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TECHNICAL REPORT # 9

HYDROLOGIC IMPACT OF URBANIZATION ON THE ROOT RIVER FLOW IN RACINE

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The findings and conclusions expressed in this report are those of authors and not of funding foundations.

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ABBREVIATIONS

SEWRPC : Southeastern Wisconsin Regional Planning Commission

USGS : US Geological Survey

SCS : Soil Conservation service

CHAPTER I

INTRODUCTION

1.1 OBJECTIVE OF THE STUDY

The Root River watershed is a rapidly urbanized area. The urbanization may cause damages by flooding and degraded water quality. Therefore there is a need for flood control awareness at the Root River Watershed and stream preservation and restoration.

The goal of this study is to examine impacts of urbanization on the discharge-frequency relationship for high flows in the Root River Watershed.

1.2 DESCRIPTION OF THE WATERSHED

The Root River watershed is located in southeast Wisconsin and covers an area of approximately 197 square miles (509 km^2). The river originates in the city of West Allis north of Cleveland Avenue. The main stem of the Root River rises in Milwaukee County within the Milwaukee metropolitan area and flows approximately southeast. The river discharges into the Lake Michigan in the City of Racine. Rivers and streams in the watershed are part of the Lake Michigan drainage system.

The watershed is located in four counties – Kenosha, Milwaukee, Racine, and Waukesha - and 18 cities, villages and towns (SEWRPC, 1995). The watershed location is shown on Figure 1.1. The watershed has a continental climate characterized by four distinct seasons. The mean daily temperature in the summer is 71.3° F and winter 21.9° F. Annual precipitation on the watershed, including snowfall, averages about 30 inches, and ranges from 18.7 to 50.4 inches.

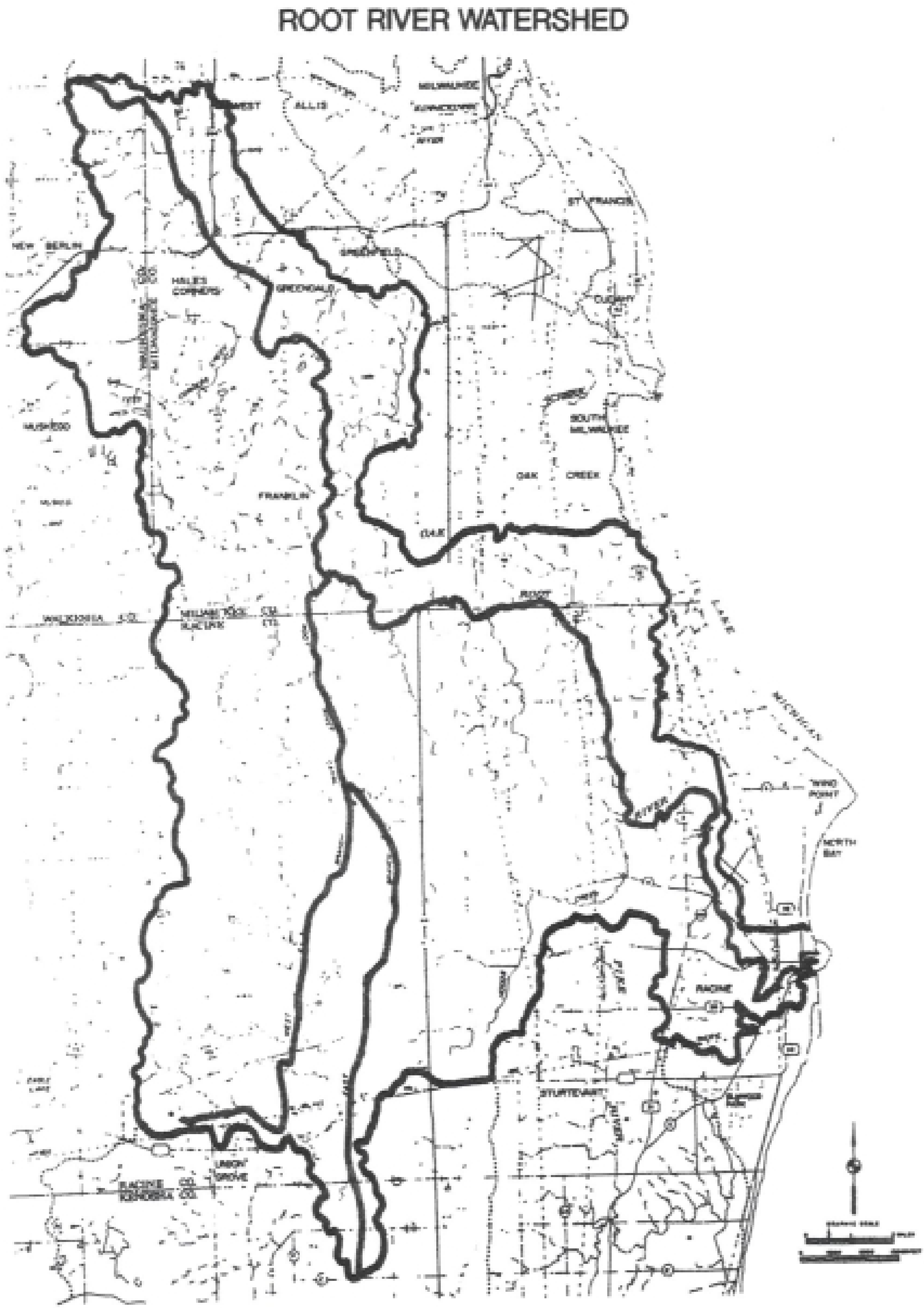

Figure 1.1 Location of the Root River Watershed

1.3 LAND USE

The spatial distribution of land use within the Root River watershed and sub watershed near Franklin (North Branch sub watershed) is shown in Table 1.1 and Figure 1.2. The largest single use within the watershed is agriculture, with nearly two-thirds of the total watershed area and more than one third of North branch sub watershed. The next important land use category is water, woodland, and wetland. The largest single urban land use category is residential.

Table1.1 Existing land use in the Root river watershed and Sub watershed (North Branch near Franklin)

Use	Root river Watershed		North Branch sub watershed	
Category	Area (sq.mi)	% Area	Area (sq.mi)	% Area
Residential Density				
Low	14.33	7.26	9.76	19.85
Medium	2.82	1.43	1.82	3.70
High	3.03	1.53	0.00	0.00
Subtotal	20.18		11.58	
Commercial	0.91	0.46	0.56	1.14
Industrial	0.47	0.24	0.13	0.26
Mining	1.17	0.59	0.47	0.96
Transportation & Utilities	14.81	7.50	5.48	11.15
Governmental & Institutional	1.82	0.92	0.85	1.73
Recreational	5.09	2.58	3.29	6.69
Agricultural	130.82	66.26	18.66	37.96
Water, Woodland & Wetland	22.16	11.22	8.14	16.56
Total	197.43	100.00	49.16	100

1.4 SOIL TYPES

The soils of the Root River watershed are a product of parent materiel, climate, living organisms, relief**,** and time. A pattern of soil types has been developed in the Root River Watershed in which glacial action has left many different kinds of parent material deposits and a landscape with moderate local relief.

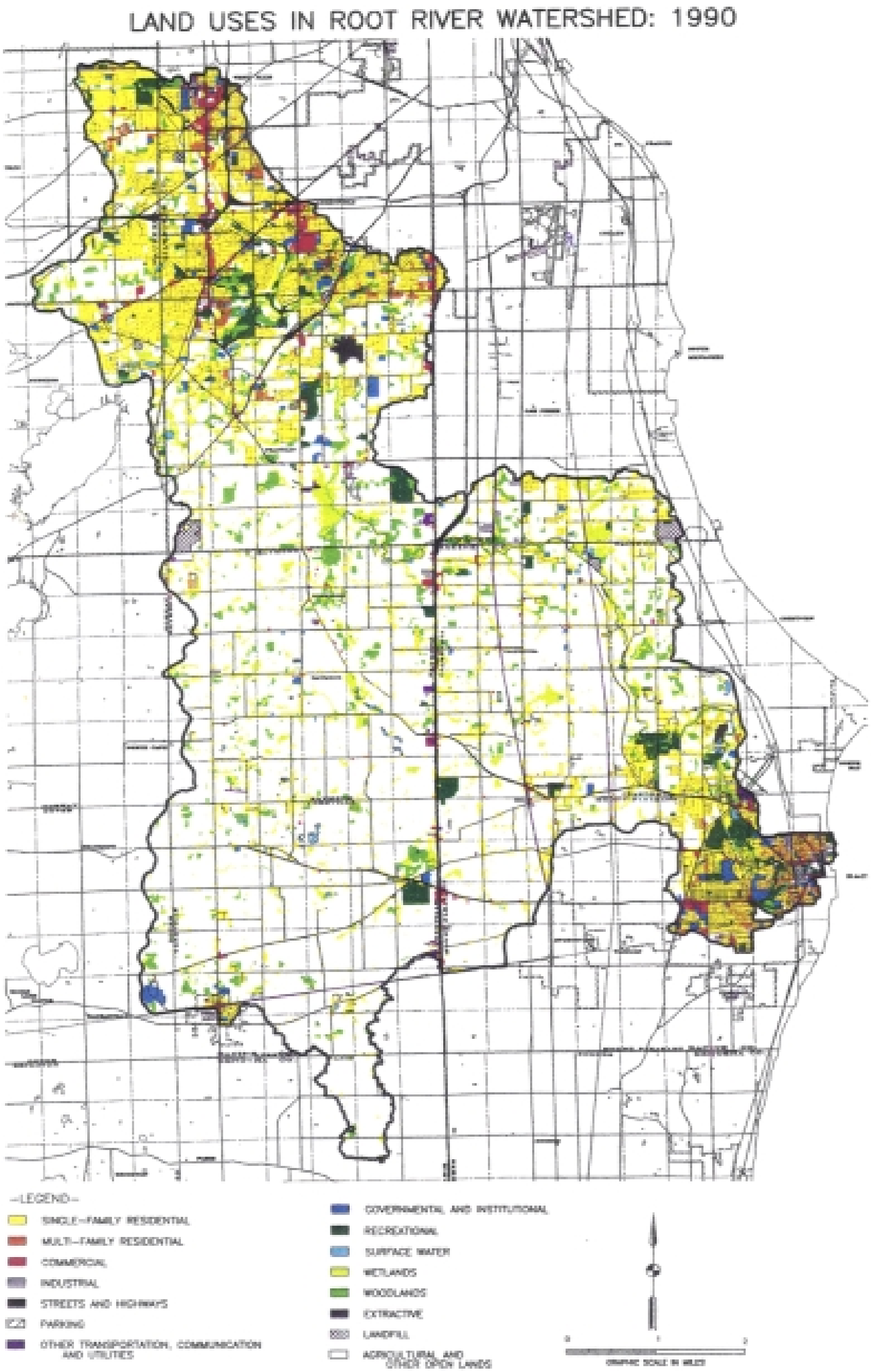

Figure 1.2 Land uses in Root River Watershed 1990

1.5 HISTORY AND CAUSES OF FLOODING

The Root River system experienced frequent minor local flooding, but the flood that occurred in March-April of 1960 was by far the most damaging. The combination of climatological events, which caused the 1960 flood, was unusual and undoubtedly rare. Based on the U. S. weather Bureau's Milwaukee station record of 111 years, the 20 inches of snow on the ground on March 1, 1960 was the highest recorded for that date. Fourteen inches of snow fell in the Root River system between the 1st and 25th of March. The average temperature during the month was the lowest ever recorded, which reduced the loss of snow water content. (SEWRPC, 1995).

This heavy rain falling immediately after a sudden thaw resulted in a peak flow of 5,000 cfs at W. Ryan Road (STH100) as later determined by an indirect measurement made by the USGS. Discharges were not measured elsewhere in the river system, but high water marks indicate that the flow was out of banks along most of the river length with several areas of wide spread inundation. The peak stage at Spring Street in Racine ,15.2 feet, was 3.7 feet higher than the next highest recorded peak in the 25 years of record.

One of the main causes of flooding is urbanization. As urbanization proceeds, a portion of the land surface becomes impervious due to cover by pavement and roofs. Urbanization modifies the hydrologic system of the watershed by decreasing the storm water retention capability on much of the area of the watershed and by increasing the rate at which storm water is transported over the land surface. The urbanization results in changes of peaks, duration**,** and frequency of floods. Moreover, the changes resulting from urbanization vary widely from watershed to watershed, depending upon such factors as soils, topography, and land use.

1.6 WATER QUALITY PROBLEMS

"Water Quality" refers to the physical, chemical, and biological characteristics of the water resources. Quality characteristics are influenced by the natural environment of the watershed and by human activity within the watershed. The ground water is susceptible to pollution from septic tank effluent and refuse seepage and from improper use of abandoned pits and quarries for refuse dumps. The quality of surface water resources however, presents serious problems in the development of potentially desirable uses of stream flow waters. The main water pollution sources are the discharge of municipal sewage and industrial wastes. Other sources of stream flow pollution include agricultural drainage, drainage from private septic tanks, and storm water runoff from urban areas.

Urban storm water runoff has been recognized as a pollution source in terms of BOD, nutrients, suspended solids, and toxic inorganic and organic pollutants. Agricultural drainage contains fertilizers, which promote growth of algae and other aquatic plants, herbicides, and pesticides, which may be harmful to fish and other aquatic life.

1.7 CAUSES OF FLOODING (BOTTLE NECKS)

The main reason for increased flooding is the changes in the land use. Urbanizing areas affect the infiltration water holding capacity of the soil, and reduce the pervious area. Reduction of the pervious area results in high runoff rates and reduces the time of concentration.

"Bottleneck" is a phenomenon, which is another cause that increases flooding intensity and depth of flow in the river. Engineering structures e.g., culvert, bridge, gates etc., along the river decrease the area of flow that results in the backwater effect and the increase in depth of the river upstream. Such structures could also cause the deposition of sediment due to the retardation of the flow, increase velocity of flow and cause reduction of the river width, which cause under cutting of riverbanks.

1.8 STORMWATER CONTROL – MANAGEMENT ALTERNATIVES

The alternatives for management are functionally different scenarios according to how water moves through a site and through the environment. Each management alternative can implement a unique combination of objectives for storm water control, conservation**,** or restoration (Ferguson, 1998).

1.8.1 Conveyance

Conveyance is the transport of surface runoff from one place to another. It ends with discharge to off-site streams, lakes, or bays. The facilities for conveyance are pipes (sewers) and channels.

1.8.2 Detention

Detention is slowing down surface flows as they move away from the area. The basic facility is a storage reservoir with constricted outlet. Its purpose is to reduce downstream flooding and erosion by reducing the rate of flow. The storage basins may also have water quality benefits. Although the peak flow rate of runoff at the point of discharge is reduced, the total volume of flow is still allowed to run downstream, stretched out over time.

1.8.3 Extended Detention

For water quality control, extended detention has become popular. When water its still in a pond or a wetland, suspended particles can settle out and chemicals can be adsorbed in bottom sediment, taken up by biota, and biodegraded.

1.8.4 Infiltration

Infiltration is the entry of water into the ground. Infiltration is qualitatively different from conveyance and detention because it makes water go to a different part of the environment, where it undergoes different types of processes.

1.8.5 Water Harvesting

Water harvesting is the direct capturing and using of runoff onsite. In some applications, water harvesting maintains the water levels in permanent ponds and wetlands.

CHAPTER TWO

HYDROLOGY

2.1 INTRODUCTION

The hydrologic regime of the Root River watershed is affected by a combination of factors – some are natural and some are caused by man's use of land. Due to of its glacial origin, the land surface is made up of a large number of different soil types with varying influence upon the relation of rainfall to runoff. Urbanization has reduced the rate of ground water recharge resulting in lowering shallow ground water aquifer levels and reducing ground water contribution to stream flow. The quality of stream has been influenced by contributions of on-site sewage disposal. It has changed from its natural condition. The watershed, however, still has a potential for beneficial land use and water resources development.

2.2 OBJECTIVE

Estimating hydrologic flows is the place to begin to design storm water alternatives of the flood control design. Flows can be estimated for short-term peak storm events or long-term average events. In this section, location and watershed parameters for the gauging stations of Root River and magnitude of 2-year, 50-year and 100-year flood derived from flow records are presented.

2.3 ROOT RIVER GAUGING STATIONS

There are two gauging stations on the Root River (Franklin and Racine). All of the data related the Root River flow information was obtained from the USGS (US GEOLOGICAL SURVEY) web page. Gauging station specifications are given below:

2.3.1 ROOT RIVER NEAR FRANKLIN

Station name	: Root River Near Franklin, WI
Station number	: 04087220
Latitude (ddmmss)	:425225
Longitude (dddmmss)	:0875945
State code	:55
County	:Milwaukee
Hydrologic unit code	:04040002
Basin name	:Pike-Root
Drainage area (square miles)	:49.2
Gage datum (feet above NGVD)	:674.5
Base discharge (cubic ft/sec)	:500

2.3.2 Root River At Racine

Station name	: Root River At Racine, WI
Station number	: 04087240
Latitude (ddmmss)	: 424505
Longitude (ddmmss)	: 0874925
State code	: 55
County	: Racine
Hydrologic unit code	: 04040002
Basin name	: Pike-Root
Drainage area (square miles)	: 190
Contributing drainage area (square miles)	: 188.76
Gage datum (feet above NGVD)	: 610
Base discharge (cubic ft/sec)	: 900

Gage heights are given in feet above gage datum elevation.

2.4 METHODOLOGY

The historical flow data for the Root River near Franklin and at Racine were obtained from the USGS home page. The time series flow data from 1963-1998 are available. Peak and the lowest annual flows records for the 1964-1998 hydrologic years were used to investigate the distribution type. Different statistical distribution types (Normal, 2 Parameter Log-Normal, 3 Parameter Log-Normal, Pearson Type III, Log Pearson Type III, Gumbel Type I) were used to examine the discharge recurrence relationship. DISTRIB 2.12 Statistical Distribution Analysis was used for the analyses.

