Recharge and Head: Preliminary Findings Using a Long-Term Data Set

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Abstract

The validity of general perceptions or "truisms" about Long Island water table was tested using data from groundwater observation well in Suffolk County. A weak linear relationship was found between movement of the water table heads and cumulative differences of rainfall and available moisture. The response of water table height was found to correlate somewhat to deviations in monthly precipitation from two-year data trends. Annual patterns of water table heights did not conform to any consistent seasonal trend. Fluctuations in water table height suggested that water table extremes are not retained for long periods. It is difficult to generate absolute statement about a dynamic system affected by variable environmental factors.

Introduction

Precipitation is the source of recharge for fresh groundwater systems. Some precipitation is lost through evapotranspiration and runoff; the remaining portion replenishes the water table. So, changes in water table head levels are a function of recharge. Along with recharge, other factors such as hydraulic conductivity of the aquifer, vegetation cover, temperature, and hydraulic gradients also affect water table aquifer heads.

There is some general awareness of the state of the water table among people living on Long Island. Certain perceptions, along with generalizations from scientific studies, have achieved common currency and become "truisms". Four such truisms are:

1. When it rains a lot, the water table is high (and when it is dry, the water table is low).
2. The response of the water table to precipitation is quick.
3. The water table is higher in winter and lower in summer.
4. When the water table is at a high level it tends to stay high and when it is at a low it tends to stay low. In other words, the water table often retains its current level.

Here, we will try to show where these perceptions have sprung from, and, using a 20 year database from an observation well in Suffolk County, illustrate instances when these perceptions hold and when they fail.

Literature review

Some studies have directly addressed relationships between precipitation, temperature and other factors that influence groundwater levels. The following is a brief summary of some of the more notable, local work.

Leggette (1942) studied the correlation between precipitation and water table height. He calculated cumulative differences of precipitation from running averages of rainfall. These were then compared to an average monthly water level. A qualitative comparison found a good correspondence. Fetter (1976) noted a 2-year running average provided a better fit and concluded that the correlation demonstrates the rapid response of the water table to changes in recharge.

Miller and Fredrick (1969) investigated the potential for differences in precipitation during “winter” (October through March) and “summer” (April through September) seasons. Steenhuis et al. (1985) expanded on this preliminary work. Steenhuis determined that because evapotranspiration was negligible in winter, recharge must necessarily be much greater in winter months than in summer. In fact, he quantified that it as a 90:10 ratio. Fetter (1976) also reported seasonal fluctuations in the water table.

Franke and McClymonds (1971) developed water budgets for different sections of Long Island. They noted that wells in the glacial outwash show a marked water level response shortly after large storms.

Peterson (1987) showed that theoretical recharge varies across Long Island. One element of his calculation was differences in annual average precipitations for weather stations across Long Island. He used soil maps, land cover and temperature data from the weather stations to infer differential evapotranspiration rates. His work suggested there could be substantial differences in recharge for parts of Long Island.

Capone and Slater (1990) compared inter-annual rainfall totals to changes in water table heights and found that there is relatively close correspondence between peaks and valleys in precipitation and water table heights.

Tonjes and Wetjen (2003) compared water table heights from a number of wells in close proximity to each other, and noted that the changes in the water table heights over time varied.

Other information

Local flooding is often attributed to elevated water tables resulting from the recent storms. For example, flooding of properties along Lake Ronkonkoma was attributed to a long duration high stand of the aquifers (Suffolk County Lake Ronkonkoma Advisory Board 2007). Newsday (March 12, 2007) reported instances of water pooling in basements near Millers Pond. On the other hand, Town of Huntington Board had to order lawn-watering restrictions in a water district from May through September of 2002 because of low water table and lack of rain (The New York Times September 1, 2002).

FEMA (1997) has also recognized susceptibility of basements to high groundwater levels. In 2002, officials on Long Island proposed to build seawater desalinization plan to mitigate water shortages (The New York Times September 1, 2002). Suffolk County recently developed a risk profile and vulnerability assessment to mitigate the impacts of shallow groundwater flooding (Hazard Mitigation Plan, Suffolk County 2008).

Materials and methods

We tested the truisms, using some of the approaches outlined above, and data from a particular well in Suffolk County.

