Bioremediation is often used in conjunction with pump and treat technologies or soil flushing. Although the combination is good for creating a potential use of bioremediation at many sites, the combination of bioremediation with other technologies only adds to the difficulty in developing a cost comparison. (Austin, 1990)

Fiorenza and his colleagues are of the opinion that bioremediation technologies will become more widely used versus pump and treat technologies because of the recent speculation on the failure of the pumping and treating to remove the source of contamination. (Fiorenza, Duston, and Ward, 1991)

"Bioremediation is only a tiny fraction of the very large and diverse hazardous waste treatment and remediation market, but it is among the fastest growing sectors in environmental management." (Thayer, 1991) Peter Perez of Environmental Remediation, Inc., claims that bioremediation will be a major technology by the turn of the century. (Abelson, 1992) "However, bioremediation remains largely undeveloped. Many companies remain skeptical or need a better assessment of how bioremediation [compares] with conventional treatment strategies." (Vervalin, 1989)

Virtually all authors imply that bioremediation can be very economical, however, McCarty (1991) proposes that the "main advantage of bioremediation is likely to be an environmental one, the contaminants are destroyed with a minimum of disruption to the surface environment." The major problem is that bioremediation is "neither universally understood nor trusted, and its success is hotly debated. Bioremediation is thus a technology in need of performance standards." (MacDonald and Rittman, 1993) This mistrust is not only within the ranks of engineers and scientists, but also within the regulatory scene. The skepticism can only be alleviated by successful applications of bioremediation from an economical point of view. (MacDonald and Rittman, 1993)

Table 3.2 lists some cost ranges for the technology options for remediating petroleum contaminated soils. These cost ranges have been published in journals and articles concerning the technologies individually, but mostly not in comparison to one another. In some cases more than one cost range was obtained, and because the published ranges differed significantly, more than one range is given in Table 3.2.

Newton (1990) attempted to compare the costs of remediation technologies to each other in a relative sense. Newton pointed out that since petroleum products contain a wide variety of volatile chemicals, often a specific remedial alternative is favored. Most technologies for soil remediation take advantage of the relative volatility of the chemicals contained in petroleum. Newton's relative evaluation of the costs of remedial technologies is as follows on page 20.

TABLE 3.2 TYPICAL PUBLISHED COSTS FOR TECHNOLOGY OPTIONS

TECHNOLOGY/ COMMON NAMES	PUBLISHED TYPICAL COST RANGES
Landfilling	$200 to $300/cy + excavation costs[4] or $300 to $500/cy + excavation costs[7]
High Temperature Thermal Treatment/ Rotary Kiln Incineration	$250 to $500/ton[11] or $1000 to $2000/cy[4] or $180 to $350/ton[9]
Enhanced In-Situ Bioremediation	$40 to $70/ton[11] or $63 to $123/cy4
Soil Farming/ Ex-Situ Bioremediation Aerated Static Piles	$50 to $80/cy for soil piles or $100 to $150/cy for bioreactors[4]
Vapor Extraction / Soil Venting Soil Vacuum Extraction	$245 to $320/cy[4]
Soil Flushing/ Soil Leaching	$150 to $200/cy[4]
Low Temperature Thermal Desorption	$120 to $250/ton[9] + $30 to $65/ton[10] for permitting
Asphalt Incorporation	

[1]Block and Clark, 1989
[2]Chermisinoff and Goessman, 1992
[3]Cooley, 1992
[5]MacDonald and Rittman, 1993
[6]McCarty, 1991
[7]Newton, 1990
[9]Sudnick, 1993
[10]Shook, 1992
[11]Vervalin, 1989

Technology	Relative Cost
Volatilization (soil venting)	Low
Soil Piles (ex-situ bioremediation)	Low
Biodegradation (in-situ bioremediation)	Moderate
Land Treatment	Moderate
Leaching	Moderate
Asphalt Incorporation	Moderate
Excavation/disposal (landfilling)	Moderate to High
Thermal Treatment	High

The relative difference in high and low costs is significant, especially for large volumes of waste. "Most of the emerging technologies depend on the chemical or physical characteristics of contaminants." (Newton, 1990)

Fiorenza, Duston, and Ward (1991), and Newton (1990) are among the few authors who have actually provided general cost estimates for remediation technologies without going into specific case studies. Much of the information in Table 3.2 is taken from these two sources. A significant lack of information exists when comparing actual costs because little research has been done to average the costs on several sites of similar characteristics. The analyses of Chapter V are intended to assist in relieving this lack of data.

CHAPTER IV

Methodology and Description of Database

Although not a hazardous waste (by exclusion in 40 CFR), petroleum contamination from leaking underground storage tanks (UST's) has very similar characteristics to those characteristics of hazardous wastes. Therefore, the UST Program of the state of Tennessee was used as a model for this study. The Division of Underground Storage Tanks in Nashville, Tennessee retains a copy of all the financial and technical records and reports of every UST remediation project in the state. Technical information from the Division of USTs was gathered for a total of 45 UST sites in the state. Individual consulting companies provided total costs of the remediation projects of those sites. This information was analyzed in order to gain an understanding of variations in costs of biological technologies and "conventional" technologies.

Beginning in August of 1992, a list of all sites for which a file exists in the state was obtained from the Nashville field office. At this point, approximately 100 sites were randomly selected for use in this study. The technical reports for each of the sites were evaluated. Technical information pertaining to defining the extent of contamination is contained in an Environmental Assessment Report (EAR). Technical information concerning the choice of treatment technologies is contained in the Corrective Action Plan (CAP). For the chosen sites, these reports were individually examined to determine if the sites would be suitable for this study. Several sites which required only groundwater contamination (therefore no soil treatment) were

included to give an estimated baseline cost of what activities other than soil treatment cost on the average. Some of the sites were discarded because the CAP was not completed or other valuable pieces of information about site characteristics were missing. After this selective elimination, a total of 45 sites were found to contain most of the pertinent information.

A computer database was constructed for analysis of information which was collected from the technical files and financial files in the Nashville office. Table 4.1 lists the technical parameters included in the database which were gained from reviewing the CAP's and EAR's.

Due to non-uniformity of corrective action plans and various exclusions of information, a complete database with all information desired for each site was impossible to obtain. Significant problems were encountered because many of the sites were in different stages of remediation. Therefore, it became necessary to contact the engineering consultants to obtain the best estimate of remediation costs for each site in the study. The "total cost" was defined as anything which was reimbursable from the Trust Fund of the State of Tennessee. The total costs include the preparation of the Environmental Assessment Reports and Corrective Action Plans as well as the costs for determining the extent of contamination, actual costs for the equipment and design and implementation of the corrective action systems. The total costs also include the cost of monitoring and closure which occur at the end of all UST remediation procedures.

TABLE 4.1: ELEMENTS OF DATABASE

Eleme	Parameter	Definition of Parameter
A	Facility	State Facility Identification #
B	Region	State Region, 1=East, 2=Mid, 3=West
C	Sitename	Name of the Site
D	Dorelease	Reported Date of Release of Product
E	Petrotype	Type of Petroleum Contamination
F	Contaminat	Contamination Matrix, Soil &/or Water
G	Fppres	Presence or absence of Free Product
H	Volsoilcont	Approx. Volume of Soil Contamination
J	Soilremepro	Process Selected for Soil Remediation
K	Gwremeproc	Process Selected for Water Remediation
L	Geology	Geologic Conditions of the Site
M	Company	Responsible Environmental Consultants
N	Soiltphppm	TPH Concentration in Soil, ppm
O	Soilbtxppm	BTX Concentration in Soil, ppm
P	Gwtphppb	TPH Concentration in Groundwater, ppb
Q	Gwbenzppb	Benzene Conc. in Groundwater, ppb

The information on costs and the information from the CAPs were entered in the database, which was then analyzed for trends in the geographic regions, average costs associated with the various technologies, costs of technologies used by the various consulting firms encountered in the study, as well as for other correlations. The results of the analysis are presented and discussed in Chapter V.

CHAPTER V

Results and Discussion

As of March, 1994, approximately 700 sites requesting reimbursement for corrective action were currently active in Tennessee. Statewide, very few sites had been declared completely remediated. According to the state, approximately 2000 sites had reported releases between 1988 and March, 1994. The distribution of the 45 Tennessee sites that were selected for cost analysis is shown in Figure 1. The sites reported estimated dates of petroleum product release between 1988 and August 1992. These dates correspond with the year the reimbursement program began and the year this study began. Dates of release were unknown for eight sites. The year of release for the remaining 35 sites is shown in Table 5.1:

TABLE 5.1: NUMBER OF SITES BY YEAR OF RELEASE

Year of Release	Number of Sites in Study
1988	4
1989	5
1990	13
1991	7
1992	8

The types of released petroleum product also varied, though the majority of the sites had gasoline contamination only. The distribution of the contaminating petroleum products is shown in Figure 2. Several sites had more than one type of

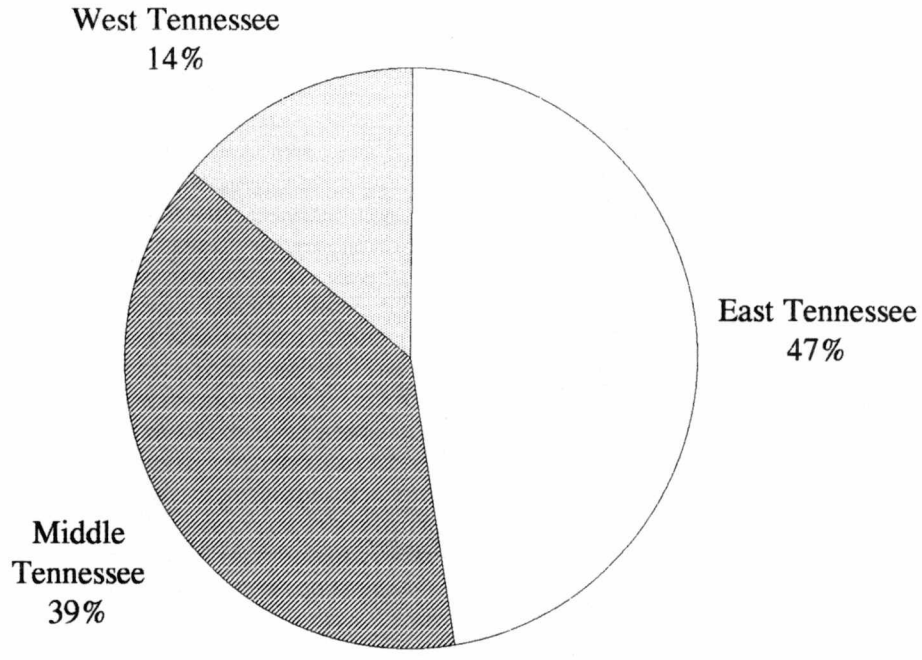


Figure 1: Distribution of Sites by Region

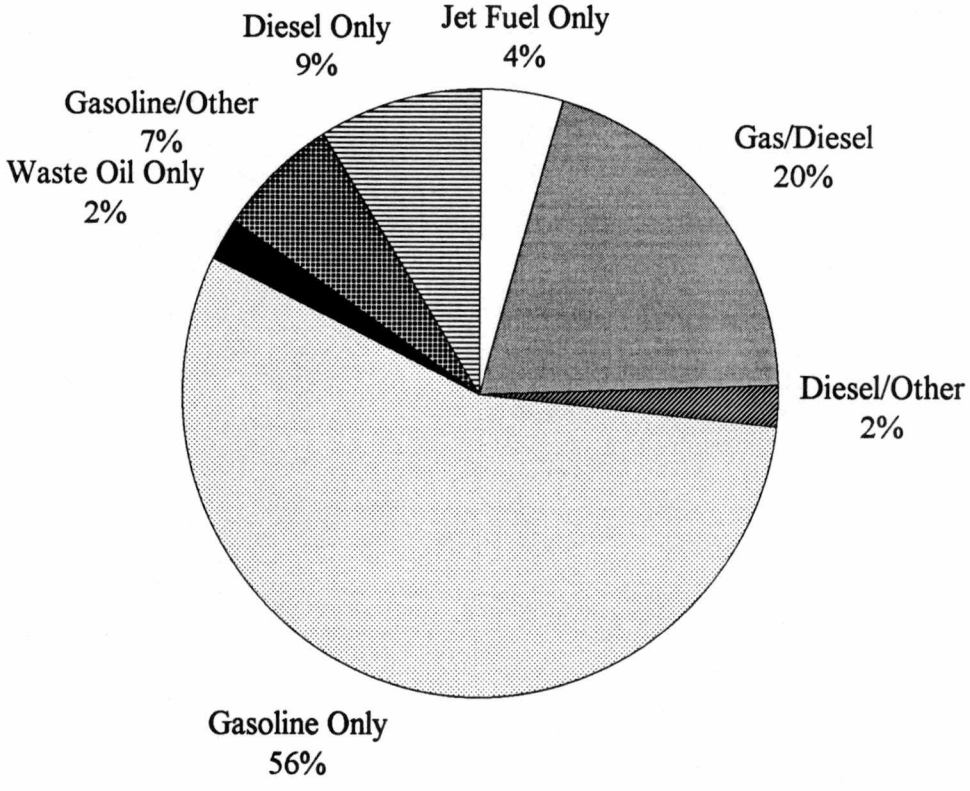


Figure 2: Distribution of Contaminating Products

petroleum product contaminating the soil and/or groundwater. The remediation of multiple contamination products is easily amenable to incineration and landfilling, but a volatilization rate dependent process, (e.g. soil venting), may be best configured for parameters associated with one particular contaminant.