2.5 ANALYSIS

2.5.1 Root River near Franklin

Peak Flow

The detailed results of statistical analysis are given in Appendix A. Figure A.1, Table A.3 and Table A.5 shows the comparison of the distributions. Regression analysis results are given in Table A.9. According to the regression analysis between predicted and actual values, Log Pearson Type III distribution best explains discharge distribution. A graph of Log Pearson Type III Distribution is given in Figure 2.1. Summary of the prediction is given in Table 2.1

Table 2.1 Summary of the prediction for Root River near Franklin

(Log Pearson Type III)

Predictions			
Exceedence Probability	Return Period	Calculated Value	Standard Deviation
0.9950	200.0	8897.9930	6448.9350
0.9900	100.0	6591.6770	3773.3980
0.9800	50.0	4847.8040	2129.9400
0.9600	25.0	3529.6960	1147.3470
0.9000	10.0	2266.4870	471.2521
0.8000	5.0	1573.3410	242.8900
0.6670	3.0	1166.8580	157.4803
0.5000	2.0	887.1581	107.9397

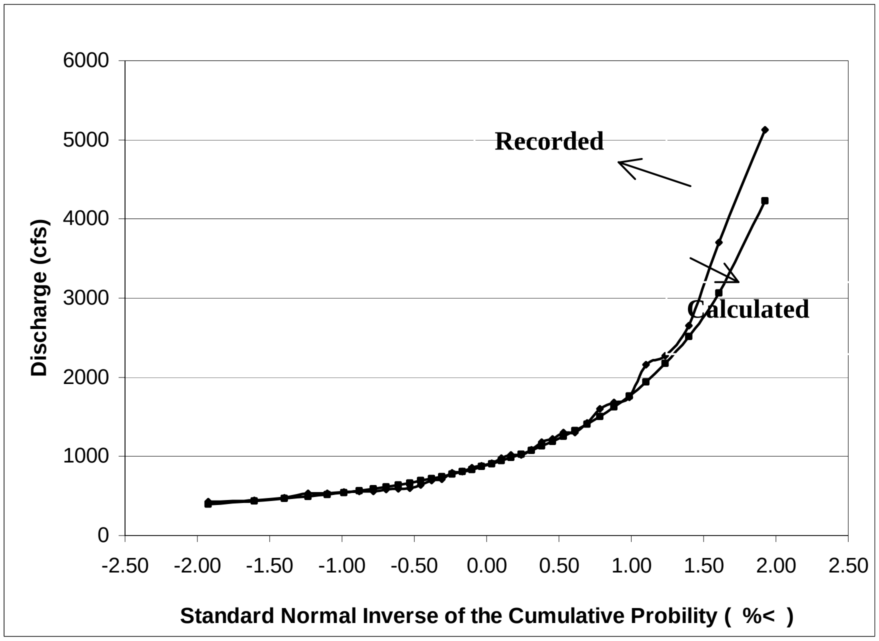

Figure 2.1 Log Pearson Type III distribution

Low Flows

The detailed results of statistical analysis are given in Appendix A. Figure A.2, Table A.4 and Table A.6 shows the comparison of the distributions. Regression analysis results are given in Table A.10. According to the regression analysis between predicted and actual values, 2 Parameter Log-Normal distributions best explains discharge distribution. Graph of the distribution is given in Figure 2.2. Summary of the prediction is given in Table 2.2

Table 2.2 Summary of the prediction (2 parameter Log-Normal)

```
---------Predictions -------
Return             Calculated
Period             Value
----------------------------
200.0              0.9
100.0              1.0
50.0               1.1
10.0               1.5
2.0                2.9
---------------------------
```

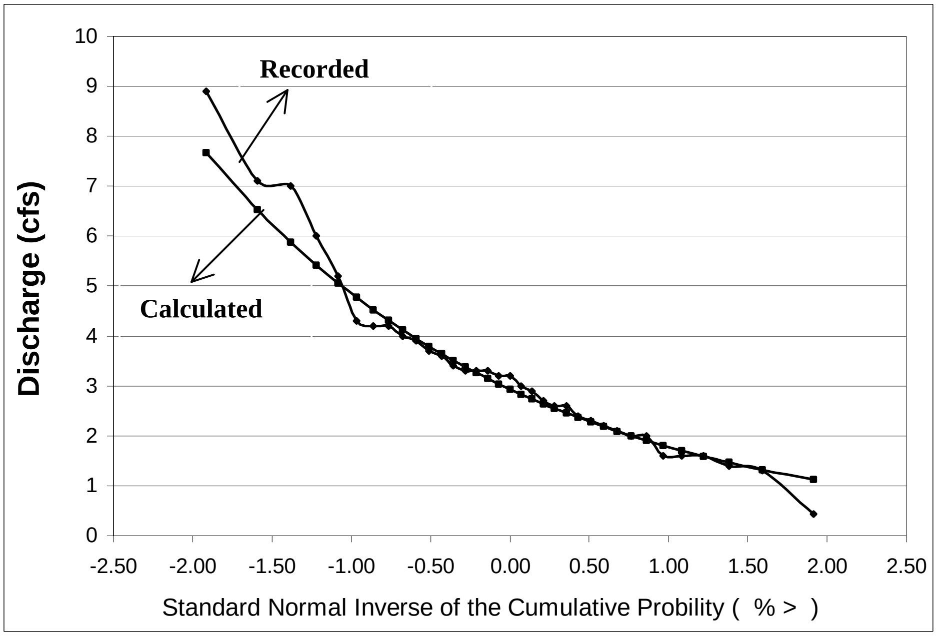

Figure 2.2 2 Parameter Log-Normal distribution

2.5.2 Root River at Racine

Peak Flow

The detailed results of statistical analysis are given in Appendix A. Figure A.3, Table A.1 and Table A.7 shows the comparison of the distributions. Regression analysis results are given in Table A.11. According to the regression analysis between predicted and actual values, 2 Parameter Log-Normal distribution best explains discharge distribution. A graph of the 2 Parameter Log-Normal Distribution is given in Figure 2.3. Summary of the predictions are given in Table 2.3

Table 2.3 Summary of the prediction (2 parameter Log-Normal)

Predictions			
Exceedence Probability	Return Period	Calculated Value	Standard Deviation
0.9950	200.0	5461.0750	807.9774
0.9900	100.0	4909.0560	696.5808
0.9800	50.0	4369.4190	588.2310
0.9600	25.0	3838.7310	482.5636
0.9000	10.0	3141.3070	346.3906
0.8000	5.0	2602.7200	246.2744
0.6670	3.0	2184.3130	176.9172
0.5000	2.0	1816.8260	132.6549

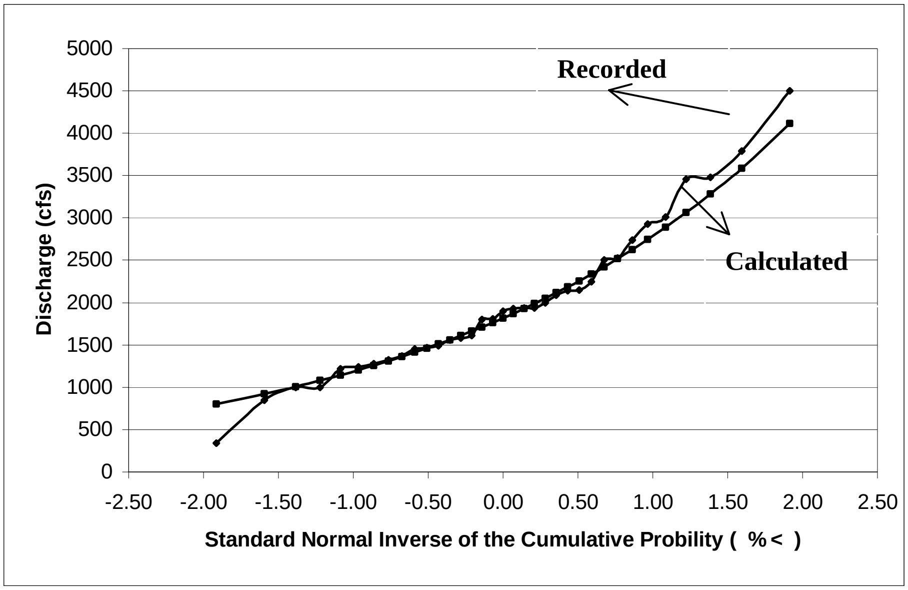

Figure 2.3 2 Parameter Log-Normal distribution

Low Flows

The detailed results of statistical analysis are given in Appendix A. Figure A.2, Table A.2 and Table A.8 show the comparison of distributions. Regression analysis results are given in Table A.12. According to the regression analysis between predicted and actual values, Pearson Type III distribution best explains discharge distribution. Graph of Pearson Type III Distribution is given in Figure 2.4. Summary of the prediction is given in Table 2.4

Table 2.4 Summary of the prediction (Pearson Type III)

```
---------Predictions ---------
Return             Calculated
Period             Value
------------------------------
200.0              0.5
100.0              0.7
50.0               1.0
10.0               1.90
2.0                  4.93
----------------------------
```

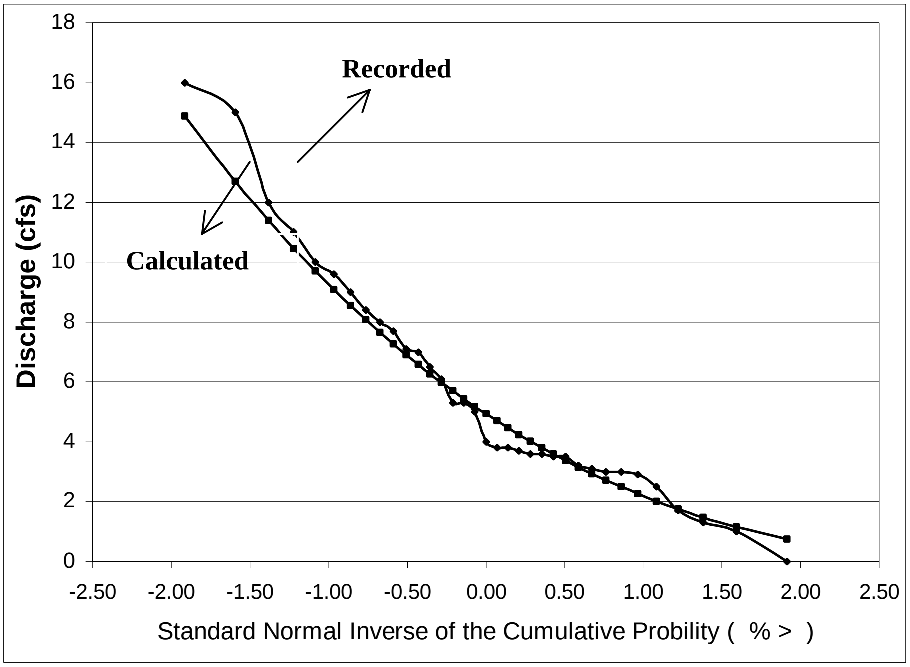

Figure 2.4 Pearson Type III distribution

2.6 DISCUSSION OF THE RESULTS

The peak flow for each year is quite different. Because of the difference of such values in each year, statistical analysis is necessary to predict the magnitude of the flood to design the engineering structures. The selection of recurrence interval depends on type of the structure.

For the peak flows: The magnitude of the 2-year flood for Root River near Franklin is equal to 887 cfs and 100-year flood is 6591 cfs. The magnitude of the 2-year flood for Root River at Racine is equal to 1817 cfs and 100-year flood is 4909 cfs. The related tables and graphs are given in Appendix A.

For the low flows: The magnitude of the 2-year flood for Root River near Franklin is equal to 2.9 cfs and 100-year flood is 1 cfs. The magnitude of the 2-year flood for Root

River at Racine is equal to 4.93 cfs and 100-year flood is 0.7 cfs. The related tables and graphs are given in Appendix A.

For different recurrence intervals, related flows were predicted by using different distribution types. It was observed that, mostly log-normal distribution explain discharge trends for the Root River. Using Log-normal distribution has a number of benefits. Some of them are as follows:

*Concise summaries of highly variable data can be developed.

*Comparison of results from different sites, events, are convenient and more easily understood

*Statements can be made about frequency of occurrence (Novotny and Olem, 1993)

For the Low flows, Pearson Type III distribution provide good estimates compared to other distribution models. It was also observed that up to a certain recurrence interval some distributions work well, and after that point some other may explain the trend better than the others. Therefore two different distributions can be used to predict flows for different recurrence intervals for a certain trend (i.e. Peak Flows)

Although none of the distributions give the exact predictions, they are very useful tools to predict flood events.

CHAPTER THREE

EFFECTS OF URBANIZATION ON THE DISCHARGE-FREQUENCY RELATIONSHIP

3.1 INTRODUCTION

Drainage systems are needed in developed urban areas because of the interaction between human activity and the natural water cycle. This interaction has two forms: the abstraction of water from the natural cycle to provide water supply for human life, and covering land with impermeable surfaces that divert rainwater away from the local natural system of drainage. (Butler and Davies, 2000)

In nature, when rainwater falls on a surface some water returns to the atmosphere through evaporation, or transpiration by plants: some infiltrates the surface and becomes groundwater; and some run off the surface. The relative proportions depend on the nature of the surface, and vary with time during the storm. Both groundwater and surface runoff are likely to find their way to a river, but surface runoff arrives much faster (Butler and Davies, 2000).

Development of an urban area, involving covering the ground with impervious surfaces, has a significant effect on these processes. The impervious surfaces increase the amount of surface runoff in relation to infiltration, and therefore increase the amount of total volume of water reaching the river during or soon after the rain (Figure 3.1). Surface runoff travels quicker over hard surfaces and through sewers than it does over natural surfaces and along natural systems. This means that the flow will arrive and recede faster, consequently the peak flow will be greater (Figure 3.2). This obviously increases the danger of sudden flooding of the river (Butler and Davies, 2000).

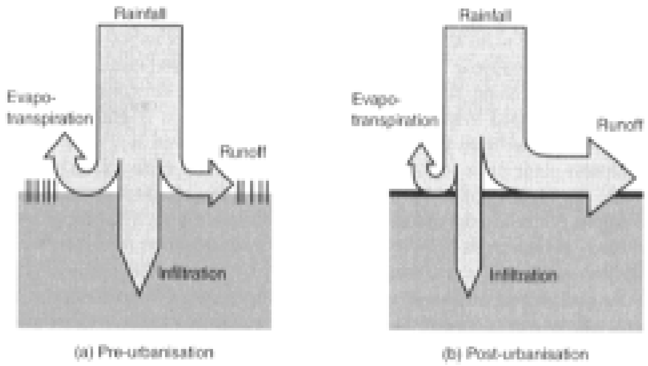

Figure 3.1 Effect of urbanization on fate of rainfall (Butler and Davies, 2000)

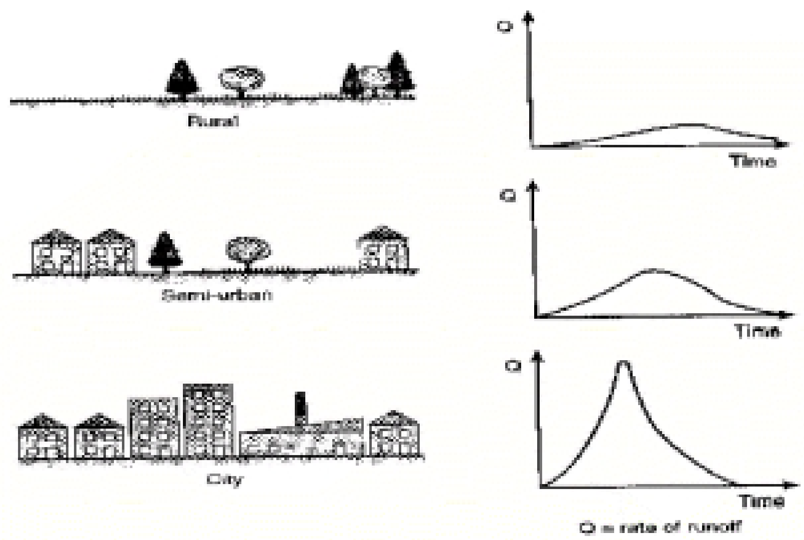

Figure 3.2 Effect of urbanization on peak rate of runoff (Butler and Davies, 2000)

Thus, the general effects of urbanization on drainage, or the effects of replacing natural drainage by urban drainage, result in higher and more sudden peaks in river flow, introduction of pollutants, and creating the need for flood control actions and wastewater disposal and treatment.

3.2 OBJECTIVE

McCuen (1998) stated that a statistical flood frequency analysis is based on the assumption of a homogeneous annual flood record. Changes in land use will violate the underlying assumption of the frequency analysis. Urbanization is a primary cause of nonhomogeneity.

The purpose is to find the discharge-frequency relationship for different imperviousness levels of the Root River Watershed. Flow record of Racine Station on the Root River is used for this purpose.

3.3 METHODOLOGY

There are several methods to adjust flow records to a change by urbanization. The method suggested by McCuen (1998) was used to estimate discharge-frequency relationship for different watershed conditions. Figure 3.3 shows the peak adjustment factor as a function of exceedence probability for percentage of imperviousness up to 60 %.

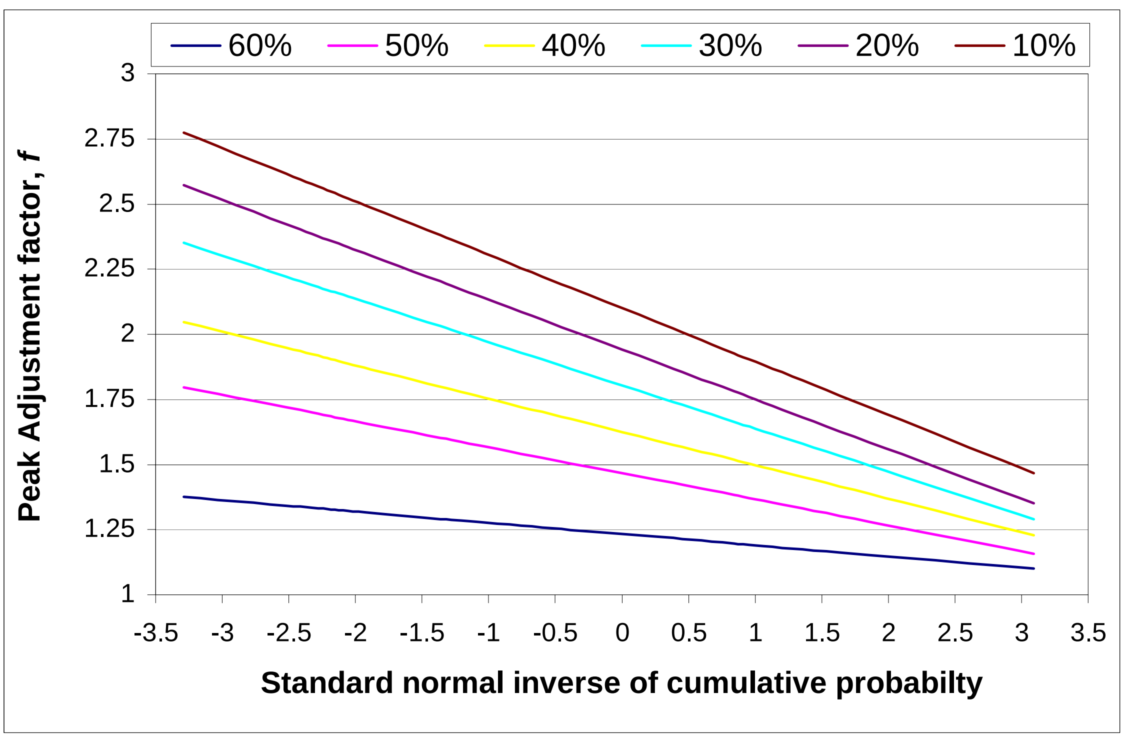

Figure 3.3 Peak Adjustment Factor

The following procedure was proposed by McCuen (1998):

1. **1.** Identify both percentage of imperviousness for each event in the flood record and the percentage of imperviousness for which an adjusted flood record is needed.
2. **2.** Compute the rank (i) and exceedence probability (p) for each event in the flood record
3. **3.** Using the actual percentage of imperviousness, find from Figure 3.5 the peak adjustment factor (f_1) to transform the measured peak from the actual level of imperviousness to nonurbanized condition.
4. **4.** Using the exceedence probability and the percentage of imperviousness for which flood series is needed, find from Figure 3.1 the peak adjustment factor (f_2) that is necessary to transform the nonurbanized peak to a discharge for the desired level of imperviousness.
5. **5.** Compute the adjusted discharge (Q_a) by

$$Q_a = f_2/f_1 * Q$$

in which Q is the measured discharge.

6. **6.** Repeat steps 3,4, and 5 for each event in the flood record and rank the adjusted series.
7. **7.** If there are significant changes in the ranks of the measured (Q) and adjusted (Q_a) flood series, repeat Steps 2 through 6 until the ranks do not change.

3.4 LAND USE AND IMPERVIOUSNESS

Land use values obtained from SEWRPC reports were used to find imperviousness of the watershed in different years. Interpolation and extrapolation were done to calculate percent imperviousness of the watershed for every year between 1963 and 2010. Land use distribution and the assumed imperviousness for different categories are given in Table 3.1. 1963, 1975, 1990 values are exact values reported by SEWRPC**;** whereas 2010 land use is the estimated by SEWERPC. In the analysis some other imperviousness levels (30 %, 40 % and 50 %) were also used to demonstrate the effects of imperviousness on the frequency discharge relationship.

