Chemical signature of a sewage plume from a cesspool, Long Island, New York

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Abstract of Thesis

Chemical signature of a sewage plume from a cesspool, Long Island, New York

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The geochemistry of sewage and the sewage plume from a typical residential cesspool located on unconsolidated sandy aquifer at Southaven, Long Island was studied. Sewage signatures near the top of the water table in the down gradient wells were weak, but recognized by slightly elevated NO_3^- and NH_4^+ and low DO. Although samples were collected at a variety of depths and distances along the groundwater flow path from the cesspool, the main part of the plume was missed. Ground water at greater depths, 10 to 20 feet below water table, had higher Na and Cl concentrations with a Na/Cl ratio consistent with an origin as road salt from nearby highways.

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Chapter I: Introduction

Ground water provides drinking water for more than half of the people in the United States. However, this important national resource is vulnerable to contamination. Nitrate is soluble in water and can persist in shallow ground water. Major sources of nitrate include fertilizer, animal manure, sewage and atmospheric deposition. Elevated concentrations of nitrate in drinking water are a cause for concern. Ingestion of nitrate by infants can cause low oxygen levels in the blood, a potentially fatal condition. Other adverse health effects potentially related to ingestion of nitrate in drinking water include spontaneous abortions and non-Hodgkin's lymphoma. The U.S. Environmental Protection Agency (USEPA) has set a maximum contaminant level (MCL) of 10 mg/L nitrate as nitrogen (N) in drinking water (U.S. Environmental Protection Agency, 1995). According to Suffolk County Water Authority (SCWA), 66% of the supply wells in Suffolk County are rated as having a high or very high susceptibility for nitrate contamination and 23% have median susceptibility. Only 10% of wells have low susceptibility for nitrate contamination. Reduced contaminant ratings in the central and eastern parts of Suffolk County are due primarily to lower population density.

Nitrate contamination of groundwater is a problem in some heavily populated areas of Long Island where septic tanks or cesspools are used for sewage treatment. Effluent from septic tanks or cesspools is enriched with ammonium ion (NH_4^+). Ammonium ion can be preferably absorbed onto sediments surrounding a cesspool and under oxidizing conditions ammonium ion (NH_4^+) is converted to nitrate ion (NO_3^-). Nitrate is quite soluble and completely mobile when it is dissolved. Once it is carried by water beyond the reach of plant roots, it ends up in ground water.

An important consideration in calculating the susceptibility of nitrate contamination is to what extent denitrification, the breakdown of nitrate to nitrogen gas, may be occurring in Long Island's groundwater. Oxygen and nitrogen isotope data for groundwater from the Northport area (Bleifuss et al., 2000) and also in other parts of Long Island (Leamond et al., 1992; Stackelberg, 1995) suggest that denitrification is not an important process. However, Eh-pH calculations for Long Island ground water show the potential for denitrification (Xu, 2005).

Description of study area:

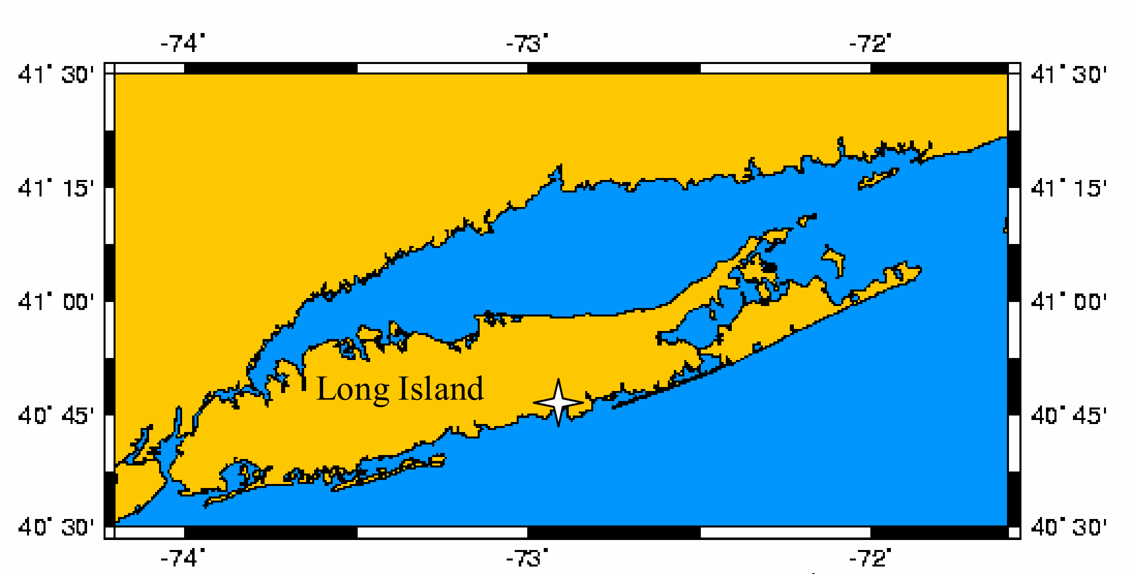

Figure 1. Star shows location of site on Long Island, NY.

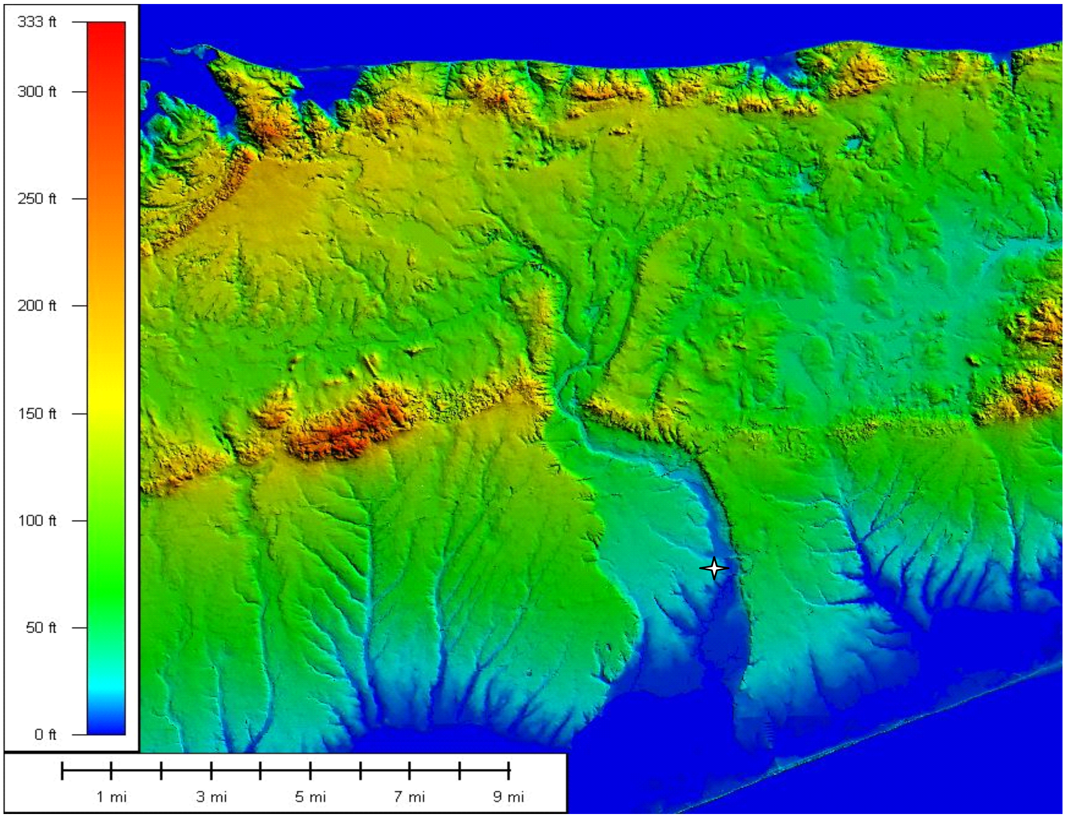

Figure 2. Yellow star shows Location of site on Digital Elevation Model of central Long Island.

