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Hydrologic Analyses
Rush Creek and the Root River
In the Vicinity of Rushford and Houston, Minnesota

&

Hydraulic Analysis
Rush Creek
In the Vicinity of Rushford, Minnesota

U.S. Army Corps of Engineers, St. Paul District, May 2008

Executive Summary

Hydrologic Analyses

Appendix A of this report presents the hydrologic analyses for development of discharge-frequency relationships for Rush Creek near Rushford and the Root River near Houston, Minnesota. These analyses were performed as part of the ongoing flood recovery effort from the August 2007 flood event. The discharge-frequency curve for Rush Creek has not been updated since 1975, and the curve for Houston has not been updated since the 1992 General Design Memorandum for the Houston flood damage reduction project. The new analyses include all of the intervening years of record and the provisional flood peaks from the August 2007 flood event that occurred in this region. The 2007 peak flows are the floods of record at both locations; 38,400 cubic feet per second (cfs) for Rush Creek near Rushford and 46,000 cfs for the Root River near Houston, respectively. The methodology used for this study is in accordance with the general guidelines for discharge-frequency analyses as provided by the Federal Emergency Management Agency (FEMA) in "Guidelines and Specifications for Study Contractors" for flood insurance studies, dated April 2003. The methods used are also in accordance with Bulletin No. 17B, "Guidelines for Determining Flood Flow Frequency," of the Interagency Advisory Committee on Water Data, dated March 1982 and current Corps of Engineers criteria. This report was prepared in cooperation with technical experts from the Minnesota Department of Natural Resources and the U.S. Geological Survey, Minnesota District. Provided below is a summary data table of discharge values.

Summary of Discharges

	Discharge-Frequency (cfs)			
	% Chance of Exceedance			
Location	10.0	2.0	1.0	0.2
Rush Creek near Rushford	6,850	14,100	18,100	29,600
Root River near Houston	23,200	36,800	43,100	58,700

Hydraulic Analysis

Appendix B of this report presents the hydraulic analysis of Rush Creek which included developing a Hydrologic Engineering Center River Analysis System (HEC-RAS) steady flow model. The model was used to develop water surface profiles for the 10-, 50-, 100-, and 500-Year events and the August 2007 flood event. The main goal of this analysis was to determine what caused the levees to overtop during the 2007 flood event and a secondary goal was to determine whether the Trail Bridge contributed to the levee overtopping. This steady flow analysis demonstrated that the levees overtopped because the 2007 event greatly exceeded the capacity of the Rush Creek channel and levees and that the Trail Bridge did not contribute to the levee overtopping.

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APPENDIX A

Hydrologic Analyses

Rush Creek and the Root River

In the Vicinity of Rushford and Houston, Minnesota

U.S. Army Corps of Engineers

St. Paul District

May 2008

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Appendix A

Hydrologic Analyses: Rush Creek and the Root River in the Vicinity of Rushford and Houston, Minnesota

Executive Summary

1. This report presents the hydrologic analyses for development of discharge-frequency relationships for Rush Creek near Rushford and the Root River near Houston, Minnesota. These analyses were performed as part of the ongoing flood recovery effort from the August 2007 flood event. The discharge-frequency curve for Rush Creek has not been updated since 1975, and the curve for Houston has not been updated since the 1992 General Design Memorandum for the Houston flood damage reduction project. The new analyses include all of the intervening years of record and the provisional flood peaks from the August 2007 flood event that occurred in this region. The 2007 peak flows are the floods of record at both locations; 38,400 cubic feet per second (cfs) for Rush Creek near Rushford and 46,000 cfs for the Root River near Houston, respectively. The methodology used for this study is in accordance with the general guidelines for discharge-frequency analyses as provided by the Federal Emergency Management Agency (FEMA) in "Guidelines and Specifications for Study Contractors" for flood insurance studies, dated April 2003. The methods used are also in accordance with Bulletin No. 17B, "Guidelines for Determining Flood Flow Frequency," of the Interagency Advisory Committee on Water Data, dated March 1982 and current Corps of Engineers criteria. This report was prepared in cooperation with technical experts from the Minnesota Department of Natural Resources and the U.S. Geological Survey, Minnesota District. Provided below is a summary data table of discharge values.

Summary Table of Discharge-Frequency Statistics

Computed Probability without Expected Probability Adjustment

				Discharge-Frequency (cfs) % Chance of Exceedance			
Location	Mean Log	Standard Deviation	Adopted Skew	10.0	2.0	1.0	0.2
Rush Creek Near Rushford	3.2735	0.4448	-0.1531	6,850	14,100	18,100	29,600
Root River Near Houston	3.9965	0.2931	-0.2020	23,200	36,800	43,100	58,700

Purpose

2. The purpose of this report is to present the hydrologic analyses for development of discharge-frequency curves for Rush Creek near Rushford and the Root River near Houston, Minnesota, using updated data and current methodology. These analyses were performed as part of the repair and rehabilitation of the Corps of Engineers flood damage reduction project at Rushford following the August 2007 flood event.

Background

3. The discharge-frequency curve for Rush Creek near Rushford has not been updated for project purposes since 1975. The curve for the Root River near Houston has not been updated since the Corps of Engineers built a flood damage reduction project there in 1992. The flood of record at both locations occurred in August 2007. The existing curve for the Rush Creek gage was developed by outdated methodology and lacked a significant portion of the observed annual peak flow data that has been recorded, with the addition of 42 years of annual peaks. The curve for the Root River near Houston had 16 years of annual peak flows added since the previous curve was computed. The current accepted methodology is contained in Bulletin 17B by the Interagency Committee on Water Data (Reference 1).

Coordination

4. This report was prepared in cooperation with technical experts from the Minnesota Department of Natural Resources (MN DNR) and the U.S. Geological Survey (USGS). The MN DNR provided input on the methods used. The USGS provided the values of the annual instantaneous peak flows for 2007 and discussions on how these were determined.

Drainage Area

5. The Root River drainage basin is characterized by a dendritic network of streams that feed the main stem through deep incised valleys and forested upland hills and ridges. See Figure 1 for a map of the basin. The basin is about twice as long as it is wide, with a central west-east axis that drains east to the Mississippi River. Some of the headwaters areas lie on thin glacial drift, but most of the basin is in the driftless area of southeastern Minnesota. The valley of the Root River becomes deeper as it heads downstream, and can get up to a mile wide in some places. Rush Creek flows from northwest to southeast in southwestern Winona County, and enters Fillmore County upstream of the City of Rushford. Rushford is at the confluence of the Root River and Rush Creek, with Rush Creek running through the middle of town. The drainage areas used in this study are listed in Table 1. These drainage areas were obtained from several sources, including the U.S. Geological Survey water resources data books and “Streams and Rivers of Minnesota (Reference 2).”

Streamflow Records

Observed Flow Data

6. The U.S. Geological Survey (U.S.G.S.) maintains two continuous stream flow recording gages on the main stem of the Root River and several partial record high flow crest stage gages on the main stem and tributaries. See Table 1. Gaged stream flow data used for this study included the stations for the Root River near Houston, Minnesota (U.S.G.S. Gage No. 05385000, water years 1911-17, 1930-1983, and 1985-2007), and Rush Creek near Rushford (U.S.G.S. Gage No. 05384500, water years 1942-2007). The annual instantaneous peak flows used in this study can be found in Table 2 for the Root River near Houston and Table 3 for Rush Creek near Rushford.

7. The 2007 peak flows are the floods of record at both locations; 38,400 cubic feet per second (cfs) for Rush Creek near Rushford and 46,000 cfs for the Root River near Houston, respectively. These values were obtained from the U.S.G.S. Minnesota District and are considered provisional and subject to revision. The number provided for Rush Creek was estimated from flow in the channel and over the adjacent roadway. A basin map showing the rainfall amounts for the 18 August 2007 storm can be found on Figure 2. This event generated most of the runoff associated with the recorded flood peaks, however, the ground was very likely saturated with water from antecedent rainfall in the days preceding 18 August.

Discharge-Frequency Analyses

General

8. Development of discharge-frequency probability relationships in this study was accomplished by fitting the annual instantaneous peak flows at the gage locations to a log-Pearson Type III distribution using the computer program HEC-FFA, Flood Frequency Analysis (Reference 3). Additional hydrologic techniques consistent with Bulletin 17B were used as necessary for Rush Creek as described in the following paragraphs. The analytical discharge-frequency curves represent computed probability without the expected probability adjustment and median plotting positions. This is consistent with current Corps of Engineers criteria for hydrologic investigations.

Methodology

9. The methodology used for this study is in accordance with the general guidelines for discharge-frequency analyses as provided by the Federal Emergency Management Agency (FEMA) in "Guidelines and Specifications for Study Contractors" for flood insurance studies, dated April 2003 (Reference 4). The methods used are also in accordance with Bulletin No. 17B, "Guidelines for Determining Flood Flow Frequency," of the Interagency Advisory Committee on Water Data, dated March 1982. The Corps of Engineers Engineering Manual EM 1110-2-1415, Hydrologic Frequency Analysis (Reference 5), was also used. Generalized skew coefficients for each gage were combined with the station skews in the HEC-FFA computer analyses to provide a weighted skew for each gage. The generalized skew values were obtained

from a U.S.G.S. report titled “Generalized Skew Coefficients for Flood-Frequency Analysis in Minnesota” (Reference 6).

Root River near Houston

10. The annual instantaneous peak discharge-frequency curve for the Root River near Houston is based on 84 systematic events from the period of record flows available at the Houston continuous stream flow gaging station. The available annual instantaneous peaks of the systematic record were 1911 through 1917, 1930 through 1983, and 1985 through 2007. The HEC-FFA computer program was used to compute the analytical discharge-frequency curve using that data. The adopted curve along with the statistics is shown on Figure 3 and tabulated in Table 4.

Rush Creek near Rushford

11. The annual instantaneous peak discharge-frequency curve for Rush Creek near Rushford is based on 66 systematic events from the period of record flows available at the Rushford continuous stream flow gaging station. The available annual instantaneous peaks of the systematic record were 1942 through 2007. The HEC-FFA computer program was used to compute the analytical discharge-frequency curve using that data. The curve is shown on Figure 4; however, it is not the adopted curve for this study.

12. A two-station comparison was done as described in Bulletin 17B, Appendix 7, with the longer record station at Houston to adjust the mean and standard deviation. The correlation coefficient for the concurrent years of the annual instantaneous peak flow data was 0.6632 as shown in Appendix 1. Statistical tests in Appendix 7 of Bulletin 17B resulted in minimum threshold values of the correlation coefficient to be 0.13 for the mean and 0.10 for the standard deviation. Since these thresholds were exceeded, adjustments of the mean and standard deviation were justified. The Beard Equation was used to compute the adjusted standard deviation, as described in "Hydrologic Frequency Analysis" by the Corps of Engineers (Reference 5). The Beard Equation is a simplified version of Equation 7-10 in Appendix 7 of Bulletin 17B. The results indicated that the adjusted statistics were improved to 72 years of equivalent record. The adjusted statistics were put into the HEC-FFA computer program to compute the analytical discharge-frequency curve. Pertinent equations and results of the two-station comparison can be found in Appendix 1. The adopted curve along with the statistics is shown on Figure 5 and tabulated in Table 4.

Coincidental Discharge Frequency

13. A starting water surface elevation is required at the confluence of Rush Creek and the Root River to establish the frequency water surface profiles through the study limits. This is needed for the HEC-RAS hydraulic model. For example, a water surface elevation consistent with a 1 percent chance of occurrence would be needed to begin a computation of a 1 percent chance water surface profile through Rush Creek. The confluence is subject to flooding from not only Rush Creek but also the Root River. Rush Creek has a drainage area of only 132 square miles compared to the Root River at this location with a drainage area of 1,250 square miles.

Therefore flooding from the Rush Creek watershed is more prone to intense summer rain events than flooding from the Root River watershed. Conversely, flooding from the Root River watershed is more prone to snowmelt flooding. Both rivers experience both conditions of flooding. Therefore, flooding from either source cannot be considered to be completely dependent nor independent on flooding from the other. Flood peaks do not occur simultaneously. In addition, timing of the respective peaks would also vary due to the size of the watersheds and other unique hydrologic factors. A coincidental discharge-frequency analysis was done to address this condition. A detailed description of the results can be found in Appendix 2.

Summary

14. The purpose of this report is to present the hydrologic analyses for development of discharge-frequency curves for Rush Creek near Rushford and the Root River near Houston, Minnesota, using updated data and current methodology. These analyses were performed as part of the repair and rehabilitation of the Corps of Engineers flood damage reduction project at Rushford following the August 2007 flood event. The resulting discharge-frequency curves are suitable for the determination of flood insurance studies and other engineering applications. Additional future studies that may provide greater insight into Root River basin hydrology are: regional discharge-frequency analysis for all gages in the basin incorporating available flow records and rain-runoff models that be used for future watershed planning activities.

References

1. U.S. Department of the Interior, Geological Survey, Interagency Advisory Committee on Water Data, Hydrology Subcommittee, March 1982, Guidelines for Determining Flood Flow Frequency, Bulletin 17B.

2. Waters, Thomas F., Streams and Rivers of Minnesota, 1977, University of Minnesota Press, Minneapolis.

3. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-FFA Flood Frequency Analysis Computer Program, Version 3.1, February 1995.

4. Federal Emergency Management Agency, April 2003, Flood Insurance Study Guidelines and Specifications for Study Contractors.

5. U.S. Army Corps of Engineers, March 5, 1993, Engineer Manual 1110-2-1415, Hydrologic Frequency Analysis.

6. Lorenz, D. L., U.S. Geological Survey, Minnesota District, 1997, Generalized Skew Coefficients for Flood-Frequency Analysis in Minnesota, Water-Resources Investigations Report 97-4089, Mounds View, Minnesota.

