WATER COMPOSITION COMPARISONS BETWEEN DEEPER PORTIONS OF THE UPPER GLACIAL AQUIFER AND SHALLOWER PORTIONS OF THE MAGOTHY AQUIFER IN SOUTH-CENTRAL BROOKHAVEN TOWN (SUFFOLK COUNTY, LONG ISLAND)

David J. Tonjes
Waste Reduction and Management Institute
Marine Sciences Research Center
SUNY at Stony Brook

Introduction

Stiff diagrams and Piper plots -- graphs of the major dissolved ions -- are used to characterize ground waters (Freeze and Cherry, 1979; Alley, 1993). A particular set of Stiff diagram parameters was developed by the United States Geological Survey to help delineate landfill leachate releases on Long Island (Kimmel and Braids, 1980). The traditional means of drawing Stiff diagrams was extremely modified to trace a leachate plume and distinguish between leachate contamination and other sources of groundwater contamination at a Long Island landfill (Tonjes, 1998). Here distinctions will be made between certain deeper Upper Glacial aquifer and shallow Magothy aquifer sampling data using the modified Stiff diagram technique, Modified Normed (M-N) Stiff diagrams, and will be related to potentiometric head data.

Study Site

Rain falling onto the central portion of Long Island has a higher probability of entering the deep-flow recharge system, and recharging the deeper aquifers. Rain falling onto the shoreline regions recharges the shallow aquifer system only. The presence of a negative head differential between shallow portions of the shallow Upper Glacial aquifer and deeper portions of the deeper Magothy aquifer, indicating a potential for flow from the Upper Glacial aquifer into the Magothy aquifer, was used to determine the planning zone areas of deep-flow recharge (Koppleman, 1976). Figure 1 (adapted from Buxton et al., 1989) shows a generalized flow pattern for a Long Island cross-section approximately 75 mi east of the East River.

Figure 1. Generalized Flow Pattern for Three Aquifers on Long Island (North-South Transect, approx. 75 mi E of East River)

A comprehensive study of groundwater flow potentials at a Town of Brookhaven landfill found that there was little to no hydraulic connection between the Upper Glacial and Magothy aquifers there (Dvirka and Bartilucci, 1994), echoing earlier studies (Camp, Dresser, and McKee, 1985; Gerraughty and Miller, 1985; New York State Environmental Facilities Corporation, 1986; Wexler and Maus, 1988), although others disagreed (Vorheis, 1986; Duggan, 1995). The Town maintains and monitors groundwater monitoring wells in the vicinity of the landfill. The wells in the monitoring network were often constructed in multi-well clusters, with the screens of each well set at different depths below the water table. Four well clusters include wells screened in both the Upper Glacial aquifer and the Magothy aquifer. Another well cluster contains wells screened in the Upper Glacial aquifer and a piezometer screened in the confining layer between the aquifers. Two other well clusters contain wells screened in the Upper Glacial aquifer and wells apparently screened in the confining layer. The evidence that these wells are screened in the confining layer is drawdown (30 ft or more) under a pumping rate of 1.5 gal min^{-1}, and grey-black silts in the well evacuation water (Tonjes, 1998).

Figure 2. Potentiometric Head Differences (in ft) (Magothy Aquifer to Upper Glacial Aquifer, Table 1), and Sampled Well Locations (U1 = MW5-D; U2 = MW6-D; U3 = MW3-D; U-4 = MW2-D; U-5 = MW8-D; U-6 = MW12-D; M-1 = 72812M; M-2 = 72813M; M-3 = 72151M; D-1 = 98439; and D-2 = 98435)

Head Differentials

Potentiometric head differences between the shallowest Upper Glacial aquifer well and the Magothy aquifer and the confining layer wells were found (Table 1). The mean differences were mapped (Figure 2), showing a transition from potential discharge from the Upper Glacial aquifer into the Magothy aquifer to potential discharge from the Magothy aquifer to the Upper Glacial aquifer.

