Groundwater quality monitoring upgradient of the Town of Brookhaven landfill in the Upper Glacial aquifer (1982-2016): a preliminary report

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1. Background

Groundwater quality reporting on particular aquifers often try to describe a water quality for the aquifer as a whole. It is not clear that is appropriate for aquifers that are extensive (in area and depth). It is also clear that human activities can affect groundwater quality, especially for water table aquifers, and that these impacts are not always evenly distributed.

In 1972, New York State Environmental Facilities Corporation constructed a landfill in a relatively isolated portion of Brookhaven Town, Long Island, NY. The landfill began accepting wastes in 1974. As part of its operations, groundwater monitoring to detect impacts from the landfill were conducted. The quality of that work improved greatly beginning in 1982 when the United States Geological Survey (USGS) became involved. As part of the monitoring efforts, a number of wells were sampled upgradient of the landfill to provide a baseline to compare downgradient results to.

We have collated data over 35 years from the upgradient wells. Partly with the impetus of new State solid waste regulations that encourage aggregating upgradient (ambient) data to generate a basis for comparison for water quality downgradient of solid waste facilities, and partly for other reasons, here we present those amassed data together with some basic statistical analyses. The data exhibit a good degree of variability, in part due to changing land use in the area resulting in more human impact to the groundwater resource, and also because of changes in environmental management practices (especially road salting to manage winter roadway conditions). Water quality also varies with depth in the aquifer.

2. Sampling Procedures

Organizations

Groundwater monitoring has been conducted at the Brookhaven landfill since it began accepting wastes. The sampling was originally conducted by landfill employees on a quarterly schedule for regulatory reporting purposes using techniques that would not meet current standards. In 1981 there was a large leachate release on the east sideslope of the landfill. The Town contracted with USGS to determine the scope and impact of any effect on the local groundwater. The USGS, which had previously conducted work at the Islip and Babylon landfills as part of a nationwide effort to characterize impacts from landfills to local water resources, took advantage of the opportunity and installed a large network of approximately 100 wells in the vicinity of the landfill (upgradient, sidegradient, and downgradient). This extensive network was sampled for groundwater quality, and was also used to provide data for a groundwater flow and transport model. USGS resampled the network in 1983, 1984, 1987, and again in 1990.

The Town also arranged for scientifically rigorous sampling to occur on a more consistent basis. John Black (Suffolk Community College) was contracted with (through LK McLean Associates, primary site engineers). He used students and landfill employees to collect samples from 1983-1991 (including once for NYSDEC in 1985). In 1992, the Town entered into a research agreement with Stony Brook University, and David Tonjes began working with Black. The ad hoc sampling effort was converted in 1993 to a regulatory -compliant monitoring effort (with additional non-required sampling) in 1993, for the older section of the landfill complex (Cells 1-4). Black retired in 1995; Tonjes continued the sampling effort through 2001, documenting the monitoring effort with Groundwater Assessment reports each year 1992-2005.

The Town had also hired the environmental consulting firm, Dvirka and Bartilucci, in 1989 to move towards complying with new New York State regulations on landfills that included more defined means to conduct landfill groundwater impact monitoring. Dvirka and Bartilucci (D&B) wrote three Groundwater Assessments for 1989-1991. D&B then conducted the investigatory and operational monitoring associated with the newer Cell 5 and Cell 6 portions of the landfill. In 2001, D&B began conducting all groundwater quality monitoring. In 2005, the two regulatory programs were combined into a “unified” program; at that time D&B began submitting all required monitoring reports to NYSDEC.

Sampling Techniques

USGS began the use of pumps to collect samples in 1982. The Town purchased a generator-pump set in 1983, and Town equipment was used by Black and Tonjes through 2001. D&B rented pumping equipment.

Samples were acquired from the wells following reasonably consistent sampling methods. Standard practice was to pump until field parameters stabilized; Tonjes and Black took regular readings (every 5 minutes or so prior to 1993; every 5 gals. thereafter; D&B typically measured every 10 gals., and generally took samples only after 3 well volumes were removed. Pumping rates were higher until 2000 (up to 2 gal./min (8 L/min), when they were reduced to approximately 1 gal/min (4 L/min). In the 1980s and 1990s, the pump was moved up and down through the assumed screen zone by D&B; after that, and for other samplers, the pump was set below the water surface and not moved. From 1991 through 2000, D&B collected all samples using a baler, in order of decreasing assumed volatility (VOCs, SVOCs, pesticides, herbicides, metals, water quality indicators); prior to 1991, and for Black and Tonjes, and for D&B from 2000-2005, all constituents were collected from the pump outlet except for VOCs, which were collected by baler. Post 2005, all constituents were collected from the pump outlet, with the pump volume reduced to approximately 100 ml/min (or less, if possible). D&B often used measures to prevent sample cross contamination, including spreading plastic sheets around the wells, decontamination of the pump and non-single use equipment with Alconox and fresh water rinse, and use of latex gloves. Since 2000, the use of plastic ground cloths and continual cleaning of dedicated equipment was considered to be unnecessary. D&B field workers continue to wear latex gloves for personal protection. All filtering equipment is rinsed after each use with deionized water, as has always been the case. Filters themselves have always been single use, disposable equipment. Since 1993 for Tonjes and Black, and always for D&B, pump hosing has been single use, disposable equipment. Standard practice has always been to start sampling events by taking upgradient samples first, so most of the sampling reported on here occurred before samples were taken from contaminated, downgradient areas. Samples are stored in pre-labeled, laboratory-prepared bottles. A metals aliquot has always been filtered, following USGS practices, but beginning in 1991 metals were also analyzed as a total fraction. Samples were stored on ice in coolers following collection.

Laboratories

All laboratories used for analyzing samples were required by the Town to hold the highest New York State certifications. The companies doing the analyses have included New York Testing Laboratory (which became NYTest) (Port Washington, NY) from 1982-1996, H2M Laboratories (Melville, NY) 1996-2001, Environmental Testing Laboratories (Farmingdale, NY) 2001-2008, and Mitkem Laboratories (Warwick, RI) 2008-2016 (Mitkem became Spectrum Laboratories which became Eurofin Laboratories), and then Pace Laboratories (formerly H2M, still in Melville, NY) for the last half of 2016. Samples were delivered at the end of the sampling day to local labs, but shipped using overnight mail to out-of-state labs. Reports generated for D&B were formally analyzed for compliance with analytical rules and regulations, such as holding times, frequency and adequacy of internal calibrations, etc., by State-certified QA-QC officers, and less rigorously checked when created for Black and/or Tonjes. Beginning in 1993, Black and Tonjes regularly took duplicate samples (at least one per sampling round), and this practice was adopted by D&B in 2005. Other QA-QC steps included "trip blanks" (analyzed for VOCs, and used whenever VOCs were sampled for) and field blanks (a practice initiated by D&B in 1991, and adopted by Tonjes and Black in 1993).

