BIODEGRADATION OF FUEL OXYGENATES IN NORTHEASTERN UNITED STATES AQUIFERS WITH AN ANALYSIS OF UNDERGROUND STORAGE TANK LEAKS

by

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Abstract

BIODEGRADATION OF FUEL OXYGENATES (MTBE) IN GROUND WATER AQUIFERS OF THE NORTHEASTERN UNITED STATES/LEAKING UNDERGROUND STORAGE TANK CAUSATION ANALYSIS

by

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During the past decade the application of monitored natural attenuation has become one of the predominant technologies used in the remediation of gasoline spills impacting subsurface soils and groundwater. The success of this method has depended, for the most part, on the biodegradation of those gasoline constituents that dissolve into groundwater and transport with the groundwater most readily.

One of the most mobile components of gasoline formulations during the past 20 years has been methyl tertiary butyl ether (MTBE), which has traditionally been viewed in both the scientific and the regulatory communities as relatively recalcitrant to biodegradation. However, cases of both *in and ex situ* MTBE biodegradation have recently been documented. In order to better understand and perhaps enhance the process of *in situ* MTBE biodegradation, a fundamental understanding of where, when and under what hydrogeological conditions MTBE biodegradation occurs is needed. To this end, the northeastern United States offers a wide range of lithologies to study. This study examines which subsurface conditions are most conducive to MTBE biodegradation.

Retail gasoline service stations with leaking underground storage tank (LUST) releases located within a variety of hydrogeological conditions in the northeastern United States were screened for lithology, MTBE concentration in ground water, monitoring well network location, and MTBE concentration trends. Ground water samples were collected from those sites that passed this initial screening phase. MTBE from the samples collected were analyzed using stable carbon isotope ratio analysis (SCIRA) to determine where biodegradation is occurring. Geochemistry in each well was also examined to determine which hydrogeological conditions are most conducive to MTBE biodegradation.

MTBE biodegradation under a variety of subsurface conditions was observed in this study. Loose soil conditions combined with reduced aquifer redox potential exhibited the greatest MTBE biodegradation frequency.

Although statistically significant correlations were not found with respect to MTBE biodegradation and aquifer geochemistry, scatter plots showed notable trends with respect to pH, dissolved oxygen, and methane concentration correlated with MTBE biodegradation. Increased biodegradation frequency in the presence of increasing methane concentrations under varied aquifer redox and lithological conditions was observed.

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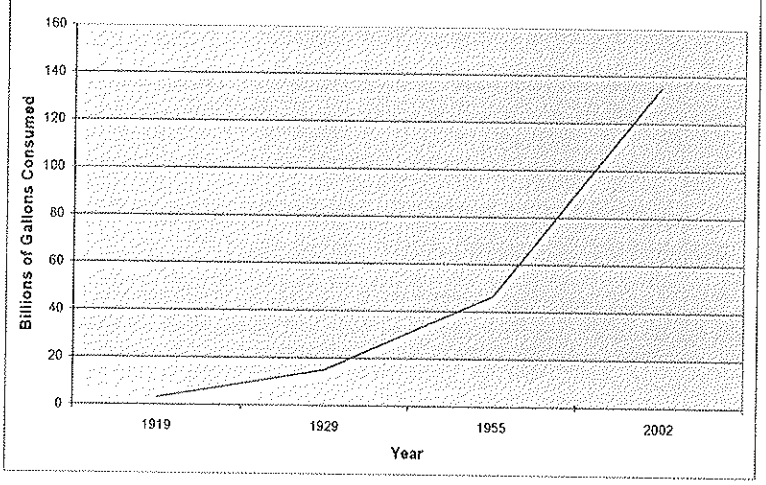
1.0 Overview

Kerosene and gasoline have been produced and stored in the United States since at least the second half of the 19th century (Anderson, 2002). Early on, these fuels were stored in above-ground tanks, which was both messy and dangerous. J.J. Tokheim is credited with the idea of storing kerosene in an underground tank for sale in his hardware store in 1898, creating the first known underground storage tank (UST) for petroleum products (Anderson, 2002).

With the introduction of Henry Ford's mass-produced automobiles in 1903, a market for gas stations was created, and stations built for the sole purpose of dispensing gasoline began to appear around 1905 (Jakle and Sculle, 1994). As automobiles and paved roads proliferated in the 20th century, the demand for gasoline increased steadily throughout the century (with the notable exception of the 1974 OPEC oil embargo) along with the need for more gas stations (Figure 1.1).

Figure 1.1: Estimated Gasoline Consumption in the United States in the 20th Century (Melosi, 2004)



The number of service stations grew proportionally to consumption throughout the century, peaking in the mid 1990s with about 190,000 stations nation wide in 1996, and about 167,000 in 2006 (NPN, 2006). The increased number of service stations over time came with a corresponding increase in fuel storage USTs. Not surprisingly, the increased number of tanks and fuel storage activities lead to a significant number of gasoline spills and leaks throughout the country. Ground water impacts resulting from these gasoline releases became more frequent and widespread, even as demand for the same ground water resources was increasing as the population grew.

In the late 1980s, Congress attacked the problem through mandated underground storage tank (UST) system upgrades to prevent releases to the subsurface (Tiemann, 2006). The upgrades were phased in over a ten year period, beginning in 1988. Although it has been several years since the completion of the UST upgrade program, a quick review of the New York State Department of Conservation (NYSDEC) spills database reveals that new spills are still documented in New York State on a regular basis (a review of equivalent lists maintained by other state environmental regulatory agencies yields similar results) and the USEPA confirmed 3,294 new releases nation wide during the first half of 2008 (USEPA, 2008). Spill/leak prevention remains a challenge to both government and private industry, and is addressed in more detail in Chapter 7.

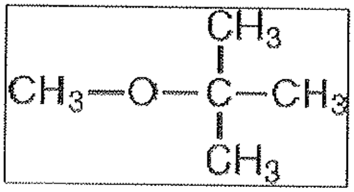
With the emphasis in the late 1980s on spill prevention failing to stop new releases combined with reports of potable well impacts increasing during the 1990s, the focus shifted from spill prevention to spill remediation during this period to address the threat to ground water resources. Historically, gasoline spill cleanups were limited to the physical removal and disposal of leaking UST systems and any impacted soil associated with the spill that could be readily excavated. This approach would successfully remove the immediate contaminant source, but some impacted soil was usually left in-place, acting as a secondary contaminant source to ground water over time. Furthermore, many leaks occurred due to piping breaks, bad joints, or other, non tank-related issues. These leaks are hard to isolate and dig up, so they can act as source areas for prolonged periods of time.

As cleanups became more common and ground water resource impacts more widespread, engineered solutions were developed to more effectively address the subsurface media impacted by gasoline leaks and spills. Ground water "pump and treat" systems were the primary means of mechanical remediation during the early 1980s. This method involved pumping contaminated ground water out of an aquifer at a rate sufficient to gain hydraulic control of the ground water contaminant plume, then treating the impacted water *ex situ* prior to discharging it to the sanitary sewer or other appropriate discharge point.

Novel approaches of mechanically extracting gasoline fuel constituents from the subsurface such as soil vapor extraction (SVE) and air sparging (AS) were first commercially applied in Europe in the mid 1980s, and gained popularity to the point where they were routinely used at LUST sites in the United States during the late 1980s (Western States Petroleum Association, 1997). These and other *in situ* mechanical extraction technologies are still widely used to treat gasoline releases, and are generally recognized to be effective in remediating petroleum hydrocarbons in the subsurface (Western States Petroleum Association, 1997).

In addition to mechanical extraction technologies, a variety of biologically-based remedial technologies (technologies based upon the degradation of contaminants in the subsurface through microbiological activities) are also available to treat petroleum hydrocarbon contamination *in situ*. These technologies range from the injection of foreign microorganisms capable of degrading specific contaminants (bioaugmentation), to the injection of nutrients or electron acceptors to stimulate the growth of indigenous microorganisms (biostimulation), to monitoring subsurface conditions to determine if contaminants are attenuating through natural processes (monitored natural attenuation). These technologies have also proven to be effective in the remediation of petroleum hydrocarbons (EPA OSWER, 1999).

The gasoline additive methyl tertiary butyl ether (MTBE), however, has led to complications in the remediation of gasoline spills. MTBE was originally used in gasoline formulations in the late 1970s as a replacement for tetraethyl lead, and has been used at higher concentrations as a fuel oxygenate to achieve a cleaner burn since the early 1990s. It was commonly used as the fuel oxygenate of choice because it is economical to manufacture and blends well with gasoline. MTBE also mixes well with water (in comparison to other petroleum hydrocarbons), does not adsorb well to soil particles, and does not biodegrade as readily as other petroleum hydrocarbons in the subsurface (Iqbal and Mason, 1999). These properties have led to MTBE-impacted ground water plumes emanating from gasoline spills that are significantly larger (in terms



$$CH_3-O-\overset{CH_3}{\underset{CH_3}{C}}-CH_3$$

Figure 1.2: Lewis structure representation of MTBE

of both length and volumetric aquifer area impacted) than similar petroleum hydrocarbon plumes that do not contain MTBE (Odencrantz, 2000).

1.1 History of MTBE Use in the United States

Domestic MTBE use is historically tied to the ban of leaded gasoline in the 1970s. By the early to mid 1970s, the scientific and legislative communities within the United States had reached an understanding regarding the impact lead was having on the environment. Lead was being used in various forms (principally as tetraethyl lead, mixed with 1,2-dibromoethane and 1,2-dichloroethane in a formulation known as *ethyl fluid*) as an "anti knocking" agent to reduce fuel detonation during the compression stroke in gasoline engines (Seyferth, 2003). During the 1970s, it became clear that lead was being released into the environment nation wide as the number of drivers increased. This fact, combined with the introduction of the catalytic converter (which was not compatible with lead) moved Congress to enact a national ban on leaded gasoline. The ban was phased in over about a 10 year period beginning in 1974.

MTBE was selected as a replacement for ethyl fluid over several other possible replacements for both practical and economic reasons. The effectiveness of tetraethyl lead (TEL) was derived from its ability to scavenge organic radicals, while non lead-based replacements all achieve their effectiveness by increasing the oxygen content of the fuel formulation, thus optimizing fuel oxidation (Seyferth, 2003). MTBE was the best choice of the available TEL replacements for two reasons. First, it was more soluble in gasoline than other possible oxygenates, making it easier to blend, transport and store.

Second, it was more economical to produce, as it is derived from methanol and isobutylene feedstocks (which are both produced from natural gas).

During the 1970s and 1980s, gasoline formulations typically did not exceed 5% MTBE by volume (California Air Resources Board, 1999). Then, in 1990, the Clean Air Act Amendments mandated the addition of "fuel oxygenates" in regions where the air quality did not meet National Ambient Air Quality Standards (NAAQS). Specifically, regions that failed to meet NAAQS for carbon monoxide were placed in the oxygenated fuels program, which required a minimal formulation of 2.7% oxygen by weight during winter months beginning in 1992 (California Environmental Protection Agency, 1997). Regions that exceeded NAAQS for ozone fell into the reformulated gasoline program, which mandated a minimum formulation of 2.0% oxygen year round beginning in 1995.

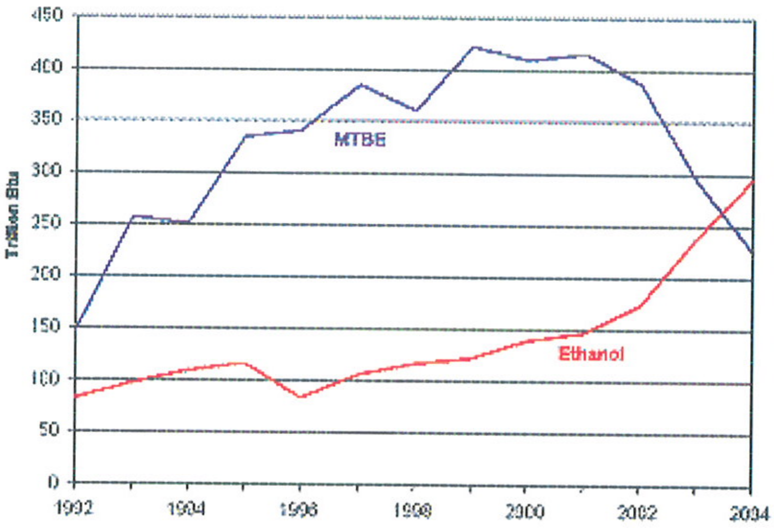
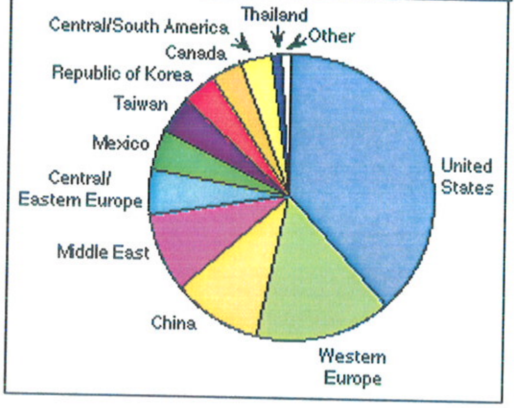


Figure 1.3: US Domestic MTBE and Ethanol consumption, 1992 through 2004 (TSECO, 2007).

The same chemical properties that made MTBE a good substitute for ethyl fluid also made it a good candidate for boosting fuel oxygen content, and it was already being used as a gasoline additive. MTBE therefore easily became the fuel oxygenate of choice to meet the oxygenated and reformulated fuel requirements, and its use proliferated in the early 1990s through 2000 (Figure 1.3). As the environmental impacts of MTBE use became increasingly evident in the late 1990s, its use as a fuel oxygenate was brought into question, and its use began to decline beginning around 2000.

Domestic use continued to decline after 2004, with state bans on MTBE use in California and New York contributing to the decline significantly. The California and New York state bans were followed by a congressional repeal of the fuel oxygenate requirement in 2005. The repeal was packaged as part of the Energy Policy Act, which also failed to indemnify major oil companies against MTBE-related lawsuits (Blum, 2005). With the perceived increase in liability associated with MTBE use resulting from the lack of indemnification, most major oil companies moved away from MTBE use after 2005. MTBE use as a fuel oxygenate has not been eliminated completely in the US, however, and its use continues (and in some cases is actually increasing) in Europe, South America, and parts of Asia (Figure 1.4).

Figure 1.4: World MTBE Consumption in 2004 (Malveda et al, 2006).



1.2 Environmental Occurrence

Throughout the 1990s, MTBE turned up with increasing frequency in both ground water supplies and in surface water bodies as well (Moran, et al, 2000). The first major discovery came in 1996, when MTBE was found in the Charnock and Arcadia well fields of Santa Monica, California. In response to the MTBE impact in their well fields, water supply officials in Santa Monica were forced to shut down more than half of their production volume and purchase water from an outside source at an estimated cost of up to 100 million dollars over the following decade (Sorensen, 1999). The Santa Monica water issue was followed a few years later by a similarly high-profile case of MTBE contamination in Lake Tahoe. The Lake Tahoe case resulted in the shutdown of almost a third of the community water supply wells, and the discovery of MTBE in the lake itself (Forsythe, 1999).

After witnessing the problems MTBE contamination created in Santa Monica and Lake Tahoe, water supply professionals, state and federal environmental regulators, and academics across the country began monitoring water resources for MTBE impacts during the late 1990s. Predictably, the more places MTBE was sought, the more frequently it was found.

A nationwide joint study conducted by the USGS in conjunction with the Oregon Graduate Institute (OGI) and the Metropolitan Water District of Southern California (MWDSC) identified MTBE impacts in 31% of the surface water bodies and 5% of the ground water aquifers sampled (Koch and Dale, 2000). The data set included samples from 52 geological regions across the United States.

Other studies tend to support the joint study findings. For example, a 1998 USEPA survey of state leaking underground storage tank (LUST) programs found that 12 of the 35 states that required sampling for MTBE in 1998 found it 80 - 100% of the time (Hitzig, 1998). Nine of the 35 states reported finding MTBE 60 – 80% of the time, while only 6 reported finding it 0 - 20% of the time.

At the state level, the New Jersey Department of Environmental Protection (NJDEP) reported in 1999 that MTBE in excess of 70 ug/l had been identified at 1900 of the 2400 sites in their ground water corrective action program (Bauer, 1999). In Virginia, 70 of the 200 active contaminated supply well sites have MTBE impacts (Cunningham, 2000). In Maine, the Department of Environmental Protection, Department of Human Services (1998) identified MTBE contamination in 11% of the water supplies located in regions using reformulated (RFG) gasoline. In Kansas, the Department of Health and Environment (KDHE) reported MTBE impacts at 88% of the 818 sites they tested in 1999 (Hattan and Blackburn, 1999).

It is evident, based on the aforementioned studies, that the extensive use of MTBE in gasoline during the past two decades has lead to pervasive environmental impacts across the country, both in and beyond those areas where MTBE formulations were used.

1.3 Regulatory Environment

As the use and corresponding environmental impacts of MTBE proliferated during the 1990s, legislative and regulatory bodies at all levels across the nation looked for ways to address the growing number of impacted ground water cases. Most established concentration limits for ground water, while some banned the use of MTBE outright.

The USEPA established a ground water "advisory level" of 20 – 40 ppb MTBE in 1997 (USEPA, 2007) based on aesthetic considerations (odor and taste) rather than human health factors. In the absence of any legally-binding action levels at the federal level, many states established their own regulatory action limits for MTBE. By 2005, 40 states had established their own action levels (Martinson, 2005), ranging from a high of 202,000 ppb in Hawaii (non-potable ground water standard) to a low of 5 ppb in California (enforceable "secondary" standard based on aesthetics), with most states landing in the 20 – 100 ppb range (Figure 1.5).

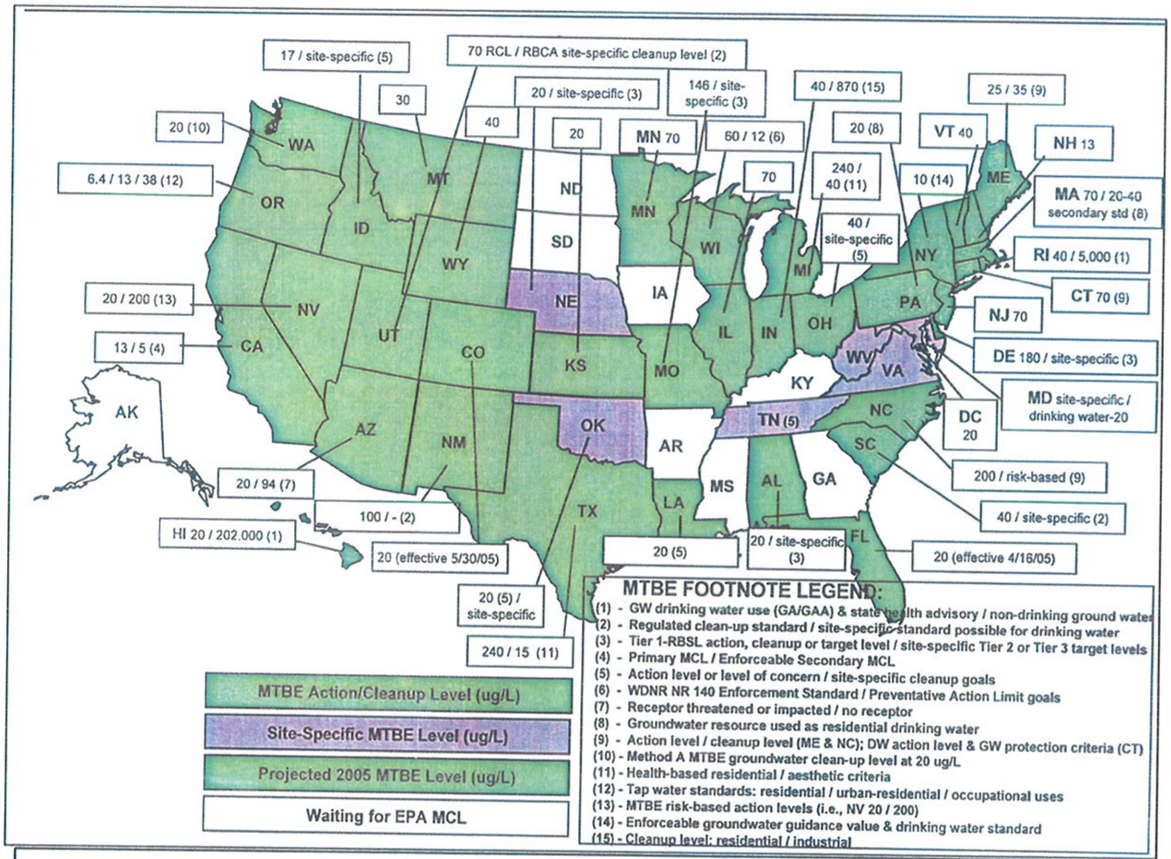


Figure 1.5: Map depicting MTBE ground water regulatory limits by state (Martinson, 2005).

In addition to the development of enforceable ground water quality concentration standards, 19 states have enacted bans on the use of MTBE in fuels (Figure 1.6). The first such ban was approved in California in 1999, the most recent in New Hampshire in 2007 (Burack, 2007).

Although MTBE use as a fuel oxygenate has been significantly curtailed domestically since 2006, its use continues in other parts of the world, and a legacy of LUST sites with MTBE impacts to soil and ground water remain in the United States.

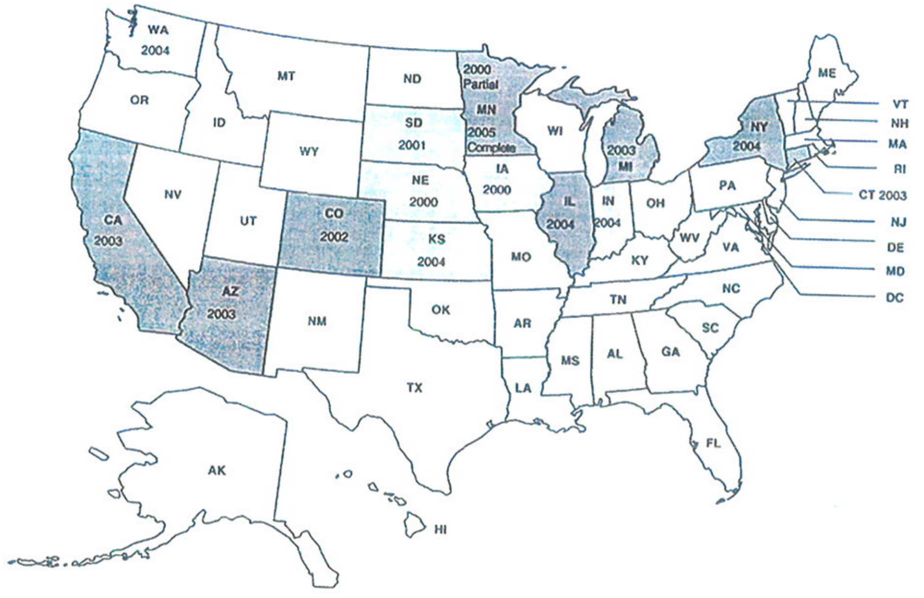


Figure 1.6: Map depicting state MTBE bans in 2002. States that have subsequently banned MTBE include Wisconsin, Ohio, Missouri, Kentucky, Maine, and New Hampshire (GAO, 2002).

1.4 Toxicity

Although the true extent of the environmental impacts of MTBE use as a fuel oxygenate became evident in the early 2000s, the impacts of MTBE on human health were less clear. A 1993 MTBE health risk assessment conducted by the USEPA examined potential acute and chronic effects of inhalation exposure to MTBE in RFG gasoline. The study was conducted in response to reports of acute exposure symptoms in Fairbanks, Alaska (USEPA Office of Research and Development, 1993). The study did not report any statistically significant evidence of acute effects. Chronic inhalation exposure reportedly resulted in increased incidences of renal tubular cell adenomas and carcinomas in male rats, and hepatocellular adenomas in female mice.

As a result of these studies, the USEPA established a reference exposure concentration (RfC) of 3 mg/m^3 of air (IRIS, 1993). Independent studies monitoring the MTBE inhalation exposure of gas station attendants and customers indicated that time-weighted average (TWA) exposures (average exposure over an eight hour period) for both groups were typically below 1 mg/m^3 (Vainiotalo et al, 1999).

During the 1990s, acute health effects were studied in New Jersey (1993), Milwaukee (1994), Maine (1994) and Connecticut (1995). None of these studies were able to establish a causal relationship between MTBE inhalation exposure and acute health symptoms. Nonetheless, acute symptoms (headache, dizziness, and nausea) were reported in all of the areas studied. The National Academy of Sciences (NAS), upon reviewing these studies in 1996, concluded that the reported symptoms might have resulted from perceived health effects due to MTBE's low odor threshold (California Environmental Protection Agency briefing paper, 1997).

Although the effects of inhalation exposure were reasonably well understood, the effects of ingestion exposure (the most likely exposure route from impacted ground water) were not as well documented, and the available literature concerning long-term exposure effects was relatively sparse (Davis, 2000). As a result of the chronic renal effects reported in rats and mice in the 1993 studies, the USEPA calculated unit carcinoma risk numbers using the available exposure data (Cal EPA briefing paper, 1997). The EPA then extrapolated a "health advisory" level for MTBE in drinking water of 20 to 200 parts per billion (ppb), but stopped short of classifying MTBE as a known or suspected carcinogen. This level was revised to 70 ppb in 1996, and subsequently to 20 – 40 ppb in 1997 to address "aesthetic" taste and odor issues.

The body of literature regarding MTBE carcinogenesis in the 1990s was limited to the inhalation studies conducted on rats and mice discussed above, and a study in which MTBE was administered by gavage (oral dose) in olive oil (Belpoggi, 1995). Interpretation of these studies was complicated by questions regarding comparability of the data sets, extrapolation of the data to human populations, and gender specificity of the test subject populations (Mennear, 1997). These interpretive complications led various organizations to different conclusions regarding the carcenogenesis of MTBE. As previously noted, the USEPA does not currently classify MTBE with regard to carcinogenesis. The International Agency for Research on Cancer (IARC, 1999) acknowledged the rat and mice studies, but also declined to classify MTBE as a carcinogen. The state of California, relying on interpretations of the available data developed at the University of California Davis, classified MTBE as a suspected carcinogen (Keller and Fernandez, 2000), and the New York State Department of Health (NYSDOH) concluded, based on the Belpoggi gavage studies described above, that MTBE is a confirmed animal carcinogen (NYSDEC Division of Water, 2000).

In the early 2000s, the increased awareness and concern over MTBE impacts to ground water resources nationwide drove the regulatory bans discussed in the Section 4.2. Most in the scientific community agreed that the toxicological evidence developed in the studies conducted during the late 1990s and early 2000s was insufficient to discern the heath risks posed by MTBE. With the regulatory drive towards decreased production and use, however, the urgency to conduct more toxicity studies was reduced, and relatively few studies were conducted from the early 2000s to the present. These studies have included human exposure effects from bathing with contaminated water (Gordon et al, 2003), a bioassay study of MTBE exposure to rainbow trout (Naddafi et al, 2008), and a toxicokinetic literature summary (Phillips et al, 2008). The human exposure to bathwater study did not come to any meaningful conclusion, while the bioassay of rainbow trout did not find significant effects at low exposure concentrations of MTBE.

1.5 Study Focus

MTBE is also harder to remove, destroy or immobilize in the subsurface than most organic contaminants, and the human health effects of MTBE remain uncertain. These factors culminate in a commonly-occurring ground water contaminant that travels well in the subsurface and is difficult to remediate.

Given the inherent limitations of traditional mechanical extraction technologies when used in the subsurface removal of dissolved-phase MTBE, the development of biologically-based remediation technologies to treat MTBE would be advantageous. The main hurdle in the development of such technologies is the general belief that MTBE is "recalcitrant" to biodegradation (EPA OSWER, 1999). Since 1994, however, MTBE has repeatedly been documented to be more biodegradable than was originally thought. Recent focus has shifted away from "does MTBE biodegrade *in situ*?" in favor of "where, when and how does it degrade *in situ*?"

In addition to having a contaminant that will biodegrade, microorganisms capable of degrading the contaminant of concern must be present in the subsurface, and environmental conditions must be conducive to microbial growth and maintenance. Without these basic factors, biodegradation cannot occur.

Chemoheterotrophic microorganisms (microbes that derive their energy from the reduction of organic carbon compounds), which are primarily responsible for the break down of most organic contaminants in the subsurface, comprise a large number of different microbial species. These species can be found, in varying abundance, under most environmental conditions, ranging from extreme heat or cold to extremely wet or dry conditions (Baker & Herson, 1994). In addition, many chemoheterotrophic genera are capable of degrading numerous different organic contaminants (Baker & Herson, 1994). To date, 33 microbial consortiums known to degrade MTBE have been isolated (Deeb et al, 2003).

If the contaminant of concern is biodegradable and the presence of microorganisms capable of degrading it can be anticipated at some, if not most spill sites, the remaining factors potentially limiting MTBE biodegradation *in situ* are environmental conditions. The conditions that likely influence microbial populations the most *in situ* include water content, temperature, pH, the presence (or absence) of toxins, carbon sources, electron acceptors, and inorganic nutrients (Baker & Herson, 1994). These factors are likely most influenced by a combination of aquifer geochemistry and hydrogeological heterogeneity.

This study is designed to explore the relationships between MTBE biodegradation, aquifer geochemistry, and aquifer lithology. This exploration is accomplished through the use of stable isotopic ratio analysis as a tool to determine where biodegradation occurs, combined with a suite of ground water geochemical analyses and an examination of well soil boring logs to determine geochemical and lithological conditions. These analyses were performed on both a well-specific (161 wells) and a site-specific basis (34 sites) at gasoline service station sites in the northeastern United States (Connecticut, Massachusetts, New York and New Jersey).

In addition to the exploration of MTBE biodegradation described above, this study also examines LUST site causation. This part of the study was accomplished through a series of analyses examining UST system construction equipment details at both LUST and non-LUST sites. A database of construction details for over 1,000 USTs at 599 retail gasoline service station sites (both LUST and non-LUST sites) in New York and New

Jersey was used to provide the data needed to complete these analyses. The LUST site causation study is detailed in Chapter 7.

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2.0 Introduction

The proliferation of MTBE contamination of soil and ground water in the United States during the 1990s and 2000s was not due solely to its increased use as a fuel oxygenate. The physical and chemical properties of MTBE also contributed to the wide-spread incidents of ground water contamination reported.

2.1 Physical and Chemical Properties

MTBE is an alkyl ether (Figure 2.1) which, at 11 to 15% (volume), is also the most abundant chemical constituent in those gasoline formulations that contain it. Some of the other common gasoline constituents such as benzene, toluene, ethyl benzene, and the o, m and p isomers of xylene (collectively known as the BTEX constituents) are also partially soluble in water. However, their solubilities (ranging from 146 to 1,780 mg/l) do not rival that of MTBE (Table 2.1), and they typically do not exceed 5% of gasoline formulations (Squillace et al, 1998). Consequently, when gasoline is released into the subsurface environment, MTBE will partition out of the nonaqueous liquid (NAPL) phase into ground water in greater quantities than other gasoline components will.

Adsorption also plays a role in extended MTBE ground water plumes. The Log Koc values for MTBE, benzene, and toluene are 1.05, 1.9, and 2.0, respectively (Table 2.1). These values indicate that MTBE will adsorb less than most other organic compounds, and will therefore be retarded less when moving through an aquifer.

Table 2.1: Physical and chemical properties of MTBE and the BTEX constituents (Zogorski, 1998)*.

Property	MTBE	Benzene	Toluene	Ethyl Benzene	Total Xylenes
% vol of fuel	10 - 15	2 - 3	5	<1	5 - 8
MW (g/mol)	88	76	92	106	106
Specific Gravity	0.74	0.88	0.87	0.87	0.87
VP (mm Hg)	251	95	28	9	8
Henry's Law Constant	0.02	0.22	0.24	0.35	0.00024
Log Koc	1.05	1.9	2.0	2.5	2.6
Solubility (pure) (mg/l)	43,000	1,780	535	161	146
Solubility (fuel mixture) (mg/l)	4,300	18	27	<2	12
Odor threshold (ppb vapor)	95	1,500 - 4,700	160	6,000	20,000
Taste threshold (ug/l)	10 - 130	500 - 4,500	No Data	No Data	No Data

*All reported values correspond to STP conditions

Additionally, the Henry's Law constant for MTBE is an order of magnitude smaller than those of the BTEX constituents (with the exception of the xylene isomers), rendering MTBE much less likely to volatilize out of the dissolved phase (Ghirelli et al, 1997). MTBE is also commonly thought to be more resistant to biodegradation than many other hydrocarbon molecules due to the structure of its tertiary butyl functional group (Hanson et al, 1999).

These properties collectively indicate that when gasoline is released in the environment MTBE will travel farther, faster, last longer, and appear at higher concentrations in ground water than other gasoline components. This is presumably why MTBE impacts on community ground water supplies have become so common.

2.2 Subsurface Transport

In an attempt to understand the transport of MTBE through the subsurface environment, a number of researchers have conducted analyses of ground water contaminant concentration data from multiple gasoline releases in various parts of the country. In California, researchers from the Los Angeles Regional Water Quality Control Board looked at contaminant plumes (the aerial distribution of aqueous-phase contaminants in ground water) from gasoline releases at 90 service station sites (Yue and Weixing, 2000). Their study reviewed MTBE and BTEX plume lengths, widths, and concentration distributions using ground water monitoring data reported to the Water Quality Control Board. They then developed contaminant transport models for all 90 sites based on the equations of Domenico and Schwartz (1990). The study concluded that MTBE plumes have certain characteristics (length, width, longitudinal dispersivity, degradation coefficient) which are unique when compared to BTEX plumes (i.e. MTBE plumes are generally longer and wider than BTEX plumes), and that Domenico transport models are generally poor predictors of MTBE subsurface behavior.

In contrast to the Yue and Weixing study, two subsequent analyses of plume data sets in California and Texas, respectively, found benzene plumes generally to be as long as, or longer than, MTBE plumes (American Petroleum Institute, 2000). The studies also found plume length to be independent of aquifer lithology. As noted in the API report, there are a number of possible explanations for these results based on the solubility and distribution of MTBE in the subsurface, and the inherent difficulty in identifying the leading edge of MTBE plumes.

An analysis of plumes from BP service station sites in Florida was conducted by Reid et al in 1999. The study incorporated earlier plume studies conducted in California (Rice et al, Buscheck) and Texas (Mace and Choi) with the Florida data set. This study, in contrast to the California and Texas studies cited above, found MTBE plumes, on average, to be 18% longer and 34% larger in aerial extent than BTEX plumes.

Odencrantz, after studying a database of over 500 LUST sites in southern California over a three year period (Odencrantz, 2000), identified an overall increasing trend in MTBE concentrations over time across the data set. The study also established a clear correlation between water table levels and MTBE concentrations. This correlation was also documented by Beckenbach and Emerson (2000), who examined the temporal relation of geometric mean MTBE and benzene concentrations with average water table depth at approximately 500 LUST sites in the Los Angeles area. Their study found a temporal reduction in benzene concentrations over a four year period, while MTBE concentrations fluctuated with the water table over the same time period.

2.3 Conventional Remediation Technologies

The general regulatory trend towards lower MTBE ground water standards has made the remediation of MTBE-impacted ground water increasingly challenging. In addition, the physical and chemical properties which allow MTBE to travel greater distances in an aquifer also make MTBE more difficult to remove from the aquifer using standard ground water remediation technologies (Ghirelli et al, 1997). Historically, the most common method of treatment is to pump the contaminated water out of the aquifer and treat it using mechanical air stripping (Western States Petroleum Association, 1997).

However, MTBE removal from the aqueous phase using this method is not an efficient process when compared to the treatment of other volatile compounds due to its high Henry's Law coefficient. Removing the water from the aquifer and treating it *ex situ* can also be difficult because MTBE tends to form longer plumes than most other ground water contaminants, which requires pumping much larger volumes of ground water.

Other common mechanical treatment methods for aqueous-phase contaminants generally include variations on the pump-and-treat theme which replace or augment air stripping with other *ex situ* treatment methods such as bioreactors, granular activated carbon (GAC) filters, or chemical destruction methods. *In situ* mechanical treatment technologies using air sparging and chemical destruction are also commonly used.

GAC units work by adsorbing contaminants from the aqueous phase as water passes through the carbon matrix. Since MTBE adsorbs poorly compared to most organic compounds, it is easily displaced from binding sites within the GAC matrix. GAC is therefore only efficient for MTBE treatment in the aqueous phase at low flow rates, low MTBE concentrations, and low total organic carbon (TOC) concentrations (Flores et al, 2000). Biofiltration units have been proven effective in treating dissolved-phase MTBE *ex situ* at high flow rates and elevated concentrations (Morales and Deshusses, 2000). However, the inoculation time required to establish a viable MTBE-degrading microbial population within the reactor is typically long (six months to a year), and effluent concentrations often still exceed regulatory discharge limits (Morales and Deshusses, 2000).

Most *in situ* and *ex situ* chemical destruction technologies are based on the generation of hydroxyl radicals, which degrade MTBE through a series of oxidation reactions (O'Shea et al, 2000). In general, the more efficient the hydroxyl radical formation is, the more efficient the overall degradation process will be. To generate the radical, most of these systems react hydrogen peroxide with a catalyst. Common catalysts include iron, acids, ozone and ultraviolet light (O'Shea et al, 2000). Buratovich-Collins and Bowman (2000) have shown *ex situ* chemical oxidation of MTBE using peroxide with ozone to be an effective process at high flow rates and high MTBE concentrations.

Drawbacks to the *ex situ* application of these methods are expense and the generation of acetone as a byproduct, which requires further treatment to remove (Buratovich-Collins and Bowman, 2000). *In situ* applications of chemical oxidation systems are limited by their non-specificity (they will react with any organic and many inorganic compounds in the subsurface), safety issues regarding the field application of the method reagents, and non-uniform subsurface distributions under all but the most homogeneous subsurface environments (Schreier, 2000). Distribution limitations *in situ* are also an issue with air sparging, which tends to create preferential airflow pathways through the subsurface (Amerson and Johnson, 2000). The establishment of these pathways prevents a uniform airflow distribution throughout the treatment area. In addition, the Amerson and Johnson study found that mass transfer of MTBE from the aqueous to the vapor phase as a result of *in situ* air sparging is an inefficient process in comparison to organic compounds with lower solubilities.

2.4 Contaminant Biodegradation Overview

Natural organic material in ground water consists primarily of compounds derived from humate degradation. Bacteria in ground water systems are generally suited to further degrade these compounds to gain energy for cell metabolism. However, many bacteria are flexible with respect to what substrates they are able to metabolize, and can degrade a wide variety of other organic compounds. Which compounds are degraded in a given ground water system is a function of the microbes present, the availability of nutrients and electron acceptors, and the substrate as well. This section focuses on the biodegradation of petroleum hydrocarbons in general (Section 2.4.1), followed by MTBE specifically (Section 2.4.2).

2.4.1 Biodegradation of Petroleum Hydrocarbons

As shown in Figure 2.1 below, hydrocarbons can be broken down into two major classifications (aliphatics and aromatics), each with several sub classifications (Potter et al, 1998). Gasoline contains a wide variety of hydrocarbons, including alkanes, cycloalkanes, alkenes, alkynes, and polynuclear aromatic hydrocarbons (PAHs). The most widely studied biodegradation pathways to date are those involving the aerobic oxidation of alkanes and cycloalkanes (Van Hamme et al, 2003). The principal pathway through which these compounds are degraded is conversion of the alkane to an intermediate alcohol, followed by oxidation of the alcohol to an aldehyde and an acid. ß oxidation followed by the Kreb's cycle then yields mineralization.

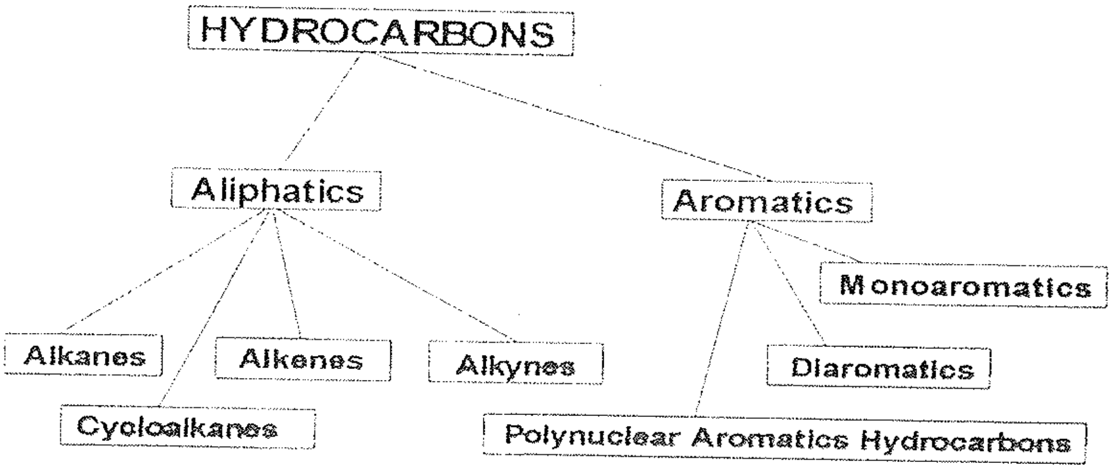
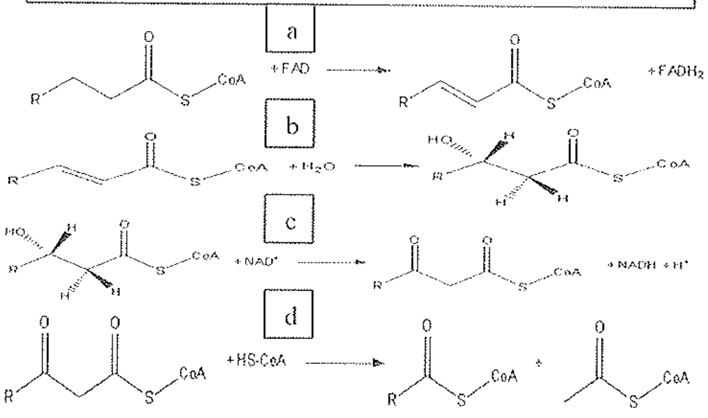


Figure 2.1: Hydrocarbon structural hierarchy *(Potter et al, 1998)*

A similar metabolic pathway which converts alkanes directly to aldehydes without an alcohol intermediate has been identified in Acinetobacter sp. Strain M1 as well (Maeng et al, 1997). Long carbon side chains are likely removed primarily through ßoxidation (Dutta and Harayama, 2001). However, some intermediate products have been identified that suggest other metabolic processes are also at work (van Beilen et al, 2001).

Figure 2.2: The ßoxidation metabolic pathway: (a) oxidation by FAD (b) hydration (c) oxidation by NAD$^+$ (d) thiolysis *(University of Akron, Dept of Chemistry, 2006)*.



ßoxidation is an important process for aerobic alkane degradation (Figure 2.2), and a large variety of microbes are capable of performing it. First, a fatty acid intermediate product is oxidized via FAD through formation of a C2-C3 double bond. Next, the newly formed double bond is broken through a hydration reaction to form L-3-hydroxyacyl

CoA, followed by conversion of the hydroxyl functional group to a keto group by NAD^+ - facilitated oxidation. Finally, two carbons are cleaved through thiolysis, yielding acetyl CoA and acyl CoA. The process continues until the hydrocarbon chain is consumed, and the acetyl CoA produced enters the Kreb's cycle.

In general, long-chain (>10) alkanes are biodegraded more readily than short chains, saturated aliphatics degrade more readily than unsaturated ones, and straight chained hydrocarbons degrade more readily than branched chains (Chapelle, 2001). This condition is likely due to the increased solubility of the shorter chains, which make control of their transport through the cell wall more difficult. This, in turn, renders short chain alkanes more toxic to the cell than longer chains.

In contrast to alkanes and cycloalkanes, aromatics in general and PAHs in particular tend to persist in the subsurface for much longer periods (Baker, 1994). This is likely due principally to the stable bond energy arrangement of the 6-carbon ring structures that comprise these molecules, making them more difficult to degrade than many alkanes, cycloalkanes and alkenes. Their relatively low solubility and high adsorption characteristics also likely render PAHs less susceptible to biodegradation (van Beilen et al, 2001). In spite of their relative recalcitrance to biodegradation in situ, both low molecular weight (three or fewer rings) and high molecular weight (four or more rings) PAHs have proven to be biodegradable by a variety of microbial consortia (Cerniglia, 1992). The information gap seems to be how these consortia work together, and under what conditions (van Beilen et al, 2001).

Monoaromatic hydrocarbons such as the BTEX constituents degrade most commonly through the formation of a catechol intermediate, which subsequently progresses through either ortho or meta cleavage pathways on to mineralization (Figure 2.3).

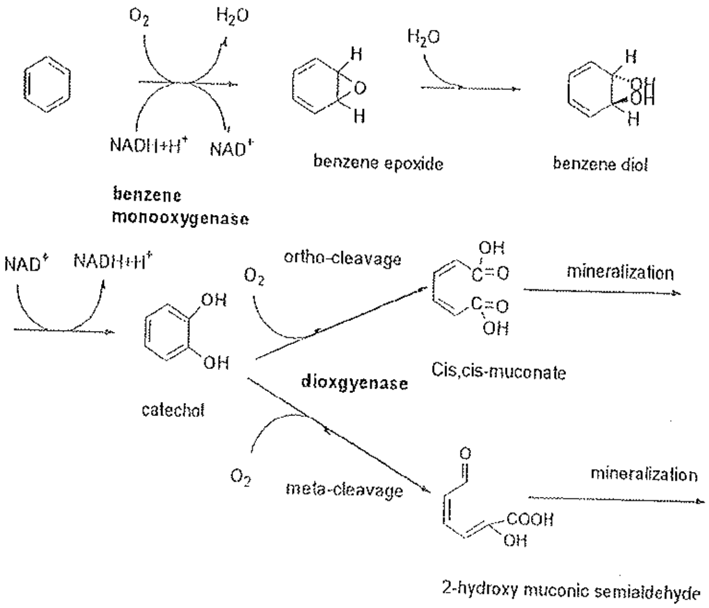


Figure 2.3: Metabolic pathway for aerobic oxidation of benzene through (a) ortho cleavage and (b) meta cleavage, with subsequent mineralization to CO_2 and water (*VanBriesen & Yuan, 2001*).

The ortho pathway involves cleavage between the hydroxyl groups, followed by oxidation to ßketoadipate. The meta pathway involves cleavage between one hydroxylated carbon and one non-hydroxylated carbon, followed by ring cleavage resulting in organic acids which subsequently undergo ß oxidation. The organic functional groups attached to the aromatic ring structure provide variable resistance to biodegradation, with toluene being the most readily degraded, and ethyl benzene being the least (VanBriesen &Yuan, 2001).

2.4.2 Overview of MTBE Biodegradation

In the past, MTBE had been viewed in both the scientific and the regulatory communities as relatively recalcitrant to biodegradation. The earliest study commonly identified in the literature, conducted by Fujiwara et al (1984), found MTBE to be recalcitrant to aerobic biodegradation in activated sludge cultures. Other early studies (Jensen & Arvin, 1990; Suflita & Mormile, 1993; Yeh & Novak, 1994) confirmed Fujiwara's findings in both activated sludge and aquifer sediments.

Jensen and Arvin (1990) postulated that MTBE's recalcitrant behavior was attributable to the ether bond and the tertiary butyl group, both of which have been recognized as difficult to biodegrade. The ether bond energy has been calculated at 360 kJ/mol (White et al, 1996), which requires a significant energy expenditure by microorganisms to cleave. Furthermore, if the ether bond of MTBE is broken through hydrolysis, the resulting products include tertiary butyl alcohol (TBA) and formaldehyde, which is toxic to microorganisms.

Ether bond biodegradation has been studied since at least 1965, and the literature varies with respect to how readily they degrade. A variety of aryl methyl ethers, as well as dialkyl and cyclic ethers can reportedly be readily degraded, while dimethyl, diethyl and dioctyl ethers have all been reported as recalcitrant (Fiorenza & Rifai, 2003). As noted in Section 2.4.1, branched-chain alkanes are harder to degrade than straight chains, which is consistent with the MTBE butyl group causing recalcitrance.

In the mid 1990s, however, several cases of aerobic MTBE biodegradation were documented. First, Salanitro et al (1994) reported aerobic MTBE biodegradation in a controlled study using a mixed culture microbial consortia isolated from a wastewater treatment plant. Following Salanitro's work, several studies confirmed aerobic MTBE biodegradation *in vivo* in the late 1990s. Park & Cowan (1997) and Fortin & Deshusses

(1999) both demonstrated biodegradation using mixed-culture microbial inoculates from existing bioreactors which had previously been conditioned with MTBE.

In addition to these results reported for mixed-culture microbial consortia, several concurrent studies identified MTBE biodegradation using pure cultures as well (Mo et al, 1995; Hanson et al, 1999; Salanitro et al, 2001; Hatzinger et al, 2001, Steffan et al, 1997). These researchers all reported success growing their respective microbial isolates on MTBE as the sole carbon source, but all reported slow microbial growth rates compared to those commonly reported for growth on other carbon sources.

Wilson et al (2005) compared the growth rate of MTBE-degrading bacterial isolates reported in the studies from the late 1990s with the growth rates of BTEX-degrading isolates reported in the literature. The reported doubling time for MTBE-degrading isolates ranged from 41 to 670 hours, while the median doubling times of BTEX degraders ranged from 2.1 to 5.0 hours. Based on this comparison, Wilson et al speculated that the early studies on MTBE biodegradation failed because they were not conducted for long enough time periods to see microbial growth.

As evidence for aerobic MTBE biodegradation mounted in the late 1990s and early 2000s, researchers began proposing metabolic pathways (Steffan et al, 1997; Deeb et al, 2000; Francois et al, 2002). All of the pathways published to date agree on the initial step: oxidation of MTBE's terminal methyl group to form the intermediary tertiary butyl alcohol (TBA) and formaldehyde, which degrades readily (Figure 2.4). The tertiary butyl alcohol then undergoes successive oxidations to the intermediary products methyl 2-hydroxy-1-propanol (MHP) and 2-hydroxyisobutyric acid (HIBA). The carboxylic acid functional group is then cleaved from HIBA to yield acetone, which is finally reduced to pyruvate and then mineralized through the Kreb's cycle (Fiorenza & Rifai, 2003).

Cometabolic aerobic biodegradation of MTBE has also been demonstrated in a number of studies (Steffan et al, 1997; Garnier et al, 1999; Hyman et al, 1998), and the addition of propane injected into the subsurface to stimulate the cometabolic biodegradation of MTBE was patented by Envirogen Corporation in 1998. Steffan et al used an isolate of the bacterial strain ENV425 to cometabolise MTBE with propane substrate in a radio-labeled assay experiment. Both formaldehyde and HIBA were identified, with HIBA accumulating during the experiment. Based on this development, the researchers concluded that HIBA oxidation is a rate-limiting step in the metabolic pathway (Figure 2.4).

Steffan et al further postulated, based on spectrophotometric evidence and enzyme inhibition experiments, that a cytochrome P-450 enzyme was involved in the catabolic process with ENV425. Others (Hyman et al, 1998) found MTBE catabolism in Xanthobacter and Mycobaterium vaccae to be facilitated by a non-heme oxygenase enzyme.

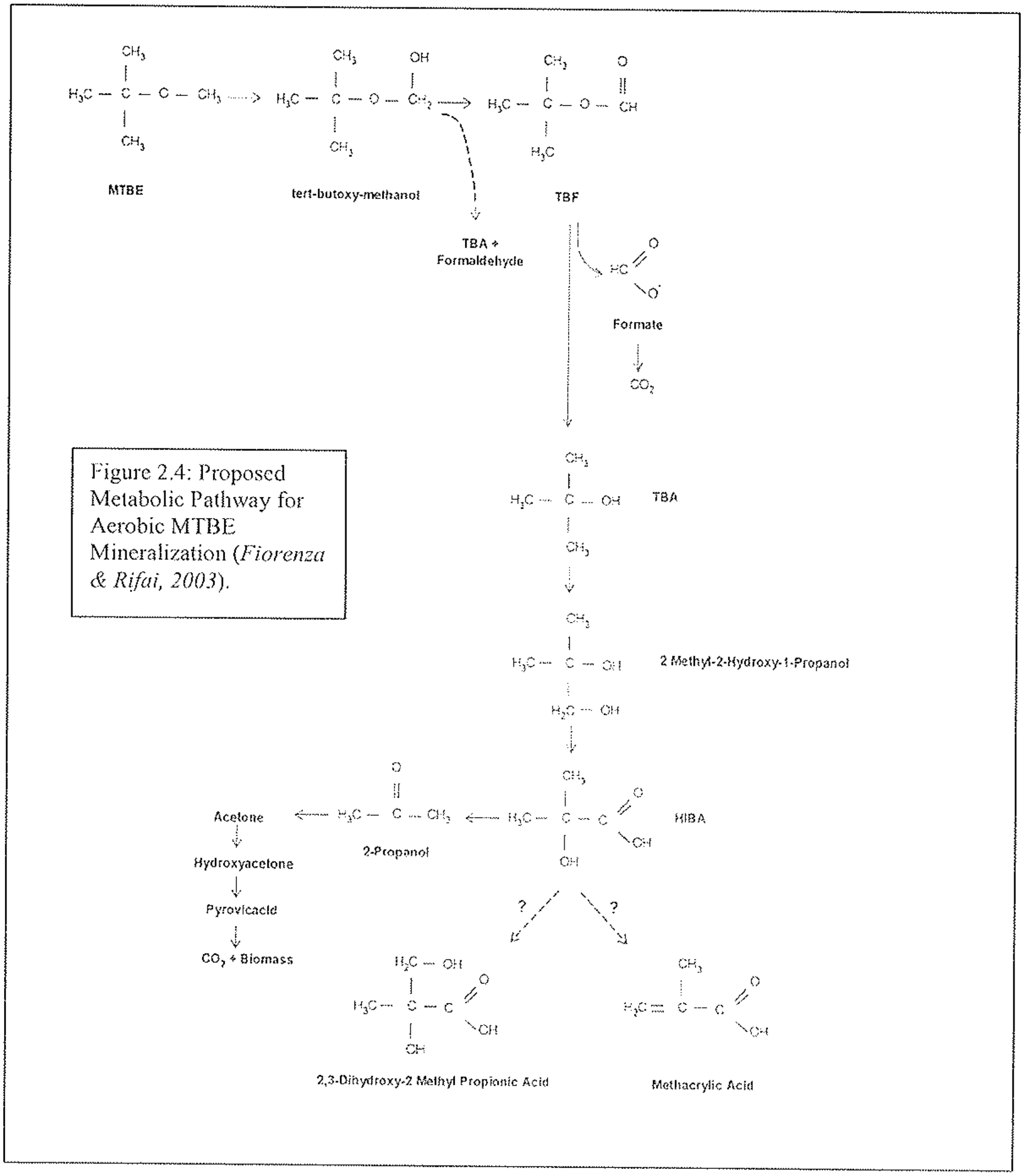


Figure 2.4: Proposed Metabolic Pathway for Aerobic MTBE Mineralization (*Fiorenza & Rifai, 2003*).

A number of *in vivo* MTBE anaerobic biodegradation studies have also been conducted in the past 12 years, with mixed results. Like the early aerobic biodegradation studies, collectively carried out under a variety of anaerobic aquifer redox conditions (methanogenic, sulfate reducing, and nitrate reducing).

In 2000, Wilson et al reported the first evidence of methanogenic MTBE biodegradation using microcosms prepared from a former fuel tank terminal site in Elizabeth City, NC. The Wilson study was followed by another multiple-redox condition study by Bradley et al (2001), which identified MTBE mineralization under nitrate, sulfate, and iron (III) redox conditions, but not under methanogenic conditions. Other studies have demonstrated MTBE biodegradation under varied redox conditions as well, including nitrate reducing (Borden et al, 1997) and sulfate reducing (Somsamak et al, 2001).

Within the past 10 years, aerobic biodegradation of MTBE has been established in the literature through both laboratory and field studies, and anaerobically through laboratory studies. Aerobically, it is clear that both pure and mixed microbial cultures are capable of MTBE biodegradation, and catabolism proceeds both directly and cometabolically. However, degradation rates are relatively slow compared to many petroleum hydrocarbon alkanes and aromatics. A general consensus has also been reached regarding the aerobic metabolic pathway through which biodegradation occurs (Figure 2.4), with rate-limiting steps at TBA and HIBA formation. Future research in this area will likely center around the enzymatic processes involved in the metabolic pathway, and what factors lead to the rate-limiting steps.

Anaerobically, laboratory studies conducted over the past decade have shown that MTBE will degrade under a variety of redox conditions, but mineralization has not always been reported, and degradation rates are highly variable and generally slow. Additionally, no metabolic pathway for anaerobic degradation has been proposed to date, and it is likely that different microbial consortia use fundamentally different pathways. At this stage, future research with respect to anaerobic MTBE biodegradation will likely center on the discernment of metabolic processes in the lab, and on aquifer conditions in the field.

2.5 Study Site Selection Process

Approximately 310 retail gasoline service stations with identified LUST spill numbers located in the northeastern United States were considered for this study. The initial candidate population of sites included approximately 150 in New Jersey, 110 in southeastern New York, 25 in Connecticut, and another 25 in Massachusetts. Prior to sampling, the candidate sites were screened to determine their suitability for inclusion in the study. Site selection criteria are discussed in detail in Sections 2.5.1 through 2.5.3 below.

2.5.1 Current MTBE Contamination

Since the study objectives are centered on MTBE biodegradation, the single most important criterion for site selection was measurable MTBE impact in the subsurface at all of the selected sites. The first screening criterion chosen, therefore, was a current MTBE concentration of at least 2,000 ug/L in at least one ground water monitoring well. "Current" was defined as occurring within the most recent quarterly ground water sampling event prior to selection for the study. Two thousand micrograms per liter was chosen as the selection criterion because it is low enough to be readily encountered at numerous LUST sites, yet high enough that detectable concentrations should be present in other downgradient wells.

Many of the original 310 sites under consideration did not meet the 2,000 ug/L criterion. In New York, 22 of the original 110 possible sites (20%) did. In New Jersey, 24 of 150 (16%) met the criterion, while in Connecticut 10 of 25 (40%) did. In Massachusetts, one site out of 25 (4%) met this requirement. Overall, 57 sites (18%) of the initial candidate population met the criterion.

2.5.2 Historical MTBE Contamination/Downgradient Monitoring Well Network

Significant, current MTBE impacts was a critical criterion in determining which candidate sites were suitable for inclusion in the study. However, this criterion alone was insufficient to determine a site's suitability. A significant confounding factor in identifying MTBE biodegradation is the age of the gasoline release. If, for example, a new spill occurred within the previous quarter, MTBE concentrations would likely be in excess of the 2,000 ug/L criterion, but the spill would be too fresh for significant MTBE biodegradation to have occurred.

