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Petroleum Cleanup in the United States:

A Historical Review and Comparison of State Programs

by

Timothy A. Terwilliger

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Environmental Engineering
Department of Civil and Environmental Engineering
College of Engineering
University of South Florida

Major Professor: Audrey D. Levine, Ph.D.
L. Donald Duke, Ph.D.
Robert Gan, Ph.D.

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Keywords: gasoline remediation, underground storage tanks, government efficiency,
progress evaluation, government performance

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Dedication

I would like to dedicate this thesis to my wife, Leigh, and my children, Haley and Zachary Terwilliger. For my wife's encouragement, understanding, and, at times forceful, support in handling the daily activities of a family and allowing me sufficient time to ponder these thoughts and conduct endless research, and my children's understanding that "daddy can't play right now; he has do some research", I am forever grateful. Without their support, I would not have been able to complete this milestone.

Additionally, I would like to dedicate this work to all of those people involved with petroleum cleanup. Given the multitude of environmental impacts across the US, thousands of people require an understanding of the numerous factors involved in petroleum cleanup. If the information contained herein gives insight to one person enabling that person to more completely address a petroleum cleanup project, then I have fulfilled my purpose with this thesis.

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Acknowledgements

I would like to first thank my major professor, Dr. Audrey D. Levine, for her guidance and tireless effort in keeping me on track throughout this thesis project. Dr. Levine was one of the first professors I encountered at the University of South Florida in beginning my Master's Degree quest. For all of her encouragement and direction in focusing this thesis, I am grateful.

I appreciate the assistance of Dr. L. Donald Duke and Dr. Robert Gan, for providing insightful comments and direction during the preparation of this thesis. Thank you for your time and efforts in serving on my thesis committee.

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Lastly, I am very grateful to the three entities with which I have been employed since my Bachelor's Degree from the University of South Carolina. From working with the South Carolina Department of Environmental Health and Control, I learned important information regarding environmental regulations. From the two companies I have been employed with in Florida, Blasland, Bouck & Lee, Inc. and ARCADIS G&M, Inc, I have had many opportunities to complete various environmental cleanup, the bulk of which has involved petroleum cleanup. Without the support of numerous people in providing me the opportunity to explore and complete many petroleum cleanup projects, I would not have established my interest in this area.

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Petroleum Cleanup in the United States:

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ABSTRACT

Cleanup of leaking underground storage tank (LUST) sites has been a priority for the United States of America (USA) for more than 20 years due to the large number of sites, the potential harmful health affects associated with gasoline components and the fact that single owners may not have the ability to pay for cleanup of these sites. In June 2006, the US Environmental Protection Agency (EPA) reported that of the 459,637 confirmed releases from USTs that had occurred previously, 342,688 had been remediated, which leaves 116,949 sites yet to be completed across the USA. Petroleum cleanup programs tend to be managed at the State level; however, there are wide variations among State programs in terms of information access, risk perception and funding availability. While each of the Federal and State UST programs has evolved to meet specific requirements, there has not been a comprehensive comparison of the individual State programs.

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In this thesis, State petroleum cleanup programs across the USA are evaluated to determine similarities and differences in an effort to identify factors that affect petroleum cleanup progress. Many parameters enter the equation in determining petroleum cleanup effectiveness. Not only are the parameters of the State program operation important, but also the characteristics of each State, including drinking water source and perceived risk associated with petroleum contamination, factor into the determination.

A representative group of States and State petroleum cleanup programs were evaluated and the characteristics of States were compared to cleanup progress to determine factors affecting efficiency. Based on trend analysis the cleanup levels for toluene, ethylbenzene and total xylenes correlate directly to the cost of LUST site cleanup. For States with less perceived risk from petroleum contamination, the cleanup goals are less stringent; therefore, fewer resources and less time are required to complete site cleanup. Consequently, petroleum cleanup in States with less-stringent goals is achieved more efficiently. The knowledge of these drivers of efficient petroleum cleanup can be used to expeditiously pursue completion of the thousands of sites remaining across the USA.

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Introduction

Since the invention of the first fuel-powered vehicle in the early 1900s, the use of gasoline has increased steadily, prompting the need for production, distribution and storage of fuel. The first fuel production, distribution and storage facilities were designed and operated without regard to health and environmental concerns, such as contamination of drinking water supplies. The use of steel underground storage tanks (USTs) to store gasoline until the 1980s resulted in the unintended release of millions of gallons of gasoline to soil and groundwater. In light of the extensive environmental contamination, the tanks used to store gasoline have evolved from steel to fiberglass and from single-walled to doubled-walled.

Storage facilities vary in the types of construction material, liner material, and leak detection methods, depending on their physical size and whether they are owned and operated by major oil companies or by individuals. In addition, day-to-day operations at facilities and the potential for fuel spills and leaks from major terminals for bulk storage are vastly different than from small fueling stations with attached convenience stores or mechanic shops.

In the 1970s and 1980s, with a new awareness of health and environmental concerns, including detection of petroleum and byproducts in drinking water supplies, the

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US Environmental Protection Agency (EPA) began implementing a strategy to prevent releases and clean up sites where releases had occurred. The agency analyzed multiple pathways of releases, including releases to the soil, groundwater, surface water and air. Consequently, new requirements were implemented, including controlling the emissions from vehicles and detecting leaks from USTs, among others (USEPA, 2004a).

The increase in UST and leaking UST (LUST) regulation caused a demand for additional resources, including funds to conduct petroleum cleanup and government staff to enforce the regulations and review the cleanup progress. The review and enforcement of the regulations is served more efficiently by people closer to the problems, such as State- and County-level government agencies. With increased government oversight, review and enforcement, the percentage of confirmed releases that have achieved cleanup completion is 75%, over the past 22 years (1984 to 2006) (USEPA, 2004a). While this percentage is relatively high, petroleum cleanup progress needs to continue at an efficient rate to provide an end to the risks posed by petroleum constituents to human health and the environment.

An increase in government resources requires maintenance of the efficient use of those resources. An evaluation of the efficient use of government resources and a determination of potential improvements in efficiency to maintain progress toward the completion of petroleum cleanup is crucial. The subsequent sections of this paper attempt to provide insight into the methods used for efficiency evaluation and the progress many States have made toward completion of petroleum release cleanup.

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Objectives

The purpose of this thesis is to assess State petroleum cleanup programs and compare the drivers that affect program and cleanup progress including regulations, funding and technology. The overall goal is to determine the major factors affecting petroleum cleanup progress.

The specific objectives are:

1. Define effectiveness to allow comparison across State programs
2. Identify factors that positively and negatively affect cleanup progress
3. Compare State programs to delineate attributes that result in cost-effective and efficient petroleum cleanup.

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Approach

The Federal and State petroleum cleanup programs were researched and evaluated to achieve the objectives of this thesis. Previous research and available information were reviewed, critiqued, and summarized. The relative effectiveness of cleanup technologies and the availability and utility of guidance documents for conducting cleanup were assessed.

The overall study design consisted of four steps:

1. Evaluate the major elements of the Federal program, including the following:
    a. Objectives of the program
    b. Cleanup funding availability
    c. Funding source.
2. Compare the major elements of State programs to the Federal program and compare programs between States.
3. Evaluate features unique to the Florida Petroleum Cleanup Program (FPCP) to determine if uniqueness's enhance or obstruct cleanup progress and why.
4. Analyze key factors affecting cleanup progress.

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Federal Program Evaluation

Because more than half of the US follows the EPA program, evaluating the EPA program is key to understanding and comparing the petroleum cleanup programs in the 50 States. The parameters that were evaluated are: 1) objectives of the program, 2) source of funding, and 3) the amount of funding available. These data were used as a baseline when evaluating individual State programs.

State Program Evaluation

The background research included collecting key information about each State program, such as number of UST sites with releases, regulatory differences, groundwater cleanup goals, program setup details, success of the program based on percentage of sites "completed", etc. Additionally, one reason why State programs and goals vary is local conditions; therefore, specific variables such as drinking water source, soil type and cleanup regulations were researched. Finally, cleanup technologies were analyzed to determine whether one cleanup technology was more prevalent or more effective than another. A comparison of State programs was summarized and presented in tabular format, to allow ease of review. The main criteria presented include the funding amount, the number of UST sites known to be leaking, and the number of sites cleaned to date.

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Questions that were asked include the following:

1. Do environmental factors influence program effectiveness, (e.g., soil type, water supply source, etc.)?
2. Is one State program more effective than others, based on the percentage of cleanups completed in a chosen timeframe? If so, why?
3. Have State programs evolved based on whether cleanup progress has increased significantly throughout the life of the program?

Evaluation of the Florida Petroleum Cleanup Program (FPCP)

A thorough review of the Florida Petroleum Cleanup Program (FPCP) was conducted to provide baseline information on a strong State program. Factors evaluated were: the initiation and evolution of the program,the procedures used to begin and maintain progress toward LUST site cleanup, and the technologies used for cleanup. Criteria used to evaluate information include commonality, effectiveness and cost. Finally, the FPCP was compared to other State programs to determine similarities and differences, and evaluate whether the FPCP Program is more or less effective than similar State programs.

Statistical Analysis

Based on the data collected throughout this thesis research, an evaluation of the factors affecting petroleum site cleanup can be conducted using statistical tools. Several

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factors were analyzed to determine correlations and identify patterns which present useful conclusive information. The two-tailed unpaired t-test was used to evaluate the following relationships:

1. The average cleanup cost per site and the funding appropriations per number of releases
2. The benzene cleanup level and the percentage of sites completed
3. The benzene cleanup level and the effectiveness for each State.

Additionally, various data were plotted to determine correlations such as those between the following:

1. Fuel consumption versus funding appropriations, number of releases and percentage of sites completed
2. Average cleanup cost per site and individual, as well as grouped, cleanup levels for benzene, toluene, ethylbenzene, total xylenes, BTEX and MTBE
3. Government involvement level and percentage of sites completed.

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Background

Regulation and cleanup of LUST sites requires significant investment of resources, varying amounts of time and reliance on physical, chemical and biological treatment technologies. To ensure that petroleum cleanup programs are targeted at protecting public health and the environment, Federal and State regulations have been enacted over the past 20 years. The cleanup of petroleum contaminants requires design and implementation of technologies to remove contaminants or convert contaminants to benign compounds, coupled with monitoring and oversight. Defining effectiveness of a petroleum cleanup program depends on the difficulty of cleanup based on geology, size and make-up of contamination, and implemented technology, the resources of personnel and funding available and the age or maturity of the program. Initiation of petroleum cleanup requires an understanding of the risks associated with petroleum contamination, the chemical composition of fuel, the numerous programs and technologies used, and the effectiveness of those programs and technologies.

Birth of a National Issue

Increased fuel usage resulted in increased production and handling of fuel in various forms. While the composition of fuel varied slightly between producers, the

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main components of fuel remained similar. This increase is fuel usage with a variety of inconsistent operations, led to increased potential risks to water supply resources.

Fuel Consumption and Composition

Little variation exists nationwide in the methods used for production, distribution, and storage of gasoline. Fuel consumption varies, however, as needed by population density. Total US fuel consumption between the period of 1999 and 2004 is shown on Figure 1. In 2004, oil provided 34.3% of the world's energy supply, and the USA population consumed approximately 25% of this supply (IEA, 2006). The total fuel consumption over this time period decreased likely due to alternative fuel options increasing in popularity.

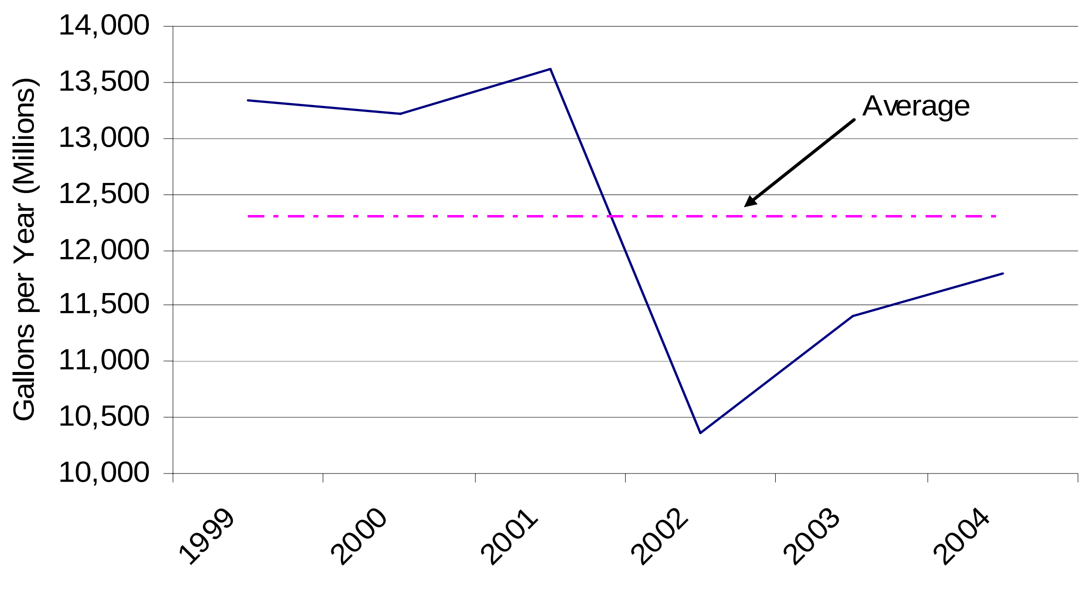

Figure 1. Total Annual US Fuel Consumption (Source: IEA, 2006)

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The 2004 distribution of fuel consumption across the US is summarized in Figures 2a and 2b. In general, population density drives the amount of fuel consumption as shown by the peaks in Figures 2a and 2b correlating to more populated States such as California, Florida, Texas, and New York.

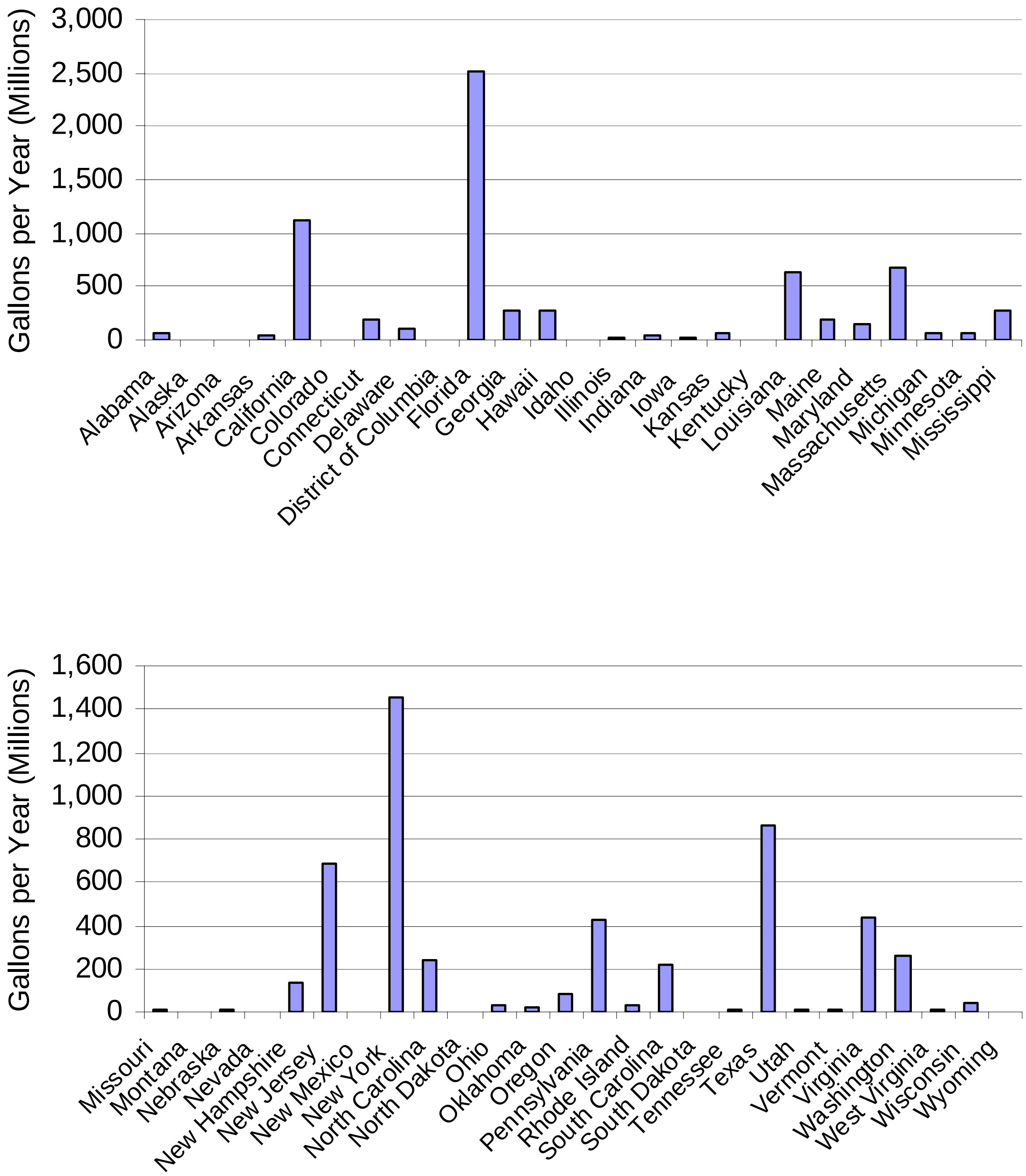

Figure 2. Fuel Consumption Per State in 2004 (Source, IEA, 2006)

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Gasoline, one of many petroleum products, is composed of numerous volatile and semivolatile organic compounds including benzene, toluene, ethylbenzene, xylenes (collectively BTEX), naphthalenes and ethylene dibromide. Originally, tetra-ethyl lead was added to gasoline to provide an octane enhancer. Following concerns with lead in engines, in 1979, methyl tert-butyl ether (MTBE) began to be used in gasoline to replace lead.

