Delaware County Regional Water Quality Control Authority (DELCORA)
CSO Long Term Control Plan Update

Typical Hydrologic Period Report (Final)

November 2015
(Updated April 2016)

GREELEY AND HANSEN

REPORT SIGNATURE COVER SHEET

Signature of this cover signifies agreement with the content of the DELCORA Typical Hydrologic Period Report.

DELCORA MANAGEMENT		
Executive Director	*Signature*	11/5/15 *Date*
DELCORA ENGINEERING		
Director of Engineering	*Signature*	11/5/15 *Date*
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DELCORA OPERATIONS AND MAINTENANCE		
Director of Operation and Maintenance	*Signature*	11/5/15 *Date*
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	Signature	*Date*
	Signature	*Date*

REVISION CONTROL

REV. NO.	DATE ISSUED	PREPARED BY	DESCRIPTION OF CHANGES
1	4/26/16	Greeley and Hansen	• Pg. 1-3, Section 1-4: Deleted paragraph at end of section. • Pg. 2-7: Added Table 2-6 – Top 5 Ranked Hydrologic Periods (IET = 12 hr). Renumbered tables accordingly. • Page 2-10: Added new Section 2.6. • Page 2-10: Added Figures 2-4, 2-5 and 2-6 and renumbered figures accordingly.

Table of Contents

List of Tables

List of Figures

Table of Contents

Section 1 Introduction

1.1 DELCORA's Consent Decree

DELCORA prepared and submitted their original Combined Sewer Overflow (CSO) Long Term Control Plan (LTCP) to the PADEP in 1999. This LTCP was subsequently approved by the PADEP, and DELCORA had started to implement the CSO control elements selected in the LTCP. In 2009, the United States Environmental Protection Agency (USEPA) informed DELCORA that the original LTCP was not in compliance with the requirements of the USEPA's CSO Policy. As such, DELCORA prepared and submitted a revised LTCP in April 2012. Subsequent to the receipt of the revised LTCP, DELCORA and the USEPA had corresponded various times including requests for additional information from the USEPA in accordance with Section 308 of the Clean Water Act. A Consent Decree was issued by the USEPA to DELCORA in June 2015. The Consent Decree requires a new LTCP to be prepared based on an agreed upon schedule, which will include interim deliverables and milestones that must be met.

According to the Consent Decree between the US EPA, PADEP, and DELCORA, within ninety (90) days after August 17, 2015 (the lodging date), DELCORA shall submit to Plaintiffs a report or technical memorandum describing DELCORA's statistical evaluation of long-term local rainfall patterns and the identification of an appropriate typical period for LTCP development purposes.

The statistical evaluation in this study utilizes local long-term rainfall record from the Philadelphia International Airport. It considers various appropriate rain year characteristics, including distributions of event rainfall totals, event durations, and peak and average rainfall intensities.

1.2 Typical Year for CSO LTCP Development

Precipitation generates urban storm water, combined sewer overflows (CSOs), and increased wet weather flows to the wastewater treatment plant. These will contribute bacteria and pollutants to the Delaware River and its tributaries. The effect of these contributors on the Delaware River mainly depends on the magnitude and duration of rainfall events and on the prevailing ambient river conditions controlling dilution and transport of the pollutants. This variability and complexity poses a significant challenge for assessing the performance of wet weather and CSO control alternatives.

In accordance with the USEPA CSO Control Policy (CSO Policy), dated April 19, 1994, the CSO control alternatives should be assessed on a "system-wide, annual average basis". This is accomplished by continuous simulation using a typical hydrologic period for the combined sewer system (CSS) and receiving water quality modeling applications. The CSO Policy supports continuous simulation modeling, i.e., using long-term rainfall records rather than records for individual storms. Long-term continuous rainfall records enable simulations to be based on a sequence of storms so that the additive effect of storms occurring close together can be examined. They also enable storms with a range of characteristics to be included.

Typically, a 3- to 5-year period is evaluated to balance between manageable model simulation time and representation of various rainfall/river conditions. In this study, a 3-year period is deemed most appropriate considering the modeling complexity. The representative three-year period is intended to

contain a relatively wet year, a dry year and an average year. Average year conditions are defined as the arithmetic average of the predictions for the selected period.

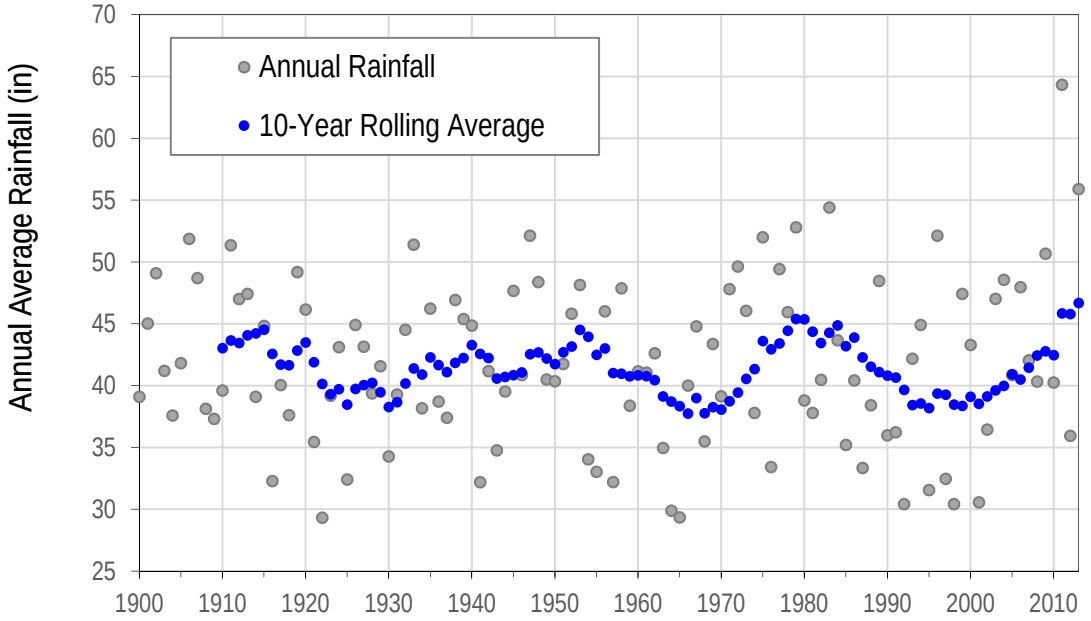
1.3 Climate Change Considerations

Average U.S. precipitation has increased since 1900, but there are regional differences, with some areas having larger increases, and others, decreases. Local climate change should be considered when selecting appropriate data records for the typical period analysis.

Rainfall data from the Philadelphia International Airport were obtained from the National Oceanic and Atmospheric Administration (NOAA). Hourly rainfall data is available from 1900 through 2013. This provides sufficient data to evaluate climate change in the area. **Figure 1-1** shows annual rainfall from 1900 to 2013. A 10-year rolling average trend line is also shown in the figure for characterizing long-term precipitation pattern. In the past 114 years, annual rainfall ranges from 29.3 to 64.33 inches, with the wettest year in 2011. The 10-year rolling average rainfall indicates that precipitation in the area runs through various dry and wet cycles, however with more extreme conditions (dry and wet) in recent years.

Considering the climate change, it is determined that the typical period for the LTCPU be selected based on statistical analysis of rainfall records in recent 30 years (i.e., 1984-2013).

