COMPARISON OF HYDRAULIC CONDUCTIVITY VALUES DETERMINED BY AQUIFER TESTS, SPECIFIC CAPACITY TESTS, SLUG TESTS, AND GRAIN SIZE ANALYSIS

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ABSTRACT

Hydraulic conductivity is an extremely important parameter in predicting groundwater movement as it represents the ease with which water moves in the subsurface environment. Estimates of the aquifer parameter of hydraulic conductivity can be determined by a number of field methods. These estimates are frequently used in groundwater models to predict groundwater flow and contaminant transport rates at Federal and State Superfund sites, state solid waste site investigations, and private party site investigations. The accuracy of the estimates with respect to the actual formation hydraulic conductivity will influence the accuracy of groundwater flow and contaminant transport predictions. Inaccurate estimates of hydraulic conductivity used in the design of groundwater remediation systems can result in underdesign problems: incomplete capture of a groundwater contaminant plume, or overdesign problems: unnecessary expenditures in capital, operation and maintenance, and treatment costs to capture the plume. This study compares the hydraulic conductivity estimates determined by four common methods for the upper glacial aquifer at three locations on Long Island: Long Island City, Farmingdale, and Montauk. The study also examines the reliability/replicability of slug tests (falling head/rising head tests) which are frequently used instead of aquifer pumping tests at sites where containment/treatment of contaminated water withdrawn from the formation is required.

Review of the data indicates that if careful attention is given to performing the field portion of the test as specified in the test methodology and the analyses of the field data are performed carefully using geohydrologic insight, all four methods can produce comparable estimates of hydraulic conductivity. The data also indicate that slug test data can be reliable and replicable, if care is taken in following the methodology during the field test and the analyses, utilizing geohydrologic insight into the formation and well drilling/construction method relationship. Proper well development is essential for accurate hydraulic conductivity estimation by the specific capacity, slug, and aquifer (pumping) test methodologies.

INTRODUCTION

Different test methodologies were used to estimate the hydraulic conductivity of the upper glacial aquifer at the three locations shown on Figure 1. The Farmingdale location represents Wisconsin age outwash plain sands and gravels (Doriski and Wilde-Katz, 1983), the Montauk location represents stratified drift of the Manhasset Formation (Prince, 1986), and the Long Island

City location consists of the variety of strata present in the glacial deposits of the ground moraine north of the Harbor Hills Terminal Moraine (Soren, 1971).

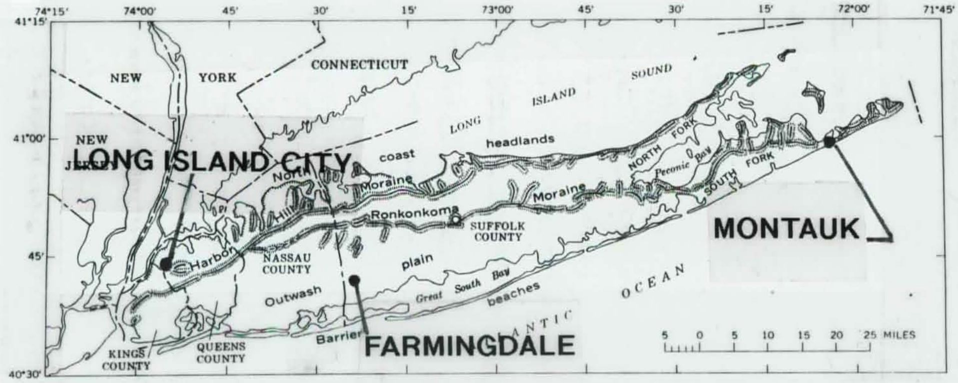

Figure 1 - Location of study areas on Long Island, New York. (Modified from McClymonds and Franke, 1972, p. 3.)

The test methodologies utilized were grain size analysis (Moretrench American Corporation analysis), falling head/rising head slug tests (Bouwer-Rice analysis), specific capacity tests (Bradbury-Rothschild analysis) and aquifer pumping tests (Jacob Approximation Method). This study compares the hydraulic conductivity estimates determined by the various methods at each site. The test methodologies are not presented here. The complete methodologies are described in detail in the following references and can also be found in numerous other geohydrologic references:

