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A Comparison of 7Q10 Low Flow between Rural and Urban Watersheds in Eastern United States

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To the Graduate Council:

I am submitting herewith a thesis written by Saeed Zabet entitled "A Comparison of 7Q10 Low Flow between Rural and Urban Watersheds in Eastern United States." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

John S. Schwartz, Major Professor

We have read this thesis and recommend its acceptance:

Joshua Fu, Glenn Tootle

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

A Comparison of 7q10 Low Flow between Rural and Urban Watersheds in Eastern United States

A Thesis
Presented for the
Master of Science
Degree
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Saeed Zabet
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Abstract: Increased runoff peaks and volumes from urbanizing watersheds have been well documented where watershed hydrology becomes modified after 10 to 25% of land area is developed. Lowering of baseflow has also been reported to be modified from urbanization; however hydrology thresholds related to percentage of land area developed are not well quantified. In this study, 100 watersheds in eastern USA were investigated to examine the potential effects of urbanization on low flows. The low flow metric chosen for this analysis is the 7Q10. Historical flow records were obtained from the USGS stream gauges, in which a minimum of 10 years of data were used for computing the 7Q10. Corresponding with flow data records, USGS Seamless land cover images for years 1992 and 2001 were used to quantify the percent land area urbanized. Using ArcGIS, land cover data for these two years were used to estimate percentage of urbanization by summing the land cover areas for industry, commercial, and high-density residential and dividing by the total watershed area above the USGS gauging station. Differences in 7Q10 values between the two periods were statistically analyzed using the Wilcoxon signed rank test. Results showed a significant decrease in low flow due to increased urbanization percentage from 0 to 11%. Decreases in low flows were sporadic as urbanization percentage increased from 11 to 23%, but for urbanization percentage more than 23% the increment of low flow were not significantly different.

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Chapter 1: Introduction

The importance of having sustainable low flow during drought seasons has increased the concern about whether a watershed exposed to an increasing rate of urbanization produces an essential amount of low flow (Brandes et al., 2005). According to International glossary of hydrology (WMO, 1974) “low flow is the flow of water in a stream during prolonged dry weather”. During a low flow event, there is not enough water available to meet the needs of effluent loadings dilution, this result in higher concentration of pollutants in stream and can endanger the aquatic and human life (EPA, 1991). It is of major concern for any urbanizing watersheds to sustain adequate amount of low flow (Brandes et al, 2005). The prediction of increases in population up to 83% and 56% in 2030 for developed and underdeveloped countries respectively, compared to 75% and 40% increases in 2000, dramatically increases these hydrological concerns (Jacobson, 2011).

Although numerous studies have been done to understand the impacts of urbanization on peak flow and runoff the knowledge of urban development impacts on low flow is scarce and the results are in contradiction (Brandes, 2005). A simplistic relation between low flow and urban development is depicted by the water budget equation (Thornthwaite and Mather, 1957) and Horton infiltration capacity equations (Horton, 1933).

Infiltration =Precipitation – Run off–Evapotranspiration+ Change in moisture storage (1)

Since infiltration to the groundwater table is the source of base flow in streams and deeper aquifers a change in amount of infiltration can alter the base flow conditions.

$$f_p = f_c + (f_c - f_o)e^{-kt} \qquad (2)$$

Where:

f_p = the infiltration capacity (depth/time) at some time t
k = a constant representing the rate of decrease in / capacity
f_c = a final or equilibrium capacity
f_o = the initial infiltration capacity

The *"f"* parameter or infiltration capacity in equation 2 varies for different media or land cover. Because the infiltration capacity for asphalt (*f*=0.036-0.36mm/hr for Asphalt Concrete type A1) is much less than for most soils (*f*=12.5-25mm/hr for sandy soils). Land cover that changes from natural material to artificial paving materials will theoretically result in decreased base flow. However, there is a possibility of increasing base flow as the consequence of increasing the amount of discharge from leaking water system and sewer systems (Meyer, 2002). Furthermore, urbanization increases the surface temperature which is known as heat islands effect (Myrup, 1969); this can exacerbate the impacts of urbanization by increasing evapotranspiration that results in reduction of both the runoff and infiltration.

Several studies have been conducted to understand the impacts of urban development on low flow (Table 1.3). Leopold (1968) displayed that increasing the amount of impervious surface cover results in declining low flow. Later Hammer (1973) confirmed Leopold's results for imperviousness ratios less than 40-50%. Hollis (1976), Klein (1979), Simmons and Reynolds (1982), Ferguson and Suckling (1990) achieved the same results doing individual researches. Spinello and Simmons (1992) and Scorca (1997) conducted a study on Long Island, NY and explored that base flow decreased due to urbanization development.

Finkenbine et al. (2000) analyzed watersheds in Vancouver, Canada with range of urbanization varying from 5 to 77 percent of total area. The results of their study showed that summer base flow stays steadily low during summer when the imperviousness percentage is larger than 20 to 40 percent. Wang et al. (2001) reported a threshold region between 8 to 12% in which the stream conditions change abruptly due to changes in urbanization. The case study included 47 small watersheds exposed to urban development in southeastern Wisconsin. Another study of 10 selected streams in Puget Sound basin in western Washington showed increases in one urban stream and one suburban stream, and decreases in one suburban and two rural streams (Konrad and Booth, 2002). Later work done by Brandes et al. (2005) on six urbanizing watersheds at the scale of 25 to 200 km^2 showed that there was no decrease in base flow as urbanization increased from 7 to 21%. Kauffman et al. (2009) investigated the effects of urbanization on 19 watersheds in Newark, Delaware, where watersheds have experienced a growth in impervious surface coverage from 3 to 44%. The results displayed a correlation between increased impervious surface cover and decreased base flow. The results also confirmed that urbanization and its byproducts are factors that reduce groundwater recharge which is the source of base flow in streams. Other researchers similarly displayed a negative effect of urbanization development on low flow, while several show opposing results (Table 1.1).

Table 1.1: Summary of research on the impact of urbanization on base flow

No	Date	Author(s)	Watershed	Area	Low Flow		Urbanization%
					Decrease	Increase	
1	**1968**	**Leopold**	**Brandywine**	**Southeastern Pa.**	√		
							< 40-50
2	**1973**	**Hammer**	**Schuylkill**	**Philadelphia, Pa.**	√		
3	**1976**	**Hollis**	**Canon's Brook**	**England**	√		
4	**1979**	**Klein**	**Chesapeake**	**Maryland**	√		
5	**1982**	**Simmons, Reynolds**	**South Shore**	**Long Island, N.Y.**	√		
6	**1990**	**Ferguson, Suckling**	**Peachtree Creek**	**Atlanta**	√		
7	**1992**	**Ku et al.**	**Nassau County**	**New York**		√ **(in growing season)**	
8	**1992**	**Spinello, Simmons**	**South Shore**	**Long Island, N.Y.**	√		
9	**1997**	**Scorca**	**East Meadow**	**Long Island, N.Y.**	√		
10	**2000**	**Finkenbine, Atwater**	**English Bay**	**Vancouver, B.C.**	√		**>20-40**
11	**2001**	**Wang, Lyons, Kanehl**	**Fox River**	**Southeastern Wis.**	√		**8-12treshhold**
12	**2001**	**Rose and Peters**	**Piedmont & Blue Ridge**	**Georgia**	√		
13	**2002**	**Jennings, Jarnagin**	**Accotink Creek**	**Virginia**		√**(stream flow)**	
14	**2002**	**Meyer**	**Illinois**			√	
15	**2002**	**Konrad and Booth**	**Puget Sound**	**Washington**	√	√	
16	**2005**	**Brandes et al.**	**Delaware River**	**New Jersey, Pa**	**-No change -**		**7–21**
17	**2005**	**Rogers and DeFee**	**White Oak**	**Houston**	√**(drought)**		
18	**2009**	**Kauffman**	**White Clay Creek**	**Delaware**	√		**3-44**

While many studies have been conducted to understand the trends of base flow due to urbanization, the final results are inconsistent. The primary problem is that studies suffer from lack of study sites, usually fewer than 20 watersheds.While in one case, Wang et al. (2000) employed 47 watersheds for the research, it seems that no one else used a large enough data set to strongly accept or reject the hypothesis that low flow decreases due to urbanization. Because most scholars report both increases and decreases in base flow, it could be hypothesized that there are thresholds that change the results.

A third problem that some researchers (Brandes et al., 2005) used population density as the indicator of urbanization. Population density is not an appropriate indicator to calculate the exact percentage of imperviousness for several reasons: First, population density is typically based on census information, while, census area boundaries do not coincide with watershed boundaries. The accuracy of population density estimates will depend on the size and distribution of the census areas and the sub-watershed being considered. Second, population is only a good measure in areas with a relatively homogeneous pattern of urbanization (e.g. heavy concentrations of industrial development have high imperviousness but low population density); as a result, population is most useful at a somewhat larger, regional scale for rough comparisons.

The objective of this research was to investigate potential effects of urbanization on low flows, as a function of 7Q10 hydrological statistics and urban area percentage. For this reason it was decided to examine the relationship between urban development and stream base flow in 100 watersheds in northeast, eastern USA between 1985 and 2005. Number of watersheds was large enough to test the hypothesis that there is a statistical difference between periods of low-urbanization and high-urbanization. Only USGS gauging stations that had enough discharge data to calculate 7Q10 low flow during this period of time were selected.

Chapter 2: Literature Review

2.1. Water Balance Equation

A water budget or water mass balance can be calculated for any time increment for a chosen control volume, where:

$\text{Inflows} - \text{Outflows} = \Delta\text{Storage}$

A more developed water budget equation, adapted from Thornthwaite and Mather (1957), could be written in this form:

$I = P - R - ET + \Delta S$

Where

I=infiltration to the groundwater table as the source of dry weather flow (low flow);

P=precipitation;

R=runoff that flows overland to a waterway;

ET =evaporation directly to the atmosphere plus transpiration by plants;

ΔS=change in moisture storage in surface water, groundwater, and/or soil.

The different parts of water budget equation are depicted in Figure2.1 to give a better understanding of how these parameters work together.

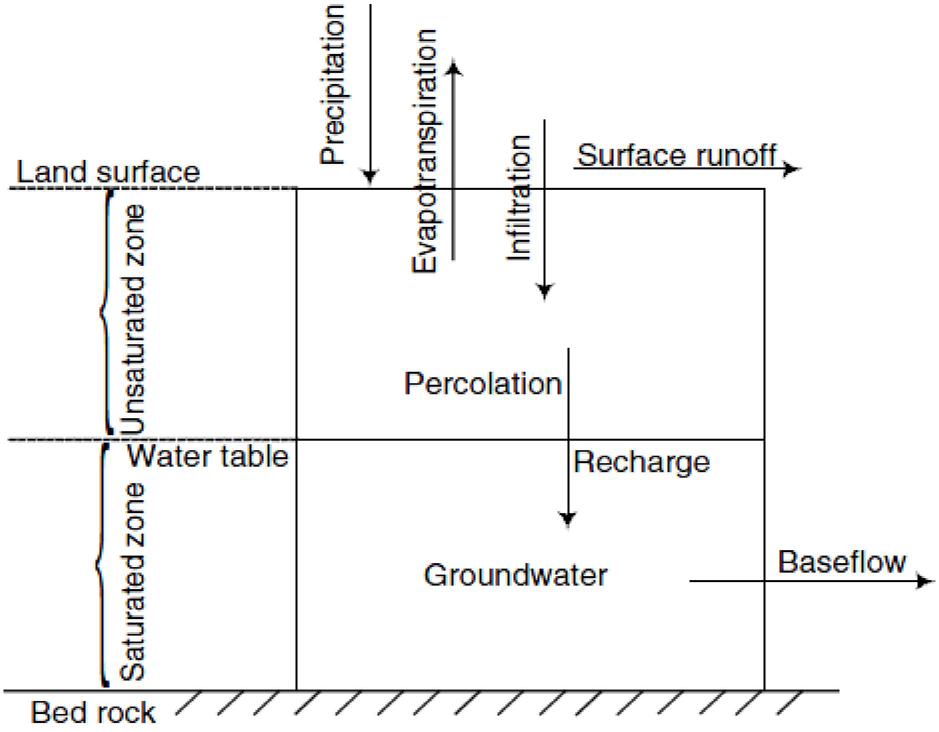


Fig 2.1: Schematic diagram of process to form the baseflow (Lin et al., 2007)

According to Horton (1933) infiltration divides rainfall into two parts. One part becomes surface runoff and the other goes initially into the soil and to the stream as base flow or it returns to the air by evaporative processes. By changing the land cover from grass or any natural area to an impervious area such as parking lots or rooftops, the infiltration capacity in Horton’s equation changes and it results in changes in water balance equation parameter, which normally decreases infiltration, therefore any change in land cover will change the infiltration amount into the ground.

2.2. Urbanization and Imperviousness

Urbanization is not a simple phenomenon but it is multidimensional (McIntyree et al, 2000) and incremental (Jacobson, 2011). Shuster et al. (2005) define urbanization as: “equivalent to the disturbance of natural landscape and eventual replacement of vegetated surfaces with impermeable surface.” It might happen gradually or rapidly and in different forms such as: industrial, retail, or housing development. In this process, topography, vegetation, soils, and channel networks can change, so the compound effect of all these alterations shape urban development (Booth et al., 2004). Imperviousness, which is an important environmental indicator, is also an essential characteristic of urbanization. Impervious land cover is any land cover that inhibits the infiltration of water into the ground. Roads and rooftops are two major types of impervious surfaces, while features such as sediment, patios, and bedrock are not as important (Arnold and Gibbons, 1996). Impervious land cover when considered for the entire area is called total impervious area (TIA) and is the most dominant measure of imperviousness (Shuster et al., 2005).

Aerial photography and satellite imagery are useful tools to identify land cover and level of urbanization. The knowledge of land mapping almost starts in mid-1940’s when Francis J. Marschner began mapping major land use in United States by using aerial photography method. Many land cover maps developed by individual companies and organizations employ both aerial and satellite imagery, but none of them were standard. It wasn’t until 1971 that Anderson developed the classification criteria for land use. The last revision of Anderson's land cover classification were used as a standard land cover for 1992, 2001, and 2006 land cover maps of United States, which is available in USGS seamless viewer website. More recently remote sensing has been used to estimate the impervious area (Weng, 2010).

While satellite images are the most accurate techniques to determine the imperviousness percentage for urban area, it is time consuming and more expensive than the other techniques like the population density method introduced by Stankowski in 1972.

Stankowski (1972) explored a correlation between population density and impervious area by using the data from New Jersey. He used population density in New Jersey to generate curves relating percentage of impervious area to corresponding population density values. He realized that the curves follow a pattern of second degree polynomials and the equations are:

$I_{low}=0.170D^{1.165-0.094\log D}$,

$I_{intermediate}=0.0218\ D^{1.206-0.100\log D}$,

$I_{high}=0.0263D^{1.247-0.108\log D}$,

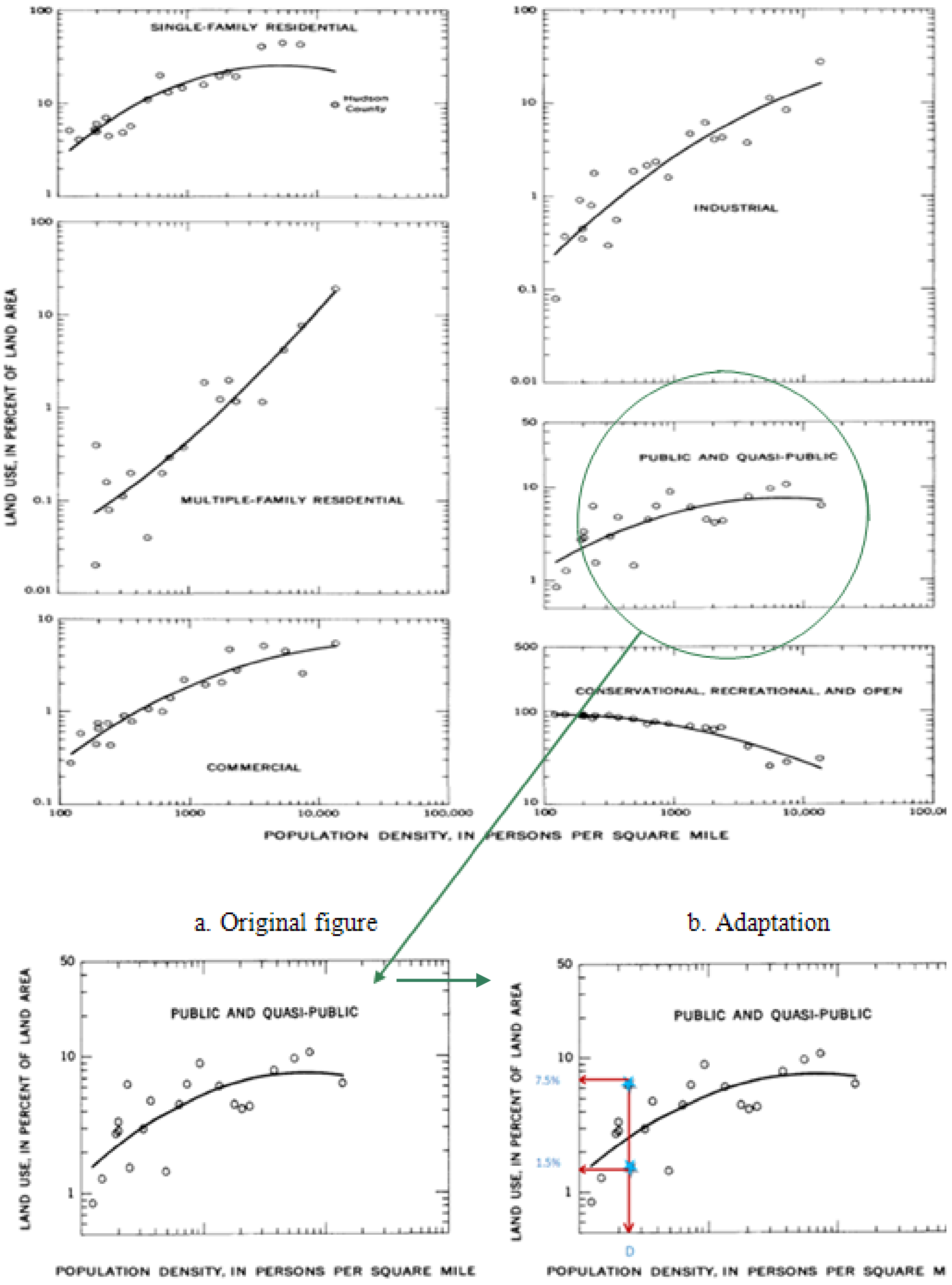
where:

I_{low}, $I_{intermediate}$,and I_{high} =Percentage of impervious land area on the low, intermediate, and high impervious area weighthing factors, respectively.

D = the population density, in persons per square mile.

By knowing the population density for each area, which is available in terms of census data, one can estimate the imperviousness percentage of that area for the given year, using the Stankowski (1972) empirical equation. Although it seems an easy and fast method it's not as accurate as satellite imagery method. In Figure 2.2 it is shown that how for the same population density we may have two different imperviousness percentages.

Figure 2.2.a is the graph used by Stankowski to find the regression between public-quasi-public area and population density. In Figure 2.2.b it can be seen that for two different counties with the population density, we assume here as “D”, the real impervious percentage is equal to 7.5% for one county and 1.5% for the other one comparing to 2.5% value estimating from regression line. Despite the inaccuracy of this method some researchers such as Brandes et al. (2005) preferred to use population density method for their research. It can be assumed as the reason that their result is different from the other studies.



a. Original figure

b. Adaptation

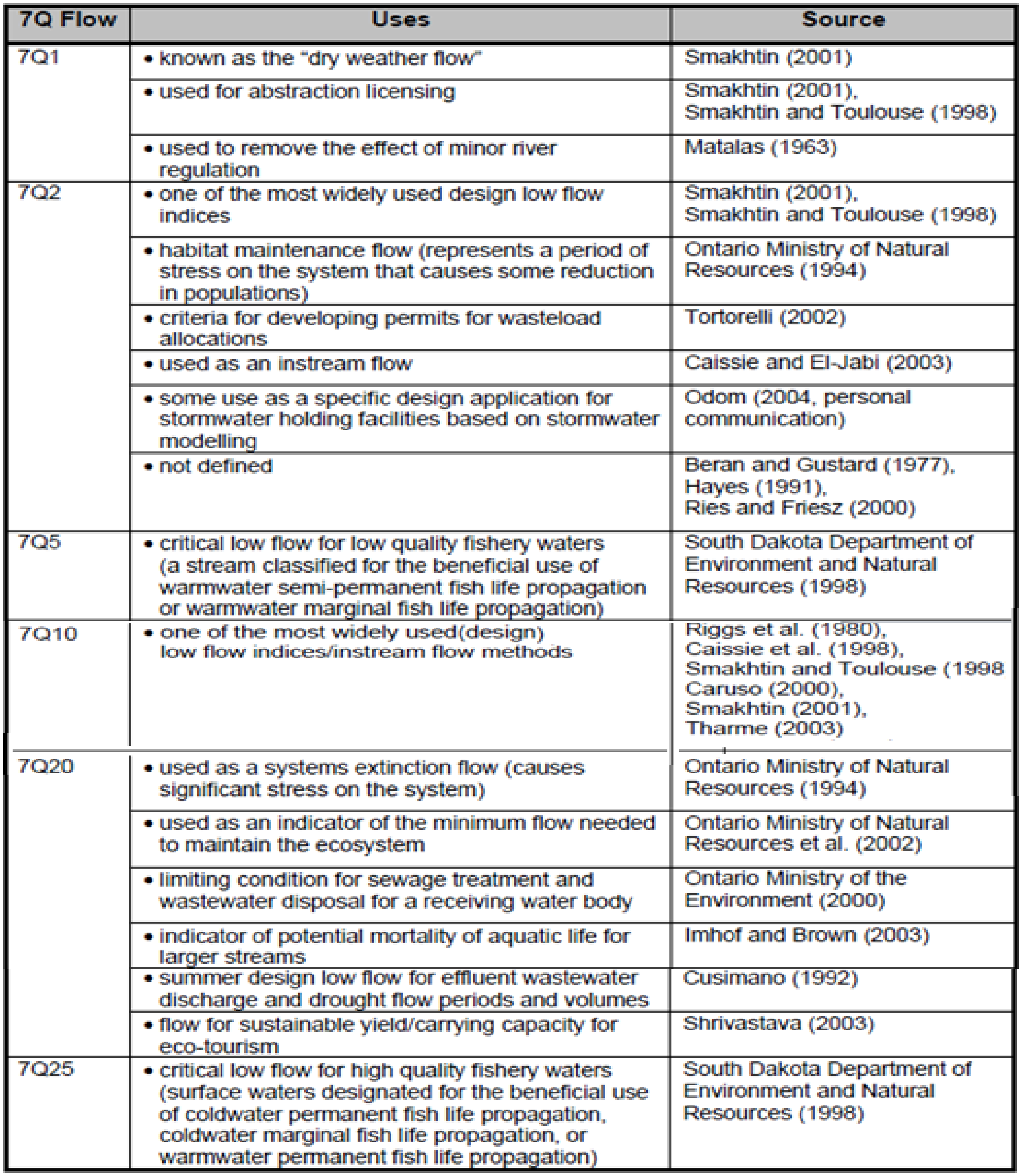
Fig 2.2: Relation between land use and population density for countries in New Jersey for public and quasi-public (Stankowski, 1972)

2.3. Low flow

Low flow is the "flow of water in a stream during prolonged dry weather," according to the World Meteorological Organization. Smakhtin (2001) emphasizes that the sources of low flow can be ground water or surface water but it always refers to lowest annual flow that occurs seasonally each year. As he emphasized there are gains and losses that affect low flows. Gains to low flows may be maintained by: lakes, reservoirs, drainage from fracture zones above the watershed, and near surface. Losses to low flows may be caused by: direct evaporation, transpiration, ground water recharge, and bed losses

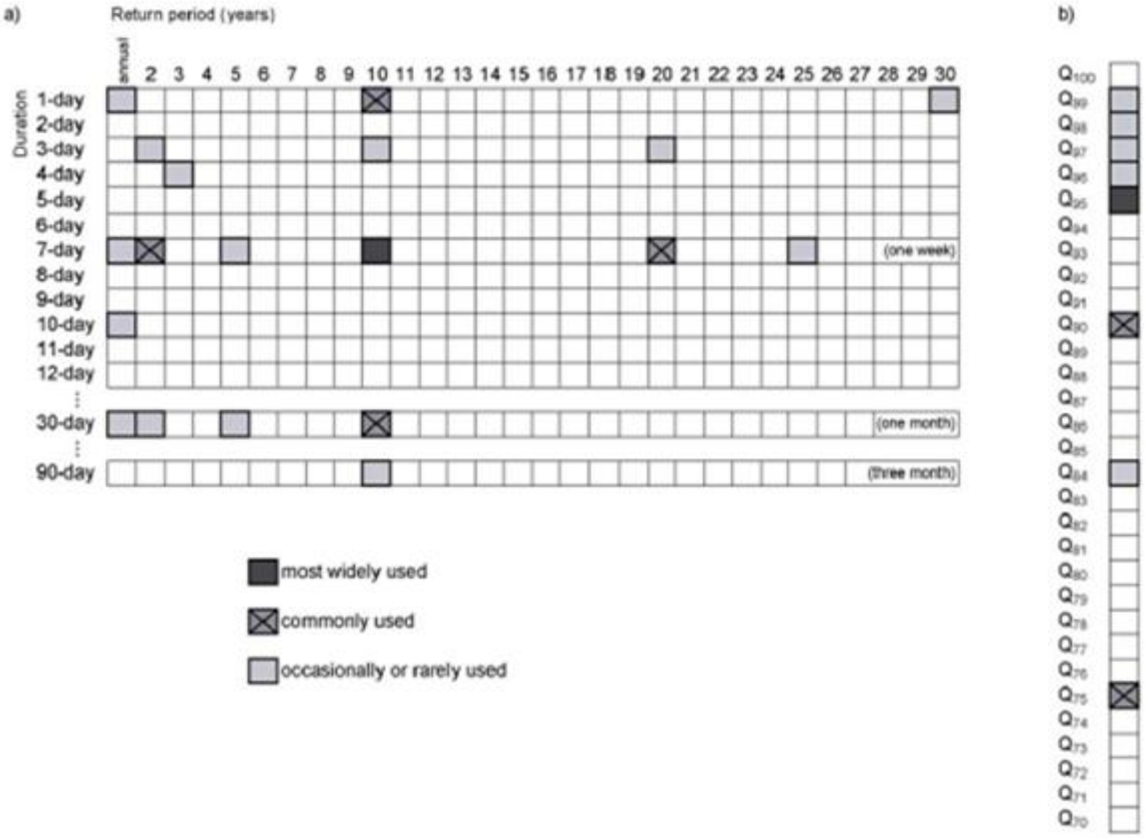
Low flow can be categorized as two different types: indices and exceedance percentiles. The notation for indices type is nQy, which can be interpreted as n-day low flow (Q) with y-year return period. On other hand the notion for the second form is Qp which can be interpreted as the flow discharge that is possibly exceeded p-percent of the time (Pyrce, 2004). The most typical types of low flow are shown in Tables 2.1 and 2.2.

