

Characteristics of Gasoline Releases in the Water Table Aquifer of Long Island

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Abstract

The aquifers of Long Island serve as the sole-source drinking water supply for approximately 3 million people. About 20 percent of this population obtain drinking water directly from the water table aquifer (Upper Glacial) whereas the remainder obtain their drinking water from deeper aquifers (Magothy and Lloyd). High population density assures a large number of gasoline stations and numerous fuel releases which directly impact the water table aquifer. Thin surface soils overlie the coarse sands and gravels of the Upper Glacial aquifer through this area, leaving the aquifer particularly vulnerable to contamination. This paper summarizes observations from four gasoline release cases investigated by the New York State Department of Environmental Conservation with input from U.S. Environmental Protection Agency. The sites chosen for study are ones where data collection efforts had generated a well-characterized plume. Since all the sites are on Long Island, they share some common general characteristics, namely similar climate and geology. Differences in observed plumes result from the differences in timing and volume of the releases, prior release history and the chemical properties of benzene, toluene, ethylbenzene, and xylene (BTEX) and Methyl tert-butyl ether (MTBE), rather than dramatic hydrogeologic variation among the sites.

At the East Patchogue and Riverhead sites, the MTBE plume is moving as a pulse ahead of the benzene and other plumes. This appears largely due to high ground water velocity and high recharge rate causing relatively rapid dissolution of MTBE from the gasoline. In contrast at the Uniondale and Lindenhurst sites, the MTBE plume is continuous with the source. Although the ground water velocity and recharge rate at these locations are also high, the releases are positively dated to a later time than either East Patchogue or Riverhead. Thus the Uniondale and Lindenhurst plumes have had roughly ten years less time to evolve. Qualitative differences between the plume configurations seem mostly related to the differing release times. Common characteristics of the detached plumes are longer *in situ* times, lack of observed free product, and unpaved surfaces. The attached plumes share the opposite characteristics.

In addition to the high ground water velocity, a reason for the long length of some of the plumes is the vertical characterization used at these sites. Vertical characterization avoids 1) averaging contaminant distributions over the arbitrarily long screen lengths and thus reducing maximum concentrations, 2) missing the down gradient edge of a plunging plume and 3) possible confusion presented by the presence of possible contaminant contributions from other sources. Vertical characterization at each of these sites showed that plume plunging in response to recharge was common. Vertical plume delineation is critical for these sites, because each of the BTEX and MTBE plumes show evidence of diving. Averaging vertical concentrations, as would implicitly occur in a screened well, generates artificially short, high gradient plumes. At East Patchogue averaging eliminated chromatographic separation of BTEX and eliminated MTBE concentrations above the action level of 50 µg/l.

Introduction

The four sites described below span a 50 mile stretch of Long Island from the head of Peconic Bay at Riverhead, New York in the east to Uniondale, New York in the west (Figure 1). The contaminant distributions reflect the hydrogeology of the island, the composition of the releases, the timing of the releases relative to their detection, and the differing chemical properties of gasoline constituents. The impacts from these releases included contamination of ground water, the presence of organic contaminants above health standards in private and public water supplies, organic vapor intrusion into commercial and residential structures, and discharges of impacted ground water to fresh and saline surface waters. The effects have been costly and disruptive, resulting in the closure of both private and public water supply wells, installation of public water supply lines and wellhead filters, and, in some cases, the evacuation of residences and businesses.

Hagerman Ave in East Patchogue, New York

The release in East Patchogue was detected when water from a private well on Hagerman Ave became suspect due to an unusual taste and odor. The residence was located just down gradient from the terminus of the public water supply line, and was the only home in the immediate area with a well used for human consumption. Subsequent investigation by the State tracked the contaminant plume 4,600 feet upgradient to its source: an abandoned gasoline station (Figure 2, and Weaver, et al., 1996). The station had been active in the 1970's and 1980's, but was abandoned in 1988 following the unreported and undocumented removal of the underground storage tanks by the property owner. One significance of this action is that it occurred before the oxygenated fuel mandates of the Clean Air Act were in place (USEPA, 1998), so that MTBE found at the site was present due to its usage as an octane enhancer.

The contaminated well water contained MTBE at concentrations from 700 µg/L to 950 µg/L. The expanded investigation was conducted using a combination of screened wells and multilevel samplers. The multilevel samplers were generally constructed to sample the aquifer on 5-7 foot intervals with individual screens of 6 inches in length. The multilevel sampler data represents discrete sample locations in the aquifer that are not subject to mixing of waters of various concentrations. Data from the multilevel samplers showed benzene concentrations nearby the contaminated water well as high as 1,400 µg/l and MTBE concentrations as high as 7,600 µg/l both at a depth of about 30 ft below the water table.

