A PARTICLE TRACKING STUDY OF THE PECONIC RIVER WATERSHED, LONG ISLAND, NY.

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Introduction

The Peconic River watershed is the single largest watershed within the Central Pine Barrens on Long Island. The Peconic River watershed covers about 100 km^2. Most of the watershed is protected under the NYS Wild, Scenic, and Recreactional River System Act. Hydrologically, the river forms an active interface between surface water and groundwater. The river influences the direction of subsurface flow. One of the goals of this paper is to delineate recharge zones within the watershed. This is important in differentiating between areas drained by the river and those recharging the deeper aquifers. It is difficult to delineate recharge zones based on a simple analytical analysis, therefore, a numerical technique was used. Our research strategy was to first simulate natural groundwater flow, followed by a particle tracking analysis, which allows one to delineate recharge zones.

Groundwater flow system

The Long Island hydrologic system has been described in many publications, including Krulikas (1986), Buxton and others (1991) and Buxton and Modica (1992). The Peconic River watershed is located in the eastern part of Long Island. The groundwater system in Eastern Long Island consist of a layered sequence of deposits that form three aquifers and two confining units (fig 1). The system is underlain by crystalline bedrock that forms an impermeable boundary. All layers dip gently to the south and east. Overlying the bedrock are, in acsending order: the Lloyd aquifer, the Raritarian confining unit, the Magothy aquifer, the Gardiners Clay confining unit and the Upper Glacial aquifer. The first three layers are of Cretaceous age, the latter deposits are of Pleistocene age.

The Lloyd aquifer consists of sand and gravel interbeds, with occasional lenses of clay and silt. The Lloyd's beds are about parallel to the bedrock surface below. The

thickness of the Lloyd aquifer increases from 200 feet in the north to over 500 feet in the south. The Raritarian confinig unit although composed mainly of clay and silt, does contain some sand and gravel beds and lenses. However, the hydraulic conductivity is low, and it confines the water in the Lloyd aquifer. The thickness of the Raritarian unit ranges from 100 feet in the north to 300 feet in the south.

The Magothy aquifer consists of highly permeable quartzose sand and gravel deposits with interbeds of clay and silt. Unlike the upper surfaces of the bedrock and the Lloyd and Raritarian deposits, the highly eroded upper surface of the Magothy aquifer does not exhibit any distinctive tilt to the southeast. Because the upper surface is so irregular, the thickness of the Magothy varies, but generally it increases to the south. The Magothy was eroded during the time period between the end of Cretaceous and the Pleistocene.
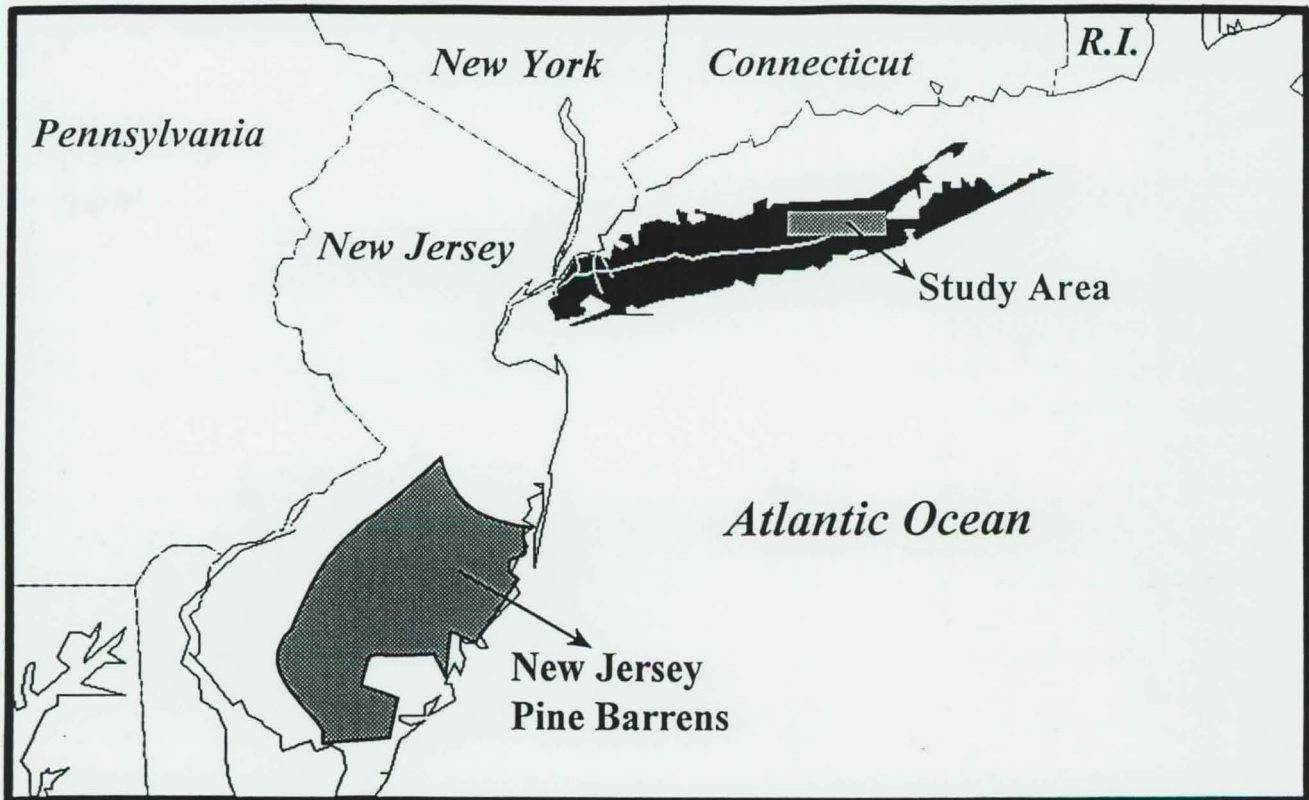
Fig.1. Localization of study area..

