IMPACTS OF SEA-LEVEL RISE ON LONG ISLAND WATER TABLES: ONE SEARCH FOR EVIDENCE

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Introduction

Changes in sea level are expected to cause increases in the water tables of coastal aquifers. The underlying theory is clear: the fresh water table is less dense than saltwater and so floats on salt water at the freshwater-salt water interface (Reilly and Goodman 1985). The pressure relationship means that as sea level increases in elevation, the water table will be buoyed up, at least near to the shoreline (Nuttle and Portnoy 1992; Cooper et al. 2013; Guha and Panday 2012). Sea level rise causing water table rises could cause flooding away from the immediate shoreline (New York State Sea Level Rise Task Force 2011), but might mitigate potential salt water intrusion (Werner et al. 2013).

Changes in the water table due to sea level rise have been modeled (Cooper et al. 2013), but is little evidence that general effects have been measured. Partly this is due to the multiple factors that affect the height of the water table: recharge, discharge, evapotranspiration, advection, and the interactions of those forces causing changes in the primary factors: precipitation, sewering, stormwater controls, impervious surfaces.

Here I relate changes in sea level over the past 70 years or so across the general region around Long Island to changes in a regionalized measure of the water table over the same time period: flows in gaged streams across Nassau and Suffolk County. I did not look at water table heights as measured directly in groundwater wells due to the difficulty in finding long-record sites that were appropriate. Also, I have showed (Tonjes and Wetjen 2002) that water table wells even in close proximity to each other can react differently over medium duration time periods (months to a year or so). Stream flows should instead reflect more regional expressions of the water table, especially on Long Island where all base flow is due to groundwater.

The stream flow proxies for the water table height also showed dissimilar patterns of change over time. This is because many local effects (sewering, changes in impervious surface cover associated with development, and construction of recharge basins) alter natural patterns of recharge. However, at least one stream system shows a significant long-term increasing trend in flow. The possibility of sea level rise contributing to this phenomenon could not be ruled out, based on correlations, although it is clear that other factors play a larger role in changes in annual flow rates.

Materials and Methods

Twenty-one streams have been gaged at one time or another in Nassau and Suffolk County by the USGS, and these records were examined. The first records begin in 1937, and data through 2009 was collected. The monthly flow records were compiled into calendar year mean flows. Note that USGS typically reports annual records in “water year” (October to September) form.

Ten long-record relative tide gage records from the vicinity of Long Island were accessed from an international data base (Woodworth and Player 2003, PMSL 2103). These extend from the 1856 to 2012, although most records began in the 1930s or 1950s. In addition, precipitation records from Central Park (Manhattan) (1937 data onwards were compiled) and Brookhaven National Laboratory (first available in 1949).

A number of linear trends and correlations were determined through graphs and regression functions, using Excel.

Results

Sea Level Rise

The international database has used a universal 7000 mm datum to rationalize worldwide measurements. This enables ready comparisons between measurements taken at different locations (Woodworth and Player 2003).

Figure 1 shows the annual mean values from the 10 locations in the data base. It is readily apparent that sea level has been rising in the vicinity of Long Island as long as records have been maintained. Table 1 provides particulars from each of the 10 sites. Except for the shorter duration record from Plum Island, all of the stations show that sea level has been increasing, although the rates are not consistent. The western-most stations (Sandy Hook and Staten Island) show higher rates while lower rates of increase are found in Long Island Sound. This general description is modified if the most recent 20 year time period (1993-2012) is considered (Fig. 2, Table 2). While the highest rates are still measured at the western two stations, New London also shows a much higher rate of increase. The data are not as consistent when considered over shorter time periods (note the lower values for the linear trend fit term, R^2). Consistent with the concepts of Anthropogene Era climate change, the sea level increases over the past 20 years are generally much higher than those considered over longer time steps.