The concentrations of MTBE in gasoline increased from between 2 and 8 percent to as high as 15 percent in 1992, to accommodate the requirements of the Clean Air Act (CAA) Amendments of 1990, which set oxygenate requirements for gasoline (NSTC, 1997, AFCEE, 1999). These requirements included the Winter Oxyfuel Program and the Year-round Reformulated Gasoline (RfG) Program which dictate an oxygen concentration requirement of greater than or equal to 2% by weight in gasoline. The areas of the US with the highest concentration of toxic and ozone-depleting air emissions, such as highly-populated areas of California, Texas and the eastern coastline portions of New York, Pennsylvania and New Jersey, were required to implement the use of RfG. Due to widespread groundwater contamination involving MTBE, in 2006, Federal legislation amended the CAA to remove the oxygen concentration requirement (EPA, 2006a). Several alternative oxygenates are available for use such as ethanol, ethyl tert-butyl ether (ETBE) and tert-butyl alcohol (TBA); however, MTBE was widely chosen based on its low volatility, blending characteristics and economic appeal. From an economic perspective if MTBE is available at less cost, competitive sales of fuel with

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alternative oxygenates would be non-existent. The main compounds in gasoline have varying physical and chemical properties as summarized in Table 1.

Table 1. Physical and Chemical Properties of Select Gasoline Components

Compound	CAS Number	Molecular Formula	Solubility[2] (grams per Liter)	Henry's Law Constant [3] (dimensionless)	Maximum Contaminant Level (micrograms per Liter)
Benzene	71-43-2	C6H6	1.79	0.152	5
Toluene	108-88-3	$C_6H_5CH_3$	0.53	0.157	1,000
Ethylbenzene	100-41-4	$C_6H_5C_2H_5$	0.15	0.183	700
Xylenes[1]	1330-20-7	$C_6H_5(CH_3)_2$	Practically insoluble	0.155	10,000
Ethylene dibromide	106-93-4	$C_2H_4Br_2$	8.68	Not available	0.05
Naphthalene	91-20-3	$C_{10}H_8$	Insoluble	0.009	Not available
MTBE	1634-04-4	$CH_3OC(CH_3)_3$	50	0.017	Not available

[1] xylenes are composed of three isomers, ortho-, meta- and para-xyelene. The values presented are based on an average of values for all three isomers.
[2] Values collected from Wikipedia 2006
[3] Values collected from EPA online calculator (EPA, 2006b)

As shown, solubility levels and Henry's Law Constants, or affinity to the vapor phase versus the water phase, vary over two orders of magnitude. These physical and chemical properties affect removal of these compounds from contaminated soil and groundwater. MTBE, for example, is highly soluble in water and less volatile than BTEX, as indicated by the comparison of data in Table 1. MTBE has a Henry's Law Constant of 0.017 whereas BTEX constituents have Henry's Law Constants an order of magnitude higher, which indicates BTEX constituents have more affinity to the vapor phase than the water phase. This higher solubility and lower volatility of MTBE resulted

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in MTBE persistence in the groundwater for a longer extent (distance and time) than BTEX constituents. Therefore, remediation of MTBE contamination requires more resources (time and money) than BTEX. Consequently, the cleanup effectiveness is impacted by longer timeframes required to complete cleanup.

Water Supply Resources

Petroleum releases threaten the use of groundwater, a valuable resource in the US. In 2000, 85% of the US population was served by public water supplies. Of that 85%, approximately 37% was supplied by groundwater. Conversely, 15% of the US population relied on self-supplied water, of which 98% was supplied by groundwater. A comparison of the percentages of public-supply versus self-supply for each State is shown in graphical form in Figure 3. The percentages of groundwater versus surface water source for public-supply water are shown in Figure 4 (USGS, 2004).

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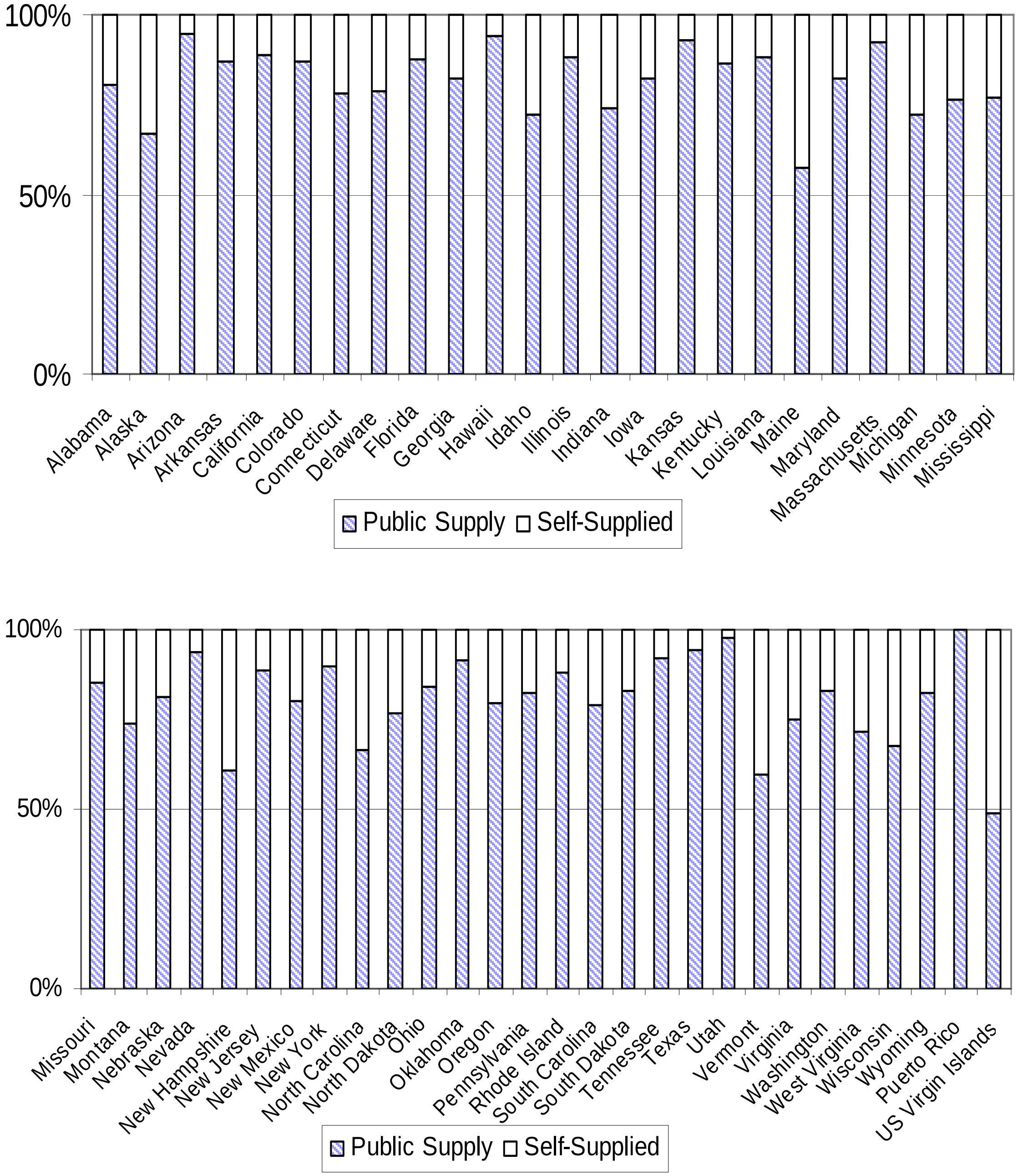

Figure 3. Public-Supply Versus Self-Supply in 2000 (Source: USGS, 2004)

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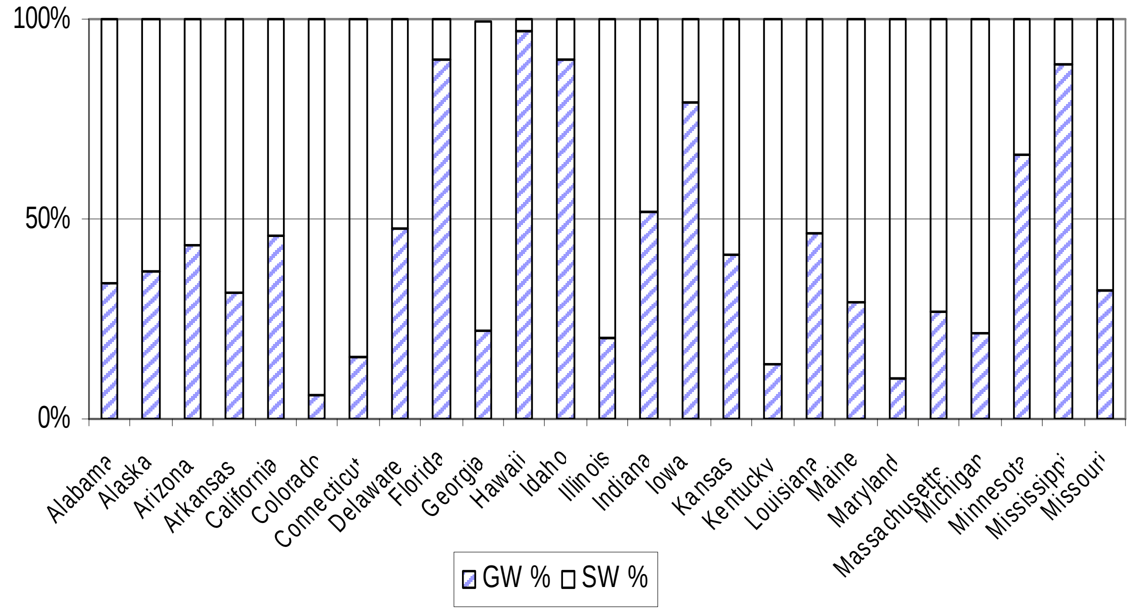

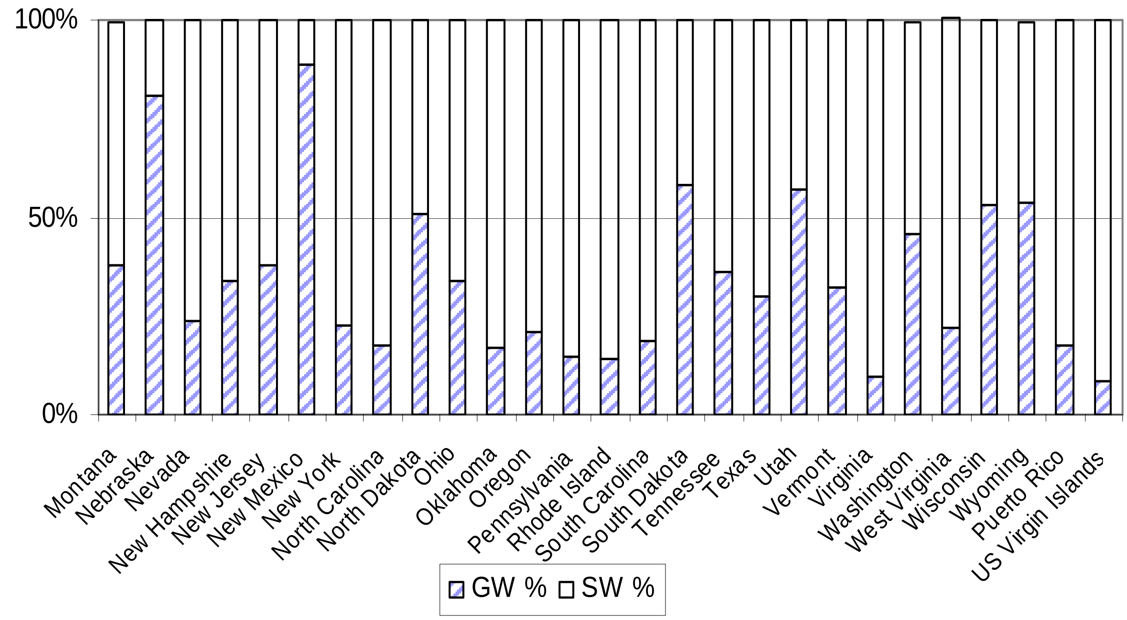

Figure 4. Public Supply by Source (USGS, 2004)

In general, public-supply is the main source of water for the population in most States and surface water is the main source of public-supply water. Groundwater resources however, supply approximately 46% of the population in the US, and therefore,

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threats to groundwater quality remain of concern. The US realized this fact in the early 1980s and began the initiation of a Federal program to address potential risks associated with LUSTs.

Federal UST Program

Cleanup of LUST sites has been a priority for the US for more than 20 years due to the large number of sites, the potential harmful affects associated with gasoline constituents and the inability of site owners to pay the high costs of cleanup. In 1984, the US Congress amended the Resource Conservation and Recovery Act (RCRA) to add Subtitle I which required EPA to establish regulations for USTs. The following year, the US EPA created the Office of Underground Storage Tanks (OUST), which remains in place today. The OUST began development of standards and rules to regulate the use of USTs. The regulations were required to address the operation and maintenance of existing USTs, the installation of new USTs and the cleanup of LUSTs. The regulations included standards such as testing the USTs and underground piping for tightness using pressurization of the USTs and lines, compliance monitoring and other leak detection methods, including inventory reconciliation. The OUST communicated with the owners and operators of UST sites, State and local officials, environmental groups, environmental consultants and companies such as McDonald's (EPA, 2004a).

The EPA conducted a survey of establishments around the US to attempt to determine the number of USTs in existence. Field verification and testing were

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conducted at a select number of the facilities to quantify the number of USTs, their general use (i.e., farm, gasoline station, etc.) and tightness testing results. Approximately 35% of the non-farm USTs tested, or 189,000 USTs, did not pass the tightness testing, which indicates a leak had occurred and/or was continuing to occur (EPA, 1986).

In 1986, the US Congress amended the RCRA, Subtitle I, to create the LUST Trust Fund (Fund). The Fund was created specifically to accomplish the following:

1. Oversee cleanups
2. Enforce cleanups
3. Pay for cleanups when the owner/operator was unwilling or unable to pay
4. Pay for emergency actions.

The US LUST Trust Fund was created to provide a 0.1 cent Federal tax on each gallon of motor fuel sold in the USA. EPA administers money from the LUST Trust Fund to assist with UST cleanup programs (EPA, 2004a). In some cases, individual States have an additional tax to supplement LUST funds and finance State cleanup programs for remediation of UST sites within the State.

The EPA OUST realized that the enormous task emplaced on the agency would require involvement from State governments. OUST used the approach of a business franchise for the implementation of the Federal UST program. Individual States could

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create their own processes, goals, etc.; however, the regulation of USTs would maintain a consistent approach based on the Federal UST program.

In 1988, the Federal UST regulations were promulgated and are located in the Code of Federal Regulations (CFR) Chapter 40, Part 280. UST operation and maintenance regulations included the requirement to install leak detection methods within five years, to close, upgrade or replace USTs within 10 years, and provide financial mechanisms to demonstrate the operator had the financial resources available to clean up leaks from their tanks. The regulations also set forth requirements to report leaks and begin cleanup of leaks.

Due to the abundance and distribution of UST sites, the EPA planned to have the UST program implemented by the States. The State programs have the option of either adopting the EPA requirements or implementing more stringent requirements for the operation and cleanup of UST sites.

