HYDROGEOLOGY OF THE AREA NORTHEAST OF THE HILLVIEW ROAD LANDFILL, TOMPKINS COUNTY, NY

By

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and the

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EXECUTIVE SUMMARY

Background

The Tompkins County Hillview Landfill was located on the site of an older landfill that had no containment and partially overlay permeable glacial deposits. After its use by the County it was capped and monitored in accordance with NYS Department of Conservation regulations, but there still remained the possibility that leachate could escape downward into local aquifers and from these into major aquifers underlying Cayuga Inlet Valley. Following closure, a number of test and monitoring wells were drilled around the periphery of the landfill, most of which showed little or no leachate migrating from the site.

A review of well data by the Hillview Landview Citizens' Committee determined, however, that the DGC-2 well cluster, at the northeastern corner of the landfill, did show significantly elevated levels of volatile organic compounds and dissolved metals. Together with a presumed northward groundwater flow gradient, based on water elevations in existing wells, this information suggested the possibility of a contaminant plume escaping from the landfill.

Accepting the Committee's recommendation, the Tompkins County Solid Waste Division authorized further study by the Committee and obtained funding for the drilling of up to four test wells in the northeast sector of the landfill. These wells, identified as the TK series, were drilled between October 8, 1999 and August 21, 2002. Over this period nearly monthly water levels were measured in these and other wells in the sector to determine groundwater gradients and their temporal fluctuations, Specific conductance of the ground water was also measured , as an inexpensive proxy for contaminant levels.

In addition to these groundwater studies, the surficial Quaternary geology of the surrounding area was investigated and various geophysical techniques were employed during a Cornell M. Sc. thesis to provide a better understanding of the overall geologic setting. Although the area is very complex and the study was hardly exhaustive, it is felt that a reasonably accurate picture of the geohydrology was generated.

Geology

The Hillview Landfill is located where Cayuga Inlet Valley, a major glacial trough, expands southward and is joined by Michigan Hollow valley. As the ice front retreated northward toward the landfill site and it's surface elevation decreased, a number of glacial and fluvial features were formed. The oldest recognized features include deltas, overflow channels and ice-margin channels associated with an ice-dammed lake in the Michigan Hollow Valley, with a surface elevation of about 1270 feet. When this ice dam broke, violent outbursts of water were released and very coarse sediment was washed into the area just east of the landfill and now developed as a sand and gravel.

Continued ice retreat led to the formation of lower-elevation kame terraces and to the development of the Valley Heads Moraine, a complex deposit of various lithologies that developed when the ice front temporarily stabilized at and just to the south of the landfill site. Rapid retreat of the ice front northward from the Valley Heads Moraine about 14,000 years ago led to the present kettle and kame topography and to the development of a relatively extensive proglacial lake in Cayuga Inlet Valley north of the moraine.

The eastern half of the landfill overlies a deposit of coarse sand and gravel that both thins and becomes finer to the west and north. Records from the TK wells suggest that this deposit originated as an outwash fan emanating from the kame terrace along the eastern border of Inlet Valley. This fan overlies a thick and extensive clay and silt deposit that formed in a lake associated with an older glacial stage, and is overlain in the west by fine-grained lake sediments that postdate the formation of the Valley Heads Moraine

Both the fan and the kame terrace lie at elevations below that of the large fan in which the Landstrom quarry has been developed. This requires that the "TK" fan and the kame terrace be younger than the "Landstrom" fan. Additional evidence also suggests that the TK fan developed as the ice front began to retreat from the Valley Heads Moraine.

Hydrology

Near-monthly measurements of water levels in wells around the northeastern corner of the landfill over a period of about 2 years led to several important conclusions. The water levels show an annual cycle, with maximum elevations occurring during the late spring to mid summer and the minimum occurring in mid to late winter. The amplitude of these fluctuations is greatest (6 ft or more) in wells closest to the kame terrace and the valley edge. A critical conclusion of the study is that the TK fan and the coarse clastics in TRI-6 are not contiguous and that the northward flow gradient deduced from earlier data was erroneous.

The direction of groundwater flow in the TK fan area, including DGC-2, I westerly to west-southwesterly during periods of high groundwater elevations and east-southeasterly when elevations are low. In wells along the eastern and southern sectors of the landfill, the flow is always southeasterly. The pattern of flow defined by all these measurements indicates that, during spring snowmelt and thaw, there is a large influx of groundwater from the kame terrace and upland further east into the TK fan, which reverses the general flow direction. Because the fan is encased on the west and north by impermeable lake sediments the spring flow is forced to swing to the south and southeast as it passes through this aquifer. The overall conclusion is that the general flow in at least the eastern part of the landfill is southeasterly, toward Michigan Creek and that there is no groundwater divide in this area.

Specific Conductance

Specific conductance measurements made during this study were not as definitive as were those of water levels, but several reasonable conclusions were reached. High conductance values mainly reflected high chloride ion concentrations, which generally follow contaminant levels in the leachate, but can also result from road salt infiltration. Differentiation of the two sources can often be made by comparing the conductance results with detailed chemical measurements, Such tests are made several times a year by Upstate Labs, Inc. to comply with DEC regulations. Two such rounds of measurements were made during this study and included those TK wells drilled to those times.

During the testing rounds by Upstate Labs, conductances were also measured, but the values were quite different from those obtained by the USGS meter used in this study. Comparison of the simultaneous conductance measurements demonstrated a simple ratio between the two systems. The reason for the difference remains unknown, but the values of both are useful for comparisons.

Conductances in DGC-2 were consistently well above background, which is most simply attributed to the high contaminant levels measured in the detailed chemical tests. Very high conductances were noted in TK-4 and attributed to road salt. Fairly high conductivities were initially obtained in TK1 and values obtained during drilling showed decreasing conductivities with drilling depth. This, together with the lack of chemically defined leachate contamination and the fact that the well is in a wetland, adjacent to the road, leads to the conclusion that the elevated conductances reflect road salt. Road salt was also assumed to be the cause of high conductances in TK-3, in which the conductance values varied with water elevations and were highest in the spring/early summer. Again there was no chemical signature of leachate in the chemical analyses at TK-3.

Conductances in the coarse clastic unit at TRI-6 were somewhat above background but were not associated with chemically-defined contamination. Because this well is the only one to test this aquifer, very little can be said about its character

There was no evidence from the conductances that contaminated leachate was flowing northward or westward from DGC-2, but its disposition is still unknown. Such leachate might be flowing though the TK fan and out toward the east or southeast, but it was not recognized in the geochemical testing in wells in that area. It might also be moving downward into a deeper aquifer,

No information was collected during this study concerning possible leachate migration from the western half of the landfill. Wells drilled in that area were useless for the determination of groundwater flow because they were screened in impermeable sediments, but those same data indicate that that part of the landfill is underlain by sediments that would act to some degree as a liner, preventing leachate escape to deeper aquifers. Moreover, the underlying, extensive fine-grained lake sediments may act as an additional barrier to flow.

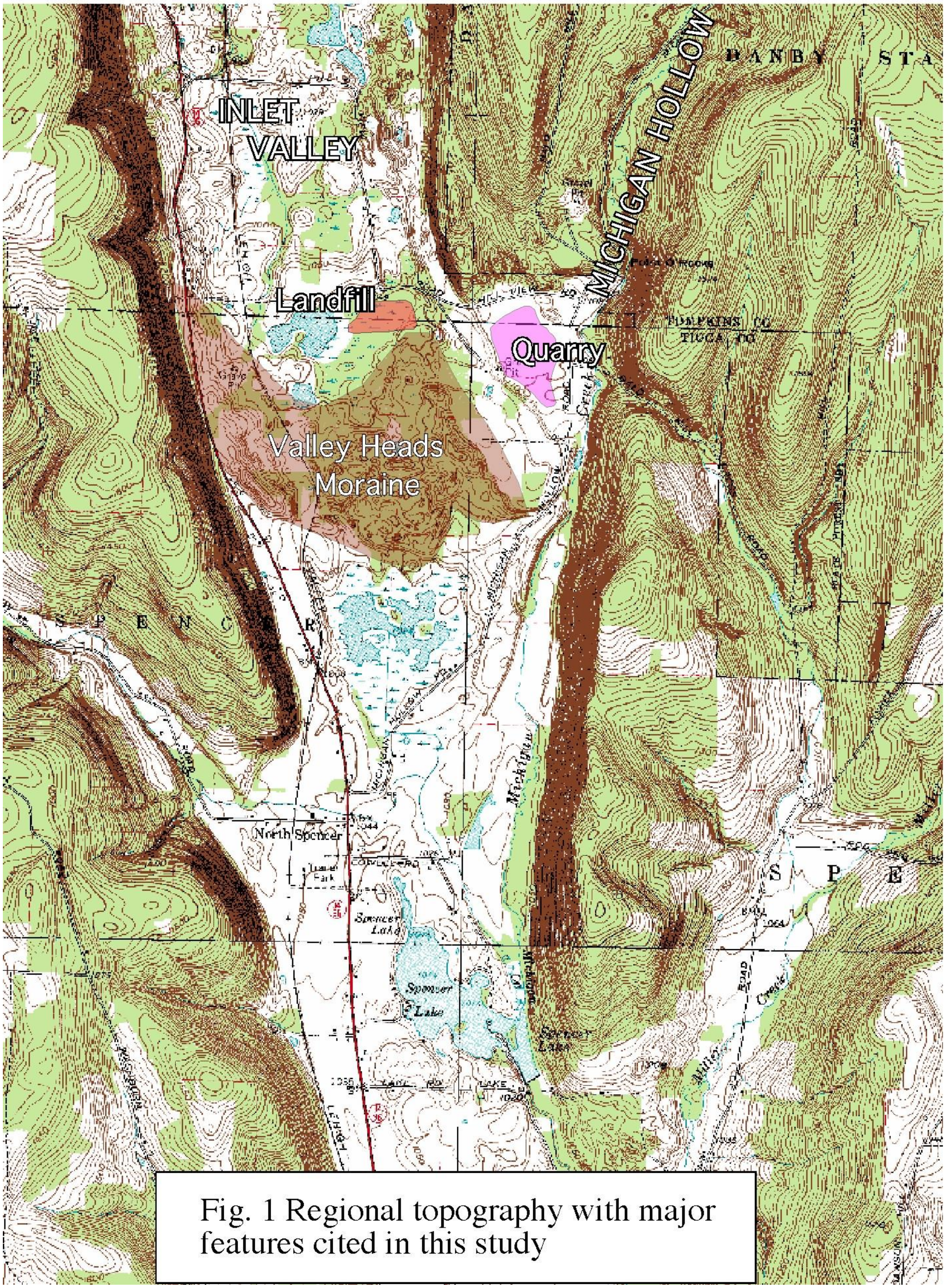


Fig. 1 Regional topography with major features cited in this study

BACKGROUND

Following closure of the Caswell Road landfill in 1985 , Tompkins County began to dispose of its solid waste at the Hillview landfill, near the Tompkins-Tioga County line and off Hillview Road (Fig. 1). This landfill was sited in part over coarse clastic sediments and has no liner. Because this combination leads to a potential for migration of leachate that could result in groundwater pollution, several studies were authorized by the Solid Waste Division of the Tompkins County Public Works Department (e.g. Dunn Geoscience, 1985; Esbaugh Consulting Engineers and Terran Research, Inc, 1991; Malcolm-Pirnie, Inc., 1996) and numerous wells were drilled to monitor possible escape of leachate into adjacent aquifers.

Most of the wells on the south and western sides of the landfill are ineffective for this purpose because they are very shallow and have screens set in impermeable sediments. However, wells on the northern and eastern flanks of the landfill did test potential aquifers. Hydrologic studies based on these wells indicated groundwater flow to the north along the northern flank and to the south along the southeastern sector of the landfill. Most of the wells showed no or very little leachate contamination, but the well cluster at site DGC-2 has persistently shown high levels of such contaminants as chlorinated volatile organics, iron and manganese. High contaminant levels of these constituents and the deduced northerly groundwater flow led to the possibility that leachate was migrating northward from the landfill into Cayuga Inlet Valley aquifers, which are some of the largest in Tompkins County (Tarr,1904, Miller, 2000).

