# GROUNDWATER FLOW SIMULATION MODEL FOR A LANDFILL SITE IN THE TOWN OF BROOKHAVEN, LONG ISLAND, NEW YORK

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## Introduction

The Town of Brookhaven, Long Island, New York has operated one of the country's first artificially lined landfill since 1974. By 1980, it was clear that the liner system had failed; the leaky landfill cells accepted waste until 1995. This resulted in a contamination plume that discharges into the surrounding surface and groundwater. As part of measures initiated by the Town to remediate the plume, we are developing a dynamic, groundwater flow and solute transport simulation model to delineate the leachate plume using Visual MODFLOW v. 4.2. In a previous work, Wexler and Maus (1988) developed a 2-dimensional, steady-state model for the landfill depicting the groundwater flow in the underlying Upper Glacial aquifer (the "Wexler model"). Since then, computers have improved and a lot more data is available about the landfill leachate. Clearly, before modeling the leachate plume, groundwater flow must be depicted accurately. The Wexler model is a reasonable approximation of the regional flow patterns. Therefore, the first step in our modeling approach is to re-simulate Wexler's 2-D model in a 3-dimensional, steady-state simulation. Here we describe the model construction, simulation and calibration process and initial results indicating our model is in reasonable accordance with Wexler.

## The leachate problem

The Town of Brookhaven Waste Management Facility is located in the hamlet of Brookhaven, Suffolk County, New York (Figure 1). The landfill was one of the first artificially lined landfills in the country, but the liner system failed some time after installation causing widespread groundwater contamination in the direction of groundwater flow (Dvirka and Bartilucci, 2000). The US Geological Survey (USGS) entered into a cooperative agreement to investigate the groundwater contamination. Its lead researcher, EJ Wexler, produced a 2-dimensional transport simulation for the plume. Three reports on the model development and results from simulation runs were produced (Wexler, 1988a; Wexler and Maus, 1988; Wexler 1988b). However, the model itself has been lost.

In 2008, Suffolk County Department of Health Services released a report on landfill contamination in surface waters in Brookhaven hamlet (SCDHS, 2008). As part of its reaction to this report, the Town determined that remediation options for the plume should be reconsidered (Dvirka and Bartilucci, 2010). Wexler (1988b) had been an important element in initial findings that capping the landfill would be sufficient to address the contamination issues, and that the effects of capping would quickly be realized; now, 15 years after the completion of the capping project, it was clear that the contamination had not diminished enough to ameliorate community concerns. Therefore, the Town determined that, because of the complex nature of the groundwater-surface water systems and their interactions with the plume, a modern model should be constructed to help select among remediation options.

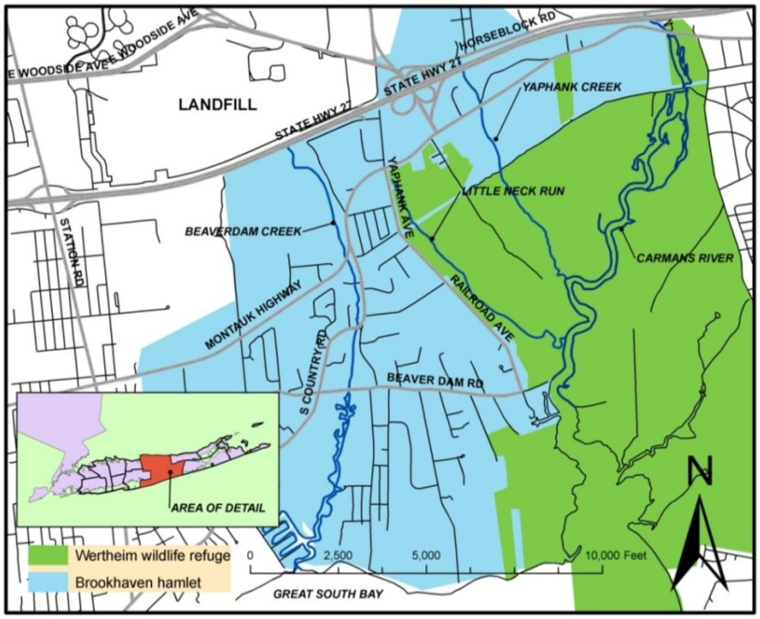


Figure 1: Town of Brookhaven landfill site and the surrounding area

## The Wexler model

The 1980s USGS model was a 2-dimesional, steady-state groundwater flow and contaminant transport model of the Upper Glacial aquifer. The model was calibrated by comparing the simulated results with the water table head observations made in September 1982, presented in the form of contours of equipotential lines drawn across the model domain (Figure 2). In addition, a schematic diagram representing the simulated, and the effects of several remedial designs on future chloride concentrations were modeled (Wexler, 1988b).