Figure 3 shows the distribution of the contamination matrices for the studied sites. A contamination matrix is defined as the media that contains levels of contamination above the limits allowed by the Division of Underground Storage Tanks. Of the 45 sites, 4 had soil contamination only, 11 had groundwater contamination only, and 30 had a contamination matrix of both soil and groundwater.

The distribution of technologies used for soil remediation is shown in Figure 4. The eleven sites which had no soil contamination above state action levels, (groundwater contamination only), were included in the study to allow the establishment of a baseline cost that could be used to compare sites that have both soil and groundwater contamination to sites with soil contamination only. These eleven sites make up 21% of the total number of sites.

Fifty percent of the sites employed cleanup schemes which involved a combination of technologies, and 50% used exclusive technologies. Among the sites which employed one technology exclusively, 7% chose in-situ bioremediation, which consists of stimulating naturally occurring bacteria to propagate and consume the contaminants in the soil. In-situ bioremediation allows the contaminants to degrade into non-harmful products. Another option for in-situ bioremediation is to physically add a population of microbes to the contaminated area, however the practice in

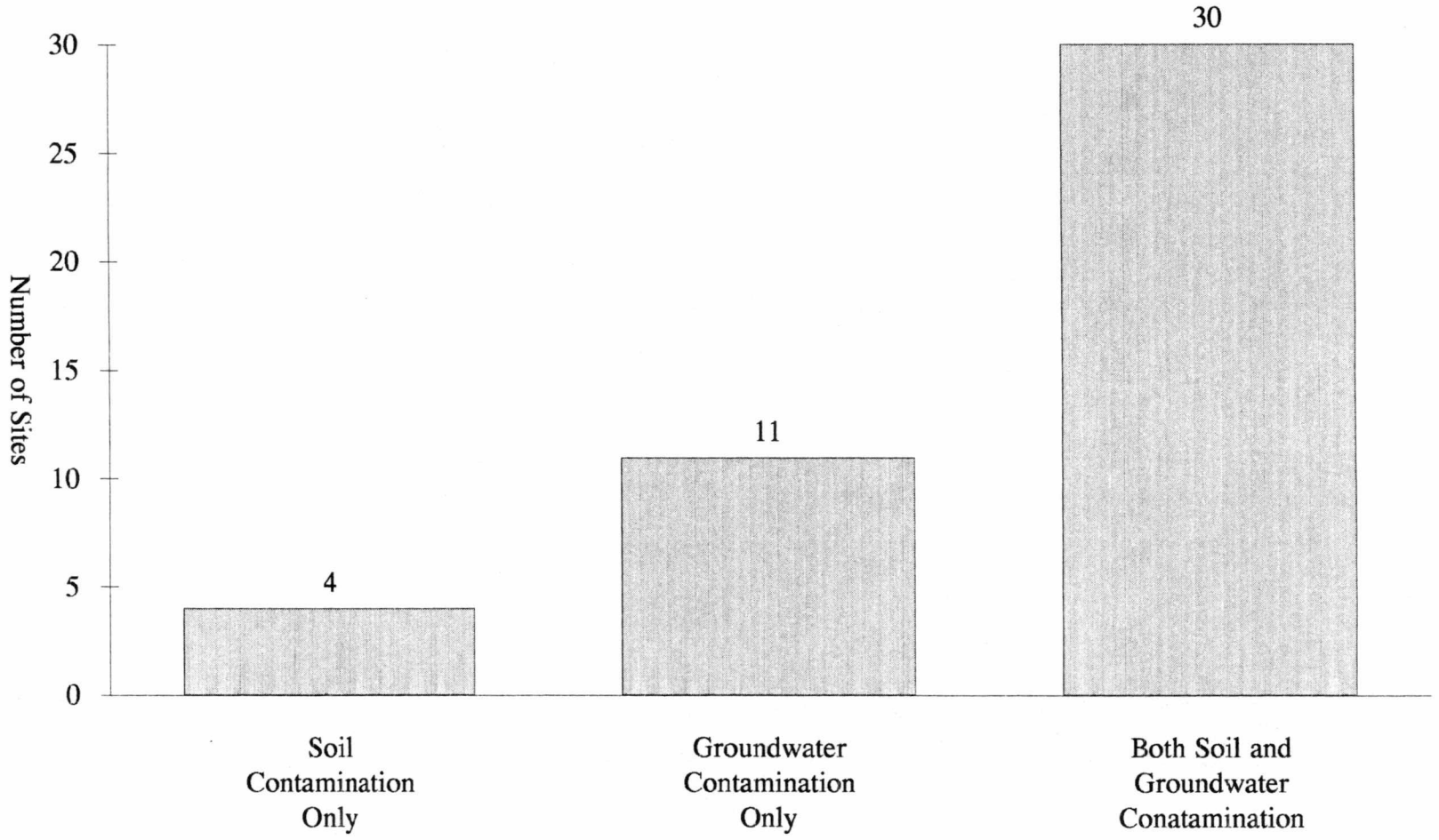


Figure 3: Distribution of Contamination Media

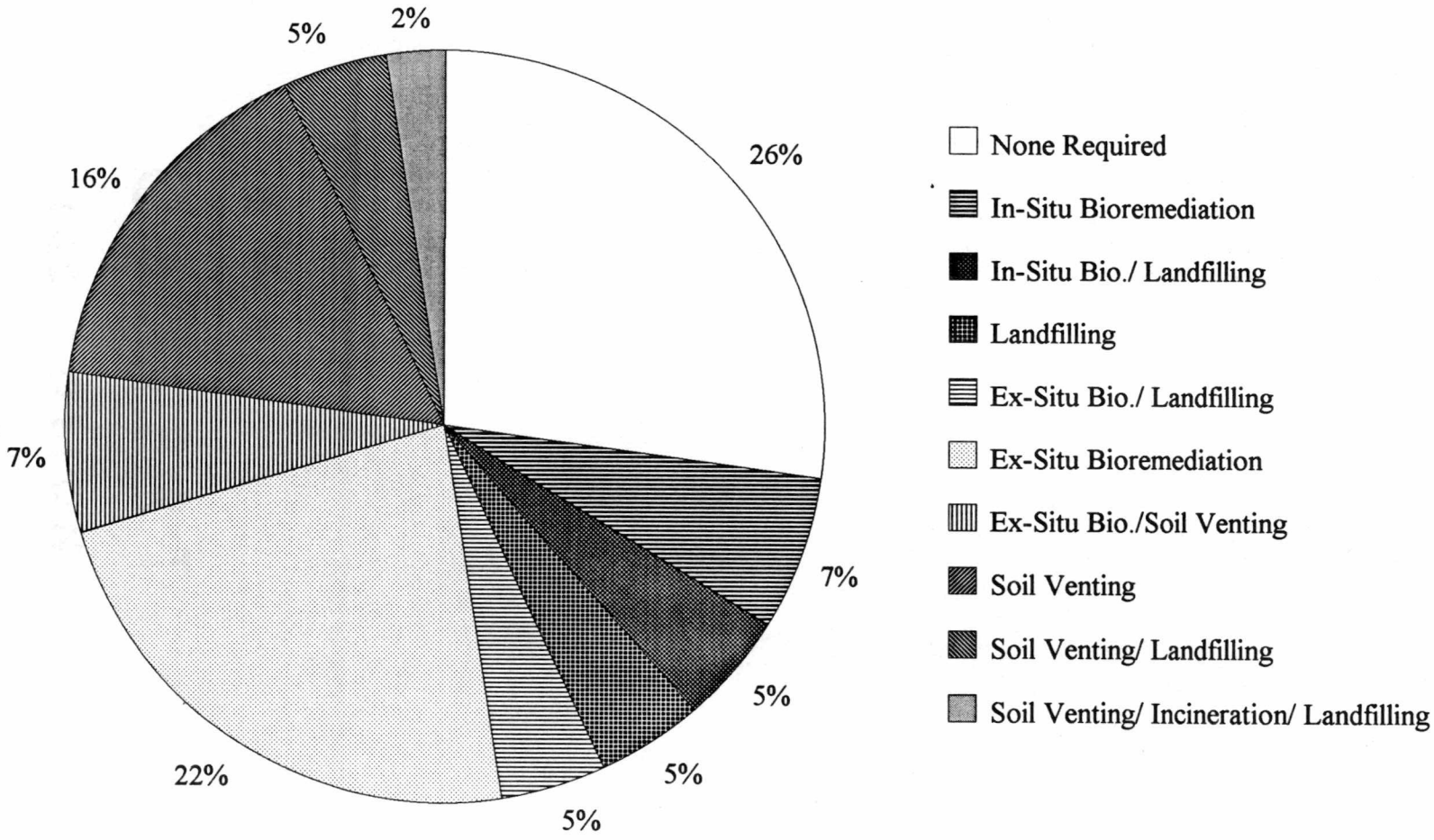


Figure 4: Distribution of Soil Technologies

Tennessee generally involves combination of the soil treatment system with the groundwater treatment system, and use of naturally occurring microbes. Three sites which used in-situ soil flushing as their soil/groundwater treatment system were included as sites employing in-situ bioremediation because the mechanism of remediation is similar. Only 5% of the sites used in-situ bioremediation with another soil remediation technology.

Ex-situ bioremediation consists of either placing excavated soil in bioreactors where nutrients and oxygen are added to the mixture, or by simply placing excavated soil on top of plastic and allowing it to aerate and biodegrade naturally. Ex-situ bioremediation was used exclusively at 22% of the sites. This technology is often the preliminary cleanup technique which is chosen to remediate the soil which is excavated when the UST is removed originally. Therefore, ex-situ bioremediation is popularly chosen as a part of a treatment scheme. In this study, ex-situ bioremediation was used in combination with other technologies at 12% of the sites.

Soil venting, also called soil vacuum extraction, is a method used to supply the oxygen needed to promote biodegradation of hydrocarbons while volatilizing contaminants to be collected at the surface. Soil venting was used exclusively at 16% of the sites and in combination with other technologies at an additional 7% of the sites. Soil venting is a technology which is often used at sites with shallow contamination, but which can be used in combination with groundwater cleanup technologies if necessary.

Landfilling was a remedial method used exclusively at only 5% of the sites, but

was used in combination with other soil remediation technologies at an additional 17% of the sites. Often, landfilling is the chosen alternative when it is necessary to dispose of contaminated soil because the area of the site is too small to allow onsite remediation, or when the site needs to be quickly remediated. The number of sites using landfilling is expected to decrease in the future, as restrictions on landfilling become more stringent. Landfilling is not the best alternative from an environmental standpoint, and other alternatives appear to be more cost effective.

Incineration was not used exclusively at any site in this study, and was used in combination with other technologies at only one site. Incineration is usually considered only for UST sites with small volumes of highly contaminated soils. Although incineration is more expensive than other types of treatments, some engineers may still prefer incineration if they have access to the proper equipment, because it is a fast way of permanently disposing of contaminated soil.

Thermal desorption is sometimes used for soil cleanup in Tennessee, although it was not the chosen technology for any of the 45 sites included in this study. The thermal technologies require extensive air pollution control devices. Low temperature thermal desorption restores soil to it's original uncontaminated condition, while incineration destroys contaminated soil. Despite the relative effectiveness of these technologies to some of the other technologies, thermal treatments are not widely used in Tennessee.