To investigate this possibility, the Solid Waste Division authorized a further study of the situation, including the drilling of up to 4 test wells around the northeastern corner of the landfill (Fig. 2) Four wells, designated the TK series, were drilled with 4 1/2” hollow-stem augers, over the period between October 8, 1999 and August 21, 2002. Each well was finished with one screened section for monitoring purposes (Table 1).

Table 1. Data on the TK wells

Well	Date Completed	Depth	Cap Elevation	Screened Interval
TK-1	11/10/99	65'	1038.78	15' to 25'
TK-2	11/16/99	68'	1059.47	35' to 45'
TK-3	4/20/00	78'	1078.52	45' to 55'
TK-4	8/21/02	97'	1042.11	10' to 20'
DGC-2I	5/7/85	44'	1049.78	37' to 42'
DO-3	10/31/94	27.5'	1035.26	17' to 27'
TRI-6D	11/10/94	140'	1039.04	115' to 125'

The goal of drilling was to investigate the hydrology and geochemistry in the shallow coarse clastic unit that showed high contaminant levels at DGC-2. The wells were initially sited to locate and define any contaminant plume that might exist, but as a hydrologic database developed, the plan shifted to create a “fence” of wells that would rule out the possibility of a north flowing plume.

This hydrologic database was created by measurements, at roughly monthly intervals from early 2000 until late 2001, of water elevations in the TK wells that had been drilled to date, as well as in DGC-I, DO-3, and TRI-6D (Table 2). These wells were those believed to be screened in the same aquifer as that with contamination in DGC-2I. At the same time conductancs were measured in these wells as an inexpensive proxy for contaminant levels. After the test period began, 3 series of detailed chemical analyses of all the landfill wells, as directed by the New York State Department of Environmental Conservation (NYDEC), were carried out. Only the last of these included all the TK wells.

Table 2:Summary of data collected from 1999-2000.

Well	Date	Water El.	Conduct(mS)	Cond.(US labs)
DGC-2I	12/14/99	1031.39		
DO-3	12/14/99	1031.00		
TK-1	12/14/99	1030.78		
TK-2	12/14/99	1029.98		
DGC-2I	2/9/00	1030.25		
DO-3	2/9/00	1031.86		
TK-1	2/9/00	1030.56		
TK-2	2/9/00	1030.32		
DGC-2I	4/18/00	1035.59		
DO-3	4/18/00	1032.69		
TK-1	4/18/00	1034.22		
TK-2	4/18/00	1035.56		
DGC-2I	4/19/00	1035.72		
TK-1	4/19/00	1034.33		
TK-2	4/19/00	1035.63		
DGC-2I	5/1/00	1036.25		
TK-1	5/1/00	1034.46		
TK-2	5/1/00	1036.18		
TK-3	5/1/00	1037.48		
DGC-2I	5/24/00	1036.46		
DO-3	5/24/00	1032.80		
TK-1	5/24/00	1034.71		
TK-2	5/24/00	1036.18		
TK-3	5/24/00	1037.29		
DGC-2I	6/19/00	1035.91		
DO-3	6/19/00	1032.46		
TK-1	6/19/00	1034.37		
TK-2	6/19/00	1035.60		
TK-3	6/19/00	1036.60		
TRI-6D	6/19/00	1028.75		
DGC-2I	8/7/00	1033.92	1236	
DO-3	8/7/00	1031.56	563	
TK-1	8/7/00	1033.38	938	
TK-2	8/7/00	1033.84	461	
TK-3	8/7/00	1034.21		
TRI-6D	8/7/00	1026.26	789	

WELL	DATE	WATER EL.	Conduct(mS)	Cond.(US labs)
DGC-2I	9/25/00	1032.43	1152	554
DO-3	9/25/00	1031.06	599	288
TK-1	9/25/00	1032.41	978	470
TK-2	9/25/00	1032.43	510	245
TK-3	9/25/00	1032.39	911	438
TRI-6D	9/25/00	1021.65	751	361
DGC-2I	10/23/00	1031.80	1241	
DO-3	10/23/00	1030.99	585	
TK-1	10/23/00	1032.02	1010	
TK-2	10/23/00	1031.96	483	
TK-3	10/23/00	1031.70	727	
TRI-6D	10/23/00	1024.32	791	
DGC-2I	12/19/00	1031.09	NA	
DO-3	12/19/00	1031.18	564	
TK-1	12/19/00	1031.75	970	
TK-2	12/19/00	1031.22	518	
TK-3	12/19/00	1030.54	1020	
TRI-6D	12/19/00	1023.65	793	
DGC-2I	1/18/01	1030.17	1175	
DO-3	1/18/01	1030.59	602	
TK-1	1/18/01	1030.47	905	
TK-2	1/18/01	1030.23	558	
TK-3	1/18/01	1029.93	640	
TRI-6D	1/18/01	1023.11	788	
DGC-2I	2/27/01	1030.11	1076	
DO-3	2/27/01	1031.12	593	
TK-1	2/27/01	1030.68	929	
TK-2	2/27/01	1030.26	622	
TK-3	2/27/01	1029.81	636	
TRI-6D	2/27/01	1023.33	780	
DGC-2I	4/30/01	1034.65	1091	
DO-3	4/30/01	1032.16	609	
TK-1	4/30/01	1033.71	775	
TK-2	4/30/01	1034.54	836	
TK-3	4/30/01	1035.18	745	
TRI-6D	4/30/01	1026.91	759	
DGC-2I	5/29/01	1033.89	1085	
DO-3	5/29/01	1031.6	592	
TK-1	5/29/01	1033.37	827	
TK-2	5/29/01	1033.85	647	
TK-3	5/29/01	1034.22	876	
TRI-6D	5/29/01	1025.89	748	

WELL	DATE	WATER EL.	Conduct(mS)	Cond.(US labs)
DGC-2I	7/31/01	1031.89	1078	
DO-3	7/31/01	1030.75	594	
TK-1	7/31/01	1031.97	855	
TK-2	7/31/01	1032.02	580	
TK-3	7/31/01	1031.93	754	
TRI-6D	7/31/01	1023.48	740	
DGC-2I	9/12/01	1030.44	1080	
DO-3	9/12/01	1030.17	609	
TK-1	9/12/01	1030.61	872	
TK-2	9/12/01	1030.52	521	
TK-3	9/12/01	1030.34	676	
TRI-6D	9/12/01	1022.39	796	
DGC-2I	10/25/01	1029.66	1087	
DO-3	10/25/01	1030.29	612	
TK-1	10/25/01	1030.09	858	
TK-2	10/25/01	1029.8	673	
TK-3	10/25/01	1029.51	605	
TRI-1	10/25/01	1028.8		
TRI-6D	10/25/01	1022	788	
DGC-2I	9/24/02	1031.51	725	
DO-3	9/24/02	1030.4	580	
TK-1	9/24/02	1031.66	787	
TK-2	9/24/02	1033.01	436	
TK-3	9/24/02	1031.54	728	
TK-4	9/24/02	1031.52	1352	
TRI-6D	9/24/02	1026.03	600	
DGC-2I	3/14/03	1032.87	655	375
DO-3	3/14/03	1032.27	463	310
TK-1	3/14/03	1033.04	581	435
TK-2	3/14/03	1031.65	530	389
TK-3	3/14/03	1032.9	852	438
TK-4	3/14/03	1032.99	2325	1121
TRI-6D	3/14/03	1026.03	551	429

Ancillary studies, not funded by the County, were undertaken by Alisa Eade as part of a Cornell University M.Sc. thesis (Eade, 2000). These included seismic refraction and reflection profiles, gravity profiles, ground penetrating radar, and electrical resistivity studies. As part of her thesis, several geological investigations of the general area were made with me, one of which included Todd Miller of the United States Geological Survey (USGS).

The combination of drilling results, geophysical studies and geological observations were used to generate a consistent picture of late Pleistocene (late Wisconsin) events and to show that groundwater flow from DGC-2 is not northward and it is unlikely that contaminants in the shallow aquifer at DGC-2 are reaching the major aquifers that underlie Cayuga Inlet Valley north of the landfill.

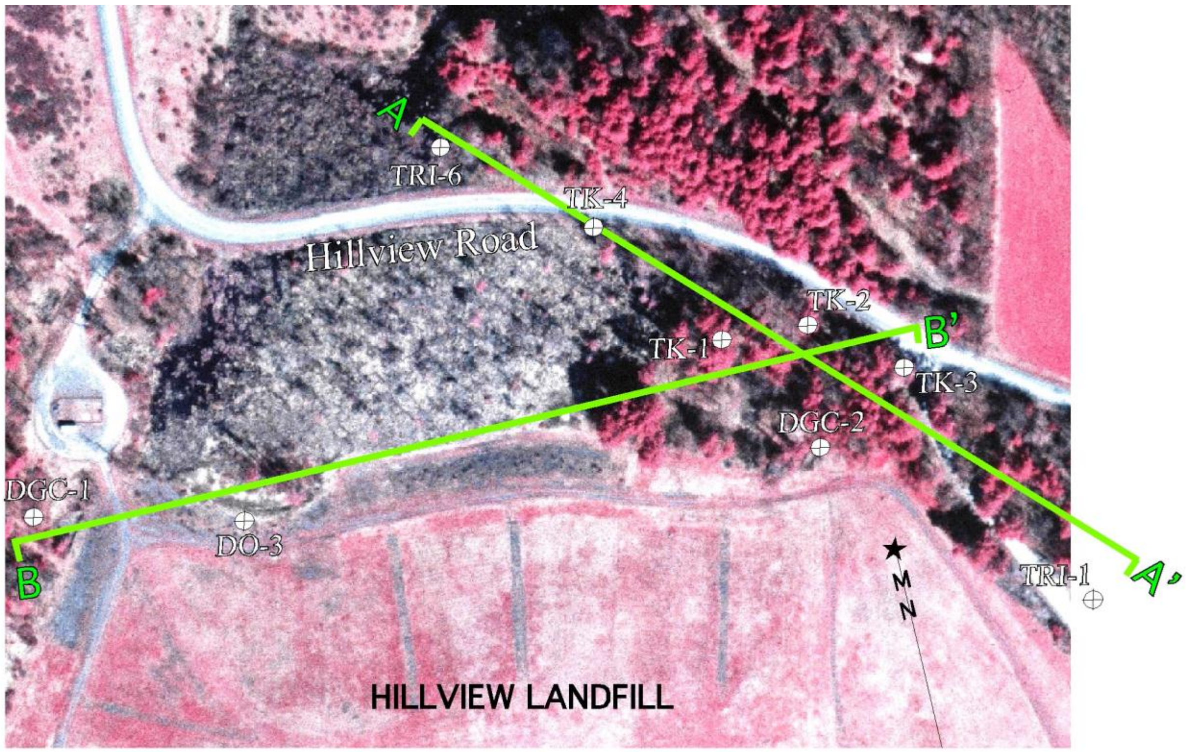


Fig 2.Orthophoto of the study area showing, the locations of the TK wells and of other monitored wells. Also shown are the locations of the geologic sections of figures 6 and 10.

GEOLOGIC SETTING

The Hillview landfill is located in the Cayuga Inlet Valley, one of the "through valleys" where major flows of ice occurred during the Pleistocene epoch and to which ice was restricted during the final, late Wisconsin advance. In addition, the landfill lies on and just north of the Valley Heads Moraine, a sediment deposit that marks the ice front about 14,000 years ago. The Valley Heads Moraine in Cayuga Inlet Valley lies at a position where the valley widens abruptly southward and is joined by the valley of Michigan Creek, known as Michigan Hollow (Fig. 1).

There remains disagreement as to whether the Valley Heads Moraine developed during a pause in the final recession of the glacial ice (a recessional moraine) or whether it marks the farthest ice advance during the last glacial pulse (an end moraine). Here it is assumed that the Valley Heads Moraine is a recessional feature, following the history documented further west (Muller and Calkin, 1993), where an end moraine, about 16,000 yrs old, lies south of the Valley Heads Moraine. Although no such moraine has been identified in central New York, it could be buried beneath or eroded by the outwash related to the Valley heads moraine.

