Urbanization and Trends in Long Island Stream Base Flow

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ABSTRACT

Previous studies have shown a correlation exists between increasing urbanization on Long Island and decreased base flow in local streams. Using the most recent USGS stream flow data, recent trends were investigated in 10 south shore Long Island streams. From 1980 to 2008, the percentage of base flow to total flow remained relatively constant for all but one stream. Valley Stream had a statistically significant base flow increase of 1.6% a year. The increase is attributed to reduced groundwater pumping in New York City after 1980.

INTRODUCTION

The negative effects of urbanization on watershed hydrology have been recognized for many years. In developed areas, a major contributing factor to stream degradation is the increase in the extent of impervious surfaces (Leopold, 1968). The addition of roads, parking lots, rooftops, and other man-made impermeable surfaces reduces the amount of precipitation that permeates the soil and recharges the ground water below. When this additional runoff is directed through storm sewers and is discharged directly to streams, the result is higher flood peaks. Additionally, urbanized areas are associated with increased groundwater pumping and the use of sanitary sewer systems. The result is a drop in the local water table and a reduction of ground water discharge, or base flow, in local streams (Sulam, 1979).

Urbanization is also associated with stream water quality issues. Studies have found elevated contaminant levels associated with streams in developed watersheds (Makepeace *et al*., 1995; Deletic, 1998; Carle *et al*., 2005; Hudak and Banks, 2006). Urbanized watersheds usually contain a variety of pollution sources and low base flows can result in low dilution rates of pollutants. Likewise, storm events result in considerable unfiltered runoff into streams as impervious surfaces are washed of contaminants. Peters (2009) found that in urbanized streams some contaminant concentrations decreased with increasing stream flow, while others, including copper, lead, and zinc, peaked during storm events. Thus, both water quantity and quality vary more in urbanized streams than in undeveloped watersheds. The result is an ecologically degraded stream with reduced biological diversity that is dominated by a few tolerant species (Walsh et al., 2005).

One relatively simple method of estimating the multiple effects that urbanization has on the ecological health of a watershed is to use stream base flow as a proxy for the degree of urbanization. USGS stream gage stations provide a readily available data source and a comprehensive record for evaluating stream flow characteristics. Due to its long history of urbanization and simple stream hydrology, the south shore of Long Island, New York has been the subject of previous base flow studies. The purpose of this study is to further investigate the stream base flow trends established in previous studies using recent USGS stream flow data.

