Appendix A-4b
Hydrology

Fargo-Moorhead Metropolitan Area Flood Risk Management

Supplemental Draft Feasibility Report and Environmental Impact Statement

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US Army Corps of Engineers®

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Preface

As described in the preface to Appendix A-4a, the hydrology associated with the Red River Reach between Fargo and Halstad had to be refined in order to produce improved hydraulic modeling results downstream of Fargo, ND. One of the major study areas that had to be improved upon was the hydrology associated with the Lower Sheyenne River Basin. The Lower Sheyenne River is hydrologically complex due to the effects of regulation, breakout flows and tributary inflow. Additionally, after the downstream impacts of the project, developed in earlier phases of analysis were analyzed, the USACE determined that they were not fully definable and another approach was needed. The USACE and local project sponsors decided to pursue an option that included raising water levels, or staging, upstream of the Fargo-Moorhead Metro area. This proposal would include constructed storage areas as well as natural storage options. To develop a design that incorporates the benefits of upstream storage and staging, an unsteady flow model was required for the study area. The unsteady model requires synthetic balanced hydrographs representative of points of interest in the basin as boundary conditions.

There are two major tributaries to the Lower Sheyenne River: the Maple River and the Rush River. The first section of this Appendix discusses the Maple River. The flows associated with the Maple River are affected by the Maple River Dam. It was necessary to model the Maple River in order to develop a homogenous flow record on the Maple River at Mapleton representative of the current conditions on the Maple River (dam in place). Utilizing this homogenous record, annual instantaneous flow-frequency analysis could be carried out at points of interest along the Maple River in order to produce balanced hydrographs associated with the 0.2-, 0.5-, 1-, 2-, 3-, 4-, and 5-% exceedance frequency events. These balanced hydrographs are utilized as inputs to hydraulic modeling. Similarly, annual instantaneous flow-frequency analysis and subsequent balanced hydrographs were developed for the Rush River. Balanced hydrographs representative of local flow in this portion of the Lower Sheyenne River Basin were also required.

There are three major points of interest along the Sheyenne River between Lisbon and its confluence with the Red River of the North: Gol Bridge, Kindred and West Fargo. These locations are effected by breakout flows and regulatory effects. Annual Instantaneous peak flow-frequency and volume duration curves are developed at each of these locations. Using the results of the flow frequency and volume duration analysis balanced hydrographs can be developed at these locations. The balanced hydrographs are used as input to the Lower Sheyenne River HEC-RAS model as a hydrograph boundary conditions.

While Sections 1-4 of this Appendix focuses on developing balanced hydrographs, to serve as boundary conditions for hydraulic modeling, Section 5 provides analysis used to develop design parameters for the Fargo-Moorhead Metro Project. Section 5 includes a description of how coincidental discharge frequency values and balanced hydrographs are determined for the 0.2-, 1-, 2-, and 10-% exceedance frequency events for locations upstream and downstream of Fargo in order to develop the design for appurtenant structures on the Sheyenne, Maple and Rush River tributaries.

1. Maple River

The Maple River is a tributary of the Sheyenne River. The Maple River flows in a northeastward direction. The confluence of the Maple River with the Sheyenne River is located about 4 miles north of West Fargo, ND. The banks of the Maple River can be described as urban land, agricultural land and open space land. Maple River flooding usually occurs as a result of the spring snowmelt runoff. Floodwaters in the Maple River rise at a slow rate. The duration of Maple River flooding is expected to be within the range of 2-5 days for each notable flood event (source: *Flood Hazard Analysis*).

1.1 GEOMORPHOLOGY

Soils within the Maple River watershed range from medium textured loam and clay loam soils to light textured sandy loam soils with heavy silty clay soils being formed on the lacustrine sediments of glacial Lake Agassiz. At Enderlin, ND the Maple River flows through the Maple Delta deposits and along the north edge of the Sheyenne River Delta. Between Enderlin and the Maple River Dam, the Maple River is deeply entrenched in the Maple Delta and thus no breakout flows are expected to occur.

As the Maple River leaves the Maple River Delta downstream of the Maple River Dam it meanders across a 7-mile wide belt of stratified gravel, sand, silt and clay shore deposits, which were formed on a wave eroded till surface. It continues its meandering course across the nearly level, featureless glacial Lake Agassiz lacustrine plain. This is where breakout flows commonly occur (Source: Flood Hazard Analysis).

1.2 AVAILABLE USGS STREAMFLOW DATA

There are five USGS streamflow gages located on the Maple River:

- USGS Gage 05056100 located Downstream of Mapleton, ND
- USGS gage 05056000 located Upstream of Mapleton, ND
- USGS Gage 05059715 located above the Maple River Dam near Sheldon, ND
- USGS Gage 05059700 located near Enderlin, ND
- USGS gage 05059600 located near Hope, ND.

A map displaying USGS gage locations on the Maple River can be found in **Figure 1.**

The USGS gage near Hope, ND was not utilized in this analysis because it is located near the headwaters of the Maple River and thus its flow record is not representative of the hydrologic characteristics of the river reach between Enderlin and Mapleton. The available USGS daily streamflow data associated with the Enderlin and Mapleton gages is visually described in **Figure 2**.

There are two USGS gages on the Maple River located near the city of Mapleton, ND. The original gage is located downstream of Mapleton. An additional gage was installed upstream of Mapleton in order to avoid recording breakout flows from the Sheyenne River. Breakout flows occur on the mainstem of the Sheyenne River near Kindred, ND and flow into the Maple River just downstream of Mapleton, ND. Currently both gages are functioning at Mapleton. The upstream gage is used primarily during spring flood events. A combination of the two gages is used for this analysis. For the dates when the two gages are functioning concurrently the flow data observed at the upstream gage is utilized.