Table 3.1 Land use (LU) and percent imperviousness of the watershed

LAND USE	% Imp. (assumed)	1963		1975		1990		2010	
		%L.U	% Imp.	%L.U	% Imp.	%L.U	% Imp.	%L.U	% Imp.
Residential	0.5	10.22	5.11	13.60	6.80	15.37	7.68	18.63	9.31
Commercial	0.85	0.55	0.47	0.59	0.50	0.74	0.63	0.87	0.74
Industrial	0.7	0.30	0.214	0.39	0.27	0.58	0.41	1.11	0.78
Mining	0.5	0.59	0.30		0	0.00	0	0	0
Transportation	0.95	7.30	6.93	7.40	7.03	8.11	7.71	9.52	9.04
Governmental	0.7	0.97	0.68	1.13	0.79	1.15	0.80	1.26	0.88
Recreational	0	2.58	0	2.02	0	2.20	0	2.40	0
Agricultural	0	66.26	0	60.35	0	55.93	0	52.95	0
Water, Woodlands, Wetlands	0	11.22	0	14.53	0	15.91	0	13.27	
Total			**13.7**		**15.39**		**17.23**		**20.75**

3.5 ADJUSTING THE DISCHARGE-FREQUENCY CURVES TO MODIFY WATERSHED CONDITIONS

Discharge adjustments were done for different imperviousness level of the watershed. These are 1963 (13.7 %), 1990 (17.23%), 2010 (20%), 30%, 40%, 50% and 60% imperviousness levels. After the adjustment, Log Pearson Type III distribution was applied to each record.

3.6 RESULTS

Table of discharge frequency shifts estimated from adjusted series for different watershed conditions are given in Table 3.2 and in Figure 3.4

Table 3.2 Discharge frequency shifts

Probability	R Period	1963	1990	2010	30%	40%	50%	60%
0.995	200	4025	4131	4220	4518	4812	5071	5505
0.99	100	3871	3986	4081	4384	4687	4949	5371
0.98	50	3682	3806	3907	4213	4524	4788	5194
0.96	25	3451	3582	3687	3994	4311	4574	4959
0.9	10	3054	3192	3300	3599	3916	4172	4520
0.8	5	2653	2790	2897	3179	3485	3727	4035
0.667	3	2269	2400	2501	2760	3047	3270	3537
0.5	2	1872	1990	2083	2310	2567	2764	2989

If the results are examined, it is observed that as the imperviousness level increases the discharge-frequency curves shift up. The one hundred year flood for the 60% imperviousness is 1.38 times bigger than that of 1963 watershed condition and the 2-year flood is 1.59 times higher, respectively. Also what was a 100-year flood in 1963 would become a 4-year flood if the imperviousness of the watershed increases to 60 %.

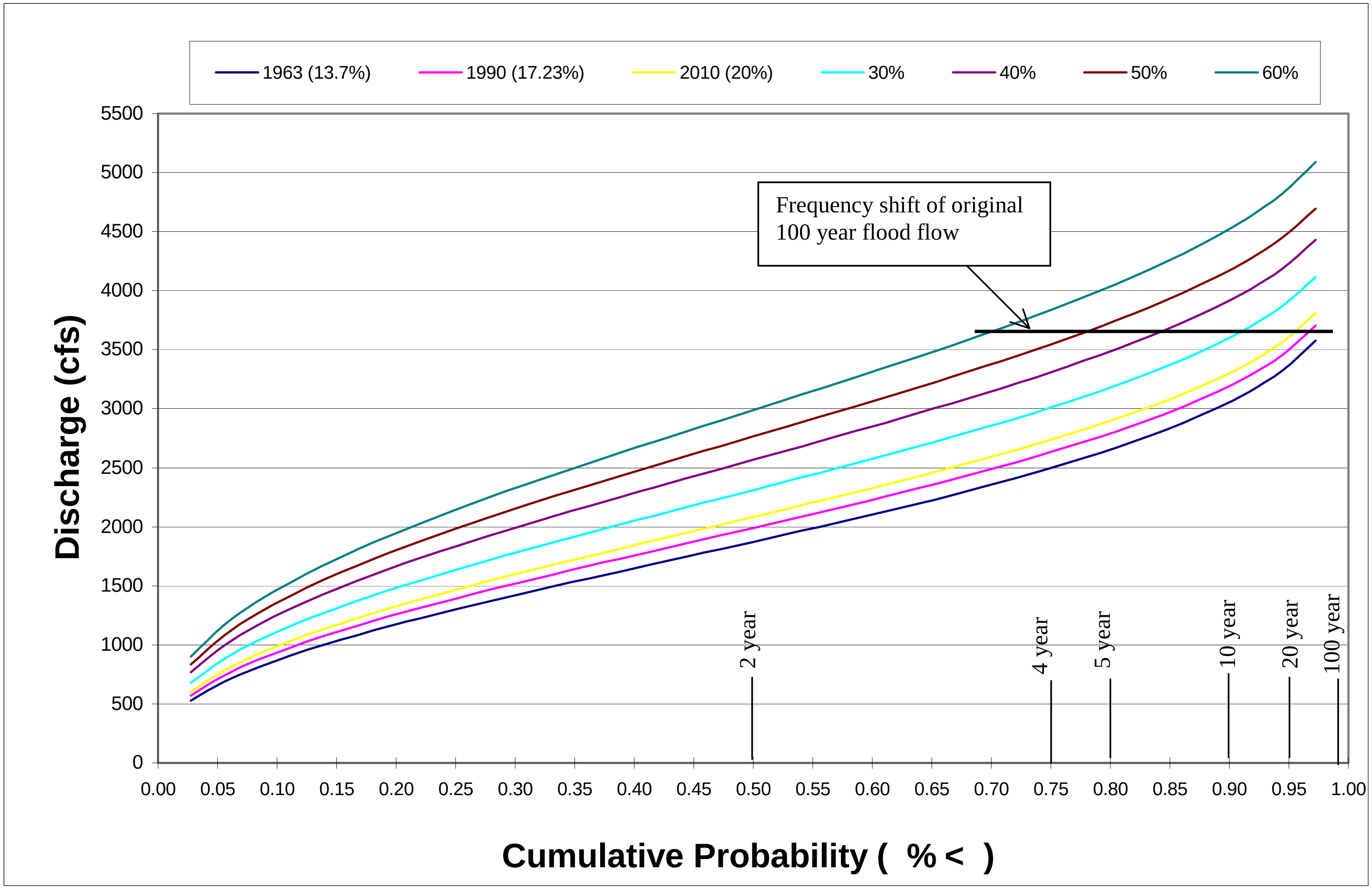

Figure 3.4 Frequency-discharge shifts

CHAPTER FOUR

DESIGN STORM

4.1 INTRODUCTION

A design storm is a specified combination of rainfall conditions for which runoff is estimated and a drainage system is designed. The magnitude of a design storm may be expressed as a total daily quantity of precipitation such as inches of rainfall, or as a short-term intensity such as inches per hour.

The 2-year storm is the key for pollution abatement and control of channel erosion. The channels of natural systems have typically a capacity to contain a 2-year flow. A 100-year flow determines the extent of the flood plain and is used for sizing major drainage components such as bridges, extend of flood plain, etc.

4.2 OBJECTIVES

In this section design rainfall hyetographs (6 hrs) are obtained by using SCS and Huffs distributions of rainfall for 2 year, and 100-year storms in Racine, WI.

4.3 SCS AND HUFF'S DISTRIBUTION OF RAINFALL

The SCS method is used to design for minor structures. Time distributions for critical storms for a small dam or other minor structure designs are usually assumed to be uniform. The SCS uses a uniform distribution for short duration storms. The SCS[1] distribution of 6 hr is satisfactory for small watershed and used in developing emergency spillway and freeboard hydrographs. However larger areas require storm depths for a period greater than 6 hr.

The storm depths for durations other than 6 hr, table or graph of multipliers for various durations developed by USBR (U.S Bureau of Reclamation) can be used. The SCS also developed a 24-hr duration for all urban watershed studies. The storm intensity distribution for this duration is very high during the middle period of the storm. It represents the critical rainfall and runoff volume for peak discharge from watersheds.

Huff's divided recorded storm distribution patterns from small Midwestern watersheds into four equal probability groups from the most severe (first quartile) to the mildest (fourth quartile). The two rainfall patterns normally investigated are first quartile and second quartile storms that have been used in this project. A first quartile distribution has greater portions of rainfall occurring during the early minutes of the storm.

4.4 METHDOLOGY

To determine the storm hyetograph by SCS method, the 2-year and the 100-year duration recurrence interval for 6 hr design storm depth was obtained by the Isopluvial map produced by the U.S. Weather Service. It is calculated by using the Normalized storm – duration – frequency – intensity curves.

In the case of Huff's storm intensity distributions, first quartile, second quartile, third quartile, and forth quartiles were used. For small basins the first and second quartile storms were found to be most prevalent. For most structural design applications, first quartile and second quartile design storms are selected. The calculations are given in Appendix B.

4.5 RESULTS

SCS Milwaukee (Type II storm)
a) 2 year recurrence interval storm pattern

$\varnothing_1$ = 0.22 (for 6 hr duration)

$\varnothing_n$ = 1.3 (for 2 year)

[1] Currently the National Resources Conservation Service

$I \cong 31$ mm/hr

Depth = 24 * ($\varnothing_n$*$\varnothing_1$*I) = 6* 0.22*1.3*31 = 53.20 mm

b) 100 year recurrence interval storm pattern

Depth = 104.1 mm (from maps)

Huff's Storm Intensity Distribution

Table of median Time distribution of heavy storm rainfall on areas of 10 to 50 square miles are used for this analysis.

The distributions of rainfall by two methods are different. In NRCS method, the high intensity of rainfall lies in the middle of the rainfall period. The intensity of rainfall for the higher recurrence interval is higher. The rainfall intensity for 2-year period is 0.94 in./hr and for 100-year period is 1.84 in./hr. The peak runoff is occurred in a 2.5 hr time interval in both cases. The 6-hour hyetograph for the 2-year and 100-year design storm is shown in Figure B.1.

In case of Huff's storm intensity, the distribution of rainfall intensity is different for different quartiles. The distribution of rainfall intensity in the 1st quartile is higher in the beginning and comparatively higher then the 2nd quartile method. The higher rainfall intensity for the 1st quartile is 0.45 in./hr for 2-year period and 0.89 in./hr for 100-year period. Graphically it is shown in Figure B.3-B.4. For both periods the higher rainfall intensity is in the first hour of the rainfall. All of the figures are given in Appendix B.

CHAPTER FIVE

EXCESS RAIN DETERMINATION

5.1 OBJECTIVES

Estimate the excess rain for 100-year and 2-year design storm for 6 hr duration storm.

5.2 THE SCS METHOD

The excess rain is a residual after simple numerical subtraction of the hydrologic losses from precipitation volume. This differentiates it from surface runoff, which refers to that part of flow in the receiving body of water that was generated by rainfall excess (Novotny and Olem, 1994).

The SCS Method was developed and documented by the Natural Resources Conservation Services (NRCS). Since its inception the NRCS Method has grown in prominence, gradually replacing Rational Method in practice (Ferguson, 1998). It is more directly useful than the Rational formula for applications requiring an estimate of runoff volume, and its thorough documentation usually allows it to be used without a lot of disagreement between designers and the municipal engineer who review the designer's work. The method can be applied to drainage areas much larger than those to which the Rational method is limited.

The NRCS method begins by finding the total depth and water volume of runoff during a storm. The depth of rainfall produces the depth of runoff**.** The equation for runoff depth is the NRCS Method's basic equation:

$$Q = (P-I_a)^2/(P-I_a+S)$$

Where

Q = Depth of runoff

P = Depth of 24 hour rainfall

I_a= Initial abstraction, the losses of rainfall to infiltration and **s**urface depression before runoff begins; 0.2S is a more or less median value that has been found in the field.

S= Potential maximum retention after runoff begins; it is defined by curve number (CN), which is a function of the drainage area's soil and land use. S= 25400/CN-254

5.3 METHODOLOGY

For the estimation of excess rain, the rainfall intensity, which was calculated in the previous design chapter for the 6-hour duration storm, is considered for estimating the excess rain. The rainfall intensity for 100-year and 2-year design storm is calculated by the NRCS method. The distribution of the rainfall during 6-hour duration and interval of 0.5 hour have been considered for the calculation. For the calculation of the excess rain, the cumulative excess rain is considered if the rainfall volume is greater than infiltration. For the first hour, the infiltration is greater than cumulative rainfall, so the rainfall in this period is not considered for the excess rain calculation for the 100-year design storm while it is 90 minutes for the 2-year design storm, respectively.

5.4 RESULTS

The rainfall excess and the runoff volume for the 100-year and 2-year design storm have been calculated for the 6-hour duration storm. Calculations are given in Table C.1 and Table C.2. 2-year and 100-year excess rainfall distributions are given in Figure C.1 and Figure C.2. All of the tables and Figures are given in Appendix C.

CHAPTER SIX

FLOOD FLOWS AT RAWSON AVENUE

6.1 OBJECTIVES

- Determination of peak flow by Rational method
- Determination of time of concentration
- Calculation of SCS unit hydrograph

6.2 TR-55

Technical Release 55 (TR-55) presents simplified procedures or calculating storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. In selecting the appropriate procedure, the scope and complexity of the problem, the available data, and the acceptable level of error should be considered. While this TR gives special emphasis to urban and urbanizing watersheds, the procedures apply to any small watershed. TR-55 utilizes the SCS runoff equation to predict the peak rate of runoff as well as the total volume.

The model described in TR-55 begins with a rainfall amount uniformly imposed on the watershed over a specified time distribution. Mass rainfall is converted to mass runoff by using a runoff curve number (CN). CN is based on soils, plant cover, amount of impervious areas, interception, and surface storage. Runoff is then transformed into a hydrograph by using unit hydrograph theory and routing procedures that depend on runoff travel time through segments of the watershed.

6.3 METHODOLOGY

To define the watershed characteristics upstream of Rawson Av. (approximately ¼ to ½ miles upstream) BASINS Geographic Information Systems (GIS) database was used to find the required data. The basin is comprised of different land use the GIS was applied to calculate the Curve Number (CN). AMCII antecedent soil moisture condition was used. For the calculation of the time of concentration, overland time of concentration was assumed as 30 minutes. The watershed has a flat to rolling topography comprised of land ranging from 0 to 5%. An average slope of 3% is considered to calculate the unit hydrograph and imperviousness of watershed is assumed equal to 45%.

6.4 RESULTS

The NRCS method provides a methodology for overland routing of excess rainfall.
Routing procedure or the excess rain to get the 100-year flood hydrograph is given below.

CN = 80 and imperviousness = 45 %

S= 25400/80 –254 = 63.5

$t_1^I = (16.9*10^3)^{0.8}*(63.5+25.4)^{0.7}/(7053*3^{0.5})=4.56$

Correct t_1;

LF = $1-45*(-0.006789 + 0.000335*80-0.0000004298*80^2-0.00000002185*80^2)= 0.72$

$t_l = LF*t_l^1 = 4.56*0.72 = 3.31$

$t_c = 1.66*t_1 = 1.66*3.31 = 5.52$

D = 0.133*5.52 = 0.73 hr

D is selected as 0.5 hr

$t_p = D/2 + t_1 = 0.5/2 + 3.31 = 3.56$ hr

$t_r = 5/3*t_p = 5/3*3.56 = 5.94$ hr

$t_b = 8/3*t_p = 8/3*3.56 = 9.51$ hr

$q_p = 0.0020833 * 9323/3.56 = 5.44$ m^3/s/mm

Calculated unit hydrograph and flood hydrograph are given in Figure 6.1-6.2

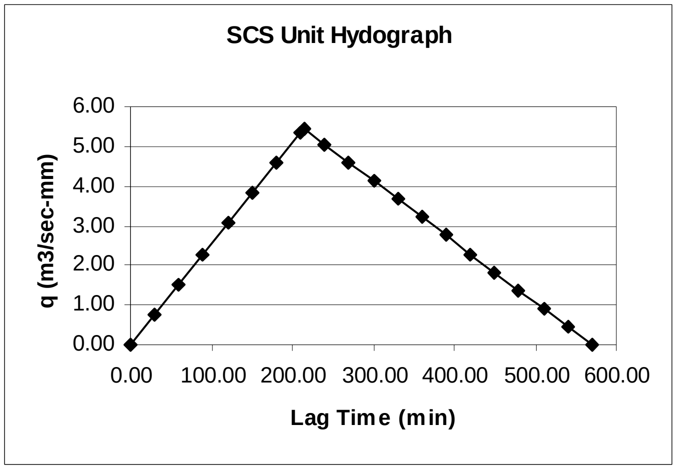

Figure 6.1. SCS Unit Hydrograph(100 year 6- hr)

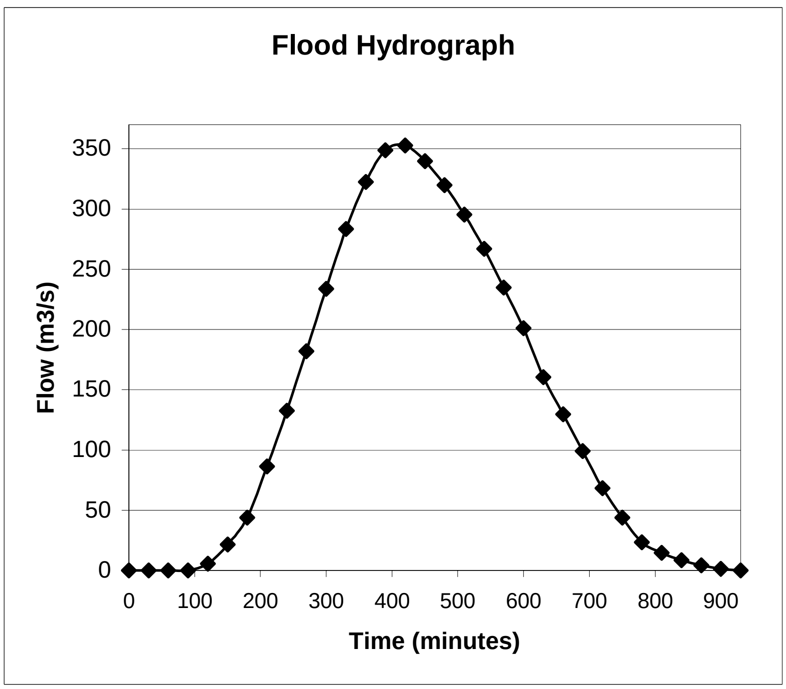

Figure 6.2. Flood Hydrograph (100 year –6hr)

6.5 DISCUSSION OF THE RESULTS

Detailed calculations, spreadsheets**,** and 2-year storm hydrographs are given in Appendix D.

The peak discharge for the 100-year, 6 hours design storm by the TR-55 is equal to 12360 cfs (350 m^3/s). Since the Root River watershed is not a small watershed, it is reasonable to use the peak flow obtained from TR-55 to design flood control facility. Note that this flow is greater than listed in Table 2.1. The following reasons can be listed:

- This calculation is for peak flow while Table 2.1 is for daily average
- The flows in Table 2.1 were developed for a long time sequence of annual high flows whereas, the TR-55 reflects the present conditions

CHAPTER SEVEN

CONCLUSION

The Root River is one of the tributaries to Lake Michigan. The main stem of the river rises in Milwaukee County within the city of Milwaukee urbanized area and flows to Lake Michigan.

This design report presents estimates of peak flows in the watershed and the volume of runoff. Normally natural streams are designed for the capacity for the two-year flood and the 100-year flood is considered for design of flood plain, and major engineering structures. In this project, the 2 year and the 100 year design storm are considered to calculate the rainfall intensity, peak flow, and excess rain and runoff volume. The duration of the storm was considered as 6 hour, which is generally considered for design purpose. Different methods are used to calculate the difference in the excess rain and peak flow. NRCS and Huff's distribution of rainfall were used for the design storms.

Storm water management is the main problem in the urbanized area. As the pervious area is decreasing as a result of urbanization the time of concentration is increasing. This results in the increase of runoff and shortens the peak flow time. To overcome this problem, detention ponds are designed to prevent the flooding. Wetland for the two-year design storm and pond for the100-year interval will attenuate the flows downstream and provides treatment.