The Gardiners Clay is a shallow marine deposit of late Pleistocene age. The unit is typically a clay but contains some beds and lenses of sand and silt. It's overall hydraulic conductivity is low, making it a confining layer for the Magothy aquifer. The Gardiners Clay is found along the south shore. The thickness of unit increases southward from tens to 100 feet.

The Upper Glacial aquifer consists of morainal deposits to the north and outwash to the south. Outwash consists of quartzose sand, fine to very coarse, and gravel, pebble to boulder sized. These highly permeable, stratified sand and gravel deposits filled in the valleys eroded in the surface of the Magothy aquifer. The thickness of Upper Glacial aquifer ranges up to 170 feet.

The fresh groundwater system is bounded on the top by the water table, on the bottom by impermeable bedrock and on the sides by an interface with saline groundwater. The only source of natural recharge to the Long Island groundwater system is precipitation. Much of the water that enters the flow system moves laterally through the Upper Glacial aquifer and discharges to streams or to the ocean bottom. Some groundwater flows downward into the deeper aquifers, moves laterally toward the shore and either returns to the Upper Glacial aquifer and discharges at the shore or continues offshore, where it mixes with saline groundwater.

Numerical model

The three dimensional finite difference computer program developed by McDonald and Harbough (1988) was used to simulate groundwater flow. The model has two layers that represent the Upper Glacial aquifer and the Magothy aquifer. The Gardiners Clay confining unit is simulated by leakance between the two aquifers. The Raritarian confining unit and the Lloyd aquifer are not simulated and the bottom of Magothy is a no flow boundary. That is because only very small amount of groundwater enters the Lloyd aquifer (Buxton and Modica, 1992) and for our study this amount is neglible. The model is solved for steady state conditions. The finite difference grid (fig.2) has 34 rows and 46 columns in each layer, and each block is 1968 by 1968 feet (600 by 600 m). The model represents the Upper Glacial aquifer as unconfined with specified recharge. The Magothy aquifer is simulated as a confined layer. Thickness of aquifers vary from block to block according to geological settings. The Peconic river is represented as river blocks. Conductance of the river bed controls the amount of flow between the river and the Upper Glacial aquifer which is determined by difference between the water table elevation and river water level. Boundary conditions consist of constant head blocks around model domain. The Long Island Sound area is simulated by inactive blocks. Similarly, the area to the south of the southern groundwater divide is inactive. Several wells are located within the model and rates of pumping are specified.