As can be seen from **Figure 2** there are some gaps in available streamflow data on the Maple River. The Enderlin USGS gage only begins recording flow data in 1957. Neither Mapleton gage is functioning during the period between 1976 and 1994. The portion of the period of record prior to 1957 and 1976-1994 are not used in this analysis. The daily flow record at Mapleton is necessary in order to develop a local flow for the contributing area between Enderlin and Mapleton.

USGS Gage 05059715, located on the Maple River above Maple River Dam near Sheldon, ND, measures discharge and water surface elevation at the dam. The water surface elevation being reported by the gage is the Maple River Dam pool elevation, while the discharge measurements being recorded are the dam's outflow based on the Maple River Dam outflow rating curve. Any flows below 300 cfs are not computed because the Maple River Dam functions as a dry dam. Data is available at this gage for the 2009 Spring Flood Event, the 2010 Spring Flood Event and for two smaller events that occurred during the spring and early summer of 2007.

1.3 DRAINAGE AREAS

The contributing drainage areas associated with the Enderlin and Mapleton gages can be acquired from the USGS. There are 23 square miles of non-contributing area between Enderlin and Mapleton. From **Figure 3,** it is evident that most of the natural storage sites (ponds, small lakes etc.) that make up the non-contributing area are located in the drainage area between Enderlin and the Dam.

Table 1 lists pertinent drainage areas. The drainage areas associated with the reach between the Maple River Dam and Durbin, ND can be estimated using NRCS/USGS Hydrologic Unit Code (HUC) data.

Table 1. Significant Drainage Areas

Gage Location/ Reach	Total D.A (Sq.mi.)	Contributing D.A (Square Miles)	Non-Contributing D.A (Square Miles)
Enderlin USGS Gage	843	796	47
Mapleton USGS Gage	1450	1, 380	70
Enderlin to Mapleton	707	584	23
Maple River Dam	906		
Enderlin to Maple River Dam	63	40	23
Swan Creek		129	
Buffalo Creek		192	
Maple R. Dam to Durbin		205	

1.4 MAPLE RIVER DAM

The construction of the Maple River Dam was authorized by the 1986 Water Resources Development Act, P.L. 99-662. The dam was designed by Moore Engineering. Construction of the Dam began in fall of 2004 and the project was completed in fall of 2006. The Dam consists of a low flow, run of the river, 66” R.C.P.P with a control elevation of 990 NGVD 29, a 125’ wide concrete baffle block chute with a control elevation of 1,048 NGVD 29, and a 1,200 food wide earthen emergency spillway with a control elevation of 1, 055 NGVD 29. The Maple River Dam was constructed in order to reduce the depth and duration of flooding along the Maple, Sheyenne, Rush and Red Rivers in eastern North Dakota. An aerial photograph of the dam can be found in **Figure 8**. The Maple River Dam functions as a dry dam.

1.5 MAPLE RIVER DAM

The Maple River model developed for the Fargo Moorhead Metro Feasibility Study extends from USGS gage 05059700 located near Enderlin, ND to USGS gage 05056000 located upstream of Mapleton, ND. The purpose of this model is to analyze the effects of the Maple River Dam on flow in the Red River basin and to develop a means of generating a homogenous flow record at Mapleton. A diagram displaying the HMS schematic used for modeling the Maple River can be found in **Figure 12.**

1.5.1 Routing Parameters

Muskingum-Cunge routing is utilized to model Maple River flow between Enderlin and Mapleton. Eight point cross sections, reach length, and channel slope are obtained from a *Flood Hazard Analyzes of the Maple River* published by the USDA in 1981. The reach lengths used in the model can be found in **Table 2**. Cross sections are displayed in **Figure 4**.

Table 2. Watershed information used for Routing

Gage Location/ Reach	River Mile/ Reach Length (mile)	Source
Enderlin USGS Gage	105.02	USGS
Maple River Dam (MRD)	88.3	Moore Engineering
Enderlin to MRD	16.72	Computed
Mapleton USGS Gage	20.1	USGS
MRD to Mapleton	68.2	USGS

Based on aerial images of the Maple River it was determined that appropriate Manning's "n" values for the Maple River channel is 0.045 and is 0.05 for the flood plain. This is based on the high degree of sinuosity associated with the channel, as well as vegetation and land usage. The floodplain within the Maple River watershed is composed primarily of agricultural land and open space land. Samples of the imagery used to make this determination can be found in **Figure 5 - Figure 7**. This conforms to the Manning's "n" used in the Sheyenne River geomorphology study prepared by West Consultants, Inc for the Corps of Engineers in 2001.

1.5.2 Hydraulic Control Structures: Maple River Dam

The dam's storage capacity was modeled in HEC-HMS using an elevation-storage relationship developed using LIDAR data. This relationship is displayed in **Figure 9**. The outflow from the Dam was modeled as a single specified spillway (as advised by HEC modelers) utilizing an Elevation Discharge Function provided by the USGS. The USGS has made adjustments to the original rating curve for the dam (provided by Moore Engineering) based on field measurements recorded just downstream of the dam. This relationship is displayed in **Figure 10**.

1.5.3 Local Inflow & Breakout flows

1.5.3.1 Breakout flows

Based on conversations with Moore Engineering and their field experience with the Maple River watershed, it can be assumed that during large flood event like the 2009 event breakout flows occur between the Maple River Dam and Mapleton. Much of these breakout flows occur near Durbin, ND and are likely on the order of 1,000-3,000 cfs. These breakout flows re-enter the Sheyenne River prior to its confluence with the Red River of the North. The breakout flows near Durbin,ND drain into Cass County Drain 14 as depicted in **Figure 11.**

In order to accurately model flows at Mapleton these breakout flows were accounted for within the local flow inputs used to calibrate the model. Because these breakout flows re-enter the Sheyenne River system downstream of Mapelton they have to be accounted for when utilizing the model output at Mapleton as an input to any comprehensive model of the Sheyenne River. This can be accomplished by applying a breakout ratio to flow hydrographs being utilized for downstream modeling. This breakout ratio can be determined itteratively using unsteady HEC-RAS modeling.