This is a study of the chemistry of sewage plume from a residential cesspool in Southaven Town, Long Island (Fig. 1). The site is south of Montauk highway and about 200 meters west of Carmans River (Figs. 2 and 3). Geologically, the site is in a large abandoned stream valley. The Carmans River is now reoccupying one of the tributaries in the valley. Carmans River originates in the western Pine Barrens area at Middle Island and cuts through the Ronkonkoma Moraine starting at an elevation of approximately 70 feet, and flows in a southerly direction through Southaven Park to Bellport Bay, which is also at mean sea level.

Figure 3. The site is located north of Montauk Highway and west of Carmans river.

The occupants of the house are three senior adults who spend most of each day in the house. The sewage treatment occurs only in a cesspool. There is no septic tank. The ground water table is about 12 ft below the surface. Nine sampling wells were installed down gradient from the cesspool along the ground water flow direction and one was installed up gradient (Figs. 4, 5 and 6). The waste water is from laundry, kitchen, bathroom and toilet. The lawn is not fertilized or irrigated. The water supply is from a shallow well (24 ft. deep).

Figure 4. Location of the site and positions of installed test wells and core samples.

Objectives:

The objective of this study is to characterize the sewage plume from the cesspool by sampling groundwater from test wells and explore plume interactions with sediments on this particular site.

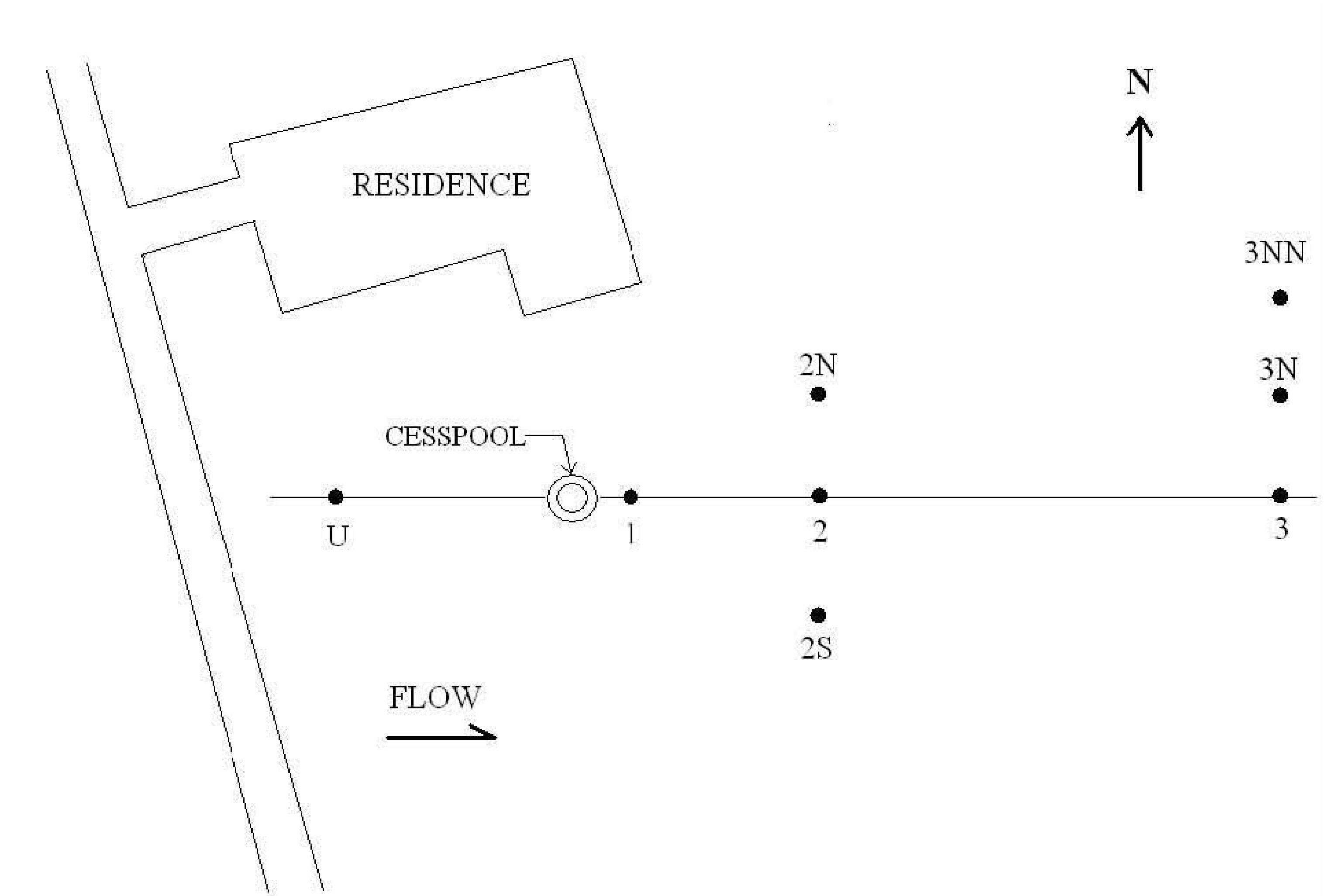

Figure 5. Sampling well locations at study site.

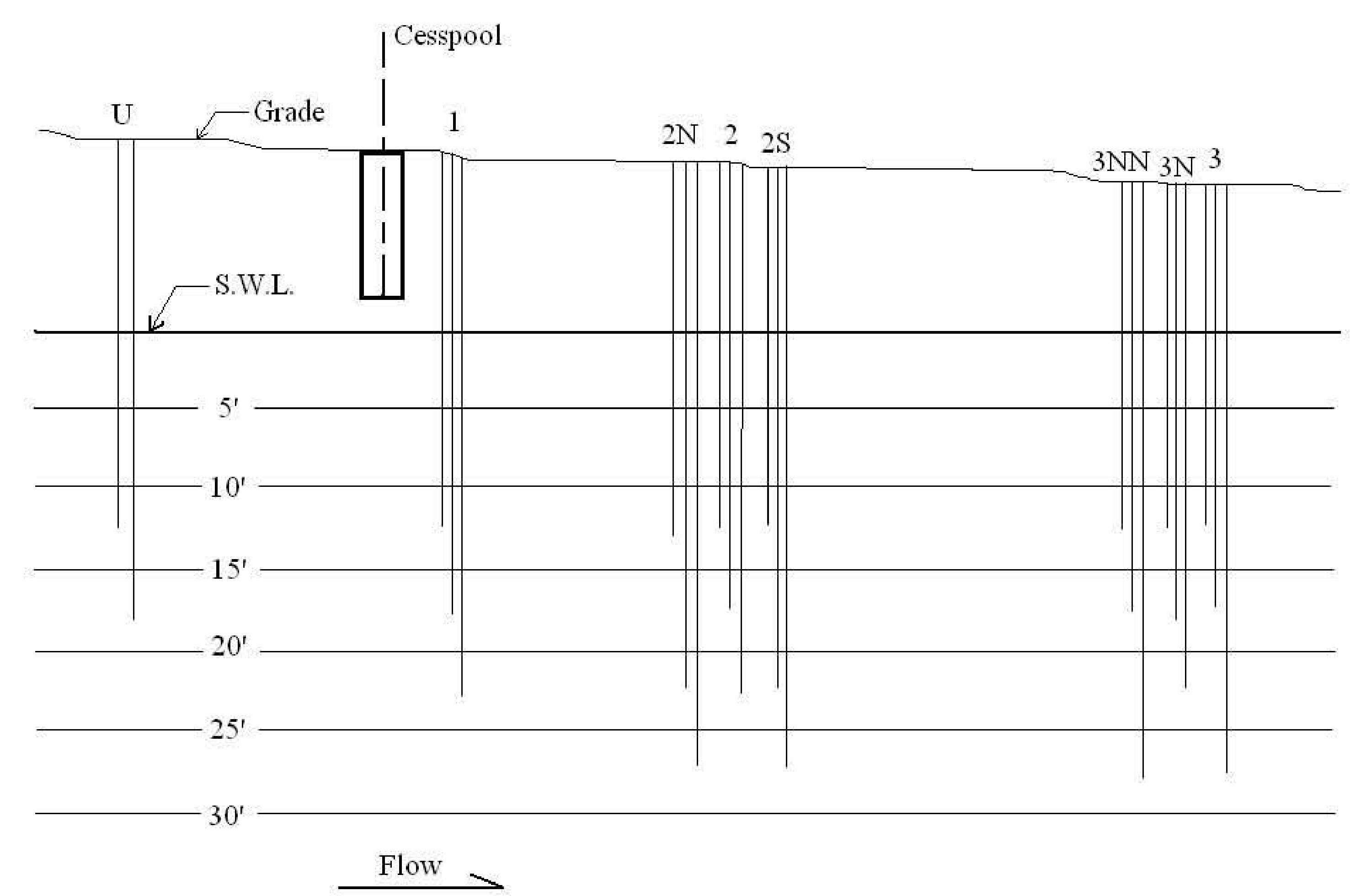

Figure 6. Sampling well profile at study site.