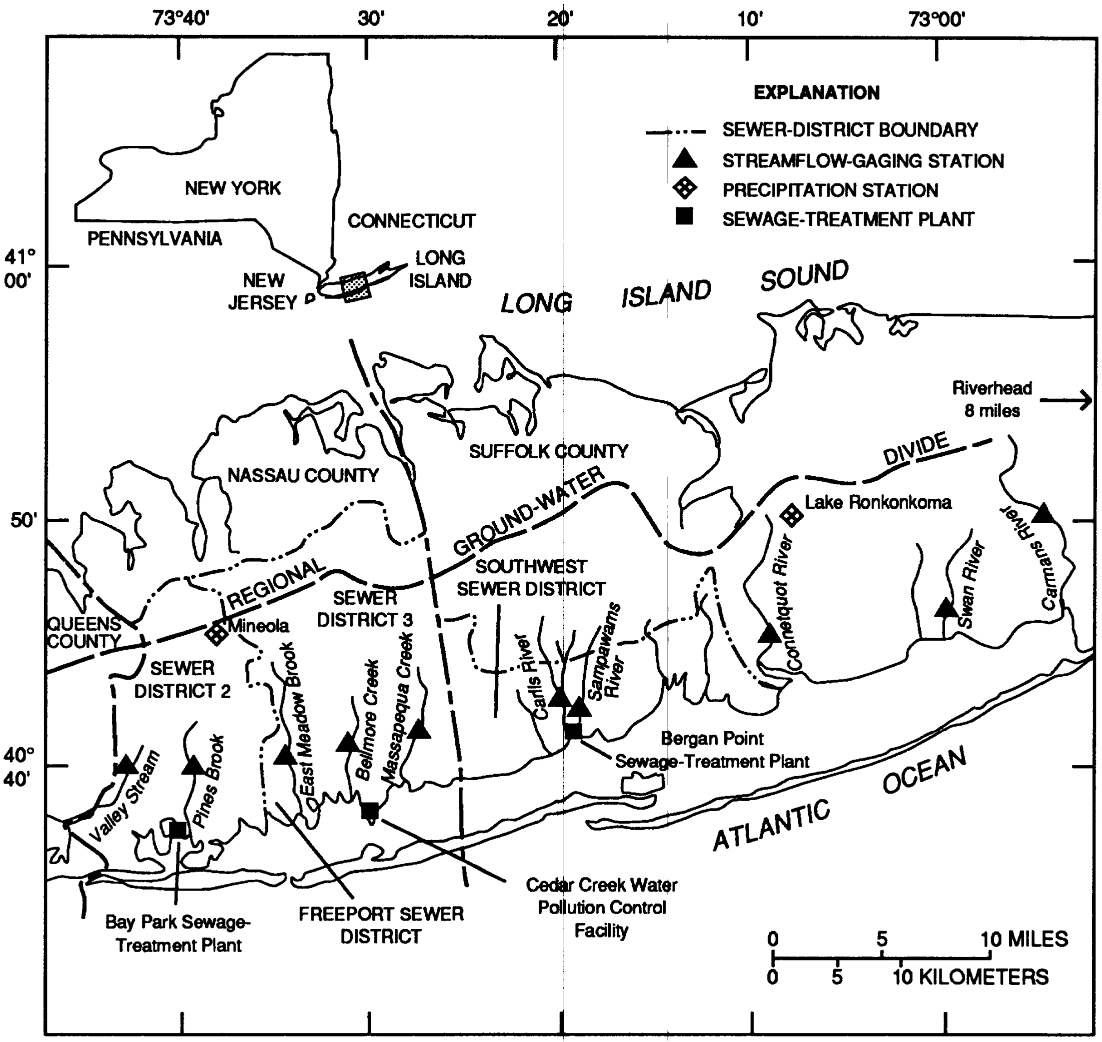
Long Island Geology

Long Island is approximately 190 kilometers long and less than 40 kilometers wide and extends into the Atlantic Ocean east of New York City and south of Connecticut (Figure 1). The island was formed from the terminal moraines of glaciers from the most recent ice age. The unconsolidated glacial deposits formed a series of aquifers with interleaved confining units over an impermeable Paleozoic or Precambrian bedrock. The uppermost aquifer, the Upper Glacial aquifer, extends upwards to the local water table. All south shore Long Island streams are fed by precipitation and ground water from the Upper Glacial aquifer (Buxton and Modica, 1992).

The terminal moraines deposited by glaciers form a line of hills running the length of Long Island that effectively split the surface hydrology of the island into two regions (Figure 1). To the north lies undulating glacial deposits and south of the terminal moraines is an outwash plain that gently slopes at an average of less than 4-m/km (Cohen, et al, 1968). Because of this geology, streams have a net gain from the aquifer (Buxton and Modica, 1992). In undeveloped drainage basins, about 95% of stream flow is contributed by the Upper Glacial aquifer (Franke and McClymonds, 1972). These streams act as groundwater drains and small changes in the water table may cause large changes in stream discharge (Garber and Sulam, 1976). In addition to the simpler topology and closeness of the water table to the ground surface, the south shore also has a higher population density than the north shore. Thus, streams on the south shore of Long Island are ideal for investigating the relationship between urbanization and ground water recharge.

Population

At the beginning of the twentieth century, Long Island was largely rural and agrarian. Excluding Kings and Queens County which are part of New York City, the 1900 U.S. Census estimated Long Island’s population at 133,000. By 1920, the population had risen to 237,000. This growth continued until World War II when the defense industry experienced rapid growth in Nassau and Suffolk counties. In the post-war housing boom that followed, Nassau County led the country in growth. The 1950, 1960, and 1970 U.S. Census data show Long Island’s population reached 0.95 million, 1.97 million, and 2.56 million, respectively. Since then, Long Island has experienced periods of slow growth and relative population stability. The current population estimate for the Nassau-Suffolk region is 2.87 million (LIPA, 2008).