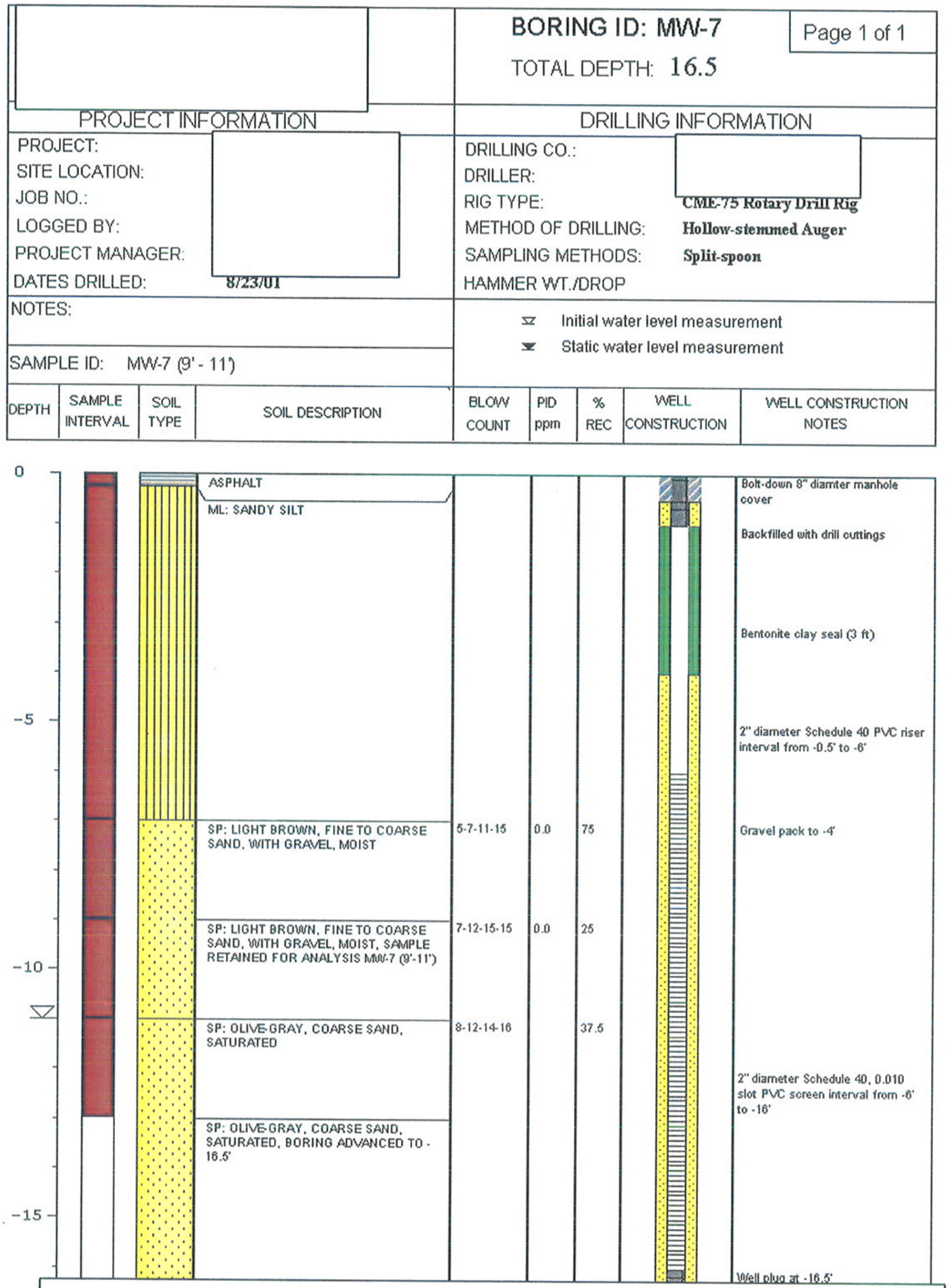
There is a significant degree of variability in published in situ biodegradation rates for MTBE (Section 2.4), and it is therefore not possible to predict biodegradation kinetics at a given site. The alternative is to simply select some suitably long time interval following the gasoline release to allow biodegradation to begin in most cases. Using the somewhat arbitrary assumption that one year is enough time for measurable biodegradation to occur (this is certainly within the reported timeframes commonly identified in the literature concerning aerobic MTBE biodegradation), an additional criterion of 2,000 ug/L in at least one well for the previous 4 quarterly sampling events (one year) was added.

Another issue of concern in the site selection process is the number of MTBE-impacted wells identified on each site. The CSIRA analysis method outlined in Chapter 6 allows wells to be tested individually with respect to MTBE biodegradation, and biodegradation could therefore be confirmed at a given site with a suitable CSIRA result in a single well. Nonetheless, having additional impacted wells increases the chances of identifying MTBE biodegradation.

The final selection criteria therefore include current MTBE concentrations in excess of 2,000 ug/L, with historical MTBE concentration trends over 2,000 ug/L for the previous four quarterly sampling events in at least one monitoring well, along with at least one additional well with measurable MTBE concentrations.

Upon screening the candidate sites for these criteria, 34 sites met the requirements outlined above (8 in Connecticut, 1 in Massachusetts, 12 in New Jersey, and 13 in New York). A total of 161 wells across the 34 sites were included in the study. The MTBE concentration data used to select the study candidates is detailed in Appendix I.

The overall study objective was not simply to identify MTBE biodegradation in situ, but to identify it under a variety of subsurface conditions. With that purpose in mind, the 161 monitoring wells selected for inclusion in the study were categorized with respect to both soil lithology and geochemistry. Soil boring logs detailing well depth, water screen interval and well construction (in addition to soil type) were compiled and recorded in compliance with ASTM Method D 2487 (Chapter 3) when each well was drilled. These boring logs were used to categorize the study monitoring wells with respect to soil type. An example boring log from a site in the Bronx, New York is included as Figure 2.5.



[redacted]

BORING ID: MW-7

TOTAL DEPTH: 16.5

Page 1 of 1

PROJECT INFORMATION

PROJECT:
SITE LOCATION:
JOB NO.:
LOGGED BY:
PROJECT MANAGER:
DATES DRILLED: 8/23/01

[redacted]

NOTES:

SAMPLE ID: MW-7 (9' - 11')

DRILLING INFORMATION

DRILLING CO.:
DRILLER:

[redacted]

RIG TYPE: **CME-75 Rotary Drill Rig**
METHOD OF DRILLING: **Hollow-stemmed Auger**
SAMPLING METHODS: **Split-spoon**
HAMMER WT./DROP

▽ Initial water level measurement
▼ Static water level measurement

SOIL DESCRIPTION	BLOW COUNT	PID ppm	% REC
ASPHALT			
ML: SANDY SILT			
SP: LIGHT BROWN, FINE TO COARSE SAND, WITH GRAVEL, MOIST	5-7-11-15	0.0	75
SP: LIGHT BROWN, FINE TO COARSE SAND, WITH GRAVEL, MOIST, SAMPLE RETAINED FOR ANALYSIS MW-7 (9'-11')	7-12-15-15	0.0	25
SP: OLIVE-GRAY, COARSE SAND, SATURATED	8-12-14-16		37.5
SP: OLIVE-GRAY, COARSE SAND, SATURATED, BORING ADVANCED TO -16.5'			

WELL CONSTRUCTION NOTES

Bolt-down 8" diamter manhole cover

Backfilled with drill cuttings

Bentonite clay seal (3 ft)

2" diameter Schedule 40 PVC riser interval from -0.5' to -6'

Gravel pack to -4'

2" diameter Schedule 40, 0.010 slot PVC screen interval from -6' to -16'

Well plug at -16.5'

Figure 2.5: Example soil boring log from a ground water monitoring well installed at a gasoline service station in Elmsford, NY (*Delta Environmental Consultants, Inc., 2001*)

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3.0 Background

As noted in Chapter 2, biodegradation entails the dynamic interaction of microbes and substrates under a variety of aquifer conditions. Sediment type and redox potential are two highly significant factors in determining which aquifer conditions are conducive, and which are not. Sediment types and their effect on biodegradation are discussed in more detail in Section 3.1 below. Aquifer geochemistry is discussed in detail in Section 3.4.

3.1 Sediment Lithology

Sediments are mixtures of gravel, sands, and fines (silts and clays) which can be classified according to which particle types predominate. The American Society of Testing Materials (ASTM) developed a standard for soil classification (ASTM D 2487) in 1985 based on the percent (by weight) composition of sands, silts and clays in soils (Figure 3.1 below).

3.2 Soil Factors Influencing Microbial Activity

Microbes in the subsurface need organic substrates, terminal electron acceptors (TEAs), nutrients, and appropriate pH and temperature conditions to function. Of these factors, the ones that most commonly limit biodegradation in subsurface environments are a shortage of TEAs and/or nutrients (Thevanayagam, 1997). Because silts and clays are much less permeable than sands and gravels, they allow less recharge of TEAs and nutrients into a given volume of aquifer. They are therefore widely viewed as less able to support contaminant biodegradation than sands and gravel (Nolan & Stoner, 2000).

Table 3.1: Unified Soil Classification (USC) System (*from ASTM D 2487*)

Major Divisions			Group Symbol	Typical Names
Course-Grained Soils More than 50% retained on the No. 200 sieve	**Gravels** 50% or more of course fraction retained on the No. 4 sieve	Clean Gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		Gravels with Fines	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	Sands 50% or more of course fraction passes the No. 4 sieve	Clean Sands	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded sands and gravelly sands, little or no fines
		Sands with Fines	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
Fine-Grained Soils More than 50% passes the No. 200 sieve	**Silts and Clays** Liquid Limit 50% or less		ML	Inorganic silts, very fine sands, rock four, silty or clayey fine sands
			CL	Inorganic clays of low to medium plasticity, gravelly/sandy/silty/lean clays
			OL	Organic silts and organic silty clays of low plasticity
	Silts and Clays Liquid Limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
			CH	Inorganic clays or high plasticity, fat clays
			OH	Organic clays of medium to high plasticity
Highly Organic Soils			PT	Peat, muck, and other highly organic soils

Prefix: G = Gravel, S = Sand, M = Silt, C = Clay, O = Organic
Suffix: W = Well Graded, P = Poorly Graded, M = Silty, L = Clay, LL < 50%, H = Clay, LL > 50%

3.3 Geological History of the Study Area

Sediment types vary significantly throughout the northeastern United States, primarily due to the geological history of the area. Portions of the northeast, including Long Island, Fishers Island, Block Island, Martha's Vineyard, Nantucket and Cape Cod are relatively young, glacial features which date back to the Pleistocene epoch (Nilsson, 1983). Most of the northeast, however, has a much longer and more varied geological history, which was dominated by the formation and subsequent break up of the "supercontinent" Pangea (Schuberth, 1968). Orogenic events associated with the formation and break up of Pangea collectively formed the Appalachian Mountains, metamorphing the Cambrian depositional zone on the Iapatus (proto Atlantic ocean) shelf into gneisses, shists and marble in the process (Schuberth, 1968).

As a result of these events, the northeastern coastal region of the United States contains a broad mixture of igneous, sedimentary and metamorphic rocks. Weathering and glaciation have redistributed the parent rock materials throughout the area, but current surficial features can still be attributed to the underlying bedrock formations (areas with common underlying geological features are identified as physiographical provinces). In more recent geological history (late Pliocene and Pleistocene Epochs) a series of glaciations covered the majority of the northeastern United States, significantly altering surficial land features in the process (Nilsson, 1983).

More specifically, at its maximum extent (about 21,000 years ago), the Laurentide (most recent) ice sheet extended as far south as what is today Long Island and northern New

Jersey, and out onto the North American continental shelf. As the ice sheet receded, it left a series of thick sedimentary deposits of unsorted till material known as terminal moraines. These formations became Long Island, Block Island, Martha's Vinyard, Nantucket, and Cape Cod when sea levels subsequently rose again.

As the ice continued to retreat, a variety of sediments were deposited through differing mechanisms. Meltwater streams carried coarse, mostly unsorted outwash sediments (glacial-fluvial) into the valleys, while finer, well sorted sediments (glacial-lacustrene and marine) were deposited by glacial lakes and marine inlets. The resulting landscape, which remains today, includes a broad range of sediments, including sands, silts and clays in both well sorted (homogenaic) and poorly sorted (heterogenaic) depositional environments.

Notable surficial features remaining include the Rocky Hill area of Connecticut, where sediment acted as a dam in the Connecticut River Valley, creating a glacial lake throughout the valley which extended as far north as St. Johnsbury, Vermont (about 200 miles). This lake, known as glacial lake Hitchcock, dominated the landscape of the area (Rittenour, 2006).

In southeastern New York, terminal moraine and subsequent sedimentary deposits overlaid earlier glacial depositions, forming the hydrogeology of Long Island (consists primarily of glacial outwash sand deposits with intermixed clays). The principal aquifers underlying the island include the Upper Glacial, the Magothy, and the Lloyd (Jensen and Soren, 1974; and Smolensky et al, 1989).

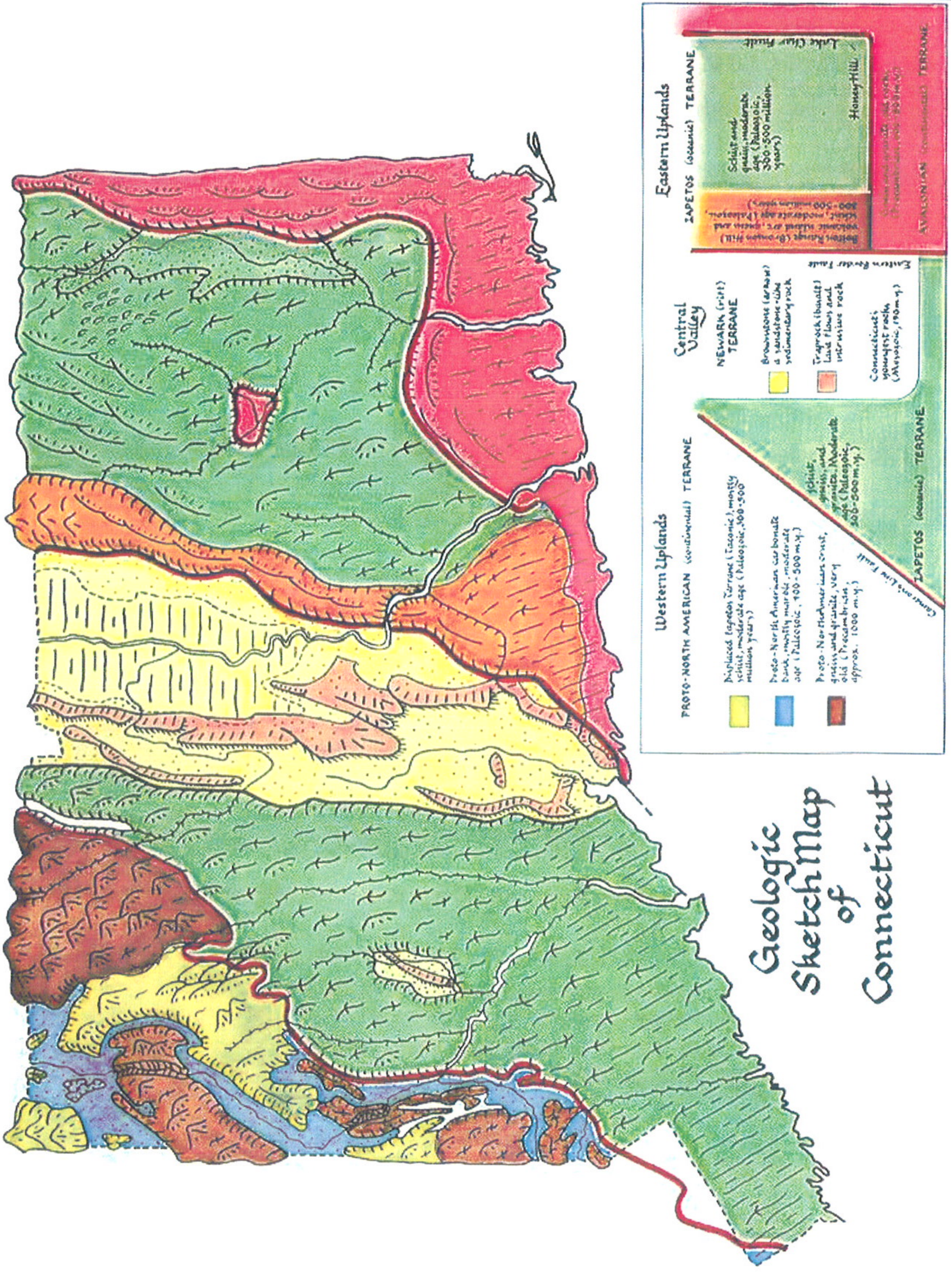
The Upper Glacial aquifer, which underlies all of Nassau and Suffolk Counties, has a probable thickness of approximately 700 ft. The Upper Glacial contains large quantities of ground water in both the outwash plain and morainal deposits. The deposits underlying the outwash plain are composed largely of stratified fine to coarse sand and gravel.

The Jameco formation is localized along the northern and southern shorelines of Nassau County, ranges in thickness from 0 - 200 feet, and is located approximately 100 - 500 below ground surface (bgs). This formation is locally influenced by saltwater intrusion.

The Magothy aquifer, which underlies both Nassau and Suffolk Counties, ranges in depth from 0 - 1,100 feet in thickness, and is found 0 - 600 bgs. Fine to medium sand is inter-bedded with clay and sandy clay of moderate permeability and silt and clay of low permeability. The basal 50 - 200 feet may commonly contain coarse sand and gravel.

The Lloyd aquifer, which lies immediately above solid bedrock, is 0 - 550 feet thick and is 200 - 1,800 feet bgs. It contains fine to coarse sand and gravel, with a clayey matrix containing some layers of silty or solid clay.

Figure 3.1: Geological Sketch Map of Connecticut detailing bedrock formations and locations. *(Connecticut Department of Environmental Protection, State Geological and Natural History Survey, 1985).*



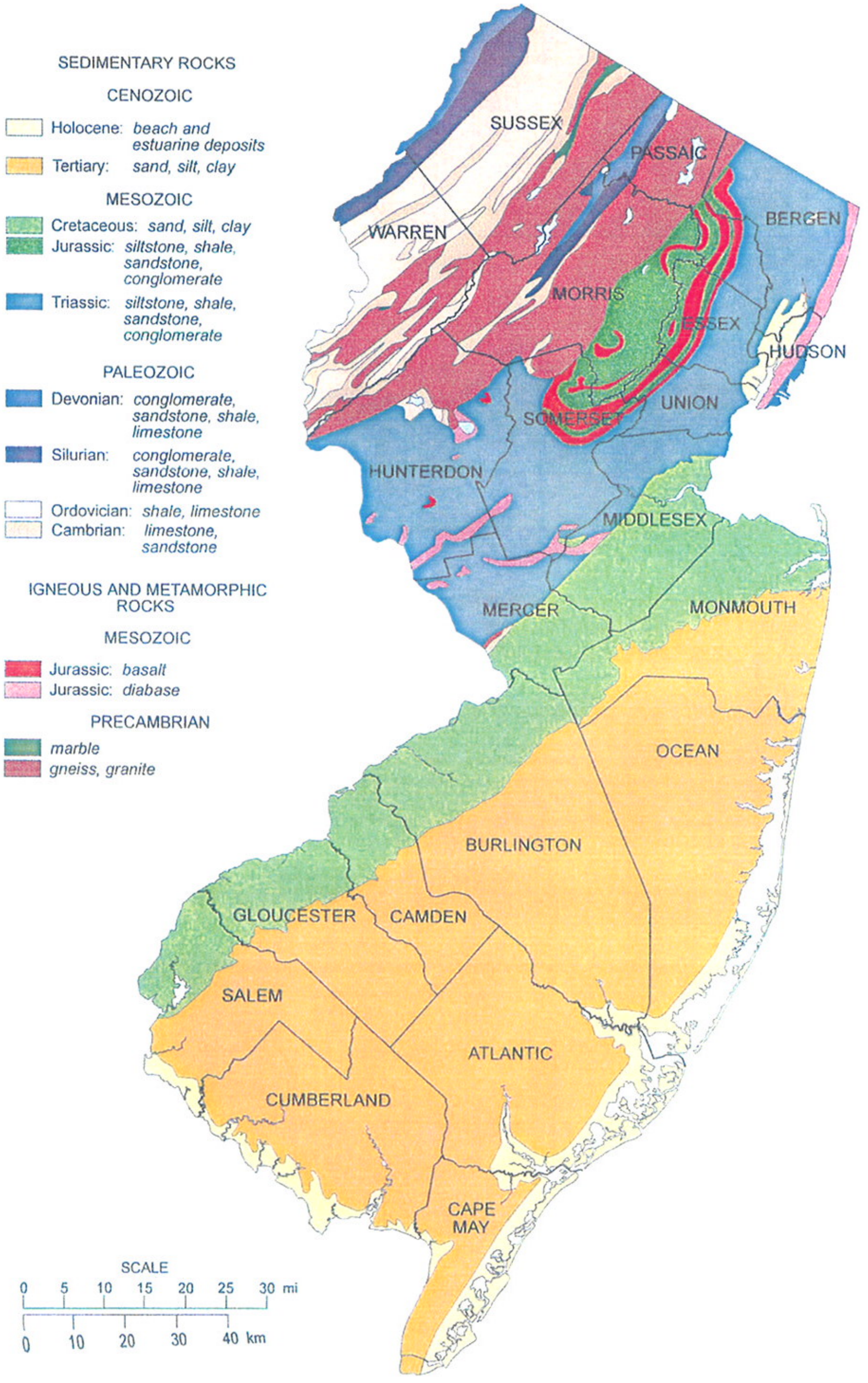


Figure 3.2: Geologic Map of New Jersey (*Department of Environmental Protection, Division of Science, Research and Technology Geological Survey*, 1999).

Figure 3.3: (a) Geologic Map of Southeastern New York State, and (b) Map Legend (insert following text)

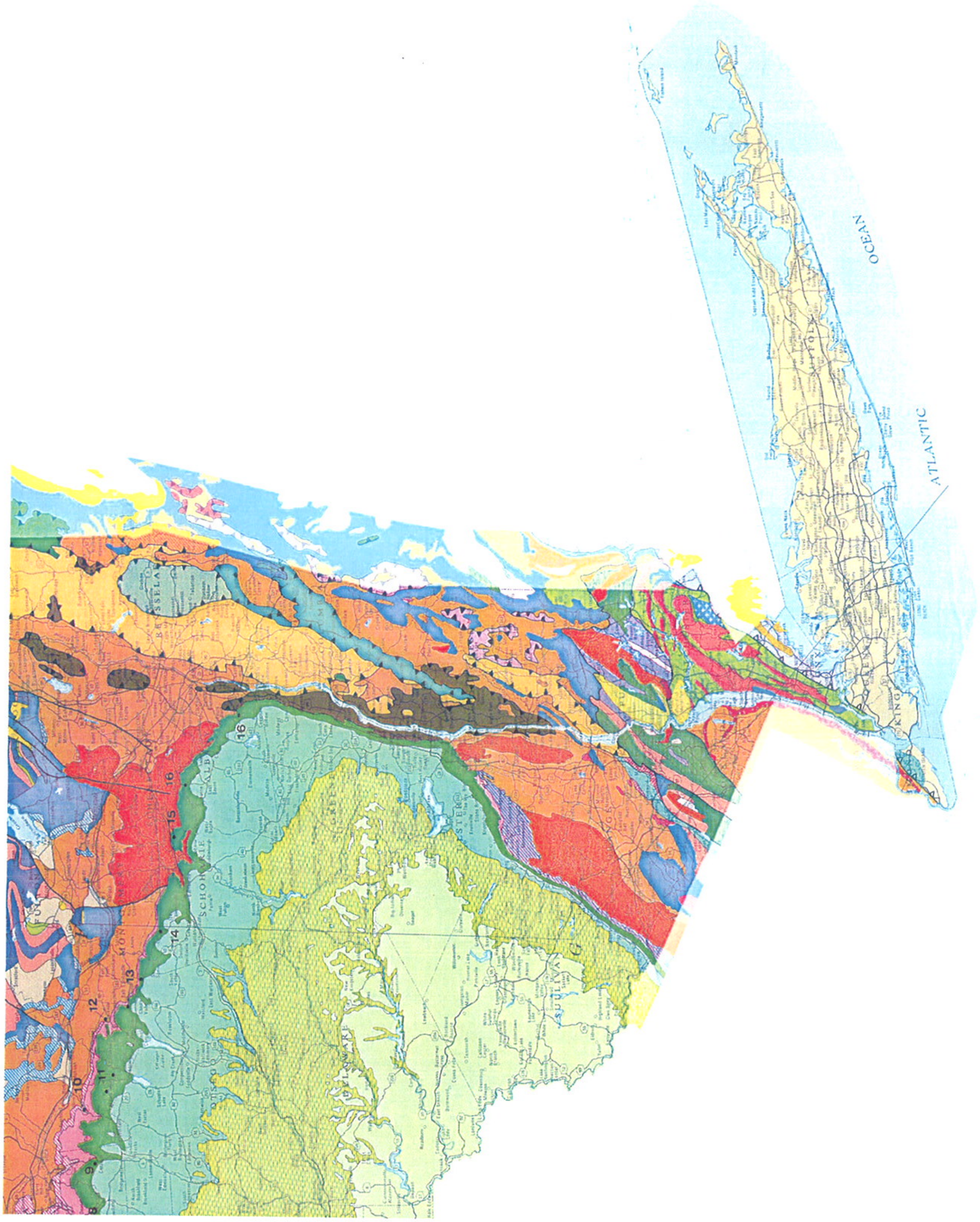
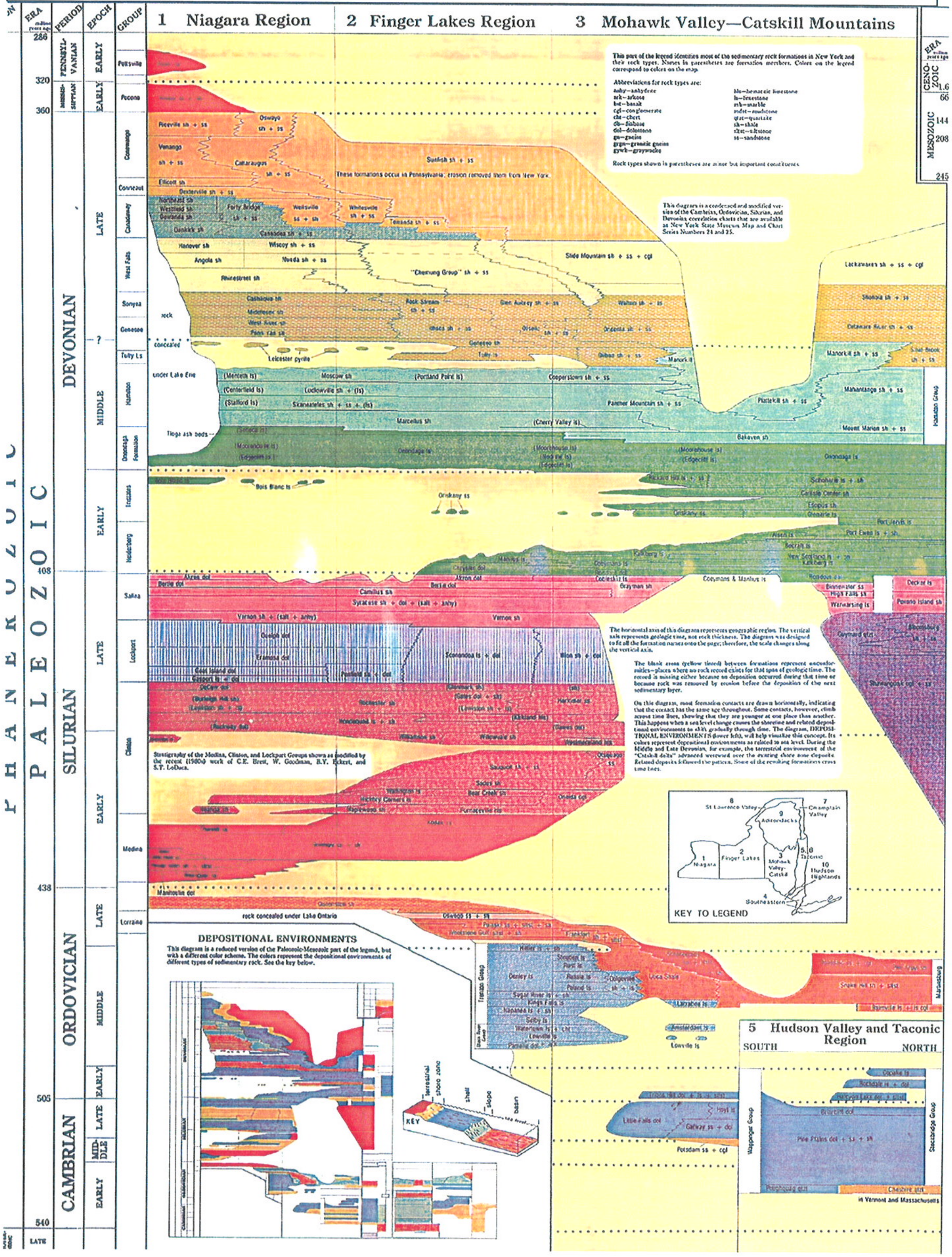


Figure 3.3: (a) Geologic Map of Southeastern New York State, and (b) Map Legend (insert following text)



This part of the legend identifies most of the sedimentary rock formations in New York and their rock types. Names in parentheses are formation members. Colors on the legend correspond to colors on the map.

Abbreviations for rock types are:

anhy—anhydrite
ark—arkose
bst—basalt
cgl—conglomerate
cht—chert
db—diabase
dol—dolostone
gn—gneiss
grgn—granitic gneiss
grwk—graywacke
hls—hematitic limestone
ls—limestone
mb—marble
mdst—mudstone
qtzt—quartzite
sh—shale
sltst—siltstone
ss—sandstone

Rock types shown in parentheses are minor but important constituents.

This diagram is a condensed and modified version of the Cambrian, Ordovician, Silurian, and Devonian correlation charts that are available as New York State Museum Map and Chart Series Numbers 24 and 25.

The horizontal axis of this diagram represents geographic region. The vertical axis represents geologic time, not rock thickness. The diagram was designed to fit all the formation names onto the page; therefore, the scale changes along the vertical axis.

The blank areas (yellow tinted) between formations represent unconformities—places where no rock record exists for that span of geologic time. The record is missing either because no deposition occurred during that time or because rock was removed by erosion before the deposition of the next sedimentary layer.

On this diagram, most formation contacts are drawn horizontally, indicating that the contact has the same age throughout. Some contacts, however, climb across time lines, showing that they are younger at one place than another. This happens when a sea level change causes the shoreline and related depositional environments to shift gradually through time. The diagram, DEPOSITIONAL ENVIRONMENTS (lower left), will help visualize this concept. Its colors represent depositional environments as related to sea level. During the Middle and Late Devonian, for example, the terrestrial environment of the "Catskill delta" advanced westward over the existing shore zone deposits. Related deposits followed the pattern. Some of the resulting formations cross time lines.

Stratigraphy of the Medina, Clinton, and Lockport Groups shown as modified by the recent (1980s) work of C.E. Brett, W. Goodman, B.Y. Eckert, and S.T. LoDuca.

DEPOSITIONAL ENVIRONMENTS

This diagram is a reduced version of the Paleozoic-Mesozoic part of the legend, but with a different color scheme. The colors represent the depositional environments of different types of sedimentary rock. See the key below.

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4.0 Methodology

The data presented in this study were collected primarily through sampling ground water monitoring wells at existing petroleum hydrocarbon LUST sites (161 wells at 34 sites). This chapter presents an overview of the sample collection and analysis procedures used during the study.

All sample collection activities were performed by three field teams supplied by Delta Environmental Consultants, Inc. (sampling teams originated in Delta's Westford, MA, Armonk, NY and Mt Laurel, NJ offices). In order to maintain sample collection method consistency across the three teams, a detailed work plan with a standard operating procedure (SOP) for micro purge ground water sampling was created for each site and issued to the teams prior to each sampling event (Appendix II).

Sample analysis was divided into two main categories: field analyses and laboratory analyses. Field analyses were also conducted by the three sample collection teams, and field analytical consistency was maintained in the same way as sample collection consistency (through the work plans and sampling SOP). The field analyses performed are discussed in detail along with the sampling methodology in Section 4.1.

All of the laboratory analyses (with the exception of the CSIRA analyses) were performed by Accutest Laboratories in Dayton, NJ. Samples were shipped to the lab following procedures appropriate to the analytical methods used (Section 4.2), and laboratory QA/QC methodology is provided as Appendix IV. CSIRA analyses were performed by Geochron Laboratories in Cambridge, MA, and are covered in detail in Section 4.2.

4.1 Field Sampling and Analysis Techniques

Ground water samples were collected following a standard micro purging method developed by the USEPA (USEPA, 1996). Method details are discussed in Section 4.1 below, while the field analyses performed are detailed in Section 4.1.2.

4.1.1 Micro Purging

Ground water flows through monitoring wells, but typically does so at fairly low velocity (typical ground water flow rates are on the order of fractions of feet per day). The water contained within a monitoring well at any given moment is therefore generally at equilibrium with the outside atmosphere rather than with the ground water contained within the aquifer formation. To ensure that the water collected during a sampling event came from the aquifer and not from the stagnant well water contained in the well, the well is usually purged by removing several well volumes of water before the sample is collected.

Purging is often accomplished simply by dropping a weighted bailer attached to a string down the well, then retrieving it. This method is simple and easy to implement, but results in exposure of the ground water to atmospheric conditions during the process, potentially resulting in a change of redox state during sampling. Redox potential plays a central role in ground water systems, and it is therefore important to preserve the redox state of a given ground water system when collecting samples for analysis.

Furthermore, hand bailing increases well turbidity, which can skew analytical sampling results. The turbidity comes primarily from colloidal suspensions within the aquifer (ferrous iron, manganese oxides, and organic particulates, among other species). These suspensions constitute a distinct, mobile phase which facilitates transport of select contaminants in aquifers (USEPA, 1996). To minimize these issues, samples must be protected from atmospheric exposure during collection, and minimal disturbance to the aquifer should occur throughout the process.

Rather than hand bailing, micro purging accomplishes both objectives by minimizing aquifer drawdown during sampling, and by preventing atmospheric exposure through the use of tubing and flow-through cells (Figure 4.1).

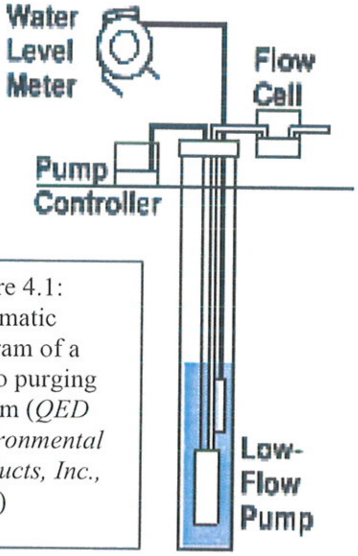

Figure 4.1: Schematic diagram of a micro purging system (*QED Environmental Products, Inc., 2006*)

Micro purging is conducted using a pump designed to operate at very low flow rates. The pump is usually set near the midpoint of the well screen interval (screens are typically 10 feet in length); below the top of the water column, but above any sediments precipitated on the well bottom and proximal to the source of fresh water input into the well. Typical pumping rates range from less than 0.5 L/min to 1.0 L/min. These flow rates result in total purge volumes ranging from 15 to 40 liters, depending on purge time (by contrast, a 2-inch internal diameter well with an 8-foot standing water column will yield about 14.35 liters total purge volume using the standard hand bailing method and removing three casing volumes). Suitable pump types include centrifugal, pneumatic, or bladder (USEPA, 1996).

In order to assure that the samples collected would be representative of the aquifer formation water, micro purging techniques were used to collect samples throughout the subject study. The sampling was accomplished using a Geotech model GEO1.66SS36 bladder pump to sample all of the wells (Figure 4.2) along with a Geotech Geocontrol Pro pump controller. The pump features a variable flow rate, with a maximum flow of 4.7 liters per minute (lpm) (Geotech Environmental Equipment, Inc., 2005). The controller features a built-in air compressor which pneumatically powers the pump at depths up to 200 feet below ground surface (bgs).

Before each well was sampled, water level measurements were taken using a Solinst interface meter model 122. Once the water level measurement was complete, polyethylene tubing was attached to the pump effluent line, and the pump was set in the well as detailed in figure 4.1. The other end of the polyethylene tubing was attached to the flow cell influent port (Figure 4.3). The flow cell is a cylindrical PVC container

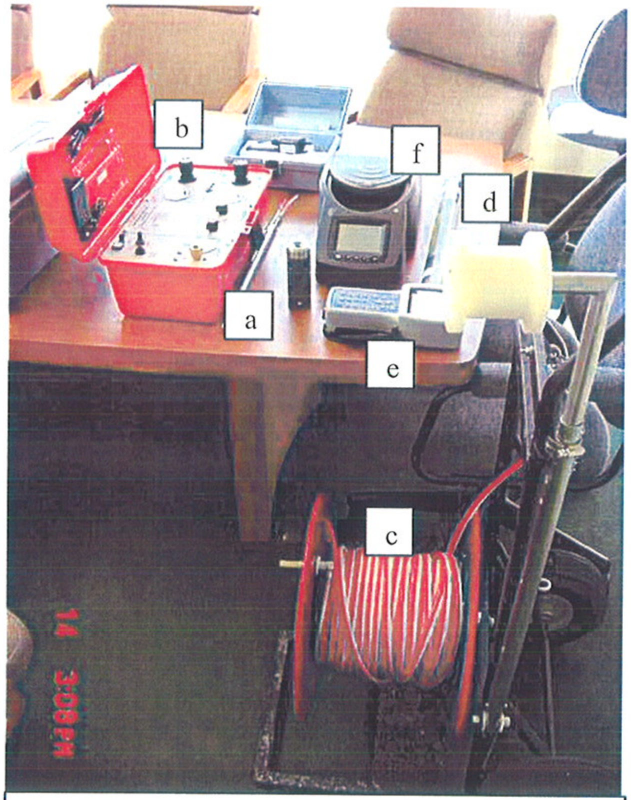

Figure 4.2: Micro purging components a) low-flow pump b) pump control unit c) PVC tubing d) multiphase probe e) Probe control unit f) field spectrophotometer (author's photo).

with an influent line attachment near the bottom of the cylinder, and an effluent line near the top. When the pump is active, fresh water is continuously pumped into the bottom of the cylinder from the well, displacing the water in the cylinder through the effluent port. Water quality monitoring probes are inserted through the top of the cylinder and extended down to the influent port (Figure 4.3).

A YSI model 600XLM Sonde multisensor probe was used during the subject study in conjunction with a YSI model 5083 flow cell (Figure 4.3) to monitor ground water parameters prior to sample collection. Once the apparatus was set up at a given monitoring well, the pump was started at the lowest possible flow rate. The flow rate was then increased until either the rate reached 1.0 LPM, or water level drawdown in the well reached 0.3 feet (USEPA 1996), whichever came first. The purge water was then monitored for stability prior to sampling.

Stability monitoring was conducted using the YSI Sonde probe by recording dissolved oxygen (DO), pH, and conductivity readings at 5 minute intervals until all three readings were stable compared to the previous readings (stability was defined as ± 10% of the previous reading for DO, ± 0.1 units for pH, and ± 3% for conductivity). The average purge time required to achieve stability throughout the study was 31 minutes. Probe field calibration was conducted in accordance with the procedures outlined in Table 4.1.

Figure 4.3: a) YSI Model 600 XL Sonde Multisensor water quality meter and b) YSI Model 5083 flow cell *(YSI Incorporated, 2005)*.

Once purge stability was achieved, stable readings for DO, temperature, pH, conductivity, and oxidation/reduction potential (ORP) were recorded using the YSI probe. Samples were then collected for both field and laboratory analyses from the flow cell influent line (the flow cell was disconnected prior to sample collection).

Table 4.1: YSI Probe Field Calibration Protocol (*YSI Incorporated, 2005*).

Parameter	Resolution	Accuracy	Calibration
pH	0.01 unit	±0.2 unit	Two point method using an automated temperature sensing program
Conductivity	0.1 mS/cm	±0.5% of reading + 0.001 mS/cm	Reported as specific conductivity (relative to 25°C)
Temperature	0.01 °C	0.15 °C	Factory calibration – metallic oxide probe with varying resistance with temperature changes
ORP	0.1 mV	±20 mV	Zobell solution referenced to Ag/AgCl
DO (% Saturation)	0.1%	±2% of reading or 2% of air saturation, whichever is greater	Temperature and barometric pressure

At each site, monitoring wells were sampled in reverse order of contamination (least to most contaminated) to avoid cross-contamination of samples. Disposable tubing was used and replaced for each well, and the pump and flow cell were decontaminated immediately following each sampling event following the procedure outlined in Table 4.2 below.

Samples were collected from the flow cell influent tube using a tilted sample jar method to minimize sample disturbance. Samples requiring preservation were collected in pre-treated laboratory jars and packed on dry ice for shipment to the lab (Section 4.2). Samples were collected for volatile organic compound analyses first, followed by all other laboratory analytes, and finally by field analytes. Field analyses conducted are discussed in detail in Section 4.1.2 below. Laboratory analyses are discussed in Section 4.2.

Table 4.2: Micro purging equipment decontamination protocol (*Delta Environmental Consultants, Inc., 2005*)
1) Flush the pump, flow cell and probes with one full system volume (approximately 0.75 gallons) of analyte-free (deionized) water
2) Flush the pump, flow cell and probes with three full system volumes (approximately 2 gallons) of analyte-free (deionized) water/phosphate-free surfactant mixture
3) Flush the pump, flow cell and probes with three full system volumes (approximately 2 gallons) of analyte-free (deionized) water
4) Check equipment to ensure excess water is removed
5) Allow equipment to air dry between wells

4.1.2 Field Analyses

Some of the field data reported was collected by reading results directly from a multisensor sonde as described in Section 4.1.1 above. The rest of the field data was collected through the use of either a portable spectrophotometer (total and ferrous iron), or a digital tritrator (total alkalinity and carbon dioxide). More specifically, a Hach D2800 (Figure 4.2) portable spectrophotometer was used for total and ferrous iron analyses, while a Hach 16900 digital titrator (Figure 4.4) was used for total alkalinity and carbon dioxide. These analyses are discussed in detail below.

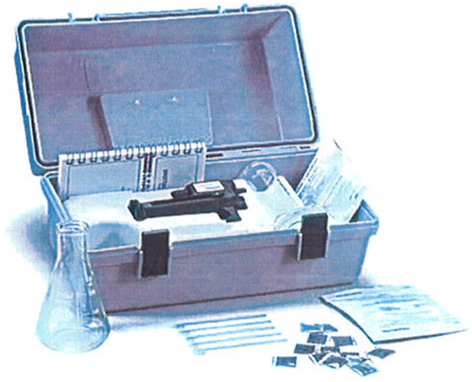

Figure 4.4: Hach Model 16900 digital titration unit kit (*Hach Company, 2006*)

Total alkalinity

Total alkalinity was determined in each well using a Hach Model 16900 digital titrator following Hach Method 8203 for total alkalinity as $CaCO_3$ (Hach, 2006). This method is a sulfuric acid titration to a specific pH end point using phenolphthalein as the indicator. First, each sample was collected in a 100 ml unpreserved jar (sample volume ranged from 10 to 100 ml, depending on expected alkalinity content (10 to 4,000 mg/L). A pre-weighed packet of phenolphthalein indicator was added to the sample, followed by titration to a clear end point with a pre-packaged aliquot of sulfuric acid. The number of "digits" recorded by the titrator was then multiplied by a pre-determined "digit multiplier" to calculate mg/L of total alkalinity (Table 4.3).

In the event that no reaction occurred with the phenolphthalein indicator, the titration was continued using bromcresol green-methyl red indicator. This was accomplished using sulfuric acid as a titrant, and titrating to a color-graded end point dependent upon pH. Once again, the number of digits recorded by the titrator multiplied by the digit multiplier yielded the alkalinity (mg/L) as hydroxide, carbonate, and bicarbonate species. Additional calculations (results dependent) were then needed to determine total alkalinity content (Hach, 2006).

Range (mg/L as $CaCO_3$)	Sample Volume (mL)	Titration Cartridge (N H_2SO_4)	Digit Multiplier
10 - 40	100	0.16	0.1
40 - 160	25	0.16	0.4
100 - 400	100	1.6	1.0
200 - 800	50	1.6	2.0
500 - 2000	20	1.6	5.0
1000 - 4000	10	1.6	10.0

Table 4.3: Sample size, titrant aliquot size, and digit multiplier as a function of total alkalinity range for Hach digital titration method 8203 (*Hach, 2006*)

Carbon dioxide

Carbon dioxide concentration in the study wells was determined using Hach digital titration method 8205, which is similar to method 8203 for total alkalinity outlined above. method 8205 titrates the sample acidity resulting from CO_2 content with sodium hydroxide, using a phenolphthalein indicator (Hach, 2006). Similar to method 8203, method 8205 uses a graded sample volume and pre-measured indicator and titrant, with digit multipliers assigned according to CO_2 concentration (Table 4.4). Results are reported in mg/L CO_2.

Range (mg/L as CO_2)	Sample Volume (mL)	Titration Cartridge (N NaOH)	Digit Multiplier
10 - 50	200	0.36	0.1
20 - 100	100	0.36	0.2
100 - 400	200	3.63	1.0
200 - 1000	100	3.63	2.0

Table 4.4: Sample size, titrant aliquot size, and digit multiplier as a function of carbon dioxide range for Hach digital titration method 8205 (*Hach, 2006*)

Ferrous iron

Ferrous iron ground water concentration was determined spectrophotometrically using Hach Method 8146 (Hach, 2005), which was adapted from *Standard Methods for the*

Examination of Water and Wastewater, Volume 15 (1980). Prior to collection, each sample was filtered using a dedicated Nalgene 0.45-micron filter attached to a Nalgene 150 ml unpreserved filter bottle. A standard solution of 2.0 mg/L Fe^{2+} was then prepared immediately prior to sample analysis using a factory-weighed packet of ferrous ammonium sulfate (hexahydrate) powder and deionized water. Once the spectrophotometer was calibrated, the sample was prepared for analysis by mixing 25 ml of sample water with a factory-weighed packet of 1,10 phenanthroline indicator. The resulting solution was allowed a 3 minute reaction period, followed by absorbance measurement against a blank of unreacted ground water sample at a wavelength of 510 nm. The results were reported directly as a concentration (mg/L).

Total iron

Total iron (ferrous plus ferric) concentration was determined using Hach Method 8008 (Hach, 2005). This method is similar to Method 8146 for ferrous iron, but uses a reducing agent (termed FerroVer) to convert ferric iron to ferrous, which is then reacted with phenanthroline indicator and analyzed. 10 ml of each sample was mixed with one pre-weighed packet of FerroVer reducing reagent and allowed to react for 3 minutes. The resulting solution was measured for absorbance against an unreacted ground water blank at 510 nm. As with Method 8146 for ferrous iron, the spectrophotometer was calibrated with a 2 mg/L standard solution of ferrous ammonium sulfate, and results were reported directly as concentration (mg/L).

4.2 Laboratory Techniques

After all field sampling and analyses were completed for a given well, samples were collected and shipped to laboratories for analyses that could not be conducted in the field. These lab analyses are divided into three broad categories; geochemistry, volatile organic compound analyses, and compound-specific stable isotope ratio analyses. Analytical methods for each are outlined in detail in Sections 4.2.1 through 4.2.3.

4.2.1 Geochemistry

Samples collected for geochemical analysis were analyzed for sulfate, sulfide, nitrate, nitrite, manganese, and methane concentration. All of the samples were shipped overnight in coolers at 4°C to Accutest Laboratories, which has labs in both Dayton, NJ and Marlborough, MA. Accutest holds certifications for the analytical work performed in all of the study states in addition to a National Environmental Laboratories Accreditation Conference (NELAC) certification. The analytical methods used are outlined briefly below.

Nitrate/Nitrite

Samples were collected for nitrate and nitrite analyses in 100 ml bottles pre-treated with sulfuric acid preservative and filled to capacity during sampling to eliminate any head space. Analyses were conducted following USEPA method 353.2 for nitrogen as nitrate, which is a colorimetric, automated cadmium reduction method (O'Dell, 1993). The analytical procedure involves sample filtration, followed by reduction on a reactive column.

The column consists of a U-shaped, 35 cm x 2 mm internal diameter (I.D.) glass tube filled with granular cadmium (CASRN 7440-43-9) 40 – 60 mesh. The cadmium mesh is pretreated with a 6N HCl / 2% copper sulfate solution followed by repeated flushing with deionized water. The sample nitrate content is reduced on the column by reaction with an ammonium chloride/EDTA solution (85 g/L ammonium chloride, 0.1 g/L sodium ethylenediamine tetracetate, 0.05% Brij-35 (CASRN 9002-92-0) and coupled with an azo dye (10% phosphoric acid, 40 g/L sulfanilamide, 2 g/L N-1-naphthylethylenediamine dihydrochloride) to induce a colorimetric reaction (O'Dell, 1993). The results are reported in mg/L, and the applicable concentration range is 0.05 mg/L – 10.0 mg/L (the range can be increased through dilution). Separate nitrate and nitrite values can be reported when the method is run concurrently with and without the Cu-Cd reduction step.

Sulfate

Samples were collected for sulfate analyses in 200 ml untreated amber bottles and filled to capacity during sampling to eliminate any head space. Analyses were conducted following USEPA method 300.1 for inorganic anions using ion chromatography (Pfaff, 1993). The analytical procedure is completed by injecting a small aliquot of sample directly into the ion chromatograph (IC) unit, running the sample through the column, and measuring the conductivity of the effluent as it comes off the column.

The system used for the study samples was a Dionex DX-500 IC system, which included a GP50 gradient pump, elution columns (discussed below), a CD20 conductivity detector, an LC20 chromatography enclosure with rear-loading injection valve, and AS40 auto sampling. Prior to injection, each sample in the subject study was filtered using a Waters

Corporation C_{18} Sep-Pak filter cartridge attached to the injection syringe. Between 50 to 200 uL of sample was injected onto the column following filtration. The "column" used included three distinct sections: a guard column (Dionex IonPac AS9-HC, 4 x 50 mm, P/N 51791), a separator column (Dionex AS9-HC, 4 x 250 mm, P/N 52244), and a suppressor column (Dionex ASRS-Ultra R/N 43187 self regenerating suppression column). Samples were run through the columns using a 9.0 mM sodium carbonate eluent and a flow rate of 1.0 mL/min.

Sulfide

Duplicate samples were collected for sulfide analyses in 250 ml amber bottles pretreated with zinc acetate and sodium hydroxide preservative and filled to capacity during sampling to eliminate any head space. Analyses were conducted following USEPA method 376.1 for sulfide by titrimetry (USEPA, 1978). The analytical procedure is completed through titration with excess iodine under acidic conditions. The ensuing reaction results in the oxidation of sulfide to sulfur.

The procedure was accomplished by adding 200 mL of sample water to an aliquot of 0.025 N iodine solution (up to 20 mL) and 2 mL of 6N HCl. Iodine was then added continuously until the blue color remained. Back titration was then accomplished using 0.025 N thiosulfate with a starch indicator until the blue color disappeared. Based on a reaction stoichiometry of 1 mL iodine solution to 0.4 mg of sulfide, the sample sulfide concentration was determined using Equation 4.1 below.

$$\text{mg/L sulfide} = 400(\text{volume}_{\text{iodine}} - \text{volume}_{\text{thiosulfate}})/\text{sample volume} \quad (\textit{Equation 4.1})$$

Manganese

Samples were collected and field filtered (Nalgene 0.45 micron filters) for manganese analysis in 200 ml amber bottles pretreated with nitric acid preservative and filled to capacity during sampling to eliminate any head space. Analyses were conducted following USEPA method 200.7 for metals using inductively-coupled plasma/atomic emissions spectroscopy (ICP-AES) (Martin et al, 1994). The analytical procedure involves sample nebulization to an aerosol via a plasma torch, followed by the development of element-specific emission spectra via a radio frequency generator. The intensity of the spectral line characteristic of Mn (λ = 257.610 nm) is then measured using a photo-sensitive detector.

Samples collected for the subject study were prepared by adding 50% nitric acid solution to at least 20 mL of sample to create a 1 L solution of 1% nitric acid. After mixing, the samples were injected directly into the ICP unit using a variable speed peristaltic pump. Results were reported in mg/L manganese.

Methane

Duplicate samples were collected for methane analyses in 40 mL sample bottles pretreated with hydrochloric acid preservative and filled to capacity during sampling to eliminate any head space. Analyses were conducted following USEPA method SW846 8015 for nonhalogenated organics using GC/FID (USEPA, 2000). The analytical procedure includes sample analyte separation via a gas chromatography column, followed by analyte detection via a flame ionization detector.

Samples were prepared for injection using a heated purge and trap method (5030; USEPA 1997) followed by auto-injection onto a 60 to 80 mesh separation column. Helium was used as the carrier gas, with a 15 mL/min flow rate. Results were reported in ug/L methane.

4.2.2 Volatile Organic Compounds (VOCs)

Duplicate samples were collected for VOC analyses in 40 mL sample bottles with rubber septum seals pretreated with nitric acid preservative and filled to capacity during sampling to eliminate any head space. Analyses were conducted following USEPA method SW846 8260B for volatile organic compounds by gas chromatography/mass spectroscopy (USEPA, 1996). The analytical procedure involves analyte amplification via purge-and-trap (or other appropriate method) and introduction into a GC unit via a capillary column (analytes progress from wide to narrow-bore capillaries via flash evaporation). Analyte separation is accomplished on a 60 – 80 mesh, temperature controlled GC column using helium or other suitable carrier gas. Detection is accomplished using a standard quadrapole mass spectrometer by comparing GC elution spectra with those of standard libraries.

All of the wells in the subject study have been monitored for the VOC subset of compounds known as BTEX (benzene, toluene, ethyl benzene, and xylenes) as well as MTBE on a quarterly basis for a number of years using method 8260.

4.2.3 Compound-Specific Stable Isotope Ratio Analysis (CSIRA)

Samples collected for CSIRA analysis during the subject study were sent to Geochron Laboratories in Cambridge, MA for analysis. The samples were collected in 1.0 L unpreserved amber bottles and shipped at 4 °C. During analysis, the samples were first pH adjusted with sodium phosphate, followed by distillation to concentrate the sample from 1.0 L down to 25 mL with minimal analyte mass loss. Following the preconcentration step, the samples were transferred to a gas chromatography column (Poropak Q porous polymer column) via a purge and trap method. Once the analyte separation phase was complete, sample combustion was accomplished via a combustion furnace operated at 850 ˚C. CO_2 from the combustion interface was then passed into a Finnigan MAT 262 isotopic mass spectrometer (Figure 4.5).

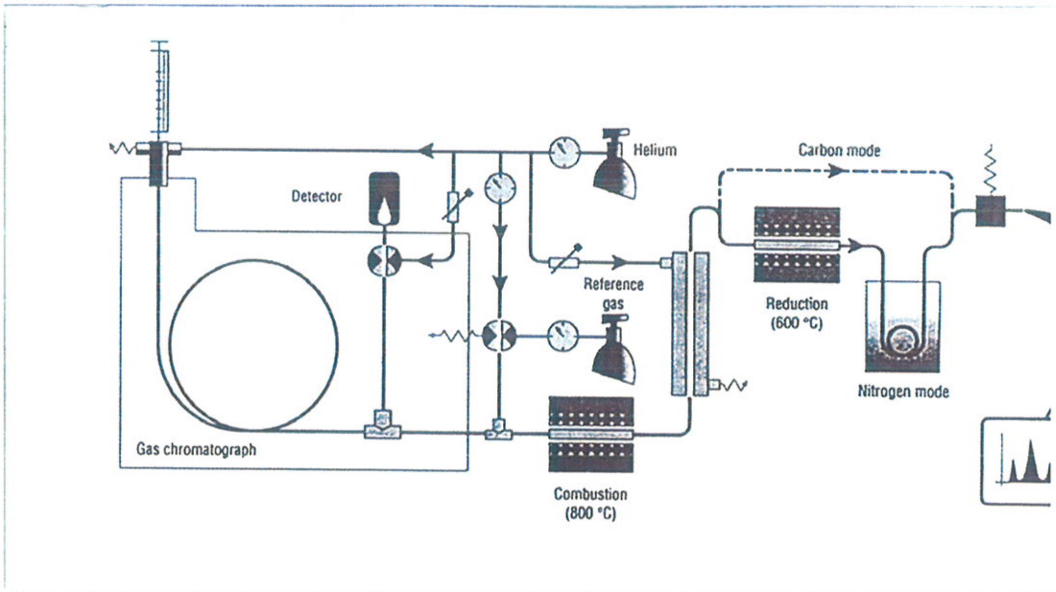

Figure 4.5: Schematic of a GC-IRMS system *(Meier-Augenstein, 1999)*.

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5.0 Results

Chapter 5 first provides an overview of how CSIRA is used to determine how much MTBE mass has anaerobically biodegraded on a well-specific basis (Section 5.1), followed by analyses of the data presented in Appendix III, which occupies the remainder of the chapter.

5.1 Compound-Specific Stable Isotope Ratio Analysis

As noted in Chapter 2, MTBE has repeatedly been documented as more biodegradable than was originally thought prior to 1994 (Mo et al, 1995; Park & Cowan, 1997; Steffan et al, 1997; Fortin & Deshusses, 1999; Hanson et al, 1999; Salanitro et al, 2001; Hatzinger et al, 2001).

Documenting field evidence of in situ biodegradation has historically been problematic, however, for several reasons. First, other (abiotic) attenuation processes (dispersion, dilution, adsorption, etc.) are always at play, acting on contaminants in the subsurface and confounding attempts to isolate contaminant transformation due to biotic degradation. Second, biotic degradation of other gasoline contaminants is generally occurring simultaneously (and often preferentially with respect to) MTBE biodegradation, making it difficult to demonstrate MTBE biodegradation through the use of traditional means such as evaluation of electron acceptors, metabolic products, or microbial "plate counts". Finally, the primary breakdown product of MTBE, tertiary butyl alcohol (TBA), is itself commonly found in gasoline formulations containing MTBE. This renders the presence of TBA in an MTBE-contaminated aquifer inconclusive with respect to the occurrence or absence of MTBE biodegradation within the aquifer.

What is needed, then, is an alternative method of identifying and demonstrating MTBE biodegradation *in situ* which is independent of these confounding factors. The most commonly available method currently fitting this description is compound-specific stable isotope ratio analysis (CSIRA).

5.1.1 Applications of CSIRA

CSIRA has been widely used as an analytical tool in a number of scientific disciplines for many years. Nier pioneered isotope ratio mass spectroscopy in 1947. McKinney et al (1950) subsequently improved the resolution of the Nier spectrometer down to 0.1 parts per thousand (‰), enabling a variety of analytical applications that were not possible before. These applications have included such divergent topics as oceanography, climatology, archaeology, and food science.

In the environmental sciences, CSIRA has been used extensively in the investigation of earth cycles (hydrological, biological, geological, etc), and in environmental forensics analysis (Morrison, 2000). In recent years, CSIRA has been used to study the biodegradation of a variety of environmental contaminants, including chlorinated ethenes (Dayan, et al, 1999), tri- and tetrachloroethene (Sherwood Lollar and Slater, 2000), dissolved inorganic carbon from jet fuel (Landmeyer et al, 1996), the BTEX constituents (Kelley and Hammer, 1997; Ward et al, 2000), and MTBE (Section 5.1.3).

5.1.2 Method Overview

Many elements have more than one isotopic form. Carbon, for example, has three: ^{12}C, ^{13}C, and ^{14}C. Of these, ^{12}C predominates in nature, while ^{13}C and ^{14}C are relatively rare, but still found in measurable ratios when compared to ^{12}C. Compounds therefore generally have measurable isotope ratios of the elements that comprise them. Naturally occurring processes (both biotic and abiotic) such as evaporation, transpiration, precipitation, condensation, photosynthesis and microbial respiration, to name a few, typically alter the elemental isotopic ratio of the compounds they act upon (Figure 5.1). This change in the ratio of isotope abundances is commonly referred to as *fractionation*, and occurs naturally because isotopes of the same element exhibit slight physical and chemical behavioral differences, which can be measured if the equipment used is sufficiently sensitive (Kendell & Caldwell, 1998).