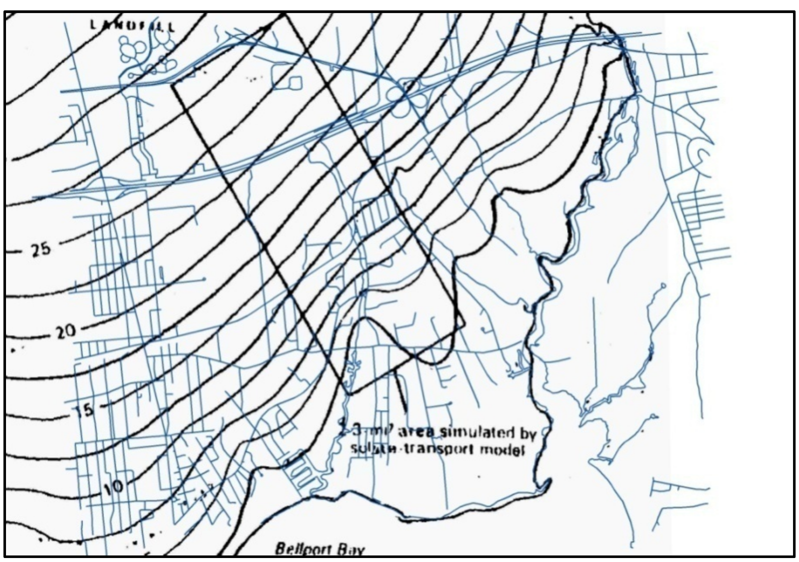


Figure 2: Equipotential line contours as simulated by Wexler and Maus in 1988

## Objective

Since Wexler's model in 1988, there has been substantial improvement in the computer computational power and speed. With advances in software programming and the graphical user interfaces (GUIs) it has become much easier to input data, modify parameters, make model runs, and visualize the model results. Also, periodic water quality and water table head monitoring since 1982 has resulted in the accumulation of a large database for landfill region hydrogeology and the leachate plume. Our long term objective is thus to develop a 3-dimensional, transient-state groundwater flow and contaminant transport simulation model for the Brookhaven landfill site that accurately captures the dynamics between groundwater and key area streams.

Contaminant transport is largely dependent on the groundwater flow patterns (Fetter, 2001). A significant step towards achieving our objective would be to simulate groundwater flow patterns at one particular time. Thus, we decided to create a model version that would reasonably match the conditions used by Wexler to calibrate the USGS model, and we could use the USGS model as a comparison as to how well we succeeded in our task.

## Methodology

Our simulation uses Visual MODFLOW version 4.2 (Waterloo Hydrogeologic, Inc). This software, similar to the USGS model, can generate maps of water table head contours. We compared outputs of equipotential lines to the Wexler figures (Wexler and Maus, 1988). MODFLOW also generate particle trackings – estimates of paths followed by parcels of water - and we compared these outputs to recent plume depictions (Dvirka and Bartilucci, 2010), assuming advection of the plume is dominated by groundwater flow patterns. MODFLOW also generates a variety of diagnostic outputs. We used the September 1982 data set as an initial test. We then adjusted model parameters, and observed changes in these outputs. We selected a set of adjusted parameters that had the least deviation from our comparators (our comparisons to the USGS model is subjective, and the comparison to 1982 head data is subjective but not quantitative). These adjusted parameters will serve as our initial "calibrated" model (i.e., a model matched to a particular set of real world data).

## Model design

In order to run a model package like MODFLOW, base data must be input. Here we describe the process of model construction: defining the boundaries of the model domain, the hydrological inputs, and the geologic units and their properties. This is a preliminary version of the model; we will show our initial values, and explain how these will be refined in the near future.

### *Model domain*

We have begun our model using a smaller model domain than Wexler used. We chose to bind the model at the northwest along Woodside Avenue. We have a set of wells immediately southeast of the road, and these wells give us data that define head at this boundary. Other domain edges were defined by the Carmans River (we assume no groundwater in our system flows beneath the river), and the mouth of Beaverdam Creek at Bellport Bay. These define a nearly rectangular model domain (Figure 3).

*Hydrology*

All groundwater input is derived from precipitation. Wexler used a precipitation value of 47.4 inches. We used 48 inches per year. We assumed about half reaches the water table (24 inches) (Buxton and Smolensky, 1999); we have ignored surface run-off.

*Constant head boundaries*

Constant head boundary (CHB) provides a continuous flux of groundwater flow through the model domain at a fixed, pre-determined rate. The value of head at this boundary is not affected by model simulation (thus, constant head boundary). We set CHBs at the domain boundaries (Table 1).

The CHB N-N' is based on head data from a well (MW 5-S) that has been monitored since 1992. We used a general approximation of its mean head for our initial value of the CHB. The CHB value at point O will be fixed; we are using 10' msl based on the approximate output of the USGS model. The CHB for point N" is also fixed, and is based on the height of the weir on the Carmans River. We used 0' msl for sea level. (Figure 3)