Several calibration runs were conducted to adjust hydraulic parameters to data from USGS measurements of water level in the wells and discharge of the Peconic river at

gauge at Riverhead. This simulation was based on an earlier numerical model by S.Stasko and M.Schoonen (1993). The results of that simulation were used as an input data. The interpolation of parameters was done to change grid spacing from 16 by 20 blocks (Stasko, Schoonen, 1993) to 34 by 46 blocks (this paper). This operation allows to digitize more properly the Peconic river and to calibrate hydrologic properties.
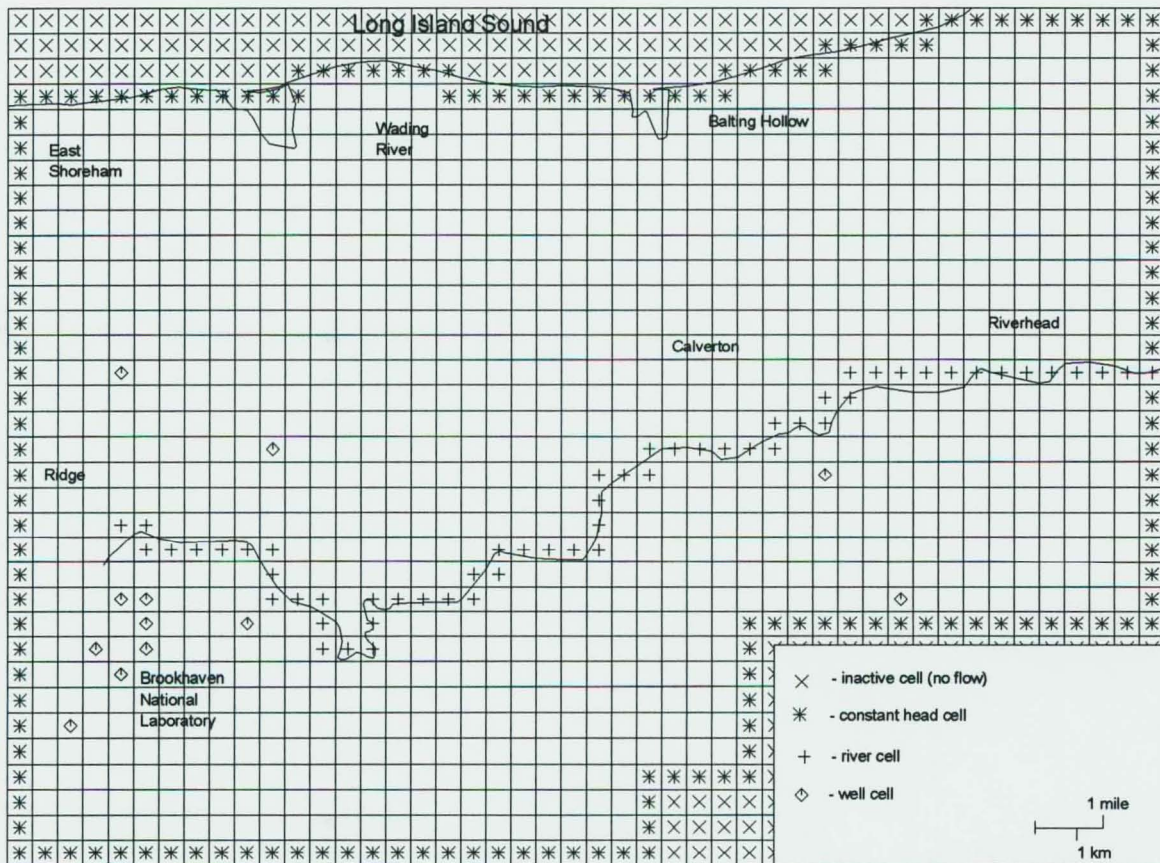

Fig. 2. Discretization of the model area and boundary conditions.