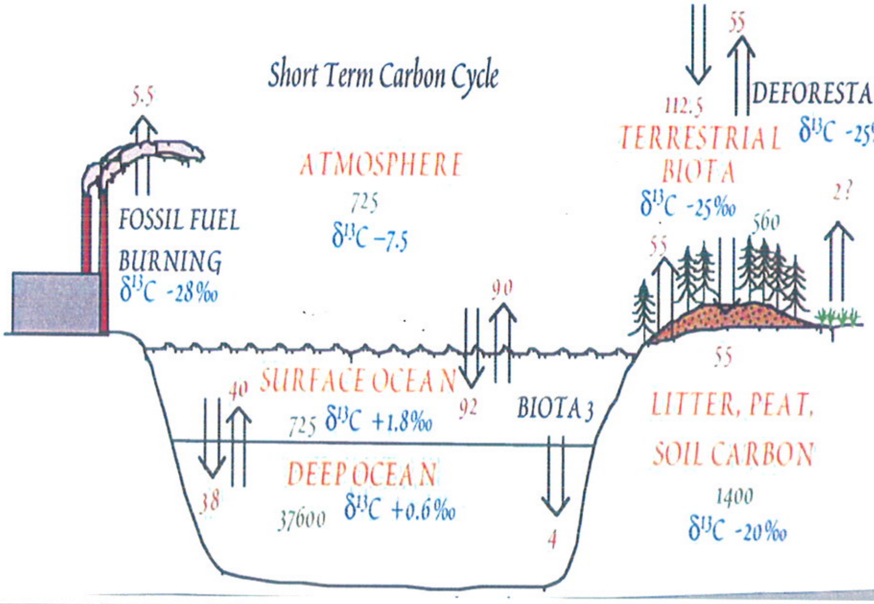


Figure 5.1: Cartoon depiction of the carbon cycle illustrating differences in $\delta^{13}C/^{12}C$ ratios resulting from physical and chemical transformations (*Cornell University Department of Earth and Atmospheric Sciences, 2000*).

The distance between atoms bound within a molecule is dictated by competing attractive and repulsive forces the sub-atomic particles exert upon each other. Simply stated, if the attractive force exerted is greater than the repulsive force, binding will occur. The difference between forces equals the kinetic energy required to break the bond, and is defined as the binding energy. Charting the potential energy inherent in bond formation vs the distance between particles yields a well-shaped plot, known appropriately as the energy well (Figure 5.2).

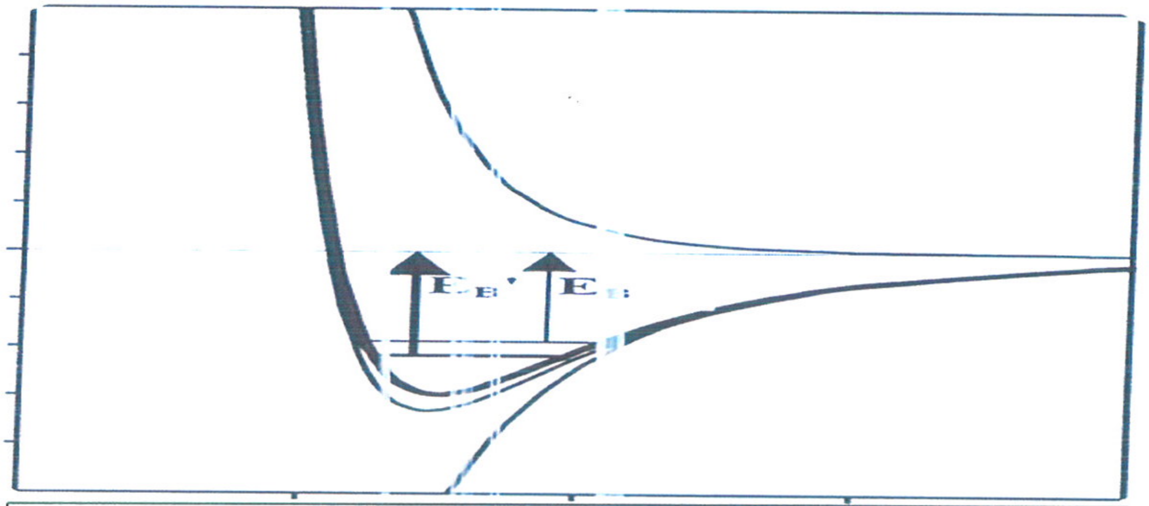


Figure 5.2: Plot of potential energy (Y-axis) vs distance between nuclei (X-axis) of a molecular bond. EB and EB' represent the kinetic energies required to overcome binding energies for light and heavy isotopes, respectively (IAEA, 1981).

As shown in Figure 5.2, the heavier of two isotopes will require more energy to break out of the energy well. Furthermore, heavier isotopes will, in general, have less kinetic energy than their lighter counterparts, and will have fewer opportunities to undergo binding reactions. These factors typically result in the preferential reaction of lighter isotopes over heavier ones in any given reactive system (Kieffer, et al, 1982). This means that a given chemical bond will have different bond energies if it's formed with different isotopes (i.e., a ^{12}C - ^{1}H bond will require a different amount of energy to cleave the bond than a ^{13}C – ^{1}H bond).

Isotopic fractionation results from the preferential uptake of lighter isotopes in many reactive processes (preferentially removing the lighter isotopes from the pool of particles available for reaction enriches the ratio of particles left with respect to the heavier isotopes). A fractionation factor (α) can thus be quantified for a given process (Equation 5.1).

$$\alpha_{(p/r)} = R_p/R_r \qquad \textit{(Equation 5.1)}$$

where R_r and R_p are the isotopic ratios of the reactants and products, respectively

The magnitude of α is dependent on the relative abundance of the different isotopes with respect to each other (the more rare a given isotope is, the less its ratio will change during a given reactive process and, correspondingly, the closer α will be to 1). The *deviation* from α, rather than α itself, is therefore commonly used to represent fractionation:

$$\varepsilon_{(p/r)} = \alpha_{(p/r)} - 1 = (R_p/R_r - 1) \text{ x } 1{,}000 \qquad \textit{(Equation 5.2)}$$

where ε is the deviation in the fractionation factor. ε is commonly used to quantify fractionation

The term $(R_p/R_r - 1)$ in Equation 5.2 is multiplied by 1,000 because ε is generally a very small number. For the same reason, ε and α are not measured directly, but against a series of international standards specified for each isotope pair. The isotope pairing of most interest to the work presented here is $^{13}C/^{12}C$, which is by convention measured against the Pee Dee Belemnite standard (a reference standard taken from a rock formation near Vienna, Italy). Incorporating the standard reference into the isotope ratio measurement yields a new entity, delta (δ), which is reported in units of parts per thousand (‰). δ was defined by McKinney (1950), as shown in Equation 5.3:

$$\delta\ (‰) = \left(\frac{(HI/LI)_{Sample} - (HI/LI)_{Standard}}{(HI/LI)_{Standard}} \right) \times 1{,}000 \qquad (\textit{Equation 5.3})$$

Where HI = Heavy Isotope
LI = Light Isotope

Isotope ratio measurements are generally reported as δ values, while fractionation is expressed using ε (‰ units). ε can be measured experimentally by regressing time series data of δ with the fraction of the compound remaining (f) in the original phase (Figure 5.3).

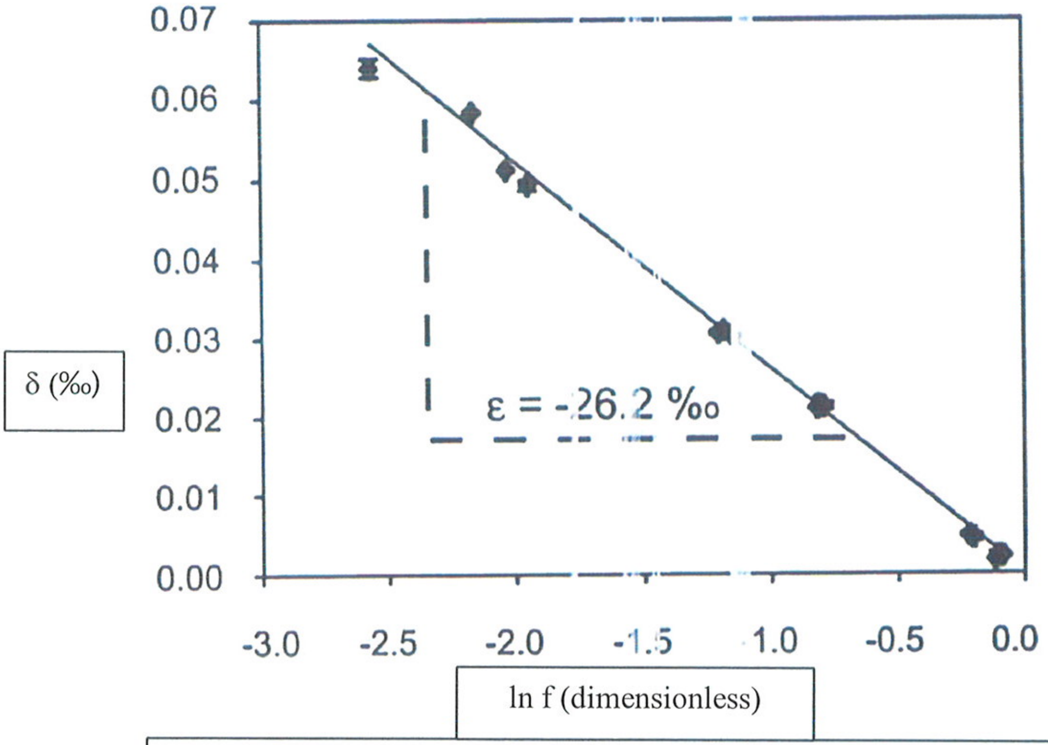


Figure 5.3: Rayleigh-type regression plot of carbon isotope ratio (y axis) vs ln of substrate fraction remaining (x axis). ε is determined by taking the slope of the regression. The plot is from a study of carbon tetrachloride dehalogenation by a reduced iron porphyrin (*Elsner et al, 2004*).

Regressions such as the one depicted in Figure 5.3 will have a linear slope equal to ε, provided that the process described obeys a simple first-order rate law. In such a model, the quantity of reactive isotopes maintains proportionality to the remaining isotopes throughout the reaction.

Next, the fraction of the reactant remaining (f) is related to reactant isotopic concentrations as defined by equation 7.4 below:

$$f = (L_t + H_t)/(L_o + H_o) \qquad \textit{(Equation 5.4)}$$

where L_o and H_o are the initial concentration of light and heavy isotope, and L_t and H_t are the light and heavy isotope concentrations at time t

The classical Rayleigh equation for fractional distillation can now be introduced. It was first used by Lord Rayleigh in 1902 to describe the fractionation of mixed liquids during distillation (Mariotti, 1981), and is fundamentally expressed as:

$$R_t / R_o = f^{(\alpha - 1)} \qquad \textit{(Equation 5.5)}$$

where R_o and R_t are the initial ratio, and ratio at time t, of light and heavy isotopes, respectively

Simple rearrangement and substitution in Equation 5.5 yields the linear form of the Rayleigh equation shown in Equation 5.6 below:

$$\delta_t = \delta_o + \varepsilon \ln f \qquad \textit{(Equation 5.6)}$$

In Equation 5.6, R_o and R_t have been expressed using δ notation. A strict substitution using Equations 5.1 and 5.2 should have yielded $(10^{-3}\delta_p+1)$ and $(10^{-3}\delta_r+1)$, respectively.

However, for ε values of less than 20 ‰, the simplification used in Equation 5.6 is common (Schmidt et al, 2003).

Applying Equation 5.6 to the biodegradation of organic contaminants could be done to solve a variety of problems, depending on whether δ values or contaminant concentrations (or both) were measured over time. If, for example, δ is measured over time and ε for the process is experimentally determined, the starting contaminant mass and degradation rate can both be back calculated using Equation 5.6, provided the process approximates first order kinetics. With respect to MTBE biodegradation specifically, several studies have been conducted to date to determine ε values for the degradation process.

Hunkeler et al (2001) first reported ε values for aerobic MTBE biodegradation. In that study, laboratory microcosms were prepared from aquifer sediments from a LUST site in Borden, Ontario. The microcosms included replicates for aerobic degradation of MTBE as the sole substrate, and cometabolic aerobic degradation of MTBE. By measuring δ_c values and regressing the data over time, Hunkeler et al calculated ε_c values that ranged from -1.97 to -1.52 ‰, with standard deviations ranging from 0.05 to 0.10 ‰. The Rayleigh plot regressions showed that the kinetics approximated first order, with R^2 values reportedly ranging between 0.9880 and 0.9942.

Hunkeler's work was followed by Gray et al (2002), who used a similar method to determine ε for aerobic MTBE biodegradation by the pure microbial isolate PM1, and by a mixed consortium of microbes. The results were similar to those of Hunkeler et al, with reported ε values ranging from -1.4 to -2.4 ‰ (standard deviations ranged from 0.1 to 0.3 ‰). Gray et al extended their work to include hydrogen isotope fractionation experiments on the same microcosms, with mixed results. Fractionation for the PM1 culture was consistent, and an order of magnitude greater than ε_c values calculated for the same replicates (-33 ± 5 ‰ to -37 ± 4 ‰), while ε_H values for the mixed culture exhibited a much greater range (-29 ± 4 ‰ and -66 ± 3 ‰). Gray et al concluded that carbon CSIRA results were more consistent with respect to the work conducted, but hydrogen CSIRA has more potential as a tool to quantify biodegradation, since the fractionations observed were significantly larger than those of carbon.

The results reported by Gray et al make sense from a theoretical perspective, given that the mass ratio between hydrogen isotopes is much larger than that of carbon (2.00 for $^2H/^1H$ vs 1.08 for $^{13}C/^{12}C$). This greater mass differential exhibited by $^2H/^1H$ creates more pronounced fractionation, as discussed earlier in this section. It also means that differences in multiple ε measurements for a given process will be magnified. For example, two different bacterial strains mineralizing a contaminant in the subsurface will have different ε values for the same end product, because they arrived at the same end point through different metabolic pathways. If multiple bacterial strains are acting on a given contaminant as a consortium, a single, composite ε value calculated for the process will have a much larger degree of error associated with the result for $^2H/^1H$ compared to $^{13}C/^{12}C$. This prediction is consistent with Gray et al's reported results for $^2H/^1H$ vs $^{13}C/^{12}C$, and indicates that the use of either isotopic pair for analysis may be appropriate, depending on the situation.

Continuing the work started by Hunkeler et al and Gray et al, Kolhatkar et al (2002) extended the effort to examine anaerobic MTBE biodegradation both *in situ* and *ex situ.* This study included the collection of ground water samples from a petroleum hydrocarbon LUST site in New Jersey for δ_c analysis over time, and the preparation of anaerobic laboratory microcosms from subsurface sediments at the same site. The resulting ε_c values for both field and laboratory studies were consistent with each other (-8.10 ± 1.4 3 ‰ for the field results and -9.16 ± 3 ‰ for the laboratory results) and significantly higher than the range of ε_c values reported by either Hunkeler et al or Gray et al for aerobic MTBE biodegradation.

Kuder et al (2005) extended the work of Kolhatkar et al by expanding the field study to include nine LUST sites, and by including δ_H as well as δ_c analysis. Once again, the range of fractionation reported from both laboratory microcosm and field study data was consistent, and in good agreement with the anaerobic ε_c values reported by Kolhatkar et al (-14.1 to -11.9 ‰). ε_H values reported (-21 to -11 ‰) were significantly smaller than those previously reported by Gray et al (-29 ‰ and -66 ‰) for aerobic MTBE biodegradation. Additional CSIRA studies on anaerobic MTBE biodegradation were conducted by Somsamak et al (2005) on a methanogenic microcosm developed from streambed sediment in the Aurthur Kill in New York City. ε_c values reported in this study (-15.6 ± 4.1 ‰) were consistent with those reported by both Kolhatkar et al and Kuder et al for anaerobic biodegradation.

The CSIRA studies on MTBE biodegradation conducted to date have shown consistency with respect to calculated ε_c values, while ε_H values have been much more variable. It is also clear from the available literature that ε_c values are significantly higher for anaerobic biodegradation compared to values reported for aerobic biodegradation. The situation is reversed for ε_H values, which are significantly higher for aerobic biodegradation. Differences in ε_c values for aerobic vs anaerobic microbial processes have been identified for the biodegradation of other organic contaminants, and such differences are a commonly-reported phenomenon in the literature (Meckenstock et al, 1999; Schmidt, et al, 2004; Elsner et al, 2005).

Kuder et al (2005) identified this trend specifically with MTBE biodegradation, and attributed it to differences in the metabolic pathways for aerobic vs anaerobic oxidation. As noted in Chapter 2, the initial step in all metabolic pathways elucidated to date for MTBE biodegradation (both aerobic and anaerobic) is the transformation of MTBE to tertiary butyl alcohol (TBA). However, degradation rates for aerobic vs anaerobic pathways vary significantly, suggesting that the mechanisms through which the MTBE - TBA metabolic transformation occurs differs by species.

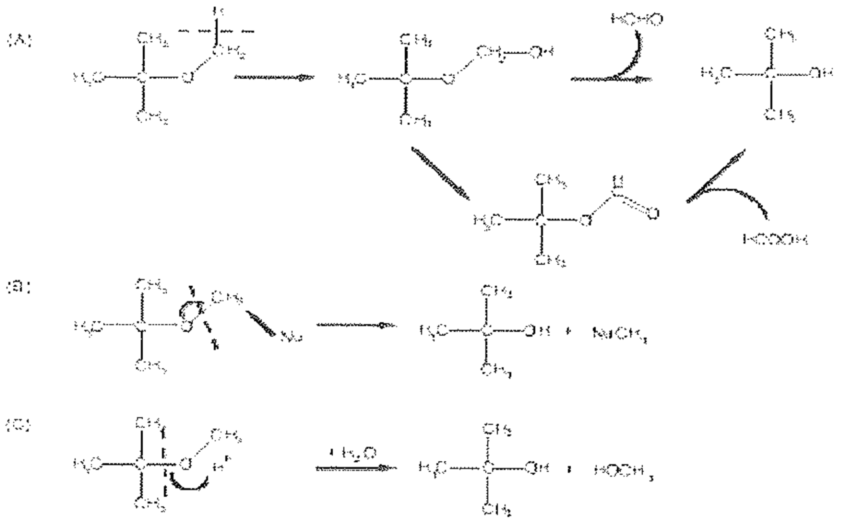


Figure 5.4: Proposed metabolic pathway for MTBE biodegradation through (a) cleavage of a methoxy group C-H bond (aerobic) (b) cleavage of the methoxy group through S_N2 nucleophilic substitution, and (c) cleavage of the methoxy group through S_N1Reaction (*Zwank, 2004*).

Aerobically, researchers believe that the transformation to TBA occurs through the monooxygenase-facilitated extraction of a proton from the MTBE methoxy group, which cleaves a C-H bond in the process (Wilson et al, 2005).

Anaerobically, the process is thought to occur through ether bond hydrolysis (Kuder et al, 2005). As shown in Figure 5.4, ether bond hydrolysis can occur through either S_N1 or S_N2 reaction mechanisms. These metabolic differences lead to the measurable variations in ε values reported for aerobic vs anaerobic metabolic processes. Kuder et at (2005) plotted the anaerobic microcosm data for both δ_c and δ_H from their experiment with the field data collected from the seven sites included in their study.

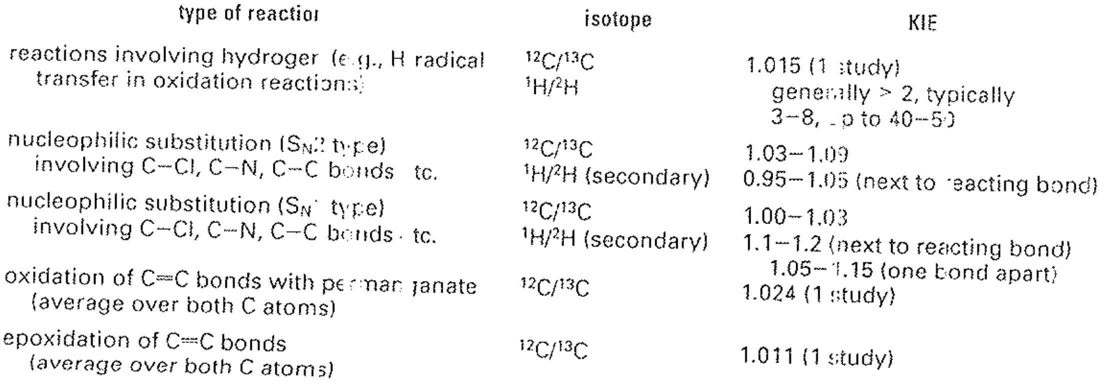
The resulting plot yielded fractionations that could not be distinguished between field and microcosm results, but field fractionations that varied widely from aerobic microcosm results previously published. Based on these results, Kuder et al concluded that biodegradation at all of the field study sites had proceeded anaerobically. Given that most petroleum hydrocarbon ground water contamination plumes are anoxic to anaerobic with respect to dissolved oxygen content, this conclusion seems appropriate for most gasoline LUST site plumes.

With the understanding that the experimental isotopic fractionation data for MTBE biodegradation published in the literature to date is consistent when viewed according to metabolic process (ie, aerobic vs anaerobic), the use of published ε_c values applied to field data collected from LUST sites could provide a method for quantifying biodegradation at these sites. The selection of an appropriate ε_c value, however, requires a look at isotope kinetics. The *kinetic isotope effect* (KIE) is defined below (Elsner et al, 2005) as:

$$\mathrm{KIE} = {}^{l}k/{}^{h}k \qquad \textit{(Equation 5.7)}$$

where ${}^{l}k$ and ${}^{h}k$ are pseudo first order rate constants for the light and heavy isotopes of a given isotopic pair

KIE's can be *primary* or *secondary*, depending on whether the isotope in question is attached to the reaction center (the atom directly involved in the reaction) or not. If a molecule contains multiple atoms of the isotopic element in question, the fractionation measured will be "diluted" by isotopes of the same element located in non-reacting positions in the molecule. Secondary isotopes can also influence the stability of the reaction transition state through the geometry of adjacent bonds. Despite these confounding factors, KIE's have been experimentally derived for a number of chemical bonds (Table 5.1). These values (known as Streitwieser limits) provide a maximum KIE value range for a given bond (nucleophilic substitution involving C-Cl, C-N, or C-O bonds range from 1.03 to 1.09 KIE, for example).



type of reaction	isotope	KIE
reactions involving hydrogen (e.g., H radical transfer in oxidation reactions)	${}^{12}C/{}^{13}C$ ${}^{1}H/{}^{2}H$	1.015 (1 study) generally > 2, typically 3−8, up to 40−50
nucleophilic substitution (S_N2 type) involving C−Cl, C−N, C−C bonds etc.	${}^{12}C/{}^{13}C$ ${}^{1}H/{}^{2}H$ (secondary)	1.03−1.09 0.95−1.05 (next to reacting bond)
nucleophilic substitution (S_N1 type) involving C−Cl, C−N, C−C bonds etc.	${}^{12}C/{}^{13}C$ ${}^{1}H/{}^{2}H$ (secondary)	1.00−1.03 1.1−1.2 (next to reacting bond) 1.05−1.15 (one bond apart)
oxidation of C=C bonds with permanganate (average over both C atoms)	${}^{12}C/{}^{13}C$	1.024 (1 study)
epoxidation of C=C bonds (average over both C atoms)	${}^{12}C/{}^{13}C$	1.011 (1 study)

Table 5.1: Compilation of reported KIE values for select chemical bonds (*Elsner et al, 2005*).

Using a correction factor to adjust for secondary isotope effects developed by Elsner et al (2005) and factoring in the effects of intramolecular competition for binding location (Zwank, 2004), Equation 5.8 relates ε and KIE (Zwank, 2004, following Elsner et al, 2005).

$$1/\mathrm{KIE} = z(\varepsilon/1{,}000) + 1 \qquad \textit{(Equation 5.8)}$$

where z = "chemically equivalent" positions on a molecule available for reaction

Following the methodology outlined above, Husky (1991) derived a theoretical ε_c value for an S_N2 C-O bond cleavage reaction of -12.2 ‰ (Kuder et al, 2005, following Husky et al, 1991). This value is in good agreement with the experimental values for ε_c reported by Kolhatkar et al (2002), Somsamak et al (2005), and Kuder et al (2005) for anaerobic biodegradation.

Returning now to the simplified Rayleigh Equation (Equation 5.6) presented earlier, the fraction of contaminant remaining (and hence the amount degraded) can be calculated if ε, δ_t, and δ_o are known. For a site with an existing contaminant ground water plume, δ_t and δ_o can be determined by sampling a given set of wells twice or more at different time intervals. If δ_o for the contaminant were known, however, a single sampling event would suffice to determine δ_t. For MTBE, the range of δ_o values in fresh gasoline formulations has been reported as -27.5 to -33.0 ‰ (Smallwood et al, 2001; O'Sullivan et al, 2003). Since fractionation will shift the δ_o value towards a more positive number, -27.5 ‰ is the most conservative predicted δ_o value for fresh gasoline formulations, and the value that should conservatively be expected in MTBE-impacted ground water in the absence of biodegradation.

Wilson et al (2005) developed this approach to quantify MTBE biodegradation at LUST sites using values of -12.2 ‰ for ε_c and -27.5 ‰ for δ_o. Plugging these values into Equation 5.6 along with δ_t values collected from LUST site wells can then be used to quantify anaerobic MTBE biodegradation independently of other factors.

5.2 Analytical Results

Ground water quality data collected for this study fall into several broad categories. The first category included data collected directly during field sampling activities, which consisted of several types of field titrations and spectrophotometric analyses (Section 4.1). These data were used, in conjunction with geochemical data reported from lab analyses, to help determine the redox potential of the study wells. Additionally, CSIRA data was used to determine which wells exhibited MTBE biodegradation, as well as those which did not. All geochemical and CSIRA data are presented in Appendix III.

Subsequently, all data was sorted into two data sets: data collected from wells exhibiting biodegradation, and data collected from wells that did not exhibit biodegradation. The distribution of central tendencies in these datasets were then examined in Section 5.4.3. The combined dataset was subsequently examined for correlation between geochemical variables and biodegradation in Section 5.4.4.

5.2.1 Geochemical Analytical Results

Geochemical analyses performed as part of the subject study included dissolved oxygen, oxidation/reduction potential, alkalinity, carbon dioxide, ferrous and total iron, nitrate, nitrite, sulfate, sulfide, manganese, and methane. As described in Chapter 4, these analyses were performed through a combination of field and laboratory analytical techniques. These results are reported in Appenix III.

The data presented in Appendix III were used to determine the aquifer redox potential at each well. Making these determinations was an interpretive process using all of the available data. Aquifer geochemical parameters such as alkalinity, pH and temperature can be evaluated spatially to qualitatively assess microbiological activity. Likewise, dissolved oxygen and ORP can be used to further assess aquifer redox potential. These factors, combined with the presence (or absence) of certain terminal electron acceptors (nitrate, ferrous iron, sulfate) and metabolic products (CO2, methane) can be used to determine the local redox potential (Figure 5.5).

The flowchart represented in Figure 5.5 offers an accepted methodology to determine redox potential in ground water, which was used in this study to help interpret multiple (and sometimes conflicting) data points. Using this approach, the localized aquifer redox potential was determined at each of the study wells (Appendix III).

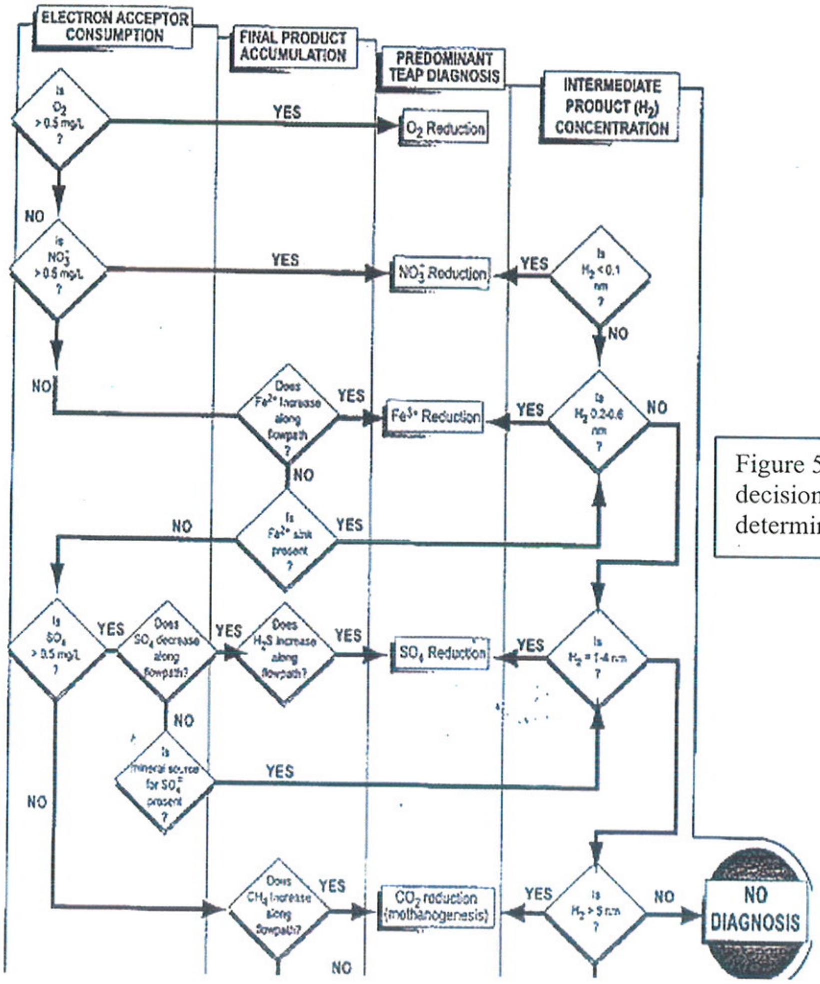


Figure 5.5: Flowchart depicting a decision-making process for the determination of redox potential

5.2.2 CSIRA Analytical Results

CSIRA analysis was conducted on the 163 study candidate wells in accordance with the methodology outlined in Chapter 4. Of the 163 samples analyzed, the laboratory was able to report results for 84 (the remaining samples did not contain enough MTBE in the samples to get a result). Based on these results, the percent MTBE that biodegraded in each of the 84 wells was quantified using the method developed by Wilson et al (Section 5.1). The conservative value of $\delta_o \geq -27.5$ ‰ was used to define biodegradation (Section 5.1). These data and corresponding calculations are presented in Appendix III.

5.3 Data Analysis

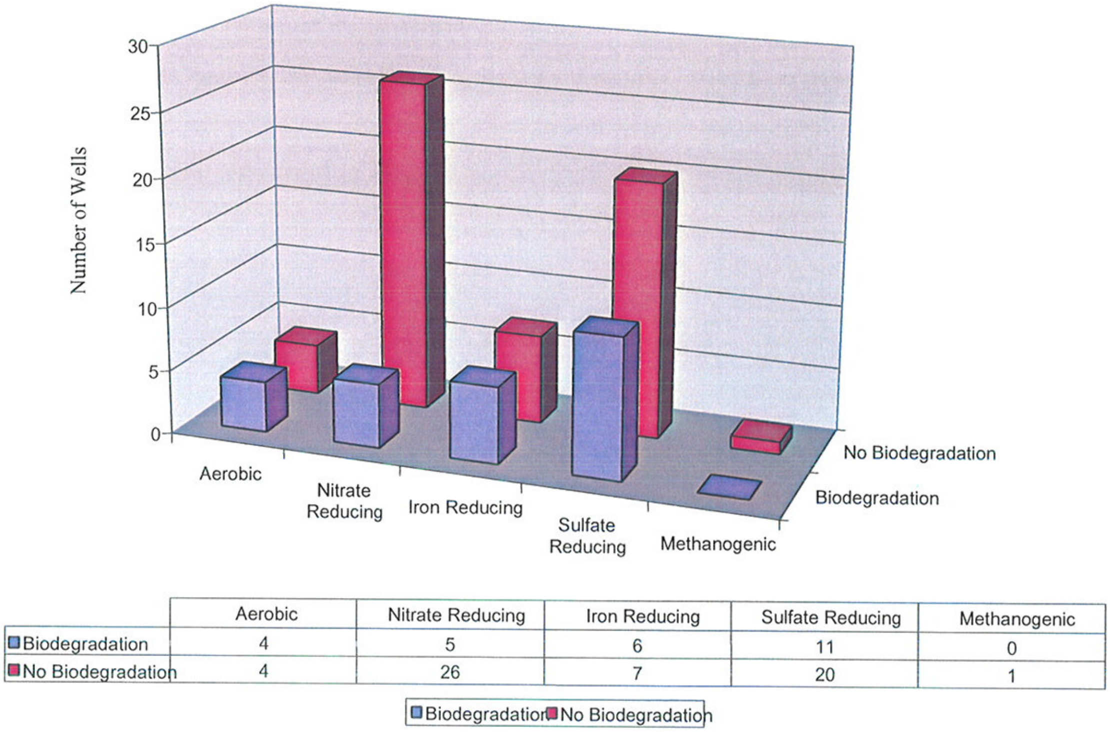
The basic study objective of identifying subsurface conditions conducive to *in situ* MTBE biodegradation was accomplished through a comparison of well conditions in wells where biodegradation was documented with wells where biodegradation was not found. Aquifer redox potential and lithological characteristics were used as determining factors for well conditions.

Once the study wells were sorted into biodegradation or no biodegradation categories, some basic comparative analyses were conducted by sorting, tabulating and charting the data, and by constructing box plots (Sections 5.4.1 and 5.4.2). A more formal comparison of means and/or medians was then conducted on the biodegradation and no biodegradation data sets using both parametric (t test) and nonparametric (Mann-Whitney U test) analyses (Section 5.4.3). Finally, data trend correlations were sought using nonparametric analyses (Spearmann's Rho, Kendall's Tau; Section 5.4.4), followed by a a more detailed analyses of select site-specific data (Section 5.4.5).

5.3.1 Comparative Analyses (Redox Potential and Aquifer Lithological Characteristics)

Of the 84 wells where CSIRA results were returned, 31% exhibited biodegradation (26 of 84). The 84 wells were sorted into "biodegradation" and "no biodegradation" categories based on these results, and then examined against all of the parameters introduced in Sections 5.3 and 5.4, as well as for aquifer lithological characteristics. First, a simple examination of aquifer characteristics distribution was conducted (Figures 5.6 and 5.7).

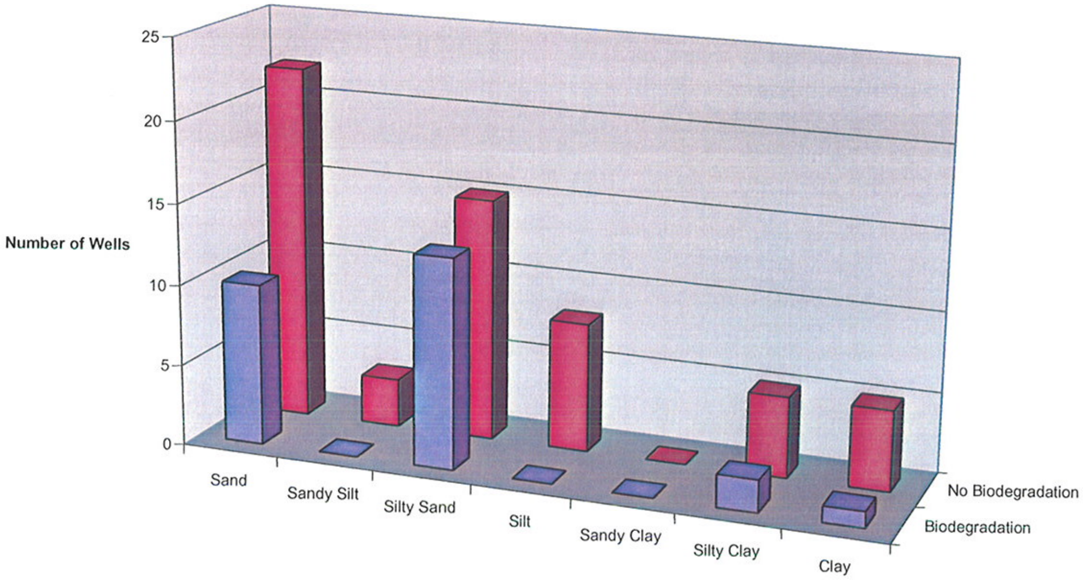
Figure 5.6: *Comparison of Redox Potential in Wells With and Without Biodegradation*



	Aerobic	Nitrate Reducing	Iron Reducing	Sulfate Reducing	Methanogenic
🟦 Biodegradation	4	5	6	11	0
🟥 No Biodegradation	4	26	7	20	1

Under aerobic and iron reducing conditions, about half the wells studied exhibited biodegradation (50% and 46% respectively), while sulfate reducing conditions exhibited biodegradation about a third of the time (35%). Nitrate reducing conditions produced biodegradation only 16% of the time, while the sole methanogenic well included in the study did not exhibit biodegradation (Figure 5.6).

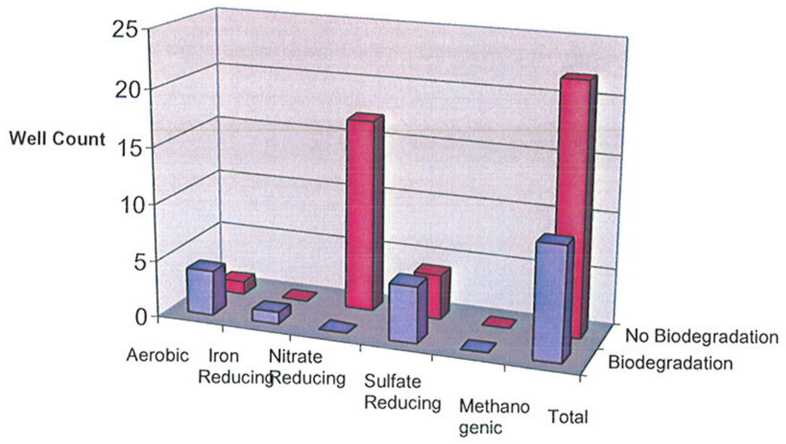
Figure 5.7: Effect of Aquifer Lithology on MTBE Biodegradation In Situ



When the data was sorted according to well lithology, biodegradation was identified half of the time (50%) in the 28 silty sand wells, and about a third of the time in the sand (31%) and silty clay (28.5%) wells (Figure 5.7). Wells identified as having clay lithology exhibited biodegradation 16.5% of the time, while sandy silts exhibited no biodegradation, and sandy clays with MTBE impacts were not encountered during the study well screening process.

Because the data exhibited no apparent trends when sorted by either aquifer redox potential or aquifer lithology, further sorting was conducted for both characteristics (redox potential and lithology). Figures 5.8 through 5.13 depict the number of wells exhibiting biodegradation across the redox potential spectrum for sandy, silty sand, sandy silt, silty clay and clay lithologies.

Figure 5.8: MTBE Biodegradation in Sandy Lithology as a Function of Aquifer Redox Potential



A total of 32 wells set in sandy lithologies were included in this stage of the study (10 exhibiting biodegradation, 22 not - Figure 5.8). Of these wells, too few were identified under iron reducing (1) and methanogenic (0) conditions to draw any conclusions. Four of the 5 sandy wells found under aerobic aquifer conditions exhibited biodegradation, while roughly half of those under sulfate reducing conditions did so (5 of 9). Most notably, none of the 17 wells identified under nitrate reducing conditions showed biodegradation. If these wells are eliminated from the analysis, biodegradation was identified in 64% of the remaining wells.

Biodegradation was identified more frequently overall in silty sand aquifers compared to sandy aquifers (50% vs 31% of wells; Figure 5.9). In this lithology, wells under nitrate reducing and iron reducing conditions demonstrated biodegradation with greater than 50% frequency (80% and 57%, respectively), while wells under sulfate reducing conditions demonstrated biodegradation 60% of the time. Of interest is the apparent disparity in biodegradation frequency under nitrate reducing conditions between sandy and silty sand aquifer conditions (0% vs 80% biodegradation frequency).

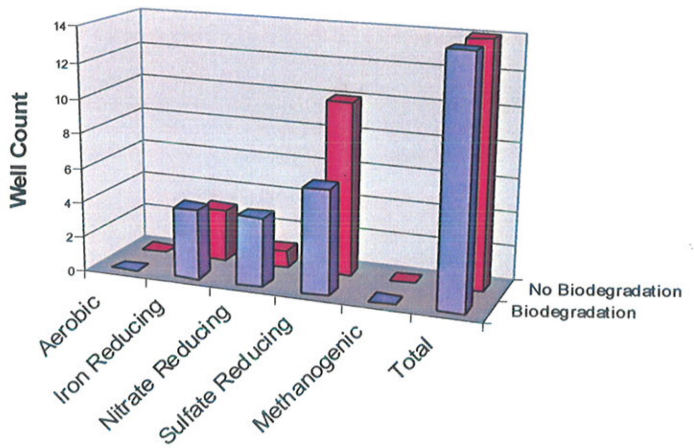


Figure 5.9: MTBE Biodegradation in Silty Sand Lithology as a Function of Aquifer Redox Potential

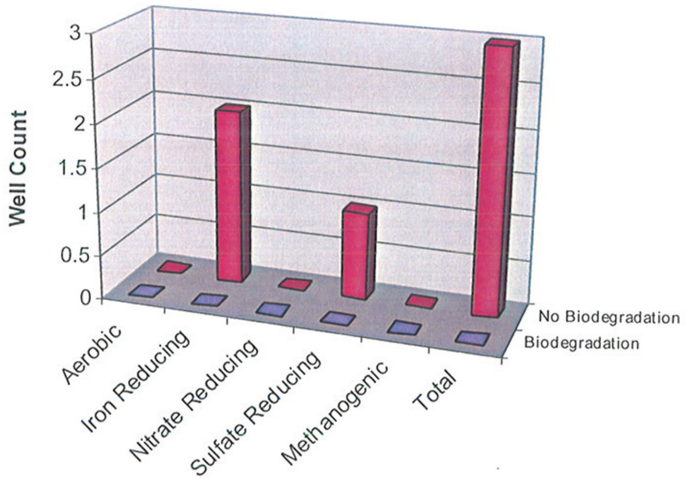
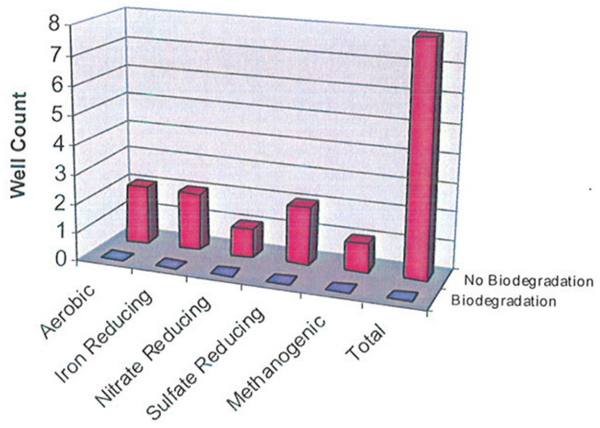


Figure 5.10: MTBE Biodegradation in Sandy Silt Lithology as a Function of Aquifer Redox Potential

Of further interest were wells identified in sandy silt conditions, which exhibited no biodegradation at all (0 out of 3 wells; Figure 5.10). This could simply be the result of a lack of available samples in this lithological categorization (3 total samples). However, despite somewhat better well representation (8 total samples) and wells under multiple redox conditions, silt lithology wells also exhibited no biodegradation under any redox conditions (Figure 5.11).

Figure 5.11: MTBE Biodegradation in Silt Lithology as a Function of Aquifer Redox Potential



Wells set in silty clay lithology exhibited biodegradation under both nitrate reducing (25% frequency) and sulfate reducing (33% frequency) conditions (Figure 5.12).

Wells set in clay showed biodegradation under iron reducing conditions (Figure 5.13), but not under aerobic or nitrate reducing conditions. Since only one well was identified under aerobic and iron reducing conditions, it is not possible to draw conclusions from these results either way, but the lack of biodegradation in wells under nitrate reducing conditions is harder to explain using this rationale.

Figure 5.12: MTBE Biodegradation in Silty Clay Lithology as a Function of Aquifer Redox Potential

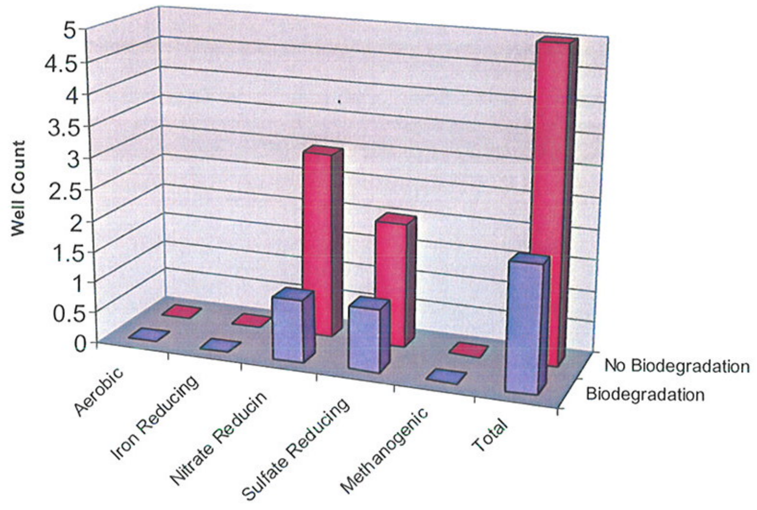
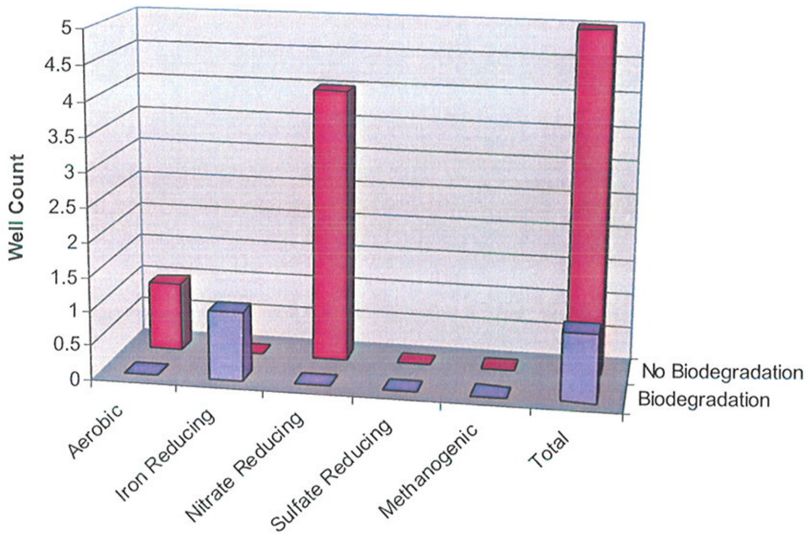


Figure 5.13: MTBE Biodegradation in Clay Lithology as a Function of Aquifer Redox Potential

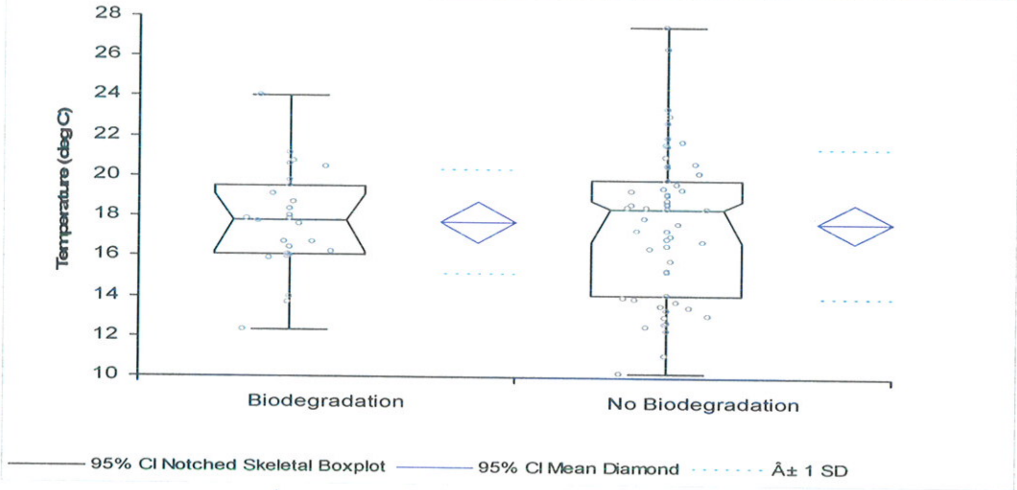


5.3.2 Comparative Analyses of Geochemical Data

In addition to determining what aquifer characteristics are conducive to MTBE biodegradation, some predictive measure of whether or not biodegradation could be expected was determined to be of value for the study. To this end, a quantitative comparison of aquifer geochemistry in the biodegradation/no biodegradation data sets was undertaken using box plots with temperature, conductivity, pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), alkalinity, carbon dioxide, ferrous iron, total iron, nitrate, nitrite, sulfate, sulfide, manganese, methane, redox condition, and soil lithology as the variables (Figures 5.14 through 5.30, respectively).

The box plots were constructed using Analyse-It for Microsoft Excel (version 2.00) from Analyse-It Software, Ltd. (www.analyse-it.com/; 2007). A "skeletal" box style was used to indicate the maximum extent of data outliers, along with a "notched" body to indicate the confidence interval around the mean or median values. Outliers were categorized as near (between 1.5 and 3.0 times the interquartile range (IQR), and far (greater than 3.0 times the IQR).

Figure 5.14: Effect of Ground Water Temperature on MTBE Biodegradation in Situ



	n	Mean	95% CI		SE	SD
Biodegradation	26	17.76	16.71	to 18.79	0.50	2.57
No Biodegradation	58	17.71	16.74	to 18.68	0.48	3.69

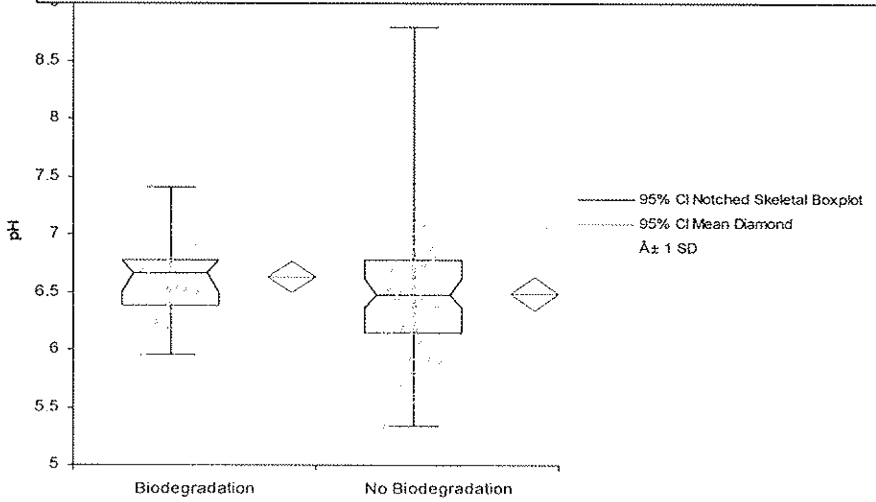
Figures 5.14 through 5.30 compare the central tendency, dispersion and distribution shape of ground water geochemical parameters in wells within the two data sets. A quantitative analysis of distribution within the data sets is included in Section 5.5.3.

Figures 5.14 through 5.18 provide central tendency comparisons of the biodegradation and no biodegradation datasets for temperature, pH, conductivity, DO, and ORP, respectively. In these plots, data distributed around the mean is represented by a vertical scatter plot, which is divided into quartiles based on data point counts (box skeletons) with data extremities represented by the vertical line end points.

Standard deviations are represented by the blue triangles located to the right of the box skeletons. Since these datasets were parametrically distributed, their mean values were compared, along with their standard deviations. This approach provided a qualitative indication of differences in dataset distributions (for those variables with mean differences of greater magnitude than the associated standard deviation values, the differences in central tendency would likely prove statistically significant). Using this approach, none of these box plots showed differences in central tendencies that would likely prove significant.

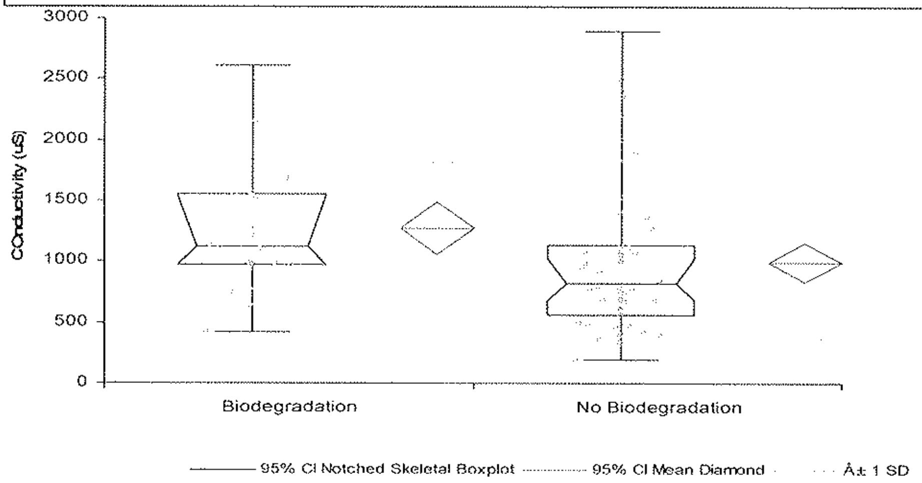
Figures 5.19 through 5.32 examine the datasets associated with the remainder of the variables (alkalinity, carbon dioxide, ferrous iron, total iron, methane, nitrate, nitrite, sulfate, sulfide, and manganese). Median values for the datasets of these variables were also compared, along with their standard deviations. None of these plots exhibited a dramatic difference in median values.