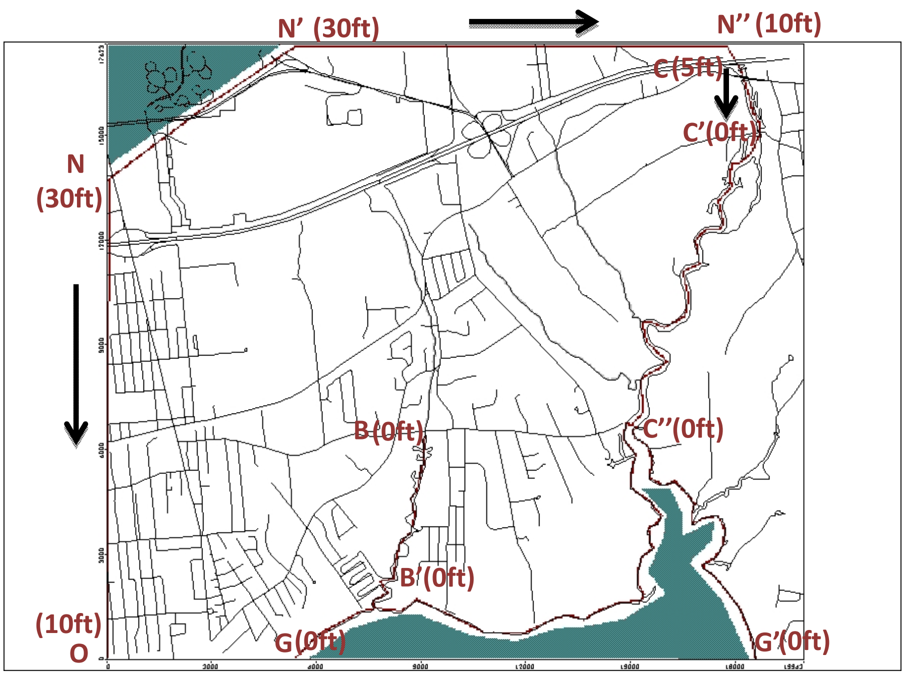


Figure 3: Constant head boundaries for the model domain (head values are shown in the brackets; blue regions indicate inactive zones; arrows show the direction of linear gradient)

| CHB | Description | Start Point Head (ft) | End Point Head (ft) |
|---|---|---|---|
| N-N' | upgradient of the landfill; parallel to the Country Route 99 | 30 | 30 |
| N-O | western edge of the model domain | 30 | 10 |
| N'-N" | northern edge of the model domain | 30 | 10 |
| N"-C | weir at the Carmans River, north of Sunrise Highway | 10 | 10 |
| C-C' | on the Carmans River, between Sunrise Hwy and railroad | 5 | 0 |
| C'-C" | tidal reaches of the Carmans River | 0 | 0 |
| G-C"-G' | land-ocean interface along the Great South Bay | 0 | 0 |
| B-B' | tidal reaches of the Beaverdam Creek | 0 | 0 |

Table 1: Constant head boundaries

*Subsurface geology*

The USGS model treated the entire Upper Glacial aquifer as a single layer, and did not address flow in any other hydrogeologic layer in the model. We have subdivided the Upper Glacial aquifer into 3 layers, and have added two other units: the Gardiners Clay, and the upper section of the Magothy aquifer.

The Upper Glacial aquifer is the unconfined aquifer in the region with total saturated thickness of about 100 feet. It is typically described as being composed of fine to coarse sand and gravel (Buxton and Modica, 1992). There are good reasons to believe that the Upper Glacial aquifer is not uniform vertically near the landfill (De Laguna, 1963; Dvirka and Bartilucci, 1994, 1998). For this reason and to increase the discrimination power of the model in the Upper Glacial aquifer, we divided the Upper Glacial aquifer into three parts. The top Upper Glacial aquifer unit (layer 1) includes the ground surface (this allows the water table to rise and fall). The topographic elevation data were derived from the Suffolk County 15 foot grid digital elevation model (DEM). The gird data was converted into Surfer grid (.grd) format using Globalmapper v. 9; these data can be imported into MODLFOW. The maximum elevation of the ground surface is 300 ft msl (on the landfill), and the minimum is at the shoreline (0 ft msl).

One issue we need to address is the modern DEM maps the modern landfill. Its extent and height are much greater that it was in 1982. However, because we assume that the leaky landfill transmitted all recharge to the subsurface, we do not need to address the elevation issue for preliminary model runs.

The Gardiners clay sits at the base of the Upper Glacial aquifer. For our initial model framework, we have assumed the clay was present continuously across the site, and increased in thickness west to east from 5 feet to 15 feet. The top of the Gardiners clay was set at -100 feet msl at the west CHB. It is likely this layer will be modified as we process more information from well logs and other sources about the site. Dvirka and Bartilucci (1994), for instance, argue that the clay lens is actually only silty sand underneath the landfill site. Tonjes (1999), however, provides long-term data showing sustained head differences between the Upper Glacial aquifer and Magothy aquifers at the landfill, which suggests that the Magothy is a confined aquifer. Exactly what is confining it needs to be further refined.

Underneath the Gardiners clay is the Magothy aquifer. The Magothy aquifer is generally said to consist of a mixture of fine to coarse sand, silt and clay (Buxton and Modica, 1992). We restricted our interest in the Magothy aquifer to the top 200 feet. We set the base of the Gardiners clay at -105 feet msl at the west CHB. There is very little local data regarding Magothy.

Based on the overall geologic arrangement of the Long Island aquifers depicted by McClymonds and Franke (1972), the aquifers in the model were tilted towards the east at specified angles. Again, as we further develop well log information, this may be modified.

Figure 4 displays a general vertical profile of the aquifers and the five layers.