The EPA approval of State programs depends mainly on the financial assurance mechanisms required of the owners/operators by each State. States submit their financial assurance program details for approval from EPA. If the State program meets or exceeds the requirements of the Federal program, the EPA approves the State program. Owners and operators located in States without EPA-approved programs have to meet Federal financial assurance requirements through other means, such as insurance, a letter of credit, bonds, etc.

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EPA published guidance for States making a transition from State Funds to alternate financial mechanisms (EPA, 1997). The guide provides information on State Funds that have made the transition to private insurance or other means, and summarizes data regarding State Funds that were making the transition in 1997. Based on the strain on resources certain States acquired by providing the financial assurance for LUST cleanup, such as cumulative reimbursement claims for more funds than the State Programs were receiving annually, the backlog of claims outgrew the available income the funds received. States such as Florida and Texas experienced this level of cleanup activity and claims and were forced to identify alternate means to pay the backlog of claims and maintain protection of human health and the environment. Texas has an EPA-approved UST program to act in lieu of the Federal program; whereas Florida does not have an EPA-approved UST program. Consequently, owners and operators in Florida need to comply with both the State regulations and the Federal regulations. The States' regulations generally are more stringent than the Federal regulations.

The LUST Trust Fund continues to receive money from a 0.1 cent tax on each gallon of fuel sold in the USA. In September 2005, the LUST Trust Fund had approximately $2.4 billion, of which the US Congress appropriated approximately $70 million for use by the program, which equals the amount the fund earns in interest each year. For fiscal year 2005, the EPA program had allocated approximately 85% of the annual appropriation to States and tribes (EPA, 2006a).

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The EPA OUST Program continues to track the status of UST regulations, UST compliance and LUST cleanup across the USA, administers grants from the LUST Trust Fund to provide assistance to States and tribal lands for LUST cleanup and funds initiatives such as technical training. During the fiscal year of 2006, EPA provided approximately $60 million for cooperative agreements to increase the number of cleanups initiated. Additionally, approximately $15 million was supplied for supplemental Hurricane funding for States in EPA Regions 4 and 6 (Gulf of Mexico States).

In June 2006, the OUST program reported that 63% of active operational UST systems are in compliance with release prevention and release detection regulations and requirements. According to results from June 2006, the number of confirmed releases is 459,637. Of these releases, approximately 430,000 cleanups have been initiated and approximately 342,700 cleanups have been completed, which represents approximately 75% (EPA, 2006a). The State programs, including 40 States, collectively accumulate and spend approximately $1 billion per year on LUST cleanup, separate from the LUST Trust Fund (EPA, 2006a).

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State UST Programs

Petroleum cleanup programs tend to be managed at the State level; however, there are variations among State programs in terms of information access, risk perception, funding availability, regulatory review and how efficiently cleanup of LUST sites is completed. Some States rely solely on guidance from the EPA for cleanup requirements. Several States, however, have highly-structured programs for petroleum cleanup that are more stringent than the Federal guidelines. While each of the State petroleum cleanup programs has evolved to meet specific requirements, and a comparison of various factors influencing program operation has been evaluated, a comprehensive comparison of the individual State programs has not been completed to date.

Programs in individual States are based on assessment of risks posed by LUSTs, the level of effort required to implement regulations and enforcement of regulations both for UST operations and LUST cleanup. Additionally, the level of support from the Federal program versus the State support factors into the decisions.

EPA encouraged the States to pursue creation of State petroleum cleanup programs based on the following ideas:

1. The size and complexity of the UST program requires numerous resources – much more than the EPA can provide alone
2. State and local agencies are located in close proximity to the individual sites

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3. State programs were required to be as stringent as the Federal regulations in order to act in lieu of the EPA.

Currently, 35 States plus the District of Columbia and Puerto Rico have approval from EPA for their UST programs (EPA, 2006a). The remaining States rely on alternate means for owners and operators to comply with financial assurance requirements, but maintain for the most part at least as stringent regulations for the installation, operation and maintenance of USTs and the cleanup of LUSTs. For those States without EPA approval, the EPA works with the States through grants or cooperative agreements and the State is the primary lead in the implementation and enforcement of the regulations. Approximately 40 States have UST cleanup fund programs. Appendix A provides a list of State program web addresses.

EPA-Approved Programs

EPA has approved 35 State Programs along with the District of Columbia and Puerto Rico. The approval mainly involves the confirmation that State regulations are as stringent as the Federal regulations, including the installation, operation and closure of USTs and the financial responsibility required to operate USTs. This thesis will discuss the characteristics of two EPA-approved State Programs in comparison to non-EPA approved States. A summary of the States with EPA-approved programs is shown in Figure 5.

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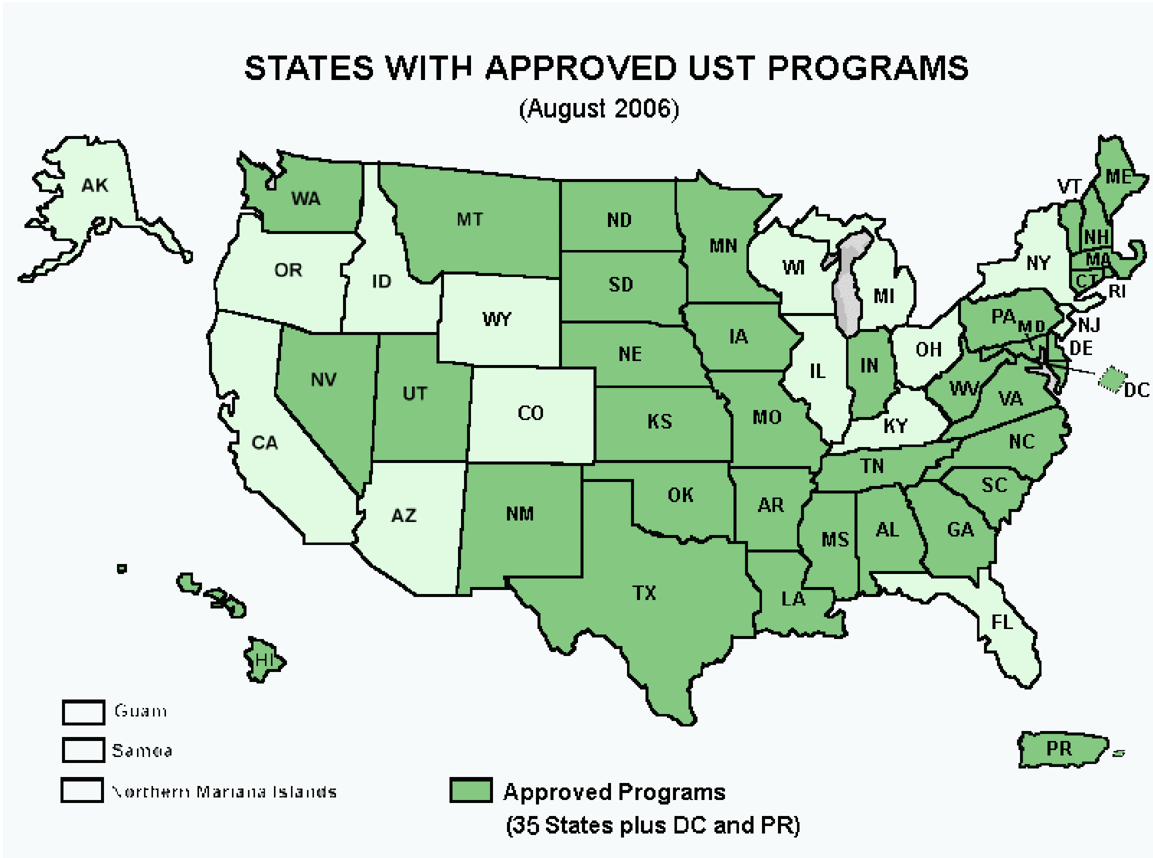

Figure 5. EPA-Approved Program States

Non-EPA Programs

Non-EPA approved State programs continue to operate under cooperative agreements or grants that provide the primary oversight in the enforcement of UST and LUST regulations. The main reason States do not have an EPA-approved program is the lack of a financial assurance mechanism to accommodate the Federal regulations regarding financial responsibility. Owners and operators in these States must show financial responsibility through other means, such as commercial insurance, a letter of credit or bond.

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Florida Petroleum Cleanup Program

The Florida Petroleum Cleanup Program (FPCP) is a unique, Non-EPA-approved program. The State of Florida passed legislation in 1984 requiring the creation of a UST Program to initiate UST compliance and leak prevention requirements. The Florida Department of Environmental Protection (FDEP), formerly the Florida Department of Environmental Regulation, was required to manage this effort. In 1986, the Inland Protection Trust Fund (IPTF) was created to provide for the cleanup of LUST sites. The FPCP established criteria for the cleanup of LUST sites and created three eligibility programs.

Remediation of petroleum sites involves coordinating engineering, field investigations, and treatment with regulatory deadlines and specific operating timeframes. Federal and State regulations have been emplaced to assign generic timeframes to various steps in the petroleum cleanup process. For example, according to Chapter 62-770, Florida Administrative Code (FAC), for sites in Florida, a site assessment report must be submitted within 270 days from notification of a release of petroleum products (FDEP, 2005b). A summary of the regulatory timeframes is presented in Table 2 and a flowchart outlining the major activities associated with a petroleum cleanup process according to Chapter 62-770, FAC is displayed in Figure 6. As shown, the entire sequence of events can take up to 12 years to complete for each individual site.

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Table 2. Regulatory Timeframes – Florida

Activity or Event	Timeframe	Previous Event
New petroleum release reporting	24 hours	Release
Free product recovery	3 days	Discovery of free product
Source Removal Report	60 days	Completion of source removal activities.
Site Assessment Report (SAR)	270 days	Release
Regulatory Review of SAR	30 days	Submittal of SAR
Remedial Action Plan (RAP)	90 days	SAR approval
Regulatory Review of RAP	60 days	Submittal
Remedial Action Implementation	120 days	RAP approval
Active Remediation	1 to 5 years	RAP Implementation
Regulatory Review of Remediation Completion	60 days	Recommendation receipt
Monitored Natural Attenuation or Post-Active Remediation Monitoring	1 to 5 years	Regulatory approval
Regulatory Review of No Further Action (NFA)	60 days	NFA recommendation receipt
	~12 years	Theoretical Maximum Timeframe

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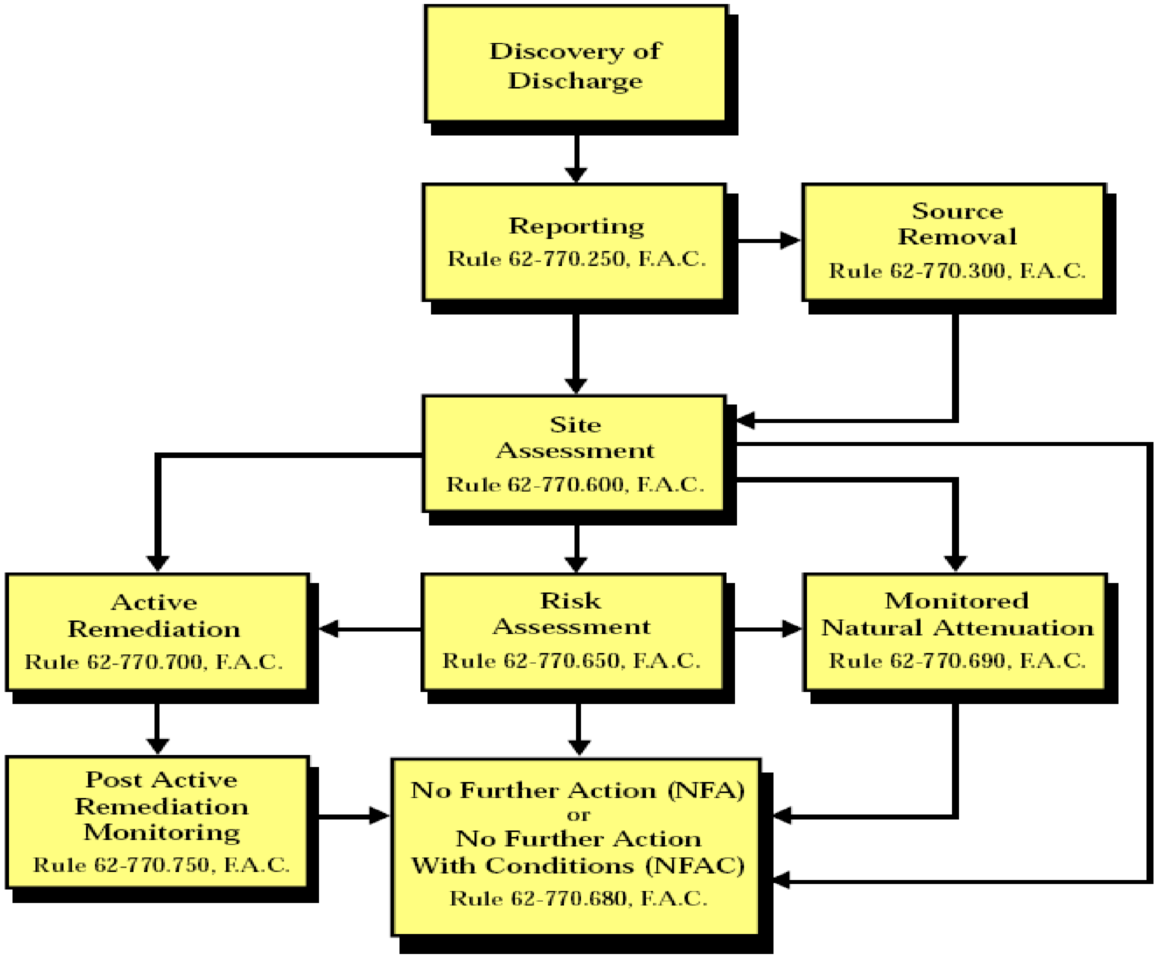

Figure 6. Regulatory Flowchart, Chapter 62-770, Florida Administrative Code

The eligibility programs encompassed various funding levels and in some cases caps on funding based on the timeframe in which a site was reported to be a LUST site. The Early Detection Incentive (EDI) program was the first program, created in 1986, which assigned cleanup eligibility to a site if an owner/operator submitted a notification to FDEP based on an actual detection of a petroleum release, or a potential indication of a release. The EDI program does not have a funding cap assigned; therefore, the FDEP provides for complete cleanup of these sites regardless of the cost. The application period for this program ended December 31, 1988.

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The second program, created in 1989, was the Petroleum Liability and Restoration Insurance Program (PLRIP). This program was meant for active UST sites and the State underwrote the restoration portion of insurance for new releases. The program had funding caps ranging from $1 million to $150,000 and deductibles ranging from $500 to $10,000, depending on the timeframe of application to the program. The application period for this program ended December 31, 1998.

The third program, created in 1990, was the Abandoned Tank Restoration Program (ATRP) which was meant primarily for inactive sites that had closed business operations prior to March 1990. The application period ended in June 1996; however, the program remains open for facilities where the owner/operator can not pay for the petroleum cleanup. This program does not have a funding cap; however, a deductible is required.

The early stages of the FPCP included these programs and cleanup was conducted either by a State-designated contractor, or a contractor designated by an owner, operator, or responsible party (RP). The work completed by the owner, operator or RP, was paid for by that entity and then a reimbursement request was submitted to the FPCP for consideration. The FPCP evaluated and issued payment for reimbursement of petroleum cleanup on a first-come, first-served basis (FDEP, 2005a).

From 1986 to 1996, the reimbursement claims submitted amounted to approximately $1.2 billion. The annual budget for reimbursement was approximately

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$100 million. Due to the magnitude of petroleum cleanup work, the reimbursement claims amount exceeded the available funds. Therefore, the 1995 Laws of Florida abruptly ended the reimbursement program, with $556 million remaining in claims unpaid (ASTSWMO, 1998).

Even with the backlog of claims requiring payment, the FPCP could not completely shut down, or risks to the public and the environment would increase while the program awaited funding to address those risks. Consequently, the State sold bonds to pay for the remaining claims under the former reimbursement program and therefore, the annual cleanup budget could remain applicable to continue reducing the risks to public and environmental health. To continue site cleanup and maintain control of the expenditures, in 1996, the FPCP created the Preapproval Program.

The Preapproval Program created a site scoring system to evaluate the risk of the site characteristics to public and environmental health receptors. A portion of the Site Scoring Checklist is displayed in Figure 7.