TABLES

Table 1

Root River and Rush Creek Drainage Areas

Location	USGS Gage Number	Drainage Area in Square Miles Area
Root River at Lanesboro	05384000*	615
Root River near Pilot Mound	05383950	565
Root River at Rushford (above Rush Creek)	05384350*	992
Rush Creek near Rushford	05384500*	132
Root River near Houston	05385000	1,250
South Fork Root River near Houston	05385500*	275
Mouth of the Root River at the Mississippi River Confluence		1,670

* These gages are operated as partial record high flow stations

TABLE 2

Annual Instantaneous Flow Peaks

Root River near Houston, MN, USGS Gaging Station 05385000

Date	Discharge CFS
8/14/1911	15200
3/30/1912	10600
3/25/1913	10000
6/28/1914	11700
3/26/1915	7330
3/26/1916	7970
3/23/1917	17000
6/4/1930	5100
7/15/1931	4580
3/27/1932	6900
3/31/1933	26600
4/4/1934	19000
8/6/1935	11700
5/1/1936	14000
3/7/1937	14500
9/11/1938	15600
3/21/1939	6620
3/30/1940	7860
5/30/1941	6280
6/30/1942	23700
3/27/1943	10600
2/26/1944	6120
3/17/1945	23900
3/6/1946	13700
4/6/1947	9300
2/29/1948	11700
3/31/1949	8450
3/27/1950	31000
7/22/1951	14800
4/1/1952	37000
7/27/1953	10400
6/21/1954	5370
3/10/1955	3760
4/3/1956	9660
7/22/1957	2230
6/6/1958	9600
6/27/1959	10100
8/29/1960	8800
3/27/1961	31400
3/30/1962	29500

3/24/1963	10700
4/3/1964	1110
3/2/1965	31000
2/10/1966	18500
3/27/1967	14200
5/16/1968	3210
4/5/1969	8280
6/18/1970	2250
4/2/1971	8970
3/16/1972	10200
4/17/1973	11700
6/22/1974	19800
4/29/1975	9430
3/13/1976	19800
6/5/1977	2290
7/1/1978	12200
3/31/1979	10400
9/21/1980	16400
7/13/1981	12600
5/14/1982	4460
7/3/1983	9500
3/11/1985	8780
9/23/1986	13600
10/13/1986	10900
3/9/1988	1600
3/24/1989	4890
4/25/1990	9520
5/7/1991	4940
3/10/1992	5760
4/2/1993	15800
3/6/1994	4780
3/12/1995	6240
3/25/1996	8710
3/29/1997	7750
6/29/1998	7590
7/21/1999	8000
6/2/2000	34600
4/13/2001	16700
6/6/2002	4660
5/13/2003	2650
9/17/2004	23800
2/6/2005	9770
4/9/2006	7890
8/18/2007	46000

Note: The discharge value shown for 2007 is provisional and subject to revision.

TABLE 3

Annual Instantaneous Flow Peaks

Rush Creek near Rushford, MN, USGS Gaging Station 05384500

Date	Discharge CFS
6/28/1942	11000
3/25/1943	3600
3/11/1944	1660
7/21/1945	4000
1/5/1946	7130
4/5/1947	2590
3/16/1948	2000
3/4/1949	3640
3/26/1950	11600
7/21/1951	6580
3/31/1952	6740
7/26/1953	3750
6/19/1954	920
7/8/1955	1180
4/3/1956	1380
2/24/1957	1980
2/25/1958	420
3/24/1959	2000
7/3/1960	3460
3/25/1961	4920
3/28/1962	4550
3/23/1963	1530
3/12/1964	53
4/6/1965	5490
2/9/1966	7490
3/24/1967	5170
7/23/1968	370
4/4/1969	620
6/18/1970	1640
3/31/1971	1290
3/17/1972	2300
8/23/1973	2030
6/21/1974	4400
7/5/1975	1220
3/12/1976	6040
6/5/1977	1300
7/1/1978	7930
8/4/1979	1500
9/21/1980	3930
7/11/1981	800

3/17/1982	600
7/1/1983	700
6/17/1984	900
3/11/1985	1770
9/21/1986	1320
10/12/1986	390
3/1988	75
3/24/1989	1950
4/25/1990	1130
7/21/1991	3480
11/19/1991	270
4/19/1993	2500
3/5/1994	600
3/12/1995	2580
3/25/1996	2550
3/23/1997	365
5/8/1998	2930
7/21/1999	510
6/1/2000	1120
4/7/2001	278
6/21/2002	740
2/21/2003	432
9/15/2004	4610
2/6/2005	2640
4/1/2006	818
8/19/2007	38400

Note: The discharge value shown for 2007 is a provisional estimated value, and is subject to revision.

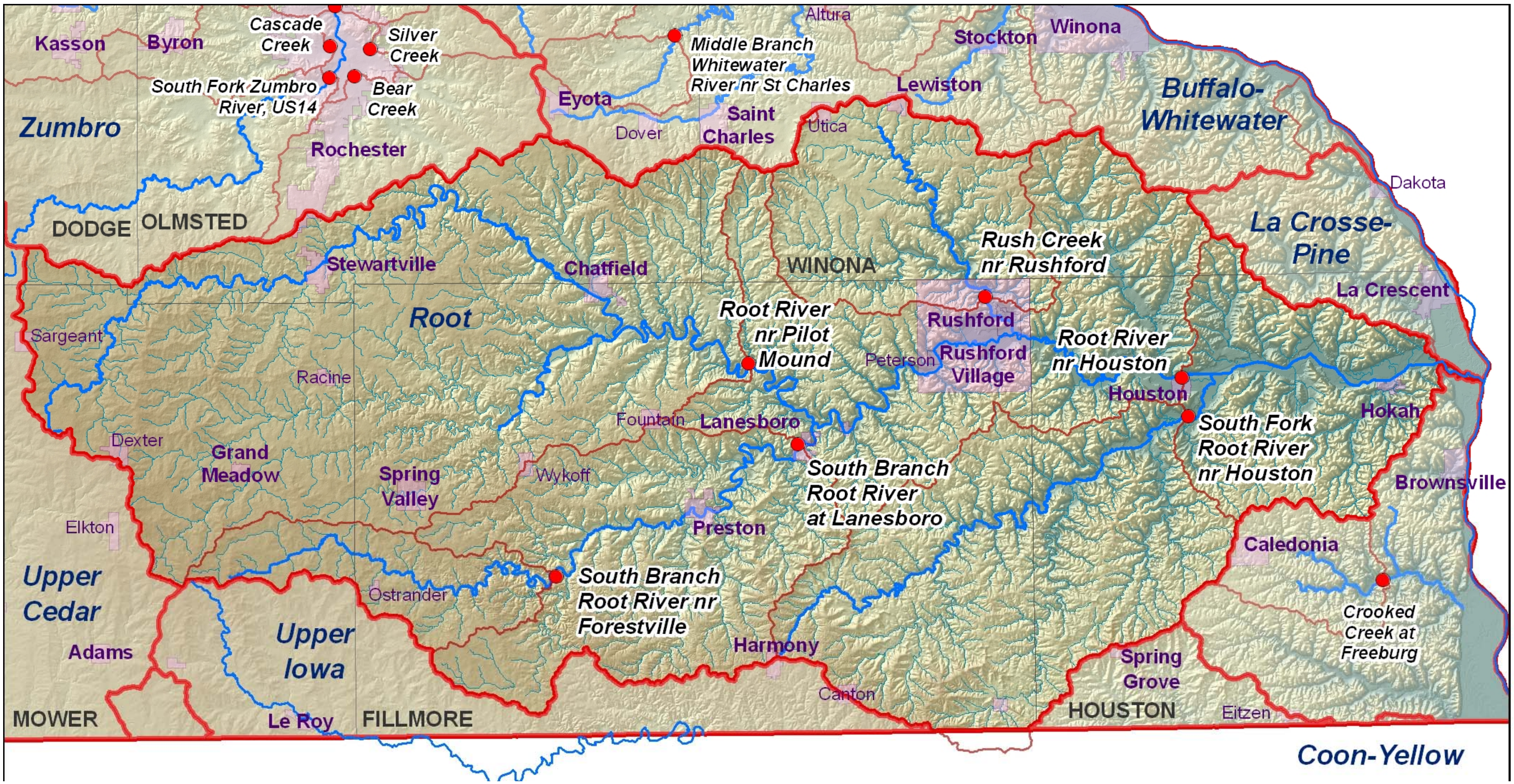
Table 4

Summary Table of Discharge-Frequency Statistics

Computed Probability without Expected Probability Adjustment

Location	Mean Log	Standard Deviation	Adopted Skew	Discharge-Frequency (cfs) % Chance of Exceedance 10.0	2.0	1.0	0.2
Rush Creek Near Rushford	3.2735	0.4448	-0.1531	6,850	14,100	18,100	29,600
Root River Near Houston	3.9965	0.2931	-0.2020	23,200	36,800	43,100	58,700