Previous Quaternary geologic summaries in the consultants' reports pertaining to the deposits and landforms around the landfill have concentrated on the period when the

Valley Heads Moraine developed and on subsequent events. There is, however, abundant evidence that earlier glacial and fluvioglacial events in this area affected, and probably controlled the geological history relevant to most of the deposits penetrated by the wells involved in this project.

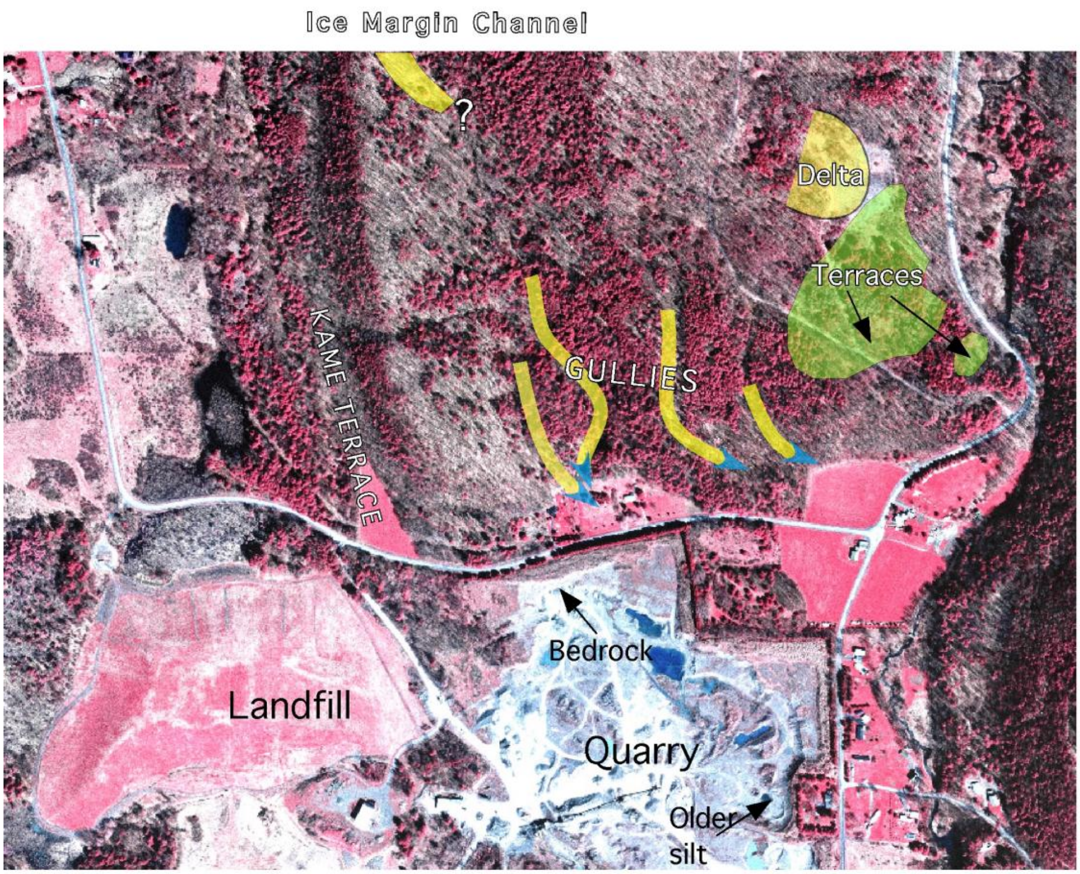
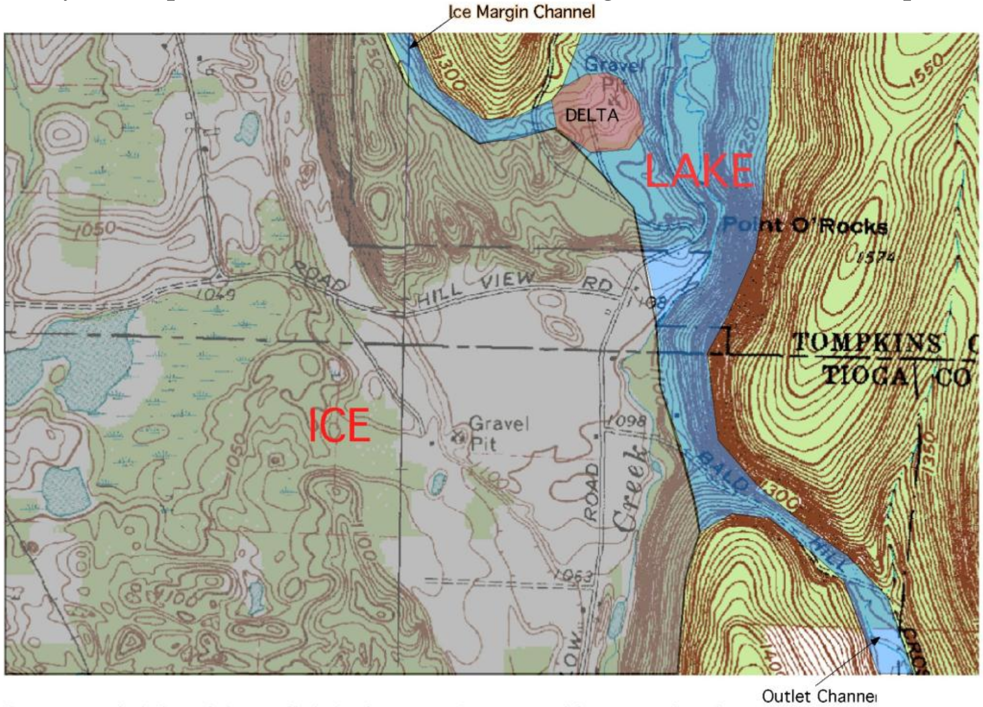


Fig 3. Orthophoto of the region including the study area, showing cultural and geologic features discussed in text.

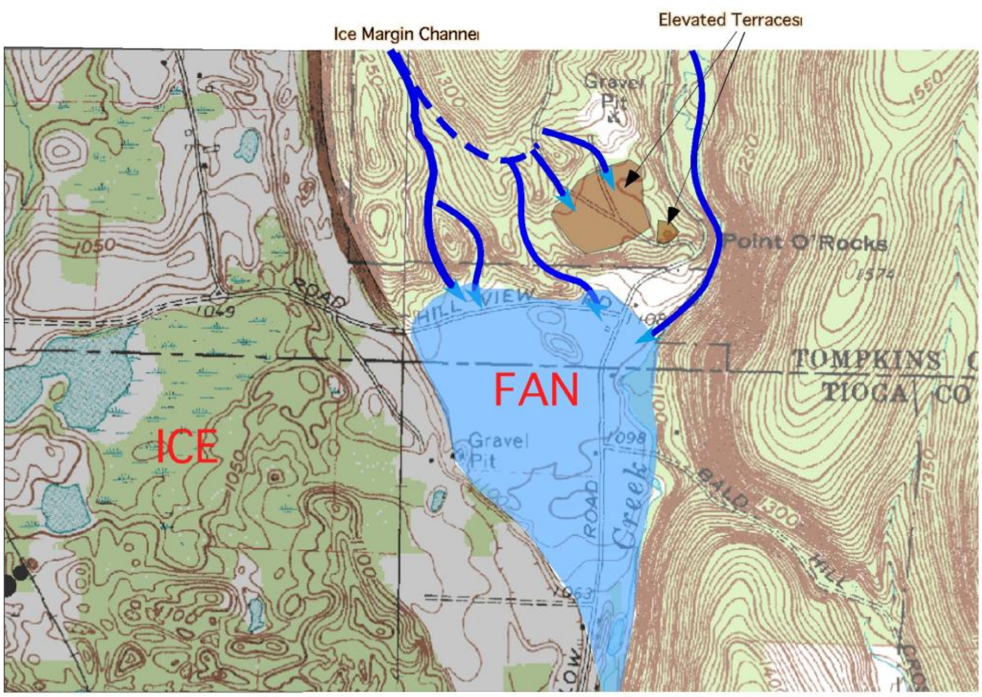
The oldest Quaternary geomorphic features recognized in the area (Fig. 3) are several indications of a lake level at an elevation of about 1270’, which is well above that of the Valley Heads Moraine. These include a delta complex, an ice-margin channel, and an overflow channel. In addition, the break from the flatlands of upper Michigan Hollow to the sharply incised section downstream lies at this elevation.

The overflow channel, identified by Todd Miller, begins at the crest of Signor Road, which ascends the east slope of Inlet Valley just south of Michigan Hollow (Fig. 4a). Between the valley and the ridge crest there is only a steep small gully, whereas, to the east there is a broad, flat-floored valley draining to the southeast. This valley was clearly formed by a stream much larger than that which now fills it, and must have been fed by a water or ice body to the west.

At the southeastern corner of the major ridge dividing Michigan Creek from Cayuga Inlet Valley is a deposit of round to sub-round sand, gravel and cobbles composed largely



Stage 1. High level (1270') lake impoundment and ice margin channel



Stage 2. Formation of Quarry Fan and drainage along Inlet valley

Fig 4a. Selected stages in the geomorphic evolution of the Hillview area of “exotic” lithologies that are not local and were transported by glacial and fluvial processes from far northern sources. Although almost no internal structure to this deposit could be seen, its shape and overall composition point to a deltaic origin. If true, it also requires a lake to have existed to the east and south (Fig. 4a).

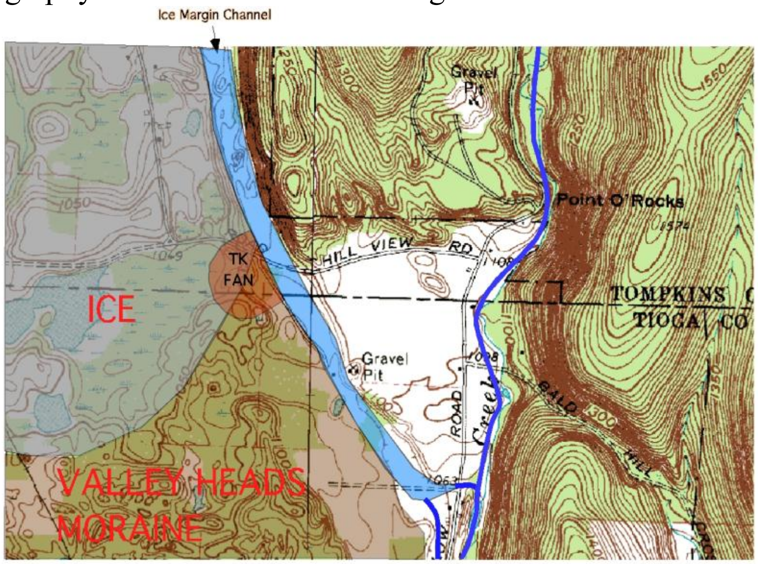
Along the western flank of this same ridge is a flat floored, gently south-sloping channel that is filled with transported clasts of exotic and local lithologies. This channel is bordered on the west by a low ridge of morainal debris and on the east by the bedrock valley wall, and is presumably an ice-margin meltwater channel. This feature was not extensively studied, but appears to disintegrate at its south end where it may once have wrapped around the nose of the ridge. An argument will be made that the channel fed the delta complex just to the east.

If there had been a lake with a surface elevation near 1270’ associated with these features, it would have flooded the Michigan Creek Valley up to the level of the wetlands, which lie at that elevation. As interpreted by von Engeln (1961), the valley that includes Michigan Creek and Jennings Pond was a meltwater channel from an ice lobe to the north and would have fed both water and sediment southward. If there had been a lake in much of this drainage system, the sediment from this flow would have been deposited at its north end and would account for the broad flat valley south of Jennings Pond. Moreover, this sediment trap would have prevented coarse sediment from moving down Michigan Creek valley at this time. This, in turn, would support the conclusion that the delta described above was fed from the west by the meltwater channel along the eastern side of Cayuga Inlet Valley.