Base from U.S. Geological Survey, 1:250,000 scale.
Hartford, 1962; New York, 1957; Providence, 1947

Figure 1: Locations of the 10 Long Island south shore streams (Spinello and Simmons, 1992)

Urbanization on Long Island

The expansive development of Long Island over the last 50 years has substantially changed the local environment including the natural hydrology. Increased ground water pumping and imperviousness of the landscape accompanied by decreased recharge of the aquifers is of special interest because residents of Nassau and Suffolk counties obtain their fresh water from the aquifers below Long Island. When precipitation is diverted through storm-water sewers and prevented from entering the ground water system or water is pumped from wells and diverted to coastal waters, via sanitary sewage treatment facilities, the water table decreases as does the recharge to the aquifers below. This scenario is most prevalent closest to the shore and in the most densely populated areas. Farther inland, where the water table is not as close to the ground surface, shallow storm-water collection basins have been dug that cause some runoff to recharge the aquifer below (Ku, et al., 1992). In areas where the combination of precipitation diversion and over pumping are most severe, such as the New York City boroughs on Long Island, saltwater intrusion into the aquifers has resulted in the need to pipe in fresh water from upstate New York at considerable expense (Franke and McClymonds, 1972).

Given, the importance of the resource and its potential for degradation, it is not surprising that many prior studies have addressed the effects of urbanization on groundwater and Long Island streams. The relationship between increasing urbanization, declining groundwater levels, and stream flow was investigated by Sawyer (1963), Franke (1968), Seaburn (1969), Garber and Sulam (1976), Pluhowski and Spinello (1978), Sulam (1979), Prince (1981), Reynolds (1982), Simon and Reynolds (1982), Spinello and Simmons (1992), Ku, Hagelin, and Buxton (1992), and Stumm and Ku (1997). Simon and Reynolds (1982) found that from 1955 to 1970, base flow was only 20 percent of total stream flow in the urbanized section southwestern Nassau County that had increased impervious surface area, storm water sewers, and sanitary sewers. In an unsewered adjacent area in southeastern Nassau County, the base flow had decreased to 84 percent of total annual stream flow. Meanwhile, base flow remained at 95 percent in rural Suffolk County. Spinello and Simmons (1992) quantified Long Island south shore stream flow from 1976 to 1985. It was found that base flow had decreased to 14 percent in highly urbanized areas with sewers, 79 percent in newly sewered areas, 88 percent in unsewered suburban areas, and 96 percent in rural areas.

METHOD

Hydrograph separation is a method of determining the distribution of base flow and direct runoff in total stream flow (Chow, 1964). The rather subjective graphical method of hydrograph separation has been improved by automated methods such as the USGS program PART (Rutledge, 1998). PART searches daily mean stream flow data for days that are not followed by a daily decline of more than 0.1 log cycles. These days are considered to be purely base flow measurements because they follow the typical recession curve decay that follows a precipitation event. The 0.1 log cycle cut-off was empirically determined by Barnes (1939). The program then repeats the search and linearly interpolates the ground-water discharge on the days that did not meet the original criteria. The original search also takes into account the empirical determination of Lindsey, et al. (1982) that the time after peak in stream flow when surface runoff and interflow are significant is given by the expression $N = A^{0.2}$ where N is the number of days after the peak, and A is the drainage area in square miles. Because of the uncertainty inherent in the method, it is recommended that the program be used to determine base flow over periods no shorter than one year (Rutledge, 1998). PART was used for this study.

Base flow and the water table to which it is coupled are highly dependent on precipitation. Thus, short-term or long-term changes in base flow may reflect weather patterns or climate changes as much as hydrological changes caused by urbanization. Instead, it is more appropriate to compare urbanization to the ratio of base flow to total flow. Increases or decreases in precipitation equally affect both base flow and surface runoff except in the case of extreme storms (Spinello and Simmons (1992). An annual base flow percentage of total flow was used in this study because it lends itself to both spatial and temporal comparisons.

Site Selection

All ten Long Island south shore streams that have at least 50 years of stream flow records are used in this study (Table 1, Figure 1). The streams were also used in the Spinello and Simmons (1992) study. The streams represent, from west to east, an approximate decrease in population density. For example, East Meadow Brook, the largest south shore stream in Nassau County by average daily flow, has a highly developed drainage basin that includes two sewer districts. A 1989 analysis of digitized aerial maps and field reconnaissance of a typical section of the drainage basin found that 29.5 percent of the surface was classified as impervious (Stumm and Ku, 1997). By contrast, the Connetquot River, the largest south shore river by flow, is located in Suffolk County and runs through a largely undeveloped state park. The two streams should represent the urbanized and undeveloped stream regimes.