FIGURES



Adapted from the Minnesota Department of Natural Resources

FIGURE 1

Root River Watershed

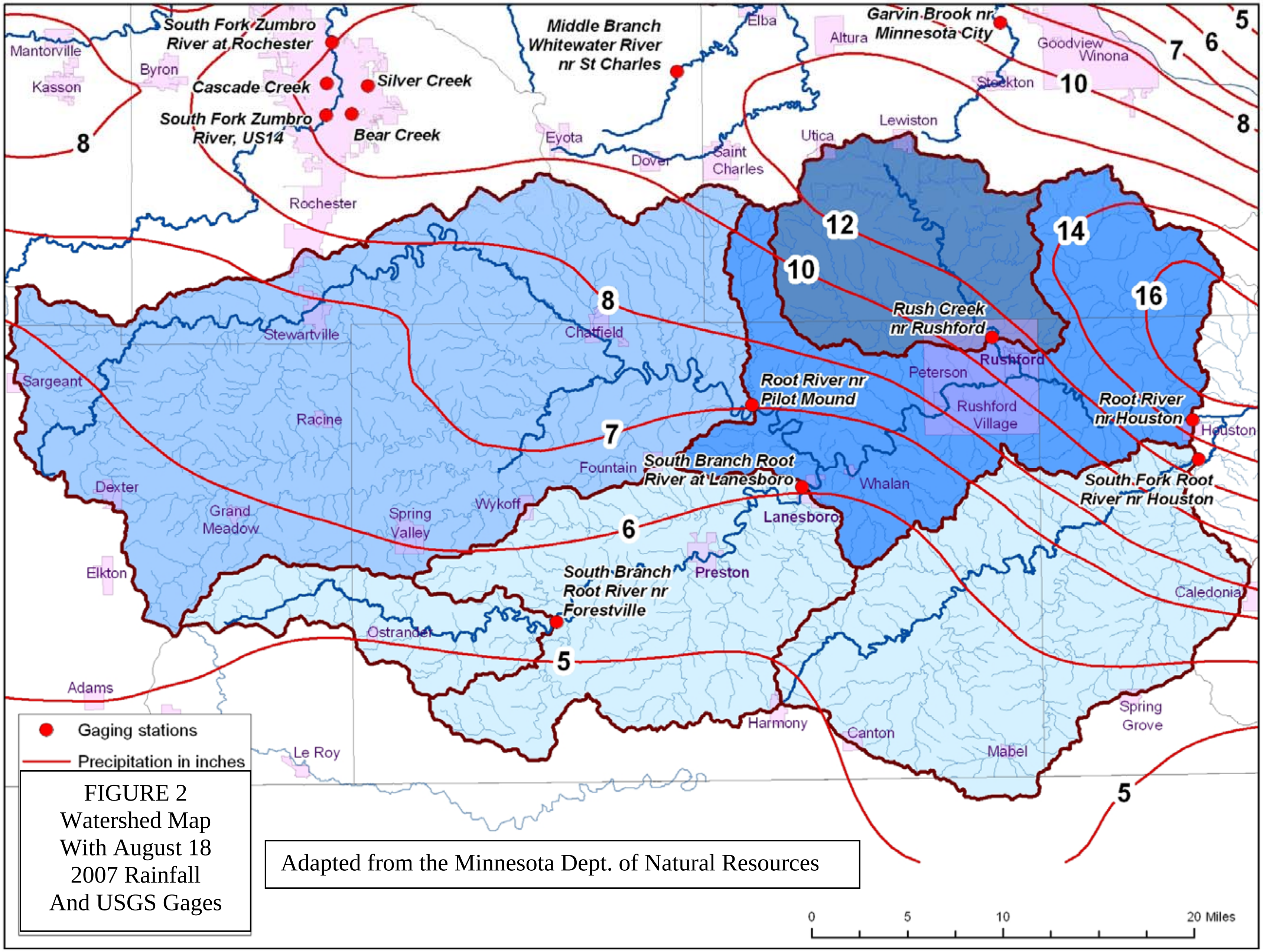


FIGURE 2
Watershed Map
With August 18
2007 Rainfall
And USGS Gages

Adapted from the Minnesota Dept. of Natural Resources

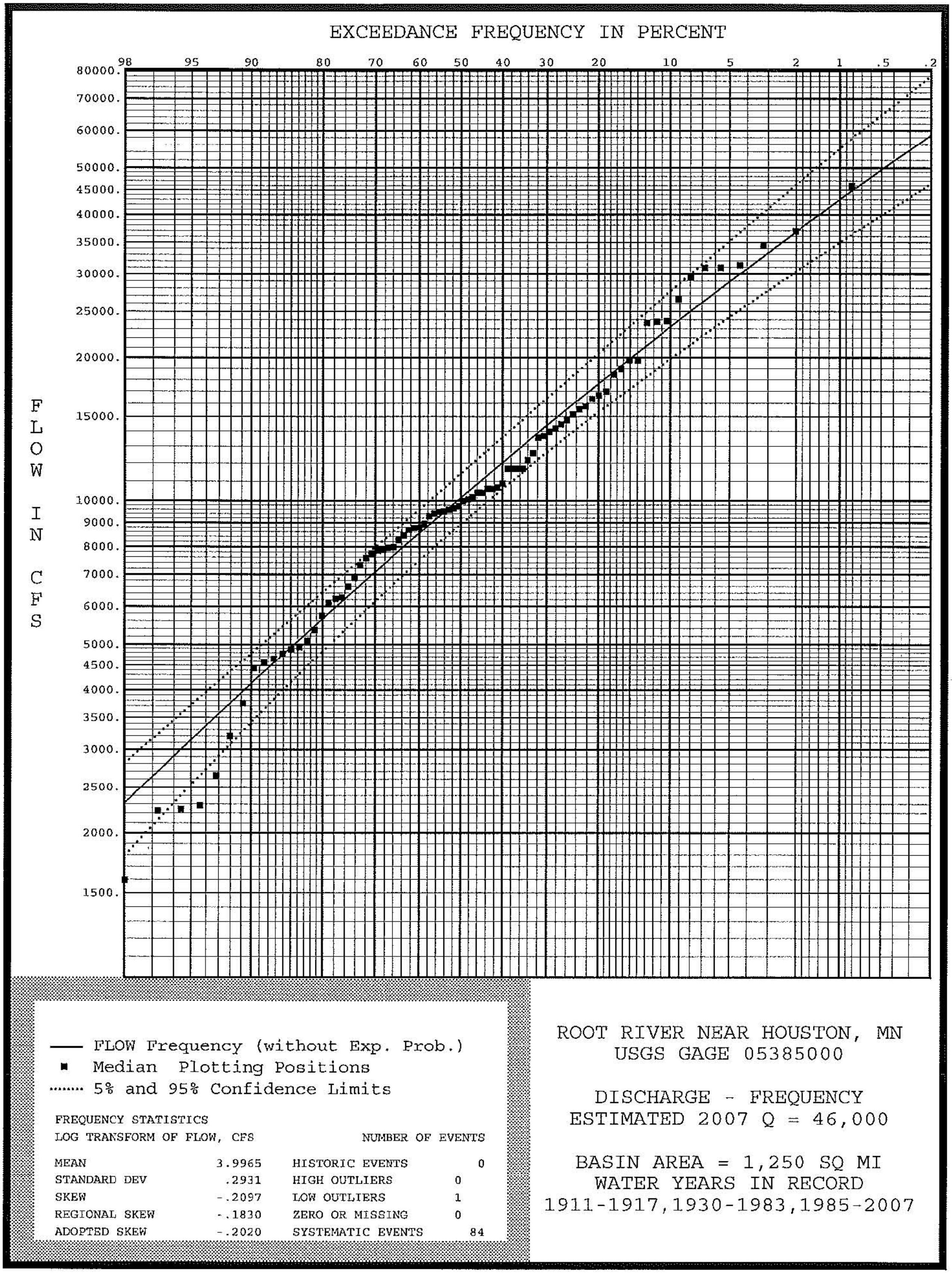

EXCEEDANCE FREQUENCY IN PERCENT
98
95
90
80
70
60
50
40
30
20
10
5
2
1
.5
.2
80000.
70000.
60000.
50000.
45000.
40000.
35000.
30000.
25000.
20000.
15000.
10000.
9000.
8000.
7000.
6000.
5000.
4500.
4000.
3500.
3000.
2500.
2000.
1500.
FLOW IN CFS
FLOW Frequency (without Exp. Prob.)
Median Plotting Positions
5% and 95% Confidence Limits
FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS
NUMBER OF EVENTS
MEAN 3.9965
STANDARD DEV .2931
SKEW -.2097
REGIONAL SKEW -.1830
ADOPTED SKEW -.2020
HISTORIC EVENTS 0
HIGH OUTLIERS 0
LOW OUTLIERS 1
ZERO OR MISSING 0
SYSTEMATIC EVENTS 84
ROOT RIVER NEAR HOUSTON, MN
USGS GAGE 05385000
DISCHARGE - FREQUENCY
ESTIMATED 2007 Q = 46,000
BASIN AREA = 1,250 SQ MI
WATER YEARS IN RECORD
1911-1917,1930-1983,1985-2007

FIGURE 3

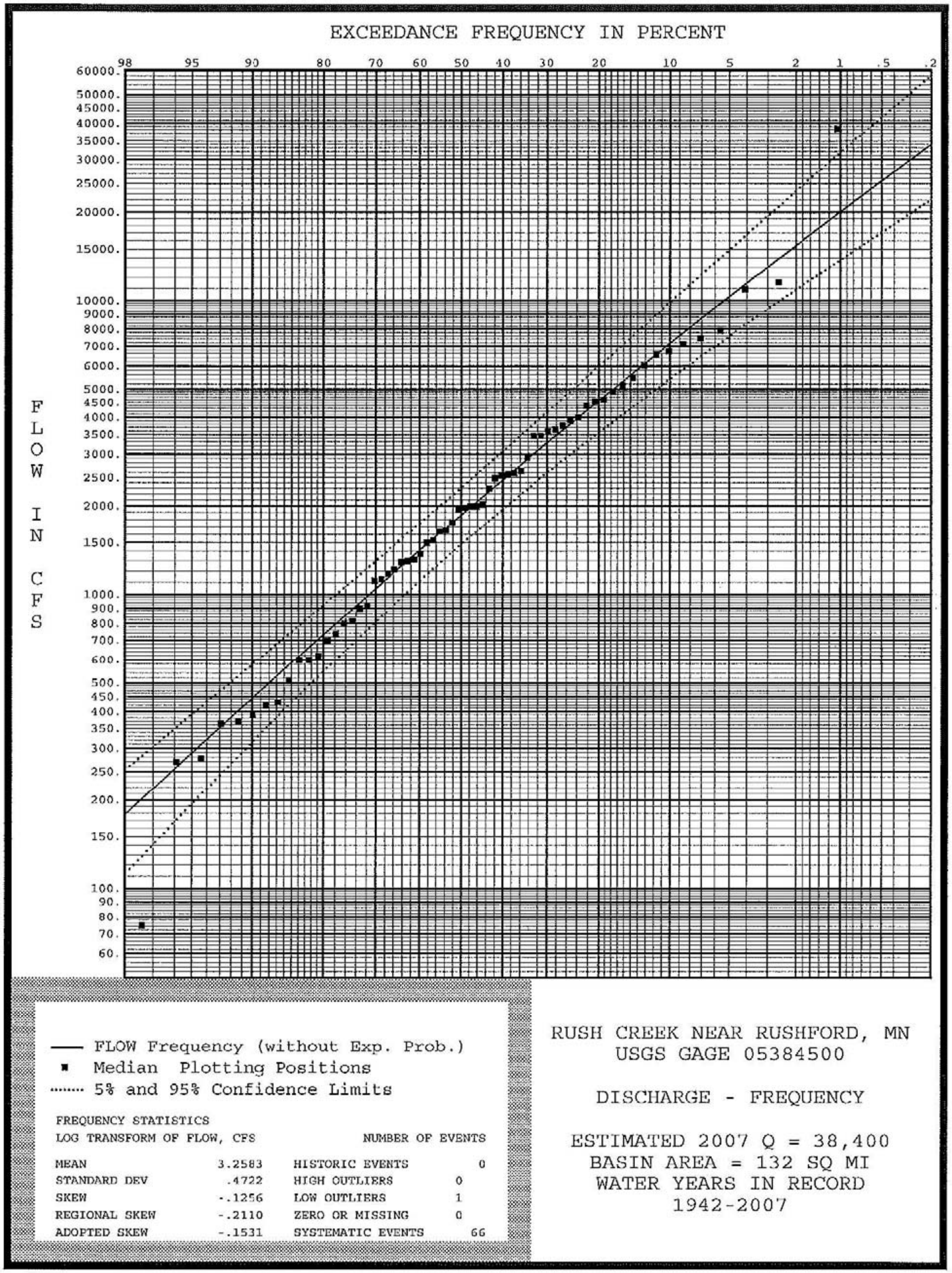
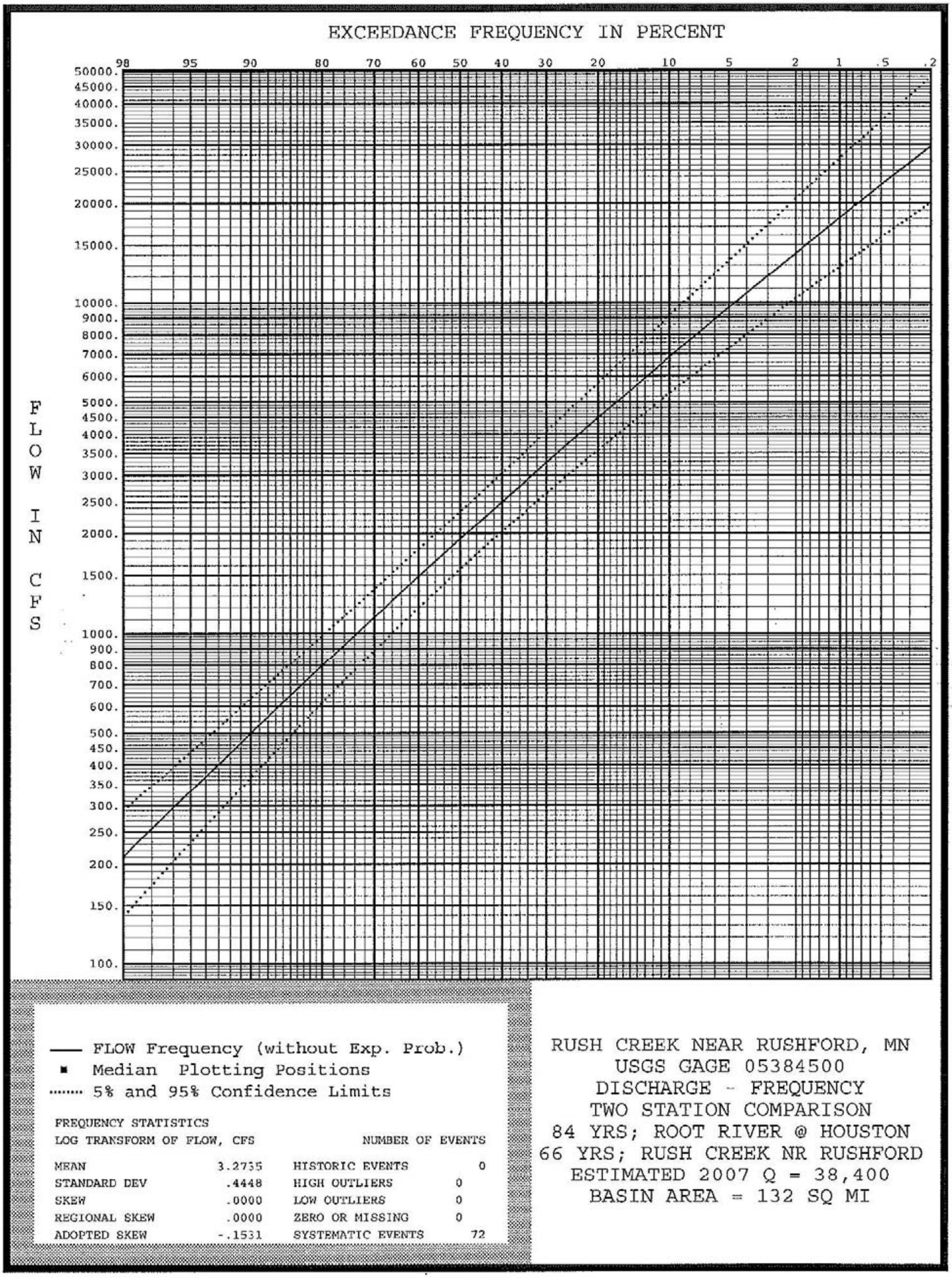

EXCEEDANCE FREQUENCY IN PERCENT
FLOW IN CFS
FLOW Frequency (without Exp. Prob.)
Median Plotting Positions
5% and 95% Confidence Limits
FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS
NUMBER OF EVENTS
MEAN 3.2583
STANDARD DEV .4722
SKEW -.1256
REGIONAL SKEW -.2110
ADOPTED SKEW -.1531
HISTORIC EVENTS 0
HIGH OUTLIERS 0
LOW OUTLIERS 1
ZERO OR MISSING 0
SYSTEMATIC EVENTS 66
RUSH CREEK NEAR RUSHFORD, MN
USGS GAGE 05384500
DISCHARGE - FREQUENCY
ESTIMATED 2007 Q = 38,400
BASIN AREA = 132 SQ MI
WATER YEARS IN RECORD
1942-2007

FIGURE 4


EXCEEDANCE FREQUENCY IN PERCENT
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FLOW IN CFS
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FLOW Frequency (without Exp. Prob.)
Median Plotting Positions
5% and 95% Confidence Limits
FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS
NUMBER OF EVENTS
MEAN 3.2735
STANDARD DEV .4448
SKEW .0000
REGIONAL SKEW .0000
ADOPTED SKEW -.1531
HISTORIC EVENTS 0
HIGH OUTLIERS 0
LOW OUTLIERS 0
ZERO OR MISSING 0
SYSTEMATIC EVENTS 72
RUSH CREEK NEAR RUSHFORD, MN
USGS GAGE 05384500
DISCHARGE - FREQUENCY
TWO STATION COMPARISON
84 YRS; ROOT RIVER @ HOUSTON
66 YRS; RUSH CREEK NR RUSHFORD
ESTIMATED 2007 Q = 38,400
BASIN AREA = 132 SQ MI

FIGURE 5

APPENDICES

APPENDIX 1

TWO-STATION COMPARISON FOR RUSH CREEK

EQUATIONS FOR TWO-STATION COMPARISON FOR ADJUSTMENT OF SHORT RECORD STATION STATISTICS TO A LONG RECORD STATION

1. Compute mean log flow, standard deviation and station skew ($\mathbf{X_S, S_S, G_S}$) for **short record station** using Bulletin 17B discharge-frequency methodology using $\mathbf{N_S}$ years of record

2. Compute mean log flow, standard deviation and station skew ($\mathbf{X_{LT}, S_{LT}, G_{LT}}$) for **long record station** using Bulletin 17B discharge-frequency methodology using total $\mathbf{N_{LT}}$ years of record

3. Compute mean log flow, standard deviation and station skew ($\mathbf{X_{LC}, S_{LC}, G_{LC}}$) for **long record station** using Bulletin 17B discharge-frequency methodology using the **same (concurrent) years of record as the short record station, $\mathbf{N_{LC}}$**

4. Compute correlation coefficient R^2 for annual flow data from 1 and 3 above

5. Adjust R^2 to remove sample bias

$$\overline{R}^2 = 1-\left(1-R^2\right)\left(\frac{N_1-1}{N_1-2}\right)$$

$$\overline{R} = \sqrt{\overline{R}^2}$$

where N_1 = number of years when flows were concurrently observed at both sites

6. $$B = \overline{R}\left(\frac{S_S}{S_{LC}}\right)$$

7. Adjust the mean log flow

$$\overline{Y} = X_S + B\left(X_{LT} - X_{LC}\right)$$

8. Adjust the standard deviation using Beard's Approximation

$$S_Y = S_S + \left(\overline{R}\right)\left(B\right)\left(S_{LT} - S_{LC}\right)$$

9. Compute equivalent years of record as a measure of improvement of the adjusted mean log

$$N_E = \frac{N_1}{1-\left(\frac{N_{LC}-N_S}{N_1+N_{LC}-N_S}\right)\left(\overline{R}^2 - \frac{\left(1-\overline{R}^2\right)}{\left(N_1-3\right)}\right)}$$

Two-Station Comparison: Adjustment of the Statistics for Rush Creek near Rushford