Chapter II: Analytical Methods:

2.1 Core samples:

Core samples were taken by Geoprobe using a dual tube direct-pushing sampling system: Four cores were collected along the flow line of groundwater, one was collected upgradient of the cesspool, and three were collected downgradient from the cesspool. All the core samples were taken below water table at a depth of 12~16 ft. The core samples were sealed immediately. The bottom 30 cm of each sample was cut and sealed in field, cooled at 4ºC and taken to Soil Food web New York, Inc. for CEC analysis on the same day. The rest of the core samples were taken back to the lab for grain-size distribution analysis.

2.2 Groundwater sampling:

Groundwater samples were collected from pre-installed ground water test wells using a Solinst® 410 peristaltic pump fitted with silicone tubing. The peristaltic pump was attached to 1/2" down-hole tubing. The other end of the sampling tubing was attached to a Solinst® flow-through cell. This flow-through cell allows the analysis of purge water in-line as it flows. Two sensors were connected into this flow-through, an Orion® 810 Dissolved Oxygen meter and a pH/ORV/Temp meter. The readings were monitored during purging. Once the DO, temperature and pH were stabilized, ground water samples were collected through a 3-way valve on the inlet of the flow-through cell. Water samples were collected in 1L plastic bottles for BOD_5 and TKN analysis seperately, stored at 4ºC and sent to the Environmental Testing Lab at the same day. Water samples for nitrate and nitrite analysis were filtered and frozen until analysis.

Samples for cations and anions were collected in polypropylene bottles and stored at 4ºC until analysis.

2.3 Grain-size distribution:

Sieve analysis was conducted to determine the grain size distribution curves. For each core sample, about 250 grams were weighed and sieved through 11 standard sieves with a Ro-Tap for 15 minutes.

2.4 Water table measurement:

Relative depth of water table at each well was determined by using differential leveling process. The relative elevation of each well was measured at least twice for precision. The first round of this differential leveling progress began forward from the reference well to the other wells. Then the same progress was repeated backward from the furthermost well to the reference well until the closure was less than 0.1cm. The relative height of the water table was measured twice using a chalked steel tape. The average of these two reading was used.

2.5 BOD$_5$, TKN:

Four groundwater samples were sent to Environmental Testing Laboratories, Inc. for Biological Oxygen Demand (BOD$_5$) and Total Kjeldaho Nitrogen (TKN). TKN was analyzed following sampling and analysis methods of EPA 351.3. BOD$_5$ samples were analyzed following sampling and analysis methods of EPA 405.1.

Chapter III: Results

A basic hydrology investigation was conducted to determine ground water flow direction and velocity. To characterize the sewage plume, major ions, BOD_5 and TKN in water column were analyzed.

3.1 Hydrology

In order to determine the hydraulic conductivity, samples from four GeoProbe cores were taken near the upgradient well U and the downgradient wells 1, 2 and 3. Cumulative probability curves were used to analyze the grain-size distribution pattern of the samples (Fig. 7). Sediments at this site are well-sorted, medium sand, typical of river sand (Fig. 7).

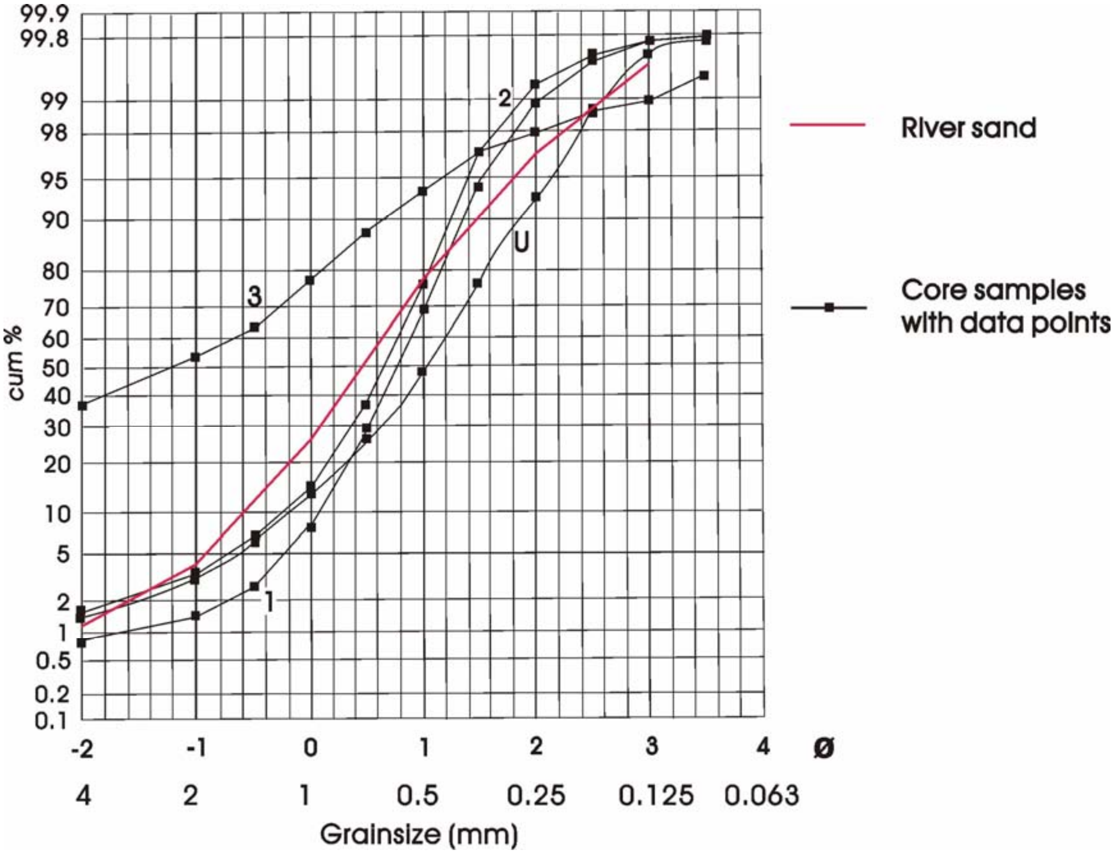

Figure 7. Grain size distribution results showing on cumulative probability. (River sand data is from R.C. Selley, 2000)

Hydraulic conductivity, K, can be estimated by the Hazen approximation (Hazen, 1911),

$$K = Cd_{10}^2$$

where K is the hydraulic conductivity in cm/s; d_{10} is grain size in cm, at the grain size where 10% of the sample is finer; C is a coefficient that factors in the sorting characteristics of the sediment.

Table 1. Calculated hydraulic conductivity.

Sample	d_{10} (cm)	C	K (cm/s)
U	0.0261	80~120	0.054~0.082
1	0.0401	80~120	0.129~0.193
2	0.0412	80~120	0.136~0.204
3	0.057	80~120	0.260~0.390

The elevation of the water table was measured in four wells in line with the cesspool and the groundwater flow direction, with U upgradient to and the other three downgradient (Table 2). The water table elevation was measured using well# 1 as reference point assigning the well top an elevation of 17 ft above sea level.

