AMBIENT WATER QUALITY IN THE UPPER GLACIAL AQUIFER NEAR THE TOWN OF BROOKHAVEN LANDFILL, SUFFOLK COUNTY, NEW YORK

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Groundwater quality in the Upper Glacial aquifer upgradient of the Town of Brookhaven landfill has been analyzed using a Stiff diagram variation (M-N Stiff diagrams) and multivariate statistics (Principal Component Analysis). The technique allows for similarities and differences between large numbers of samples to be organized in a meaningful fashion. It shows that simple groupings based solely on well depth or clusters are not appropriate at this site, for example, but more sophisticated groupings similiar to the simple concepts appear to be valid.

A groundwater monitoring program was begun in 1992 in conjunction with an expansion of the Town of Brookhaven landfill. The Long Island aquifer system near the site consists of three aquifers, the Upper Glacial aquifer, the Magothy aquifer, and the Lloyd aquifer. The Upper Glacial aquifer is a water table aquifer, and immediately upgradient of the landfill site extends from approximately 30' msl to -100' msl. In 1992, four monitoring wells were installed to monitor the upgradient water quality, two as water table wells (MW5-S and MW6-S) and two to monitor the lowest portions of the aquifer (MW5-D and MW6-D). In 1993, a mid-depth well, MW5-I, was added to the network (Dvirka and Bartilucci, 1994). As of December, 1999, MW5-S had been sampled 23 times, MW5-I had been sampled 20 times, and MW5-D, MW6-S and MW6-D had been sampled 22 times. The first sample drawn from each well was analyzed for a set of parameters that included leachate contamination indicators, metals, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), herbicides, pesticides, polychlorinated biphenyls (PCBs), dioxins, and furans, as defined in the NYSDEC Part 360 "Expanded Parameters." Samples since that first round were analyzed for either NYSDEC Part 360 "Routine Parameters" (leachate indicators and certain metals) or NYSDEC Part 360 "Baseline Parameters" (leachate indicators, metals, and VOCs) (Dvirka and Bartilucci, 2000; NYSDEC, 1997).

There have been very few detections of VOCs (Table 1). In the first round of sampling, some non-target list SVOCs were detected (Table 2), but none of the other, non-VOCs organic compounds were. No organic compounds other than VOCs have been analyzed for since the first round of sampling.

Twenty-five metals, plus the compound cyanide, have been analyzed for in metals fractions (see Table 3). Exceedances of State GA groundwater standards or guidelines are somewhat common: 106 in the 109 samples, counting both filtered and total fractions (Table 4). There are differences in mean metals concentrations among the wells. For example, the mean calcium concentrations at well MW6-D are 10.87 mg/l (± a standard deviation of 2.73 mg/l), but those at well MW6-S are 4.89 mg/l (± 0.77 mg/l). The mean unfiltered chromium concentration at well MW5-S is 442 μg/l (with a large standard deviation of 685 μg/l), and the mean total chromium concentration at well MW5-D is 3.4 μg/l (± 4.3 μg/l).

Table 1. VOCs Detections (all data in μg/l)

Well (# of samples)	MW5-S (13)	MW5-I (12)	MW5-D (12)	MW6-S (12)	MW6-D (12)
Chloroform 67-66-3		1 (6/95) 1 (1/96) 1 (7/98) 2 (7/99)			
Trichloroethene 79-01-6				5 (6/92)	
Toluene 108-88-3				1 (7/98)	
59 compounds analyzed	none detected		none detected		none detected

Table 2. VOCs Detections (all data in µg/l) (TIC = tentatively identified compound)

Well	MW5-S	MW5-I	MW5-D	MW6-S	MW6-D
unknown TIC	26		38	19	16
unknown acid TIC				3	3
unknown alkane TIC					3
122 compounds analyzed	none detected	none detected	none detected	none detected	none detected

Nineteen "leachate indicator" compounds have also been tested, along with six field parameters (Table 5). Fewer leachate indicators have standards. However, exceedances were found for some of the parameters (Table 6), and occurred in nearly half the samples for phenols. Differences can also be found between mean concentrations calculated for different wells. Mean nitrate concentrations in well MW5-D were 4.39 mg/l (± 1.70 mg/l), but those in well MW5-I were 0.66 mg/l (± 1.97 mg/l). Mean chloride concentratiuons in well MW5-S were 63.6 mg/l (± 39.5 mg/l), and mean chloride concentrations in well MW6-S were 13.0 mg/l (± 4.8 mg/l).

The organic compound data suggested there was a consistency to this "upgradient" water quality, in that almost all samples appear to be pristine. The metals and leachate indicator compound data suggests that there can be large differences in water quality between the sampling points, and that water quality does not attain GA standards on a regular basis. Any general patterns of concentration differences or to the exceedances of water quality standards are not extremely obvious.