WATER YEAR	HOUSTON FLOW	RUSHFORD FLOW
1942	23700	11000
1943	10600	3600
1944	6120	1660
1945	23900	4000
1946	13700	7130
1947	9300	2590
1948	11700	2000
1949	8450	3640
1950	31000	11600
1951	14800	6580
1952	37000	6740
1953	10400	3750
1954	5370	920
1955	3760	1180
1956	9660	1380
1957	2230	1980
1958	9600	420
1959	10100	2000
1960	8800	3460
1961	31400	4920
1962	29500	4550
1963	10700	1530
1964	1100	53
1965	31000	5490
1966	18500	7490
1967	14200	5170
1968	3210	370
1969	8280	620
1970	2250	1640
1971	8970	1290
1972	10200	2300
1973	11700	2030
1974	19800	4400
1975	9430	1220
1976	19800	6040
1977	2290	1300
1978	12200	7930
1979	10400	1500
1980	16400	3930
1981	12600	800
1982	4460	600
1983	9500	700
1985	8780	1770
1986	13600	1320
1987	10900	390
1988	1600	75
1989	4890	1950
1990	9520	1130
1991	4940	3480
1992	5760	270
1993	15800	2500
1994	4780	600
1995	6240	2580
1996	8710	2550
1997	7750	365
1998	7590	2930
1999	8000	510
2000	34600	1120
2001	16700	278
2002	4660	740
2003	2650	432
2004	23800	4610
2005	9770	2640
2006	7890	818
2007	46000	38400

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.6697
R Square	0.4485
Adjusted R Square	0.4398
Standard Error	3815.9511
Observations	65

	Coefficients	*Standard Error*
Intercept	-1252.6164	790.1426
X Variable 1	0.3621	0.0506

R-BAR 0.6632 — R-BAR^2 0.4398

RUSHFORD (SHORT RECORD)		RUSHFORD (FULL RECORD) Note: No 1984 Q at Houston
N	65	66
X	3.2630	3.2583
S	0.4744	0.4722
G	-0.1725	-0.1531

HOUSTON (LONG RECORD STATION)

CONCURRENT RECORD		TOTAL RECORD
N	65	84
X	3.9802	3.9965
S	0.3374	0.2931
G	-0.3350	-0.2020

B 0.9324

ADJUSTMENT OF THE MEAN (X) — (Rushford Full Record)

Y-BAR 3.2735

ADJUSTMENT OF THE STANDARD DEVIATION (BEARD EQN.) — (Rushford Full Record)

Sy 0.4448

Long Record YRS minus Short Record YRS 18

EQUIVALENT LENGTH OF RECORD

Ne 72

APPENDIX 2

COINCIDENTAL DISCHARGE-FREQUENCY ANALYSIS

Coincidental Discharge Frequency

To establish the frequency water surface profiles through the study limits, a starting water surface elevation is required at the confluence of Rush Creek and the Root River. This is needed for the Hec-Ras hydraulic model. For example, a water surface elevation consistent with a 1 percent chance of occurrence would be needed to begin a computation of a 1 percent chance water surface profile through Rush Creek. The confluence is subject to flooding from not only Rush Creek but also the Root River. Rush Creek has a drainage area of only 132 square miles compared to the Root River at this location with a drainage area of 1,250 square miles. Therefore flooding from the Rush Creek watershed is more prone to intense summer rain events than flooding from the Root River watershed. Conversely, flooding from the Root River watershed is more prone to snowmelt flooding. Both rivers experience both conditions of flooding. Therefore, flooding from either source cannot be considered to be completely dependent nor independent on flooding from the other. Flood peaks do not occur simultaneously. In addition, timing of the respective peaks would also vary due to the size of the watersheds and other unique hydrologic factors.

To address this condition, a coincidental discharge-frequency analysis was done. First dates were sequenced for peak flooding on Rush Creek at the USGS gauging station 05384500. The corresponding flow magnitude was then determined for the Root River at Houston (gauging station 05385000). A discharge-frequency analysis was then performed on these coincidental flows for the Root River at Houston. Second, dates of peak floods on the Root River at Houston were sequenced and the corresponding coincidental flows on Rush Creek were determined. A discharge-frequency analysis was then done on these coincidental flows for Rush Creek at Rushford. Elevations for the Root River at the confluence were determined for each respective condition; coincident and peak. The elevations for the Root River at the confluence with Rush Creek were determined by a rating curve developed for this location. The Hydraulics Appendix describes the derivation of the rating curve on page B-2, paragraph 7.

Table 1 shows the years of record for each portion of the analysis. Not all years that were included in the peak discharge analysis were included in the coincidental analysis because they were not available.

Two scenarios were then modeled with the Hec-Ras hydraulic model. One scenario was the one percent coincident elevation for the Root River at the confluence, matched with the one percent flow on Rush Creek. The second scenario was the peak one percent elevation for the Root River at the confluence, matched with the coincidental flow from Rush Creek. The profile that resulted in the most critical elevation in the region of the confluence was then adopted. This profile was adopted through the reach until the effect of the flows from the Root River had diminished. There the peak discharge on Rush Creek was critical for the remaining reach upstream. Table 2 shows the results of this analysis.

Tables 3 and 4 show the coincidental flows used in the analysis at each gauge. They are ranked chronologically according to date and according to magnitude.

Table 1
Annual Peak and Coincidental Flows; Years of Record

	Annual Peak	Coincidental Peak	Flow Hydrograph
Rush Cr. nr Rushford	1942-07	1943-79	01 Oct 1942 - 20 Sept 1979
Root R. nr Houston	1911-17, 1930-83, 1985-07	1942-83, 1985-86, 1991-00, 2004-07	01 Oct 1909 – 01 Oct 1917 01 May 1929 – 22 Nov 1983 01 May 1929 – 22 Nov 1983 01 Oct 1990 – 01 Oct 2000 01 Jan 2004 - present

Table 2
Rush Creek at Rushford
Coincidental Discharge-Frequency Analysis

	Rush Creek		Root River	
	Annual Peak	Coincidental	Annual Peak	Coincidental
Event	Q cfs	Q cfs	Q cfs	Q cfs
10-yr	6,850	940	23,200	10,940
50-yr	14,100	2,450	36,800	22,920
100-yr	18,100	3,450	43,100	29,620
500-yr	29,600	6,990	58,700	49,400

Table 3.
Root River @ Houston, MN; Coincidental

Events Analyzed				Ordered Events			
			FLOW		Water	FLOW	Median
Day	Mon	Year	cfs	Rank	Year	cfs	Plot Pos
28	Jun	1942	973	1	2007	30,000	1.20
25	Mar	1943	6,300	2	1952	17,800	2.91
11	Mar	1944	2,100	3	1965	16,300	4.62
21	Jul	1945	7,660	4	1974	14,900	6.34
05	Jan	1946	1,100	5	1980	13,100	8.05
05	Apr	1947	4,000	6	1978	10,600	9.76
16	Mar	1948	950	7	1966	8,800	11.47
04	Mar	1949	500	8	1961	8,040	13.18
26	Mar	1950	5,790	9	1956	8,000	14.90
21	Jul	1951	643	10	1945	7,660	16.61
31	Mar	1952	17,800	11	1999	7,020	18.32
26	Jul	1953	3,680	12	1962	6,960	20.03
19	Jun	1954	2,480	13	1960	6,530	21.75
08	Jul	1955	1,440	14	1997	6,430	23.46
03	Apr	1956	8,000	15	1996	6,310	25.17
24	Feb	1957	385	16	1943	6,300	26.88
25	Feb	1958	1,330	17	1972	6,000	28.60
24	Mar	1959	1,720	18	1950	5,790	30.31
03	Jul	1960	6,530	19	1995	5,120	32.02
25	Mar	1961	8,040	20	2005	5,100	33.73
28	Mar	1962	6,960	21	1967	4,860	35.45
23	Mar	1963	3,500	22	1971	4,780	37.16
12	Mar	1964	304	23	1969	4,520	38.87
06	Apr	1965	16,300	24	2004	4,130	40.58
09	Feb	1966	8,800	25	1981	4,040	42.29
24	Mar	1967	4,860	26	1947	4,000	44.01
23	Jul	1968	975	27	1953	3,680	45.72
04	Apr	1969	4,520	28	1982	3,650	47.43
18	Jun	1970	1,810	29	2000	3,510	49.14
31	Mar	1971	4,780	30	1963	3,500	50.86
17	Mar	1972	6,000	31	1993	3,400	52.57
23	Aug	1973	2,790	32	1983	3,100	54.28
21	Jun	1974	14,900	33	1973	2,790	55.99
05	Jul	1975	1,360	34	1992	2,560	57.71
12	Mar	1976	580	35	1954	2,480	59.42
05	Jun	1977	1,320	36	2006	2,320	61.13
01	Jul	1978	10,600	37	1979	2,100	62.84
04	Aug	1979	2,100	38	1944	2,100	64.55
21	Sep	1980	13,100	39	1970	1,810	66.27
11	Jul	1981	4,040	40	1959	1,720	67.98
17	Mar	1982	3,650	41	1955	1,440	69.69
01	Jul	1983	3,100	42	1986	1,420	71.40
11	Mar	1985	1,420	43	1985	1,420	73.12
21	Sep	1986	1,420	44	1994	1,370	74.83
21	Jul	1991	881	45	1975	1,360	76.54
19	Nov	1991	2,560	46	1958	1,330	78.25
19	Apr	1993	3,400	47	1977	1,320	79.97
05	Mar	1994	1,370	48	1946	1,100	81.68
12	Mar	1995	5,120	49	1968	975	83.39
25	Mar	1996	6,310	50	1942	973	85.10
23	Mar	1997	6,430	51	1948	950	86.82
08	May	1998	897	52	1998	897	88.53
21	Jul	1999	7,020	53	1991	881	90.24
01	Jun	2000	3,510	54	1951	643	91.95
15	Sep	2004	4,130	55	1976	580	93.66
06	Feb	2005	5,100	56	1949	500	95.38
01	Apr	2006	2,320	57	1957	385	97.09
19	Aug	2007	30,000	58	1964	304	98.80

Table 4.
Rush Cr. @ Rushford, MN

Events Analyzed			FLOW	Ordered Events	Water	FLOW	Median
Day	Mon	Year	cfs	Rank	Year	cfs	Plot Pos
27	Mar	1943	100	1	1961	2,670	1.87
26	Feb	1944	400	2	1978	2,540	4.55
17	Mar	1945	36	3	1952	1,530	7.22
06	Mar	1946	420	4	1972	977	9.89
06	Apr	1947	187	5	1956	896	12.57
29	Feb	1948	76	6	1965	699	15.24
31	Mar	1949	603	7	1949	603	17.91
27	Mar	1950	420	8	1977	484	20.59
22	Jul	1951	382	9	1967	480	23.26
01	Apr	1952	1,530	10	1950	420	25.94
27	Jul	1953	265	11	1946	420	28.61
21	Jun	1954	46	12	1944	400	31.28
10	Mar	1955	217	13	1951	382	33.96
03	Apr	1956	896	14	1953	265	36.63
22	Jul	1957	62	15	1976	262	39.30
06	Jun	1958	33	16	1974	257	41.98
27	Jun	1959	53	17	1963	230	44.65
29	Aug	1960	158	18	1955	217	47.33
27	Mar	1961	2,670	19	1966	187	50.00
30	Mar	1962	135	20	1947	187	52.67
24	Mar	1963	230	21	1960	158	55.35
03	Apr	1964	40	22	1962	135	58.02
02	Mar	1965	699	23	1975	119	60.70
10	Feb	1966	187	24	1979	116	63.37
27	Mar	1967	480	25	1969	106	66.04
16	May	1968	93	26	1943	100	68.72
05	Apr	1969	106	27	1973	96	71.39
18	Jun	1970	40	28	1968	93	74.06
02	Apr	1971	85	29	1971	85	76.74
16	Mar	1972	977	30	1948	76	79.41
17	Apr	1973	96	31	1957	62	82.09
22	Jun	1974	257	32	1959	53	84.76
29	Apr	1975	119	33	1954	46	87.43
13	Mar	1976	262	34	1970	40	90.11
05	Jun	1977	484	35	1964	40	92.78
01	Jul	1978	2,540	36	1945	36	95.45
31	Mar	1979	116	37	1958	33	98.13

US Army Corps
of Engineers®

APPENDIX B

Hydraulic Analysis
of
Rush Creek

In the Vicinity of Rushford, Minnesota

U.S. Army Corps of Engineers

St. Paul District

April 2008

(Root River Coincidental Discharges & Starting Water Surface Elevations, Updated 7 May 2008)

Appendix B
Hydraulic Analysis of Rush Creek
In the Vicinity of Rushford, MN

General

1. Record rainfall that caused severe flooding occurred across parts of the Upper Mississippi River Valley in late August of 2007. This included the Root River basin in southeastern Minnesota. The Rush Creek watershed is a sub-basin of the Root River basin. Rushford is located in Fillmore County on the north bank of the Root River at the junction with Rush Creek. Rainfall over the 132 square mile Rush Creek watershed was estimated to average 12 inches of precipitation with local amounts as high as 15 to 17 inches. This resulted in a record flow of 38,400 cubic feet per second (cfs) on Rush Creek as estimated by the United States Geological Survey (USGS). As a comparison, the previous flood of record occurred on 26 March 1950 with a discharge of 11,600 cfs. The August 2007 flood overtopped the three levee reaches of the United States Army Corps of Engineers, St. Paul District (USACE) flood control project in Rushford. This flood control project, completed in 1968, consists of channelization of the Root River and Rush Creek, levees along the left (north) bank of the Root River, levees along both banks of Rush Creek and interior flood control facilities consisting of storm sewers, ponding areas, gravity outlets and pump stations. The major project features are shown on Plate B-1.

2. Based on the March 1965 General Design Memorandum (GDM) for the flood control project, the Rush Creek channel and levees were originally designed to provide three to four feet of freeboard for the then-computed 100-year discharge of 14,000 cfs. However, in October 1965 after higher level review, the design level of protection was changed to the 200-year flood with a then-computed discharge of 16,200 cfs. A subsequent hydrologic reanalysis in 1975, that included coordination with other agencies, resulted in a significant increase in the Rush Creek 100-year peak discharge to 21,100 cfs. A hydraulic analysis at that time indicated the Rush Creek channel and levees provided two to three feet of freeboard for the revised 100-year discharge of 21,100 cfs. Appendix A of this report presents an update of the hydrologic analysis including the period-of-record through the August 2007 record flow of 38,400 cfs. Discharges from this analysis are presented in the table on the following page. As a comparison, the 100-year discharge from this analysis is 18,100 cfs.