Station	**Interval**	**Rate of Change (mm/yr)**	**R^2**
The Battery	1856-2012	+2.85*	0.94
Bergen Pt. (Staten Island)	1985-2012	+5.84*	0.70
Sandy Hook	1933-2011	+4.05*	0.90
Montauk	1948-2012	+3.01*	0.74
Willetts Pt.	1938-1999	+2.39*	0.69
Port Jefferson	1958-1990	+2.19*	0.35
Plum Island	1958-1967	-4.41	0.23
New Rochelle	1958-1981	+0.63	0.01
Bridgeport	1965-2012	+2.74*	0.56
New London	1939-2012	+2.60*	0.79

Table 1. Sea level change in the vicinity of Long Island (based on linear regressions) (* = significant increasing trend at $p<0.05$)

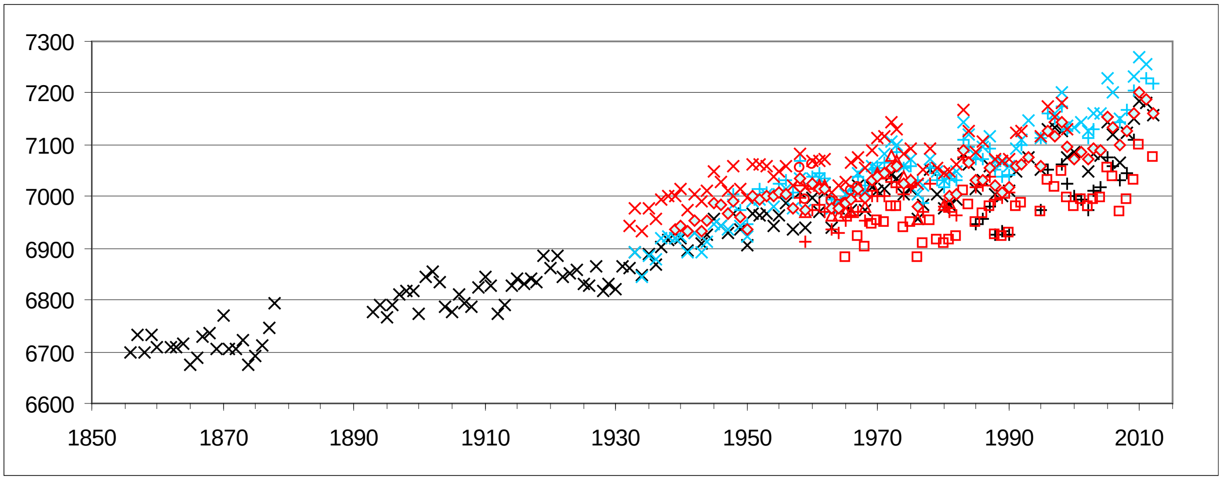

Figure 1. Sea level change, 10 stations in the vicinity of Long Island (black = stations in New York Harbor, blue = stations on the Atlantic Ocean, red = stations in Long Island Sound)

Station	**Rate of Change (mm/yr)**	**R^2**
The Battery	+4.09#	0.32
Bergen Pt. (Staten Island)*	+5.89#	0.44
Sandy Hook**	+6.61#	0.54
Montauk*	+4.51#	0.49
Bridgeport*	+3.28	0.20
New London	+4.85#	0.46

* 1995-2012 ** 1993-2011

Table 2. Sea level change at Long Island-vicinity stations, 1993-2012 (based on linear regressions) (# = significant increasing trend at $p<0.05$)