Analytes

Prior to 1991, all samples were analyzed for the "USGS parameters": total dissolved solids (TDS), chloride, sulfate, total Kjehldahl nitrogen (TKN), nitrate, nitrite, ammonia, sodium, potassium, calcium, magnesium, cadmium, and lead. At some time in the late 1980s Black added selenium to the compound list. Laboratories sometimes reported conductivity and pH as well. Sometimes samples were analyzed for volatile organic compounds (VOCs), a list of varying compounds detectable by gas chromatography. In 1991, D&B began having samples analyzed for NYSDEC regulatorily-required compounds: "routine" parameters (similar to the USGS parameters but also including hardness, TOC, BOD, and COD), "baseline" parameters (routine parameters plus color, bromide, hexavalent chromium, aluminum, antimony, barium, beryllium, boron, chromium, cobalt, copper, mercury, nickel, selenium, silver, thallium, vanadium, zinc, and VOCs), and expanded parameters (baseline parameters plus semi-volatile compounds [SVOCs], pesticides, and herbicides) (expanded parameters are supposed to include dioxins and furans, although they were never sampled for in the upgradient wells). Field parameters that were measured and recorded included temperature and specific conductivity, then as metering capabilities grew, pH, Eh, turbidity, and dissolved oxygen were added (beginning circa 1995). Field parameters were measured in sampling collection buckets through about 2005 when in-line meters were used. The recorded values were taken just prior to sample collection.

Well Network

Some wells onsite pre-date the USGS well installation effort in 1982, but only one is included in this report: S-3529, a 1.5 in shallow plastic well, which was originally installed in the woods north of Horseblock Rd, was destroyed in 1975 (apparently by fire fighting equipment), and was "relocated" onto the landfill property in 1975. In 1982, USGS installed one iron, 4-inch well (S-73769), and five two-inch PVC wells (S-72815, S-72816, S-72122, S-72123, and S-72124). The plastic wells were all shallow wells; S-73769 was a mid-depth well. In 1990, D&B installed 2-inch PVC wells to monitor the Town recycling facility, one of which (MRF-4) is used here as a shallow upgradient well. In 1991, D&B installed two pairs of 2-in PVC shallow-deep well clusters (MW5-S and MW5-D, and MW6-S and MW6-D). In 1992, a mid-depth 2-in. PVC well

(MW5-I) was added. In 1994, a mid-depth and deep well were installed at S-72816 (MW12-I and MW12-D); when MW12-I was destroyed in 1995, a new mid-depth well was installed (MW12-IR). Landfill expansion meant that S-72815 and S-73769 were abandoned, site construction work accidentally destroyed S-72124, and careless heavy equipment use destroyed MW12-D. Well S-72123 cannot be found.

The well network can be characterized as follows:

Cluster	Approx. Depth to Water (ft)	Wells	Materials	Screen Length (ft)	Screen Depth (ft)	Condition
MRF-4	10	**MRF-4**	2 in PVC	5	25	
3529	15	S-3529	1.5 in plastic	5	45	
72123	5	S-72123	2 in PVC	5	23	missing
72124	15	S-72124	2 in PVC	5	43	destroyed
72816	50	**S-72816** MW12-I MW12-IR MW12-D	2 in PVC 2 in PVC 2 in PVC 2 in PVC	5 5 5 5	67 113 90 168	 destroyed destroyed
73769	55	S-72815 S-73769	2 in PVC 4 in iron	5 5	66 82	destroyed destroyed
72121	40	**S-72121**	2 in PVC	5	66	missing
MW5	50	**MW5-S** **MW5-I** **MW5-D**	2 in PVC 2 in PVC 2 in PVC	10 5 5	61.5 92 159.5	
MW6	50	**MW6-S** MW6-D	2 in PVC 2 in PVC	10 5	59.5 155	

This network was sampled as follows (no samples were taken in 1986):

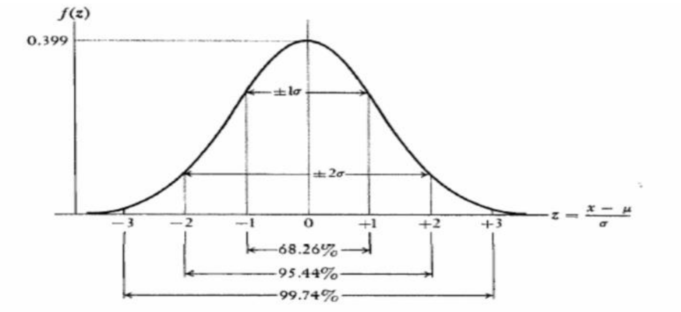
		Shallow									Mid-depth				Deep		
Year		**MRF-4**	**3529**	**72123**	**72124**	**72816**	**72815**	**72121**	**MW5-S**	**MW6-S**	**MW12-I**	**MW12-IR**	**73769**	**MW5-I**	**MW12-D**	**MW5-D**	**MW6-D**
1982			1	1	1	1	1	1					1				
1983						1											
1984						2											
1985						1*											
1987						2		1									
1988						1											
1989			1		1	2											
1990		1			2	2											
1991		1			2*	1											
1992					1				2*	2*						2*	2*
1993						2			4	3				2		3	3
1994						5			3*	3*				4*		3*	3*
1995						3	1		1	1	1		1	1	1	1	1
1996						3			2	2	3*			2	3	2	2
1997						3			3	4		2		4	3	4	4
1998		1				2*	1		4	4		2	1	4	2	4	4
1999						2			3	3		2*		3	2	3	3
2000						2*			3	3		2		3	2	3	3
2001						3			3	3		2		3	2	3	3
2002						2			3	3		2		3	2	3	3
2003						2			3	3		2		3	2	3	3
2004						4			4	3		4		4	4	4	3
2005		2*				2			2	2				2		2	
2006		2				2*			2	2				2		2	
2007		2				2			2	2				2		2*	
2008		2				2			2	2*				2		2	
2009		2*				2			2	2				2		2	
2010		2				2			2	2				2		2	
2011		2				2			2	2*				2		2	
2012		2*				2			2	2				2		2	
2013		2				2*			2	2				2*		2	
2014		2				2			2*	2*				2		2	
2015		2				2			2	2				2*		2	
2016		2				2			2	2*				2		2	
Total		30 (3)	2	1	8 (1)	75 (5)	3	2	65 (3)	67 (6)	4	19 (1)	3	63 (3)	23	65 (3)	39 (2)