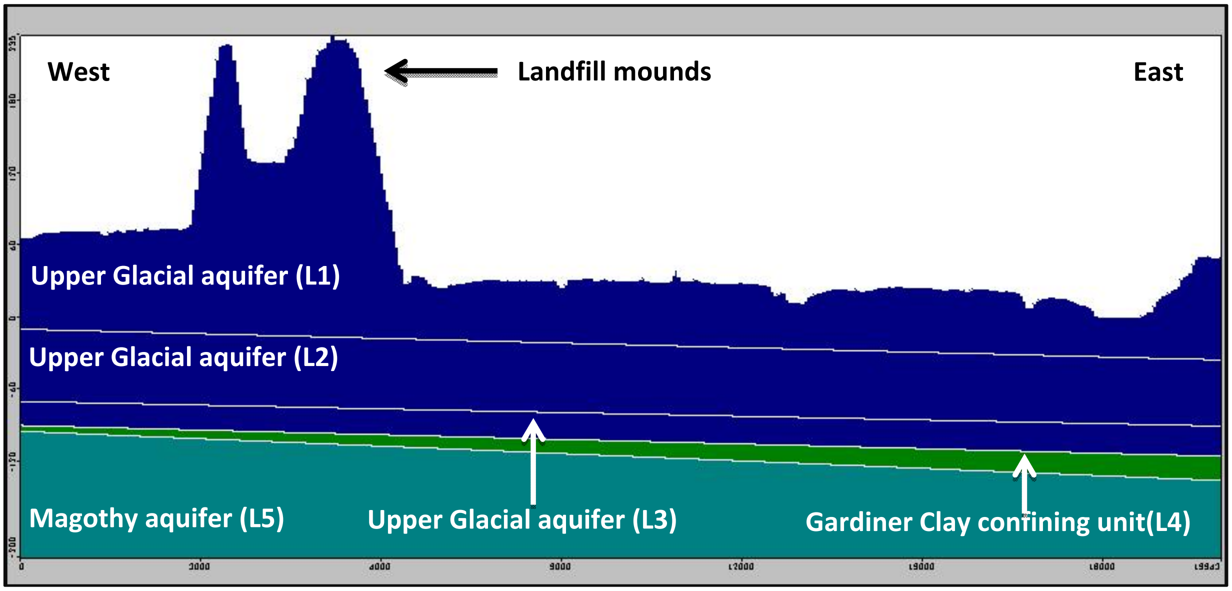


Figure 4: Vertical profile of the aquifer layers in the model domain (vertical profile at a cross section drawn across the landfill site)

*Aquifer properties*

MODFLOW requires that aquifer properties be specified. These include hydraulic conductivity ($K_x$, $K_y$, $K_z$; we assumed $K_x = K_y = 10\ K_z$), dispersivity (longitudinal αH, transverse αL and vertical αV, assuming αH = 5 αL = 10 α L), specific yield ($S_y$), total porosity (n), effective porosity ($n_e$, set 0.3 for all layers), and a molecular diffusion coefficient (set to $1x\ 10^{-7}$ $ft^2/d$) (Gurgehian et al. 1981). Specific storage is only determined for the first model layer (it was set to $1x\ 10^{-4}$). Table 2 summarizes the aquifer properties that were used as inputs for the model.

| Units | Layer | Kx (ft/d) | Sy[3] | n[3] | αH (ft) |
|---|---|---|---|---|---|
| Upper Glacial | L1 | 270[1] | 0.25 | 0.3 | 70[4] |
| Upper Glacial | L2 | 250[1] | 0.25 | 0.3 | 70[4] |
| Upper Glacial | L3 | 200[1] | 0.25 | 0.3 | 70[4] |
| Gardiners clay | L4 | 0.04[2] | 0.02 | 0.3 | 20[5] |
| Magothy | L5 | 50[2] | 0.2 | 0.3 | 20[5] |

[1] Wexler reports, 1988; [2] Buxton and Modica, 1992; [3] Fetter, 2001; [4] Pinder, 1973; [5] professional judgment

Table 2: Aquifer properties inputs for the model

*Streams*

Streams of Long Island are gaining streams, in that they gain flow over stretches because the bottom of the stream is lower in elevation that the water table. Such streams can be simulated in MODFLOW by “drains”, which withdraw from the aquifer.

The USGS model included 9 streams. We have included only three, Yaphank Creek, Little Neck Run, and Beaverdam Creek. Yaphank Creek and Little Neck Run are tributaries of the Carmans River, and are approximately 4,000 ft long. We assumed flow begins in Yaphank Creek at Montauk Highway. We have modeled the stream as one continuous feature. We have assumed that flow in Little Neck Run begins at the LIRR train tracks (there is standing water north of the tracks, but there is no apparent flow there). We divided Little Neck Run into two equal length reaches. Both streams run nearly parallel to the regional groundwater flow (Figure 5, Table 3).

Beaverdam Creek has intermittent water in what seems to be a streambed north of Sunrise Highway, but contiguous flow appears to always start south of Sunrise Highway. It flows for approximately 8,000 feet across the regional groundwater flow direction, and becomes tidal at Beaverdam Rd. We divided Beaverdam Creek into four reaches (Figure 5, Table 3).