Table 2.1: Most typical types of 7Q indices and their usage (Pyrce, 2004)



7Q Flow	Uses	Source
7Q1	• known as the "dry weather flow"	Smakhtin (2001)
	• used for abstraction licensing	Smakhtin (2001), Smakhtin and Toulouse (1998)
	• used to remove the effect of minor river regulation	Matalas (1963)
7Q2	• one of the most widely used design low flow indices	Smakhtin (2001), Smakhtin and Toulouse (1998)
	• habitat maintenance flow (represents a period of stress on the system that causes some reduction in populations)	Ontario Ministry of Natural Resources (1994)
	• criteria for developing permits for wasteload allocations	Tortorelli (2002)
	• used as an instream flow	Caissie and El-Jabi (2003)
	• some use as a specific design application for stormwater holding facilities based on stormwater modelling	Odom (2004, personal communication)
	• not defined	Beran and Gustard (1977), Hayes (1991), Ries and Friesz (2000)
7Q5	• critical low flow for low quality fishery waters (a stream classified for the beneficial use of warmwater semi-permanent fish life propagation or warmwater marginal fish life propagation)	South Dakota Department of Environment and Natural Resources (1998)
7Q10	• one of the most widely used(design) low flow indices/instream flow methods	Riggs et al. (1980), Caissie et al. (1998), Smakhtin and Toulouse (1998 Caruso (2000), Smakhtin (2001), Tharme (2003)
7Q20	• used as a systems extinction flow (causes significant stress on the system)	Ontario Ministry of Natural Resources (1994)
	• used as an indicator of the minimum flow needed to maintain the ecosystem	Ontario Ministry of Natural Resources et al. (2002)
	• limiting condition for sewage treatment and wastewater disposal for a receiving water body	Ontario Ministry of the Environment (2000)
	• indicator of potential mortality of aquatic life for larger streams	Imhof and Brown (2003)
	• summer design low flow for effluent wastewater discharge and drought flow periods and volumes	Cusimano (1992)
	• flow for sustainable yield/carrying capacity for eco-tourism	Shrivastava (2003)
7Q25	• critical low flow for high quality fishery waters (surface waters designated for the beneficial use of coldwater permanent fish life propagation, coldwater marginal fish life propagation, or warmwater permanent fish life propagation)	South Dakota Department of Environment and Natural Resources (1998)

Table 2.2: Hydrologically based low flow estimates using: a) flow indices b) flow Duration (Pyrce, 2004)



a)

Return period (years)

Duration	annual	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1-day	▨									☒																				▨
2-day																														
3-day		▨								▨										▨										
4-day			▨																											
5-day																														
6-day																														
7-day	▨	☒			▨					■										☒					▨			(one week)		
8-day																														
9-day																														
10-day	▨																													
11-day																														
12-day																														
⋮																														
30-day	▨	▨			▨					☒																		(one month)		
⋮																														
90-day										▨																		(three month)		

■ most widely used

☒ commonly used

▨ occasionally or rarely used

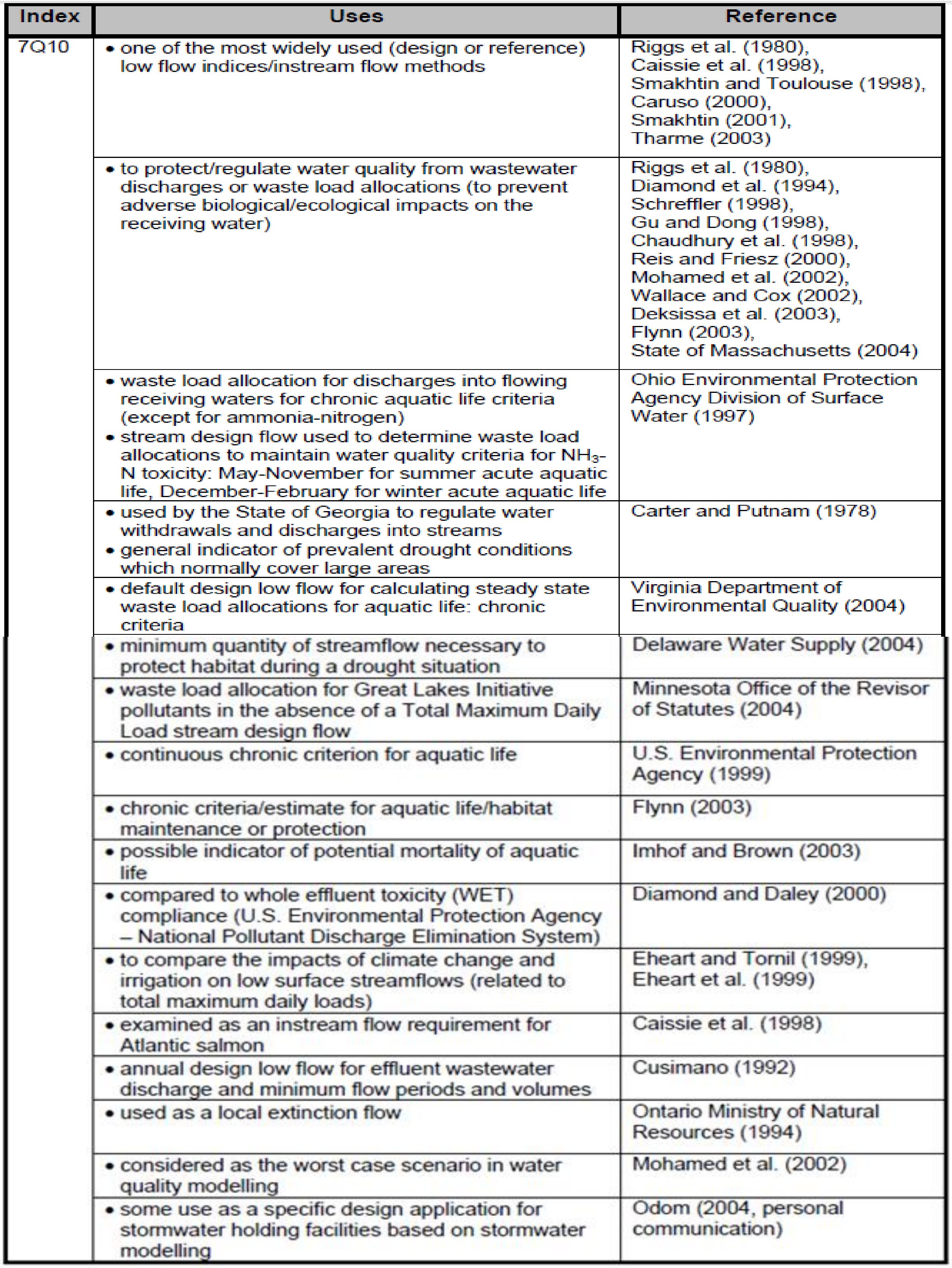
b)

Q_{100}	
Q_{99}	▨
Q_{98}	▨
Q_{97}	▨
Q_{96}	▨
Q_{95}	■
Q_{94}	
Q_{93}	
Q_{92}	
Q_{91}	
Q_{90}	☒
Q_{89}	
Q_{88}	
Q_{87}	
Q_{86}	
Q_{85}	
Q_{84}	▨
Q_{83}	
Q_{82}	
Q_{81}	
Q_{80}	
Q_{79}	
Q_{78}	
Q_{77}	
Q_{76}	
Q_{75}	☒
Q_{74}	
Q_{73}	
Q_{72}	
Q_{71}	
Q_{70}	

2.4. 7Q10 Low Flow

The most commonly used low flow metrics are 7Q10 and Q95. 7Q10 is the most dominant low flow metrics used by US agencies and researchers (Smakhtin, 2001). It’s the lowest 7-day average flow that occurs on average once every 10 years. In Russia and Eastern Europe 1-day and 30-day indices are mostly used for summer and winter respectively, and in UK 7-day average flow or dry weather flow is used for low flow (Smakhtin, 2001). General usage of 7Q10 is given in Table 2.3.

Table 2.3: General usage of 7Q10 low flow (Pyrce, 2004)



Index	Uses	Reference
7Q10	• one of the most widely used (design or reference) low flow indices/instream flow methods	Riggs et al. (1980), Caissie et al. (1998), Smakhtin and Toulouse (1998), Caruso (2000), Smakhtin (2001), Tharme (2003)
	• to protect/regulate water quality from wastewater discharges or waste load allocations (to prevent adverse biological/ecological impacts on the receiving water)	Riggs et al. (1980), Diamond et al. (1994), Schreffler (1998), Gu and Dong (1998), Chaudhury et al. (1998), Reis and Friesz (2000), Mohamed et al. (2002), Wallace and Cox (2002), Deksissa et al. (2003), Flynn (2003), State of Massachusetts (2004)
	• waste load allocation for discharges into flowing receiving waters for chronic aquatic life criteria (except for ammonia-nitrogen) • stream design flow used to determine waste load allocations to maintain water quality criteria for NH_3-N toxicity: May-November for summer acute aquatic life, December-February for winter acute aquatic life	Ohio Environmental Protection Agency Division of Surface Water (1997)
	• used by the State of Georgia to regulate water withdrawals and discharges into streams • general indicator of prevalent drought conditions which normally cover large areas	Carter and Putnam (1978)
	• default design low flow for calculating steady state waste load allocations for aquatic life: chronic criteria	Virginia Department of Environmental Quality (2004)
	• minimum quantity of streamflow necessary to protect habitat during a drought situation	Delaware Water Supply (2004)
	• waste load allocation for Great Lakes Initiative pollutants in the absence of a Total Maximum Daily Load stream design flow	Minnesota Office of the Revisor of Statutes (2004)
	• continuous chronic criterion for aquatic life	U.S. Environmental Protection Agency (1999)
	• chronic criteria/estimate for aquatic life/habitat maintenance or protection	Flynn (2003)
	• possible indicator of potential mortality of aquatic life	Imhof and Brown (2003)
	• compared to whole effluent toxicity (WET) compliance (U.S. Environmental Protection Agency – National Pollutant Discharge Elimination System)	Diamond and Daley (2000)
	• to compare the impacts of climate change and irrigation on low surface streamflows (related to total maximum daily loads)	Eheart and Tornil (1999), Eheart et al. (1999)
	• examined as an instream flow requirement for Atlantic salmon	Caissie et al. (1998)
	• annual design low flow for effluent wastewater discharge and minimum flow periods and volumes	Cusimano (1992)
	• used as a local extinction flow	Ontario Ministry of Natural Resources (1994)
	• considered as the worst case scenario in water quality modelling	Mohamed et al. (2002)
	• some use as a specific design application for stormwater holding facilities based on stormwater modelling	Odom (2004, personal communication)

2.5. 7Q10 estimation methods

There four major methods to compute low flow 7Q10 are given here (Tasker, 1978):

2.5.1. Log-Pearson III (LPLII) Distribution

This method was described by Bobee (1975). Using this method, the nonzero 7-day annual minimum for each day should be transformed to logarithms and then the other parameters should calculate as follows:

$$y_{ij} = \ln x_{ij} \quad \text{for } i = 1, \ldots, n_j$$

$$\bar{Y}_j = \frac{1}{n_j} \sum_{i=1}^{n_j} y_{ij}$$

$$S_j = \left(\frac{\sum_{i=1}^{n_j} (y_{ij} - \bar{y}_j)^2}{n_j - 1} \right)^{1/2}$$

$$g_j = \frac{n_j \Sigma (y_{ij} - \bar{y}_j)^3}{(n_j - 1)(n_j - 2) S_j^3}$$

$$X_{jT} = \exp(\bar{Y}_j + K_T S_j)$$

where:

x_{ij} = the 7-day annual minimum for year i at site

n_j = the number of years of record at site j

Y = the mean at site i are

S = standard deviation at site i are

gj = skewness coefficient at site i are

K_T =a function of the skewness coefficient

(Tables of KT are available in texts such as Haan (1977))

X_{jT} = The 7-day, T-year low flow

2.5.2. Three Parameter Weibull (WB) Distribution

The Weibull distribution is often used as the distribution of low stream flows. The probability density function is:

$$f(x) = \frac{a}{u-e}\left(\frac{x-e}{u-e}\right)^{a-1} \exp -\left(\frac{x-e}{u-e}\right)^{a}$$

where:

e: is the lower boundary,

u: the characteristic drought,

a: the shape parameter.

The parameters are estimated using the algorithm suggested by Condie and Nix (1975).

2.5.3. Box-Cox Transformation Method

Box-Cox method initially introduced by Chander, et al (1978) and Kuczera (1983) individualy and later were generalized by Box and Cox in 1964 (Tasker, 1987). To estimate low flow with this method we need to develop an approximately normal arbitrary variable named q as follow:

$$q = \begin{cases} \frac{x^{\lambda}-1}{\lambda} & \lambda \neq 0 \\ \log(x) & \lambda = 0 \end{cases}$$

where λ is chosen so as to make q an approximately normal random variable with mean μ and standard deviation σ, and x is the annual 7-day low flow. λ should satisfy the following equation given by Cohn (1986):

$$f(x) = x^{\lambda-1} \exp \Big\} -0.5\sigma^{-2} \left[(x^{\lambda}-1)/\lambda-\mu\right]^{2} \Big\{ /(\Omega \cdot \sigma \sqrt{2\pi}$$

$$\Omega = \begin{cases} \Phi[(-1/\lambda-\mu)/\sigma] & \lambda<0 \\ 1 & \lambda=0 \\ 1-\Phi[(-1/\lambda-\mu)/\sigma] & \lambda>0 \end{cases}$$

Where φ is the CDF of the standard normal distribution.

$$X_T = \left[(\sigma z_p + \mu)\lambda + 1\right]^{1/\lambda}$$

$$p = \begin{cases} \dfrac{\Omega}{T} \text{ for } \lambda<0 \\ 1-\Omega + \dfrac{\Omega}{T} \text{ for } \lambda>0 \end{cases}$$

Zp is the standard normal deviate for probability p and Xt is the low flow.

2.5.4. Log-Boughton Method

This method was developed by Loganathan, et al (1985). In this method the observed 7-day annual minimums (Xi) are transformed to log (base 10) values and standardized as follows:

$$z_i = \log_{10}(x_i)$$

Then Ki were computed by knowing Zi:

$$K_i = \frac{z_i - M_z}{S_z}$$

Where:

K is the standardized transformed flow,

Mz the sample mean of the z's,

Sz the sample standard deviation of the z's,

Then plotting positions, PPi' are obtained for each observation using the Cunnane (1978) formula, so that:

$$pp_i = \frac{m_i - 0.4}{n + 0.2}$$

where m is the rank, from largest to smallest, of observation i and n is the number of observations. Then variable G1 is computed:

$$G_i = \ln\left[\ln\left(\frac{1}{1 - pp_i}\right)\right]$$

Boughton (1980) observed that the relation between K and G very nearly fits a curve given by:

$$C = (K_i - A)\ (G_i - A)$$

where C and A are constants to be determined. Parameters A and C are estimated using a least squares fit to minimize the mean square error of KG1. The fitted frequency factor is determined from:

$$K_i^* = \hat{A} + \frac{\hat{C}}{G_i - \hat{A}}$$

where A and are the least squares estimates of A and C. A linear least squares regression is used to determine an adjusted mean, M*, and adjusted standard deviation, S*, from the equation

$$z_i = M^* + K_i^*\ S^*$$

The T-year flow is

$$X_T = 10^{(M^* + K_T S^*)}$$

The results of a study done by Tasker (1987) showed that the LPIII and Weibull methods perform better in terms of mean square error than did the Box-Cox transformation method or the Log-Boughton method which is based upon a fit of plotting positions.

Chapter 3: Methods

3.1. Study Design

3.1.1. Study Area

Study sites 100 watersheds were selected from northeast, east central and east central United States, i.e., including Indiana (33watersheds), Virginia (12 watersheds), New Jersey (9 watersheds), Illinois (9 watersheds), Michigan (9 watersheds), Maryland (6 watersheds), Delaware (5 watersheds), Kentucky (3 watersheds), Mississippi (3 watersheds), Georgia (2 watersheds), and Wyoming (2 watersheds), and Florida, West Virginia, Pennsylvania, California, Texas, and Tennessee with one watershed each. The watershed areas ranged from 8.39 km2 to 1973 km^2, and the altitude varying from -3 to 1960 feet above NGVD29 (National Geodetic Vertical Datum of 1929, USGS).

Choosing watersheds was based on the following assumptions:

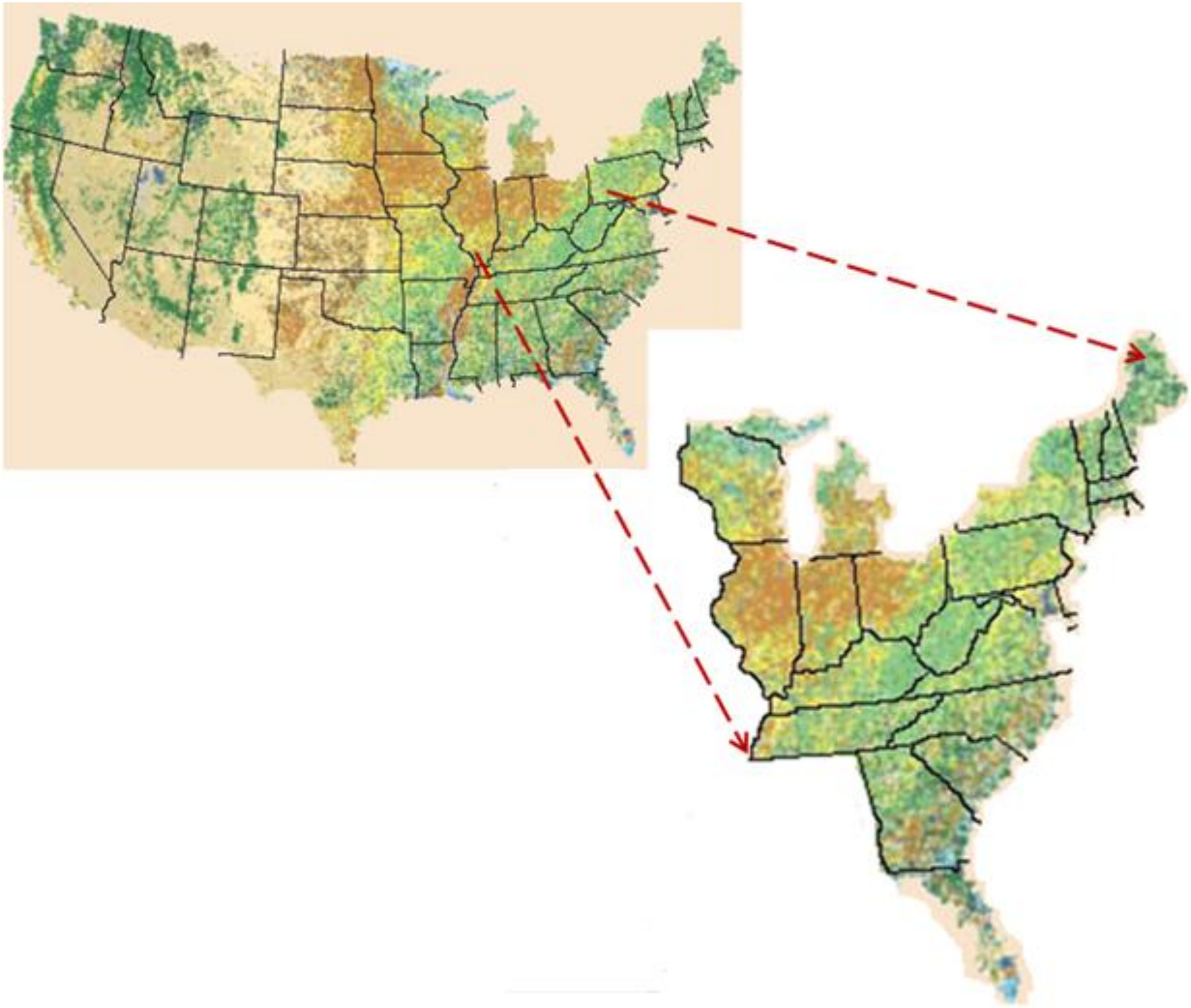


Fig 3.1: Study area (USGS seamless viewer, land cover 1992)

Almost all the watersheds were located in the same climatic zone (Figure 3.2) with a humid continental climate to have the same precipitation.

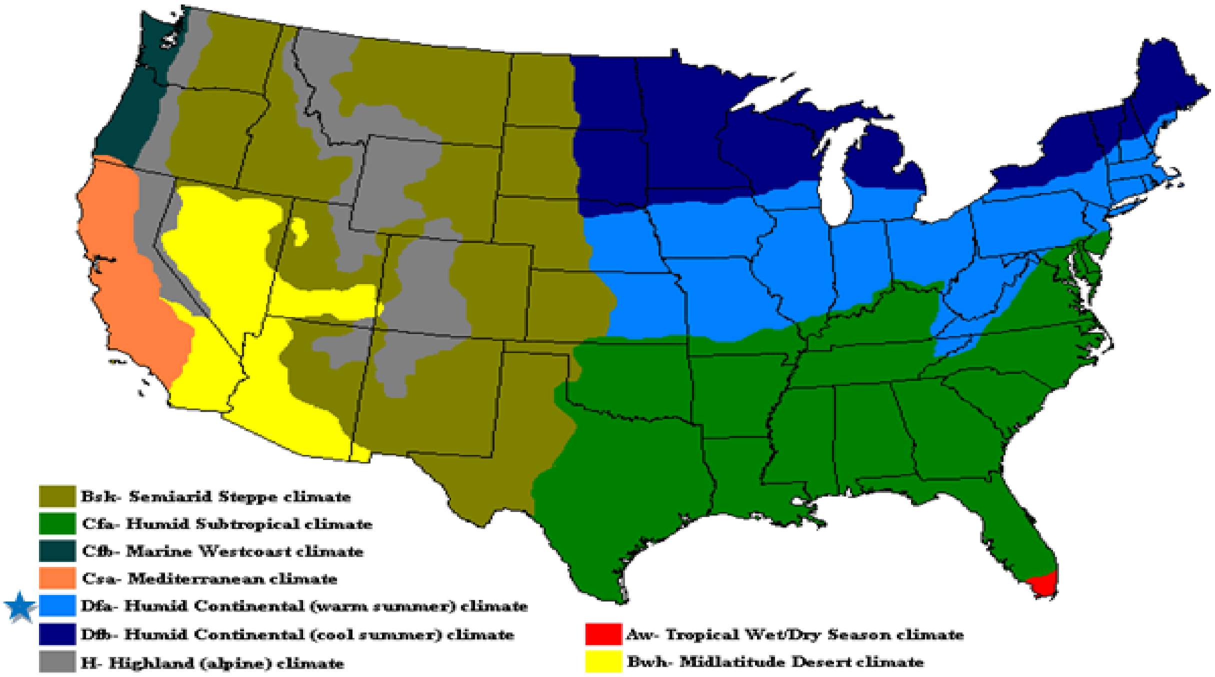


Fig 3.2: Climate zones of continental United States (The climatic zone were used in this thesis is shown by a blue asterisk)

3.1.2. Discharge data and calculation of 7Q10

Historical discharge data were obtained from the USGS through their National Water Information System (NWIS) website. The daily discharge data then were downloaded from watersheds which met the following criterion:

1. Watersheds were located in areas with no dams or reservoirs within 3 kilometers upstream or downstream of the discharge data point (Brandes et al., 2005) to minimize the effects of dams on stream flow.