Figure 1-1 Historical Annual Rainfall at Philadelphia International Airport



1.4 Methodology of Typical Year Selection

The typical hydrologic period is selected to provide representative and unbiased approximations of expected future conditions in terms of both averages and historical variability. Representativeness is

assessed using objective criteria for each of the ambient factors (i.e., river flow and rainfall). As indicated in the previous section, the selection of the typical hydrologic period is based on the historical records in the past 30 years from 1984 through 2013.

The following datasets are used for the analysis of the typical hydrologic period:

- Hourly precipitation data for the National Climate Data Center gauge at Philadelphia International Airport for 1984 - 2013.
- Daily Delaware River stream flow data from the U.S. Geological Survey gauge at Trenton, NJ (USGS 01463500) for 1984 - 2013. This is the closest USGS gauge that with daily river flow available.

Key criteria parameters used in the evaluation are listed in **Table 1-1**. Each parameter is given a weighting factor to describe the individual importance on the averageness of the analyzed time period. The parameters that are given the highest impact weighting include the following:

- The total annual rainfall depth, which drives the total runoff volume.
- The maximum peak intensity, which usually defines the biggest overflow event.
- The median Delaware River flow; the impact of sewer overflows on the water quality of the receiving water is dependent on the magnitude of the flows in river, and in the project area, intense local rainfall events are typically independent from watershed wide high flow events.

Table 1-1 Hydrologic Period Ranking Parameters

Key Parameter	Weighting Factor	Comments
Annual rainfall depth	25.0%	Important for evaluating annual overflow volume
Number of events > 0.1” rainfall depth	2.5%	Typically storms over 0.1” would start to cause surface runoff
Number of events > 0.25” rainfall depth	2.5%	Previous model indicates system overflows at storms over 0.25”
Number of events > 1.5” rainfall depth	7.5%	Storms to be controlled to meet potential presumption approach
Number of back-to-back events	5.0%	Important for evaluating the antecedent conditions
Maximum peak intensity	20.0%	Storms with high intensity causes overflows
Average rainfall duration	2.5%	Important for evaluating wet weather durations
Average rainfall intensity	5.0%	Important for evaluating overall rainfall intensity
Delaware River flow - 25th percentile	2.5%	Important for evaluating dilution power of the Delaware River flow for water quality
Delaware River flow - 50th percentile	25.0%	
Delaware River flow - 75th percentile	2.5%	

Section 2 Typical Year Selection for DELCORA

2.1 Annual Rainfall and River Flow Statistics

30-year hourly precipitation data (1984 - 2013) from the Philadelphia International Airport was analyzed to evaluate all individual rainfall events in the period. An inter-event time (IET) of 6 hours (i.e. minimum dry time of 6 hours between rainfall events was used to differentiate between individual events. Precipitation periods with a total rainfall volume of greater than 0.1 inch were counted as rainfall events. If the next rainfall event's starting time is within one day of the previous rainfall event's ending time, these two rainfall events are considered as back-to-back rainfall events. All rainfall events for the data period were analyzed for duration, inter-event duration, total rainfall amount, as well as maximum and average rainfall intensities.

A total of 1,934 rainfall events were counted for the period of 1984 - 2013. **Table 2-1** summarizes rainfall events on an annual basis for rainfall volume, max rainfall intensity, average intensity, average rainfall duration, quantities of rainfall events above 0.1 inch and 0.25 inch, and back-to-back rainfall event number. Statistical river flow information is also included in **Table 2-1**.

Table 2-1 Annual Rainfall and River Flow Statistics 1984-2013

Year	Rainfall								Delaware River Flow (cfs)		
	Annual Rainfall (in)	Max Rainfall Intensity (in/hr)	Average Rainfall Intensity (in/hr)	Average Rainfall Duration (hr)	Events ≥0.10 in.	Events ≥0.25 in.	Events ≥1.5 in.	Back-to-Back Event	25th Percentile	50th Percentile	75th Percentile
1984	43.7	1.14	0.096	9.6	70	50	5	14	4,675	8,615	15,675
1985	35.2	1.10	0.091	9.7	56	40	3	8	4,470	6,340	9,000
1986	40.4	1.06	0.079	11.0	62	44	5	12	5,190	9,190	16,500
1987	33.3	0.66	0.073	11.3	56	40	1	7	5,660	9,000	12,500
1988	38.4	1.69	0.083	10.3	57	37	7	9	4,473	6,605	10,775
1989	48.5	1.50	0.076	11.0	69	51	8	14	5,210	7,610	13,400
1990	36.0	0.48	0.070	10.2	64	44	1	8	7,110	10,800	17,600
1991	36.2	1.26	0.082	11.2	55	40	5	7	3,240	5,720	12,400
1992	30.4	1.31	0.057	11.0	64	31	2	9	5,460	7,610	10,900
1993	42.2	1.11	0.098	9.8	61	43	8	6	4,070	7,210	13,600
1994	44.9	1.50	0.088	11.0	67	50	4	8	5,680	8,460	15,000
1995	31.6	1.00	0.070	9.5	53	34	3	1	4,260	6,670	10,700
1996	52.1	1.03	0.087	9.7	75	57	8	12	6,893	14,000	24,625
1997	32.5	0.84	0.078	10.2	65	46	1	11	3,860	6,870	13,000
1998	30.4	0.54	0.065	11.2	58	39	2	12	3,070	8,550	19,100
1999	47.4	0.95	0.077	11.7	60	47	6	10	3,500	7,650	11,400
2000	43.3	2.43	0.111	10.3	61	48	5	6	5,243	8,510	16,575
2001	30.6	1.03	0.072	11.0	50	36	5	4	3,370	5,400	9,770
2002	36.4	0.69	0.082	12.5	53	39	4	4	3,630	7,610	13,600

Year	Rainfall								Delaware River Flow (cfs)		
	Annual Rainfall (in)	Max Rainfall Intensity (in/hr)	Average Rainfall Intensity (in/hr)	Average Rainfall Duration (hr)	Events ≥0.10 in.	Events ≥0.25 in.	Events ≥1.5 in.	Back-to-Back Event	25th Percentile	50th Percentile	75th Percentile
2003	47.0	0.62	0.068	10.9	78	52	7	17	10,300	15,600	26,400
2004	48.6	1.17	0.077	10.8	67	48	6	8	8,158	12,500	18,125
2005	40.9	1.55	0.084	11.1	58	45	5	8	4,690	11,200	17,000
2006	48.0	1.23	0.089	10.2	64	52	8	13	8,180	12,200	19,000
2007	42.1	1.09	0.091	10.5	60	38	4	9	5,220	7,950	16,600
2008	40.3	1.29	0.083	11.1	59	38	7	6	4,910	9,825	20,200
2009	50.7	1.42	0.100	11.5	76	51	10	18	8,700	11,100	16,400
2010	40.3	1.24	0.094	12.4	52	39	5	8	4,680	9,610	14,100
2011	64.3	1.31	0.109	10.5	68	49	11	11	10,400	18,100	28,600
2012	35.9	1.46	0.098	7.9	62	44	4	10	5,255	8,235	12,700
2013	55.9	2.86	0.118	10.2	64	50	9	10	5,750	8,900	12,000
Average 1984-2013	**41.6**	**1.22**	**0.085**	**10.6**	**62**	**44**	**5.3**	**9.3**	**5,510**	**9,255**	**15,575**

2.2 Three-year Rainfall and River Flow Analysis

Three-year rainfall and river flow characteristics were developed based on an annual average of the three consecutive years. **Table 2-2** summarizes rainfall and river flow statistics in the 28 individual three-year periods.