Groundwater flow patterns

Results for the Upper Glacial aquifer (fig 3) shows three main direction of groundwater flow. These are: 1) to the north toward Long Island Sound; 2) to the south toward the Atlantic Ocean; and 3) to the east toward the Peconic Bay. The influence of the Peconic River is very distinct. Between the two groundwater divides most of the water flows into the river. The distribution of the piezometric surface in the Magothy aquifer (fig 4) has three directions of flow, similar to the upper layer. However there are
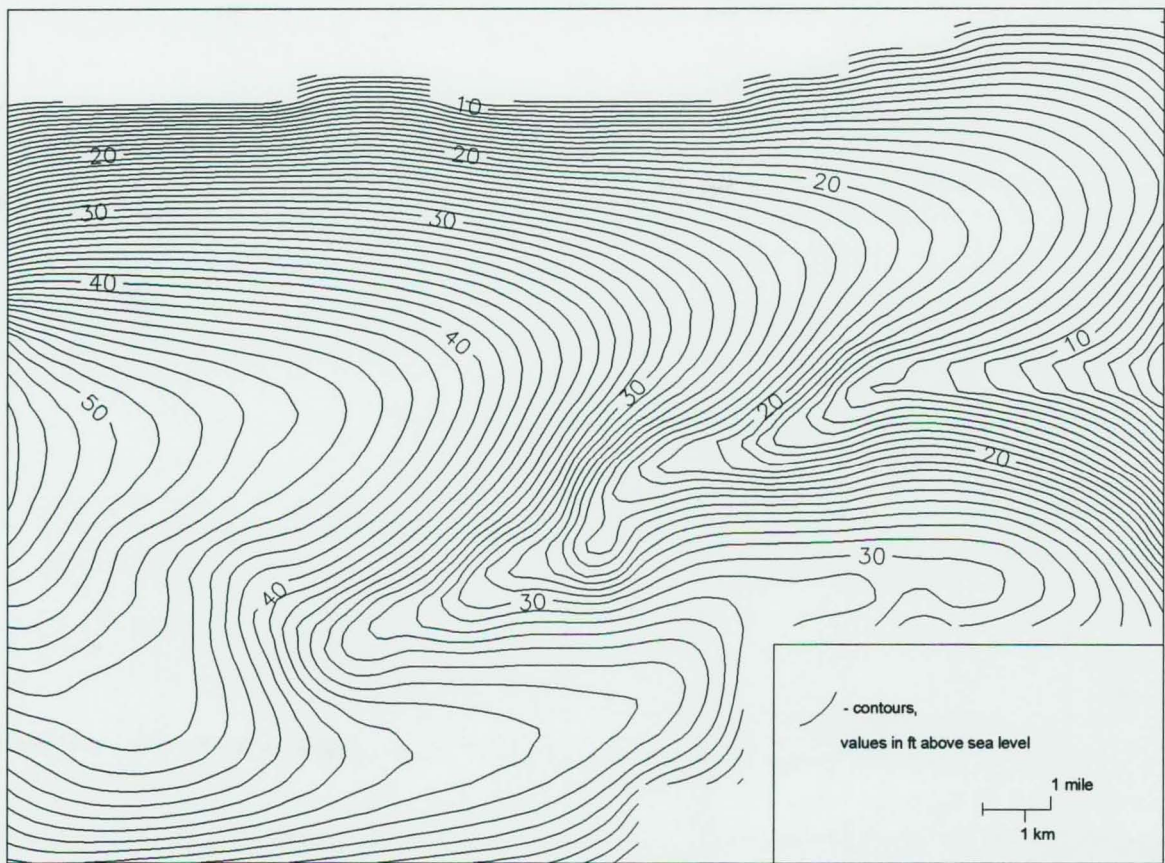
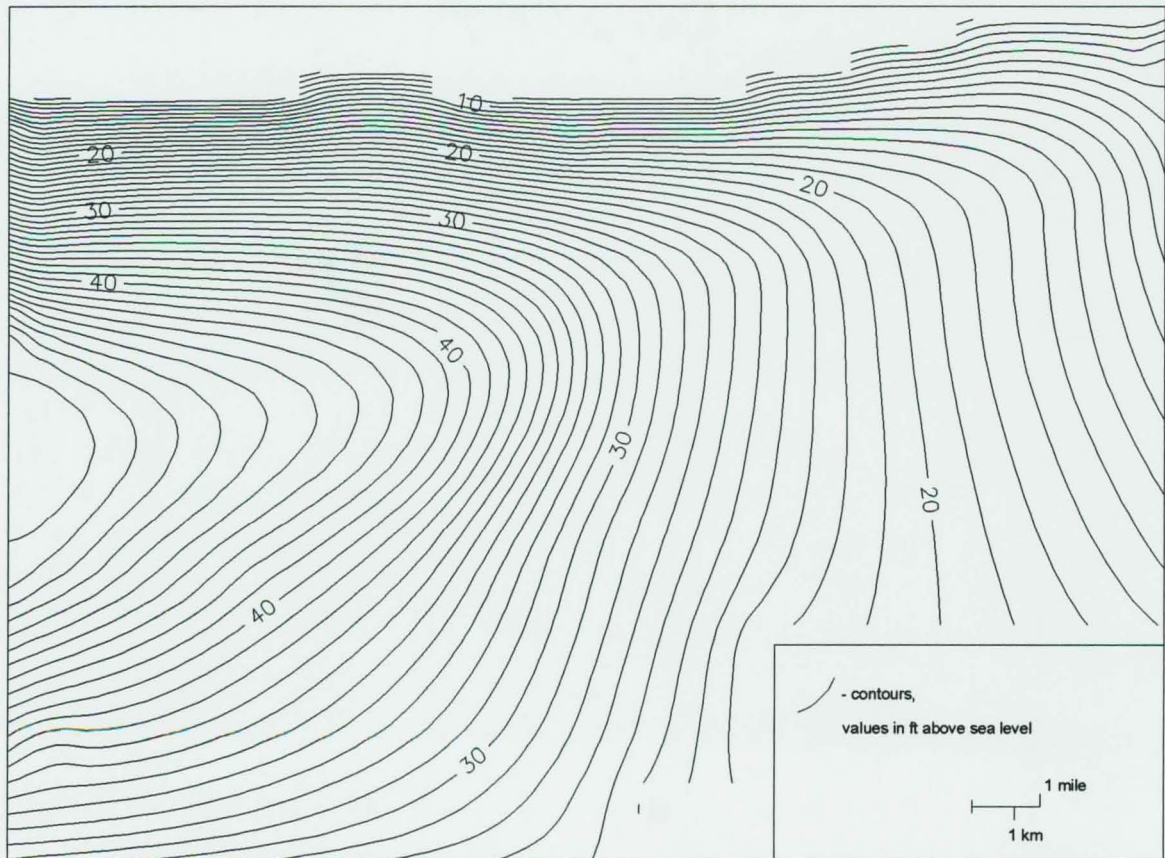Fig.3. Water table map of the Upper Glacial aquifer.