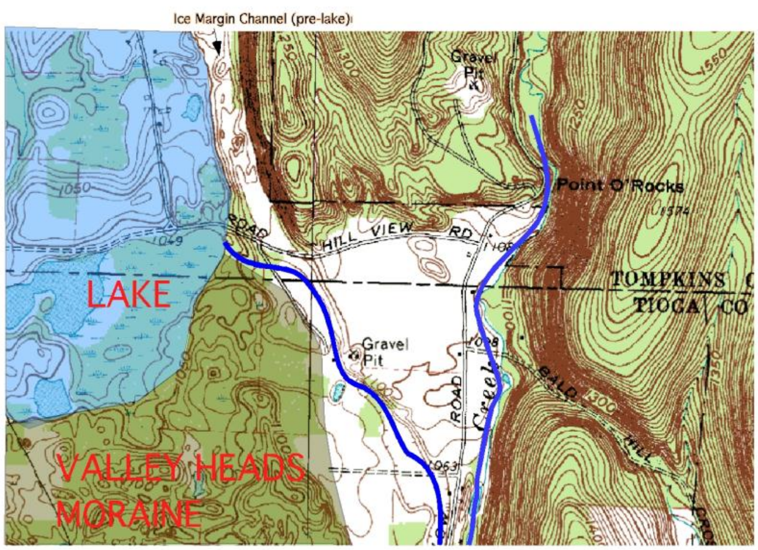
The proposed lake would have had to be dammed on its western and southern side by ice, in the form of a valley glacier with a surface elevation greater than 1270’. The location of this dam is quite uncertain, but, if the ice margin channel did wrap around the nose of the ridge on its way to the delta, it must have been constrained on the south, and that constraint would logically have been glacial ice. In that case the lake would have been quite narrow and constrained to the eastern part of the indentation south of Michigan Creek (Fig. 4a). The ice in this indentation was relatively thin and probably nearly stagnant because bedrock lies at a shallow depth there and because this identation was outside the main ice flow path. Both these factors would have led to an unstable situation.

This high-level lake was ephemeral and was doomed as the valley glacier retreated northward, lowered its surface level and failed as a dam. There are a number of features in the landfill area that suggest that the destruction of this lake was violent and occurred several times.

Several gullies are incised into the nose of the ridge north of the indentation and trend south from the high-level meltwater channel (Fig.4b). At the base of these gullies, and confined to the northern flank of the quarry, are huge angular blocks of local bedrock.(Fig. 6 in Eade,2000). These blocks almost certainly originated nearby and were transported down the gullies, probably by enormous outbursts of water from the meltwater channel. These outbursts could be attributed to withdrawal of the ice from south edge of the channel, leading to rapid erosion of the underlying bedrock. At this time the meltwater flow no longer reached the delta. The avulsion of flow from the meltwater channel into these gullies is interpreted as the cause for the irregular topography at the south end of the ridge and destruction of the channel morphology there.



Stage 3. Valley heads Moraine formation and development of kame terrace. The clastic fan in the study area would have developed late in this stage.



Stage 4. Ice recession from Valley Heads Moraine and development of a proglacial lake

Fig 4b. Selected stages in the geomorphic evolution of the Hillview area

Most sediments in the quarry are clearly fan or outwash deposits and not deltaic. The source of this mixed local and exotic material is interpreted to be the ice-margin channel along the eastern edge of Cayuga Inlet Valley because imbricate cross-bedding in the basal alluvial strata along the northern side of the quarry show an eastward component of flow (Fig 5).

Two terraces at the mouth of Michigan Hollow and just below the 1270’ delta lie at elevations of 1200’ and 1180’. Both these have cappings of alluvium comprised of both angular local and more rounded exotic clasts, but both have bedrock exposures along their eastern edges. These terraces probably developed during a stepwise lowering of the lake level, at which time coarse detritus could have been transported down Michigan Hollow as well as having come from the meltwater channel to the west. A progressive eastward displacement of the Michigan Creek channel in this area, to its present position against the eastern wall of the valley, may have resulted from this influx of detritus from the west.

With the drainage of the lake meltwater flowed southward along the eastern ice margin of Cayuga Inlet Valley north of the Michigan Hollow reentrant. This meltwater channel, and probably also Michigan Creek, fed the large fan at 1100’ in which the quarry has been developed.

This fan probably formed before the ice front retreated to the study area and created the Valley Heads Moraine. Support for this interpretation is the kame terrace at 1060’, where it lies just west of the quarry fan (Fig. 4c). This terrace is significantly lower than the fan surface and thus would be younger. The kame terrace is contiguous with, and seems related to the earliest overflow channel of Olsen (1962), which he associated with the Valley Heads Moraine.

The geomorphologic development of the Hillview area from this stage to present seems to have followed the scenario outlined by Olsen (1962). The highest outwash from the Valley Heads Moraine on the west side of Inlet Valley is near 1100’ but drops rapidly to the south and east to1050’ or less, about same elevation as outwash that Olsen related to the Valley Heads Moraine on the eastern side of the valley.

Another penultimate event in the area north of the moraine was the development of a proglacial lake, which lasted only until the ice front retreated to South Hill, just south of Ithaca, at which time meltwater flowed eastward toward a lower (980’) Sixmile valley overflow near Wilseyville.

QUATERNARY STRATIGRAPHY

Geologic events prior to, during, and subsequent to the formation of the Valley Heads Moraine were responsible for the deposition of the Quaternary sediments observed in the wells drilled around the landfill and in exposures around the quarry. The problem is to correlate these deposits correctly with those events.

The Quaternary stratigraphy in the landfill area is complex, as is typical of glacial settings, and especially in the vicinity of the Valley Heads moraines. Moreover, it appears to be different east and west of the steep rise in the Devonian bedrock, which occurs just east of the TK wells (Fig 6). This slope, defined by 3 wells that penetrated bedrock and by various geophysical methods (Eade, 2000), marks the eastern flank of the main glacial valley

The eastern stratigraphic section is exposed in the quarry walls and was recovered in a few wells in the western part of the quarry floor. Strata that have been exposed around the quarry rim range from dominantly sand to boulder sized clastics and show a rough internal stratigraphy. The lowermost unconsolidated strata along the west side of the northern quarry wall lie directly on Devonian sandstone and siltstone bedrock, but to the east they overlie a finer-grained unit that is described below. The Devonian bedrock is exposed at several places along or near the northern quarry wall (Fig. 5), was rpenetrated in wells TRI-3, DGC-2, DGC-3 and UO-1, and was imaged by several geophysical techniques (Eade, 2000). Combined, this information defined a subtle SSW-trending bedrock ridge through the western side of the quarry, to the east of which there must be a shallow bedrock trough, probably extending south from the Michigan Hollow valley.

Clasts in the coarse basal unit consist of both exotic.lithologies and local Devonian strata. The exotic clasts, including igneous and metamorphic lithologies as well as of Paleozoic sediments, are round to sub-round and in sizes up to about a foot in diameter. The locally derived clasts, on the other hand, are sub-angular to very angular. These clasts, especially the more angular ones, range in size up to that of a car (Fig, 7). The largest of these clasts occur in the northwestern part of the quarry and near the base of the section. The size of the angular clasts decreases southward and eastward.

Sedimentary structures within this section include clast imbrication, current cross-bedding, and lenses of well sorted sand. Although these structures show flow in various directions, except northerly, the clast imbrication observed in the western section of the north quarry wall shows a current flow with a consistently eastward component.

Fig 5. Photograph of the Devonian bedrock exposure on the northern wall of the Landstrom quarry. Overlying bedrock is a unit composed largely of angular clasts of local origin with clast imbrication that indicates a component of flow toward the east. This unit is overlain by one with smaller and more rounded clasts, largely of exotic origin. The height of this exposure is about 25‘. *Reproduced from Fig. 9 in Eade, 2000*

This basal unit grades upward to a significantly finer-grained unit with a higher degree of rounding (Fig. 5). Few very angular clasts were noted in this upper section. Clasts are still dominantly of exotic lithologies and range is size from sand to about 6".

This entire coarse clastic unit is clearly alluvial rather than deltaic in origin, deposited either in an alluvial fan or outwash plain. An alluvial fan origin, as suggested by Olsen (1962) is preferred because of its tie to the ice-margin channel and to the gullies just to the north of the quarry that are the logical source of the huge blocks of bedrock. An outwash fan would have a more direct tie to the ice source. If the association between the fan and the ice margin channel is correct, the fan is pre-Valley Heads in age.

Recent excavation in the southeastern corner of the quarry has revealed fine-grained sediments beneath the coarser alluvial unit (Fig 8). The contact is an irregular, gradual downward-fining of grain size, to coarse sand and granule size and finally to fine sand and silt. There is very little clay in this lower section and the only sedimentary structure noted was a faint horizontal layering.

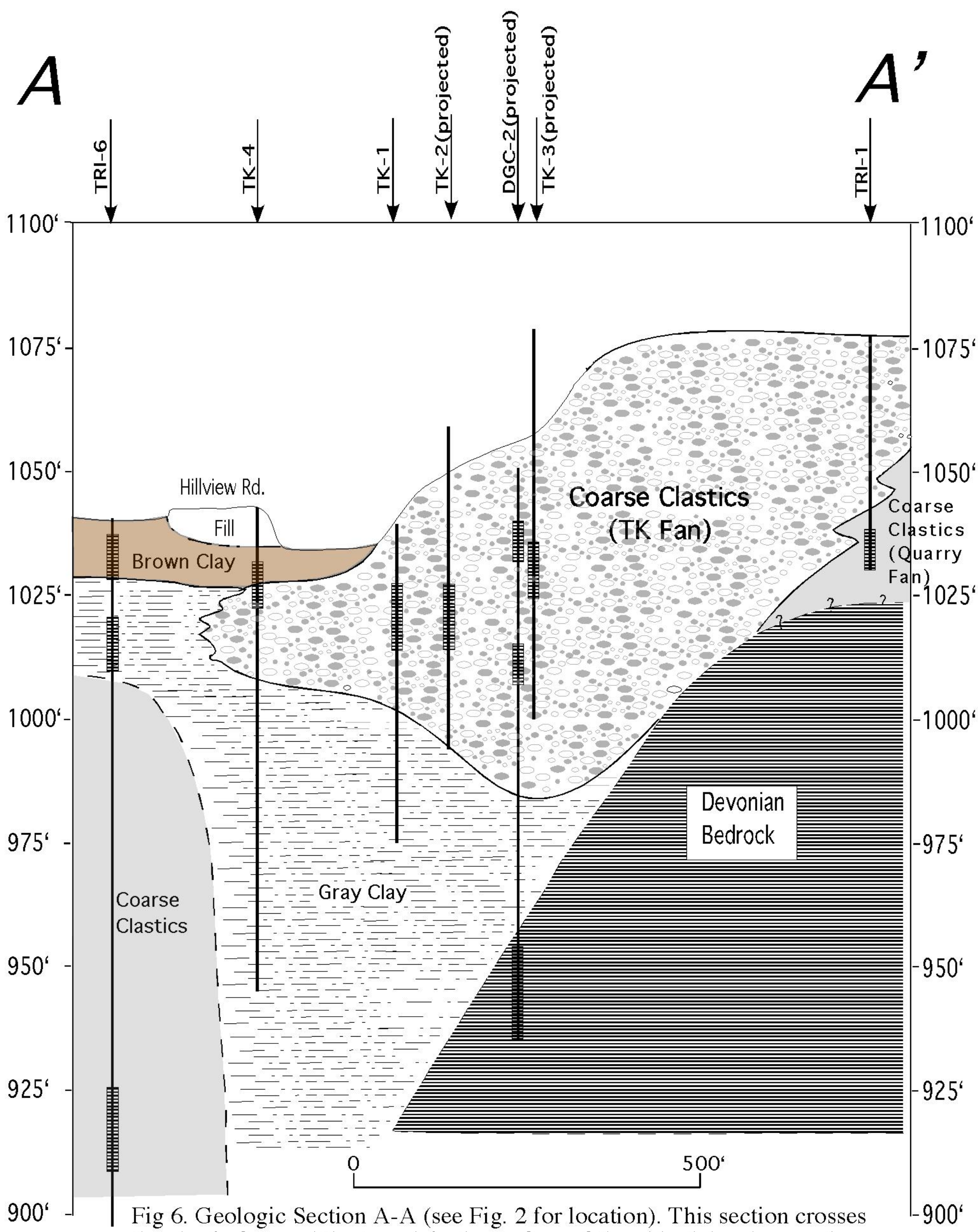


Fig 6. Geologic Section A-A (see Fig. 2 for location). This section crosses the clastic fan and the trough in the surface of the older lake clay nearly perpendicularly.