3. The August 2007 event and levee overtopping resulted in severe flooding of Rushford and also damaged the flood control project. Surveys of the Rush Creek channel, levees and bridges and the Root River levees were obtained by the USACE in November/December of 2007. The main purpose for obtaining these surveys was to develop plans to repair the flood control project to pre-flood conditions. However, these surveys were also used to develop a Hydrologic Engineering Center River Analysis System (HEC-RAS) steady flow model of Rush Creek. This model was developed for two reasons. The first reason was to develop velocity information for design of the replacement riprap in areas where the riprap was damaged during the August 2007 flood. The second reason was to compute water surface profiles for the August 2007 flood and other events. This report covers the HEC-RAS steady flow model development, results and conclusions regarding the 2007 flood.

4. The main goal of this analysis and report was to determine what caused the levees to overtop during the 2007 flood event and a secondary goal was to determine whether the Trail Bridge contributed to the levee overtopping.

5. All elevations in the HEC-RAS steady flow model and this appendix are in NGVD 1929.

HEC-RAS Model Development

6. The surveys, bridge drawings and discharges were supplied to the Minnesota Department of Natural Resources (MNDNR) and they developed the HEC-RAS model. The model was supplied to the USACE on 26 March 2008. Minor changes were made to the model which included adding several cross sections, changing the contraction/expansion coefficients at two cross sections, checking the model calibration and analyzing starting water surface elevation impacts.

7. Plate B-2 shows a schematic of the HEC-RAS model. Cross sections were developed from the surveys. Two example cross section plots are shown on Plate B-3. The bridge input was developed from the surveys and Minnesota Department of Transportation drawings. Plots of the Trail Bridge and Park Street Bridge are shown on Plate B-4. Four scenarios were considered for starting water surface elevations to determine the impact on the Rush Creek water surface profiles. The four scenarios were a USGS rating curve upstream of Highway 16/43, a USACE rating curve at the mouth of Rush Creek based on the 1965 GDM for the flood control project, normal depth and critical depth. The USGS and USACE rating curves are shown on Plate B-5. It should be noted that high flows on the Root River are often affected by back water from Rush Creek; therefore, the USGS considers the elevation-discharge relationship to be poor. The USGS is considering moving the gage farther upstream to eliminate this issue. Discharges for the 10-, 50-, 100- and 500-year events based on the discharge-frequency analysis presented in Appendix A along with starting water surface elevations are summarized in the following table.

Rush Creek Starting Water Surface Elevation Scenarios
(Root River Coincidental Flow & Starting Water Surface Elevation Updated 05/01/08)

Recurrence Interval	Rush Creek Annual Peak in cfs	Root River Coincidental Flow in cfs (Updated 2 May 2008)	Starting Water Surface Elevation (NGVD 1929)			
			USGS Rating Curve Upstream of Highway 16/43 Updated 7 May 2008 (1)	USACE Rating Curve at Mouth of Rush Creek Updated 7 May 2008 (1)	Normal Depth (2)	Critical Depth (3)
10-Year	6,850	10,940	724.0	721.5	720.78	716.56
50-Year	14,100	22,920	725.7	724.2	723.79	720.71
100-Year	18,100	29,620	726.2	725.4	724.57	724.03
500-Year	29,600	49,400	727.4	728.6	726.33	725.33

(1) – Starting water surface elevations based on the rating curves were updated based on an update of the Root River coincidental flows.

(2) – Calculated by program based on an entered energy slope of 0.0016 feet/foot which is the approximate channel bottom slope.

(3) – Calculated by program based on discharge and cross section.

8. Manning's "n" values were based on standard references and engineering judgment. The model calibration was checked, but high water mark data in Rushford was only available for April 1965 and June 1974. Data was also available for the 2007 flood event, but the in-channel discharge varied due to the levee overtopping so this data could not be used for the steady flow model. The water surface profiles for the April 1965 and June 1974 events are shown on Plate B-6. The water surface profiles at the upstream side of the Highway 43 Bridge are about 0.7 feet higher than the observed high water marks for both events. Further calibration was not done because the Manning's "n" values used for the channel and overbanks in the project reach were considered the minimum reasonable. The main channel Manning's "n" of 0.030 was considered the minimum reasonable for a straight channel with some pools, weeds and rocks. The overbank Manning's "n" of 0.033 was considered the minimum reasonable for the short grass and riprap. Contraction and expansion coefficients are generally 0.1 and 0.3, respectively, except at the bridges where they are increased to 0.3 and 0.5.

HEC-RAS Model Results

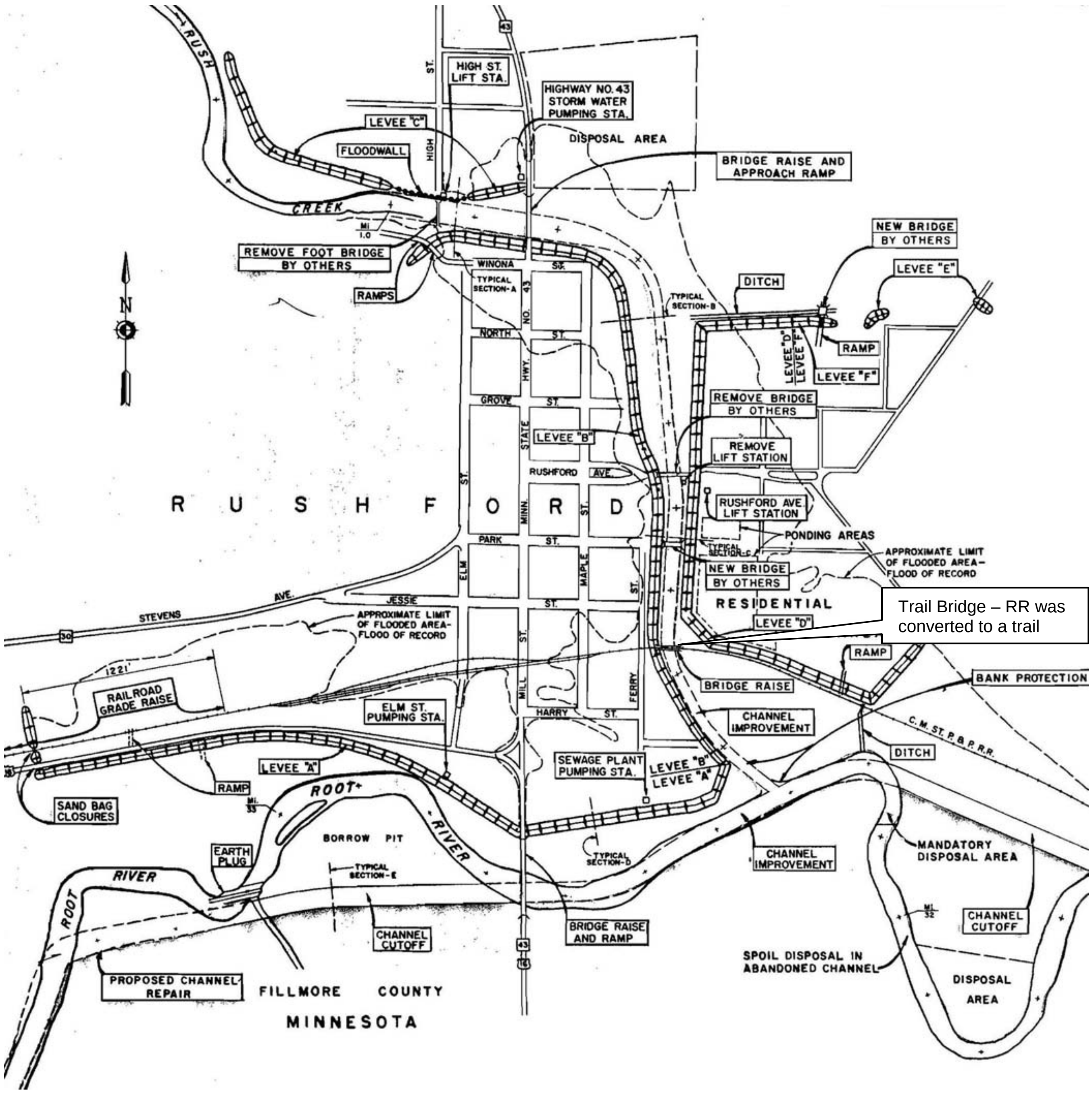
9. Water surface profiles were developed for the 10-, 50-, 100-, and 500-year events for the four starting water surface elevation scenarios discussed in paragraph 4. The water surface profiles for the four events with the USGS rating curve starting water surface elevations are shown on Plate B-7. The 100-year profile with the four different starting water surface elevation scenarios are shown on Plate B-8. As can be seen, the profiles converge before the Trail Bridge. A review of the 50- and 500-year profiles indicates that these profiles also converge before the Trail Bridge. However, the 10-year profiles do not converge until farther upstream at about cross section 31. All further analysis was based on the USGS rating curve starting water surface elevations which were generally the highest of the four scenarios. These profile plots also show the left (east) and right (west) bank levee profiles.

10. The 2007 flood event was analyzed next. The starting water surface elevation was based on the high water elevation at the Highway 16/43 Bridge. The steady flow model developed for Rush Creek assumes that all flow is contained levee to levee even if the levees are overtopped. The in-channel flow continuing downstream is not reduced by the amount of flow overtopping the levees. This approach will overestimate the water surface profile because the flow is not reduced. However, if computed water surface profile is higher than the levee profiles, it will indicate that the 2007 flood event exceeded the capacity of the Rush Creek channel and levees. To determine whether the Trail Bridge contributed to the levee overtopping, the model was run with the bridge removed. Plate B-9 shows the 2007 flood profiles assuming all flow is contained levee to levee with the Trail Bridge in-place and removed. The water surface profiles are generally three to four feet higher than the levee profiles, so it is obvious that the 2007 event exceeded the capacity of Rush Creek channel and levees and that is the reason why the levees overtopped.

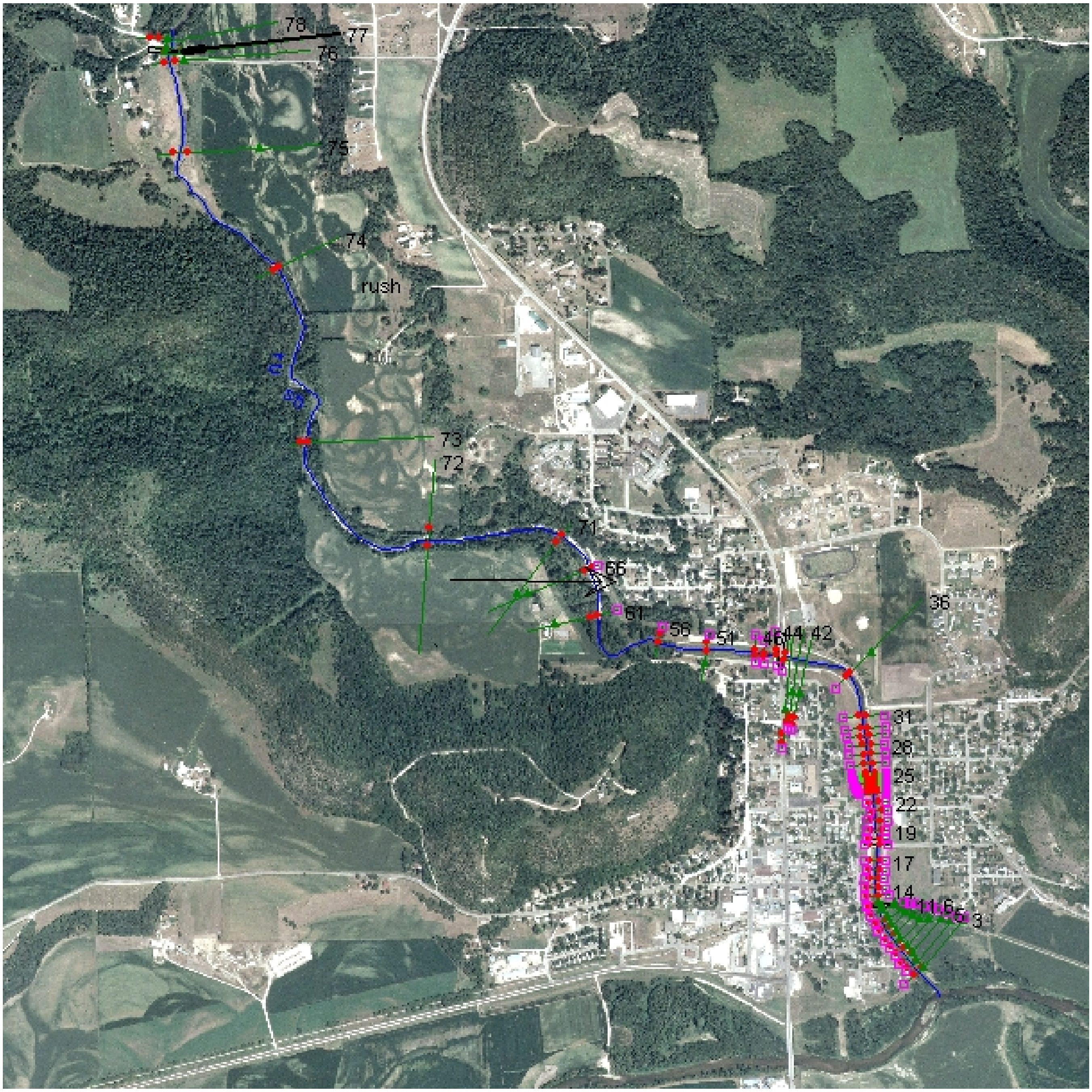
11. The 2007 event profile with the Trail Bridge removed is lower than the profile with the bridge in-place between the Trail Bridge location and the Park Street Bridge. Above the Park Street Bridge, the profiles are essentially the same. Since the actual levee overtopping locations

were upstream of the Park Street Bridge, this indicates the Trail Bridge did not contribute to the levee overtopping. On Plate B-9, the computed water surface profile exceeds the top-of-levee profile by a small amount just upstream of the Trail Bridge. This is caused by the higher in-channel discharge resulting from the steady flow model. If an unsteady flow model were developed, the water surface profile would not be higher than the levees at this location. Note that this analysis does not include plugging of any of the bridges, including the Trail Bridge. However, this is not considered significant because the levees did not overtop between the Trail Bridge and the Park Street Bridge and because the steady flow analysis shows the 2007 event profile so much higher than the levees. The 10-, 50-, 100- and 500-year profiles were also run with the Trail Bridge removed. The 100- and 500-year water surface profiles with the bridge in-place and removed are shown on Plates B-10 and B-11, respectively. As can be seen, there is almost no difference between the profiles for the 100-year event and a small difference for the 500-year event. This supports the conclusion that the Trail Bridge did not contribute to the levee overtopping.