Well location

The observation well used in this study was S3529-2, installed by the US Geological Survey (USGS) in 1976, located at the northern edge of the Town of Brookhaven landfill facility (Figure 1). The water table heights were collected by USGS, Suffolk County Department of Health Services and researchers working for the Town. We consolidated the data into single monthly values, for the period 1987-2007. When there was more than one datum in a month, the USGS measurement was used. For comparisons of these head values to other measures, often transformations were used. Commonly, residuals from the 20-year monthly mean (25.80 feet) were used, often translated to inches, so that units were comparable to other measures. For display purposes, further transformations (e.g. dividing the residuals by constant values) were sometimes made so that comparisons could be made on the same scale.

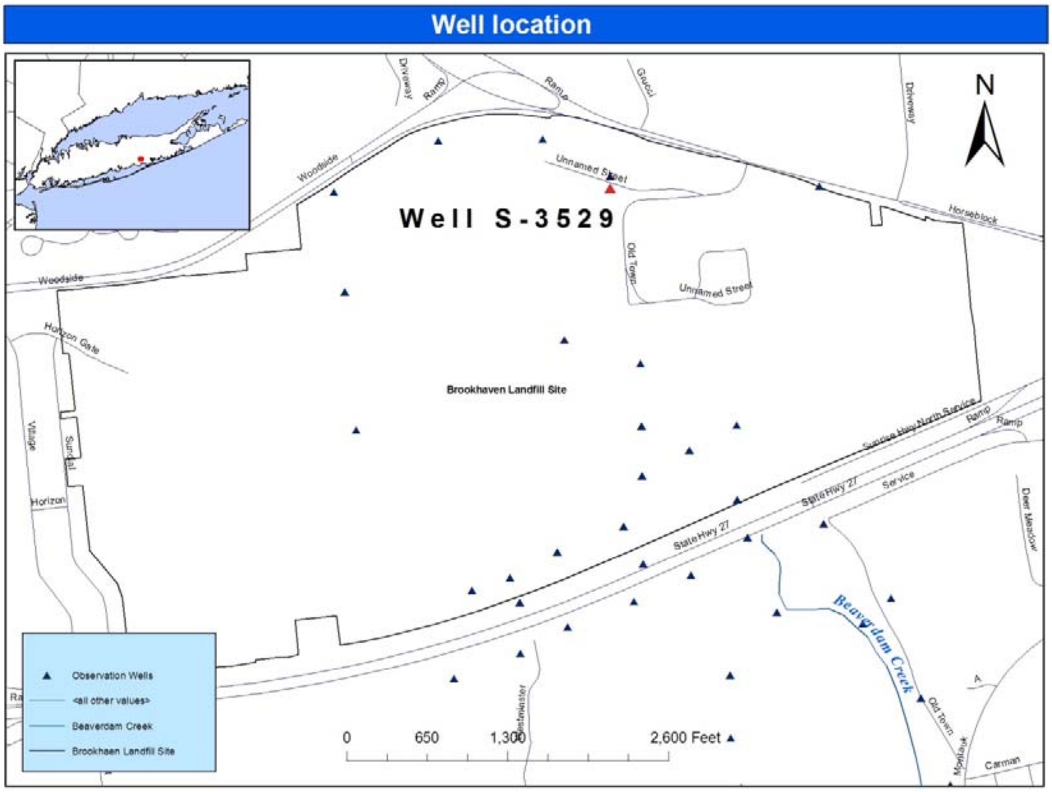

Figure 1: Map showing location of observation well S-3529

Weather data

Total monthly precipitation and monthly average temperature data for the period 1987-2007 were derived from Brookhaven National Laboratory (Upton) weather station records. The monthly water table height data were downloaded from the US Geological Survey's National Water Information System for the same period. Other measurements were available from Town records.

Calculation of cumulative differences of precipitation from running averages (Leggette method)

Cumulative differences of precipitation from running averages were calculated by taking the difference between the rainfall during a given month and the average rainfall for the preceding n months (with n = 6, 12, 24, 36) and then accumulating the differences. The cumulative differences were then plotted and compared with an average water level graph. The water table head values were transformed to adjust the scale.