1.5.3.2 Local Flow Determination

During POR simulations of the Maple River flows were first routed to the Mapleton without inputing a inflow record representing local flow. The resulting flow at Mapleton was subtracted from the USGS gaged record at Mapleton to determine the local inflow record between Enerlin and Mapleton. In order to determine the local flow record between Enderlin and the Maple River Dam a drainage area ratio was applied to the total local flow hydrograph. The drainage area ratio utilized can be found in **Table 3**.

Table 3. Drainage Area Ratio for Local Flow: Enderlin to Maple River Dam

Gage Location/ Reach	Contributing D.A (Square Miles)
Enderlin USGS Gage	796
Mapleton USGS Gage	1, 380
Enderlin to Mapleton	584
Enderlin to Maple R. Dam	40
Drainage Area Ratio	**0.07**

The local flow hydrograph between Enderlin and Maple River Dam was applied to the model and flows are once again routed from Enderlin to Mapleton and subtracted from the USGS gaged record at Mapleton. The resulting data series is representative of the local flow record between Maple River Dam and Mapleton.

Note that these "local inflows" are representative of not only local flows, but also of the flow lost by the breakout flows known to occur near Durbin, ND.

1.5.4 Model Results

Modeling was carried out in two phases. First, the model was calibrated using USGS gage data and then POR simulations were run in order to develop a homogenous reocord for both the with dam and without dam conditions.

1.5.4.1 Calibration Runs

Calibration runs were carried out utlizing the gaged elevation and discharge record located above Maple River Dam near Sheldon to compare modeled results for the 2009 spring flood event. **Figure 13** and **Figure 14** display the results of model calibration.

1.5.4.2 POR Simulations

The construction of the Maple River Dam has resulted in a lapse in the homogenity of the flow record recorded by the Mapelton, ND USGS gage. In order to produce a homogenous flow record for both the regulated and unregulated conditions at Mapleton is is necessary to utlize a HEC-HMS model to simulate portions of the POR. The POR prior to the construction of the dam from 1957-1975 and 1995-2006 must be simulated with the dam in place. The POR following the construction of the dam, 2006 -2009, must be simulated without the dam in place.

1.5.4.3 Homogenous Flow Records

The results from the Maple River Model Simulations can be found in **Figure 15.** As can be seen in the figure the Maple River Dam has a significant effect on the peak flows being recorded at Mapleton, ND.

Table 4 lists all the annual peaks at Mapleton for the “With Dam” and “Without Dam” conditions. When there was less than a 5% change between the regulated and unregulated flows it can be concluded that the Dam had little effect on reducing flow. This is indicated by the years highlighted in purple. For the majority of years the Maple River Dam significantly reduced the annual peak flow value at Mapleton, ND.

Table 4. Comparison between Homogenous Regulated to Unregulated Flow records at Mapleton, ND

Annual Peak Flows (cfs)			
Water Year	***Unregulated Flows***	**Regulated Flows**	**% Reduction in Peak**
1957	430.0	415.9	
1958	195.0	183.1	6%
1959	1160.0	1,016.00	12%
1960	1220.0	1,128.10	8%
1961	49.0	45.9	6%
1962	2740.0	2,563.10	6%
1963	779.0	728	7%
1964	314.0	284.8	9%
1965	3210.0	2,642.20	18%
1966	3610.0	3,092.60	14%
1967	1420.0	1,332.70	6%
1968	302.0	316.3	
1969	7000.0	5,015.10	28%
1970	3340.0	2,923.80	12%
1971	778.0	733.8	6%
1972	2430.0	2,265.90	7%
1973	1300.0	1,106.60	15%
1974	1970.0	1,840.30	7%
1975	11600.0	8,031.10	31%
1995	2360.0	2182.9	8%
1996	3460.0	1936.1	44%
1997	7150.0	6167.8	14%
1998	4000.0	3284.7	18%
1999	3210.0	2850.4	11%
2000	4110.0	3898.3	5%
2001	6890.0	5921.5	14%
2002	868.0	717.3	17%
2003	751.0	692.5	8%
2004	1450.0	1397.2	
2005	4680.0	4283.4	8%
2006	9900.0	7825.0	21%
2007	2499.5	2460.0	
2008	1917.3	1990.0	
2009	8465.2	6470.0	24%

Key
DS Mapleton USGS Gage
Simulated Flows
Low Outlier
US Mapleton USGS Gage
No Significant Effect

1.6 FREQUENCY ANALYSIS

1.6.1 Maple River Dam Inflow & Outflow

1.6.1.1 Flow-Frequency Curve

Both the inflows into the dam and the outflows from the dam can be simulated for the period of record: 1957-1975, 1995-2009. An annual peak record could be developed from the simulated record. The annual peak inflows could be used to develop an analytical curve representative of flows into the dam. The flow frequency curve representative of inflows into the dam can be found in **Table 5**. This inflow flow-frequency curve is utilized to provide guidance while drawing the outflow frequency curve and is displayed in **Figure 16**. The regional skew value used for the analytical curve is adopted from USGS "Generalized Skew coefficients for Flood Frequency Analysis in Minnesota." The regional skew value (-0.405) at the Enderlin gage can be assumed to be a good estimate of regional skew for inflows into the dam.