Since for the flood protection, the citizens and the authorities require the 100-year protection. Results show that if the watershed imperviousness is allowed to increase to full urbanization (60 % imperviousness) the 100-year flood could be 1.4 times greater than that for 1960 watershed condition. Decision makers should consider this fact while making future land use management plan.

These problems create a need for flood control and water quality control actions. For flood protection, the 100-year protection is required. For quality control, the design storm is typically on the order of one to two years.

8. REFERENCES

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APPENDIX A

STATISTICAL FLOW ANALYSIS

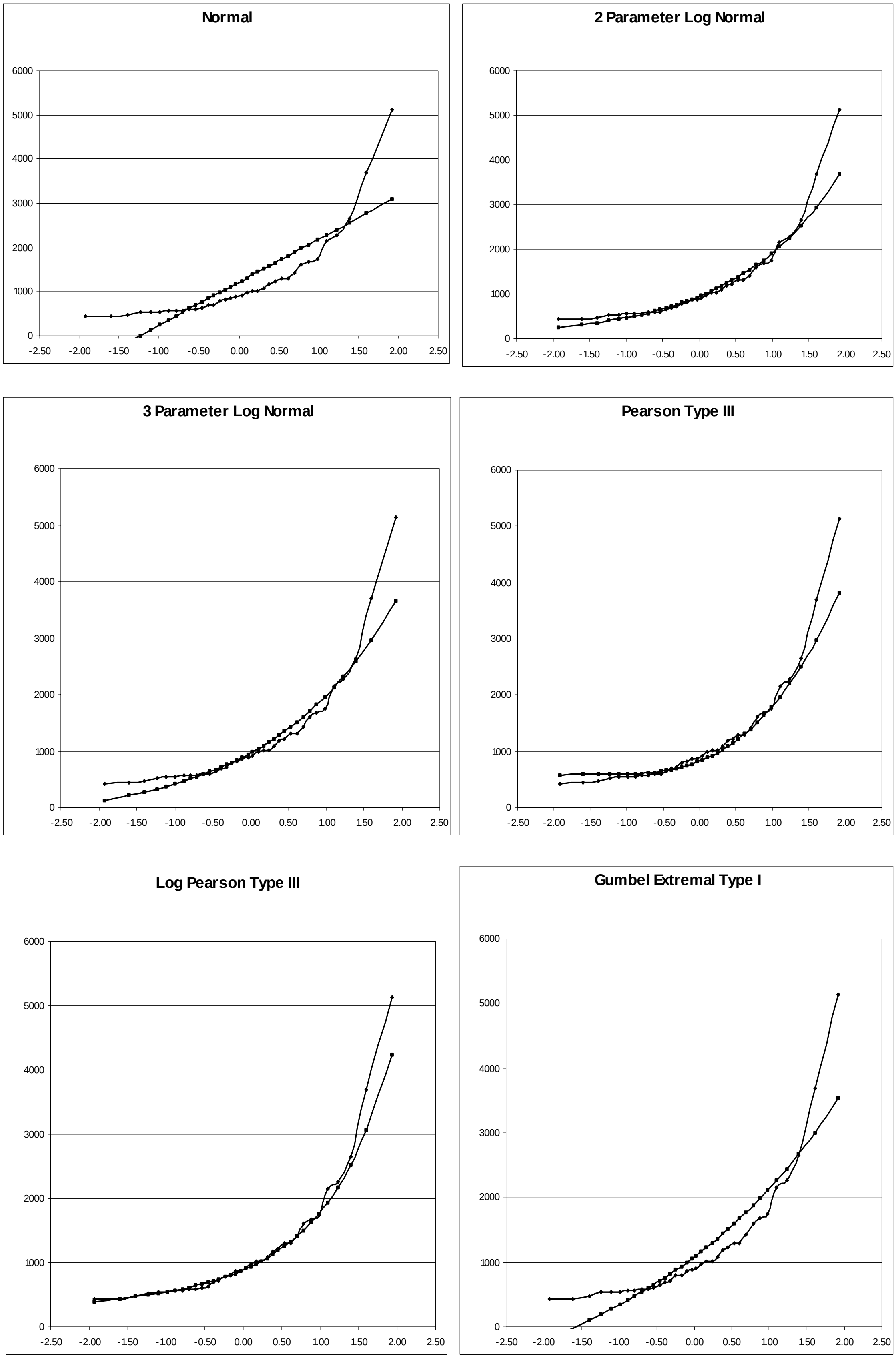


Figure A.1 Comparison of the distributions- Franklin Station – Peak Flow

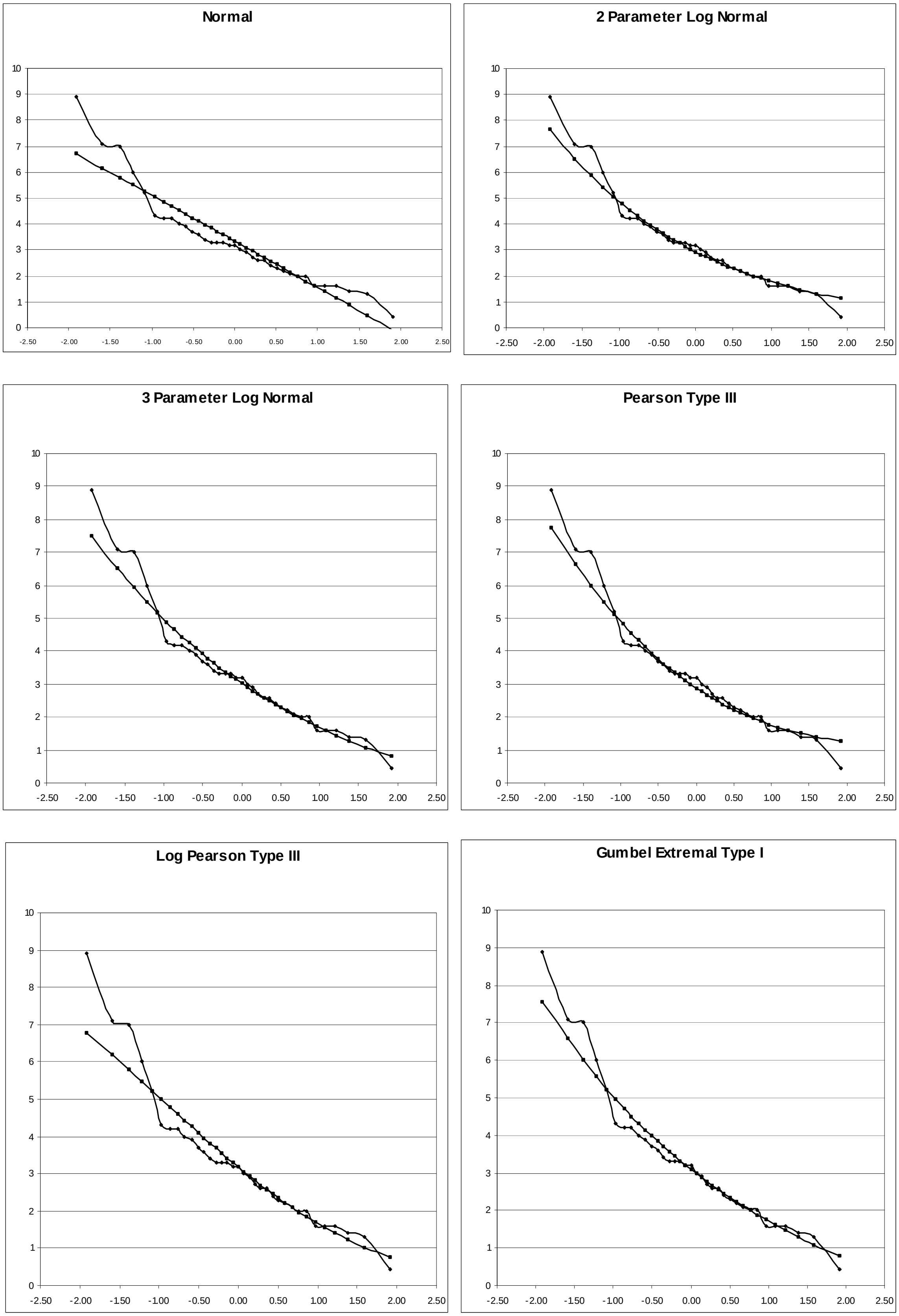
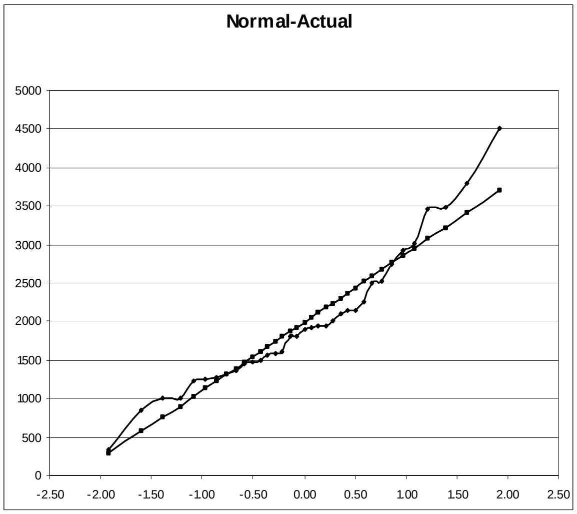
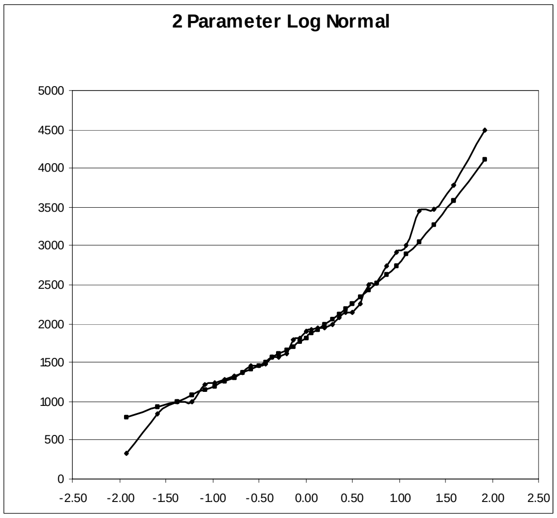
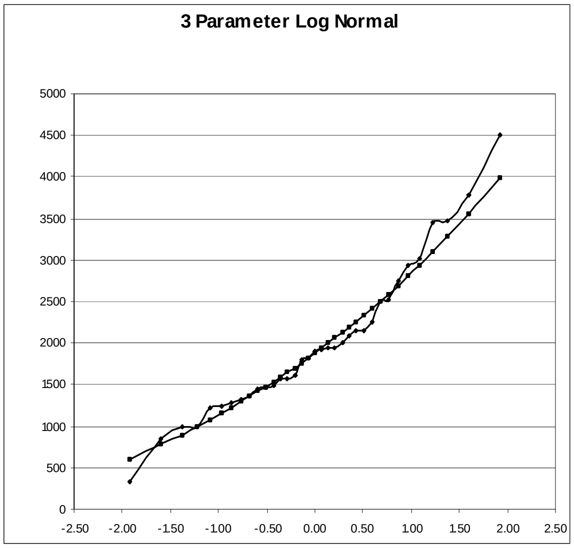
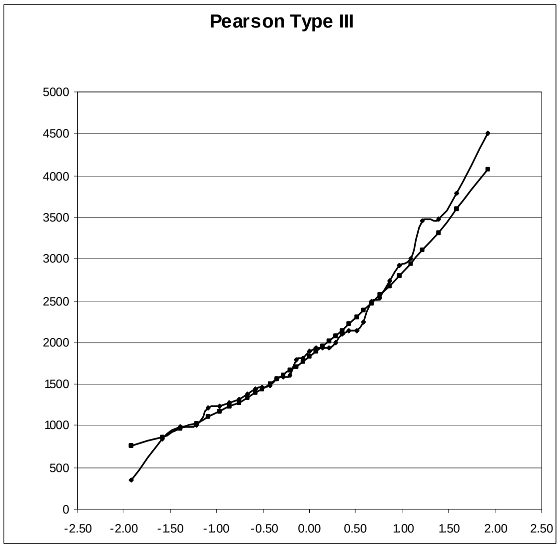


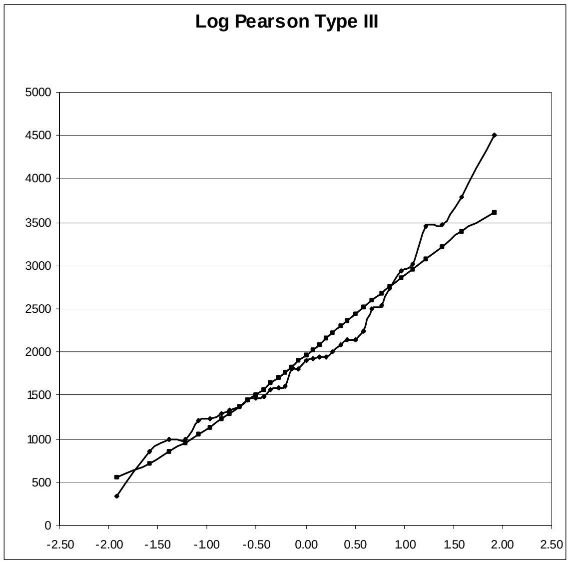
Figure A.2 Comparison of the distributions- Franklin Station – Low Flow











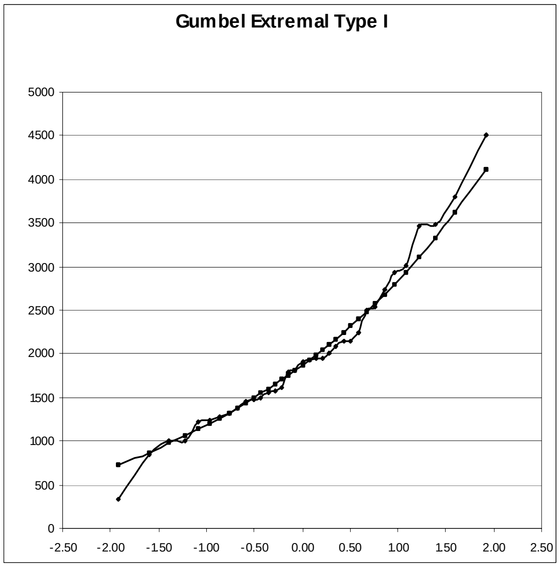


Figure A.3 Comparison of the distributions- Racine Station – Peak Flow

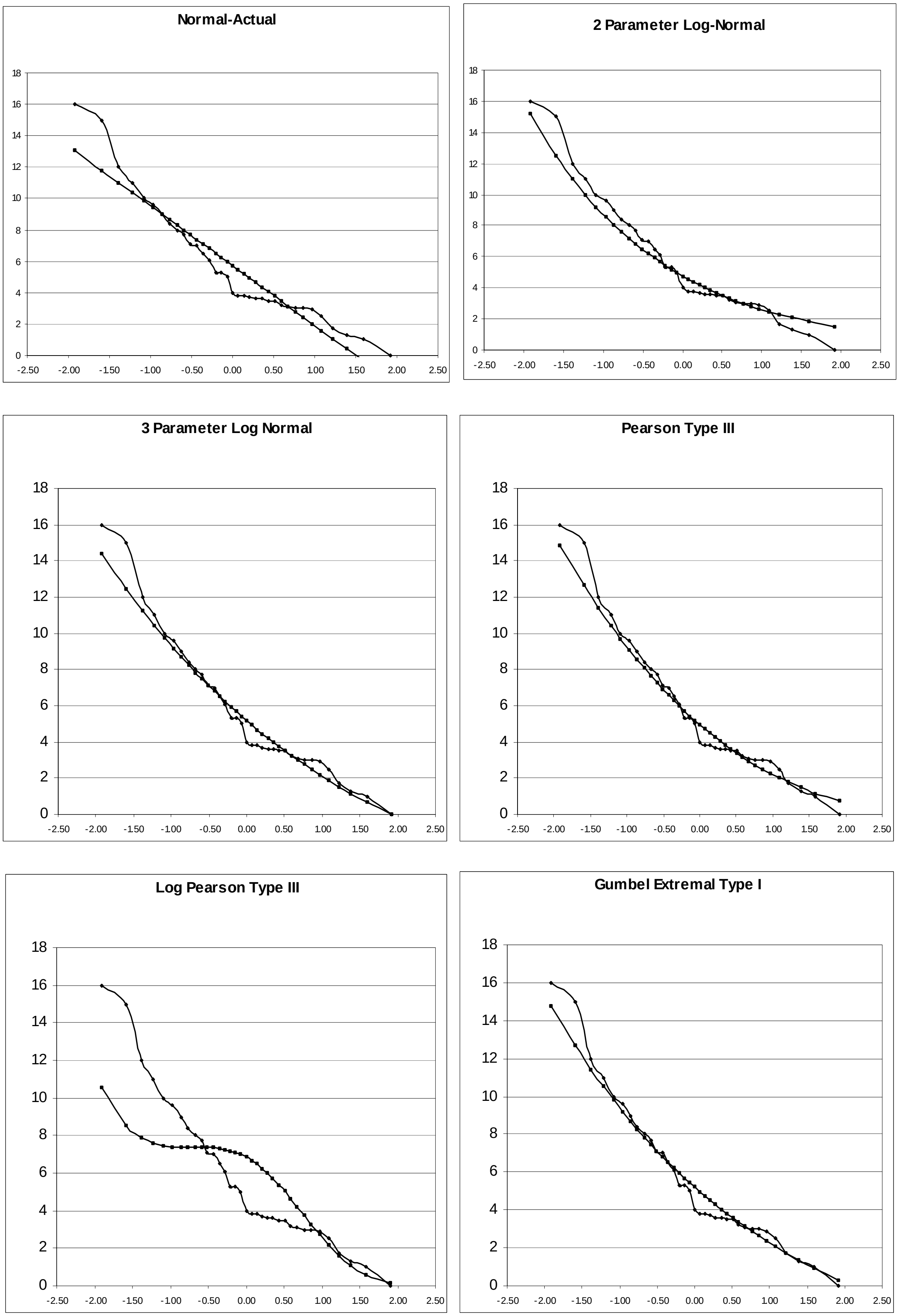


Figure A.4 Comparison of the distributions- Racine Station – Low Flow

Table A.1 Comparison of The Distributions (Peak Flows 1963-1998) – Racine Station

		PREDICTIONS					
Cum.Pr	**Actual Data**	**Normal**	**2 parameter Log Normal**	**3 Parameter Log Normal**	**Pearson Type III**	**Log Pearson Type III**	**Gumbel Extremal Type I**
2.78	340	285	802	606	756	554	720
5.56	847	571	920	777	873	724	870
8.33	997	758	1006	897	962	851	976
11.11	1000	903	1079	995	1037	958	1062
13.89	1220	1024	1143	1079	1105	1053	1137
16.67	1240	1129	1202	1155	1168	1140	1205
19.44	1280	1223	1257	1226	1228	1221	1268
22.22	1320	1310	1311	1292	1285	1297	1327
25.00	1370	1390	1362	1355	1340	1370	1384
27.78	1450	1466	1413	1416	1395	1441	1439
30.56	1470	1538	1462	1475	1449	1509	1493
33.33	1490	1607	1512	1533	1502	1576	1547
36.11	1560	1674	1561	1591	1555	1641	1600
38.89	1580	1739	1611	1647	1609	1706	1652
41.67	1610	1803	1661	1704	1663	1770	1706
44.44	1800	1866	1712	1761	1717	1834	1759
47.22	1810	1928	1764	1819	1773	1898	1813
50.00	1900	1990	1817	1877	1830	1962	1869
52.78	1930	2052	1872	1936	1889	2026	1926
55.56	1940	2115	1928	1997	1949	2091	1984
58.33	1940	2177	1987	2060	2012	2157	2045
61.11	2000	2241	2049	2124	2077	2224	2108
63.89	2090	2307	2114	2192	2145	2292	2174
66.67	2140	2374	2183	2262	2218	2363	2244
69.44	2150	2443	2257	2337	2294	2436	2318
72.22	2250	2515	2337	2416	2377	2511	2398
75.00	2500	2591	2423	2501	2466	2590	2484
77.78	2530	2671	2519	2593	2563	2673	2578
80.56	2740	2758	2625	2695	2670	2762	2684
83.33	2930	2852	2747	2808	2792	2857	2803
86.11	3010	2957	2889	2939	2933	2962	2941
88.89	3460	3078	3061	3094	3101	3079	3108
91.67	3480	3222	3281	3288	3312	3216	3320
94.44	3790	3410	3589	3551	3601	3384	3614
97.22	4500	3696	4117	3983	4079	3619	4109
SSE (sum of squares of errors)		1,780,005	738,929	777,897	681,374	1,756,398	632,469