Fig. 7. Photograph of the basal strata in the northeastern sector of the quarry showing one of the immense angular blocks of local bedrock. *Reproduced from Fig. 6 in Eade, 2000.*

Fig 8. Photograph of the fine-grained sediments in the southeastern corner of the quarry that lie beneath the coarse fan units shown in Figs. 5 and 7, and that occur as a finer facies at this site.

This section was deposited in a lower energy environment than was the overlying coarse alluvium, but that environment is not obvious. It could well be lacustrine and, if so, would most likely have been the lake trapped in Michigan Hollow and in the eastward indentation of CayugaInlet Valley. The sediments observed may have been deposited during a late stage of that lake when there was sufficient current to flush the clay fraction out to the south.

Wells drilled west of the eastern bedrock slope of Cayuga Inlet Valley penetrated quite a different section, not easily correlated with that in the quarry. Various interpretations of depositional environments have been made in the consultants' reports for this western area but most are suspect, especially those for the coarser grained units, which show no structure in the split-spoon cores.

In almost all the wells drilled along the northeastern margin of the landfill a surficial section of coarse clastics (sand, gravel and boulders) overlies a section comprised of silt and/or clay. A very sharp contact between these two units was logged in all the TK wells and was actually recovered in a single split spoon sample in TK-1 at 39'. The contact between these units thus seems to be an unconformity at all the TK wellsites that marks a drastic change in depositional environment, separated by a period of erosion. When contoured, this erosional surface defines a shallow trough that opens southwestward (Fig. 9). The topography of this unconformity is probably more irregular than suggested by the contours, which are based on only a few data points.

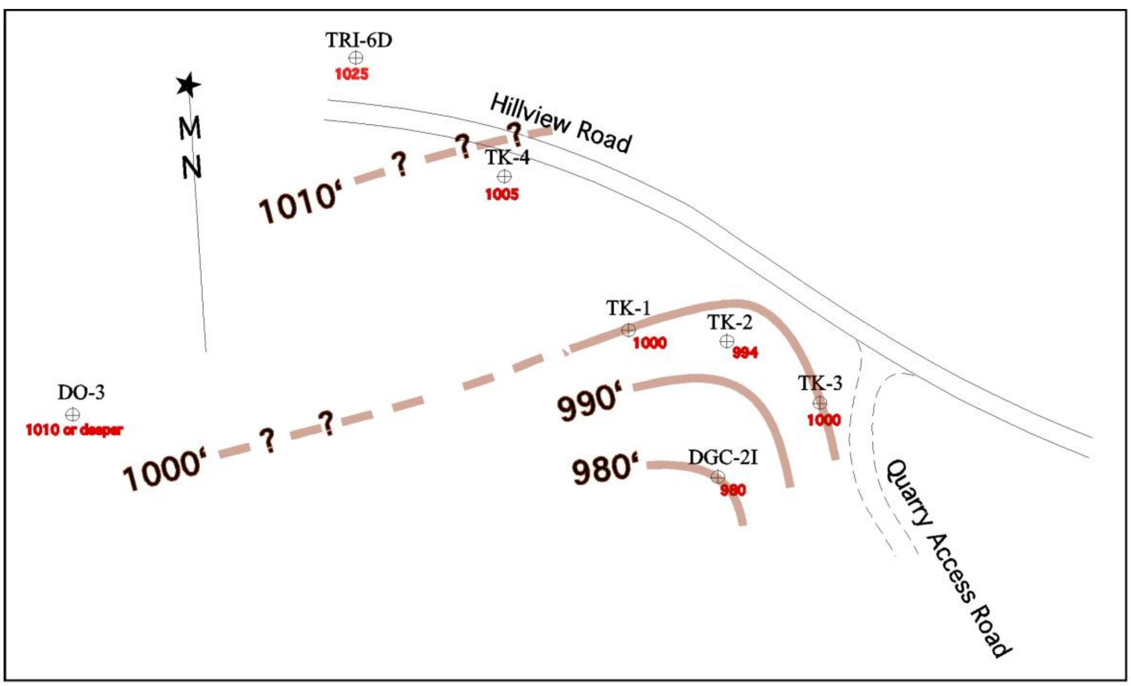


Fig 9. Structural contours on the top of the older, gray lake clay showing the trough formed at this discontinuity.

The lower unit consists of gray silty clay or clayey silt with a minor and variable component of matrix-supported coarse sand to pebble sized grains. It was easily penetrated by the augers and cores and was uniform in character with depth. This unit was at least 100' thick in DGC-1 and over 65' thick in TK-4 (Fig 6), and extends from the buried valley wall at least as far westward as DGC-1 Fig.10). Drill holes along the western and southern flanks of the landfill were too shallow to adequately document the presence of this unit but it appears to be at least 100' thick and extensively distributed.

The lower clay has been interpreted as either lacustrine (Dunn Geoscience,1985) or till (Malcomb-Pirnie, 2000). Its softness and uniformity favor a lacustrine origin, with the scattered pebbles interpreted as dropstones. Correlation with other units, to be presented, indicates that this unit was deposited before the last ice re-advance to or beyond the Valley Heads Moraine.

The overlying coarse clastic unit is composed primarily of gravel to cobble sized clasts, with thin sand or silt zones but with very little clay. The clasts are largely exotic in origin and are sub-to moderately-rounded. Surface exposures of this unit show rounded cobbles to 6" in diameter but no large, angular blocks of local bedrock.

This coarse-grained unit is 75' thick in TK-3 and appears to lap eastward onto the Devonian bedrock and/or coarse quarry clastics (Fig.6). Evidence will be presented to indicate that this unit is younger than the very coarse clastics exposed in the quarry, This upper coarse clastic unit thins and becomes finer toward the west and northwest, becoming predominantly sand in TK-4 and DO-3.

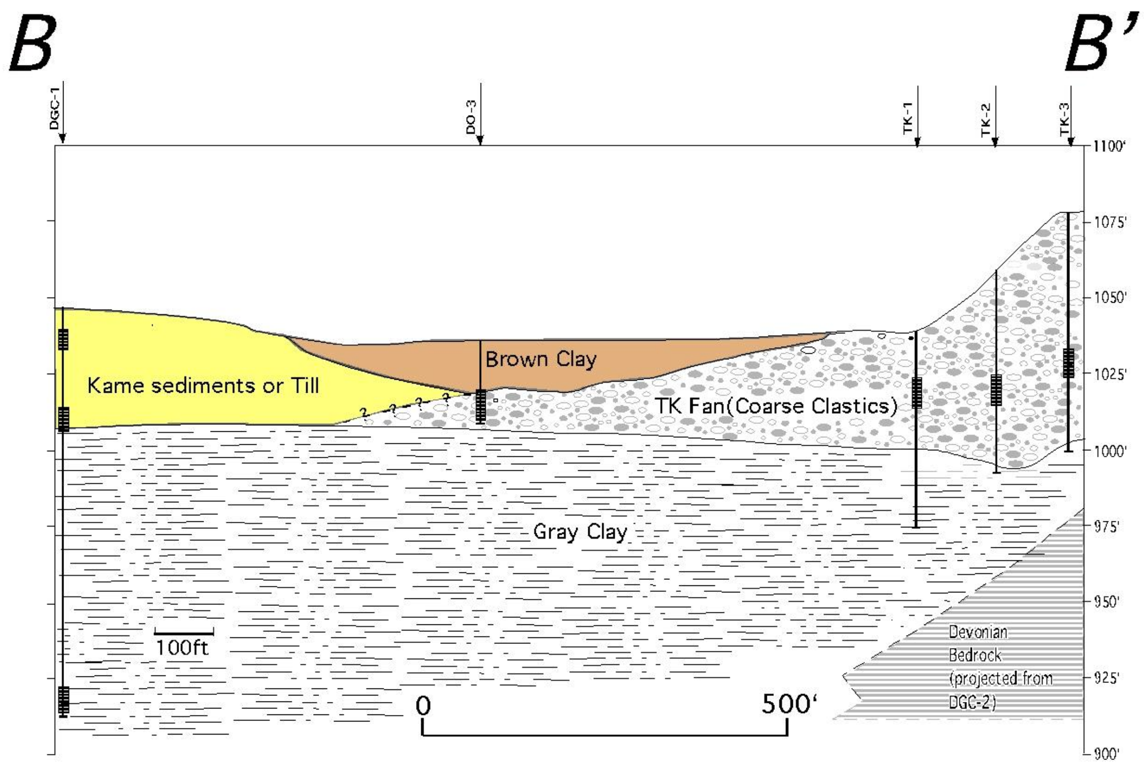


Fig 10. Geologic Section B-B' (see Fig. 2 for location).

Coarse clastics were also recovered in DGC-1 to a depth of 38', where the lower part of the section had a large gravel component (Fig 10). The relationship of this section to that further east is unclear. It is possible that some of these clastics originated as till or kame deposits related to the Valley Heads Moraine. Water levels in DGC-1 are always higher than in DO-3 by about 1 foot, resulting in a flow reversal in that area during the spring and early summer, assuming that there is hydraulic continuity. That may not be the case and lends some support to the idea that the permeable unit in DGC-1 is unrelated in origin and not hydraulically connected to the “fan” of clastics beneath the TK wells and DGC-2.

The degree of rounding and interbedding of silt to cobble sized beds or lenses in the clastic unit beneath the TK wells indicates an alluvial, or less likely, a deltaic environment of deposition. The unit thickens to the east toward the kame terrace (Fig. 6, which suggests that the two are genetically related. Because the kame terrace continues southward as the oldest channel of Valley Heads age identified by Olsen (1962) and both are significantly lower in elevation that the surface of the “quarry fan” this channel, and the sediments derived from it are thought to be younger than the quarry clastics. The lack or paucity of local angular blocks supports this interpretation.

Overlying the clastic unit in TK-1, TK-4, and DO-3 is a sequence dominated by silt, clay, and organic sediments (Figs. 6 and 10). This unit is not present east of TK-1 and thickens westward at about 15’ at DO-3. The sites underlain by this brown clay and silt unit are in the lowest part of the study area and are adjacent to present wetlands. The setting, lithology, and a few snail shells observed in TK-4 all indicate that this unit was deposited in a proglacial lake formed between the retreating glacier and the Valley Heads Moraine.

The sequence penetrated at TRI-6 is quite different from that in all the other wells in the study area. At this northern site 34’ of clay and silt overlies at least 100’ dominated by coarse sand, gravel and cobbles. It was initially thought that these coarse clastics correlated with those in the TK wells, DO-3 and DGC-2, but this is now clearly not the case. The drilling of TK-4, only 200’ southeast of TRI-6, demonstrated that the two coarse clastic units were at different depths and had significantly different lithologies (Fig 6). Furthermore, the groundwater levels in the two units differed by about 5’, indicating that they were not hydraulically connected.

It is also difficult to correlate the fine-grained unit in TRI-6 with the stratigraphic section to the south. The uppermost part of the clay and silt at TRI-6, to a depth of about 13’, is brown and probably correlates with the younger lacustrine unit to the south (Fig. 6). The downward color change in the fine grained section of TRI-6, from brown to gray, is not correlated with oxidation at the groundwater surface. It may instead mark an unconformable contact with the gray pre-Valley Heads lacustrine unit beneath. It has been noted that the youngest proglacial lake clays are red to brown (reflecting a source including Paleozoic red shale) in contrast to older blue/gray clays (A. L. Bloom, personal communication, 2003).

Interpretation of the thick coarse clastic unit in TRI-6 is very difficult, given its single observation in this well. The occurrence of interbedded gravel, sand and minor silt, with a large component of rounded exotic clasts suggests some sort of glaciofluvial origin. The unit seems to have a very steep eastern boundary because it is not observed in TK-4 to that well’s maximum depth of 95’. Support for this sharp boundary is found in the seismic refraction data which showed sharp lateral velocity variations and a high velocity body along Hillview Road just south of TRI-6 (Eade, 2000).

One possibility is that the unit represents an esker or some sort of kame deposit. The fact that the groundwater level in this unit is so much lower than in all the rest of the adjacent wells suggests that it has good internal hydraulic continuity, which is more likely typical of an esker. The depressed water level also suggests that this unit may be hydraulically connected to a deeper aquifer. There is simply not enough evidence available to be more conclusive.