Calculation of evapotranspiration

Evapotranspiration was computed using the Thronthwaite and Mather method (1957). This method requires temperature as the only input variable. The method estimates "potential" evapotranspiration (evapotranspiration losses when sufficient soil moisture is present) using an empirical relationship between potential evapotranspiration and mean air temperature. The relationship is given as follows,

$$e = 1.6\ (10T/I)^{a} \qquad (1)$$

Where,
e = monthly potential evapotranspiration (cm)
T= monthly mean temperature (°C)
I = heat index which is a constant for a given location and is the sum of 12 monthly index values
a= an empirically determined exponent which is a function of I,
$a = (6.75 \times 10^{-7} \times I^3) - (7.71 \times 10^{-5} \times I^2) + (1.79 \times 10^{-2} \times I) + 0.49$
Note: When the temperature is below 0°C, it was set to 0°C. All values were transformed from centimeters to inches to conform to weather data.

Calculation of available moisture

The available moisture was defined as the difference between rainfall for the given month and the corresponding potential evapotranspiration calculated using Thronthwaite and Mather method (1957). Available moisture can be a negative quantity. Runoff was discounted, as it typically represents small portion (0.7%) of the regional groundwater recharge rates (Peterson 1988).

Results and discussion

Figure 2 is a plot of 20 years of monthly head and rainfall data. Figure 3 is a plot of 20 years of monthly head data plotted against available moisture. The graphs are intended to test truism 1 (When it rains a lot, the water table rises, and when it is dry, the water table falls). Although the positive slop of the linear regression for Figure 2 indicates that higher heads are associated with more rain (and so lower heads are associated with lower rains), the R^2 value was calculated to be 0.042. This suggests the linear model only accounts for 4% of the data. Available moisture (Figure 3) accounts for loss of precipitation to evapotranspiration, a better approximation of recharge than only using rainfall. However, higher heads did not correspond well with monthly available moisture (the R^2 value was 0.0047). This indicates that both rainfall differences and available moisture in a month do not correlate with head levels. Therefore, truism 1 is not true over monthly scales.