Table 1: Long Island south shore streams

USGS Station Number	Stream Drainage Area (km^2)	Stream Name and Location	Years of Record
		NASSAU COUNTY	
01311500	12	Valley Stream, Valley Stream	1954-2009
01311000	26	Pines Brook, Malverne	1936-1999
01310500	80	East Meadow Brook, Freeport	1937-2009
01310000	44	Bellmore Creek, Bellmore	1937-2008
01309500	98	Massapequa Creek, Massapequa	1936-2009
		SUFFOLK COUNTY	
01308500	91	Carlls River, Babylon	1944-2009
01308000	60	Sampawams Creek, Babylon	1944-2009
01306500	62	Connetquot River, Oakdale	1943-2007
01305500	23	Swan River, East Patchogue	1946-2009
01305000	184	Carmans River, Yaphank	1942-2009

RESULTS

Figure 2 shows the percent base flow by year from 1937 to 2008. The average stream base flow and other summary statistics from 1980 to 2008 are shown in Table 2. The correlations of base flow amongst the streams from 1980 to 2008 are shown in Table 3. A comparison of the average annual flow rates (m^3/s) for all streams is shown in Figure 3, while the average annual percent base flow for all streams is shown in Figure 4. It should be noted that data was not available for all streams each year. Table 4 summarizes the results of the regression analysis conducted that looked for trends in the base flow data.