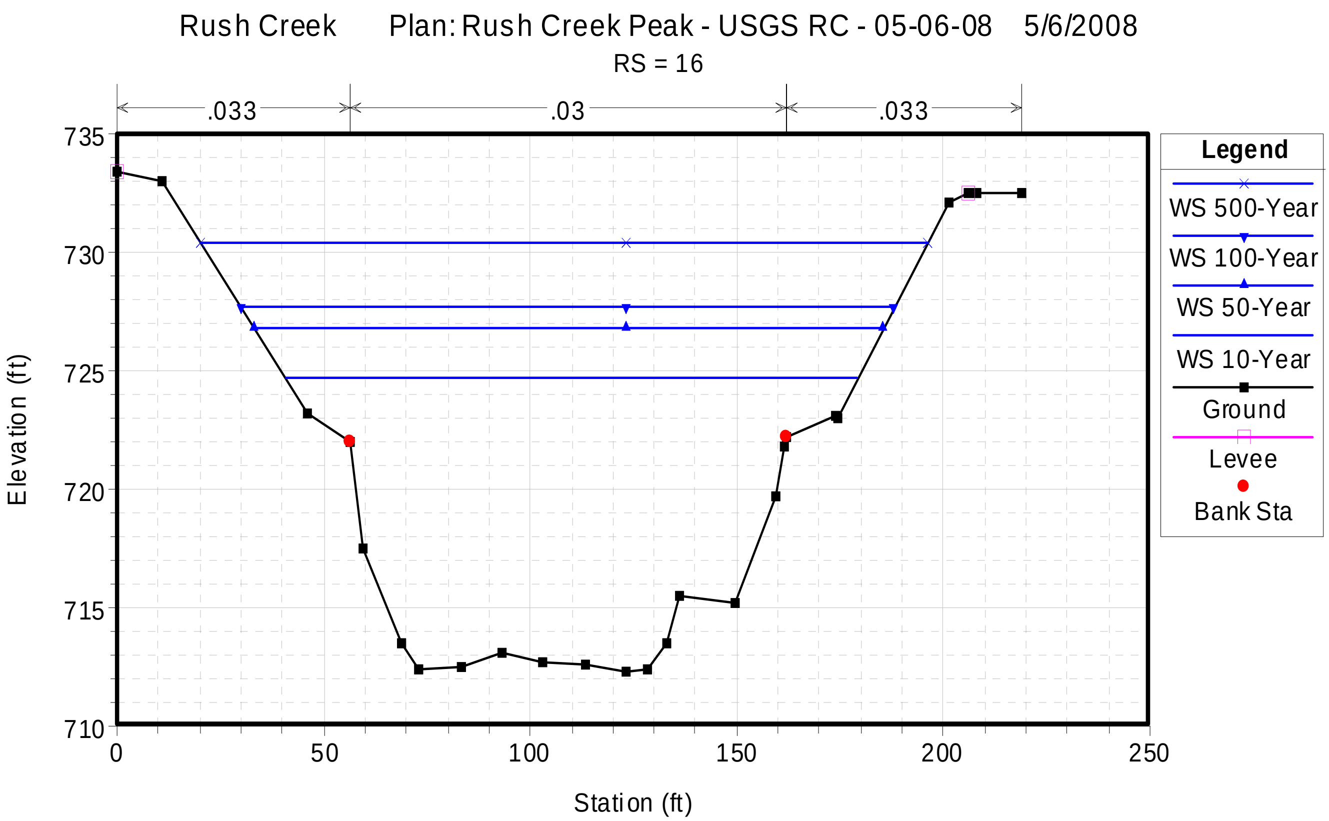
12. The 2007 flood event was an unsteady flow event and a better approach would have been to analyze it with an unsteady flow model. An unsteady flow model would have accounted for the levee overtopping and reduced the in-channel discharge downstream of each overtopping location. This would have resulted in a computed water surface profile that more closely matched what happened. It was decided that the unsteady flow model was not necessary since the steady flow analysis demonstrated that the levees overtopped because the 2007 event greatly exceeded the capacity of Rush Creek channel and levees and that the Trail Bridge did not contribute to the levee overtopping.



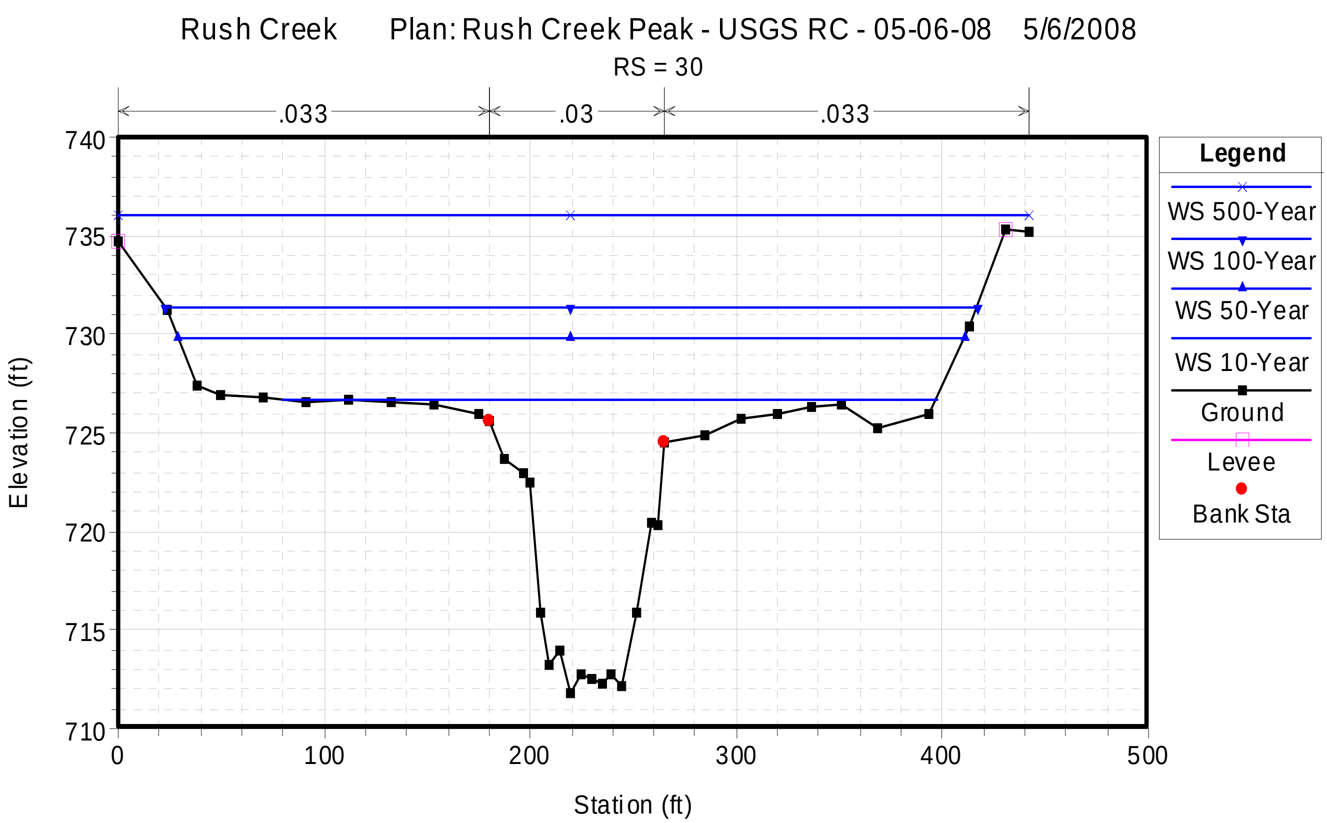
General Schematic of Project Features



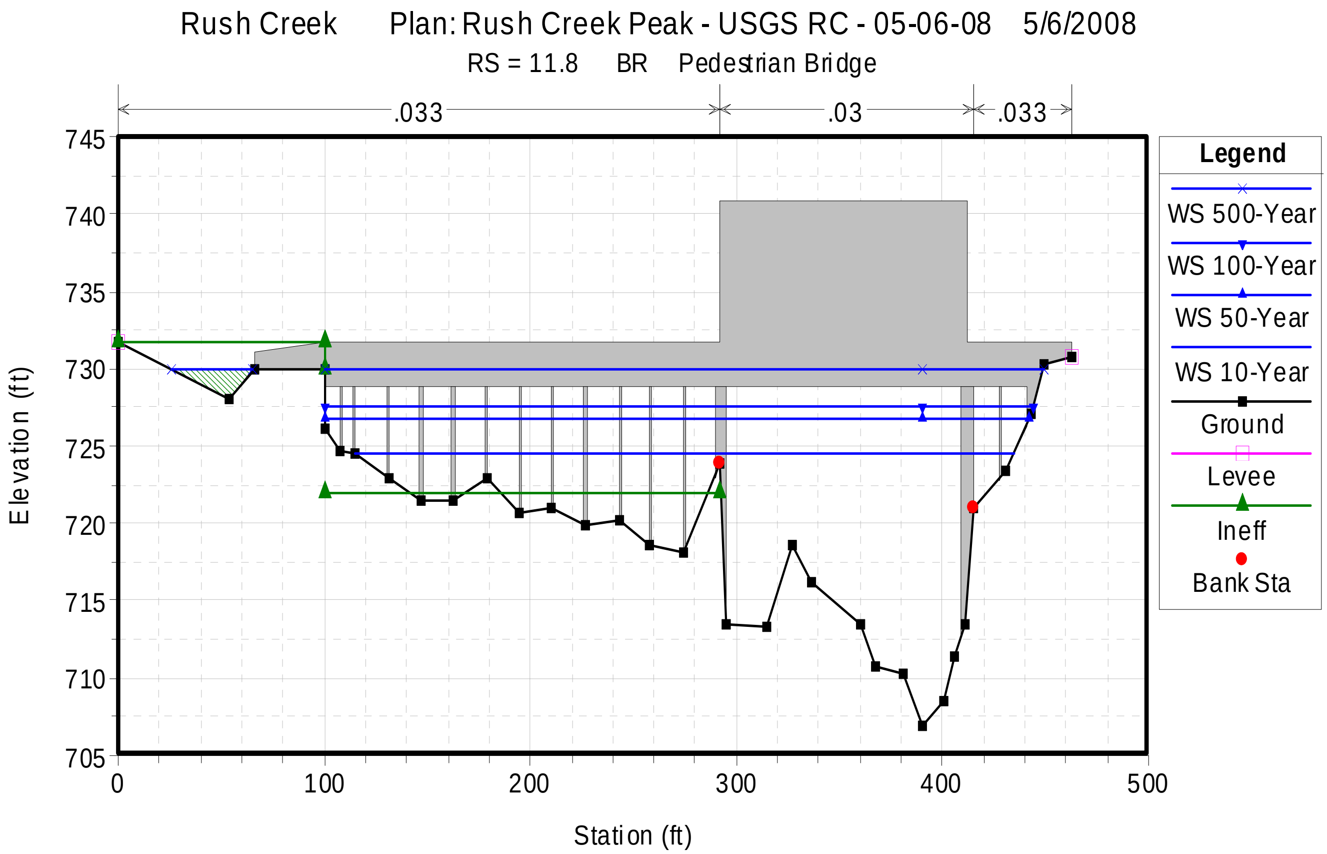
HEC-RAS Model Schematic



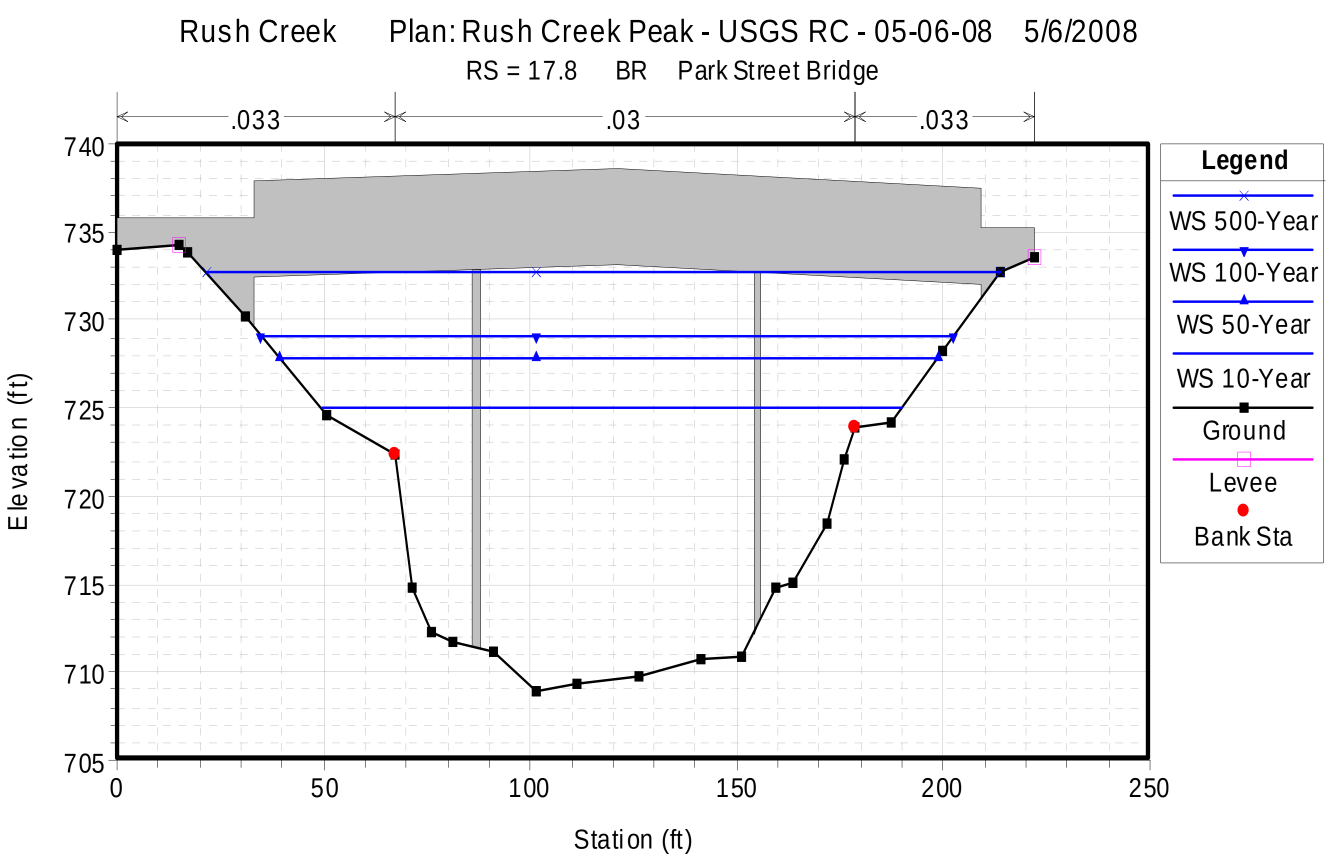
Rush Creek Cross Section 16 – Just Downstream of Park Street Bridge