Year	Shallow	Mid-depth	Deep	Total
1982	6	1		**7**
1983	1			**1**
1984	2			**2**
1985	1*			**1***
1987	3			**3**
1988	1			**1**
1989	4			**4**
1990	5			**5**
1991	4*			**4***
1992	5**		4**	**9*******
1993	9	2	6	**17**
1994	11**	4*	6**	**21*********
1995	6	3	3	**12**
1996	7	5*	7	**12***
1997	10	6	11	**27**
1998	12*	7	10	**29***
1999	8	5*	8	**21***
2000	8*	5	8	**21***
2001	9	5	8	**22**
2002	8	5	8	**21**
2003	8	5	8	**21**
2004	11	8	11	**30**
2005	8*	2	2	**12***
2006	8*	2	2	**12***
2007	8	2	2*	**12***
2008	8*	2	2	**12***
2009	8*	2	2	**12***
2010	8	2	2	**12**
2011	8*	2	2	**12***
2012	8*	2	2	**12***
2013	8*	2*	2	**12*****
2014	8**	2	2	**12*****
2015	8	2*	2	**12***
2016	8*	2	2	**12***
Total	223 (18)	89 (4)	127 (5)	**439 (27)**

Data Analyses

The Normal Distribution is continuous data. It is commonly used in statistics since it describes the data distribution for many natural phenomena (e.g., heights of adult men or women). However, other distributions exist.

The normal distribution include that it is symmetric (bell shaped) and is continuous for all values of X between -∞ and ∞; the mean (average) (μ) and the variance (the spread around the mean) (σ^2) define the normal distribution.



68% of all data lie within 1 standard deviation (σ) from the mean, and 95% of the data lie within 2 standard deviations from the mean.

The normal distribution is helpful in statistical analyses because:

- Many things (natural phenomena) are approximately normal, or very close to it (e.g. height); measurement errors also usually have normal distribution
- The normal distribution is easy to work with mathematically. In many practical cases, the methods developed using normal theory work quite well even when the distribution is not normal.
- There is a very strong connection between the size of a sample (N) and the extent to which a sampling distribution approaches the normal form. Many sampling distributions based on large N can be approximated by the normal distribution even though the population distribution itself is not normal.
- Many common statistical techniques (e.g. linear regressions) rely on the assumption of normal distributions of errors.

Data can also have different distributions (some of which can be converted to normal distributions. One common transformation is the log transformation (taking the natural log of data) which will undo certain forms of skewness ("log-normal transformations"). Income is often found to be log-normally distributed.

When the data are discrete (e.g. count of events), there are different family of discrete distributions to use.

Skewness indicates distortion of the normal distribution. Negative skew means the left tail is longer and the mass of the distribution is concentrated on the right of the figure. Positive skew means the opposite, so that the right tail is longer, and the mass of the distribution is concentrated on the left of the figure.

Box Plots are more commonly used in water quality data than is the case in most other science. A box plot summarizes the information on the data distribution primarily in terms of the median, the upper quartile, and lower quartile. The line within the box = median. “Whiskers” are drawn outside the box at what are called the “adjacent values.” The upper adjacent value is the largest observation that does not exceed the upper quartile plus 1.5 interquartile range.

Results:

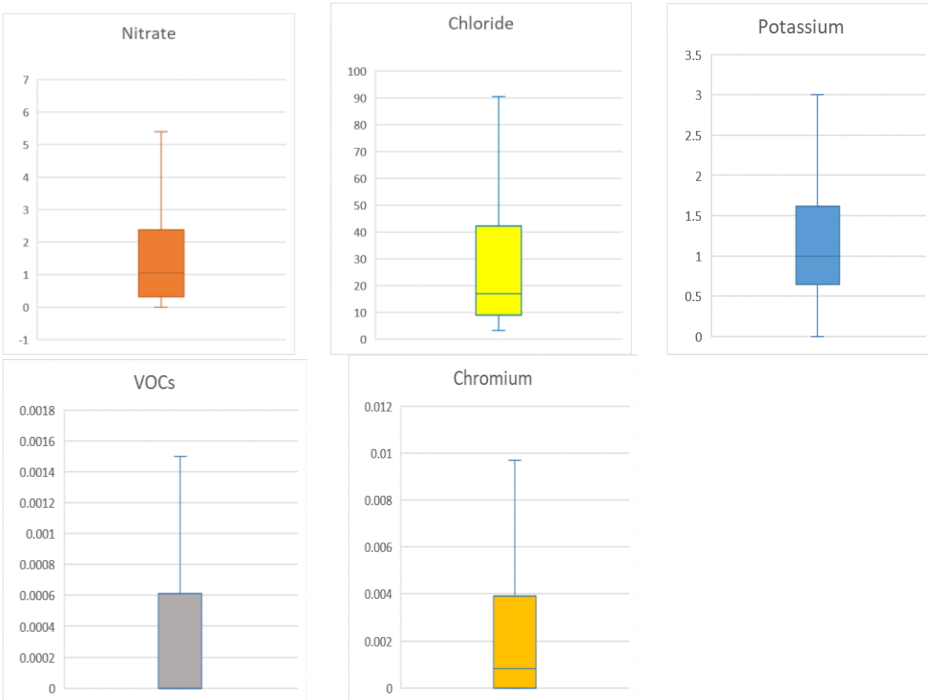
We are going to present basic information on five parameters: chloride, nitrate (as nitrogen), sodium, potassium, chromium, and volatile organic compounds (VOCs). Chloride is important in landfill investigations (it’s a common indicator of leachate contamination). Nitrate is the water quality indicator that is of the greatest current interest on Long Island. Sodium is often linked to chloride, but is also of interest because it is identified as having potential health effects at a relatively low concentration for a major groundwater ion (20 mg/L). Potassium is another salt of interest: it is a major issue with the nearby compost site plume, and also is a general indicator of anthropogenic effects on fresh water. Chromium is one of the trace metals tested for at this site; it is more soluble and therefore is detected more often than other such trace metals. Volatile organic compounds are a set of organic molecules that tend to be smaller and also contain halogens; their small size tends to increase solubility, and halogen content often correlates to environmental concerns.

Considering all samples from 1982 to 2016, the following table of basic attributes was generated. Note the large relative differences between means and medians, the relatively large standard deviations compared to the mean values, and the positive (and large) skewness values.