Figure 3 shows vertical sections of the benzene, MTBE and total xylenes contaminant plumes. Data from two sampling events are depicted in the figures spanning the dates from mid 1994 to October, 1995. The gasoline station is located at the right hand edge of the cross sections and the Hagerman Ave residence is located at the monitoring point labeled MW-1,4. MTBE appears as a pulse moving ahead of the benzene and xylene plumes. The leading edge of the MTBE plume extends 5,500 feet downgradient with the trailing edge separated from the source by a distance of 3,200 feet. Modeling work (Weaver and Earle, 1999) shows that a release of MTBE gasoline occurring in the years prior to the tank removal in 1988 could have produced the plume shown in Figure 3. The benzene plume extends from the source area to roughly 4,600 feet downgradient by sample round 1 (5,200 feet by sample round 3) downgradient. The xylenes are more nearly confined to the source area, as would be expected from their chemical properties and abundance in gasoline.

Plume Diving

All three contaminants show evidence of plume diving as their distributions become progressively deeper

below the water table along the flow path. Plume diving is apparently associated with localized recharge distribution. Stratigraphic variation has been ruled out as a cause, because of the uniformity of aquifer material notes in the well logs, the results of a ground penetrating radar survey, and, mostly, because borehole flowmeter data showed insignificant variation in hydraulic conductivity at these locations. Although diving was observed along the entire length of the flow system, a noticeable increase in plunge was apparent in the benzene and xylene distributions between wells MW-13 and MW-17. This location corresponds to a change in land use from light commercial to residential, and also the location of a gravel pit. The gravel pit, located directly over the plume is believed to serve as a localized recharge zone, since the surface cover has been removed forming a bowl shaped depression in the land surface.

Figure 4 shows a computed upper bound on the contaminant distribution, using a methodology based on one-dimensional analytic solutions of the ground water flow equation and the position of a streamline in Dupuit-Forcheimer flow (Weaver, 1999). The aquifer is divided into uniform segments which can be assigned varying properties. Here, three segments were used to represent the commercial area, gravel pit and residential zone. The position of the upper bound (line B) is determined from measured aquifer properties, water table elevations, and the estimated 22 inches per year of recharge on Long Island (Franke and McClymonds, 1972). Localized recharge from the gravel pit was accounted for, and explains, in the proven absence of heterogeneity, the reason for the observed increased plume diving.

Effect of Vertical Averaging on Plume Length

Figure 5 shows a comparison of the vertically averaged concentration, the maximum concentration and the average concentration in the top ten feet of the aquifer from the first sample round. The vertically averaged concentrations only include concentrations above the detection limit. Non-detects were excluded because the wells may be deeper than the plume and resulting reduction in concentration was not desired for this analysis. For each chemical, the length of the contaminant plume would have been judged to be shorter than actuality if the only data were from the upper ten feet of the aquifer (solid lines in Figure 4). Also the concentration gradient is exaggerated, because initially the highest concentrations were observed in the upper ten feet of the aquifer. As the contaminants begin to plunge, however, the concentrations in the upper ten feet decrease faster than those at depth. The resulting apparent gradient is higher than either other case plotted. The vertically averaged concentrations (short dashed lines in Figure 4) generally indicated the same plume length as the plots of maximum concentration, but are of lower magnitude. Including non-detects, as would implicitly occur with a fully screened well, would result in even lower concentrations which could lead to shorter apparent plume lengths.

The long benzene plume is believed to be a consequence of the high ground water velocity in the surficial aquifer (approximately 1.5 ft/day). The detachment of the MTBE plume from the source is similarly related to the high velocity. Dissolution of MTBE from the gasoline source zone is driven by a combination of the chemical's properties, the availability of transport water for vadose migration and the high ground water velocity at this site. Transport away from the source once the MTBE is dissolved in the aquifer, is a function of the high ground water velocity and the recalcitrant nature of the compound. Modeling of the site confirms this conceptualization as it shows that with specific parameter values from the site, the modeled plume matches the observed plume (Weaver and Earle, 1999).