2. The watersheds contained USGS stations with at least 20 years daily discharge data so that 7Q10 for two ten-year time periods could be calculated. The periods for this research are assumed from 1985 to 1995 for first period and from 1996 to 2010 for the second period.

Daily mean streamflows were downloaded from the USGS database (http ://wdr.water . usgs.gov/nwisgmap/). From this page, the user should selected Surface Water from the pull down menu at the top right and then either United States or the appropriate state from the other pull down menu. The streamflow link on the Surface Water page loaded daily mean streamflow query page. The following is an abbreviated list of searchable criteria which was selected singularly or together to form complex queries: County, Lat-Long box, Site Name, Site Number, Drainage Area, Number of Observations, and Period of Record.

Using downloaded daily means, a MATLAB code (Appendix B) was written to calculate the 7Q10 low flow for each period of time and for each watershed. The Weibull methods were employed to compute the 7Q10 for each site in this research because it was purported by Tasker (1987) to have performed better than other methods.

3.1.3. Land cover data and calculation of impervious area percentage

All land cover data were downloaded directly from USGS (2011) seamless viewer (http://seamless.usgs.gov/website/seamless/viewer.htm). Some important presumptions were considered in this procedure as follow:

The land cover we used for this research were the National Land Cover Data (NLCD) for 1992 and 2001, flow data was complied for ten year periods, five years before and after these "snap-shot-in-time" land cover images for 1992 and 2001. It is assumed that the land cover estimates represent a mean for the ten-year flow records. This assumption was tested by a comparison of land cover data for 2001 and 2006 for some sample watersheds (Appendix E), whereby it was found that the average change in land cover was less than 2 percent between 2001 and 2006.

The cover classification for 1992 is slightly different than for 2001. In 1992, we used cover class codes 22 and 23 (Figure 3.3), which are described as:

1992 class 22 or High Intensity Residential: Highly developed areas where people reside in high numbers such as apartment complexes and row houses. Vegetation accounts for less than 20% of the cover and constructed materials account for 80% to100% of the cover.

1992 class 23 or Commercial/Industrial/Transportation: Areas of infrastructure such as roads, railroads and so on and all highly developed areas that are not classified as High Intensity Residential.

In 2001, however, cover classes were described as:

2001 class 22 or Developed, Low Intensity: areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.

2001 class 23 or Developed, Medium Intensity: areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.

2001 class 24 or Developed High Intensity: highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.

The codes 22 and 23 for land cover 1992 are correspondent to the codes 22 and 23 for land cover 2001 because they result in same values if one calculates the urban area for both land covers 1992 and 2001, though they have different notions. The only difference between land cover 1992 and 2001 is code 24 that make these two separate from each other. All the existing codes in both land cover classification is shown in Figure 3.3.

NLCD 1992 Land Cover Classification Legend

- 🟦 11 Open Water
- ⬜ 12 Perennial Ice/Snow
- 🟧 21 Low Intensity Residential
- 🟥 22 High Intensity Residential
- 🟥 23 Commercial/Industrial/Transportation
- ⬜ 31 Bare Rock/Sand/Clay
- ⬜ 32 Quarries/Strip Mines/Gravel Pits
- 🟪 33 Transitional Barren
- 🟩 41 Deciduous Forest
- 🟩 42 Evergreen Forest
- 🟩 43 Mixed Forest
- 🟨 51 Shrubland
- 🟩 61 Orchards/Vineyards/Other
- ⬜ 71 Grassland/Herbaceous
- 🟨 81 Pasture/Hay
- 🟫 82 Row Crops
- 🟧 83 Small Grains
- ⬜ 84 Fallow
- 🟧 85 Urban/Recreational Grasses
- 🟦 91 Woody Wetlands
- 🟦 92 Emergent Herbaceous Wetlands

NLCD 2001 Land Cover Classification Legend

- 🟦 11 Open Water
- ⬜ 12 Perennial Ice/ Snow
- ⬜ 21 Developed, Open Space
- 🟧 22 Developed, Low Intensity
- 🟥 23 Developed, Medium Intensity
- 🟥 24 Developed, High Intensity
- ⬜ 31 Barren Land (Rock/Sand/Clay)
- 🟩 41 Deciduous Forest
- 🟩 42 Evergreen Forest
- 🟩 43 Mixed Forest
- 🟨 51 Dwarf Scrub*
- 🟨 52 Shrub/Scrub
- ⬜ 71 Grassland/Herbaceous
- 🟨 72 Sedge/Herbaceous*
- 🟩 73 Lichens*
- 🟩 74 Moss*
- 🟨 81 Pasture/Hay
- 🟫 82 Cultivated Crops
- 🟦 90 Woody Wetlands
- 🟦 95 Emergent Herbaceous Wetlands

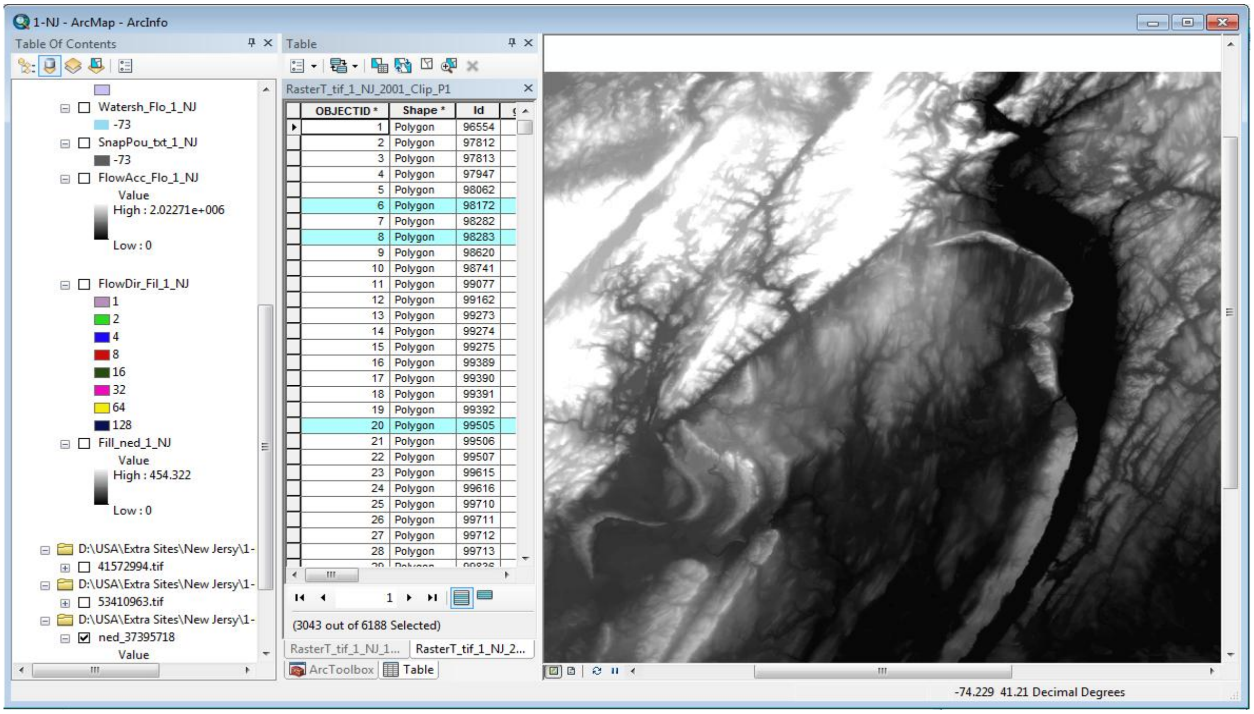
* Alaska only

Figure 3.3: Land cover classification legend (Anderson, 1976)-left: Land Cover 1992; Right: Land Cover 2001

3.2. Computation of Urbanization

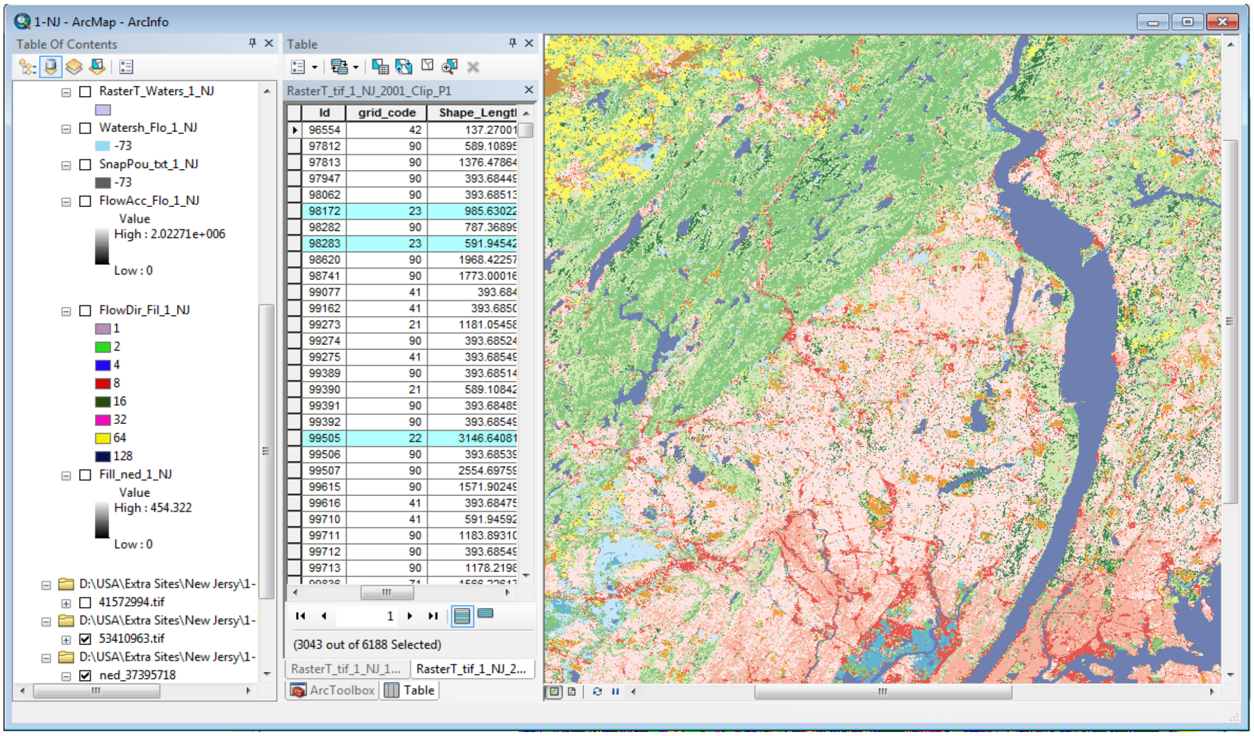
In order to determine urban area percentage, the following steps were taken for each watershed. First the latitude and longitude of each watershed downloaded from the website http://waterdata.usgs.gov, were converted to decimal degree. Then 1992 and 2001 land cover and also 1” NED were downloaded from USGS Seamless site, at http://seamless.usgs.gov.

After land cover and raster file have been downloaded, they can be opened by using Arc Map from the ESRI system Arc GIS version 10. An example of what the raster and land cover files may look like is shown in Figures 3.4, 3.5 and 3.6, respectively.



OBJECTID *	Shape *	Id
1	Polygon	96554
2	Polygon	97812
3	Polygon	97813
4	Polygon	97947
5	Polygon	98062
6	Polygon	98172
7	Polygon	98282
8	Polygon	98283
9	Polygon	98620
10	Polygon	98741
11	Polygon	99077
12	Polygon	99162
13	Polygon	99273
14	Polygon	99274
15	Polygon	99275
16	Polygon	99389
17	Polygon	99390
18	Polygon	99391
19	Polygon	99392
20	Polygon	99505
21	Polygon	99506
22	Polygon	99507
23	Polygon	99615
24	Polygon	99616
25	Polygon	99710
26	Polygon	99711
27	Polygon	99712
28	Polygon	99713

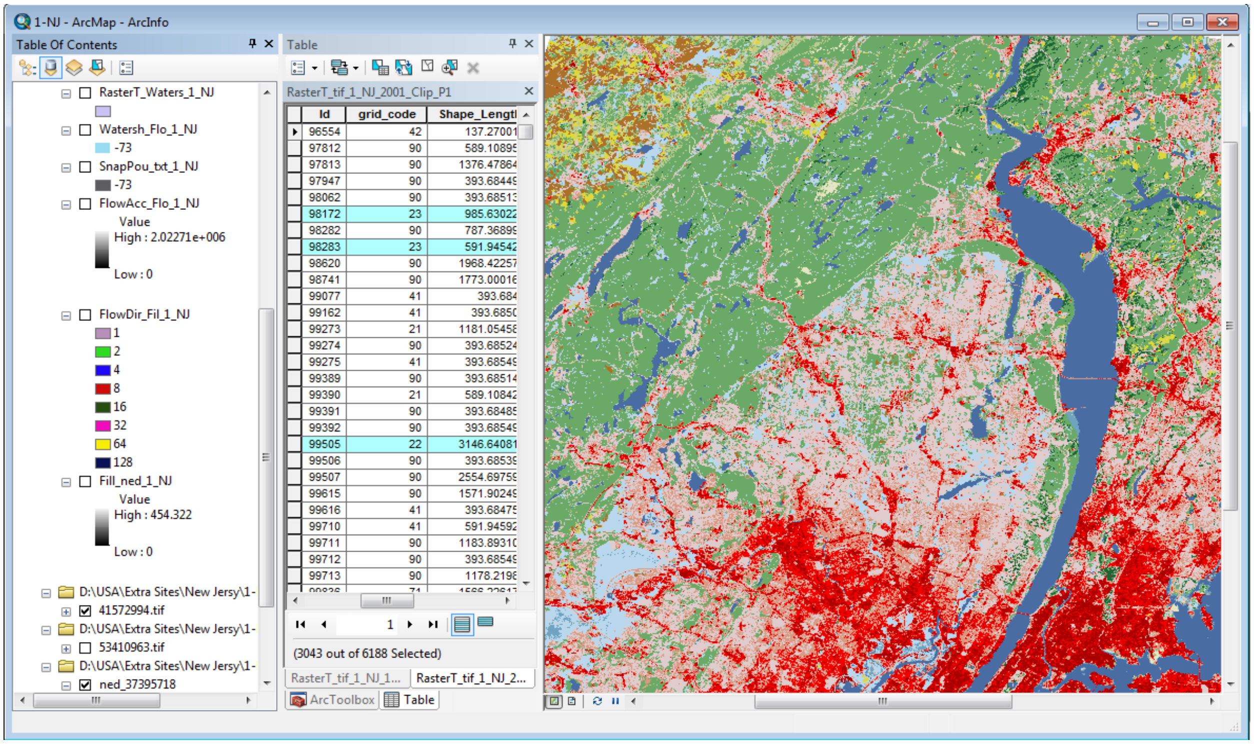
Figure 3.4: 1” National Elevation Data, USGS seamless viewer 2011



Id	grid_code	Shape_Lengtl
96554	42	137.27001
97812	90	589.10895
97813	90	1376.47864
97947	90	393.68449
98062	90	393.68513
98172	23	985.63022
98282	90	787.36899
98283	23	591.94542
98620	90	1968.42257
98741	90	1773.00016
99077	41	393.684
99162	41	393.6850
99273	21	1181.05458
99274	90	393.68524
99275	41	393.68549
99389	90	393.68514
99390	21	589.10842
99391	90	393.68485
99392	90	393.68549
99505	22	3146.64081
99506	90	393.68539
99507	90	2554.69759
99615	90	1571.90249
99616	41	393.68475
99710	41	591.94592
99711	90	1183.89310
99712	90	393.68549
99713	90	1178.2198

(3043 out of 6188 Selected)

Figure 3.5: Land cover 1992, USGS seamless viewer 2011

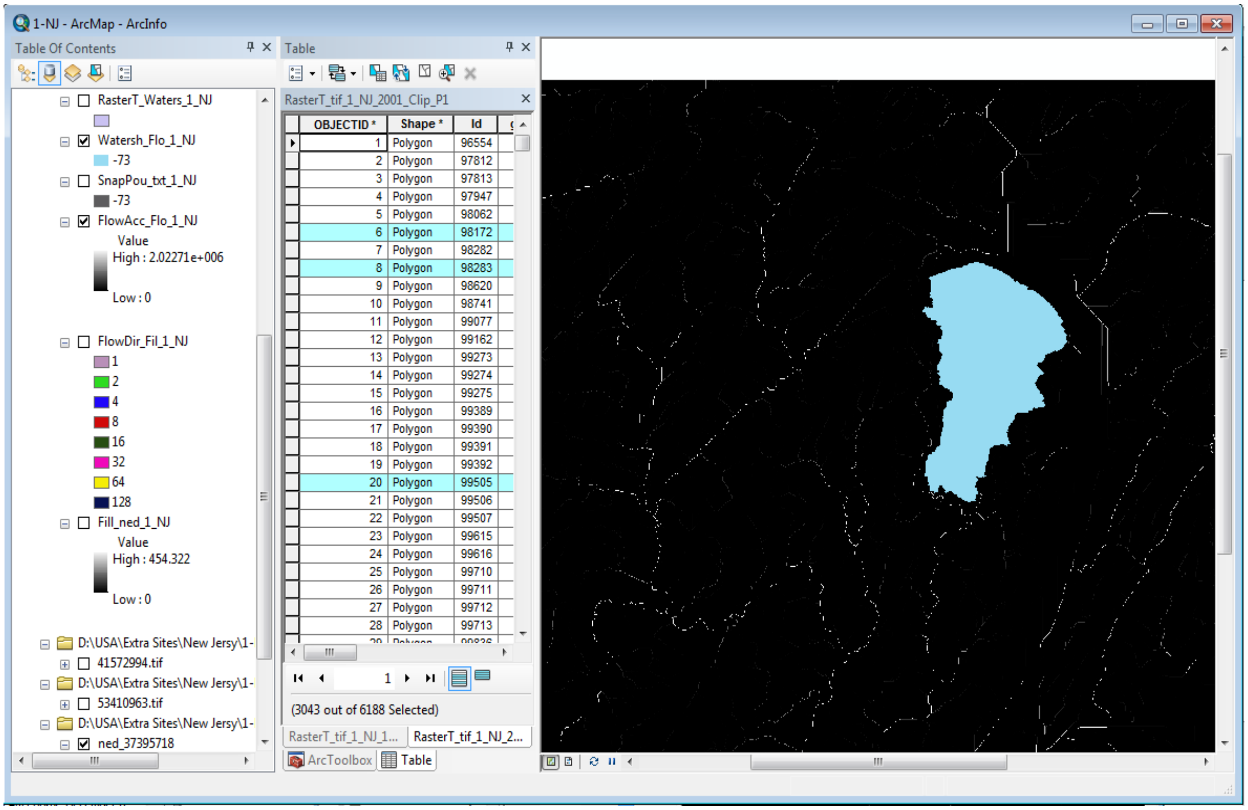


Id	grid_code	Shape_Lengtl
96554	42	137.27001
97812	90	589.10895
97813	90	1376.47864
97947	90	393.68449
98062	90	393.68513
98172	23	985.63022
98282	90	787.36899
98283	23	591.94542
98620	90	1968.42257
98741	90	1773.00016
99077	41	393.684
99162	41	393.6850
99273	21	1181.05458
99274	90	393.68524
99275	41	393.68549
99389	90	393.68514
99390	21	589.10842
99391	90	393.68485
99392	90	393.68549
99505	22	3146.64081
99506	90	393.68539
99507	90	2554.69759
99615	90	1571.90249
99616	41	393.68475
99710	41	591.94592
99711	90	1183.89310
99712	90	393.68549
99713	90	1178.2198

(3043 out of 6188 Selected)

Figure 3.6: Land cover 2001, USGS seamless viewer 2011

The raster file can be used to delineate the watershed and then we need to determine the flow direction which is shown in Figure 3.7.



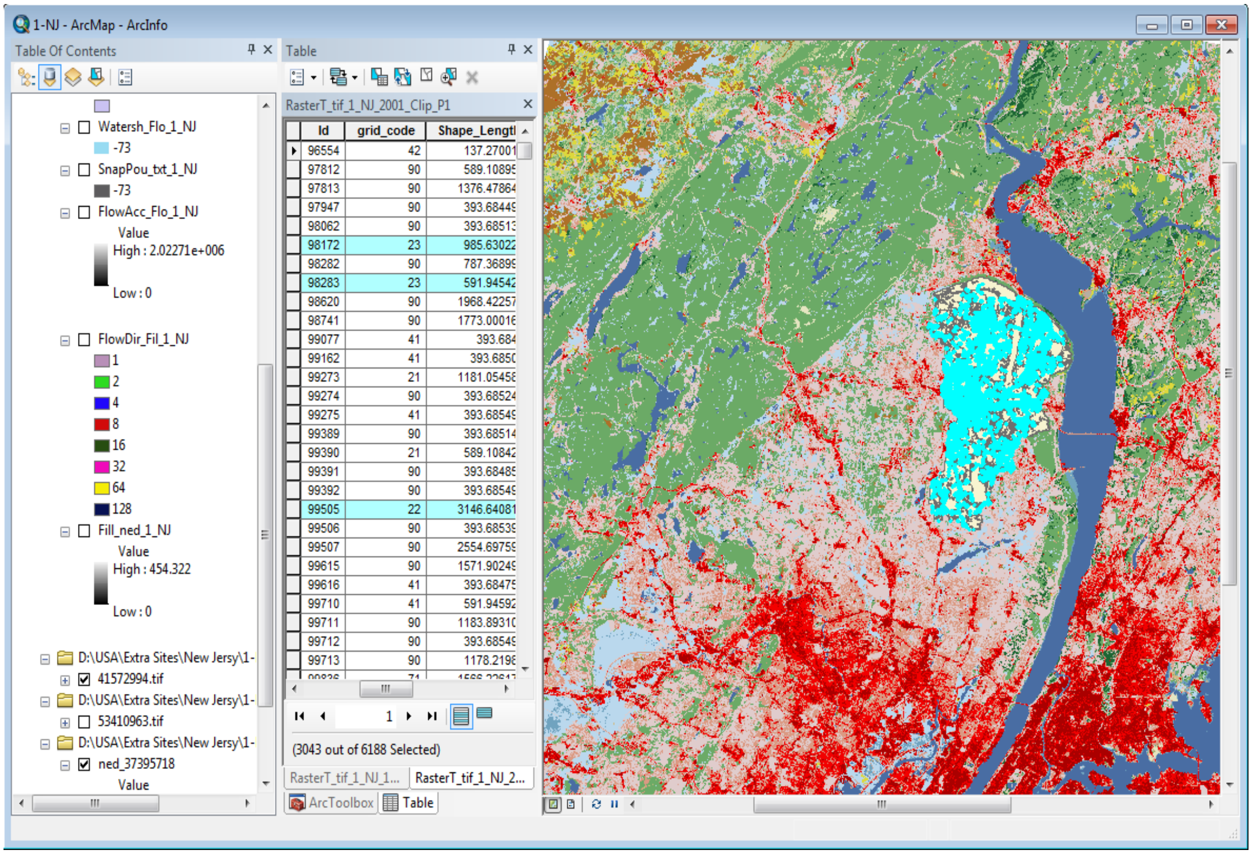
OBJECTID *	Shape *	Id
1	Polygon	96554
2	Polygon	97812
3	Polygon	97813
4	Polygon	97947
5	Polygon	98062
6	Polygon	98172
7	Polygon	98282
8	Polygon	98283
9	Polygon	98620
10	Polygon	98741
11	Polygon	99077
12	Polygon	99162
13	Polygon	99273
14	Polygon	99274
15	Polygon	99275
16	Polygon	99389
17	Polygon	99390
18	Polygon	99391
19	Polygon	99392
20	Polygon	99505
21	Polygon	99506
22	Polygon	99507
23	Polygon	99615
24	Polygon	99616
25	Polygon	99710
26	Polygon	99711
27	Polygon	99712
28	Polygon	99713

(3043 out of 6188 Selected)

Figure 3.7: Watershed area

Now that the watershed has been delineated the next procedure is to convert it and the land cover or “tif” file into “shape file”. Then it needs to be clipped so that the land cover area is the same as the watershed area. Afterward land cover file has been projected into an utilizable coordinate system such as NAD 1983 (feet). The output needs to be named and when the process is complete will have units of feet.

The final step is to calculate the area of the watershed and the amount of urban area in the watershed. Figure 3.8, will be a cut out of the land cover shape file to match the watershed area.