Table 2-2 Three-year Rainfall and River Flow Statistics 1984-2013

Year	Rainfall								Delaware River Flow (cfs)		
	Annual Rainfall (in)	Max Rainfall Intensity (in/hr)	Average Rainfall Intensity (in/hr)	Average Rainfall Duration (hr)	Events ≥0.10 in.	Events ≥0.25 in.	Events ≥1.5 in.	Back-to-Back Event	25th Percentile	50th Percentile	75th Percentile
1984-1986	39.8	1.14	0.089	10.1	63	45	4	11	4,778	8,048	13,725
1985-1987	36.3	1.10	0.081	10.7	58	41	3	9	5,107	8,177	12,667
1986-1988	37.4	1.69	0.078	10.9	58	40	4	9	5,108	8,265	13,258
1987-1989	40.1	1.69	0.077	10.9	61	43	5	10	5,114	7,738	12,225
1988-1990	41.0	1.69	0.076	10.5	63	44	5	10	5,598	8,338	13,925
1989-1991	40.2	1.50	0.075	10.8	63	45	5	10	5,187	8,043	14,467
1990-1992	34.2	1.31	0.069	10.8	61	38	3	8	5,270	8,043	13,633
1991-1993	36.3	1.31	0.079	10.7	60	38	5	7	4,257	6,847	12,300
1992-1994	39.2	1.50	0.081	10.6	64	41	5	8	5,070	7,760	13,167
1993-1995	39.5	1.50	0.086	10.2	60	42	5	5	4,670	7,447	13,100
1994-1996	42.9	1.50	0.083	10.1	65	47	5	7	5,611	9,710	16,775
1995-1997	38.7	1.03	0.079	9.8	64	46	4	8	5,004	9,180	16,108
1996-1998	38.3	1.03	0.078	10.3	66	47	4	12	4,608	9,807	18,908

Year	Rainfall								Delaware River Flow (cfs)		
	Annual Rainfall (in)	Max Rainfall Intensity (in/hr)	Average Rainfall Intensity (in/hr)	Average Rainfall Duration (hr)	Events ≥0.10 in.	Events ≥0.25 in.	Events ≥1.5 in.	Back-to-Back Event	25th Percentile	50th Percentile	75th Percentile
1997-1999	36.8	0.95	0.074	11.0	61	44	3	11	3,477	7,690	14,500
1998-2000	40.4	2.43	0.085	11.1	60	45	4	9	3,938	8,237	15,692
1999-2001	40.4	2.43	0.087	11.0	57	44	5	7	4,038	7,187	12,582
2000-2002	36.8	2.43	0.090	11.2	55	41	5	5	4,081	7,173	13,315
2001-2003	38.0	1.03	0.073	11.4	60	42	5	8	5,767	9,537	16,590
2002-2004	44.0	1.17	0.075	11.3	66	46	6	10	7,363	11,903	19,375
2003-2005	45.5	1.55	0.075	10.9	68	48	6	11	7,716	13,100	20,508
2004-2006	45.8	1.55	0.083	10.7	63	48	6	10	7,009	11,967	18,042
2005-2007	43.6	1.55	0.088	10.6	61	45	6	10	6,030	10,450	17,533
2006-2008	43.4	1.29	0.088	10.6	61	43	6	9	6,103	9,992	18,600
2007-2009	44.3	1.42	0.092	11.1	65	42	7	11	6,277	9,625	17,733
2008-2010	43.7	1.42	0.093	11.6	62	43	7	11	6,097	10,178	16,900
2009-2011	51.7	1.42	0.102	11.4	65	46	9	12	7,927	12,937	19,700
2010-2012	46.8	1.46	0.101	10.2	61	44	7	10	6,778	11,982	18,467
2011-2013	52.1	2.86	0.109	9.6	65	48	8	10	7,135	11,745	17,767
Average 1984-2013	41.3	1.18	0.084	10.7	62	44	5	9	5,540	9,325	15,770

2.3 Ranking Analysis

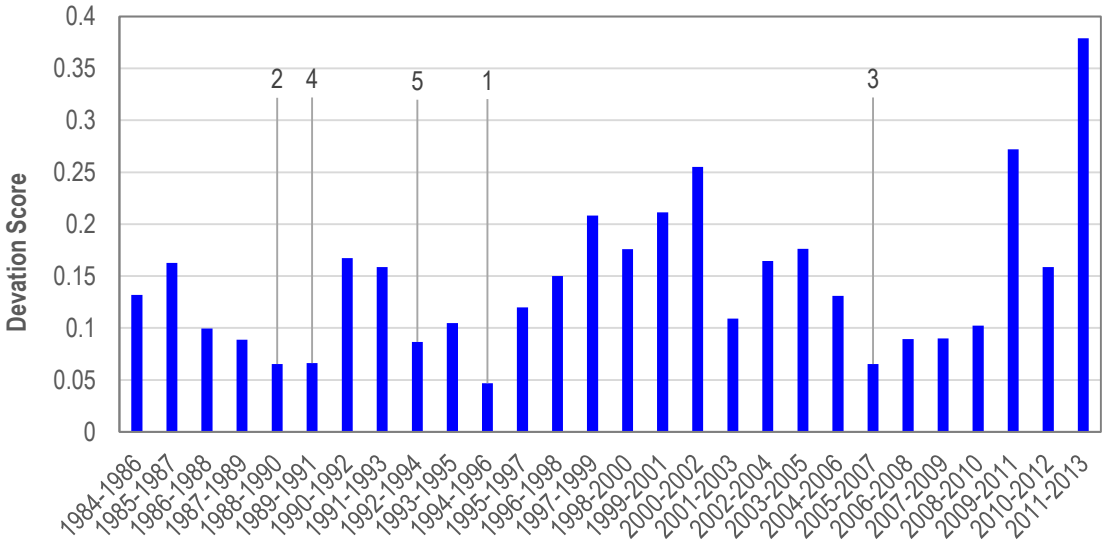
From **Table 2-2** the relative deviation for each parameter was calculated for individual 3-year period. With the weighting factors listed in **Table 1-1**, a deviation score was developed for each individual period. The 3-year periods were then ranked based on the deviation score. The lower the deviation score (**Figure 2-1** Y-axis), the higher the rank for the hydrologic period (i.e., the closer it is to the average condition). **Table 2-3** and **Figure 2-1** shows the ranking results of the 28 hydrologic periods, with a ranking of 1 being the highest and a ranking of 28 being the lowest ranked hydrologic period. Hydrologic period 1994-1996 is ranked No.1 because it has the lowest deviation score of 0.047.