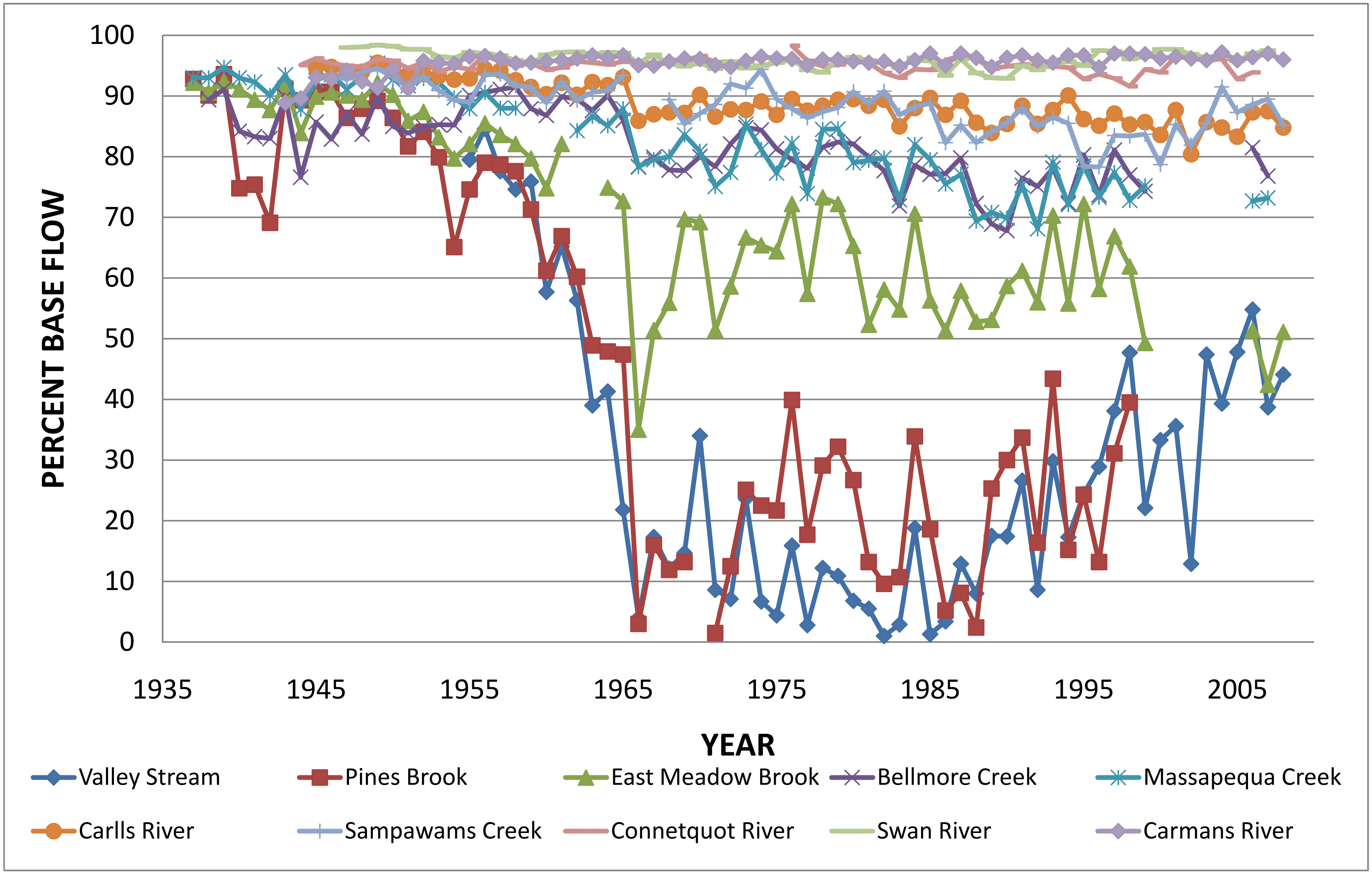


Figure 2: Long Island Stream Base Flow: 1937 - 2008

Table 2: Summary Statistics for 1980 to 2008

Summary	Valley Stream Base Flow	Pines Brook Base Flow	East Meadow Brook Base Flow	Bellmore Creek Base Flow	Massapequa Creek Base Flow	Carlls River Base Flow	Sampawams Creek Base Flow	Connetquot River Base Flow	Swan River Base Flow	Carmans River Base Flow
Mean (%)	23.89	21.08	57.735	76.368	75.136	86.452	85.500	94.648	95.800	96.1586
Variance	264.84	144.27	55.872	15.587	15.169	5.035	12.653	1.776	1.928	0.5189
Std. Dev.	16.27	12.01	7.475	3.948	3.895	2.244	3.557	1.333	1.389	0.7204
Skewness	0.2373	0.2457	0.3597	-0.5957	-0.0705	-0.4433	-0.3987	-0.3465	-0.6131	-0.4698
Kurtosis	1.8364	1.9836	2.8829	2.7384	1.9611	3.3595	2.7747	2.4699	2.6673	2.3519
Median	22.10	18.60	56.150	77.000	75.200	86.200	85.500	94.700	95.900	96.2000
Mean Abs. Dev.	13.93	10.34	5.758	3.140	3.288	1.833	2.738	1.076	1.086	0.5905
Minimum	1.00	2.40	42.400	67.800	68.100	80.400	78.300	91.600	92.900	94.7000
Maximum	54.80	43.40	72.200	82.100	82.000	90.100	91.500	96.700	97.700	97.2000
Range	53.80	41.00	29.800	14.300	13.900	9.700	13.200	5.100	4.800	2.5000
Count	29	19	23	22	22	29	29	27	28	29

Table 3: Correlation Table for 1980 to 2008

Correlation Table	Valley Stream Base Flow	Pines Brook Base Flow	East Meadow Brook Base Flow	Bellmore Creek Base Flow	Massapequa Creek Base Flow	Carlls River Base Flow	Sampawams Creek Base Flow	Connetquot River Base Flow	Swan River Base Flow	Carmans River Base Flow
Valley Stream	1.000	0.708	0.016	0.222	-0.158	-0.278	-0.060	-0.306	0.504	0.314
Pines Brook		1.000	0.720	0.154	0.215	-0.051	0.124	-0.375	0.172	0.241
East Meadow Brook			1.000	0.352	0.504	0.184	-0.148	-0.276	0.047	0.028
Bellmore Creek				1.000	0.685	0.550	0.257	-0.006	0.603	0.277
Massapequa Creek					1.000	0.623	0.326	0.017	0.401	0.054
Carlls River						1.000	0.483	0.136	0.037	0.203
Sampawams Creek							1.000	0.210	0.042	0.140
Connetquot River								1.000	-0.051	0.019
Swan River									1.000	0.360
Carmans River										1.000