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FDEP Site Priority Score Sheet

Facility ID#: ____________________ Site Name: ____________________
Site Address: ____
Latitude: ______________ Longitude: ______________

Criteria:	Yes	No	Points
Fire/Explosion Hazard:			
1. Free product or volatilized petroleum products at or above 20% of the Lower Explosive Limit (LEL) in existing utility conduits or vaults, buildings or other inhabited confined spaces (60 points).	______	______	______
2. Ignitable free product on surface waters or impoundments (60 points).	______	______	______
Threat to Uncontaminated Drinking Water Supplies:			
1. Uncontaminated municipal or community well fields of greater than 100,000 gallons per day permitted capacity with a well within 1/2 mile of the site (30 points).	______	______	______

Figure 7. FPCP Site Scoring Checklist

The FPCP Preapproval Program relies on designated consultants to submit proposals for work to be completed and paid for by funds from the IPTF. The FPCP staff review and approve the proposals by issuing work orders to the consultants. Over the last ten years, the Preapproval Program procedures and library of guidance documents has grown significantly. The guidance documents include a variety of cost guidelines, technical guidelines and program policies.

The cost guidelines limited the specific cleanup components based on a lump sum amount per task. Tasks such as mobilization, soil boring installation, monitor well sampling, and various reporting are included. There is also a generic spreadsheet to use

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for building up the cost for a task that does not already have a template amount. Additionally, sections for subcontractor costs and in-house service costs are included. A portion of the template cost worksheet used by the FPCP is displayed in Figure 8.

Work Description:

Template	Comments / Notes	Allowed Cost	Original: Number of Items	Original: Item Cost	Change: Change Amount	Change: Change Costs	Template Total Cost
Section A: Packaged Work Scopes							
1 Pumping Test or Multiphase Pilot Test		$2,855.79		$0.00		$0.00	$0.00
2 VES or Sparging Pilot Test		$1,920.79		$0.00		$0.00	$0.00
3 Sparging & VES Pilot Test		$2,987.89		$0.00		$0.00	$0.00
4 Monthly O&M Visit		$795.65		$0.00		$0.00	$0.00
5 RAI Monthly O&M Allowance - Small System		$2,595.11		$0.00		$0.00	$0.00
6 RAI Monthly O&M Allowance - Medium System		$3,041.27		$0.00		$0.00	$0.00
7 RAI Monthly O&M Allowance - Large System		$3,580.87		$0.00		$0.00	$0.00
8 RAI Supplemental O&M Monthly Allowance - Thermox/Catox Treatment		$444.86		$0.00		$0.00	$0.00
			Section A Subtotals:	$0.00		$0.00	$0.00
Section B: Office Activities, Part I							
1 Proposal Preparation		$500.98		$0.00		$0.00	$0.00
2 File Review		$544.96		$0.00		$0.00	$0.00
3 Permits		$682.63		$0.00		$0.00	$0.00
4 Site Health & Safety Plan		$319.32		$0.00		$0.00	$0.00
			Section B Subtotals:	$0.00		$0.00	$0.00
Section C: Field Activities							
1 Mobilization (2 persons)		$757.65		$0.00		$0.00	$0.00
2 Mobilization (1 person)		$407.61		$0.00		$0.00	$0.00
3 Drilling Setup (w/utility clearance)		$528.87		$0.00		$0.00	$0.00
4 SB for Soil Screening or Piezometer Install (≤ 10 ft)		$221.16		$0.00		$0.00	$0.00
5 SB for Soil Screening or Piezometer Install (> 10 ft to ≤ 30 ft)		$331.73		$0.00		$0.00	$0.00
6 SB for Soil Screening or Piezometer Install (> 30 ft)		$442.31		$0.00		$0.00	$0.00
7 Well Install (≤ 20 ft)		$452.55		$0.00		$0.00	$0.00
8 Well Install (> 20 ft to ≤ 40 ft)		$678.82		$0.00		$0.00	$0.00

Figure 8. FPCP Cost Template Worksheet

The allowed cost for each task is determined based on typical values for personnel used, the time required to complete the task, pay rates for personnel, overhead costs and equipment costs. Additionally, laboratory analytical costs and drilling rates are set by a survey of average costs. Periodically, the program evaluates whether a new survey of costs is needed to account for inflation or other changes that affect the cost of conducting cleanup activities (FDEP, 2005c).

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The FPCP has created many technical and policy guidance documents over the 20-year history of the program. These documents range from the preferred procedures for installation of monitor wells to the complete guide for information to be considered for a Site Assessment Report (SAR). As the FPCP evolved, additional guidance documents were issued to accommodate consistent issues which required consistent resolution.

The FPCP relies on five teams located in the State capitol, Tallahassee, and issues contracts to Local Programs, often times a County government department. Currently, the FPCP has contracted 14 local programs to assist with the review and processing of the multiple reports, proposals, work orders and invoices generated each month. The five teams in Tallahassee and the staff from the Local Programs amount to approximately 230 people. The FPCP contracts the Local Programs due to the following: 1) provide personnel in close proximity to the sites to allow ease of site inspections, 2) have local knowledge of site conditions and local geology, and 3) have local contact with the local community. Through the use of Local Programs, the FPCP has less of a burden filling all the staffing needs from one central location. As reported at the June 2006 Annual Tanks Conference by the FPCP, approximately 6,700 petroleum cleanup sites are actively conducting assessment and/or remediation activities.

Each site is assigned a priority score as detailed above and funding is appropriated each fiscal year according to the volume of activity anticipated for the high priority sites. For the 2006-2007 fiscal year, the funding amounts to approximately $181 million, to

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provide for the administrative processing and cleanup activities associated with 4,201 sites scored 37 and above. The distribution of site scores is presented in Figure 9.

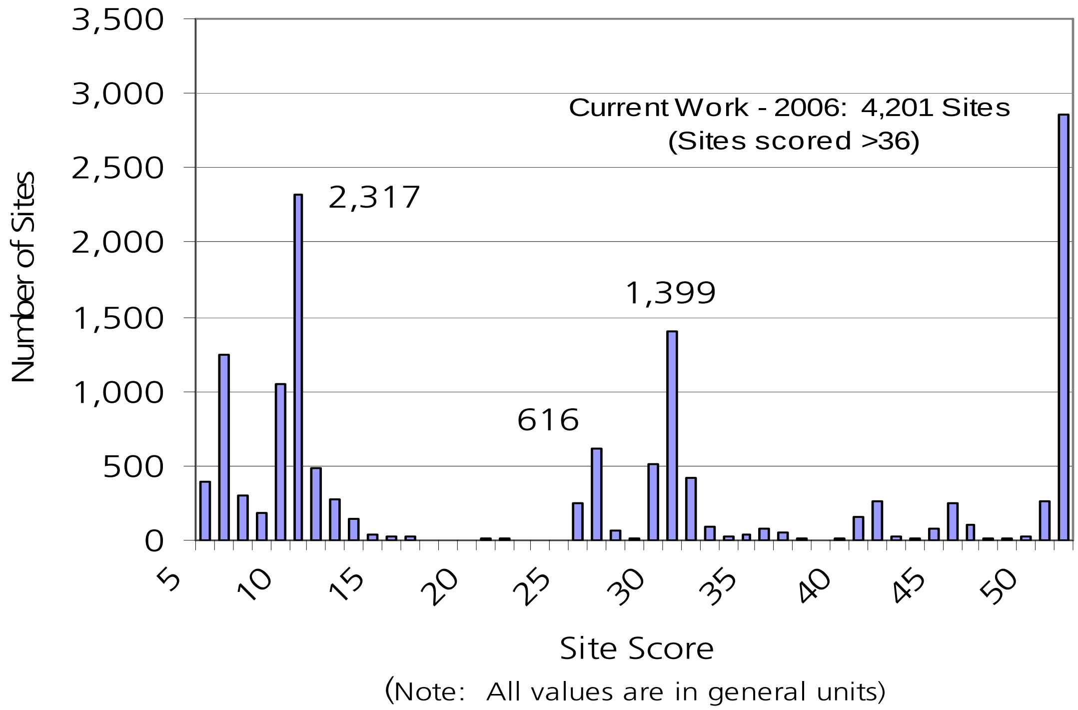

Figure 9. Florida Petroleum Cleanup Program Site Score Chart

The numbers presented next to each peak of the chart in Figure 9 represent the number of sites with the corresponding score for the peak. For example, there are 1,399 sites with a score of 30. The distribution of sites in these groups of score correlates to the scoring checklist in Figure 7. For example, a petroleum site located within ½-mile of a community well field producing 100,000 gallons per day or more receives a score of 20 for that characteristic. As can be determined in reviewing the entire scoring system, sites within ¼-mile of a private potable well receive 20 points for this designation. Additionally, the geology and types of petroleum present in the groundwater increase the

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score. Consequently, numerous sites have similar characteristics and distance from private and public wells, which result in the trimodal distribution of the groups of sites shown in Figure 9.

When funding reaches a sufficient surplus to fund the assessment and remediation of 1,399 sites, the FPCP will lower the eligible funding score to 30. Actually, large groups of sites such as those scored 30 will likely be sub-grouped to allow a lesser impact on the financial strain of the FPCP.

For example, during the 2005-2006 fiscal year, the funding level was lowered to sites scored 30; however, only a group of approximately 300 sites were eligible for funding. This sub-group was based on those sites which had the earliest dated determination of eligibility for the EDI program within the group of sites scored 30. Upon initiating this funding level, a backlog of work orders from the FPCP developed and the work could not be funded due to the controlled spending in place. Therefore, the funding eligibility level was raised at the end of the fiscal year to a score of 37 and above (FDEP, 2006).

Throughout the history of the FPCP, the program has experienced fluctuations in fiscal health, including receiving cleanup reimbursement claims for a cumulative amount in excess of the annual funding amount. Funding for the program has steadily increased over the last 10 years, from a low of approximately \$45 million to the current budget of approximately \$181 million. With increased funding came the ability to increase the

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amount of petroleum cleanup work; however, increased program management requirements also followed. As a surplus arose, the eligible funding score decreased to allow initiation of work on additional sites; however, as the funding experienced backlog, the funding score increased, thereby creating an undulating program operation with uncontrolled uncertainty. The history of the eligible site scoring, detailing the fluctuations in eligible funding scores, is shown in Figure 10.

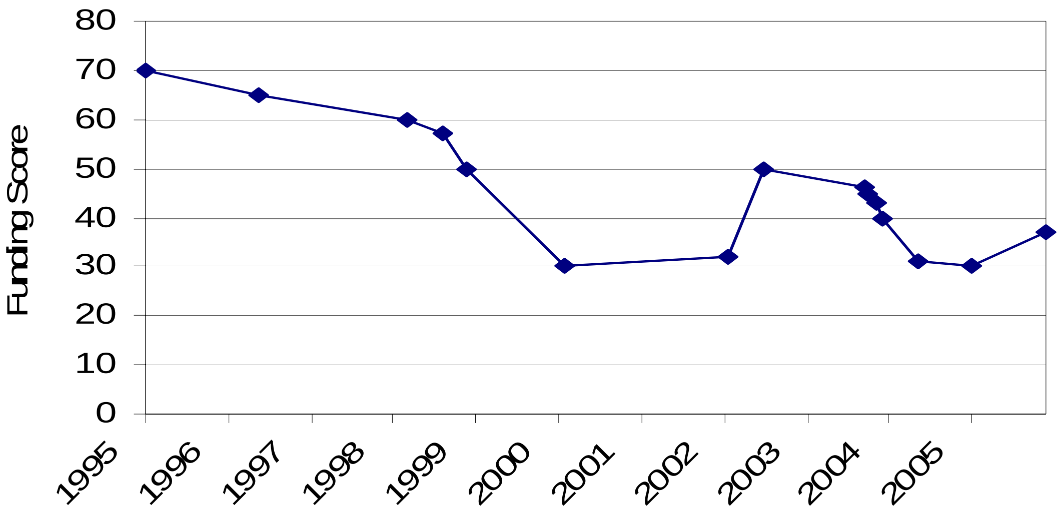

Figure 10. Funding Score History

The number of site closures achieved during each fiscal year (FY) and the fiscal year budgets are shown in Figure 11. As shown by the chart, the fiscal year budget increased over time followed subsequently by an increase in the number of site closures. Due to the multiple factors and timeframes included in obtaining site closures, a delay of effect is evident by the graphs in Figures 11 and 12. For example, a fiscal year peak in FY01 presented a site closures peak in FY03. This trend is clearly identified by the plot in Figure 12, which includes the site closures per year versus the funding of the prior

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fiscal year. Based on the plot in Figure 12, an increase in funding caused an increase in the number of site closures the following year.

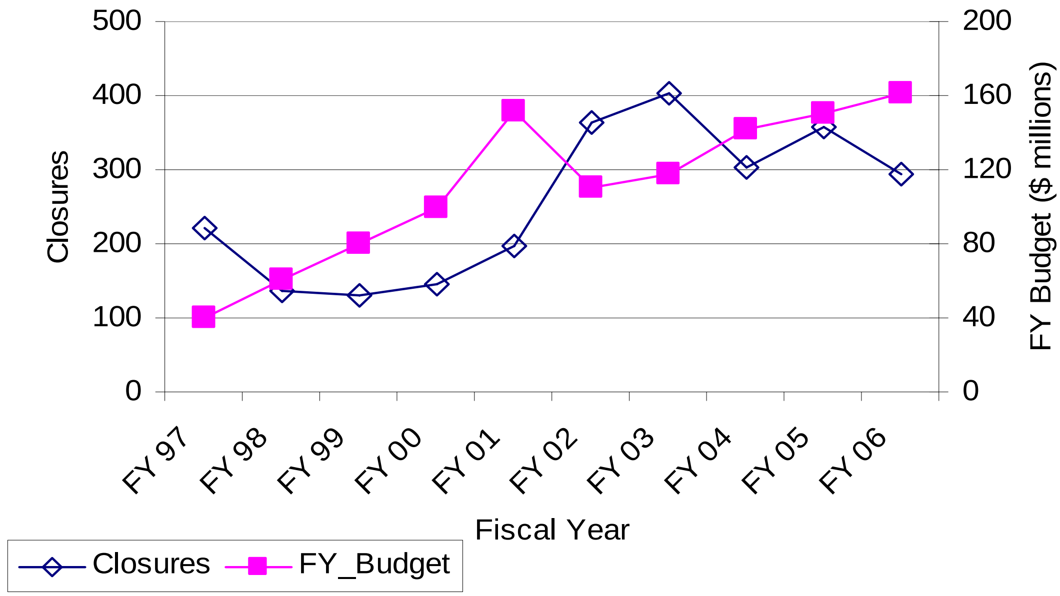

Figure 11. FPCP Operation History

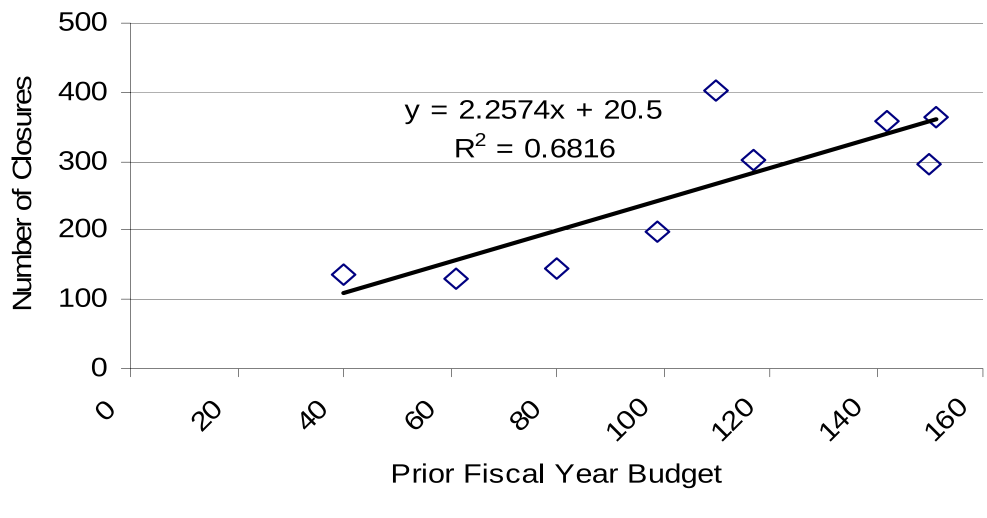

Figure 12. Site Closures Versus Prior Fiscal Year Budget

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Determination of Program Effectiveness

In recent years, government agencies have experienced increased scrutiny of their operations. Many factors affect petroleum cleanup including government efficiency. The following sections attempt to evaluate effectiveness for the purposes of this thesis and present methods of efficiency evaluation previously used.

Definition

The US Congress passed legislation in 1993 entitled the Government Performance Results Act (GPRA). The purposes of the GPRA are:

1. Holding Federal agencies accountable for achieving program results
2. Measuring program performance against set goals, and publicly reporting the progress toward those goals
3. Improving Federal program effectiveness and public accountability
4. Helping Federal managers improve service delivery
5. Improving internal management of the Federal Government.