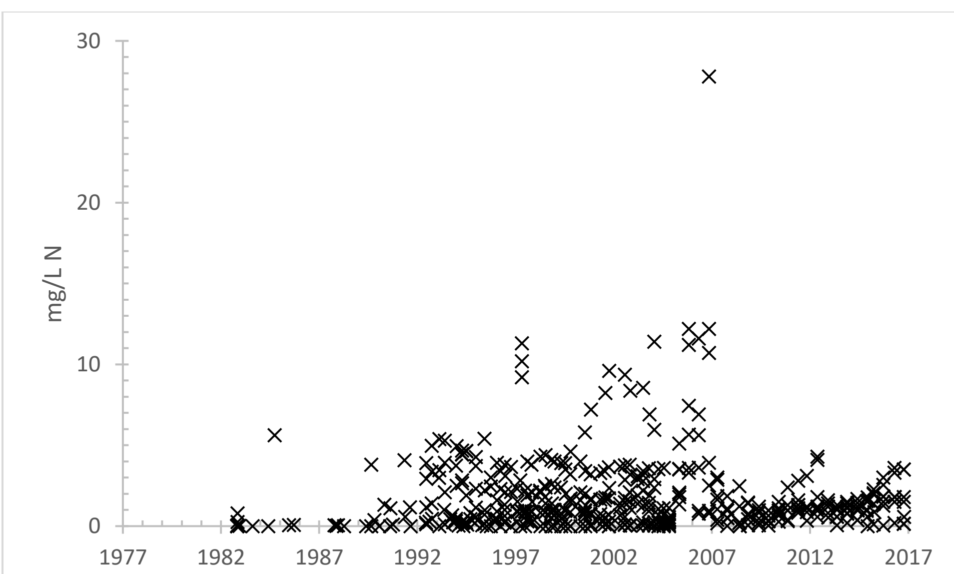
	Chloride	Nitrate	Sodium	Potassium	Chromium	VOC
Mean	40.2	1.8	23.5	1.3	0.03	0.002
Median	17	1	8.7	1	0.00083	0
Standard Deviation	53.3	2.4	30.9	1.1	0.22	0.008
Skewness	2.4	4.1	2.1	1.4	11	6.4
Min	3.1	0	0	0	0	0
Max	360	27.8	173	6.04	2.81	0.073
Range	356.9	27.8	173	6.04	2.81	0.073
N	460	461	451	451	321	340

Box Plots

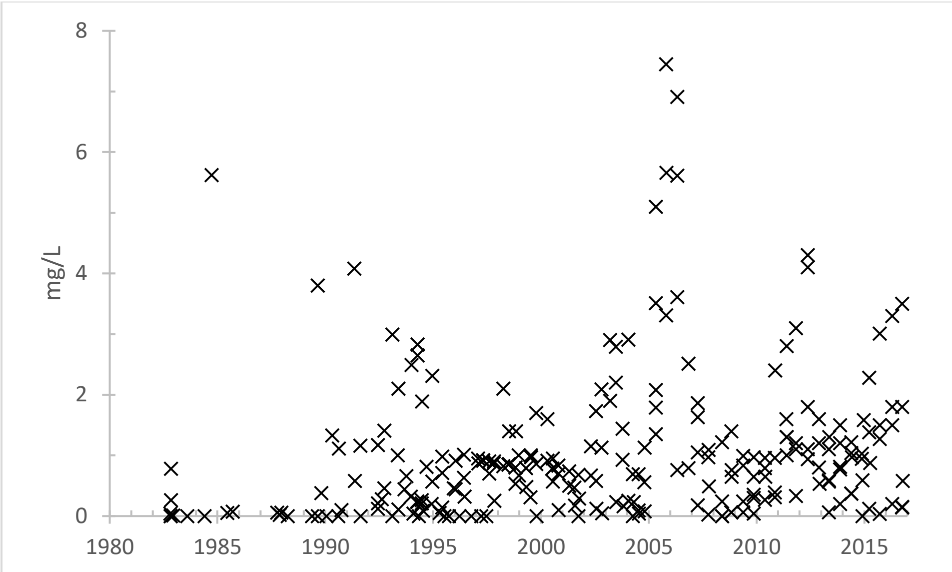
The distributions for sodium, chloride, nitrate have a distinct long tail to the right and are skewed to the right. The spread of the three variables are also wide (measured by the width of the box). The interquartile range of nitrate is within <10 mg/L (which is the New York State drinking water standard), but there are also outliers that are greater than 10 mg/L. For chloride, the median value is 17 mg/L, however, the average measurement is 40 mg/L. Sodium has a similar pattern as chloride, although the mean value is only ~20 mg/L. The potassium distribution is relatively slightly less skewed, with mean and median ~1 mg/L. More than 75% of all VOCs results were non-detections (recorded here as 0), although the mean result was 0.002 mg/L (2 µg/L). Chromium was detected more frequently, although almost half of the results were non-detects. The mean was much greater than the median because of some infrequent but relatively very large results.



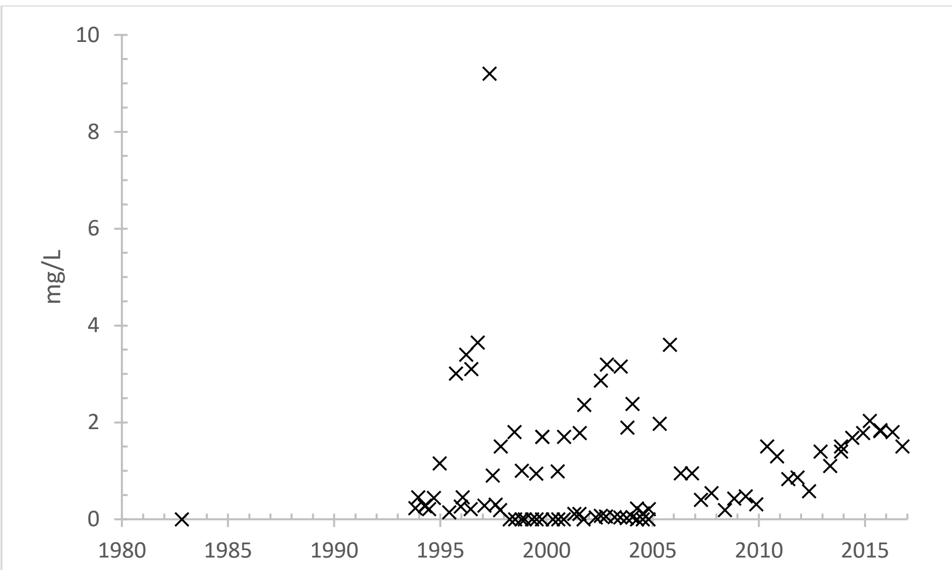
Other preliminary results include the following time series analyses. Nitrate-N concentrations, contrary to most reports for Long Island, here do not show a clear upwards trend. The total data package has some anomalously high values for 2005, which appear to be due to spuriously elevated laboratory work. Otherwise, there is no single trend. It may be that shallow and mid-depth results trend somewhat upward, but deep results show a clear declining trend.