Table A.2 Comparison of The Distributions (Low Flows 1963-1998)- Racine Station

		PREDICTIONS					
Cum.Pr	**Actual Data**	**Normal**	**2 parameter Log Normal**	**3 Parameter Log Normal**	**Pearson Type III**	**Log Pearson Type III**	**Gumbel Extremal Type I**
97.22	0	-1.6	1.5	0.0	0.8	0.2	0.28
94.44	1.00	-0.4	1.8	0.7	1.2	0.6	0.92
91.67	1.3	0.4	2.1	1.1	1.5	1.1	1.37
88.89	1.7	1.1	2.3	1.5	1.8	1.6	1.74
86.11	2.5	1.6	2.5	1.9	2.0	2.2	2.06
83.33	2.9	2.0	2.6	2.2	2.3	2.7	2.35
80.56	3	2.4	2.8	2.5	2.5	3.2	2.62
77.78	3	2.8	3.0	2.7	2.7	3.7	2.88
75.00	3.1	3.1	3.2	3.0	2.9	4.2	3.12
72.22	3.20	3.5	3.3	3.2	3.2	4.6	3.36
69.44	3.5	3.8	3.5	3.5	3.4	5.0	3.59
66.67	3.5	4.1	3.7	3.7	3.6	5.4	3.82
63.89	3.60	4.4	3.8	4.0	3.8	5.7	4.05
61.11	3.6	4.6	4.0	4.2	4.0	6.0	4.27
58.33	3.7	4.9	4.2	4.4	4.2	6.3	4.50
55.56	3.8	5.2	4.4	4.7	4.5	6.5	4.73
52.78	3.8	5.5	4.6	4.9	4.7	6.7	4.96
50.00	4	5.7	4.8	5.2	4.9	6.8	5.20
47.22	5	6.0	5.0	5.4	5.2	7.0	5.44
44.44	5.3	6.3	5.2	5.7	5.4	7.1	5.69
41.67	5.3	6.5	5.4	5.9	5.7	7.2	5.95
38.89	6.1	6.8	5.6	6.2	6.0	7.3	6.22
36.11	6.5	7.1	5.9	6.5	6.3	7.3	6.51
33.33	7	7.4	6.2	6.8	6.6	7.3	6.81
30.56	7.1	7.7	6.5	7.1	6.9	7.4	7.12
27.78	7.7	8.0	6.8	7.5	7.3	7.4	7.46
25.00	8	8.3	7.2	7.8	7.6	7.4	7.83
22.22	8.4	8.6	7.6	8.2	8.1	7.4	8.24
19.44	9	9.0	8.0	8.7	8.5	7.4	8.69
16.67	9.6	9.4	8.6	9.2	9.1	7.4	9.20
13.89	10	9.9	9.2	9.7	9.7	7.5	9.79
11.11	11	10.4	10.0	10.4	10.4	7.6	10.51
8.33	12	11.0	11.0	11.3	11.4	7.9	11.42
5.56	15	11.8	12.5	12.5	12.7	8.5	12.68
2.78	16	13.0	15.2	14.4	14.9	10.6	14.80
SSE (sum of squares of errors)		44	21	17	13	179	14

Table A.3 Comparison of The Distributions (Peak Flows 1963-1998) – Franklin Station

		PREDICTIONS					
Cum. Pr	**Actual Data**	**Normal**	**2 parameter Log Normal**	**3 Parameter Log Normal**	**Pearson Type III**	**Log Pearson Type III**	**Gumbel Extremal Type I**
2.7	430	-663.7932	242.3415	132.4487	573.8749	399.5981	-176.5356
5.4	442	-352.6939	303.6859	212.583	585.3948	437.3709	-14.4832
8.1	474	-149.3208	351.9554	274.0695	586.0859	467.753	99.2724
10.8	530	7.6088	394.3854	327.1663	586.523	494.9186	191.7353
13.5	534	138.2923	433.5971	375.5436	588.5732	520.4028	272.0998
16.2	550	252.0593	470.894	421.0057	592.6641	544.9818	344.7185
18.9	556	354.0401	507.046	464.6042	598.8786	569.1248	412.0389
21.6	558	447.3832	542.5636	507.0256	607.212	593.1529	475.5983
24.3	579	534.1754	577.8171	548.7577	617.6473	617.3085	536.4426
27.0	587	615.8822	613.0955	590.1724	630.1788	641.7903	595.3295
29.7	600	693.5814	648.6398	631.571	644.8207	666.7727	652.8376
32.4	641	768.097	684.6619	673.2111	661.61	692.4186	709.4297
35.1	698	840.0811	721.3587	715.3244	680.6073	718.8878	765.4931
37.8	708	910.0654	758.9208	758.1287	701.8984	746.3434	821.3649
40.5	792	978.4968	797.54	801.8369	725.5962	774.9581	877.3507
43.2	808	1045.763	837.4161	846.6652	751.8427	804.9194	933.7387
45.9	860	1112.207	878.7624	892.8394	780.8126	836.4355	990.8101
48.6	880	1178.147	921.8124	940.6022	812.7188	869.7424	1048.85
51.4	910	1243.909	966.8474	990.2421	847.8333	905.1277	1108.154
54.1	980	1309.849	1014.213	1042.111	886.5083	942.9489	1169.042
56.8	1020	1376.293	1064.288	1096.589	929.1553	983.6154	1231.867
59.5	1020	1443.559	1117.501	1154.099	976.2579	1027.605	1297.028
62.2	1080	1511.99	1174.368	1215.145	1028.411	1075.507	1364.986
64.9	1180	1581.974	1235.518	1280.341	1086.354	1128.059	1436.289
67.6	1220	1653.959	1301.74	1350.45	1151.016	1186.196	1511.6
70.3	1300	1728.474	1374.032	1426.431	1223.584	1251.139	1591.742
73.0	1300	1806.173	1453.692	1509.526	1305.606	1324.506	1677.756
75.7	1420	1887.88	1542.447	1601.38	1399.146	1408.508	1771.004
78.4	1600	1974.672	1642.668	1704.239	1507.029	1506.266	1873.315
81.1	1680	2068.015	1757.734	1821.282	1633.272	1622.356	1987.24
83.8	1750	2169.996	1892.68	1957.224	1783.833	1763.845	2116.505
86.5	2160	2283.763	2055.484	2119.484	1968.084	1942.363	2266.87
89.2	2270	2414.447	2259.851	2320.71	2201.983	2178.845	2447.971
91.9	2650	2571.376	2532.287	2585.153	2516.012	2516.156	2677.857
94.6	3700	2774.749	2934.782	2968.892	2980.217	3062.402	2997.024
97.3	5130	3085.849	3677.67	3659.126	3825.526	4229.686	3534.661
SSE (sum of squares of errors)		**6,207,964**	**834,992**	**1,076,082**	**725,308**	**520,452**	**2,685,884**

Table A.4 Comparison of The Distributions (Low Flows 1963-1998)- Franklin Station

Cum. Pr	Actual Data	PREDICTIONS					
		Normal	2 parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Gumbel Extremal Type I
97.2	0.44	-0.0832	1.1227	0.8135	1.2891	0.7601	0.7872
94.4	1.3	0.4896	1.3193	1.0843	1.4053	1.0214	1.088
91.7	1.4	0.8644	1.4662	1.2798	1.5075	1.2234	1.2996
88.9	1.6	1.154	1.5907	1.4415	1.6025	1.3969	1.4718
86.1	1.6	1.3953	1.7026	1.5838	1.6932	1.5532	1.6216
83.3	1.6	1.6056	1.8065	1.7138	1.7813	1.6982	1.7573
80.6	2	1.7943	1.9051	1.8354	1.868	1.8351	1.8832
77.8	2	1.9672	2.0001	1.951	1.9541	1.9662	2.0022
75.0	2.1	2.1281	2.0929	2.0624	2.04	2.093	2.1163
72.2	2.2	2.2798	2.1842	2.1709	2.1264	2.2166	2.227
69.4	2.3	2.4242	2.2748	2.2773	2.2136	2.3379	2.3352
66.7	2.4	2.5628	2.3654	2.3826	2.3021	2.4576	2.4419
63.9	2.6	2.6969	2.4564	2.4873	2.3921	2.5763	2.5477
61.1	2.6	2.8275	2.5484	2.5921	2.4842	2.6946	2.6535
58.3	2.7	2.9553	2.6419	2.6975	2.5786	2.8128	2.7596
55.6	2.9	3.0812	2.7372	2.8041	2.6759	2.9316	2.8668
52.8	3	3.2058	2.835	2.9123	2.7763	3.0512	2.9755
50.0	3.2	3.3297	2.9356	3.0227	2.8804	3.1722	3.0864
47.2	3.2	3.4536	3.0399	3.1359	2.9889	3.2951	3.2001
44.4	3.3	3.5782	3.1484	3.2528	3.1024	3.4204	3.3172
41.7	3.3	3.7041	3.262	3.374	3.2218	3.5488	3.4385
38.9	3.3	3.8319	3.3816	3.5004	3.3479	3.6807	3.5648
36.1	3.4	3.9625	3.5083	3.6329	3.4818	3.817	3.6972
33.3	3.6	4.0966	3.6433	3.7728	3.6248	3.9585	3.8369
30.6	3.7	4.2353	3.7884	3.9216	3.7788	4.1061	3.9854
27.8	3.9	4.3796	3.9456	4.0812	3.9457	4.2611	4.1447
25.0	4	4.5313	4.1178	4.254	4.1285	4.4251	4.3172
22.2	4.2	4.6922	4.3087	4.4434	4.3309	4.6001	4.5063
19.4	4.2	4.8651	4.5237	4.6541	4.5584	4.7888	4.7168
16.7	4.3	5.0538	4.7706	4.8927	4.8188	4.9953	4.9555
13.9	5.2	5.2641	5.0617	5.17	5.1242	5.2253	5.233
11.1	6	5.5055	5.4177	5.5033	5.495	5.4883	5.567
8.3	7	5.795	5.8779	5.9259	5.9693	5.8008	5.9908
5.6	7.1	6.1699	6.5324	6.5119	6.633	6.1978	6.5789
2.8	8.9	6.7426	7.6758	7.5	7.7604	6.7797	7.5691
SSE (sum of squares of errors)		**12.19**	**4.56**	**4.94**	**4.48**	**9.33**	**4.78**

Table A.5 Comparison Of The Distributions - % Change (Peak 1963-1998)- Franklin

% Change = (Actual Value - Predicted Value)/Actual Value*100

Pr	Actual Data	Normal	2 parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Gumbel Extremal Type I
2.7	430	-254	-44	-69	33	-7	-141
5.4	442	-180	-31	-52	32	-1	-103
8.1	474	-132	-26	-42	24	-1	-79
10.8	530	-99	-26	-38	11	-7	-64
13.5	534	-74	-19	-30	10	-3	-49
16.2	550	-54	-14	-23	8	-1	-37
18.9	556	-36	-9	-16	8	2	-26
21.6	558	-20	-3	-9	9	6	-15
24.3	579	-8	0	-5	7	7	-7
27.0	587	5	4	1	7	9	1
29.7	600	16	8	5	7	11	9
32.4	641	20	7	5	3	8	11
35.1	698	20	3	2	-2	3	10
37.8	708	29	7	7	-1	5	16
40.5	792	24	1	1	-8	-2	11
43.2	808	29	4	5	-7	0	16
45.9	860	29	2	4	-9	-3	15
48.6	880	34	5	7	-8	-1	19
51.4	910	37	6	9	-7	-1	22
54.1	980	34	3	6	-10	-4	19
56.8	1020	35	4	8	-9	-4	21
59.5	1020	42	10	13	-4	1	27
62.2	1080	40	9	13	-5	0	26
64.9	1180	34	5	9	-8	-4	22
67.6	1220	36	7	11	-6	-3	24
70.3	1300	33	6	10	-6	-4	22
73.0	1300	39	12	16	0	2	29
75.7	1420	33	9	13	-1	-1	25
78.4	1600	23	3	7	-6	-6	17
81.1	1680	23	5	8	-3	-3	18
83.8	1750	24	8	12	2	1	21
86.5	2160	6	-5	-2	-9	-10	5
89.2	2270	6	0	2	-3	-4	8
91.9	2650	-3	-4	-2	-5	-5	1
94.6	3700	-25	-21	-20	-19	-17	-19
97.3	5130	-40	-28	-29	-25	-18	-31

Table A.6 Comparison of The Distributions - % Change (Low 1963-1998)- Franklin

% Change = (Actual Value - Predicted Value)/Actual Value*100

Pr	Actual Data	Normal	2 parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Gumbel Extremal Type I
97.2	0.44	-119	155	85	193	73	79
94.4	1.3	-62	1	-17	8	-21	-16
91.7	1.4	-38	5	-9	8	-13	-7
88.9	1.6	-28	-1	-10	0	-13	-8
86.1	1.6	-13	6	-1	6	-3	1
83.3	1.6	0	13	7	11	6	10
80.6	2	-10	-5	-8	-7	-8	-6
77.8	2	-2	0	-2	-2	-2	0
75.0	2.1	1	0	-2	-3	0	1
72.2	2.2	4	-1	-1	-3	1	1
69.4	2.3	5	-1	-1	-4	2	2
66.7	2.4	7	-1	-1	-4	2	2
63.9	2.6	4	-6	-4	-8	-1	-2
61.1	2.6	9	-2	0	-4	4	2
58.3	2.7	9	-2	0	-4	4	2
55.6	2.9	6	-6	-3	-8	1	-1
52.8	3	7	-6	-3	-7	2	-1
50.0	3.2	4	-8	-6	-10	-1	-4
47.2	3.2	8	-5	-2	-7	3	0
44.4	3.3	8	-5	-1	-6	4	1
41.7	3.3	12	-1	2	-2	8	4
38.9	3.3	16	2	6	1	12	8
36.1	3.4	17	3	7	2	12	9
33.3	3.6	14	1	5	1	10	7
30.6	3.7	14	2	6	2	11	8
27.8	3.9	12	1	5	1	9	6
25.0	4	13	3	6	3	11	8
22.2	4.2	12	3	6	3	10	7
19.4	4.2	16	8	11	9	14	12
16.7	4.3	18	11	14	12	16	15
13.9	5.2	1	-3	-1	-1	0	1
11.1	6	-8	-10	-8	-8	-9	-7
8.3	7	-17	-16	-15	-15	-17	-14
5.6	7.1	-13	-8	-8	-7	-13	-7
2.8	8.9	-24	-14	-16	-13	-24	-15

Table A.7 Comparison of The Distributions - % Change (Peak 1963-1998)- Racine

% Change = (Actual Value - Predicted Value)/Actual Value*100

Cum. Pr	Actual Data	Normal	2 parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Gumbel Extremal Type I
2.78	340.00	16.19	-135.81	-78.25	-122.43	-62.81	-111.73
5.56	847.00	32.57	-8.59	8.24	-3.06	14.56	-2.74
8.33	997.00	23.92	-0.92	10.00	3.55	14.62	2.11
11.11	1000.00	9.68	-7.85	0.53	-3.71	4.15	-6.20
13.89	1220.00	16.08	6.33	11.54	9.42	13.66	6.81
16.67	1240.00	8.96	3.08	6.83	5.81	8.06	2.85
19.44	1280.00	4.44	1.76	4.25	4.10	4.62	0.97
22.22	1320.00	0.79	0.71	2.14	2.67	1.73	-0.53
25.00	1370.00	-1.46	0.57	1.10	2.17	-0.02	-1.03
27.78	1450.00	-1.09	2.58	2.36	3.81	0.65	0.73
30.56	1470.00	-4.62	0.52	-0.34	1.46	-2.65	-1.59
33.33	1490.00	-7.86	-1.46	-2.90	-0.80	-5.76	-3.81
36.11	1560.00	-7.32	-0.07	-1.96	0.31	-5.22	-2.54
38.89	1580.00	-10.09	-1.95	-4.27	-1.82	-7.98	-4.59
41.67	1610.00	-12.01	-3.16	-5.86	-3.28	-9.96	-5.93
44.44	1800.00	-3.68	4.90	2.15	4.58	-1.90	2.27
47.22	1810.00	-6.55	2.56	-0.49	2.03	-4.85	-0.19
50.00	1900.00	-4.76	4.38	1.21	3.68	-3.25	1.64
52.78	1930.00	-6.34	3.03	-0.33	2.15	-4.97	0.23
55.56	1940.00	-9.00	0.60	-2.94	-0.46	-7.77	-2.28
58.33	1940.00	-12.24	-2.44	-6.16	-3.69	-11.17	-5.40
61.11	2000.00	-12.07	-2.46	-6.21	-3.84	-11.19	-5.39
63.89	2090.00	-10.36	-1.17	-4.86	-2.65	-9.68	-4.02
66.67	2140.00	-10.92	-2.03	-5.71	-3.63	-10.41	-4.85
69.44	2150.00	-13.62	-4.99	-8.68	-6.72	-13.28	-7.82
72.22	2250.00	-11.78	-3.85	-7.37	-5.63	-11.61	-6.56
75.00	2500.00	-3.63	3.07	-0.03	1.38	-3.61	0.65
77.78	2530.00	-5.58	0.45	-2.49	-1.29	-5.67	-1.91
80.56	2740.00	-0.64	4.19	1.66	2.54	-0.80	2.06
83.33	2930.00	2.66	6.26	4.15	4.71	2.47	4.34
86.11	3010.00	1.76	4.04	2.35	2.57	1.59	2.28
88.89	3460.00	11.05	11.54	10.57	10.39	11.00	10.16
91.67	3480.00	7.40	5.73	5.52	4.83	7.59	4.59
94.44	3790.00	10.04	5.31	6.30	4.99	10.72	4.64
97.22	4500.00	17.87	8.51	11.50	9.35	19.57	8.69