Ground water is flowing from west to east. The first water table leveling made on April, 2006 gave a water table slope of about 0.0029 with 99.51% confidence (Fig. 8). The measurement made on October, 2006 showed a slope of 0.0028 with 99.93% confidence (Fig. 8). These results are consistent with slopes of 0.001 to 0.003 in Brookhaven Town (Tonjes, 2001).

Since the slope of the water table is about 0.003, the ground water flow velocity in this area is about 4.8×10^{-4} cm/s, which is somewhat faster than the 3.5×10^{-4} cm/s ground water flow velocity elsewhere on Long Island, but consistent with being close to a stream (Buxton,1992).

Table 2. Relative water table elevation in different wells.

		elevation above sea level (ft)	
		13th April., 2006	13th Oct, 2006
	Distance from U (ft)	Water table level	Water table level
U	0	4.680±0.004	4.905±0.002
1	49.21	4.595±0.005	4.811±0.024
2	95.47	4.509±0.005	4.667±0.007
3	234.58	4.077±0.014	4.299±0.008
Set top of D1 well as reference point with elevation as 17ft above sea level			

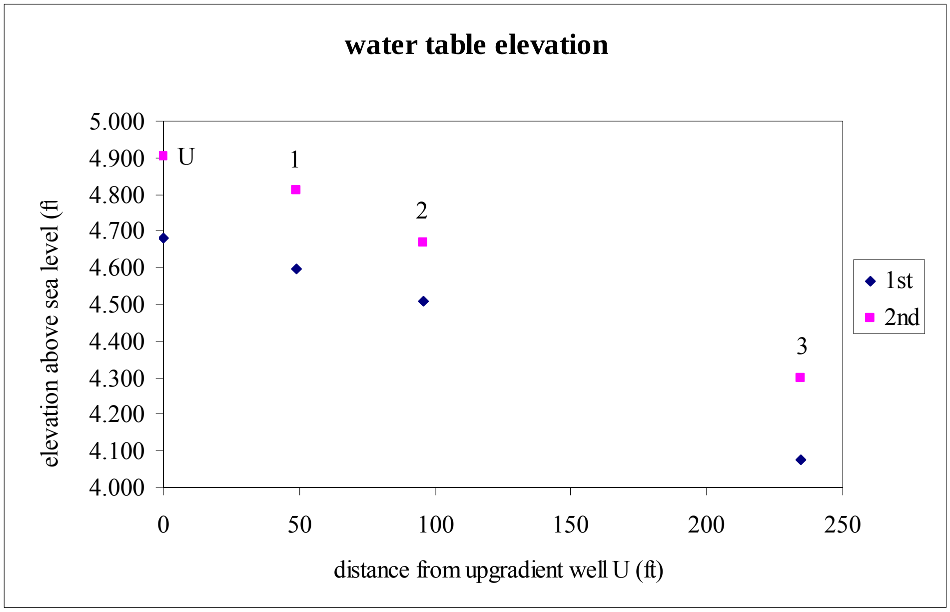

Figure 8. Elevation of water table above sea level at different wells. The first measurement was on 13th April., 2006; the second was on 13th Oct, 2006.

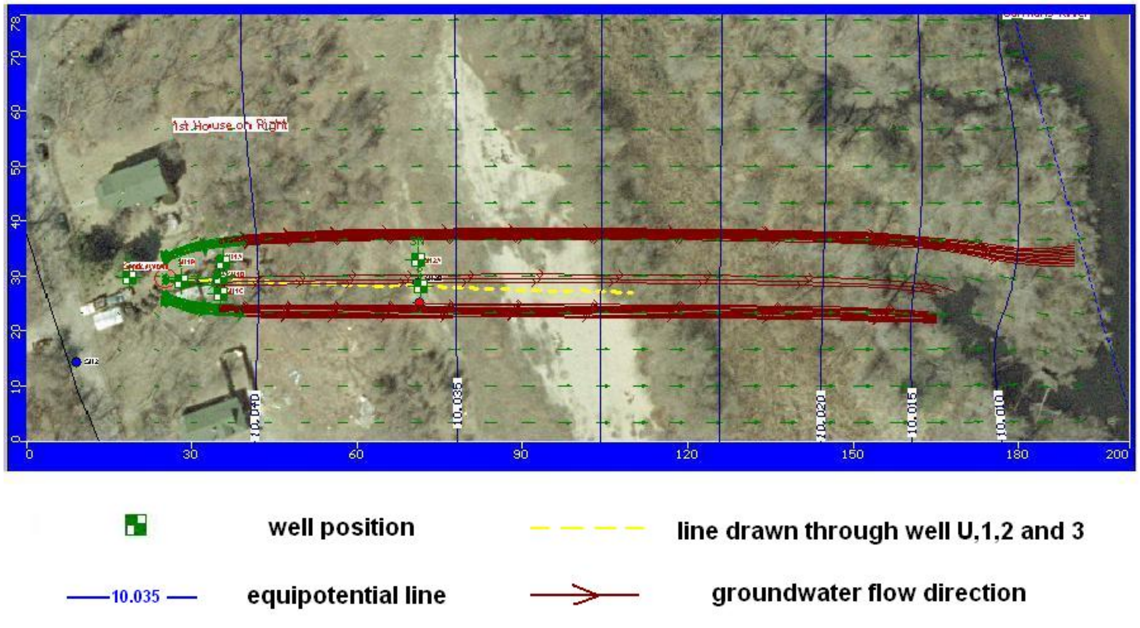

Figure 9. MODFLOW modeling result.

The three-dimensional finite-difference ground-water model MODFLOW was used to determine the ground water flow direction based on water table measurement. Result is shown in Fig. 9. The yellow dashed line in Fig. 9 connects wells U, 1, 2 and 3. The red lines show the ground water flow paths from north of, south of and directly from the cesspool. As can be seen, the wells are directly in the flow path from the cesspool.

3.2 Bacteria in Cores

Samples from the four Geoprobe cores were analyzed for E.coli abundance. High concentrations of E. Coli were found in the upgradient core sample (Table 3). No E. Coli were found in the three other samples which were downgradient from cesspool. E.coli presence in groundwater is a common indicator of fecal contamination. E. coli and other coliform bacteria in the upgradient core samples may suggest possible contamination from the cesspool. The lack of E. coli in the other cores may be because sand is effective at removing bacteria from sewage.

Table 3. E. Coli and other Coliform Concentrations in core samples.

	E.coli	Other Coliform
	CFU in 1g of fresh soil	CFU in 1g of fresh soil
U	20.0	210.0
1	0.0	60.0
2	0.0	40.0
3	0.0	30.0
* Analyzed by SoilFood Web. Inc.		

3.3 Groundwater and Sewage chemistry

Nine wells were installed at this site. Groundwater from each well was sampled at two or three different levels below the water table (Fig. 6). Temperature, dissolved oxygen, pH and conductivity were recorded at the time of sample collection (Table 4). Water samples were analyzed by Suffolk County Public & Environmental Health laboratory for major and minor ion concentrations (Table 8). Along the plume core flow path, at 10 to 15 feet below the surface, electrical conductivity was three to five times higher than background. pH was 5.66 in the first downgradient well 1, 5.49 in well 2 and 5.30 in well 3.

Dissolved oxygen concentrations in the upgradient well range from 1.3 mg/L to 1.7 mg/L (Table. 4) by Suffolk County Division of Health Services in August 2005 and were 2.4 mg/L in April, 2006 and 0.6 mg/L in August, 2006. The downgradient wells had 7.27~9.23 mg/L in well 1 and 2, 0.1~1.2mg/L in well 3 in August 2005, measured from 10~30 ft below the ground surface.