Table 2-3 Typical Period Ranking Analysis

Year	Rainfall								Delaware River Flow			Deviation Score	Rank
	Annual Rainfall	Max Rainfall Intensity	Average Rainfall Intensity	Average Rainfall Duration	Events ≥0.10 in	Events ≥0.25 in	Events ≥1.5 in.	Back-to-Back Event	25th Pct	50th Pct	75th Pct		
Wt. Factor	25%	20%	5%	2.5%	2.5%	2.5%	7.5%	5%	2.5%	25%	2.5%		
1984-1986	4%	26%	6%	6%	1%	2%	18%	23%	14%	14%	13%	0.132	15
1985-1987	12%	28%	3%	0%	6%	6%	43%	2%	8%	12%	20%	0.163	19
1986-1988	10%	10%	7%	1%	6%	8%	18%	1%	8%	11%	16%	0.100	9

Year	Rainfall								Delaware River Flow			Deviation Score	Rank
	Annual Rainfall	Max Rainfall Intensity	Average Rainfall Intensity	Average Rainfall Duration	Events ≥0.10 in	Events ≥0.25 in	Events ≥1.5 in.	Back-to-Back Event	25th Pct	50th Pct	75th Pct		
Wt. Factor	25%	20%	5%	2.5%	2.5%	2.5%	7.5%	5%	2.5%	25%	2.5%		
1987-1989	3%	10%	8%	1%	2%	3%	1%	9%	8%	17%	22%	0.089	6
1988-1990	1%	10%	9%	2%	2%	0%	1%	12%	1%	11%	12%	0.065	2
1989-1991	3%	2%	10%	1%	1%	3%	11%	5%	6%	14%	8%	0.066	4
1990-1992	17%	15%	18%	1%	2%	13%	49%	13%	5%	14%	14%	0.167	21
1991-1993	12%	15%	6%	1%	3%	13%	5%	20%	23%	27%	22%	0.159	18
1992-1994	5%	2%	3%	1%	3%	6%	11%	17%	8%	17%	17%	0.087	5
1993-1995	4%	2%	3%	5%	3%	3%	5%	46%	16%	20%	17%	0.105	11
1994-1996	4%	2%	1%	6%	5%	7%	5%	24%	1%	4%	6%	0.047	1
1995-1997	6%	33%	5%	8%	4%	4%	24%	13%	10%	2%	2%	0.120	13
1996-1998	7%	33%	7%	4%	6%	8%	30%	27%	17%	5%	20%	0.150	16
1997-1999	11%	38%	12%	3%	2%	0%	43%	19%	37%	18%	8%	0.208	24
1998-2000	2%	58%	1%	3%	4%	2%	18%	1%	29%	12%	0%	0.176	22
1999-2001	2%	58%	4%	3%	8%	0%	1%	28%	27%	23%	20%	0.211	25
2000-2002	11%	58%	7%	5%	12%	6%	11%	49%	26%	23%	16%	0.255	26
2001-2003	8%	33%	13%	6%	3%	3%	1%	10%	4%	2%	5%	0.109	12
2002-2004	6%	24%	11%	5%	6%	6%	8%	5%	33%	28%	23%	0.165	20
2003-2005	10%	1%	10%	2%	9%	10%	14%	19%	39%	40%	30%	0.176	23
2004-2006	11%	1%	0%	0%	2%	10%	20%	5%	27%	28%	14%	0.131	14
2005-2007	6%	1%	5%	1%	2%	3%	8%	9%	9%	12%	11%	0.065	3
2006-2008	5%	16%	5%	1%	2%	3%	20%	1%	10%	7%	18%	0.089	7
2007-2009	7%	7%	10%	3%	5%	3%	33%	19%	13%	3%	12%	0.090	8
2008-2010	6%	7%	11%	8%	1%	3%	39%	16%	10%	9%	7%	0.102	10
2009-2011	25%	7%	21%	6%	5%	6%	65%	34%	43%	39%	25%	0.272	27
2010-2012	13%	5%	21%	5%	2%	0%	27%	5%	22%	28%	17%	0.159	17
2011-2013	26%	86%	30%	11%	4%	9%	52%	12%	29%	26%	13%	0.379	28

Figure 2-1 Ranking Score of 3-year Period, 1984-2013



2.4 Top 5 Ranked 3-year Hydrologic Periods

Based on the ranking analysis, the top 5 ranked hydrologic periods are:

- Rank 1: 1994-1996
- Rank 2: 1988-1990
- Rank 3: 2005-2007
- Rank 4: 1989-1991
- Rank 5: 1992-1994

Table 2-4 shows rainfall and river flow statistics for these top ranked hydrologic periods.

Table 2-4 Top 5 Ranked Hydrologic Periods

Rank	Year	Rainfall								Delaware River Flow (cfs)		
		Annual Rainfall (in)	Max Rainfall Intensity (in/hr)	Average Rainfall Intensity (in/hr)	Average Rainfall Duration (hr)	Events ≥0.10 in.	Events ≥0.25 in.	Events ≥1.5 in.	Back-to-Back Event	25th Percentile	50th Percentile	75th Percentile
1	1994-1996	42.9	1.50	0.08	10.1	65	47	5	7	5,611	9,710	16,775
2	1988-1990	41.0	1.69	0.08	10.5	63	44	5	10	5,598	8,338	13,925
3	2005-2007	43.6	1.55	0.09	10.6	61	45	6	10	6,030	10,450	17,533
4	1989-1991	40.2	1.50	0.08	10.8	63	45	5	10	5,187	8,043	14,467
5	1992-1994	39.2	1.50	0.08	10.6	64	41	5	8	5,070	7,760	13,167
Average 1984-2013		41.3	1.53	0.08	10.7	62	44	5	9	5,540	9,325	15,770

Figure 2-2(a) shows the max rainfall day for each month from 1988 through 2013. Max rainfall day in the month is determined by analyzing the daily rainfall amount and the day with the maximum rainfall amount is selected as the max rainfall day for the month. Max rainfall day in the month is probably the precipitation day that causes the maximum wet weather inflow to the collection system and CSO overflows in the month. **Figure 2-2(b)** shows the river flow and flow statistics for the max rainfall day in the month. The selected typical hydrologic period must ensure that large storm events do not occur under the extremely low river flow conditions. **Figure 2-2** indicates that all the top 5 ranked hydrologic periods meet this criteria.

Rainfall return frequency during 1988 through 2013 was analyzed to understand the distribution of the large rainfall events with return frequencies above 1-year. Rainfall return frequency is shown for each month in **Figure 2-2** (the number in the parentheses indicates the quantity of rain events at the return frequency). **Table 2-5** summarizes quantity of large rainfall events with return frequencies for the top 5 ranked hydrologic periods.

- All of the top 5 hydrologic periods have a 25-yr storm.
- Hydrologic period 1994-1996 (Rank 1) contains one 25-yr storm, one 10-yr storm and three 1-year storm. Hydrologic period 1988-1990 (Rank 2) contains one 25-yr storm, one 10-yr storm, three 2-year storm and one 1-year storm.
- Hydrologic period 1994-1996 (Rank 1) is more conservative because its annual average rainfall amount of 42.9" is slightly greater than the 30-yr average. It is considered a better option than hydrologic period 1988-1990 (Rank 2), which has a slightly less annual rainfall than the average.