Figure 5.15: Effect of Ground Water pH on MTBE Biodegradaton In Situ



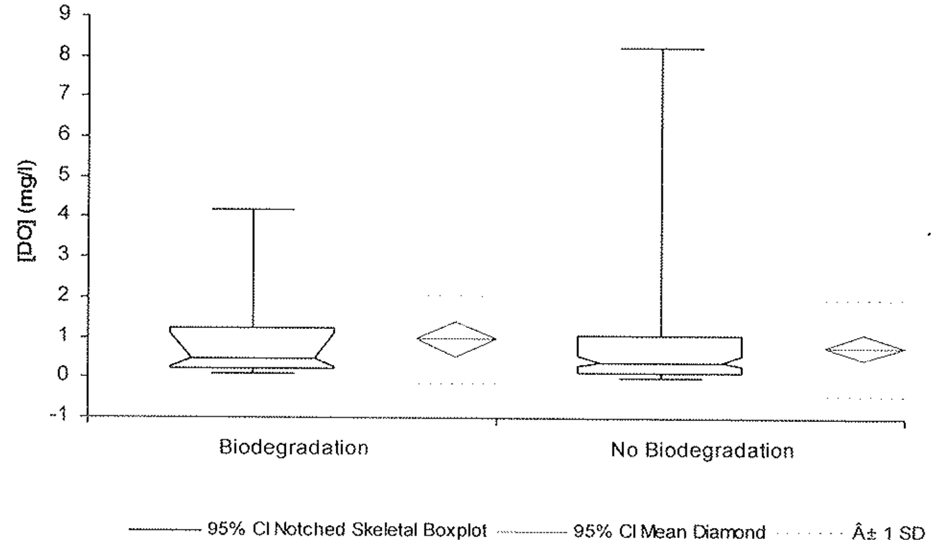
	n	Mean	95% CI		SE	SD
Biodegradation	26	6.6	6.5	to 6.8	0.07	0.3
No Biodegradation	58	6.5	6.4	to 6.6	0.08	0.6

Figure 5.16: Effect of Ground Water Conductivity on MTBE Biodegradation



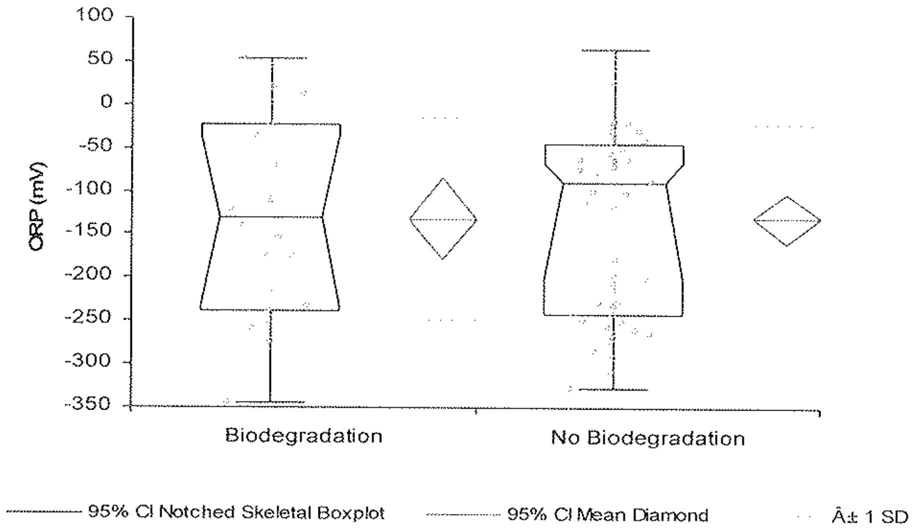
	n	Mean	95% CI		SE	SD
Biodegradation	26	1272	1054	to 1492	107	543
No Biodegradation	58	991	831	to 1151	80	609

Figure 5.17: Effect of Dissolved Oxygen Concentration on MTBE Biodegradation In Situ



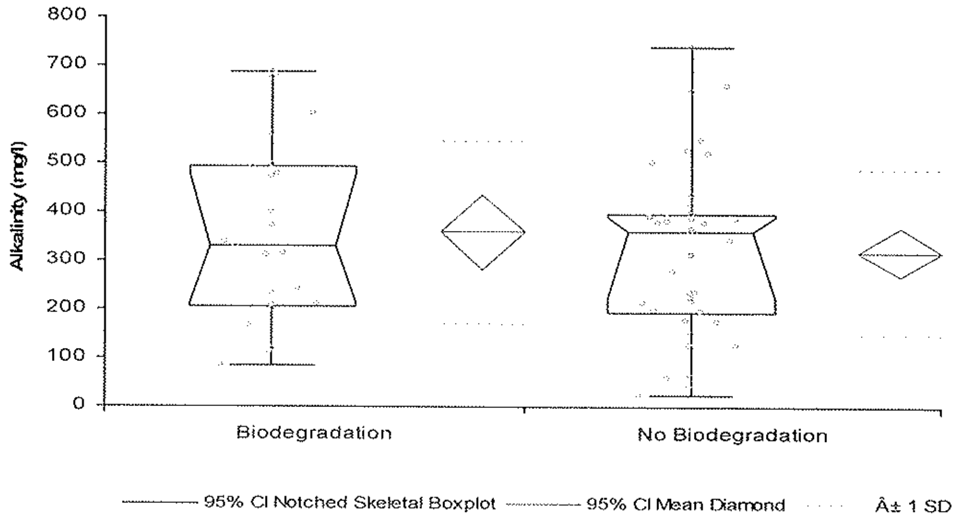
	n	Mean	95% CI		SE	SD
Biodegradation	26	0.97	0.53	to 1.41	0.21	1.08
No Biodegradation	58	0.78	0.47	to 1.09	0.15	1.18

Figure 5.18: Effect of Oxidation Reduction Potential (ORP) on MTBE Biodegradation In Situ



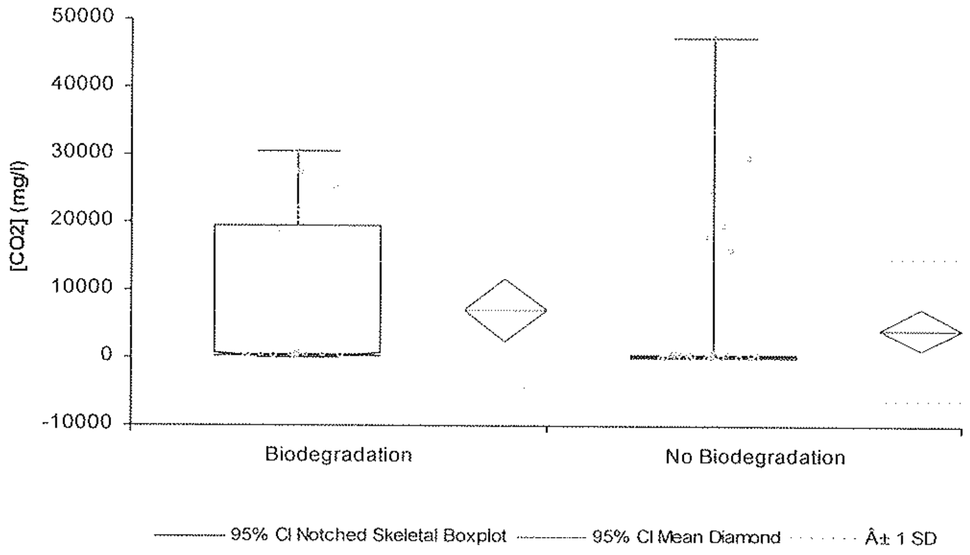
	n	Mean	95% CI		SE	SD
Biodegradation	26	-131.5	-178.3	to -84.8	22.7	115.7
No Biodegradation	58	-131.2	-159.6	to -102.8	14.2	107.9

Figure 5.19: Ground Water Alkalinity Effect on MTBE Biodegradation In Situ



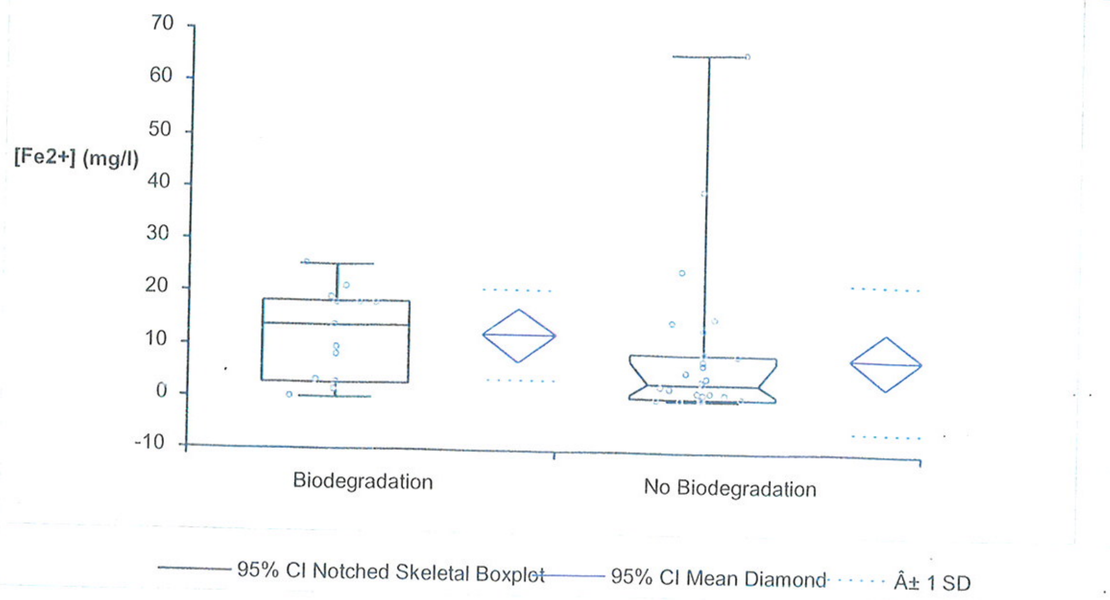
	n	Min	Median	95% CI		Max	IQR
Biodegradation	25	84	329.0	212.0	to 478.0	688	287.0
No Biodegradation	46	25	362.0	223.0	to 390.0	740	203.0

Figure 5.20: Effect of Ground Water CO_2 Concentration on MTBE Biodegradation In Situ



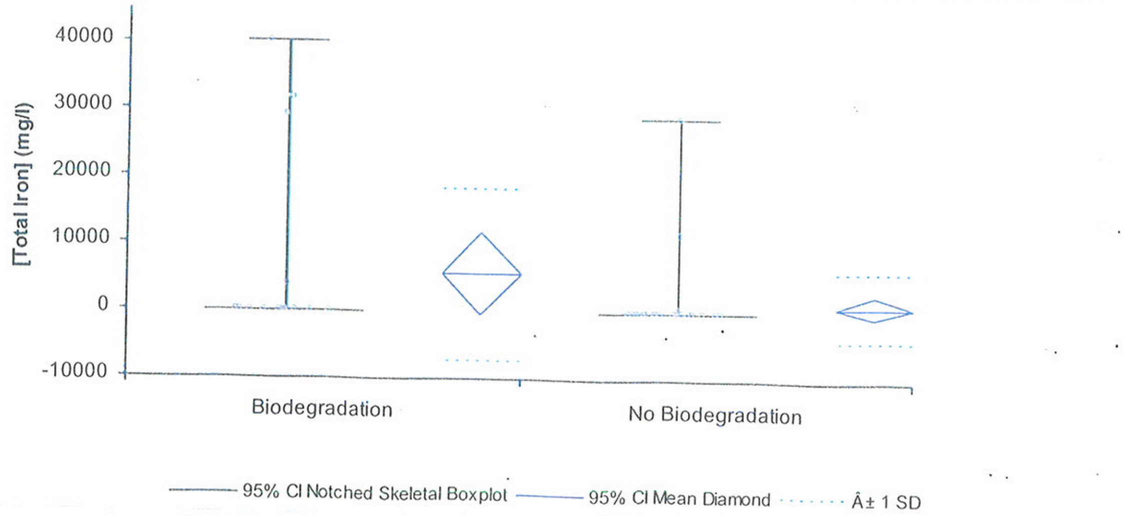
	n	Min	Median	95% CI		Max	IQR
Biodegradation	25	86	492.0	358.0	to 728.0	30500	19144.7
No Biodegradation	47	25	334.0	140.0	to 442.0	47200	495.7

Figure 5.21: Effect of Ground Water Ferrous Iron Concentration on MTBE Biodegradation In Situ



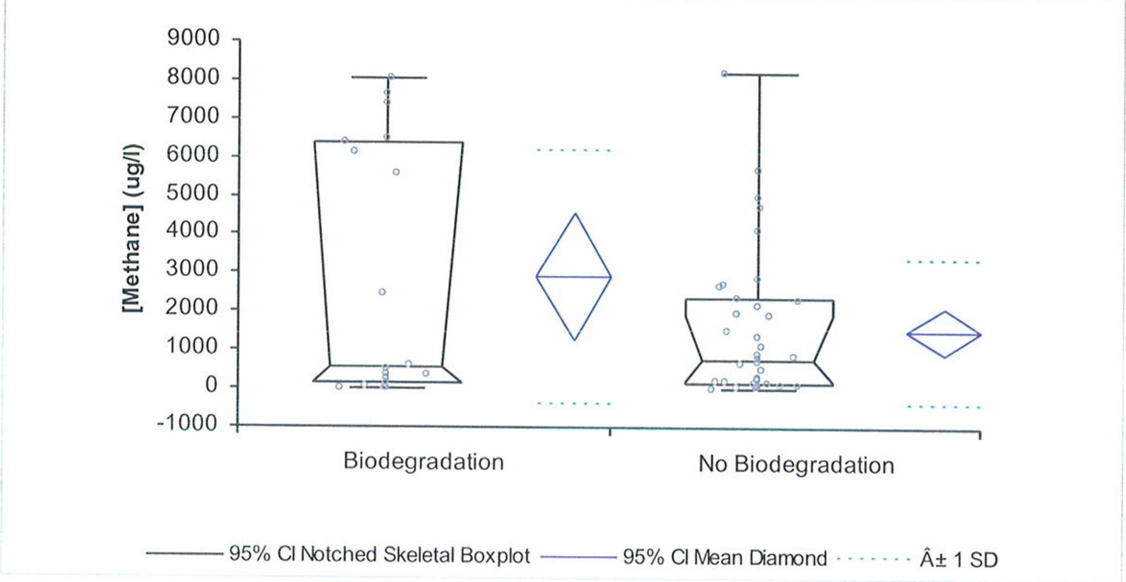
	n	Min	Median	95% CI		Max	IQR
Biodegradation	13	0.07	13.83	2.73	to 18.92	25.34	15.41
No Biodegradation	30	0.02	3.07	1.10	to 7.35	66.08	8.39

Figure 5.22: Effect of Ground Water Total Iron Concentration on MTBE Biodegradation In Situ



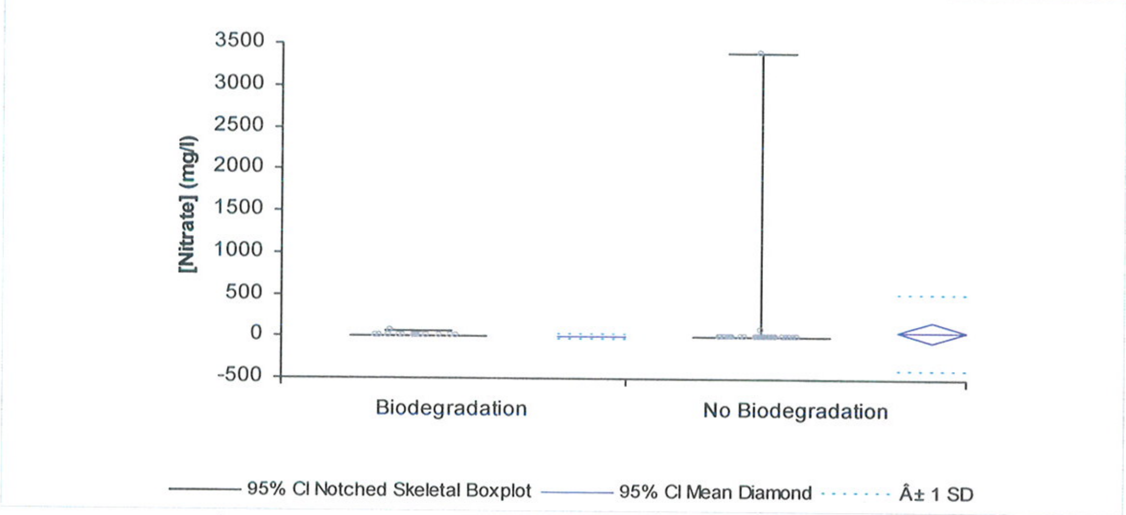
	n	Min	Median	95% CI		Max	IQR
Biodegradation	19	3.23	27.84	10.63	to 151.5	40400	128.9
No Biodegradation	38	0.05	19.30	13.66	to 40.2	29000	56.9

Figure 5.23: Effect of Ground Water Methane Concentration on MTBE Biodegradation In Situ



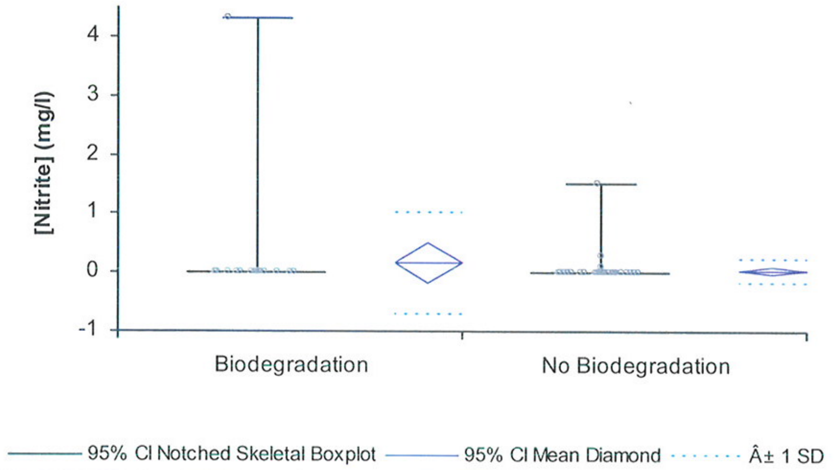
	n	Min	Median	95% CI		Max	IQR
Biodegradation	18	2.6	561.0	151.0	to 6400.0	8060.0	6264.9
No Biodegradation	40	13.0	736.5	217.0	to 1904.0	8210.0	2219.2

Figure 5.24: Effect of Ground Water Nitrate Concentration on MTBE Biodegradation In Situ



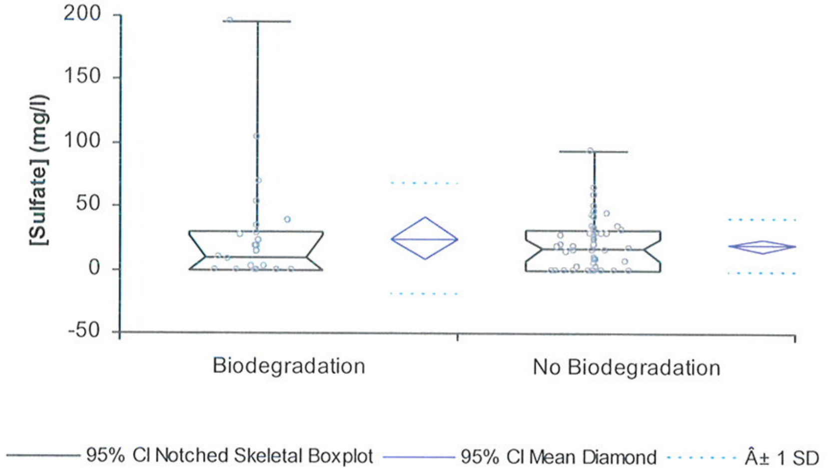
	n	Min	Median	95% CI		Max	IQR
Biodegradation	26	0.0	0.0	0.0	to 0.0	66.7	0.0
No Biodegradation	58	0.0	0.0	0.0	to 0.0	3400.0	0.0

Figure 5.25: Effect of Ground Water Nitrite Concentration on MTBE Biodegradation In Situ



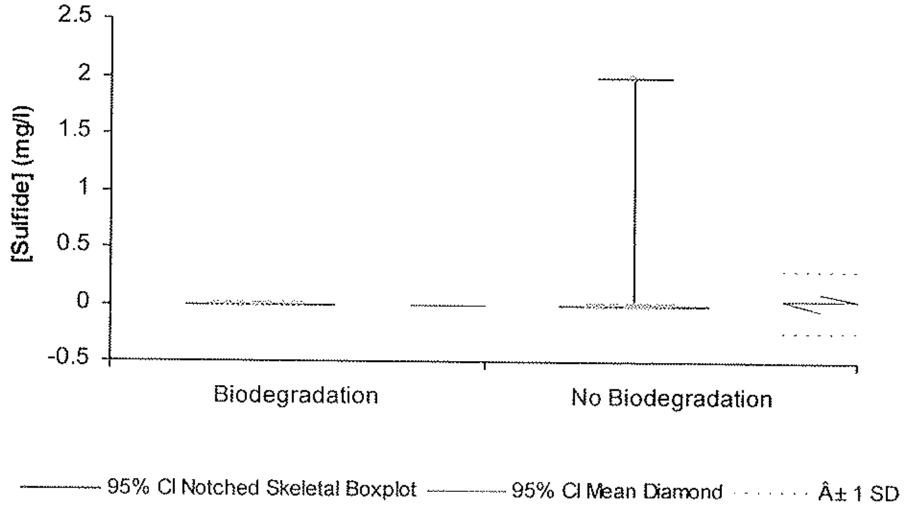
	n	Min	Median	95% CI		Max	IQR
Biodegradation	26	0.0	0.0	0.0	to 0.0	4.3	0.0
No Biodegradation	58	0.0	0.0	0.0	to 0.0	1.5	0.0

Figure 5.26: Effect of Ground Water Sulfate Concentration on MTBE Biodegradation In Situ



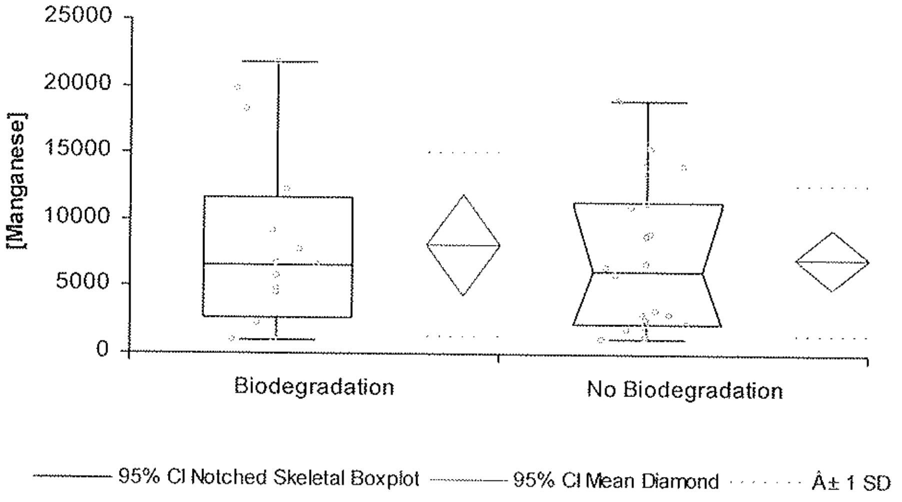
	n	Min	Median	95% CI		Max	IQR
Biodegradation	26	0.0	9.0	0.0	to 27.0	195.0	29.5
No Biodegradation	58	0.0	16.7	7.3	to 24.8	93.5	31.1

Figure 5.27: Effect of Ground Water Sulfide Concentration on MTBE Biodegradation In Situ



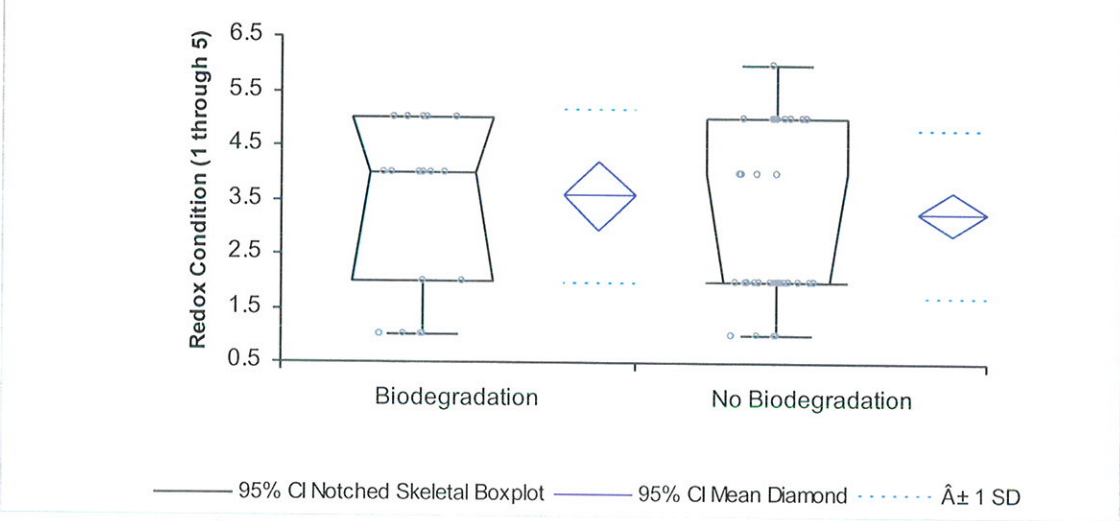
	n	Min	Median	95% CI		Max	IQR
Biodegradation	26	0.0	0.0	0.0	to 0.0	0.0	0.0
No Biodegradation	58	0.0	0.0	0.0	to 0.0	2.0	0.0

Figure 5.28: Effect of Ground Water Manganese Concentration on MTBE Biodegradation In Situ



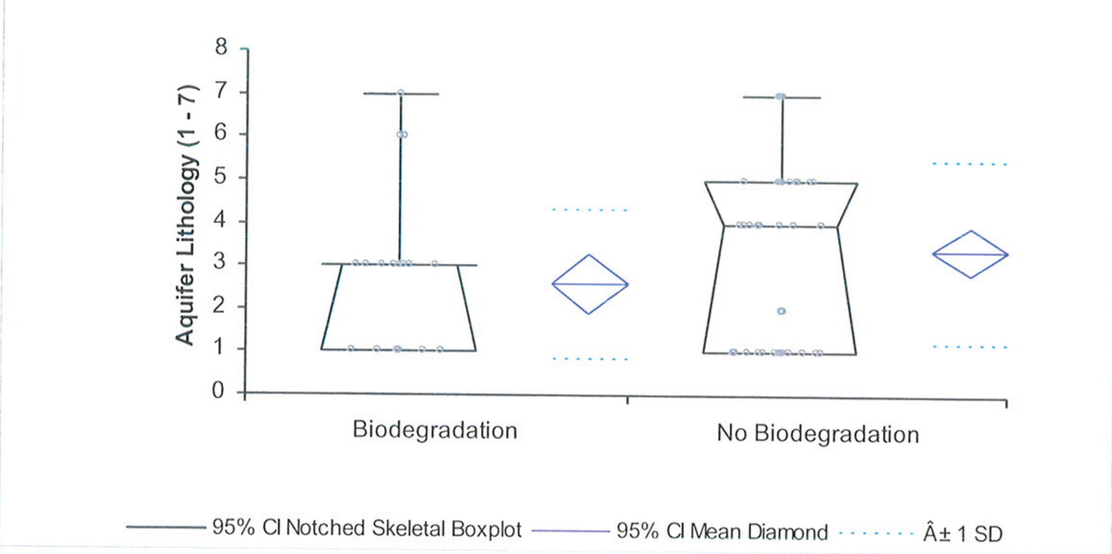
	n	Min	Median	95% CI		Max	IQR
Biodegradation	15	931.0	6600.0	2270.0	to 12200.0	21800.0	9053.3
No Biodegradation	26	1160.0	6180.0	2280.0	to 11000.0	19000.0	9172.5

Figure 5.29: Effect of Ground Water Redox Conditions on MTBE Biodegradation In Situ



	n	Min	Median	95% CI		Max	IQR
Biodegradation	26	1.0	4.0	2.0	to 5.0	5.0	3.0
No Biodegradation	58	1.0	2.0	2.0	to 4.0	6.0	3.0

Figure 5.30: Effect of Aquifer Lithology on MTBE Biodegradation In Situ



	n	Min	Median	95% CI		Max	IQR
Biodegradation	25	1.0	3.0	1.0	to 3.0	7.0	2.0
No Biodegradation	58	1.0	4.0	1.0	to 5.0	7.0	4.0

To construct the box plots in Figures 5.29 and 5.30, the categorizations of "redox potential" and "aquifer lithology" were converted from nominal to ordinal by assigning a numerical value to each category (Table 5.2). Those variables that approximated a normal distribution within the data sets using the Shapiro-Wilk W test (www.analyse-it.com/; 2007) were analyzed by comparing mean values, while those exhibiting non-parametric distributions were analyzed through a comparison of median values. Standard deviations from the mean were included in all of the box plots as a point of reference.

Table 5.2: *Numerical designations assigned to nominal data sets for comparative analyses*

Aquifer Lithology	**Numeric Designation**	**Aquifer Redox Potential**	**Numeric Designation**
Sand	1	Aerobic	1
Sandy Silt	2	Nitrate Reducing	2
Silty Sand	3	Manganese Reducing	3
Silt	4	Iron Reducing	4
Sandy Clay	5	Sulfate Reducing	5
Silty Clay	6	Methanogenic	6
Clay	7		

5.3.3 Comparison of Data Distributions

Once the data sets were compared in a qualitative manner using box plots, a quantitative comparison of data tendencies was undertaken using parametric (t test) and nonparametric (Mann-Whitney U test) analyses. First, the data subsets for all of the analytical and categorical parameters were examined for normalcy using the Shapiro-Wilk W test (www.analyse-it.com/; 2007). Example Shapiro-Wilk W test results are included as Figures 5.31 and 5.32. Those data sets approximating normal distribution were analyzed by comparing mean values through a t-test, while those exhibiting nonparametric distributions were analyzed through a comparison of median values (Mann-Whitney U test). Statistics from the t and Mann-Whitney tests are summarized in Tables 5.3 and 5.4.

Figure 5.31: Frequency Distribution of Ground Water pH data in wells (a) with MTBE biodegradation and (b) with no biodegradation. Both data sets approximate a normal distribution.

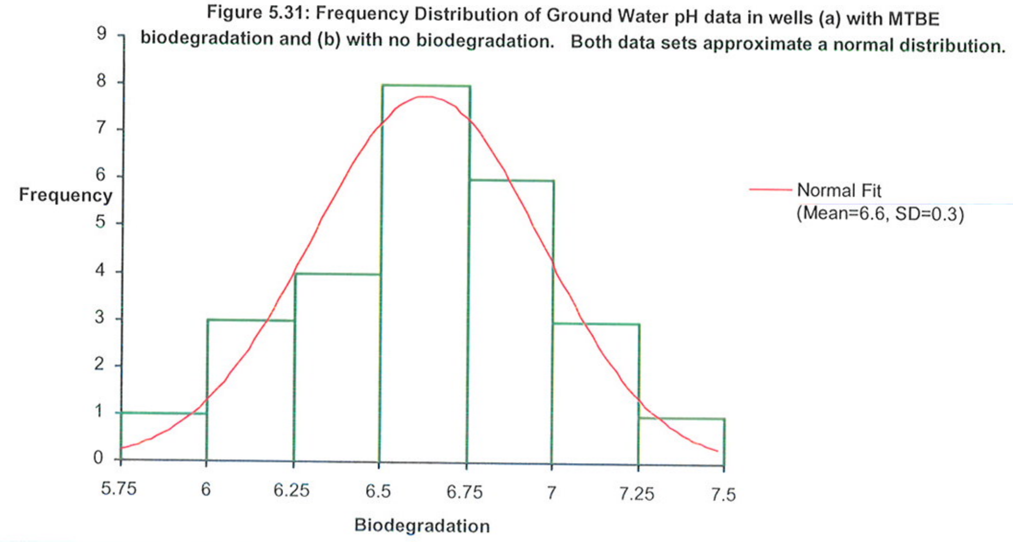
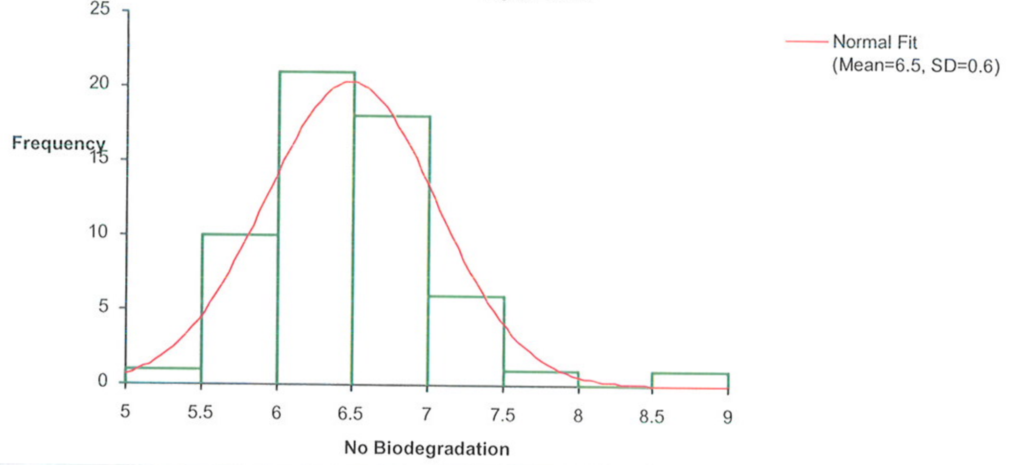


Figure 5.31b



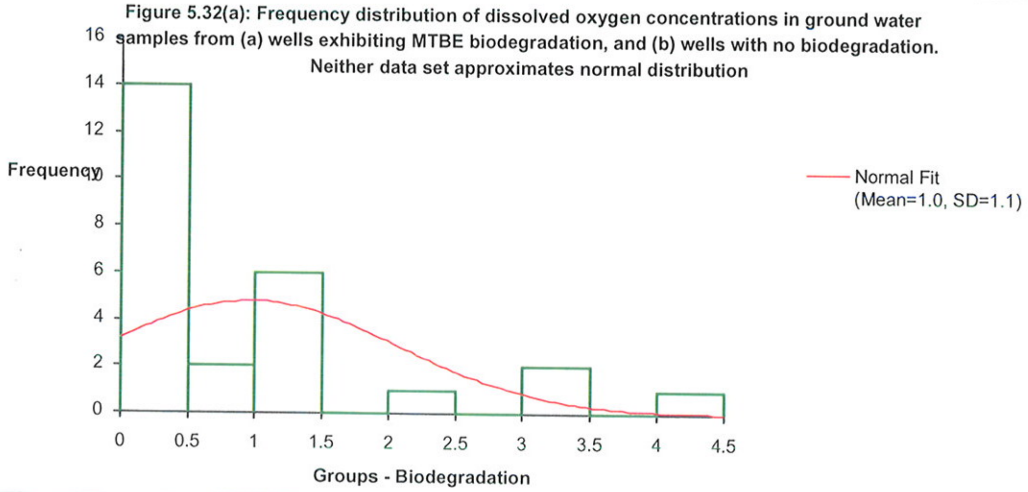


Figure 5.32(a): Frequency distribution of dissolved oxygen concentrations in ground water samples from (a) wells exhibiting MTBE biodegradation, and (b) wells with no biodegradation. Neither data set approximates normal distribution

Figure 5.32b

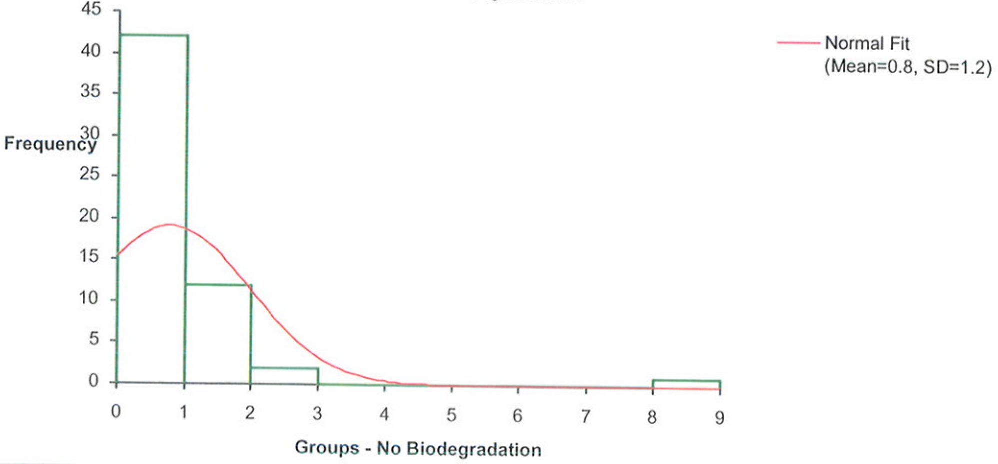


Table 5.3: Results of Student's t-test for comparison of means in biodegradation/no biodegradation data sets

Parameter	Dataset	n	Mean	Standard Error	Standard Deviation
Temperature	Biodegradation	26	17.76	0.50	2.57
	No Biodegradation	58	17.71	0.48	3.69
pH	Biodegradation	26	6.63	0.07	0.33
	No Biodegradation	58	6.48	0.07	0.57
Conductivity	Biodegradation	26	1521	249	1271
	No Biodegradation	58	990	79	608
DO	Biodegradation	26	0.97	0.21	1.08
	No Biodegradation	57	0.78	0.16	1.19
ORP	Biodegradation	26	-131.5	22.7	115.7
	No Biodegradation	58	-131.2	14.2	107.9
Alkalinity	Biodegradation	25	359.7	37.4	187.1
	No Biodegradation	46	319.5	24.9	168.9
CO2	Biodegradation	25	7143.5	2254.8	11274.2
	No Biodegradation	47	4223.6	1509.4	10348.1
Fe2+	Biodegradation	15	10.5	2.3	8.9
	No Biodegradation	32	7.6	2.4	13.6
Total Fe	Biodegradation	21	5043.2	2667.7	12224.7
	No Biodegradation	40	1063.2	771.5	4879.7
Methane	Biodegradation	18	2919.3	775.7	3291.0
	No Biodegradation	40	1506.2	295.5	1868.9
NO3-	Biodegradation	26	2.6	2.6	13.1
	No Biodegradation	57	2.2	1.5	11.2
NO2-	Biodegradation	26	0.2	0.2	0.8
	No Biodegradation	58	0.03	0.03	0.2
SO4-	Biodegradation	26	24.8	8.4	43.0
	No Biodegradation	58	19.4	2.6	20.0
Mn	Biodegradation	15	8199.4	1771.1	6859.5
	No Biodegradation	26	7120.0	1089.9	5557.5
Lithology	Biodegradation	26	2.6	0.3	1.7
	No Biodegradation	58	3.4	0.3	2.1

Table 5.4: Results of Student's t-test for comparison of means in biodegradation/no biodegradation data sets (continued)

Parameter	Mean Difference	95% Confidence Interval	Standard Error	t Statistic	Degrees of Freedom	P (2-tailed)
Temperature	0.04	-1.55 1.63	0.80	0.05	82	0.96
pH	0.15	-0.09 0.38	0.12	1.21	82	0.23
Conductivity	531.03	124.36 937.70	204.43	2.60	82	0.01
DO	0.19	-0.35 0.74	0.27	0.71	81	0.48
ORP	-0.33	-52.15 51.49	26.05	-0.01	82	0.99
Alkalinity	40.22	-46.75 127.19	43.60	0.92	69	0.36
CO2	2919.9	-2350.3 to 8190.0	2642.42	1.11	70.0	0.2729
Fe2+	2.93	-4.87 10.73	3.87	0.76	45	0.45
Total Fe	3980.09	-413.81 8373.98	2195.85	1.81	59	0.07
Methane	1413.07	53.20 2772.93	678.83	2.08	56	0.04
NO3-	0.41	-5.15 5.97	2.80	0.15	81	0.88
NO2-	0.13	-0.10 0.36	0.12	1.13	82	0.26
SO4-	5.42	-8.19 19.03	6.84	0.79	82	0.43
Mn	1079.40	-2893.03 5051.83	1963.93	0.55	39	0.59
Lithology	-0.75	-1.68 0.18	0.47	-1.60	82	0.11

Table 5.5: Results of Mann-Whitney U test for comparison of central tendencies in biodegradation/no biodegradation data sets

Variable	n	Median Difference	Confidence	Interval (95%)	Mann-Whitney Statistic	p (2-tailed)
Temperature	84	-0.1	-1.5	to 1.56	764.5	0.919
Conductivity	84	371	146	to 593	451	0.003
DO	83	0.1	-0.1	to 0.38	651.0	0.377
ORP	84	-1.0	-56.0	to 56.75	758.0	0.969
Alkalinity	71	33.5	-58.0	to 128	523.5	0.535
Carbon Dioxide	72	178.0	28.0	to 395	385.5	0.017
Ferrous Iron	47	3.0	-0.3	to 11.46	176.5	0.147
Total Iron	61	4.7	-8.0	to 31.5	371.0	0.457
Methane	58	180.7	-227.0	to 3250	314.0	0.439
Sulfate	84	0.0	-9.9	to 2.6	811.0	0.575
Manganese	41	405.0	-2380.0	to 4460	186.0	0.808
Redox Potential	84	0.0	0.0	to 1.0	697.0	0.560
Lithology	84	-1.0	-2.0	to 0.0	911.5	0.113

5.3.4 Data Correlation Analyses

To quantify data trend relationships, correlations were sought using nonparametric analyses (Spearmann's Rho, Kendall's Tau). Spearman's Rho is most often used as a correlative measure among nonparametric data sets. Both analyses used are similar, but Kendall's Tau tends to calculate higher p values than Spearman's Rho, and therefore tends to be more conservative.

To complete the analyses, the biodegradation and no biodegradation datasets were combined, and geochemical variables were examined individually against the CSIRA dataset using Analyse-It software (www.analyse-it.com/; 2007). First, scatter plots were prepared for each variable vs. CSIRA data. These plots were constructed by charting the identified variables vs. the corresponding CSIRA values across the combined dataset (biodegradation and no biodegradation). A linear function on the resulting plot would indicate a perfect correlation, while random scatter in the data would indicate no correlation. Next, Spearman's and Kendall's analyses were performed. The scatter plots and correlative analyses are presented in Figures 5.33 through 5.49 below. Summary correlation results are presented in Table 5.6.

Figure 5.33: Scatter plot illustrating correlation between ground water temperature and CSIRA

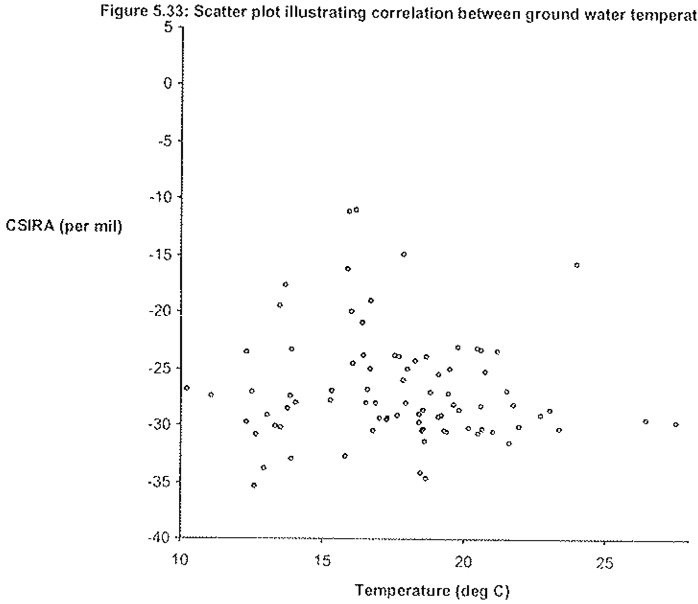


Figure 5.34: Scatter plot illustrating correlation between ground water pH and CSIRA

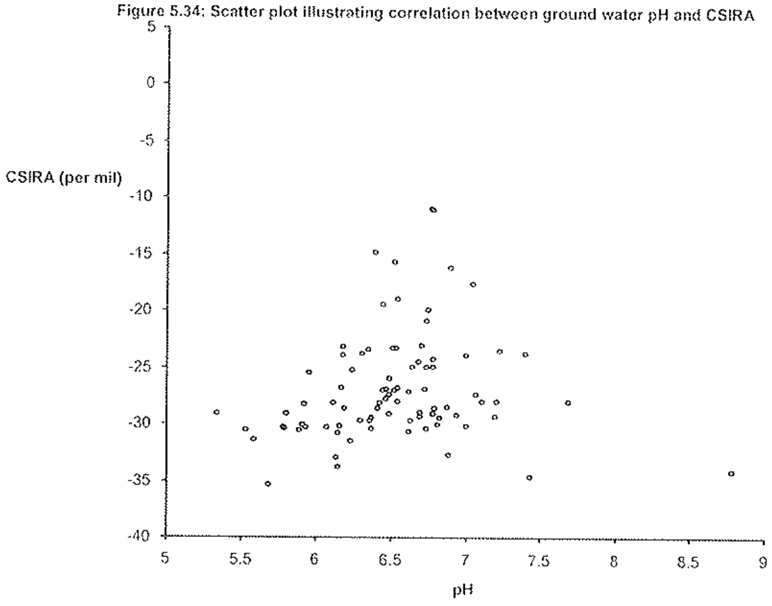


Figure 5.35: Scatter plot illustrating correlation between ground water conductivity and CSIRA

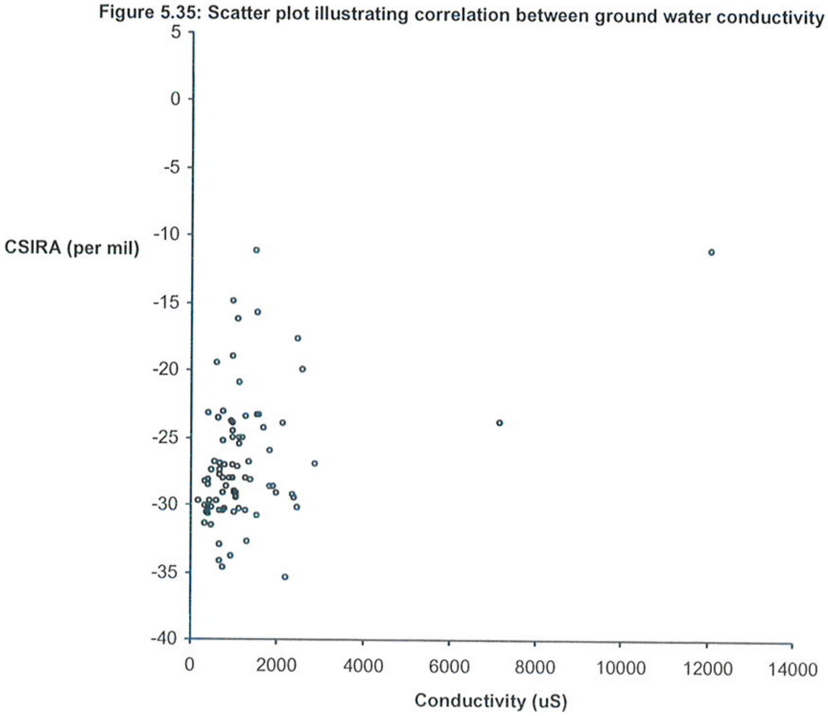


Figure 5.36: Scatter plot illustrating correlation between ground water dissolved oxygen concentration and CSIRA

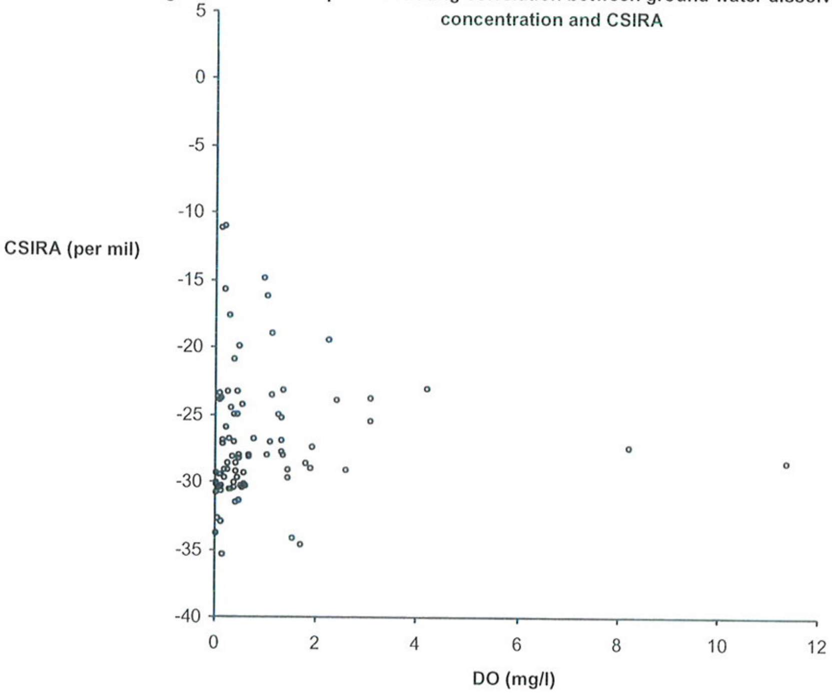


Figure 5.37: Scatter plot illustrating correlation between ground water oxidation/reduction potential and CSIRA

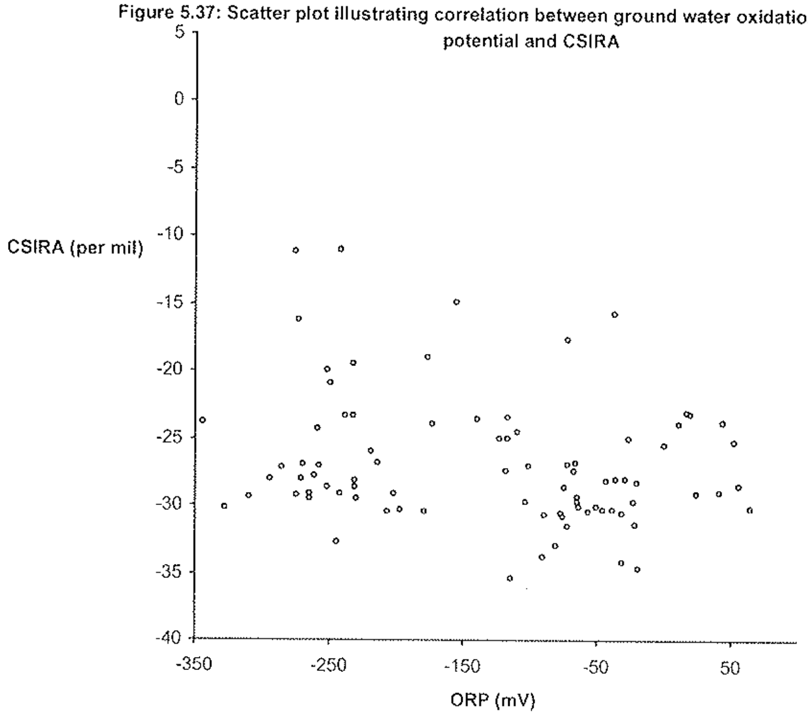


Figure 5.38: Scatter plot illustrating correlation between ground water alkalinity and CSIRA

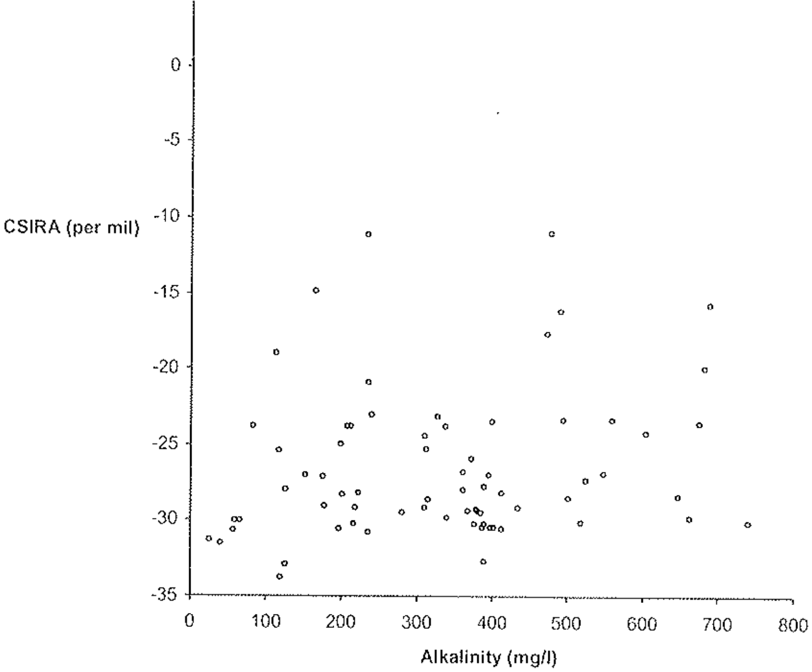


Figure 5.39: Scatter plot illustrating correlation between ground water dissolved carbon dioxide concentration and CSIRA

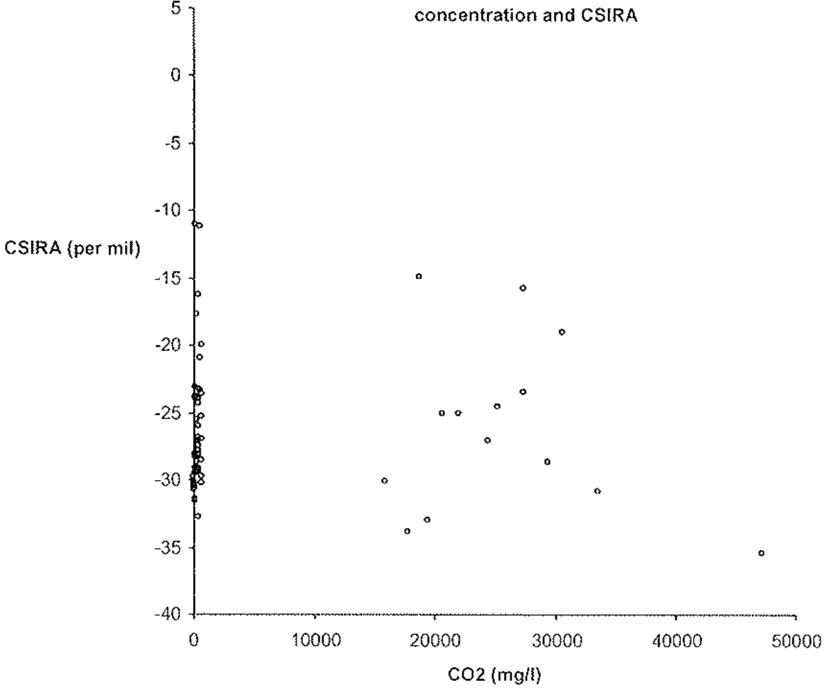


Figure 5.40: Scatter plot illustrating correlation between ground water ferrous iron concentration and CSIRA

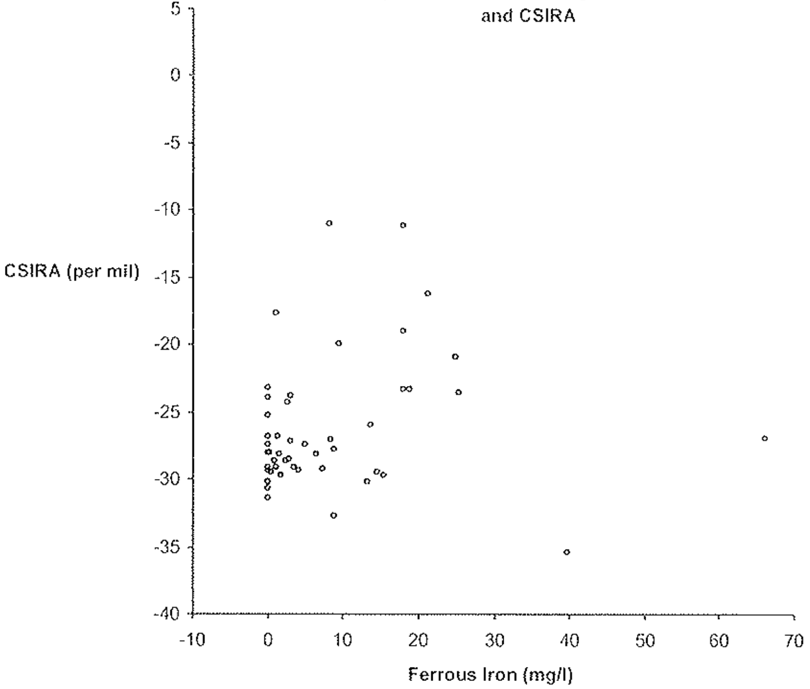


Figure 5.41: Scatter plot illustrating correlation between ground water total iron concentration and CSIRA

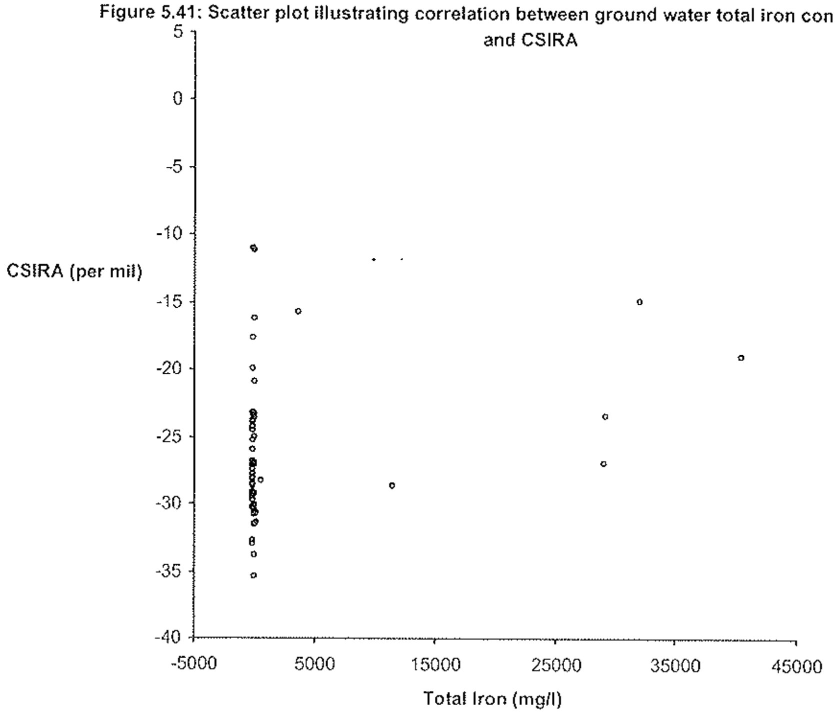


Figure 5.42: Scatter plot illustrating correlation between ground water methane concentration and CSIRA

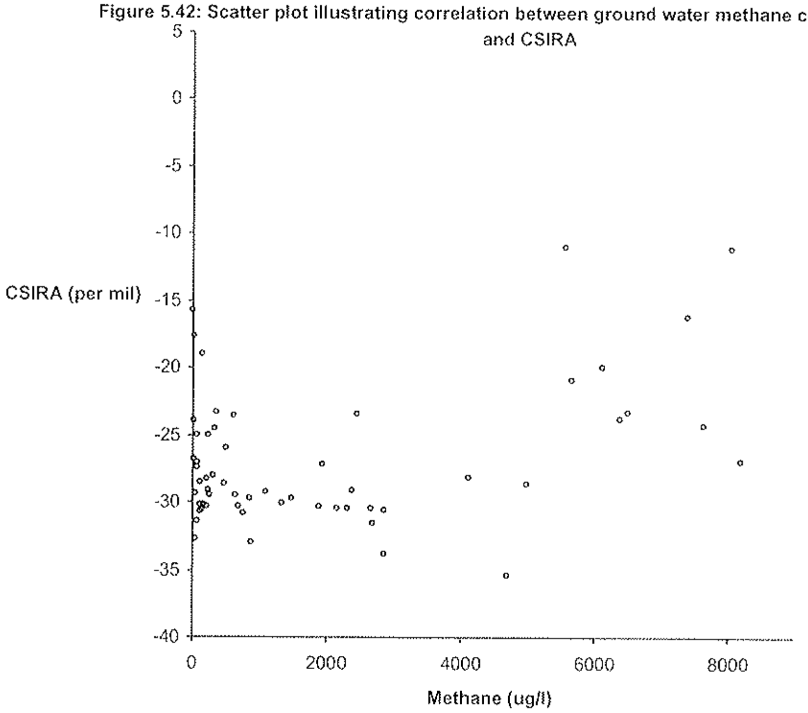


Figure 5.43: Scatter plot illustrating correlation between ground water nitrate concentration and CSIRA

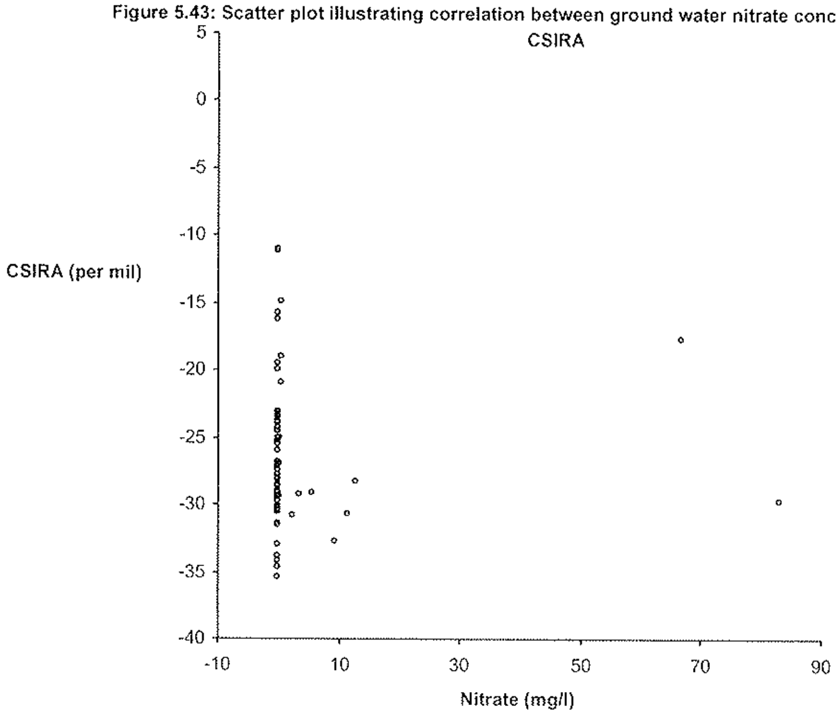


Figure 5.44: Scatter plot illustrating correlation between ground water nitrite concentration and CSIRA

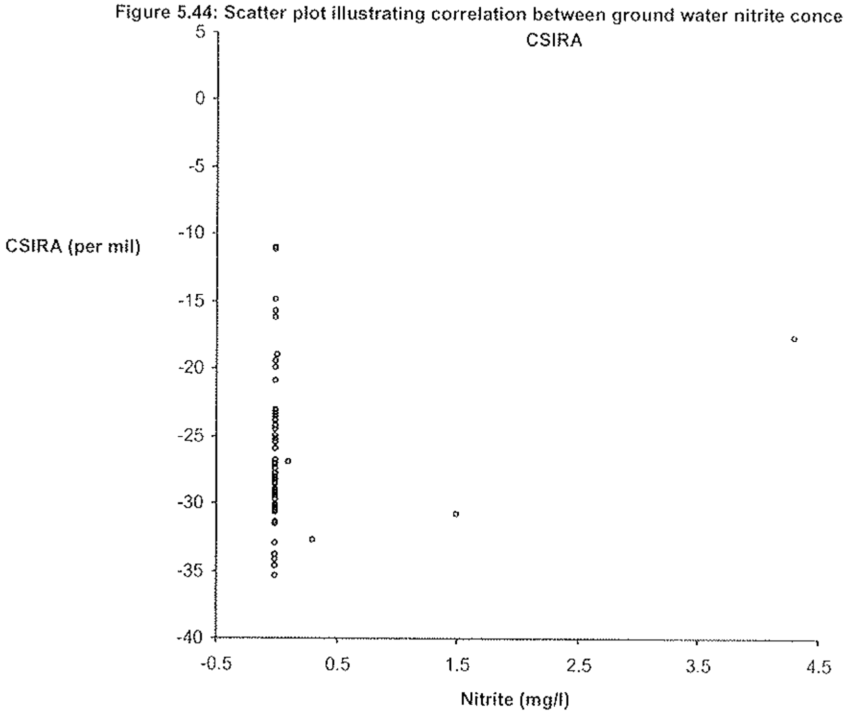


Figure 5.45: Scatter plot illustrating correlation between ground water sulfate concentration and CSIRA