Grain Size Analysis (Moretrench American Corporation Method)	(Driscoll, 1986, pp. 737-738) and (Hough, 1969, pp. 20-21)
Falling Head/Rising Head Slug Tests (Bouwer-Rice Method)	(Bouwer and Rice, 1976) and (Bouwer, 1989)
Specific Capacity Tests (Theis-Jacob Approximation)	(Bradbury and Rothschild, 1985)
Aquifer Pumping Tests (Jacob Approximation Method)	(Dawson and Istok, 1991)

TEST RESULTS

Long Island City

The most extensive comparison of the methodologies was performed at this location where all four methodologies were used to estimate the hydraulic conductivity of the upper glacial aquifer. The location had three specific sites where one pumping well and numerous piezometers were installed. At each site, grain size distribution data was obtained from sieve analysis of soil samples from the pumping well. Table 1 presents the estimates of hydraulic conductivities obtained by the four methods for the Long Island City location.

TABLE 1. - COMPARISON OF CONDUCTIVITIES CALCULATED USING VARIOUS METHODS LONG ISLAND CITY, NEW YORK

Site #/ Well #		Aquifer Pumping Test	Grain Size Analysis	Specific Capacity Test	Slug Test
		Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (ft/day)
Site 1	P-1	NA	--	--	--
	P-2	90-95	--	--	92.3
	P-3	40-45	--	--	0.3
	P-4	10	--	--	--
	P-5	20-30	--	--	0.7
	P-6	15	--	--	49.4
	P-7	10	--	--	0.5
	P-8	NA	--	--	1.8
	PW-1	--	0.03	1.68	16.4
Site 2	P-9	NA	--	--	3.8
	P-10	4	--	--	0.5
	P-11	NA	--	--	0.5
	P-12	4	--	--	9.5
	P-13	NA	--	--	1.9
	P-14	4	--	--	7.1
	P-15	2	--	--	--
	P-16	3	--	--	--
	P-17	9	--	--	2.9
	P-18	9-10	--	--	10.0
	P-19	8	--	--	0.4
	P-20	5-5.5	--	--	80.4
	PW-2	--	UC	6.2	--
Site 3	P-23	90-95	--	--	77.9
	P-24	85-90	--	--	21.0
	P-25	65	--	--	32.2
	P-26	65	--	--	66.6
	PW-3	--	35 to 85	66.2	--

NA Not analyzed due to no drawdown during pump test -- Test not performed

UC Uniformity coefficient out of range applicable for method

The wells and piezometers at sites 2 and 3 were installed by the mud rotary method using polymer drilling fluids which break down naturally. This method appeared to result in the least effect on the formation (e.g., smearing of borehole walls with low conductivity cuttings during hollow stem auger advancement and clogging of the formation from the drilling fluid which is common with bentonite fluids). The site 1 geology was diversified; the pumping well and some of the piezometers were screened in fine silty sand and sandy silt while other piezometers were screened in the equivalent of outwash sand - fine to medium grained sand with little silt. The piezometers were installed utilizing hollow stem augers and the pumping well was installed by the mud rotary method using bentonite drilling fluid.

The site 1 hydraulic conductivity estimates exhibit a greater diversity of estimates within each test method for all the wells (may be related to geology) and between the test methods for each well. In general, the hydraulic conductivity estimates determined by the aquifer pumping test method were slightly higher and more consistent than the hydraulic conductivity estimates obtained by the slug test, the grain size distribution, and the specific capacity test methods.

The site 2 hydraulic conductivity estimates ranged between 0.4 and 10 ft/d for all methods with the exception of P-20, which had a slug test estimate of 80.4 ft/d. Retesting of this well one year later by the slug test method resulted in hydraulic conductivity estimates ranging from 9 to 16 ft/d. The sieve analyses method could not be used on the aquifer sample from PW-2 because the uniformity coefficient was out of the range applicable for the method.

The site 3 hydraulic conductivity estimates exhibit consistent results between the four methods, which may be due to the uniform nature of the formation at this site - primarily fine to coarse sands with only a trace of silt. The aquifer pumping test hydraulic conductivity estimates range from 65 to 95 feet per day (ft/d), the hydraulic conductivity estimates from grain size distributions range from 35 to 85 ft/d, the specific capacity test method resulted in a hydraulic conductivity estimate of 66 ft/d for the pumping well, and the slug test estimates ranged from 21 to 78 ft/d. The slug test field data for the two-inch piezometers screened in the more conductive strata at the Long Island City location had recovery curves which were of very short duration (usually less than 5 seconds) and which exhibited fluctuation. This allowed a greater number of possible placements of the straight line on the recovery data curves and may account for the lower hydraulic conductivity estimates for P-24 and P-25.