RasterT_tif_1_NJ_2001_Clip_P1

Id	grid_code	Shape_Lengtl
96554	42	137.27001
97812	90	589.10895
97813	90	1376.47864
97947	90	393.68449
98062	90	393.68513
98172	23	985.63022
98282	90	787.36899
98283	23	591.94542
98620	90	1968.42257
98741	90	1773.00016
99077	41	393.684
99162	41	393.6850
99273	21	1181.05458
99274	90	393.68524
99275	41	393.68549
99389	90	393.68514
99390	21	589.10842
99391	90	393.68485
99392	90	393.68549
99505	22	3146.64081
99506	90	393.68539
99507	90	2554.69759
99615	90	1571.90249
99616	41	393.68475
99710	41	591.94592
99711	90	1183.89310
99712	90	393.68549
99713	90	1178.2198

1

(3043 out of 6188 Selected)

Figure 3.8: Pictorial Urbanization area

By right clicking on the map name, a box appears where the attributes table can be opened. Once the table has been opened it shows the id, grid code, and F_Area. The watershed area is calculated by summing the F_Area column. Then for each land cover the correspondent codes of urban area in land cover classification should be selected (the green rows in figure 3.8) and then the values of those rows should be summed in order to get the total urban area in the watershed. Finally the percent urban is determined by dividing the total urban area by the watershed area.

3.3. 7Q10 Computation

An easy and arguably as accurate method of determining the 7Q10 is to use Weibull distribution to plot the seven-day minimum flows for the selected period of record. This is the hydrological method used to analyze each site in this project. Daily mean streamflows can be obtained over the Internet through the USGS NWISWeb water data page. From this page, the user should select “Surface Water” from the pull down menu at the top right and then either United States or the appropriate state from the other pull down menu. The streamflow link on the “Surface Water” page loads daily mean streamflow query page. The following is an abbreviated list of searchable criteria which can be selected singularly or together to form complex queries: County, Lat-Long box, Site Name, Site Number, Drainage Area, Number of Observations, and Period of Record.

3.4. The Wilcoxon Signed-Rank Test

Wilcoxon Signed-Rank Test is used to test the hypothesis of this research and to find the possible thresholds. According to Ott et al. (2010) the Wilcoxon signed-rank test, which makes use of the sign and the magnitude of the rank of the differences between pairs of measurements is used as an alternative to the paired t test. Since the t test cannot be used for nonnormal distributions, the Wilcoxon signed-rank test is the best method for population with a nonnormal distribution of the differences (Appendix G).

Chapter 4: Results

4.1. Preliminary analysis

In this research, we are dealing with comparison of two populations:

a.The 7Q10 data for the interval from 1986 to 1995 or 1st period.

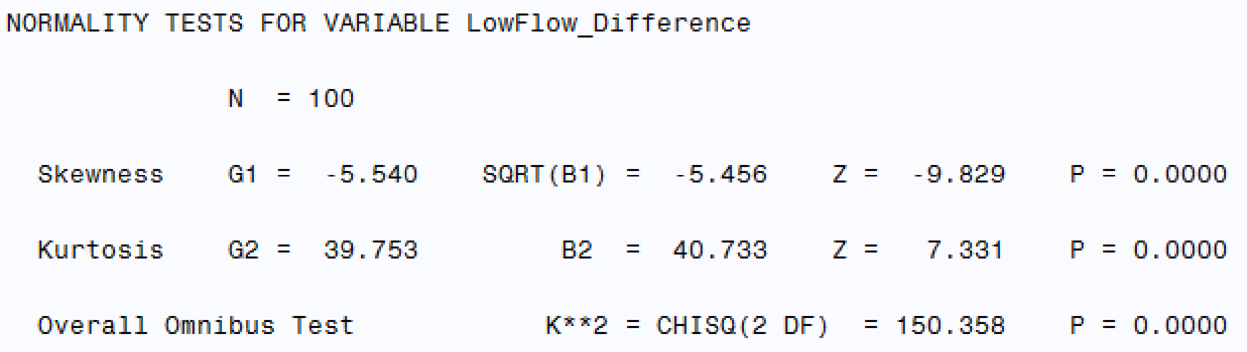
b.The 7Q10 data for the interval from 1996 to 2005 or 2nd period.

The useful statistical methods to compare two populations are t test or nonparametric To define which of these methods is appropriate to compare the two population in this research we need to follow these steps:

1- Computing the difference between two populations
2- Test the normality of difference distribution
3- Test the dependency of samples.

A code was written with SAS9.2 (Appendix C) to test whether the difference distribution wasnormal or not. It was done by looking at the p-values of normtest; which is an inter code in SAS to define the normality of any distributions. If the resulted p-values from SAS code for both Skewness and Kurtosis are large enough, the distribution is normal and vice versa.

Since the p-values were so small (Figure 4.1), it was concluded that the difference distribution is nonnormal. The t-test is not appropriate and a nonparametric test was employed. Both Wilcoxon rank sum and Wilcoxon signed rank test do not require normality of the underlying populations (Appendix G). The only difference between these two tests is that Wilcoxon rank sum is applicable for those samples that are independent. Whereas the 7Q10 discharge were calculated for the same watershed at two different intervals, they are no longer independent and the only applicable test is Wilcoxon signed-rank test.



```
NORMALITY TESTS FOR VARIABLE LowFlow_Difference

            N   = 100

  Skewness     G1 =   -5.540    SQRT(B1) =   -5.456    Z =   -9.829    P = 0.0000

  Kurtosis     G2 =   39.753         B2   =   40.733    Z =    7.331    P = 0.0000

  Overall Omnibus Test             K**2 = CHISQ(2 DF)  = 150.358    P = 0.0000
```

Figure 4.1: Normal test results on low flow difference data for all watersheds

4.2. Data Analysis Using Wilcoxon Singed Rank Test

The objective of this research is to find changes in low flow due to urbanization. For this purpose the null and research hypothesis can be defined as:

Null hypothesis H0 : $\mu2-\mu1=0$ (7Q10 mean for 1st period is equal to 7Q10 mean for 2nd period)

Research hypothesis Ha: $\mu2-\mu1\neq0$ not H0

The α=0.01 is chosen to test the hypothesis.

Another SAS code was written to compare the two populations (Appendix C). The p-value is less than 0.0001< α=0.01 therefore we reject the null hypothesis and concluded that 7Q10 mean for first period is not equal to 7Q10 mean for second period but the p-value doesn't tell us if there is an increase in 7Q10 or decrease between two intervals. This can be determined by looking at the tables because Wilcoxin singed rank test computed the differences between 7Q10 for two intervals and then assigned a minus (–) sign to the negative differences and a plus (+) sign to the positive differences. Different parts that were distinguishable from the tables can be divided into three categories (Appendix E):

1. The watersheds with urban percntage less than 11% :

For these watesheds the differences between 7Q10 for two intervals are mostly negative. Since the difference is computed by subtracting 7Q10 for second period (1996-2005) from 7Q10 for first period (1986-1995). It means that the 7Q10 decreased due to urban development for these watersheds though this is just a hypothesis and needs to do extra statistical test to be accepted.

2. The watersheds with urban percntage between 11% and 23 %:

For these watesheds the difference between 7Q10 for two intervals is altering between negative and positive. It means that the 7Q10 doesn't change due to urban development for these watersheds. This also needs to be tested.

3. The watersheds with urban percentage greater than 23%:

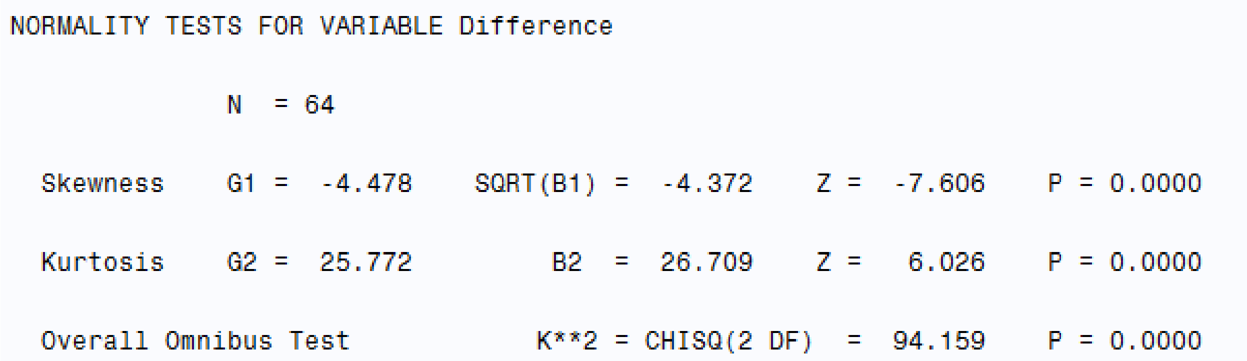
For these watesheds the differences between 7Q10 for two intervals are mostly positive. It means that the 7Q10 increased due to urban development for these watersheds.

Now we have three categories with three different hypothises. Each of which is a subset of the whole data set and can be considered as a subset that needs to be tested and to determine whether our assumptions are correct or not.

4.2.1. Comparison of 7Q10 for Watersheds with urbanization less than 11%

In this part we have 64 watersheds with urban areas ranging from close to zero to almost 11%. For these watersheds we have to follow the same process we did in section 4.1 to see if the distribution is normal or not and which method is more appropriate to employ.

Using SAS program, p-values for normality test obtained. Since the p-values were very small (Figure 4.2), it was concluded that the difference distribution is nonnormal and the t-test is not appropriate. As it mentioned earlier the populations are not independent therefore the only applicable test is Wilcoxon signed-rank test.



```
NORMALITY TESTS FOR VARIABLE Difference

             N  = 64

  Skewness    G1 =  -4.478    SQRT(B1) =  -4.372    Z =  -7.606    P = 0.0000

  Kurtosis    G2 =  25.772         B2  =  26.709    Z =   6.026    P = 0.0000

  Overall Omnibus Test            K**2 = CHISQ(2 DF)  =  94.159    P = 0.0000
```

Fig 4.2: Normal test results on 7Q10 difference for watersheds with urban area less 11 %

Now we should define the hypothesis. For this subset the null hypothesis is as same as the null hypothesis for the whole data but the research hypothesis (Ha) is different:

Null hypothesis H0 : $\mu2-\mu1=0$ (7Q10 mean for 1st period is equal to 7Q10 mean for 2nd period)

Research hypothesis: Ha: $\mu2-\mu1\leq 0$ (7Q10 mean for 1st period is greater than 7Q10 mean for 2nd period)

the “$\alpha=0.01$” were used to test the hypothesis.

Using the Wilcoxon signed rank test the out put p-value is less than 0.0001 for a two-tailed test. Since we are testing the probabilty of $\mu2-\mu1=<0$ we need to divide p-value by 2 so the p-value < 0.00005 and is less than $\alpha=0.01$

We reject the null hypothesis and conclude that 7Q10 mean for first period is greater than 7Q10 mean for second period. In other word the low flow 7Q10 decreases.

It also can be interpreted from box plots and average and variance table (Figures 4.3 and 4.4).

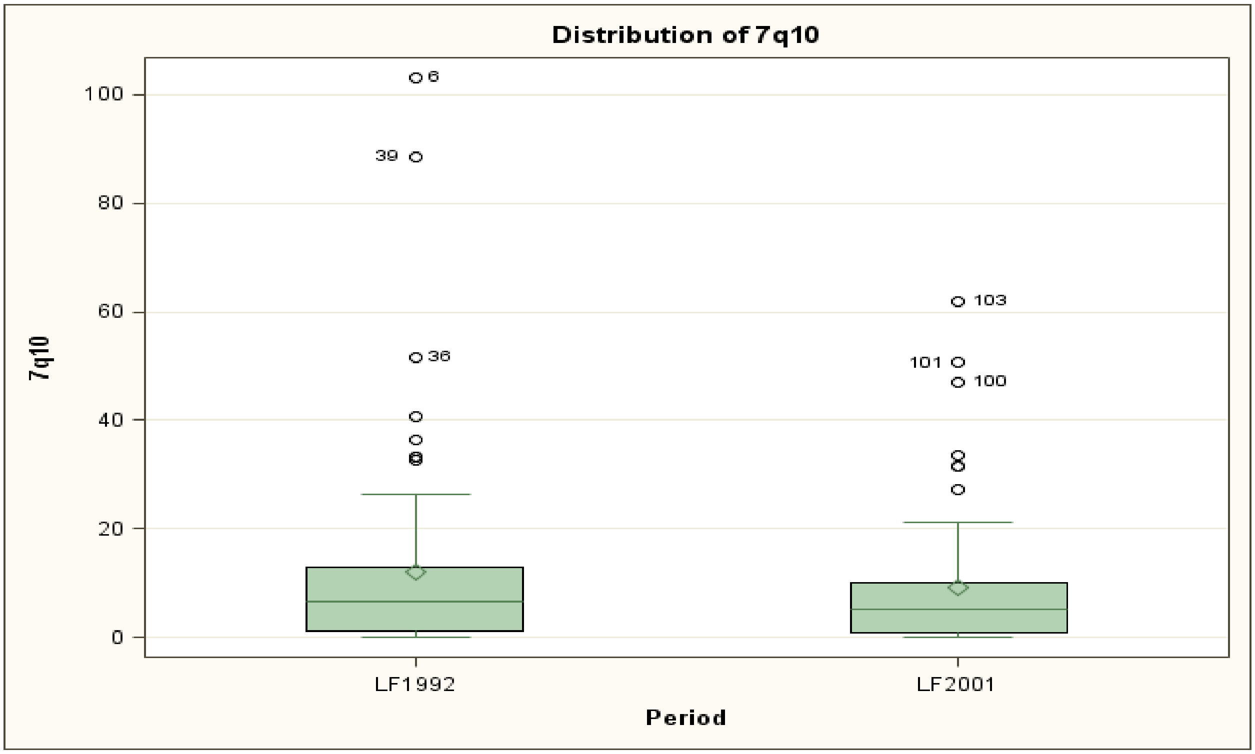
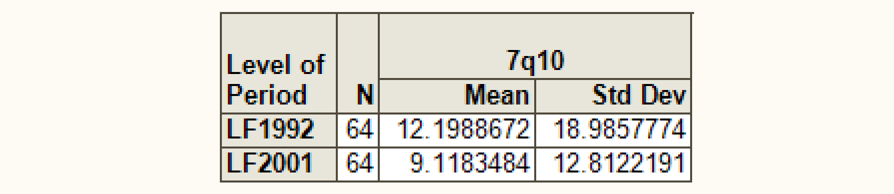


Fig 4.3: Box plots for low flow data for watersheds with urbanization percentage less than 11% (LF is abbreviation for low flow).



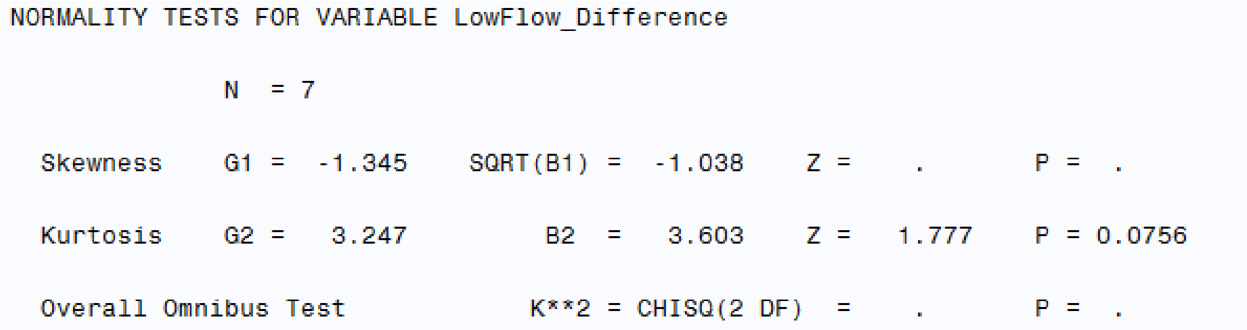
Level of Period	N	7q10	
		Mean	Std Dev
LF1992	64	12.1988672	18.9857774
LF2001	64	9.1183484	12.8122191

Fig 4.4: Mean and standard deviation of low flow for watersheds with urbanization percentage Less than 11

Both plots show there was a decrease in low flow mean that occurs from 12.1988 ft^3/sec in 1986-1995 to 9.118272 ft^3/sec in 1996-2005. There is also a decrease in maximum of 7Q10 for those periods from 103.1429 ft^3/sec to 62 ft^3/sec.

4.2.2. Comparison of 7Q10 for Watersheds with urbanization 11 - 23%

In this part we have 7 watersheds with urban areas ranging from 11% to 23%. Using SAS program p-values for normality test obtained. Since the p-values were very small (Figure 4.5), we concluded that the difference distribution is nonnormal and the t-test is not appropriate. Furthermore the populations are not independent so the only applicable test is Wilcoxon signed-rank test.



```
NORMALITY TESTS FOR VARIABLE LowFlow_Difference

             N  = 7

  Skewness    G1 =  -1.345    SQRT(B1) =  -1.038    Z =    .        P =  .

  Kurtosis    G2 =   3.247         B2  =   3.603    Z =   1.777     P = 0.0756

  Overall Omnibus Test              K**2 = CHISQ(2 DF)  =    .        P =  .
```

Fig 4.5: Normal test results on Low Flow Difference data for watersheds with urbanization between 11 & 23 %

For this subset the null hypothesis is as same as the null hypothesis for the whole data but the research hypothesis (Ha) is different:

Null hypothesis H0 : $\mu 2-\mu 1=0$ (7Q10 mean for 1st period is equal to 7Q10 mean for 2nd period)

Research hypothesis: Ha: $\mu 2-\mu 1\neq 0$ (7Q10 mean for 1st period is not equal to 7Q10 mean for 2nd period) the “α=0.01” were used to test the hypothesis.

Since p-value =0.4688>α=0.01, we do not reject the null hypothesis and conclude that 7Q10 mean for first period is equal to 7Q10 mean for second period, though by comparing the box plots and the mean and variance of two samples population it can be seen that there is a decrease in low flow 7Q10 due to increasing urbanization.

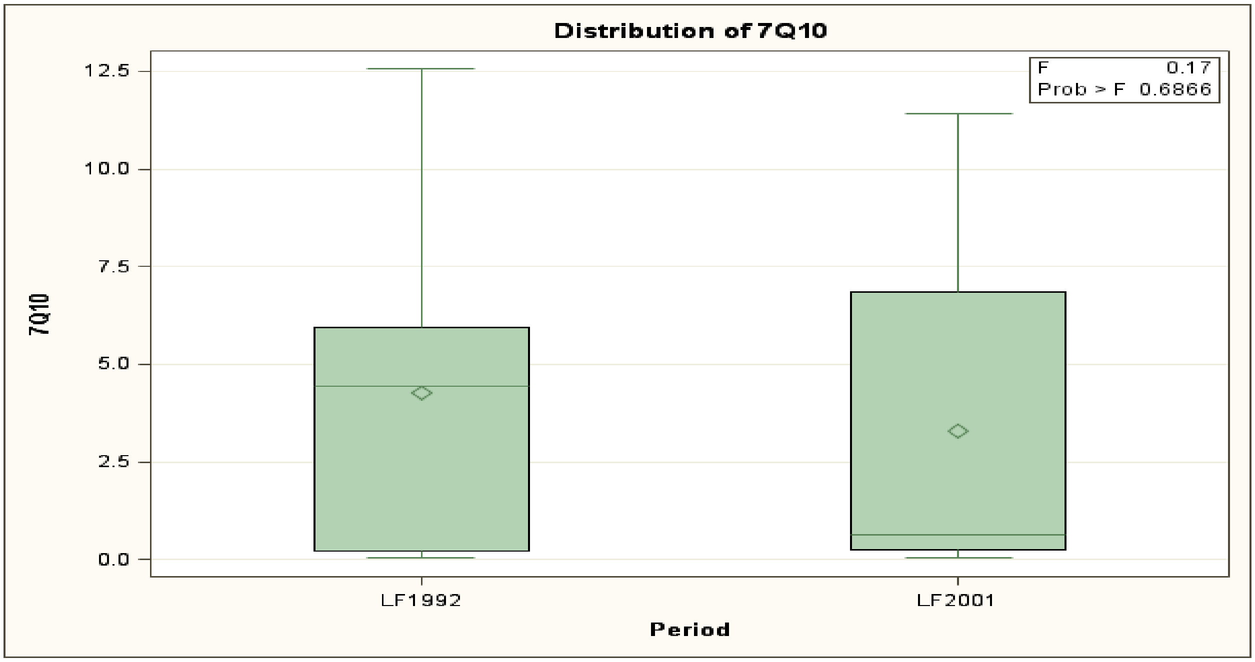
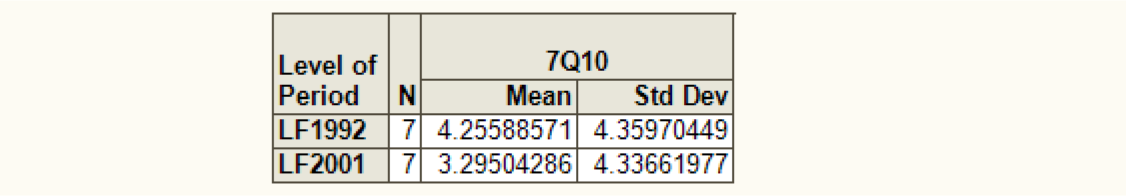


Fig 4.6: Box plots for low flow data for watersheds with urbanization percentage 11-23%

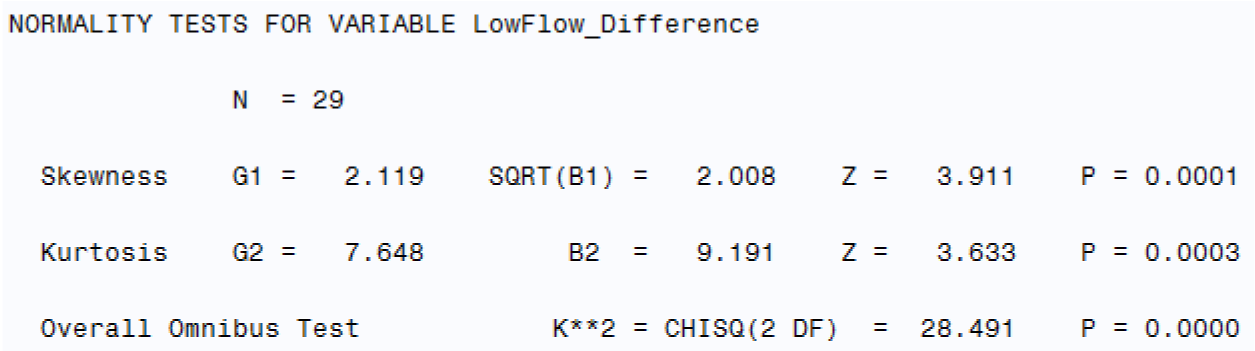


Level of Period	N	7Q10	
		Mean	Std Dev
LF1992	7	4.25588571	4.35970449
LF2001	7	3.29504286	4.33661977

Fig 4.7: Mean and standard deviation of low flow for watersheds with urbanization percentage 11-23%

4.2.3. Comparison of 7Q10 for Watersheds with urbanization greater than 23%

In this part we have 29 watersheds with urban areas greater than 23%. Using SAS program p-values for normality test obtained. Since the p-values were very small (Figure 4.8), we concluded that the difference distribution is nonnormal and the t-test is not appropriate. Furthermore the populations are not independent so the only applicable test is Wilcoxon signed-rank test.