At air pressure of 760 mm Hg and 13ºC, the saturated dissolved oxygen concentration in water is about 11 mg/L. The depressed oxygen concentration combined with high E. coli in upgradient well suggests contamination by sewage. Discrepancy existed between my observation and SCDHS at well 1 and 2, where SCDHS analyses show oxygen concentration as 2.2 mg/L and 7.27-9.23 mg/L whilst my analyses gave 1.1~2.2 mg/L in April, 2006 and 0.6 mg/L in August 2006 in all the downgradient wells, measured at 12 ft below ground surface. This may due to different methods and equipments used, or seasonal fluctuation of water table, change of aeration of unsaturated and saturated zone, precipitation, evapotranspiration and irrigation etc. Through my observations, dissolved oxygen values are consistently low, 0.6 ~2.2 mg/L, in all the wells indicating presence of sewage contaminations and no evidence of re-oxygenation of the polluted ground waters within the downstream distances studied.

Table 4. Dissolved oxygen, temperature, pH and conductivity of ground water samples.

Sample ID#	Sample Dep.(ft)	D.O. (mg/L)	TEMP (℃)	pH	COND. (S/m)
U	10~15	1.7	14.3	4.58	114.4
U	15~20	1.3	13.7	5.47	384.8
D	24	2.5	12.3	7.24	470.8
1	10~15	8.06	13.2	4.87	120
1	15~20	7.27	12.2	5.66	368.5
1	20~25	7.42	11.6	5.62	421.5
2N	10~15	1.8	12.9	5.48	129.1
2N	20~25	1.6	12.4	5.31	490.9
2N	25~30	2.3	12.1	5.78	494.7
2	10~15	7.75	14.1	5.14	223.6
2	15~20	7.27	13.7	5.49	362.6
2	20~25	9.23	13.5	5.69	458.5
2S	10~15	2.2	13.1	4.93	183.4
2S	20~25	1.9	11.9	5.51	462.1
2S	25~30	1.9	11.8	5.36	414.1
3N	10~15	1.5	13.5	5.28	108.3
3N	15~20	1.3	13.8	5.36	415
3N	25~30	1.8	11.8	5.17	426.2
3	10~15	0.3	13.7	4.90	146.3
3	15~20	0.1	12.6	5.30	375.4
3	25~30	1.2	12.4	5.38	451.5
3NN	10~15	0.6	13.4	5.12	107.2
3NN	15~20	1.5	13.4	5.46	464
3NN	25~30	2.6	12.3	7.94	540
* Measurements were done by Suffolk County Department of Health Services during sampling					

Septic–system effluent contains elevated concentrations of dissolved organic carbon (DOC) and nutrients, in particular nitrate and phosphorous, ammonia, and pathogens. Table 5 compares major ion chemistry in the cesspool and downgradient well 2 of this research with other studies. Nutrients in the cesspool are within the common range of sewage (Table 5). The nitrogen species in sewage are dominantly ammonium and organic nitrogen with extremely low concentrations of nitrate. Total nitrogen (TKN + NO_3-N + NO_2-N) in sewage at this site is 98.2 mg/L (Table 5). The total nitrogen contributed to sewage is estimated to be around 6.09~14.45 g/person/day, mainly from urine. (Jennie Munster, 2004). If each person in the household contributes 50 gal wastes per day into the cesspool, the total nitrogen will be 76 mg/L, which is comparable to our measurement.

Table 5. Comparison of sewage concentration in disposal system.

	A	B	C	D	E	F	G
Na	78.2	39	42.8	98	90	83.6	—
K	29	27	20.6	12	21	18.77	—
Ca	20.1	9	83.6	40	14	19.47	—
Mg	6.3	3	12.9	14	3	6.10	—
SO_4	31.6	9	34.1	27	42	8.99	2-177
Cl	114.5	53	57	45	55	66.44	50-70
NO_3-N	0.2	0.1	0.05	1	0.1	0.44	0.02-0.95
NH_4-N	86.3	88	97.9	30	59	—	52-115
PO_4	7.1	9	11.8	8	13	26.07	58-122
pH	5.5	6.4	—	7.9	7.6	—	4.5-7.1
	Cesspool	weeping tile	Septic tank	weeping tile	weeping tile	Residentail septic tank/cesspool influent	Sewage in disposal system

* A from this research ; B from W.D. Robertson (1995); C from C.J. Ptacek (1998); D from Cambridge site in W.D. Robertson (1991); E from Muskoka site in W.D. Robertson (1991); F from Residential septic tank/cesspool influent in Jennie Munster (2004); G from the Long Island Ground Water Pollution Study (1972).

* Data reported in mg/L

Cl, Na and K concentrations in the cesspool are similar to that in sewage from other sewage studies (Ptacek, 1998; Jennie, 2006, Long Island Ground Water Pollution Study, 1976). However, Cl concentration is noticeably higher than that in other studies. Na/Cl is around 0.68, comparable to pure salt. On this site, the drinking water is from a basement well 29 ft below ground surface. Chemistry of the drinking water is shown in Table 6.

Concentrations of major cations (Ca, Na, K and Mg) and anions (HCO_3^-, SO_4^{2-} and Cl^-) in pristine shallow groundwater on Long Island are usually less than 10 mg/L (Kimmel, et al., 1980).

Table 6. Chemistry of drinking water. Concentrations are shown in mg/L.

Na	K	Ca	Mg	SO_4	Cl	NO_3-N	NH_4-N	PO_4	pH
36.80	1.42	12	3.39	21.4	62.3	3.35	0	0	—

Table 7. Comparison of sewage plume concentration in plume core.

	this research	Cambridge W.D.Robertson 1991	Muskoka W.D.Robertson 1991	Long Island Ground water Pollution Study 1972
Na	16.4	86	45	
K	5.7	11	14	
Ca	12.3	90	44	
Mg	2.4	17	3	
SO_4	9	63	32	40.5
Cl	26	24	38	45.6
NO_3-N	11.1	33	39	53.5
NH_4-N	<0.02	0.1	0.5	19.7
PO_4	1	4	0.01	24.7
pH	5.14	7	5.1	
	well# 2 10~15ft	plume core	plume core	Site 3

The total cation charge in this sewage is 10.73meq/L and total anion charge is 2.58meq/L. This difference between total cation charge and total anion charge is probably due to bicarbonate which gives an alkalinity as $CaCO_3$ of 410 mg/L, comparable to reported alkalinity of sewage 300 mg/L to 550 mg/L (Table 7, Long Island Groundwater Pollution Study, 1972; W. D. Robertson, 1991, 1995; C.J. Ptacek ,1998;).

Fig.11 shows conductivity, DO, NO_3^-, NH_4^+, PO_4^{3-}, Cl^- and SO_4^{2-} distribution along ground water flow path from cesspool. Nitrate as nitrogen concentrations in the expected sewage plume varied from below 0.5 mg/L to 11.1 mg/L. Nitrate concentration in the in the upgradient well is 3.0~3.8 mg/L,. Water from well 1 has a nitrate concentration of 4-5 mg/L at 10-20ft. In well 2, nitrate concentration is 11.1mg/L in 10~15ft, 7.8 mg/L in 15-20ft, and 2.1 mg/L in 25-30ft. At well 3, nitrate concentration is reduced. Several investigation on septic system impacted ground waters reported NO_3-N concentration in the subsurface as 10~50 mg/L. Ammonia was detected in well 1, 2 and 3 and was generally increasing. The highest amount of ammonia, 2.41 mg/L, was found in well 3 at 15-20ft deep. Nitrite was virtually void in all ground water samples.

Concentrations of cations in the downgradient wells are generally elevated compared with upgradient well due to sewage input. Major cations, Na, K, Ca and Mg, were found concentrated with depth in each wells. The plume water also contains high concentration of Al, Fe, Mn (Table 8).

Table 8. Groundwater Chemistry.