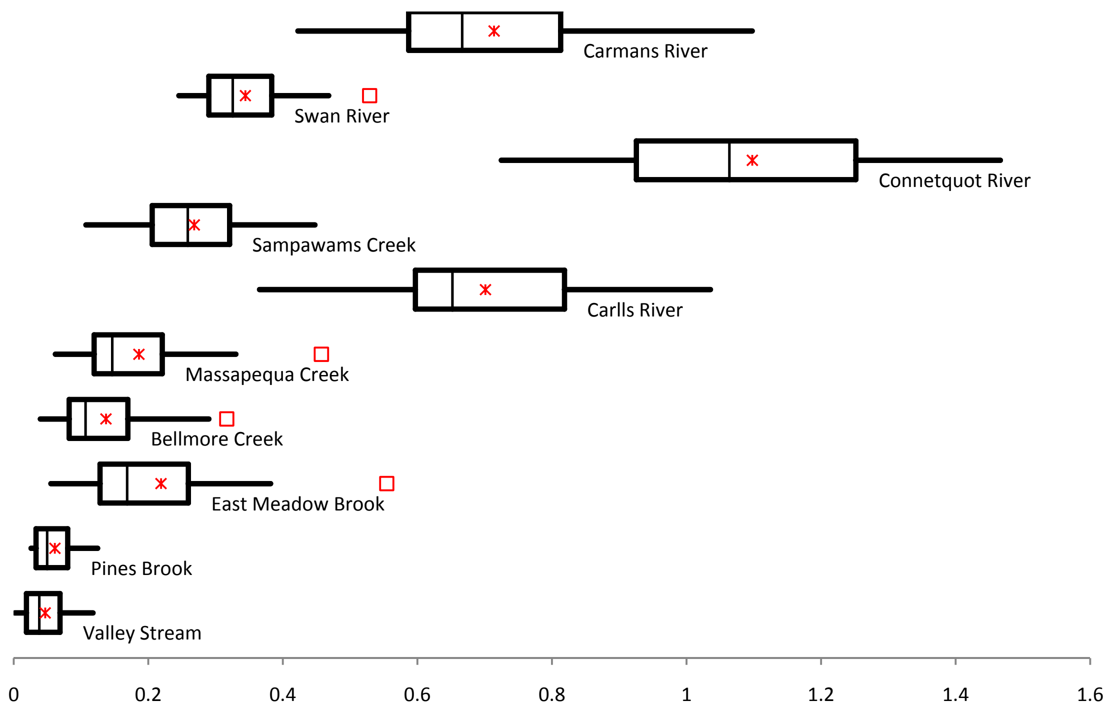


Figure 3: Average Annual Total Flow Rate (m^3 / s) from 1980 - 2008

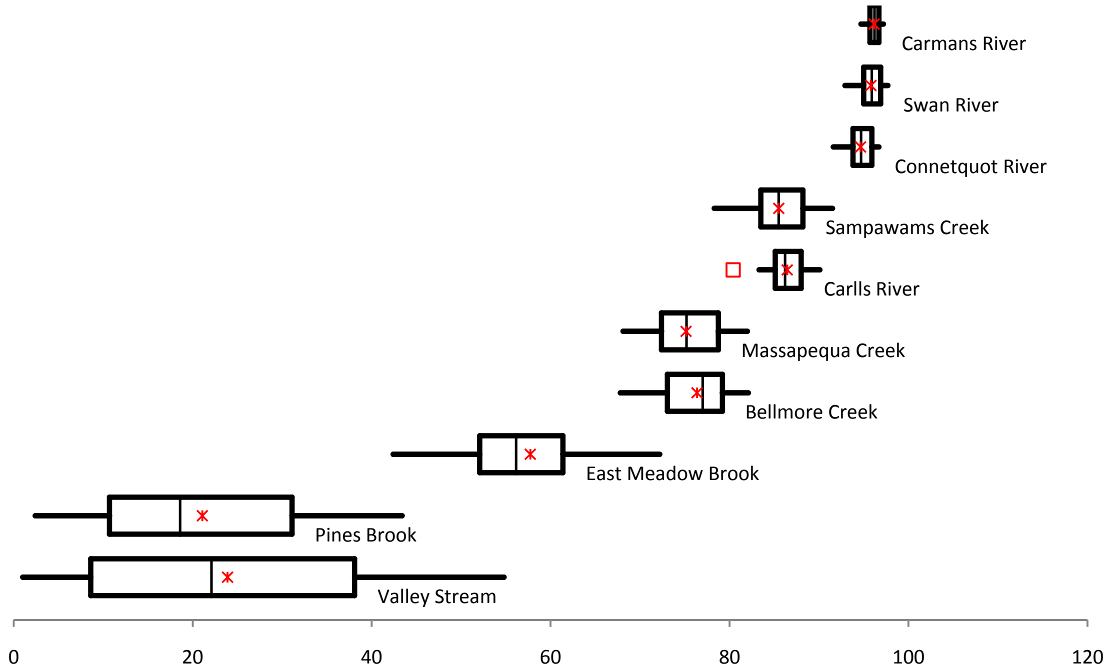


Figure 4: Average Annual Base Flow Percent: 1980 - 2008

Table 4: Regression statistics for LI south shore stream from 1980 - 2008

Stream Name	Regression Coefficient (slope)	R^2	t-Value	p-Value
Valley Stream	1.6324	0.7295	8.5328	< 0.0001
Pines Brook	0.8479	0.1578	1.7848	0.0922
East Meadow Brook	-0.2689	0.0863	-1.4079	0.1738
Bellmore Creek	0.0135	0.0007	0.1149	0.9097
Massapequa Creek	-0.1979	0.1465	-1.8527	0.0787
Carlls River	-0.1287	0.2386	-2.9084	0.0072
Sampawams Creek	-0.0771	0.0341	-0.9757	0.3379
Connetquot River	-0.0216	0.0165	-0.6472	0.5234
Swan River	0.0871	0.2665	3.0733	0.0049
Carmans River	0.0315	0.1384	2.0828	0.0469

In Table 4, the t-Value represents the ratio of the coefficient to its standard error. Using a t-distribution, the null hypothesis of the regression coefficient being equal to 0 was tested. The null hypothesis was rejected for associated p-values less than 0.05 (95% confidence). Using this criterion, only Valley Stream, Carlls River, Swan River, and Carmans River had statistically significant changes in their base flow. However, Valley Stream had the only coefficient of determination above 0.5. Given, the low R^2 values and small regression coefficients, it was reasonable to conclude that the only significant change in base flow over the last 25 years occurred at Valley Stream.

DISCUSSION

The most noteworthy finding of the study was that Valley Stream appeared to be gaining base flow relative to its overall flow between 1980 and 2008. The percentage of base flow increased at about 1.6 percent a year and by approximately 40 percent over the study time period. Busciolano (2005) attributes the base flow improvement in Valley Stream to a sharp decrease in groundwater pumping in central and eastern Queens County in the mid1980's due to concerns of saltwater intrusion. The resulting local water table rise extended to western Nassau County and Valley Stream. To a lesser extent, the water table rise appeared to have also improved the base flow of Pines Brook. Given that the correlation between Valley Stream and Pines Brook was 0.708, it is possible that Pines Brook would have also show similar