Table A.8 Comparison of The Distributions - % Change (Low 1963-1998)- Racine

% Change = (Actual Value - Predicted Value)/Actual Value*100

Pr	Actual Data	Normal	2 parameter Log Normal	3 Parameter Log Normal	Pearson Type III	Log Pearson Type III	Gumbel Extremal Type I
97.22	0	-	-	-	-	-	-
94.44	1.00	135.94	-81.00	33.84	-16.19	43.94	7.83
91.67	1.3	65.92	-58.18	12.28	-14.05	18.08	-5.73
88.89	1.7	37.48	-33.49	9.92	-3.71	5.10	-2.54
86.11	2.5	36.82	1.46	25.11	19.22	13.15	17.44
83.33	2.9	30.01	8.74	24.80	22.04	6.24	18.82
80.56	3	18.88	5.94	17.76	16.94	-8.15	12.54
77.78	3	6.54	0.23	8.74	9.48	-24.70	4.05
75.00	3.1	-1.55	-1.98	3.33	5.32	-35.64	-0.74
72.22	3.20	-8.52	-4.03	-1.49	1.50	-44.80	-4.99
69.44	3.5	-8.05	0.09	0.22	3.79	-43.62	-2.61
66.67	3.5	-16.53	-4.73	-6.66	-2.37	-53.83	-9.13
63.89	3.60	-21.27	-6.58	-10.31	-5.55	-58.51	-12.40
61.11	3.6	-29.03	-11.42	-16.90	-11.62	-66.52	-18.69
58.33	3.7	-32.94	-13.23	-20.15	-14.60	-68.93	-21.62
55.56	3.8	-36.54	-15.08	-23.28	-17.53	-70.39	-24.46
52.78	3.8	-43.56	-20.06	-29.63	-23.62	-75.51	-30.58
50.00	4	-43.01	-18.98	-29.28	-23.37	-70.90	-29.99
47.22	5	-19.71	0.72	-8.43	-3.59	-39.53	-8.86
44.44	5.3	-17.97	2.28	-7.14	-2.52	-33.82	-7.42
41.67	5.3	-23.05	-1.99	-12.15	-7.52	-35.58	-12.32
38.89	6.1	-11.40	7.44	-1.95	2.04	-18.99	-2.02
36.11	6.5	-8.84	9.19	-0.10	3.57	-12.49	-0.11
33.33	7	-5.17	11.74	2.74	6.04	-4.98	2.77
30.56	7.1	-7.87	8.78	-0.39	2.72	-3.82	-0.34
27.78	7.7	-3.48	11.65	3.01	5.68	4.13	3.05
25.00	8	-3.66	10.46	2.06	4.40	7.69	2.07
22.22	8.4	-2.82	9.92	1.97	3.91	12.08	1.92
19.44	9	-0.08	10.83	3.60	5.08	17.89	3.45
16.67	9.6	1.97	10.86	4.45	5.44	22.82	4.16
13.89	10	1.39	8.07	2.54	3.01	25.38	2.06
11.11	11	5.66	9.27	5.19	5.04	31.06	4.46
8.33	12	8.35	8.22	5.95	5.08	34.56	4.86
5.56	15	21.33	16.58	16.93	15.37	43.36	15.50
2.78	16	18.59	4.97	9.98	7.06	33.98	7.53

Table A.9 Results of Regression Analysis –Franklin Station – Peak Flow

Dependent variable: Actual
Independent variable: Normal

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	121.962	153.425	0.79493	0.4322
Slope	0.89929	0.102104	8.80755	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.30382E7	1	2.30382E7	77.57	0.0000
Residual	1.00976E7	34	296988.0		
Total (Corr.)	3.31358E7	35			

Correlation Coefficient = 0.833826
R-squared = 69.5267 percent
Standard Error of Est. = 544.966

Dependent variable: Actual
Independent variable: 2 Parameter Log-Normal

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-189.05	71.2894	-2.65187	0.0121
Slope	1.20916	0.0512619	23.5878	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	3.12275E7	1	3.12275E7	556.39	0.0000
Residual	1.90827E6	34	56125.7		
Total (Corr.)	3.31358E7	35			

Correlation Coefficient = 0.970778
R-squared = 94.2411 percent
Standard Error of Est. = 236.909

Dependent variable: Actual
Independent variable: 3 Parameter Log-Normal

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-126.672	82.0808	-1.54325	0.1320
Slope	1.1489	0.0580799	19.7813	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	3.04868E7	1	3.04868E7	391.30	0.0000
Residual	2.64899E6	34	77911.5		
Total (Corr.)	3.31358E7	35			

Correlation Coefficient = 0.959196
R-squared = 92.0057 percent
Standard Error of Est. = 279.126

```
-----------------------------------------------------------------------------
Dependent variable: Actual
Independent variable: Pearson Type III
-----------------------------------------------------------------------------
                               Standard          T
Parameter       Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
Intercept       -245.108        43.4693       -5.63865         0.0000
Slope            1.27928      0.0319912        39.9886         0.0000
-----------------------------------------------------------------------------
                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                   3.24459E7      1    3.24459E7    1599.09       0.0000
Residual                 689868.0     34      20290.2
-----------------------------------------------------------------------------
Total (Corr.)           3.31358E7     35
Correlation Coefficient = 0.989536
R-squared = 97.9181 percent
Standard Error of Est. = 142.444


-----------------------------------------------------------------------------
Dependent variable: Actual
Independent variable: Log Pearson Type III
-----------------------------------------------------------------------------
                               Standard          T
Parameter       Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
Intercept       -170.056         27.306       -6.22778         0.0000
Slope            1.19944      0.0195047        61.4948         0.0000
-----------------------------------------------------------------------------
                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                   3.28405E7      1    3.28405E7    3781.61       0.0000
Residual                 295265.0     34      8684.28
-----------------------------------------------------------------------------
Total (Corr.)           3.31358E7     35
Correlation Coefficient = 0.995535
R-squared = 99.1089 percent
Standard Error of Est. = 93.1895


-----------------------------------------------------------------------------
Dependent variable: Actual
Independent variable: Gumbel
-----------------------------------------------------------------------------
                               Standard          T
Parameter       Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
Intercept       -28.9396        112.735      -0.256705         0.7990
Slope             1.0239      0.0758959        13.4908         0.0000
-----------------------------------------------------------------------------
                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                     2.792E7      1      2.792E7     182.00       0.0000
Residual                5.21578E6     34     153405.0
-----------------------------------------------------------------------------
Total (Corr.)           3.31358E7     35

Correlation Coefficient = 0.917929
R-squared = 84.2594 percent
Standard Error of Est. = 391.67
```

Table A.10 Results of Regression Analysis –Franklin Station – Low Flow

```
-----------------------------------------------------------------------------
Dependent variable: Actual
Independent variable: Normal
-----------------------------------------------------------------------------
                               Standard          T
Parameter       Estimate          Error       Statistic        P-Value
-----------------------------------------------------------------------------
Intercept      -0.058455       0.233841      -0.249977         0.8042
Slope            1.01756      0.0631049        16.1249         0.0000
-----------------------------------------------------------------------------
                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                     95.8355      1      95.8355     260.01       0.0000
Residual                  12.1632     33     0.368582
-----------------------------------------------------------------------------
Total (Corr.)             107.999     34
Correlation Coefficient = 0.942006
R-squared = 88.7376 percent
Standard Error of Est. = 0.60711
```

```
-----------------------------------------------------------------------------
Dependent variable: Actual
Independent variable: 2 Parameter Log-Normal
-----------------------------------------------------------------------------
                               Standard          T
Parameter       Estimate          Error       Statistic        P-Value
-----------------------------------------------------------------------------
Intercept       -0.39773       0.114408        -3.4764         0.0014
Slope             1.1445      0.0318492        35.9351         0.0000
-----------------------------------------------------------------------------
                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                     105.308      1      105.308    1291.33       0.0000
Residual                  2.69113     33    0.0815495
-----------------------------------------------------------------------------
Total (Corr.)             107.999     34
Correlation Coefficient = 0.987462
R-squared = 97.5082 percent
Standard Error of Est. = 0.285569
```

Dependent variable: Actual
Independent variable: 3 Parameter Log-Normal

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-0.27434	0.135874	-2.01908	0.0517
Slope	1.10034	0.0374218	29.4036	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	104.028	1	104.028	864.57	0.0000
Residual	3.97066	33	0.120323		
Total (Corr.)	107.999	34			

Correlation Coefficient = 0.981445
R-squared = 96.3234 percent
Standard Error of Est. = 0.346876

Dependent variable: Actual
Independent variable: Pearson Type III

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-0.324298	0.119425	-2.71549	0.0104
Slope	1.12302	0.0331671	33.8593	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	104.977	1	104.977	1146.46	0.0000
Residual	3.0217	33	0.0915666		
Total (Corr.)	107.999	34			

Correlation Coefficient = 0.985911
R-squared = 97.2021 percent
Standard Error of Est. = 0.3026

Dependent variable: Actual

Independent variable: Log Pearson Type III

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-0.364269	0.204068	-1.78504	0.0835
Slope	1.11277	0.0559137	19.9015	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	99.6925	1	99.6925	396.07	0.0000
Residual	8.30622	33	0.251704		
Total (Corr.)	107.999	34			

Correlation Coefficient = 0.960776

R-squared = 92.309 percent

Standard Error of Est. = 0.501701

Dependent variable: Actual

Independent variable: Gumbel

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-0.303628	0.138161	-2.19764	0.0351
Slope	1.09119	0.0374899	29.1061	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	103.95	1	103.95	847.17	0.0000
Residual	4.04919	33	0.122703		
Total (Corr.)	107.999	34			

Correlation Coefficient = 0.981074

R-squared = 96.2507 percent

Standard Error of Est. = 0.350289

Table A.11 Results of Regression Analysis –Racine Station – Peak Flow

```
-----------------------------------------------------------------------------
Dependent variable: Actual
Independent variable: Normal
-----------------------------------------------------------------------------
                               Standard          T
Parameter       Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
Intercept        -89.231         102.46      -0.870888         0.3901
Slope            1.04485      0.0476582        21.9237         0.0000
-----------------------------------------------------------------------------
                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                   2.5235E7      1     2.5235E7     480.65       0.0000
Residual               1.73256E6     33      52502.0
-----------------------------------------------------------------------------
Total (Corr.)          2.69676E7     34
Correlation Coefficient = 0.967344
R-squared = 93.5754 percent
Standard Error of Est. = 229.133
```

```
-----------------------------------------------------------------------------
Dependent variable: Normal
Independent variable: 2 Parameter Log-Normal
-----------------------------------------------------------------------------
                               Standard          T
Parameter       Estimate         Error       Statistic        P-Value
-----------------------------------------------------------------------------
Intercept       -220.289        48.1159       -4.57829         0.0001
Slope            1.12835      0.0228459        49.3894         0.0000
-----------------------------------------------------------------------------
                           Analysis of Variance
-----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
-----------------------------------------------------------------------------
Model                  2.66076E7      1    2.66076E7    2439.31       0.0000
Residual                359958.0     33      10907.8
-----------------------------------------------------------------------------
Total (Corr.)          2.69676E7     34
Correlation Coefficient = 0.993304
R-squared = 98.6652 percent
Standard Error of Est. = 104.441
```

```
----------------------------------------------------------------------------
Dependent variable: Actual
Independent variable: 3 Parameter Log-Normal
----------------------------------------------------------------------------
                               Standard          T
Parameter       Estimate         Error       Statistic        P-Value
----------------------------------------------------------------------------
Intercept       -154.873        60.2801       -2.56923         0.0149
Slope            1.08848      0.0283519        38.3919         0.0000
----------------------------------------------------------------------------
                           Analysis of Variance
----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
----------------------------------------------------------------------------
Model                   2.6377E7      1     2.6377E7    1473.93       0.0000
Residual                590557.0     33      17895.7
----------------------------------------------------------------------------
Total (Corr.)          2.69676E7     34
Correlation Coefficient = 0.98899
R-squared = 97.8101 percent
Standard Error of Est. = 133.775
```

```
----------------------------------------------------------------------------
Dependent variable: Actual
Independent variable: Pearson Type III
----------------------------------------------------------------------------
                               Standard          T
Parameter       Estimate         Error       Statistic        P-Value
----------------------------------------------------------------------------
Intercept       -167.055        52.2556       -3.19688         0.0031
Slope            1.09874      0.0246791        44.5211         0.0000
----------------------------------------------------------------------------
                           Analysis of Variance
----------------------------------------------------------------------------
Source             Sum of Squares     Df  Mean Square    F-Ratio      P-Value
----------------------------------------------------------------------------
Model                   2.6526E7      1     2.6526E7    1982.13       0.0000
Residual                441624.0     33      13382.6
----------------------------------------------------------------------------
Total (Corr.)          2.69676E7     34
Correlation Coefficient = 0.991778
R-squared = 98.3624 percent
Standard Error of Est. = 115.683
```

Dependent variable: Actual

Independent variable: Log Pearson Type III

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-186.84	101.374	-1.84308	0.0743
Slope	1.09257	0.0473747	23.0623	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.53921E7	1	2.53921E7	531.87	0.0000
Residual	1.57546E6	33	47741.2		
Total (Corr.)	2.69676E7	34			

Correlation Coefficient = 0.97035

R-squared = 94.1579 percent

Standard Error of Est. = 218.498

Dependent variable: Actual

Independent variable: Gumbel

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-207.135	50.2916	-4.11867	0.0002
Slope	1.10405	0.0234879	47.0051	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	2.65707E7	1	2.65707E7	2209.48	0.0000
Residual	396851.0	33	12025.8		
Total (Corr.)	2.69676E7	34			

Correlation Coefficient = 0.992615

R-squared = 98.5284 percent

Standard Error of Est. = 109.662

Table A.12 Results of Regression Analysis –Racine Station – Low Flow

Dependent variable: Actual
Independent variable: Normal

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-0.166994	0.376916	-0.443054	0.6606
Slope	1.02873	0.0562421	18.2911	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	450.451	1	450.451	334.56	0.0000
Residual	44.4305	33	1.34638		
Total (Corr.)	494.882	34			

Correlation Coefficient = 0.954054
R-squared = 91.022 percent
Standard Error of Est. = 1.16034

Dependent variable: Actual
Independent variable: 2 Parameter Log-Normal

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-0.88332	0.166187	-5.31521	0.0000
Slope	1.19137	0.0261043	45.639	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	487.163	1	487.163	2082.92	0.0000
Residual	7.7182	33	0.233885		
Total (Corr.)	494.882	34			

Correlation Coefficient = 0.992171
R-squared = 98.4404 percent
Standard Error of Est. = 0.483617

Dependent variable: Actual
Independent variable: 3 Parameter Log-Normal

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-0.419437	0.204508	-2.05096	0.0483
Slope	1.09248	0.031143	35.0794	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	481.957	1	481.957	1230.56	0.0000
Residual	12.9246	33	0.391656		
Total (Corr.)	494.882	34			

Correlation Coefficient = 0.986855
R-squared = 97.3883 percent
Standard Error of Est. = 0.625824

Dependent variable: Actual
Independent variable: Pearson Type III

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-0.489812	0.157681	-3.10634	0.0039
Slope	1.11008	0.0241606	45.9459	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	487.265	1	487.265	2111.03	0.0000
Residual	7.61702	33	0.230819		
Total (Corr.)	494.882	34			

Correlation Coefficient = 0.992274
R-squared = 98.4608 percent
Standard Error of Est. = 0.480436

Dependent variable: Actual

Independent variable: Log Pearson Type III

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-1.57939	0.970237	-1.62784	0.1131
Slope	1.26354	0.15477	8.16399	0.0000

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	330.998	1	330.998	66.65	0.0000
Residual	163.883	33	4.96616		
Total (Corr.)	494.882	34			

Correlation Coefficient = 0.817829

R-squared = 66.8844 percent

Standard Error of Est. = 2.22849

Dependent variable: Actual

Independent variable: Gumbel

Parameter	Estimate	Standard Error	T Statistic	P-Value
Intercept	-0.571501	0.186796	-3.05949	0.0044
Slope	1.10007	0.0281129	39.1305	0.0000

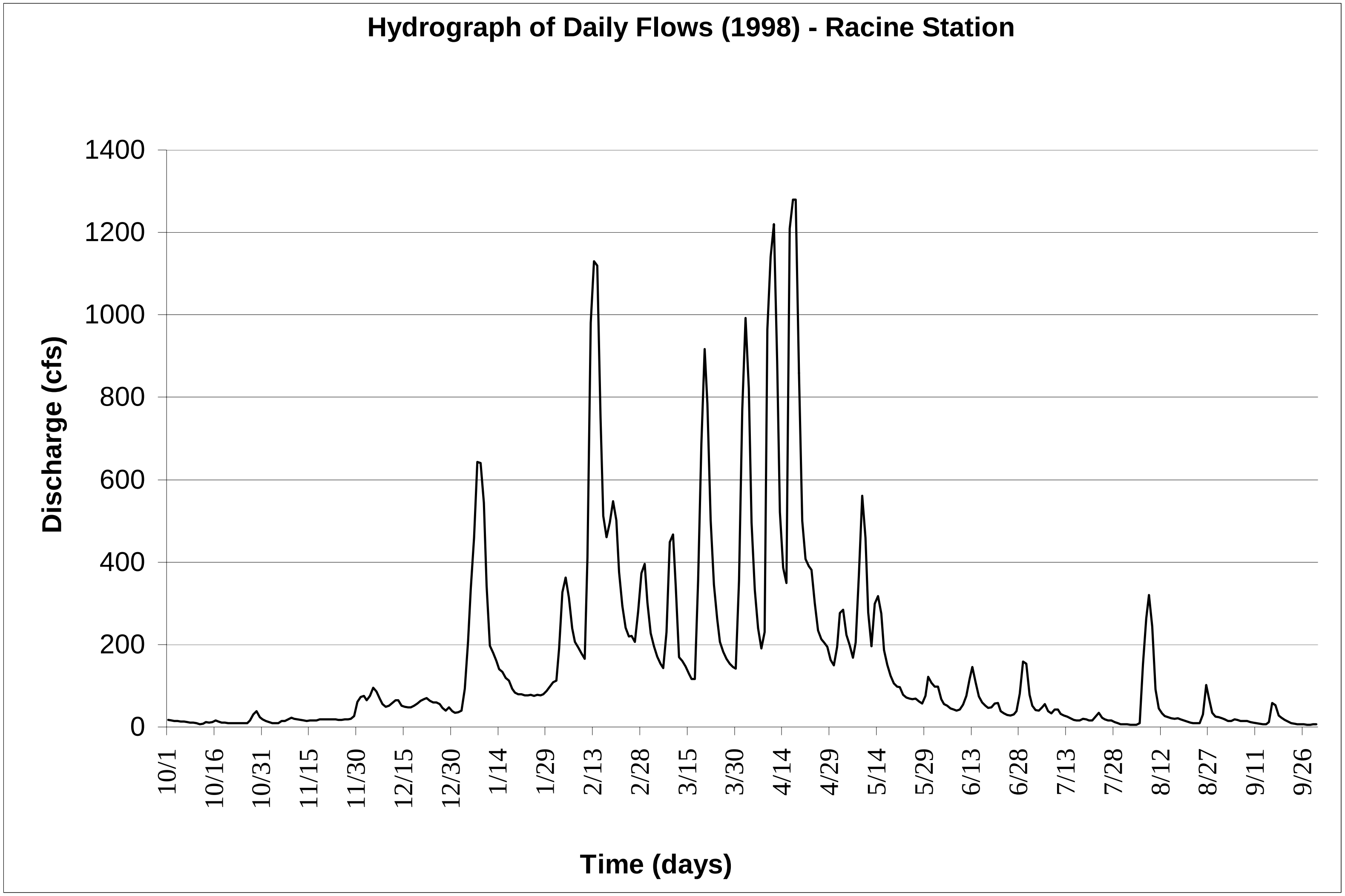
Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	484.441	1	484.441	1531.20	0.0000
Residual	10.4405	33	0.31638		
Total (Corr.)	494.882	34			