Combining the in-situ and ex-situ bioremediation categories shows that bioremediation was employed exclusively of other technologies at 30% of the sites.

The other soil treatments of landfilling, soil venting and incineration were used at 27% of the sites, and bioremediation was combined with the traditional technologies of soil venting, incineration, and landfilling at 16% of the sites. This distribution is shown in Figure 5.

A significant gap in information occurred because Tennessee does not require reporting of estimated contamination volumes, and until 1991, regulatory guidance for preparing Environmental Assessments or Corrective Action Plans (CAPs) did not request estimated volumes of contamination plumes. Volumes for 19 of the 34 sites with soil contamination were obtained from text in the CAPs or obtained by measuring contamination plumes as depicted in the CAPs. The available volumes were used to calculate a total cost per cubic yard of soil contamination. Because predicting the extent to which each individual treatment technology played a role was not possible, no attempt to determine the actual cost associated with each individual technology was made. The average total cost of total sie cleanup by technology is given in Figure 6. These costs include the baseline cost of $111,467. The baseline cost is the average of the eleven sites which had no soil contamination and one site which was not required to do soil remediation, and is assumed to represent the average cost of everything other than soil remediation at a typical site.

The average cost of the ex-situ bioremediation site was $183,100, but would have been lower if it had not included the American Airlines site at which $553,000 was spent to remediate 3500 cubic yards of soil contaminated with jet fuel. The American Airlines site was the only location in the study at which bioreactors were

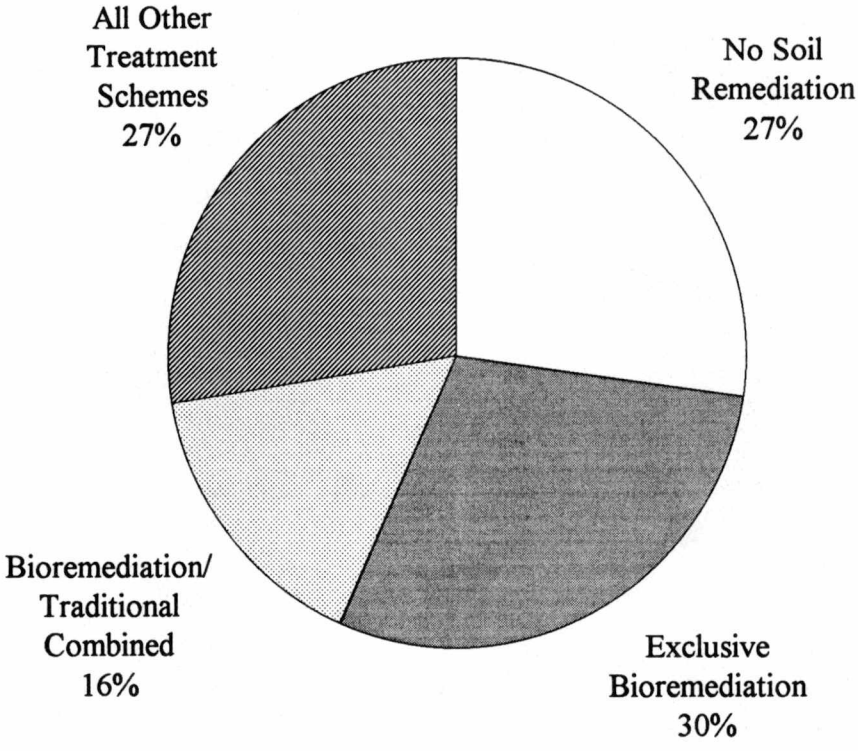
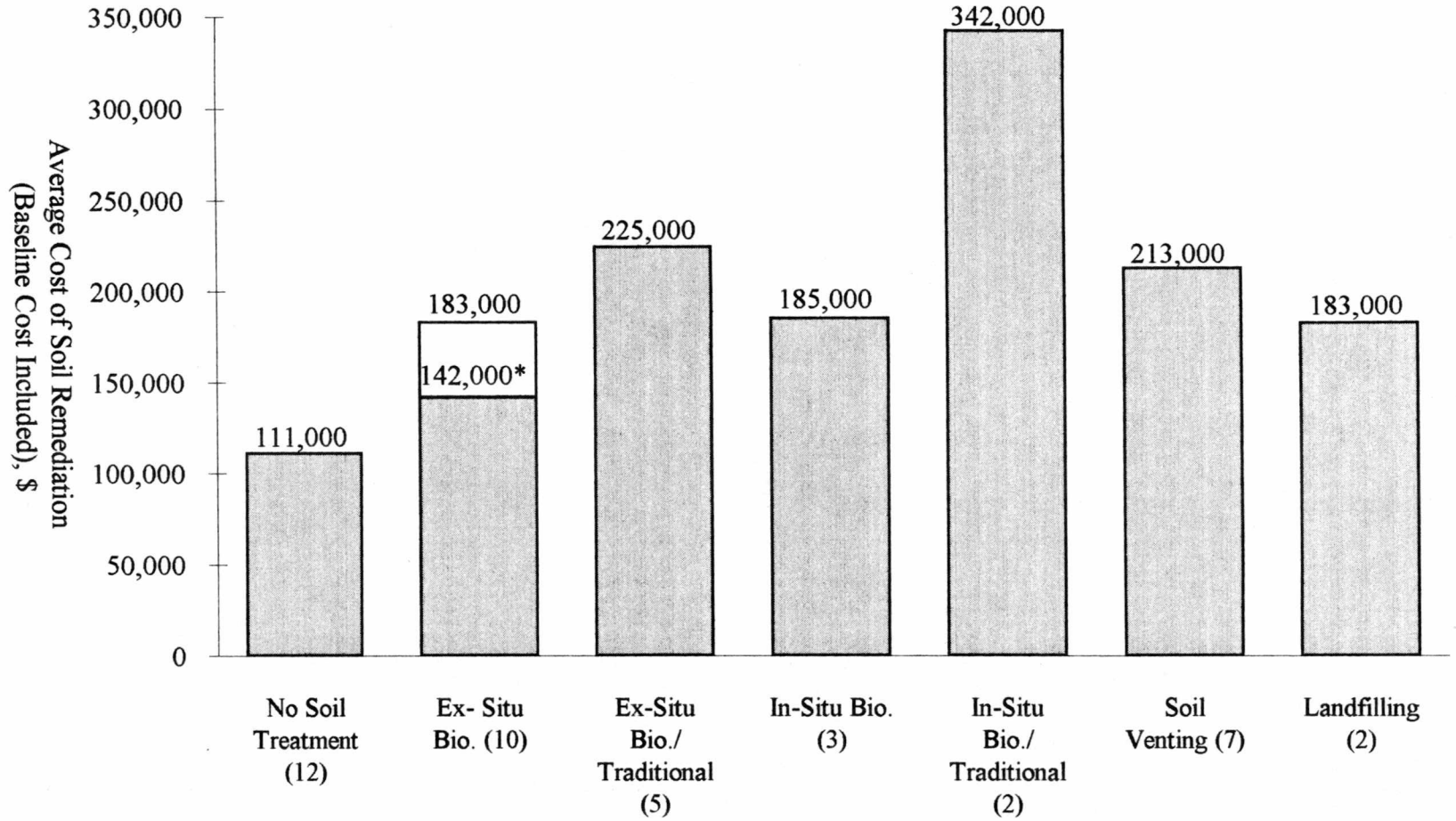


Figure 5: Distribution of Bioremediation vs. All Other Treatments



(#) denotes number of sites contributing to average

*cost excluding American Airlines Site

Figure 6: Average Cost of Total Site Cleanup by Technology

constructed. The bioreactors significantly increased the total cost of the remediation. The remainder of the ex-situ bioremediation sites placed the soil on liners of either plastic or concrete, or simply landfarmed the contaminated soil, at significantly lower costs. The average cost of the ex-situ bioremediation sites excluding the American Airlines site was $142,000. The five sites using ex-situ bioremediation in combination with other technologies averaged a total cost of $225,000. All the sites which used combination technologies averaged higher costs than the sites where technologies were employed exclusively. This is most likely due to the complex nature of sites where is is best to use more than one technology. Sites which employ multiple technologies often have a large groundwater plume in addition to a complex soil contamination plume. Often the soil treatment systems are combined with the groundwater treatment systems, naturally leading to a higher total site cleanup cost.

The same logic can be applied to sites using in-situ bioremediation in combination with other technologies. The average cost of sites using in-situ bioremediation in combination with other technologies was the highest of any of the examined technology combinations. All five sites where in-situ bioremediation was employed had contaminated groundwater as well as contaminated soil. In-situ bioremediation was used exclusively at three sites, and in combination with landfilling at two sites. The average exclusive in-situ bioremediation cost was approximately $185,000 including $111,000 for groundwater contamination and assessment which leaves $74,000 as the average in-situ bioremediation cost. The in-situ bioremediation cost was determined from the arithmetic average of three sites shown in Table 5.2.

TABLE 5.2: EXCLUSIVE IN-SITU BIOREMEDIATION COSTS

Site Name	Treated Soil Volume	Total Cost ($)
Bowman Transportation	4440	163,000
Golden Gallon #117	148	340,000
Junior Food #54	67	53,000
Average	1552	185,000

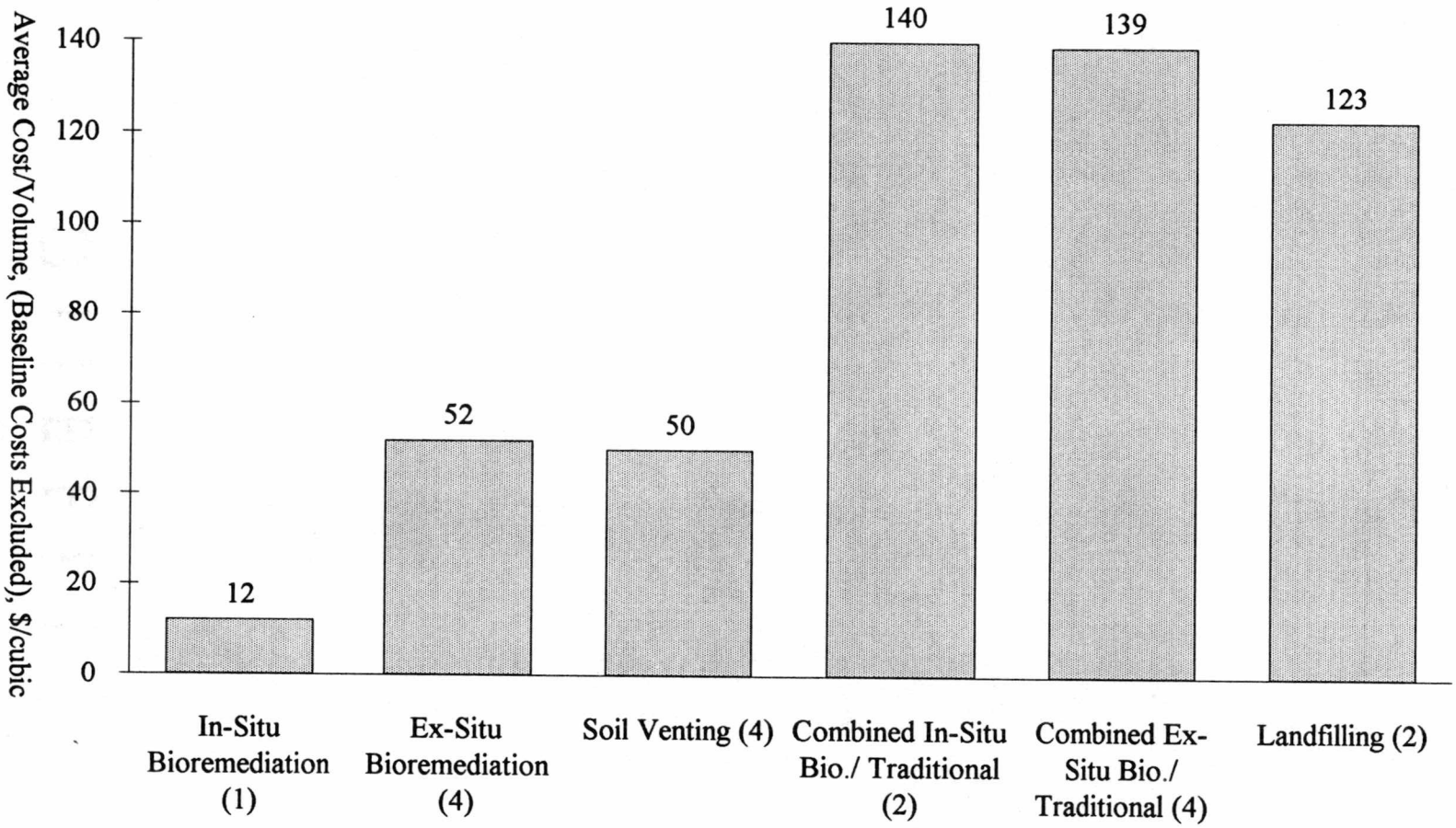
The average total cost for sites using soil venting exclusively was $213,000, and the average cost for sites using landfilling was $183,000. The higher cost of soil venting sites may be due to their typically large extent of contamination, and the lower cost associated with landfilling may be attributed to the lower volumes of contaminated soil which are associated with sites which use landfilling exclusively. Only two sites used landfilling exclusively for soil remediation.