In 2002, President George W. Bush, published the "President's Management Agenda" (PMA) calling for improved governmental agency management. The report outlined initiatives to improve fiscal management and reduce waste and abuse of government agency resources (OMB, 2002). In response to the PMA, the USEPA developed a Strategic Plan which set goals over a three-year period to continue

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improving management of their programs for results. For example, the USEPA reported 7,332 cleanups completed, which represented 54 percent of their GPRA goal (EPA, 2006a). Additionally, the USEPA set up the Environmental Council of States to involve State agencies with the Strategic Plan.

Typically, petroleum cleanup programs use the number of sites cleaned up to quantify program effectiveness. A summary of the 2006 details for each State and territory is given in Table 3.

Table 3. State Petroleum Cleanup Statistics (Source: EPA, 2006b)

State/ Territory	Confirmed Releases	Cleanups Initiated	Cleanups Completed	Percentage Completed
AK	2,292	2,218	1,577	68.8%
AL	10,962	10,802	9,362	85.4%
AR	1,308	1,002	976	74.6%
AZ	8,221	5,712	6,619	80.5%
CA	44,510	44,510	30,133	67.7%
CO	6,620	6,683	5,684	85.9%
CT	2,483	2,431	1,636	65.9%
DC	830	830	583	70.2%
DE	2,309	2,194	2,044	88.5%
FL	24,224	14,893	9,311	38.4%
GA	11,183	10,798	8,683	77.6%
GU	135	135	111	82.2%
HI	1,856	1,760	1,532	82.5%
IA	5,817	5,540	4,008	68.9%

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Table 3. (Continued)

State/ Territory	Confirmed Releases	Cleanups Initiated	Cleanups Completed	Percentage Completed
ID	1,356	1,321	1,193	88.0%
IL	22,626	21,415	14,969	66.2%
IN	8,373	7,581	5,254	62.7%
KS	4,648	4,425	2,705	58.2%
KY	13,354	13,320	10,888	81.5%
LA	3,034	3,034	1,810	59.7%
MA	6,147	5,934	5,152	83.8%
MD	10,346	10,089	9,489	91.7%
ME	2,285	2,205	2,136	93.5%
MI	20,962	20,525	11,924	56.9%
MN	9,623	9,096	8,588	89.2%
MO	6,214	5,837	4,873	78.4%
MS	6,583	6,396	6,267	95.2%
MT	2,918	2,131	1,799	61.7%
NC	23,681	22,493	17,229	72.8%
ND	813	804	779	95.8%
NE	5,975	4,214	3,901	65.3%
NH	2,254	2,254	1,436	63.7%
NJ	9,799	8,942	5,807	59.3%
NM	2,483	1,802	1,691	68.1%
NV	2,418	2,410	2,188	90.5%
NY	24,447	24,432	21,459	87.8%
OH	23,799	23,224	20,838	87.6%

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Table 3. (Continued)

State/ Territory	Confirmed Releases	Cleanups Initiated	Cleanups Completed	Percentage Completed
OK	3,557	3,557	2,940	82.7%
OR	6,886	6,643	5,543	80.5%
PA	14,017	13,542	10,031	71.6%
PR	1,023	872	448	43.8%
RI	1,253	1,253	997	79.6%
SC	8,757	8,269	5,406	61.7%
SD	2,354	2,354	2,170	92.2%
TN	12,993	13,090	12,144	93.5%
TX	24,460	21,721	20,750	84.8%
UT	4,191	4,163	3,733	89.1%
VA	10,641	10,364	9,845	92.5%
VI	22	14	4	18.2%
VT	1,937	1,925	1,159	59.8%
WA	6,181	5,846	4,158	67.3%
WI	18,451	17,817	15,284	82.8%
WV	2,938	2,738	1,804	61.4%
WY	1,992	1,592	933	46.8%

Based on the data in Table 3, North Dakota, South Dakota and Tennessee have the most effective petroleum cleanup programs. However, this analysis overlooks other factors that may be important in determining the effectiveness of a State petroleum cleanup program, such as: groundwater cleanup target levels (also known as maximum contaminant level or action level), number of releases and available funding.

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Furthermore, a State's definition of "cleanup" may vary. For example, in Colorado, actions completed beyond "No Action" are considered to be "cleanup completion". While other States require actual completion of contaminant reduction before a "cleanup" is considered complete (ASTSWMO, 2004).

In this thesis, the definition of program effectiveness is expanded to include the percentage of site cleanups completed in a State divided by the total number of releases in the US, divided by the dollars spent to achieve these cleanups, as shown by Equation 1:

$$Effectiveness = \frac{\left(\frac{\text{\# of Sites Completed}}{\text{Total \# of Confirmed Releases in the US}}\right)}{\left(\frac{\text{Dollars Spent to Cleanup the Sites Completed}}{\text{Total US Cleanup Funding}}\right)} \qquad (1)$$

It is evident that a single definition of effectiveness cannot encompass the variability among State programs. To develop a meaningful measure of effectiveness a detailed analysis of several State programs was conducted.

Methods of Evaluating Efficiency

Over the past century the efficiency of governmental programs has been assessed and criticized by various entities. The earliest document discovered through this research indicates a Georgia Gorvernor's Commission for Efficiency and Improvement in Government was created in 1963 to study the organization and operation of the State

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government and determine methods of improving government efficiency (Georgia, 2006).

Several US Congressional Hearings have evaluated the effectiveness of programs such as the GPRA, GPRA tools for performance budgeting, LUST Cleanup Programs, and Federal Government assistance to States in preparing for biological, chemical or nuclear attack, etc. One article supporting information discussed during a US Congressional Hearing provides suggested methods of linking funding to program results. The methods include the creation of a Program whose sole purpose would be analysis of government programs to provide results to Congress and increased oversight by Congress of demonstrated results prior to allocating resources to programs. The report proceeds in evaluating the current approaches used and the details of the recommended approaches (US House of Representatives, 2002).

The Association of State Underground Storage Tank Cleanup Funds (ASUSTCF) published at least two reports summarizing success stories of State Fund Programs. In June 1998 and June 2000, the Third and Fifth Editions of the State Fund Success Stories Compendium were published by the ASUSTCF, supported by ASTSWMO. The report presents details from various State agencies regarding financial success, policy, innovation and productivity successes and success with stakeholders. These editions of the Compendium provided an excerpt of more than 25 State Fund achievements in these three categories. The documents do not analyze specifically the efficiency of State

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programs, but share methods of achieving success in petroleum cleanup (ASUSTCF, 1998 and 2000).

The financial success category reported a variety of financial aspects related to UST operation and LUST cleanup. From providing grants to owners and operators to upgrade their UST systems, to innovative approaches of reducing the backlog of cleanup reimbursement claims, State programs have benefited by evaluating a more efficient system of conducting State business, saving time and money.

The policy, innovation and productivity category reported successes involving ideas such as technology design modifications, standard report and invoice formats, and review process changes. Each of these ideas, as well as the others reported, provided time and cost savings.

The successes with stakeholders category contained reports of enhanced communication between regulators, the regulated community and the public in general. Providing open communication between the multitude of stakeholders in many cases allows improved acceptance of the cost and progress of petroleum cleanup. Through increased understanding of the activities involved with completing petroleum cleanup at a site, all parties involved are more educated, thereby providing more agreeable approaches to the cleanup completion.

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These reports provide case studies in an effort to share lessons learned and the results of evaluating new approaches to petroleum cleanup. The reports provide sufficient detail to allow other State programs to benefit and increase their efficiency in addressing consistent factors affecting cleanup progress.

Factors Affecting Cleanup

Numerous factors are involved in the effective cleanup of petroleum in the Nation's soil and groundwater. Theses factors include:

1. Site Operations
2. Physical and chemical characteristics of the petroleum constituents involved
3. Size and age of the soil and groundwater impacts
4. Geology and hydrogeology of the LUST site
5. Cleanup goals
6. Funding available for cleanup
7. Level of government involvement
8. Use of effective cleanup technologies.

Each factor has input into the more comprehensive equation for petroleum cleanup efficiency. Site operations can include properties that are vacant to properties with dentist's offices and a variety in between. As discussed previously, the physical and chemical characteristics of petroleum constituents affect how readily those constituents

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will degrade, desorb or disperse. Newer releases of petroleum have not traveled as far or had as much opportunity to adsorb to soils as older releases. Removing contaminants from less permeable soil can be more difficult that removing contaminants from soil that easily allows air and water passage. If funding is not available for cleanup, contaminants will remain in the ground continuing to disperse. If government has stringent controls on the progress of petroleum cleanup, that progress can be slowed considerably as compared to a government that allows cleanup progress without stringent control. Finally, innovative technology attempts are made to remain cost-effective; however, the successful completion of petroleum cleanup may not occur as rapidly using an innovative technology versus a proven traditional technology.

Petroleum Remediation Technology

Petroleum remediation technology plays a key role in the timeframes associated with petroleum cleanup. The selected technology for a given site depends on the following site characteristics, among others:

1. Geology, including soil types, porosity
2. Hydrogeology, including depth to groundwater, groundwater flow characteristics
3. Contaminant Concentrations, including the distribution of mass in the soil and groundwater
4. Site operations, including land uses, locations of structures, underground and overhead utilities

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5. Distance to potential exposure points or receptors, such drinking water sources.

Based on the site characteristics, an analysis of appropriate technologies was conducted including considerations regarding methods of conducting the remedial action, effectiveness of technologies, and costs associated with each technology. Common technologies include the following:

1. Soil Excavation with Ex-Situ Soil Treatment
2. Vapor Extraction
3. Air Sparging
4. Groundwater Recovery and Treatment (also known as Pump and Treat)
5. Multi-phase Extraction
6. Chemical Oxidation
7. Multiple forms of *insitu* innovative technologies including the injection of microorganisms, injection of butane gas and steam injection.

Each technology has parameters that determine whether the petroleum cleanup site is suited for the select technology. For example, the use of air sparging with vapor extraction is common in Florida due to the widespread sandy soils in the subsurface at varying depths. Air sparging involves the injection of air into the groundwater forming bubbles which promote mass transfer through contaminant volatilization. Vapor extraction involves the application of a negative pressure to the subsurface soil to promote contaminant volatilization as well as collect the volatilized contaminants from

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the air sparging operation. These operations depend on air as the carrier of contaminants to be removed from the subsurface. Therefore, soil porosity is an important factor in the determination of site conditions suitable for the technology based on the fact that if the air cannot move through the subsurface, the technology operations will not be able to recover the contaminants (Nyer et. al., 2001). A representation of air sparging with vapor extraction *insitu* treatment is displayed in Figure 13.

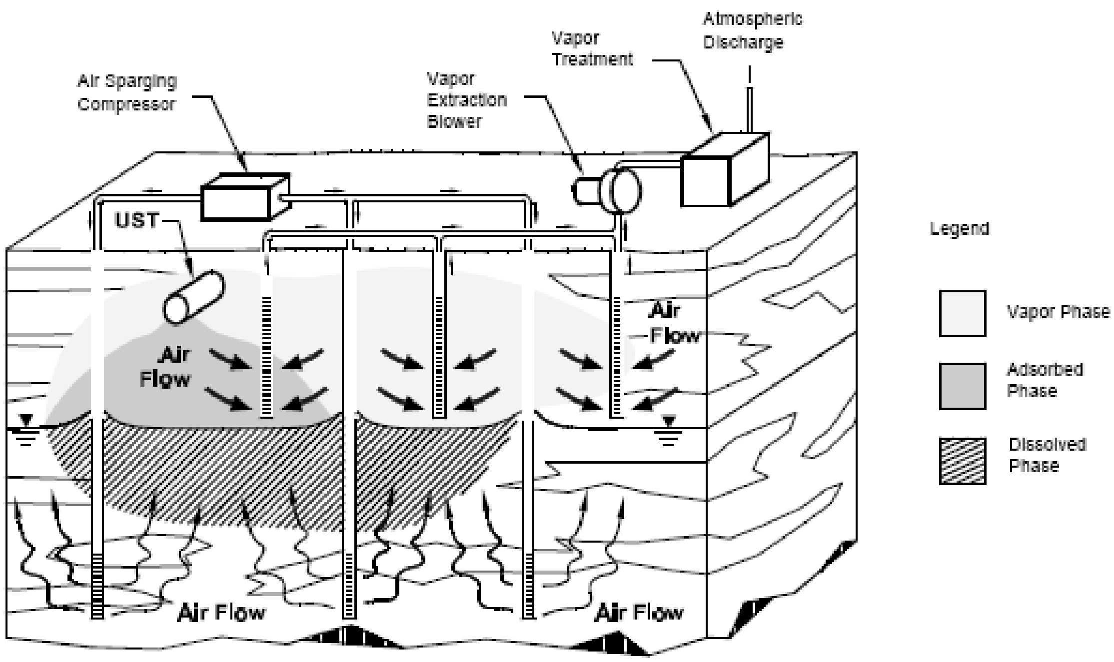

Figure 13. Air Sparging with Vapor Extraction Technology (Source: EPA, 2004)

A technology formerly common during the 1990s was groundwater recovery and treatment. This technology relied on water as the carrier of contaminants and exsitu treatment, to reduce the distribution of contaminant mass. Groundwater was pumped from extraction wells and flowed through a variety of exsitu treatment operations, including air stripping, granular activated carbon and air sparging, for example.

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Each of these *insitu* and exsitu treatment technologies rely on air or water as the carriers of contaminants. One issue with this reliance is the ability of the fluid to reach the contaminants. These methods rely on diffusion, dispersion and drainage characteristics of the subsurface soil and groundwater. Due to interstitial forces, soil pores cannot be entirely drained; therefore, a limit of recoverability exists termed the drainage porosity (Hillel, 1998). Cleanup technologies that rely on removing the water or air from pore spaces in soil will experience this physical limitation which may constrain the ability of the technology in completing site cleanup. Modifications to technology designs can overcome these limitations; however, early attempts involving these technologies suffered from this occurrence.

Soil excavation and treatment is a common technology. This approach relies on physical removal of impacted soil, thereby providing a more effective removal of mass than the *insitu* treatment methods. Transportation and treatment of removed soil became increasingly costly and innovative technologies, and/or commonly used technologies evolved to present a cost benefit versus excavation. Depending on the site conditions, soil excavation and treatment can provide a cost efficient approach versus multiple years of operation and maintenance of an *insitu* treatment system (USEPA, 2004b).

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Table 4. State Petroleum Remediation Technology Statistics

State/ Territory	Excavation %	Air Sparging %	Bioremediation %	Dual Phase Extraction %	Pump & Treat %
FL	12.9	44.3	11.3	15.0	16.4
OH	44.8	9.9	7.0	19.4	19.0
TX	NA		10	90.0	NA

Note: These data were gathered from personnel working in each State program (Chace, et al, 2006).

The frequency of various treatment technologies by State is summarized in Table 4 for three States that provided data. These technologies have varying success based on the treatment system design, site lithology, and the treatment system implementation, operation and maintenance.

Given the variables entering the petroleum cleanup equation, State programs have received varying amounts of funding based on perceived risk to public and environmental health, legislative priorities and community involvement. Petroleum cleanup occurs at sites requiring varying amounts of funding per site. According to a 1995 study, the California LUFT program could have been enhanced by modification of various items and site cleanup would require an average of approximately $400,000 (University of California, 1995). As shown in Figure 14, the average cost per site varies by State. As indicated in Figure 14, the cost per site is highest in Florida, Michigan and California.

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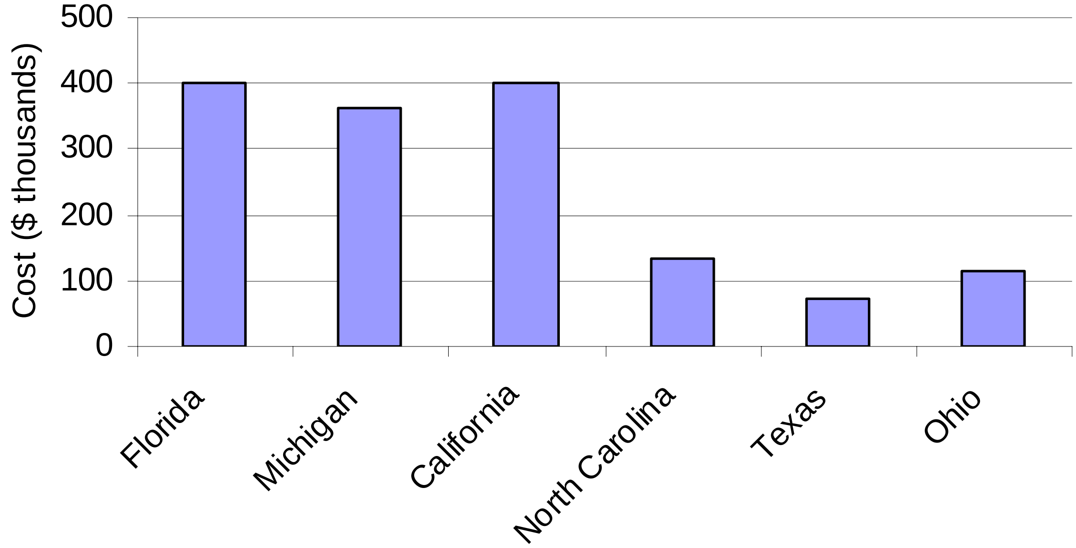

Figure 14. Average Cleanup Cost per Site by State

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Results

A thorough review of the background information provides insight to the various ingredients of a petroleum cleanup process. Based on the information collected, results can be gathered to provide a useful comparison of State petroleum cleanup programs. The factors affecting petroleum cleanup and a comparison of how State programs addressed these factors are presented in the following paragraphs.