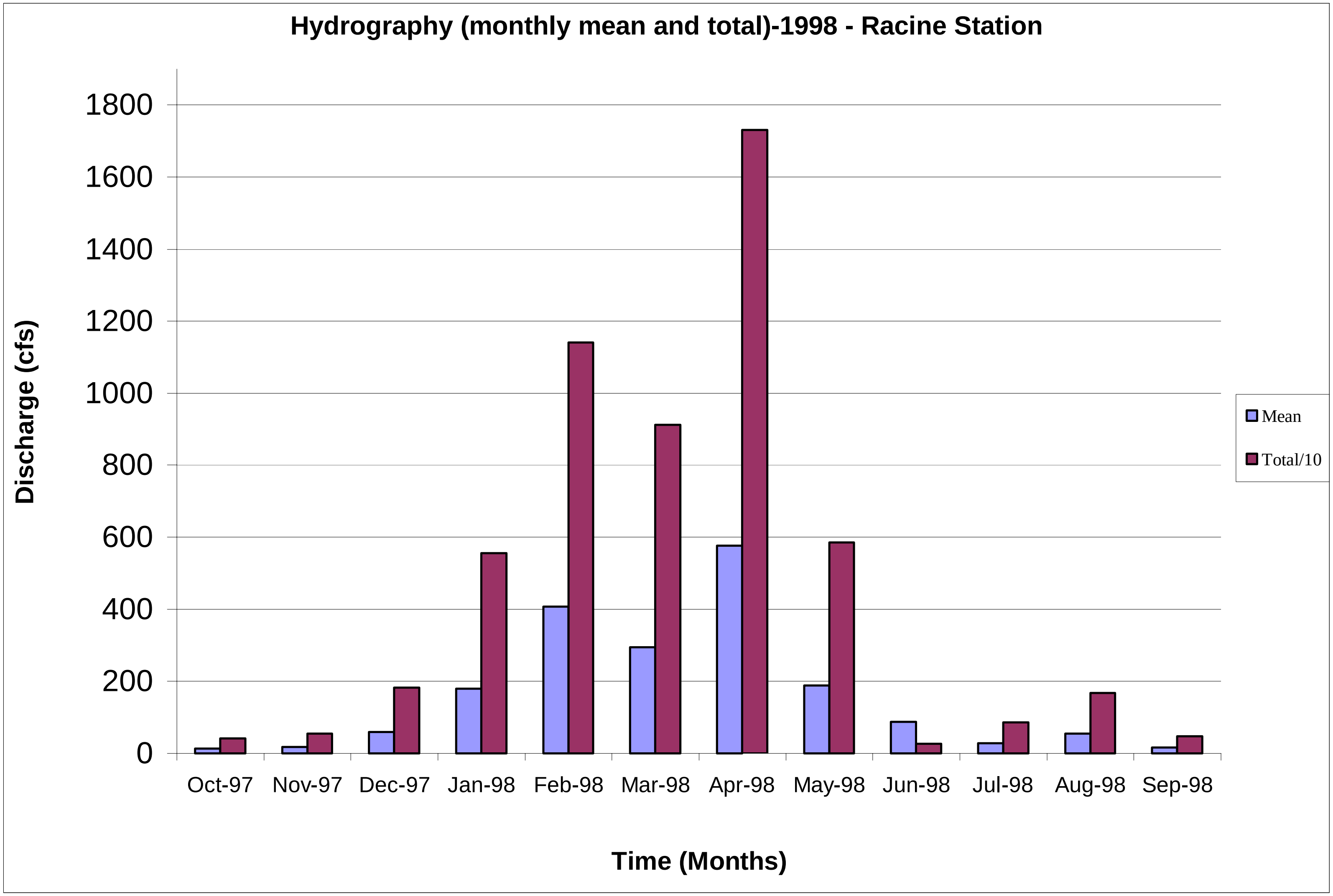
Correlation Coefficient = 0.989395

R-squared = 97.8903 percent

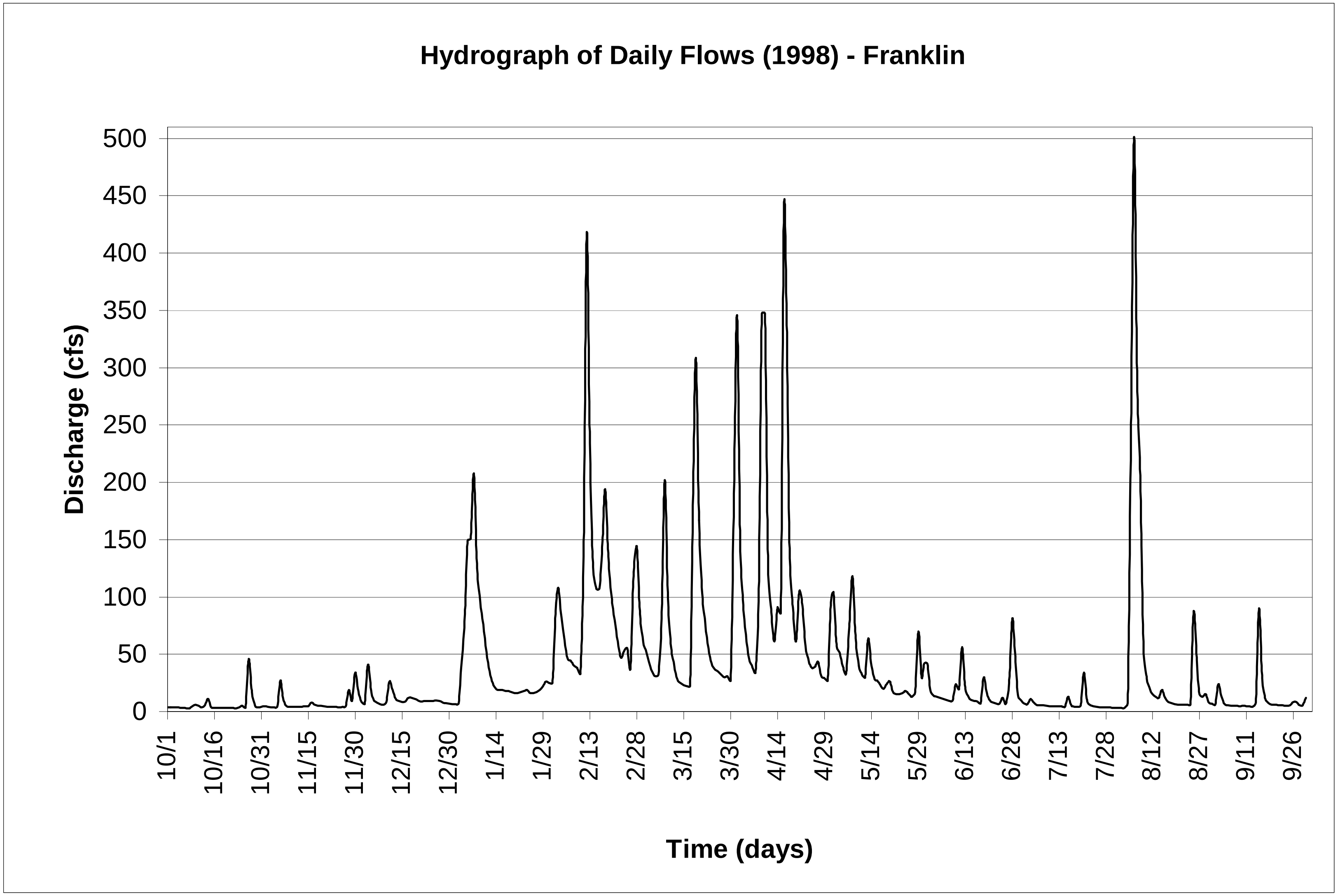
Standard Error of Est. = 0.562477



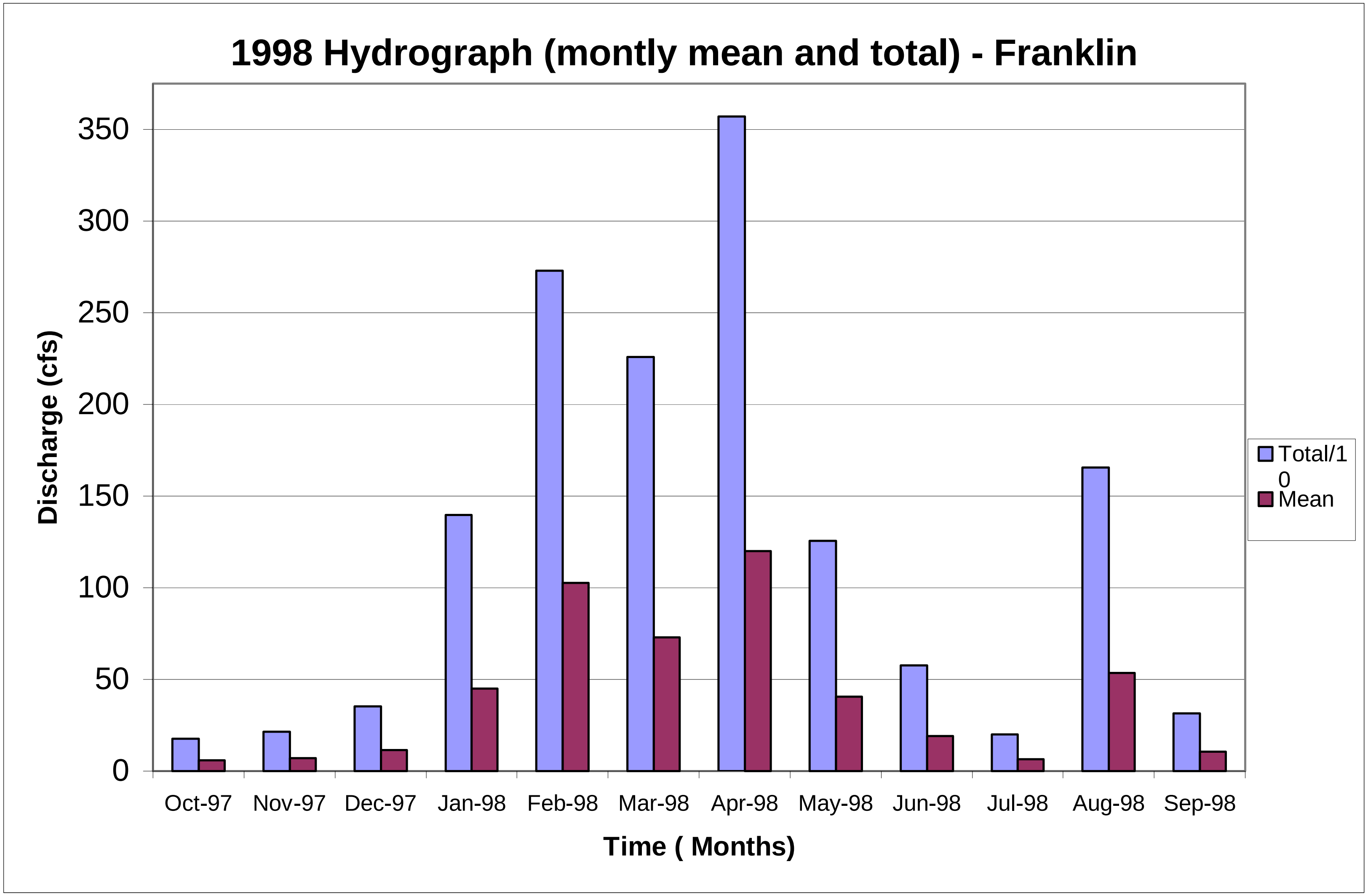
Graph A.3 Hydrograph for the 1998 – Racine Station



Graph A.4 Hydrograph for the 1998- Racine Station



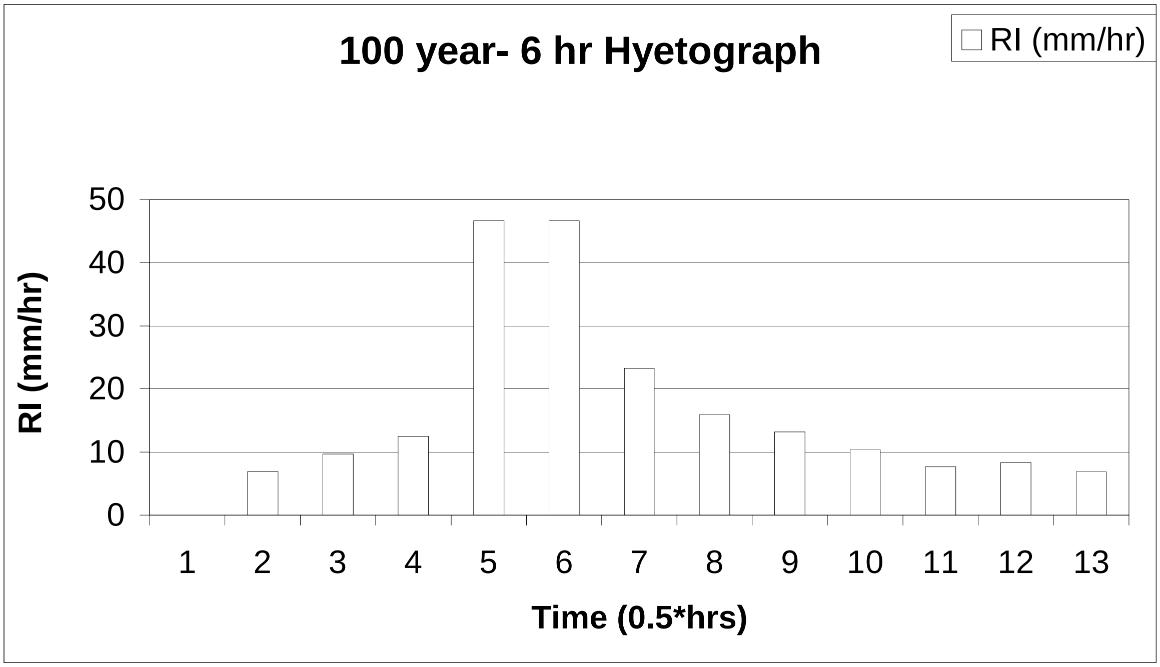
Graph A.3 Hydrograph for the 1998 – Franklin Station



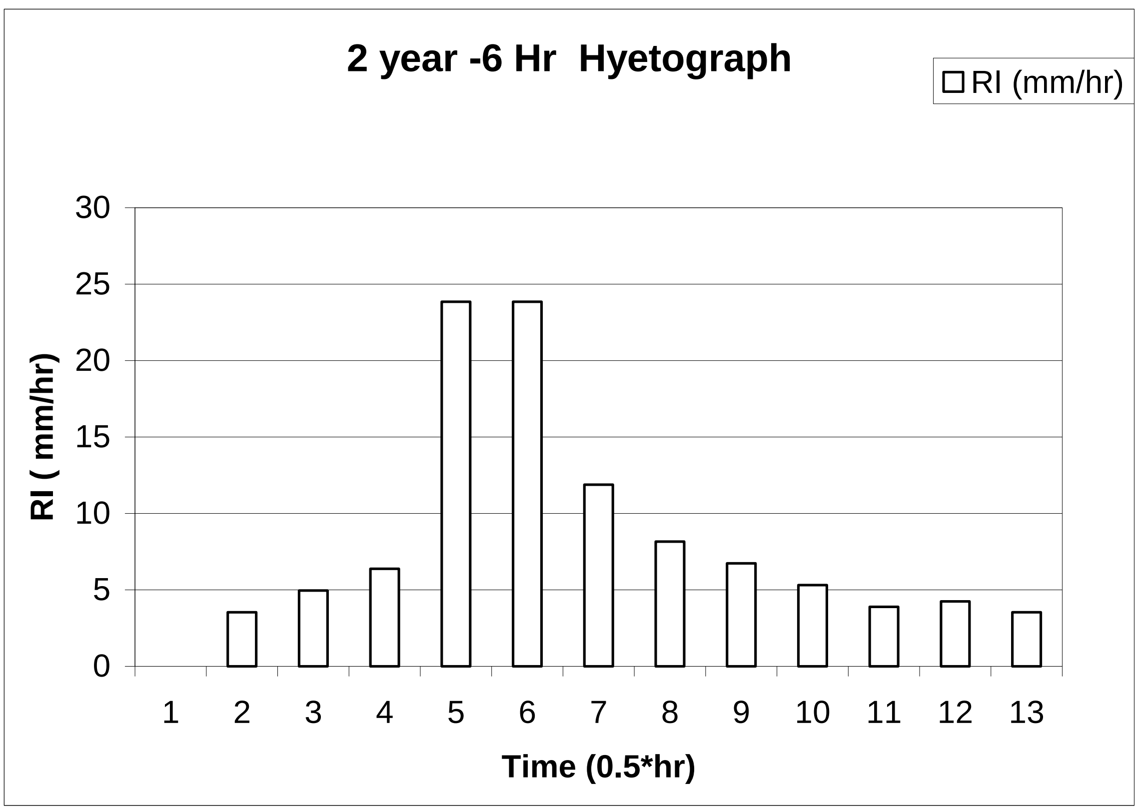
Graph A.4 Hydrograph for the 1998- Franklin Station