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NORMALITY TESTS FOR VARIABLE LowFlow_Difference

              N  = 29

  Skewness    G1 =   2.119    SQRT(B1) =   2.008    Z =   3.911    P = 0.0001

  Kurtosis    G2 =   7.648         B2  =   9.191    Z =   3.633    P = 0.0003

  Overall Omnibus Test           K**2 = CHISQ(2 DF)  =  28.491    P = 0.0000
```

Fig 4.8: Normal test results on low flow difference data for watersheds with urbanization greater than 23 %.

For this subset the null hypothesis is as same as the null hypothesis for the whole data but the research hypothesis (Ha) is different:

Null hypothesis $H0 : \mu 2-\mu 1=0$ (7Q10 mean for 1st period is equal to 7Q10 mean for 2nd period)

Research hypothesis: Ha: $\mu 2-\mu 1\neq 0$ (7Q10 mean for 1st period is not equal to 7Q10 mean for 2nd period)

the “$\alpha=0.01$” were used to test the hypothesis.

Since p-value $<0.0001/2=0.00005<\alpha=0.01$, we do reject the null hypothesis and conclude that 7Q10 mean for first period is smaller than 7Q10 mean for second period. By comparing the box plots and the mean and variance of two samples population the same results will be achieved (Figures 4.9 and 4.10).

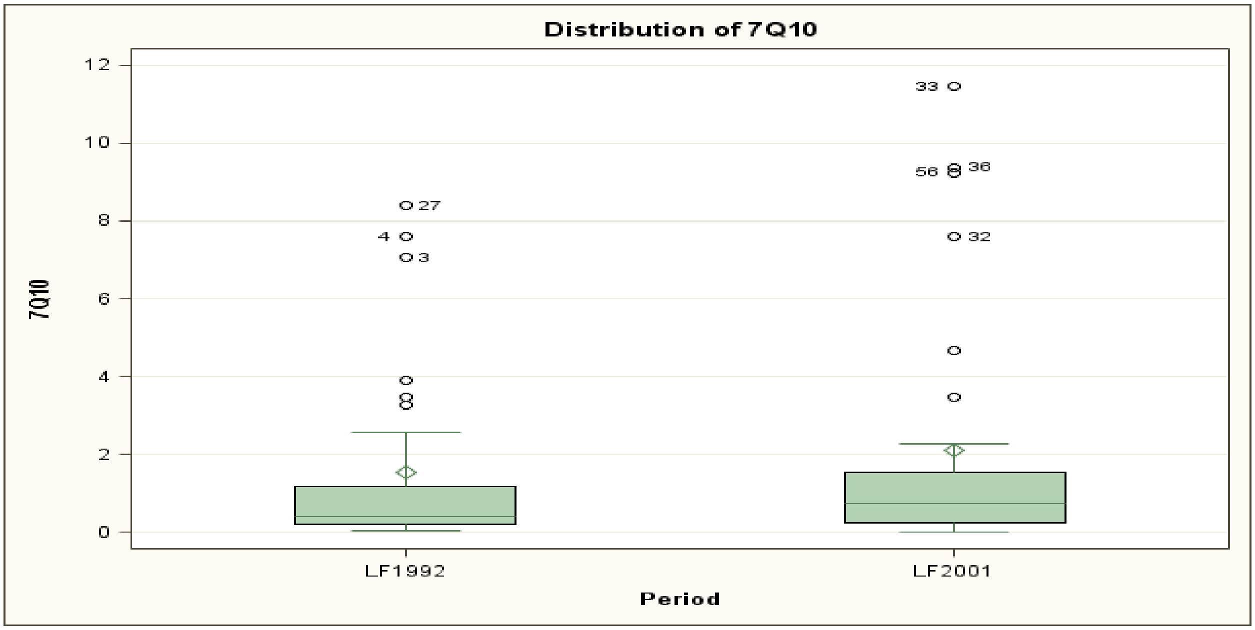
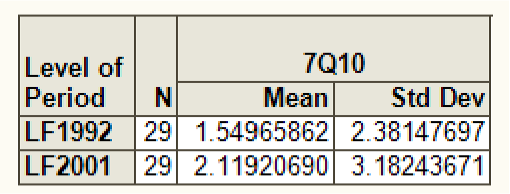


Fig 4.9: Box plots for low flow data for watersheds with urbanization percentage above 23%



Level of Period	N	7Q10	
		Mean	Std Dev
LF1992	29	1.54965862	2.38147697
LF2001	29	2.11920690	3.18243671

Fig 4.10: Mean and standard deviation of low flow for watersheds with urbanization percentage above 23%.

Chapter 5: Discussion

The results of the Wilcoxon signed-rank test supported the objectives of this research in determining the impacts of urban development within three different levels of the urbanization. Wicoxon signed-rank test was capable of establishing thresholds that represented the three scenarios in this research. The results of the test for urbanization percentage between 11 and 23 did not show evidence of change in low flow values. This is in concordant with study results done by Meyer (2002) and Brandes et al. (2005). For watersheds with urbanization percentage less than 11% the results showed a significant decrease in low flow, the same result Kauffman (2009) and others have had. Likewise, the Wilcoxon signed-rank test of the watersheds with urbanization percentage above 23 showed a significant increase in low flow. The results of the low flow with the urbanization between 11 and 23 percent had more differences than the Wilcoxon signed-rank test of the other two scenarios.

For a final conclusion and debate the water balance equation is repeated below. As earlier mentioned, in introduction chapter, based on equation (1) low flow should increase due to urban development unless other factors become dominant. By considering this assumption the change of low flow is due to urban development, one can speculate three possible scenarios:

1) As urban area increases from zero to values less than 11%, infiltration is more dominant in comparison to evapotranspiration, and discharges to storm sewer systems and leakage from water and sewer lines.

2) For urban percentage between the 11 and 23% the increasing impacts of evapotranspiration and discharges become greaer but still cannot compensate the infiltration reductive effects.

3) After urban area passes 23% the evapotranspiration and recharge factors become dominant and overshadow the effect of infiltration. It seems that evapotranspiration should play an important rule because during dry seasons trees and other plants play an important rule to break down the heat wave by pumping the water from deep levels of ground water to the air. In urban area by changing the land cover the process will be halted especially in large degrees of urbanization and it results in increasing the low flow.

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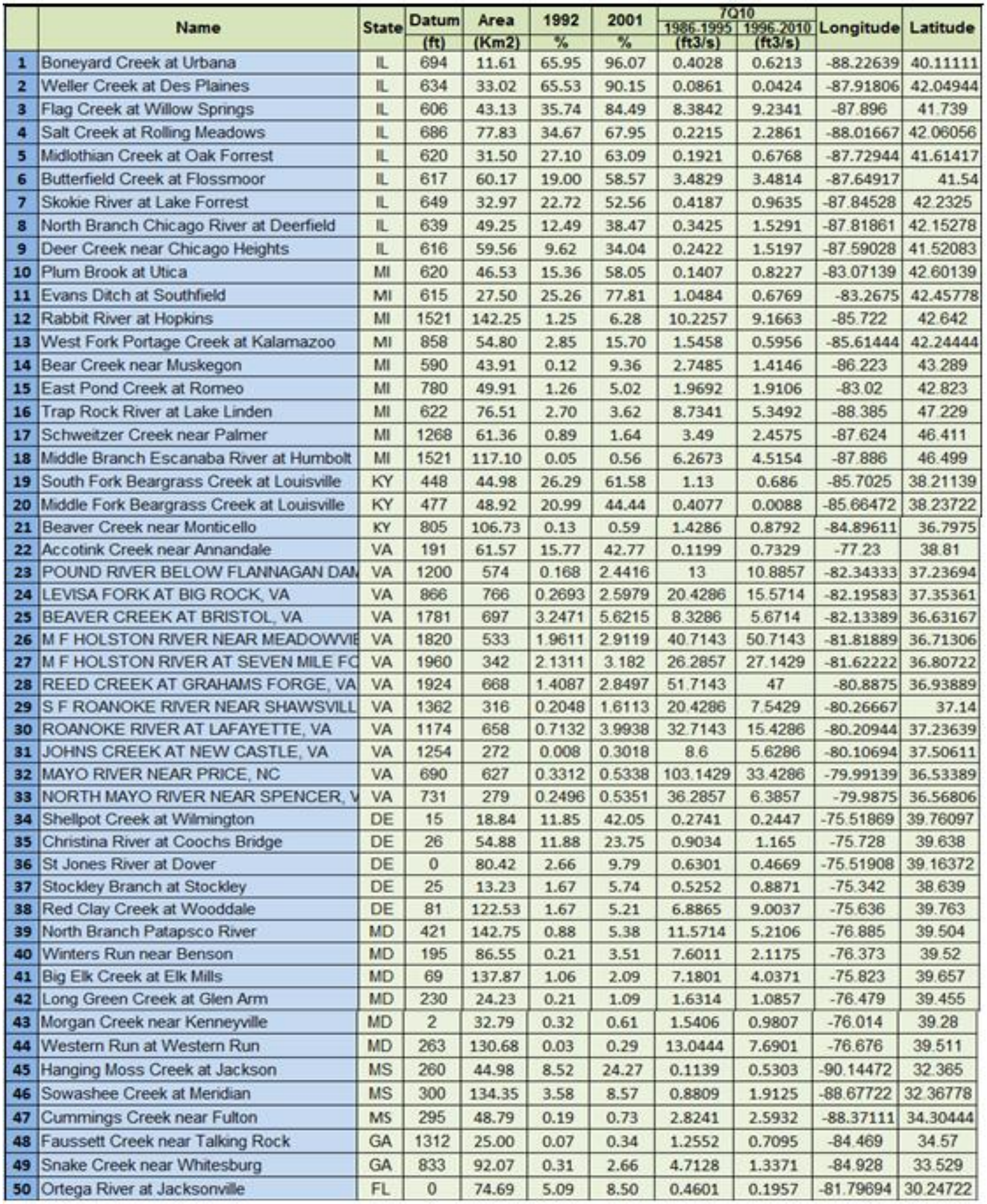
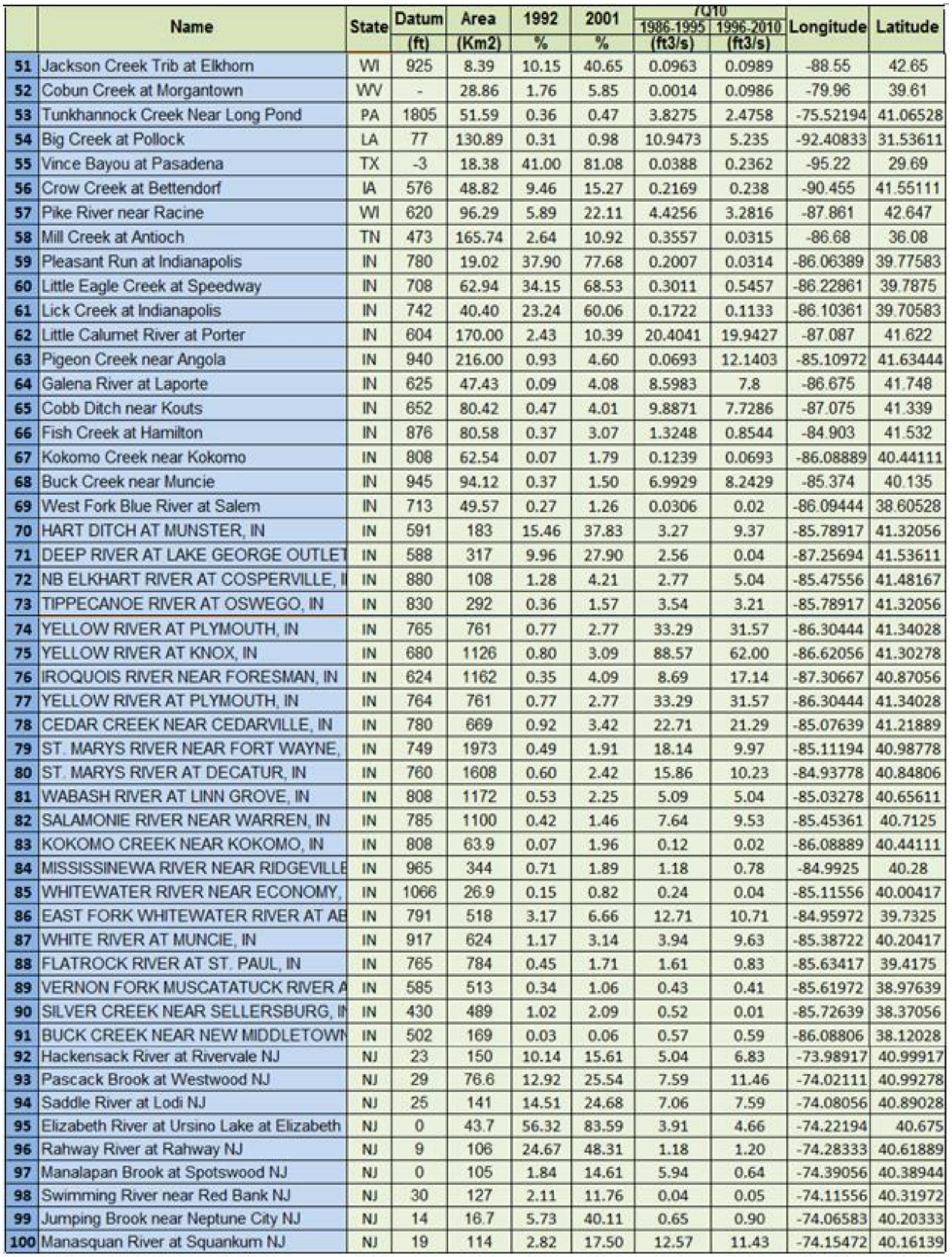
Appendices

Appendix A

Watershed's data



	Name	State	Datum	Area	1992	2001	7Q10		Longitude	Latitude
			(ft)	(Km2)	%	%	1986-1995 (ft3/s)	1996-2010 (ft3/s)		
1	Boneyard Creek at Urbana	IL	694	11.61	65.95	96.07	0.4028	0.6213	-88.22639	40.11111
2	Weller Creek at Des Plaines	IL	634	33.02	65.53	90.15	0.0861	0.0424	-87.91806	42.04944
3	Flag Creek at Willow Springs	IL	606	43.13	35.74	84.49	8.3842	9.2341	-87.896	41.739
4	Salt Creek at Rolling Meadows	IL	686	77.83	34.67	67.95	0.2215	2.2861	-88.01667	42.06056
5	Midlothian Creek at Oak Forrest	IL	620	31.50	27.10	63.09	0.1921	0.6768	-87.72944	41.61417
6	Butterfield Creek at Flossmoor	IL	617	60.17	19.00	58.57	3.4829	3.4814	-87.64917	41.54
7	Skokie River at Lake Forrest	IL	649	32.97	22.72	52.56	0.4187	0.9635	-87.84528	42.2325
8	North Branch Chicago River at Deerfield	IL	639	49.25	12.49	38.47	0.3425	1.5291	-87.81861	42.15278
9	Deer Creek near Chicago Heights	IL	616	59.56	9.62	34.04	0.2422	1.5197	-87.59028	41.52083
10	Plum Brook at Utica	MI	620	46.53	15.36	58.05	0.1407	0.8227	-83.07139	42.60139
11	Evans Ditch at Southfield	MI	615	27.50	25.26	77.81	1.0484	0.6769	-83.2675	42.45778
12	Rabbit River at Hopkins	MI	1521	142.25	1.25	6.28	10.2257	9.1663	-85.722	42.642
13	West Fork Portage Creek at Kalamazoo	MI	858	54.80	2.85	15.70	1.5458	0.5956	-85.61444	42.24444
14	Bear Creek near Muskegon	MI	590	43.91	0.12	9.36	2.7485	1.4146	-86.223	43.289
15	East Pond Creek at Romeo	MI	780	49.91	1.26	5.02	1.9692	1.9106	-83.02	42.823
16	Trap Rock River at Lake Linden	MI	622	76.51	2.70	3.62	8.7341	5.3492	-88.385	47.229
17	Schweitzer Creek near Palmer	MI	1268	61.36	0.89	1.64	3.49	2.4575	-87.624	46.411
18	Middle Branch Escanaba River at Humbolt	MI	1521	117.10	0.05	0.56	6.2673	4.5154	-87.886	46.499
19	South Fork Beargrass Creek at Louisville	KY	448	44.98	26.29	61.58	1.13	0.686	-85.7025	38.21139
20	Middle Fork Beargrass Creek at Louisville	KY	477	48.92	20.99	44.44	0.4077	0.0088	-85.66472	38.23722
21	Beaver Creek near Monticello	KY	805	106.73	0.13	0.59	1.4286	0.8792	-84.89611	36.7975
22	Accotink Creek near Annandale	VA	191	61.57	15.77	42.77	0.1199	0.7329	-77.23	38.81
23	POUND RIVER BELOW FLANNAGAN DAM	VA	1200	574	0.168	2.4416	13	10.8857	-82.34333	37.23694
24	LEVISA FORK AT BIG ROCK, VA	VA	866	766	0.2693	2.5979	20.4286	15.5714	-82.19583	37.35361
25	BEAVER CREEK AT BRISTOL, VA	VA	1781	697	3.2471	5.6215	8.3286	5.6714	-82.13389	36.63167
26	M F HOLSTON RIVER NEAR MEADOWVIE	VA	1820	533	1.9611	2.9119	40.7143	50.7143	-81.81889	36.71306
27	M F HOLSTON RIVER AT SEVEN MILE FC	VA	1960	342	2.1311	3.182	26.2857	27.1429	-81.62222	36.80722
28	REED CREEK AT GRAHAMS FORGE, VA	VA	1924	668	1.4087	2.8497	51.7143	47	-80.8875	36.93889
29	S F ROANOKE RIVER NEAR SHAWSVILL	VA	1362	316	0.2048	1.6113	20.4286	7.5429	-80.26667	37.14
30	ROANOKE RIVER AT LAFAYETTE, VA	VA	1174	658	0.7132	3.9938	32.7143	15.4286	-80.20944	37.23639
31	JOHNS CREEK AT NEW CASTLE, VA	VA	1254	272	0.008	0.3018	8.6	5.6286	-80.10694	37.50611
32	MAYO RIVER NEAR PRICE, NC	VA	690	627	0.3312	0.5338	103.1429	33.4286	-79.99139	36.53389
33	NORTH MAYO RIVER NEAR SPENCER, V	VA	731	279	0.2496	0.5351	36.2857	6.3857	-79.9875	36.56806
34	Shellpot Creek at Wilmington	DE	15	18.84	11.85	42.05	0.2741	0.2447	-75.51869	39.76097
35	Christina River at Coochs Bridge	DE	26	54.88	11.88	23.75	0.9034	1.165	-75.728	39.638
36	St Jones River at Dover	DE	0	80.42	2.66	9.79	0.6301	0.4669	-75.51908	39.16372
37	Stockley Branch at Stockley	DE	25	13.23	1.67	5.74	0.5252	0.8871	-75.342	38.639
38	Red Clay Creek at Wooddale	DE	81	122.53	1.67	5.21	6.8865	9.0037	-75.636	39.763
39	North Branch Patapsco River	MD	421	142.75	0.88	5.38	11.5714	5.2106	-76.885	39.504
40	Winters Run near Benson	MD	195	86.55	0.21	3.51	7.6011	2.1175	-76.373	39.52
41	Big Elk Creek at Elk Mills	MD	69	137.87	1.06	2.09	7.1801	4.0371	-75.823	39.657
42	Long Green Creek at Glen Arm	MD	230	24.23	0.21	1.09	1.6314	1.0857	-76.479	39.455
43	Morgan Creek near Kenneyville	MD	2	32.79	0.32	0.61	1.5406	0.9807	-76.014	39.28
44	Western Run at Western Run	MD	263	130.68	0.03	0.29	13.0444	7.6901	-76.676	39.511
45	Hanging Moss Creek at Jackson	MS	260	44.98	8.52	24.27	0.1139	0.5303	-90.14472	32.365
46	Sowashee Creek at Meridian	MS	300	134.35	3.58	8.57	0.8809	1.9125	-88.67722	32.36778
47	Cummings Creek near Fulton	MS	295	48.79	0.19	0.73	2.8241	2.5932	-88.37111	34.30444
48	Faussett Creek near Talking Rock	GA	1312	25.00	0.07	0.34	1.2552	0.7095	-84.469	34.57
49	Snake Creek near Whitesburg	GA	833	92.07	0.31	2.66	4.7128	1.3371	-84.928	33.529
50	Ortega River at Jacksonville	FL	0	74.69	5.09	8.50	0.4601	0.1957	-81.79694	30.24722



	Name	State	Datum	Area	1992	2001	7Q10		Longitude	Latitude
			(ft)	(Km2)	%	%	1986-1995 (ft3/s)	1996-2010 (ft3/s)		
51	Jackson Creek Trib at Elkhorn	WI	925	8.39	10.15	40.65	0.0963	0.0989	-88.55	42.65
52	Cobun Creek at Morgantown	WV	-	28.86	1.76	5.85	0.0014	0.0986	-79.96	39.61
53	Tunkhannock Creek Near Long Pond	PA	1805	51.59	0.36	0.47	3.8275	2.4758	-75.52194	41.06528
54	Big Creek at Pollock	LA	77	130.89	0.31	0.98	10.9473	5.235	-92.40833	31.53611
55	Vince Bayou at Pasadena	TX	-3	18.38	41.00	81.08	0.0388	0.2362	-95.22	29.69
56	Crow Creek at Bettendorf	IA	576	48.82	9.46	15.27	0.2169	0.238	-90.455	41.55111
57	Pike River near Racine	WI	620	96.29	5.89	22.11	4.4256	3.2816	-87.861	42.647
58	Mill Creek at Antioch	TN	473	165.74	2.64	10.92	0.3557	0.0315	-86.68	36.08
59	Pleasant Run at Indianapolis	IN	780	19.02	37.90	77.68	0.2007	0.0314	-86.06389	39.77583
60	Little Eagle Creek at Speedway	IN	708	62.94	34.15	68.53	0.3011	0.5457	-86.22861	39.7875
61	Lick Creek at Indianapolis	IN	742	40.40	23.24	60.06	0.1722	0.1133	-86.10361	39.70583
62	Little Calumet River at Porter	IN	604	170.00	2.43	10.39	20.4041	19.9427	-87.087	41.622
63	Pigeon Creek near Angola	IN	940	216.00	0.93	4.60	0.0693	12.1403	-85.10972	41.63444
64	Galena River at Laporte	IN	625	47.43	0.09	4.08	8.5983	7.8	-86.675	41.748
65	Cobb Ditch near Kouts	IN	652	80.42	0.47	4.01	9.8871	7.7286	-87.075	41.339
66	Fish Creek at Hamilton	IN	876	80.58	0.37	3.07	1.3248	0.8544	-84.903	41.532
67	Kokomo Creek near Kokomo	IN	808	62.54	0.07	1.79	0.1239	0.0693	-86.08889	40.44111
68	Buck Creek near Muncie	IN	945	94.12	0.37	1.50	6.9929	8.2429	-85.374	40.135
69	West Fork Blue River at Salem	IN	713	49.57	0.27	1.26	0.0306	0.02	-86.09444	38.60528
70	HART DITCH AT MUNSTER, IN	IN	591	183	15.46	37.83	3.27	9.37	-85.78917	41.32056
71	DEEP RIVER AT LAKE GEORGE OUTLET	IN	588	317	9.96	27.90	2.56	0.04	-87.25694	41.53611
72	NB ELKHART RIVER AT COSPERVILLE, I	IN	880	108	1.28	4.21	2.77	5.04	-85.47556	41.48167
73	TIPPECANOE RIVER AT OSWEGO, IN	IN	830	292	0.36	1.57	3.54	3.21	-85.78917	41.32056
74	YELLOW RIVER AT PLYMOUTH, IN	IN	765	761	0.77	2.77	33.29	31.57	-86.30444	41.34028
75	YELLOW RIVER AT KNOX, IN	IN	680	1126	0.80	3.09	88.57	62.00	-86.62056	41.30278
76	IROQUOIS RIVER NEAR FORESMAN, IN	IN	624	1162	0.35	4.09	8.69	17.14	-87.30667	40.87056
77	YELLOW RIVER AT PLYMOUTH, IN	IN	764	761	0.77	2.77	33.29	31.57	-86.30444	41.34028
78	CEDAR CREEK NEAR CEDARVILLE, IN	IN	780	669	0.92	3.42	22.71	21.29	-85.07639	41.21889
79	ST. MARYS RIVER NEAR FORT WAYNE,	IN	749	1973	0.49	1.91	18.14	9.97	-85.11194	40.98778
80	ST. MARYS RIVER AT DECATUR, IN	IN	760	1608	0.60	2.42	15.86	10.23	-84.93778	40.84806
81	WABASH RIVER AT LINN GROVE, IN	IN	808	1172	0.53	2.25	5.09	5.04	-85.03278	40.65611
82	SALAMONIE RIVER NEAR WARREN, IN	IN	785	1100	0.42	1.46	7.64	9.53	-85.45361	40.7125
83	KOKOMO CREEK NEAR KOKOMO, IN	IN	808	63.9	0.07	1.96	0.12	0.02	-86.08889	40.44111
84	MISSISSINEWA RIVER NEAR RIDGEVILLE	IN	965	344	0.71	1.89	1.18	0.78	-84.9925	40.28
85	WHITEWATER RIVER NEAR ECONOMY,	IN	1066	26.9	0.15	0.82	0.24	0.04	-85.11556	40.00417
86	EAST FORK WHITEWATER RIVER AT AB	IN	791	518	3.17	6.66	12.71	10.71	-84.95972	39.7325
87	WHITE RIVER AT MUNCIE, IN	IN	917	624	1.17	3.14	3.94	9.63	-85.38722	40.20417
88	FLATROCK RIVER AT ST. PAUL, IN	IN	765	784	0.45	1.71	1.61	0.83	-85.63417	39.4175
89	VERNON FORK MUSCATATUCK RIVER A	IN	585	513	0.34	1.06	0.43	0.41	-85.61972	38.97639
90	SILVER CREEK NEAR SELLERSBURG, I	IN	430	489	1.02	2.09	0.52	0.01	-85.72639	38.37056
91	BUCK CREEK NEAR NEW MIDDLETOWN	IN	502	169	0.03	0.06	0.57	0.59	-86.08806	38.12028
92	Hackensack River at Rivervale NJ	NJ	23	150	10.14	15.61	5.04	6.83	-73.98917	40.99917
93	Pascack Brook at Westwood NJ	NJ	29	76.6	12.92	25.54	7.59	11.46	-74.02111	40.99278
94	Saddle River at Lodi NJ	NJ	25	141	14.51	24.68	7.06	7.59	-74.08056	40.89028
95	Elizabeth River at Ursino Lake at Elizabeth	NJ	0	43.7	56.32	83.59	3.91	4.66	-74.22194	40.675
96	Rahway River at Rahway NJ	NJ	9	106	24.67	48.31	1.18	1.20	-74.28333	40.61889
97	Manalapan Brook at Spotswood NJ	NJ	0	105	1.84	14.61	5.94	0.64	-74.39056	40.38944
98	Swimming River near Red Bank NJ	NJ	30	127	2.11	11.76	0.04	0.05	-74.11556	40.31972
99	Jumping Brook near Neptune City NJ	NJ	14	16.7	5.73	40.11	0.65	0.90	-74.06583	40.20333
100	Manasquan River at Squankum NJ	NJ	19	114	2.82	17.50	12.57	11.43	-74.15472	40.16139

Appendix B

MATLAB code