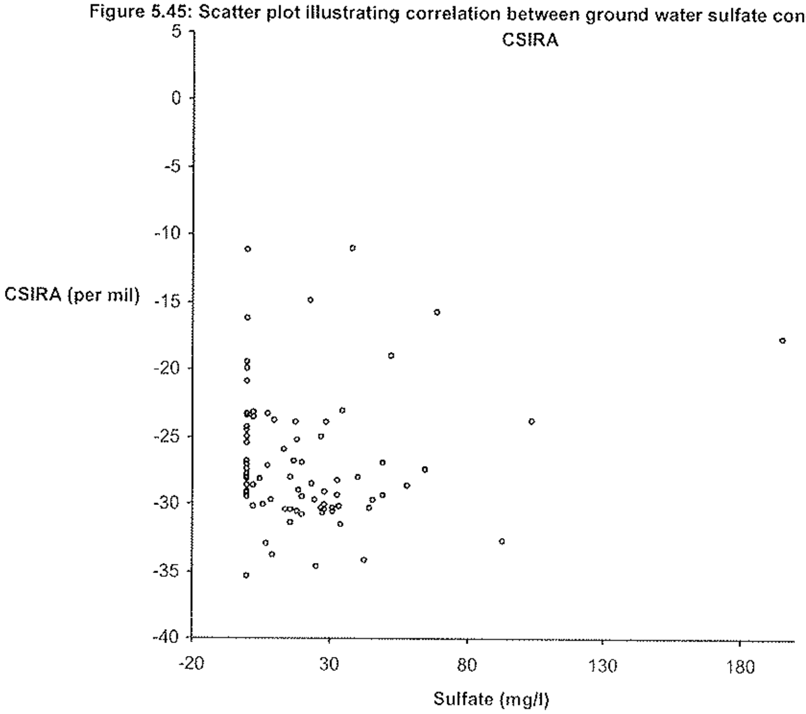


Figure 5.46: Scatter plot illustrating correlation between ground water sulfide concentration and CSIRA

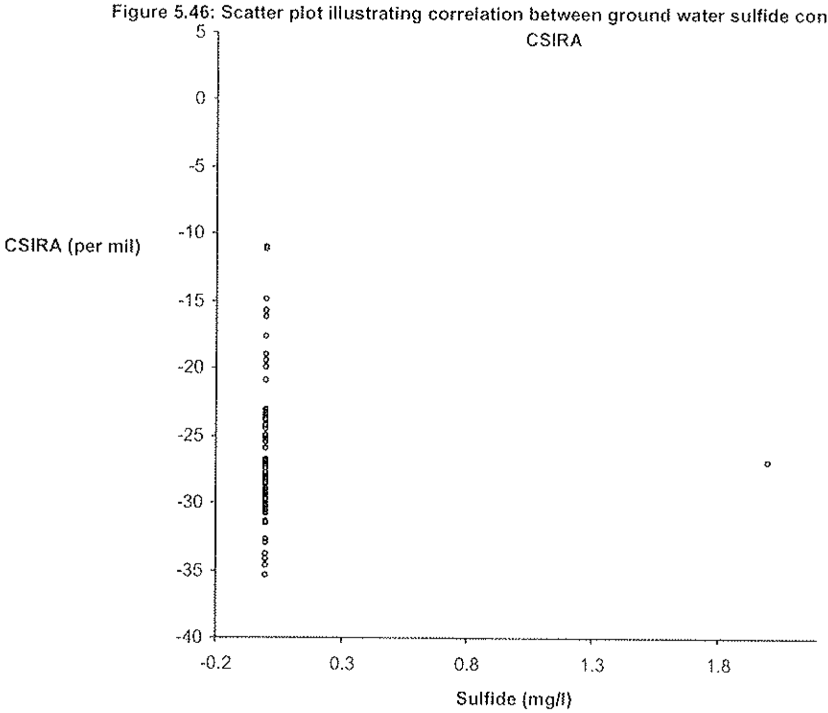


Figure 5.47: Scatter plot illustrating correlation between ground water manganese concentration and CSIRA

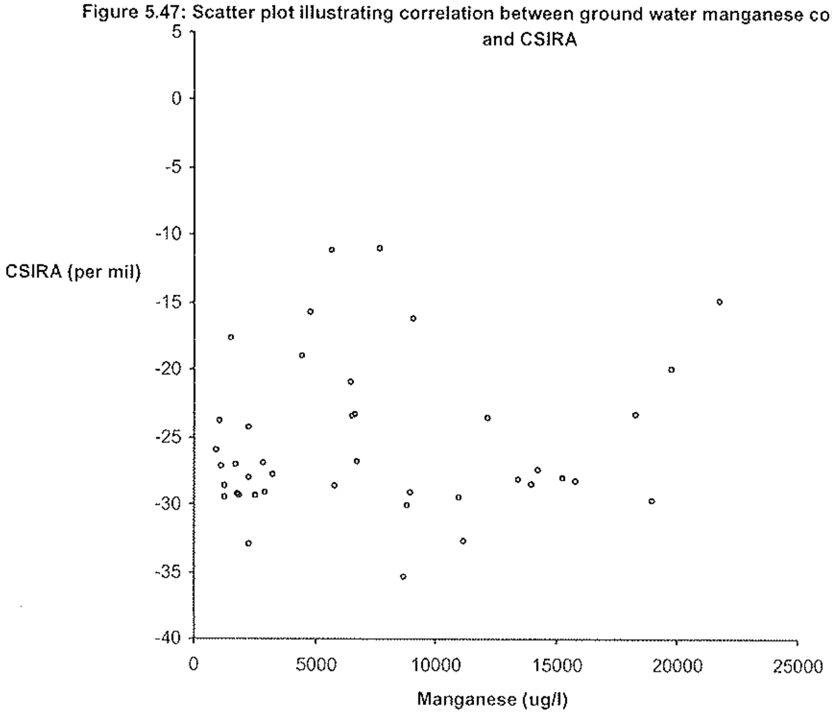


Figure 5.48: Scatter plot illustrating correlation between ground water redox potential and CSIRA

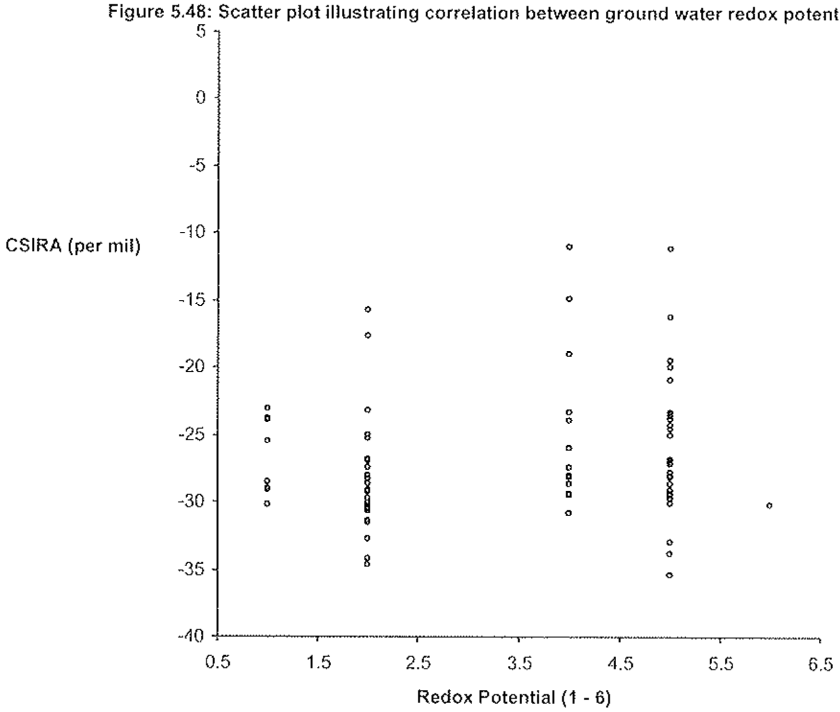


Figure 5.49: Scatter plot illustrating correlation between aquifer lithology and CSIRA

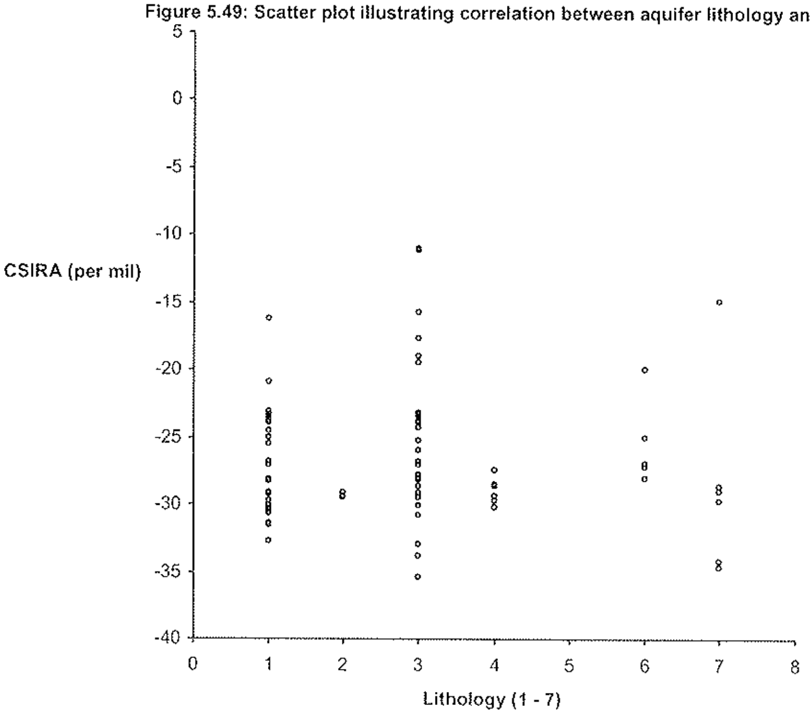


Table 5.6: summary statistics for geochemical variables correlated with CSIRA results

Variable	n	r_s statistic	Confidence Interval (95%)	t statistic	Degrees of Freedom	p (2-tailed)	tau statistic	p (2-tailed)
Temperature	84	-0.13	-0.33 to 0.09	-1.15	82	0.251	-0.09	0.208
pH	84	0.28	0.07 to 0.47	2.67	82	0.009	0.21	0.006
Conductivity	84	0.31	0.11 to 0.49	2.99	82	0.004	0.20	0.006
DO	84	0.24	0.03 to 0.43	2.25	82	0.027	0.16	0.029
ORP	84	-0.19	-0.39 to 0.03	-1.74	82	0.085	-0.13	0.092
Alkalinity	71	0.18	-0.05 to 0.40	1.56	69	0.124	0.11	0.160
Carbon Dioxide	72	0.28	0.05 to 0.48	2.46	70	0.016	0.21	0.010
Ferrous Iron	47	0.23	-0.06 to 0.48	1.56	45	0.125	0.14	0.160
Total Iron	61	0.02	-0.23 to 0.27	0.15	59	0.882	0.00	1.000
Methane	58	0.09	-0.17 to 0.34	0.66	56	0.511	0.03	0.727
Nitrate	84	0.01	-0.20 to 0.23	0.11	82	0.910	0.02	0.853
Sulfate	84	-0.20	-0.39 to 0.02	-1.82	82	0.073	-0.14	0.065
Sulfide	84	0.05	-0.17 to 0.26	0.45	82	0.653	0.04	0.650
Manganese	41	0.06	-0.25 to 0.36	0.38	39	0.707	0.05	0.637
Redox Potential	84	0.20	-0.01 to 0.40	1.87	82	0.065	0.15	0.075
Lithology	84	0.08	-0.14 to 0.29	0.70	82	0.487	0.06	0.492
Distance from Source	82	-0.33	-0.51 to -0.12	-3.12	80	0.003	-0.23	0.003

5.3.5 Site-Specific Analyses

Given the inconsistency associated with biodegradation frequency results across the redox spectrum and within varied aquifer lithologies, some of the available data was examined on a site-specific basis. The most obvious inconsistency identified with respect to biodegradation frequency was the disparity in frequencies under nitrate reducing conditions between sand and silty sand lithologies (Figures 5.8 and 5.9).

Of the 17 sandy wells identified under nitrate reducing conditions, 15 were located at a single site on Long Island, NY (Deer Park; Appendix III). All 15 site wells were located downgradient of the MTBE source area (the original tank field at the service station) with respect to ground water flow direction and MTBE plume migration (all downgradient along the axis of plume migration is expected, given that the wells were originally selected for inclusion in the study based on their MTBE impacts).

The wells ranged in distance from the source area between 20 and 900 feet, with the majority of wells located between 600 and 900 feet downgradient (measurable MTBE concentrations have been found 11,000 feet downgradient of the source area at this site). With contaminant seepage velocities approaching 0.5 ft/day (Delta Environmental Consultants, unpublished data) the 600 to 900 foot distance downgradient represents transport times ranging between 3.3 and 4.9 years (more than enough time for biodegradation to have occurred if it was going to).

The extent of the nitrate reducing zone in the local aquifer seems extreme when compared to redox zonation associated with other hydrocarbon releases (the nitrate reducing zone at the Deer Park site extends at least 900 feet beyond the hydrocarbon release source area; most sites have a nitrate reduction zone that extends less than 100 feet downgradient of the source area). Since the downgradient area at the Deer Park site is located in a suburban residential development with a significant number of lawns and septic systems, it is likely that lawn fertilizing and septic organic loading in the neighborhood have had a more profound effect on the aquifer geochemistry than the gasoline release did.

It has been widely postulated in the literature (Chapter 2) that microorganisms favor a number of other organic materials over MTBE as substrates. This is likely the reason no MTBE biodegradation occurred at Deer Park despite the prolonged residence time of the MTBE within the aquifer.

Biodegradation under sulfate reducing conditions occurred in a variety of aquifer lithologies, but was not demonstrated consistently across the data. Sulfate reducing conditions were the most prevalent in the study, and a number of sites exhibited sulfate reducing conditions in all wells, including sites in Westport, CT (4 wells), Fourth Avenue, Brooklyn (3) (4 wells), and Bridgeport, CT (3 wells). Two other sites of interest (Woodside, Queens and Fourth Avenue, Brooklyn (2)), had wells that were identified under a variety of redox conditions.

Three of the 4 Westport wells sampled showed moderate MTBE biodegradation (up to about 15% of the total mass degraded). All of the wells were under sulfate reducing conditions, and biodegradation must have occurred under these conditions (as opposed to MTBE migration between redox potential zones). The local aquifer is highly transmissive sand and gravel with contaminant seepage velocities approaching 0.75 feet/day (Delta Environmental Consultants, unpublished data). This velocity translates into a contaminant transport timeframe of less than a year (0.3 – 0.7 years), which may explain the relatively small amount of MTBE mass that has degraded.

The Fourth Avenue, Brooklyn (3) site has a somewhat tighter silty sand lithology compared to the Westport site, and seepage velocity is less than 0.5 feet/day (Delta Environmental Consultants, unpublished data). The monitoring well network ranges from 15 to 90 feet downgradient of the source area, with estimated transport times still less than a year throughout the network. None of the 4 wells sampled at this site exhibited any biodegradation. Of note, ground water flow dynamics are significantly affected at the site by a subway tunnel, which runs along Fourth Avenue directly across the street from the site. It is unlikely, however, that the subway has had any significant effect on contaminant biodegradation at the site.

The Bridgeport site is analogous to the Fourth Avenue (3) site in that it has a fairly uniform silty sand aquifer, which is under sulfate reducing conditions throughout most of the aerial extent of the contaminant plume (a single well 90 feet downgradient of the source area was identified under iron reducing conditions – another well at 80 feet was found to be sulfate reducing, so it is likely that the 90 foot well is located at the leading edge of the iron reduction redox zone). None of the Bridgeport site wells exhibited biodegradation. These results, combined with those of the Fourth Avenue (3) site already discussed, strengthen the conclusion that MTBE will not degrade significantly under sulfate reducing, silty sand site conditions.

The Fourth Avenue, Brooklyn (2) site exhibits redox zonation, with wells under aerobic, iron reducing, and sulfate reducing conditions (some of the other sites already discussed likely do as well, but the zonation likely spreads out beyond the established monitoring well network at those sites). The Fourth Avenue (2) site had an active soil and ground water remediation system at the time study samples were collected (dual-phase extraction using PVC stingers below the water table combined with well-head vacuum extraction), leading to aerobic conditions in some of the monitoring wells.

The site has a tight silt lithology with a few sand lenses interspersed, and the estimated contaminant seepage velocity is much lower (0.25 feet/day) than what has been reported for more transmissive aquifers (0.5 – 1.0 feet/day typically). Contaminant transport times within the existing monitoring well network are on the order of between 1 and 2 years.

Of the site wells sampled during the study, 1 was found to have biodegraded MTBE. This well was the only well placed within a sandy lens, and was under sulfate reducing conditions. Based on the position and distance of the various wells from the source area, the sandy lens well was determined to be near the interface between the sulfate reducing and iron reducing zones. The sulfate reducing zone extends back close to the source area at the site (little or no methanogenic zone appears present), and the sandy zone biodegradation seems likely to have occurred wholly under sulfate reducing conditions. No other site wells demonstrated biodegradation.

It is anticipated that MTBE biodegradation may be happening in the aerobic zone created by the remediation system, but the CSIRA method used here is specific to anaerobic biodegradation (Section 5.1), so a lack of biodegradation under aerobic conditions is not surprising.

A second site with aerobic conditions was also identified in the study (West Islip, Long Island). This site also had a remediation system (ISOC oxygen injection system) to treat ground water contaminants, which accounts for the aerobic conditions identified. Curiously, four of the five study samples collected showed anaerobic biodegradation despite the aerobic aquifer conditions.

The treatment system was set up 50 – 75 feet downgradient of the contaminant source area, perpendicular to the direction of contaminant plume migration as an oxygen barrier. It is therefore likely that the MTBE degraded in the zone immediately downgradient of the source area, but upgradient of the oxygen infusion zone (unfortunately, there are no wells within this area, and so samples in this zone were not collected). Contaminant transport time into the aerobic zone was estimated at about 0.75 years, and percent mass degraded estimates ranged from 8 to 24. These results are consistent with the sandy aquifer sites that exhibited anaerobic biodegradation under sulfate reducing conditions with respect to amount degraded and transport times.

The Woodside, Queens site is heterogeneous with respect to lithology, with sediments that range from loose sands to silty sands to sandy silts. This site has also been remediated with dual-phase extraction technology, but the resultant air flow through the vadose zone did not create a corresponding aerobic ground water condition. Wells were identified and sampled under nitrate reducing, iron reducing, and sulfate reducing conditions. Two wells exhibited biodegradation: one under iron reducing and sandy conditions, the other under sulfate reducing and silty sand conditions. Both wells were located in the 30 – 40 foot downgradient area, near the presumed iron reduction/sulfate reduction redox zone interface, and each demonstrated mass degradation around 20%.

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6.0 Conclusions

A preliminary review of Figures 5.6 and 5.7 reveals that a significant proportion of the 26 study wells exhibiting MTBE biodegradation did so under silty sand (13/26), sandy (10/26), or sulfate reducing (11/26) conditions. However, when viewed in comparison to the total number of wells in each category (both with and without biodegradation), wells under aerobic (50%) and iron reducing (46%) conditions appeared to exhibit biodegradation in a significant proportion of the wells, while sulfate reducing conditions were less compelling (about 30%).

Since no clear trends in the data were immediately discernable with respect to MTBE biodegradation, aquifer redox potential, and soil lithology, a more detailed, site-specific data review was performed (Sections 5.4.5 and 6.1) followed by a systematic statistical treatment of the data using both quantitative and qualitative analyses (Sections 5.4 and 6.2).

6.1 Site-Specific Data Analysis

Figure 5.6 shows fairly consistent biodegradation across the redox spectrum, with the notable exception of wells under nitrate reducing conditions. A closer examination of the data on a site-specific basis (Section 5.4.5) revealed that 15 of the 26 wells under nitrate reducing conditions that showed no biodegradation were from a single site with aquifer redox potential unrelated to the site's hydrocarbon plume and significant anthropogenic sources of microbial nutrients and organic substrates. Removing this site from the data yields 5 of 16 wells exhibiting biodegradation (31%), which is similar to the biodegradation frequency found across the sulfate reducing wells.

As already noted (Chapter 5), biodegradation under sulfate reducing conditions occurred in a variety of aquifer lithologies, but was not demonstrated consistently across the data. A more detailed examination of six study sites (Section 5.4.5) showed that biodegradation occurs readily, consistently, and relatively rapidly (up to about 20% of the MTBE mass degraded within 0.5 – 1.5 year timeframe) in transmissive, sandy aquifers under sulfate reducing conditions.

The 6-site data review also showed that a tighter aquifer lithology (silty sand) under sulfate reducing conditions did not support biodegradation. These analyses help clarify the apparent inconsistencies identified in Figures 5.6 and 5.7.

6.2 Statistical Analyses

Preparation and review of the box plots in Section 5.4.2 showed potentially significant differences in the mean/median values of the biodegradation/no biodegradation datasets for several geochemical variables, as well as aquifer redox potential and soil lithology. Table 6.1 below provides the mean/median differences between datasets for those variables where the differences were thought to be potentially significant, along with the box plot figure reference for each variable (potential significance was judged through a simple comparison of the magnitude of the difference to the magnitude of the mean/median results).

Table 6.1: Summary of box plot central tendency differences in MTBE biodegradation/no biodegradation data sets.

Variable	Mean/Median Difference	Box Plot Figure
Conductivity	282	10.6
Carbon Dioxide Concentration	158	10.10
Ferrous Iron Concentration	10.8	10.11
Total Iron Concentration	8.5	10.12
Methane Concentration	175.5	10.13
Sulfate Concentration	7.7	10.16
Redox Potential	2	10.19
Soil Lithology	1	10.20

The redox potential and soil lithology differences in Table 6.1 are somewhat arbitrary, given that numerical values were assigned to the different redox and lithological classifications used (Table 5.2). The box plot results for redox potential showed central tendencies of 4 and 2 for the biodegradation and no biodegradation datasets, respectively, which equates to a tendency centered on iron reducing conditions for the biodegradation dataset, and nitrate reducing conditions for the no biodegradation dataset. This result seems to fundamentally match the preliminary data reduction presented in Figure 5.6, which demonstrated that iron reducing wells exhibited biodegradation in about half of the wells sampled, while nitrate reducing wells exhibited biodegradation only 16% of the time. If MTBE biodegradation occurs more frequently under iron reducing conditions, it should be expected that ferrous and total iron concentrations will vary significantly between the biodegradation and no biodegradation datasets. The central tendency differences in these variables identified in Table 6.1 may also be consistent with this idea.

Similarly, the central tendency of 3 for the biodegradation dataset and 4 for the no biodegradation dataset with respect to soil lithology equates to silty sand vs silt conditions, respectively. Again, this result fundamentally matches those depicted in Figure 5.7, where wells set in silty sand exhibited biodegradation in 46% of the wells sampled, while wells set in silt conditions exhibited no biodegradation at all.

The central tendency differences among sulfate and methane shown in Figure 6.1 don't fit any preconceived pattern. As noted above, the total number of wells under sulfate reducing conditions that exhibited biodegradation comprised a significant portion of the total biodegradation wells, but only about a third of the sulfate reducing wells exhibited biodegradation overall. If, however, methanogenic conditions are more suitable to MTBE biodegradation, a significant central tendency difference between datasets with respect to methane would be expected, but sulfate (as well as nitrate, manganese, and ferrous iron concentrations) should then be fairly uniformly depleted (in other words, there should be no significant variation in central tendencies between the datasets for these variables).

Carbon dioxide is the mineralization end product of many microbiological respiratory processes (Chapter 2), and a significant difference in carbon dioxide concentration among wells is likely demonstrative of increased microbiological activity at a given subsurface location. However, such results are tentative at best, as CO_2 concentration will vary with the atmospheric equilibrium condition it establishes. Likewise, the differential in ground water conductivity central tendencies between datasets is difficult to draw conclusions from, given the overall variability within the datasets.

A more formal, quantitative comparison of central tendencies was undertaken next. The most common statistical treatment used to complete such analyses when the data approximates a normal distribution is the Student's t-test (Snedecor & Cochran, 1989). An analogous treatment which is appropriate for nonparametric data is the Mann-Whitney U test. The U test is significantly less prone to errors introduced by outlying data values, but also less powerful than the t-test (Davis, 1986). Since the distribution of data varied substantially across the datasets, all of the variables were analyzed for central tendencies between datasets using both the t test and Mann-Whitney U test (Tables 5.3 and 5.4).

Both sets of analyses were conducted using a null hypothesis of equality between data sets with respect to central tendency, and a type I error tolerance level (α) of 5% (two-tailed p value of 0.05 or less) for rejection of the null hypothesis. Table 6.2 below summarizes the p values from Tables 5.8 and 5.9 for both tests.

Table 6.2: Summary of p values for Student's t-test and Mann-Whitney U test comparison of central tendencies for bodegradation/no biodegradation data sets

Variable	t-test p	Mann-Whitney p
Temperature	0.96	0.92
Conductivity	0.01	0.003
DO	0.48	0.38
ORP	0.99	0.97
Alkalinity	0.36	0.54
Carbon Dioxide	0.27	0.02
Ferrous Iron	0.45	0.15
Total Iron	0.07	0.46
Methane	0.04	0.44
Sulfate	0.43	0.57
Manganese	0.59	0.81
Redox Potential	0.41	0.56
Lithology	0.11	0.11

From Table 6.2 it is clear that ground water conductivity was the only variable exhibiting a significant difference in central tendencies at the preset α value in both tests, allowing rejection of the null hypothesis for that variable. Of the variables potentially identified in the box plot analyses above, carbon dioxide concentration had a p value below 0.05 in the Mann-Whitney analysis, but exceeded 0.05 in the t-test. Likewise, methane exhibited a p value under 0.05 in the t-test, but not in the U test. Ferrous iron, total iron, sulfate, redox potential, and lithology all failed to show p values in the required range in either test, preventing a rejection of the null hypothesis for these variables.

The final set of analyses conducted were nonparametric treatments of the CSIRA data against the various geochemical ground water variables (Section 5.4.4). Both Spearman's Rho and Kendall's Tau were performed on all variables using a correlation coefficient equal to zero as the null hypothesis, and maintaining the convention of $\alpha = 5\%$

for rejection of the null hypothesis. Table 6.3 summarizes the p values for both analyses (previously presented in Table 5.6).

Table 6.3: Summary of p values from Spearman's Rho and Kendall's Tau analyses of CSIRA data against ground water geochemical variables (summarized from Table 10.9)

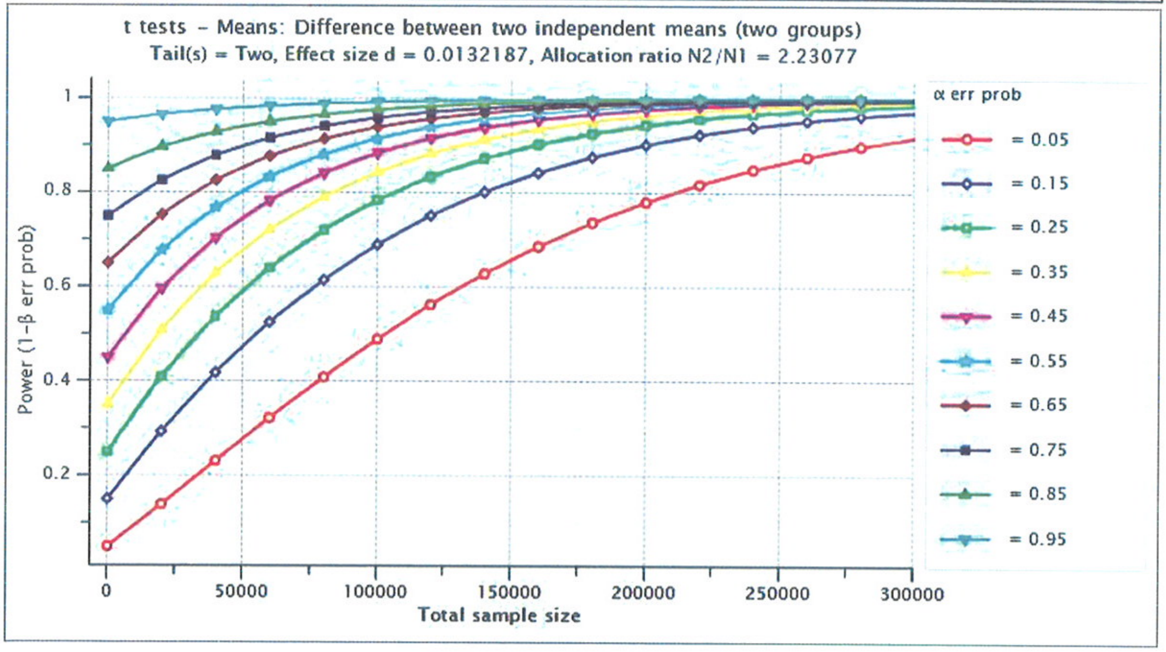
Variable	Spearman's Rho p (2-tailed)	Kendall's Tau p (2-tailed)
Temperature	0.251	0.208
pH	0.009	0.006
Conductivity	0.004	0.006
DO	0.027	0.029
ORP	0.085	0.092
Alkalinity	0.124	0.160
CO_2	0.016	0.010
Ferrous Iron	0.125	0.160
Total Iron	0.882	1.000
Methane	0.510	0.727
Nitrate	0.910	0.853
Sulfate	0.073	0.065
Sulfide	0.653	0.650
Manganese	0.707	0.637
Redox Potential	0.065	0.075
Lithology	0.487	0.492

From Table 6.3, pH, DO and CO_2 concentration all demonstrated p values below 0.05, while ground water conductivity had a p value below 0.05 in the Spearman's Rho analysis only. Of note, the p values for redox potential and ORP were both slightly above the 0.05 threshold in both sets of analyses. However, the r_s and tau statistics did not exceed 0.28 for any of the variables analyzed (Table 5.6), suggesting that any potential correlations present are not strong. These results, combined with the central tendencies analysis performed above, indicate that no clear ground water geochemical trend relating to MTBE biodegradation can be discerned.

When statistically significant ($p \leq 0.05$) results are not found, it is possible that there was no difference in central tendencies and no correlation between datasets, or it is possible that a weak difference or correlation exists, but the number of samples collected was insufficient to identify the trend (a Type II (β) error)(Houser, 2007). Since a finite number of sites were originally available as study candidate sites and, of these, only a subset met the study inclusion criteria outlined in Chapter 2, it was not possible to select the number of study sites or wells prior to commencing the study. For those variables exhibiting "borderline" results approaching significance, however, it is possible to apply power analysis to determine the probability that a β error was committed in the analysis (Houser, 2007).

As an example, a power test result for the variable ground water temperature is provided in Figure 6.1 below. The analysis was conducted using G*Power 3 analysis software (Faul et al, 2007), with α preset at 0.05.

Figure 6.1: Power analysis output for t-test results of ground water temperature biodegradation/no biodegradation datasets



The x-axis of Figure 6.1 projects the required number of samples, while the y-axis projects the probability of a β-type error. The bottom, red curve illustrates the relationship between power and sample size under the actual test analysis conditions (ie, with $\alpha = 0.05$ as a preset test condition). The additional curves above the red one illustrate how projected sample size and β error change when α changes.

Because the sample mean values were close together (17.76 vs 17.71, or a mean difference of 0.05), and the standard deviations of the two sample populations were relatively larger (2.56 and 3.69, respectively), an unrealistically large sample population would be required to bring β error to an acceptable level while maintaining α error at a similarly acceptable level. In fact, from Figure 6.1, if α is maintained at 0.05 (the commonly accepted value used in many scientific studies) β error does not change significantly until the sample population is in the multiple thousands, and does not approach a level of common acceptance (0.80) until the sample population surpasses 200,000.

With such a small difference in sample means and p values from both the t and Mann-Whitney U tests far removed from any consideration for rejection of the null hypothesis, it is most likely that there is simply no difference in sample means between the biodegradation and no biodegradation data sets with respect to ground water temperature. The power test, although an extreme example, does not contradict this finding, but does demonstrate that a more definitive negative result (failure to reject the null hypothesis) could not practically be achieved simply by increasing the sample population in this analysis.

Similar analysis were run for the other ground water geochemistry variables included in the study using G*Power software, with a results summary tabulation in Table 6.4 below. The analyses used in the parametric examination of central tendency (t-test results) were used to determine the power associated with each set of results, since similar power tests for nonparametric results were not available. Table 6.4 includes the sample population means, standard deviations, sample sizes, effects size (a measure of the sensitivity needed based on means differences, SD, and population size), and calculated β error at $\alpha = 0.05$).

Clearly, some subsurface conditions were not adequately represented in the study (methanogenic and sandy clay) simply because a suitable number of candidate wells could not be found during the well selection process (Chapter 2). That MTBE biodegradation does readily occur *in situ* and does so under a variety of subsurface conditions can safely be concluded based on this study. Furthermore, that it degrades more readily in loose soil conditions (sand) can also be concluded, and is predictable based on a fundamental understanding of aquifer geochemistry and microbiology.

Although statistically significant correlations were not found with respect to MTBE biodegradation and aquifer geochemistry, the scatter plots presented in Section 5.3 do show some trends worth noting with respect to pH, dissolved oxygen, and methane (figures 5.34, 5.36, and 5.42, respectively). These plots exhibit data clusters around neutral pH conditions, low (<0.5 mg/l) DO conditions, and high methane concentrations. Neutral pH and anoxic conditions can be expected when observing anaerobic microbial behavior, but increased biodegradation frequency in the presence of increasing methane concentrations under varied aquifer redox and lithological conditions is a new observation.

Table 6.4: Summary of power analyses results conducted on t-test analyses for ground water geochemistry variables in biodegradation/no biodegradation datasets

Variable	n	Biodeg Mean	Biodeg SD	No Biodeg Mean	No Biodeg SD	Mean Difference	Effect Size	Power (1 - β Error Probability)	n Required for 1 - β = 0.80
pH	84	6.6	0.3	6.5	0.6	0.1	0.21	0.14	800
Conductivity	84	1522	1271	991	609	531	0.53	0.61	135
DO	83	0.97	1.08	0.78	1.19	0.19	0.19	0.12	1025
ORP	84	-131.5	115.7	-131.2	107.9	0.3	0.003	0.05	170000
Alkalinity	71	359.7	187.1	319.5	168.9	40.2	0.23	0.15	690
CO_2	72	7143.5	11274.2	4223.6	10348.1	2919.9	0.27	0.19	490
Ferrous Iron	47	10.5	9.0	7.6	13.6	2.9	0.25	0.12	590
Total Iron	61	5043.3	12224.7	1063.2	4879.7	3980.1	0.43	0.35	185
Methane	58	2919.3	3291.0	1506.2	1868.9	1413.1	0.53	0.45	140
Nitrate	83	2.6	13.1	2.2	11.2	0.4	0.03	0.05	34000
Sulfate	84	24.8	43.0	19.4	20.0	5.4	0.16	0.10	1400
Manganese	41	8199.4	7120.0	6859.5	5557.4	1339.9	0.21	0.10	750
Lithology	84	2.6	3.4	1.7	2.1	0.9	0.32	0.27	360
Redox Potential	84	3.6	3.3	1.6	1.5	2.0	0.78	0.9	60

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7.0 Leaking Underground Storage Tank System Analysis

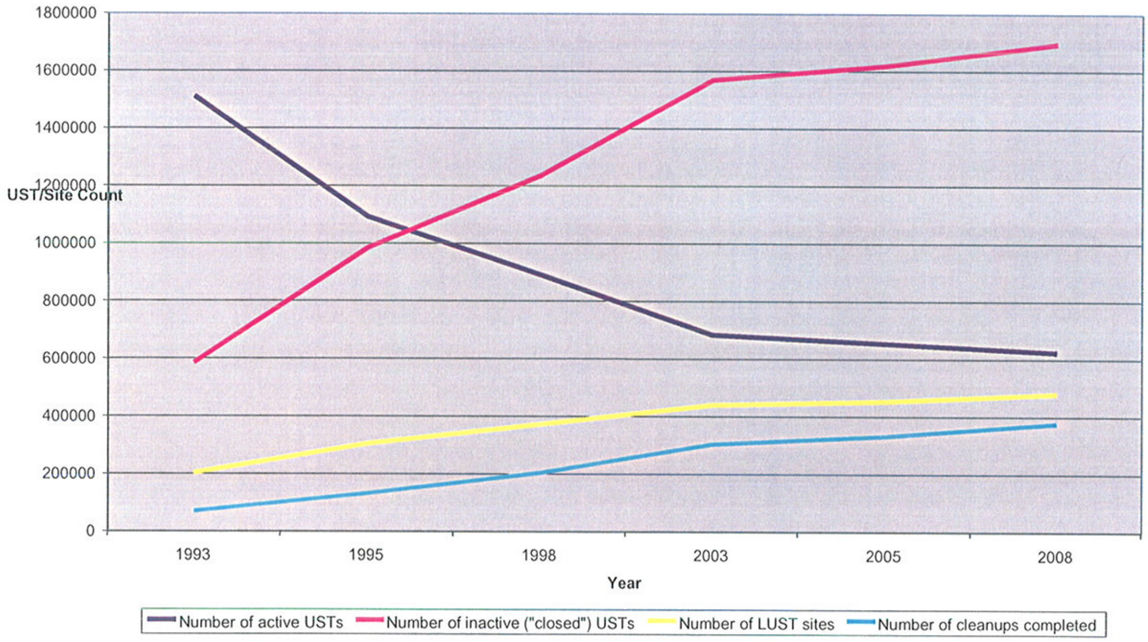
Leaking underground storage tank systems have been a significant source of ground water contamination for decades and, despite both regulatory and industry attempts to eliminate leaks in the 1990s, remain so today. Since leaking underground storage tank (LUST) systems have not been well studied to date with respect to causation, it is difficult to determine why systems leak as frequently as reported. This chapter reviews the available literature on LUST causation (Section 7.1), followed by an overview of typical tank system components and their functions (Section 7.2), and concludes with a comparative analysis of LUST and non-LUST service station sites (Section 7.3).

7.1 LUST Causation Studies

Since the early twentieth century, bulk storage of petroleum products in the United States has typically occurred underground, primarily to reduce fire and explosion hazards. This storage method is certainly safer than above-ground storage. However, an unwelcome consequence is leaking underground storage tanks, which sometimes release petroleum hydrocarbons into surrounding soil and ground water. Earlier in the previous century (World War I through the 1930's) there were simply not enough gas stations nationwide to raise any concern over soil and ground water impacts from leaking USTs. By mid-century, the number of gas stations had increased dramatically, but little attention was paid to leaking tanks at that time.

When environmental issues began to gain prominence in the late 1960s and early 1970s, leaking USTs first began to get noticed. By the 1980s, the problem had become pronounced enough for Congress to create a leak prevention, detection and cleanup program in 1984 as part of the reauthorization of the Resource Conservation and Recovery Act (RCRA) of 1976 (subtitle I) with a LUST trust fund to support it in 1986 (Tiemann, 2006). At the time, the USEPA estimated that there were somewhere around 2.2 million leaking USTs in the United States (Tiemann, 2006). Assuming that old and/or poorly designed USTs were the problem, Congress included a UST upgrade requirement as part of RCRA Subtitle I. The provision required upgrades in tank construction and installation, product delivery spill and overflow protection, corrosion protection for steel tanks, and leak detection methods. Since the required upgrades represented a considerable expenditure per tank, they were phased in over a ten year period between 1988 and 1998.

Figure 7.1: United States UST inventory, 1995 - 2008



In theory, by 1998 no new leaks would occur, and considerable progress would have been made on remediating the existing ones. In reality, however, gasoline storage and dispenser systems are much more complicated than just the tanks, and the tank upgrades did not stop the occurrence of new releases. In fact, the USEPA Office of Underground Storage Tanks has reported that 447,233 new leaks were confirmed nationwide between 1988 and 2004 (USEPA, 2005). The problem was further exacerbated by the emergence of MTBE from leaking tanks as a ground water contaminant nationwide in the late 1990s.

In spite of the continued occurrence of new LUST sites following promulgation of the tank upgrade requirements, the focus remained on LUST site remediation rather than determining causation. Some efforts were made by major oil companies to determine cause (most notably Shell in 2004), but the only major causation studies conducted to date have been for the California Water Resources Control Board (SWRCB), which formed an advisory panel to study the issue in 1999.

The advisory panel employed a three-pronged approach to tackle the problem. First, a review of existing spill documentation records in California was conducted, followed by a commissioned field study performed by a joint team from the University of California, Davis and Tracer Research Corporation. Finally, a compatibility study of UST system components and fuel oxygenates was conducted by a team of USEPA and SWRCB personnel.

The panel efforts with respect to spill records review included the identification of 26 reported spill sites with tank systems that complied with 1998 upgrade requirements and a history of MTBE impact (CSWRCB, 1999a). The report concluded that existing records were not sufficient to separate new releases from existing ones in most cases, and that improper component installation and/or maintenance is the most common cause of leaks, rather than equipment failure or system design flaws.

The field study conducted by the UCAL Davis/TRC team was designed to determine if new and/or upgraded tank systems leak (Young & Golding, 2002). A field study designed to address this issue needed to either examine the tank system interior to find leaks, or search the surrounding environment to detect releases after they occurred. The Young & Golding study was of the latter design, but instead of monitoring for gasoline constituents around the tank systems, a chemical tracer was placed in the tanks to track leaks into the surrounding environment, with the intent of avoiding any confusion over impacts from previously existing releases with those from new ones.

A total of 182 tank systems at 55 facilities were tested in the study. Sixty one percent of the 182 tanks exhibited detectable tracer concentrations in at least one surrounding probe, as did 80% of the facilities. By examining the spatial distribution relative to the tank systems of those probes exhibiting detectable tracer concentrations the authors were able to infer where within the tank systems the releases originated. Using this method they concluded that the most frequently observed leak origin was the area surrounding the fill and/or vent risers on top of the tanks (Young & Golding, 2002). They further concluded that almost all of the releases were in the vapor phase, and that MTBE was generally not the sole gasoline constituent released.

The final prong of the SWRCB study was an oxygenate compatibility study conducted to determine if fuel oxygenates (principally MTBE) were corroding or permeating tank system components (CSWRCB, 1999a). Study data were collected through a literature review and an industry survey. The study concluded that alcohol-based fuel oxygenates (methanol, ethanol, tertiary butyl alcohol, etc.) can be both corrosive (metal constituents) and render the tank system components more permeable. Ether-based fuel oxygenates (including MTBE) were not found to significantly increase either corrosivity or permeability. The study did find, however, that ether-based oxygenates will swell the elastomers used to seal joints and fittings in tank systems, which may contribute to releases.

With the notable exception of the SWRCB studies discussed above, most efforts with respect to new leaks have focused on delineating the extent of soil and ground water impacts, rather than investigating why new releases are still occurring. This is partly due to the need to remediate spills before contaminated ground water can impact a downgradient sensitive receptor, and partly due to the inherent difficulty in pinpointing why new releases happen.

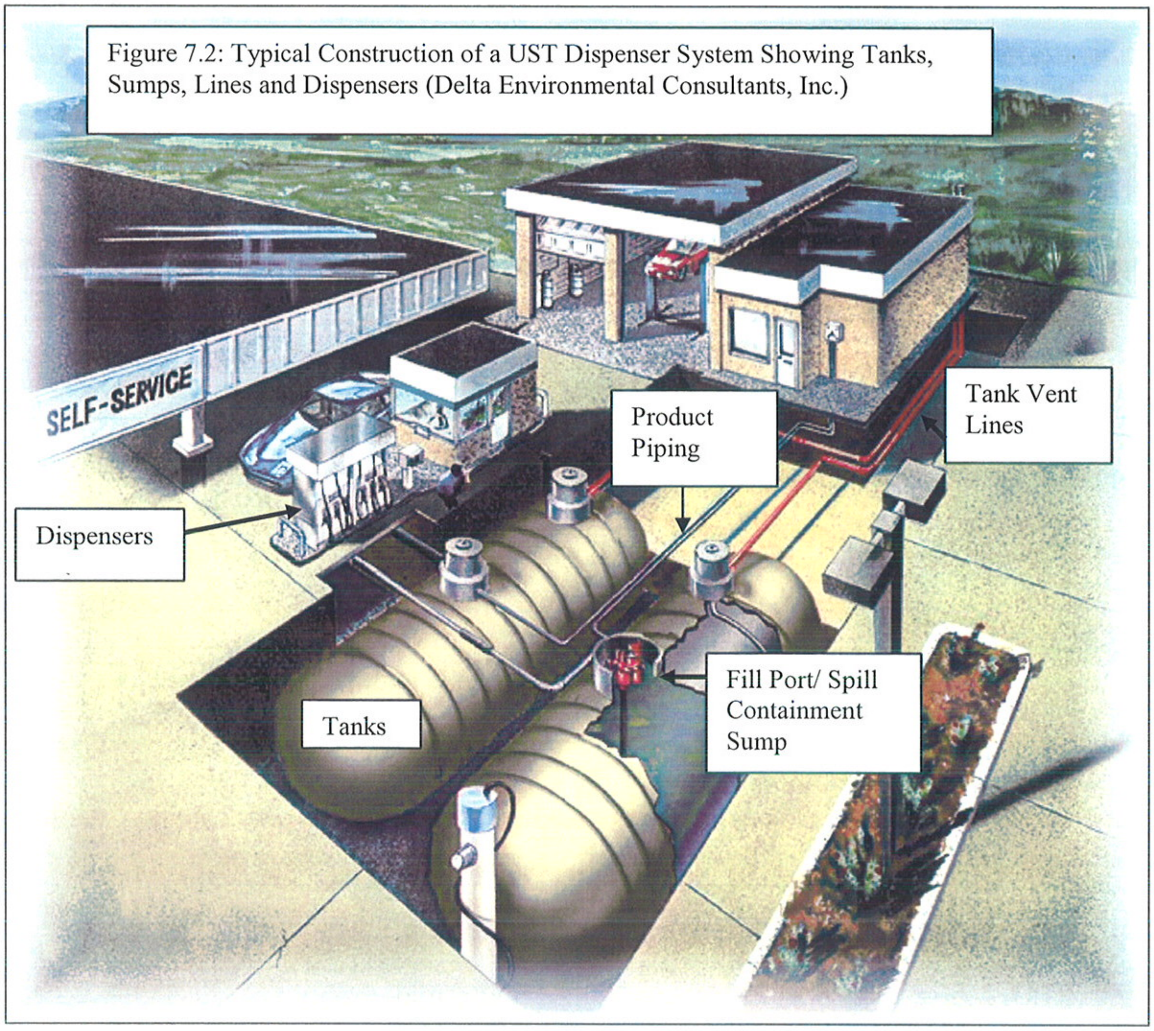
7.2 UST System Overview

Understanding why new spills continue to occur a decade after the tank upgrade initiative was completed in 1998 requires a basic understanding of gasoline dispenser systems. As shown in Figure 7.2 below, the principle working components of a dispenser system include the tank, a turbine sump (where product is lifted out of the tank and transferred to the dispenser), a fill port with an associated "spill bucket" (a leak-tight sump surrounding the fill port to capture overfills), a vapor recovery port with an associated sump, product transfer piping between the tank and the dispenser, and the dispenser itself, also with an associated sump to capture spills and leaks. These system components are described in greater detail below in order to illustrate which components are prone to failure and why.

Tanks

USTs are divided into two broad categories based on their construction materials: steel and fiberglass. Steel tanks were traditionally used (and still are), but are subject to corrosion in the subsurface over time. In the 1980s, fiberglass tanks were introduced as an alternative. These tanks don't corrode, but they also don't stand up to subsurface pressures exerted by freeze-thaw cycles as well as steel tanks. Since both construction materials have drawbacks, various types of "composite" tanks have been designed, including fiberglass-coated steel tanks, and tanks with an interior rubber "bladder" which acts as a secondary tank.

Figure 7.2: Typical Construction of a UST Dispenser System Showing Tanks, Sumps, Lines and Dispensers (Delta Environmental Consultants, Inc.)



Both steel and fiberglass UST construction designs are often improved with an outer "shell" or secondary tank. This design feature is known as double-walled construction. The area in between the tanks, known as the interstitial space, is monitored with sensors that can detect when fluid (product or water) enters the space. The California SWRCB study discussed in Section 7.1 divided the tanks studied into three basic categories: corrosion-resistant single-walled tanks and piping (piping also comes with single and double walls), double-walled tanks and piping, and "hybrid" systems which had some combination of both single and double walls (CSWRCB, 1999a). All three types were examined in the tracer study, but no statistically significant ($p<0.05$ at 95% confidence

Figure 7.3: Typical Construction of a Single-Walled UST System
Source: Delta Environmental Consultants, Inc.

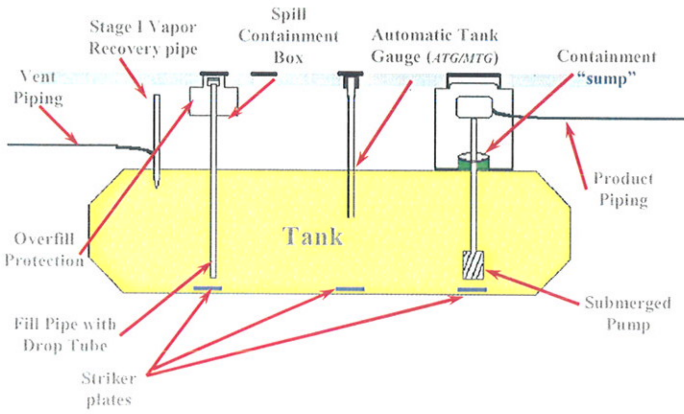
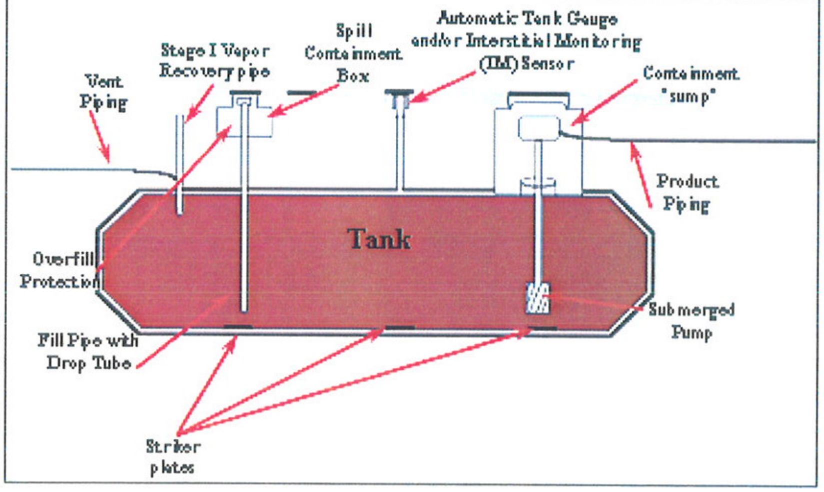


Figure 7.4: Typical Construction of a Double-Walled UST System
Source: Delta Environmental Consultants, Inc.



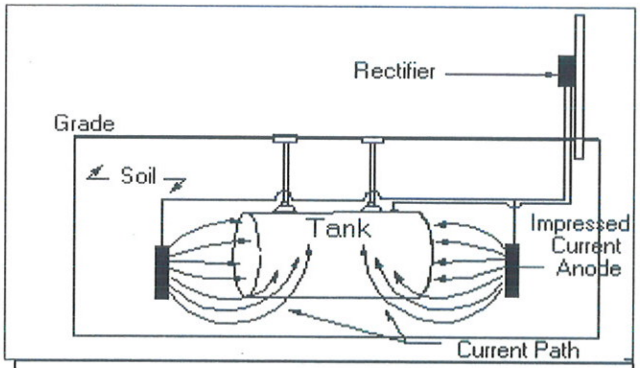


Figure 7.5: Schematic Representation of an Impressed Current Cathodic Protection System
Source: USEPA Office of Underground Storage

interval) difference in leak occurrence was found among the system types (the authors postulated that a very low study population for both the single-walled (n=5) and hybrid (n=10) systems led to this result).

In a further effort to determine the leak frequency of double-walled tanks, the SWRCB team followed their spill records review up with some field visits, which included monitoring the "annular" space (area between the inner and outer shells of a double-walled tank) of six USTs using a lower explosive limit (LEL) meter (SWRCB, 1999a). Three of the 6 USTs had detectable readings of explosive vapors in the annular space, indicating that at least the inner tank had been breached.

Steel USTs also commonly have a design feature known as cathodic protection, which comes in two basic design types: sacrificial anodes and impressed current systems. Sacrificial anodes are steel wires buried in close proximity to the tank. Both the tank and the anode are covered with electrically active coatings of varying magnitude (ie, the anode coating is more electrically active than the tank coating). Because the anode is more electrically active than the tank, it will preferentially corrode, extending the tank's life span. Since the anode is corroded in the process and must be replaced after several years, this method is termed "sacrificial anode".

An impressed current system also has a steel anode buried near the tank, but also has an insulated electrical wire connecting the components. DC current is introduced into the system from a "rectifier", which converts AC current from a power source to DC. An electrical circuit is established between the tank system and the rectifier, which diverts the corrosive current normally encountered in the subsurface away from the tank. This system, like the sacrificial anode, must be maintained over time.

These improvements to UST designs are clearly better than what was commonly used prior to the tank upgrades, and the USEPA qualitatively estimates that they have contributed to a reduction in reported leaks over time (USEPA, 2005). However, proper system installation and maintenance are needed to ensure these systems work.

Turbine Sump

The turbine sump is an enclosed area directly above the tank which usually contains the turbine pump head (the pump itself is submersible and resides near the bottom of the tank) and leak detection equipment. Product passes through the sump as it's transported from the tank to the dispensers. The sump therefore also contains product input and output lines. Both the walls of the sump and the product lines are typically doubled to ensure that no leaks occur between the tank and the sump. In addition, a leak detection sensor is located within the sump to identify releases. Finally, inner and outer covers are fitted to ensure that the sump area is protected and that stormwater runoff does not enter the sump from above.

These systems are greatly improved from older systems used prior to the tank upgrades of the 1990s. However, proper installation and maintenance is required to ensure that the system works and the sump remains leak-tight. Improper or loose connections and/or improper use of leak detection equipment are factors often cited for releases within these sumps. The SWRCB team documented such issues during their 1999 report field audits

(SWRCB, 1999a). Of the 13 turbine sumps inspected by the team, 9 were found to be improperly installed, 6 had water and/or product accumulated within the sump, and 5 had system alarm probes pulled up so they would not trigger an alarm condition when liquid accumulated in the sump.

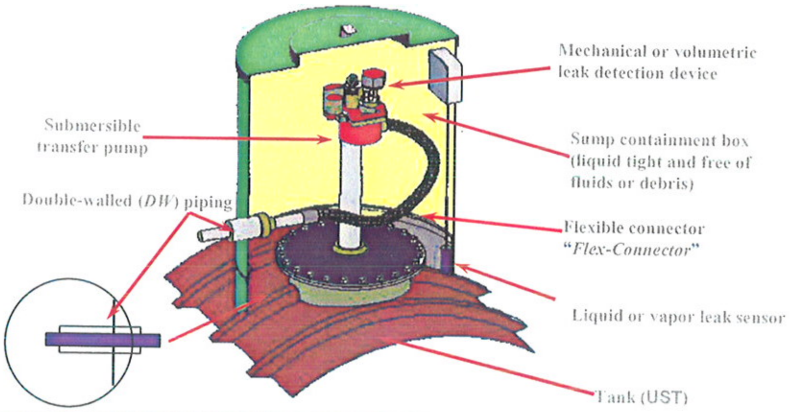


Figure 7.6: Typical Construction of a UST Turbine Sump Containment Box
Source: Delta Environmental Consultants, Inc.

The integrity of the sump containment must also be monitored and maintained over time. Unfortunately, improper installation or maintenance is generally not equipment specific, so an operator that does not maintain the equipment within the sump is also not likely to maintain the sump tightness integrity either. The result is often a persistent product release within the sump that works its way out of the sump into the subsurface.

Fill/Vapor Ports and Spill Buckets

The fill port is a product transfer line which provides access to the tank at ground level, and is used to fill the tank. The vapor port is a line connecting the tank to the Stage II Vapor Recovery Unit, which is attached to the dispenser and returns fugitive vapors released during fueling back into the tank. Both units typically have "spill buckets" attached at ground level to capture overfills or spills. Spill buckets are basically enclosed sumps, sealed off so that spilled product does not leak out to the environment below and storm water does not run in from the paving above.

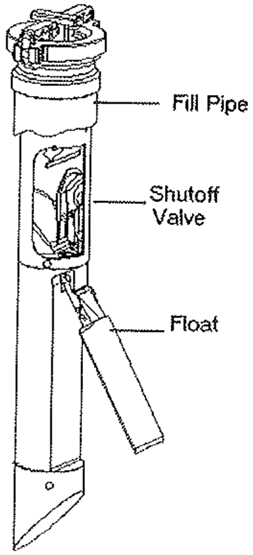


Figure 7.7: Cartoon Depiction of a UST Fill Pipe Equipped With a Shutoff Valve and Level Float
Source: USEPA Office of Underground Storage Tanks

Piping

Piping is used to deliver product from the UST to the dispensers, and to return vapors from the dispensers back to the tank (stage II vapor recovery systems). UST vents may also have significant lengths of piping, if the vents are not in close proximity to the tanks. In addition, multiple USTs are often manifolded together by piping for vapor recovery. As previously noted, like USTs, piping can be single or double walled. Post 1998 upgrade systems are typically double walled, but older single piping is still commonly in service.

In addition to the piping itself, there are a variety of claps and couplings which seal pipe joints to each other, or to other system components. The SWRCB study (SWRCB, 1999a) identified a number of piping components which commonly lead to compromised systems, including hose clamp connectors which did not remain liquid tight, flex-connector gaskets that were not sealed, incompatible epoxy for the piping material, and silicon caulking substituted for epoxy finish. Flex connectors were commonly used in New York State whenever service stations were rebuilt from about 1999 through 2001 or 2002. Many leaks have subsequently been associated with improper installation of this particular component (personal communication with Delta Environmental Consultants, Inc. Health, Safety, Security, and Environment (HSSE) Audit Team personnel). The length of typical piping runs combined with their general inaccessibility once installed make piping leaks particularly difficult to isolate and identify.

Dispenser/Sump

Dispensers are typically the only above-ground feature of a UST system, and come both with and without sumps to contain spills. Product flows up through the dispenser and out to fuel vehicles, while vapors captured during the fueling process are piped back through the dispenser to the tank. The SWRCB concluded in their 1999 report that dispenser systems were the most likely single component of UST systems to cause a release, due to the number of working parts contained within the dispenser (SWRCB, 1999a). Although most upgraded systems have dispenser sumps, leaks still occur as the result of poor installation and/or maintenance.