Uniondale, New York

Contamination at the site in Uniondale, New York was discovered when gasoline vapors were detected in the basement of a business near a service station (Figure 6). The release was believed to be recent due to the timing of vapor detection, the reported failure of a tank tightness test approximately 6 months prior, and the presence of fresh nonaqueous phase liquid (NAPL) on-site. Investigation methodology included the use of push-probe sampling and on-site analysis with a mobile laboratory, followed by the installation of a 3-dimensional multi-level monitoring well network.

During the initial stages of the investigation, the NAPL plume encompassed an area of 8,600ft² (799 m²) with an estimated volume of 7,375 gallons (27,917L). The benzene, MTBE and xylene plumes formed a halo around the NAPL area approximately 80 feet in width. Concentrations were highest near the source and reflected the relative solubility of each constituent (MTBE: 2,300 mg/l, benzene: 22 mg/l, xylene: 9 mg/l). The initial site characterization (Figure 7, left hand column) revealed that the contaminant plume lengths corresponded generally to their effective solubilities; where MTBE was longest, followed by benzene, then xylene. The site data also showed a likely downgradient contaminant source, based on the relatively high concentrations of benzene and xylene observed in MW1, MW2, MW3, MW5, and NP23, located about 700 feet downgradient from the originally-investigated release. The second source is also indicated by the gap between the upgradient and downgradient plumes. Later (Figure 7 right hand column), the upgradient and downgradient benzene and xylene plumes have merged; while the MTBE plume has expanded further downgradient. Because of a pump and treat recovery system between MW17 and MW19, that began operation in December 1998, MTBE concentrations decreased in these wells. Between sample round 1 and 3, NAPL continued to migrate, appearing in wells as far downgradient as MW20 (105 feet from the source). This shows depletion of the MTBE from the free product as the concentrations observed in this area had decreased from over 1,400,000 µg/l to 18,000 µg/l over this time period.

Plume Diving

Plume diving appears to begin approximately 1000 feet downgradient. This location coincides with the beginning of a suburban residential area in contrast to the 95% paved, commercial district present between this point and the upgradient source. Figure 8 shows the computed upper bound on the contaminant distribution, assuming 22 inches/year aquifer recharge that is applied only to the residential zone. The actual benzene plume appears deeper than the estimated upper bound, because of its delineation by 1000 ug/l contour lines.

Riverhead, New York

MTBE was detected in the Riverhead, New York (Figure 2) water distribution system during routine point-of-use testing by the Suffolk County Department of Health. Follow-up testing identified that one of three wells operated by the Riverhead Water District was contaminated with MTBE. Although the initial concentration at the well head was 12 ug/l, well below the NYS MCL of 50 ug/l, samples collected from monitoring points in the supply well's vicinity contained MTBE at 240 ug/l. A subsurface investigation, utilizing accelerated site characterization techniques (probe points/mobile laboratory), was initiated to quickly identify the source(s) of the MTBE and to delineate the vertical and horizontal extent of the dissolved MTBE plume. Following this phase, twenty-five multi-level samplers were installed along the centerline axis for long term monitoring. The accelerated investigation was completed in one month and it identified two service stations located approximately 3,800 feet upgradient, as sources (stations A and B on Figure 2). Both of the service stations had prior documented releases, which were discovered and reported during State-observed underground storage tank (UST) removal operations: station A in 1989 and station B in 1991. Groundwater modeling and flow velocity calculations combined with the date of UST removal at the stations, gave an estimate that the MTBE had been in transit for eleven years (Sosik, 1996).

Excavation of about 1000 cubic yards of soil at station A removed a large fraction of the contamination from the property. This action removed most of the source and was followed by repavement of the site. Lack of contamination in the former source was confirmed by soil borings along the downgradient edge of the station, and under and across the adjacent roadway (NYSDEC, 1998). Source reduction at station A, is believed responsible for the lack of a BTEX plume and an MTBE plume where most of the mass is located at depth in the aquifer downgradient from the source (Figure 9). The MTBE plume is indicated by 50 µg/l and 500 µg/l contours. The detached MTBE plume was found between 1100 feet downgradient from the source and the municipal water supply wells. The 2000 µg/l contour located near the source is believed to be associated with a minor secondary release occurring after the excavation. The tanks were replaced at station A in May 1989, giving an upper limit on the release date.