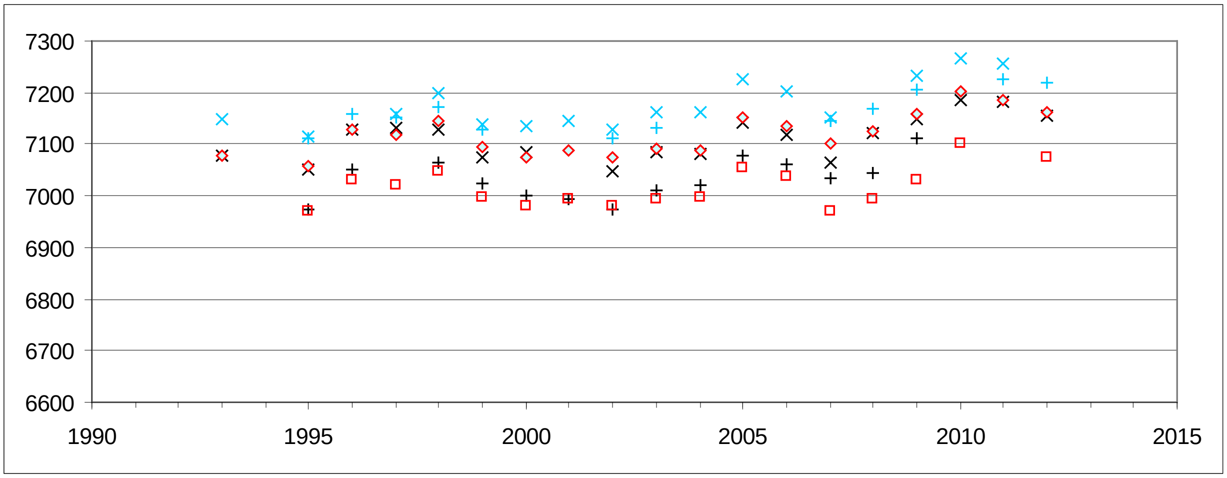

Figure 2. Sea level change, stations in the vicinity of Long Island (black = stations in New York Harbor, blue = stations on the Atlantic Ocean, red = stations in Long Island Sound)

Stream Flow Trends

Annual stream flow data for particular streams can vary by nearly an order of magnitude (e.g., Bellmore Creek, Figure 3, but also East Meadow Brook, Pines Brook, and Valley Stream), although for most streams on Long Island peak annual flow rates are only 2-3 times low flow rates (see Connetquot River, Figure 4).