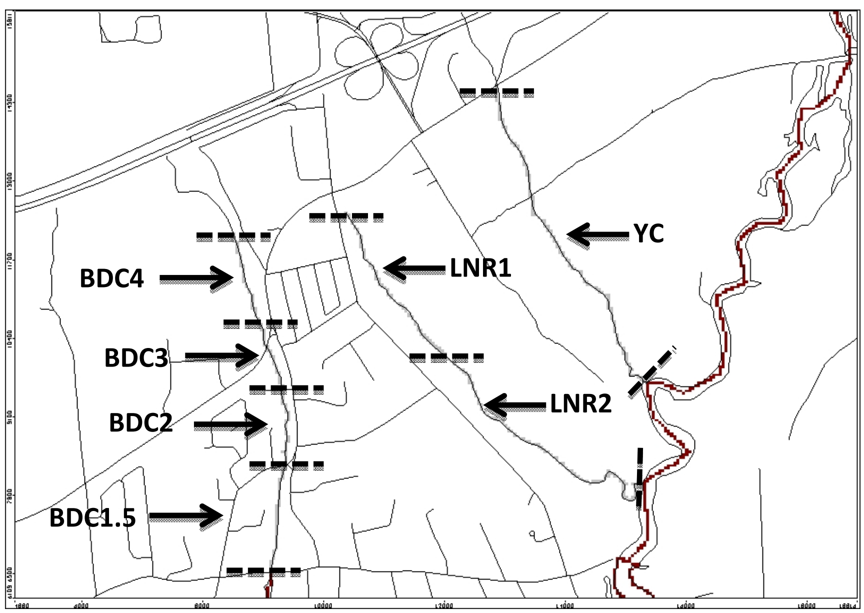


Figure 5: drains in the model domain (dashed lines show the limits of the drain)

| Drains | Abbreviation | Surveyed Elevation (ft msl) | | Streambed thickness (ft) |
|---|---|---|---|---|
| | | Starting Point | End Point | |
| Beaverdam Creek -4 | BDC4 | 15 | 10 | 2 |
| Beaverdam Creek -3 | BDC3 | 10 | 8 | 2 |
| Beaverdam Creek -2 | BDC2 | 8 | 5 | 2 |
| Beaverdam Creek -1.5 | BDC1.5 | 5 | 0.5 | 2 |
| Little Neck Run-1 | LNR1 | 8* | 3* | 2 |
| Little Neck Run-2 | LNR2 | 3 | 0 | 2 |
| Yaphank Creek | YC | 10* | 1* | |

* estimated from Google Earth

Table 3: Properties of the streams used as drain inputs for the model

**Initial model run and calibration**

Using these input data, an initial model run was made. The results were compared to the USGS simulation results and the base 1982 head observations. The primary tool was residuals derived by subtracting our simulated heads from the observation values.

Calibration (minimization of the differences among the MODFLOW simulation, the USGS simulation, and the observed heads) was accomplished by altering MODFLOW parameter values for subsequent model iterations. We modified one value per iteration. MODFLOW offers calibration tools such as plots of observed vs. calculated values, residual distribution curves, development of residual 95% confidence intervals, and maps of residual "bubbles".

Modified parameter values (Table 4) resulted in reasonable agreement between observed and simulated heads (Figures 6-9). Increasing the hydraulic conductivity ($K_x = K_y$) in the Upper Glacial aquifer essentially allows more water to be transmitted through the aquifer. However, using a constant conductivity across the Upper Glacial aquifer appears to violate some assumptions regarding the comparison of the aquifer. The thickness of the streambed defines the conductance of the drains – the resistance to flow between groundwater and surface water. Decreasing the streambed thickness transmitted more water from the aquifer to the streams. Overall, our alterations increased flow through the system.

| Parameter | Initial value | Final value |
|---|---|---|
| Streambed thickness (ft) for all layers | 2 | 0.5 |
| $K_h$ (ft/d) Layer 2 | 250 | 270 |
| $K_h$ (ft/d) Layer 3 | 200 | 250 |

Table 4: Adjusted parameter values

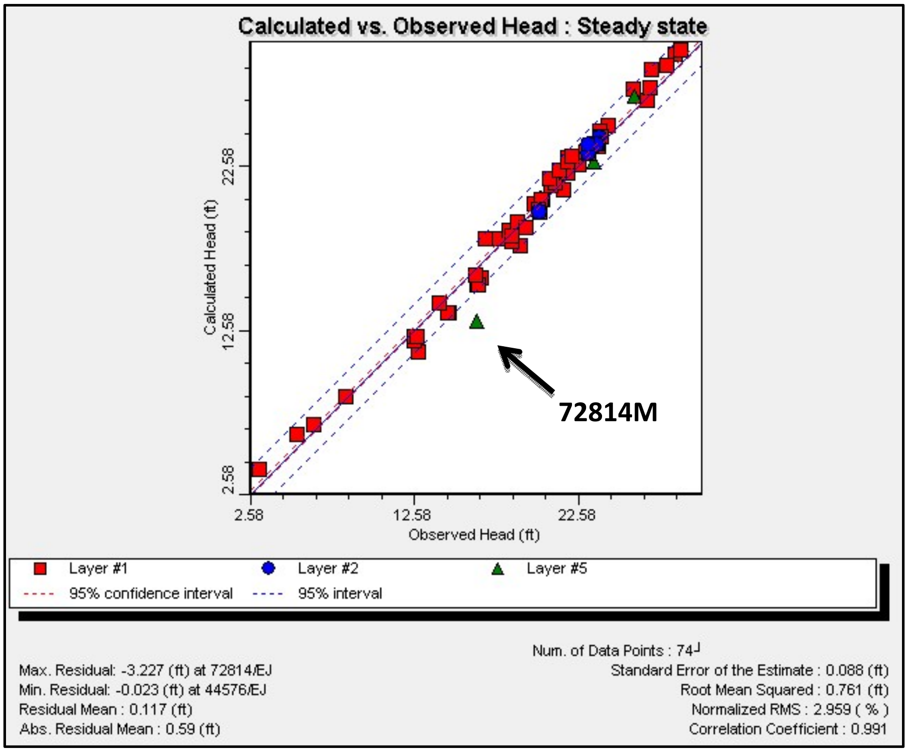


Figure 6: Distribution of residuals (95% confidence interval)