ID#	Dep.(ft) From surface	Cl ppm	SO_4 ppm	NH_4 ppm	NO_2 ppm	NO_3 ppm	PO_4 ppm	Na ppm	K ppm	Ca ppm	Mg ppm	Fe ppm	Al ppb	Mn ppb	Estimated density (kg/m^3)
U	10~15	15	12	<.020	<.02	3.8	0.3	8.8	2.1	6.0	1.4	<0.1	238.0	83.8	999.270
U	15~20	94	16	<.02	<.02	3.0	<.2	55.1	2.8	9.7	2.1	<0.1	30.8	7.8	999.457
D	24	126	19	<.02	<.02	2.0	<.2	68.0	2.9	11.3	3.2	<0.1	5.9	6.9	999.673
1	10~15	15	10	0.02	<.02	4.1	<0.2	9.1	2.0	7.2	1.8	0.95	274.0	200.0	999.420
1	15~20	72	14	0.07	<0.02	5.1	<0.2	45.4	3.0	11.9	2.8	1.68	<5	294.0	999.625
1	20~25	96	17	0.07	<0.02	1.5	<0.2	62.0	2.7	10.0	3.0	1.74	70.6	226.0	999.755
2N	10~15	12	11	<0.02	<0.02	2.7	<0.2	7.2	0.9	6.4	1.5	1.26	738.0	38.5	999.452
2N	20~25	116	16	<0.02	<0.02	2.7	<0.2	68.2	2.9	11.7	3.9	0.19	114.0	50.7	999.653
2N	25~30	132	16	<0.02	<0.02	2.7	<0.2	66.6	3.7	12.8	4.1	<0.1	33.1	190.0	999.701
2	10~15	26	9	<0.02	<0.02	11.1	1	16.4	5.7	12.3	2.4	1.62	615.0	376.0	999.326
2	15~20	64	13	1.06	<0.02	7.8	<0.2	44.5	3.7	13.6	3.1	2.01	474.0	557.0	999.434
2	25~30	106	17	<0.02	<0.02	2.1	<0.2	68.0	3.5	10.5	3.6	2.94	499.0	160.0	999.508
2S	10~15	19	13	0.02	<0.02	6.7	0.8	12.0	2.0	10.6	2.0	1.02	650.0	146.0	999.446
2S	20~25	121	16	<0.02	<0.02	1.8	<0.2	66.5	2.2	10.7	3.6	1.61	870.0	34.3	999.724
2S	25~30	107	17	<0.02	2.1	<0.5	<0.2	58.1	2.4	10.3	3.4	0.12	48.8	42.3	999.694
3N	10~15	11	8	<0.02	<0.02	2.2	<0.2	6.3	0.8	7.6	1.4	0.25	299.0	18.6	999.370
3N	15~20	100	14	<0.02	<0.02	2.5	<0.2	59.1	2.3	11.0	3.3	0.18	173.0	15.8	999.451
3N	25~30	106	14	<0.02	<0.02	2.4	<0.2	57.2	3.1	12.0	3.7	<0.1	29.5	334.0	999.704
3	10~15	13	9	1.35	<0.02	4.1	<0.2	9.3	1.5	6.5	1.5	1.01	350.0	304.0	999.351
3	15~20	68	16	2.41	<0.02	8.3	<0.2	45.8	3.6	12.1	2.8	0.28	175.0	1330.0	999.581
3	25~30	106	17	0.06	<0.02	2.1	<0.2	68.0	2.6	9.3	3.1	0.16	66.2	11.7	999.642
3NN	10~15	10	7	<0.02	<0.02	2.8	<0.2	6.1	1.1	8.5	1.4	0.6	404.0	88.2	999.384

3NN	15~20	107	12	<0.02	<0.02	2.9	<0.2	62.3	3.2	12.7	3.0	0.23	131.0	41.4	999.513
3NN	25~30	141	14	<0.02	<0.02	1.7	<0.2	74.7	3.4	11.3	3.8	<0.1	24.6	554.0	999.687

* Samples were analyzed in Suffolk County Public & Environmental Health laboratory.
* <0.20 and <0.02 are the detection limits.

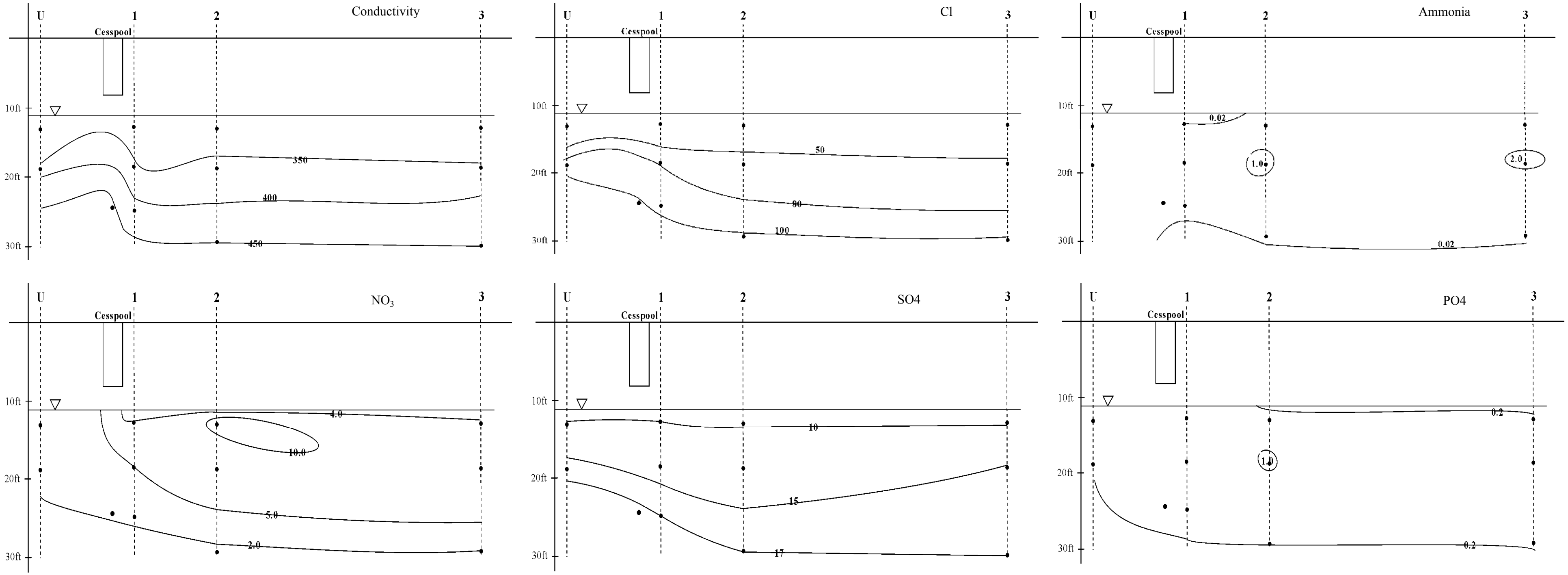

Figure 10. Cross-section map along plume core showing position of wells, contours of equal values of conductivity (m/S), Cl (mg/L), NH_3 (mg/L), PO_4 (mg/L) and SO_4(mg/L) .

3.4 BOD_5 and TKN results

BOD_5 and TKN were analyzed at the Environmental testing lab Inc., Farmingdale, NY.

Total Kjehldahl nitrogen (TKN) is the combination of organically bound nitrogen and ammonium in wastewater. The combination of the TKN and nitrate nitrogen ($N\text{-}NO_3$) and nitrite nitrogen ($N\text{-}NO_2$) make up the total nitrogen. TKN is the highest in the cesspool effluent and decreases due to gaseous loss of nitrogen during denitrification.

Biochemical Oxygen Demand (BOD) refers to the amount of oxygen that would be consumed if all the organics in one liter of water were oxidized by bacteria and protozoa. Most unpolluted rivers have a 5 day BOD (BOD_5) of less than 1 mg/L. Untreated sewage is very variable but averages about 600 mg/L

BOD, Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC) are the major parameters used to measure the load of organic carbon in the environment. However, in my study, due to difficulties in properly sampling ground water for DOC and TOC, only BOD_5 was measured for four ground water samples upgradient to the cesspool and in the plume core. But empirical equations for raw sewage as $COD = 4.18\ DOC - 2$ and $BOD = 0.46\ COD + 5$ were used to calculate DOC and TOC (Fadini, 2004).