Fig.4.Piezometric surface of the Magothy aquifer.

no irregularities caused by the river. In the northern part of the study area values of heads for both aquifers are similar, because there is no hydraulic separation between them. In the southern part of the model domain, the occurence of the Gardiners Clay unit causes a physical boundary between the Upper Glacial and the Magothy.

It is important to note that the area modelled in this study represents hydrological conditions that are unique for Long Island. Whereas on the rest of Long Island there is only one groundwater divide and flow is either toward the north or to the south, the Peconic River watershed has a eastward flow component. This study and earlier work by Stasko and Schoonen (1993) resolves for the first time the details of the hydrology in this part of Eastern Long Island. The results of a larger scale USGS model (Buxton and others 1991) are consistent with the results presented here but offer less detail.

Recharge areas.

A computer program developed by Pollock (1989) was used to compute flow lines in a three-dimensional finite difference groundwater model using a particle tracking method. Particle tracking simulation provides a powerful tool to delineate recharge areas by following the pathway of a particle from the source (water table) to its point of discharge. The particle tracking method is based on the assumption that each directional velocity component varies linearly within a grid block in its own coordinate direction (Pollock, 1988). Particles are tracked through a flow field explicitly by computing velocity components at a particle's current position and moving the particle to a new location that is determined by multiplying those velocity components by a finite time step. By following the particle as it moves from block to block, this method can be used to trace the path of a particle through any multidimensional flow field generated from a block-centered finite difference flow model, such as the model used here.

An even spaced array of 16 particles (4 by 4) was placed in each model block at the top of the first layer, then the coordinates of pathlines for each particle were computed. Finally the analysis of starting and ending points of particles was conducted and recharge zones were defined.

The results of the particle tracking simulation show that there are four different types of flow paths in the model domain:

A: groundwater flowing in the Upper Glacial aquifer and discharging at or beyond the shores. These flow paths have either a northward direction (toward the Long Island Sound) or a southward direction (toward the Atlantic Ocean).

B: groundwater flowing in the Upper Glacial aquifer and discharging to the Peconic River. Within the watershed (i.e., between the two groundwater divides), nearly all water follows this flow path.

C: groundwater flowing in the Upper Glacial aquifer then entering the Magothy aquifer, moving upward and reentering the Upper Glacial aquifer, and finally discharging into the Peconic River. This component is very small.

D: groundwater flowing in the Upper Glacial aquifer then moving downward into the Magothy aquifer and discharging at the shore. These flow paths have three directions: a northward direction (toward the Long Island Sound), an eastward direction (toward the Peconic Bay) and a southward direction (toward the Atlantic Ocean).