Based on the number of releases reported in various States, a baseline selection of States with 20 to 24 thousand releases was chosen for comparison. A summary of the States and key data for each State are presented in Table 5. California is included based on the petroleum cleanup statistics for the State, which includes the highest number of releases and one of the highest percentages for sites completed. A comparison of the percentage of groundwater supply per State and the number of sites completed is presented in Figure 15.

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Table 5. Summary of States Chosen for Comparison

State	EPA or Non-EPA	Number of Releases	Cleanup Program Type	Groundwater Supply %	% of Sites Completed
Florida	Non	24,224	Pre-approval	90.2 %	38.4 %
Michigan	Non	20,962	Reimbursement	21.7 %	56.9 %
Illinois	Non	22,626	Reimbursement	20.1 %	66.2 %
California	Non	44,510	Reimbursement	45.8 %	67.7 %
North Carolina	EPA	23,681	Pre-approved Reimbursement	22.7 %	72.8 %
Texas	EPA	24,460	Pre-approved Reimbursement	29.8 %	84.8 %
Ohio	Non	23,799	Reimbursement	34.0 %	87.6 %
New York	Non	24,447	None*	17.6 %	87.8 %

*No funding available for responsible parties cleaning up old releases.

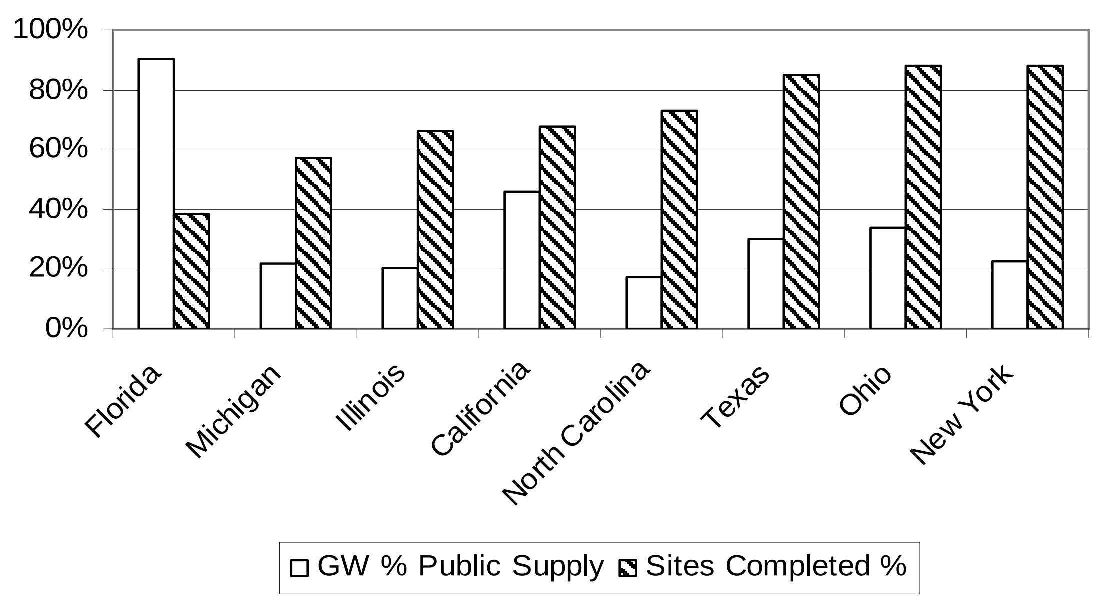

Figure 15. Comparison of Groundwater Supply Percentage and Percentage of Sites Completed

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Florida relies mainly on the groundwater resources of the State to supply public water. Based on this fact, the FDEP and Florida legislature emplaced stringent requirements on the cleanup of contaminated groundwater. A summary of the groundwater cleanup action levels for select petroleum constituents in each State, as weel as the Federal drinking water maximum contaminant level (MCL), is presented in Table 6.

Table 6. Summary of State Groundwater Cleanup Action Levels

State	Benzene	Toluene	Ethylbenzene	Total Xylenes	MTBE
Florida	1	40	30	20	20
Illinois	5	1,000	700	10,000	NA
Michigan	5	140	18	35	40
New York	1	5	5	5	10
North Carolina	1	1,000	550	530	200
Ohio	5	1,000	700	10,000	40
Texas	5	1,000	700	10,000	NA
Federal MCL	5	1,000	700	10,000	NA

The State of New York has more stringent requirements; therefore, petroleum cleanup in New York versus Florida requires a longer timeframe. The Oil Spill Fund (OSF) in New York was created by legislature in 1977, to address cleanup of releases for which the responsible party was unknown or unwilling to pay for cleanup, or could not afford to clean up the release. Additionally, the fund provided settlements for claims against the responsible parties. The OSF pursued cost recovery to the maximum extent

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possible (NYSOSC, 2006). Therefore, with the early origins of the program and the approach of firm protection of the public and environment, persons responsible for petroleum releases had many reasons to conduct cleanup quickly and limit their liability. As shown in Table 5, New York has the highest percentage of completed sites.

In general, Florida has the second most-stringent cleanup levels in comparison to the States listed in Table 6. This is due mainly to the high reliance on groundwater as a public-water supply source. Consequently, cleanup of petroleum releases to more stringent levels causes the need for additional time and resources to complete those cleanups thereby resulting in the low percentage of completed sites shown in Table 5. Progress is shown by Florida cleanup data as determined by the funding score trend in Figure 16. The trend identified indicates a combination of occurrences including an increase in funding received and the completion of higher-scored sites; thereby providing an opportunity to lower the funding score and begin cleanup of lower-scored sites. Even with fluctuation, the overall trend is downward, thereby indicating progress in addressing additional sites as higher-scored sites are completed.

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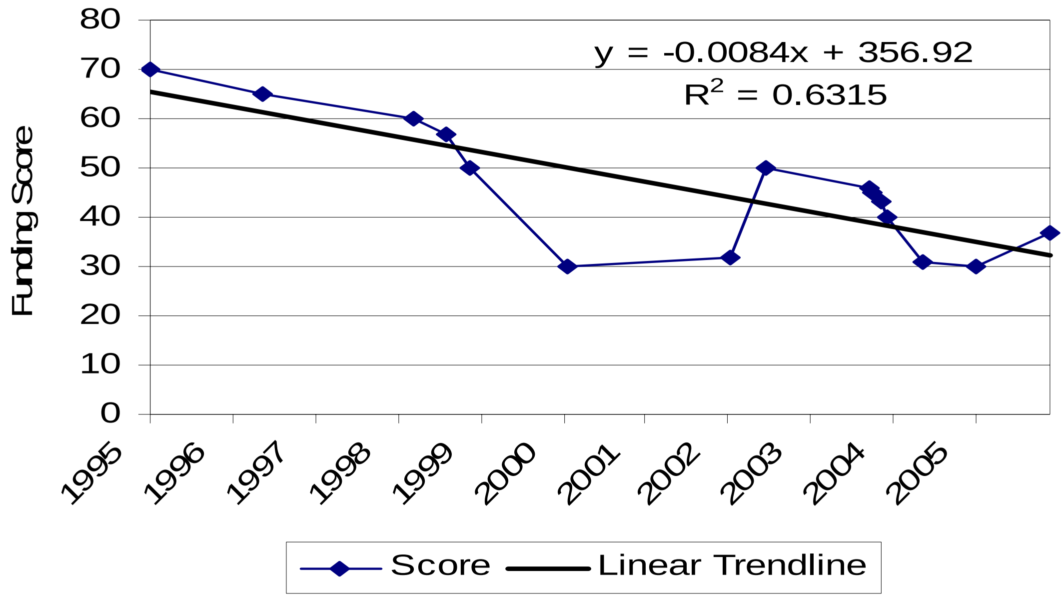

Figure 16. Florida Funding Score Trend

Statistical analytical methods can be used to determine conclusive results. The two-tailed unpaired t-test was used to evaluate relationships as detailed in the methodology section. A summary of data used for statistical analysis is presented in Table 7.

Table 7. Summary of Statistical Data Inputs

State	Benzene Cleanup Level (µg/L)	% of Sites Completed	% of US Releases	% of US Funding Spent	Effectiveness
Florida	1	38.4	2.02	11.10	0.18
Michigan	5	56.9	2.59	1.06	2.45
California	1	67.7	6.56	20.00	0.33
North Carolina	1	72.8	3.75	2.85	1.32
Ohio	5	87.6	4.54	1.20	3.78
Texas	5	84.8	4.51	7.78	0.58

Note: Total US dollars spent is approximately $10 billion (USEPA,2006a)

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Upon analyzing the relationship between the benzene cleanup level per State and the percentage of sites completed, as well as the benzene cleanup level versus the effectiveness of the State program, the results indicate no significant difference between the means and variances. Therefore, the benzene cleanup level does not have a significant impact on the effectiveness of individual State petroleum cleanup programs. The statistical analyses were conducted using the software program GraphPad, for which the print out of results is provided in Appendix B.

Based on the various data collected, data plots assist in determining the correlations of variables. Data such as the average cleanup cost per site versus the individual petroleum constituents' cleanup levels per State provide valuable information. Data included in Tables 6, 7 and 8 were used to evaluate plotted relationship trends.

Table 8. State Data Summary

State	Benzene Cleanup Level (µg/L)	Number of Petroleum Cleanup Staff	10-year Appropriation ($ millions)
Florida	1	230	1,110
Michigan	5	48	106
California	1	250	2,000
North Carolina	1	139	285
Ohio	5	17	120
Texas	5	63	778

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Based on fuel consumption data presented in Figure 2, three relationships were evaluated. The relationship between fuel consumption per State and the 10-year appropriation, the appropriation per number of releases and the percentage of site completed are displayed in Figures 17 through 19, respectively.

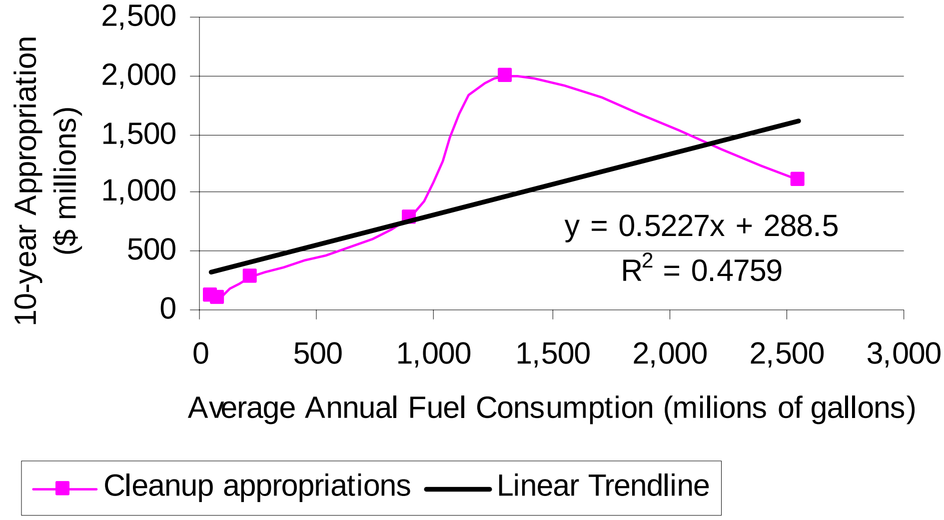

Figure 17. Fuel Consumption Versus 10-year LUST Cleanup Appropriations

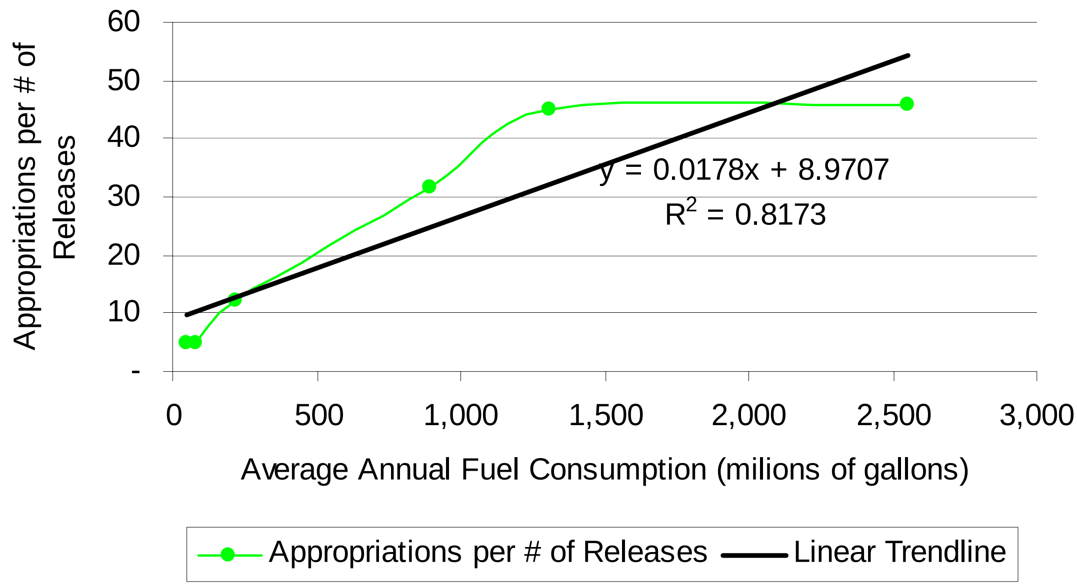

Figure 18. Fuel Consumption Versus Appropriations per Number of Releases

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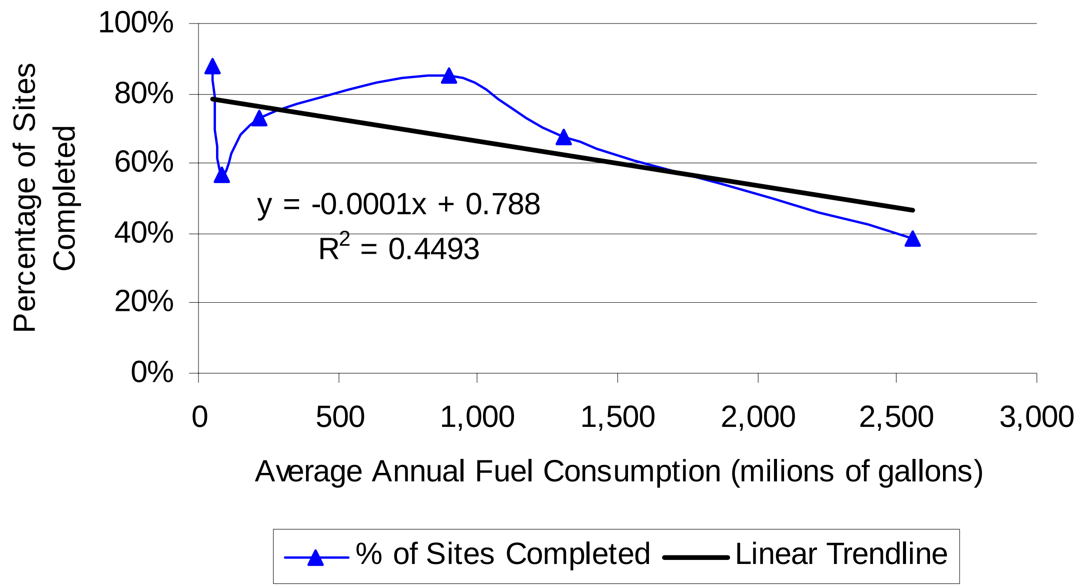

Figure 19. Fuel Consumption Versus Percentage of Site Completed

The data presented in Figure 17 indicates that as fuel consumption increases, the amount of LUST funding increases. This relates directly to the LUST funds creation being populated by a percentage of a cent tax on each gallon of fuel sold in each State. Consequently, more fuel sold in a State resulted in an increase in tax thereby providing an increase of cleanup funding appropriations.