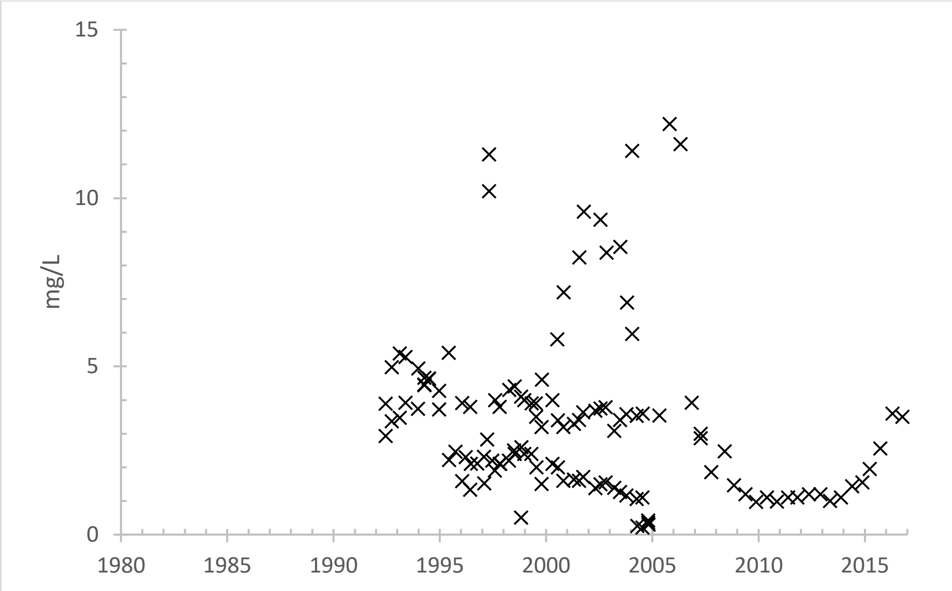
All nitrate results



Shallow nitrate results (excluding the highest 2005 result)