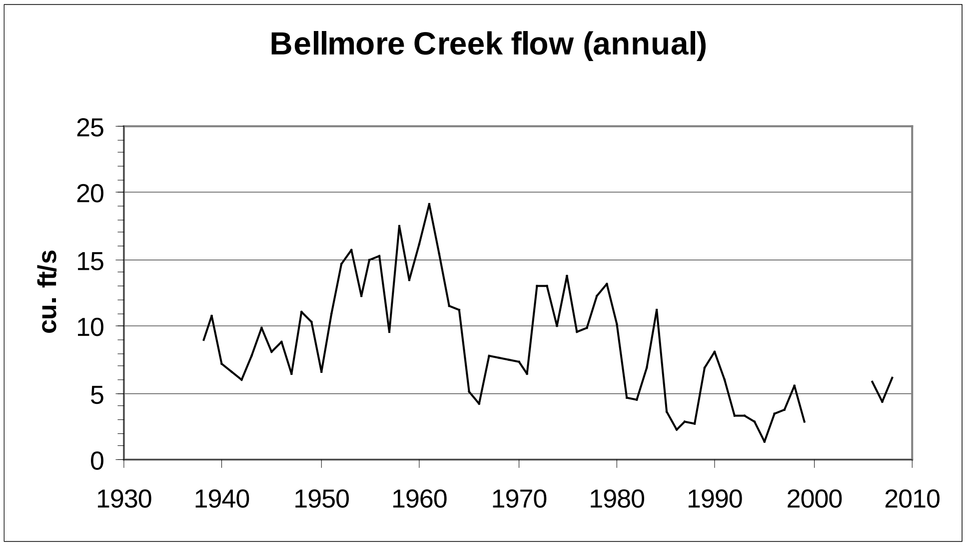

Figure 3. Large variations in annual flow rates for Bellmore Creek

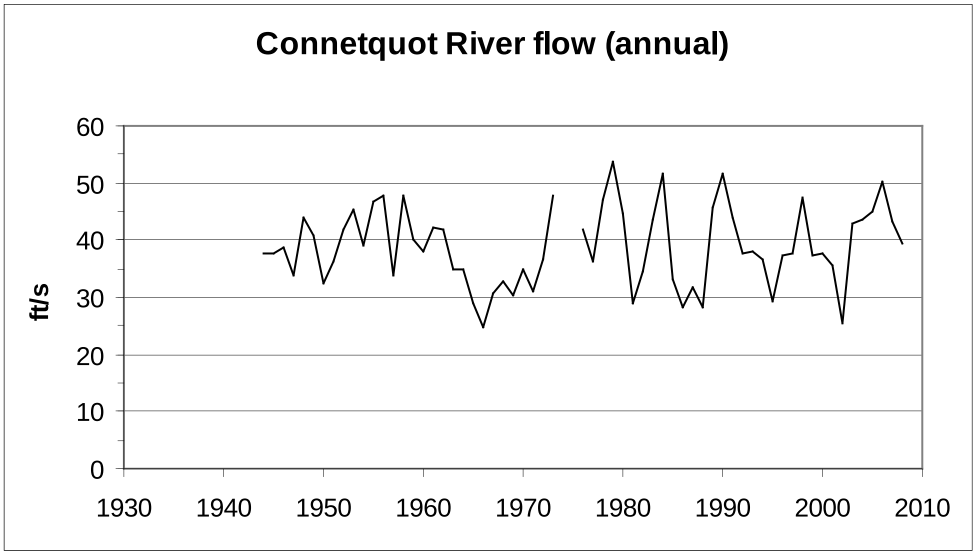

Figure 4. 100% variation in flow from low to high stands for Connetquot River

Streams along the south shore in Nassau County were clearly impacted by sewering in the 1950s, which reduced recharge by diverting large portions of water withdrawn for household use to ocean-discharge treatment plants (see Figure 5). The impact of sewering was exacerbated by several years of low rainfall in the mid-1960s, which caused reduced flow in Suffolk County streams as well (see Figure 4). The effects of sewering were not consistent. Prior to the 1960s, East Meadow Creek had considerably greater flow rates than Bellmore Creek; after the 1960s, the difference was not as manifest. Prior to the 1960s, Pine Brook and Valley Stream had similar flow patterns, but after 1970 Pine Brook had considerably more flow every year than Valley Stream. The impact of sewering is further illustrated by the divergence in flow patterns after the mid-1960s between a Nassau County south shore stream (Bellmore Creek) and a Suffolk County south shore stream (Carlls Creek) (Figure 6). The Town of Babylon was sewered in the 1960s, but not as completely as Nassau County, and Babylon’s population density and relative water withdrawals are less. Note that in fact it is difficult to differentiate the flow patterns between

Carlls Creek and Carmans River, although there is no sewering in the Carmans River watershed to speak of.

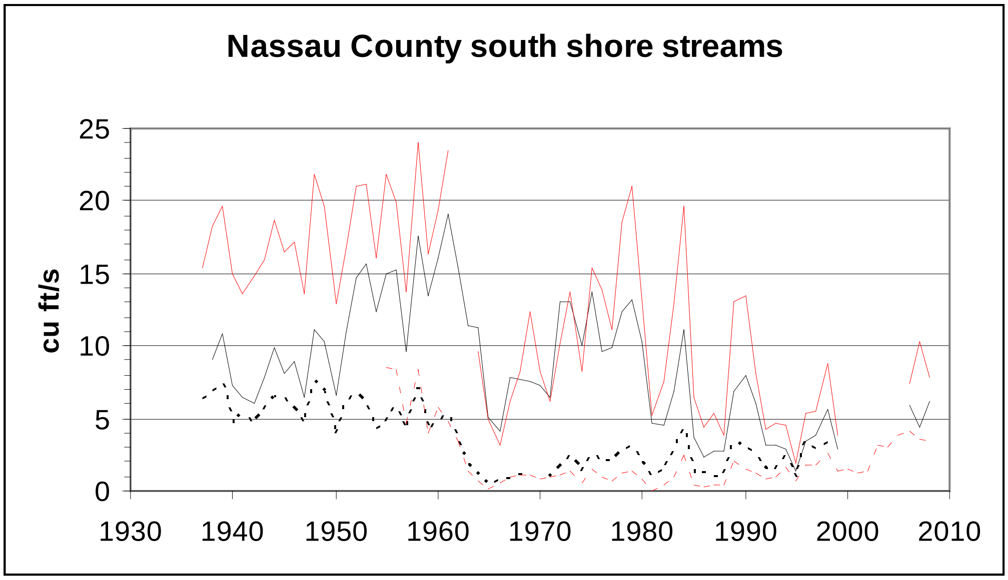

Figure 5. Impact of sewering (and reduced rainfall) on south shore Nassau County streams (Bellmore Creek = black solid line; East Meadow Creek = red solid line; Pines Brook = black dotted line; Valley Stream = red dotted line).