The data displayed in Figure 18 presents a similar trend as Figure 17. The appropriations over the last decade per the number of releases in each State increased with fuel consumption increase. This trend is skewed by the baseline of the data set chosen for analysis. The data set includes States with a similar number of releases, nearly 20 thousand, with the addition of California, which has over 40 thousand releases. As expected, an increase in fuel consumed in a State resulted in an increase in the appropriations for that State.

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The plot in Figure 19 indicates that as fuel consumption increases, the percentage of sites completed decreases. This result is counterintuitive based on the previous two figures, which indicate States with higher fuel consumption receive an increase in cleanup appropriations. Alternatively, an increase in fuel consumption resulted in an increase in spill potential, which requires additional resources to complete cleanup. Therefore, additional factors beyond appropriations affect the cleanup completion of these LUST sites.

One of these additional factors is governmental involvement. As Stated earlier, The State of New York has less involvement in petroleum cleanup than Florida. The New York petroleum cleanup program and regulations has also existed more than 10 years longer than Florida, for example. With the high percentage of sites completed in New York, an evaluation of government involvement is necessary. The government staff data summarized in Table 8 was used to create the plots in Figure 20.

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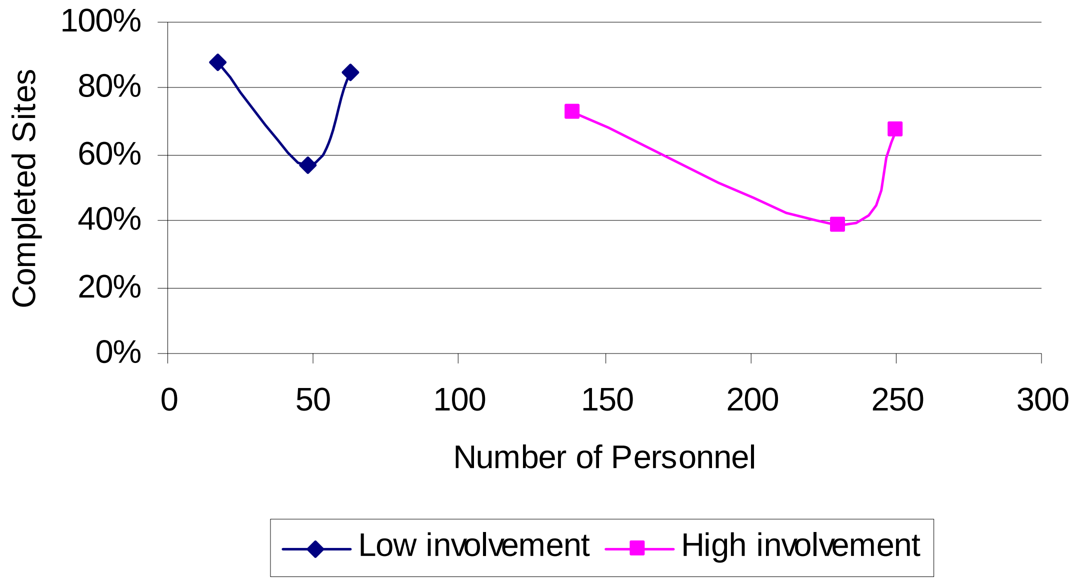

Figure 20. Government Involvement Plot

The plots in Figure 20 suggest that an increase in the number of government personnel does not necessarily provide an increase in the number of completed sites. The trends for low versus high government involvement are similar; however, additional data points are needed to verify this hypothesis.

One final factor evaluated as part of this thesis is the individual and grouped cleanup levels for various States. As shown in Table 6, the selected States have a wide range of cleanup goals for constituents in groundwater. The trends for average site cleanup cost versus cleanup goals for benzene, toluene, ethylbenzene, total xylenes, BTEX and MTBE are displayed in Figures 21 through 26, respectively.

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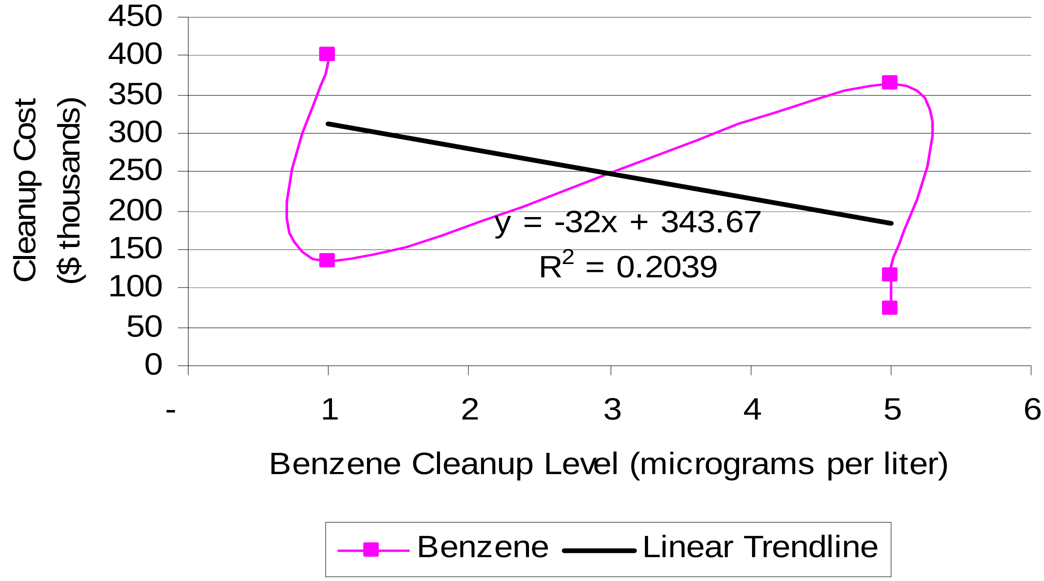

Figure 21. Benzene Cleanup Level Versus Average Site Cleanup Cost

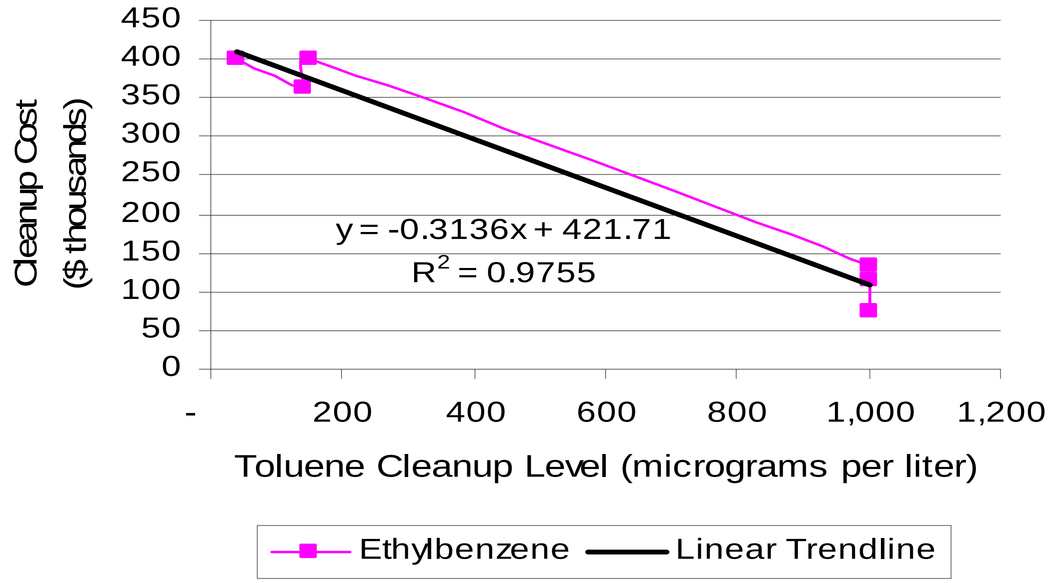

Figure 22. Toluene Cleanup Level Versus Average Site Cleanup Cost

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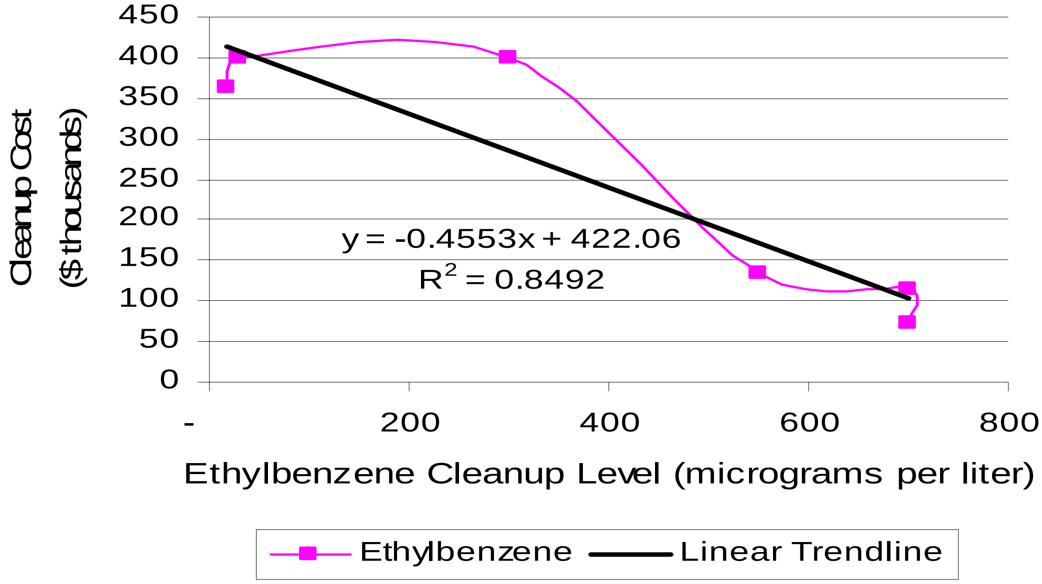

Figure 23. Ethylbenzene Cleanup Level Versus Average Site Cleanup Cost

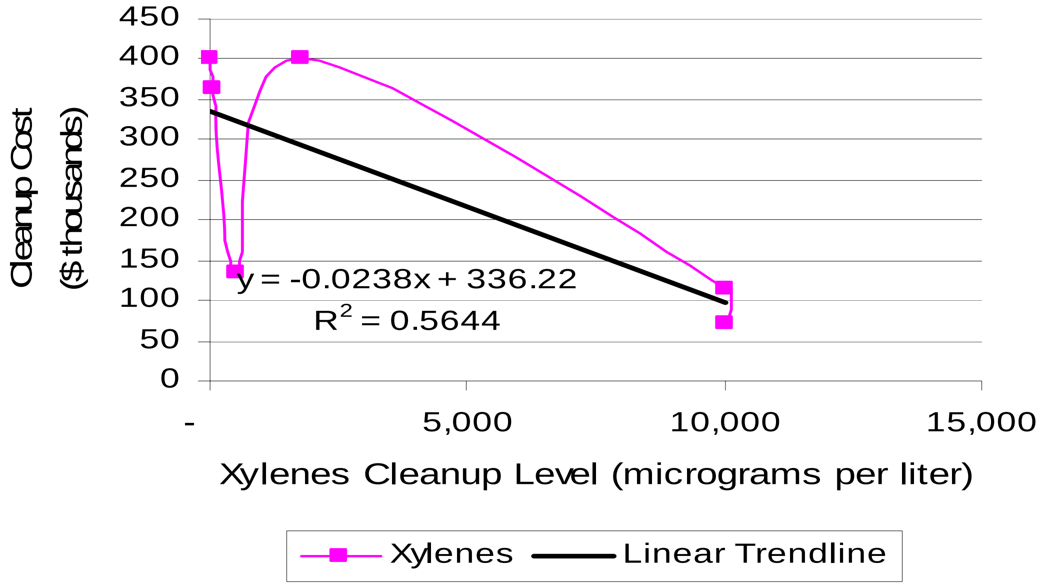

Figure 24. Total Xylenes Cleanup Level Versus Average Site Cleanup Cost

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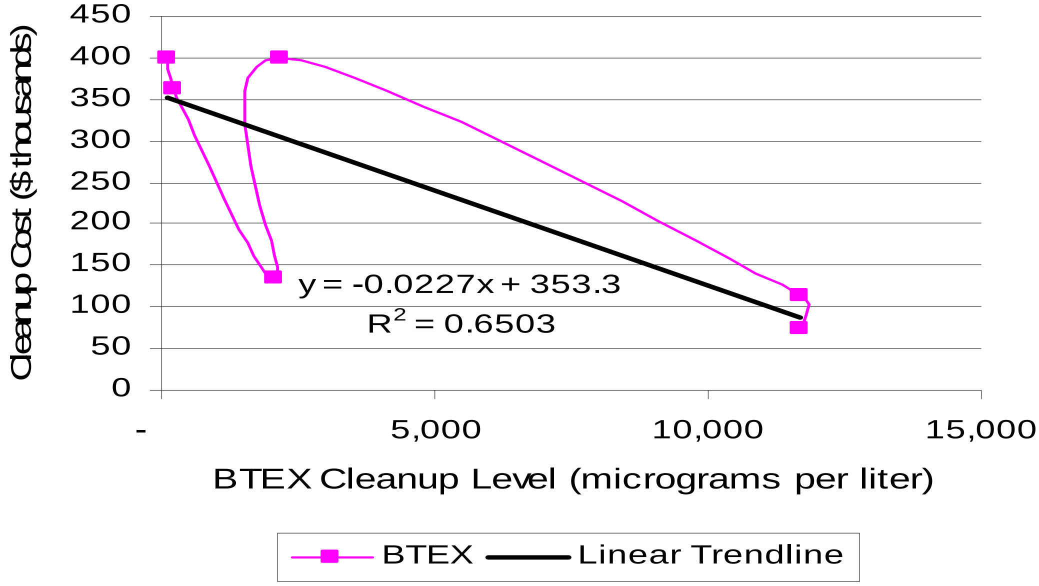

Figure 25. BTEX Cleanup Level Versus Average Site Cleanup Cost

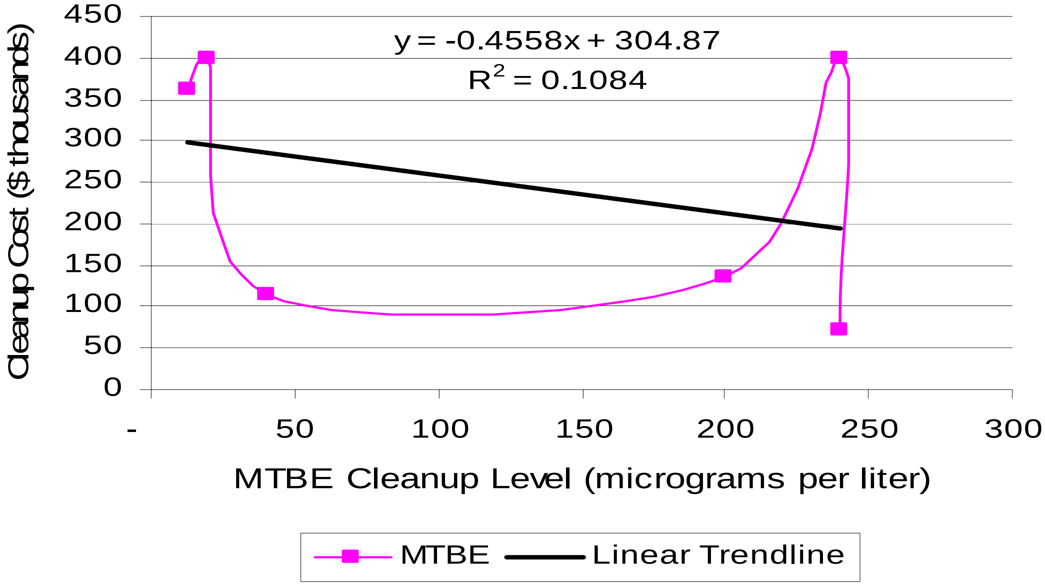

Figure 26. MTBE Cleanup Level Versus Average Site Cleanup Cost

The data presented in Figures 21 through 26 indicate that toluene, ethylbenzene and total xylenes influence the average site cleanup cost. Target levels of benzene and MTBE are not controlling factors in site cleanup costs.

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Conclusions

Each factor identified in this thesis is inherently involved in defining effectiveness of petroleum cleanup programs. For the purposes of this thesis, effectiveness is defined by Equation 1. The data in Table 7 summarize the effectiveness of State programs based on the definition in Equation 1.

Factors that negatively affect cleanup progress include:

1. Stringent government involvement
2. MTBE presence (or other recalcitrant compounds)
3. Difficult lithology or hydrogeology that allows rapid movement
4. No available funding for cleanup
5. Inefficient technology or inadequately-designed technology implementation
6. Busy site operations or a building situated over the petroleum impacts below-ground
7. Stringent cleanup goals.