GEOLOGIC SUMMARY

The Landstrom Landfill lies in a very complicated Quaternary geologic setting. Not only is it adjacent to the Cayuga Valley Heads moraine, but also lies at the boundary between the major glacial trough of Inlet Valley and a re-entrant involving a glacial overflow channel (Michigan Hollow) with a shallow bedrock floor. This setting seems to have led to a complex of lakes, deltas and alluvial fans, as well as primary glacial landforms. Nevertheless, a combination of field observations and the results of drilling lead to a somewhat clearer and more complete understanding of the late Quaternary history for this area than heretofore presented. Systematic field studies would undoubtedly improve this history significantly. The following is a plausible, but not the only possible scenario.

The earliest event clearly represented by strata penetrated by drilling around the landfill is the pre-Valley Heads age lake in which the thick gray clay unit was deposited. This unit is extensive and probably underlies most of the Cayuga Inlet Valley. It cannot be determined whether this lake formed during a glacial advance or retreat. The coarse clastic unit recognized in TK-6 underlies this clay and is thus older but its origin is uncertain. An esker is plausible.

No obvious lodgement till from the glacial advance that led to the Valley Heads moraine was recognized, but the very sharp upper contact of the older lake clay suggests that this unit was overridden by the glacial advance. The simplest interpretation of the last major late Wisconsin glacial advance in the study area is that it reached well south of the Valley Heads Moraine, which would then represent a pause in the subsequent retreat or perhaps a minor oscillation. This model would associate the high-level delta, the ice margin channel and the overflow channel, all at about 1270’, with a time when the ice front was still south of the Valley Heads moraine. A narrow lake seems to have been trapped between the glacier and the valley wall just south of Michigan Hollow valley and was responsible for the fine-grained sediments exposed in the deep pit at the southeastern corner of the quarry.

As the ice front retreated northward and the glacial surface dropped, a younger, lower outlet formed at the eastern edge of the glacier. It is probable that the ice dam reformed and broke several times, which could explain the several terrace levels at the mouth of Michigan Hollow.

Following drainage of this lake, probably closely in time, would be retreat of the ice from the southern end of the ridge between Cayuga Inlet Valley and Michigan Hollow valley. This would have allowed the “spilling” of flow from the ice margin channel along the east side of Cayuga Inlet Valley into the reentrant from which the ice had retreated. The accompanying violent erosion of the underlying bedrock resulted in the huge angular blocks of bedrock along the northern side of the quarry as well as the generally-coarse “exotic” clastics forming the alluvial fan with a surface elevation about 1100’.

When the glacial front lay at the location where it created the Valley Heads moraine, a large amount of meltwater drained down the east side of Cayuga Inlet Valley to form the kame terrace just east of the landfill at 1060’. This kame terrace is at the correct height and location to have been a principal feeder for the outwash plain south of the Valley Heads Moraine.

The relationships among the kame terrace, the clastic fan beneath the TK wells and the trough in the upper surface of the underlying clay unit are unclear. The fan is almost certainly younger than the outwash plain, because the kame terrace exists south of the point where the fan emanates. One plausible explanation is that flow from the meltwater channel represented by the kame terrace was diverted into the area behind the Valley Heads Moraine as the ice withdrew, both cutting the trough and depositing the clastics. A serious difficulty in this model is that the trough lies at elevations much lower than the accepted outlet channel to the proglacial lake (Olsen, 1962) and must have been tied to a much lower baselevel. A possible escape would have the fan-forming event occur during the evolution of the Valley Heads Moraine, which probably involved minor ice advances and retreats (Miller, 1993)

The final glacial-related event in the study area was the deposition of the brown clay in a short-lived proglacial lake trapped between the moraine and the northward retreating ice front.

HYDROLOGY

The determination of the direction and rate of flow of groundwater is obtained by the measurement of water levels (potentiometric sufaces) in geohydrologic units that are interpreted to be contiguous aquifers. This requires the measurement of water levels in several wells that are screened in units that represent the same aquifer, which can be a matter of interpretation.

At the beginning of this study, the coarse clastic units in wells DO-3, DGC-2I, and TRI-6D were interpreted as contiguous and with a very strong northerly groundwater flow, principally because water levels in TRI-6D were about 5 ft lower than in the other 2 wells. This interpretation also supported the earlier conclusion of a groundwater divide near the north end of the landfill, with wells to the south defining a southeasterly flow (Malcolm-Pirnie, 1995).

The results of groundwater measurements made in the new TK wells changed this interpretation radically. As a result of drilling it became obvious that the gravel-rich unit at the base of TRI-6 could not be correlated with that in the rest of the wells in the study area. This changed the flow pattern determined in the northeastern sector of the landfill area and brought into question the idea of a simple groundwater divide.

DATA

Water level data from wells DO-3, TRI-6, DGC-2, and from the TK wells as they became available, were the principal source of data for this study. Some data from other wells (e.g. DGC-1, TRI-3, and wells to the south were used for a more regional assessment of groundwater flow directions. DGC-2I and TRI-6D were used from those well clusters because only those screens were set in units that could be contiguous. For example, TRI-6I was screened in the impermeable lower lacustrine unit and was clearly not correlatable with the screens in the gravel-rich sections of the other wells.

Water level data are available from the late 1980's to the present, but only those measurements collected from February 2000 to October 2001, plus those obtained during the two most recent rounds of measurements (Table 3) were used for the hydrologic analysis in the northeastern sector of the landfill. The reason for this selection is that, beginning in early 2000, measurements were made nearly every month and it was during this period that the TK well data became available. The most recent data were incorporated because only then were measurements from all the TK wells available. Data obtained during a comprehensive monitoring period in 1994 and 1995 (Table 3) were used to develop a general flow pattern in the southeastern sector of the landfill, for comparison with that in the northeastern sector.

The most general conclusion about water level elevations is that they fluctuate with time in all wells. Elevations vary from year to year depending on average precipitation but more importantly they show annual cyclic fluctuations. Water levels are at a maximum in the late spring (April-May), following snowmelt, and at a minimum in mid winter (December to February). The rise in levels during the spring is more rapid than is the decline over the summer and fall months (Fig 11). These annual fluctuations are generally of the order of several feet but in some wells (e.g. DGC-2I, TK-2 and TK-3) can be 6 ft or more.

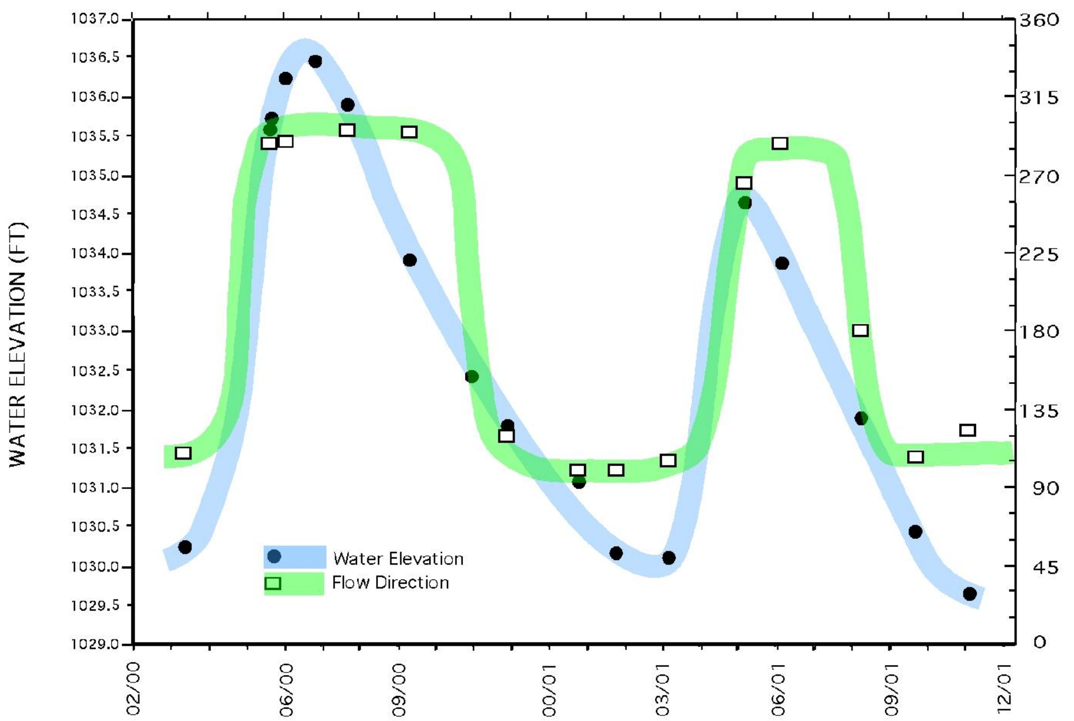
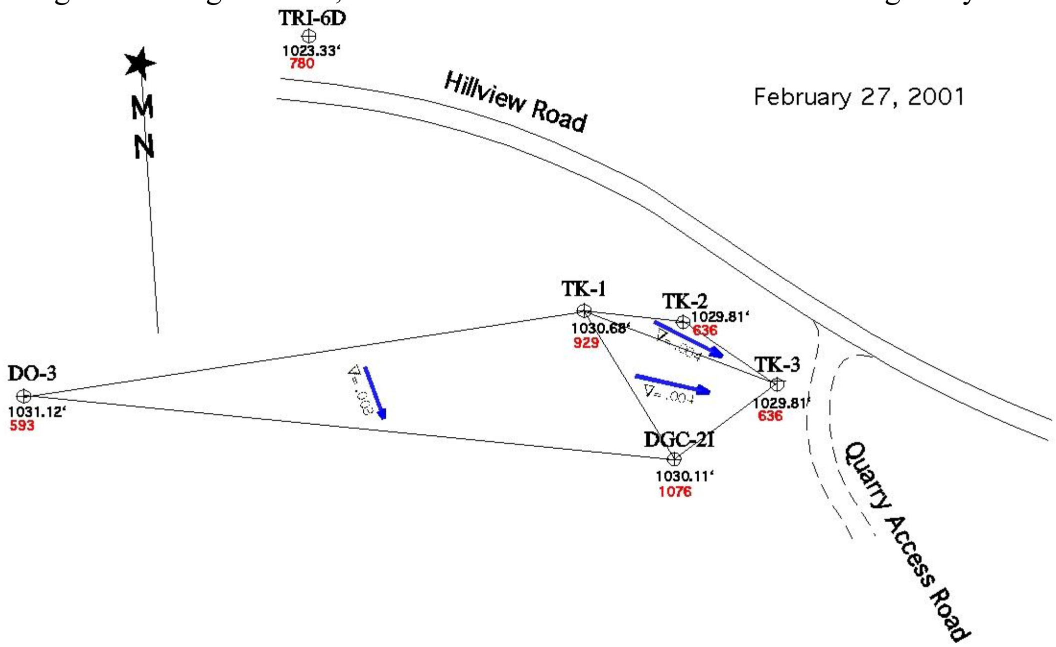


Fig. 11. Plot of groundwater elevations and flow directions during the most intensive monitoring period. Although all wells showed similar annual cycles, the plot is based on elevations in DGC-2I and flow directions are from the well net including DGC-I, TK-1 and TK-3

In this investigation of a possible contaminant plume the direction of groundwater flow, its variation in direction over the yearly cycle, and the variation in the gradient of the potentiometric surface are more important than the general annual fluctuation in water level. The flow direction and gradient in a given aquifer were determined by the triangulation method (water elevations determined at 3 points measured on the same date). Thus a network of directions and gradients (in feet of drop per foot of distance) were constructed for neighboring sets of 3 wells for each measuring date used in the study and plotted as vectors in the centers of the triangles so formed (Fig. 12). Two representative plots of these gradients, in the spring and fall, plus the gradients from the triangle including DGC-2I, TK-1 and TK-3 were used in the following analysis.