All sites using soil venting had both soil and groundwater contamination. The average soil venting cost of $213,000 includes the average cost of $111,000 for cleaning groundwater contamination and completing assessment work, leaving $102,000 as the average cost for soil remediation alone. This value is in excellent agreement with the estimate made by Newton (1990), who stated that "Soil venting is a plausible option for sites which do not require immediate cleanup action. The equipment required for soil venting can be placed in operation for less than $100,000 and can take anywhere from months to over a year to clean contaminated soil to the desired levels."

The nineteen sites for which soil contamination volumes could be calculated were analyzed to provide a remediation cost per cubic yard. Figure 7 shows the average cost of soil remediation/cubic yard, by technology. The costs which were averaged to provide the numbers in Figure 7 do not include the baseline cost. The baseline cost of $111,000 was subtracted from the total cost of remediation of each site, and the values which remained positive were averaged to get this unit cost. There are obvious problems associated with this technique. Sites which did not have total costs amounting to over $111,000 were not included in the unit cost analysis. Subsequently, the small numbers of sites contributing to each of the averages in Figure 7 leaves room for statistical doubt in any of these figures.

Comparing the averages from the sites using exclusive technologies in Figure 7 to the average costs per cubic yard from published literature produced some agreeable and some disagreeable results. The published cost of landfilling, a minimum of $200/cy, was 62% higher than the average cost per cubic yard of the two sites included in this study. The average unit cost of ex-situ bioremediation was in agreement with the published unit cost, at around $50. The average unit costs of both the soil venting and the in-situ bioremediation were well below the published minimum averages of $245/cy for soil venting and $40/cy for in-situ bioremediation. It is possible that the sites in this study are more specific in their characteristics that influence the remediation costs than can be shown by the collected information.

Figure 8 is a comparison of the total costs and their respective volumes of contaminated soil. There is no apparent correlation revealed in this data between the



(#) denotes the number of sites contributing to the shown average

Figure 7: Average Cost of Soil Remediation/Cubic Yard, by Technology

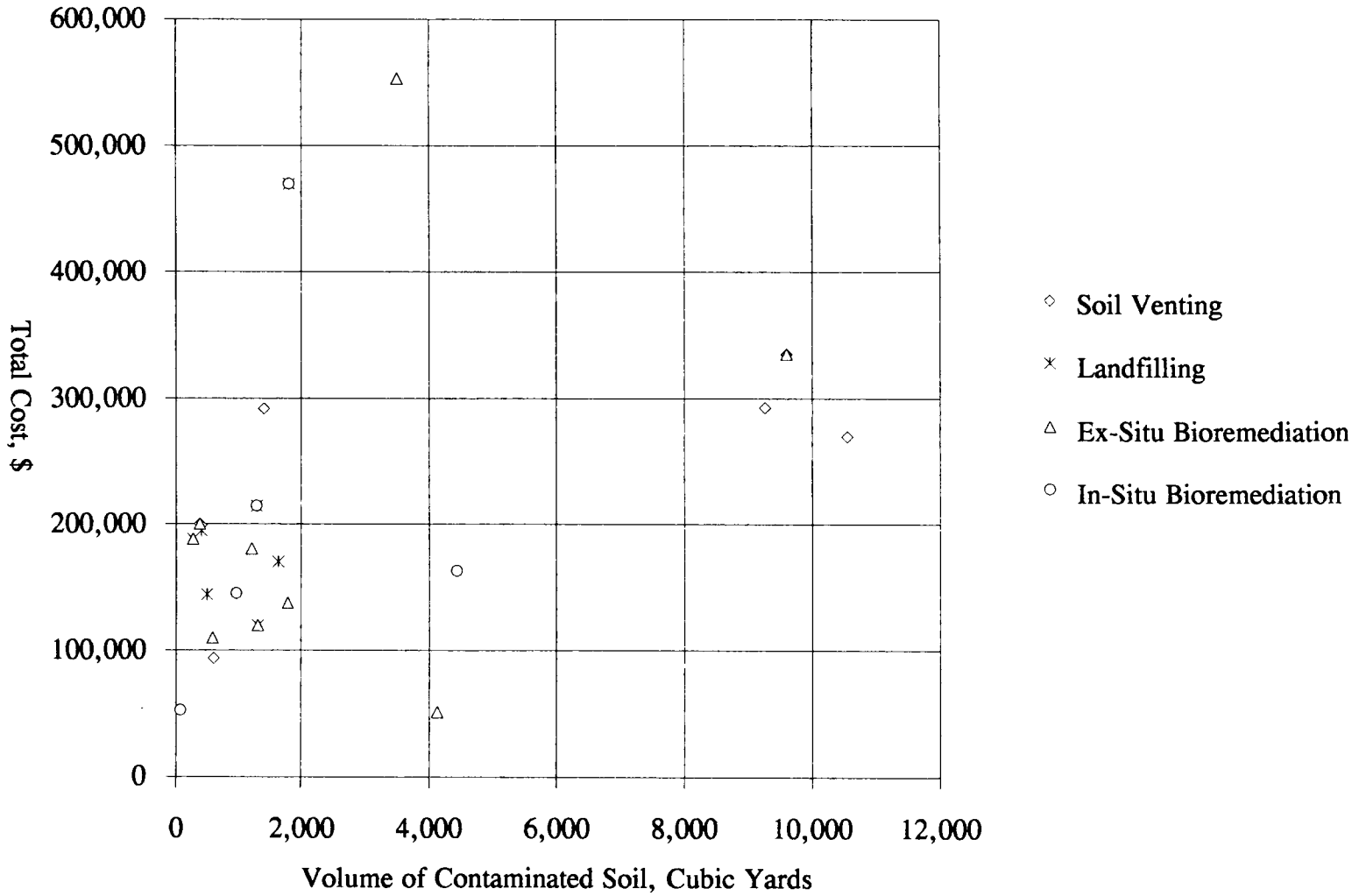


Figure 8: Total Cost vs. Volume of Contaminated Soil (up to 12,000 c.y.)

total cost of remediation and the amount of contaminated soil. No trends can be identified, partially due to the extremely variable costs in the site specific cases. The variable costs also explain the wide variations in cost analyses as shown in Figures 6 and 7. Another reason for the poor correlation between the total costs and the volumes of contaminated soil is the variability in the concentrations of pollutants as demonstrated by Figure 9. Two of the key parameters for selection of remedial technologies are concentration and extent of contamination.

Concentrations of pollutants and volumes of contamination are specific for each individual site, as shown in Figure 10. These two parameters were widely distributed among the sites in this study. Several sites with large volumes of contaminated soil were examined in this study, although these sites did not necessarily have high concentrations of Total Petroleum Hydrocarbons (TPH) in the soil. The TPH concentration includes both gasoline and diesel range organics. The extreme variability of volumes and concentrations of contaminants affected the correlations between total costs versus volume of contaminated soil and total costs versus concentration of TPH in the soil. The combined effects of concentration and volume of pollution produced a wide range of total costs for each individual parameter.

Figure 11 provides a summary of the different treatments which are affected by volatilization rates of contaminants. To determine the effect of the various types of petroleum contaminants on the total remediation costs, sites with lighter fractioned hydrocarbon contamination (gasoline) were compared to sites with heavier fractioned hydrocarbons (i.e. jet fuel, kerosene, waste oil, diesel). The "No Soil Treatment"