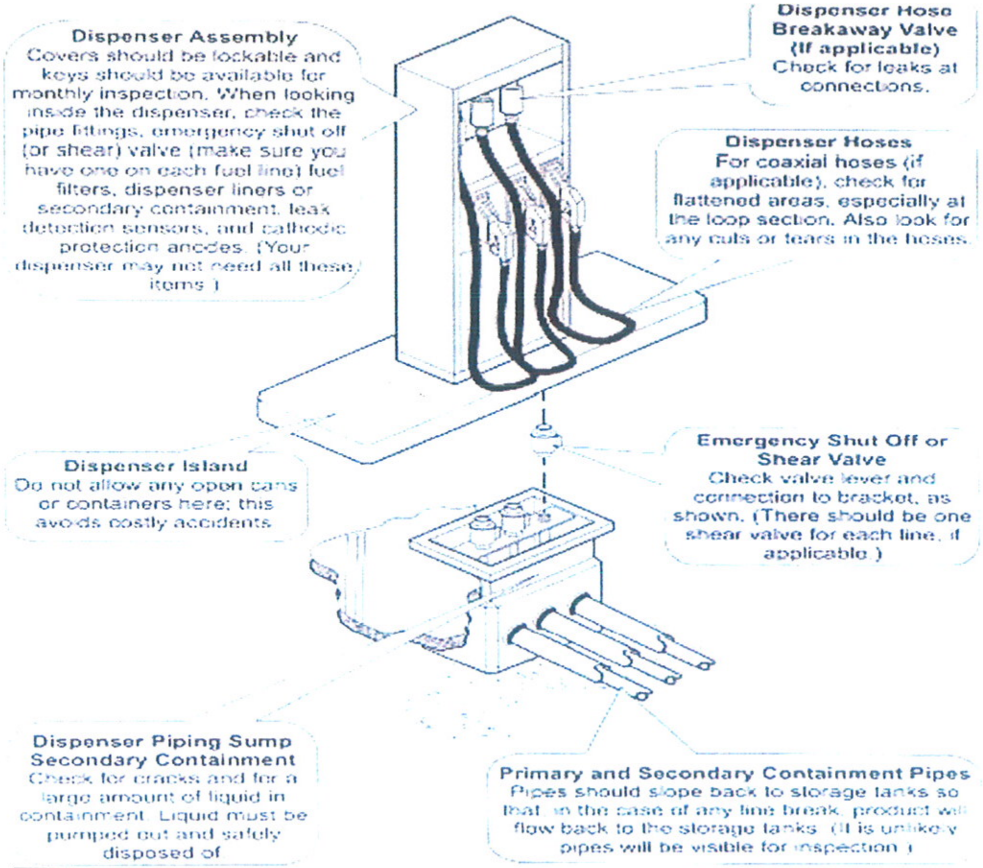


Figure 7.8: Schematic Diagram of a Typical Gasoline Dispenser
Source: Ohio State Department of Commerce

Given the number of leaking tank systems nation wide estimated by the USEPA and the frequency with which new leaks and spills occur there are surprisingly few documented studies that examine the cause of these releases, as opposed to their consequences. The likely reason for this is that tank systems have many working components, most of which can fail over time. Some of these components can be easily accessed for maintenance (equipment located in sumps), while others can't (lines, fittings, etc). Even when equipment is easily accessible, it is often not properly maintained, usually due to a lack of knowledge or interest by site personnel. In addition, system components are often not installed correctly in the first place.

When the MTBE content of gasoline was increased in non-attainment areas in the early 1990s, the consequences of these releases increased with respect to public water supplies significantly (Chapter 3). The SWRCB study, which is the only documented study examining why leaks occur that considered MTBE specifically, did not identify any unique cause that would increase the frequency of leaks with MTBE-formulated gasoline (SWRCB, 1999a).

7.3 Comparative Study of LUST/Leak Not Identified (LNI) Sites

This study looks at system components in both LUST and LNI sites to identify equipment components that may be associated with leaks. To conduct this part of the study, tank system construction records were obtained from a database of retail gasoline station sites in New York and New Jersey owned or supplied by a major oil company. The construction records included details regarding tank installation dates, tank construction types, cathodic protection, tank spill containment, tank overfill protection, and type of piping. A total of 599 retail sites were included in this part of the study.

Methodology:

The 599 sites fell into three basic categories: current LUST sites, closed LUST sites (sites with LUST cases that were remediated to the satisfaction of the New York State Department of Environmental Conservation or New Jersey Department of Environmental Protection, the lead agencies responsible for monitoring LUST sites in their respective states), and sites with no documented leaks. Sites with existing or closed releases were confirmed by cross-referencing site addresses with the NYSDEC spills database, which provides spill numbers, locations, and site status information for all reported spills from 1979 to the present on-line (http://www.dec.ny.gov/cfmx/extapps/derfoil/index.cfm?pageid=2). Sites with no documented spills were assumed not to have had any leaks from their UST systems. It is possible that some number of these sites either have currently or have had in the past undocumented leaks or spills, but proving as much would require an individual soil and ground water investigation at each site (a prospect well beyond the practical scope of this study).

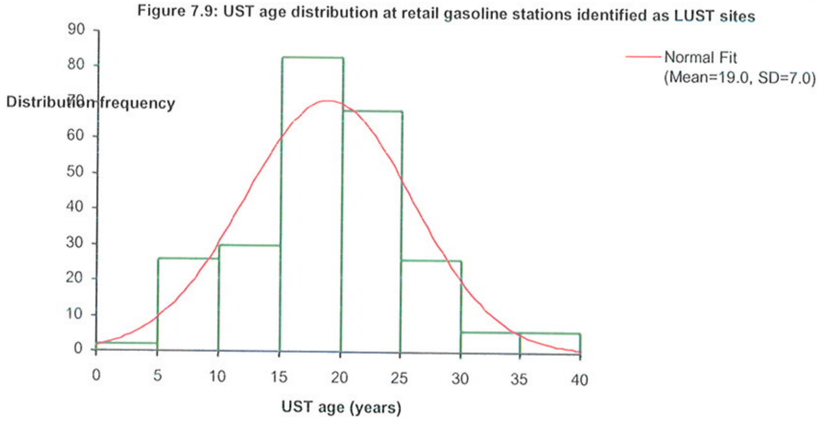
In this study, the 599 retail sites were divided into LUST (310 sites) and Leak-Not-Identified (LNI) (289 sites) sites. LNI sites included those that had been remediated to closure by the appropriate regulatory agency, and those that had never had a release identified.

The LUST and LNI data were then examined with respect to tank age, size, and construction materials, piping system age and construction materials, and the presence or absence of cathodic tank protection. Two statistical methods were used to complete this process. When a comparison of central tendencies was required, the Mann-Whitney U Test for nonparametric comparison of central tendencies was selected for the analysis. When determination of LUST frequency deviation from the expected frequency was appropriate, Pearson's Chi-Squared Analysis (GraphPad Instat, 2005) was used.

The Mann-Whitney U Test is a nonparametric method used to determine if two sample populations are from the same distribution (Conover, 1980). It is commonly applicable in situations similar to the Student's T Test, but is less prone to influence from data outliers. Data compared using this approach were first sorted, then examined for normalcy through a combination of histograms plots (Figures 2.8 and 2.9 are example plots) and performance of the Shapiro-Wilk normalcy test (Analyse-It Software, Ltd., 2007).

Pearson's Chi-Squared (χ^2) Analysis is commonly used to determine if distribution frequencies within a data set deviate from an expected theoretical distribution. It was used when LUST and LNI actual frequencies required comparison to expected distribution frequencies based on specific tank system features.

Figure 7.9: UST age distribution at retail gasoline stations identified as LUST sites



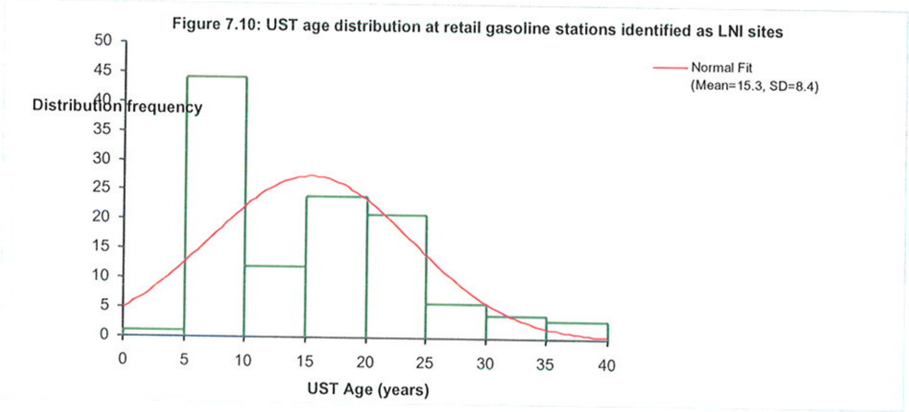


Figure 7.10: UST age distribution at retail gasoline stations identified as LNI sites

Results

The first factor considered was the age of the tanks. If tank age is a significant contributing factor in LUST site occurrences, then a significant difference in collective tank ages should be evident between the LUST and LNI sites. The Mann-Whitney U Test was used to evaluate the datasets.

Table 7.1: Mann-Whitney U Test results for comparison of central tendencies in tank ages for LUST vs LNI sites

Groups	n	Rank sum	Mean rank	U
LUST (yrs)	247	48624.0	196.86	10409.0
LNI (yrs)	115	17079.0	148.51	17996.0
Median difference	3.95		Mann-Whitney's statistic	10409.0
95.0% CI	1.97 to 6.08		2-tailed p	<0.0001
Z statistic	4.10			

The Mann-Whitney test results (Table 7.1) show a median difference in datasets of 3.95 years with $\alpha = 0.05$ and $p < 0.001$. This result demonstrates that older tanks leak more frequently than newer ones, with a difference in median ages (15 years for LNI sites vs 19 for LUST sites) of about four years.

The next factors considered were tank size and construction. The 599 study sites included a total of 1,538 USTs (1,071 at LUST sites and 467 at LNI sites). Tank sizes ranged from 275 gallon capacity at the smallest to 20,000 gallons at the largest, with a median value around 7,000 gallons (Table 7.2). Tank size distribution was nonparametric in both the LUST and LNI datasets, and a Mann-Whitney comparison of central tendencies was therefore conducted to determine if a difference in tank size between datasets could be identified.

The Mann-Whitney results (Table 7.2) found no difference between data set means with $\alpha = 0.05$ and $p = 0.12$. This result indicates that tank size is not a significant factor influencing leak frequency.

Table 7.2: Mann-Whitney U Test results for comparison of central tendencies in tank sizes for LUST vs LNI sites

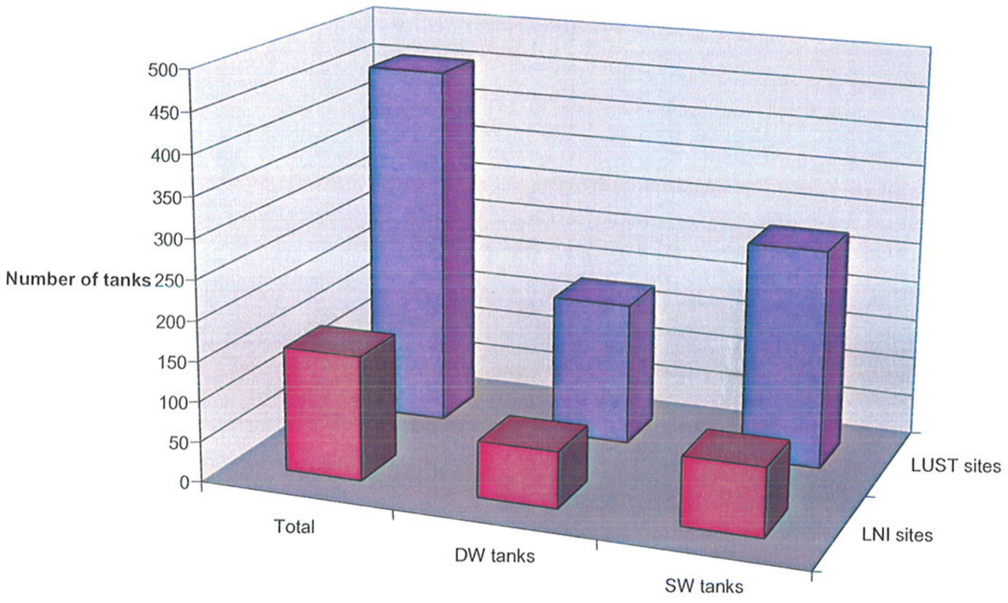
Groups	n	Rank sum	Mean rank	U
LUST Sites	1071	836251.5	780.81	237961.5
LNI Sites	467	347239.5	743.55	262195.5
Median difference	0.0	Mann-Whitney's statistic	237961.5	
95.0% CI	0.0 to 0.0	Z statistic	1.57	
		2-tailed p	0.1158	

Tank construction was examined first by categorizing the tanks by containment apparatus (single-walled, double-walled, or "composite" construction) in keeping with the SWRCB study (CSWRCB, 1999a), then by construction material (steel, fiberglass, or composite). The analysis was conducted by tallying the count in each category for both LUST and LNI sites. This methodology has an obvious disadvantage given that all sites have more than one UST, making it difficult at LUST sites to determine which tank (if any) leaked.

However, since tanks are generally uniform (i.e. uniform tank construction and installation) it is unlikely that multiple construction types co-exist on a single site (excluding historical tanks that were abandoned in place).

Overall, construction data was identified for 608 USTs in the database: 453 associated with LUST sites, 155 with LNI sites (75% LUST, 25% LNI). Figure 7.11 illustrates the breakdown of single-walled versus double-walled tanks for both LUST and LNI sites, without regard for tank construction material.

Figure 7.11: Breakdown of double-walled vs single-walled USTs at LUST and LNI sites



	Total	DW tanks	SW tanks
🟥 LNI sites	155	70	85
🟦 LUST sites	453	179	274

The frequency of LUST vs LNI site tanks remained consistent for both single-walled tanks (76% LUST, 24% LNI) and double-walled tanks (72% LUST, 28% LNI). Three quarters of all the sites with identified tank construction components have recorded leaks or spills, and the frequency remains consistent for both double and single-walled tanks, indicating that either the majority of leaks are not attributable to the tanks, or the additional containment provided by double-walled tanks is ineffectual.

This result appears counterintuitive, and the expected leak frequency of 75% LUST in both data sets was examined against the observed LUST frequencies (72% for double-walled tanks, 76% for single-walled USTs) using Pearson's Chi-Squared Analysis (GraphPad Instat, 2005). Table 7.3 illustrates the expected vs observed frequency distributions, as well as the Chi squared (χ^2) test results.

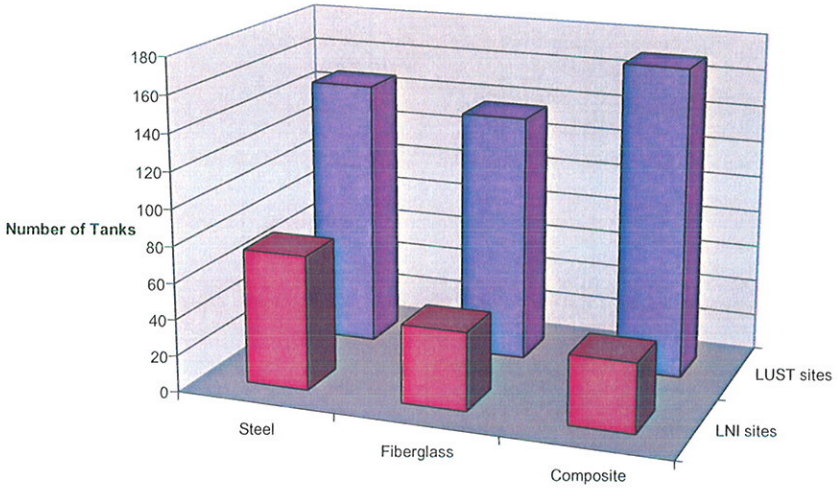
Table 7.3: Observed and expected LUST frequencies for double-walled and single-walled USTs

Tank Construction	Frequency	LUST Sites	LNI Sites	χ^2	p
Double-Walled	Observed	179	70	1.375	0.241
	Expected	187	62		
Single-Walled	Observed	274	85	0.371	0.543
	Expected	269	89		

The calculated p values (0.241 and 0.543 for double-walled and single-walled USTs, respectively) indicate that the observed (4%) difference in leak frequency between the tank types in not significant.

Tank construction materials were examined next. This step was accomplished by sorting the tanks by their three principle construction components (steel, fiberglass, or composite, meaning a combination of steel and fiberglass together, or steel with a resin coating), then determining their distribution frequency at LUST and non-LUST sites (Figure 7.12). The tanks were evenly distributed with respect to construction material (221 steel, 208 composite, and 179 fiberglass). With respect to LUST site association frequency (66.5% of steel tanks were associated with LUST sites, 76.0% of fiberglass tanks, and 81.7% of composite tanks).

Figure 7.12: Analysis of UST construction material frequencies at LUST and LNI indentified sites



	Steel	Fiberglass	Composite
🟥non-LUST sites	74	43	38
🟦LUST sites	147	136	170

To test this contention, the actual (observed) LUST site and non-LUST site frequencies for each tank construction type were compared to the expected frequency distributions using Pearson's Chi-Squared Analysis. Expected frequencies were determined by simply assuming that leak frequency should approximate tank construction frequency (in other words, if 30% of all tanks are steel, then 30% of LUST-site tanks should also be steel, if leak frequency is equal for all construction types). Table 7.4 illustrates the expected vs observed frequency distributions, as well as the Chi squared (χ^2) test results.

Table 7.4: Observed and expected UST construction material frequency distributions

Tank Construction	Frequency	LUST Sites	non-LUST Sites	χ^2	p
Steel	Observed	147	74	7.749	0.005
	Expected	165	56		
Fiberglass	Observed	136	43	0.263	0.608
	Expected	133	46		
Composite	Observed	170	38	5.697	0.017
	Expected	155	53		

Based on the tank construction frequency distribution of all tanks included in the study, as well as the total number of LUST sites identified, it was anticipated that 165 of the 221 sites with steel tank construction would be LUST sites (74.7%). The actual number identified was 147 (66.5%), while the number of steel tank sites identified as LNI sites was greater than anticipated (33.5% vs 25.3%). This result shows that steel tank sites are identified as LUST sites 8.2% less frequently than anticipated based on the frequency of steel tank use. The χ^2 test result ($p = 0.005$) demonstrates that this result is significant, supporting the conclusion that steel tanks leak less frequently than expected.

Fiberglass tank construction leak frequency was more predictable with fiberglass tank sites identified as LUST sites 2.3% more frequently than expected. This result was not viewed as significant (ie, no difference between predicted and observed results was found) based on the χ^2 test result ($p = 0.608$).

One hundred fifty five composite tank LUST sites were anticipated (74.5%), while 170 were actually identified (81.7%). This disparity (7.2%) was deemed significant ($p = 0.017$) by χ^2 analysis. Based on these results, the tank construction analysis shows that steel tanks are somewhat less likely to leak than expected, fiberglass tanks leak with an expected frequency, and composite tanks leak somewhat more frequently than anticipated.

The next tank system components investigated were cathodic protection systems applied to steel tanks. As discussed in Section 7.2 above, cathodic protection comes in two basic varieties: sacrificial anodes and impressed current systems. Sufficient data was not available, however, to differentiate between system types in this study. Instead, the frequency with which cathodic protection systems were identified in association with LUST vs LNI sites was examined (Figure 7.13).

A total of 824 tanks in the study database were identified as having (or not having) cathodic protection (the remainder of the tanks in the study database had no information either way). The breakdown between LUST and LNI sites within these tanks was almost 50/50 (407 LNI, 416 LUST). Sixty one percent (61%) of the LNI tanks had cathodic protection (248 tanks), as did 42% of the LUST site tanks (174 tanks). Presuming that cathodic protection has no effect on leak frequency, it would be expected that the ratio of cathodically-protected tanks to non cathodically-protected tanks at both LUST and LNI sites would match that of the study tank population at large (51.3% cathodically protected). A χ^2 analysis found the differences in cathodic protection frequencies to be significant between LUST and LNI sites ($p=0.0001$, Table 7.5). This result shows that cathodically-protected tanks leak about 10% less frequently than anticipated, based on the frequency of their use.

Figure 7.13: frequency of CP use at LUST and LNI sites

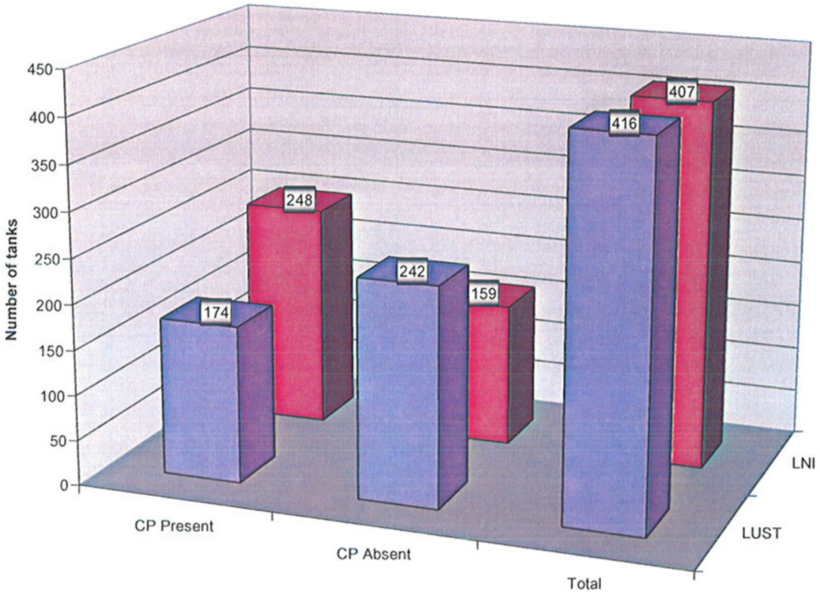


Table 7.5: observed and expected frequency of cathodic protection apparatus at LUST and LNI sites

Frequency	LUST Sites	LNI Sites	χ^2	p
Observed	174	248		
Expected	213	209	14.418	0.0001

The final tank system construction category considered in this study was piping. Like USTs, tank system piping can be single or double walled, constructed of fiberglass, steel, or composite materials, and may or may not have cathodic protection (there was insufficient data on piping cathodic protection systems to perform an analysis on this aspect of piping construction). The piping data set was therefore treated with an analytical approach similar to that used on the UST data.

The first factor considered was the installation date of the tank system piping. Similar to the tanks themselves, if piping age is a significant contributing factor in LUST site occurrences, then a significant difference in collective piping ages should be evident between LUST and LNI sites. Overall, 283 tank piping systems had installation dates identified in the study database (186 LUST site systems, 97 LNI site systems). Both the LUST and LNI datasets were identified as nonparametric using the Shapiro-Wilk normalcy test, and a Mann-Whitney U Test for comparison of central tendencies was therefore conducted (Table 7.6).

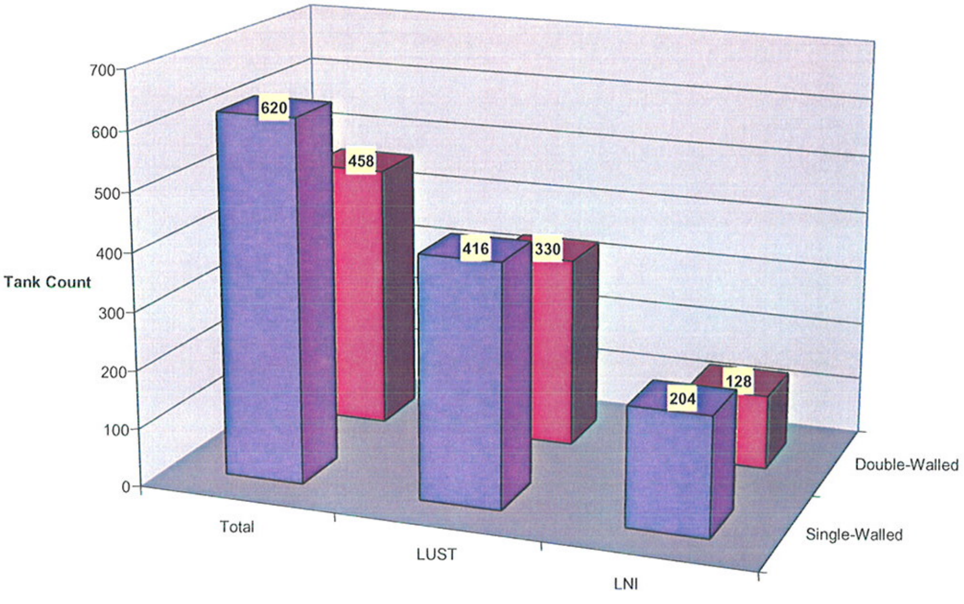
Table 7.6: Mann-Whitney U Test Comparison of Central Tendencies for Tank System Piping Age in LUST and LNI Datasets

	n	Rank sum	Mean rank	U
Elapsed Time Since Piping Installation (yrs): LUST Sites	186	25610.5	137.69	9822.5
Elapsed Time Since Piping Installation (yrs): LNI Sites	97	14575.5	150.26	8219.5
Median difference	-1		Mann-Whitney's statistic	9822.5
95.0% CI	-3	to 0	Z statistic	-1.23
2-tailed p	0.220			

The difference in median piping system ages between datasets was less than one year (12.9 years for LUST sites vs 12.2 for LNI sites), and the Mann-Whitney U Test results showed no significant difference in piping age between data sets (p=0.220).

Again, similar to the tank construction analyses, piping was examined first by containment apparatus (single-walled vs double-walled construction), and then by construction material (steel, fiberglass, or composite). Construction data was identified for 1078 piping systems in the database: 746 associated with LUST sites, 332 with LNI sites (69.2% LUST, 30.8% LNI). Figure 7.14 illustrates the breakdown of single-walled versus double-walled piping systems for both LUST and LNI sites, without regard for piping construction material.

Figure 7.14: LUST Site Frequency in Single- and Double-Walled Tank System Piping



The frequency of LUST vs LNI site piping systems differed somewhat between single-walled tanks (67% LUST, 33% LNI) and double-walled tanks (72% LUST, 28% LNI). Pearson's Chi-Squared Analysis was used to test the significance of this difference against the distribution of LUST and LNI sites in the overall database. Similar to the tank construction analysis, expected frequencies were determined by assuming that leak frequency in the single and double-walled datasets should approximate leak frequency in the combined dataset. Table 7.7 illustrates the expected vs observed frequency distributions, as well as the Chi squared (χ^2) test results.

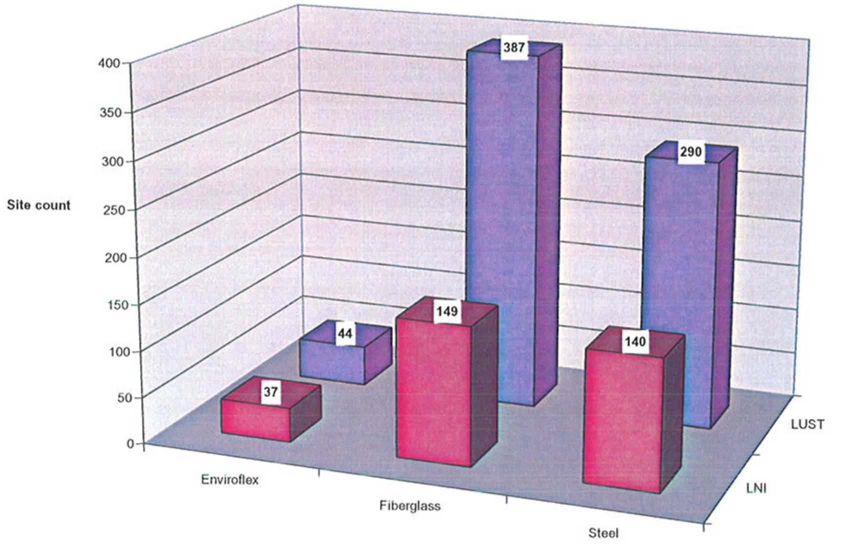
Table 7.7: observed and expected LUST site frequency distributions for single and double-walled piping systems

Piping System Containment	**Frequency**	**LUST Sites**	**LNI Sites**	χ^2	**p**
Single-Walled	Observed	416	204	1.279	0.258
	Expected	429	191		
Double-Walled	Observed	330	128	1.732	0.188
	Expected	317	141		

The high (>0.05) p values calculated in Table 7.7 indicate that the difference in leak frequency between single and double-walled piping systems is not statistically significant, and the additional containment layer of piping afforded by double-walled systems does not reduce the frequency of identified LUST sites.

Piping construction materials were examined next. Like the tank construction analysis, this step was accomplished by sorting the piping systems into their three principle construction components (steel, fiberglass, or enviroflex, which is a flexible plastic tubing introduced in the late 1990s), then determining their distribution frequency at LUST and LNI sites (Figure 7.15). Piping construction data was available for 1047 of the 1078 piping systems identified in the study database, and construction materials were fairly evenly split between steel and fiberglass (430 and 535 systems, respectively), while enviroflex piping was not as prevalent (81 systems).

Figure 7.15: LUST site frequency vs piping system construction materials



Observed LUST site and LNI site frequencies for each piping system construction type were compared to the expected frequency distributions using Pearson's Chi-Squared Analysis. Table 7.8 illustrates the expected vs observed frequency distributions, as well as the Chi squared (χ^2) test results.

Table 7.8: observed and expected UST piping system construction material frequency distributions

Tank Construction	Frequency	LUST Sites	LNI Sites	χ^2	p
Steel	Observed	290	140	0.390	0.532
	Expected	296	134		
Fiberglass	Observed	387	149	2.818	0.093
	Expected	369	167		
Enviroflex	Observed	44	37	8.331	0.004
	Expected	56	25		

The χ^2 test results for the steel and fiberglass piping systems ($p = 0.532$ and $p=0.093$, respectively) show no statistically significant deviation from the expected LUST site frequencies, indicating that the construction materials have no bearing on the leak frequencies. Enviroflex piping, however, was associated with LUST sites 13% less frequently than anticipated, which is a significant result ($p = 0.004$). It can therefore be concluded that piping systems using enviroflex piping leak less frequently than more traditional systems.

7.4 Conclusions

This study included more than a thousand USTs at 599 retail gasoline station sites in NY and NJ, with the intent of determining if system component failures could be identified. UST and piping system age and construction were the variables considered. Tank and piping system ages were determined for those USTs and piping with available data simply by calculating elapsed time from the recorded installation dates.

Mann Whitney U Tests for the comparison of nonparametric central tendencies were then run on the LUST and LNI age datasets to determine if any significant age difference could be identified. The difference in median UST ages for LUST and LNI sites (19 and 15 years, respectively), was statistically significant ($\alpha = 0.05$ and $p < 0.001$), indicating that tanks do leak more frequently as they age. Furthermore, the magnitude of the median difference (4 years) is significant compared with the tank ages (15 – 19 years). This result suggests that a UST's useful life span may be considerably shorter (less than 20 years) than commonly believed.

UST system piping, however, showed less than a year difference between median age values (12.2 vs 12.9 years), and no significant age difference between LUST and LNI datasets was found. This result suggests that the age of the UST is a more significant factor than the age of the associated piping with respect to Leak causation.

Tank and piping system construction was also evaluated in this study. Components were categorized by their construction materials (steel, fiberglass, or composite for tanks, steel, fiberglass or enviroflex for piping). Pearson's Chi-Squared analysis was run on the observed and expected frequencies with which each construction material was associated with LUST and LNI sites. For USTs, this analysis determined that fiberglass tanks leak with the expected frequency, while steel tanks leak 8.2% less frequently, and composite tanks 7.2% more frequently than anticipated. With respect to piping systems, the steel and fiberglass systems both performed as anticipated (leak frequencies were within the expected range), while enviroflex piping leaked 13% less frequently than anticipated. These results suggest that the optimal combination of USTs and piping system component materials to minimize leaks include steel USTs with enviroflex piping.

UST and piping system containment were considered as well in the study. Both tanks and piping were categorized as single- or double-walled, and Pearson's Chi Squared test was run on the piping data. The χ^2 test result for both the tanks and the piping did not identify any significant difference in piping leak frequencies between single- and double-walled piping systems.

Tank size was evaluated by categorizing USTs by capacity and running a Mann Whitney nonparametric analysis on the LUST and LNI site tank capacity datasets. This result showed that tank capacity is not a significant factor with respect to leak frequency (α = 0.05 and p = 0.12).

Finally, the effectiveness of cathodic protection associated with steel tanks was evaluated through a χ^2 analysis of LUST and LNI associated sites, with and without cathodically-protected tanks. The χ^2 analysis showed that tank systems with cathodic protection leak 10% less frequently than anticipated (p=0.0001), suggesting that cathodic protection does reduce leak frequencies.

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Chapter 1

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Appendix I: Historical Volatile Organic Carbon (VOC) Analytical Data Used in Support of the Study Site Selection Process

Appendix I: Historical MTBE concentration trends in subject study site wells used to determine eligibility for the study.

Concentrations are expressed in micrograms per liter (ug/L). NS signifies "not sampled", and ND signifies "not detected". All samples were analyzed using USEPA Method 8260 (Chapter 9).

Location	State	Sample Date	MW-2	MW-4	MW-11		
Bronx	NY	1/3/2003	600000	2330	NS		
		4/25/2003	1090000	19000	NS		
		7/28/2003	660000	18000	NS		
		10/2/2003	785000	18400	NS		
		1/6/2004	1260000	20200	NS		
		4/8/2004	959000	39700	NS		
		7/9/2004	413000	24700	10200		
		2/23/2005	198	50.5	6560		
		6/6/2005	45300	43500	5630		
		8/5/2005	154000	19800	5080		
Location	**State**	**Sample Date**	**MW-1**	**MW-2**	**MW-5**	**MW-7**	**MW-8**
Danbury	CT	11/22/2002	72600	2980	2340	29300	10900
		3/11/2003	121000	NS	1850	45800	11700
		6/25/2003	86000	5130	608	52400	10500
		9/22/2003	64100	9610	450	18700	5920
		12/19/2003	31900	365	46.3	29500	1830
		2/27/2004	25500	976	8.3	36000	4420
		5/3/2004	32800	167	295	16000	2600
		8/30/2004	66300	243	396	5430	320
Location	**State**	**Sample Date**	**MW-1**	**MW-3**	**MW-4**	**MW-5**	**MW-6**
Woodside (Bronx)	NY	10/21/2002	6650	33400	67000	34300	17100
		1/21/2003	24000	35700	66600	19900	16600
		4/23/2003	20900	47200	82400	48800	23300
		8/7/2003	31800	34000	70800	20000	18700
		10/29/2003	402	40800	83100	24600	24100
		1/7/2004	12700	43800	63500	31000	25800
		4/5/2004	7900	33400	55600	15800	21300
		7/19/2004	26200	44800	106000	13900	NS
		10/19/2004	38100	46400	134000	11000	28300
		1/31/2005	35900	42500	90300	9350	31100
		4/21/2005	35600	38900	66100	9050	30800
		6/14/2005	33200	38400	110000	4150	29100
		7/29/2005	6.5	4070	27700	120000	7940

Location	State	Sample Date	MW-9	MW-10			
Woodside (Bronx) (Continued)	NY	10/21/2002	14000	8400			
		1/21/2003	20200	5670			
		4/23/2003	29000	8900			
		8/7/2003	21400	6710			
		10/29/2003	27200	7960			
		1/7/2004	35700	8370			
		4/5/2004	25100	7680			
		7/19/2004	28400	6460			
		10/19/2004	31400	5660			
		1/31/2005	35200	7970			
		4/21/2005	34100	5400			
		6/14/2005	39400	9720			
		7/29/2005	38200	40600			

Location	State	Sample Date	MW-2	MW-4	MW-15	MW-16	MW-17
Totowa	NJ	7/3/2002	61.5	3860	133	14400	5370
		10/11/2002	599	503	168	40000	3090
		1/28/2003			11.5	9240	1060
		4/28/2003	860	297	1530	10600	57.5
		7/10/2003	216	283	899	3240	566
		11/4/2003	107	507	940	10500	283
		2/16/2004	86.7	234	2260	8650	1020

Location	State	Sample Date	MW-6	MW-9	MW-10	MW-12	MW-15
Paramus	NJ	6/9/2004	ND	25.2	NS	14500	35.3
		9/15/2004	NS	NS	NS	NS	NS
		3/31/2003	364	352	1560	2200	197
		3/23/2004	ND	14.6	272	20000	NS
		9/15/2004	239	ND	26.1	33300	78.9
		12/1/2004	12.1	16.2	325	1000	1.6
		3/8/2005	ND	1.9	175	1180	47.6
		6/11/2002	3410	2660	7780	10700	6540
		9/26/2002	3700	4980	34100	22200	211000
		10/14/2002	NS	6640	18100		175000
		12/27/2002	436	342	1630	19100	5220
		6/23/2003	52.5	771	1830	18700	386
		9/29/2003	39.1	102	7620	33800	805
		12/9/2003	99.6	ND	878	64000	184
		6/1/2005	ND	7.5	7890	886	17.6

Location	State	Sample Date	MW-17S				
Paramus (Continued)	NJ	6/9/2004	230				
		9/15/2004	153				
		3/31/2003	NS				
		3/23/2004	1030				
		9/15/2004	NS				
		12/1/2004	90.4				
		3/8/2005	77.7				
		6/11/2002	NS				
		9/26/2002	NS				
		10/14/2002	NS				
		12/27/2002	NS				
		6/23/2003	3930				
		9/29/2003	8350				
		12/9/2003	NS				
		6/1/2005	1400				

Location	State	Sample Date	MW-1	MW-2	MW-4	MW-7	MW-11
New Rochelle	NY	10/22/2002	9300	69300	10600	NS	NS
		1/16/2003	3450	18000	5610	NS	NS
		4/9/2003	3970	25700	5140	NS	NS
		8/5/2003	2380	9120	2800	NS	NS
		10/2/2003	2500	7720	3300	NS	NS
		1/7/2004	3420	4040	2160	NS	NS
		4/9/2004	1140	1690	917	NS	1030
		7/1/2004	441	1870	382	NS	1420
		10/15/2004	318	3260	178	1090	934
		1/28/2005	298	1720	0.38	892	8400
		4/14/2005	338	1450	1	760	7830

Location	State	Sample Date	MW-5	MW-8	MW-9	MW-10	
Westport	CT	3/10/2003	31.8	46.4	NS	3130	
		5/14/2003	8.8	743	4370	7700	
		9/3/2003	8.8	3600	9780	11300	
		11/11/2003	17.4	13800	6750	7870	
		2/24/2004	12.4	786	2510	10500	
		6/1/2004	7.6	1070	2280	5280	

Location	State	Sample Date	MW-2r	MW-3r	MW-4r	MW-9	MW-11r
Edison	NJ	6/26/2002	1030	NS	776	NS	177
		12/30/2002	540	1180	6410	186	2940
		7/25/2003	1040	1230	158	99.1	NS
		12/18/2003	1180	376	168	228	2350

Location	State	Sample Date	TW-1	TW-2	MW-6		
Westhaven	CT	1/14/2003	11100	92400	NS		
		4/15/2003	31900	23300	NS		
		7/15/2003	21600	6510	NS		
		1/12/2004	14500	35900	NS		
		4/16/2004	496000	747	603000		
		8/2/2004	841	NS	550000		

Location	State	Sample Date	MW-2	MW-6	MW-7	MW-10	MW-14
Bridgeport	CT	12/31/2002	NS	NS	348000	1540000	NS
		1/20/2003	NS	NS	222000	735000	NS
		3/24/2003	NS	NS	70500	369000	NS
		6/24/2003	197000	1950000	4200	173000	NS
		9/29/2003	101000	1210000	3500	37800	457000
		12/17/2003	22000	568000	NS	49200	371000
		4/1/2004	15200	271000	NS	8410	55400
		7/28/2004	NS	281000	NS	1400	3950

Location	State	Sample Date	MW-15				
Bridgeport (Continued)	CT	12/31/2002	789000				
		1/20/2003	1210000				
		3/24/2003	1780000				
		6/24/2003	1840000				
		9/29/2003	1880000				
		12/17/2003	946000				
		4/1/2004	174000				
		7/28/2004	568000				

Location	State	Sample Date	TF-1	MW-8	MW-9		
Englewood	NJ	9/18/2002	815	4610	NS		
		12/19/2002	266	3580	1200		
		3/17/2003	1260	3010	529		
		8/19/2003	6000	1390	1770		
		11/7/2003	2700	NS	6760		
		8/19/2004	2240	5160	3330		
		10/28/2004	277	4960	2580		
		1/24/2005	346	2930	1530		
		4/26/2005	1690	2860	2140		
		7/12/2005	3280	1380	3080		

Location	State	Sample Date	MW-14	MW-15	MW-16		
Mapleshade	NJ	8/22/2002	532	95.8	25900		
		11/14/2002	233	4930	21800		
		3/21/2003	1010	320	15600		
		5/28/2003	219	NS	NS		
		9/5/2003	189	634	NS		
		12/5/2003	238	NS	NS		
		2/27/2004	93.4	29.2	NS		

Location	State	Sample Date	MW-3	MW-4	MW-10	MW-11	
Brooklyn	NY	11/7/2002	4170	13.8	NS	NS	
		2/6/2003	6170	6.4	NS	NS	
		5/13/2003	6030	8.7	NS	NS	
		9/10/2003	2360	132	NS	NS	
		12/16/2003	502	7.7	NS	230	
		2/9/2004	566	45.3	6300	332	
		5/19/2004	295	5.6	6820	444	
		8/5/2004	346	106	1740	209	
		11/24/2004	2500	45.3	2930	8.7	
		2/25/2005	2430	3.5	3570	134	
		5/10/2005	1180	28.8	7860	72.4	
		5/19/2005	366	29.2	5360	77.3	

Location	State	Sample Date	MW-1	MW-2	MW-4	MW-7	
North Bergen	NJ	2/26/2003	15900	3170	1480	310	
		10/8/2003	4420	1390	686	506	
		2/11/2004	4830	450	618	322	
		6/14/2004	3990	2700	1340	627	

Location	State	Sample Date	EW-1	MW-4	MW-6		
Elmhurst	NY	12/4/2002	NS	488	253000		
		2/14/2003	NS	298	330000		
		5/30/2003	NS	884	100000		
		8/26/2003	NS	707	111000		
		11/7/2003	NS	572	80900		
		2/12/2004	NS	339	154000		
		5/11/2004	NS	34.9	14100		
		8/30/2004	20800	486	45700		
		11/11/2004	10500	130	55500		
		2/25/2005	8620	358	20000		
		5/11/2005	2240	317	21000		
		5/17/2005	5290	323	24800		

Location	State	Sample Date	MW-5	MW-6	MW-7		
Edison	NJ	8/28/2002	6070	2340	35000		
		11/12/2002	465	272	18200		
		2/4/2003	2590	83.7	2510		
		5/19/2003	1150	21.6	4930		
		9/19/2003	1430	539	27300		
		2/10/2004	1110	14	134		
		8/13/2004	366	565	7280		
		2/9/2005	715	73.2	40.8		
		5/17/2005	200	10	600		
		8/24/2005	247	211	6970		

Location	State	Sample Date	MW-1	MW-6	MW-7		
Manhattan	NY	12/16/2002	47400	23300	NS		
		2/5/2003	6690	3720	NS		
		5/9/2003	9830	28400	NS		
		9/5/2003	149000	54100	NS		
		11/24/2003	174000	45600	NS		
		2/4/2004	117000	38800	NS		
		5/19/2004	58700	32800	2190		
		8/2/2004	36100	31000	20900		
		11/12/2004	38200	23300	7980		
		2/25/2005	8930	16900	990		
		5/18/2005	5660	14700	1200		
		5/20/2005	4410	9810	929		

Location	State	Sample Date	MW-1	MW-2	MW-4	MW-7	MW-8
Maspeth 2107	NY	6/2/2003	NS	2670	0.78	NS	NS
		9/19/2003	NS	1470	ND	NS	NS
		12/22/2003	NS	2340	5.8	6550	NS
		3/17/2004	1410	2430	12900	12200	7200
		6/2/2004	1620	2430	1600	12800	6950
		9/3/2004	1390	1940	2270	12600	7710
		12/10/2004	1430	980	1120	13900	6640
		3/25/2005	1020	625	1200	723	4080
		5/19/2005	1190	368	122	13600	4010
		6/3/2005	1000	640	1300	10400	3850

Location	State	Sample Date	MW-9	MW-10	MW-11		
Maspeth (Continued)	NY	6/2/2003	NS	NS	NS		
		9/19/2003	NS	NS	NS		
		12/22/2003	NS	NS	NS		
		3/17/2004	481	21.2	342		
		6/2/2004	765	15.3	232		
		9/3/2004	1090	18.2	259		
		12/10/2004	928	22.5	244		
		3/25/2005	751	9.7	230		
		5/19/2005	956	6	205		
		6/3/2005	767	8.6	195		

Location	State	Sample Date	MW-1	MW-2	MW-4	MW-5	
Brooklyn (4th Ave)	NY	12/4/2002	554	NS	NS	26300	
		3/26/2003	624	NS	NS	99100	
		5/15/2003	647	NS	NS	49000	
		9/4/2003	309	NS	10.3	25900	
		12/17/2003	114	521	212	16200	
		2/11/2004	156	720	127	15900	
		5/18/2004	70.8	NS	55	7820	
		8/18/2004	206	411	142	11700	
		11/23/2004	166	NS	158	21900	
		2/15/2005	159	77.8	131	22500	
		5/12/2005	305	193	60	39500	
		5/27/2005	248	133	39.4	18200	

Location	State	Sample Date	GMW-2	MW-7	MW-13	GP-25	
Garfield 4115	NJ	11/20/2002	1280	2260	543	14400	
		5/23/2003	1010	1840	220	17600	
		5/4/2004	131	18	6.3	8060	
		11/3/2004	132	ND	6.3	12900	
		5/19/2005	67.8	40.7	7.1	3750	

Location	State	Sample Date	MW-3	MW-4	MW-5	MW-7	MW-8
Manhattan (10th Ave)	NY	10/15/2002	100000	184000	11800	NS	NS
		1/28/2003	NS	101000	7370	NS	NS
		4/4/2003	NS	60700	17900	NS	NS
		7/31/2003	NS	27700	1990	NS	NS
		10/16/2003	NS	16400	3280	4750	18600
		1/13/2004	NS	5840	2870	5930	9290
		4/1/2004	NS	2040	4620	3910	1260
		7/29/2004	NS	805	3150	1460	2480
		10/26/2004	114000	244	926	1570	744

Location	State	Sample Date	MW-9	MW-10			
Manhattan (10th Ave) - Cont'd	NY	10/15/2002	NS	NS			
		1/28/2003	NS	NS			
		4/4/2003	NS	NS			
		7/31/2003	NS	NS			
		10/16/2003	6880	6360			
		1/13/2004	1880	745			
		4/1/2004	24000	1010			
		7/29/2004	4160	506			
		10/26/2004	699	80.1			

Location	State	Sample Date	MW-1	MW-2	MW-3	MW-5	MW-7
Brooklyn 4th Ave (2)	NY	10/16/2002	NS	451	NS	26.4	NS
		1/8/2003	NS	3330	NS	205	NS
		4/8/2003	33500	24000	1130	21200	15100
		7/29/2003	NS	22700	NS	6730	8820
		10/10/2003	NS	34300	NS	5430	7720
		1/6/2004	NS	21800	NS	1980	7940
		4/9/2004	NS	34200	NS	1540	13400
		7/6/2004	NS	22900	NS	596	10600
		10/25/2004	NS	21300	NS	172	4490

Location	State	Sample Date	MW-8	MW-9	MW-10	MW-12	
Brooklyn 4th Ave (2) - Cont'd	NY	10/16/2002	NS	NS	NS	NS	
		1/8/2003	NS	NS	NS	NS	
		4/8/2003	NS	NS	NS	NS	
		7/29/2003	NS	NS	NS	NS	
		10/10/2003	NS	NS	NS	NS	
		1/6/2004	36600	11800	2800	2640	
		4/9/2004	76200	NS	4820	1360	
		7/6/2004	63800	NS	18500	666	
		10/25/2004	17000	NS	47900	99	

Location	State	Sample Date	CMW-si	CMW-3f			
Deer Park	NY	9/26/2002	258	NS			
		3/21/2003	321	4.5			
		8/20/2003	56.8	5.8			
		12/8/2003	136	8850			
		2/16/2004	4.3	12.4			
		4/20/2004	107	0.67			
		7/22/2004	236	3.9			
		11/19/2004	350	29.6			

Location	State	Sample Date	MW-1	MW-4A	MW-10	MW-11	
Staten Island	NY	12/19/2002	7290	107000	5470	12900	
		3/31/2003	3940	18500	1350	3550	
		6/11/2003	2630	162000	302	491	
		9/16/2003	7710	NS	604	76.1	
		12/22/2003	2940	101000	130	5.7	
		3/9/2004	2030	35300	111	140	
		6/10/2004	5820	58500	111	ND	
		9/16/2004	6590	11100	239	ND	
		12/15/2004	2390	588	328	ND	
		3/22/2005	3760	9370	478	25.7	
		6/15/2005	3570	9870	323	10.6	
		6/21/2005	7490	7720	247	8.1	

Location	State	Sample Date	MW-3	MW-4			
Parsippany	NJ	7/12/2002	16.7	25.2			
		9/27/2002	17.9	41.4			
		12/23/2002	573	128			
		3/13/2003	262	122			
		6/9/2003	8.6	5.8			
		8/14/2003	93.9	2.2			
		12/16/2003	46000	19500			
		1/30/2004	30300	880			

Location	State	Sample Date	MW-16	MW-20			
Norwalk	CT	9/26/2002	209	77			
		12/9/2002	10500	4020			
		3/13/2003	8970	185			
		6/16/2003	17400	6820			
		12/29/2003	7610	567			
		4/19/2004	4740	152			

Location	State	Sample Date	MW-2	MW-5	MW-7		
Hoboken	NJ	10/10/2002	241	958	1600		
		4/11/2003	733	415	781		
		12/9/2003	5930	368	1140		
		4/8/2004	2970	224	780		

Location	State	Sample Date	MW-2	MW-5	MW-4		
Bridgeport (Boston Ave)	CT	11/21/2002	3.9	2.8	77900		
		3/5/2003	4.6	0.66	100000		
		5/30/2003	2.6	3.7	224000		
		8/28/2003	3.2	1.4	96000		
		11/13/2003	4	93.8	60200		
		3/4/2004	2.5	3.3	49100		
		5/18/2004	1.6	4.4	51900		

Location	State	Sample Date	MW-6	MW-8	MW-9	MW-12	MW-13
Delran	NJ	10/21/2002	139000	93600	NS	NS	NS
		2/12/2003	31800	148000	NS	NS	NS
		5/14/2003	18400	187000	NS	NS	NS
		9/23/2003	185000	160000	NS	NS	NS
		12/4/2003	471000	169000	528000	5080	80800
		2/12/2004	180000	124000	643000	1330	51200
		2/12/2004	180000	124000	643000	1330	51200
		5/24/2004	394000	89700	598000	29900	90400
		8/24/2004	90900	35900	729000	40500	35900
		11/10/2004	187000	41300	543000	87300	117000

Location	State	Sample Date	MW-2	TW-3	MW-5	MW-6	
East Haven	CT	11/14/2002	626	52000	ND	490	
		3/3/2003	1130	8570	NS	NS	
		5/21/2003	4270	56600	176	2290	
		8/21/2003	217	12700	107	552	
		11/10/2003	72	2530	1140	313	
		2/23/2004	149	6990	3.1	6	

Location	State	Sample Date	MW-1	MW-2	MW-3	MW-4	
Brooklyn 4th Ave (3)	NY	3/17/2004	64600	11200	12800	9050	
		5/28/2004	192000	81700	14700	27900	
		8/16/2004	164000	105000	14700	18900	
		11/23/2004	174000	23500	7320	33600	
		2/14/2005	204000	15200	10500	26000	
		5/31/2005	172000	7700	9640	55400	

Location	State	Sample Date	TW-2	TW-3	TW-4	MW-5	MW-6
Milford	CT	9/27/2002	NS	NS	NS	ND	3.8
		12/23/2002	7230	NS	NS	1.4	13.5
		3/27/2003	123000	NS	NS	4.5	ND
		6/26/2003	163000	NS	NS	7.5	9.8
		9/25/2003	495000	376000	246000	78.8	169
		12/30/2003	213000	278000	219000	565	1.8
		3/18/2004	179000	189000	184000	675	552
		6/25/2004	108000	151000	135000	208	1050

Location	State	Sample Date	MW-9				
Milford (Continued)	CT	9/27/2002	1.4				
		12/23/2002	47				
		3/27/2003	38.9				
		6/26/2003	52.7				
		9/25/2003	118				
		12/30/2003	103				
		3/18/2004	3300				
		6/25/2004	2920				

Location	State	Sample Date	MW-1	MW-2	MW-3		
Maplewood	NJ	10/23/2002	3280	674	17900		
		4/3/2003	10.5	1090	24100		
		11/12/2003	480	62.9	4770		
		5/19/2004	3	3.1	1610		

Standard Appendix II: Micropurging Standard Operating Procedure

STANDARD OPERATING PROCEDURE.

Low-Flow Purging Procedure For Groundwater Sampling.

0.0 Scope and Application:

This SOP is applicable to the collection of representative groundwater samples under ambient aquifer flow conditions from groundwater monitoring wells (this method is also known as low-stress or minimal drawdown sampling).

Samples may be collected from various depths using various techniques, and may involve sampling on private and government property.

Samples may be analyzed for a range of constituents, including (but not limited to) volatile organic compounds, semi-volatile organics, pesticides, PCBs, metals, and other inorganics.

This method does not apply to the collection of light or dense non-aqueous phase liquids (LNAPLs or DNAPLs).

1.0 Method Summary:

Objective: To extract groundwater samples from the subsurface that are representative of formation-quality water in a manner that minimizes stress to the groundwater system to the greatest extent practical.

- Method objectives are achieved by aligning the pump intake with the well screen interval and operating the pump at a flow rate less than the natural recharge rate of the well. This approach will minimize well drawdown and isolate the water from the well screen interval from the overlying stagnant well water.
- Monitoring wells are generally placed to determine the extent of any contamination plume and a sampling event could involve some or all of the monitoring wells.
- NOTE: For BP work and according to BP unit pricing technical specifications, sampling should occur no less than 24 hours following the development of a monitoring well. Some regulatory agencies or clients may have different requirements regarding the time frame following monitoring well installation in which groundwater samples should be collected.

The general procedure is to:

- Set up traffic control barricades around wells to be sampled (required if wells are located in an area traversed by vehicles). Follow client specific Traffic control guidelines if available.
- Open designated wells (see Field Work Request).
- Gauge the depth of water in each open well.
- Set pump intake at the midpoint of the well screen interval. Affix PVC tubing from the pump to the upflow cell inlet port. Attach PVC effluent line to the cell effluent port. Use a ground water probe to measure variation in field parameters in the upflow cell. Purge well until field parameters stabilize.
- Prepare sample containers and labels while well is purging.
- Collect samples from the effluent flow line (see Field Work Request and SOP on "Sample Preparation, Preservation and Hold-Times"), apply labels, and place in appropriate container (e.g., iced cooler).
- Dispose of purge water according to local practice (drum, pour on asphalt, or treat).
- Secure all wells caps/covers.
- Clean up/decon equipment.
- Depart site.

2.0 Health and Safety:

The Delta Environmental Consultants' Site Health and Safety Plan, Petroleum Class III, is specific to each remediation site. The SHSP may change depending upon the project phase or site activities. Ensure you have the latest version prior to arriving at the site.

The SHSP, which will be available on site during sampling, defines utility, site, and chemical hazards, emergency contacts, emergency routes and personal protective equipment.

For low-flow purging groundwater sampling, the PPE level is generally level D (hard hats, safety shoes, safety glasses/face shields, gloves, protective clothing). Consult the SHSP for additional site-specific requirements.

Contact lenses should not be worn.

Work zones will be defined by the use of yellow tape, barricades, or cones.

All field team members must have completed the OSHA 40-hour HAZWOPER and/or the annual refresher course, CPR and First Aid training.

Each Field team member will be provided with a complete safety kit/duffel bag. Refer to Attachment 1 for contents and verify prior to arrival on the sampling site.

Monitor the work-area breathing zones using a PID/OVA once per hour and record readings in the fieldwork documentation. Monitoring is intended to detect potential explosive vapors. Consult the SHSP for appropriate actions depending upon the readings obtained.

3.0 Interferences:

There are three primary interferences or potential problems with low-flow purging groundwater sampling from wells: cross contamination, sample exposure to atmospheric conditions, and/or improper sample collection.

- Cross contamination is eliminated or minimized by use of dedicated sampling equipment, by not sampling under environmental conditions that may impart contamination (e.g., while service station refueling activities are ongoing), or using equipment decontamination procedures before each sampling event.
- Contamination is likely to result from: improper storage/transport of equipment, exposure of equipment/sample containers to on-site sources such as vehicle exhaust, uncovered ground, dirty gloves/clothing; improper cleaning of equipment/sample collection devices, and exposure of sample containers to airborne dust or volatiles.
- Sample exposure to atmospheric conditions will most likely occur through the lack of (or improper use of) the upflow cell. Continuous flow of purged water through the cell (and across the probe membrane) should eliminate the potential for atmospheric exposure.
- Improper sample collection should be eliminated or minimized by following this SOP.

4.0 Equipment and Supplies:

Equipment required for low-flow purging groundwater sample collection includes:

- Personal Protective Equipment.
- Site traffic control barricades.
- Wellhead opening tool.
- Keys for locking well caps.
- Pump (centrifugal, pneumatic, or bladder pumps are recommended: peristaltic pumps can be used as long as the influent port is set at the midpoint of the well screen interval, but their use is not recommended).
- Upflow cell (any cylindrical unit with inlet and outlet ports).
- Nitrile gloves.
- Polyethylene tubing (can also use Teflon tubing or Teflon-lined tubing). Polyethylene tubing requires the use of equipment blanks to ensure that the tubing does not off-gas into the samples.
- Oil/Water interface probe.
- Water level indicator (if non-aqueous phase liquids not present at site).
- Groundwater probe or combination of probes capable of monitoring the following groundwater parameters real time: pH, Temperature, Conductivity, and Dissolved Oxygen. Monitoring for

turbidity is desired, but not required. All probes need to fit together within the upflow cell, such that the probe membranes are completely submerged during purging and sampling activities.

- 5-gallon pails – at least one with volume gradations.
- Sample container(s), labels.
- Alconox, or equivalent decontamination solution.
- Deionized water.
- Waterproof, permanent markers.
- Drum dolly (if purge water is to be drummed for subsequent removal/disposal).
- Traffic control/HSSE equipment

5.0 Procedure:

(1) Preparation and Surveillance:

The site project manager is responsible for all site activities including supervision of team members, data recording and records management.

All site personnel (names, affiliations, arrival/departure times), activities, procedures and observations must be recorded in the site-specific Field Notebook or Fieldwork documentation for each sampling day. Refer to the SOP on "Completing Fieldwork Documentation – Notebooks and Forms" for instructions on how to fill out the field records.

Upon arrival, check in with the site manager/owner, provide identification and discuss purpose of the work.

Discuss use of equipment, barricading, placement of work vehicles, length of anticipated stay and additional resources that may be used (e.g. drilling equipment/personnel, utility impacts, traffic control).

Discuss with the site representative any waste disposal and/or drum storage and agree to storage location and future disposal.

If work involves access to private property, meet with the property owner and discuss/resolve any issues. (Generally, prior access/permission from the private property owners has been granted and documented in the project file.)

The field project manager or designated site safety officer must review the SHSP with all members of the field crew, including visitors or contractors, **PRIOR** to beginning any fieldwork. This review must occur with each additional crewmember upon their arrival.

Each Delta employee must sign and date the SHSP Review acknowledgement form to testify the SHSP was reviewed.

Each visitor or subcontractor must similarly date and sign the SHSP, review the acknowledgement form, and indicate his or her company affiliation.

Conduct a tailgate meeting to review project expectations, assignments, workflow, sample requirements and any specific site information or issues that may impact activities. Major exceptions to the work plan, delays or any uncertainties should be communicated/agreed with the project manager prior to proceeding.

NO smoking or consumption of food or drink is allowed within the work zone. Appropriate hygiene (e.g. hand washing) should be followed prior to any personal activities.

After review of the SHSP, complete an initial tour of the site and include any contractors.

  - If possible, include the site manager/ owner or representative with site knowledge in the initial tour.
  - Discuss any potential serious site traffic disruption with the site owner/ representative and plan to minimize any impacts.

- Set up traffic control.
  - Follow Client specific traffic control guidelines if available.

- In a public right of way/street, a permit is generally required and is usually obtained by the drilling contractor. An independent contractor generally provides off-site traffic control.
- For on-site activities, appropriate cones/yellow tape and/or barricades are required. Follow client specific guidelines if available.
- Only the area actively being worked should be barricaded/controlled. Move the control area as work progresses.

Calibrate instruments such as the Photo Ionization or Flame Ionization detectors (PID, FID) at the beginning and end of field activities. See the SOP on "Equipment Calibration and Maintenance" for calibration procedures.