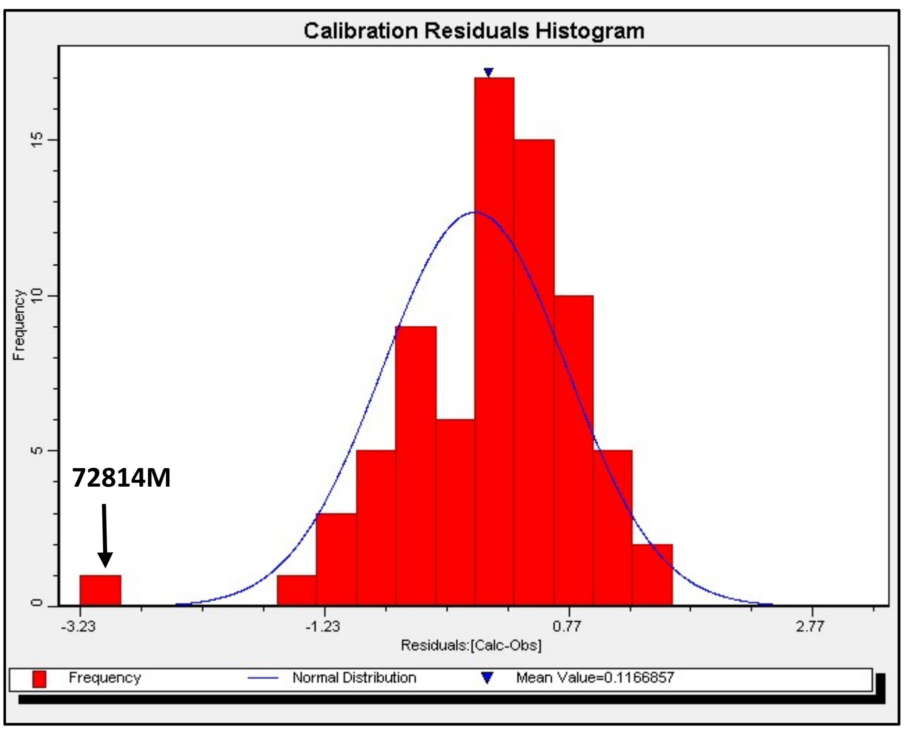


Figure 7: Distribution of residual frequencies

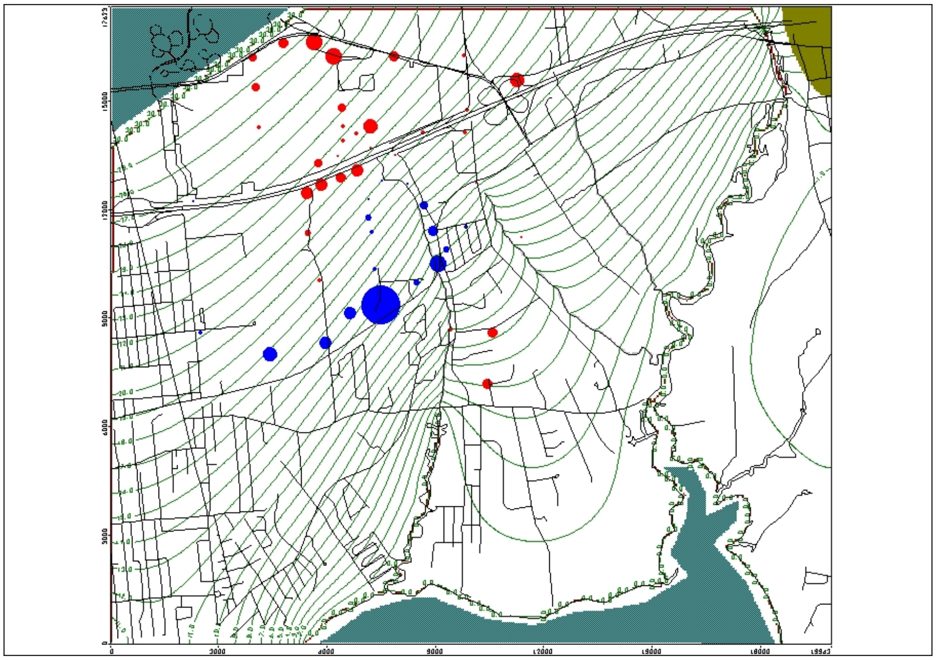

Figure 8: Residuals as “bubbles” (red = simulation > observation; blue = simulation < observation)

The average residual in the MODFLOW simulation was 0.12 feet; in the USGS model it was 0.59 feet. The maximum residual for Upper Glacial aquifer in the MODFLOW was -1.48 feet (a Magothy aquifer residual was 3.23 feet); for the USGS model the maximum residual was 2.6 ft (Wexler did not simulate Magothy aquifer flows). The distribution of the residuals shows some geographical bias (simulated heads are too great on the landfill site and in the far downgradient, but too low between).