```
%A MATLAB code is written to calculate the 7Q10 low flow based on Weibull
%Distribution

clear all; close all;  clc;
fid = fopen('16-Daily Discharge1986-1995.txt');
C = textscan(fid, '%s %s %s %f32 %s');
fclose(fid);
C{3};
A=C{4};
A = A(~isnan(A));
n=max(size(A));
x=zeros(n,1);
z=zeros(1,10);
for i=2:n-7;
   m=(i+6)/365;
      x(:)=0;
            for j=i:i+6
            x(j)=x(j-1)+A(j-1);
      end
      y(i)=x(j)/7;
end
y;
Q=y';
m=max(size(Q));
%f=365-(((m/365)-fix(m/365))*365);
l=fix(n/365);
f=l*365-m;
if f<0
    f=365+f;
    l=l+1;
elseif f>=0
    f=l*365-m;
end
Q(1)=100;
for k=0:f-1
   Q(n-6+k,1)=1000;
end
Q;
B=reshape(Q,365,l);
sevenQ=zeros(l,1);
for g=1:l
    sevenQ(g)=min(B(:,g))  ;
end
sevenQ
sevenQ10=min(sevenQ)
```

Appendix C

SAS codes and plots

SAS code for comparing the 7Q10 of all the watersheds

```
Options PageNo=1 NoDate FormDLim='';
Title ' Low Flow data VS. Urbanization ';
Title2 'Wilcoxon Signed Ranks Test';

Data A;
 Input WatershedDatum WatershedArea UrbanPercentage1992 UrbanPercentage2001
LowFlow1992 LowFlow2001;
 LowFlow_Difference=Round(LowFlow2001-LowFlow1992,.001);
 Abs_Diff=Abs(LowFlow_Difference);
 Datalines;
502 169 0.029 0.063 0.5743 0.59
263 130.6849287 0.033386117 0.287813423 13.0444 7.6901
1254 272 0.008039447 0.301805595 8.6 5.6286
1312 25 0.070084154 0.341660575 1.2552 0.7095
1805 51.5859639 0.359708595 0.470254887 3.8275 2.4758
690 627 0.331194749 0.533800864 103.1429 33.4286
731 279 0.249625833 0.535141982 36.2857 6.3857
1521 117.1042225 0.054781008 0.564702149 6.2673 4.5154
805 106.7322551 0.134261701 0.585121698 1.4286 0.8792
2 32.78937527 0.31837997 0.613873875 1.5406 0.9807
295 48.78796526 0.188609026 0.72642122 2.8241 2.5932
1066 26.9 0.153382985 0.8204126 0.2414 0.0371
77 130.8870986 0.308098213 0.976811349 10.9473 5.235
585 513 0.339502075 1.058534411 0.4271 0.41
230 24.23021749 0.211913591 1.092798586 1.6314 1.0857
713 49.56624253 0.266886075 1.255002159 0.0306 0.02
785 1100 0.417292401 1.460216279 7.6429 9.5286
945 94.11728305 0.368731433 1.504000354 6.9929 8.2429
830 292 0.356111998 1.574783011 3.5429 3.2143
1362 316 0.204800407 1.611270678 20.4286 7.5429
1268 61.36 0.885036665 1.642469183 3.49 2.4575
765 784 0.449133588 1.708972504 1.6143 0.8271
808 62.54201335 0.071718081 1.789231207 0.1239 0.0693
965 344     0.71142923 1.890154052 1.18 0.7757
749 1973 0.486489536 1.91056687 18.1429 9.9714
808 63.9 0.071641342 1.963055987 0.1186 0.0206
430 489 1.019228292 2.085031079 0.5157 0.0114
69 137.8717555 1.061139005 2.091644874 7.1801 4.0371
808 1172 0.526016044 2.253221102 5.0857 5.0429
760 1608 0.599978937 2.416728217 15.8571 10.2286
1200 574 0.168031814 2.441620991 13 10.8857
866 766 0.26926167 2.597851296 20.4286 15.5714
833 92.06545906 0.313120993 2.659706921 4.7128 1.3371
765 761 0.7723999 2.774313193 33.2857 31.5714
764 761 0.7723999 2.774313203 33.2857 31.5714
1924 668 1.408730582 2.849672636 51.7143 47
1820 533 1.961129687 2.911884676 40.7143 50.7143
876 80.57940801 0.367404007 3.069310625 1.3248 0.8544
680 1126 0.798848475 3.088071779 88.5714 62
```

```
917 624 1.165308026 3.138441089 3.9429 9.6286
1960 342 2.13105213 3.182004962 26.2857 27.1429
780 669 0.916020628 3.422266999 22.7143 21.2857
195 86.5511611 0.211027561 3.514150489 7.6011 2.1175
622 76.51385515 2.701795204 3.62461961 8.7341 5.3492
1174 658 0.713249554 3.993752078 32.7143 15.4286
652 80.41852493 0.474282577 4.005340559 9.8871 7.7286
625 47.42542566 0.091855769 4.082155062 8.5983 7.8
624 1162 0.354552867 4.09211908 8.6857 17.1429
880 108 1.277166959 4.21194493 2.7714 5.0429
940 216 0.929326631 4.602567988 0.0693 12.1403
780 49.90926147 1.26042389 5.019852047 1.9692 1.9106
81 122.5348556 1.67031386 5.20886623 6.8865 9.0037
421 142.7517684 0.87569876 5.377378353 11.5714 5.2106
1781 697 3.247073983 5.621497627 8.3286 5.6714
25 13.22658831 1.665799978 5.739033712 0.5252 0.8871
0 28.85600941 1.756041808 5.849574267 0.0014 0.0986
1521 142.2541594 1.25339344 6.2806018 10.2257 9.1663
791 518 3.168559483 6.661180495 12.7143 10.7143
0 74.68500426 5.091311292 8.498513601 0.4601 0.1957
300 134.3480819 3.5750477 8.567099469 0.8809 1.9125
590 43.90696153 0.120947183 9.361985751 2.7485 1.4146
0 80.41549734 2.659841837 9.788442777 0.6301 0.4669
604 170 2.42889775 10.38794377 20.4041 19.9427
473 165.7356179 2.641293268 10.92229914 0.3557 0.0315
30 127 2.11 11.76 0.0443 0.05
0 105 1.84 14.61 5.9443 0.6429
576 48.82178171 9.46211821 15.27115306 0.2169 0.238
23 150 10.136 15.612 5.0429 6.8286
858 54.79963377 2.850960095 15.69657112 1.5458 0.5956
19 114 2.82 17.5 12.5714 11.4286
620 96.29238802 5.888358117 22.10977526 4.4256 3.2816
26 54.87879104 11.87551006 23.75123603 0.9034 1.165
260 44.97724911 8.523775204 24.26758599 0.1139 0.5303
25 141 14.51 24.68 7.0571 7.5857
29 76.6 12.92 25.54 7.5857 11.4571
588 317 9.956674816 27.89856705 2.5643 0.0414
616 59.55626173 9.623930081 34.04035185 0.2422 1.5197
591 183 15.45546234 37.82636297 3.2714 9.3714
639 49.25 12.48620677 38.47438897 0.3425 1.5291
14 16.7 5.73 40.11 0.6457 0.8971
925 8.386723776 10.15192955 40.64942871 0.0963 0.0989
15 18.84107271 11.85008582 42.04683 0.2741 0.2447
191 61.57477522 15.77471567 42.77342466 0.1199 0.7329
477 48.91835109 20.9948384 44.44199264 0.4077 0.0088
9 106 24.67 48.31 1.1814 1.2
649 32.96858853 22.71657329 52.56399899 0.4187 0.9635
620 46.52900563 15.36259809 58.05383552 0.1407 0.8227
617 60.16687598 18.99673091 58.57210624 3.4829 3.4814
742 40.4 23.24154015 60.05670284 0.1722 0.1133
448 44.9845201 26.28713052 61.57517786 1.13 0.686
620 31.5 27.09602335 63.08987638 0.1921 0.6768
686 77.83218863 34.66732908 67.94894149 0.2215 2.2861
708 62.94 34.14545576 68.52628288 0.3011 0.5457
780 19.01998913 37.90466995 77.68317186 0.2007 0.0314
615 27.50323239 25.26149817 77.80826762 1.0484 0.6769
```

```
-3 18.37537655 41.0008899 81.07877875 0.0388 0.2362
0 43.7 56.32 83.59 3.9143 4.6571
606 43.12545831 35.74273355 84.48649917 8.3842 9.2341
634 33.02131302 65.53357214 90.14666478 0.0861 0.0424
694 11.60832438 65.95105851 96.07069701 0.4028 0.6213
;
Run;
%include' \\Client\C$\Sta538\Normtest.sas';
%Normtest(Data=A,var=LowFlow_Difference);
Proc Rank Data=A Out=B;
 Var Abs_Diff;
 Ranks Rank;
Run;
Data C;
 Set B;
 Drop S;
 S=Sign(LowFlow_Difference);
 If S<0 Then Sign='-'; Else If S=0 Then Sign='0'; Else Sign='+';
 SignedRank=Sign(LowFlow_Difference)*Rank;
Run;
Proc Print Data=C;
Run;
Options FormDLim='-';
Proc Univariate Data=A;
 Var LowFlow_Difference;
 ODS Select TestsforLocation;
Run;
Proc TTest Data=A;
 Paired LowFlow2001*LowFlow1992;
 ODS Select TTests;
 run;
quit;
proc corr data=A;
var  WatershedArea  LowFlow1992 LowFlow2001;
run;
Proc Print Data=A;
Run;
Proc Corr Data=A;
 Var WatershedDatum WatershedArea UrbanPercentage1992 UrbanPercentage2001
LowFlow1992 LowFlow2001;
 ODS Select PearsonCorr;
Run;

Proc Reg Data=A;
 Model LowFlow1992=WatershedArea  / VIF Collin;
 plot LowFlow1992*WatershedArea;
Run; Quit;
Proc Reg Data=A;
 Model LowFlow2001=WatershedArea / VIF Collin;
 plot LowFlow2001*WatershedArea;
Run; Quit;
Proc Reg Data=A;
 Model LowFlow1992=WatershedArea;
 Weight W; Run;
 Plot RStudent.*(WatershedArea Pred.) / NoModel NoStat; Title3 'Residual
Plot'; Run;
```

```
Quit;
Proc Reg Data=A;
 Model LowFlow2001=WatershedArea;
 Weight W; Run;
 Plot RStudent.*(WatershedArea Pred.) / NoModel NoStat; Title3 'Residual
Plot'; Run;
Quit;
```

SAS code for comparing the 7Q10 of watersheds with urban area less than 11%

```
Options PageNo=1 NoDate FormDLim='';
Title ' Low Flow data VS. Urbanization ';
Title2 ' Wilcoxon Signed Ranks Test';

Data A;
 Input WatershedDatum WatershedArea UrbanPercentage1992 UrbanPercentage2001
LowFlow1992 LowFlow2001;
 LowFlow_Difference=Round(LowFlow2001-LowFlow1992,.001);
 Abs_Diff=Abs(LowFlow_Difference);
 Datalines;
502 169 0.029 0.063 0.5743 0.59
263 130.6849287 0.033386117 0.287813423 13.0444 7.6901
1254 272 0.008039447 0.301805595 8.6 5.6286
1312 25 0.070084154 0.341660575 1.2552 0.7095
1805 51.5859639 0.359708595 0.470254887 3.8275 2.4758
690 627 0.331194749 0.533800864 103.1429 33.4286
731 279 0.249625833 0.535141982 36.2857 6.3857
1521 117.1042225 0.054781008 0.564702149 6.2673 4.5154
805 106.7322551 0.134261701 0.585121698 1.4286 0.8792
2 32.78937527 0.31837997 0.613873875 1.5406 0.9807
295 48.78796526 0.188609026 0.72642122 2.8241 2.5932
1066 26.9 0.153382985 0.8204126 0.2414 0.0371
77 130.8870986 0.308098213 0.976811349 10.9473 5.235
585 513 0.339502075 1.058534411 0.4271 0.41
230 24.23021749 0.211913591 1.092798586 1.6314 1.0857
713 49.56624253 0.266886075 1.255002159 0.0306 0.02
785 1100 0.417292401 1.460216279 7.6429 9.5286
945 94.11728305 0.368731433 1.504000354 6.9929 8.2429
830 292 0.356111998 1.574783011 3.5429 3.2143
1362 316 0.204800407 1.611270678 20.4286 7.5429
1268 61.36 0.885036665 1.642469183 3.49 2.4575
765 784 0.449133588 1.708972504 1.6143 0.8271
808 62.54201335 0.071718081 1.789231207 0.1239 0.0693
965 344     0.71142923 1.890154052 1.18 0.7757
749 1973 0.486489536 1.91056687 18.1429 9.9714
808 63.9 0.071641342 1.963055987 0.1186 0.0206
430 489 1.019228292 2.085031079 0.5157 0.0114
69 137.8717555 1.061139005 2.091644874 7.1801 4.0371
808 1172 0.526016044 2.253221102 5.0857 5.0429
760 1608 0.599978937 2.416728217 15.8571 10.2286
1200 574 0.168031814 2.441620991 13 10.8857
866 766 0.26926167 2.597851296 20.4286 15.5714
833 92.06545906 0.313120993 2.659706921 4.7128 1.3371
```

```
765 761 0.7723999 2.774313193 33.2857 31.5714
764 761 0.7723999 2.774313203 33.2857 31.5714
1924 668 1.408730582 2.849672636 51.7143 47
1820 533 1.961129687 2.911884676 40.7143 50.7143
876 80.57940801 0.367404007 3.069310625 1.3248 0.8544
680 1126 0.798848475 3.088071779 88.5714 62
917 624 1.165308026 3.138441089 3.9429 9.6286
1960 342 2.13105213 3.182004962 26.2857 27.1429
780 669 0.916020628 3.422266999 22.7143 21.2857
195 86.5511611 0.211027561 3.514150489 7.6011 2.1175
622 76.51385515 2.701795204 3.62461961 8.7341 5.3492
1174 658 0.713249554 3.993752078 32.7143 15.4286
652 80.41852493 0.474282577 4.005340559 9.8871 7.7286
625 47.42542566 0.091855769 4.082155062 8.5983 7.8
624 1162 0.354552867 4.09211908 8.6857 17.1429
880 108 1.277166959 4.21194493 2.7714 5.0429
940 216 0.929326631 4.602567988 0.0693 12.1403
780 49.90926147 1.26042389 5.019852047 1.9692 1.9106
81 122.5348556 1.67031386 5.20886623 6.8865 9.0037
421 142.7517684 0.87569876 5.377378353 11.5714 5.2106
1781 697 3.247073983 5.621497627 8.3286 5.6714
25 13.22658831 1.665799978 5.739033712 0.5252 0.8871
0 28.85600941 1.756041808 5.849574267 0.0014 0.0986
1521 142.2541594 1.25339344 6.2806018 10.2257 9.1663
791 518 3.168559483 6.661180495 12.7143 10.7143
0 74.68500426 5.091311292 8.498513601 0.4601 0.1957
300 134.3480819 3.5750477 8.567099469 0.8809 1.9125
590 43.90696153 0.120947183 9.361985751 2.7485 1.4146
0 80.41549734 2.659841837 9.788442777 0.6301 0.4669
604 170 2.42889775 10.38794377 20.4041 19.9427
473 165.7356179 2.641293268 10.92229914 0.3557 0.0315
;
Run;
%include' \\Client\C$\Sta538\Normtest.sas';
%Normtest(Data=A,var=LowFlow_Difference);
Proc Rank Data=A Out=B;
 Var Abs_Diff;
 Ranks Rank;
Run;
Data C;
 Set B;
 Drop S;
 S=Sign(LowFlow_Difference);
 If S<0 Then Sign='-'; Else If S=0 Then Sign='0'; Else Sign='+';
 SignedRank=Sign(LowFlow_Difference)*Rank;
Run;
Proc Print Data=C;
Run;
Options FormDLim='-';
Proc Univariate Data=A;
 Var LowFlow_Difference;
 ODS Select TestsforLocation;
Run;
Proc TTest Data=A;
 Paired LowFlow2001*LowFlow1992;
 ODS Select TTests;
```

```
 run;
quit;
proc corr data=A;
var  WatershedArea  LowFlow1992 LowFlow2001;
run;
Proc Print Data=A;
Run;
Proc Corr Data=A;
 Var WatershedDatum WatershedArea UrbanPercentage1992 UrbanPercentage2001
LowFlow1992 LowFlow2001;
 ODS Select PearsonCorr;
Run;

Proc Reg Data=A;
 Model LowFlow1992=WatershedArea  / VIF Collin;
 plot LowFlow1992*WatershedArea;
Run; Quit;
Proc Reg Data=A;
 Model LowFlow2001=WatershedArea / VIF Collin;
 plot LowFlow2001*WatershedArea;
Run; Quit;
Proc Reg Data=A;
 Model LowFlow1992=WatershedArea;
 Weight W; Run;
 Plot RStudent.*(WatershedArea Pred.) / NoModel NoStat; Title3 'Residual
Plot'; Run;
Quit;
Proc Reg Data=A;
 Model LowFlow2001=WatershedArea;
 Weight W; Run;
 Plot RStudent.*(WatershedArea Pred.) / NoModel NoStat; Title3 'Residual
Plot'; Run;
Quit;
```

SAS code for comparing the 7Q10 of watersheds with urban area 11%-23%

```
Options PageNo=1 NoDate FormDLim='';
Title ' Low Flow data VS. Urbanization ';
Title2 ' Wilcoxon Signed Ranks Test';

Data A;
 Input WatershedDatum WatershedArea UrbanPercentage1992 UrbanPercentage2001
LowFlow1992 LowFlow2001;
 LowFlow_Difference=Round(LowFlow2001-LowFlow1992,.001);
 Abs_Diff=Abs(LowFlow_Difference);
 Datalines;
30 127 2.11 11.76 0.0443 0.05
0 105 1.84 14.61 5.9443 0.6429
576 48.82178171 9.46211821 15.27115306 0.2169 0.238
23 150 10.136 15.612 5.0429 6.8286
858 54.79963377 2.850960095 15.69657112 1.5458 0.5956
```

```
19 114 2.82 17.5 12.5714 11.4286
620 96.29238802 5.888358117 22.10977526 4.4256 3.2816
;
Run;
%include' \\Client\C$\Sta538\Normtest.sas';
%Normtest(Data=A,var=LowFlow_Difference);
Proc Rank Data=A Out=B;
 Var Abs_Diff;
 Ranks Rank;
Run;
Data C;
 Set B;
 Drop S;
 S=Sign(LowFlow_Difference);
 If S<0 Then Sign='-'; Else If S=0 Then Sign='0'; Else Sign='+';
 SignedRank=Sign(LowFlow_Difference)*Rank;
Run;
Proc Print Data=C;
Run;
Options FormDLim='-';
Proc Univariate Data=A;
 Var LowFlow_Difference;
 ODS Select TestsforLocation;
Run;
Proc TTest Data=A;
 Paired LowFlow2001*LowFlow1992;
 ODS Select TTests;
 run;
quit;
proc corr data=A;
var  WatershedArea  LowFlow1992 LowFlow2001;
run;
Proc Print Data=A;
Run;
Proc Corr Data=A;
 Var WatershedDatum WatershedArea UrbanPercentage1992 UrbanPercentage2001
LowFlow1992 LowFlow2001;
 ODS Select PearsonCorr;
Run;

Proc Reg Data=A;
 Model LowFlow1992=WatershedArea  / VIF Collin;
 plot LowFlow1992*WatershedArea;
Run; Quit;
Proc Reg Data=A;
 Model LowFlow2001=WatershedArea / VIF Collin;
 plot LowFlow2001*WatershedArea;
Run; Quit;
Proc Reg Data=A;
 Model LowFlow1992=WatershedArea;
 Weight W; Run;
 Plot RStudent.*(WatershedArea Pred.) / NoModel NoStat; Title3 'Residual
Plot'; Run;
Quit;
Proc Reg Data=A;
 Model LowFlow2001=WatershedArea;
```

```
 Weight W; Run;
 Plot RStudent.*(WatershedArea Pred.) / NoModel NoStat; Title3 'Residual
Plot'; Run;
Quit;
```

SAS code for comparing the 7Q10 of watersheds with urban area greater than 23%

```
Options PageNo=1 NoDate FormDLim='';
Title ' Low Flow data VS. Urbanization ';
Title2 ' Wilcoxon Signed Ranks Test';

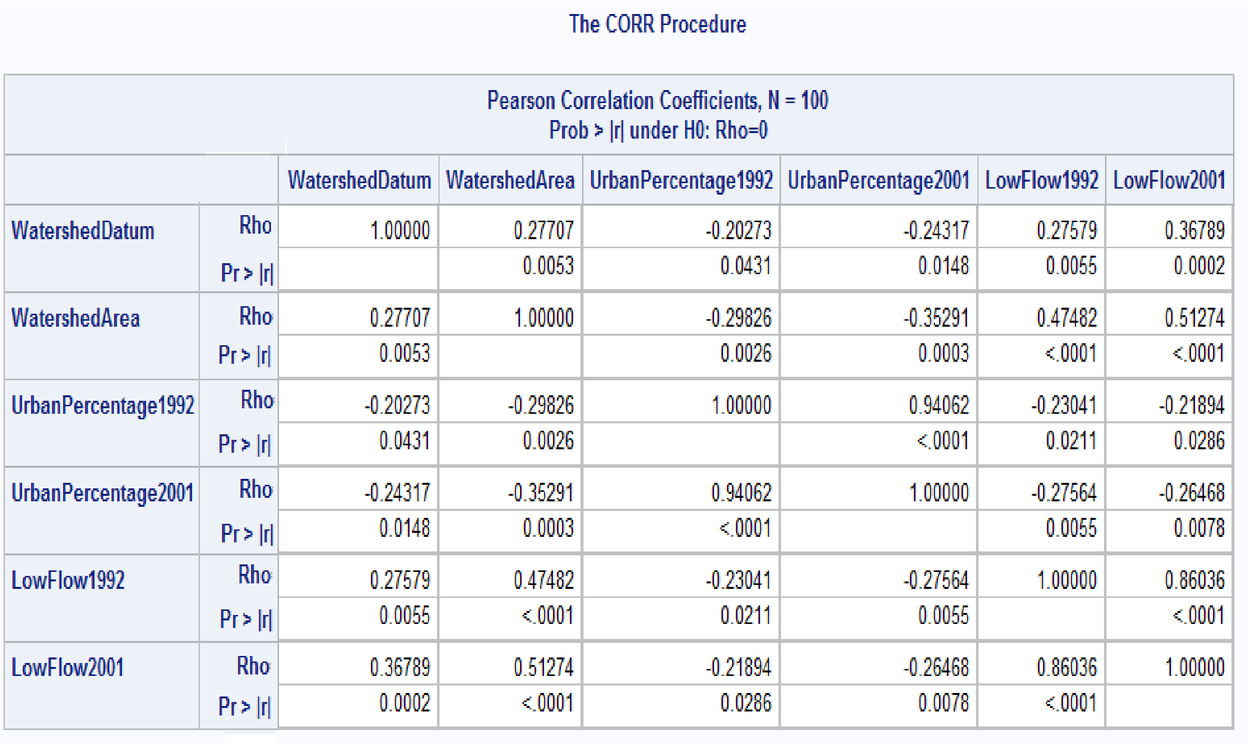
Data A;
 Input WatershedDatum WatershedArea UrbanPercentage1992 UrbanPercentage2001
LowFlow1992 LowFlow2001;
 LowFlow_Difference=Round(LowFlow2001-LowFlow1992,.001);
 Abs_Diff=Abs(LowFlow_Difference);
 Datalines;
26 54.87879104 11.87551006 23.75123603 0.9034 1.165
260 44.97724911 8.523775204 24.26758599 0.1139 0.5303
25 141 14.51 24.68 7.0571 7.5857
29 76.6 12.92 25.54 7.5857 11.4571
588 317 9.956674816 27.89856705 2.5643 0.0414
616 59.55626173 9.623930081 34.04035185 0.2422 1.5197
591 183 15.45546234 37.82636297 3.2714 9.3714
639 49.25 12.48620677 38.47438897 0.3425 1.5291
14 16.7 5.73 40.11 0.6457 0.8971
925 8.386723776 10.15192955 40.64942871 0.0963 0.0989
15 18.84107271 11.85008582 42.04683 0.2741 0.2447
191 61.57477522 15.77471567 42.77342466 0.1199 0.7329
477 48.91835109 20.9948384 44.44199264 0.4077 0.0088
9 106 24.67 48.31 1.1814 1.2
649 32.96858853 22.71657329 52.56399899 0.4187 0.9635
620 46.52900563 15.36259809 58.05383552 0.1407 0.8227
617 60.16687598 18.99673091 58.57210624 3.4829 3.4814
742 40.4 23.24154015 60.05670284 0.1722 0.1133
448 44.9845201 26.28713052 61.57517786 1.13 0.686
620 31.5 27.09602335 63.08987638 0.1921 0.6768
686 77.83218863 34.66732908 67.94894149 0.2215 2.2861
708 62.94 34.14545576 68.52628288 0.3011 0.5457
780 19.01998913 37.90466995 77.68317186 0.2007 0.0314
615 27.50323239 25.26149817 77.80826762 1.0484 0.6769
-3 18.37537655 41.0008899 81.07877875 0.0388 0.2362
0 43.7 56.32 83.59 3.9143 4.6571
606 43.12545831 35.74273355 84.48649917 8.3842 9.2341
634 33.02131302 65.53357214 90.14666478 0.0861 0.0424
694 11.60832438 65.95105851 96.07069701 0.4028 0.6213
;
Run;
%include' \\Client\C$\Sta538\Normtest.sas';
%Normtest(Data=A,var=LowFlow_Difference);
Proc Rank Data=A Out=B;
 Var Abs_Diff;
 Ranks Rank;
Run;
Data C;
```