Rush Creek Cross Section 30 – Downstream of Dry Run



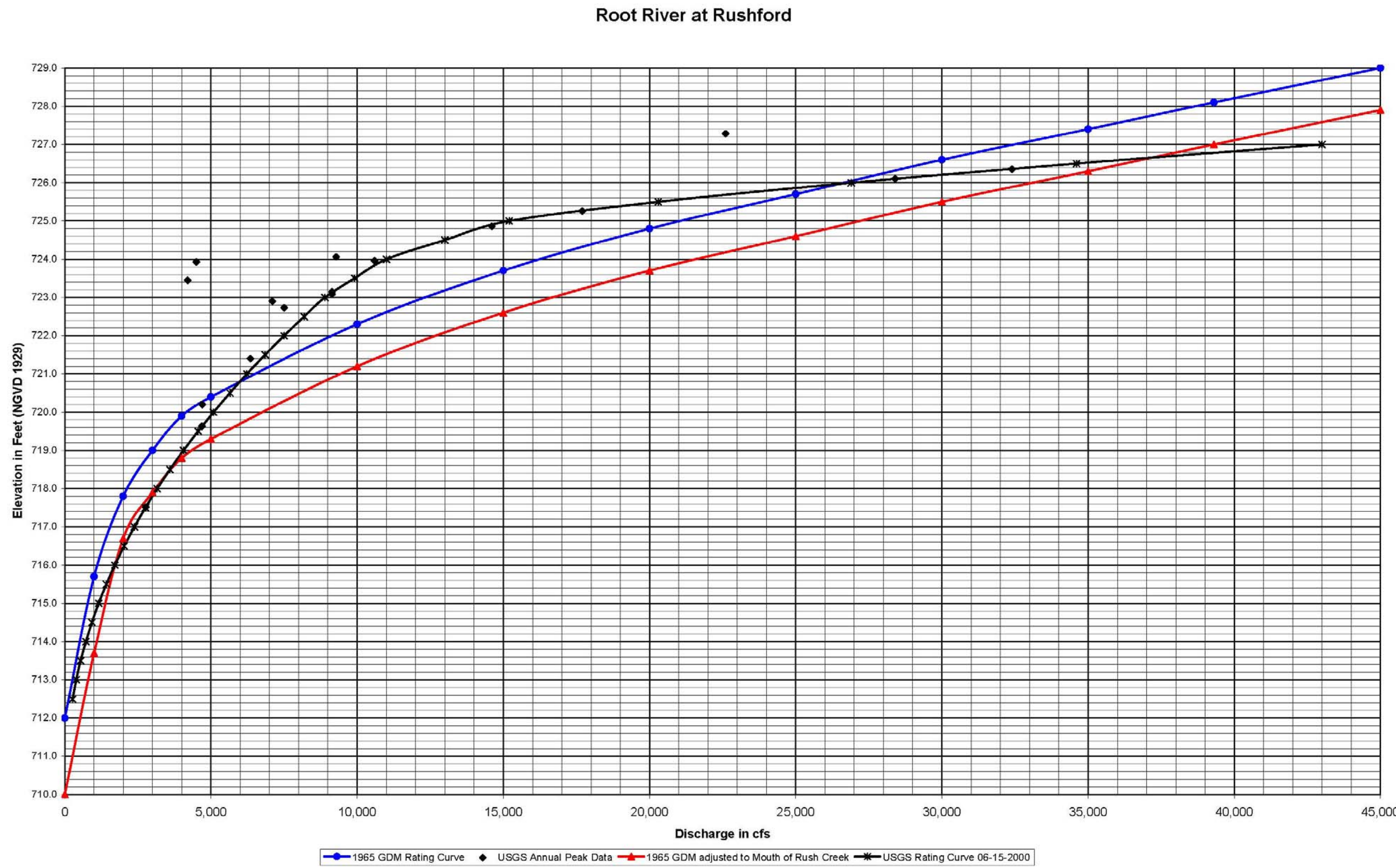
Rush Creek – Trail Bridge



Rush Creek - Park Street Bridge

Plate B-4

Updated 7 May 2008



Root River at Rushford
729.0
728.0
727.0
726.0
725.0
724.0
723.0
722.0
721.0
720.0
719.0
718.0
717.0
716.0
715.0
714.0
713.0
712.0
711.0
710.0
Elevation in Feet (NGVD 1929)
0
5,000
10,000
15,000
20,000
25,000
30,000
35,000
40,000
45,000
Discharge in cfs
1965 GDM Rating Curve
USGS Annual Peak Data
1965 GDM adjusted to Mouth of Rush Creek
USGS Rating Curve 06-15-2000

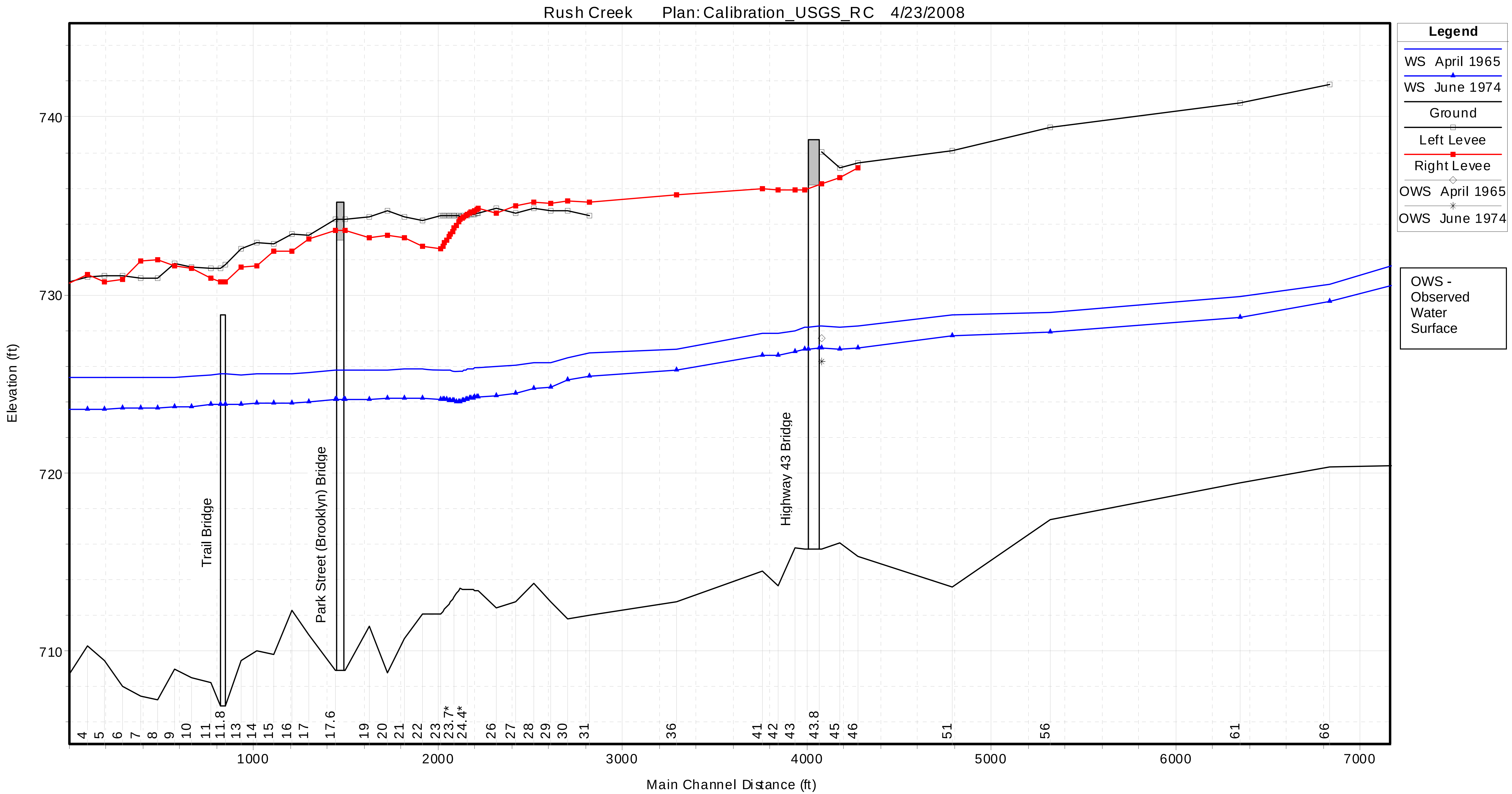
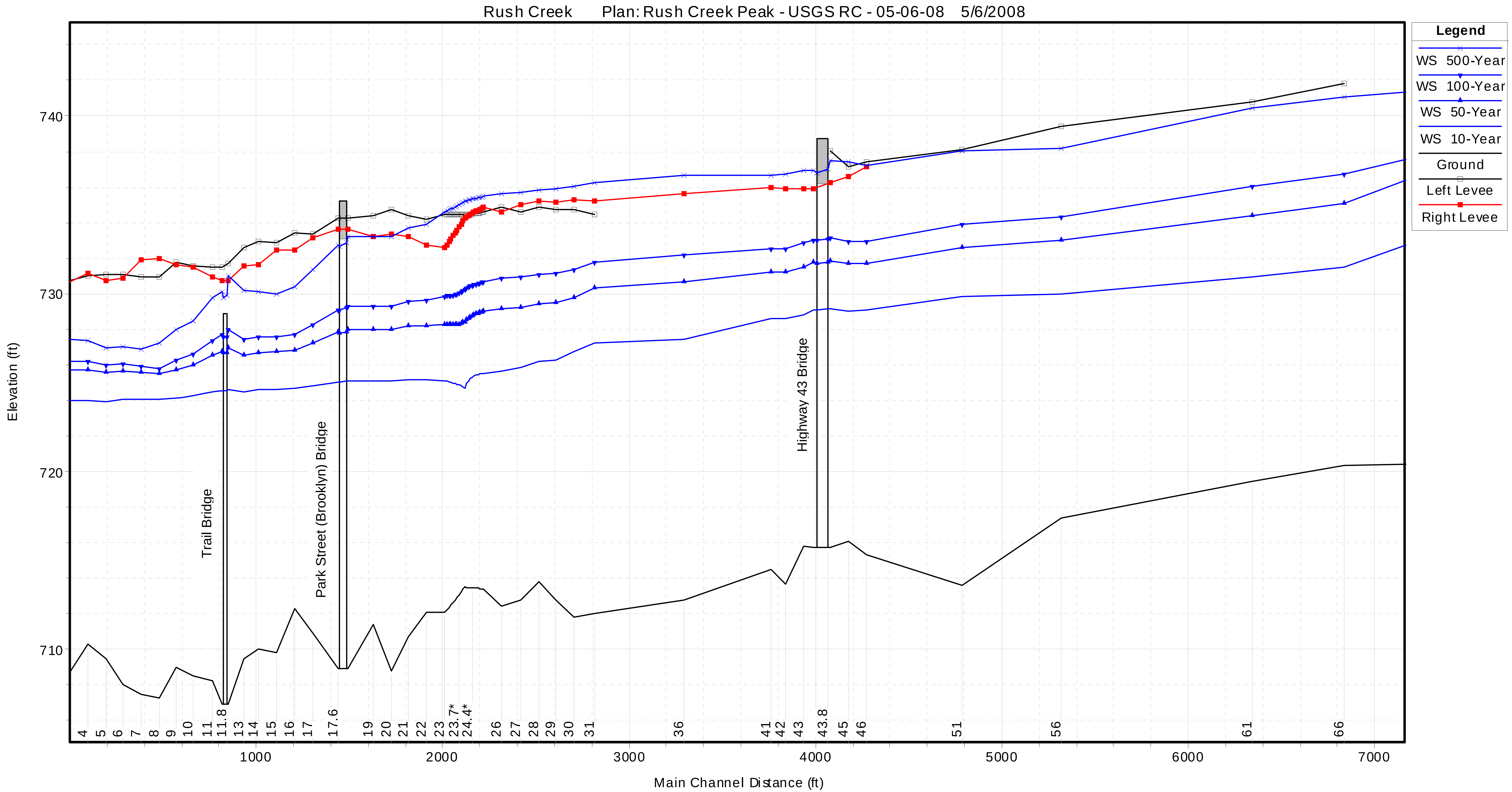