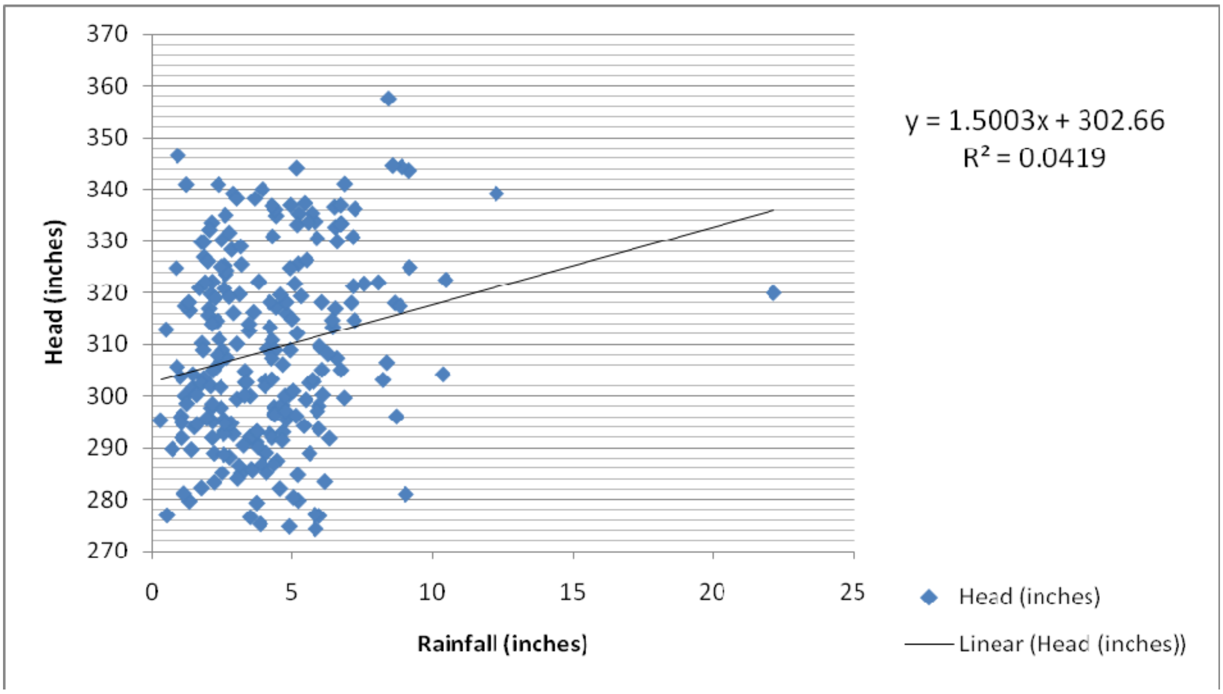

Figure 2: Scatter plot of 20 years of head and rainfall data

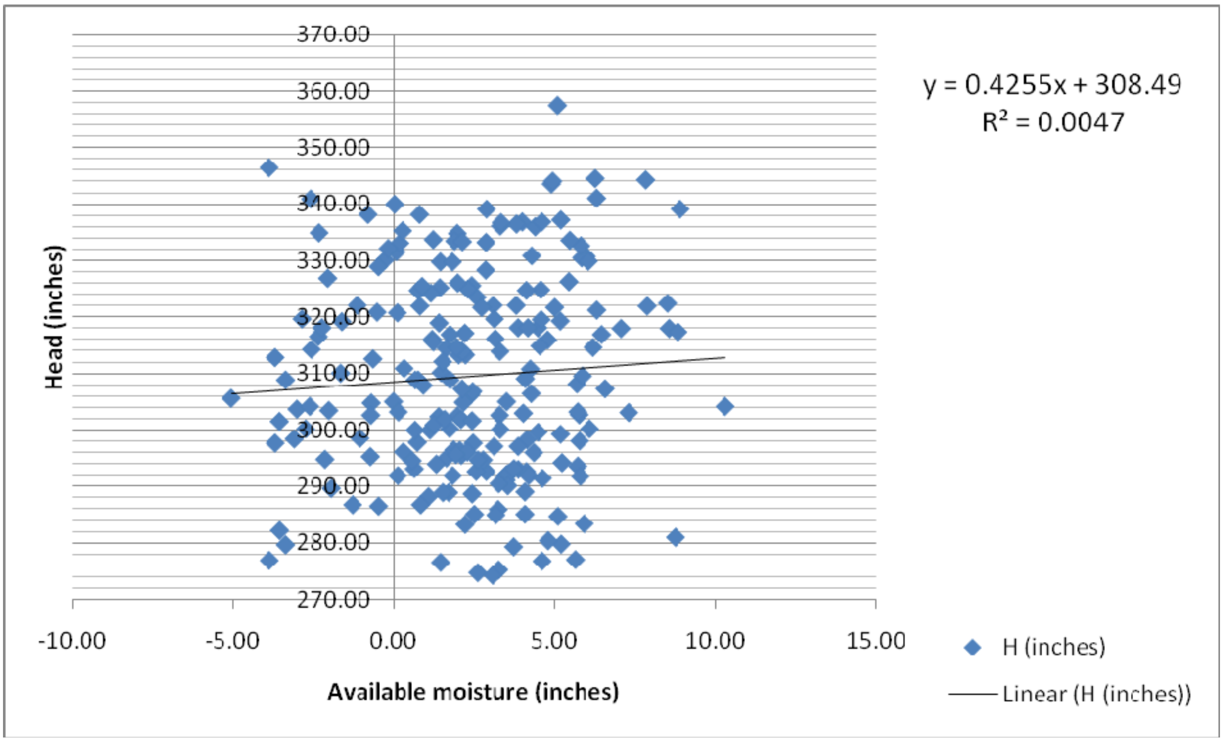

Figure 3: Scatter plot of 20 years of water table heads and calculated available moisture using Thronthwaite and Mather method (1957)

Figure 4 is a comparison of cumulative differences of precipitation calculated using Leggette method for *n* = 24 months and the average monthly water levels. A 24-month graph was chosen because it gave a better visual correlation than graphs with *n* = 6, 12, 36 months (data not shown). Also, a linear regression analysis of head against precipitation values produced higher R^2 value (0.6) than the other values of *n*.