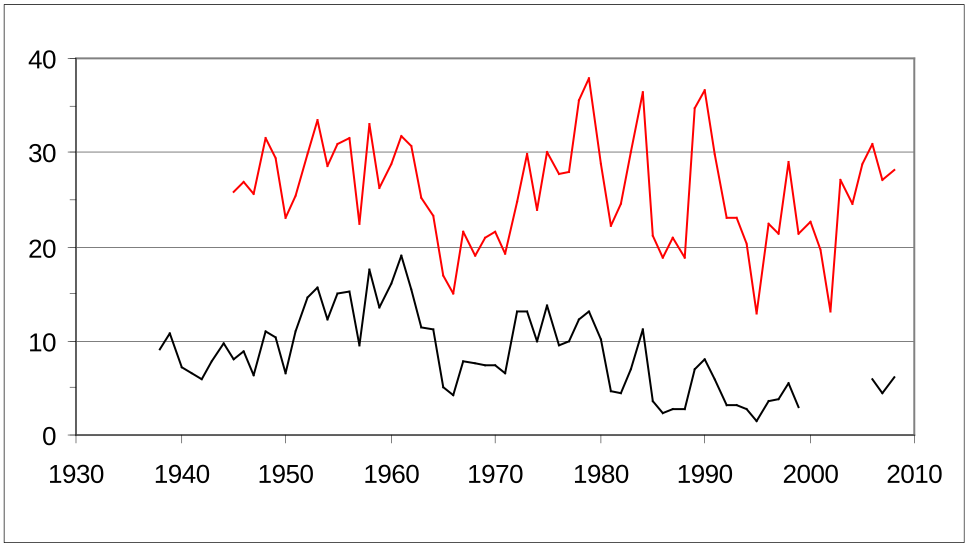

Figure 6. Differential impact of sewering: Carlls Creek (red solid line) and Bellmore Creek (black solid line)

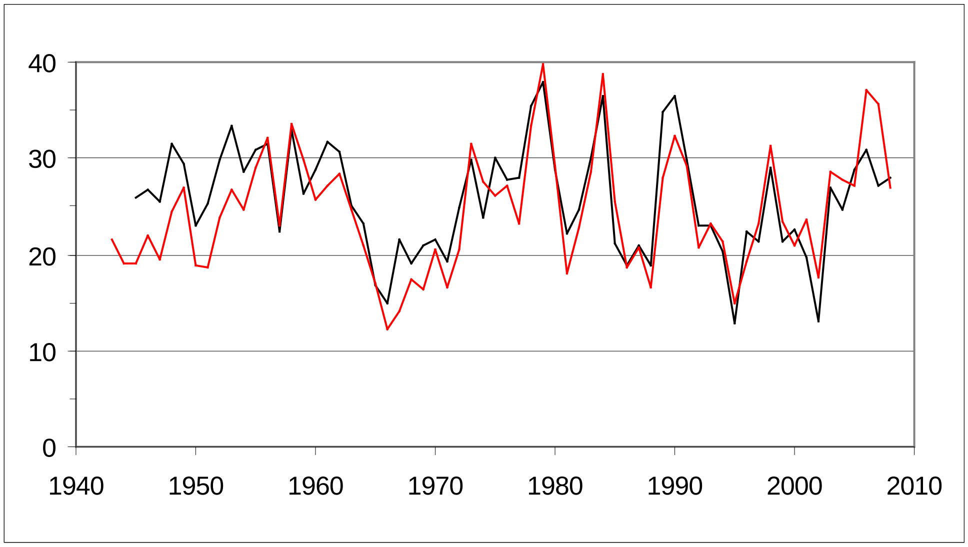

Figure 7. Synchronous flows in Carlls Creek (black line) and Carmans River (red line)