The site project manager is responsible for all site activities including supervision of team members, data recording and records management.

All site personnel (names, affiliations, arrival/departure times), activities, procedures and observations must be recorded in the site-specific fieldwork documentation each sampling day. Refer to the SOP on "Fieldwork Documentation - Notebooks and Forms" for instructions on how to fill out the field records.

(2) Opening/Gauging Wells.

ALL wells must be gauged even if only selected wells will be sampled.

Locate the well to be sampled and install appropriate barricade(s).

- Follow client specific requirements. At a minimum use 4 orange cones/yellow warning tape for each location. Generally this barricade will be moved from well to well.

Open the well to be sampled. Don Nitrile gloves (fresh pair for each well).

- Make a note of the condition of the well head (missing parts, repairs needed).
- Do not allow any surface materials to fall into the open well, including surface waters or waters contained in the catch basin at the top of the well. Carefully remove any water from the catch basin prior to removing the well cap.

Use the Oil/Water Interface probe to measure:

- Depth to product, DTP (free product if present).
- Depth to water, DTW.
- Depth to well bottom, DTB.

Refer to the Oil/Water Interface probe instruction manual for operating instructions.

- All measurements must be taken from the north side at the top of the well PVC casing, or from a surveying mark on the casing.
- Record measurements for each well on the Groundwater Sample Field Data Sheet to the nearest 1/100-foot and record the time of measurement for each well.
- Decontaminate the Oil/Water interface probe by rinsing in an Alconox solution after each well measurement, followed by tap water and deionized water rinses).
- Don fresh gloves for each well.

(3) Well Purging: low-flow method.

(Repeat for each well to be sampled).

For each well, don a fresh pair of nitrile gloves. Place plastic sheeting on the ground to provide a clean work surface.

Decontaminate the pump and upflow cell before and after each use by rinsing in an Alconox solution, followed by tap water and deionized water rinses). Decontaminate the ground water probe using tap and deionized water rinses.

Use dedicated tubing for each well sampled, replacing all tubing (this may include both air and water lines, depending on the type of pump used) between wells.

Attach a line to the pump discharge line, then SLOWLY lower the pump and the discharge line into the well to minimize disturbance. Secure the pump at the mid point of the well screen interval in the middle of the well column.

Attach opposite end of the pump discharge line to the upflow cell influent port. Attach another line to the upflow cell effluent port – place the opposite end of this line into a volume-graded 5 gallon bucket.

Lower interface probe down well to monitor drawdown during purging.

If a variable-rate pump is used, start on the lowest setting, then gradually increase flow until a measurable effect is identified on the interface probe. Operate the pump at the highest flow rate that can be attained without measurable drawdown in the well (this will typically be somewhere between 100 ml/min and 500 ml/min). Up to 1L/min is acceptable, but no higher.

If a variable rate pump is not available, or the interface probe, pump and tubing cannot all fit down the well, purge at a steady rate without measuring drawdown, but do not exceed 500 ml/min flow rate.

Once the purge rate has been determined, collect probe readings of temperature (°C), dissolved oxygen (mg/L), pH, and conductivity (µS/cm). Turbidity and oxidation reduction potential are optional, but should be collected if possible.

Continue to monitor and record readings every five minutes until DO, pH, and conductivity are stable.

Stable is defined as follows:

DO: ± 10%
pH: ± 0.1 units
Conductivity: ± 3%

If an extremely low producing well does not recover sufficiently to stabilize readings, it should not be sampled.

If a well does not recharge enough to take a sample the same day as purging, then the well should not be sampled.

Note the color of water, type of sediment, sheen and or odor as appropriate on the Sheet.

(4) Well Sampling: (Repeat for each purged well).

Consult the SOP on "Sample Preparation, Preservation and Holding Times" for required sample volumes, preservation and container types.

Consult the SOP on "Sample Handing and Shipping" for instructions on preparing and shipping samples/coolers to the laboratory for analyses.

The correct sample containers should have been supplied by the laboratory or obtained from stock prior to mobilization to the site.

- CAUTION: sample containers may contain preservative acids or bases.
- Wear appropriate PPE and handle carefully.
- Consult the SHSP and material safety data sheets for actions to be taken in the event of acid or base contact.

For each well don a fresh pair of nitrile gloves.

Sampling should be done starting with the well of least contamination and progressing to the most contaminated well, based on historical data.

- Once DO, pH and conductivity have stabilized, begin collecting samples from the upflow cell effluent line.
- Samples that require field filtration or analysis, or are sensitive to atmospheric exposure, should be collected first.
- Containers should be filled to the top with no air bubble present when capped.
  - Invert capped container to observe any bubbles.
  - Hold the sample containers over the previously collected purge containers while filling to catch any spillage.

Wipe sample container clean and apply correct label.

Note time of sample collection and well designation on the Groundwater Sample Field Data Sheet.

Consult the SOP on "Sample Preparation, Preservation and Hold-Times" for required sample volumes, preservation and container types.

Consult the SOP on "Sample Handling and Shipping" for details on protecting and shipping samples.

Consult the SOP on "Completing Chain of Custody Form" for instructions on correctly completing the COC.

Remove all equipment from the well (decontaminate the pump, upflow cell, interface and groundwater monitoring probes).

Remove all barricades and secure well caps/covers.

- Note any repairs/replacements needed on the Groundwater Sample Field Data Sheet and inform the Project Manager/Requestor upon return to the office.

(5) Purge Water Treatment: (If required).

Refer to the SOP on "Treating Well Purge Water" (to be developed) for procedures on treatment of all collected well purge water.

After collecting a sample of the treated purge water return the treated water back to the work site, but within the plume boundaries.

- Since the treated purge water is contaminant- free, disposal on the surface is acceptable.
- Do not dispose of in a well, unless state regulations allow for in-well disposal.

(6) Cleanup:

Refer to the SOP on "Equipment Decontamination" for details on decontamination of field equipment.

Seek permission from the site manager/owner for waste disposal on site.

Place disposable field equipment in the site dumpster. This could include cord, gloves, disposable clothing, field sampling reagent kits, and cartons.

Notify site manager/owner that the fieldwork is complete.

Gather and remove all equipment and barricades. Record departure time(s) in field documentation.

(7) Special Situations:

(a) LIQUID PHASE HYDROCARBONS

If unexpected LPH (liquid phase hydrocarbons, or "free product") is observed at a

site/well, the Project Manager/Requestor must be notified **immediately**, in person, if on site, or by
phone. Determine if a sample of the LPH is required. If so, proceed as follows:

- Measure and record depth to product (DTP) and depth to water (DTW). These values will allow the requestor to determine the volume of LPH within the well.
- Follow the procedure given above for opening/gauging wells but -
- DO NOT PURGE THE WELL
- After gauging the well, don appropriate PPE and insert stringed bailer down well so that the end of the bailer is just below the water surface.
- Slowly retrieve bailer and empty LPH contents (using slow emptying device) into a glass container.
- Visually inspect the LPH, recording its appearance (color, clarity, etc.) in the Fieldwork documentation.
- Prepare samples for shipment. Refer to the SOP on Product Shipment for required volumes, potential restrictions and shipping instructions.
- If requested by the project manager or client, repeat the bailing procedure until LPH is no longer present in bailer. Try to minimize the amount of water bailed from the well.
- Empty bailer contents into a 5-gallon non-metallic high-density polyethylene Type 1 safety can for use with flammable liquids.
- Speak with station manager/owner or attendant to determine where the 5-gallon non-metallic high-density polyethylene Type-

1 safety-can should be safely stored until pick-up can be arranged.

(b) SAMPLING OVER NON-CONSECUTIVE DAYS.

Generally, groundwater sampling should be completed within a 24-hour period of purging, and the procedures outlined above can be applied.

In the event sampling cannot be completed within the 24-hour period or occurs on non- consecutive days, then all wells MUST be gauged
on the same day, even if some wells have been previously gauged during the first sample visit.

- This is because an accurate evaluation of plume/water flow direction and level/gradient can only be made with data collected within a reasonable period of time, < 24 hours.
- Samples collected and then held overnight prior to shipment must be kept on ice or at 4 degrees C.
- DO NOT SAMPLE USING LOW FLOW TECHNIQUE IF NAPL IS IDENTIFIED IN THE WELL

(8) Quality Assurance Samples:

In addition to the collection of samples, additional samples are generally collected for quality assurance.

Refer to the Field Work Request for additional specific sample requirements such as sample duplicates, or samples for laboratory Matrix Spike/Matrix Spike Duplicate, (MS/MSD), field sample blanks, equipment/ rinseate blanks, trip blanks analyses, etc.

Randomly select one well for a Sample Duplicate.

- Ideally this well should contain analytes of interest and not be ND, "non-detect".
- Generally the Sample Duplicate is analyzed for BTEX so collect an additional 3x40 ml vials.
- Duplicate samples should simply be labeled as "Duplicate" on the label and on the COC.
- Alternatively duplicate samples can be labeled with a well number one higher than the highest well number currently at the site (e.g., if the highest number well at a site is MW-7, then the duplicate sample should be named "MW-8"). This method however may cause subsequent confusion if the site well count is increased in the future.
  - Information on the duplicate samples/ corresponding wells should be recorded on the Fieldwork documentation.
  - For duplicate samples do not record a collection time on the COC.

For MS/MSD samples, the well selected should historically be "low" or "ND" in the analyte of interest.

- Prior well history data should be consulted prior to selecting the MS/MSD well.
- Collect the required sample volumes, ideally from the same bailer volume as the actual sample from the selected well.
- The sample labels should contain the well designation with indication on the COC as "MS/MSD".
- In general, one MS/MSD sample should be submitted for each batch of samples.

Collect a sample of treated purge water (processed through a truck effluent system for example) if purge water is being treated prior to on-site disposal and an analysis is required. See following section on treating purge water.

- Label purge water sample as Purge Water or Truck Effluent and submit for analysis, generally BTEX.

The cooler supplied by the laboratory should contain a labeled Trip blank and Temperature blank. Both must be returned with the site samples in the same cooler.

NOTE: In the event sampling is conducted over a two-day period, the COC must reflect both sampling dates and which samples were obtained on the respective days. Samples from the first day must be placed on ice and held at 4 +/- 2 degrees C in a cooler.

6.0 Personnel Qualifications:

All field team members must have completed the OSHA 40-hour HAZWOPER and or the annual refresher course, CPR and First Aid training.

Additional client specific training may be required. For example "BP Traffic Control" or "BP Passport"

All field team members engaged in Ground Water sampling must have on file a completed Demonstration of Capability for this SOP.

7.0 Definitions:

BTEX: Benzene, Toluene, Ethyl benzene and Xylenes.
COC: Chain Of Custody.
CPR: Cardiopulmonary Resuscitation.
DTB: Depth to bottom (of well).

DTP: Depth to free product, (if present in well).
DTW: Depth to water (in well).
HAZWOPER: OSHA's Hazardous Waste Operations and Emergency Response Standard.
LPH: Liquid Phase Hydrocarbons.
MS/MSD: Matrix Spike/Matrix Spike Duplicate (quality control field sample).
MW: Monitoring Well.
OSHA: Occupational Safety and Health Administration.
ppb: parts per billion.
PPE: Personal Protective Equipment.
ppm: parts per million.
SOP: Standard Operating Procedure.

8.0 Quality Control and Assurance:

Since Groundwater samples can contain very low level of regulated materials (e.g. down to ppb levels), a very high potential exists for cross contamination between the various sampling points. Groundwater gradients can result in widely varying contaminant levels within closely spaced wells (e.g. from Non-detect or zero to ppm levels).

To the greatest extent possible dedicated collection equipment must be used for each sampling point.

- This includes using fresh gloves and dedicated bailers, clean plastic sheeting for protection from the ground.
- Sample from the least contaminated to the most contaminated wells or if unknown, sample in the water table down gradient direction. Consult the site contour map for details.
- Any equipment that is not dedicated must be decontaminated between each use. Consult the SOP on "Equipment Decontamination" for correct procedures.

All data, observations and calculations must be recorded on the fieldwork documentation.

- Consult the SOP on "Completing Fieldwork Documentation – Notebooks and Forms" for details.
- Data may also be entered into Personal Digital Assistants (PDA) or a laptop computer. There must be adequate traceability between any Field Notebook and complimentary data sheets.

All instruments must be operated in accordance with manufacturer's operating instructions, unless documented otherwise.

- Equipment should be calibrated prior to the sampling event and calibrations must be documented in the Instrument logbooks. This includes instruments such as the Photo Ionization or Flame Ionization detectors (PID, FID). Consult the SOP on "Equipment Calibration and Maintenance" for calibration procedures.

Upon completion of fieldwork, the site project manager should return the field documentation, the site SHSP, and the signed

Review Acknowledgement form to the correct project folder.

A copy of the field notes, Field Work request, completed COC, and any other field documents must be given to the project requestor or placed in his/her mailbox.

Provide a copy of any repair work needed, issues to be resolved, and indicate any uncompleted fieldwork.

9.0 References:

Low Stress (Low Flow) Purging and Sampling, USEPA Region II, Final Ground Water Sampling SOP, 3/16/98
Puls & Barcelona, EPA/540/S-95/504, April 1996
ASTM D-6771, *Standard Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground Water Quality Investigations* (2002)
SHSP: Site Health & Safety Plan (Delta).
SOP on Sample Handling and Shipping.
SOP on Completing Chain of Custody Form.
SOP on Sample Preparation, Preservation and Hold-Times.
SOP on Purge Water Treatment.
SOP on Equipment Decontamination.
SOP on Equipment Calibration and Maintenance.
SOP on Completing Fieldwork Documentation – Notebooks, Forms and PDA's.

10.0 Attachments:

Attachment 1: Health and Safety Gear Bag Checklist".

ATTACHMENT 1

Name: ____________________

Health and Safety Gear Bag Checklist

(Please check box next to equipment present in H&S bag)

- ☐ Hardhat
- ☐ Eye Protection (Safety Glasses/Goggles)
- ☐ Ear Plugs
- ☐ Safety Vest (plus one extra)
- ☐ Fire Extinguisher (fully charged?)
- ☐ Tyvek Suit
- ☐ Respirator (fit-tested within last year?)
    - ○ with spare set of Organic Vapor Cartridges and Dust Filters
- ☐ Nitrile Gloves
- ☐ First Aid Kit
    - ○ Prepared First Aid Kit
    - ○ Eye Wash
    - ○ Exposure Protection Kit
    - ○ Antibiotic Ointment
    - ○ Aspirin
    - ○ Extra Band-Aid's
    - ○ Antiseptic and Disinfectant (Isopropyl Alcohol)
    - ○ CPR Mouth Barrier
- ☐ Leather Gloves
- ☐ Knee Pads
- ☐ Rain Gear (jacket, pants, and boots)
- ☐ Caution Tape
- ☐ Sun block and Insect Repellant
- ☐ Lock-Out/Tag-Out Kit

I hereby certify that my Health and Safety Bag contains all of the above gear:

Signature: ____________________
Date: ____________________

Unit Manager Signature: ____________________
Date: ____________________

Appendix III: Geochemical and SCIRA Data Collected from Study Wells

Appendix IV: Underground Storage Tank (UST) Study Data

City	State	Tank Content	Tank Size	Installed Date	Tank Construction	Cathodic Protection	Tank Spill Containment	Tank Overfill Protection	Pipe Construction	Piping Installed
Union	NJ	BLUE	10000	1/1/1987	DW FG	NTD	YES	TIGHT FILL	DW FG	1/1/1987
Avenel	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
Cliffwood	NJ	BLUE	10000	1/1/1987	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1990
Paterson	NJ	BLUE	10000	7/1/1998	DW FG	NR	YES	YES	W ENVIROFLE	7/1/1998
Bloomfield	NJ	BLUE	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Bayonne	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Edison	NJ	BLUE	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Vauxhall	NJ	BLUE	10000	1/1/1988	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1988
Irvington	NJ	BLUE	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Middletown	NJ	BLUE	10000	1/1/1987	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1987
Rockaway	NJ	BLUE	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
North Plainfield	NJ	BLUE	10000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Cherry Hill	NJ	BLUE	10000	11/1/1996	DW FG	NR	YES	YES	W ENVIROFLE	11/1/1996
Bayville	NJ	BLUE	10000	1/1/1996	DW FG	NR	YES	YES	DW FG	1/1/1996
Asbury Park	NJ	BLUE	10000	1/1/1996	DW FG	NR	YES	YES	DW FG	1/1/1996
Glassboro	NJ	BLUE	10000	1/1/1990	STIP3	SA	YES	EMCO /TF	FG	1/1/1990
Toms River	NJ	BLUE	10000	1/1/1991	DW FG	NR	YES	EMCO FILL	DW FG	1/1/1991
Jersey City	NJ	BLUE	10000	1/1/1990	DW FG	NTD	YES	EMCO /TF	FG	1/1/1990
Trenton	NJ	BLUE	10000	1/1/1987	STIP3	SA	YES	EMCO /TF	FG	1/1/1987
Bordentown	NJ	BLUE	10000	1/1/1901	STIP3	NTD	YES	EMCO /TF	FG	1/1/1901
Bordentown	NJ	BLUE	10000	1/1/1901	STIP3	NTD	YES	EMCO /TF	FG	1/1/1901
Burlington	NJ	BLUE	10000	1/1/1990	STIP3	NTD	YES	EMCO /TF	FG	1/1/1990
Trenton	NJ	BLUE	10000	1/1/1983	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1993
Clarksburg	NJ	BLUE	10000	1/1/1989	STIP3	NTD	YES	EMCO FILL	FG	1/1/1989
Clarksburg	NJ	BLUE	10000	1/1/1989	STIP3	NTD	YES	EMCO FILL	FG	1/1/1989
Clarksburg	NJ	BLUE	10000	1/1/1989	STIP3	NTD	YES	EMCO FILL	FG	1/1/1989
Union	NJ	GOLD	12000	1/1/1987	DW FG	NTD	YES	TIGHT FILL	DW FG	1/1/1987
Union	NJ	SILVER	10000	1/1/1987	DW FG	NTD	YES	TIGHT FILL	DW FG	1/1/1987
Union	NJ	BLUE	10000	1/1/1987	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1987
North Brunswick	NJ	BLUE	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Jersey City	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
Totowa	NJ	BLUE	10000	1/1/1983	STIP3	SAC ANODE	YES	EMCO FILL	STEEL	1/1/1983
Budd Lake	NJ	BLUE	10000	1/1/1992	DW FG	NR	YES	EMCO /TF	DW FG	1/1/1992

City	State	Tank Content	Tank Size	Installed Date	Tank Construction	Cathodic Protection	Tank Spill Containment	Tank Overfill Protection	Pipe Construction	Piping Installed
Lodi	NJ	BLUE	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
S. Brunswick	NJ	BLUE	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1984
Union	NJ	BLUE	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1982
Edison	NJ	BLUE	10000	1/1/1983	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1983
North Bergen	NJ	BLUE	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Fort Lee	NJ	BLUE	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Metuchen	NJ	BLUE	10000	1/1/1989	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Edison	NJ	BLUE	10000	8/1/1995	DW FG	NTD	YES	EMCO FILL	W ENVIROFLE	8/1/1995
Clifton	NJ	BLUE	10000	1/1/1993	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1993
Kearny	NJ	BLUE	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Tenafly	NJ	BLUE	10000	1/1/1989	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1989
Linden	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
Mountainside	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
Elizabeth	NJ	BLUE	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1993
North Bergen	NJ	BLUE	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Hackensack	NJ	BLUE	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1982
Englewood	NJ	BLUE	10000	1/1/1983	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1983
Totowa	NJ	BLUE	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Somerset	NJ	BLUE	10000	1/1/1989	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1989
Little Ferry	NJ	BLUE	10000	1/1/1990	STIP3	NTD	YES	EMCO /TF	FG	1/1/1990
Iselin	NJ	BLUE	10000	1/1/1987	STIP3	NTD	YES	TIGHT FILL	STEEL	1/1/1987
Marlton	NJ	BLUE	10000	1/1/1983	STIP3	SA	YES	HEATON/AUD/	FG	1/1/1991
Marlton	NJ	BLUE	10000	1/1/1983	STIP3	SA	YES	HEATON/AUD/	FG	1/1/1991
Bridgewater	NJ	BLUE	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
Parsippany	NJ	BLUE	10000	1/1/1990	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1990
Lawnside	NJ	BLUE	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1991
Lawnside	NJ	BLUE	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1991
Turnersville	NJ	BLUE	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Turnersville	NJ	BLUE	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Mt. Ephraim	NJ	BLUE	10000	1/1/1986	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Mt. Ephraim	NJ	BLUE	10000	1/1/1986	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Bernardsville	NJ	BLUE	10000	1/1/1989	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Linden	NJ	BLUE	10000	1/1/1983	STIP3	NTD	YES	EMCO FILL	DW FG	1/1/1993

City	State	Tank Content	Tank Size	Installed Date	Tank Construction	Cathodic Protection	Tank Spill Containment	Tank Overfill Protection	Pipe Construction	Piping Installed
Westfield	NJ	BLUE	10000	1/1/1991	DW FCS	NTD	YES	EMCO /TF	DW FG	1/1/1991
Englewood	NJ	BLUE	10000	1/1/1995	DW FG	NTD	YES	EMCO /TF	W ENVIROFLE	1/1/1995
Elizabeth	NJ	BLUE	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Whippany	NJ	BLUE	10000	1/1/1994	DW FCS	NR	YES	EMCO /TF	DW FG	1/1/1994
Wallington	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1988
Aberdeen	NJ	BLUE	10000	1/1/1989	STIP3	SA	YES	EMCO /TF	FG	1/1/1989
Lincroft	NJ	BLUE	10000	1/1/1988	STIP3	SA	YES	EMCO /TF	FG	1/1/1988
Hillside	NJ	BLUE	10000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Newfoundland	NJ	BLUE	10000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991
Pompton Lakes	NJ	BLUE	10000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991
Lake Hopatcong	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1988
Parsippany	NJ	BLUE	10000	1/1/1989	STIP3	NTD	YES	EMCO /TF	FG	1/1/1989
Delran	NJ	BLUE	10000	1/1/1970	B/P/A Steel	IC	YES	EMCO /TF	STEEL	1/1/1985
East Brunswick	NJ	BLUE	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Spring Lake	NJ	BLUE	10000	1/1/1981	B/P/A Steel	SA	YES	EMCO /TF	W ENVIROFLE	1/1/1981
Freehold	NJ	BLUE	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1985
Maple Shade	NJ	BLUE	10000	7/1/1996	DW FG	NR	YES	YES	W ENVIROFLE	7/1/1996
Brooklawn	NJ	BLUE	10000	11/1/1996	DW FG	NR	YES	YES	W ENVIROFLE	11/1/1996
Cherry Hill	NJ	BLUE	10000	1/1/1997	DW FG	NR	YES	YES	DW FG	1/1/1997
Hillsborough	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
Lakewood	NJ	BLUE	10000	1/1/1991	DW FG	NR	YES	EMCO FILL	DW FG	1/1/1991
Piscataway	NJ	BLUE	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Hoboken	NJ	BLUE	10000	1/1/1992	DW FG	NTD	YES	EMCO FILL	DW FG	1/1/1992
Delanco	NJ	BLUE	10000	1/1/1987	STIP3	SA	YES	EMCO FILL	FG	1/1/1987
Delanco	NJ	BLUE	10000	1/1/1987	STIP3	SA	YES	EMCO FILL	FG	1/1/1987
Hamilton Square	NJ	BLUE	10000	1/1/1990	DW FCS	NR	YES	EMCO /TF	DW FG	1/1/1990
Cranbury	NJ	BLUE	12000	1/1/1994	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1994
Williamstown	NJ	BLUE	12000	1/1/1993	DW FG	NR	YES	EMCO /TF	DW FG	1/1/1993
Maple Shade	NJ	BLUE	12000	1/1/1971	B/P/A Steel	IC	YES	EMCO /TF	STEEL	1/1/1986
Maple Shade	NJ	BLUE	12000	1/1/1971	B/P/A Steel	IC	YES	EMCO FILL	STEEL	1/1/1984
West Collingswood	NJ	BLUE	12000	1/1/1971	B/P/A Steel	IC	YES	EMCO /TF	STEEL	1/1/1984
Rutherford	NJ	BLUE	6000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Hasbrouch Heights	NJ	BLUE	6000	1/1/1968	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1985

City	State	Tank Content	Tank Size	Installed Date	Tank Construction	Cathodic Protection	Tank Spill Containment	Tank Overfill Protection	Pipe Construction	Piping Installed
Teaneck	NJ	BLUE	6000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Jersey City	NJ	BLUE	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Iselin	NJ	BLUE	8000	1/1/1977	FG	NTD	YES	EMCO /TF	STEEL	1/1/1977
West Long Branch	NJ	BLUE	8000	1/1/1984	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Paramus	NJ	BLUE	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Newark	NJ	BLUE	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Lodi	NJ	BLUE	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
South River	NJ	BLUE	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Morris Plains	NJ	BLUE	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Sayreville	NJ	BLUE	8000	1/1/1984	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Emerson	NJ	BLUE	8000	1/1/1977	B/P/A Steel	NTD	YES	EMCO /TF	DW FG	1/1/1993
Paramus	NJ	BLUE	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Carteret	NJ	BLUE	8000	1/1/1984	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1984
Iselin	NJ	BLUE	8000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Elizabeth	NJ	BLUE	8000	1/1/1979	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1979
Cliffside Park	NJ	BLUE	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
River Edge	NJ	BLUE	8000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1980
Secaucus	NJ	BLUE	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
North Brunswick	NJ	BLUE	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
Greenbrook	NJ	BLUE	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Woodbridge	NJ	BLUE	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Perth Amboy	NJ	BLUE	8000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991
Rahway	NJ	BLUE	8000	1/1/1984	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1984
Wachtung	NJ	BLUE	8000	1/1/1982	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Neptune	NJ	BLUE	8000	1/1/1981	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1981
Iselin	NJ	BLUE	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Camden	NJ	BLUE	8000	1/1/1980	B/P/A Steel	SA	YES	EMCO FILL	STEEL	1/1/1988
Camden	NJ	BLUE	8000	1/1/1980	B/P/A Steel	SA	YES	EMCO FILL	STEEL	1/1/1988
Paramus	NJ	DIESEL	10000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Union	NJ	GOLD	10000	1/1/1987	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1987
Rutherford	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Totowa	NJ	GOLD	10000	1/1/1984	STIP3	SAC ANODE	YES	EMCO FILL	STEEL	1/1/1984
West Long Branch	NJ	GOLD	10000	1/1/1984	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992

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S. Brunswick	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1984
Edison	NJ	GOLD	10000	1/1/1983	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1983
Edison	NJ	GOLD	10000	1/1/1983	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1983
North Bergen	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
North Bergen	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Edison	NJ	GOLD	10000	1/1/1982	STIP3	NTD	NO	NTD	STEEL	1/1/1982
Morris Plains	NJ	GOLD	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1986
Kearny	NJ	GOLD	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Sayreville	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1984
Emerson	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO FILL	DW FG	1/1/1993
North Bergen	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
North Bergen	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Iselin	NJ	GOLD	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Hackensack	NJ	GOLD	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1982
Hackensack	NJ	GOLD	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1982
Englewood	NJ	GOLD	10000	1/1/1983	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1983
Totowa	NJ	GOLD	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Totowa	NJ	GOLD	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Little Ferry	NJ	GOLD	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	FG	1/1/1982
Little Ferry	NJ	GOLD	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	FG	1/1/1982
Iselin	NJ	GOLD	10000	1/1/1987	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1987
Iselin	NJ	GOLD	10000	1/1/1987	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1987
Marlton	NJ	GOLD	10000	1/1/1983	STIP3	SA	YES	HEATON/AUD/	FG	1/1/1991
Bridgewater	NJ	GOLD	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
Lawnside	NJ	GOLD	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1991
Turnersville	NJ	GOLD	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Mt. Ephraim	NJ	GOLD	10000	1/1/1986	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Cliffside Park	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Linden	NJ	GOLD	10000	1/1/1983	STIP3	NTD	YES	EMCO FILL	DW FG	1/1/1993
Linden	NJ	GOLD	10000	1/1/1983	STIP3	NTD	YES	EMCO FILL	DW FG	1/1/1993
North Brunswick	NJ	GOLD	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
Woodbridge	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Elizabeth	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984

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Elizabeth	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Teaneck	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Hillside	NJ	GOLD	10000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Lake Hopatcong	NJ	GOLD	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1988
Delran	NJ	GOLD	10000	1/1/1970	B/P/A Steel	IC	YES	EMCO /TF	STEEL	1/1/1985
East Brunswick	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	11/1/1993
Spring Lake	NJ	GOLD	10000	1/1/1984	STIP3	SA	YES	EMCO /TF	W ENVIROFLE	1/1/1992
Freehold	NJ	GOLD	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1985
Camden	NJ	GOLD	10000	1/1/1980	B/P/A Steel	SA	YES	EMCO FILL	STEEL	1/1/1988
Maple Shade	NJ	GOLD	10000	7/1/1996	DW FG	NR	YES	YES	W ENVIROFLE	7/1/1996
Brooklawn	NJ	GOLD	10000	11/1/1996	DW FG	NR	YES	YES	W ENVIROFLE	11/1/1996
Cherry Hill	NJ	GOLD	10000	1/1/1997	DW FG	NR	YES	YES	DW FG	1/1/1997
North Brunswick	NJ	GOLD	12000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Budd Lake	NJ	GOLD	12000	1/1/1992	DW FG	NR	YES	EMCO /TF	DW FG	1/1/1992
Lodi	NJ	GOLD	12000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Metuchen	NJ	GOLD	12000	1/1/1989	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Edison	NJ	GOLD	12000	8/1/1995	DW FG	NTD	YES	EMCO FILL	W ENVIROFLE	8/1/1995
Clifton	NJ	GOLD	12000	1/1/1993	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1993
Tenafly	NJ	GOLD	12000	1/1/1989	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1989
Paramus	NJ	GOLD	12000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Elizabeth	NJ	GOLD	12000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1993
Cranbury	NJ	GOLD	12000	1/1/1994	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1994
Somerset	NJ	GOLD	12000	1/1/1989	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1989
Parsippany	NJ	GOLD	12000	1/1/1990	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1990
Bernardsville	NJ	GOLD	12000	1/1/1989	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Secaucus	NJ	GOLD	12000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
Westfield	NJ	GOLD	12000	1/1/1991	DW FCS	NTD	YES	EMCO /TF	DW FG	1/1/1991
Englewood	NJ	GOLD	12000	1/1/1995	DW FG	NTD	YES	EMCO /TF	W ENVIROFLE	1/1/1995
Whippany	NJ	GOLD	12000	1/1/1994	DW FCS	NR	YES	EMCO /TF	DW FG	1/1/1994
Williamstown	NJ	GOLD	12000	1/1/1993	DW FG	NR	YES	EMCO /TF	DW FG	1/1/1993
Wallington	NJ	GOLD	12000	1/1/1988	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1988
Aberdeen	NJ	GOLD	12000	1/1/1989	STIP3	SA	YES	EMCO /TF	FG	1/1/1989
Pompton Lakes	NJ	GOLD	12000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991

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Parsippany	NJ	GOLD	12000	1/1/1989	STIP3	NTD	YES	EMCO /TF	FG	1/1/1989
Maple Shade	NJ	GOLD	12000	1/1/1971	B/P/A Steel	IC	YES	EMCO /TF	STEEL	1/1/1986
Maple Shade	NJ	GOLD	12000	1/1/1971	B/P/A Steel	IC	YES	EMCO FILL	STEEL	1/1/1984
West Collingswood	NJ	GOLD	12000	1/1/1971	B/P/A Steel	IC	YES	EMCO /TF	STEEL	1/1/1984
Hillsborough	NJ	GOLD	12000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
North Brunswick	NJ	GOLD	500	1/1/1993	NTD	NTD	YES	NTD	NTD	1/1/1993
Carteret	NJ	GOLD	6000	1/1/1977	B/P/A Steel	NTD	YES	EMCO FILL	STEEL	1/1/1977
Jersey City	NJ	GOLD	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Iselin	NJ	GOLD	8000	1/1/1977	FG	NTD	YES	EMCO /TF	STEEL	1/1/1977
Paramus	NJ	GOLD	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Paramus	NJ	GOLD	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Newark	NJ	GOLD	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Newark	NJ	GOLD	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Lodi	NJ	GOLD	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Lodi	NJ	GOLD	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
South River	NJ	GOLD	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
South River	NJ	GOLD	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Mountainside	NJ	GOLD	8000	1/1/1977	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1977
Mountainside	NJ	GOLD	8000	1/1/1977	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1977
Hasbrouch Heights	NJ	GOLD	8000	1/1/1968	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1985
Elizabeth	NJ	GOLD	8000	1/1/1979	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1979
Elizabeth	NJ	GOLD	8000	1/1/1979	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1979
River Edge	NJ	GOLD	8000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1980
River Edge	NJ	GOLD	8000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1980
Greenbrook	NJ	GOLD	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Greenbrook	NJ	GOLD	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Perth Amboy	NJ	GOLD	8000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991
Perth Amboy	NJ	GOLD	8000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991
Rahway	NJ	GOLD	8000	1/1/1984	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1984
Wachtung	NJ	GOLD	8000	1/1/1982	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Neptune	NJ	GOLD	8000	1/1/1981	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1981
Neptune	NJ	GOLD	8000	1/1/1981	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1981
Iselin	NJ	GOLD	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978

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Iselin	NJ	GOLD	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Camden	NJ	GOLD	8000	1/1/1980	B/P/A Steel	SA	YES	EMCO FILL	STEEL	1/1/1988
Union	NJ	SILVER	10000	1/1/1987	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1987
North Brunswick	NJ	SILVER	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Totowa	NJ	SILVER	10000	1/1/1983	STIP3	SAC ANODE	YES	EMCO FILL	STEEL	1/1/1983
Budd Lake	NJ	SILVER	10000	1/1/1992	DW FG	NR	YES	EMCO /TF	DW FG	1/1/1992
Lodi	NJ	SILVER	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
S. Brunswick	NJ	SILVER	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1984
Edison	NJ	SILVER	10000	1/1/1983	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1983
North Bergen	NJ	SILVER	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Metuchen	NJ	SILVER	10000	1/1/1989	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Edison	NJ	SILVER	10000	1/1/1995	DW FG	NTD	YES	EMCO FILL	W ENVIROFLE	8/1/1995
Clifton	NJ	SILVER	10000	1/1/1993	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1993
Kearny	NJ	SILVER	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Tenafly	NJ	SILVER	10000	1/1/1989	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1989
Elizabeth	NJ	SILVER	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1993
North Bergen	NJ	SILVER	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Hackensack	NJ	SILVER	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1982
Totowa	NJ	SILVER	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Somerset	NJ	SILVER	10000	1/1/1989	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1989
Little Ferry	NJ	SILVER	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	FG	1/1/1982
Iselin	NJ	SILVER	10000	1/1/1987	STIP3	NTD	YES	TIGHT FILL	STEEL	1/1/1987
Marlton	NJ	SILVER	10000	1/1/1983	STIP3	SA	YES	HEATON/AUD/	FG	1/1/1991
Bridgewater	NJ	SILVER	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
Parsippany	NJ	SILVER	10000	1/1/1990	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1990
Lawnside	NJ	SILVER	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1991
Turnersville	NJ	SILVER	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Mt. Ephraim	NJ	SILVER	10000	1/1/1986	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Bernardsville	NJ	SILVER	10000	1/1/1989	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Linden	NJ	SILVER	10000	1/1/1983	STIP3	NTD	YES	EMCO FILL	DW FG	1/1/1993
Westfield	NJ	SILVER	10000	1/1/1991	DW FCS	NTD	YES	EMCO /TF	DW FG	1/1/1991
Englewood	NJ	SILVER	10000	1/1/1995	DW FG	NTD	NO	EMCO /TF	W ENVIROFLE	1/1/1995
Elizabeth	NJ	SILVER	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984

City	State	Tank Content	Tank Size	Installed Date	Tank Construction	Cathodic Protection	Tank Spill Containment	Tank Overfill Protection	Pipe Construction	Piping Installed
Whippany	NJ	SILVER	10000	1/1/1994	DW FCS	NR	YES	EMCO /TF	DW FG	1/1/1994
Wallington	NJ	SILVER	10000	1/1/1988	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1988
Aberdeen	NJ	SILVER	10000	1/1/1989	STIP3	SA	YES	EMCO /TF	FG	1/1/1989
Hillside	NJ	SILVER	10000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Pompton Lakes	NJ	SILVER	10000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991
Lake Hopatcong	NJ	SILVER	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1988
Parsippany	NJ	SILVER	10000	1/1/1989	STIP3	NTD	YES	EMCO /TF	FG	1/1/1989
Delran	NJ	SILVER	10000	1/1/1970	B/P/A Steel	IC	YES	EMCO /TF	STEEL	1/1/1985
East Brunswick	NJ	SILVER	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Spring Lake	NJ	SILVER	10000	1/1/1984	STIP3	SA	YES	EMCO /TF	W ENVIROFLE	1/1/1984
Freehold	NJ	SILVER	10000	1/1/1985	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1985
Maple Shade	NJ	SILVER	10000	7/1/1996	DW FG	NR	YES	YES	W ENVIROFLE	7/1/2001
Brooklawn	NJ	SILVER	10000	11/1/1996	DW FG	NR	YES	YES	W ENVIROFLE	11/1/1996
Cherry Hill	NJ	SILVER	10000	1/1/1997	DW FG	NR	YES	YES	DW FG	1/1/1997
Hillsborough	NJ	SILVER	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
Cranbury	NJ	SILVER	12000	1/1/1994	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1994
Williamstown	NJ	SILVER	12000	1/1/1993	DW FG	NR	YES	EMCO /TF	DW FG	1/1/1993
Maple Shade	NJ	SILVER	12000	1/1/1971	B/P/A Steel	IC	YES	EMCO /TF	STEEL	1/1/1986
Maple Shade	NJ	SILVER	12000	1/1/1971	B/P/A Steel	IC	YES	EMCO FILL	STEEL	1/1/1984
West Collingswood	NJ	SILVER	12000	1/1/1971	B/P/A Steel	IC	YES	EMCO /TF	STEEL	1/1/1984
Paramus	NJ	SILVER	4000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Paramus	NJ	SILVER	4000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Carteret	NJ	SILVER	6000	1/1/1977	B/P/A Steel	NTD	YES	EMCO FILL	STEEL	1/1/1977
Hasbrouch Heights	NJ	SILVER	6000	1/1/1968	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1985
Teaneck	NJ	SILVER	6000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Rutherford	NJ	SILVER	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Jersey City	NJ	SILVER	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Iselin	NJ	SILVER	8000	1/1/1977	FG	NTD	YES	EMCO /TF	STEEL	1/1/1977
West Long Branch	NJ	SILVER	8000	1/1/1984	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1992
Paramus	NJ	SILVER	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Newark	NJ	SILVER	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1985
Lodi	NJ	SILVER	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
South River	NJ	SILVER	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981

City	State	Tank Content	Tank Size	Installed Date	Tank Construction	Cathodic Protection	Tank Spill Containment	Tank Overfill Protection	Pipe Construction	Piping Installed
Morris Plains	NJ	SILVER	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Sayreville	NJ	SILVER	8000	1/1/1984	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Emerson	NJ	SILVER	8000	1/1/1984	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Mountainside	NJ	SILVER	8000	1/1/1977	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1977
Iselin	NJ	SILVER	8000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Englewood	NJ	SILVER	8000	1/1/1983	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1983
Elizabeth	NJ	SILVER	8000	1/1/1979	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1979
Cliffside Park	NJ	SILVER	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
River Edge	NJ	SILVER	8000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1980
Secaucus	NJ	SILVER	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
North Brunswick	NJ	SILVER	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
Greenbrook	NJ	SILVER	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Woodbridge	NJ	SILVER	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Perth Amboy	NJ	SILVER	8000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991
Rahway	NJ	SILVER	8000	1/1/1984	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1984
Wachtung	NJ	SILVER	8000	1/1/1982	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1993
Neptune	NJ	SILVER	8000	1/1/1981	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1981
Iselin	NJ	SILVER	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO FILL	STEEL	1/1/1978
Camden	NJ	SILVER	8000	1/1/1980	B/P/A Steel	SA	YES	EMCO FILL	STEEL	1/1/1988
Fort Lee	NJ	eaded Gas	10000	1/1/1978	DW FCS	NTD	NTD	EMCO /TF	NTD	1/1/2001
Fort Lee	NJ	eaded Gas	10000	1/1/1978	DW FCS	NTD	NTD	EMCO /TF	NTD	1/1/2001
Fort Lee	NJ	eaded Gas	12000	1/1/1977	DW FCS	NTD	NTD	EMCO /TF	NTD	1/1/2001
Burlington	NJ	BLUE	10000	1/1/1992	DW FCS	NTD	YES	EMCO /TF	DW FG	1/1/1992
Pennington	NJ	BLUE	10000	1/1/1989	STIP3	SA	YES	EMCO /TF	FG	1/1/1989
Princeton	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	FG	1/1/1988
South Brunswick	NJ	BLUE	10000	1/1/1992	DW FCS	NTD	YES	EMCO /TF	DW FG	1/1/1992
South Hampton	NJ	BLUE	10000	1/1/1991	STIP3	SA	YES	EMCO /TF	FG	1/1/1991
North Brunswick	NJ	BLUE	10000	8/1/1997	DW FG	NR	YES	YES	W ENVIROFLE	8/1/1997
Fairlawn	NJ	BLUE	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Plainfield	NJ	BLUE	10000	1/1/1986	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1986
West Orange	NJ	BLUE	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Jersey City	NJ	BLUE	10000	1/1/1984	BT10	NTD	YES	EMCO /TF	STEEL	1/1/1984
Bound Brook	NJ	BLUE	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1994

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Edison	NJ	BLUE	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Clifton	NJ	BLUE	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Lakewood	NJ	BLUE	12000	1/1/1991	DW FG	NR	YES	EMCO FILL	DW FG	1/1/1991
Cherry Hill	NJ	BLUE	12000	1/1/1990	STIP3	SA	YES	EMCO FILL	FG	1/1/1990
North Plainfield	NJ	BLUE	8000	1/1/1979	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1979
Riverdale	NJ	BLUE	8000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1980
Hillside	NJ	BLUE	8000	1/1/1970	FG	NTD	YES	EMCO /TF	STEEL	1/1/1970
Livingston	NJ	BLUE	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
Hackensack	NJ	BLUE	8000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Union	NJ	BLUE	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Saddle Brook	NJ	BLUE	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Totowa	NJ	BLUE	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
West Paterson	NJ	BLUE	8000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Springfield	NJ	BLUE	8000	1/1/1985	STIP3	NTD	YES	EMCO FILL	DW FG	1/1/1990
Cranford	NJ	BLUE	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
West Orange	NJ	BLUE	8000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Hamilton Square	NJ	DIESEL	10000	1/1/1990	DW FCS	NR	YES	EMCO /TF	DW FG	1/1/1990
Burlington	NJ	DIESEL	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Union	NJ	GOLD	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1982
Union	NJ	GOLD	10000	1/1/1982	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1982
Fort Lee	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Fort Lee	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Hillside	NJ	GOLD	10000	1/1/1984	FG	NTD	YES	EMCO /TF	STEEL	1/1/1984
Toms River	NJ	GOLD	10000	1/1/1990	DW STIP3	IC	YES	EMCO /TF	DW FG	1/1/1990
Livingston	NJ	GOLD	10000	1/1/1989	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1989
North Bergen	NJ	GOLD	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Hackensack	NJ	GOLD	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Edison	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Union	NJ	GOLD	10000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Irvington	NJ	GOLD	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Irvington	NJ	GOLD	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Cherry Hill	NJ	GOLD	10000	11/1/1996	DW FG	NR	YES	YES	W ENVIROFLE	11/1/1996
Glassboro	NJ	GOLD	10000	1/1/1990	STIP3	SA	YES	EMCO /TF	FG	1/1/1990

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Jersey City	NJ	GOLD	10000	1/1/1991	DW FG	NTD	YES	EMCO /TF	FG	1/1/1991
Jersey City	NJ	GOLD	10000	1/1/1990	DW FG	NTD	YES	EMCO /TF	FG	1/1/1990
Cherry Hill	NJ	GOLD	10000	1/1/1990	STIP3	SA	YES	EMCO FILL	FG	1/1/1990
Trenton	NJ	GOLD	10000	1/1/1987	STIP3	SA	YES	EMCO /TF	FG	1/1/1987
Bordentown	NJ	GOLD	10000	1/1/1901	STIP3	NTD	YES	EMCO /TF	FG	1/1/1901
Burlington	NJ	GOLD	10000	1/1/1990	STIP3	NTD	YES	EMCO /TF	FG	1/1/1990
Delanco	NJ	GOLD	10000	1/1/1987	STIP3	SA	YES	EMCO FILL	FG	1/1/1987
Delanco	NJ	GOLD	10000	1/1/1987	STIP3	SA	YES	EMCO FILL	FG	1/1/1987
Trenton	NJ	GOLD	10000	1/1/1983	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1993
Hamilton Square	NJ	GOLD	10000	1/1/1990	DW FCS	NR	YES	EMCO /TF	DW FG	1/1/1990
Burlington	NJ	GOLD	10000	1/1/1992	DW FCS	NTD	YES	EMCO /TF	DW FG	1/1/1992
Pennington	NJ	GOLD	10000	1/1/1989	STIP3	SA	YES	EMCO /TF	FG	1/1/1989
Princeton	NJ	GOLD	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	FG	1/1/1988
South Brunswick	NJ	GOLD	10000	1/1/1992	DW FCS	NTD	YES	EMCO /TF	DW FG	1/1/1992
South Hampton	NJ	GOLD	10000	1/1/1991	STIP3	SA	YES	EMCO /TF	FG	1/1/1991
Saddle Brook	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Fairlawn	NJ	GOLD	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Totowa	NJ	GOLD	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
West Paterson	NJ	GOLD	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Springfield	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO FILL	DW FG	1/1/1990
Plainfield	NJ	GOLD	10000	1/1/1986	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1986
West Orange	NJ	GOLD	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Cranford	NJ	GOLD	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Jersey City	NJ	GOLD	10000	1/1/1984	BT10	NTD	YES	EMCO /TF	STEEL	1/1/1984
Jersey City	NJ	GOLD	10000	1/1/1984	BT10	NTD	YES	EMCO /TF	STEEL	1/1/1984
Avenel	NJ	GOLD	12000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
Toms River	NJ	GOLD	12000	1/1/1990	DW STIP3	IC	YES	EMCO /TF	DW FG	1/1/1990
Cliffwood	NJ	GOLD	12000	1/1/1987	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1990
Paterson	NJ	GOLD	12000	7/1/1998	DW FG	NR	YES	YES	W ENVIROFLE	7/1/1998
Bloomfield	NJ	GOLD	12000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Linden	NJ	GOLD	12000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
Bayonne	NJ	GOLD	12000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Vauxhall	NJ	GOLD	12000	1/1/1988	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1988

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Middletown	NJ	GOLD	12000	1/1/1987	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1987
Lincroft	NJ	GOLD	12000	1/1/1988	STIP3	SA	YES	EMCO /TF	FG	1/1/1988
Newfoundland	NJ	GOLD	12000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991
Rockaway	NJ	GOLD	12000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Bayville	NJ	GOLD	12000	1/1/1996	DW FG	NR	YES	YES	DW FG	1/1/1996
Asbury Park	NJ	GOLD	12000	1/1/1996	DW FG	NR	YES	YES	DW FG	1/1/1996
Toms River	NJ	GOLD	12000	1/1/1991	DW FG	NR	YES	EMCO FILL	DW FG	1/1/1991
Piscataway	NJ	GOLD	12000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Hoboken	NJ	GOLD	12000	1/1/1992	DW FG	NTD	YES	EMCO FILL	DW FG	1/1/1992
North Brunswick	NJ	GOLD	12000	8/1/1997	DW FG	NR	YES	YES	W ENVIROFLE	8/1/1997
Bound Brook	NJ	GOLD	12000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1994
Edison	NJ	GOLD	12000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Clifton	NJ	GOLD	12000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
West Orange	NJ	GOLD	12000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
North Plainfield	NJ	GOLD	6000	1/1/1977	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1977
North Plainfield	NJ	GOLD	8000	1/1/1979	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1979
North Plainfield	NJ	GOLD	8000	1/1/1979	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1979
Riverdale	NJ	GOLD	8000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1980
Riverdale	NJ	GOLD	8000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1980
Hillside	NJ	GOLD	8000	1/1/1970	FG	NTD	YES	EMCO /TF	STEEL	1/1/1970
Livingston	NJ	GOLD	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
North Bergen	NJ	GOLD	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Union	NJ	GOLD	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Union	NJ	GOLD	8000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
North Plainfield	NJ	GOLD	8000	1/1/1977	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1977
Avenel	NJ	SILVER	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988
Union	NJ	SILVER	10000	1/1/1982	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1982
Fort Lee	NJ	SILVER	10000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
Toms River	NJ	SILVER	10000	1/1/1990	DW STIP3	IC	YES	EMCO /TF	DW FG	1/1/1990
Cliffwood	NJ	SILVER	10000	1/1/1987	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1990
Paterson	NJ	SILVER	10000	7/1/1998	DW FG	NR	YES	YES	W ENVIROFLE	7/1/1998
Bloomfield	NJ	SILVER	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Linden	NJ	SILVER	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1988

City	State	Tank Content	Tank Size	Installed Date	Tank Construction	Cathodic Protection	Tank Spill Containment	Tank Overfill Protection	Pipe Construction	Piping Installed
Bayonne	NJ	SILVER	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Edison	NJ	SILVER	10000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
Vauxhall	NJ	SILVER	10000	1/1/1988	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1988
Irvington	NJ	SILVER	10000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Middletown	NJ	SILVER	10000	1/1/1987	STIP3	SA	YES	EMCO /TF	STEEL	1/1/1987
Lincroft	NJ	SILVER	10000	1/1/1988	STIP3	SA	YES	EMCO /TF	FG	1/1/1988
Newfoundland	NJ	SILVER	10000	1/1/1991	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1991
Rockaway	NJ	SILVER	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
North Plainfield	NJ	SILVER	10000	1/1/1981	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1981
Cherry Hill	NJ	SILVER	10000	11/1/1996	DW FG	NR	YES	YES	W ENVIROFLE	11/1/1996
Bayville	NJ	SILVER	10000	1/1/1996	DW FG	NR	YES	YES	DW FG	1/1/1996
Asbury Park	NJ	SILVER	10000	1/1/1996	DW FG	NR	YES	YES	DW FG	1/1/1996
Glassboro	NJ	SILVER	10000	1/1/1990	STIP3	SA	YES	EMCO /TF	FG	1/1/1990
Lakewood	NJ	SILVER	10000	1/1/1991	DW FG	NR	YES	EMCO FILL	DW FG	1/1/1991
Toms River	NJ	SILVER	10000	1/1/1991	DW FG	NR	YES	EMCO FILL	DW FG	1/1/1991
Jersey City	NJ	SILVER	10000	1/1/1990	DW FG	NTD	YES	EMCO /TF	FG	1/1/1990
Cherry Hill	NJ	SILVER	10000	1/1/1990	STIP3	SA	YES	EMCO FILL	FG	1/1/1990
Piscataway	NJ	SILVER	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Hoboken	NJ	SILVER	10000	1/1/1992	DW FG	NTD	YES	EMCO FILL	DW FG	1/1/1992
Trenton	NJ	SILVER	10000	1/1/1987	STIP3	SA	YES	EMCO /TF	FG	1/1/1987
Bordentown	NJ	SILVER	10000	1/1/1901	STIP3	NTD	YES	EMCO /TF	FG	1/1/1901
Burlington	NJ	SILVER	10000	1/1/1990	STIP3	NTD	YES	EMCO /TF	FG	1/1/1990
Delanco	NJ	SILVER	10000	1/1/1987	STIP3	SA	YES	EMCO FILL	FG	1/1/1987
Delanco	NJ	SILVER	10000	1/1/1987	STIP3	SA	YES	EMCO FILL	FG	1/1/1987
Trenton	NJ	SILVER	10000	1/1/1983	STIP3	SA	YES	EMCO /TF	DW FG	1/1/1993
Hamilton Square	NJ	SILVER	10000	1/1/1990	DW FCS	NR	YES	EMCO /TF	DW FG	1/1/1990
Burlington	NJ	SILVER	10000	1/1/1992	DW FCS	NTD	YES	EMCO /TF	DW FG	1/1/1992
Pennington	NJ	SILVER	10000	1/1/1989	STIP3	SA	YES	EMCO /TF	FG	1/1/1989
Princeton	NJ	SILVER	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	FG	1/1/1988
South Brunswick	NJ	SILVER	10000	1/1/1992	DW FCS	NTD	YES	EMCO /TF	DW FG	1/1/1992
South Hampton	NJ	SILVER	10000	1/1/1991	STIP3	SA	YES	EMCO /TF	FG	1/1/1991
North Brunswick	NJ	SILVER	10000	8/1/1997	DW FG	NR	YES	YES	W ENVIROFLE	8/1/1997
Fairlawn	NJ	SILVER	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987

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Plainfield	NJ	SILVER	10000	1/1/1986	STIP3	NTD	YES	EMCO FILL	STEEL	1/1/1986
West Orange	NJ	SILVER	10000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Jersey City	NJ	SILVER	10000	1/1/1984	BT10	NTD	YES	EMCO /TF	STEEL	1/1/1984
Bound Brook	NJ	SILVER	10000	1/1/1988	STIP3	NTD	YES	EMCO /TF	DW FG	11/1/1994
Edison	NJ	SILVER	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Clifton	NJ	SILVER	10000	1/1/1992	DW FG	NTD	YES	EMCO /TF	DW FG	1/1/1992
Hackensack	NJ	SILVER	6000	1/1/1984	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1984
North Plainfield	NJ	SILVER	8000	1/1/1979	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1979
Riverdale	NJ	SILVER	8000	1/1/1980	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1980
Hillside	NJ	SILVER	8000	1/1/1970	FG	NTD	YES	EMCO /TF	STEEL	1/1/1970
Livingston	NJ	SILVER	8000	1/1/1978	B/P/A Steel	NTD	YES	EMCO /TF	STEEL	1/1/1978
North Bergen	NJ	SILVER	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Saddle Brook	NJ	SILVER	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	DW FG	1/1/1992
Totowa	NJ	SILVER	8000	1/1/1986	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1986
West Paterson	NJ	SILVER	8000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Springfield	NJ	SILVER	8000	1/1/1985	STIP3	NTD	YES	EMCO FILL	DW FG	1/1/1990
Cranford	NJ	SILVER	8000	1/1/1985	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1985
West Orange	NJ	SILVER	8000	1/1/1987	STIP3	NTD	YES	EMCO /TF	STEEL	1/1/1987
Avenel	NJ	eaded Gas	10000	1/1/1997	DW FG	NR	YES	YES	ENVIROFLEX	1/1/1997
Avenel	NJ	eaded Gas	10000	1/1/1997	DW FG	NR	YES	YES	ENVIROFLEX	1/1/1997
Newark	NJ	eaded Gas	10000	1/1/1996	DW FG	NR	YES	YES	DW FG	1/1/1997
Newark	NJ	eaded Gas	10000	1/1/1996	DW FG	NR	YES	YES	DW FG	1/1/1997
Avenel	NJ	eaded Gas	12000	1/1/1997	DW FG	NR	YES	YES	ENVIROFLEX	1/1/1997
Newark	NJ	eaded Gas	12000	1/1/1996	DW FG	NR	YES	YES	DW FG	1/1/1997
Hempstead	NY	BLUE	8000	1-Mar-85	FRP	NA	YES	YES	FRP	3/1/1985
Hempstead	NY	GOLD	8000	1-Mar-85	FRP	NA	YES	YES	FRP	3/1/1985
Hempstead	NY	SILVER	8000	1-Mar-85	FRP	NA	YES	YES	FRP	3/1/1985
Lawrence	NY	BLUE	10000	11/1/1994	DW FG	NR	YES	LE & VISIBLE	DW FG	11/1/1994
Farmingville	NY	BLUE	10000	1/1/1990	DW FG	NTD	YES	ISIBLE ALAR	DW FG	1/1/1990
Hicksville	NY	BLUE	10000	1/1/1988	DW FG	NR	YES	EMCO FILL	FG	1/1/1988
Port Chester	NY	BLUE	10000	1/1/1986	STIP3	IC	YES	LE & VISIBLE	FG	1/1/1986
Mamaroneck	NY	BLUE	10000	1/1/1992	DW FG	NR	YES	VISIBLE/TIGH	DW FG	1/1/1992
Smithtown	NY	BLUE	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990

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Brentwood	NY	BLUE	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1990
Greenvale	NY	BLUE	10000	1/1/1994	DW FG	NR	YES	OPW FILL	DW FG	1/1/1994
Great Neck	NY	BLUE	10000	1/1/1984	FG	NR	YES	BALL FLOAT	FG	1/1/1984
Roosevelt	NY	BLUE	10000	1/1/1985	FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1985
Brewster	NY	BLUE	10000	4/1/1990	DW STIP3	SAC ANODE	YES	FLOAT & TIGH	FG	1/1/1991
Lindenhurst	NY	BLUE	10000	1/1/1991	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1991
Melville	NY	BLUE	10000	1/1/1991	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1991
Lindenhurst	NY	BLUE	10000	1/1/1982	FG	NR	YES	LE & VISIBLE /	FG	1/1/1982
Lindenhurst	NY	BLUE	10000	1/1/1982	FG	NR	YES	LE & VISIBLE /	FG	1/1/1982
Port Jefferson	NY	BLUE	10000	1/1/1984	FG	NR	YES	LE & VISIBLE /	FG	1/1/1984
Port Jefferson	NY	BLUE	10000	1/1/1984	FG	NR	YES	LE & VISIBLE /	FG	1/1/1984
Holtsville	NY	BLUE	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1990
East Northport	NY	BLUE	10000	1/1/1988	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1988
Albertson	NY	BLUE	10000	1/1/1984	FG	NR	YES	LE & VISIBLE /	FG	1/1/1984
Farmingdale	NY	BLUE	10000	1/1/1981	FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1991
Commack	NY	BLUE	10000	1/1/1991	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1991
Commack	NY	BLUE	10000	1/1/1991	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1991
Pelham Manor	NY	BLUE	10000	1/1/1995	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/2001
St. James	NY	BLUE	10000	1/1/1987	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1987
Brooklyn	NY	BLUE	10000	1/1/1998	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1998
Hicksville	NY	BLUE	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1990
West Islip	NY	BLUE	10000	1/1/1984	FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1984
Elmsford	NY	BLUE	10000	1/1/1984	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	1/1/1984
Franklin Square	NY	BLUE	10000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1993
Garden City Park	NY	BLUE	10000	1/1/1983	FG	NR	YES	TIGHT FILL	FG	1/1/1983
Levittown	NY	BLUE	10000	1/1/2001	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/2001
Deer Park	NY	BLUE	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1990
Ronkonkoma	NY	BLUE	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1990
West Islip	NY	BLUE	10000	6/1/1989	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/2001
Bohemia	NY	BLUE	10000	1/1/1990	DW FG	NTD	YES	LE & VISIBLE /	DW FG	1/1/1990
Syosset	NY	BLUE	10000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1994
Port Washington	NY	BLUE	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1990
Port Washington	NY	BLUE	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1990