Table 2-5 Rainfall Return Frequency Summary for the Top 5 Ranked Hydrologic Periods

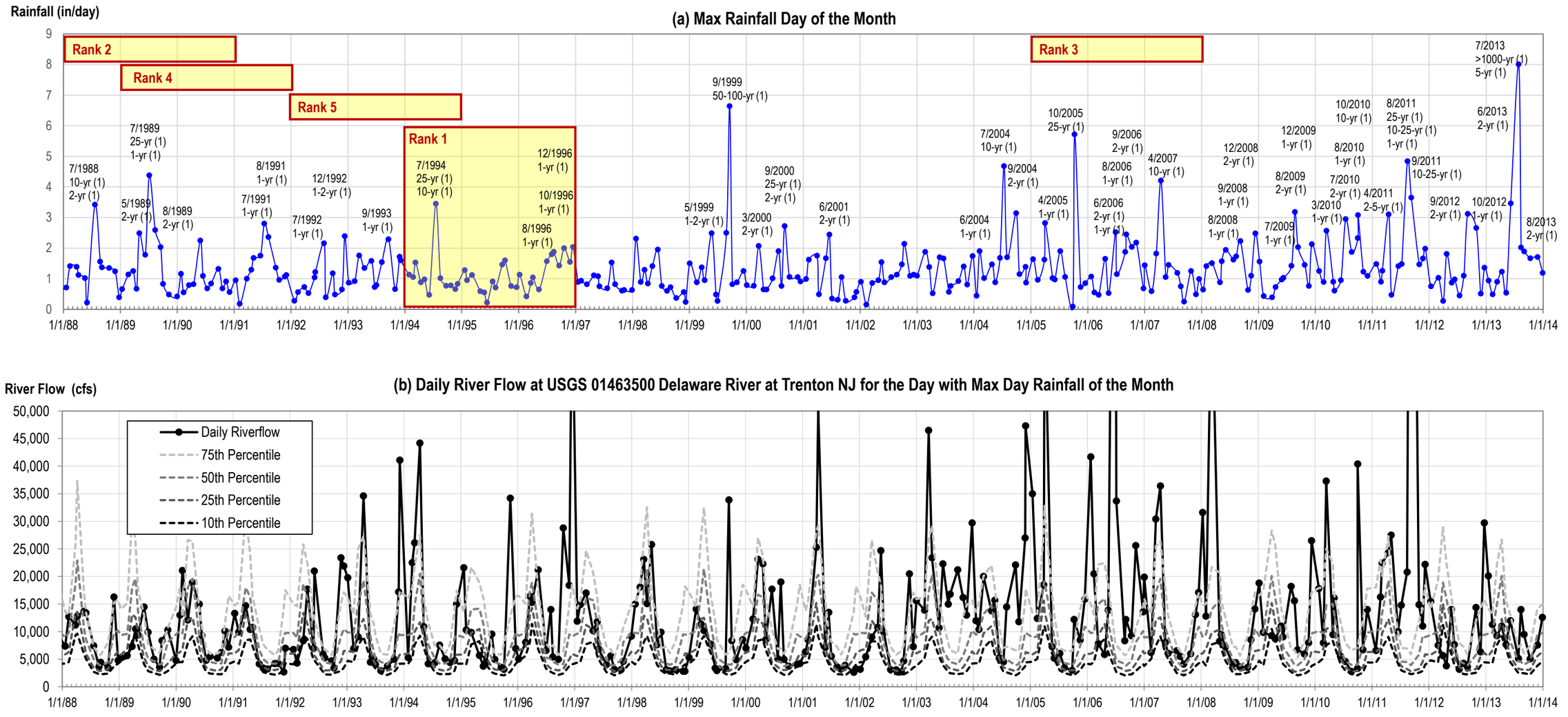
Rank	Year	Quantity of Rainfall Events with Return Frequency above				
		25-yr	10-yr	5-yr	2-yr	1-yr
1	1994-1996	1	1			3
2	1988-1990	1	1		3	1
3	2005-2007	1	1		2	4
4	1989-1991	1			2	3
5	1992-1994	1	1			3

The analysis was also conducted with an IET of 12 hours, and the top five ranked hydrologic periods were shown in **Table 2-6**. The top four hydrologic periods based on the IET of 12 hours are the same as the analysis based on the IET of 6 hours, which include the 3-year period 1994 - 1996 remaining as Rank 1.

Table 2-6 Top 5 Ranked Hydrologic Periods (IET = 12 hr)

Rank	Year	Rainfall								Delaware River Flow (cfs)		
		Annual Rainfall (in)	Max Rainfall Intensity (in/hr)	Average Rainfall Intensity (in/hr)	Average Rainfall Duration (hr)	Events ≥0.10 in.	Events ≥0.25 in.	Events ≥1.5 in.	Back-to-Back Event	25th Percentile	50th Percentile	75th Percentile
1	1994-1996	42.9	1.50	0.08	12.5	62	47	6	4	5,611	9,710	16,775
2	1988-1990	41.0	1.69	0.07	13.9	59	43	6	5	5,598	8,338	13,925
3	2005-2007	43.6	1.55	0.08	14.3	55	43	6	5	6,030	10,450	17,533
4	1989-1991	40.2	1.50	0.06	14.9	57	43	5	4	5,187	8,043	14,467
5	2007-2009	44.3	1.42	0.08	14.6	60	42	8	6	6,277	9,625	17,733
Average 1984-2013		**41.3**	**1.53**	**0.07**	**14.1**	**58**	**43**	**6**	**5**	**5,540**	**9,325**	**15,770**

Figure 2-2 Max Day Rainfall in the Month and Delaware River Daily Flows 1988-2013



2.5 Recommendation

It is recommended the 3-year period 1994-1996 (Rank 1) be selected as the typical hydrologic period for the CSO LTCPU. This period contains a wide range of storms and antecedent conditions. The hydrologic period of 1994-1996 is also evaluated for longer historical rainfall records up to 100 years. It is ranked No. 1 for the 50-years record and No.2 for the 100-year records (**Table 2-7**).

Table 2-7 Rank of Hydrologic Period 1994-1996 from Various Rainfall Data Set

	30-year Rainfall Records, 1984-2013	50-year Rainfall Records, 1964-2013	100-year Rainfall Records, 1914-2013
Rank of 1994-1996	1	1	2 (1925-1927 as Rank 1)

2.6 Additional Information on Statistical Analysis of Rainfall and River Flow Data

Figure 2-3 shows annual rainfall and average annual rainfall for years 1983-2013. The hydrologic period 1994-1996 contains a relatively wet year (1996 with 52.1 inches), a dry year (1995 with 31.6 inches) and a year close to average conditions (1994 with 44.9 inches).

Figure 2-4 shows annual average Delaware River flow and average flow for years 1983-2013. The hydrologic period 1994-1996 contains a relatively high flow year (1996 with 19,000 cfs), a low flow year (1995 with 9,000 cfs) and a year close to average conditions (1994 with 13,500 cfs).