Table 1. Head differences (in ft) between Magothy aquifer and confining layer wells and shallow Upper Glacial aquifer wells. Data from 1982 (but most data 1992 - 1998); quarterly averages compiled to minimize bias from uneven distributions; quarterly data averaged to single datum.

Well Pair	Quarter	Count	Mean Head Difference
MW2-S	1	15	-0.36
MW11-M	2	20	-0.52
	3	23	-0.52
	4	22	-0.46
	Mean		-0.46

MW10-S PZ-2*	1 2 3 4 Mean	17 18 24 23	-0.03 -0.05 -0.06 -0.06 -0.05
3529-45** 72812M-198	1 2 3 4 Mean	4 6 17 14	-0.30 -0.42 -0.27 -0.29 -0.32
73760-65 72813M-219	1 2 3 4 Mean	8 9 18 15	-0.07 -0.17 -0.08 0.00 -0.08
72827-14 95310-142*	1 2 3 4 Mean	5 7 12 12	0.12 0.16 0.14 0.11 0.13
95323-35 72151M-164	1 2 3 4 Mean	4 7 13 13	3.54 3.16 3.44 3.42 3.39
96201-75 96202-148*	1 2 3 4 Mean	4 7 11 11	5.07 5.35 4.68 4.71 4.95

* = well screened in confining layer
** = 3529 is 195 ft downgradient from 72812M;
water level data were adjusted by +0.29 ft (195 ft x 1.5 x 10^{-3} ft/ft -- the calculated Upper Glacial aquifer head gradient near Cell 5 for June 1998)

Hypothesis

If ground water discharges from the Upper Glacial aquifer into the Magothy aquifer in the northern (upgradient) part of this well network, then the composition of deeper Upper Glacial aquifer ground water would influence the composition of shallower Magothy aquifer ground water. And, if Magothy aquifer ground water discharges into the Upper Glacial aquifer in the southern (downgradient) part, then the composition of the shallower Magothy aquifer ground water would influence the composition of the deeper Upper Glacial aquifer ground water.

M-N Stiff Diagrams

The M-N Stiff diagrams can test this hypothesis. Stiff diagrams are normally drawn using the milliequivalent (meq.) values for the selected major ions, and plotting cations versus anions around a central axis. M-N Stiff diagrams are different, in that the meq. values are divided by the sum of the meq. values, normalizing the parameter measures. Each diagram is drawn in a standardized space, bounded by the largest parameter. This permits quick subjective comparisions of the shapes of the diagrams, and eliminates dilution as a confounding factor. The method is thus appropriate for tracing plumes (Tonjes, 1998).

Studies of shape similarity and differences suggest relations between the diagram shapes can be displayed by using the parameters to map each into an eight-dimensional space (Attali and Montanvert, 1997) and using an appropriate means of reducing the dimensionality. Those shapes that are similar will plot close together in eight-space, and those that are different should not. The distances between points in a two- or three-dimensional representation of the data should adequately represent the similarity and differences in shapes if the dimensional reduction technique chosen accounts for the eight-space data variability well (Schau, 1992; Jahne, 1993). Those diagrams like each other should plot together, and those that are different should not.

Water Composition Analyses

Six upgradient wells, screened in the deepest portion of the Upper Glacial aquifer (100 ft or more below the water table), were sampled 106 times (1992 - 1998). Two downgradient wells, screened 100 ft or more below the water table, were sampled 14 times (1990 - 1998). Three shallow Magothy aquifer wells (screened 160 - 185 ft below the water table) were sampled 29 times (1982 - 1998). Well locations are shown on Figure 2.

The M-N Stiff diagram parameter sets were analyzed by Principal Component Analysis (PCA) (Manley, 1986). A two-dimensional portrayal of the distance relations in eight-space accounted for 86% of the eight-space data variability. Outlier points were identified by this process, and six samples were excluded (Table 2). Figure 3 represents the edited PCA graph.

Table 2. Discussion of outlier points identified in original PCA graph, based on sampling data.