Results of the particle tracking study and delineation of recharge zones (fig.5) agree with larger scale studies (Buxton and others, 1991), however, the influence of the Peconic river and local flow systems are better characterized. The recharge zone of the Peconic River calculated here is wider than the one defined by Krulikas (1986).
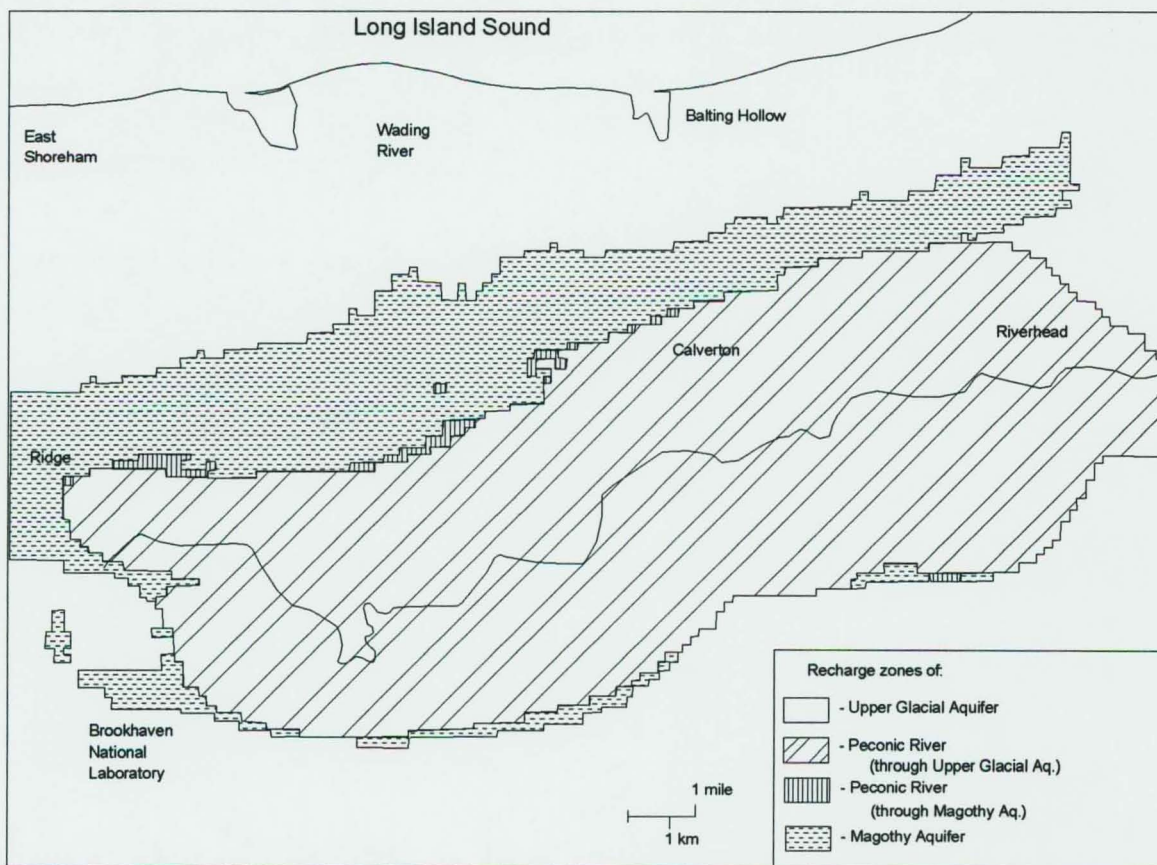

Fig.5. Delineation of recharge zones in the Peconic River watershed.

The recharge zone as defined by Krulikas (1986) is an estimate based on hydrological analysis but not on a hydrological model. The advantage of a numerical model is that it forces the results to be consistent with a large number of hydrological and hydrogeological data. The disadvantage of using a numerical model is that the delineation of recharge zones is based on rectangular grids. With the grid used in this model, the position of boundaries between recharge zones can only be delineated to within a zone of 200 meters. It should also be noted that the position of the calculated boundaries is dependent on the values of the hydrological parameters. Finally, variation in net recharge will shift the boundaries. What is presented here is based on average conditions between 1986 and 1990.

Summary

Numerical simulation of the hydrology of the Peconic River watershed is a very efficient tool to analyze groundwater flow and define recharge zones. The Peconic River drains a significant part of the Central Pine Barrens of Long Island. Most of the water in the Peconic River watershed is drained by the river. Directly along the two groundwater divides, water recharges the Magothy aquifer. North of the nothern groundwater divide, water flows toward the Long Island Sound. South of the southern groundwater divide, water flows toward the Atlantic Ocean.

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