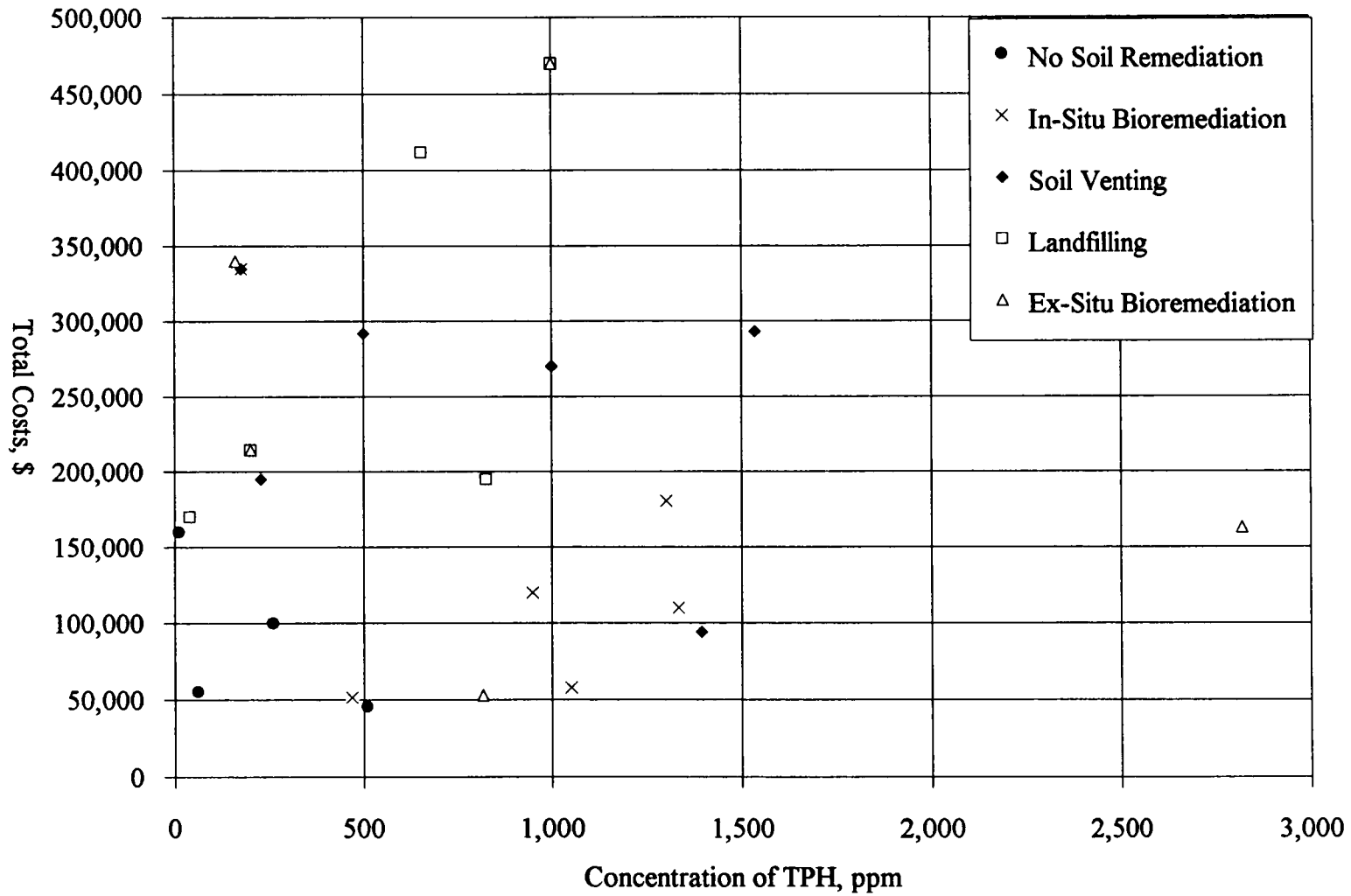


Figure 9: Cost vs. Soil TPH Concentration

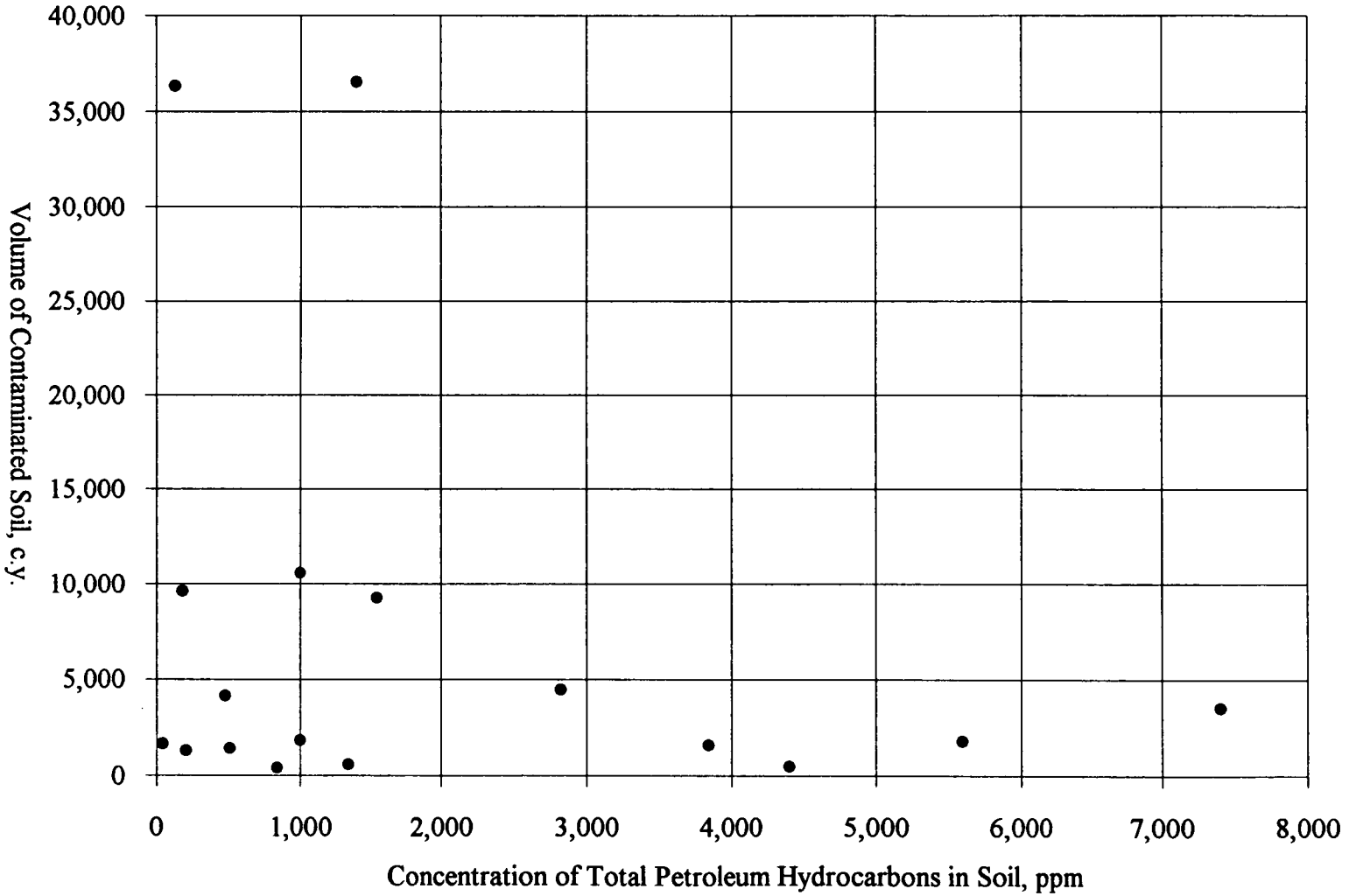


Figure 10: Soil Volume vs. TPH Concentration

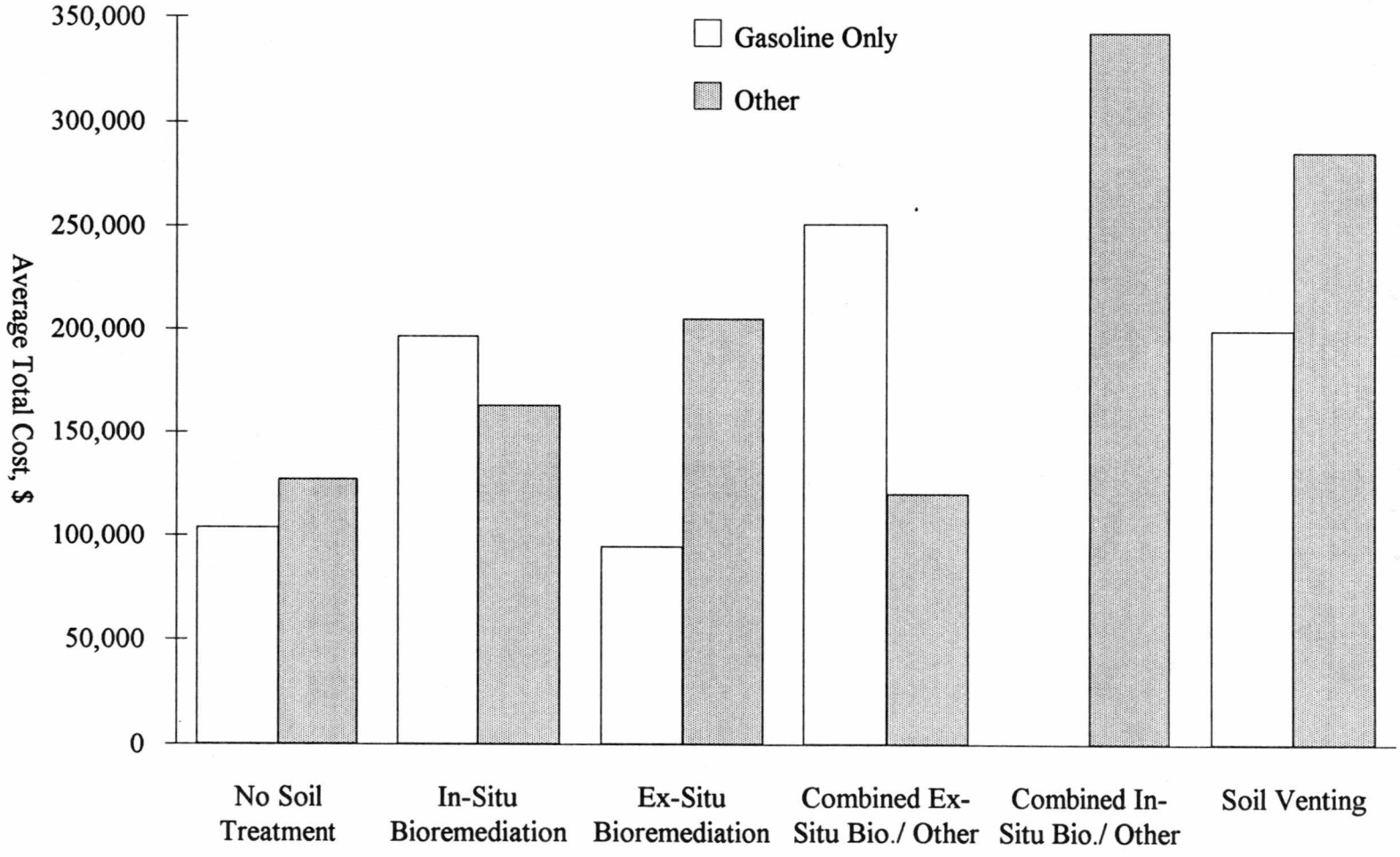


Figure 11: Effect of Petroleum Type on Total Costs

category establishes the baseline cost of site assessment, petroleum release investigation and confirmation, laboratory analysis and groundwater treatment, all of which are inherent in each of the other categories. The heavier petroleum fractions were more expensive to remediate for both the soil venting and exclusive ex-situ bioremediation sites evaluated in this study, as was the no soil treatment category. The faster rate of volatilization of gasoline than the other contaminating products or a mixture of gasoline and another product is the cause of this difference. The combined ex-situ bioremediation/other technology category exhibited the opposite effect, although there is no apparent reason for this. The percentage difference between the remediation costs of gasoline and the heavier fractioned products was smaller for the sites which utilized in-situ bioremediation in combination with other treatments, however, the effect of differing rates of volatilization are evident in Figure 11.

As the remediation technologies mature, research and development costs are reduced and the remediation itself is in the process of becoming a product or commodity that is driven by price. Therefore, a downward trend in the average cost of remediation between consecutive years was expected and observed, as shown in Figure 12. Competition between manufacturers of remedial equipment as well as between environmental consulting firms has increased over the last five years. The regional distribution of the 16 consultant companies involved in the development of corrective action plans for each of the study sites is shown in Figure 13. As the working knowledge of the firms becomes more concrete in their respective regions, the companies naturally tend to restrict their selection of technologies to those that they