Outlier Identification	Discussion
MW6-D, Apr. 1997	[TDS] = 331 mg/l; [nitrate] = 10.2 mg/l; mean [nitrate] (all UPG wells) = 4.08 +/- 1.66 mg/l; therefore, **outlier**
MW8-D, Sep. 1995 MW8-D, Aug. 1997	Comparision of metals data with MW8-S indicates probable mislabelled bottles; therefore, **outlier** [TDS] = 249 mg/l; [nitrate] = 6.4 mg/l; mean [nitrate] (all UPG wells) = 4.08 +/- 1.66 mg/l; not significant variation; **not an outlier**
98439-122, May 1991	pH = 10.35; [alkalinity] = 312 mg/l; next highest [alkalinity] (all data points) = 54 mg/l; therefore, **outlier**
72151M, Dec. 5, 1995 98435, Dec. 5, 1995	[sulfate] = 68 mg/l [sulfate] = 51 mg/l all samples this date [sulfate] order of magnitude > others samples from same wells; lab. reported no analytical problems; but, **outliers**
72812M, Sep. 1995	comparatively high [alkalinity], [TOC], [sulfide]; low [DO], [sulfate]; suggests organic matter decay; therefore, **outlier**

Upgradient data plot separately from downgradient data. Much of the upgradient data cluster in the upper right-hand corner. The downgradient data is more dispersed. Several of the data points for Magothy well 72812M plot near the upgradient data; the remainder of the Magothy well data plot close to the downgradient data.