Farmingdale

This location provides a comparison of the hydraulic conductivity estimates obtained from the grain size distribution analysis, the specific capacity, and the slug test methods. The specific capacity method was not performed on wells SW-1 through SW-5 due to the small diameter of the wells, the depth to water, and the minimal available drawdown in each well precluding pumping. Table 2 presents the estimates of hydraulic conductivity obtained by the three methods.

For wells SW-1 through SW-5, the grain size analysis method produced hydraulic conductivity estimates that are several times lower, but same order of magnitude as the slug test method estimates. For wells SW-6 through SW-9, the specific capacity test method estimates exhibit consistency between the shallow wells (235 to 303 ft/d) which is consistent with the relatively uniform nature of the outwash plain sands. The slug test method for these wells resulted in higher hydraulic conductivity estimates which may be a function of the short data recovery curve (less than 10 seconds) which precluded accurate analysis. The deep well (DW-6) which is screened in slightly finer upper glacial aquifer material had a longer data recovery curve. The estimates from the specific capacity test method and slug test method are consistent at DW-6, 104 and 122 ft/d, respectively. All wells at the Farmingdale site were installed by the hollow stem auger method. This method is not expected to have greatly reduced the hydraulic conductivity of the formation at the borehole wall because low conductivity strata are absent at this location.

TABLE 2. COMPARISON OF HYDRAULIC CONDUCTIVITIES CALCULATED USING VARIOUS METHODS FARMINGDALE, NEW YORK

Site#/ Well #	Grain Size Analysis	Specific Capacity Test	Slug Test
	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (ft/day)
SW-1	107	--	291
SW-2	--	--	526
SW-3	271	--	387
SW-4	343	--	481
SW-5	157	--	514
SW-6	--	303	--
SW-7	--	235	944
SW-8	--	292	582
SW-9	--	260	715
DW-6	--	104	122

-- Test not performed

Montauk

The Montauk site provides a comparison of the hydraulic conductivity estimates from the grain size distribution, specific capacity test, and slug test methods. Table 3 presents the hydraulic conductivity estimates obtained by the three methods.

TABLE 3. COMPARISON OF HYDRAULIC CONDUCTIVITIES CALCULATED USING VARIOUS METHODS MONTAUK, NEW YORK

Site#/ Well #	Grain Size Analysis	Specific Capacity Test	Slug Test
	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (ft/day)
IW-1	25.62	95.7	62.83
SW-2	13.47	13.3	28.55
IW-2	35.59	30.9	14.41
DW-2	14.52	8.6	0.24[(1)]
SW-3	17.08	28.1	36.50
IW-3	12.81	31.1	20.55

[(1)] - Insufficient development.

The results between the methods for each well are in close agreement. All wells were installed by mud rotary drilling using bentonite fluid. The low hydraulic conductivity estimate from the slug test method for well DW-2 appears related to insufficient well development. The specific capacity test method, performed after further development, resulted in an estimate that is in close agreement with the sieve analysis method.

Slug Test Replicability

Additional wells were installed at the Long Island City location to obtain additional hydraulic conductivity data for the strata present within the upper glacial aquifer at the site. Each new and existing well had a slug test (falling head and rising head curves) performed three times to yield six hydraulic conductivity estimates for each well. Table 4 presents the hydraulic conductivity estimates from this recent testing and a statistical analysis of the data sets for each well. The slug tests produced very consistent results. There was little difference between rising head and falling head tests. All six tests provide similar values and comparison to Table 1 indicates that the hydraulic conductivity estimates obtained at P-wells in 1993 are similar to the estimates obtained previously in 1992. It was determined that the well that showed the most significant difference, P-2, with a hydraulic conductivity in 1992 of 92.3 and in 1993 of 5.3 probably sustained well screen damage in the interim period.

SUMMARY

Four methods of hydraulic conductivity estimation were used at three sites on Long Island to obtain hydraulic conductivity values for the upper glacial aquifer. All four methods can produce comparable results if the methodologies for data collection and analysis are followed carefully and geohydrologic insights regarding the formation and well installation method are used in the analysis.