Precipitation Trends

There is surprisingly poor visible correspondence between Central Park and BNL rainfall data (Figures 8 and 9). There is good agreement over 20 years from 1975-1997, but not good matching before or after. The 1960s rainfall deficit is more pronounced for Central Park, and BNL experienced similarly sized rainfall deficits as the mid-1960s in the mid-1980s and early 1990s. There was a low rainfall period at Central Park in the early 2000s. The lack of correlation between the two data sets does not appear to be due to extreme values measured at either site, but just generally different amounts measured at all ranges of values. The slope of the regression line is 0.80 and it does not pass through the origin, implying there is generally not good agreement between the data sets.

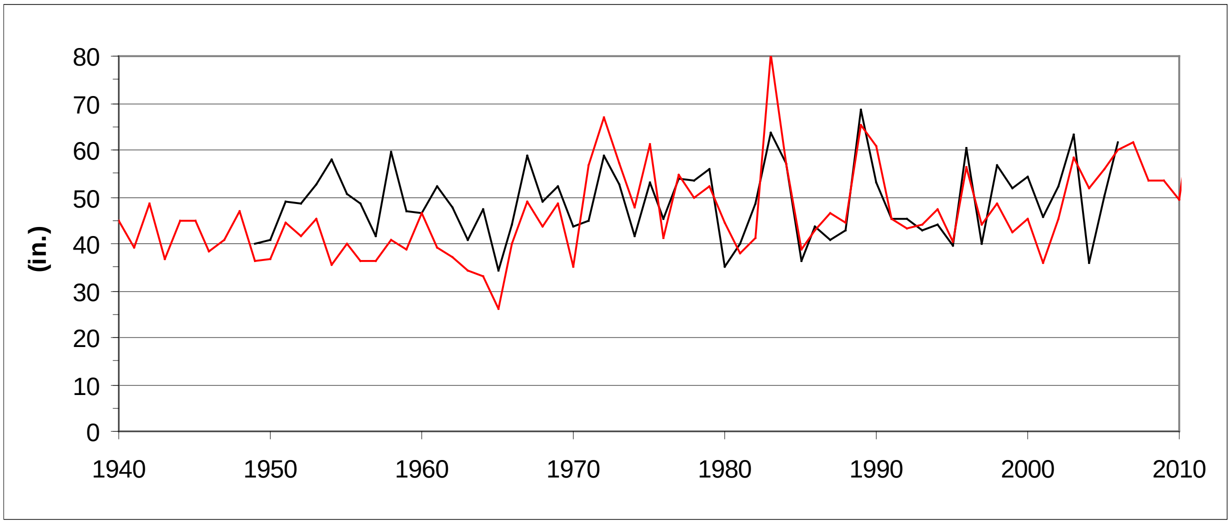

Figure 8. Annual rainfall totals, BNL (black line) and Central Park (red line)