The graph shows noticeable convergence between groundwater heads and cumulative difference values, similar to those made by Leggette (1942) and Fetter (1976). Fetter (1976) used this correlation to suggest the water table respond quickly to changes in precipitation trends. This is not really the same as saying the water table responds quickly to precipitation. A data set of monthly values does not test the response of the water table to precipitation events. But, the correspondence of a set based on longer-term data trends suggests that a good portion of the height of the water table depends on long-term precipitation values, not just on individual rainfall events.

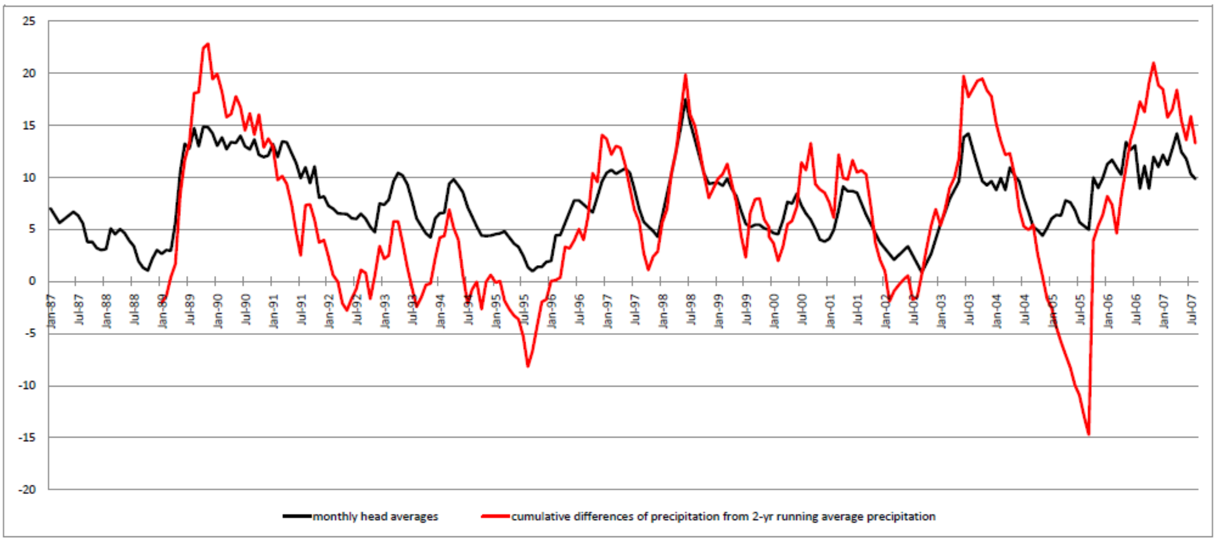

Figure 4: Comparison between cumulative differences of precipitation calculated using Leggette method and the average monthly water table heads (*n* =24 months)

The water table distribution for selected warm (April to September) and cold (October to March) periods are displayed below in Figure 5. Each graph shows monthly water height measurements from April of one year through the March of the subsequent year. The graphs were plotted to test the validity of truism 3 (water table is lower in winter and higher in summer). It is obvious that no absolute pattern holds.

Figure 5: Plots showing monthly water table head distributions for different warm and subsequent cold periods. The red bar divides warm and cold periods.

Our calculation of evapotranspiration found only 10% of evapotranspiration occurred in cold period and 90% occurred in the warm period. Steenhuis et al. (1985) found that for a somewhat similar distribution of the year into warm and cold periods, 90% of recharge occurs in the cold period. This means recharge (simply thought as precipitation minus evapotranspiration) should be greatly reduced in warm periods (exactly what Steenhuis reported).

So, recharge (which leads to change in the water table head) is generally greatest in winter and least in summer. This means on average, the water table height will reach a minimum when precipitation rates begin to exceed evapotranspiration each year, about September, and a maximum when evapotranspiration rates begin to exceed rate of precipitation around May. So, although truism 3 does not hold, but is accurate if recharge, not water table height, is the subject.