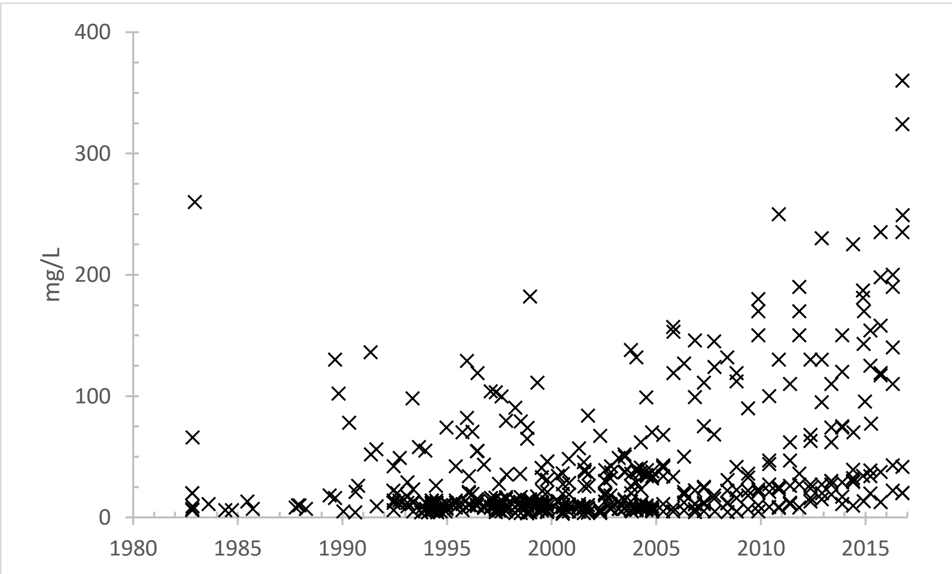


Mid-depth nitrate results

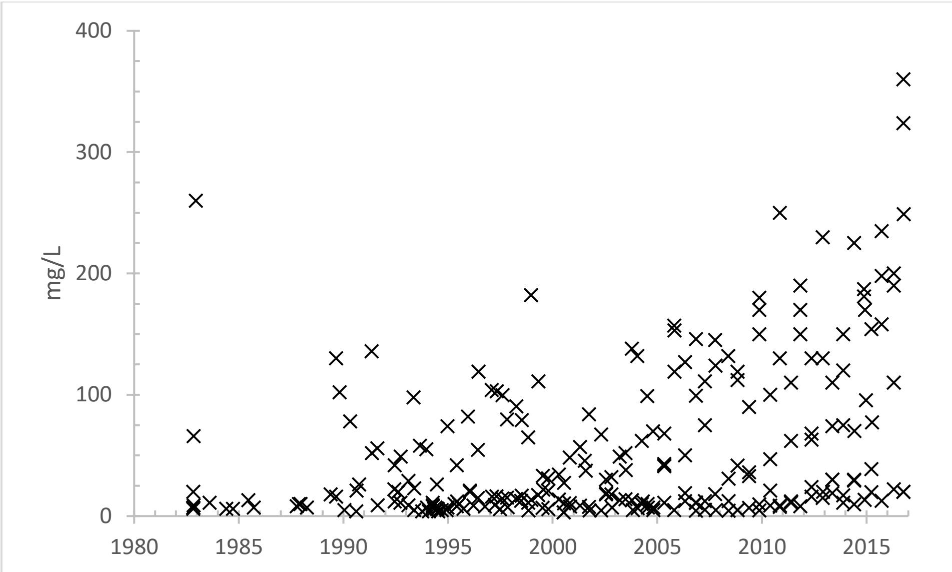


Deep nitrate results

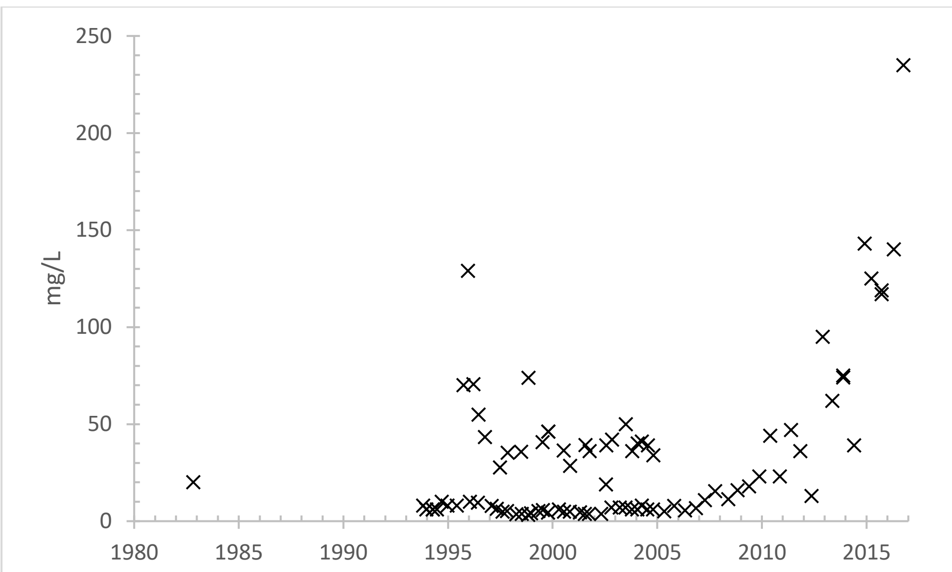
Chloride (and sodium) data show unambigiously increasing trends, which can be seen (at different scales) at all three depth levels. Certainly the shallow data reflect more aggressive use of salt for snow and ice conditions on roads in winter; that may be the case for the mid-depth well, although the installation of a package sewage treatment plant in the apartment complex upgradient of MW5-I may be a factor. It hard to say, given the assumed 50-75 year age of the deep Upper Glacial aquifer, what might be increasing the chloride in those waters, although extension of the Long Island Expressway in the late 1960s may be related. Potassium concentrations also seem to be increasing, although the rate of increase is much less. Potassium is often an indicator of sewage disposal and other anthropogenic impacts.