BOD_5 and TKN show highest value in cesspool at 240 mg/L and 98 ppm separately (Table 9). BOD_5 of typical home waste water is 278 mg/L in average and COD is 905 mg/L (Bennett, E.R. et al., 1974). Studies reported BOD_5 in cesspools or leaching septic tanks as 100-550mg/L and COD as 142-309 mg/L. These numbers varied with different detergent usage, soil types and strength of sewage plume. BOD_5 in water from upgradient well is around 29 mg/L, which shows slight pollution. In well 1, both BOD_5 and TKN are effectively reduced. This is due to consumption of organic nitrogen through which NO_3^- is converted into nitrogen gas.

Table 9. BOD_5 and TKN results*.

Analyte	Units	U	Cesspool	1	3
BOD_5	mg/L	29	240	44.7	13.9
TKN	ppm	<0.59	98	<0.59	1.16
COD	mg/L	52.2	510.9	86.3	19.3
DOC	mg/L	13.0	122.7	21.1	5.1

* BOD_5 was analyzed by following procedures of EPA 405.1; TKN was analyzed by following standard of EPA 351.3; COD and TOC were calculated by empirical equations (Fadini, P.S. et al, 2004).

Chapter IV:Discussion

4.1 Sewage signature

Average discharge of wastewater from a household is estimated as 50 gal/day/person (Bennett, 1974). For this site, the total discharge is estimated as 150 gal/day for three residents. The cesspool bottom is 1.3 m in diameter or about 1.3 m^2. This yields only an additional 0.44 m/day of sewage loaded onto ground water and 1.23 m for the thickness of the sewage plume, if assuming every day sewage discharge is loaded right on top of the sewage discharged the day before. During sampling, the sampling wells were screened every 1.5 m.

Compared with other reported sewage plumes, the concentrations in the groundwater downgradient from the cesspool are relatively low at this site, in particular the nitrogen species (Table 7, Long Island Ground water Pollution study, 1974). It appears that we missed the main part of the plume during sampling.

Depression of the plume could be possible due to the density difference between ground water and the sewage plume. Density of water is dependent mainly on temperature and salinity (McCutcheon, 1993; Fofonoff, 1983). The calculated densities for water in the downgradient wells are 0.005% to 0.026% greater than the water in the upgradient well at the same depth. Researches on variable density flow and solute transportation in homogenous and heterogeneous porous media show that when a dense fluid overlies a less dense layer, the dense layer sinks (Simmons et al, 2001; Liu and Dane, 1996). 2-D and 3-D density dependent models and studies on plume-groundwater boundary behaviors indicated that gravitational instabilities in a 2-D horizontal flow system can be predicted upon hydraulic properties of the aquifer and density difference (Liu and. Dane, 1996).

The Upper Glacial aquifer on Long Island is relatively homogeneous with constant vertical and horizontal hydraulic conductivity ratio as 1:10. So the flow can be simplified in a 2-D horizontal flow model. Based on calculations from Liu, H.H. (1996), when the dense plume hits the less dense ground water, the plume begins to sink and comes to equilibrium in 48 hours. Since the cesspool has been used for more than five years, the plume and groundwater interaction should have come to a stable stage and a lobe-shaped plume can be predicted. So if this is scenario at this site, the sewage may have sunk to a depth beyond our reach.

4.2 Road salt plume

Stiff diagrams, on which cation concentrations are plotted on one side and anion concentrations on the other, are popular among hydrologist for characterizing different waters. The patterns tend to maintain their shapes upon concentration or dilution. In order to discriminate water types, stiff diagram were plotted for the water samples in each well at different depths (Fig. 11).

According to the stiff diagrams (Fig. 11), two distinct water types were identified. One is in the shallow ground water about 10-15 ft below the surface and a deeper one 20-30 ft below surface which is characterized by high Na and Cl concentration. On the plot of Na vs. Cl, all data points, except for the upgradient well U, fall around the straight line defined by pure NaCl and NaCl concentration ratio in seawater (Fig. 12). Average concentration ratio of Na/Cl in domestic septic tank or cesspool is 0.56 (Jennie Munster,

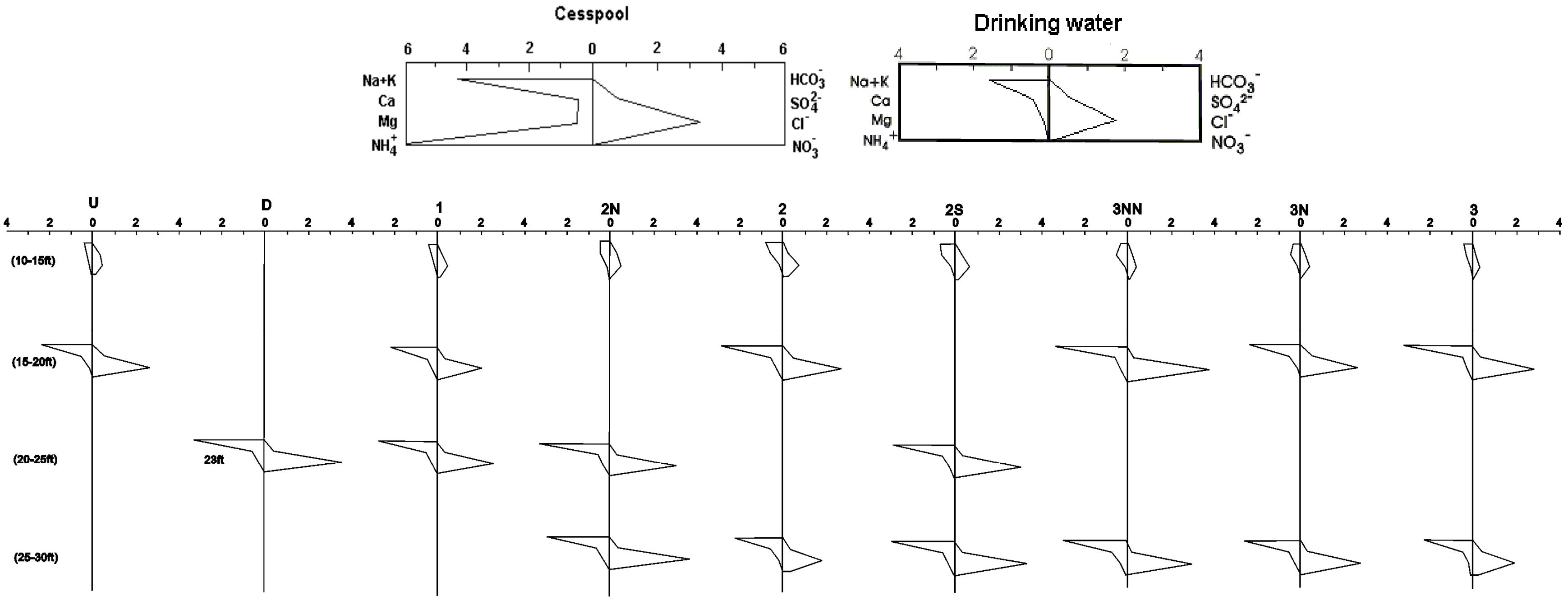

Figure 11. Stiff diagrams for ground water samples from all test wells at different depth. Concentrations of all cations and anions are shown in meq/l. Stiff diagrams for drinking water and cesspool were given on top. Stiff diagrams in below are drawn in the same units as the examples given above.

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2004). The mole ratio of Na/Cl ranging from 0.98 to 1.06 for the deeper 20-30 ft suggests that its source could be salt (Fig. 12).

Road salt usage increased rapidly during 1950s and 1960s. Since high concentration of sodium in ground water will replace Ca and Mg on soil surfaces, molar ratio of (Ca+Mg)/Na in ground water will decrease. In Fig. 13, it can be seen that the deeper water has a lower (Ca+Mg)/Na than the shallow water which is consistent with road-salt in the deep ground water. Since this site is a couple of hundred meters away from Rt.27A and quite near to Sunrise Highway (Fig.14), these roads are most likely the sources of this salt.