Figure 2-3 Annual Rainfall 1983 - 2013

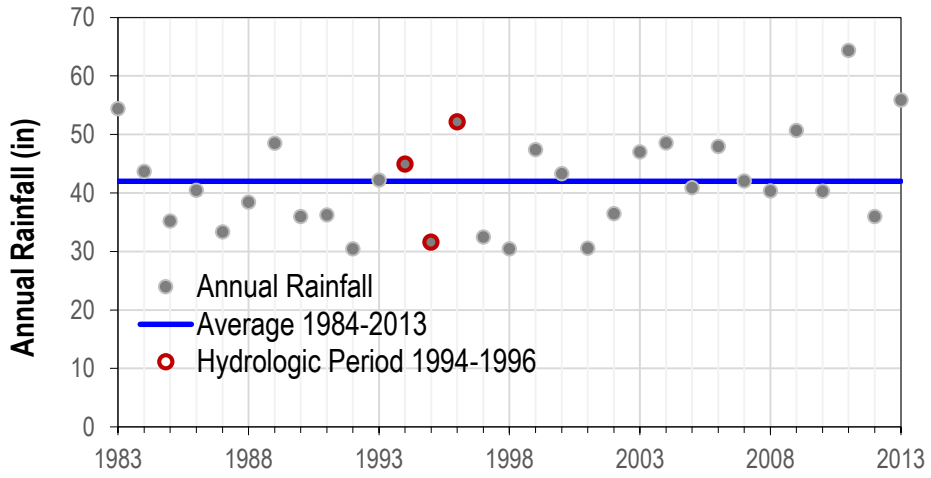
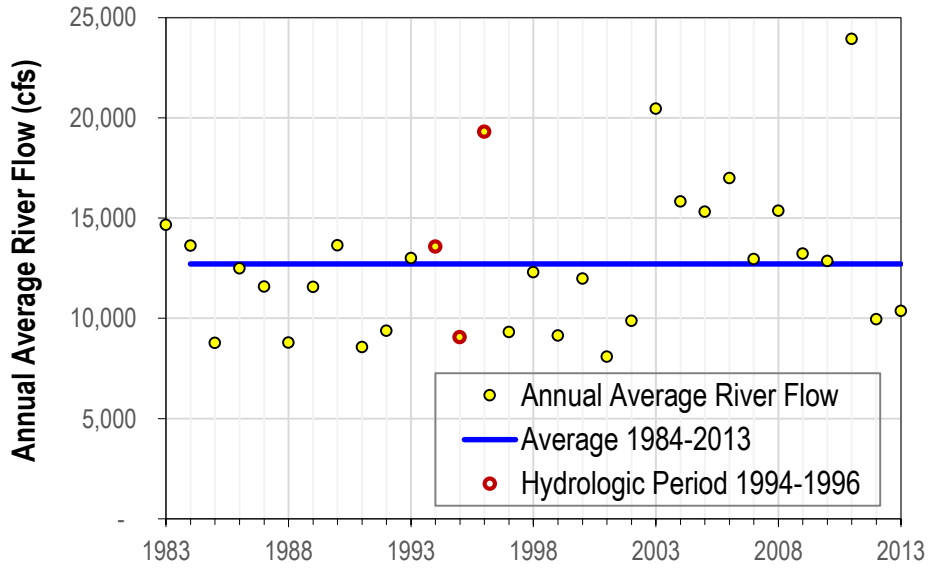


Figure 2-4 Annual Average Delaware River Flow 1983 - 2013



Delaware River flow distribution was developed for each calendar day using 100 years of records from 1913 to 2013, as shown in **Figure 2-5**. The River flow varies through the year with high flow season around March-April, and low flow season around June-August. **Figure 2-6** shows the Delaware River flow distribution during rainfall events at and above 1-year return frequency. Each dot on the plot represents an individual day during the storm events. It is observed that the river flows have a wide range of distribution during rainfall events below 2-yr return frequency. During larger storm events (greater than 5-year storms), the river flows tend to be relatively higher, as indicated by more dots with higher distribution percentiles on the plot. For example, during most of the 10-year storm events, the river flows are above the 35th percentile. In rare cases, large storm events occurred during a relatively low flow condition (e.g., the lowest dot for the 10-year storm), which is not a typical condition.

Figure 2-5 Delaware River Daily Flow Distribution

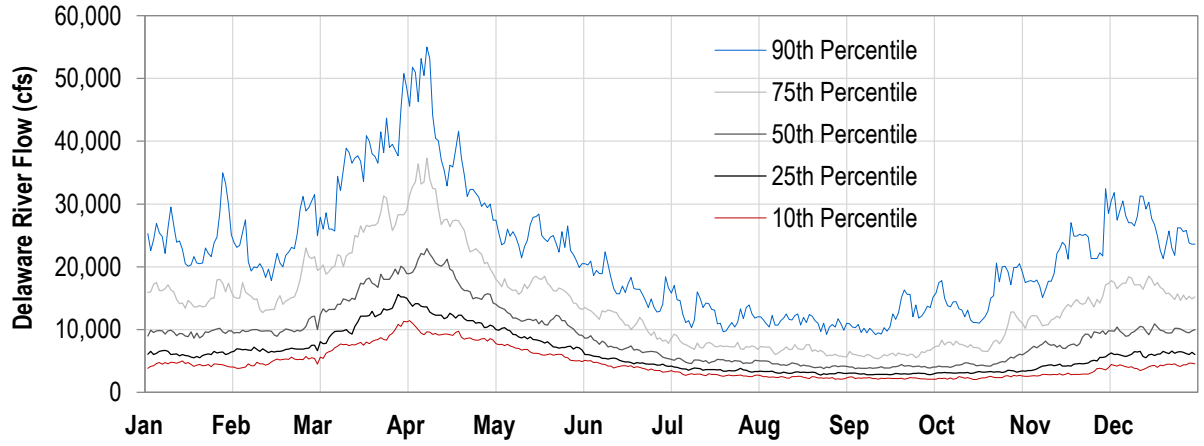


Figure 2-6 River Flow Distribution during Rainfall Events Greater Than 1-year Return Frequency

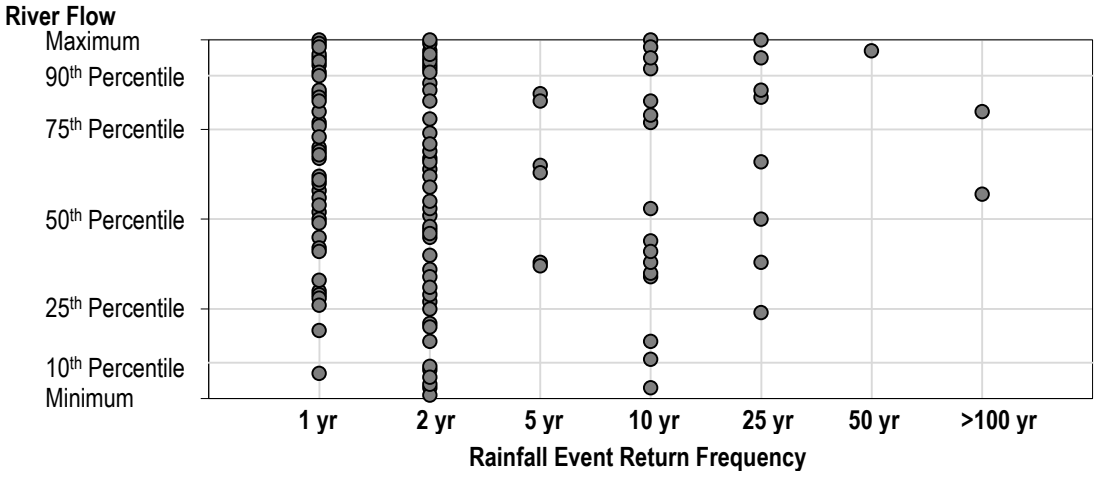


Figure 2-7 shows the daily rainfall profile and daily Delaware River flow hydrograph for the hydrologic period 1994-1996. This period includes two large storm events in July 1994 (a 10-year storm in July 14, 1994 and a 25-year storm in July 18, 1994). During these large storm events, the River flows were around 40th to 50th percentile (**Figure 2-8**). This is consistent with the typical trend shown in **Figure 2-6**. **Figure 2-9** shows Chester Creek and Ridley Creek flows in July 1994, it is obvious that creek flows are highly influenced by local precipitation and the big storms in July 1994 resulted in high creek flows.