Table 5. Maple River Dam- Inflow Frequency Curve

Flow-Frequency Curve	
Maple River Dam Inflows	
% Chance of Exceedance	**Flow (cfs)**
0.2	15,980
0.5	12,913
1	10,686
2	8,564
5	5,966
10	4,196
20	2,631
50	946
80	284
90	141
95	75
99	21
Statistics	
Mean	2.921
Standard Dev	0.583
Station Skew	-0.776
Regional Skew	-0.405
Weighted Skew	-0.571
Adopted Skew	-0.571
Systematic Events	33

The annual peak outflows from the dam as listed in **Table 6**, plotted using the Weibull plotting position, can be used to develop a graphical flow-frequency curve. As can be seen in **Figure 16** the outflow frequency curve displays regulatory effects between the 2-year event and the 100-year event. It appears that the 10-year event is most affected.

Table 6. Simulated Annual Peak Outflows- Maple River Dam

Maple River Dam-Annual Peak Outflows	
Year	Flow (cfs)
1957	853
1958	145
1960	506
1961	25
1962	690
1963	232
1964	74
1965	930
1966	885
1967	532
1968	305
1969	1,000
1970	687
1971	144
1972	582
1973	624
1974	501
1975	971
1995	865
1996	945
1997	2,534
1998	849
1999	941
2000	642
2001	901
2002	128
2003	382
2004	808
2005	843
2006	905
2007[1]	888
2008[1]	574
2009[1]	5,010
[1]USGS recorded Outflows	

1.6.1.2 Volume-Frequency Analysis

A graphical volume duration frequency analysis could be developed for the outflow of the Maple River Dam. Data is plotted using the Weibull plotting position. Only the daily data for the calendar years between 1957-1975 and 1995-2009 is utilized. The family of curves can be seen in **Figure 16.**

1.6.2 Mapleton

1.6.2.1 Flow-Frequency Curve

The observed flow record, as well as a simulated record for 2007-2009 could be used to develop an analytical curve representative of the unregulated condition at Mapleton. The annual peak flow data for the unregulated condition at Mapleton is displayed in **Table 4.** The regional skew value used for the analytical curve is adopted from USGS "Generalized Skew coefficients for Flood Frequency Analysis in Minnesota." The regional skew value (-0.405) at the Enderlin gage can be assumed to be a good estimate of regional skew for Mapleton gage, as well. The flow-frequency curve for the without dam condition is displayed in **Figure 18**. This analytical flow-frequency curve is utilized to provide guidance when drawing the graphical With Dam flow-frequency curve. The values associated with the Mapleton without Dam Flow Frequency curve are displayed in **Table 7**.

Table 7. Mapleton Without Dam Flow-Frequency Curve

Flow-Frequency Curve	
Mapleton, ND Without Dam	
% Chance of Exceedance	Flow (cfs)
	24,297
0.2	19,787
0.5	16,563
1	13,516
2	9,786
5	7,211
10	4,863
20	2,123
50	835
80	492
90	310
95	124
Statistics	
Mean	3.295
Standard Dev	0.458
Station Skew	-0.428
Regional Skew	-0.405
Weighted Skew	-0.416
Adopted Skew	-0.416
Low Outliers	1
Systematic Events	34

The flow record at Mapleton with the dam in place can be simulated for the period of record: 1957-1975 and 1995-2006. An annual mean daily peak record could be developed from the simulated record, along with the observed annual peaks from 2007-2009. The annual mean daily peak flow at Mapleton, plotted using the Weibull plotting position could be used to develop a graphical flow-frequency curve.

It is necessary to adjust the annual mean daily peak flow-frequency curve to be representative of the instantaneous annual peak flow frequency curve. This is done by developing a relationship between mean daily annual peaks and instantaneous annual peaks using the unregulated observed flow record at Mapleton. This relationship can be seen in **Figure 17**. Due to the effects of regulation, the flow hydrographs representative of dam outflows have very gradual peaks (slope ~ 0 near peaks). Thus, it is unnecessary to make this adjustment for the flow-frequency curve representative of outflows.

As can be seen in **Figure 18** the Mapleton frequency curve displays regulatory effects between the 2-year event and the 100-year event. As with the dam outflow curve, it appears that the 10-year event is affected most. The flow-frequency values representative of the regulated condition at Mapleton are also listed in **Table 8**.

Table 8. With Dam at Mapleton- Frequency Curves

	Graphical Flow-Frequency Curve	
	Mean Daily Curve (cfs)	Annual Inst. Curve (cfs)
0.2	24,297	24,297
0.5	19,787	19,787
1	15,000	16,247
2	11,600	12,564
5	7,900	8,556
10	5,800	6,282
20	4,200	4,549

Volume-Frequency Analysis

A graphical volume-frequency curve could be developed for the regulated record at Mapleton. Data is plotted using the Weibull plotting position. Only the daily data for the calendar years between 1957-1975 and 1995-2009 is utilized. The family of curves can be seen in **Figure 19**.

1.7 BALANCED HYDROGRAPHS

A HEC-RAS Unsteady Model is being developed for the Fargo Moorhead Metro Feasibility Study. Hydraulic engineers require synthetic balanced hydrographs representative of the current conditions on the Maple River (dam in place) for the Swan Creek, Buffalo Creek, and at Durbin, ND.

Moore Engineering developed a methodology that has successfully been used to produce these hydrographs using the hydrographs representative of Maple River Dam outflows and Mapleton.

1.7.1 Mapleton & Maple River Dam Outflows

Balanced hydrographs for the 10, 50, 100, 200 and 500 year events are developed at Mapleton and for the outflow from the dam using the volume duration curves described in Section 1.6, the simulated 2006 spring flood event hydrographs and HEC-1.

1.7.2 Durbin, Swan Creek, Buffalo Creek

1.7.2.1 Time Shift

The first step in defining the balanced hydrographs at these locations is to apply a lag time to the balanced hydrograph representative of Dam Outflow. The lag time is representative of the time it takes for flow to travel between the dam and Mapleton, ND. Because this time step is unknown a range of time steps (between 0 and 3 days) was utilized to lag the balanced hydrographs. The HEC-RAS modelers will be able to determine which set of hydrographs works best during the calibration process.