At station B, about 100 cubic yards of soil were excavated during the tank removal and station abandonment in September, 1991. Here the site was not repaved, allowing infiltration through the source. Soil contamination was found on the station property and on property across the adjacent roadway, indicating the presence of a continuing source. Data showed the clear persistence of BTEX plumes. Benzene and xylene concentrations were highest 150 feet downgradient at respective concentrations of 2,800 and 3,600 ug/l (Figure 9). The benzene plume was approximately 1,000 feet in length, while the xylene plume was limited to about 600 feet. The highest MTBE concentration was 800 ug/l at a depth of 35 feet below the water table, 3500 feet downgradient from the source. At both stations, the plumes were plunging at approximately 0.014 ft/ft with distance from the source area as a result of the vertical flow component imposed by both areal recharge through the undeveloped open area between the source and the well field, and operation of the supply wells at the southern end of the plumes.

Lindenhurst, New York

This spill was discovered when high water levels in the water table aquifer caused NAPL to enter the crawl space of a downgradient residence. Following emergency abatement action to mitigate vapor impact, a full-scale site characterization effort was implemented to delineate the three dimensional extent of dissolved, residual and NAPL contamination. The initial investigatory work confirmed an active service station located 120 feet upgradient from the source (Figure 6). UST system inspection and testing at the station indicated only a minor valve leak. This, along with the presence of free phase NAPL and the distribution of dissolved contaminants, suggested a slow, continuous release. Further investigation revealed that releases had occurred at least as early as 1995 and continued until May, 1998, when a broken fitting on the piping system was finally repaired.

The free phase NAPL was apparently limited, because product levels in wells ranged from a trace to only a few millimeters. This zone covered an area 30 feet wide by 160 feet in length. As shown in Figure 2, the MTBE plume is still attached to the source area indicating that the groundwater has recently been in contact with MTBE-containing NAPL. The highest concentration for all three contaminants was found within 600 feet of the source area: benzene- 2,992 ug/l, xylene-8,673 ug/l, MTBE- 54,000 ug/l (Figure 10). The maximum extent of the xylene and benzene plumes was between 600 and 900 feet, and between 1,000 and 1,300 feet, respectively. The MTBE plume terminates in a downgradient boat channel, 4,000 feet from the source. The plumes begin to dive approximately 400 feet downgradient from the source, due to recharge induced throughout the residential area. Figure 11 shows the calculated upper bound for the vertical extent of the plume. For Lindenhurst, a single segment of uniform conductivity and recharge rate was used to determine the upper bound. Generally the estimated position of the top is just above that observed in the field.

The rapid dissolution of MTBE from the NAPL phase combined with the high concentration of MTBE near the source confirms that at least some of the NAPL is fresh. The extent of the MTBE plume and the concentration gradient in benzene, xylenes and MTBE (highest near the source) suggests a slow release continuing (<5 years) until the time of discovery.

Comparison of Release Scenarios to Plume Configurations

The four sites share characteristics of the Upper Glacial aquifer. The aquifer material is primarily a coarse sand with some gravel overlain by shallow surface soils of less than 2 feet thickness (USDA, 1975). Representative hydraulic conductivities measured at the sites were around 200 ft/day. Generally these sites are highly homogeneous with little evidence of heterogeneity found in boring logs, contaminant distributions, and a ground penetrating radar survey and bore hole flow meter study performed at the Hagerman Avenue site. Thus the primary differences observed between the sites are attributable to the varying release dates, release durations, fuel compositions, distribution of impervious cover and recharge zones, and remedial activities undertaken at the sites. Table 1 lists characteristics of the sources. At none of the sites were the release dates, nor volumes, known with

certainty. Regulatory activities at the sites give a bound on the latest date for the release, based on tank removals (Riverhead A & B, and East Patchogue), or repairs (Lindenhurst and Uniondale). Beginning dates were estimated for Lindenhurst and Uniondale. At Lindenhurst the estimate was based on an initial detection of a release, that was followed by the refusal of the station owner to take action. At Uniondale the beginning date was estimated from presumed tank integrity. Recognizing that these estimates are uncertain, the observed leading and trailing edges of the MTBE plumes were also used to generate independent estimate of the release dates. Travel times to the approximated edges of the plumes were calculated and used to estimate the beginning and end of the events. Times so estimated generally agreed with those determined by the regulatory actions (Table 1). Both approaches date the end of the Lindenhurst and Uniondale releases to approximately 1 year or less from the collection of the initial data shown in Figures 7 and 10, while those at East Patchogue and Riverhead (A & B) were at least 5 to 6 years before the data were first collected (Table 2).