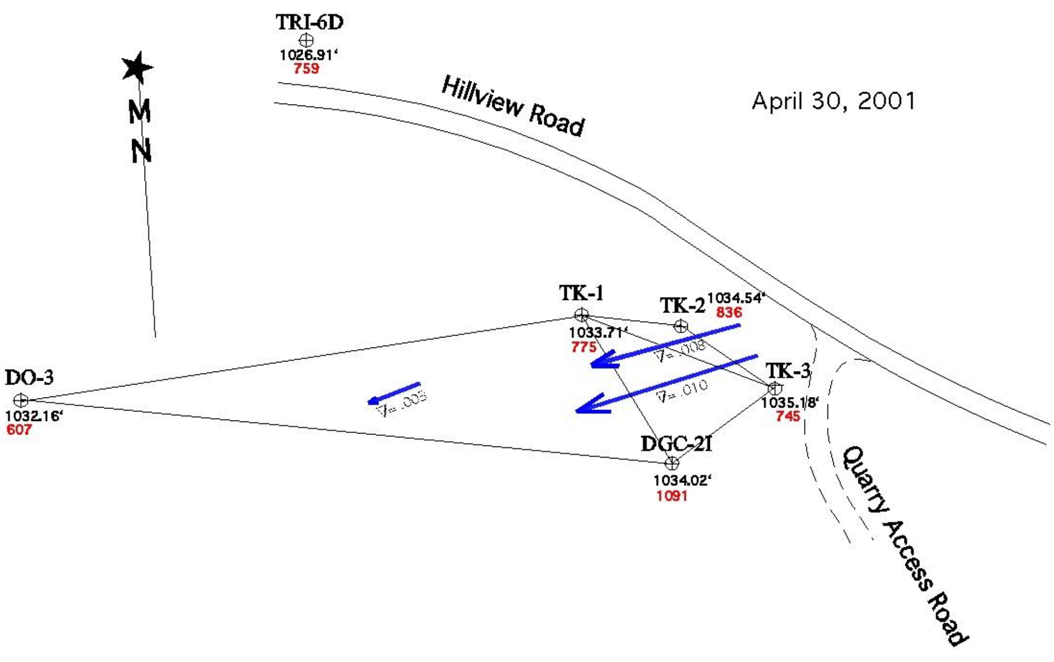


Fig 12. Well nets in the study area for times of low easterly flow(February) and high westerly flow(April). Water surface elevations (black) and conductivities (red) are shown at each well. The heavy arrows show flow direction. The length of the arrows is proportional to the flow gradient, which is also shown numerically.

These data demonstrate that the groundwater gradient is bimodal. In the fall and winter the flow is eastward (105°to110°) but it rapidly changes to a westward to southwestward flow in the spring as the water elevations rise. Although there is a very good correlation between this eastward to westward gradient flip and the elevation rise, there is no correlation between the westward to eastward flow and water level drop (Fig 11). That gradient reversal is as rapid or nearly as rapid as the spring reversal but at a time (fall) when the water level is still dropping.

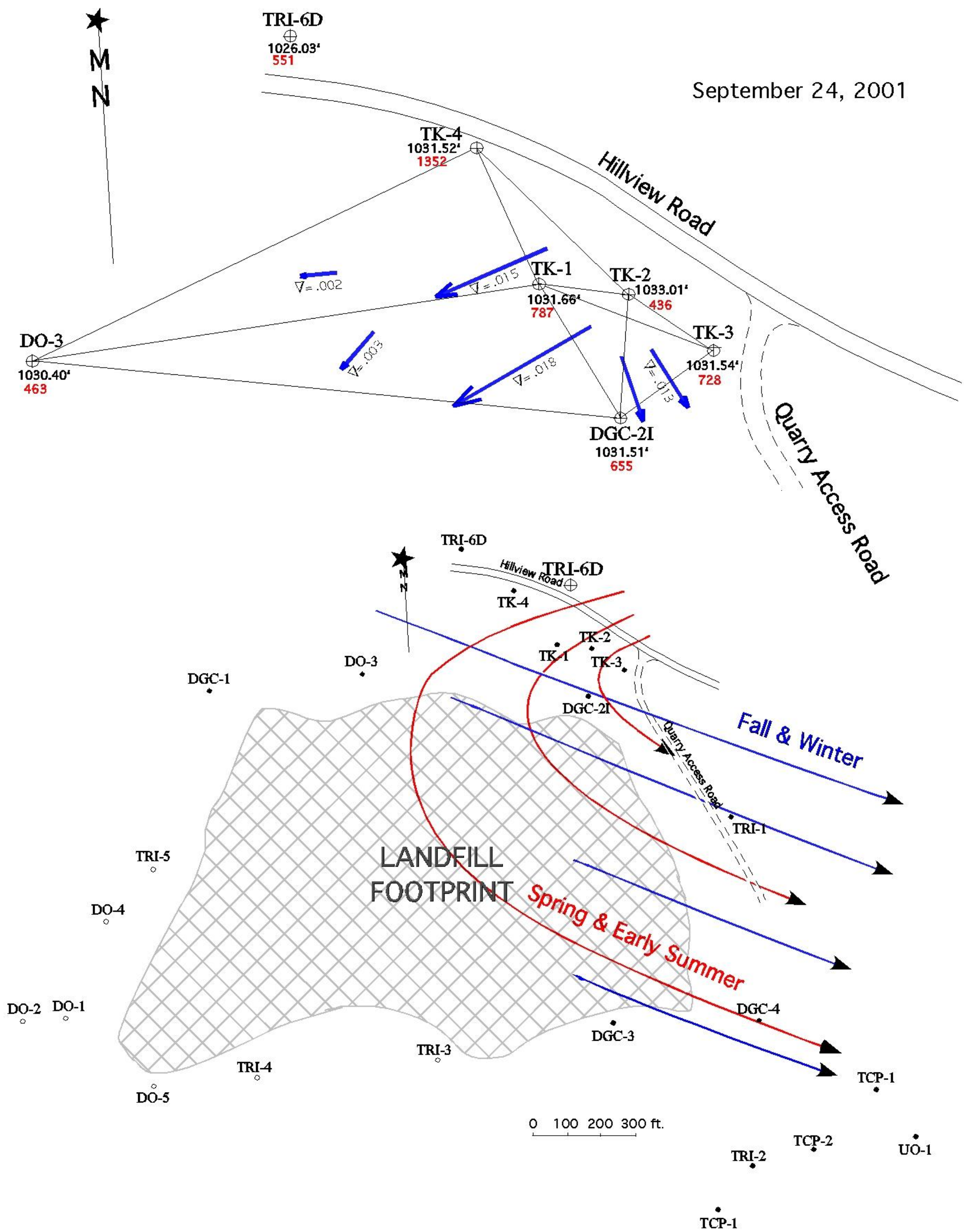


Fig 13. TOP. Well net for September 2001, which shows a radial flow pattern suggesting a transition from the high to low flow conditions.
BOTTOM: Map of all wells in the landfill area and diagrammatic flow patterns during low flow (fall and winter) and high flow(spring and early summer) conditions. Wells marked by solid circles are those with screens in permeable units. Those marked by open circles have screens set in impermeable sediments

Although this flow pattern appears to have been quite consistent over most of the study period, the final two rounds of measurements, in September 2002, and March 2003, showed significantly different patterns. The flow in September ranged from westerly between TK-1 and DO-3 to southeasterly near DGC-2 and TK-3, with the highest groundwater elevation at TK-2 (Fig. 13). The gradients describe a radial or spiral pattern, with the flow rotating counterclockwise. During March the flow was southwesterly in the western part of the net, but northeast to northwest in the eastern part. This was largely due to the lowest water elevation being at TK-2. It could be that this measurement was incorrect. If it were ignored the gradient around DGC-2 would be very low and to the southeast, as would be expected just before the spring snowmelt started.

The older data from wells around the eastern and southern periphery of the landfill that had screens set in the shallow coarse clastic unit show a general eastward flow. No evidence of a seasonal reversal in flow direction was recognized. On the basis of the available data, there does not seem to be any groundwater divide in the upper clastic (alluvial) unit in the eastern section of the landfill. If anything, there might be a divide between groundwater flowing westerly in the area north of the landfill and easterly on its eastern flank during the summer and early fall. Nothing can be said about groundwater flow on the western and southern sides of the landfill because all the wells in those sectors had screens set in impermeable silts and clays

The groundwater flow in the gravel unit penetrated by TRI-6 is most likely quite different from that in the upper alluvial clastic unit, but with only one measuring point, no flow direction can be determined. If the unit were an esker it would probably have a flow along the esker with a northerly component because the valley deepens in that direction. Because water levels in the 3 screens at the TRI-6 cluster consistently decrease with increasing depth, there is also very likely a downward component to flow at that site.

Table 3. Monitoring well water elevation data (1994-95)

WELL	DATE	WATER_EL	WELL	DATE	WATER_EL
B-1	11/17/1994	1029.25	B-1	2/17/1995	1030.40
B-2	11/17/1994	1028.40	B-2	2/17/1995	1028.90
B-3	11/17/1994	1032.21	B-3	2/17/1995	1032.41
B-4A	11/17/1994	1053.88	B-4A	2/17/1995	1054.66
DGC-1D	11/17/1994	1031.77	DGC-1D	2/17/1995	1032.16
DGC-1I	11/17/1994	1032.42	DGC-1I	2/17/1995	1032.48
DGC-1S	11/17/1994	1032.39	DGC-1SB	2/17/1995	1032.47
DGC-2D	11/17/1994	1031.88	DGC-2D	2/17/1995	1033.23
DGC-2I	11/17/1994	1032.56	DGC-2I	2/17/1995	1033.65
DGC-2S	11/17/1994	1032.20	DGC-2SB	2/17/1995	1033.23
DGC-3D	11/17/1994	1033.11	DGC-3D	2/17/1995	1034.16
DGC-3I	11/17/1994	1033.12	DGC-3I	2/17/1995	1034.12
DGC-3S	11/17/1994	1051.51	DGC-3S	2/17/1995	1052.49
DGC-4	11/17/1994	1030.13	DGC-4	2/17/1995	1031.39
DO-1	11/17/1994	1034.25	DO-1	2/17/1995	1033.98
TRI-1	11/17/1994	1032.07	DO-3	2/17/1995	1031.77
TRI-2I	11/17/1994	1032.75	DO-4	2/17/1995	1028.34
TRI-3	11/17/1994	1032.07	DO-5	2/17/1995	1030.13
TRI-4	11/17/1994	1037.27	TRI-1	2/17/1995	1033.35

WELL	DATE	WATER_EL	WELL	DATE	WATER_EL
TRI-5	11/17/1994	1029.32	TRI-2D	2/17/1995	1030.95
TRI-6I	11/17/1994	1028.30	TRI-2I	2/17/1995	1030.98
TRI-6S	11/17/1994	1032.35	TRI-3	2/17/1995	1041.15
DO-3	11/29/1994	1031.56	TRI-4	2/17/1995	1037.07
DO-5	11/29/1994	1030.40	TRI-6D	2/17/1995	1026.94
TRI-6D	11/29/1994	1025.79	TRI-6I	2/17/1995	1029.13
			TRI-6S	2/17/1995	1032.51
B-1	4/25/1995	1030.84	B-1	7/19/1995	1028.57
B-2	4/25/1995	1029.89	B-2	7/19/1995	1026.48
B-3	4/25/1995	1033.09	B-3	7/19/1995	1028.45
B-4A	4/25/1995	1055.18	B-4A	7/19/1995	1052.56
DGC-1D	4/25/1995	1032.74	DGC-1D	7/19/1995	1031.04
DGC-1I	4/25/1995	1033.10	DGC-1I	7/19/1995	1030.20
DGC-1SB	4/25/1995	1033.11	DGC-1SB	7/19/1995	1030.24
DGC-2D	4/25/1995	1034.09	DGC-2D	7/19/1995	1031.78
DGC-2I	4/25/1995	1034.36	DGC-2I	7/19/1995	1032.37
DGC-2SB	4/25/1995	1033.94	DGC-2SB	7/19/1995	1032.09
DGC-3D	4/25/1995	1034.83	DGC-3D	7/19/1995	1032.73
DGC-3I	4/25/1995	1034.82	DGC-3I	7/19/1995	1032.76
DGC-3S	4/25/1995	1053.20	DGC-3S	7/19/1995	1050.02
DGC-4	4/25/1995	1031.81	DGC-4	7/19/1995	1029.45
DO-1	4/25/1995	1034.43	DO-1	7/19/1995	1032.49
DO-3	4/25/1995	1032.08	DO-2	7/19/1995	1032.41
DO-4	4/25/1995	1028.31	DO-3	7/19/1995	1030.73
DO-5	4/25/1995	1030.23	DO-3PZ	7/19/1995	1031.56
TRI-1	4/25/1995	1034.19	DO-4	7/19/1995	1027.80
TRI-2D	4/25/1995	1031.48	DO-4PZ	7/19/1995	1027.56
TRI-2I	4/25/1995	1031.41	DO-5	7/19/1995	1029.54
TRI-3	4/25/1995	1041.69	DO-5PZ	7/19/1995	1029.27
TRI-4	4/25/1995	1037.69	TCP-1	7/19/1995	1041.26
TRI-5	4/25/1995	1030.94	TCP-2	7/19/1995	1028.82
TRI-6D	4/25/1995	1028.05	TCP-3	7/19/1995	1028.68
TRI-6I	4/25/1995	1030.08	TRI-1	7/19/1995	1031.81
TRI-6S	4/25/1995	1032.92	TRI-2D	7/19/1995	1029.03
			TRI-2I	7/19/1995	1029.05
			TRI-2S	7/19/1995	1029.01
			TRI-3	7/19/1995	1040.40
			TRI-4	7/19/1995	1034.05
			TRI-5	7/19/1995	1030.94
			TRI-6D	7/19/1995	1024.83
			TRI-6I	7/19/1995	1027.16
			TRI-6S	7/19/1995	1030.16