signs of improvement in base flow if data after 1999 was available. Without the last 10 years of data, it is difficult to show statistically significant improvement in the stream. Given the improvement of Valley Stream, and presumably Pines Brook, further research into the current water quality and ecological health of the western Nassau County streams is suggested.

The correlation table (Table 3) shows that, at least in Nassau County, the percent base flow in streams appeared to have an above average correlation with the adjacent stream. This was reasonable and most likely because the streams were relatively close together (Figure 1) and the level of development in both areas was similar.

Other than Valley Stream, and possibly Pines Brook, little has changed in the base flow characteristics of Long Island south shore streams. The average base flow as a portion of total stream flow varies from 21 percent in western Nassau County to 96 percent in Suffolk County. These results are in agreement with the results of Simon and Reynolds (1982) and Spinello and Simmons (1992). Likewise, given the relatively stable population on Long Island for the last 30 years, it appears that U.S. Census population trends can be used as a rough approximation of stream urbanization trends.

CONCLUSION

The increase in groundwater pumping, impervious surfaces, storm sewers, and sanitary sewers in urbanized watersheds causes changes in the flow characteristics of local streams. Urbanized streams have depressed base flow and are more prone to flash flooding. These urbanized streams are also associated with decreased and highly variable water quality and decreased ecological diversity.

Prior studies, (Simon and Reynolds, 1982; Spinello and Simmons, 1992) found that from 1955 to 1985, base flow had decreased to 14 percent in highly urbanized areas with sewers, 79 percent in newly sewered areas, 88 percent in unsewered suburban areas, and 96 percent in rural areas. From 1980 to 2008, the base flow has remained stable in all streams except for Valley Stream where the base flow has increased by 1.6 percent a year to approximately 45 percent in 2008. The increase is attributed to reduced groundwater pumping in New York City after 1980.

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