Characteristics of the top 10 storms (by rainfall depth) in each year of the hydrologic period 1994-1996 are shown in **Table 2-8**, **Table 2-9**, and **Table 2-10**.

Figure 2-7 Daily Rainfall and River Flow Conditions 1994-1996

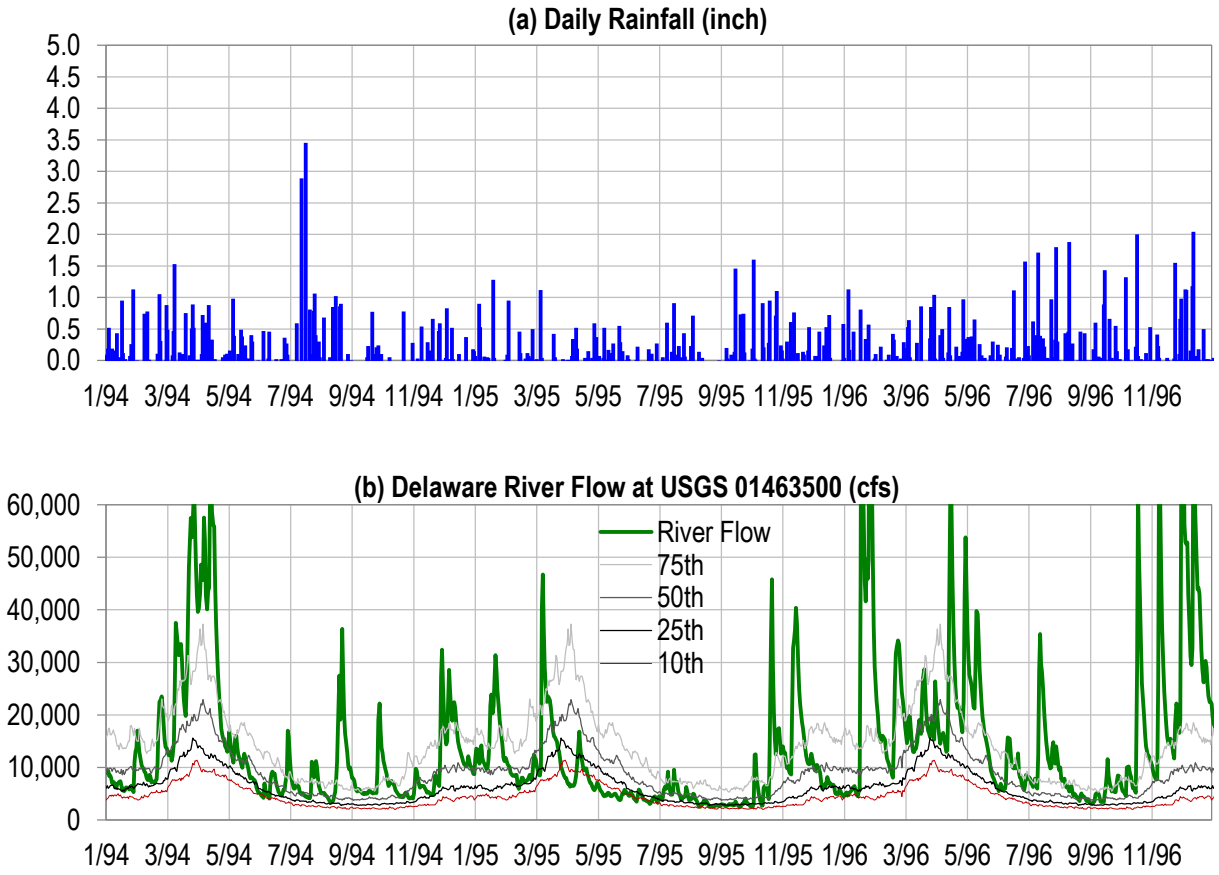


Figure 2-8 Rainfall and River Flow in July, 1994

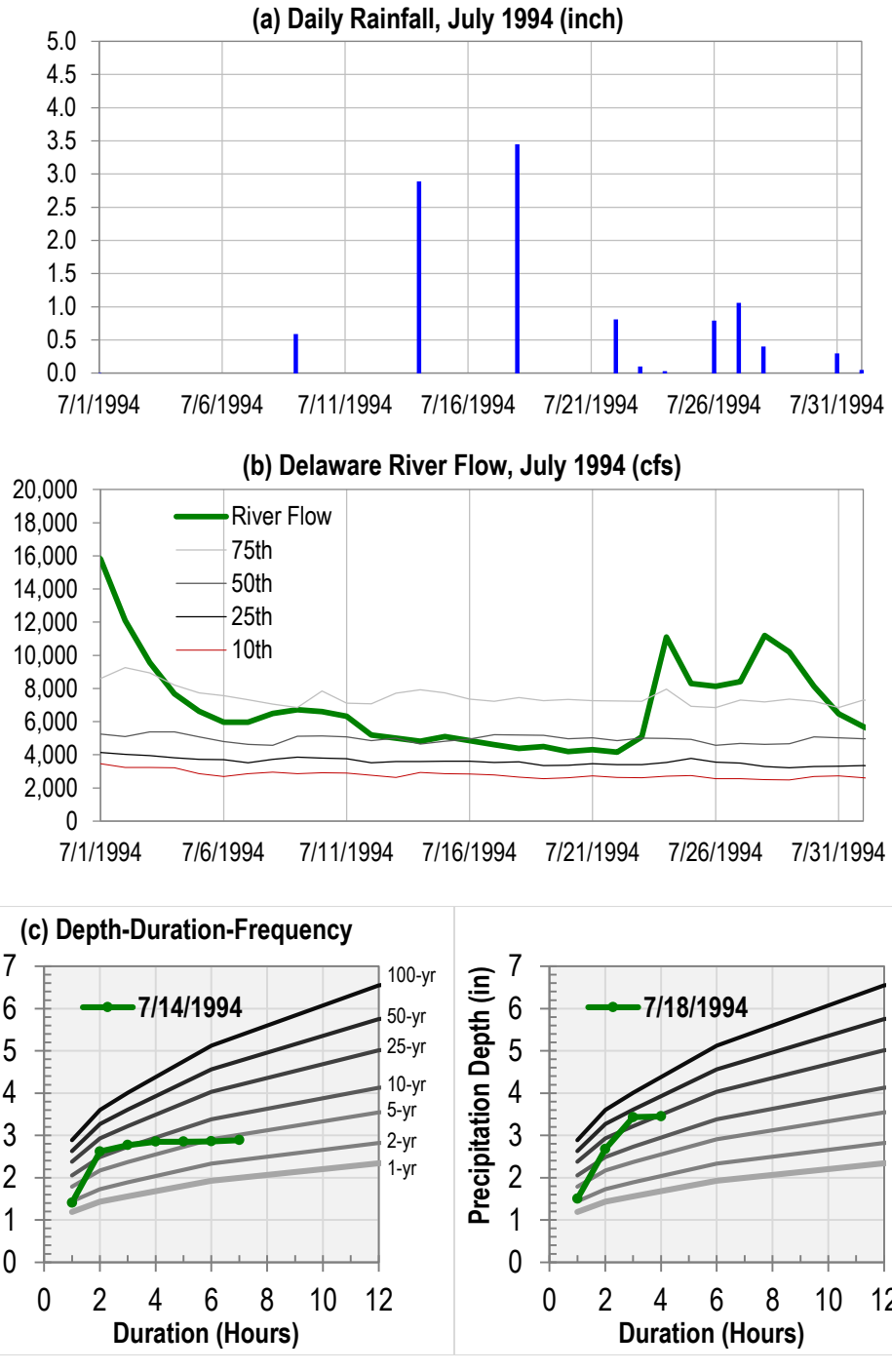


Figure 2-9 Rainfall and Creek Flow in July, 1994

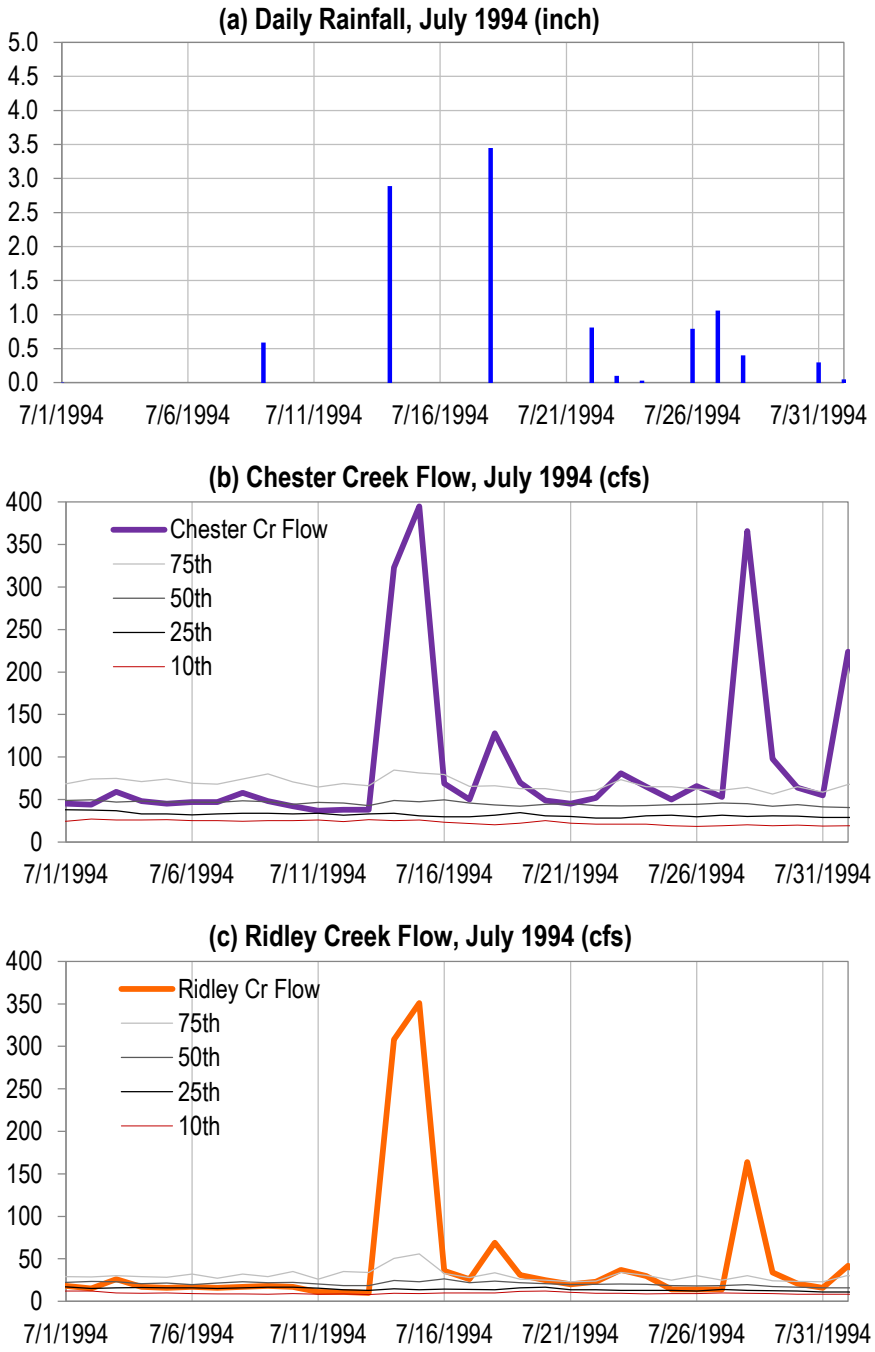


Table 2-8 Ten Largest Storms and Return Frequencies in 1994

Top 10 Rainfall Event	Rainfall Start Date and Time	Rainfall Volume (in)	Rainfall Duration (hr)	Max Rainfall Intensity (in/hr)	Rainfall Return Period
1	7/18/1994 7:00	3.45	4	1.5	25-yr
2	7/14/1994 15:00	2.89	7	1.41	10-yr
3	3/9/1994 11:00	2.00	27	0.37	< 1 year
4	8/21/1994 19:00	1.76	18	0.49	< 1 year
5	3/28/1994 0:00	1.41	37	0.14	< 1 year
6	5/7/1994 15:00	1.37	15	0.25	< 1 year
7	3/2/1994 9:00	1.32	22	0.14	< 1 year
8	1/27/1994 19:00	1.15	20	0.2	< 1 year
9	7/27/1994 17:00	1.11	8	0.49	< 1 year
10	1/17/1994 10:00	1.07	18	0.18	< 1 year

Table 2-9 Ten Largest Storms and Return Frequencies in 1995