1.7.2.2 Local Flow Hydrograph: Dam to Mapleton

The cumulative local flow hydrograph between the Dam and Mapleton can be determined by finding the difference hydrograph between the dam outflow hydrograph (with the time step applied) and the Mapleton.

1.7.2.3 Breakout flow factor

As the HEC-RAS modelers input the hydrographs into their model they will adjust the hydrographs using a breakout factor. This breakout factor is modified iteratively until the modeled Mapleton balanced hydrograph matches the adopted Mapleton balanced hydrograph developed with HEC-1.

1.7.2.4 Superposition

This methodology assumes that the flow hydrographs representative of Swan Creek, Buffalo Creek and the local area flow between the dam and Durbin have the same shape and timing. Using this assumption the theory of superposition can be applied to the local flow hydrograph representative of the area between the dam and Mapleton to develop three hydrographs representative of Swan Creek, Buffalo Creek and the Dam to Durbin local flow. The cumulative hydrograph is broken down by using drainage area ratios as shown in **Table 9**. By adding the local flow hydrograph between the dam and Durbin to the dam outflow hydrograph you get a balanced hydrograph representative of hydrologic conditions at Durbin, ND.

Table 9. Drainage Area Ratios

Reach	Drainage Area (sq mi)	D.A ratio
Enderlin to Mapleton	526	1
Swan Creek	129	0.25
Buffalo Creek	192	0.36
Local Flow Dam to Durbin	205	0.39

2. Rush River Analysis

The Rush River is a tributary of the Lower Sheyenne River. It lies within the Lake Agassiz Plain. **Figure 20** displays the Rush River watershed.

2.1 AVAILABLE USGS STREAMFLOW DATA

USGS gage 0506500 is located on the Rush River at Amenia, ND. It has a contributing drainage area of 116 square miles. Its period of record is from April 14, 1947 to present. These values are presented in **Table 10**.

Table 10. Annual Instantaneous Peak Flow Record at USGS gage 0506500 on the Rush River at Amenia, ND

Water Year	Annual Instantaneous Peak Flow (cfs)	Water Year	Annual Instantaneous Peak Flow (cfs)
1947	1,230	1982	710
1948	590	1983	428
1949	400	1984	987
1950	620	1985	164
1951	368	1986	767
1952	600	1987	475
1953	1,050	1988	30
1954	120	1989	602
1955	200	1990	64
1956	250	1991	43
1957	115	1992	255
1958	77	1993	2,970
1959	100	1994	470
1960	437	1995	700
1961	25	1996	750
1962	450	1997	1,680
1963	68	1998	1,000
1964	100	1999	1,060
1965	900	2000	1,100
1966	300	2001	1,480
1967	384	2002	457
1968	190	2003	613
1969	1,690	2004	1,070
1970	380	2005	863
1971	97	2006	1,690
1972	252	2007	856
1973	200	2008	357
1974	790	2009	2,000
1975	2,550		
1976	150		
1977	41		
1978	375		
1979	3,490		
1980	63		
1981	22		
1982	710		

2.2 FREQUENCY ANALYSIS

2.2.1 Flow-Frequency Analysis

An analytical flow frequency study is carried out at Amenia using the USGS annual instantaneous peak flow record at Amenia, ND. Weighted skew, using a generalized skew coefficient from the USGS Generalized Skew study, is utilized to carry out analysis. The resulting flow-frequency curve is displayed in **Figure 21** and **Table 11.**

Table 11. Flow-Frequency Curve and Statistics for USGS gage 0506500 Rush River at Amenia, ND

Annual Instantaneous Peak Flow-Frequency Curve			
POR: 1947-2009			
% Chance of Exceedance		**Computed Curve**	
		Flow in cfs	
0.2		6,419	
0.5		5,128	
1		4,215	
2		3,365	
5		2,346	
10		1,664	
20		1,064	
50		411	
80		139	
90		75	
95		43	
99		15	
Statistics			
Mean	2.573	Historic Events	0
Standard Dev	0.53	High Outliers	0
Station Skew	-0.508	Low Outliers	0
Regional Skew*	-0.388	Zero Or Missing	0
Weighted Skew	-0.461	Systematic Events	63
Adopted Skew	-0.461	Historic Period	none

2.2.2 Volume Duration Analysis

HEC-SSP is used to generate a flood volume frequency analysis at Amenia, ND. The USGS mean daily flow record for water years 1947 through 2009 is available for analysis. In order to develop a consistent set of curves for all durations smoothing functions are developed and applied to skew and standard deviations for the family of flood volume curves. Smoothed statistics are anchored by the annual instantaneous flow-frequency statistics displayed in **Table 11**. **Table 12** shows the adopted smoothed statistics for each duration. The flood volume frequency curves identify peak flows for all durations.