At East Patchogue, no free product was observed in wells located in the source area. This indicates that gasoline has flowed out from the source and had time to disperse itself so that free product was not generated in observation wells. At East Patchogue, the release is relatively old, and the MTBE plume is detached. At Riverhead age and source removal may have contributed to the plume detachment. In contrast, the presence of free product and its migration was observed at the younger sites (Lindenhurst and Uniondale). In both cases the release is relatively recent, and the MTBE plume is still attached to the source (Table 2), due to the presence of mobile product and residually impacted soils which still contain high levels of MTBE. Thus the characteristics that apparently contribute to plume detachment at these sites include high ground water velocity (common to each of these sites); greater age of the source, which gives more time for leaching, lack of free product, absence of surface paving, and source removal/remediation.

Site	Source						
	Release Dates				Free Product	Removal	Paved
	Est. from Regulatory Actions (NYSDEC, 1998)		Est. from MTBE plume leading and trailing edges				
	Begin	End	Begin	End			
Riverhead, A	?	° 5/1989	9/1985	6/1990	V	T	T
Riverhead, B	?	° 9/1991	2/1985	6/1990	V	r	V
East Patchogue	?	° 9/1988	3/1984	4/1988	V	V	V
Lindenhurst	° 6/1995	5/1998	2/1995	<	T	V	T
Uniondale	° 12/1996	° 5/1997	12/1995	<	T	V	T

Key: T= yes, V= no, r= partially, ° = prior to, ?= unknown, <= not determined

Table 1. Source characteristics at each site.

Site	Time between release end date and initial data collection (years)	MTBE Plume Configuration			BTEX Plume (s) Configuration		
		Diving	Detached	Discharging	Diving	Detached	Discharging
Riverhead, A	>6.25	T	T	T	—	—	—
Riverhead, B	>4.9	T	T	T	T	V	V
East Patchogue	>6.5	T	T	r	T	r	V
Lindenhurst	>1	T	V	T	T	V	V
Uniondale	>0.3	T	V	V	T	V	V

Key: T= yes, V= no, r = partially, > more than, — = none present

Table 2: Plume characteristics at each site.

Conclusions

Generally MTBE plumes are thousands of feet long. Because of vertical characterization of the sites, each of the plumes has been documented to dive into the aquifer as it moves away from its source. Conventional approaches to site characterization that rely on monitor wells with long screens generally do not delineate the extent of diving plumes such as these. If the screens are located near the top of the aquifer in a diving plume, then the observed concentrations decrease more rapidly down gradient than actual. In the case of data from the East Patchogue site, the observed concentration gradient averaged from the top ten feet of the aquifer is too steep, both because of the shortened apparent length of the plume and because the upgradient concentrations averaged from the top ten feet of the aquifer are higher than the average concentration in the aquifer. Averaging made the plumes appear to be the same length, falsely negating the effects of chromatographic separation. The impact of this sampling on the detached MTBE plume at East Patchogue is to render it insignificant from the point of view of the State's standard of 50 µg/l. The message from the East Patchogue data set is clear, however: without vertical delineation of the plumes a wholly incorrect view of the contaminant distribution would be obtained. Similar averages were not performed on the other plumes, because the data collection tended to focus on deeper locations, because of the experience gained by the State in investigating Long Island plumes. The occurrence of diving depends on the amount and areal distribution of recharge, the conductivity of the aquifer, stratigraphy, and the distance from the source of contaminants. For the plumes with simple flow systems, a semi-analytical approach to estimating diving was applied which gives a first cut estimate of the likelihood of finding contamination at depth. At the four sites described above, the plumes would have been thought shorter than they actually were are if vertical characterization had not been properly used.

The attached MTBE plumes at Lindenhurst and Uniondale are late releases where the relatively early stages of plume formation were observed. Occurring after 1992, these releases would have included gasoline with MTBE at 15% by volume because of the Clean Air Act. The amount of MTBE contained in the gasoline is uncertain, however, because lower levels of MTBE are likely found in summertime gasoline in areas under the Oxyfuel Program (at concentration of 2% to 8% by volume USEPA, (1998)). Thus, depending on the time of the year,

there could be variation in the MTBE content of the leaked fuel. With higher MTBE content in the fuel, higher concentrations should be observed in the aquifer. This is the likely cause of the high concentrations observed at Uniondale. Leaching of MTBE from the recent plumes has obviously had less time to remove constituents of the gasoline. At Uniondale, the leak occurred about before detection while at Lindenhurst leaks continued until 1 year before action was taken on the site.