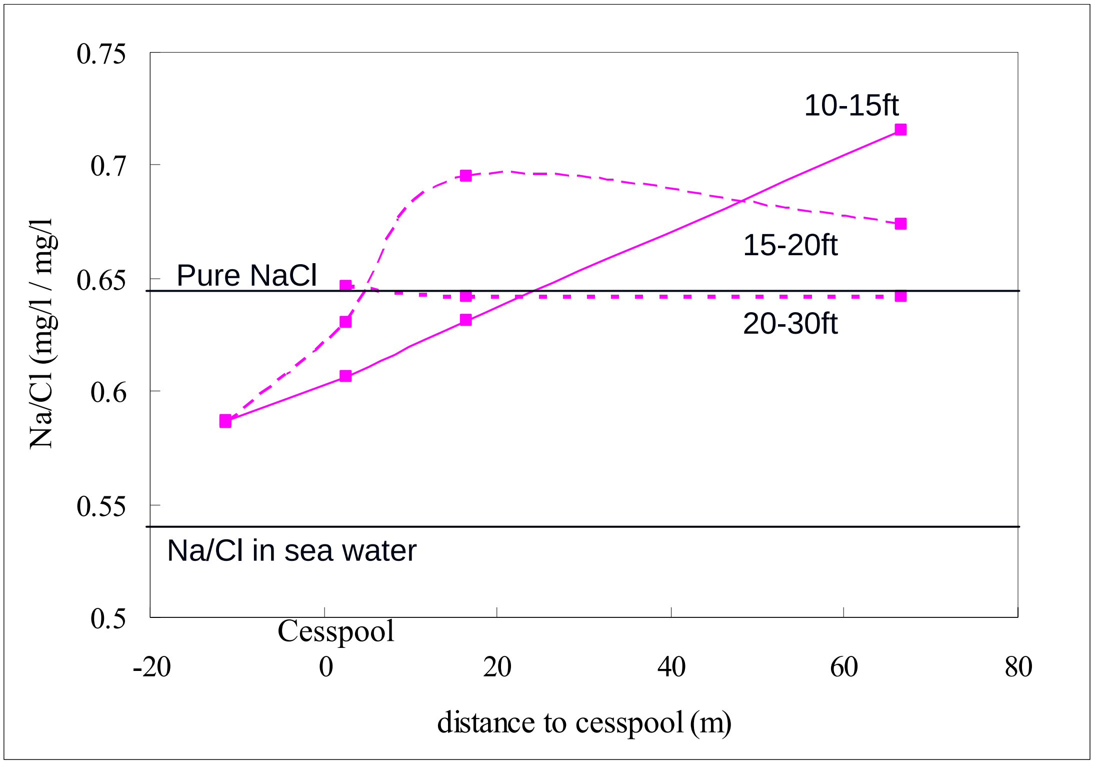

Figure 12. Na/Cl in different depth compared with pure NaCl (~0.647) and Na/Cl ratio in seawater (~0.539).

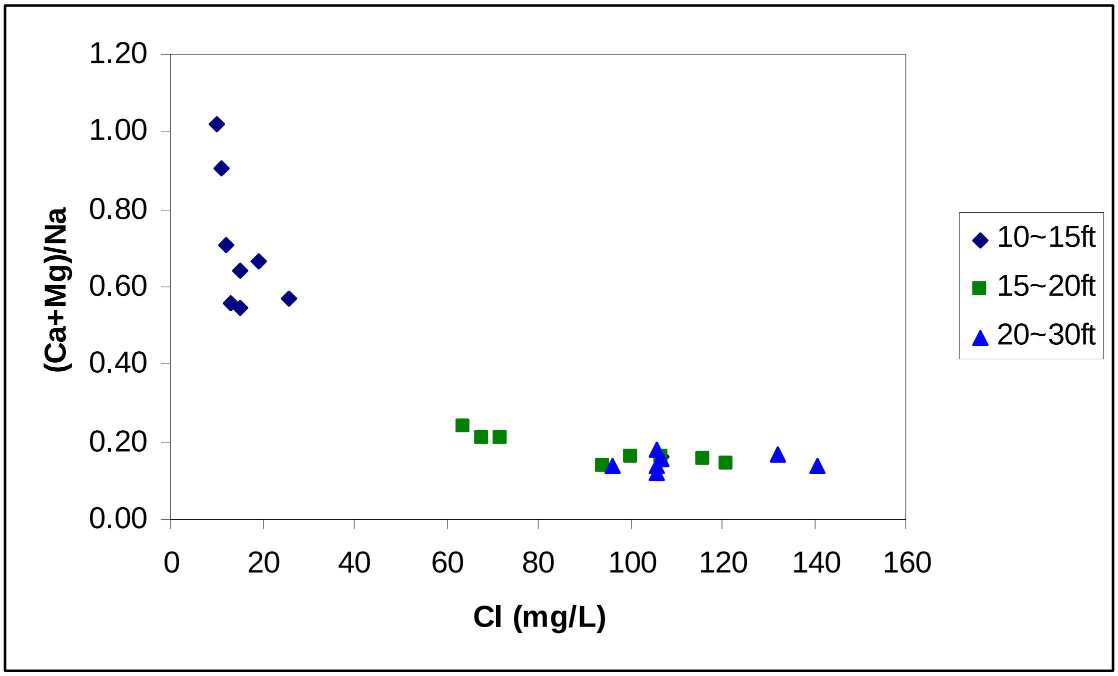

Figure 13. (Ca+Mg)/Na in molar ratio vs. Cl in mg/L. Cl concentration increases with depth in all the wells.

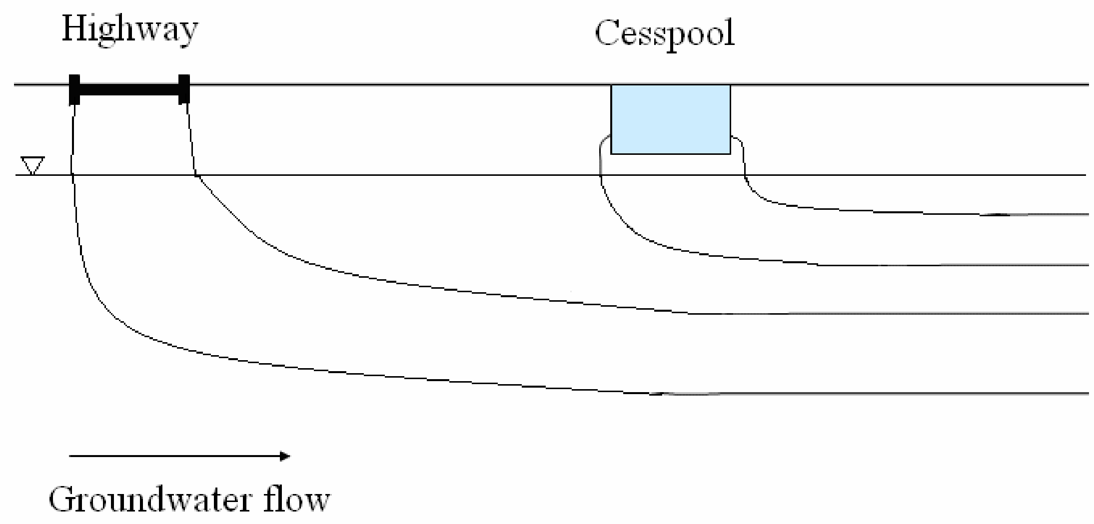

Figure 14. Sketch diagram showing flow of sewage plume and road salt plume from nearby highway.

Chapter V: Conclusion

Ground water samples were collected from various depth upgradient and downgradient from a domestic cesspool on Long Island, New York. However, except for slightly elevated NO_3^- and NH_4^+ and low dissolved oxygen content, sewage signatures are too weak to be considered as the main part of the plume. Based on those observations, the reason for the weak sewage signature is proposed due to missing of the plume during sampling. Possibilities are that the main part of the plume either sank to some depth beyond the deepest sampling depth, or was floating above the shallowest sampling depth and below water table. High concentration of Na and Cl with a consistent Na/Cl ratio in ground water from 10 to 20 feet below water table is identified as road salt plume from nearby highways.

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