Table 12. Flood Volume Frequency Statistics for USGS gage 0506500 Rush River at Amenia, ND

Adjusted Statistic	Instant. Peak	1-day	3-day	7-day	15-day	30-day	60-day	90-day	120-day	183-day
Mean Logarithm	2.5734	2.4822	2.3773	2.2102	2.0172	1.8131	1.5822	1.4634	1.3932	1.3606
Pre-adj. stats.										
Standard deviation	0.5301	0.5434	0.5458	0.5474	0.5364	0.511	0.4953	0.4807	0.4587	0.4049
Skew	-0.4612	-0.4883	-0.4625	-0.4594	-0.4876	-0.3601	-0.3146	-0.3222	-0.3902	-0.5555
Adj. stats.										
Standard deviation	0.5301	0.5253	0.5197	0.5109	0.5006	0.4898	0.4776	0.4713	0.4675	0.4658
Skew	-0.4612	-0.4563	-0.4507	-0.4417	-0.4314	-0.4204	-0.4081	-0.4017	-0.3979	-0.3962

2.3 BALANCED HYDROGRAPHS AT AMENIA, ND

The flood volume frequency curves identify peak flows for all durations. The balanced hydrograph feature of HEC-1 is used to configure the balanced hydrographs. HEC-1 is limited to only five durations. The following durations are specified in the HEC-1 input file: 1 (instantaneous peak), 3-, 7-, 15-, and 30-day durations. To be consistent with the methodology adopted throughout the Fargo Moorhead Metro Feasibility Study, the 2006 event as recorded by the USGS gage at Amenia, is used as a pattern hydrograph for configuring the balanced hydrographs. Balanced hydrographs are computed for the 0.5-, 0.2-, 1-, 2-, and 10 % exceedance frequencies. HEC-DSSVue is then used to smooth out the resulting Hec-1 output hydrographs.

3. Balanced Hydrographs for Ungaged Sites

Balanced Hydrographs representative of the local flow between Durbin, ND and the confluence of the Maple River, as well as for the local flow associated with Drain 14 are developed using a drainage area ratio with USGS gage 05060500 Rush River at Amenia, ND.

It is assumed that the hydrographs representative of the local flow that runs into Drain 14 and into the Maple River between Durbin, ND and the Maple River's confluence with the Sheyenne River are similar in shape and timing as the hydrographs at Amenia. Based on this assumption local flow hydrographs can be estimated using drainage area ratios and the balanced hydrographs developed for Amenia. Amenia's drainage area come from the USGS website. Moore Engineering has provided an estimate for the Drain 14 drainage area. The local area between Durbin and the Maple River's confluence with the Sheyenne River can be estimated using HUC data. These areas, along with the drainage area ratios utilized to develop balanced hydrographs are listed in **Table 13.**

Table 13. Drainage Areas and Drainage Area ratios used to get local flows

Location	Drainage Area (sq. miles)
Drain 14 Drainage Area	125.50
Local Area Durbin to Confluence of Maple & Sheyenne Rivers	19.70
Amenia Gage	116
Drain 14 Ratio	1.08
Local Area Flow Ratio	0.17

4. Sheyenne River

There are three major points of interest along the Sheyenne River between Lisbon and its confluence with the Red River of the North: Gol Bridge, Kindred and West Fargo. These locations are effected by breakout flows and regulatory effects. Flow-frequency and volume duration curves are developed at each of these locations. **Table 14** displays the flow-frequency values adopted for each of these locations on the Sheyenne River. Using the results of the flow frequency and volume duration analysis balanced hydrographs can be developed at these locations. The balanced hydrographs are used as input to the Lower Sheyenne River HEC-RAS model as a hydrograph boundary conditions.

Table 14. Annual Peak Discharge-Frequency; Sheyenne River @ GOL, Kindred, & W Fargo

Location Annual Peak	Discharge-Frequency (cfs) % Chance Exceedance				
	10	2	1	0.5	0.2
GOL Bridge	4,190	7,140	8,500	9,900	11,800
Kindred	4,190	5,839	5,930	5,962	5,996
West Fargo	3,800	4,800	4,900	4,950	5,000

4.1 BALDHILL DAM

Sheyenne River flow is regulated to a large degree by Baldhill Dam which creates the impoundment of Lake Ashtabula. USGS gage station 05057500 records outflows from Baldhill Dam. Baldhill Dam began to regulate flows in April of 1950. Previous and current dam regulation is predicated based on the snow water equivalent in the upper portion of the watershed. During major flood events Baldhill Dam stores flow and then releases flow when channel capacity is available or flood storage is consumed. This generally produces a double peak hydrograph on the Lower Sheyenne River. For hydrological analysis at locations downstream of the dam only flows for the period of record from the inception of the dam onward are included in analysis (1950 to 2009).

In the spring of 2004, Baldhill Dam increased its flood control storage capacity by allowing a 5'raise in the top of flood control. This creates a discontinuity in the flows recorded by the USGS gage at Baldhill Dam and at downstream gaging stations.

A reservoir simulation model was developed for the post 5' raise condition and a period of record simulation was carried out down to Kindred. The increase in drainage area of 1,415 square miles between Baldhill Dam and Kindred dampened the effect that the change in regulation had at Kindred resulting in changes in annual peak flow that appeared minimal (less than 5% for the 1997 flood and less than 1 % for smaller events). The flow records at the Kindred gage and downstream can be assumed to be relatively homogenous despite the 2004 change in flood control operation at Baldhill Dam. Thus, for this analysis no adjustments were made to the peak flows recorded between 1950 and 2004 to render the POR homogeneous.

4.2 SHEYENNE RIVER NEAR KINDRED, ND

Significant break outflows occur on the Sheyenne River upstream and downstream of USGS gage 05059000 located at Kindred, ND. The breakout flows that flow out of the Sheyenne River near Kindred occur to the southeast toward the Wild Rice River, ND and to the north towards Drain 34 and 14. Drains 34 and 14 drain into the Maple River above the Maple River's confluence with the Sheyenne River.

The flow record at Kindred has a period of record of 1947, 1950 to 2009. The drainage area at the Kindred gage, according to the USGS, is 8,880 square miles. At least 5,780 square miles is non-contributing area. The non-contributing area includes 3,800 square miles from the Devils Lake Basin. Intervening area between Kindred and Baldhill Dam is approximately 1,415 square miles.

4.2.1 GOL Bridge

Gol Bridge is located upstream of the break flows that occur from the Sheyenne River between Lisbon and Kindred, ND. Flows at Gol Bridge are representative of the total flow translated downstream from Baldhill Dam before breakouts occur.