APPENDIX B

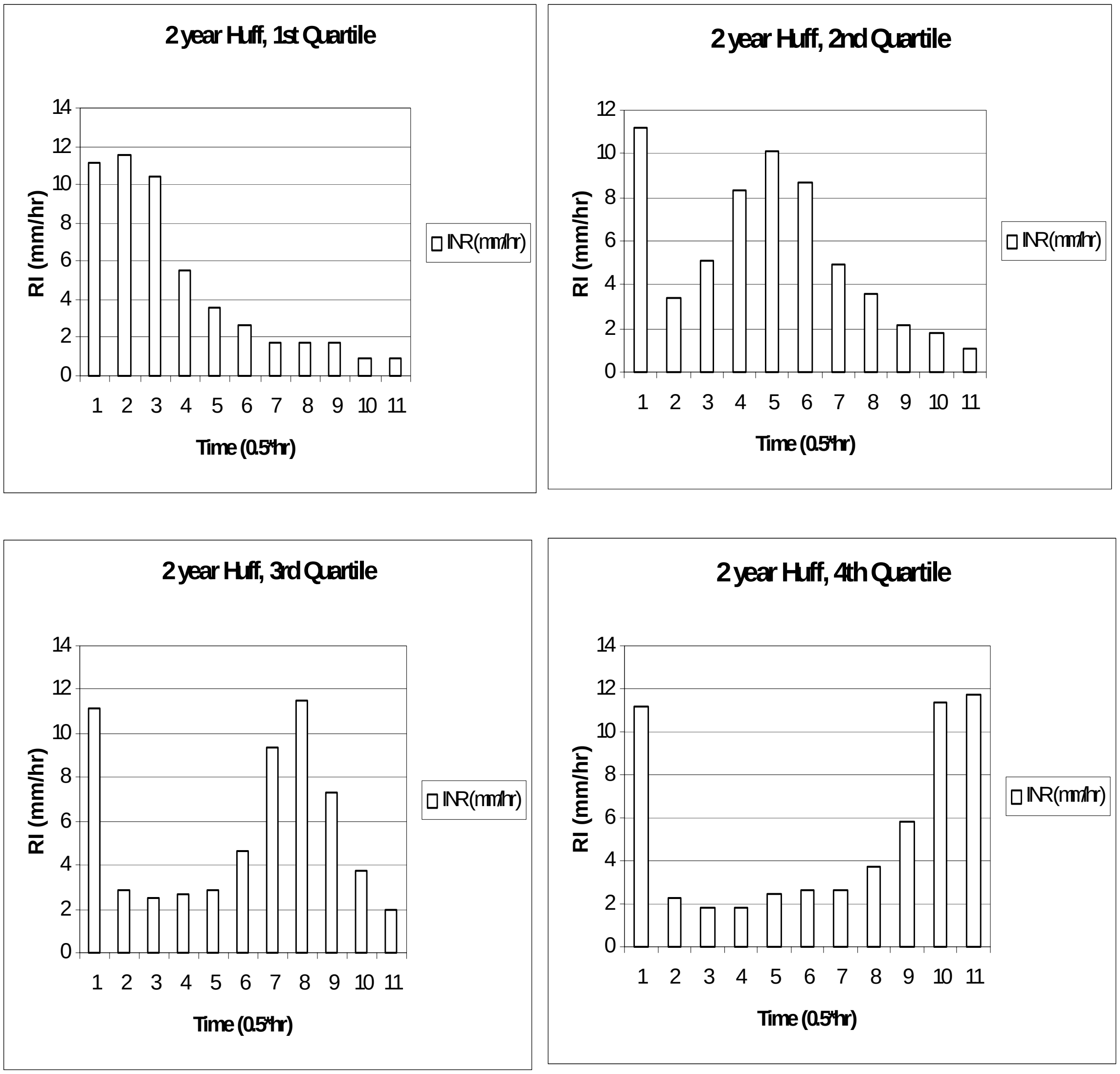
DESIGN STORM CALCULATIONS



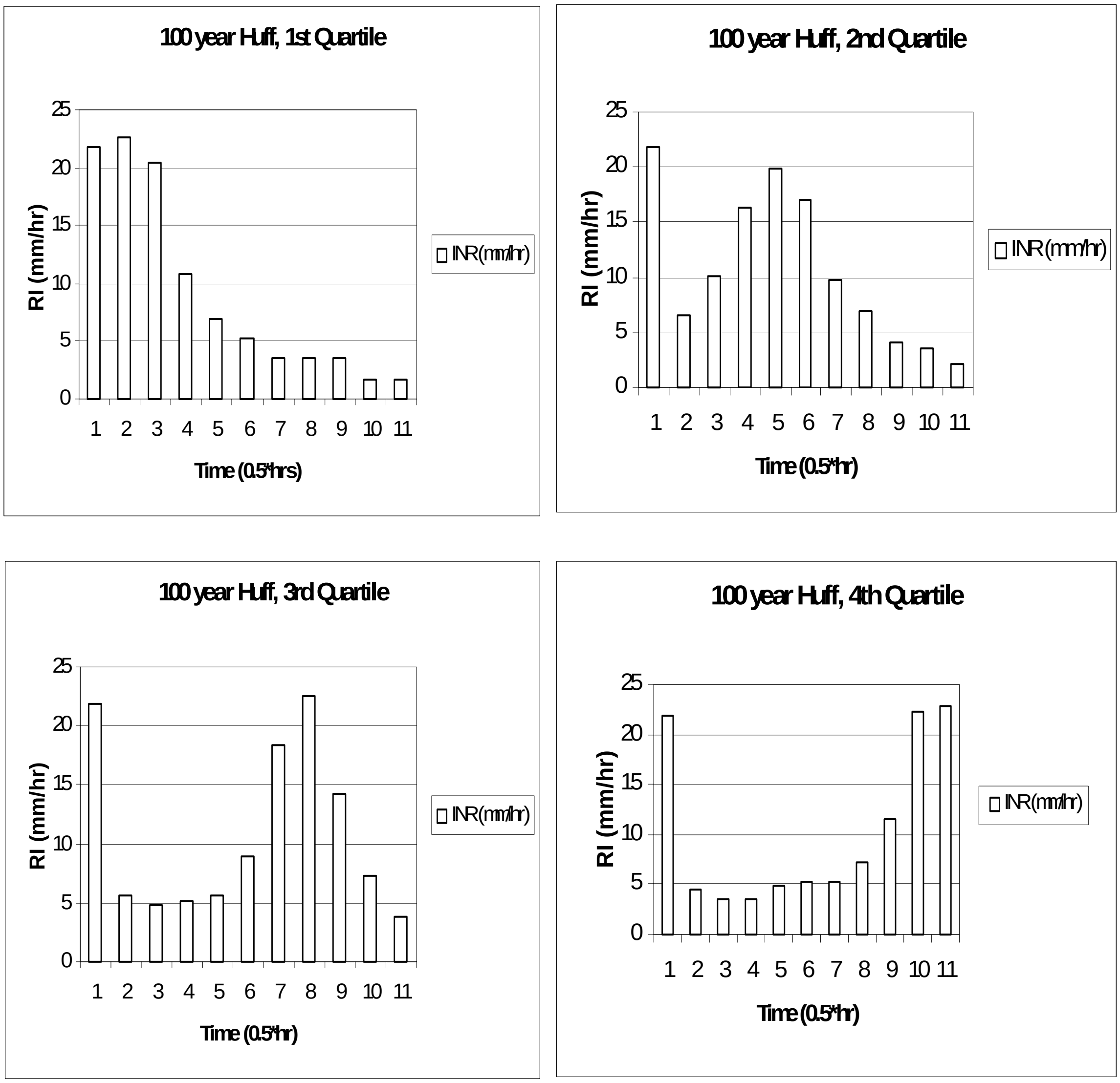
Graph B.1 100 year-6 hr Hyetograph



Graph B.2 2 year-6 hr Hyetograph



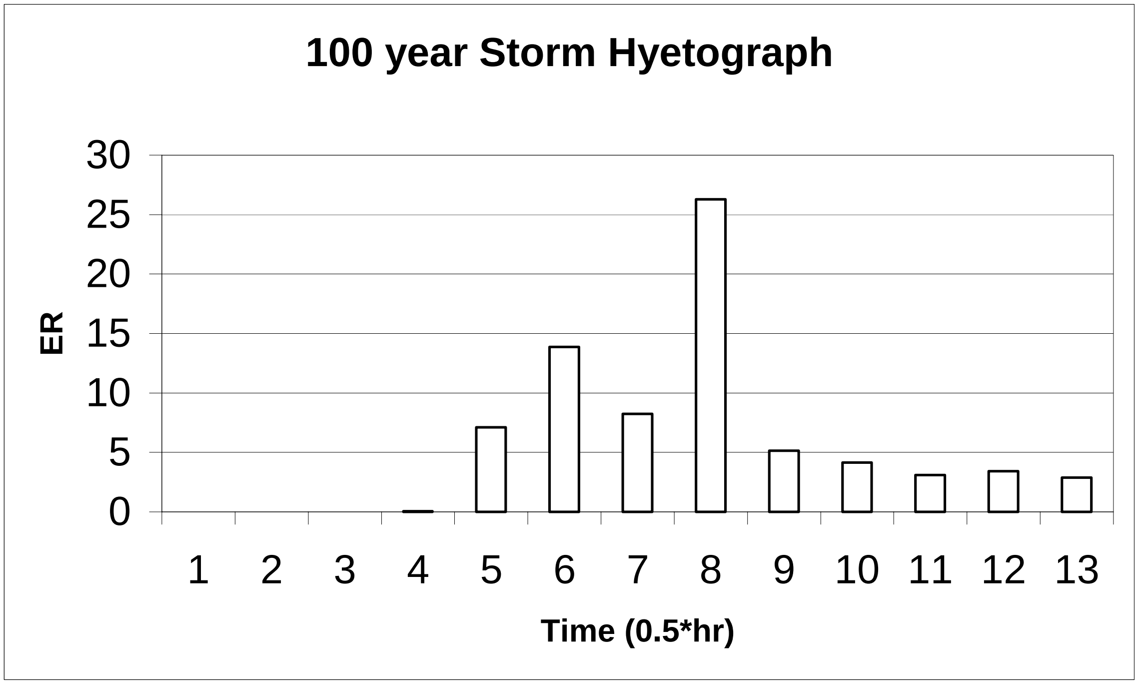
Graph B.3 2-year Huff



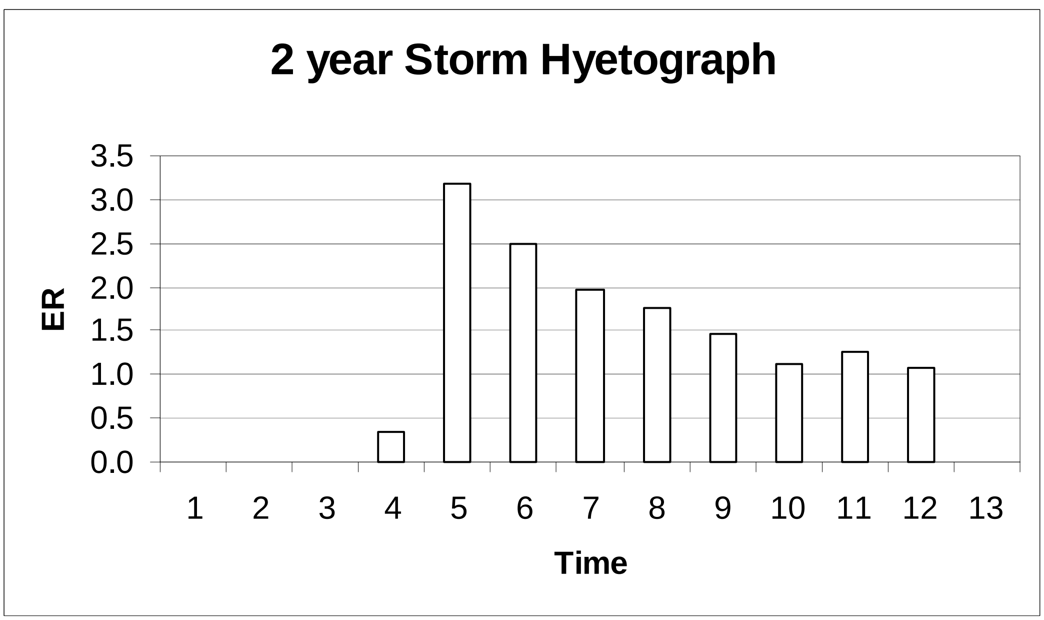
Graph B.4 100-year Huff

APPENDIX C

EXCESS RAIN DETERMINATION



Graph C.1 100 year storm hytegraph



Graph C.2 2- year Hyetograph

Table C.1 2-year Excess Rain Calculations

Hour t	Delta t	RI (mm/hr)	Cum. P	I	Ex. Rain.
0.00	0.00	0.00	1.773	12.7	0.00
0.50	0.50	3.55	2.4822	12.7	0.00
1.00	0.50	4.96	5.6736	12.7	0.00
1.50	0.50	6.38	17.59703	12.7	0.35
2.00	0.50	23.85	29.52045	12.7	3.17
2.50	0.50	23.85	35.46	12.7	2.48
3.00	0.50	11.88	39.5379	12.7	1.97
3.50	0.50	8.16	42.9066	12.7	1.76
4.00	0.50	6.74	45.5661	12.7	1.47
4.50	0.50	5.32	47.5164	12.7	1.12
5.00	0.50	3.90	49.644	12.7	1.26
5.50	0.50	4.26	51.417	12.7	1.08
6.00	0.50	3.55	51.417	12.7	0.00

Table C.2 100-year Excess Rain Calculations

Hour t	Delta t	RI (mm/hr)	Cum. P	I	Ex. Rain.
0	0.000	0.000	0	12.7	0
0.5	0.500	6.940	3.47	12.7	0
1	0.500	9.716	8.328	12.7	0
1.5	0.500	12.492	14.574	12.7	0.05372
2	0.500	46.672	37.90975	12.7	7.110448
2.5	0.500	46.672	61.2455	12.7	13.86894
3	0.500	23.249	72.87	12.7	8.241804
3.5	0.500	15.962	80.851	12.7	26.27933
4	0.500	13.186	87.444	12.7	5.132303
4.5	0.500	10.410	92.649	12.7	4.146662
5	0.500	7.634	96.466	12.7	3.088433
5.5	0.500	8.328	100.63	12.7	3.411089
6	0.500	6.940	104.1	12.7	2.873496

APPENDIX D

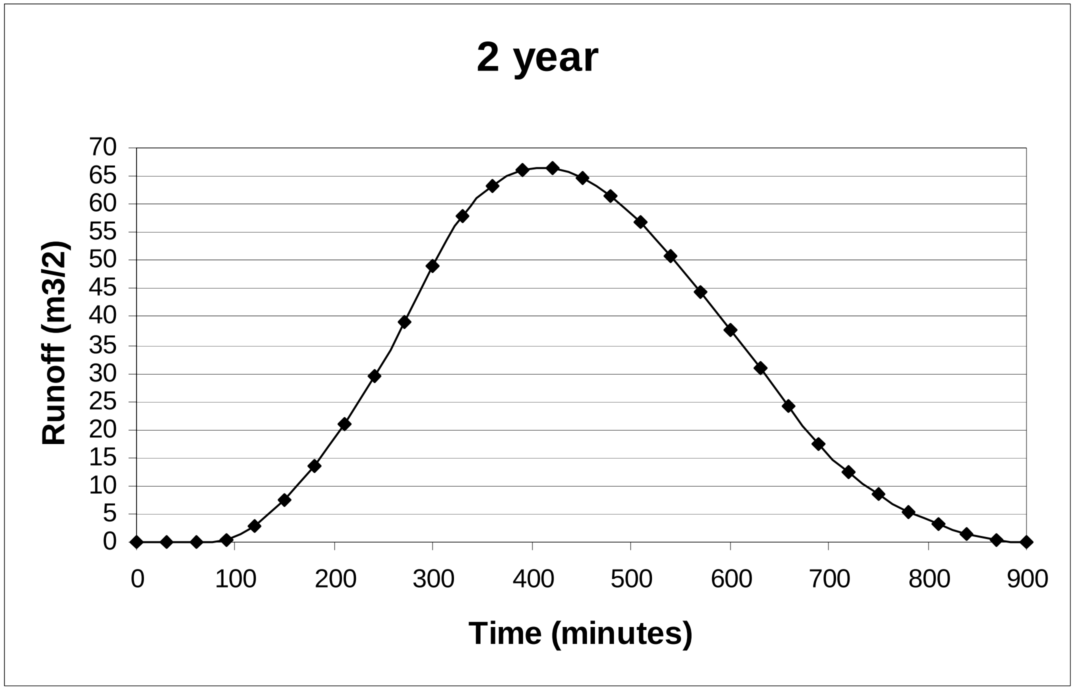
FLOOD FLOWS AT RAWSON AVENUE IN FRANKLIN

Table D.1 TR-55 100 year

				Convolution										
				Real Storm Time (min)										
				60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	
				Excess Rain (mm)										
				0.05	7.11	13.87	8.24	26.28	5.13	4.15	3.09	3.41	2.87	
Unit Hydrograph				**Partial Hydrograph (m3/s)**										
t/tp	**q (m3/sec-mm)**	**q/qp**	**Runoff Time (min) (I)**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**iX**	**X**	**XI**	**Total Runoff (m3/s) (XII)**
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
0.14	0.76	0.14	30.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
0.28	1.53	0.28	60.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
0.42	2.29	0.42	90.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
0.56	3.05	0.56	120.00	0.08	5.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6
0.70	3.81	0.70	150.00	0.12	10.85	10.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22
0.84	4.58	0.84	180.00	0.16	16.27	21.15	6.29	0.00	0.00	0.00	0.00	0.00	0.00	44
0.98	5.34	0.98	210.00	0.20	21.69	31.73	12.57	20.04	0.00	0.00	0.00	0.00	0.00	86
1.00	5.44	1.00	240.00	0.25	27.11	42.31	18.86	40.08	3.91	0.00	0.00	0.00	0.00	133
1.12	5.04	0.93	270.00	0.29	32.54	52.88	25.14	60.12	7.83	3.16	0.00	0.00	0.00	182
1.26	4.58	0.84	300.00	0.29	37.96	63.46	31.43	80.16	11.74	6.32	2.36	0.00	0.00	234
1.40	4.13	0.76	330.00	0.27	38.68	74.04	37.71	100.21	15.66	9.49	4.71	2.60	0.00	283
1.54	3.67	0.67	360.00	0.25	35.86	75.45	44.00	120.25	19.57	12.65	7.07	5.20	2.19	322
1.68	3.21	0.59	390.00	0.22	32.60	69.94	44.84	140.29	23.48	15.81	9.42	7.80	4.38	349
1.82	2.75	0.51	420.00	0.20	29.34	63.58	41.56	142.96	27.40	18.97	11.78	10.41	6.57	353
1.96	2.29	0.42	450.00	0.17	26.08	57.22	37.78	132.52	27.92	22.14	14.13	13.01	8.77	340
2.10	1.83	0.34	480.00	0.15	22.82	50.86	34.00	120.47	25.88	22.56	16.49	15.61	10.96	320
2.24	1.38	0.25	510.00	0.12	19.56	44.51	30.23	108.42	23.53	20.91	16.80	18.21	13.15	295
2.38	0.92	0.17	540.00	0.10	16.30	38.15	26.45	96.38	21.18	19.01	15.57	18.56	15.34	267
2.52	0.46	0.08	570.00	0.07	13.04	31.79	22.67	84.33	18.82	17.11	14.16	17.20	15.63	235
2.66	0.00	0.00	600.00	0.05	9.78	25.43	18.89	72.28	16.47	15.21	12.74	15.64	14.49	201
			630.00	0.02	0.00	19.07	15.11	60.24	14.12	13.31	11.33	14.07	13.17	160
			660.00	0.00	0.00	12.72	11.33	48.19	11.76	11.41	9.91	12.51	11.86	130
			690.00	0.00	0.00	6.36	7.56	36.14	9.41	9.50	8.49	10.95	10.54	99
			720.00	0.00	0.00	0.00	3.78	24.09	7.06	7.60	7.08	9.38	9.22	68
			750.00	0.00	0.00	0.00	0.00	12.05	4.71	5.70	5.66	7.82	7.90	44
			780.00	0.00	0.00	0.00	0.00	0.00	2.35	3.80	4.25	6.25	6.59	23
			810.00	0.00	0.00	0.00	0.00	0.00	0.00	1.90	2.83	4.69	5.27	15
			840.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.42	3.13	3.95	8
			870.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.56	2.63	4
			900.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.32	1
			930.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0

Table D.2 TR-55 2- year

					Convolution										
					Real Storm Time (min)										
					60-90	90-120	120-150	150-180	180-210	210-240	240-270	270-300	300-330	330-360	
					Excess Rain (mm)										
					0.35	3.17	2.48	1.97	1.76	1.47	1.12	1.26	1.08	0.00	
Unit Hydrograph					Partial Hydrograph (m3/s)										
Lag Time (min)	**t/tp**	**q (m3/sec-min)**	**q/qp**	**Runoff Time (min) (I)**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**iX**	**X**	**XI**	**Total Runoff (m3/s) (XII)**
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
30.00	0.14	0.76	0.14	30.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
60.00	0.28	1.53	0.28	60.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
90.00	0.42	2.29	0.42	90.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
120.00	0.56	3.05	0.56	120.00	0.53	2.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3
150.00	0.70	3.81	0.70	150.00	0.80	4.84	1.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8
180.00	0.84	4.58	0.84	180.00	1.07	7.26	3.79	3.00	0.00	0.00	0.00	0.00	0.00	0.00	15
210.00	0.98	5.34	0.98	210.00	1.34	9.68	5.68	4.50	2.69	0.00	0.00	0.00	0.00	0.00	24
214.00	1.00	5.44	1.00	240.00	1.60	12.09	7.57	6.00	4.04	2.25	0.00	0.00	0.00	0.00	34
240.00	1.12	4.95	0.91	270.00	1.87	14.51	9.47	7.50	5.38	3.37	0.85	0.00	0.00	0.00	43
270.00	1.26	4.58	0.84	300.00	1.91	16.93	11.36	9.00	6.73	4.49	1.71	0.96	0.00	0.00	53
300.00	1.40	3.75	0.69	330.00	1.73	17.25	13.25	10.50	8.07	5.61	2.56	1.92	0.82	0.00	62
330.00	1.54	3.09	0.57	360.00	1.61	15.70	13.51	10.70	9.42	6.74	3.42	2.88	1.64	0.00	66
360.00	1.68	2.21	0.41	390.00	1.32	14.54	12.29	9.74	9.60	7.86	4.27	3.84	2.46	0.00	66
390.00	1.82	1.56	0.29	420.00	1.08	11.90	11.38	9.02	8.73	8.01	5.13	4.80	3.28	0.00	63
420.00	1.96	0.93	0.17	450.00	0.78	9.80	9.32	7.39	8.09	7.28	5.98	5.76	4.11	0.00	58
450.00	2.10	0.53	0.10	480.00	0.55	7.02	7.67	6.08	6.62	6.75	6.09	6.72	4.93	0.00	52
480.00	2.24	0.24	0.04	510.00	0.33	4.96	5.50	4.36	5.45	5.52	5.54	6.85	5.75	0.00	44
510.00	2.38	0.09	0.02	540.00	0.18	2.96	3.88	3.07	3.91	4.55	5.14	6.23	5.86	0.00	36
540.00	2.52	0.02	0.00	570.00	0.08	1.67	2.32	1.84	2.76	3.26	4.20	5.77	5.33	0.00	27
570.00	2.66	0.00	0.00	600.00	0.03	0.75	1.31	1.04	1.65	2.30	3.46	4.72	4.94	0.00	20
				630.00	0.01	0.00	0.59	0.46	0.93	1.37	2.48	3.89	4.04	0.00	14
				660.00	0.00	0.00	0.22	0.00	0.00	0.78	1.75	2.79	3.33	0.00	9
				690.00	0.00	0.00	0.05	0.00	0.00	0.00	1.04	1.97	2.38	0.00	5
				720.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.17	1.68	0.00	3
				750.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1
				780.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
				810.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0



Graph D.2 2 year storm hydrograph