Table 3. Metals Analyzed For, with GA Standards or Guidance Values (in µg/l)

Metal	"Routine"	"Baseline"	Std. or GV
Aluminum		x	
Antimony		x	3
Arsenic		x	25
Barium		x	1,000
Beryllium		x	3
Boron		x	1,000
Cadmium	x	x	10
Calcium	x	x	
Chromium		x	50
Cobalt		x	
Copper		x	200
Iron	x	x	300
Lead	x	x	25
Magnesium	x	x	35,000
Manganese	x	x	300
Mercury		x	2
Nickel		x	
Potassium	x	x	
Selenium		x	10
Silver		x	50
Sodium	x	x	20,000
Thallium		x	3
Vanadium		x	
Zinc		x	300
Cyanide		x	10

Table 4. Exceedances of Class GA Metals Standards and Guidelines

"Filtered" "Total"	MW5-S	MW5-I	MW5-D	MW6-S	MW6-D
Antimony	1 4	 1	2 1	 1	1 3
Beryllium			1		
Cadmium					 1
Chromium	1 10				
Iron	2 21	 1	 3	1 16	 2
Manganese				1	
Mercury					 1
Sodium	13 16		 1		
Cyanide				 1	
Totals	68	2	8	20	8

Stiff diagrams (Stiff, 1951) have been used to characterize overall water quality. They have been found to be useful in landfill contamination investigations, because of the large amounts of dissolved salts in leachate plumes, and have often been used in Long Island studies (Kimmel and Braids, 1980; Black and Dellaria, 1992; Pearsall and Aufderheide, 1995). A modification of Stiff diagrams has been used at the Town of Brookhaven landfill for earlier investigations (Tonjes *et al*., 1995). A further modification, which will be used in this paper, has been developed and presented (Tonjes, 1999).

Stiff diagrams balance cations versus anions in a simple closed curve around a central axis. The shape that is so generated is believed to characterize a water type. Certainly, the major cations and anions are often used to describe general water quality. In landfill investigations, the cations used are typically: sodium plus potassium, calcium, magnesium, and ammonia. the anions typically used are: bicarbonate, sulfate, chloride, and nitrate.

Table 5. Leachate Indicators, with GA Standards or Guidance Values (in µg/l)
italics = field parameters

Parameter or Compound	Std. or GV
Dissolved Oxygen	
pH	
Redox	
Specific Conductance	
Temperature	
Turbidity	
Ammonia	2,000
Bicarbonate	
Biological Oxygen Demand	
Bromide	2,000
Chemical Oxygen Demand	
Chloride	250,000
Color	
Hardness	
Hexavalent Chromium	50
Nitrate	10,000
Phenols	1
Sulfate	250,000
Sulfide	50
Total Alkalinity	
Total Dissolved Solids	
Total Kjehldahl Nitrogen	
Total Organic Carbon	