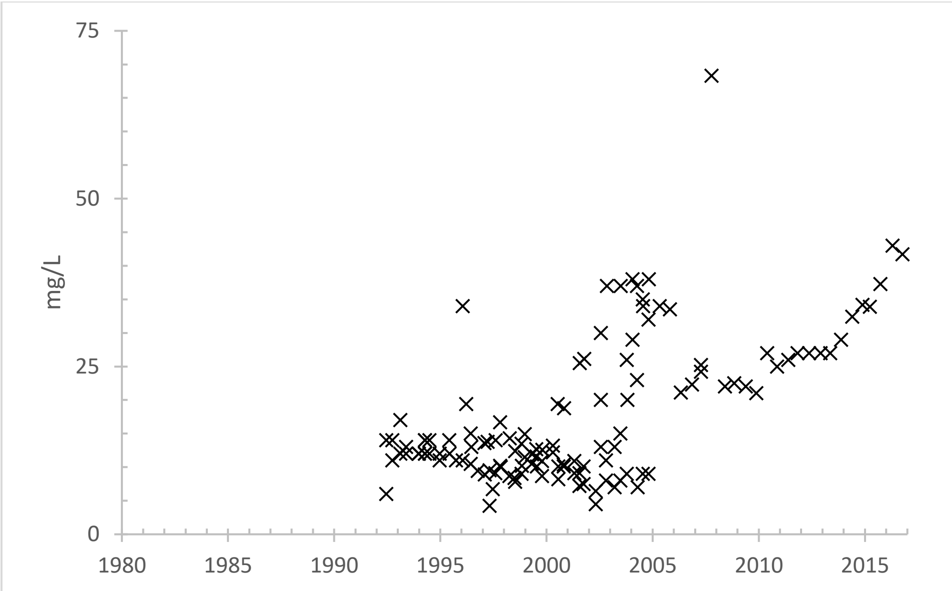
All chloride results



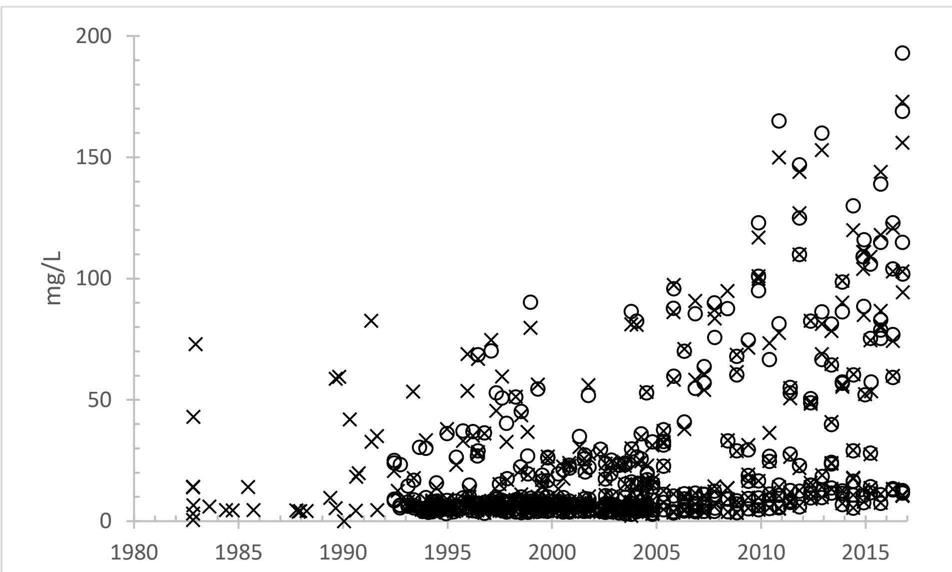
Shallow chloride results



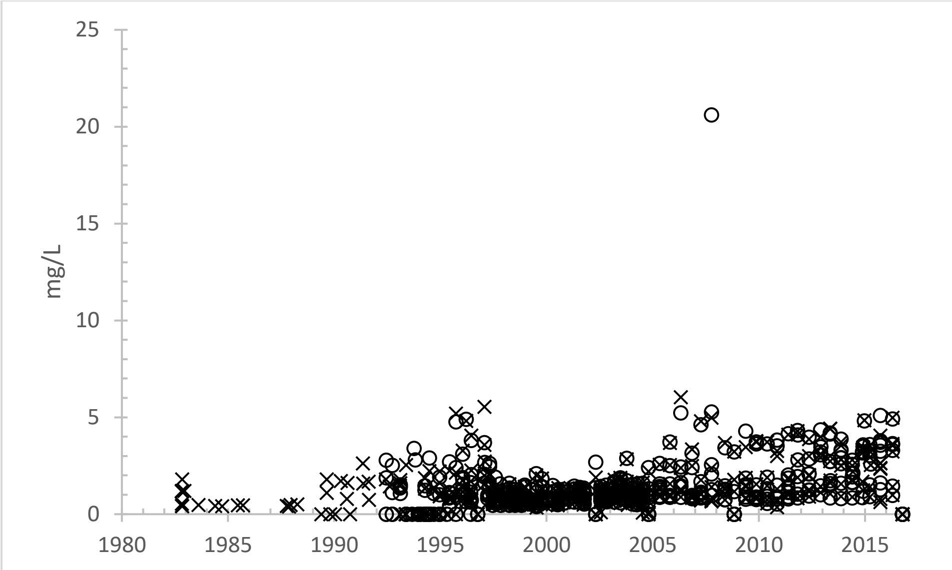
Mid-depth chloride results



Deep chloride results

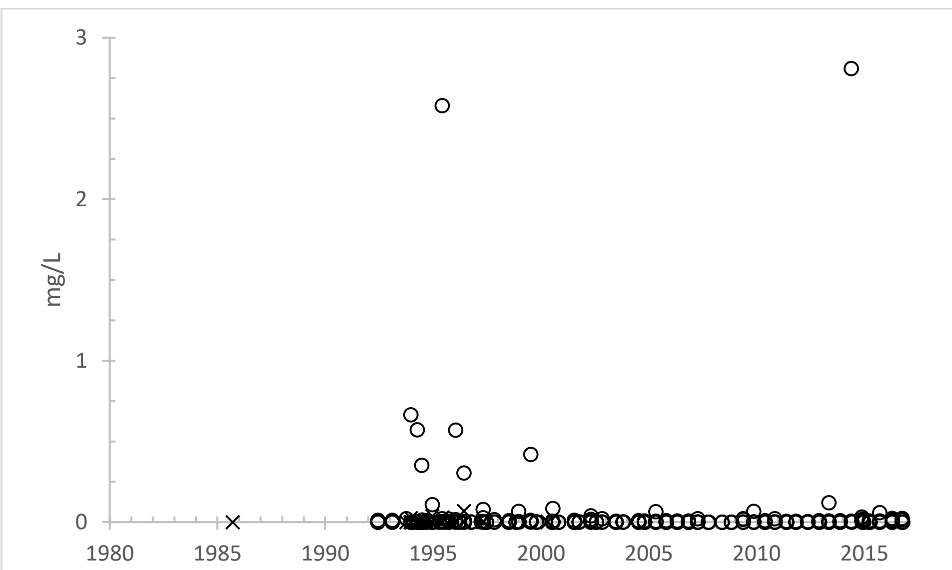


All sodium results (×= dissolved, ○= total)

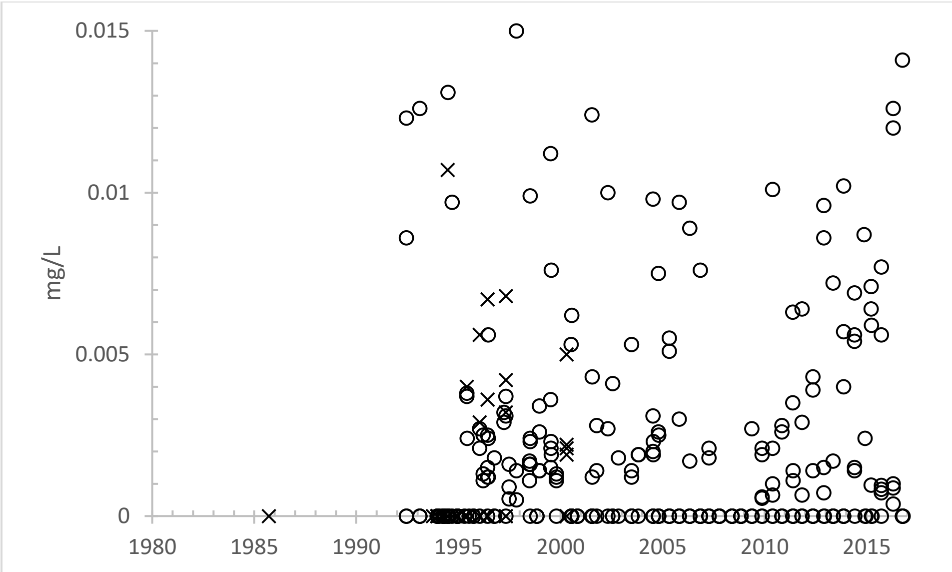


All potassium results (×= dissolved, ○= total)

There appear to be fewer chromium non-detections with time, although once the extremely high (ppm) data points are ignored, there does not seem to be differences in detected concentrations. The greater rate of detected concentrations might be the result of decreasing MDLs for trace metals in approved laboratory procedures. Because the Town's labs have always reported "estimated" metals concentrations (determined values lower than MDL levels), it may be that lower MDLs may result in more estimated and "actual" reported results, without changing the range of reported values much.

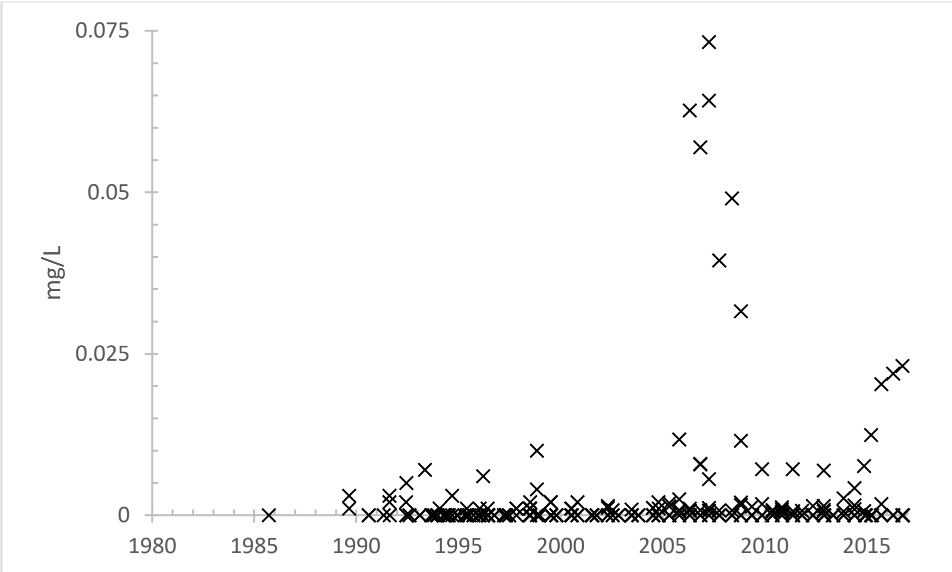


All chromium results (×= dissolved, ○= total)