Plate B-6

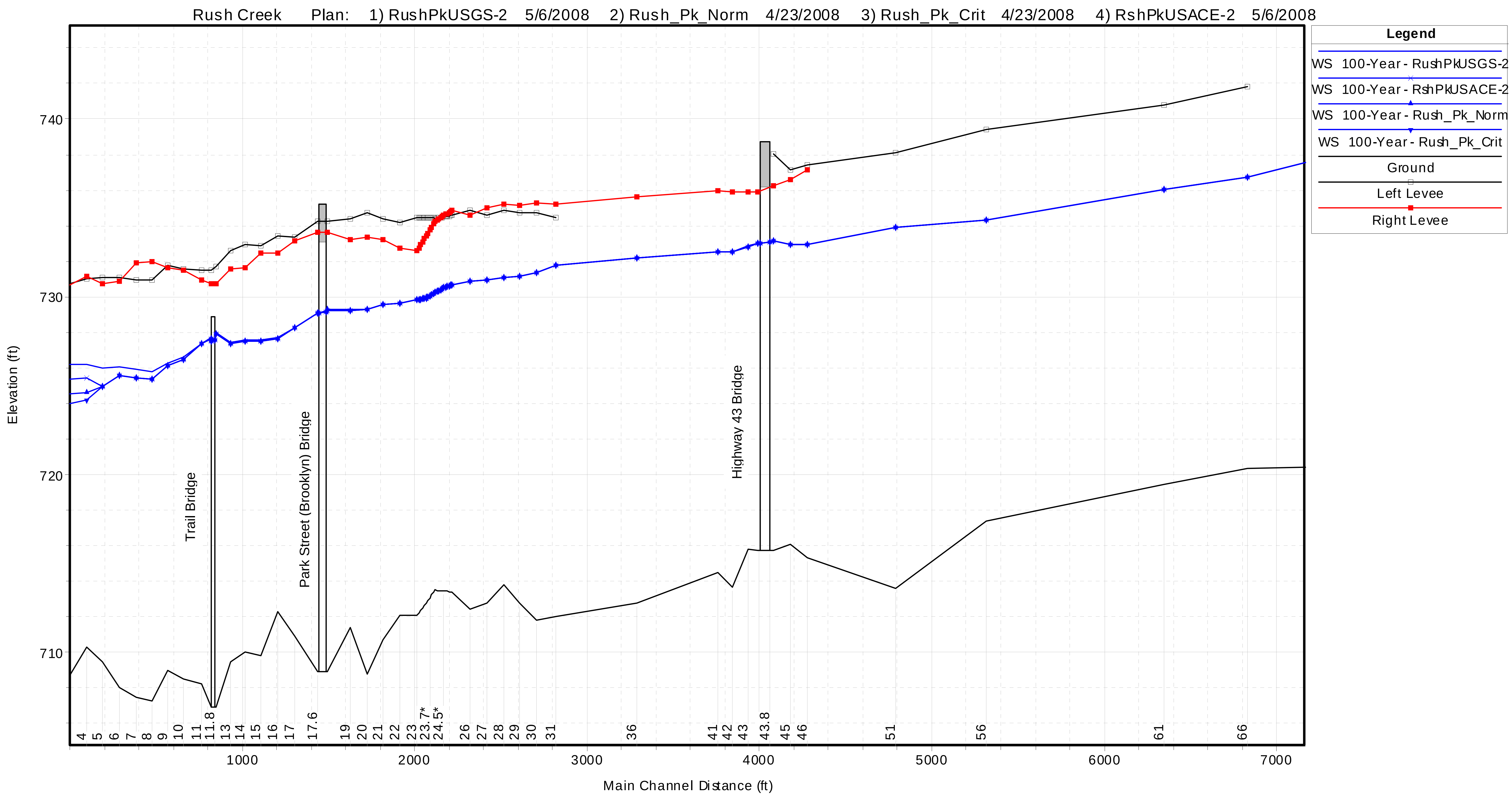
Updated 7 May 2008



10-, 50-, 100- and 500-Year Water Surface Profiles with USGS Rating Curve Starting Water Surface Elevations

Plate B-7

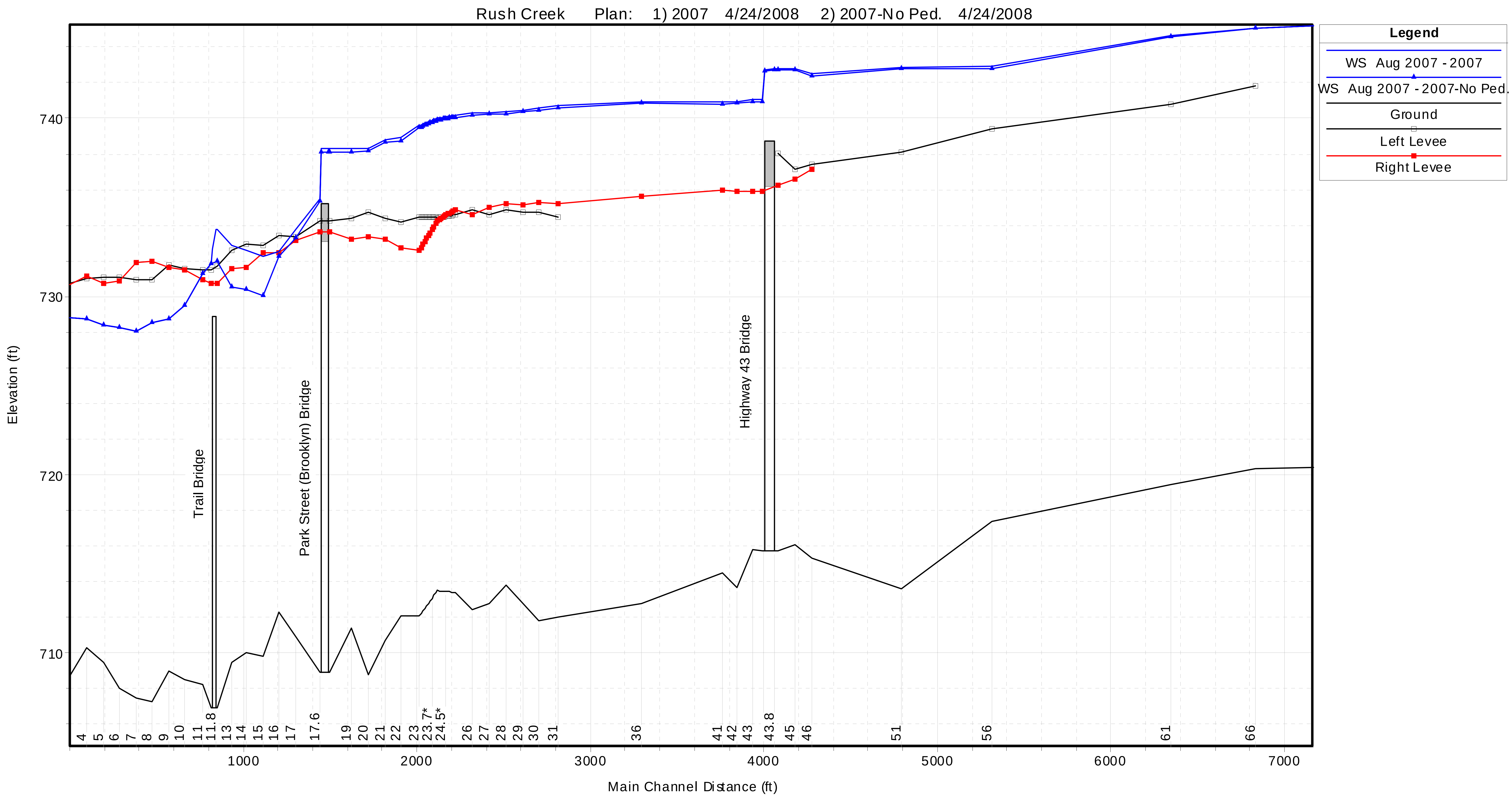
Updated 7 May 2008



100-Year Event – With Starting Water Surface Elevations based on USGS Rating Curve, Normal Depth, USACE Rating Curve and Critical Depth

Plate B-8

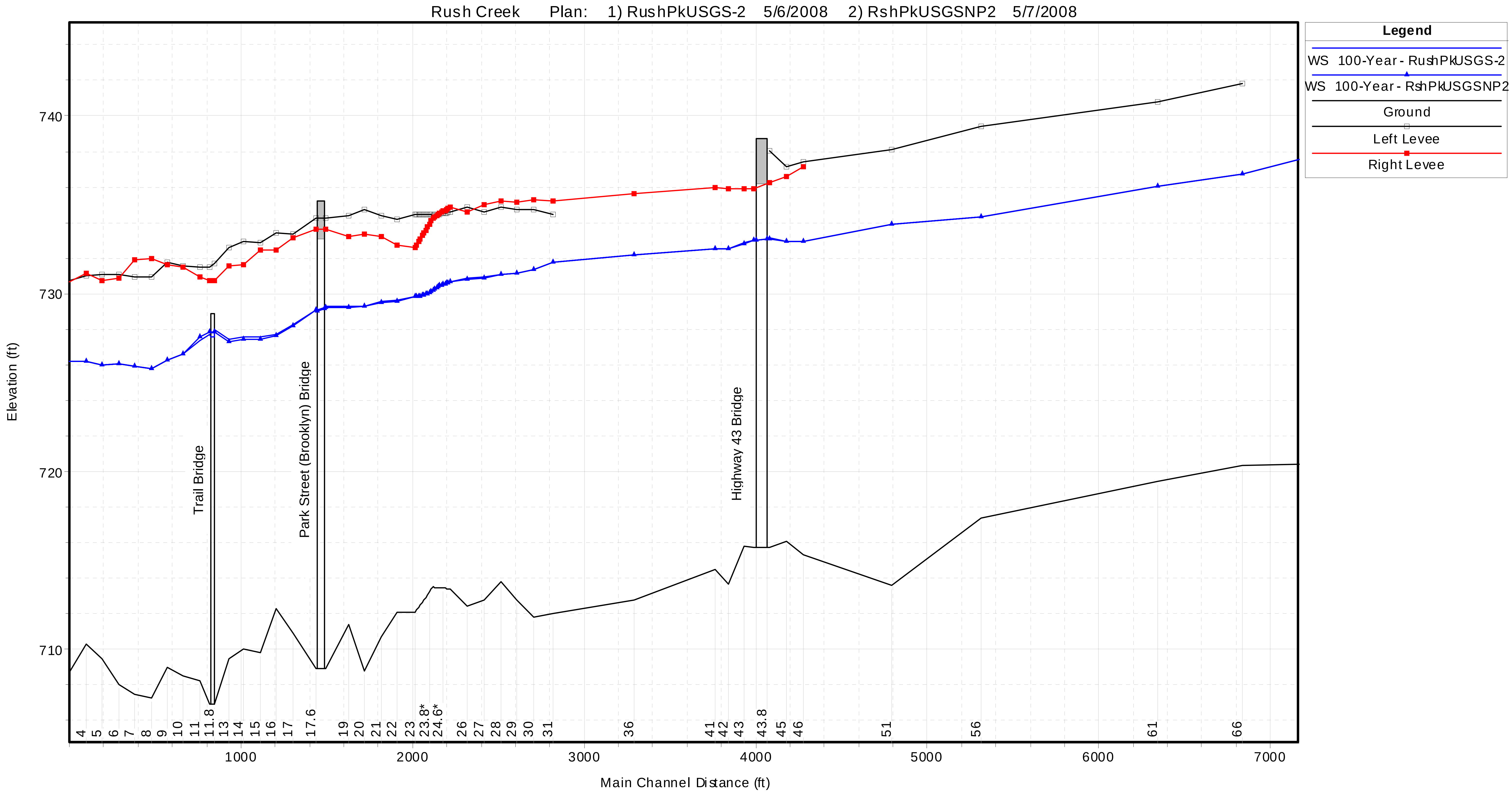
Updated 7 May 2008



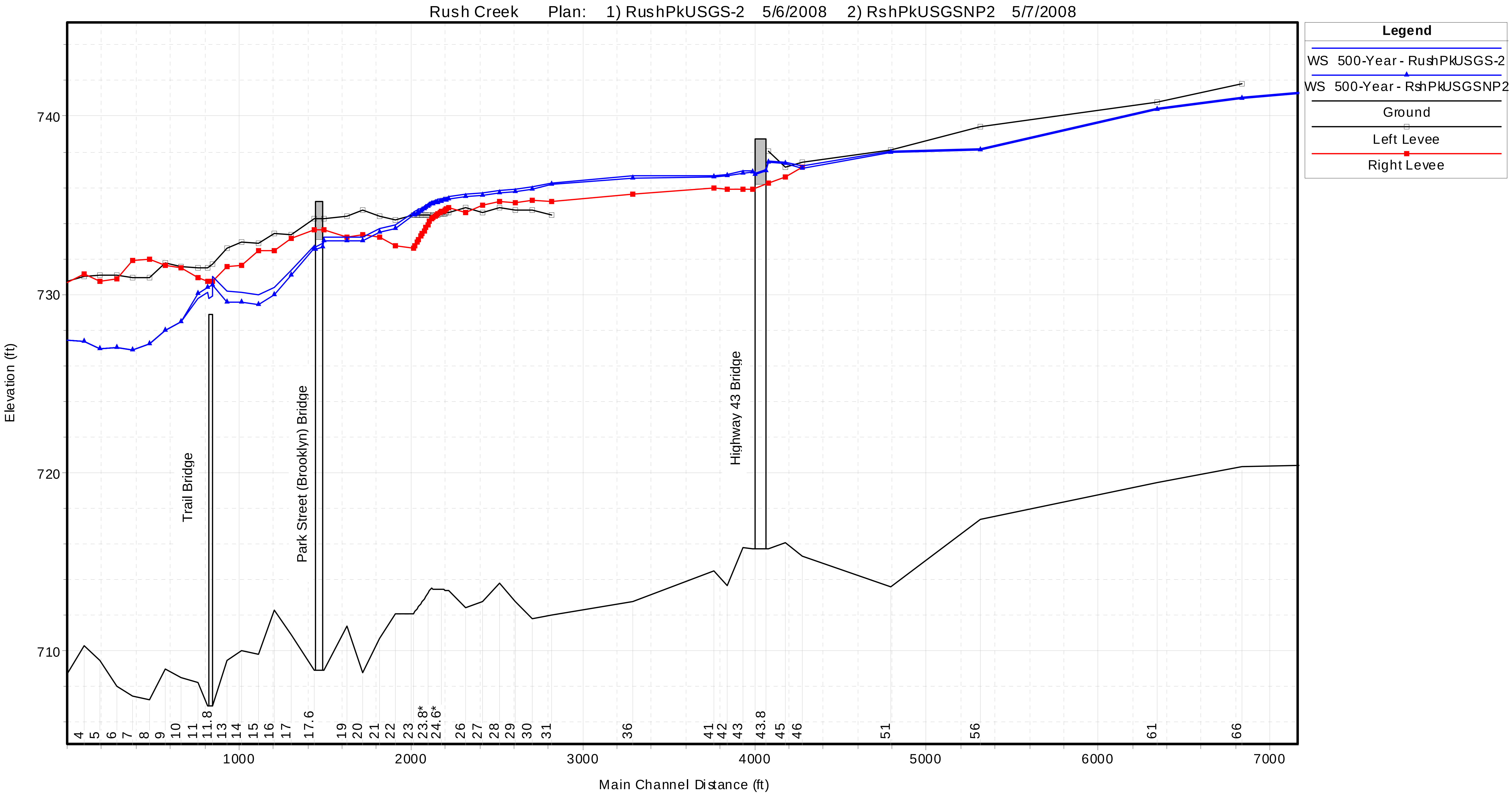
August 2007 Flood – With & Without Trail Bridge, Starting Water Surface Elevation based on USGS Rating Curve

Plate B-9

Updated 7 May 2008



100-Year Event – With & Without Trail Bridge, Starting Water Surface Elevation based on USGS Rating Curve



500-Year Event – With & Without Trail Bridge, Starting Water Surface Elevation based on USGS Rating Curve

Plate B-11

Updated 7 May 2008