4.2.1.1 Flow-Frequency Analysis

There is not a continuous annual instantaneous peak streamflow record available for Gol Bridge, ND. Because Gol Bridge is located relatively close to Kindred, ND the annual instantaneous peaks at Kindred, ND can be assumed to be equivalent to the streamflow record at Gol Bridge for the portions of the POR when no breakouts occurred. For those years when breakouts are known to have occurred upstream of Kindred the annual peak flows at the Kindred gage can be adjusted using a breakout flow relationship. This relationship has been developed based on a combination of flow measurements and hydraulic modeling using HEC-RAS. **Figure 22** displays the breakout relationship between Gol Bridge and Kindred. This relationship is based on the data displayed in **Table 15**.

Table 15 Upstream Breakout – Gol Bridge to Kindred

Unsteady HEC RAS Model Results							
	Gol Bridge	Left Breakouts	Right Breakouts	Total	Left	Right	Gol Breakout
Old 10-Year	3,456	0	0	0	0%	0%	3,456
Old 50-Year	5,768	207	13	220	94%	6%	5,548
Old 100-Year	7,342	788	788	1,576	50%	50%	5,766
March-April 2009 modeled based on NWS forecast hydrographs	8,950	1,179	1,924	3,103	38%	62%	5,847
Old 500-Year	1,1929	1,963	4,030	5,993	33%	67%	5,936
Actual 2009 based on Gage Records and Measurements				**Kindred**			
2009 based Gage records and Measurements	8,700			5,770	2,930		
	Measurement 4/23/09			Mean Daily 4/23/09			

Using the data displayed in **Table 15** and the breakout relationship displayed in **Figure 22,** a rating curve could be developed and inputted into HEC-DSSVUE in order to back translate peak flows from Kindred to Gol Bridge. **Table 16** lists the rating curve values used in DSSVUE to translate peak flows from Kindred to Gol Bridge. Annual peak flows at Gol Bridge are shown in **Table 17**.

Table 16. Breakout Rating Curve-Gol Bridge to Kindred

Gol Bridge cfs	Kindred cfs
0	0
5,200	5,200
5,500	5,400
6,000	5,650
6,500	5,770
7,000	5,825
7,500	5,875

Table 17. Annual Peak Discharges – GOL Bridge

RANK	WATER YEAR	DISCHARGE CFS	RANK	WATER YEAR	DISCHARGE CFS
1	1997	10,360	31	1972	1,530
2	2009	8,720	32	1956	1,460
3	1996	5,100	33	1967	1,460
4	1969	4,690	34	1989	1,430
5	1975	4,640	35	1978	1,410
6	1979	4,160	36	1992	1,400
7	1995	3,970	37	1970	1,230
8	1993	3,550	38	1955	1,120
9	1966	3,380	39	1968	1,010
10	2001	3,310	40	1951	1,010
11	1950	3,210	41	1976	925
12	2004	3,080	42	2003	760
13	1987	3,000	43	1980	750
14	1999	2,840	44	1973	710
15	1965	2,760	45	2008	695
16	2006	2,600	46	1953	679
17	1962	2,310	47	1954	631
18	1952	2,240	48	1964	600
19	2007	2,160	49	1977	570
20	1983	2,060	50	1985	555
21	1982	2,040	51	2002	549
22	1994	2,030	52	1957	547
23	1998	2,000	53	1958	480
24	2000	1,960	54	1988	460
25	1974	1,940	55	1981	435
26	2005	1,870	56	1963	430
27	1960	1,820	57	1961	350
28	1984	1,810	58	1990	286
29	1971	1,750	59	1959	204
30	1986	1,740	60	1991	184

Utilizing the adopted annual peak discharge record displayed in **Table 17,** a graphical flow-frequency curve could be developed for Gol Bridge. The flow-frequency curve at Gol Bridge is plotted alongside the flow-frequency curve at Kindred in **Figure 23**. The peak flows at Gol Bridge appear to be log-normally distributed. A Bulletin 17B can be applied to the data to develop the flow-frequency curve. **Table 14** lists the synthetic discharge values for the 0.2-, 1-, 2, and 10-% exceedance frequency events.

4.2.1.2 Flood Volume Frequency

HEC-SSP is used to generate flood volume frequency relationships for subsequent development of balanced hydrographs at GOL Bridge. This analysis is conducted using mean daily flows recorded by the USGS gage at Kindred from 1950 to 2009. The period of record mean daily flows at Kindred are "reverse routed" through the breakout transform in **Table 16** for the reach just above Kindred. The resulting mean daily flow series is considered to be representative of the flow record at Gol Bridge and is log-normally distributed and therefore amenable to Bulletin

17B procedures. Skew and standard deviations are smoothed to generate a consistent set of curves for all durations. Skew and standard deviation for the curves are anchored using the statistics associated with the annual instantaneous peak discharge-frequency curve determined by Bulletin 17B analysis. **Table 18** shows the adopted smoothed statistics for each duration.