SUMMARY

The general direction of groundwater flow in the northeastern sector of the landfill is easterly from late summer or fall through the winter months when groundwater levels are lowest. The groundwater flow direction reverses and flows westerly in late spring and summer, when water levels are higher. The flow from DGC-2I is almost never northerly. The flow in the eastern and southeast sector of the landfill is always southeasterly.

This flow pattern could be explained by a model derived from other groundwater studies in the region (Todd Miller, personal communication, 2003) whereby an increase in spring recharge from the uplands that seeps into the valley aquifers along the valley edges can temporarily change and even reverse the normal flow direction, In the case of the landfill this spring recharge would be from the northeast, from the kame terrace, and the bedrock hill to the northeast. The greater annual fluctuation of water levels in the wells closest to these sources supports this model. During the spring groundwater flows westerly through the northern section of the shallow coarse clastic aquifer beneath the northeast part of the landfill. It then appears to loop counterclockwise to become a southeasterly flow in the southern part of the study area (Fig. 13).

Later in the summer and further from the source area the flow becomes uniformly southeasterly, which is probably the more general flow direction in this area. This would be consistent with the late glacial flow directions mapped by Olsen (1962) and with the Michigan Creek drainage.

GEOCHEMISTRY

Collection and analysis of geochemical data from the wells in the landfill were not in the purview of this project, but the specific conductances of the groundwater were measured in the wells from which water level data were collected during the study. Specific conductances were intended to be an inexpensive proxy for contaminants, more specifically for the chloride ion, which was associated with the leachate contamination at DGC-2. However, chloride contamination can also occur in groundwater from road salt, and the two sources cannot be differentiated with conductivity measurements alone.

Results of the conductivity measurements are not as conclusive as the other geohydrologic components of the study but can be interpreted to show the lack of a contaminant plume migratingfrom DGC-2 and the influence of road salt on several wells.

METHODS

Specific conductances were measured using a specific conductance meter borrowed from the U.S. Geological Survey (USGS) in Ithaca. This meter measured specific conductance in units of µmhos/cm, and also water temperature (which was recorded but not reported here). Attempts were initially made to purge the wells with a battery driven pump, also borrowed from the USGS. However, too many mechanical problems developed so we reverted to hand bailing and measuring conductances in each bail until the values stabilized.

It was noted that the values obtained with the USGS specific conductance meter were always significantly higher than values obtained in the same wells by Upstate Labs personnel during their scheduled geochemical sampling, To understand this difference, parallel sampling by both pieces of equipment were made in March 2003, when Upstate Labs sampled all the wells in the study area. The differences in the two sets of values were systematic, with an approximately linear relationship of the form:

Upstate Lab values = .414 USGS values + 155
or
USGS values = 2.42 Upstate lab values – 375
In this report all conductance values are from the USGS meter.

RESULTS

DGC-2 was the problem well, with high contaminant values, and it also had significantly higher than background conductance, which seems to be about 500 µmhos/cm, using the USGS equipment. Values in DGC-2I were above 1000 for all but the last two rounds of measurements, when values decreased to 655.

DO-3 and TK-2 had the lowest values, consistently around 500, which was probably close to background (one early value of 836 in TK-2 was probably due to an incomplete purge).

TK-1 had moderately high values (950 or so) at first but decreased, especially at end, to final value of 581. Conductances measured during drilling were highest near the surface and decreased with drilling depth (Malcomb-Pirnie, 2000)).

With the exception of TK-3, conductance values in the wells were fairly consistent over time and showed no systematic seasonal variations or any correlation with water levels. Conductances in TK-3 varied significantly over the measuring period and, when analyzed, the data showed that the conductance varied systematically with the water level and seasonally. Conductances rose with water level and were highest in the late spring and lowest in late fall and winter. TK-3 was the well in which the annual water levels fluctuations were the greatest, which strengthens the conclusion that the variations in conductance are systematic Detailed chemical analyses of the study wells in September, 2002, showed that the high conductance in TK-3 was associated with high chloride, but not with other contaminants detected in DGC-2. Both this chemical difference and the fact that conductances were higher in the spring with higher water elevations suggests that the cause of the high spring conductance is road salt applied along Hillview Road and/or the quarry entrance road.

Only 2 values were measured at TK-4 but both were extremely high, 1350 in the fall of 2002 and 2325 in the spring of 2003. Again these high conductances were not associated with high levels of other contaminants and can most easily be attributed to road salt, because this site was on the shoulder of Hillview Road. High conductances in the shallower sections of TK-1 are also probably a results of either surface salt contamination or another surficial source, as in the adjacent wetland, which collects road salt runoff.

All the specific conductance values above are assumed to have been measured in the same contiguous aquifer, whereas the conductances measured in TRI-6D are now known to be from a different aquifer. The TRI-6 values were consistently somewhat higher than background (750±50) until the last two rounds of measurements when the values decreased to 600 and then 550. The source of the groundwater in this aquifer is unknown, but this is a confined aquifer at the well site. If the source is to the south, the aquifer would be confined there by the younger proglacial lake clays and protected from infiltration of road salt along Hillview Road.

SUMMARY OF HYDROLOGY AND CONDUCTIVITY

The coarse clastic unit in which the contaminants at DGC-2 persist is apparently contiguous with that in all the TK wells and probably in DO-3. This conclusion is based on their similar water levels and coherent flow directions. This unit thickens and coarsens to the east, and is probably derived by overflow from the area of the kame terrace, which marks an ice margin channel. Although this unit is probably contiguous with the alluvium in the quarry it is felt to be younger. The coarse clastics in TRI-6 almost certainly comprise a different unit and seem to be contained within and under the lacustrine gray clay that is interpreted to be of pre-Valley Heads age.

Groundwater within the aquifer under investigation fluctuates annually, with the amplitude of the fluctuations being greatest to the northeast (TK-2,TK-3 and DGC-2). The flow is easterly to southeasterly when the water level is lower, from fall to late winter or early spring. Upon snowmelt, the flow rapidly reverses to a westerly or southwesterly direction. Although there are fewer water level data from the wells on the east side of the landfill, south of the study area, those data do not show any seasonal reversal in flow direction. In particular, measurements in the late spring show a strong easterly flow.

The most likely explanation for this pattern of groundwater flow is that a large influx of recharge, probably from the east valley wall and the kame terrace, results from spring snowmelt. This inlux decreases throughout the summer, and at some time during the fall flow reversal occurs (Fig. 13). During the rest of the year, and to the south, the flow is easterly to southeasterly.

The picture seems to be that the spring influx fills and floods the shallow aquifer in the northeastern part of the landfill. During the drier season the aquifer “empties” and the flow is easterly. It would appear that the general groundwater flow beneath the landfill is easterly, toward Michigan Creek and then probably to the south.

The rate of flow depends on both the gradient and permeability within an aquifer (Darcy’s law) but good permeability data are lacking. Rapid changes in water elevation, direction of flow, and in gradients suggests that permeabilities in the alluvial unit are quite high.

Several relevant questions were not addressed in this study or could not be resolved. The most important of these is the source and disposition of the contaminated groundwater detected at DGC-2. This study shows that it does not migrate to the north or west, but no data was collected that shows where the contaminated groundwater does flow. Nor is it obvious, given the groundwater patter deduced from this study, how the contaminated groundwater could have reached DGC-2 from the Hillview landfill. Only a few ideas can be presented with the data now available.

The flow pattern shown on Fig. 13 is only approximate. The area where the spring flow swings to the southeast could be somewhat further south and still satisfy the data. In such case it would be possible for the contaminated groundwater to have come from the old Tioga County dump, which lies not far to the east.

A second possibility is that the groundwater flow is more complex and irregular than shown, much as a stream has local eddies. DGC-2 lies very close to the Hillview landfill and some very local northward leachate dispersal might occur in this location., particularly at very shallow depths or even surficially.

Where the contaminated groundwater detected at DGC-2 does go is an equally difficult question. It may flow southeasterly, but was not detected at TRI-1, which is located in that direction. Again, the flow pattern shown in Fig 13 is approximate and TRI-1, which is the only well site southeast of DGC-2, may not lie along a groundwater flow line that carries the contaminants. Another possibility is that the contaminated groundwater sampled in the two shallower screens at DGC-2 flows downward and enters the lower, fractured basement aquifer. This lower aquifer also shows contamination, but was initially assumed to have too low a permeability to effective transport contaminants away from the landfill. Additional drilling would be necessary to address this problem.

Another major unresolved problem is what the groundwater behavior is beneath the western and southern flanks of the landfill. Wells in these sections were not completed in a manner to answer this question, but the western half of the landfill seems to be underlain by lake clay and thus may not have access to permeable sediments.

Yet another question is the role of the clastic unit in TRI-6. This aquifer, with its lower potentiometric surface may have hydraulic continuity with the larger aquifers beneath Inlet valley, but so far no elevated contaminant levels have been reported from this site.

REFERENCES

Dunn Geoscience Corp., 1985, Geohydrologic Investigation of Tompkins County SLF #1, unpublished consultants' report.

Eade, Alissa, 2000, Investigating the Geologic Setting of Hillview Road Landfill from a Geophysical Perspective, M.Sc thesis, Cornell University, 85p.

Esbaugh Consulting Engineers and Terran Research, 1991, Landfill Environmental Monitoring Program at the Tompkins County Landstrom Landfill, unpublished consultants' report.

Malcomb-Pirnie Inc., 1996, Hydrogeological Investigation of the Hillview Road Landfill, unpublished consultants' report

Malcom-Pirnie, Inc., 2000, Title unknown. unpublished consultants' report.

Miller, T.S., 1993, Glacial geology and the origin and distribution of aquifers at the Valley-Heads Moraine in the Virgil Creek and Dryden Lake-Harford valleys, Tompkins and Cortland Counties, N.Y.: U.S. Geological Survey Water-Resources Investigations Report 90-4168, 34p.

Miller, T.S., 2000, Unconsolidated Aquifers in Tompkins County, New York; U.S. Geological Survey, Water-Resources Investigations Report 00-4211.

Muller, E.H., and Calkin, P.E., 1993, Timing of Pleistocene Glacial Events in New York State: Can. J, Earth Sci., v. 30, p. 1829-1845.

Olsen, G.P., 1962 Micro-geomorphology of the Valley Heads Moraine in Inlet Valley, Tioga County, New York: unpublished Senior Thesis, dept. of Geology, Cornell University.

Tarr, R.S. 1904, Artesian Well Sections at Ithaca, N.Y.: J. Geology, v. 12, p. 69-82.

Von Engeln, O.D., 1961, The Finger Lakes Region: its Origin and Nature: Cornell University Press, Ithaca, N.Y.