These factors lengthen the amount of time required and require additional funding to complete LUST site cleanup. For example, a small areal extent of petroleum impacts

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may pose a difficult cleanup if the lithology is not permeable, or if the lithology is highly permeable, the impacts can be spread in groundwater over more than a ¼-mile.

Factors that positively affect cleanup progress include:

1. Less government involvement
2. Vacant sites
3. Sufficient funding
4. Conservative design, adequate installation and operation of remediation technology
5. Small size of impacts with lithology permeable enough to allow efficient *insitu* treatment
6. Less-stringent cleanup goals.

Conservative design can often increase costs of remediation system installation; however, overall cleanup timeframe and consequently cleanup costs can be reduced by instituting more effective treatment. One example of this approach to cleanup is the Florida Remedial Action Intiative (RAI). The RAI specified guidelines for system design, installation and operation to maintain remedial system operations at 80% runtime or greater. If runtimes decreased below 80%, the contractor responsible for operating the system faces potential penalties, including being removed from the project (FDEP, 2004). This initiative may provide Florida with a unique approach to maintaining the progress toward site cleanup.

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In comparing State petroleum cleanup programs, many conclusions can be inferred. One conclusion is that New York has less government involvement than Florida and yet more stringent cleanup goals; therefore, responsible parties are required to cleanup petroleum sites according to the regulations. In Florida, petroleum cleanup of sites that are eligible for State-funding do not have to abide by the timeframes of the regulations due to the fact that the cleanups are implemented and controlled by the State program. Less government involvement is more effective in this case.

Secondly, Texas and Florida are similar in State characteristics and pre-approval of petroleum cleanup costs; however, Texas requires cleanup to less stringent goals. Consequently, cleanup to less–stringent goals requires fewer resources and can occur in less timeframe. Additionally, pre-approval of petroleum cleanup costs in Texas involves submitting a proposal for work, but not awaiting a State work order to initiate the work; therefore, the timeframe of regulatory review is reduced thereby reducing the overall timeframe of site cleanup.

Thirdly, toluene, ethylbenzene and total xylenes cleanup goals affect cleanup costs and inherently affect the timeframe for States with more stringent cleanup goals for these compounds. These States will experience increased cost and timeframes for cleanup. Consequently, the State effectiveness may generally appear less than comparable States.

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Finally, the Florida petroleum cleanup program is based on objectives protective of public health and the environment due to the shallow groundwater and the potential of LUST sites to impact the groundwater resources of the State. This heightened duty to protect public health and the environment positions Florida with the responsibility of providing more structured control of cleanup progress to ensure that cleanup approaches accommodate the multi-faceted concerns of the State.

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Engineering Implications

This thesis should provide environmental professionals with an initial understanding of factors that affect petroleum cleanup to allow efficient planning, implementation and maintenance of petroleum cleanup progress. The information contained herein can assist environmental engineers in understanding the requirements of petroleum cleanup in the State in which their site is located.

The efficiency of petroleum cleanup programs is currently evaluated as simply as can be without reservation of additional resources to conduct in-depth analyses of programs. Certainly, a maturing program should experience constant improvement; however, the tools currently used in evaluating efficiency are sufficient for the government-mandated requirements emplaced on petroleum cleanup programs. Tools such as providing average cost of activities, pre-approving the costs of cleanup and instituting standard, conservative designs, will enhance and expedite the process of government review and approval of costs and technologies.

Given the multitude of factors involved in determining petroleum cleanup effectiveness, an optimum program does not exist. Further evaluation of individual program details may expose potential enhancements to optimize a cleanup program.

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Additional Research

The timeframes for site closure impact evaluation of program effectiveness. Unfortunately, the data required to estimate cleanup expenditures are not readily available. The majority of petroleum cleanup programs report the total number of closures and the total dollars spent; therefore, evaluation based on site-specific data is not feasible without significant investment of time for researching individual site data. Additional research should be conducted to review and evaluate individual site data to statistically analyze the factors involved in petroleum cleanup. With additional data and statistical analysis, perhaps an overwhelming factor can be identified and addressed to increase the efficiency of petroleum cleanup programs across the US.

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Appendices

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Appendix A: State Petroleum Program Web Addresses

Table 9. State Petroleum Program Web Addresses

State/ Territory	Program Type	World Wide Web Address
AK	U	http://www.dec.State.ak.us/spar/ipp/ust.htm
	L	http://www.dec.State.ak.us/spar/csp/leaking.htm
	F	http://www.dec.State.ak.us/spar/rfa/index.htm
AL	U	http://www.adem.State.al.us/WaterDivision/Ground/UST%20GW/GWUSTCompli.htm
	L	http://www.adem.State.al.us/WaterDivision/Ground/UST%20GW/GWUSTCorrAction.htm
	F	http://www.adem.State.al.us/WaterDivision/Ground/UST%20GW/GWALTankTrustFund.htm
AR	U,L	http://www.adeq.State.ar.us/rst/
	F	http://www.adeq.State.ar.us/rst/branch_programs/trustfund.htm
AZ	U,L	http://www.azdeq.gov/environ/ust/index.html
	F	http://www.azdeq.gov/environ/ust/saf/index.html
CA	U,L	http://www.swrcb.ca.gov/cwphome/ust/
	F	http://www.swrcb.ca.gov/cwphome/ustcf/index.html
CO	U,L	http://oil.cdle.State.co.us/
	F	http://oil.cdle.State.co.us/OIL/Fund/fundindex.asp
CT	U,L	http://www.dep.State.ct.us/wst/ust/indexust.htm
DC	U,L,F	http://doh.dc.gov/doh/cwp/view,a,1374,Q,585826,dohNav_GID,1813,.asp
DE	U,L	http://www.dnrec.State.de.us/dnrec2000/Divisions/AWM/ust/
	F	http://www.dnrec.State.de.us/dnrec2000/Divisions/AWM/ust/firstfund/default.asp

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Appendix A: (Continued)

Table 9. (Continued)

State/ Territory	Program Type	World Wide Web Address
FL	U,L	http://www.dep.State.fl.us/waste/categories/pss/default.htm
	F	http://www.dep.State.fl.us/waste/categories/pcp/default.htm
GA	U,L	http://www.gaepd.org/Documents/index_land.html
HI	U,L	http://www.hawaii.gov/health/environmental/waste/ust/index.html
IA	U,L	http://www.iowadnr.com/land/ust/index.html
	F	http://www.iowadnr.com/land/ust/ustfundindex.html
ID	U,L	http://www.deq.State.id.us/waste/prog_issues/ust_lust/index.cfm
	F	http://www2.State.id.us/pstf/
IL	U	http://www.State.il.us/osfm/PetroChemSaf/home.htm
	L	http://www.epa.State.il.us/land/lust/index.html
	F	http://www.epa.State.il.us/land/lust/ust-fund.html
IN	U	http://www.in.gov/idem/programs/land/ust/index.html
	L	http://www.in.gov/idem/programs/land/lust/index.html
	F	http://www.in.gov/idem/programs/land/eltf/index.html
KS	U,L	http://www.kdhe.State.ks.us/tanks/
	F	http://www.kdheks.gov/tanks/trust_fund/index.html
KY	U,L	http://www.waste.ky.gov/programs/ust/default.htm
	F	http://www.waste.ky.gov/programs/ust/claims/
LA	U,L	http://www.deq.louisiana.gov/portal/Default.aspx?tabid=2440
	F	http://www.deq.louisiana.gov/portal/tabid/230/Default.aspx

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Appendix A: (Continued)

Table 9. (Continued)

State/ Territory	Program Type	World Wide Web Address
MA	U	http://www.mass.gov/dfs/osfm/fireprevention/ust/index.htm
	L	http://www.magnet.State.ma.us/dep/bwsc/bwschome.htm
	F	http://www.dor.State.ma.us/ust/ust_home.htm
MD	U,L,F	http://www.mde.State.md.us/Programs/LandPrograms/Oil_Control/PollutionManagement/index.asp
MO	U,L	http://www.dnr.mo.gov/env/hwp/tanks/tanks.htm
	F	http://www.pstif.org
MS	U,L,F	http://www.deq.State.ms.us/MDEQ.nsf/page/UST_PageHome?OpenDocument
MT	U	http://www.deq.State.mt.us/ust/
	L	http://www.deq.State.mt.us/rem/Index.asp
	F	http://www.deq.State.mt.us/pet/index.asp
NC	U,L	http://wastenot.enr.State.nc.us/programs.htm
	F	http://ust.enr.State.nc.us/trustfunds.html for forms see http://ust.ehnr.State.nc.us/forms.html
ND	U,L	http://www.health.State.nd.us/wm/ust/index.htm
NE	U	http://www.sfm.State.ne.us/programs-services/fuels/flst/ust.html
	L,F	http://www.deq.State.ne.us/LUST-RA.nsf/Pages/LUST
NH	U	http://www.des.State.nh.us/orcb/ustprog.htm
	L	http://www.des.State.nh.us/orcb/irs_intro.htm
	F	http://www.des.State.nh.us/ORCB/costprog.asp
NJ	U,L	http://www.State.nj.us/dep/srp/bust/bust.htm
	F	http://www.nj.gov/dep/srp/finance/ustfund/

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Table 9. (Continued)

State/ Territory	Program Type	World Wide Web Address
NM	U,L	http://www.nmenv.State.nm.us/ust/ustbtop.html
	F	http://www.nmenv.State.nm.us/ust/caf.html
NV	U	http://ndep.nv.gov/bca/ust_home.htm
	L	http://ndep.nv.gov/bca/rem_home.htm
	F	http://ndep.nv.gov/bca/fundhome.htm
NY	U	http://www.dec.State.ny.us/website/der/bulkstor/index.html
	L	http://www.dec.State.ny.us/website/der/spills/index.html
	F	http://nysosc3.osc.State.ny.us/oilspill/
OH	U,L	http://www.com.State.oh.us/sfm/bust/
	F	http://www.petroboard.com
OK	U,L,F	http://www.occ.State.ok.us/Divisions/PST/USTDEAD.HTM
OR	U,L	http://www.deq.State.or.us/wmc/tank/ust-lust.htm
PA	U	http://www.depweb.State.pa.us/landrecwaste/cwp/view.asp?a=1240&Q=453631&landrecwasteNav=|30786|30715|
	L	http://www.depweb.State.pa.us/landrecwaste/cwp/view.asp?a=1241&Q=461919&landrecwasteNav=|30816|
	F	http://www.ins.State.pa.us/ins/cwp/view.asp?a=1333&Q=542426&insNav=%7C&insNav_GID=1637
RI	U,L	http://www.State.ri.us/dem/programs/benviron/waste/index.htm
	F	http://www.ustrb.State.ri.us/
SC	U,L,F	http://www.scdhec.gov/eqc/ust/index.html
SD	U,L	http://www.State.sd.us/denr/DES/ground/tanks/tanksection.htm
	F	http://www.State.sd.us/drr/reg/prcf/Prcfhome.htm

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Appendix A: (Continued)

Table 9. (Continued)

State/ Territory	Program Type	World Wide Web Address
TN	U,L	http://www.tennessee.gov/environment/ust/
	F	http://www.tennessee.gov/environment/ust/fund&reimburs.shtml
TX	U	http://www.tceq.State.tx.us/nav/permits/pst_cert.html
	L	http://www.tceq.State.tx.us/nav/cleanups/pst.html
	F	http://www.tceq.State.tx.us/permitting/review/reimbursement/
UT	U,L	http://undergroundtanks.utah.gov
	F	http://www.deq.State.ut.us/EQERR/ust/ustcomp/whatisthepstfund.htm
VA	U,L	http://www.deq.State.va.us/tanks
	F	http://www.deq.State.va.us/tanks/reimbrs.html
VT	U,L,F	http://www.anr.State.vt.us/dec/wastediv/ust/home.htm
WA	U,L	http://www.ecy.wa.gov/programs/tcp/ust-lust/tanks.html
	F	http://www.plia.wa.gov/ust/index.htm
WI	U	http://www.commerce.State.wi.us/ER/ER-BST-HomePage.html
	L	http://www.dnr.State.wi.us/org/aw/rr/cleanup/ust_lust.html
	F	http://www.commerce.State.wi.us/er/er%2Dpecfa%2Dhome.html
WV	U,L	http://www.dep.State.wv.us/item.cfm?ssid=13&ss1id=729
WY	U,L	http://deq.State.wy.us/shwd/stp/
U.S. Territories		
CNMI	U,L	http://www.deq.gov.mp/aupm/AUPM%20main.htm
GU	U,L	http://www.guamepa.govguam.net/
VI	U,L	http://www.dpnr.gov.vi/dep/tanks.htm

U = UST, L = LUST, F = Fund

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Appendix B: Statistical Analysis Input & Outputs

State	Cleanup Levels (micrograms per liter)					
	Benzene	Toluene	Ethylbenzene	Xylenes	BTEX	MTBE
Florida	1	40	30	20	91	20
Michigan	5	140	18	35	198	13
Illinois	5	1,000	700	10,000	11,705	70
California	1	150	300	1,750	2,201	240
North Carolina	1	1,000	550	530	2,081	200
Texas	5	1,000	700	10,000	11,705	240
Ohio	5	1,000	700	10,000	11,705	40
New York	1	5	5	5	16	10
National	5	1,000	700	10,000	11,705	--

State	Average Annual Fuel	Number of Releases	Government Involvement	Petroleum Cleanup	Sites Completed %	Average Cost per site
Florida	2552	24,224	High	230	38.4%	400
Michigan	83	20,962	Low	48	56.9%	363
Illinois	51	22,626	Low		66.2%	
California	1305	44,510	High	250	67.7%	400
North Carolina	218	23,681	Medium	139	72.8%	135
Texas	897	24,460	Medium	63	84.8%	73
Ohio	49	23,799	Low	17+	87.6%	115
New York	1370	24,447	Very Low		87.8%	
National		459637	--		75.0%	

State	10-year appropriation (millions $)	Appropriation per releases	% of US releases	% of US $ spent	Effectiveness
Florida	1110	45.82	2.02%	11.10%	0.18
Michigan	106	5.06	2.59%	1.06%	2.45
Illinois		-			
California	2000	44.93	6.56%	20.00%	0.33
North Carolina	285	12.03	3.75%	2.85%	1.32
Texas		-	4.51%		
Ohio	120	5.04	4.54%	1.20%	3.78
New York		-			
National		-			

Total $ spent on cleanup across US (Millions $)
10000

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Appendix B: (Continued)

GraphPad Results

Table Analyzed	Data 1
Column I	Petroleum Cleanup Government Staff
vs	vs
Column J	Sites Completed %
Unpaired t test	
P value	0.1966
P value summary	ns
Are means signif. different? (P < 0.05)	No
One- or two-tailed P value?	Two-tailed
t, df	t=1.384 df=10
How big is the difference?	
Mean ± SEM of column I	124.5 ± 40.12 N=6
Mean ± SEM of column J	68.03 ± 7.503 N=6
Difference between means	56.47 ± 40.81
95% confidence interval	-34.46 to 147.4
R squared	0.1607
F test to compare variances	
F,DFn, Dfd	28.59, 5, 5
P value	0.0022
P value summary	**
Are variances significantly different?	Yes

Table Analyzed	Data 2
Column D	Average Cost per site (thousands $)
vs	vs
Column F	Appropriation per releases
Unpaired t test	
P value	0.0057
P value summary	**
Are means signif. different? (P < 0.05)	Yes
One- or two-tailed P value?	Two-tailed
t, df	t=3.501 df=10
How big is the difference?	
Mean ± SEM of column D	247.7 ± 63.38 N=6
Mean ± SEM of column F	24.12 ± 7.824 N=6
Difference between means	223.6 ± 63.86
95% confidence interval	81.27 to 365.8
R squared	0.5506
F test to compare variances	
F,DFn, Dfd	65.62, 5, 5
P value	0.0003
P value summary	***
Are variances significantly different?	Yes

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Appendix B: (Continued)

GraphPad Results

Table Analyzed	Data 3
Column A	Effectiveness
vs	vs
Column B	Benzene
Unpaired t test	
P value	0.1739
P value summary	ns
Are means signif. different? ($P < 0.05$)	No
One- or two-tailed P value?	Two-tailed
t, df	t=1.464 df=10
How big is the difference?	
Mean ± SEM of column A	1.440 ± 0.5794 N=6
Mean ± SEM of column B	3.000 ± 0.8944 N=6
Difference between means	-1.560 ± 1.066
95% confidence interval	-3.934 to 0.8143
R squared	0.1765
F test to compare variances	
F,DFn, Dfd	2.383, 5, 5
P value	0.3624
P value summary	ns
Are variances significantly different?	No

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