Table 6. Leachate Indicator Exceedances of GA Standards or Guidance Values

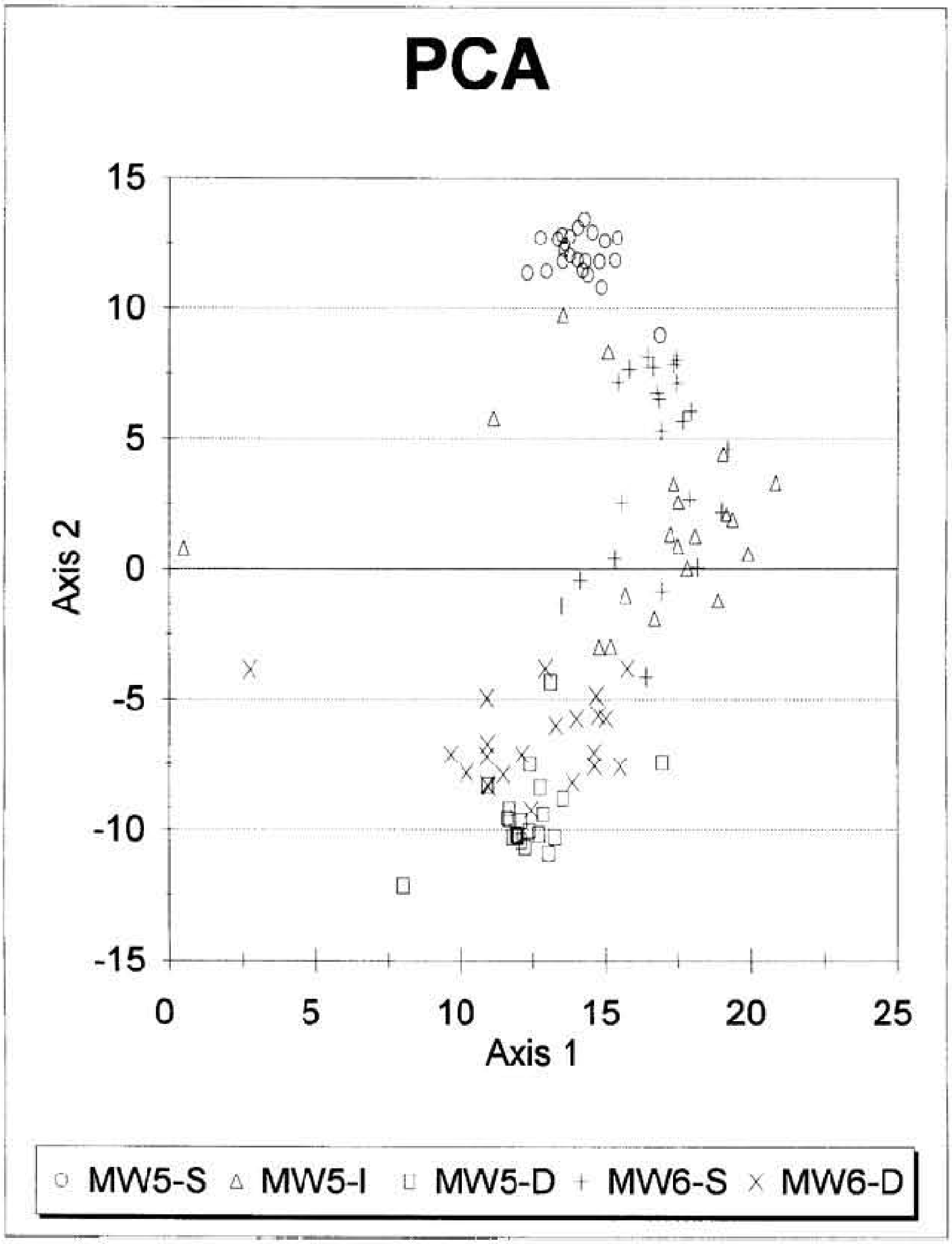
Parameter or Compound	MW-5S	MW5-I	MW5-D	MW6-S	MW6-D

Bromide	2	2	2	5	3
Nitrate			1		1
Phenols	9	7	10	11	12
Sulfide	4	2	4	3	3
Totals	15	11	17	19	19

The diagram shapes are very important. To emphasize similarities or differences in these shapes, modified, normed Stiff diagrams (M-N Stiff diagrams) frame each diagram within a consistently sized box. Each diagram is normed by the sum of the constituent ions. This "ion sum" can be used as a measure of concentration associated with any diagram.

The parameters associated with each Stiff diagram element can be used to create an *8-dimensional* plotting for a diagram. It has been hypothesized that diagrams that plot close to one another in *8-space* will be perceived as having similar shapes (Tonjes, 1998). Dimensional reductions, such as principal components analysis (PCA), can be used to find groupings of the diagrams in a more objective manner than eyeballing the individual diagrams.

Figure 1 is a PCA of the upgradient samples. The *2-dimensional* graph captures 87.8% of the variability of the *8-dimensional* plot. The data points nearly form a continuum. However, it is clear that it is an ordered continuum.



PCA of 109 Upgradient Samples

Figure 1. PCA of 109 Upgradient Samples

There are four outliers, three of which all resulted form very high nitrate concentrations reported in April, 1997 analyses. Otherwise, beginning with the greater *y*-axis values, the points are ordered: well MW5-S; mostly well MW6-S; mostly well MW5-I; well MW6-D; and well MW5-D. The results for wells MW6-D and MW5-D are somewhat intertwined.

Subjective analyses of the diagram shapes grouped these results similarly (Tonjes *et al*., 1995). The well MW5-S results are characterized by strong sodium and chloride signals, apparently from road-salting. The deeper wells (MW5-D and MW6-D) have a more evenly drawn shape. The results from wells MW5-S and MW5-D and MW6-D can be stereotyped as in Figure 2. Typical shapes for the wells MW6-S and, especially, MW5-I, are more elusive.

Figure 2. Examples of Upgradient M-N Stiff Diagrams

This approach to groundwater quality analysis has intrinsic value, in that it characterizes the ground water in terms of its major ions. Moreso, it provides a means of furthering identifying similarities and differences among samples. It does this by creating an organizing principle for the results set. Because it is based upon a well-accepted, intuitive approach to groundwater compositional analysis that integrates a great many parameters (Stiff diagrams), and yet is objective and rational in its analytical approach, M-N Stiff diagrams hold great promise in understanding and working with groundwater sampling data.

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