```
 Set B;
 Drop S;
 S=Sign(LowFlow_Difference);
 If S<0 Then Sign='-'; Else If S=0 Then Sign='0'; Else Sign='+';
 SignedRank=Sign(LowFlow_Difference)*Rank;
Run;
Proc Print Data=C;
Run;
Options FormDLim='-';
Proc Univariate Data=A;
 Var LowFlow_Difference;
 ODS Select TestsforLocation;
Run;
Proc TTest Data=A;
 Paired LowFlow2001*LowFlow1992;
 ODS Select TTests;
 run;
quit;
proc corr data=A;
var  WatershedArea  LowFlow1992 LowFlow2001;
run;
Proc Print Data=A;
Run;
Proc Corr Data=A;
 Var WatershedDatum WatershedArea UrbanPercentage1992 UrbanPercentage2001
LowFlow1992 LowFlow2001;
 ODS Select PearsonCorr;
Run;

Proc Reg Data=A;
 Model LowFlow1992=WatershedArea  / VIF Collin;
 plot LowFlow1992*WatershedArea;
Run; Quit;
Proc Reg Data=A;
 Model LowFlow2001=WatershedArea / VIF Collin;
 plot LowFlow2001*WatershedArea;
Run; Quit;
Proc Reg Data=A;
 Model LowFlow1992=WatershedArea;
 Weight W; Run;
 Plot RStudent.*(WatershedArea Pred.) / NoModel NoStat; Title3 'Residual
Plot'; Run;
Quit;
Proc Reg Data=A;
 Model LowFlow2001=WatershedArea;
 Weight W; Run;
 Plot RStudent.*(WatershedArea Pred.) / NoModel NoStat; Title3 'Residual
Plot'; Run;
Quit;
```

Appendix D

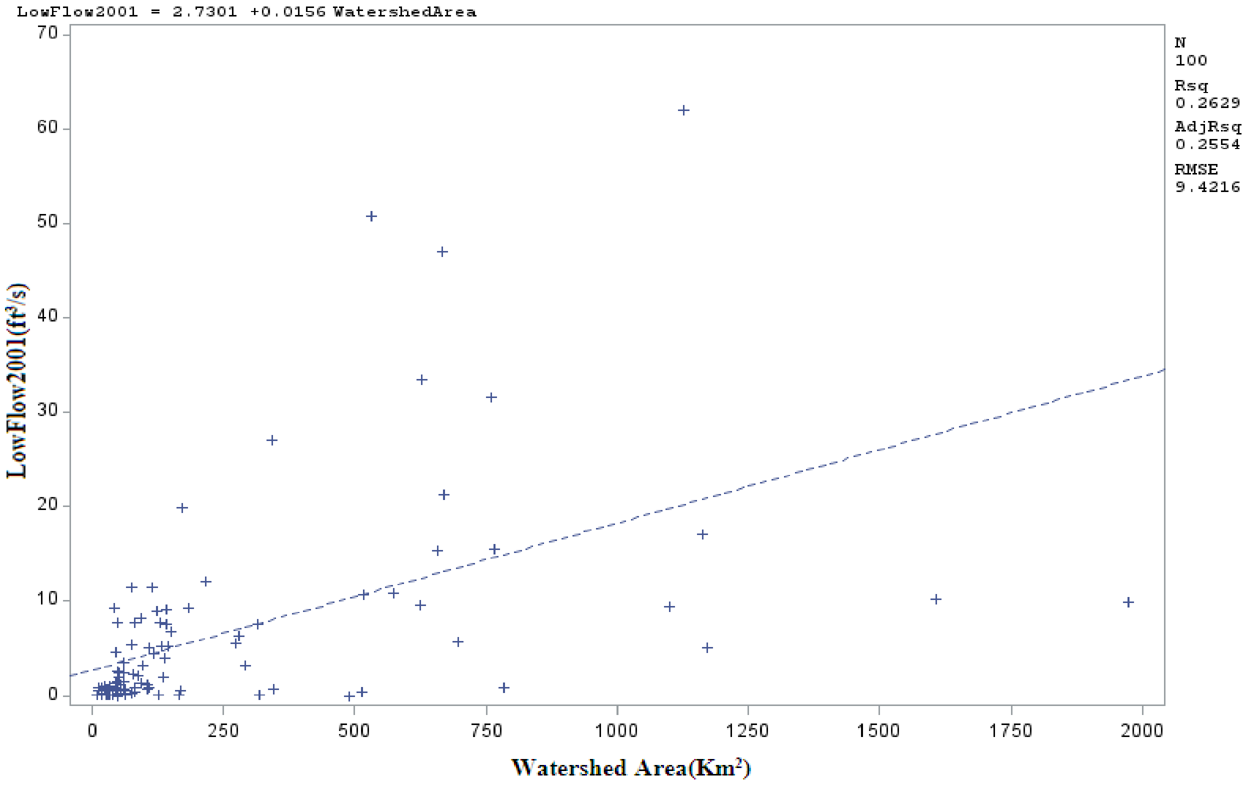
Regression Plots



The CORR Procedure

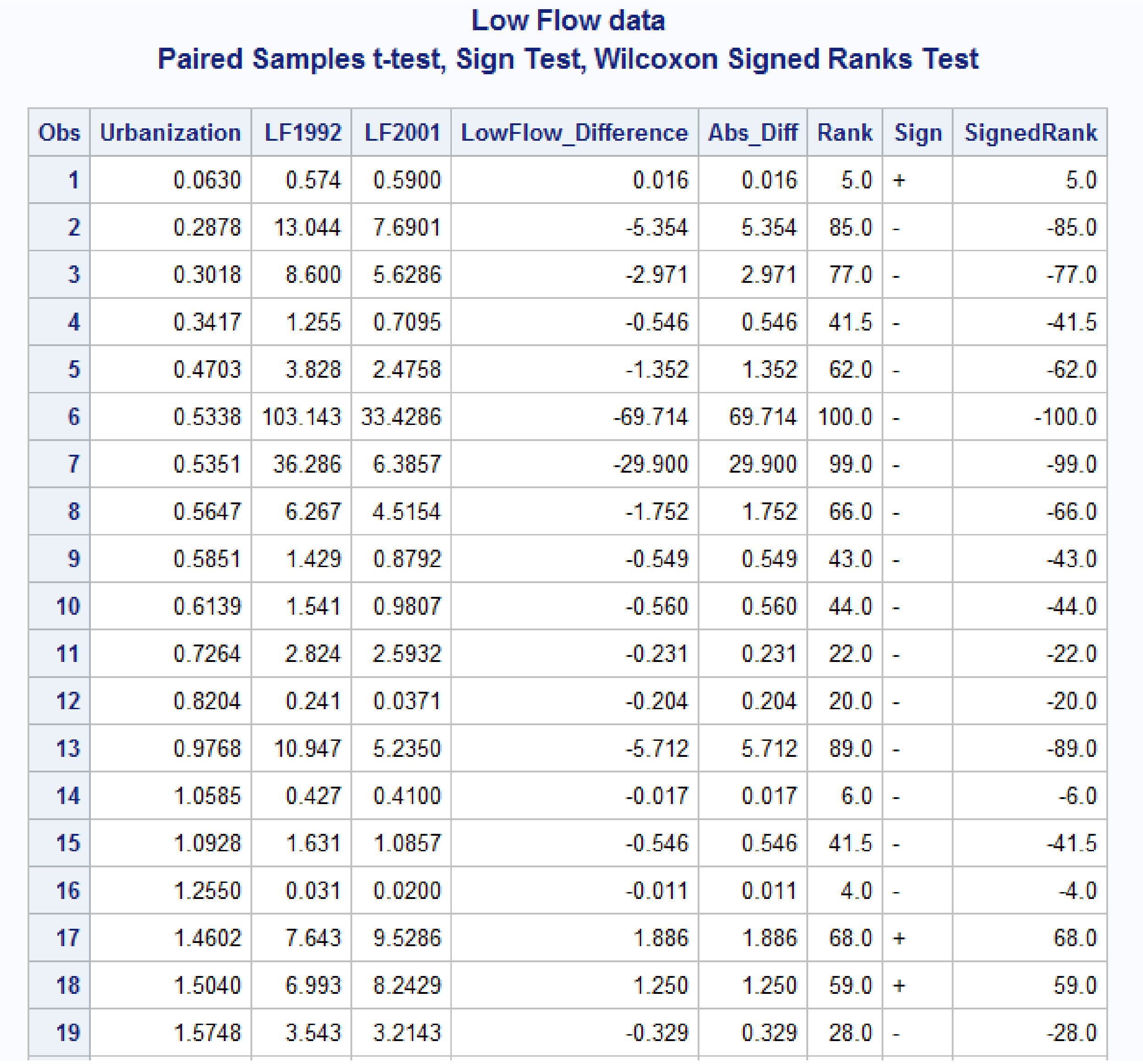
Pearson Correlation Coefficients, N = 100
Prob > |r| under H0: Rho=0

		WatershedDatum	WatershedArea	UrbanPercentage1992	UrbanPercentage2001	LowFlow1992	LowFlow2001
WatershedDatum	Rho	1.00000	0.27707	-0.20273	-0.24317	0.27579	0.36789
	Pr > |r|		0.0053	0.0431	0.0148	0.0055	0.0002
WatershedArea	Rho	0.27707	1.00000	-0.29826	-0.35291	0.47482	0.51274
	Pr > |r|	0.0053		0.0026	0.0003	<.0001	<.0001
UrbanPercentage1992	Rho	-0.20273	-0.29826	1.00000	0.94062	-0.23041	-0.21894
	Pr > |r|	0.0431	0.0026		<.0001	0.0211	0.0286
UrbanPercentage2001	Rho	-0.24317	-0.35291	0.94062	1.00000	-0.27564	-0.26468
	Pr > |r|	0.0148	0.0003	<.0001		0.0055	0.0078
LowFlow1992	Rho	0.27579	0.47482	-0.23041	-0.27564	1.00000	0.86036
	Pr > |r|	0.0055	<.0001	0.0211	0.0055		<.0001
LowFlow2001	Rho	0.36789	0.51274	-0.21894	-0.26468	0.86036	1.00000
	Pr > |r|	0.0002	<.0001	0.0286	0.0078	<.0001	



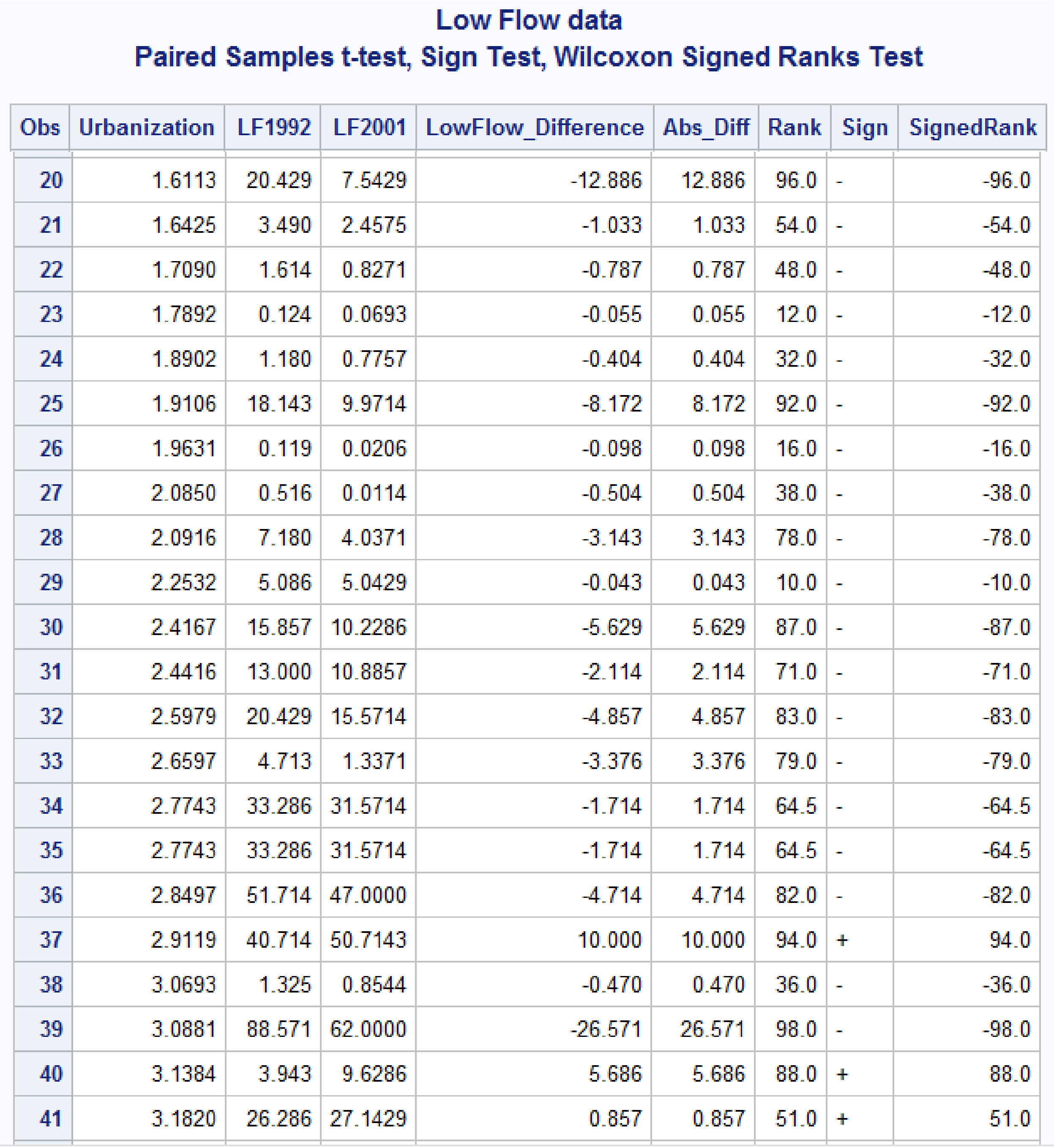
Appendix E

Wilcoxon signed rank results



Low Flow data
Paired Samples t-test, Sign Test, Wilcoxon Signed Ranks Test

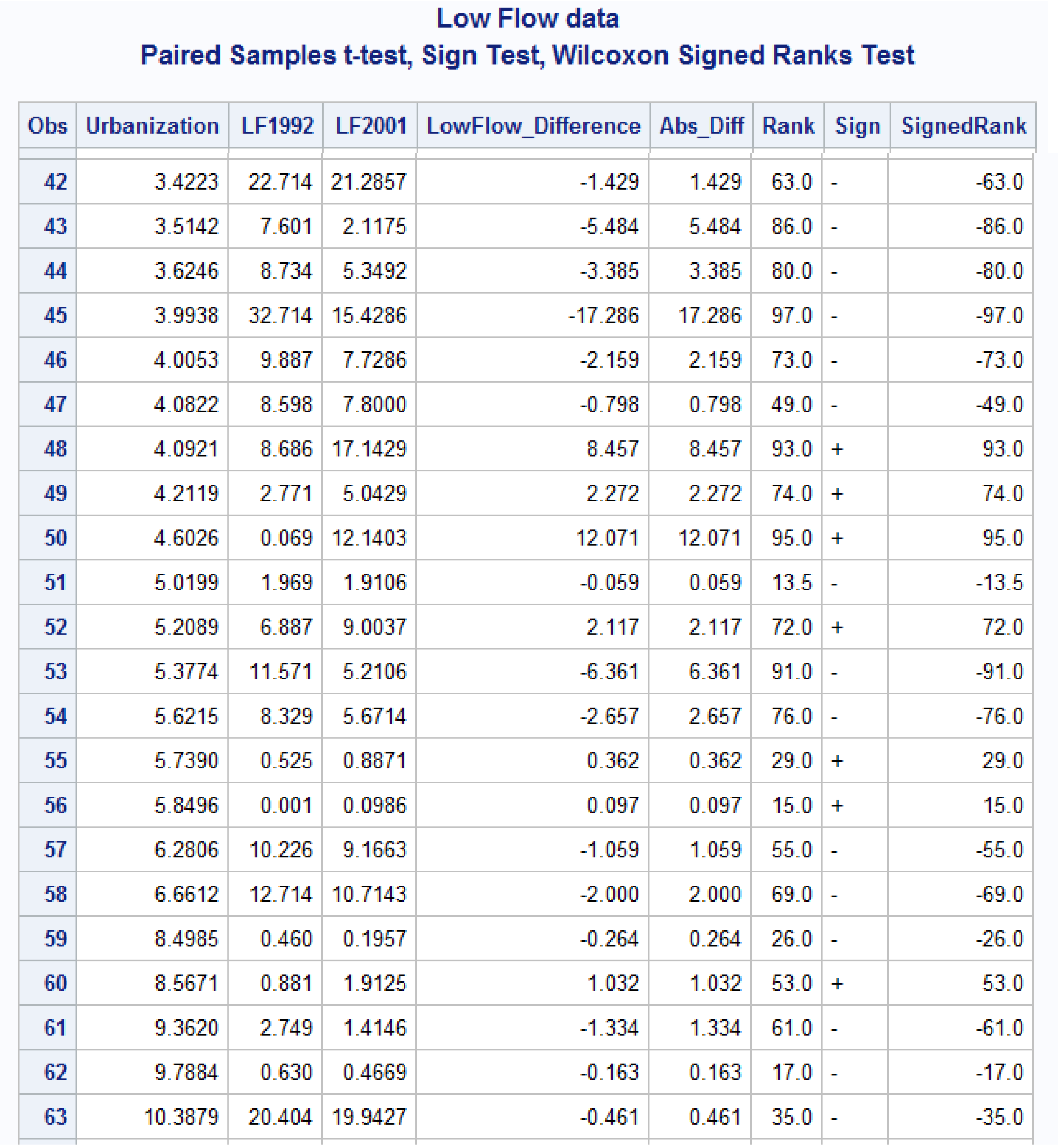
Obs	Urbanization	LF1992	LF2001	LowFlow_Difference	Abs_Diff	Rank	Sign	SignedRank
1	0.0630	0.574	0.5900	0.016	0.016	5.0	+	5.0
2	0.2878	13.044	7.6901	-5.354	5.354	85.0	-	-85.0
3	0.3018	8.600	5.6286	-2.971	2.971	77.0	-	-77.0
4	0.3417	1.255	0.7095	-0.546	0.546	41.5	-	-41.5
5	0.4703	3.828	2.4758	-1.352	1.352	62.0	-	-62.0
6	0.5338	103.143	33.4286	-69.714	69.714	100.0	-	-100.0
7	0.5351	36.286	6.3857	-29.900	29.900	99.0	-	-99.0
8	0.5647	6.267	4.5154	-1.752	1.752	66.0	-	-66.0
9	0.5851	1.429	0.8792	-0.549	0.549	43.0	-	-43.0
10	0.6139	1.541	0.9807	-0.560	0.560	44.0	-	-44.0
11	0.7264	2.824	2.5932	-0.231	0.231	22.0	-	-22.0
12	0.8204	0.241	0.0371	-0.204	0.204	20.0	-	-20.0
13	0.9768	10.947	5.2350	-5.712	5.712	89.0	-	-89.0
14	1.0585	0.427	0.4100	-0.017	0.017	6.0	-	-6.0
15	1.0928	1.631	1.0857	-0.546	0.546	41.5	-	-41.5
16	1.2550	0.031	0.0200	-0.011	0.011	4.0	-	-4.0
17	1.4602	7.643	9.5286	1.886	1.886	68.0	+	68.0
18	1.5040	6.993	8.2429	1.250	1.250	59.0	+	59.0
19	1.5748	3.543	3.2143	-0.329	0.329	28.0	-	-28.0



Low Flow data

Paired Samples t-test, Sign Test, Wilcoxon Signed Ranks Test

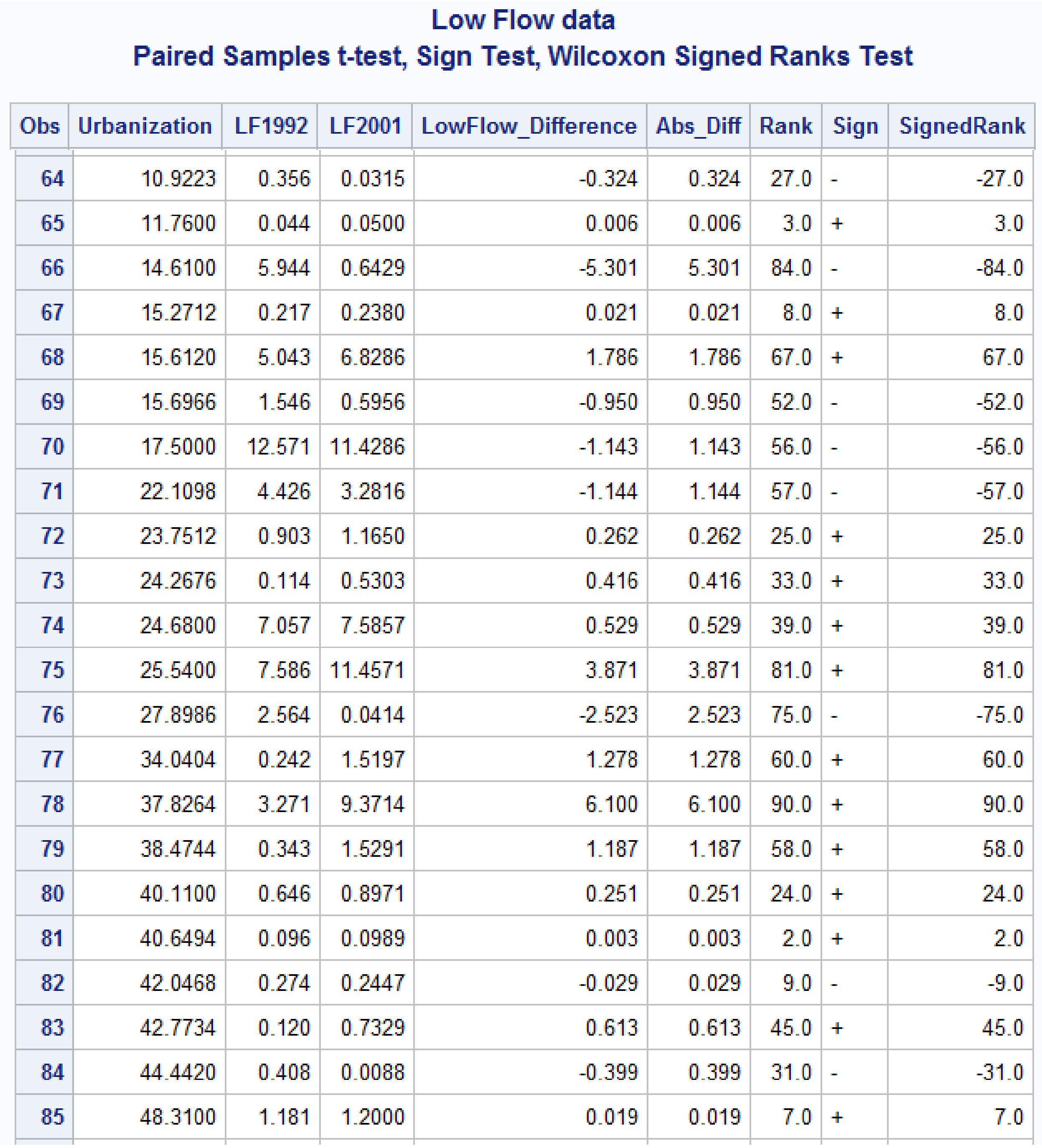
Obs	Urbanization	LF1992	LF2001	LowFlow_Difference	Abs_Diff	Rank	Sign	SignedRank
20	1.6113	20.429	7.5429	-12.886	12.886	96.0	-	-96.0
21	1.6425	3.490	2.4575	-1.033	1.033	54.0	-	-54.0
22	1.7090	1.614	0.8271	-0.787	0.787	48.0	-	-48.0
23	1.7892	0.124	0.0693	-0.055	0.055	12.0	-	-12.0
24	1.8902	1.180	0.7757	-0.404	0.404	32.0	-	-32.0
25	1.9106	18.143	9.9714	-8.172	8.172	92.0	-	-92.0
26	1.9631	0.119	0.0206	-0.098	0.098	16.0	-	-16.0
27	2.0850	0.516	0.0114	-0.504	0.504	38.0	-	-38.0
28	2.0916	7.180	4.0371	-3.143	3.143	78.0	-	-78.0
29	2.2532	5.086	5.0429	-0.043	0.043	10.0	-	-10.0
30	2.4167	15.857	10.2286	-5.629	5.629	87.0	-	-87.0
31	2.4416	13.000	10.8857	-2.114	2.114	71.0	-	-71.0
32	2.5979	20.429	15.5714	-4.857	4.857	83.0	-	-83.0
33	2.6597	4.713	1.3371	-3.376	3.376	79.0	-	-79.0
34	2.7743	33.286	31.5714	-1.714	1.714	64.5	-	-64.5
35	2.7743	33.286	31.5714	-1.714	1.714	64.5	-	-64.5
36	2.8497	51.714	47.0000	-4.714	4.714	82.0	-	-82.0
37	2.9119	40.714	50.7143	10.000	10.000	94.0	+	94.0
38	3.0693	1.325	0.8544	-0.470	0.470	36.0	-	-36.0
39	3.0881	88.571	62.0000	-26.571	26.571	98.0	-	-98.0
40	3.1384	3.943	9.6286	5.686	5.686	88.0	+	88.0
41	3.1820	26.286	27.1429	0.857	0.857	51.0	+	51.0



Low Flow data

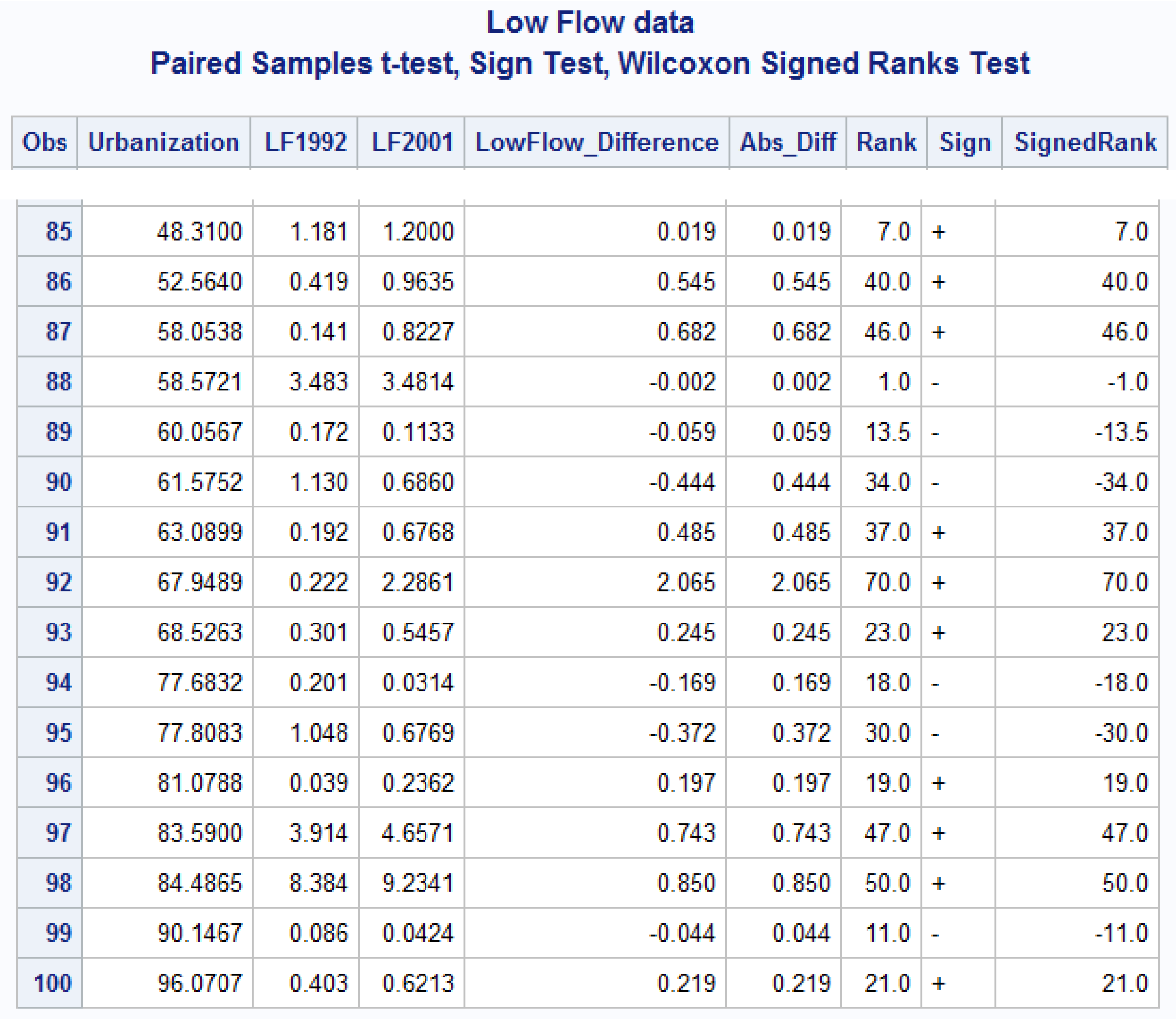
Paired Samples t-test, Sign Test, Wilcoxon Signed Ranks Test

Obs	Urbanization	LF1992	LF2001	LowFlow_Difference	Abs_Diff	Rank	Sign	SignedRank
42	3.4223	22.714	21.2857	-1.429	1.429	63.0	-	-63.0
43	3.5142	7.601	2.1175	-5.484	5.484	86.0	-	-86.0
44	3.6246	8.734	5.3492	-3.385	3.385	80.0	-	-80.0
45	3.9938	32.714	15.4286	-17.286	17.286	97.0	-	-97.0
46	4.0053	9.887	7.7286	-2.159	2.159	73.0	-	-73.0
47	4.0822	8.598	7.8000	-0.798	0.798	49.0	-	-49.0
48	4.0921	8.686	17.1429	8.457	8.457	93.0	+	93.0
49	4.2119	2.771	5.0429	2.272	2.272	74.0	+	74.0
50	4.6026	0.069	12.1403	12.071	12.071	95.0	+	95.0
51	5.0199	1.969	1.9106	-0.059	0.059	13.5	-	-13.5
52	5.2089	6.887	9.0037	2.117	2.117	72.0	+	72.0
53	5.3774	11.571	5.2106	-6.361	6.361	91.0	-	-91.0
54	5.6215	8.329	5.6714	-2.657	2.657	76.0	-	-76.0
55	5.7390	0.525	0.8871	0.362	0.362	29.0	+	29.0
56	5.8496	0.001	0.0986	0.097	0.097	15.0	+	15.0
57	6.2806	10.226	9.1663	-1.059	1.059	55.0	-	-55.0
58	6.6612	12.714	10.7143	-2.000	2.000	69.0	-	-69.0
59	8.4985	0.460	0.1957	-0.264	0.264	26.0	-	-26.0
60	8.5671	0.881	1.9125	1.032	1.032	53.0	+	53.0
61	9.3620	2.749	1.4146	-1.334	1.334	61.0	-	-61.0
62	9.7884	0.630	0.4669	-0.163	0.163	17.0	-	-17.0
63	10.3879	20.404	19.9427	-0.461	0.461	35.0	-	-35.0



Low Flow data
Paired Samples t-test, Sign Test, Wilcoxon Signed Ranks Test

Obs	Urbanization	LF1992	LF2001	LowFlow_Difference	Abs_Diff	Rank	Sign	SignedRank
64	10.9223	0.356	0.0315	-0.324	0.324	27.0	-	-27.0
65	11.7600	0.044	0.0500	0.006	0.006	3.0	+	3.0
66	14.6100	5.944	0.6429	-5.301	5.301	84.0	-	-84.0
67	15.2712	0.217	0.2380	0.021	0.021	8.0	+	8.0
68	15.6120	5.043	6.8286	1.786	1.786	67.0	+	67.0
69	15.6966	1.546	0.5956	-0.950	0.950	52.0	-	-52.0
70	17.5000	12.571	11.4286	-1.143	1.143	56.0	-	-56.0
71	22.1098	4.426	3.2816	-1.144	1.144	57.0	-	-57.0
72	23.7512	0.903	1.1650	0.262	0.262	25.0	+	25.0
73	24.2676	0.114	0.5303	0.416	0.416	33.0	+	33.0
74	24.6800	7.057	7.5857	0.529	0.529	39.0	+	39.0
75	25.5400	7.586	11.4571	3.871	3.871	81.0	+	81.0
76	27.8986	2.564	0.0414	-2.523	2.523	75.0	-	-75.0
77	34.0404	0.242	1.5197	1.278	1.278	60.0	+	60.0
78	37.8264	3.271	9.3714	6.100	6.100	90.0	+	90.0
79	38.4744	0.343	1.5291	1.187	1.187	58.0	+	58.0
80	40.1100	0.646	0.8971	0.251	0.251	24.0	+	24.0
81	40.6494	0.096	0.0989	0.003	0.003	2.0	+	2.0
82	42.0468	0.274	0.2447	-0.029	0.029	9.0	-	-9.0
83	42.7734	0.120	0.7329	0.613	0.613	45.0	+	45.0
84	44.4420	0.408	0.0088	-0.399	0.399	31.0	-	-31.0
85	48.3100	1.181	1.2000	0.019	0.019	7.0	+	7.0