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Manhasset	NY	BLUE	10000	1/1/1983	FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1983
East Meadow	NY	BLUE	10000	1/1/1983	FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1983
Freeport	NY	BLUE	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1990
Lake Grove	NY	BLUE	10000	1/1/1989	DW FG	NTD	YES	LE & VISIBLE /	DW FG	1/1/1989
Blue Point	NY	BLUE	10000	1/1/1990	DW FG	NTD	YES	LE & VISIBLE /	DW FG	1/1/1990
Rocky Point	NY	BLUE	10000	1/1/1988	DW FG	NTD	YES	LE & VISIBLE /	DW FG	1/1/1988
Medford	NY	BLUE	10000	1/1/1989	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1988
Holtsville	NY	BLUE	10000	1/1/1991	DW FG	NTD	YES	LE & VISIBLE /	DW FG	1/1/1991
Franklin Square	NY	BLUE	10000		DW FG	NR	LON BUCKET	LE & VISIBLE /	DW FG	11/1/1996
Centereach	NY	BLUE	10000	1/1/2001	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/2001
Brooklyn	NY	BLUE	12000	1/1/1998	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/2001
Yonkers	NY	BLUE	12000	1/1/1992	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/1992
Hicksville	NY	BLUE	12000	7/1/1995	DW FG	NR	YES	LE & VISIBLE /	W ENVIROFLE	7/1/1995
Bronx	NY	BLUE	4000	1/1/1984	DW STEEL	NTD	NO	NONE	STEEL	1/1/1984
Bronx	NY	BLUE	4000	1/1/1984	DW STEEL	NTD	NO	NONE	STEEL	1/1/1984
Bronx	NY	BLUE	4000	1/1/1979	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1979
Bronx	NY	BLUE	4000	1/1/1985	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	12/1/1985
Bronx	NY	BLUE	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED C	1/1/1987
Woodside	NY	BLUE	4000	1/1/1986	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	DW FG	12/1/1986
Woodside	NY	BLUE	4000	1/1/1989	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	DW FG	12/1/1986
Brooklyn	NY	BLUE	4000	1/1/1982	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1982
Brooklyn	NY	BLUE	4000	1/1/1986	STIP3	NTD	NO	NTD	STEEL	1/1/1986
Brooklyn	NY	BLUE	4000	1/1/1986	STIP3	NTD	NO	NTD	STEEL	1/1/1986
Hollis	NY	BLUE	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED C	5/1/1989
Hollis	NY	BLUE	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED C	5/1/1989
Brooklyn	NY	BLUE	4000	1/1/1971	STEEL	IC	NO	NONE	STEEL	12/1/1971
Brooklyn	NY	BLUE	4000	1/1/1978	STEEL	IC	NO	NONE	STEEL	12/1/1978
Brooklyn	NY	BLUE	4000	6/1/1994	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1994
Brooklyn	NY	BLUE	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1994
Queens Village	NY	BLUE	4000	1/1/1989	B/P/A Steel	IC	YES	LE & VISIBLE /	/APPROVED C	12/1/1986
Queens Village	NY	BLUE	4000	1/1/1989	B/P/A Steel	IC	YES	LE & VISIBLE /	/APPROVED C	12/1/1986
Brooklyn	NY	BLUE	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	FG	6/1/1993
Brooklyn	NY	BLUE	4000	1/1/1972	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1972

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Brooklyn	NY	BLUE	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	FG	6/1/1993
Brooklyn	NY	BLUE	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	FG	6/1/1993
Brooklyn	NY	BLUE	4000	1/1/1983	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1983
Brooklyn	NY	BLUE	4000	1/1/1983	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1983
Brooklyn	NY	BLUE	4000	1/1/1986	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1986
Bronx	NY	BLUE	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1986
Bronx	NY	BLUE	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1986
Brooklyn	NY	BLUE	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	DW FG	6/1/1993
Brooklyn	NY	BLUE	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	DW FG	6/1/1993
Brooklyn	NY	BLUE	4000	1/1/1978	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1978
New Rochelle	NY	BLUE	4000	1/1/1986	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	1/1/1986
New Rochelle	NY	BLUE	4000	1/1/1986	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	1/1/1986
Flushing	NY	BLUE	4000	1/1/1986	DW STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1986
Woodside	NY	BLUE	4000	1/1/1983	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1983
East Elmhurst	NY	BLUE	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	DW FG	6/1/1993
East Elmhurst	NY	BLUE	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	DW FG	6/1/1993
Brooklyn	NY	BLUE	4000		FG	IC	YES	LE & VISIBLE	/APPROVED	12/1/1991
Brooklyn	NY	BLUE	4000	1/1/1991	FG	IC	YES	LE & VISIBLE	/APPROVED	12/1/1991
Staten Island	NY	BLUE	4000	1/1/1985	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1985
Staten Island	NY	BLUE	4000	1/1/1985	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1985
Bronx	NY	BLUE	4000	1/1/1978	B/P/A Steel	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1978
Flushing	NY	BLUE	4000	1/1/1986	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1986
Maspeth	NY	BLUE	4000	1/1/1990	FCS	IC	YES	LE & VISIBLE	/APPROVED	8/1/1990
Brooklyn	NY	BLUE	4000	1/1/1992	DW STEEL	NTD	YES	UDIBLE ALAR	/APPROVED	12/1/1992
Brooklyn	NY	BLUE	4000	1/1/1992	DW STEEL	NTD	YES	UDIBLE ALAR	/APPROVED	12/1/1992
Elmhurst	NY	BLUE	4000	1/1/1979	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1979
Jackson Heights	NY	BLUE	4000	1/1/1984	IPRESSED C	IC	YES	LE & VISIBLE	/APPROVED	1/1/1984
Bronx	NY	BLUE	4000	1/1/1990	DW STEEL	SAC ANODE	YES	LE & VISIBLE	/APPROVED	12/1/1989
Bronx	NY	BLUE	4000	1/1/1990	DW STEEL	SAC ANODE	YES	LE & VISIBLE	/APPROVED	12/1/1989
Brooklyn	NY	BLUE	4000	1/1/1983	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	12/1/1983
Elmhurst	NY	BLUE	4000	1/1/1982	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1982
Elmhurst	NY	BLUE	4000	1/1/1982	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1982
Bronx	NY	BLUE	4000	1/1/1982	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1982

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Brooklyn	NY	BLUE	4000	12/1/1978	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1978
St. Albans	NY	BLUE	4000	1/1/1989	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	
St. Albans	NY	BLUE	4000	1/1/1989	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	
Jamaica	NY	BLUE	4000	1/1/1987	DW FG	NR	YES	LE & VISIBLE	STEEL	12/1/1987
Jamaica	NY	BLUE	4000	1/1/1987	DW FG	NR	YES	LE & VISIBLE	STEEL	12/1/1987
Flushing	NY	BLUE	4000	1/1/1983	DW STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1983
Flushing	NY	BLUE	4000	1/1/1983	DW STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1983
Bronx	NY	BLUE	4000	1/1/1986	B/P/A Steel	SAC	YES	LE & VISIBLE	/APPROVED C	12/1/1986
Brooklyn	NY	BLUE	4000	1/1/1988	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED C	1/1/1988
Brooklyn	NY	BLUE	4000	1/1/1988	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED C	1/1/1988
New York	NY	BLUE	4000	1/1/1996	DW STEEL	IC	YES	LE & VISIBLE	STEEL	4/1/1989
Howard Beach	NY	BLUE	4000	1/1/1996	DW FG	NR	YES	LE & VISIBLE	DW FG	6/1/1995
Howard Beach	NY	BLUE	4000	1/1/1996	DW FG	NR	YES	LE & VISIBLE	DW FG	6/1/1995
New York	NY	BLUE	4000	1/1/1984	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1984
Bronx	NY	BLUE	4000	1/1/1986	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	12/1/1986
Bronx	NY	BLUE	4000	1/1/1985	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	12/1/1985
Brooklyn	NY	BLUE	4000	1/1/1977	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1977
Bayside	NY	BLUE	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED C	1/1/1989
Bayside	NY	BLUE	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED'C	1/1/1989
Flushing	NY	BLUE	4000		DW STEEL	SAC ANODE	YES	LE & VISIBLE	/APPROVED C	5/1/1989
Flushing	NY	BLUE	4000		DW STEEL	SAC ANODE	YES	IBLE & TIGHT	/APPROVED C	5/1/1989
Bronx	NY	BLUE	4000	1/1/1986	STEEL	SAC ANODE	YES	LE & VISIBLE	/APPROVED C	12/1/1987
Bronx	NY	BLUE	4000	1/1/1984	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1984
Brooklyn	NY	BLUE	4000	1/1/1976	STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1976
Brooklyn	NY	BLUE	4000	6/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE	/APPROVED C	6/1/1990
Brooklyn	NY	BLUE	4000	6/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE	/APPROVED C	6/1/1990
Richmond Hill	NY	BLUE	4000	1/1/1987	PRESSED C	IC	YES	LE & VISIBLE	/APPROVED C	3/1/1985
Richmond Hill	NY	BLUE	4000	1/1/1987	PRESSED C	IC	YES	LE & VISIBLE	/APPROVED C	3/1/1985
Brooklyn	NY	BLUE	4000	1/1/1984	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	10/1/1982
Brooklyn	NY	BLUE	4000	1/1/1984	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	10/1/1982
Jamaica	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	9/1/1977
Jamaica	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	9/1/1977
Brooklyn	NY	BLUE	4000	1/1/2000	FG	IC	YES	LE & VISIBLE	/APPROVED C	11/1/1991

City	State	Tank Content	Tank Size	Installed Date	Tank Construction	Cathodic Protection	Tank Spill Containment	Tank Overfill Protection	Pipe Construction	Piping Installed
Rosedale	NY	BLUE	4000	1/1/1998	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	4/1/1987
New York	NY	BLUE	4000	1/1/1978	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	5/1/1982
New York	NY	BLUE	4000	1/1/1978	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	5/1/1982
Brooklyn	NY	BLUE	4000		B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1988
Brooklyn	NY	BLUE	4000	1/1/2000	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	6/1/1984
Howard Beach	NY	BLUE	4000	1/1/1990	DW STIP3	SA	YES	LE & VISIBLE	/APPROVED	12/1/1989
Howard Beach	NY	BLUE	4000	1/1/1990	DW STIP3	SA	YES	LE & VISIBLE	/APPROVED	12/1/1989
Brooklyn	NY	BLUE	4000	1/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	1/1/1990
Brooklyn	NY	BLUE	4000	1/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	1/1/1990
Long Island City	NY	BLUE	4000	1/1/1987	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	1/1/1987
Brooklyn	NY	BLUE	4000	1/1/1992	DW BUFFHIDE	IC	YES	LE & VISIBLE	/APPROVED	8/1/1992
Brooklyn	NY	BLUE	4000	1/1/1992	DW BUFFHIDE	IC	YES	LE & VISIBLE	/APPROVED	8/1/1992
Brooklyn	NY	BLUE	4000	6/1/1988	STEEL	IC	YES	LE & VISIBLE	STEEL	11/1/1986
Brooklyn	NY	BLUE	4000		DW STIP3	SAC ANODE	YES	LE & VISIBLE	/APPROVED	10/1/1990
Brooklyn	NY	BLUE	4000		DW STIP3	SAC ANODE	YES	LE & VISIBLE	/APPROVED	10/1/1990
Little Neck	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	1/1/1991
Little Neck	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	1/1/1991
New York	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	6/1/1987
Hollis	NY	BLUE	4000		B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	9/1/1986
Hollis	NY	BLUE	4000		B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	9/1/1986
New York	NY	BLUE	4000	1/1/1992	DW STEEL	NTD	YES	LE & VISIBLE	/APPROVED	11/1/1992
South Ozone Park	NY	BLUE	4000	1/1/1990	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	10/1/1990
Corona	NY	BLUE	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1987
Corona	NY	BLUE	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1987
Bronx	NY	BLUE	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	1/1/1989
Bronx	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	3/1/1989
Bronx	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	3/1/1989
Staten Island	NY	BLUE	4000	6/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	6/1/1990
Staten Island	NY	BLUE	4000	6/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	6/1/1990
Springfield Gardens	NY	BLUE	4000		DW STIP3	IC	YES	LE & VISIBLE	STEEL	8/1/1989
Springfield Gardens	NY	BLUE	4000		DW STIP3	IC	YES	LE & VISIBLE	STEEL	8/1/1989
Brooklyn	NY	BLUE	4000	12/1/1989	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	12/1/1989
Brooklyn	NY	BLUE	4000	12/1/1989	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	12/1/1989

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Staten Island	NY	BLUE	4000		B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	5/1/1992
Staten Island	NY	BLUE	4000		B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	5/1/1992
Richmond Hill	NY	BLUE	4000	########	DW BUFFHIDE	SAC ANODE	YES	LE & VISIBLE /	STEEL	10/1/1990
Richmond Hill	NY	BLUE	4000	########	DW BUFFHIDE	SAC ANODE	YES	LE & VISIBLE /	STEEL	10/1/1990
Staten Island	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	4/1/1991
Staten Island	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	4/1/1991
Bronx	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	1/1/1990
Bronx	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	1/1/1990
Fresh Meadows	NY	BLUE	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE /	STEEL	12/1/1989
Fresh Meadows	NY	BLUE	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE /	STEEL	12/1/1989
Bronx	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1990
Bronx	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1990
Brooklyn	NY	BLUE	4000	11/1/1989	FG	SAC ANODE	YES	LE & VISIBLE /	DW FG	11/1/1989
Brooklyn	NY	BLUE	4000	11/1/1989	FG	SAC ANODE	YES	LE & VISIBLE /	DW FG	11/1/1989
Brooklyn	NY	BLUE	4000	10/1/1989	DW FG	NR	YES	LE & VISIBLE /	FG	10/1/1989
Brooklyn	NY	BLUE	4000	10/1/1989	DW FG	NR	YES	LE & VISIBLE /	FG	10/1/1989
Bronx	NY	BLUE	4000		FG	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1991
Bronx	NY	BLUE	4000		FG	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1991
Staten Island	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	10/1/1991
Staten Island	NY	BLUE	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	10/1/1991
Bronx	NY	BLUE	4000		FG	SAC ANODE	YES	LE & VISIBLE /	//APPROVED C	7/1/1991
Bronx	NY	BLUE	4000		FG	SAC ANODE	YES	LE & VISIBLE /	//APPROVED C	7/1/1991
Brooklyn	NY	BLUE	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	DW FG	10/1/1993
Brooklyn	NY	BLUE	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	DW FG	10/1/1993
Brooklyn	NY	BLUE	4000		FG	SAC ANODE	NO	LE & VISIBLE /	//APPROVED C	12/1/1991
Brooklyn	NY	BLUE	4000		FG	SAC ANODE	NO	LE & VISIBLE /	//APPROVED C	12/1/1991
Elmont	NY	BLUE	6000	1/1/1985	FG	NR	YES	LE & VISIBLE /	FG	1/1/1985
Elmont	NY	BLUE	6000	1/1/1985	FG	NR	YES	NTD	FG	1/1/1985
Greenburgh	NY	BLUE	6000	1/1/1982	B/P/A Steel	IC	YES	TIGHT FILL	FG	1/1/1982
Hempstead	NY	BLUE	6000	1/1/1986	FG	NR	NO	NO	//APPROVED C	1/1/1986
Huntington Station	NY	BLUE	6000	1/1/1984	FG	NTD	YES	LE & VISIBLE /	DW FG	1/1/1984
Huntington Station	NY	BLUE	6000	1/1/1984	FG	NTD	YES	LE & VISIBLE /	DW FG	1/1/1984
Hempstead	NY	BLUE	8000	1/1/1985	FG	NR	YES	BALL FLOAT	FG	1/1/1985

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Rockville Centre	NY	BLUE	8000	1/1/2001	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/2001
Seaford	NY	BLUE	8000	1/1/1970	FG	SAC ANODE	YES	BALL FLOAT	STEEL	1/1/1970
Huntington Station	NY	BLUE	8000	1/1/1992	DW FG	NTD	YES	ISIBLE ALAR	DW FG	1/1/1992
North Amityville	NY	BLUE	8000	1/1/1980	FG	NR	YES	LE & VISIBLE	FG	1/1/1980
Mineola	NY	BLUE	8000	1/1/1985	FG	NR	YES	LE & VISIBLE	FG	1/1/1985
Brooklyn	NY	BLUE	8000	9/1/1997	DW FG	NR	YES	LE & VISIBLE	STEEL	12/1/1984
Central Islip	NY	BLUE	8000	1/1/1985	STIP3	IC	YES	LE & VISIBLE	DW FG	1/1/1985
West Babylon	NY	BLUE	8000	1/1/1982	FG	NR	YES	LE & VISIBLE	FG	1/1/1982
Harrison	NY	BLUE	8000	1/1/1978	B/P/A Steel	NTD	YES	BALL FLOAT	STEEL	1/1/1978
Uniondale	NY	BLUE	8000	1/1/1985	FG	NR	YES	TIGHT FILL	FG	1/1/1985
Yonkers	NY	BLUE	8000	1/1/1980	STEEL	IC	YES	TIGHT FILL	STEEL	12/1/1980
Commack	NY	BLUE	8000	1/1/1984	STIP3	IC	YES	LE & VISIBLE	DW FG	1/1/1989
South Hempstead	NY	BLUE	8000	1/1/1986	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1986
Brentwood	NY	BLUE	8000	1/1/1981	FG	NR	YES	LE & VISIBLE	FG	1/1/1981
Greenvale	NY	DIESEL	10000	1/1/1994	DW FG	NR	YES	OPW FILL	DW FG	1/1/1994
Pelham Manor	NY	DIESEL	10000	1/1/1995	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/2001
Syosset	NY	DIESEL	10000	1/1/1994	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1994
Lawrence	NY	GOLD	10000	11/1/1994	DW FG	NR	YES	LE & VISIBLE	DW FG	11/1/1994
Farmingville	NY	GOLD	10000	1/1/1990	DW FG	NTD	YES	ISIBLE ALAR	DW FG	1/1/1990
Hicksville	NY	GOLD	10000	1/1/1988	DW FG	NR	YES	EMCO FILL	FG	1/1/1988
Port Chester	NY	GOLD	10000	1/1/1986	STIP3	IC	YES	LE & VISIBLE	FG	1/1/1986
Port Chester	NY	GOLD	10000	1/1/1986	STIP3	IC	YES	LE & VISIBLE	FG	1/1/1986
Mamaroneck	NY	GOLD	10000	1/1/1992	DW FG	NR	YES	VISIBLE/TIGH	DW FG	1/1/1992
Smithtown	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Brentwood	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Brentwood	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Greenvale	NY	GOLD	10000	1/1/1994	DW FG	NR	YES	OPW FILL	DW FG	1/1/1994
Great Neck	NY	GOLD	10000	1/1/1984	FG	NR	YES	BALL FLOAT	FG	1/1/1984
Great Neck	NY	GOLD	10000	1/1/1984	FG	NR	YES	BALL FLOAT	FG	1/1/1984
Roosevelt	NY	GOLD	10000	1/1/1985	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1985
Brewster	NY	GOLD	10000	4/1/1990	DW STIP3	SAC ANODE	YES	LOAT & TIGH	FG	1/1/1991
Lindenhurst	NY	GOLD	10000	1/1/1991	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Lindenhurst	NY	GOLD	10000	1/1/1982	FG	NR	YES	LE & VISIBLE	FG	1/1/1982

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Port Jefferson	NY	GOLD	10000	1/1/1984	FG	NR	YES	LE & VISIBLE	FG	1/1/1984
Holtsville	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
East Northport	NY	GOLD	10000	1/1/1988	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1988
Albertson	NY	GOLD	10000	1/1/1984	FG	NR	YES	LE & VISIBLE	FG	1/1/1984
Farmingdale	NY	GOLD	10000	1/1/1981	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Farmingdale	NY	GOLD	10000	1/1/1981	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Commack	NY	GOLD	10000	1/1/1991	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Pelham Manor	NY	GOLD	10000	1/1/1995	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/2001
St. James	NY	GOLD	10000	1/1/1987	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1987
Hicksville	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
West Islip	NY	GOLD	10000	1/1/1984	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1984
Elmsford	NY	GOLD	10000	1/1/1984	IPRESSED C	IC	YES	LE & VISIBLE	STEEL	1/1/1984
Elmsford	NY	GOLD	10000	1/1/1984	IPRESSED C	IC	YES	LE & VISIBLE	STEEL	1/1/1984
Franklin Square	NY	GOLD	10000	1/1/1993	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1993
Garden City Park	NY	GOLD	10000	1/1/1983	FG	NR	YES	TIGHT FILL	FG	1/1/1983
Garden City Park	NY	GOLD	10000	1/1/1983	FG	NR	YES	TIGHT FILL	FG	1/1/1983
Levittown	NY	GOLD	10000	1/1/2001	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/2001
Deer Park	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Deer Park	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Ronkonkoma	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
West Islip	NY	GOLD	10000	1/6/1989	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/2001
Bohemia	NY	GOLD	10000	1/1/1990	DW FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1990
Syosset	NY	GOLD	10000	1/1/1994	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1994
Port Washington	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Manhasset	NY	GOLD	10000	1/1/1983	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1983
East Meadow	NY	GOLD	10000	1/1/1983	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1983
Bellmore	NY	GOLD	10000	1/1/1997	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/2001
Freeport	NY	GOLD	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Lake Grove	NY	GOLD	10000	1/1/1989	DW FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1989
Lake Grove	NY	GOLD	10000	1/1/1989	DW FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1989
Blue Point	NY	GOLD	10000	1/1/1990	DW FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1990
Blue Point	NY	GOLD	10000	1/1/1990	DW FG	NTD	NO	NTD	DW FG	1/1/1990
Rocky Point	NY	GOLD	10000	1/1/1988	DW FG	NTD	NO	NTD	DW FG	1/1/1988

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Rocky Point	NY	GOLD	10000	1/1/1988	DW FG	NTD	YES	LE & VISIBLE /	DW FG	1/1/1988
Medford	NY	GOLD	10000	1/1/1989	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1988
Holtsville	NY	GOLD	10000	1/1/1991	DW FG	NTD	YES	LE & VISIBLE /	DW FG	1/1/1991
Franklin Square	NY	GOLD	10000		DW FG	NR	LON BUCKET	LE & VISIBLE /	DW FG	11/1/1996
Centereach	NY	GOLD	10000	1/1/2001	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/2001
Brooklyn	NY	GOLD	12000	1/1/1998	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/2001
Brooklyn	NY	GOLD	12000	1/1/1998	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1998
Yonkers	NY	GOLD	12000	1/1/1992	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/1992
Hicksville	NY	GOLD	12000	7/1/1995	DW FG	NR	YES	LE & VISIBLE /	W ENVIROFLE	7/1/1995
Bronx	NY	GOLD	4000	1/1/1984	DW STEEL	NTD	NO	NONE	STEEL	1/1/1984
Bronx	NY	GOLD	4000	1/1/1989	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1989
Bronx	NY	GOLD	4000	1/1/1989	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1989
Bronx	NY	GOLD	4000	1/1/1979	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1979
Bronx	NY	GOLD	4000	1/1/1985	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	12/1/1985
Bronx	NY	GOLD	4000	1/1/1985	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	12/1/1985
Bronx	NY	GOLD	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED (	1/1/1987
Bronx	NY	GOLD	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED (	1/1/1987
Woodside	NY	GOLD	4000	1/1/1986	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	DW FG	12/1/1986
Woodside	NY	GOLD	4000	1/1/1980	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	DW FG	7/1/1989
Brooklyn	NY	GOLD	4000	1/1/1982	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1982
Brooklyn	NY	GOLD	4000	1/1/1982	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1982
Brooklyn	NY	GOLD	4000	1/1/1983	STIP3	NTD	NO	NTD	STEEL	1/1/1983
Hollis	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED (	5/1/1989
Hollis	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED (	5/1/1989
Brooklyn	NY	GOLD	4000	1/1/1971	STEEL	IC	NO	NONE	STEEL	12/1/1971
Brooklyn	NY	GOLD	4000	6/1/1994	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1994
Brooklyn	NY	GOLD	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	DW FG	1/1/1994
Queens Village	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED (	12/1/1988
Queens Village	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED (	12/1/1988
Brooklyn	NY	GOLD	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	FG	6/1/1993
Brooklyn	NY	GOLD	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	FG	6/1/1993
Brooklyn	NY	GOLD	4000	1/1/1972	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1972
Brooklyn	NY	GOLD	4000	1/1/1972	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1972

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Brooklyn	NY	GOLD	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	FG	6/1/1993
Brooklyn	NY	GOLD	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	FG	6/1/1993
Brooklyn	NY	GOLD	4000	1/1/1979	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1979
Brooklyn	NY	GOLD	4000	1/1/1986	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED C	12/1/1986
Brooklyn	NY	GOLD	4000	1/1/1986	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED C	12/1/1986
Bronx	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED C	5/1/1989
Bronx	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE /	/APPROVED C	5/1/1989
Brooklyn	NY	GOLD	4000	########	DW FG	NR	YES	LE & VISIBLE /	DW FG	6/1/1993
Brooklyn	NY	GOLD	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	DW FG	6/1/1993
Brooklyn	NY	GOLD	4000	1/1/1978	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1978
Brooklyn	NY	GOLD	4000	1/1/1978	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1978
New Rochelle	NY	GOLD	4000	1/1/1986	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	1/1/1986
New Rochelle	NY	GOLD	4000	1/1/1986	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	1/1/1986
New Rochelle	NY	GOLD	4000	1/1/1986	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	1/1/1986
New Rochelle	NY	GOLD	4000	1/1/1986	IPRESSED C	IC	YES	LE & VISIBLE /	STEEL	1/1/1986
Flushing	NY	GOLD	4000	1/1/1986	DW STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1986
Flushing	NY	GOLD	4000	1/1/1986	DW STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1986
Woodside	NY	GOLD	4000	1/1/1983	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1983
Woodside	NY	GOLD	4000	1/1/1983	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1983
East Elmhurst	NY	GOLD	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	DW FG	6/1/1993
East Elmhurst	NY	GOLD	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE /	DW FG	6/1/1993
Brooklyn	NY	GOLD	4000		FG	IC	YES	LE & VISIBLE /	/APPROVED C	12/1/1991
Brooklyn	NY	GOLD	4000		FG	IC	YES	LE & VISIBLE /	/APPROVED C	12/1/1991
Staten Island	NY	GOLD	4000	1/1/1985	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1985
Staten Island	NY	GOLD	4000	1/1/1985	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1985
Staten Island	NY	GOLD	4000	1/1/1985	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1985
Staten Island	NY	GOLD	4000	1/1/1985	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1985
Bronx	NY	GOLD	4000	1/1/1978	B/P/A Steel	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1978
Brooklyn	NY	GOLD	4000	1/1/1984	DW STEEL	SAC ANODE	NO	NONE	STEEL	12/1/1984
Flushing	NY	GOLD	4000	1/1/1986	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1986
Flushing	NY	GOLD	4000	1/1/1986	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/1986
Maspeth	NY	GOLD	4000	1/1/1990	FCS	IC	YES	LE & VISIBLE /	/APPROVED C	8/1/1990
Maspeth	NY	GOLD	4000	1/1/1990	FCS	IC	YES	LE & VISIBLE /	/APPROVED C	8/1/1990

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Maspeth	NY	GOLD	4000	1/1/1990	FCS	IC	YES	LE & VISIBLE	/APPROVED	8/1/1990
Brooklyn	NY	GOLD	4000	1/1/1992	DW STEEL	NTD	YES	UDIBLE ALAR	/APPROVED	12/1/1992
Brooklyn	NY	GOLD	4000	1/1/1992	DW STEEL	NTD	YES	UDIBLE ALAR	/APPROVED	12/1/1992
Elmhurst	NY	GOLD	4000	1/1/1979	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1979
Elmhurst	NY	GOLD	4000	1/1/1979	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1979
Jackson Heights	NY	GOLD	4000	1/1/1984	MPRESSED C	IC	YES	LE & VISIBLE	/APPROVED	1/1/1984
Jackson Heights	NY	GOLD	4000	1/1/1984	MPRESSED C	IC	YES	LE & VISIBLE	/APPROVED	1/1/1984
Bronx	NY	GOLD	4000	1/1/1990	DW STEEL	SAC ANODE	YES	LE & VISIBLE	/APPROVED	12/1/1989
Bronx	NY	GOLD	4000	1/1/1990	DW STEEL	SAC ANODE	YES	LE & VISIBLE	/APPROVED	12/1/1989
Brooklyn	NY	GOLD	4000	1/1/1983	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	12/1/1983
Brooklyn	NY	GOLD	4000	1/1/1983	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	12/1/1983
Elmhurst	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1972
Elmhurst	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	STEEL	5/1/1989
Bronx	NY	GOLD	4000	1/1/1982	STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1982
Bronx	NY	GOLD	4000	1/1/1982	STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1972
Brooklyn	NY	GOLD	4000	12/1/1978	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1978
Brooklyn	NY	GOLD	4000	12/1/1978	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1978
St. Albans	NY	GOLD	4000	1/1/1901	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	6/1/1989
St. Albans	NY	GOLD	4000	1/1/1901	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	6/1/1989
Jamaica	NY	GOLD	4000	1/1/1987	DW FG	NR	YES	LE & VISIBLE	STEEL	12/1/1987
Jamaica	NY	GOLD	4000	1/1/1987	DW FG	NR	YES	LE & VISIBLE	STEEL	12/1/1987
Flushing	NY	GOLD	4000	1/1/1990	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	8/1/1989
Flushing	NY	GOLD	4000	1/1/1990	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	8/1/1989
Bronx	NY	GOLD	4000	1/1/1986	B/P/A Steel	SAC	YES	LE & VISIBLE	/APPROVED	12/1/1986
Bronx	NY	GOLD	4000	1/1/1986	B/P/A Steel	SAC	YES	LE & VISIBLE	/APPROVED	12/1/1986
Brooklyn	NY	GOLD	4000	1/1/1988	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	1/1/2001
Brooklyn	NY	GOLD	4000	1/1/1988	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	1/1/1988
New York	NY	GOLD	4000	1/1/1996	DW STEEL	IC	YES	LE & VISIBLE	STEEL	4/1/1989
New York	NY	GOLD	4000	1/1/1996	DW STEEL	IC	YES	LE & VISIBLE	STEEL	4/1/1989
New York	NY	GOLD	4000	1/1/1996	DW STEEL	IC	YES	LE & VISIBLE	STEEL	4/1/1989
Howard Beach	NY	GOLD	4000	1/1/1996	DW FG	NR	YES	LE & VISIBLE	DW FG	6/1/1995
Howard Beach	NY	GOLD	4000	1/1/1996	DW FG	NR	YES	LE & VISIBLE	DW FG	6/1/1995
Yonkers	NY	GOLD	4000	1/1/1980	STEEL	IC	YES	TIGHT FILL	STEEL	12/1/1973

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New York	NY	GOLD	4000	1/1/1984	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1984
New York	NY	GOLD	4000	1/1/1984	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1984
Bronx	NY	GOLD	4000	1/1/1986	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1986
Bronx	NY	GOLD	4000	1/1/1990	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	STEEL	6/1/1989
Bronx	NY	GOLD	4000	1/1/1985	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1985
Bronx	NY	GOLD	4000	1/1/1985	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1985
Brooklyn	NY	GOLD	4000	1/1/1977	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1977
Brooklyn	NY	GOLD	4000	1/1/1977	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1977
Bayside	NY	GOLD	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE /	/APPROVED C	1/1/1989
Bayside	NY	GOLD	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE /	/APPROVED C	1/1/1989
Flushing	NY	GOLD	4000		DW STEEL	SAC ANODE	YES	LE & VISIBLE /	/APPROVED C	5/1/1989
Flushing	NY	GOLD	4000		DW STEEL	SAC ANODE	YES	IBLE & TIGHT	/APPROVED C	5/1/1989
Bronx	NY	GOLD	4000	1/1/1986	STEEL	SAC ANODE	YES	LE & VISIBLE /	/APPROVED C	12/1/1987
Bronx	NY	GOLD	4000	1/1/1989	STEEL	SAC ANODE	YES	LE & VISIBLE /	/APPROVED C	7/1/1989
Bronx	NY	GOLD	4000	1/1/1984	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1984
Bronx	NY	GOLD	4000	1/1/1984	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1984
Brooklyn	NY	GOLD	4000	1/1/1976	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1976
Brooklyn	NY	GOLD	4000	1/1/1976	STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1976
Brooklyn	NY	GOLD	4000	6/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE /	/APPROVED C	6/1/1990
Brooklyn	NY	GOLD	4000	6/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE /	/APPROVED C	6/1/1990
Richmond Hill	NY	GOLD	4000	1/1/1990	IPRESSED C	IC	YES	LE & VISIBLE /	/APPROVED C	1/1/1990
Richmond Hill	NY	GOLD	4000	1/1/1990	IPRESSED C	IC	YES	LE & VISIBLE /	/APPROVED C	1/1/1990
Brooklyn	NY	GOLD	4000	6/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE /	STEEL	6/1/1990
Brooklyn	NY	GOLD	4000	6/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE /	STEEL	6/1/1990
Jamaica	NY	GOLD	4000		STEEL	IC	YES	LE & VISIBLE /	STEEL	3/1/1990
Jamaica	NY	GOLD	4000		STEEL	IC	YES	LE & VISIBLE /	STEEL	3/1/1990
Brooklyn	NY	GOLD	4000	1/1/2000	FG	IC	YES	LE & VISIBLE /	/APPROVED C	11/1/1991
Brooklyn	NY	GOLD	4000	1/1/2000	FG	IC	YES	LE & VISIBLE /	/APPROVED C	11/1/1991
Rosedale	NY	GOLD	4000	1/1/1998	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	4/1/1987
New York	NY	GOLD	4000	1/1/1978	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	5/1/1982
New York	NY	GOLD	4000	1/1/1978	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	5/1/1982
Brooklyn	NY	GOLD	4000	1/1/2001	B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	1/1/2001
Brooklyn	NY	GOLD	4000		B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	12/1/1988

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Brooklyn	NY	GOLD	4000	1/1/2000	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	6/1/1984
Brooklyn	NY	GOLD	4000	5/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	5/1/1990
Brooklyn	NY	GOLD	4000	5/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	5/1/1990
Howard Beach	NY	GOLD	4000	1/1/1990	DW STIP3	SA	YES	LE & VISIBLE	/APPROVED	12/1/1989
Howard Beach	NY	GOLD	4000	1/1/1990	DW STIP3	SA	YES	LE & VISIBLE	/APPROVED	12/1/1989
Brooklyn	NY	GOLD	4000	1/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	1/1/1990
Brooklyn	NY	GOLD	4000	1/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	1/1/1990
Long Island City	NY	GOLD	4000	1/1/1987	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	1/1/1987
Long Island City	NY	GOLD	4000	1/1/1991	FCS	IC	YES	LE & VISIBLE	/APPROVED	1/1/1991
Brooklyn	NY	GOLD	4000	1/1/1992	W BUFFHID	IC	YES	LE & VISIBLE	/APPROVED	8/1/1992
Brooklyn	NY	GOLD	4000	1/1/1992	W BUFFHID	IC	YES	LE & VISIBLE	/APPROVED	8/1/1992
Brooklyn	NY	GOLD	4000	6/1/1988	STEEL	IC	YES	LE & VISIBLE	STEEL	11/1/1986
Brooklyn	NY	GOLD	4000	6/1/1988	STEEL	IC	YES	LE & VISIBLE	STEEL	11/1/1986
Brooklyn	NY	GOLD	4000	11/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE	/APPROVED	10/1/1990
Brooklyn	NY	GOLD	4000	11/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE	/APPROVED	10/1/1990
Little Neck	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	1/1/1991
Little Neck	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	1/1/1991
New York	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	6/1/1987
New York	NY	GOLD	4000	1/1/1979	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	6/1/1987
Hollis	NY	GOLD	4000	1/1/2000	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	4/1/1991
Hollis	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	4/1/1991
New York	NY	GOLD	4000	1/1/1992	DW STEEL	NTD	YES	LE & VISIBLE	/APPROVED	11/1/1992
New York	NY	GOLD	4000	1/1/1992	DW STEEL	NTD	YES	LE & VISIBLE	/APPROVED	11/1/1992
South Ozone Park	NY	GOLD	4000	1/1/1990	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	10/1/1990
South Ozone Park	NY	GOLD	4000	1/1/1990	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	10/1/1990
South Ozone Park	NY	GOLD	4000	1/1/1990	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	10/1/1990
Corona	NY	GOLD	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1987
Corona	NY	GOLD	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1987
Bronx	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	1/1/1989
Bronx	NY	GOLD	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	1/1/1989
Bronx	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	3/1/1989
Bronx	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	3/1/1989
Staten Island	NY	GOLD	4000	6/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	6/1/1990

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Staten Island	NY	GOLD	4000	6/1/1990	DW STIP3	IC	YES	LE & VISIBLE /	/APPROVED C	6/1/1990
Springfield Gardens	NY	GOLD	4000		DW STIP3	IC	YES	LE & VISIBLE /	STEEL	8/1/1989
Springfield Gardens	NY	GOLD	4000		DW STIP3	IC	YES	LE & VISIBLE /	STEEL	8/1/1989
Brooklyn	NY	GOLD	4000	12/1/1989	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1989
Brooklyn	NY	GOLD	4000	12/1/1989	DW STEEL	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1989
Staten Island	NY	GOLD	4000		B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	5/1/1992
Staten Island	NY	GOLD	4000		B/P/A Steel	IC	YES	LE & VISIBLE /	STEEL	5/1/1992
Richmond Hill	NY	GOLD	4000	########	DW BUFFHID	SAC ANODE	YES	LE & VISIBLE /	STEEL	10/1/1990
Richmond Hill	NY	GOLD	4000	########	DW BUFFHID	SAC ANODE	YES	LE & VISIBLE /	STEEL	10/1/1990
Staten Island	NY	GOLD	4000	1/1/2001	DW STEEL	IC	YES	LE & VISIBLE /	STEEL	4/1/1991
Staten Island	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	4/1/1991
Bronx	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	1/1/1990
Bronx	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	1/1/1990
Fresh Meadows	NY	GOLD	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE /	STEEL	12/1/1989
Fresh Meadows	NY	GOLD	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE /	STEEL	12/1/1989
Bronx	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1990
Bronx	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	12/1/1990
Brooklyn	NY	GOLD	4000	11/1/1989	FG	SAC ANODE	YES	LE & VISIBLE /	DW FG	11/1/1989
Brooklyn	NY	GOLD	4000	11/1/1989	FG	SAC ANODE	YES	LE & VISIBLE /	DW FG	11/1/1989
Brooklyn	NY	GOLD	4000	10/1/1989	DW FG	NR	YES	LE & VISIBLE /	FG	10/1/1989
Brooklyn	NY	GOLD	4000	10/1/1989	DW FG	NR	YES	LE & VISIBLE /	FG	10/1/1989
Bronx	NY	GOLD	4000		FG	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1991
Bronx	NY	GOLD	4000		FG	SAC ANODE	YES	LE & VISIBLE /	STEEL	12/1/1991
Staten Island	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	10/1/1991
Staten Island	NY	GOLD	4000		DW STEEL	IC	YES	LE & VISIBLE /	STEEL	10/1/1991
Bronx	NY	GOLD	4000		FG	SAC ANODE	YES	LE & VISIBLE /	/APPROVED C	7/1/1991
Bronx	NY	GOLD	4000		FG	SAC ANODE	YES	IBLE & TIGHT	/APPROVED C	7/1/1991
Brooklyn	NY	GOLD	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	DW FG	10/1/1993
Brooklyn	NY	GOLD	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE /	DW FG	10/1/1993
Brooklyn	NY	GOLD	4000		FG	SAC ANODE	NO	LE & VISIBLE /	/APPROVED C	12/1/1991
Brooklyn	NY	GOLD	4000		FG	SAC ANODE	NO	LE & VISIBLE /	STEEL	12/1/1991
Seaford	NY	GOLD	6000	1/1/1970	FG	SAC ANODE	YES	BALL FLOAT	STEEL	1/1/1970
Elmont	NY	GOLD	6000	1/1/1985	FG	NR	YES	LE & VISIBLE /	FG	1/1/1985

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Greenburgh	NY	GOLD	6000	1/1/1985	BT10	IC	YES	TIGHT FILL	FG	1/1/1982
Hempstead	NY	GOLD	6000	1/1/1986	FG	NR	NO	NO	/APPROVED	1/1/1986
Hempstead	NY	GOLD	8000	1/1/1985	FG	NR	YES	BALL FLOAT	FG	1/1/1985
Rockville Centre	NY	GOLD	8000	1/1/2001	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/2001
Melville	NY	GOLD	8000	1/1/1991	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Melville	NY	GOLD	8000	1/1/1991	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Huntington Station	NY	GOLD	8000	1/1/1992	DW FG	NTD	YES	VISIBLE ALAR	DW FG	1/1/1992
North Amityville	NY	GOLD	8000	1/1/1980	FG	NR	YES	LE & VISIBLE	FG	1/1/1980
North Amityville	NY	GOLD	8000	1/1/1980	FG	NR	YES	LE & VISIBLE	FG	1/1/1980
Mineola	NY	GOLD	8000	1/1/1985	FG	NR	YES	LE & VISIBLE	FG	1/1/1985
Brooklyn	NY	GOLD	8000	9/1/1997	DW FG	NR	YES	LE & VISIBLE	STEEL	12/1/1984
Central Islip	NY	GOLD	8000	1/1/1985	STIP3	IC	YES	LE & VISIBLE	DW FG	1/1/1985
West Babylon	NY	GOLD	8000	1/1/1982	FG	NR	YES	LE & VISIBLE	FG	1/1/1982
Harrison	NY	GOLD	8000	1/1/1978	B/P/A Steel	NTD	YES	BALL FLOAT	STEEL	1/1/1978
Uniondale	NY	GOLD	8000	1/1/1985	FG	NR	YES	TIGHT FILL	FG	1/1/1985
Commack	NY	GOLD	8000	1/1/1984	STIP3	IC	YES	LE & VISIBLE	DW FG	1/1/1989
South Hempstead	NY	GOLD	8000	1/1/1986	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1986
Elmont	NY	GOLD	8000	1/1/1987	DW FG	NR	YES	NTD	FG	1/1/1987
Brentwood	NY	GOLD	8000	1/1/1981	FG	NR	YES	LE & VISIBLE	FG	1/1/1981
Huntington Station	NY	GOLD	8000	1/1/1984	FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1984
Brooklyn	NY	NTD	10000	1/1/2001	DW FG	NTD	NTD	NTD	DW FG	1/1/2001
Brooklyn	NY	NTD	10000	1/1/2001	DW FG	NTD	NTD	NTD	DW FG	1/1/2001
Bellmore	NY	NTD	10000	1/1/1997	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/2001
Brooklyn	NY	NTD	12000	1/1/2001	DW FG	NTD	NTD	NTD	DW FG	1/1/2001
Brooklyn	NY	NTD	275	1/1/2000	B/P/A Steel	NTD	NTD	NTD	NTD	2/1/1993
Howard Beach	NY	NTD	275	1/1/2000	DW STEEL	NTD	NTD	NTD	NTD	
Bronx	NY	NTD	4000		DW FG	NTD	NO	NONE	NTD	
Mamaroneck	NY	NTD	500	1/1/1992	DW FG	SAC ANODE	NO	NTD	NTD	1/1/1992
Bronx	NY	NTD	550		NTD	NTD	NTD	NTD	NTD	1/1/2001
Lawrence	NY	SILVER	10000	11/1/1994	DW FG	NR	YES	LE & VISIBLE	DW FG	11/1/1994
Farmingville	NY	SILVER	10000	1/1/1990	DW FG	NTD	YES	VISIBLE ALAR	DW FG	1/1/1990
Hicksville	NY	SILVER	10000	1/1/1988	DW FG	NR	YES	EMCO FILL	FG	1/1/1988
Port Chester	NY	SILVER	10000	1/1/1986	STIP3	IC	YES	LE & VISIBLE	FG	1/1/1986

City	State	Tank Content	Tank Size	Installed Date	Tank Construction	Cathodic Protection	Tank Spill Containment	Tank Overfill Protection	Pipe Construction	Piping Installed
Smithtown	NY	SILVER	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Brentwood	NY	SILVER	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Greenvale	NY	SILVER	10000	1/1/1978	B/P/A Steel	SAC ANODE	YES	BALL FLOAT	STEEL	1/1/1978
Greenvale	NY	SILVER	10000	1/1/1994	DW FG	NR	YES	OPW FILL	DW FG	1/1/1994
Great Neck	NY	SILVER	10000	1/1/1984	FG	NR	YES	BALL FLOAT	FG	1/1/1984
Roosevelt	NY	SILVER	10000	1/1/1985	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1985
Brewster	NY	SILVER	10000	4/1/1990	DW STIP3	SAC ANODE	YES	FLOAT & TIGH	FG	1/1/1991
Lindenhurst	NY	SILVER	10000	1/1/1991	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Lindenhurst	NY	SILVER	10000	1/1/1982	FG	NR	YES	LE & VISIBLE	FG	1/1/1982
Port Jefferson	NY	SILVER	10000	1/1/1984	FG	NR	YES	LE & VISIBLE	FG	1/1/1984
Holtsville	NY	SILVER	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
East Northport	NY	SILVER	10000	1/1/1988	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1988
Farmingdale	NY	SILVER	10000	1/1/1981	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Commack	NY	SILVER	10000	1/1/1991	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Pelham Manor	NY	SILVER	10000	1/1/1995	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/2001
St. James	NY	SILVER	10000	1/1/1987	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1987
Brooklyn	NY	SILVER	10000	1/1/1998	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1998
Hicksville	NY	SILVER	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
West Islip	NY	SILVER	10000	1/1/1984	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1984
Elmsford	NY	SILVER	10000	1/1/1984	IPRESSED C	IC	YES	LE & VISIBLE	STEEL	1/1/1984
Franklin Square	NY	SILVER	10000	1/1/1993	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1993
Garden City Park	NY	SILVER	10000	1/1/1983	FG	NR	YES	TIGHT FILL	FG	1/1/1983
Levittown	NY	SILVER	10000	1/1/2001	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/2001
Deer Park	NY	SILVER	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Ronkonkoma	NY	SILVER	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
West Islip	NY	SILVER	10000	1/1/1989	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/2001
Bohemia	NY	SILVER	10000	1/1/1990	DW FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1990
Syosset	NY	SILVER	10000	1/1/1994	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1994
Port Washington	NY	SILVER	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990
Manhasset	NY	SILVER	10000	1/1/1983	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1983
East Meadow	NY	SILVER	10000	1/1/1983	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1983
Bellmore	NY	SILVER	10000	1/1/1997	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/2001
Freeport	NY	SILVER	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990

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Lake Grove	NY	SILVER	10000	1/1/1989	DW FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1989
Blue Point	NY	SILVER	10000	1/1/1990	DW FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1990
Rocky Point	NY	SILVER	10000	1/1/1988	DW FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1988
Medford	NY	SILVER	10000	1/1/1989	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1988
Holtsville	NY	SILVER	10000	1/1/1991	DW FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1991
Franklin Square	NY	SILVER	10000		DW FG	NR	LON BUCKET	LE & VISIBLE	DW FG	11/1/1996
Centereach	NY	SILVER	10000	1/1/2001	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/2001
Brooklyn	NY	SILVER	12000	1/1/1998	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/2001
Yonkers	NY	SILVER	12000	1/1/1992	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/1992
Hicksville	NY	SILVER	12000	7/1/1995	DW FG	NR	YES	LE & VISIBLE	W ENVIROFLE	7/1/1995
Harrison	NY	SILVER	3000	1/1/1972	B/P/A Steel	NTD	YES	BALL FLOAT	STEEL	1/1/1972
Bronx	NY	SILVER	4000	1/1/1984	DW STEEL	NTD	NO	NONE	STEEL	1/1/1984
Bronx	NY	SILVER	4000	1/1/1979	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	1/1/1979
Bronx	NY	SILVER	4000	1/1/1985	PRESSED C	IC	YES	LE & VISIBLE	STEEL	12/1/1985
Bronx	NY	SILVER	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	1/1/1987
Bronx	NY	SILVER	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	1/1/1987
Woodside	NY	SILVER	4000	1/1/1986	DW STEEL	SAC ANODE	YES	LE & VISIBLE	DW FG	12/1/1986
Brooklyn	NY	SILVER	4000	1/1/1982	STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1982
Brooklyn	NY	SILVER	4000	1/1/1983	STIP3	NTD	NO	NTD	STEEL	1/1/1983
Hollis	NY	SILVER	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	5/1/1989
Brooklyn	NY	SILVER	4000	1/1/1971	STEEL	IC	NO	NONE	STEEL	12/1/1971
Brooklyn	NY	SILVER	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1994
Queens Village	NY	SILVER	4000	1/1/1989	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	12/1/1986
Brooklyn	NY	SILVER	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE	FG	6/1/1993
Brooklyn	NY	SILVER	4000	1/1/1972	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	1/1/1972
Brooklyn	NY	SILVER	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE	FG	6/1/1993
Brooklyn	NY	SILVER	4000	1/1/1983	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	1/1/1983
Brooklyn	NY	SILVER	4000	1/1/1986	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1986
Bronx	NY	SILVER	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1986
Brooklyn	NY	SILVER	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE	DW FG	6/1/1993
Brooklyn	NY	SILVER	4000	1/1/1978	STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1978
New Rochelle	NY	SILVER	4000	1/1/1986	PRESSED C	IC	YES	LE & VISIBLE	STEEL	1/1/1986
New Rochelle	NY	SILVER	4000	1/1/1986	PRESSED C	IC	YES	LE & VISIBLE	STEEL	1/1/1986

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Flushing	NY	SILVER	4000	1/1/1986	DW STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1986
Woodside	NY	SILVER	4000	1/1/1983	STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1983
East Elmhurst	NY	SILVER	4000	1/1/1994	DW FG	NR	YES	LE & VISIBLE	DW FG	6/1/1993
Brooklyn	NY	SILVER	4000		FG	IC	YES	LE & VISIBLE	/APPROVED	12/1/1991
Staten Island	NY	SILVER	4000	1/1/1985	STEEL	IC	YES	IBLE & TIGHT	STEEL	12/1/1985
Staten Island	NY	SILVER	4000	1/1/1985	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1985
Bronx	NY	SILVER	4000	1/1/1978	B/P/A Steel	SAC ANODE	YES	LE & VISIBLE	STEEL	12/1/1978
Flushing	NY	SILVER	4000	1/1/1986	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	1/1/1986
Maspeth	NY	SILVER	4000	1/1/1990	FCS	IC	YES	LE & VISIBLE	/APPROVED	8/1/1990
Brooklyn	NY	SILVER	4000	1/1/1992	DW STEEL	NTD	YES	UDIBLE ALAR	/APPROVED	12/1/1992
Elmhurst	NY	SILVER	4000	1/1/1979	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1979
Jackson Heights	NY	SILVER	4000	1/1/1984	PRESSED C	IC	YES	LE & VISIBLE	/APPROVED	1/1/1984
Bronx	NY	SILVER	4000	1/1/1990	DW STEEL	SAC ANODE	YES	LE & VISIBLE	/APPROVED	12/1/1989
Brooklyn	NY	SILVER	4000	1/1/1983	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	12/1/1983
Elmhurst	NY	SILVER	4000	1/1/1982	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1982
Bronx	NY	SILVER	4000	1/1/1982	STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1982
Brooklyn	NY	SILVER	4000	12/1/1978	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1978
St. Albans	NY	SILVER	4000	1/1/1901	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	
Jamaica	NY	SILVER	4000	1/1/1987	DW FG	NR	YES	LE & VISIBLE	STEEL	12/1/1987
Flushing	NY	SILVER	4000	1/1/1983	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1983
Bronx	NY	SILVER	4000	1/1/1986	B/P/A Steel	SAC	YES	LE & VISIBLE	/APPROVED	12/1/1986
Brooklyn	NY	SILVER	4000	1/1/1988	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	1/1/1988
New York	NY	SILVER	4000	1/1/1996	DW STEEL	IC	YES	LE & VISIBLE	STEEL	4/1/1989
Howard Beach	NY	SILVER	4000	1/1/1996	DW FG	NR	YES	LE & VISIBLE	DW FG	6/1/1995
New York	NY	SILVER	4000	1/1/1984	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1984
Bronx	NY	SILVER	4000	1/1/1986	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	12/1/1986
Bronx	NY	SILVER	4000	1/1/1985	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	12/1/1985
Brooklyn	NY	SILVER	4000	1/1/1977	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1977
Bayside	NY	SILVER	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	1/1/1989
Flushing	NY	SILVER	4000		DW STEEL	SAC ANODE	YES	LE & VISIBLE	/APPROVED	5/1/1989
Bronx	NY	SILVER	4000	1/1/1986	STEEL	SAC ANODE	YES	LE & VISIBLE	/APPROVED	12/1/1987
Bronx	NY	SILVER	4000	1/1/1984	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1984
Brooklyn	NY	SILVER	4000	1/1/1976	STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1976

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Brooklyn	NY	SILVER	4000	6/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE	/APPROVED	6/1/1990
Richmond Hill	NY	SILVER	4000	1/1/1987	PRESSED C	IC	YES	LE & VISIBLE	/APPROVED	1/1/1990
Brooklyn	NY	SILVER	4000	1/1/1984	DW STEEL	SAC ANODE	YES	LE & VISIBLE	STEEL	10/1/1982
Jamaica	NY	SILVER	4000		STEEL	IC	YES	LE & VISIBLE	STEEL	9/1/1977
Brooklyn	NY	SILVER	4000	1/1/2000	FG	IC	YES	LE & VISIBLE	/APPROVED	11/1/1991
Rosedale	NY	SILVER	4000	1/1/1998	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	4/1/1987
New York	NY	SILVER	4000	1/1/1978	B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	5/1/1982
Brooklyn	NY	SILVER	4000		B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	12/1/1988
Brooklyn	NY	SILVER	4000	1/1/2000	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	5/1/1990
Howard Beach	NY	SILVER	4000	1/1/1990	DW STIP3	SA	YES	LE & VISIBLE	/APPROVED	12/1/1989
Brooklyn	NY	SILVER	4000	1/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	1/1/1990
Long Island City	NY	SILVER	4000	1/1/1987	B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	1/1/1987
Brooklyn	NY	SILVER	4000	1/1/1992	W BUFFHID	IC	YES	LE & VISIBLE	/APPROVED	8/1/1992
Brooklyn	NY	SILVER	4000	6/1/1988	STEEL	IC	YES	LE & VISIBLE	STEEL	11/1/1986
Brooklyn	NY	SILVER	4000	11/1/1990	DW STIP3	SAC ANODE	YES	LE & VISIBLE	/APPROVED	10/1/1990
Little Neck	NY	SILVER	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	1/1/1991
New York	NY	SILVER	4000		DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	6/1/1987
Hollis	NY	SILVER	4000		B/P/A Steel	IC	YES	LE & VISIBLE	/APPROVED	9/1/1986
New York	NY	SILVER	4000	1/1/1992	DW STEEL	NTD	YES	LE & VISIBLE	/APPROVED	11/1/1992
South Ozone Park	NY	SILVER	4000	1/1/1990	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	10/1/1990
Corona	NY	SILVER	4000	1/1/1987	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	12/1/1987
Bronx	NY	SILVER	4000	1/1/1989	DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	1/1/1989
Bronx	NY	SILVER	4000		DW STEEL	IC	YES	LE & VISIBLE	/APPROVED	3/1/1989
Staten Island	NY	SILVER	4000	6/1/1990	DW STIP3	IC	YES	LE & VISIBLE	/APPROVED	6/1/1990
Springfield Gardens	NY	SILVER	4000		DW STIP3	IC	YES	LE & VISIBLE	STEEL	8/1/1989
Brooklyn	NY	SILVER	4000	12/1/1989	DW STEEL	SAC	YES	LE & VISIBLE	STEEL	12/1/1989
Staten Island	NY	SILVER	4000		B/P/A Steel	IC	YES	LE & VISIBLE	STEEL	5/1/1992
Richmond Hill	NY	SILVER	4000	########	W BUFFHID	SAC ANODE	YES	LE & VISIBLE	STEEL	10/1/1990
Staten Island	NY	SILVER	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	4/1/1991
Bronx	NY	SILVER	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	1/1/1990
Fresh Meadows	NY	SILVER	4000	1/1/1989	DW STIP3	IC	YES	LE & VISIBLE	STEEL	12/1/1989
Bronx	NY	SILVER	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	12/1/1990
Brooklyn	NY	SILVER	4000	11/1/1989	FG	SAC ANODE	YES	LE & VISIBLE	DW FG	11/1/1989

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Brooklyn	NY	SILVER	4000	10/1/1989	DW FG	NR	YES	LE & VISIBLE	FG	10/1/1989
Bronx	NY	SILVER	4000		FG	SAC ANODE	YES	LE & VISIBLE	STEEL	12/1/1991
Staten Island	NY	SILVER	4000		DW STEEL	IC	YES	LE & VISIBLE	STEEL	10/1/1991
Bronx	NY	SILVER	4000		FG	SAC ANODE	YES	LE & VISIBLE	/APPROVED	7/1/1991
Brooklyn	NY	SILVER	4000	1/1/1993	DW FG	NR	YES	LE & VISIBLE	DW FG	10/1/1993
Brooklyn	NY	SILVER	4000		FG	SAC ANODE	NO	LE & VISIBLE	/APPROVED	12/1/1991
Seaford	NY	SILVER	6000	1/1/1970	FG	SAC ANODE	YES	EMCO FILL	STEEL	1/1/1970
Greenburgh	NY	SILVER	6000	1/1/1982	B/P/A Steel	IC	YES	TIGHT FILL	FG	1/1/1982
Hempstead	NY	SILVER	6000	1/1/1986	FG	NR	NO	NO	/APPROVED	1/1/1986
Hempstead	NY	SILVER	8000	1/1/1985	FG	NR	YES	BALL FLOAT	FG	1/1/1985
Rockville Centre	NY	SILVER	8000	1/1/2001	DW FG	NR	YES	TIGHT FILL	DW FG	1/1/2001
Melville	NY	SILVER	8000	1/1/1991	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1991
Huntington Station	NY	SILVER	8000	1/1/1992	DW FG	NTD	YES	ISIBLE ALAR	DW FG	1/1/1992
North Amityville	NY	SILVER	8000	1/1/1980	FG	NR	YES	LE & VISIBLE	FG	1/1/1980
Mineola	NY	SILVER	8000	1/1/1985	FG	NR	YES	LE & VISIBLE	FG	1/1/1985
Brooklyn	NY	SILVER	8000	9/1/1997	DW FG	NR	YES	LE & VISIBLE	STEEL	12/1/1984
Central Islip	NY	SILVER	8000	1/1/1985	STIP3	IC	YES	LE & VISIBLE	DW FG	1/1/1985
West Babylon	NY	SILVER	8000	1/1/1982	FG	NR	YES	LE & VISIBLE	FG	1/1/1982
Albertson	NY	SILVER	8000	1/1/1984	FG	NR	YES	LE & VISIBLE	FG	1/1/1984
Uniondale	NY	SILVER	8000	1/1/1985	FG	NR	YES	TIGHT FILL	FG	1/1/1985
Yonkers	NY	SILVER	8000	1/1/1972	STEEL	IC	YES	TIGHT FILL	STEEL	12/1/1980
Commack	NY	SILVER	8000	1/1/1984	STIP3	IC	YES	LE & VISIBLE	DW FG	1/1/1989
South Hempstead	NY	SILVER	8000	1/1/1986	FG	NR	YES	LE & VISIBLE	DW FG	1/1/1986
Elmont	NY	SILVER	8000	1/1/1987	DW FG	NR	YES	LE & VISIBLE	FG	1/1/1987
Brentwood	NY	SILVER	8000	1/1/1981	FG	NR	YES	LE & VISIBLE	FG	1/1/1981
Huntington Station	NY	SILVER	8000	1/1/1984	FG	NTD	YES	LE & VISIBLE	DW FG	1/1/1984
Smithtown	NY	CULAR DI	10000	1/1/1990	DW FG	NR	YES	LE & VISIBLE	DW FG	1/1/1990