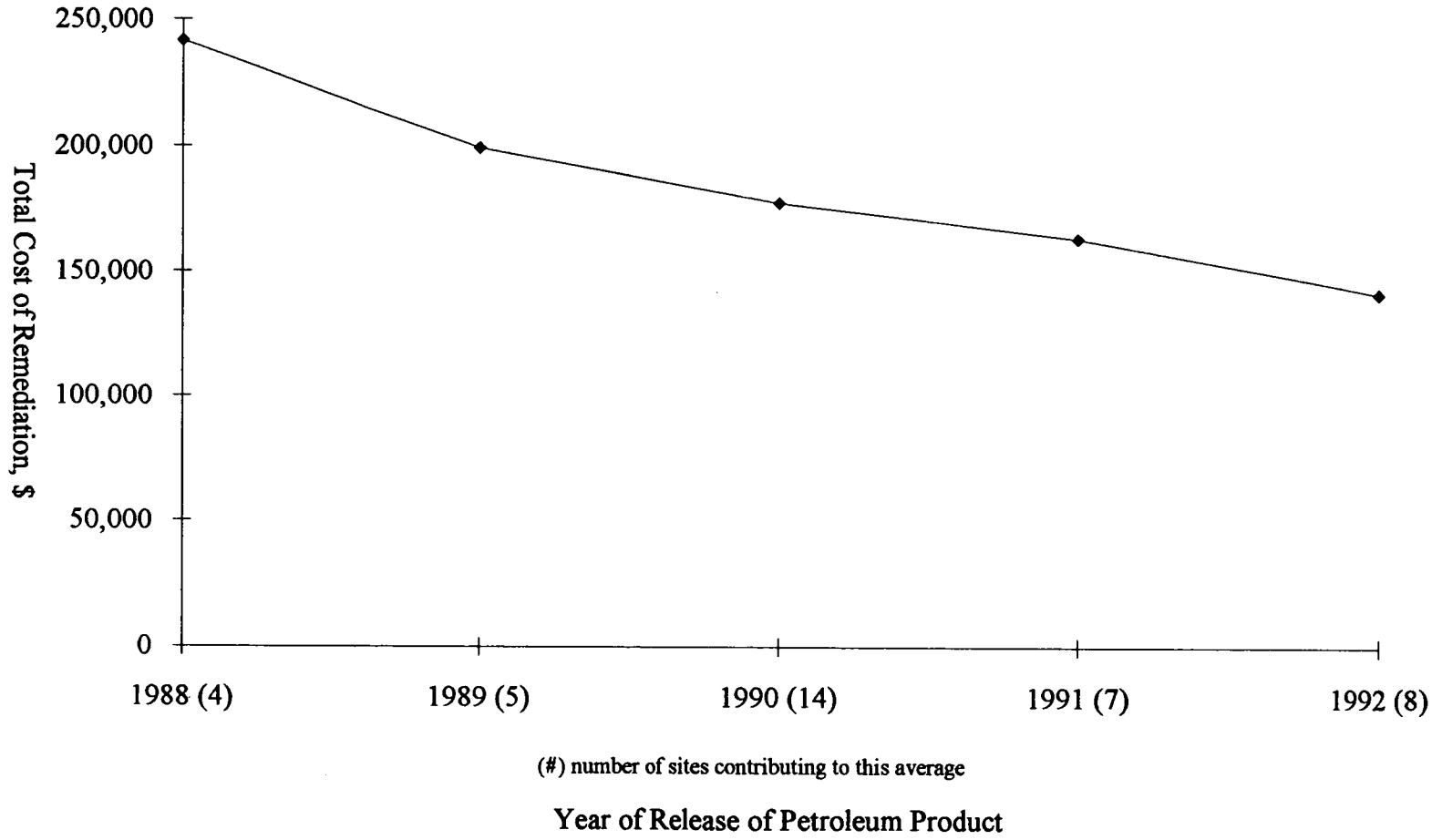


Figure 12: Year of Release of Petroleum Product vs. Average Total Cost

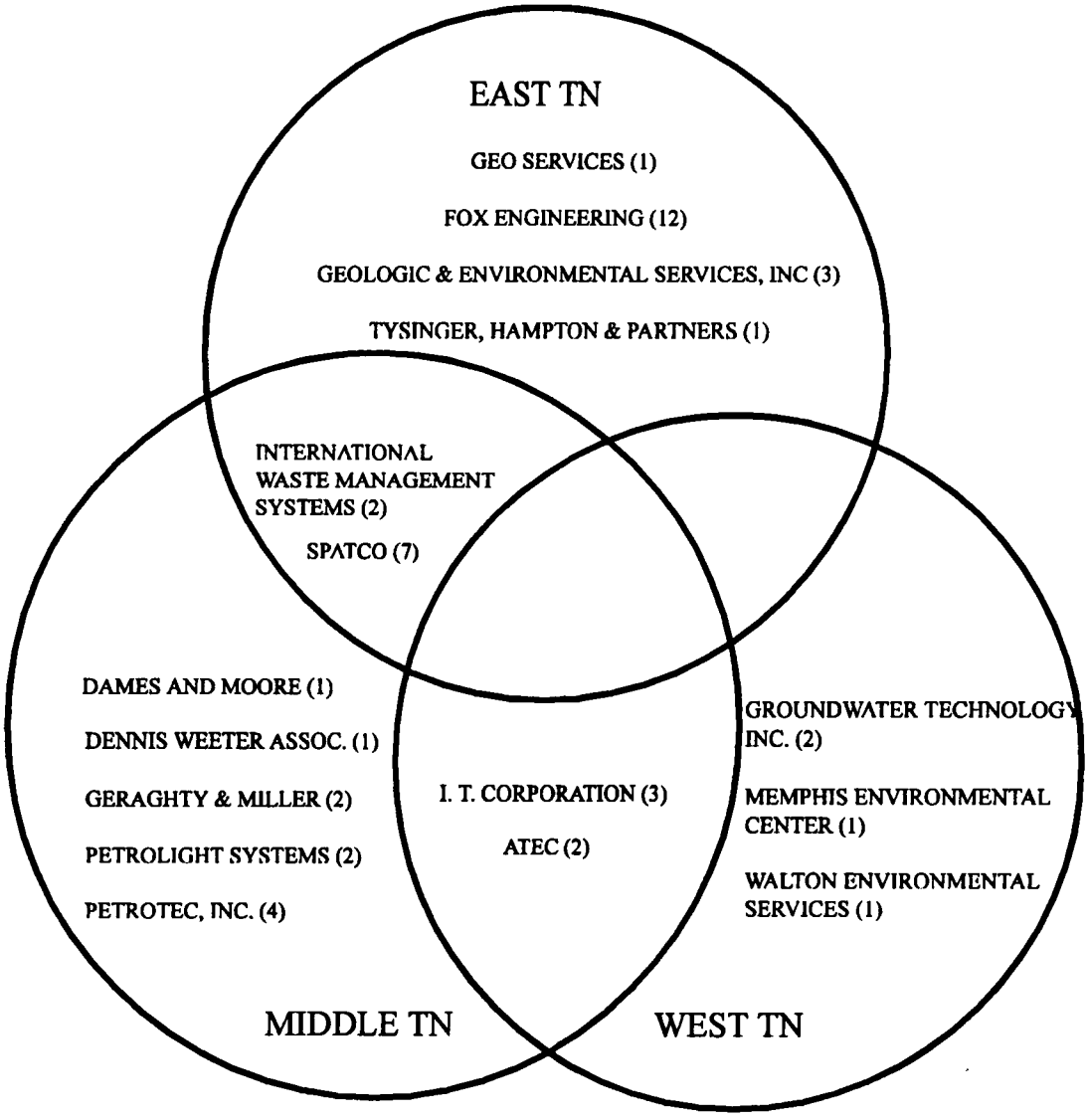
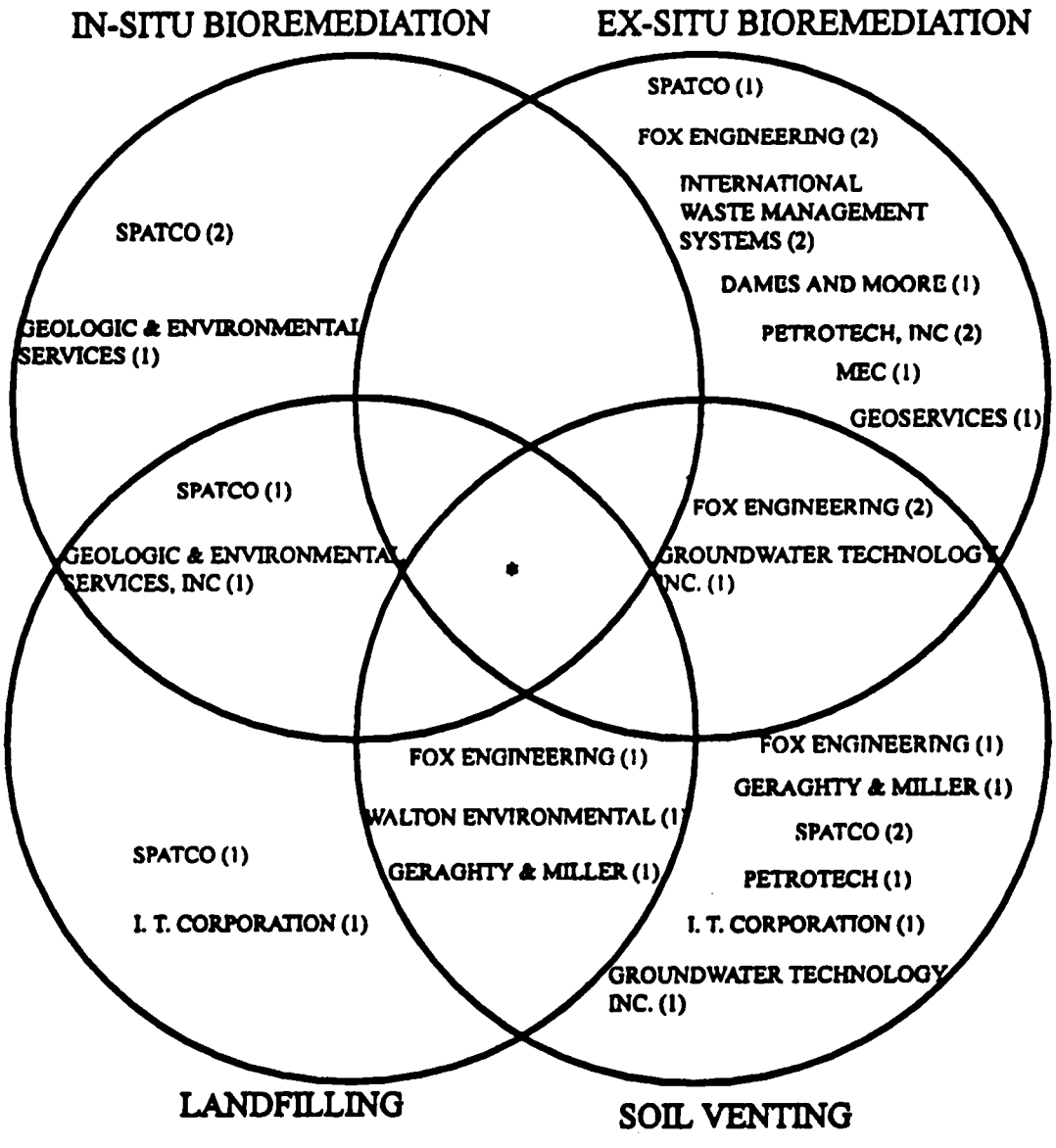


Figure 13: Environmental Consultants Involoved in this Study by Region.

have successfully utilized in the past. While this helps to drive the final cost of the remediations down, it limits the overall number of different technologies that are employed by the various consultants.

Figure 14 depicts the remediation combinations chosen by consultants. Only two of the sixteen subject consulting companies used in-situ bioremediation exclusively, while seven companies employed ex-situ bioremediation exclusively. A total of thirteen sites were remediated by bioremediation alone. Seven sites were remediated by bioremediation in combination with other technologies, under the direction of five of the sixteen consultants. Three consultants utilized a combination of soil venting and landfilling at a total of three different sites. It may not be readily apparent that combination technologies are often the most economically effective alternative. For example, close-to-source contamination concentrations may be relatively high and make less expensive technologies impractical due to time constraints or technical ineffectiveness. As contamination concentrations decrease with distance from the contamination source, the same low cost technologies may be used with great success. A total of ten sites were remediated by combination technologies. The remaining 35 sites in this study were remediated by one technology exclusively. The remediation costs were examined on a regional basis. The average cost for each of the three regions of Tennessee is shown in Figure 15. The arithmetic average for the middle Tennessee site is biased by the inclusion of the atypical American Airlines site. Without that site, the average middle Tennessee remediation cost is $180,000, which makes remediation costs very similar for all three regions. Local geologies

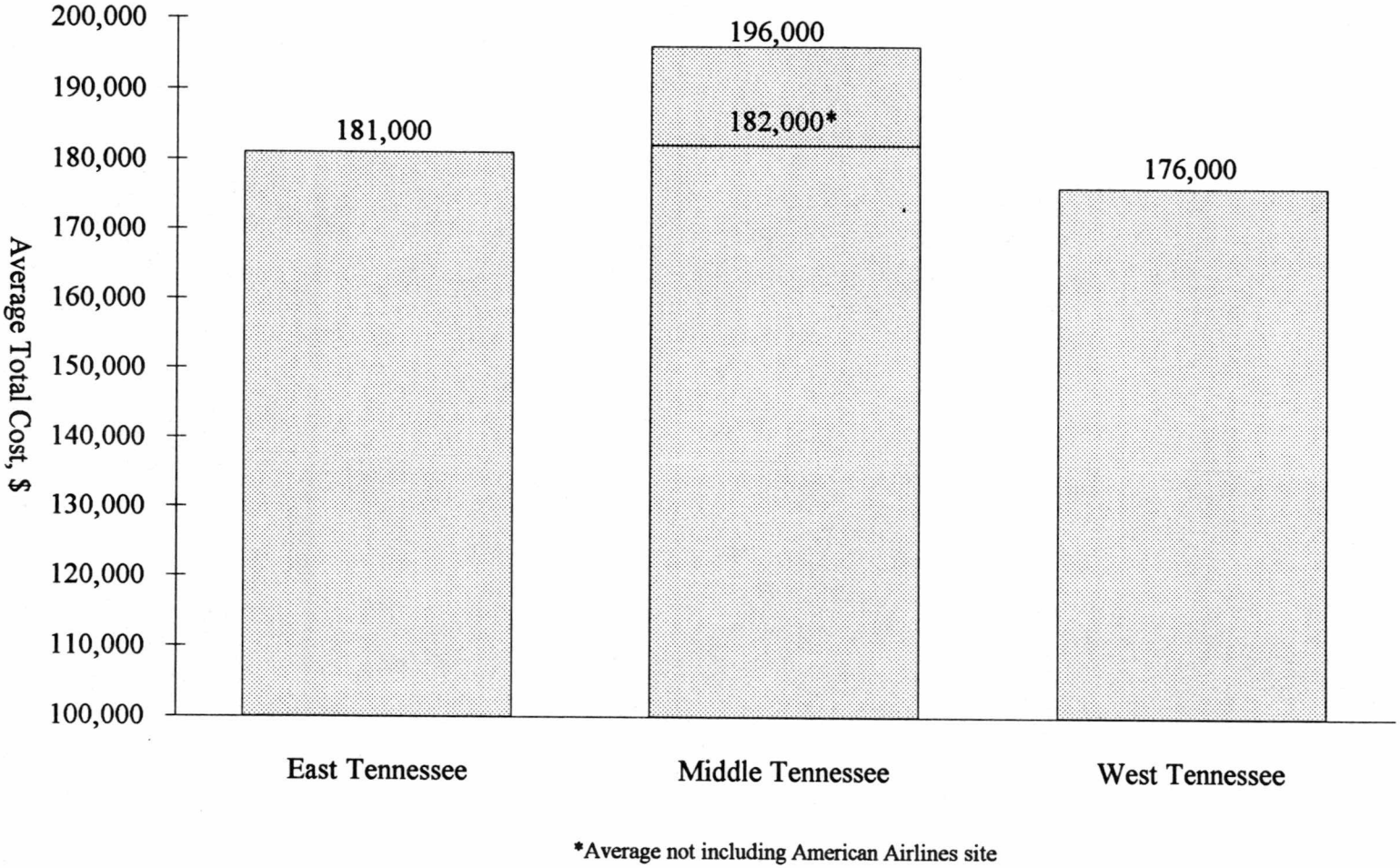


• OTHER COMBINATION
LANDFILLING & EX-SITU BIOREMEDIATION:
GEOLOGIC & ENVIRONMENTAL SERVICES (1)
DENNIS WHEETER & ASSOCIATES (1)

(#) Number of sites using that technology combination

Figure 14: Remediation Combinations Chosen by Consultants

were assumed to be a large contributing or in the average costs for the different regions. The geology of western Tennessee is much different than the geologies in middle and eastern Tennessee. Characterized by alluvial silts and deep sands, western Tennessee geology should allow contaminants to spread more evenly than the Karst terrain which is predominant in the geology of middle and eastern Tennessee. The expected geological effect was not evident in these analyses. The relative smallness of UST sites compared to hazardous waste sites may be contributing to the similarity in costs of UST cleanup projects in all three regions. The same technologies are used to clean hazardous waste sites as are used for cleaning UST sites. Larger differences in costs that are attributable to local geologic differences might be better demonstrated by larger hazardous waste sites than UST sites. There are certain costs which are built into every contaminated site. It is suspected that these large built in costs are diminishing any difference in regional costs which might be caused by geological differences. The similarity of costs across the three regions implies that industrial competition extends beyond regional boundaries. Beyond the scope of this study, it is evident that a number of consulting companies and suppliers work in at least two of the three regions of Tennessee and several work in all three regions.