The grain size distribution method can provide an initial estimate of hydraulic conductivity in formations that can be sieved and that have some degree of uniformity. However, it is representative of a very small portion of the formation, the sample interval, usually a 2-foot long sample. The slug test method produces reliable estimates for low to moderately conductive formations. As the formation conductivity increases, the analysis of the field data (short recovery curves that may exhibit fluctuating data) becomes more difficult and can result in less accurate hydraulic conductivity estimates. The specific capacity test can produce reliable hydraulic conductivity estimates in formations that can be pumped. This method requires little effort for data collection and a very short time for analysis, but does generate ground water that must be disposed and possibly treated for contaminant removal. The aquifer pumping test method, while expensive (especially if treatment is necessary) and time consuming, offers the advantage of hydraulic conductivity estimation over a larger portion of the formation.

In all aquifer testing, the selection of well installation method can be important, especially in areas where low conductivity strata may be present. Rotary drilling appears to cause less borehole wall formation "smearing" than auger drilling. In locations where rotary drilling is preferred, drilling fluids that breakdown naturally offer advantages over bentonite, which must be removed by physical methods during development. In more conductive formations, the selection of drilling method has less effect on subsequent hydraulic conductivity testing.

TABLE 4
SLUG TEST REPRODUCABILITY COMPARISON
LONG ISLAND CITY, NEW YORK

Well Number	Strata Designation	TEST RESULTS KF1 ft/day	KR1 ft/day	KF2 ft/day	KR2 ft/day	KF3 ft/day	KR3 ft/day	STATISTICAL ANALYSIS Range	Median Value	Arithmetic Mean	Standard Deviation	Coefficient of Variation
B-102	3	4.03	5.03	4.22	4.71	3.98	5.1	3.98 to 5.1	4.54	4.51	0.50	0.11
B-105	4	0.1	0.12	0.11	0.18	0.11	0.18	0.1 to 0.18	0.14	0.13	0.04	0.28
B-135	4	6.84	4.46	3.97	4.82	8.31	3.79	3.79 to 8.31	6.05	5.37	1.81	0.34
P-2	2/3	---	8.36	---	4.39	---	3.15	3.15 to 8.36	5.76	5.30	2.72	0.51
P-3	3	0.29	0.85	0.24	0.19	0.22	0.21	0.19 to 0.85	0.52	0.33	0.26	0.77
P-4	2/3/4	---	1.26	---	1.14	---	1.2	1.14 to 1.26	1.20	1.20	0.06	0.05
P-5	3	---	4.04	---	4.32	---	3.89	3.89 to 4.32	4.11	4.08	0.22	0.05
P-6	2/3	---	82.53	---	102.49	---	84.63	82.53 to 102	92.51	89.88	10.97	0.12
P-7	3/4	0.35	0.31	0.35	0.32	0.33	0.27	0.27 to 0.35	0.31	0.32	0.03	0.09
B-107	2	39.22	19.12	29.52	24.27	31.68	27.54	19.12 to 39.2	29.17	28.56	6.82	0.24
B-112	4	2.24	2.37	2.61	2.27	2.58	2.37	2.24 to 2.61	2.43	2.41	0.16	0.06
N-8-1	1/2	---	1.99	---	2.14	---	2.18	1.99 to 2.18	2.09	2.10	0.10	0.05
N-9-1	4/5	5.27	5.48	5.81	5.94	6.05	5.96	5.27 to 6.05	5.66	5.75	0.31	0.05
S-202	7A/7B	4.74	4.04	3.57	5.08	4.97	4.76	3.57 to 5.08	4.33	4.53	0.59	0.13
S-203	3A	37.97	31.84	34.63	41.66	33.14	37.83	31.84 to 41.7	36.75	36.18	3.65	0.10
S-204	4	0.653	0.64	0.612	0.572	0.656	0.596	0.572 to 0.66	0.61	0.62	0.03	0.05