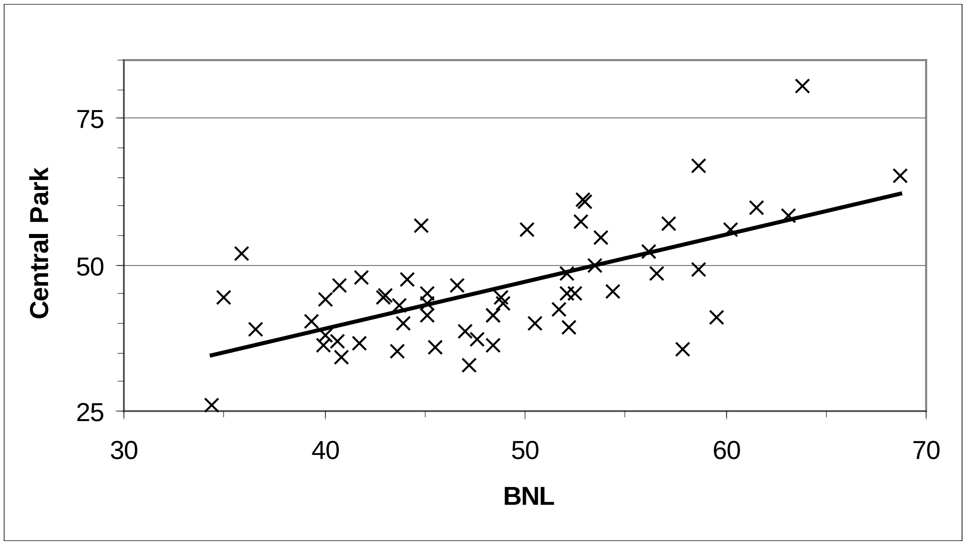

Figure 9. Correlation in annual rainfall between BNL and Central Park (linear fit shown)

Discussion

It is clear sea level has risen considerably in the waters around Long Island, and that the rate is increasing with time. It is also clear that stream flows on Long Island are not constant from one year to the next, and that long-term trends in flow can be discerned for many of the 21 gaged streams (Table 3). The south-shore Nassau County streams show effects from sewering, despite stabilization and even augmentation of flows post-1970. This is in opposition to the stable flow patterns seen in North Shore streams over the long term (e.g., Mill Neck Creek, Cold Spring Creek, Glen Cove Creek). Sewering in the Southwest Sewer District of Suffolk County, where impacts on stream flow were intended to be mitigated, appear to have had minimal if any impacts (Carlls Creek, Sampawams Creek, and Connetquot River). Data presented by Rozell (2010) generally agreed with the latter conclusion, although Rozell did not find effects from sewering or other urbanization effects on any south shore streams he analyzed, including those in Nassau County. Partially this is because his analysis began in 1980.

Streams with no trend	**Interval**	**Rate of Change (ft^3/yr)**	**R^2**
Mill Neck Cr.	1938-2008	-0.01	0.03
Swan R.	1947-2008	-0.01	0.01
Cold Spring Cr.	1951-2008	+0.00	0.00
Sampawams Cr.	1945-2008	+0.00	0.00
Glen Cove Cr.	1939-2008	+0.01	0.01
Connetquot R.	1944-2008	+0.02	0.00
Streams with decreasing trends			
Valley Str.	1955-2008	-0.04*	0.08
Carlls Cr.	1945-2008	-0.05	0.03
Patchogue R.	1946-1968	-0.07	0.03
Pines Br.	1937-1998	-0.08*	0.51
Bellmore Cr.	1938-2008	-0.11*	0.25
Massapequa Cr.	1937-2009	-0.11*	0.26
Champlin Cr.	1949-1968	-0.13*	0.25
Santapogue Cr.	1948-1968	-0.18*	0.48
East Meadow Br.	1937-2008	-0.20*	0.42
Streams with increasing trends			
Pentaquit Cr.	1946-1975	+0.03	0.09
Carmans R.	1943-2008	+0.06	0.04
Nissequogue R.	1944-2008	+0.13*	0.11
Peconic R.	1943-2008	+0.13	0.05

Table 3. Long-term stream flow trends (* = significant non-zero trend at $p < 0.05$)

Note that two of the creeks in the Southwest Sewer District did show significant losses of stream flow (Champlin Creek and Santpogue Creek). However, monitoring of both creeks ceased prior to the construction of sewers. Instead, the records there seem to show the effect of lower precipitation in the early and mid-1960s (as does the record for Patchogue River, which also shows a declining flow trend albeit not significant). The rainfall record for Central Park could be interpreted as showing lower than average rainfall from the early 1950s almost without exception though about 1965 (see Figure 8). The trends for BNL are not as marked. The reason for the decreasing trends in flow for these three eastern streams on the south shore is the result of the duration of the monitoring periods, which captured a regional loe rainfall period, but not the recovery.