An explicit comparison of the equipotential head contours of the USGS model and our model is shown in Figure 9. We believe there is good agreement here.

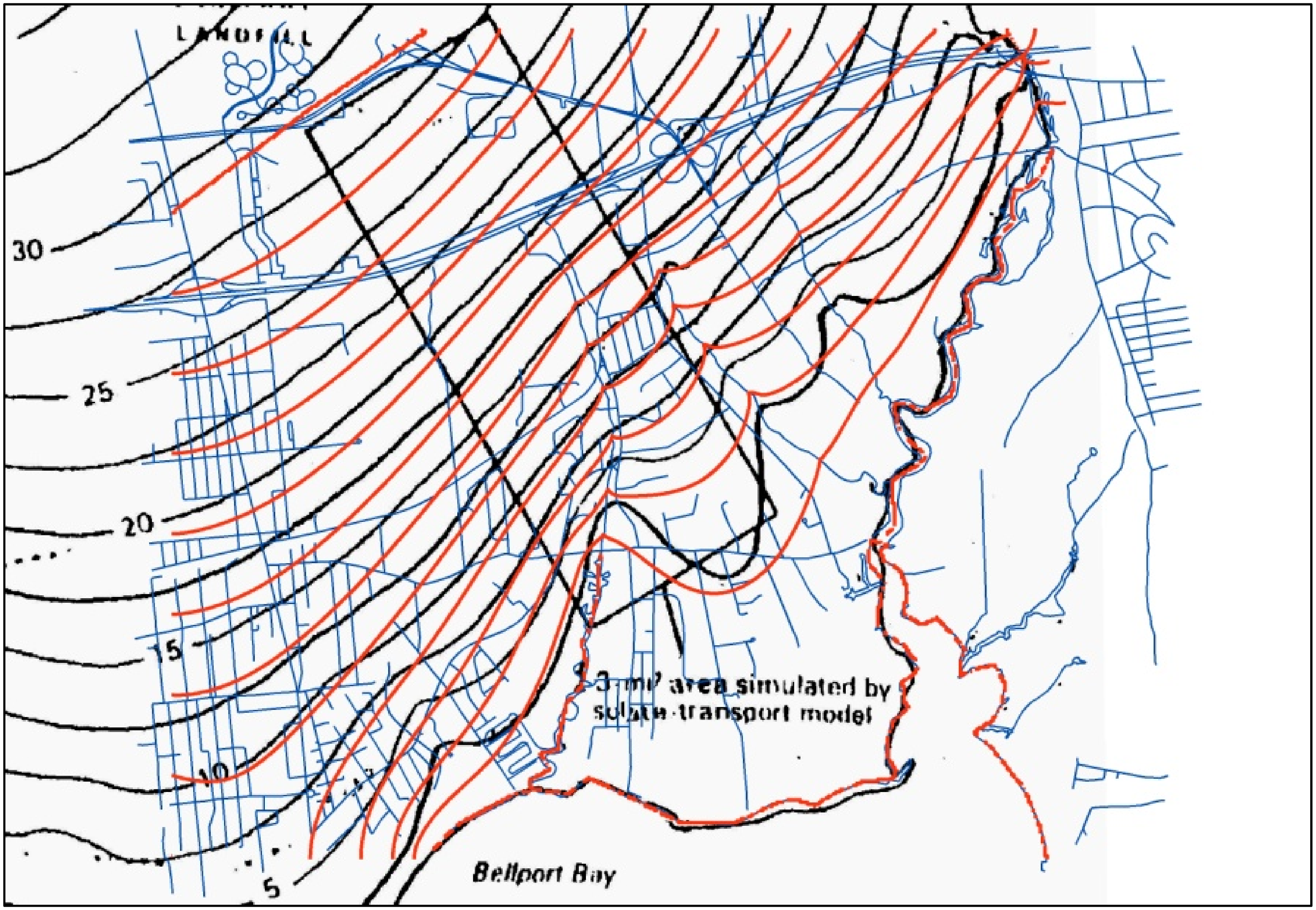


Figure 9: USGS and MODFLOW water table contours (USGS = black; MOFLOW = red)

## Comparison to more recent information

In response to the SCDHS report (2008), the Town commenced a more active groundwater and surface water monitoring program in Brookhaven hamlet. Dvirka and Bartilucci (2010) summarizes that effort. It is clear that much of the plume discharge into Beaverdam Creek, and some discharges into Yaphank Creek. Particle tracking from the landfill site (layer 1 shown in Figure 10) generally support s this depiction. However, some of the subtleties interpreted from the monitoring data are not yet reflected in the model; for instance, it appears that some portions of the plume, at some time periods (perhaps low stream flows) passes under the Beaverdam Creek initially, but wraps back into the creek further south. Diffuse, diluted landfill contamination is also generally present in the hamlet north of Beaverdam Rd., although the model suggests it should all discharge to Beaverdam Creek or Yaphank Creek further north. However, flow vectors suggest that there is discharge to the Magothy aquifer north of the landfill, and discharge from the Magothy aquifer downgradient of the creek, as hypothesized by Tonjes (1999), based on water quality data.