*Average not including American Airlines site

Figure 15: Average Total Costs by Region

CONCLUSIONS

The low-tech remediation methods of in-situ or ex-situ bioremediation, or landfilling proved to be the least expensive of any of the examined treatments or combinations of treatments on a total site cost basis. Analysis of the average total remediation costs indicated that these three technologies contribute to a lower overall site remediation cost than all of the other treatment schemes. The average total costs for sites using in-situ or ex-situ bioremediation, or landfilling were very similar, at around $185,000. The relatively low costs of ex-situ bioremediation and landfilling may be due to rather simplistic conditions associated with sites using these technologies exclusively. The reasons for lower ex-situ bioremediation costs include inexpensive design and equipment for remedial systems, and the use of this approach at sites with relatively small volumes of soil contamination. Average total costs ranged from $183,000 for ex-situ bioremediation or landfilling to $342,000 for combination treatments involving in-situ bioremediation. The high cost of remediation by in-situ bioremediation and traditional technology combination may be attributed to the complex nature of sites which would typically employ such a combination of treatments.

Although bioremediation has the advantage of destroying the pollutant without creating a harmful substitute, only the ex-situ bioremediation process seems to be used frequently in Tennessee. Naturally, site specific conditions help to dictate the selection of a remedial alternative. A common problem at sites is the need to conduct remediation without excavating large volumes of soil. The in-situ technology of soil

venting appears to have been more frequently used than in-situ bioremediation in Tennessee. One possible cause for this is that consultants tend to recommend technologies with which they are most comfortable. The lack of published field data for in-situ bioremediation enhances the reluctance to use that technology.

Most UST sites have not only contaminated soil but contaminated groundwater also. The inclusion of several sites which had only groundwater contamination provided the means to determine the average cost of $111,000 for all other activities and equipment used for soil remediation. The additional costs included environmental assessment work, groundwater remediation, and laboratory analyses. These baseline costs allowed the cost comparison of soil treatment alternatives for an average site with both soil and groundwater contamination. Average costs for soil remediation without the baseline costs were approximately $72,000 for sites using ex-situ bioremediation and sites using landfilling, and $100,000 for sites employing soil venting exclusively. The averages for total costs of sites using combination technologies were higher in cases of multiple technology selection. The average total cost of sites using ex-situ bioremediation and traditional technologies was $114,000 not including the baseline cost. Sites employing in-situ bioremediation in concert with a traditional technology averaged $231,000 for soil remediation alone. Groundwater contamination probably impacted the in-situ bioremediation costs by more than the baseline cost because of the need for well defined plumes of contamination to institute in-situ approaches.

Because the in-situ initial equipment costs somewhat fixed and proportionally

high to the total cost, in-situ costs are fairly consistent regardless of contamination volume. This is not the case with alternatives which depend on excavation and transportation of the contaminated soils. The analysis conducted to analyze the cost per cubic yard, (unit cost analysis), indicated that at in-situ bioremediation was the most economical alternative. This number did not provide statistically sound data point because there was only one piece of data available for this average. Ex-situ bioremediation was expected to be the most economical alternative after excluding a baseline cost for everything except soil remediation. However, the equipment intensive soil venting treatment appears to be as cost-effective as ex-situ bioremediation, based on the unit cost analysis of these sites. The unit cost analysis may have an error which may be associated with removing the baseline cost from the total site cost or because there were not enough data points to produce statistically sound results. The combined treatments of in-situ or ex-situ bioremediation with a traditional technology were very consistent on average cost per cubic yard, at around $140/cy. It is likely that the unit cost analysis is not valid because of a lack of contaminant volume information. Analysis of exclusive technology sites did not appear to produce statistically sound results.

Volatility rates have a definite effect on cost effectiveness of some soil remediation techniques. Obviously, the costs of sites using landfilling incineration for remediation should not be affected by the concentration or type of petroleum product. The success of soil venting, however, is very dependent on the concentration and volatility rates of pollutants. The ex-situ bioremediation process that is used by most

consultants, tilling fertilized soil on a quarterly basis promotes volatilization of contaminants as much or more than actual remediation, so that ex-situ bioremediation is also effected by volatility rates. This effect was shown in the analysis of gasoline versus other contaminants. Large differences in the average costs of remediating sites with gasoline contamination versus the costs of remediating sites with heavier fractioned petroleum products was well demonstrated in all of the analyses. Remediating gasoline contamination only was much less expensive than remediating the heavier fractioned products for exclusive ex-situ bioremediation and exclusive soil venting treatments. These two treatments are the most dependent of any of the treatment schemes on volatility rates. There was a pronounced reverse effect for sites using a combined treatment scheme involving ex-situ bioremediation and other technologies. It is suspected that the ex-situ bioremediation only comprised a small portion of the remediation scheme at those sites. The difference in heavy and light hydrocarbon remediation costs was evident in the no soil treatment category as well, implying that part of the difference may be caused by groundwater remediation costs.

It is apparent from the results of this study that the extent and concentration of contamination do not necessarily determine the cost of a site. The sites included on this study did not show any trend between volume of contamination and total cost or between concentration of contamination and total cost. Thus it must be assumed that site specific conditions play an important role in determining the total cleanup cost.

The level of competition in the remediation industry has steadily increased since UST remediation began. Increased competition and standardization of equipment

and techniques have resulted in the continually decreasing average total remediation costs from year to year. It is expected that the market will eventually become saturated with competitors. At this point, additional companies will not make a difference in the total remediation cost unless new, more effective technologies are developed.

The continual cleanup of additional sites has prompted many consultants to work beyond their local regions. As the regional boundaries are crossed, competition increases, further contributing to the decline in remediation costs. However, the reduced cost effect may be somewhat offset by the inefficiency associated with learning about the geology of a new region. When considering only typical sites (i.e. excluding the American Airlines site), the average total costs for each region were strikingly similar for the three regions of Tennessee. The average site remediation cost in Tennessee was approximately $180,000, regardless of region. This was not the expected result since the geology of eastern and middle Tennessee is much different from that of western Tennessee.

There appears to be a reluctance among most of the consultants in this study toward the use of in-situ bioremediation. In-situ bioremediation may have been used more frequently at non-study sites, but it is the author's opinion that there is not a widespread use of this technology across the state. Conversations with the employees of the Division of USTs confirm this supposition. A commonly used approach seems to be a combination of more than one technology. Integrated technologies were used for remediating the soil contamination at 22% of the sites. A number of other sites

utilized one technology for both soil and groundwater remediation. Consultants in general seem to be reluctant to continue the use of incineration and landfilling. Environmentally, this is a positive direction, because it eliminates the transfer of pollution from property-to-property or across media that occurs with landfilling or incineration.

Because so few of the sites across Tennessee had applied for final reimbursement from the State Trust Fund, incremental costs for each specific phase of the assessment and remediation process were unavailable. A future study would benefit from the availability of expenditures as additional UST site remediations are declared complete. New guidelines for UST remediations by the state Division of USTs have been developed for implementation in 1994. These guidelines should alleviate the problem of estimating contamination volumes. A larger amount of complete field data subjected to these same analyses will substantiate the cost effectiveness of the respective technologies. In this study a methodology was developed and implemented to compare remedial actions of contaminated sites. The same methodology is applicable to other types of waste than only petroleum contaminants. A more complete set of information could be subjected to the same types of analyses to produce broader results.

Although the results of this engineering cost analysis are inconclusive as far as determining the cost-effectiveness of conventional and innovative means of petroleum remediation, some general statements may be made about the trends observed for each of the technologies examined in this study. Because of the simplicity of the methods

associated with ex-situ bioremediation used at most of the sites in this study, this alternative is the most economical alternative of the four alternatives analyzed. The costs of the other three technologies were very similar. Incineration is a proven, though relatively expensive technology, that is seldom used because it appears to be cost ineffective.

This study demonstrated that biotechnologies are competitive solutions to soil contamination. Biotechnologies are gaining strength in the remediation arena as they become more proven and costs become more consistent and identifiable. Despite air emissions problems associated with ex-situ bioremediation, that technology is often a first step in remediating a contaminated site. It is the author's opinion that both in-situ and ex-situ bioremediation will be used more as engineers gain confidence in the technologies. This confidence will be gained as more sites are subjected to biotechnologies and results are analyzed and published.