Figure 6 shows the average heads for each month over the 20 year period. The water table fluctuated by more than 7 feet (from a minimum of 22.86 feet in September 2002 to a maximum of 29.79 feet in June 1997) during the period 1987-2007. The figure also shows that water table height substantially fluctuated within particular year. For example, in 1998, the head rose by about 5 feet (from 25 feet in January to 29.79 feet in June) and again fell by 3 feet (from 29.79 feet in June to 26.45 in December). To the contrary, the water table head remained almost unchanged from June 1989 to June 1990. From these observations, it can be concluded that water table heights are not consistent in retaining their current levels. Thus truism 4 does not hold true for the observation well over the entire study period.

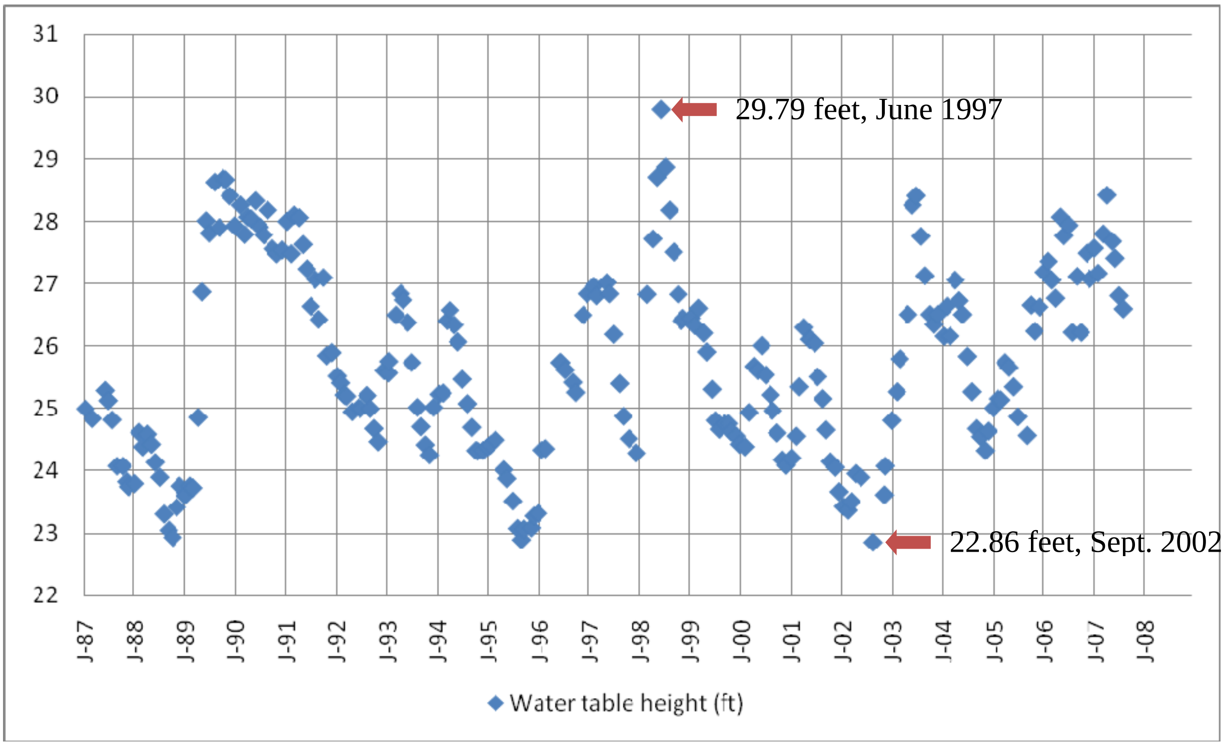

Figure 6: Water table height fluctuation (1987-2007) (in inches)

Conclusion

Some of the common perceptions about the behavior of water table on Long Island are based on long-term averages. We conclude that deviations in these perceptions can occur over a short-term basis. Our preliminary research suggests that simplified relationships between the water table heads and other hydrologic factors will give only a partial explanation of the behavior of the water table. It is clear that weather (temperature, as proxy for evapotranspiration and precipitation) is the driver of head levels. These are general patterns to Long Island's weather: warm in summer, cold in winter, and, on average, evenly distributed rainfall across the seasons. But, each year has different weather from other years, and so generates different results in terms of water table heights. Thus, every year can be expected to have variation from general descriptions of water table patterns.

This preliminary report will be further refined as we add statistical rigor and data from other long-term monitoring points.

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