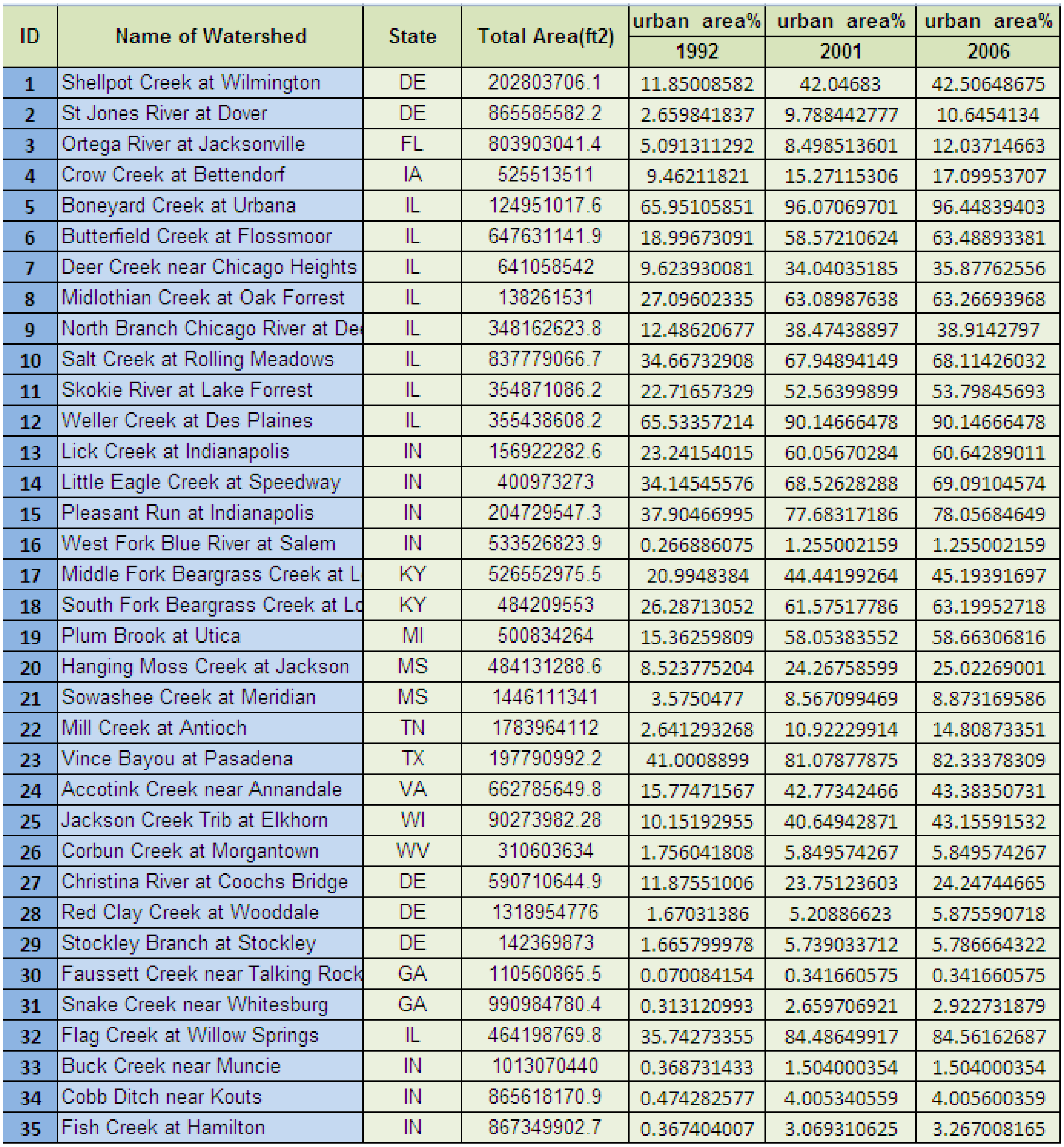


Low Flow data
Paired Samples t-test, Sign Test, Wilcoxon Signed Ranks Test

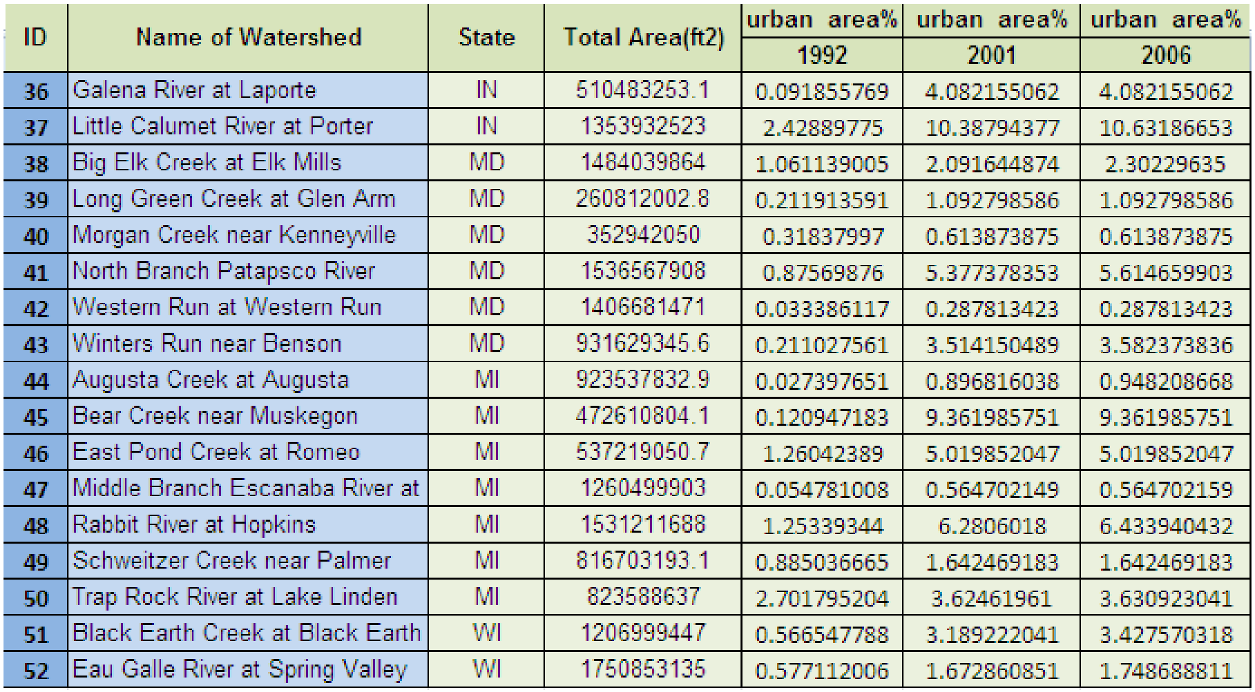
Obs	Urbanization	LF1992	LF2001	LowFlow_Difference	Abs_Diff	Rank	Sign	SignedRank
85	48.3100	1.181	1.2000	0.019	0.019	7.0	+	7.0
86	52.5640	0.419	0.9635	0.545	0.545	40.0	+	40.0
87	58.0538	0.141	0.8227	0.682	0.682	46.0	+	46.0
88	58.5721	3.483	3.4814	-0.002	0.002	1.0	-	-1.0
89	60.0567	0.172	0.1133	-0.059	0.059	13.5	-	-13.5
90	61.5752	1.130	0.6860	-0.444	0.444	34.0	-	-34.0
91	63.0899	0.192	0.6768	0.485	0.485	37.0	+	37.0
92	67.9489	0.222	2.2861	2.065	2.065	70.0	+	70.0
93	68.5263	0.301	0.5457	0.245	0.245	23.0	+	23.0
94	77.6832	0.201	0.0314	-0.169	0.169	18.0	-	-18.0
95	77.8083	1.048	0.6769	-0.372	0.372	30.0	-	-30.0
96	81.0788	0.039	0.2362	0.197	0.197	19.0	+	19.0
97	83.5900	3.914	4.6571	0.743	0.743	47.0	+	47.0
98	84.4865	8.384	9.2341	0.850	0.850	50.0	+	50.0
99	90.1467	0.086	0.0424	-0.044	0.044	11.0	-	-11.0
100	96.0707	0.403	0.6213	0.219	0.219	21.0	+	21.0

Appendix F

Comparing the percentage of three different land cover



ID	Name of Watershed	State	Total Area(ft2)	urban area% 1992	urban area% 2001	urban area% 2006
1	Shellpot Creek at Wilmington	DE	202803706.1	11.85008582	42.04683	42.50648675
2	St Jones River at Dover	DE	865585582.2	2.659841837	9.788442777	10.6454134
3	Ortega River at Jacksonville	FL	803903041.4	5.091311292	8.498513601	12.03714663
4	Crow Creek at Bettendorf	IA	525513511	9.46211821	15.27115306	17.09953707
5	Boneyard Creek at Urbana	IL	124951017.6	65.95105851	96.07069701	96.44839403
6	Butterfield Creek at Flossmoor	IL	647631141.9	18.99673091	58.57210624	63.48893381
7	Deer Creek near Chicago Heights	IL	641058542	9.623930081	34.04035185	35.87762556
8	Midlothian Creek at Oak Forrest	IL	138261531	27.09602335	63.08987638	63.26693968
9	North Branch Chicago River at De	IL	348162623.8	12.48620677	38.47438897	38.9142797
10	Salt Creek at Rolling Meadows	IL	837779066.7	34.66732908	67.94894149	68.11426032
11	Skokie River at Lake Forrest	IL	354871086.2	22.71657329	52.56399899	53.79845693
12	Weller Creek at Des Plaines	IL	355438608.2	65.53357214	90.14666478	90.14666478
13	Lick Creek at Indianapolis	IN	156922282.6	23.24154015	60.05670284	60.64289011
14	Little Eagle Creek at Speedway	IN	400973273	34.14545576	68.52628288	69.09104574
15	Pleasant Run at Indianapolis	IN	204729547.3	37.90466995	77.68317186	78.05684649
16	West Fork Blue River at Salem	IN	533526823.9	0.266886075	1.255002159	1.255002159
17	Middle Fork Beargrass Creek at L	KY	526552975.5	20.9948384	44.44199264	45.19391697
18	South Fork Beargrass Creek at Lo	KY	484209553	26.28713052	61.57517786	63.19952718
19	Plum Brook at Utica	MI	500834264	15.36259809	58.05383552	58.66306816
20	Hanging Moss Creek at Jackson	MS	484131288.6	8.523775204	24.26758599	25.02269001
21	Sowashee Creek at Meridian	MS	1446111341	3.5750477	8.567099469	8.873169586
22	Mill Creek at Antioch	TN	1783964112	2.641293268	10.92229914	14.80873351
23	Vince Bayou at Pasadena	TX	197790992.2	41.0008899	81.07877875	82.33378309
24	Accotink Creek near Annandale	VA	662785649.8	15.77471567	42.77342466	43.38350731
25	Jackson Creek Trib at Elkhorn	WI	90273982.28	10.15192955	40.64942871	43.15591532
26	Corbun Creek at Morgantown	WV	310603634	1.756041808	5.849574267	5.849574267
27	Christina River at Coochs Bridge	DE	590710644.9	11.87551006	23.75123603	24.24744665
28	Red Clay Creek at Wooddale	DE	1318954776	1.67031386	5.20886623	5.875590718
29	Stockley Branch at Stockley	DE	142369873	1.665799978	5.739033712	5.786664322
30	Faussett Creek near Talking Rock	GA	110560865.5	0.070084154	0.341660575	0.341660575
31	Snake Creek near Whitesburg	GA	990984780.4	0.313120993	2.659706921	2.922731879
32	Flag Creek at Willow Springs	IL	464198769.8	35.74273355	84.48649917	84.56162687
33	Buck Creek near Muncie	IN	1013070440	0.368731433	1.504000354	1.504000354
34	Cobb Ditch near Kouts	IN	865618170.9	0.474282577	4.005340559	4.005600359
35	Fish Creek at Hamilton	IN	867349902.7	0.367404007	3.069310625	3.267008165



ID	Name of Watershed	State	Total Area(ft2)	urban area%	urban area%	urban area%
				1992	2001	2006
36	Galena River at Laporte	IN	510483253.1	0.091855769	4.082155062	4.082155062
37	Little Calumet River at Porter	IN	1353932523	2.42889775	10.38794377	10.63186653
38	Big Elk Creek at Elk Mills	MD	1484039864	1.061139005	2.091644874	2.30229635
39	Long Green Creek at Glen Arm	MD	260812002.8	0.211913591	1.092798586	1.092798586
40	Morgan Creek near Kenneyville	MD	352942050	0.31837997	0.613873875	0.613873875
41	North Branch Patapsco River	MD	1536567908	0.87569876	5.377378353	5.614659903
42	Western Run at Western Run	MD	1406681471	0.033386117	0.287813423	0.287813423
43	Winters Run near Benson	MD	931629345.6	0.211027561	3.514150489	3.582373836
44	Augusta Creek at Augusta	MI	923537832.9	0.027397651	0.896816038	0.948208668
45	Bear Creek near Muskegon	MI	472610804.1	0.120947183	9.361985751	9.361985751
46	East Pond Creek at Romeo	MI	537219050.7	1.26042389	5.019852047	5.019852047
47	Middle Branch Escanaba River at	MI	1260499903	0.054781008	0.564702149	0.564702159
48	Rabbit River at Hopkins	MI	1531211688	1.25339344	6.2806018	6.433940432
49	Schweitzer Creek near Palmer	MI	816703193.1	0.885036665	1.642469183	1.642469183
50	Trap Rock River at Lake Linden	MI	823588637	2.701795204	3.62461961	3.630923041
51	Black Earth Creek at Black Earth	WI	1206999447	0.566547788	3.189222041	3.427570318
52	Eau Galle River at Spring Valley	WI	1750853135	0.577112006	1.672860851	1.748688811

Appendix G

As Ott et al. (2010) emphasizes:”The Wilcoxon signed-rank test requires that the population distribution of differences be symmetric about the unknown median M. Let D0 be a specified hypothesized value of M. The test evaluates shifts in the distribution of differences to the right or left of D0; in most cases, D_0 is 0. The computation of the signed-rank test involves the following steps:

1. Calculate the differences in the n pairs of observations.
2. Subtract D_0 from all the differences.
3. Delete all zero values. Let n be the number of nonzero values.
4. List the absolute values of the differences in increasing order, and assign them the ranks 1, . . . , n (or the average of the ranks for ties).

We define the following notation before describing the Wilcoxon signed-rank test:

$$\begin{aligned} n &= \text{the number of pairs of observations with a nonzero difference} \\ T_+ &= \text{the sum of the positive ranks; if there are no positive ranks, } T = 0 \\ T_- &= \text{the sum of the negative ranks; if there are no negative ranks, } T = 0 \\ T &= \text{the smaller of } T_+ \text{ and } T_- \\ \boldsymbol{\mu_T} &= \frac{n(n+1)}{4} \\ \boldsymbol{\sigma_T} &= \sqrt{\frac{n(n+1)(2n+1)}{24}} \end{aligned}$$

If we group together all differences assigned the same rank, and there are g such groups, the variance of T is

$$\sigma_T^2 = \frac{1}{24}\left[n(n+1)(2n+1) - \frac{1}{2}\sum_j t_j(t_j-1)(t_j+1)\right]$$

where tj is the number of tied ranks in the jth group. Note that if there are no tied ranks, g = n, and tj =1 for all groups. The formula then reduces to

$$\sigma_T^2 = \frac{n(n+1)(2n+1)}{24}$$

VITA

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