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APPENDIX

	K	L	M	N	O	P	Q	R	S
1	GEOLOGY	COMPANY	SOILTPHPPM	SOILBTXPPM	WTPHPPB	WBENZENPPB	Total Cost	Cost/Vol	Total -Baseline Cost
2	shale, limestone	Fox Engineering	60.000	0.000	95666.000	7203.000	55400.00		
3	limestone, bedrock	Fox Engineering	1536.000	70.570	130628.000	10212.000	293000.00	32	182000.00
4	clay & rock fill, shale & ls	Fox Engineering	1200.000	1.708	18350.000	504.000	124000.00		13000.00
5	Nolichucky shale	SPATCO	2820.000	3.800	590000.000	624.000	163000.00	36	52000.00
6	Silt, clay, shale &limestone	SPATCO	1392.000	139.300	637.000	80000.000	94000.00	3	
7	clay, limestone, shale	Fox Engineering	175.000	10.000	78467.000	2191.000	335000.00	35	224000.00
8	silty shales, sandstone, clay	International Waste Mgmt. Systems	130.000	0.000	300.000	0.000	479500.00	13	368500.00
9	shale, siltstone ,limestone	Fox Engineering	4411.000	201.100	984250.000	4.000	144200.00	296	33200.00
10	clay, shale,sandstone & ls br	Geologic & Environmental Services	0.000	0.000	220.000	15.000	120000.00	92	9000.00
11	shales and limestone bedrock	Geologic & Environmental Services	1000.000	0.000	400.000	0.000	470000.00	261	359000.00
12		SPATCO	1333.000	0.000	365.000	0.028	110000.00	190	
13	clay, limestone fragments	Fox Engineering	258.000	0.925	590079.000	0.000	100000.00		
14	silty, sandy clays over ls	Fox Engineering	3839.000	613.000	809000.000	8030.000	150000.00	95	39000.00
15	shale	Fox Engineering	11.000	1.000	2530.000	6907.000	160000.00		49000.00
16	limestone, Karst	Fox Engineering	469.000	32.050	36000.000	2583.000	51400.00	12	
17	limestone	Fox Engineering	43899.000	9.750	493052.000	1143.000	51800.00		
18		SPATCO	0.000	0.000	0.000	0.000	145000.00	151	34000.00
19		Fox Engineering	0.000	0.000	125250.000	3900.000	200000.00	541	89000.00
20		Fox Engineering	12500.000	166.000	962734.000	1017.000	160000.00		49000.00
21		Geologic & Environmental Services	160.000	260.800	0.000	0.000	340000.00		229000.00
22	Karst to bedrock sinkhole near	International Waste Mgmt. Systems	950.000	2.400	2010.000	1300.000	120000.00		9000.00
23	silty clay over limestone br	Dames & Moore	7400.000	0.000	0.000	0.000	553000.00	158	442000.00
24	loam over ls, shale, br @ 1.8'	Petrolight Systems	510.000	0.112	200.000	1.000	45800.00		
25	Clay over limestone	Petrotech , Inc.	5592.000	0.000	1440.000		137500.00	77	26500.00
26	alluvial deposits over ls br	SPATCO	200.000	0.217	208000.000	0.000	214500.00	167	103500.00
27		Geraghty & Miller Inc.	227.000	19.100	4.700	71.300	195000.00		84000.00
28	limestone, bedrock	Geraghty & Miller, Inc.	656.000	31.600	392000.000	9960.000	412000.00		301000.00
29		SPATCO	39.000	0.290	126250.000	3900.000	170000.00	105	59000.00
30	silty limestone	Petrotec, Inc.	0.000	0.000	41.700	10.900	181000.00		70000.00
31	limestone, shale, alluvial dep	SPATCO	821.000	321.000	0.000	11.000	53000.00	791	
32	alluvial deposits over sands	Memphis Environmental Center, Inc.	0.000	0.000	10800.000	904.000	88000.00		
33	alluvial silts & sands, gravel	Groundwater Technology, Inc.	0.000	480.000	606000.000	4100.000	280000.00		169000.00
34	alluvial soils over sands	Groundwater Technology, Inc.	4500.000	1231.000	120000.000	19000.000	200000.00		89000.00
35	unconsolidated sediments	IT Corporation	0.000	0.000	169.200	0.000	75000.00		
36	loess over sands, clay lenses	Walton Environmental Services	0.000	0.000	0.000	0.000	290000.00		179000.00
37	clay and gravelly silt over ls, kar	IT Corporation	830.000	28.500	3100.000	360.000	195000.00	488	84000.00
38	sands and clay deposits	ATEC Associates, Inc.	0.000	0.000	64300.000	20000.000	121000.00		10000.00
39		Tysinger, Hampton & Partners	0.000	0.000	700.000	0.000	63600.00		
40		Dennis Weeter Associates	0.000	0.000	1090.000	5068.000	188000.00	696	77000.00
41	silty clays over bedrock	Petro-light Systems	0.000	0.000	#########	219.000	51300.00		
42		ATEC Associates, Inc.	0.000	0.000	33500.000	3110.000	200500.00		89500.00
43	surficial clay over limestone	IT Corporation	500.000	20.500	2.600	170.000	292000.00	209	181000.00
44	silty clay over bedrock	GEO Services	1300.000	0.000	0.000	0.000	180500.00	150	69500.00
45	silty clay over limestone	Petrotec, Inc.	1050.000	31.030			58000.00		
46	fill material over clay	Petrotec, Inc.	1000.000	0.000	20.100	2.500	270000.00	26	159000.00

	A	B	C	D	E	F	G	H
1	Number	FACILITY	SITENAME	DORELEAS	PETROTYPE	CONTAMINAT	FREEPROD	VOL. SOI
2	1	2050024	BROADWAY GULF (BP)	2/28/91	gas	gw	yes	0
3	2	2050161	PILOT OIL 208	5/21/90	gas/diesel	soil/gw		9259
4	4	2470044	BLACK OAK AMOCO	2/9/90	gas	gw	yes	0
5	5	2470048	BOWMAN TRANSPORTATION	5/1/90	diesel	soil/gw	no	4440
6	6	2470151	TOC RETAIL #303-40	6/1/90	gas	soil/gw	yes	36560
7	8	2470165	EAGLE DISTRIBUTING CO.	6/8/90	gas	soil/gw	yes	9600
8	9	2470341	JFG COFFEE CO.	9/12/90	diesel	soil/gw	no	36350
9	10	2470427	LAY PACKING COMPANY	10/24/91	gas/diesel	soil/gw	no	487
10	11	2470599	AIRCO, INC.	6/14/91	gas/diesel	soil/gw	no	1305
11	12	2470660	GOLDEN GALLON #142	4/5/91	diesel	soil/gw	no	1800
12	13	2470742	RISH EQUIPMENT	7/30/90	waste oil	soil/gw	no	580
13	14	2470776	PILOT OIL #191	3/26/91	gas/diesel	gw	no	0
14	15	2470779	PILOT STATION #214		gas	soil/gw	yes	1575
15	16	2470784	PILOT STATION #219	9/28/89	gas	gw	yes	0
16	17	2470808	WIEGEL'S #29	9/30/90	gas	soil/gw	no	4130
17	18	2470897	PILOT STATION #173	4/11/91	diesel	soil/gw	no	
18	19	2620089	MR.ZIP #515		gas	soil/gw	no	960
19	20	2780070	GREEN'S GROCERY	2/16/91	gas	soil/gw	no	370
20	21	2780136	STACY'S GULF	7/17/90	gas/kero	gw	yes	0
21	23	3330338	GOLDEN GALLON STORE #117		gas	soil/gw	yes	
22	26	4890132	WARREN COUNTY HWY GARAGE		gas/diesel	soil/gw	no	
23	28	5190015	AMERICAN AIRLINES		jet fuel	soil	no	3500
24	29	5190055	AUTOW TRUCK LEASING	12/4/90	gas/diesel	soil/gw		
25	30	5190168	CLAYBROOKS TEXACO	10/31/92	gas	soil/gw	no	1778
26	31	5190770	TRANSCO LEASING	12/10/90	diesel/waste oil	soil/gw	yes	1285
27	32	5190870	DELTA EXPRESS #1025	1/16/89	gas	soil/gw	no	
28	34	5750060	DELTA EXPRESS #1020	7/27/88	gas/lead	soil/gw	no	
29	35	5750335	INTERSTATE SIXTY-SIX	1/28/92	gas/diesel	soil	no	1620
30	36	5830217	STOP AND BUY #1		gas	gw	yes	0
31	37	5830242	JR FOOD STORE #54	7/17/89	gas	soil/gw	yes	67
32	38	9790322	FISHER STEEL CORPORATION	7/17/90	gas/diesel	gw	no	0
33	39	9790775	UNOCAL	8/1/88	gas	soil/gw	yes	
34	40	9790779	UNOCAL	8/1/88	gas	soil/gw	yes	
35	41	9791224	DELTA EXPRESS 3002	8/30/88	gas	gw	no	0
36	42	9791440	OIL CITY USA	4/20/89	gas/ wo	soil/gw	yes	
37	44	6020036	DELTA EXPRESS #1086	2/15/92	gas	soil/gw	no	400
38	45	7030013	DELTA EXPRESS #3130	4/13/92	gas	gw	yes	0
39	46	1100110	T.A. DUGGER SCHOOL	3/14/92	gas	soil/gw	no	
40	47	4180029	E-Z STOP MARKET #5	5/5/92	gas	soil/gw	yes	270
41	48	5190765	TLC CARWASH	1/10/92	gas	gw	no	0
42	49	5190874	DELTA EXPRESS #1040	5/28/92	gas/kero/wo	gw	yes	0
43	50	5191878	DELTA EXPRESS #7456	5/14/89	gas	soil/gw	yes	1400
44	51	2320370	MORRISTOWN MUN. AIRPORT	3/7/90	jet fuel	soil	no	1200
45	53	5940094	KIRBY'S TEXACO		gas/diesel	soil	no	
46	54	5950079	INTERSTATE BP		gas	soil/gw	no	10555

	I	J
1	SREMEDPROC	GWREMEPROC
2	none required	air stripping, discharge to sewer
3	vertical soil venting	air stripping, discharge to sewer
4	none required	air stripping
5	Overexcavation, reinjecting treated groundwater, use of surfactants	Pump and treat, air stripping, carbon adsorption, reinject gw, dispose to sewer
6	soil venting	pump and treat, oil/water separator, dispose to sewer
7	soil venting, excavation & mechanical aeration, bio-enhancement	air stripper, pump & treat in gw restoration unit
8	Excavation, ex-situ bioremediation, use of fertilizer	Pump directly to sewer
9	soil venting w/ carbon adsorption, incineration of excavated soils then landfilled	pump & treat in gw restoration unit, air stripping, dispose of the water in sewer.
10	excavated soil was aerated & landfilled	quarterly monitoring
11	initially overexcavated & landfilled, then soil flushing	extraction well, cycled pump & treat w/ oil/water separator & filtering
12	initially soil overexcavated, placed on plastic	extraction well, Pump & treat, oil/water separator. filtration & carbon adsorption
13	none required	air stripping, discharge to sewer
14		pump & treat, oil/water separator, air stripper
15	none required	pump & treat, air stripper, series of recovery pumps set in monitoring wells
16	excavated & aerated, nothing further necessary	pump & treat, air stripping, discharge to sewer
17	excavation & aeration	pump & treat, air stripping, discharge to sewer
18	*closed in place, insitu treatment, vapor extraction & forced volatilization	pump & treat, air stripping, carbon adsorption, discharge to an upstream surface strea
19	soil venting, excavation and aeration	pump and treat
20	none required	recovery by trench and well system
21	soil flushing, biostimulation by adding nutrients & oxygen	pump and treat, oil/water separator, tray aeration, carbon filtration, reinject partially
22	overexcavation, mechanical aeration w/ fertilizer	pump and treat, airstripping, discharge to sewer, dispose of 3061 gal to Phillips
23	Excavation and stockpiling for biological decomposition within biocells.	none required
24	None required (TPH in sample is from coal deposit.)	Quarterly monitoring
25	Metabolically treated off site	Pump and dispose
26	insitu soil leaching w/ carbon ads. bioremediation w/ surfactants, 950 c.y. landfilled	pump and treat w/ oil/water separator and carbon adsorption, initial disposal @ greent
27	soil vapor extraction system	pump and treat, air sparging, dispose to POTW
28	vapor removal system, excavation & aeration, landfill	pump and treat, air stripping & discharge to sewer
29	excavated and landfilled	pump and treat
30	None required	pump and treat, activated carbon, nutrient mixture, peroxide reinjection
31	overexcavate, matl under plastic, biotreatment by soil flushing	pump and treat, air diffusion, activated carbon filtration, discharge to NPDES point
32	initial overexcavation, stored without a plastic cover, nothing further required.	pump directly to sanitary sewer.
33	excavation, aeration, proposed in situ vapor extraction	pump and treat, air stripping, discharge to sewer
34	vapor extraction, soil venting	pump and treat, airstripping, discharge to sewer
35	none required	pump and treat, discharge to sewer
36	vapor extraction system with french drain, partial excavation and landfill disposal	pump and treat, air stripping, activated carbon, dispose to sanitary sewer.
37	initial overexcavation, stored under plastic, landfill	pump and treat, air sparging, effluent to sewer
38	none required	pump and treat, oil/water separator, air stripping
39	none required	change standards, none required
40	initial overexcavation, disposal	NDW standards, tray air stripper, inject hydrogen peroxide, reinject clean gw
41	none required	NDW standards, activated carbon filtering system, oil/water separator
42	none required	NDW standards, pump and treat, air stripper/sparging system
43	soil venting	pump and treat, air stripping, discharge to POTW or NPDES
44	excavated, aerated mechanically and wasted on site	none required
45	overexcavation, place on plastic, add nutrients, mechanical aeration	none required
46	soil venting	in-situ bioremediation, addition of nutrients and oxygen, reinject water

VITA

Helen Rene Smith was born in Johnson City, Tennessee on September 14, 1969. She grew up on the Smith Dairy Farm in Conklin, Tennessee. She attended West View Elementary School in Limestone, Tennessee and graduated from David Crockett High School of Jonesborough, Tennessee in May, 1987. The following August she entered East Tennessee State University, where she completed two years of liberal arts classwork before transferring to Tennessee Technological University, in Cookeville, Tennessee. Helen worked at the engineering firm of Tysinger, Hampton & Partners, in Johnson City in the summers. She received the degree of Bachelor of Science in Civil Engineering from Tennessee Technological University in May, 1992. She entered the University of Tennessee, Knoxville in August, 1992 and in May, 1994 received a Master of Science in Environmental Engineering.

She is presently employed as an environmental engineer at International Waste Management Systems, a division of Environmental Systems Corporation, in Knoxville, Tennessee.