Top 10 Rainfall Event	Rainfall Start Date and Time	Rainfall Volume (in)	Rainfall Duration (hr)	Max Rainfall Intensity (in/hr)	Rainfall Return Period
1	10/4/1995 18:00	1.82	33	0.54	< 1 year
2	10/27/1995 20:00	1.81	13	0.5	< 1 year
3	9/16/1995 22:00	1.6	13	0.24	< 1 year
4	1/6/1995 18:00	1.43	11	0.27	< 1 year
5	1/20/1995 0:00	1.25	10	1	< 1 year
6	10/20/1995 21:00	1.21	16	0.52	< 1 year
7	3/8/1995 17:00	1.16	8	0.29	< 1 year
8	10/14/1995 7:00	1.12	21	0.25	< 1 year
9	2/3/1995 22:00	1.04	15	0.2	< 1 year
10	7/17/1995 22:00	1.00	4	0.48	< 1 year

Table 2-10 Ten Largest Storms and Return Frequencies in 1996

Top 10 Rainfall Event	Rainfall Start Date and Time	Rainfall Volume (in)	Rainfall Duration (hr)	Max Rainfall Intensity (in/hr)	Rainfall Return Period
1	12/13/1996 13:00	3.03	33	0.27	1-yr
2	8/12/1996 19:00	2.34	13	0.52	1-yr
3	9/16/1996 14:00	2.26	16	0.38	< 1 year
4	10/18/1996 16:00	2.22	19	0.54	1-yr
5	7/12/1996 15:00	2.11	22	0.4	< 1 year
6	12/1/1996 7:00	1.62	23	0.56	< 1 year
7	6/29/1996 22:00	1.61	17	0.26	< 1 year
8	11/25/1996 23:00	1.58	10	0.38	< 1 year
9	7/31/1996 20:00	1.48	4	1.03	< 1 year
10	10/8/1996 10:00	1.32	11	0.24	< 1 year

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