S-208	4	0.718	0.458	0.659	0.46	0.623	0.422	0.422 to 0.72	0.57	0.56	0.12	0.22
B-25B	6/7A	2.01	1.96	2.14	1.97	2.06	2.04	1.96 to 2.14	2.05	2.03	0.07	0.03
B-25A	3/4	5.05	6.58	5.69	5.66	5.12	5.82	5.05 to 6.58	5.82	5.65	0.55	0.10
B-128	4	0.124	0.0997	0.114	0.0962	0.117	0.0995	0.096 to 0.12	0.11	0.11	0.01	0.11
B-129	4	0.691	0.607	0.695	0.656	0.695	0.654	0.607 to 0.7	0.65	0.67	0.03	0.05
B-115	3	1.31	1.3	1.37	1.29	1.32	1.39	1.29 to 1.39	1.34	1.33	0.04	0.03
B-116	2/3	---	1.29	---	1.37	---	1.51	1.29 to 1.51	1.40	1.39	0.11	0.08
B-118	5	2.58	3.42	2.59	2.76	2.45	2.71	2.45 to 3.42	2.94	2.75	0.34	0.13
S-206	3A	5.9	6.33	5.27	6.73	5	6.28	5 to 6.73	5.87	5.92	0.67	0.11
B-119	5	2.83	3.05	3.24	2.79	2.85	3.16	2.79 to 3.24	3.02	2.99	0.19	0.06
B-120	3A	3.79	5.41	4.97	3.39	4.6	4.19	3.39 to 5.41	4.40	4.39	0.75	0.17
B-121	5	6.73	7.92	7	7.44	6.55	8.08	6.55 to 8.08	7.32	7.29	0.63	0.09
N-23- 2	3/5	17.8	17.9	15.03	19.32	21.75	15.66	15.03 to 21.8	18.39	17.91	2.45	0.14
B-123	3A	26.55	34.55	26.33	29.18	26.64	44.87	26.33 to 44.9	35.60	31.35	7.32	0.23
OW-1	3A	34.76	24.96	23.25	33.85	33.67	43.01	23.25 to 43	33.13	32.25	7.22	0.22
P-23	2/3/5	47.21	45.74	36.53	48.28	68.6	52.05	36.53 to 68.6	52.57	49.74	10.58	0.21
P-24	3A	35.13	51.59	34.91	50.54	26.42	54.66	26.42 to 54.7	40.54	42.21	11.53	0.27
P-25	3A	44.75	63.82	34.26	29.89	25.52	16.37	16.37 to 63.8	40.10	35.77	16.65	0.47
B-132	5	6.52	8.32	4.93	8.14	6.18	8.32	4.93 to 8.32	6.63	7.07	1.41	0.20
B-133	3	0.763	0.587	0.825	0.627	0.869	0.655	0.587 to 0.87	0.73	0.72	0.11	0.16
P-9	3/5	1.64	1.75	1.58	1.71	1.75	1.8	1.58 to 1.8	1.69	1.71	0.08	0.05
P-10	6	1.16	0.72	0.99	0.68	0.906	0.714	0.68 to 1.16	0.92	0.86	0.19	0.22
P-11A	5	0.71	0.477	0.722	0.409	0.633	0.488	0.409 to 0.72	0.57	0.57	0.13	0.23
P-12A	5	7.19	7.21	6.4	7.19	6.81	6.88	6.4 to 7.21	6.81	6.95	0.32	0.05
P-14- Pre	7A	7.44	6.74	6.29	7.47	7.6	6.73	6.29 to 7.6	6.95	7.05	0.53	0.08
P-14- Post	7A	13.37	11.88	11.43	12.43	13.62	14.46	11.43 to 14.5	12.95	12.87	1.15	0.09
P-16A	5	6.89	7.79	7.1	8.07	7.39	6.94	6.89 to 8.07	7.48	7.36	0.48	0.07
P-17	5	2.89	2.89	2.74	3.15	3.01	3.11	2.74 to 3.15	2.95	2.97	0.15	0.05
P-18	7A	5.45	6.44	6.12	6.31	6.42	6.63	5.45 to 6.63	6.04	6.23	0.42	0.07
P-19	5	0.76	0.277	0.269	0.253	0.22	0.309	0.22 to 0.76	0.49	0.35	0.20	0.59
P-20	5	16.14	9.14	12.45	10.72	11.24	10.13	9.14 to 16.1	12.64	11.64	2.47	0.21

R1	Rising Head Test No. 1
F1	Falling Head Test No. 1
K	Hydraulic Conductivity
----	Falling head test not valid in wells that screen the unsaturated zone.
Pre	Pre - Redevelopment
Post	Post - Redevelopment

STRATA DESCRIPTION

Stratum	Description
1	Miscellaneous fill.
2	Loose to medium dense, coarse to fine sand, little to trace silt, medium to fine silty sands.
3	Medium dense to dense, fine silty sand to sandy silt.
3A	Medium dense to very dense, coarse to fine sand, little to some gravel, trace silt.
4	Soft to stiff, nonplastic silts to varved silts and clays.
5	Dense to very dense heterogeneous mixture of sand, silt, gravel with binder and without binder (till).
6	Decomposed rock.
7A	Highly fractured and jointed gneiss.
7B	Moderately weathered to unweathered gneiss.

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