It is interesting that the three longest streams draining mostly-unsewered watersheds, (Carmans River, Nissequogue River, and Peconic River) all show long-term increases in stream flow, although only the trend in Nissequogue River flows is significant (at $p<0.05$). This could be a reflection of long-term rainfall trends, as the Central Park precipitation data show a significant increasing trend over the past 75 years. The BNL data do not; that data set is a decade shorter data set, however. It would seem that BNL rainfall records should be more relevant to eastern Long Island stream flows than New York City data. Correlations between precipitation records and rainfall are not great, but they tend to be a little better between BNL and flows than between Central Park and flows. Not all streams closer to BNL have better correlations with BNL, however (Table 4).

Station	**Interval**	**Correlation with Central Park Rainfall (R^2)**	**Correlation with BNL (1948-2006) Rainfall (R^2)**
Bellmore Cr.	1938-2008	0.00	0.09*
Carlls Cr.	1945-2008	0.12*	0.24*
Carmans R.	1943-2008	0.12*	0.13*
Champlin Cr.	1949-1968	0.08	0.33*
Cold Spring Cr.	1951-2008	0.07*	0.01
Connetquot R.	1944-2008	0.16*	0.21*
East Meadow Br.	1937-2008	0.00	0.12*
Glen Cove Cr.	1939-2008	0.22*	0.16*
Massapequa Cr.	1937-2009	0.01	0.15*
Mill Neck Cr.	1938-2008	0.06*	0.14*
Nissequogue R.	1944-2008	0.21*	0.16*
Patchogue R.	1946-1968	0.00	0.19
Peconic R.	1943-2008	0.22*	0.32*
Pentaquit Cr.	1946-1975	0.23*	0.40*
Pines Br.	1937-1998	0.01	0.09*
Sampawams Cr.	1945-2008	0.22*	0.32*
Santapogue Cr.	1948-1968	0.18	0.23*
Swan R.	1947-2008	0.11*	0.25*
Valley Str.	1955-2008	0.00	0.07

Table 4. Linear correlations of stream flows to precipitation records (* = significant non-zero trend at $p < 0.05$)

Four streams showed increasing stream flows over time (although only one correlation was significant for p <0.05). Surprisingly, the linear correlations against sea level rise showed stronger relationships in some cases than the relationships found for precipitation. Many of the correlations were significant, which relates to the number of data points and that both data sets were trending upward over time (see Table 5).

Correlation		**Carmans River**	**Nissequogue River**	**Peconic River**	**Pentaquit Creek**
	Time Period	1943-2008	1944-2008	1943-2008	1946-1975
Increasing with time		0.06	0.13*	0.13	0.03
Rainfall					
Central Park	1943-2008	0.12*	0.21*	0.22*	0.23*
BNL	1948-2006	0.13*	0.16*	0.32*	0.40*
Sea Level Rise					
Bridgeport	1965-2008	0.05	0.13*	0.04	0.65*
New London	1943-2008	0.09*	0.21*	0.14*	0.44*
Port Jefferson	1958-1990	0.11	0.23*	0.17*	0.31*
Sandy Hook	1943-2007	0.07*	0.15*	0.11*	0.35*
The Battery	1943-2008	0.06	0.16*	0.09*	0.35*
Willetts Point	1943-1999	0.03	0.12*	0.11*	0.36*

Table 5. Linear correlations (R^2) to rainfall and sea-level rise (for streams with increasing flow rates over time) (* = significant non-zero trend at $p < 0.05$)

It is understood that precipitation patterns are a strong forcing factor for water table changes; however, if relative comparisons have any value, then it seems that some of the sea level rise data explain flow patterns in the Nissequogue River and Pentaquit Creek better than rainfall patterns do. However, in the case of Pentaquit Creek, note that the time period in question was not one of the greatest changes in sea level (as suggested by the short records for Island and New Rochelle, Table 1). In the case of the Nissequogue River, neither precipitation nor sea level rise create compelling explanations for flow data.

Still, it is possible that sea level rise could be a factor in explaining some of the variations found for certain Long Island streams. It seems clear that other factors are more important; but, precipitation patterns, as measured on an annual basis, do not seem to account for most of the changes in flow, either.

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