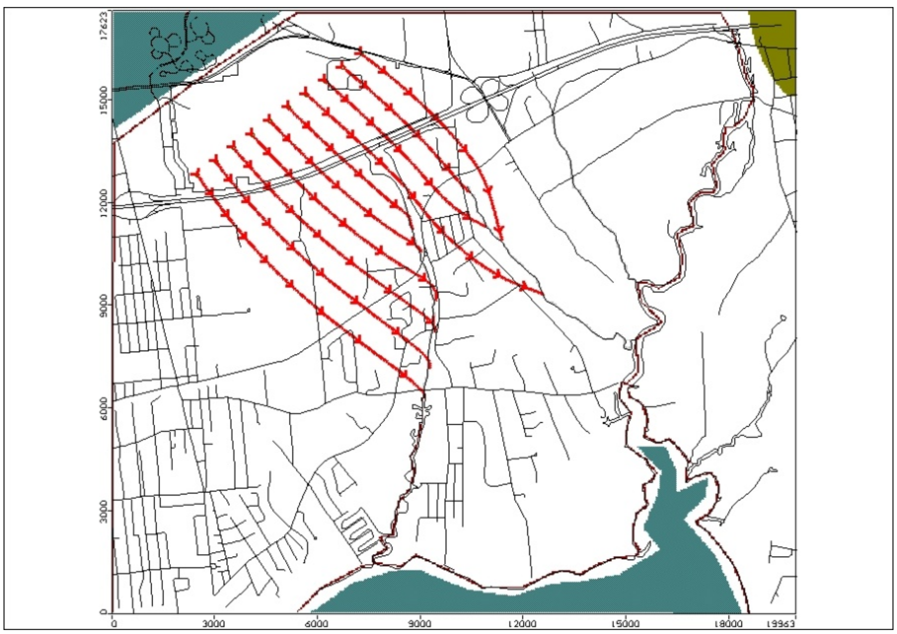

Figure 10: Particle tracking, layer 1

The simulated water table across the model domain is shown in Figure 11. This map is in close agreement with a map drawn by Dvirka and Bartilucci (2010), based on an expanded monitoring well network.

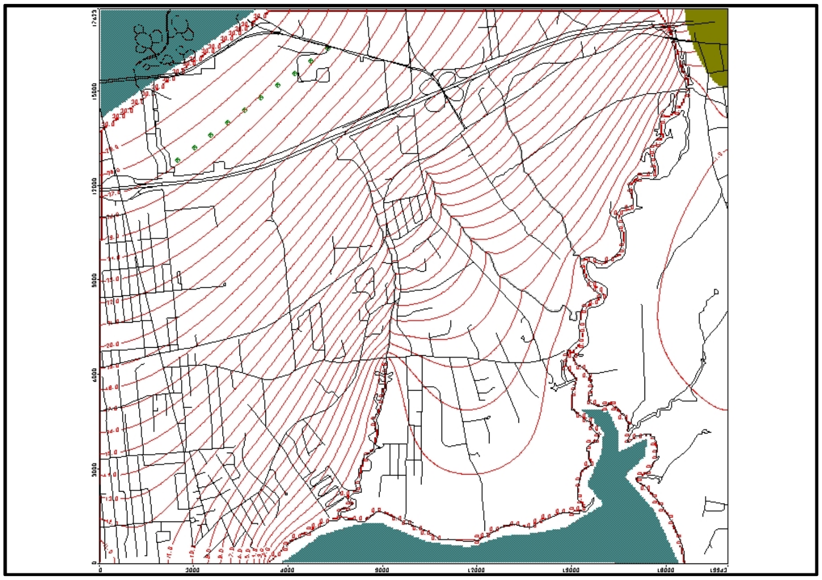

Figure 11: Water table simulation

**Issues to be resolved**

We are continuing to collect geological and hydrogeological information for the study area, and this new information will need to be incorporated into and used to modify the model framework.

The current discretization of the model needs to be modified. All cells (including those representing streams) are at least 50 ft wide; this makes the streams much too large (the physical streams tend to be five ft or less wide).

We will seek for a calibration approach that retains differences in hydraulic conductivity among layers of the Upper Glacial. Altering key stream components will require extensive recalibration of the model, in any case. Modifications to CHB values may also have substantial effects on model output.

We also wish to compare the 1982 calibration of the model to other good head data sets. We have extensive head data from the late 1980s, 1996-2000, and from recent work. Ultimately, we would like to have a general calibration for static conditions of various kinds, and then seek to exercise the model under dynamic conditions, especially changes in recharge.

**Conclusion**

We have shown that there exists sufficient data to create a MODLFOW model framework for the area near the Town of Brookhaven landfill. The MODFLOW model was calibrated to 1982 head data, and in many ways appeared to be a better fit to the field data than a USGS model created in the mid-1980s. Directions to further improve and test the model have been identified.

## Acknowledgements

This work has been funded by the Town of Brookhaven Department of Waste Management. We thank Ed Hubbard, Chief Deputy Commissioner, for his support. Many thanks to Gil Henson and Paul Misut for their continued guidance. Special thanks to Dan Johnson, Anthony Caniano, Chris Kiernan and Russell Wetjen for technical assistance.

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