Two of the sites have “detached” MTBE plumes (East Patchogue and Riverhead). Of these, remedial activities could have been responsible for the detachment observed at Riverhead (A). Here, excavation removed all of the source, while MTBE already in place in the aquifer continued moving downgradient. At Riverhead station B, the source was partially removed by excavation, and no free product was observed. The two Riverhead plumes illustrate the effects of source removal on BTEX plumes. Extensive excavation at source A so reduced the liquid fuel, so that no BTEX plumes were sustained. Across the street at source B, the amount of source material left in place caused the persistent BTEX plumes. Removal of the source effectively eliminated the BTEX plumes at site A, but, obviously, did not remove downgradient MTBE. Thus in contrast to BTEX, the MTBE persists without being sustained by contaminated soil. At East Patchogue, no remedial activities were undertaken to remove the source as of the time the data shown on Figure 3 was collected. Detachment from the source in this case is due to leaching caused by the high ground water velocity, infiltration through the unpaved source area, and the nature of the gasoline in the aquifer: the residual contamination exists as a diffuse smear zone where no free product was observed. Here the source is spread wide enough to enhance leaching from the source. In all three of these cases, site characterization, either limited areally to the property boundaries or limited in vertical characterization would have concluded that potential off-site impacts from MTBE were non-existent. The investigations undertaken when the tanks were removed at Riverhead A and B failed to find the downgradient contamination because they focussed on and near the station properties. MTBE was only found after the municipal water supply wells were impacted. Similarly, at East Patchogue the contamination was detected only after the private well was impacted. In both cases the absence of MTBE in on-site soil and groundwater samples was insufficient for predicting potential future impacts to off-site receptors. A better approach would be to determine if MTBE should be present, based on its typical percentage in the original fuel, relative to the residual compounds remaining. If there is no mechanism which can adequately account for the absence of mass on site, then logically it may have left the boundaries of the property. Investigative plans should then be developed using both a suite of travel time estimates, based on distances to receptors and estimated bounds on release dates, and the estimates of plume diving. These should be used to estimate how far and to what depth an MTBE plume might have traveled from its source. Data should then be collected to confirm/deny the presumed release scenario. The objective of this approach is to prevent late term detection of contamination by impacts to receptors, as occurred at these two sites.

Each of the sites described above has unique characteristics. Conceptual models, which provide qualitative explanations for the differing plume configurations, can be developed for the sites. These sites fall into one of two categories. The sites with detached plumes share the common characteristics of unpaved source areas, presumably lower initial MTBE concentrations in gasoline, relatively long times *in situ*, and diffuse sources. Source removal at these sites may have contributed to MTBE plume detachment, but further quantitative studies are necessary to demonstrate if the plumes had detached prior to source removal. Of these factors, the most important seem to be the interrelated long *in situ* times and diffuse sources. The sites with attached plumes have relatively short *in situ* times, presumably higher initial MTBE concentrations in gasoline, paved sources, free product in the source area, and no source removal. Source configuration with free product and short *in situ* times are probably the most important factors for these plumes.

The BTEX plumes at these sites were universally shorter than the MTBE plumes. At East Patchogue, the benzene plume appeared close to being detached as it showed its highest concentrations at the downgradient edge. Even in this case, benzene and xylene plumes were always associated with the source. Excavation at one of the Riverhead sources (A) effectively eliminated the BTEX plume, where across the street at station B the BTEX plume persisted as did the source. Few insights on the MTBE plumes can be gained from the BTEX plumes. Releases dating after April, 1979 (when MTBE was approved as an octane enhancer) and show no on-site MTBE should be investigated further.

Disclaimer

This paper has been reviewed in accordance with the US Environmental Protection Agency's peer and administrative review policies and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the US EPA.

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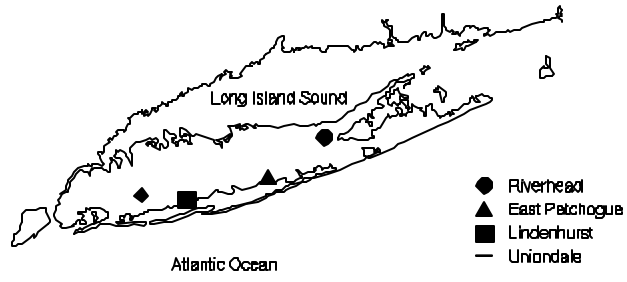


Figure 1 Long Island and the location of the four sites.

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