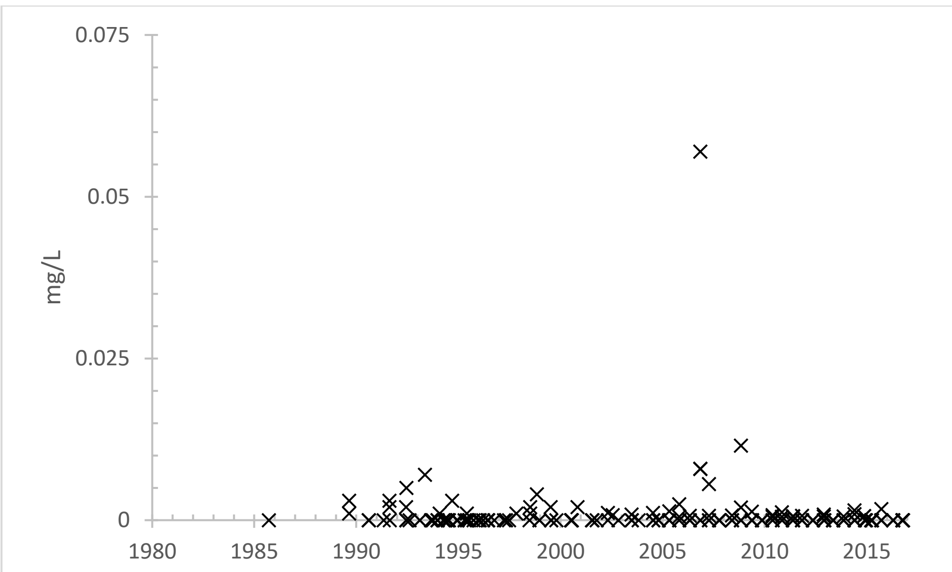


Chromium results < 15 ppb (×= dissolved, ○= total)

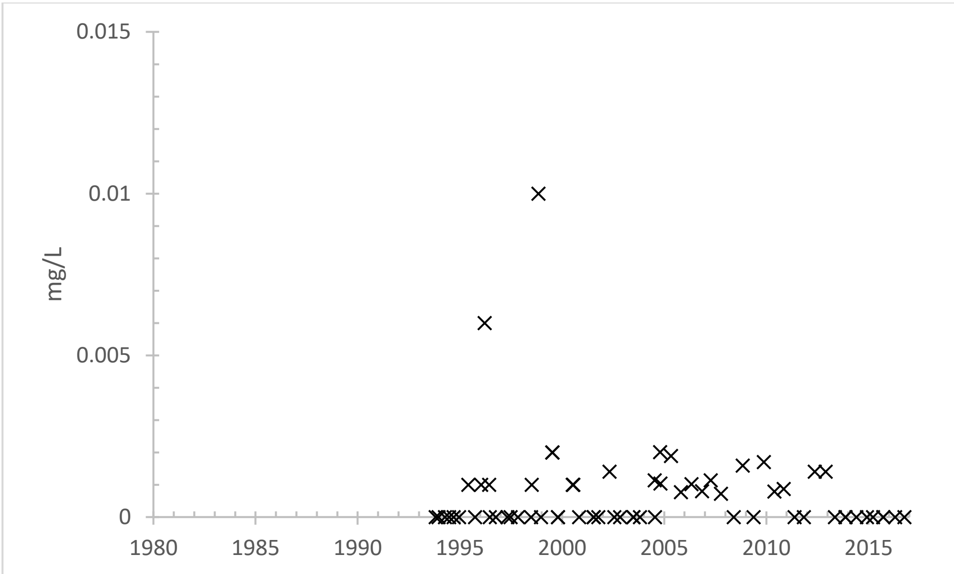
The VOCs time series are interesting. Almost all reported VOCs are degradates of perchloroethylene (dry cleaning fluid, “perc”) (tetrachloroethane, trichloroethanes, dichloroethanes, although all of these are used as solvents in their own rights), no matter in which well they were detected. There was a spike in detections in 2005 at the MW5 cluster, with the greatest concentrations detected at the shallow and deep well, and a lesser spike at the same well cluster in 2015. The results are those that might occur if perc had been dumped into a shallow drainage structure upgradient of the wells. Higher concentrations might be found as the perc dissolved at the water table, and if there were any DNAPLs (denser than water non-aqueous phase liquids – solvent that sank through the aquifer without dissolving) that accumulated at the bottom of the aquifer at the confining layer there, they could have contributed dissolved chemicals into the flow of water towards the deep well. Lower concentrations that were not measured for as long a time period at the mid-depth well would fit this scenario.



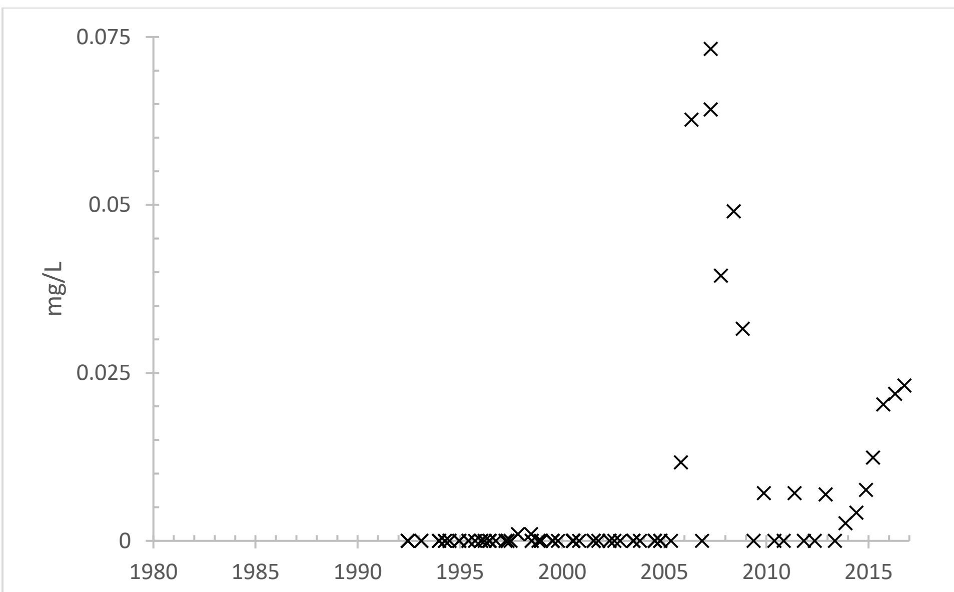
All VOCs results



Shallow VOCs



Mid-depth VOCs



Deep VOCs

This work was partially supported by the Town of Brookhaven through on-going grants of support. Thanks to USGS, especially to John Black, lots of Town landfill workers over the years, and all the good folk at Dvirka and Bartilucci.