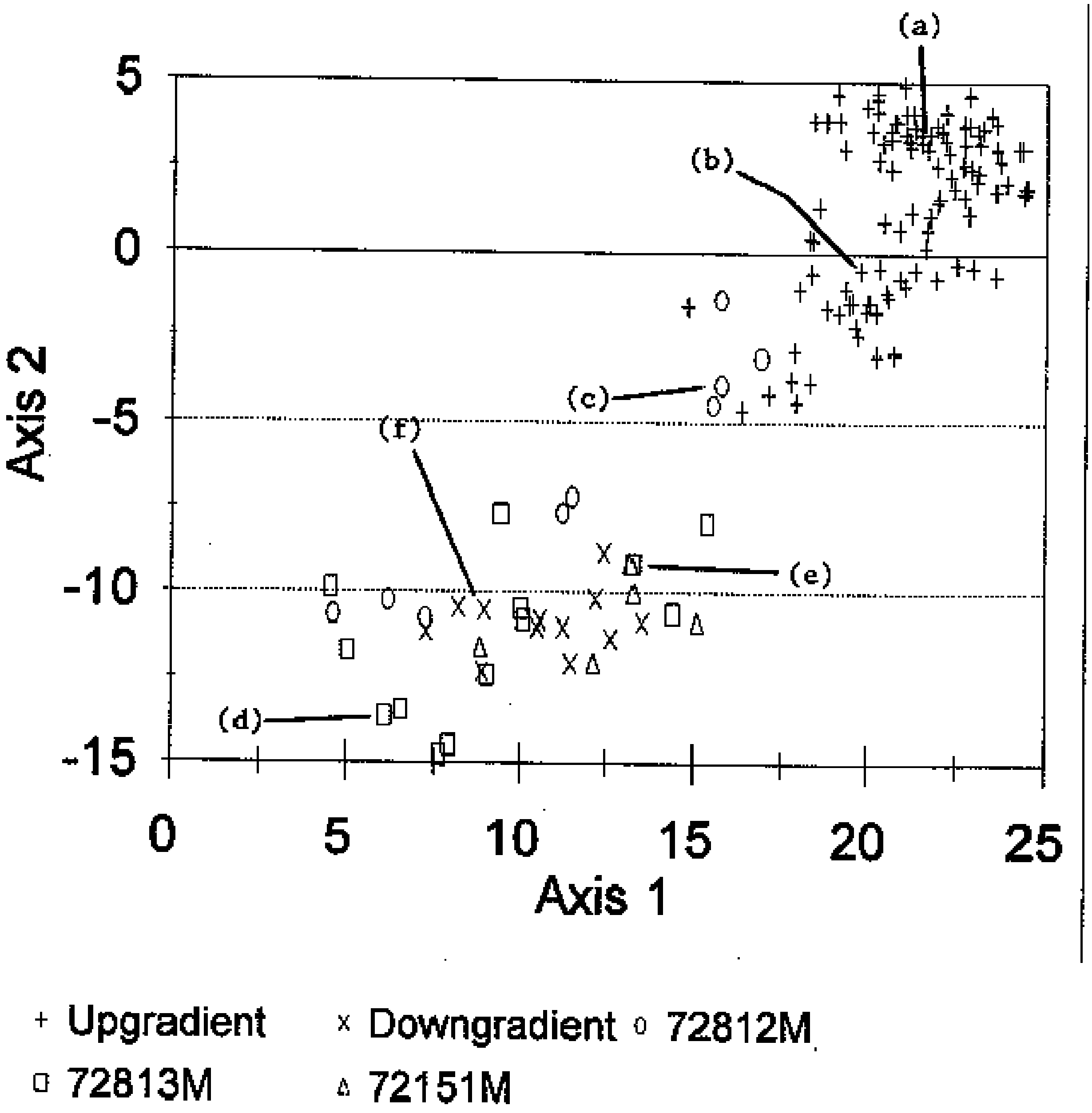

Figure 3. First Two Axes, PCA of Sample Data (Samples (a) - (f), Figure 4, Located)

Discussion

Figure 3 suggests the upgradient Upper Glacial aquifer ground water is similar in composition to some of the upgradient shallow Magothy aquifer ground water, as expected if head differentials were driving Upper Glacial aquifer ground water into the Magothy aquifer there. Figure 3 also supports a relationship between shallow Magothy aquifer groundwater and downgradient groundwater composition, as expected if head differentials were driving ground water up through the confining layer.

Representative M-N Stiff diagrams (Figure 4) show the two deep Upper Glacial aquifer groundwater compositions are different. Statistical comparisions between the two groundwater types (Table 3) show most major ions have higher concentrations upgradient than downgradient. Exceptions include iron, manganese, and bicarbonate data.

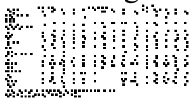

Table 3. Means, Standard Deviations and Maximum and Minimum values for select parameters at six upgradient and two downgradient Upper Glacial Wells, compared to three Magothy aquifer wells data.

The increase in iron and manganese concentrations can be contrasted to decreases in nitrate and sulfate concentrations. The lack of oxygen in the downgradient samples may be due to biological activity occurring over time. Once oxygen were unavailable as an electron acceptor, organic decomposition would consume nitrate, insoluble manganese and iron would be reduced to soluble forms, and, finally, sulfate would be reduced and consumed. Each reaction generates bicarbonate (Froehlich et al., 1979). The decline in other major ions between the upgradient Upper Glacial aquifer and Magothy aquifer ground waters may result from ions reacting to finer-grained confining layer sediments.

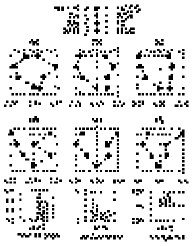

Figure 4. Selected M-N Stiff Diagrams from Sample Data: (a)MW5-D, 10/24/97; (b) MW10-D, 5/19/93; (c) 72812M, 6/29/98; (d) 72813M, 11/6/97; (e) 72151M, 5/18/94; (f) 5/19/94.

Conclusions

Clear differences were found between deeper Upper Glacial aquifer ground waters from two locales. Both potentiometric head data and multivariate statistical analysis of geochemical data support flow-paths from the Upper Glacial aquifer into the Magothy aquifer and back to the Upper Glacial aquifer again. This is contrary to earlier reports.

Two implications for the siting of public drinking water wells result. One is drinking water drawn from the Magothy aquifer may contain contaminants found in the Upper Glacial aquifer, if the well is sited at the edge of the Deep-recharge Zones and is screened in the shallower portions of the Magothy aquifer. Secondly, a public water well screened in deeper portions of the Upper Glacial aquifer may produce "Magothy" water (which may be free of anthropogenic contaminants due to greater age), if the well is outside of the Deep-recharge Zones where discharge from the Magothy aquifer may occur.

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