Table 18. Flood Volume Frequency Statistics - GOL

Adjusted Statistic	Instant. Peak	1-day	3-day	7-day	15-day	30-day	60-day	90-day	120-day	183-day
Mean Logarithm	3.1473	3.1300	3.1100	3.0690	3.0030	2.9090	2.7730	2.6890	2.6290	2.5150
Pre-adj. stats.										
Standard deviation	0.3854	0.3870	0.3990	0.4190	0.4290	0.4360	0.4230	0.4070	0.3870	0.3670
Skew	-0.4000	-0.3800	-0.4040	-0.4590	-0.3720	-0.2140	-0.1180	-0.1060	-0.1000	-0.0730
Adj. stats.										
Standard deviation	0.3854	0.3855	0.3862	0.3875	0.3895	0.3924	0.3966	0.3992	0.4011	0.4047
Skew	-0.4000	-0.3974	-0.3854	-0.3601	-0.3198	-0.2638	-0.1819	-0.1314	-0.0947	-0.0260

4.2.1.3 Balanced Hydrograph

The flood volume frequency curves identify peak flows for all durations. The balanced hydrograph feature of HEC-1 is used to configure the balanced hydrographs. HEC-1 is limited to only five durations. The following durations are specified in the HEC-1 input file: 1 (instantaneous peak), 3-, 7-, 15-, and 30-day durations. The 2006 event is used as a pattern hydrograph for configuring the balanced hydrographs. Balanced hydrographs are computed for the 0.5-, 0.2-, 1-, 2-, and 10 % exceedance frequencies. HEC-DSSVue is then used to smooth out the resulting Hec-1 output hydrographs. The balanced hydrograph was used as input to the Lower Sheyenne River HEC-RAS model as a hydrograph boundary condition.

4.2.2 Kindred

4.2.2.1 Flow-Frequency Analysis

Kindred, ND is located downstream of the first reach of the Sheyenne River known to exhibit breakout flows during flood events. In order to correctly represent the breakout flows know to occur during large events, the annual peak discharge-frequency curve at Kindred, ND is determined by translating the values from the flow frequency curve developed at Gol Bridge through the breakout transform displayed in **Table 16**. This was done for the 0.2-, 0.5-, 1-, 2-, 3-, 4-, and 5-% exceedance frequency events displayed in **Table 14**. Because of the effect of the breakout flows just upstream, this curve was drawn graphically. **Figure 23** shows the Kindred curve with the GOL discharge-frequency curve. The curves are identical for flows below 5,000 cfs (~6 % exceedance frequency) because no significant breakout flows occur until channel flow exceeds this value.

4.2.2.2 Balanced Hydrograph
The balanced hydrograph for the Sheyenne River at Kindred is computed within the Lower Sheyenne River HEC-RAS unsteady flow model by routing the input boundary condition hydrograph, determined upstream at GOL Bridge, through the breakout flow relationship.

4.2.3 West Fargo

4.2.3.1 Flow-Frequency Analysis
The annual discharge-frequency curve for West Fargo is based on recorded instantaneous peak discharges at USGS gage station 05059500. The POR for the USGS at West Fargo is from 1903 to present. West Fargo is downstream of Baldhill Dam. Construction of Baldhill Dam was only completed in 1950. To maintain homogeneity, only the West Fargo flow record from 1950 to present is adopted for analysis. Flows recorded by USGS gage 05059500 are representative of flow through the West Fargo Diversion, the Horace diversion and flow through the natural channel. The flow frequency curve at West Fargo has to be developed graphically due to the breakout flows know to occur between Kindred, ND and West Fargo, ND. The breakout flows above Kindred cap the peak flow downstream at West Fargo at approximately 5,000 cfs. This information provides a guide for the upper end of the graphically drawn curve. **Figure 24** shows the West Fargo flow-frequency curve. **Table 14** lists the synthetic discharge values for the 0.2-, 1-, 2-, and 10-% exceedance frequency events.

4.2.3.2 Flood Volume Frequency
Flood Volume Frequency Analysis is conducted at West Fargo using the mean daily flow record for the regulated portion of the period of record from 1950 to 2009. Because flows break out from the Sheyenne River upstream of West Fargo, a graphical volume-frequency analysis must be carried out. HEC-SSP is used to generate the Weibull plotting positions for the flow-volume frequency analysis. Graphical flood volume frequency curves are drawn through the plotting positions using the adopted instantaneous peak curve as a guide. As described for the flow-frequency analysis, the breakout flow above Kindred caps the peak flow downstream at West Fargo at approximately 5,000 cfs. As a result, the flood volume curves converge to 5,000 cfs at the upper end**.** **Figure 25** displays the flood volume curves for the 1-, 3-, 7-, 15-, and 30-day durations. The adopted instantaneous peak discharge-frequency curve is plotted in red. **Table 19** displays the estimated discharges for each duration and frequency from the discharge volume-frequency curve.

Table 19. Estimated Discharge Volume Duration Frequencies; Sheyenne River @ West Fargo

Event Exceedance Frequency	Inst. Pk cfs	1-Day cfs	3-Day cfs	7-Day cfs	15-Day cfs	30-Day cfs
0.5 %	5,000	4,925	4,850	4,775	4,700	4,625
0.2 %	4,950	4,870	4,790	4,710	4,630	4,550
1 %	4,900	4,815	4,730	4,645	4,560	4,475
2 %	4,800	4,650	4,500	4,350	4,200	4,050
10 %	3,800	3,600	3,400	3,200	2,800	2,400

4.2.3.3 Balanced Hydrograph

The flood volume frequency curves identify peak flows for all durations. The balanced hydrograph feature of HEC-1 is used to configure the balanced hydrographs. HEC-1 is limited to only five durations. The following durations are specified in the HEC-1 input file: 1 (instantaneous peak), 3-, 7-, 15-, and 30-day durations. The 2006 event is used as a pattern hydrograph for configuring the balanced hydrographs. Balanced hydrographs are computed for the 0.5-, 0.2-, 1-, 2-, and 10 % exceedance frequencies. HEC-DSSVue is then used to smooth out the resulting Hec-1 output hydrographs. The balanced hydrograph was used as input to the Lower Sheyenne River HEC-RAS model as a hydrograph boundary condition.

5. Mainstem Analysis

5.1 COINCIDENT PEAK ANALYSIS- UPSTREAM

Coincidental discharge frequency values and balanced hydrographs are determined for the 500-, 100-, 50, and 10-yr events for locations on the Wild Rice, ND at Abercrombie, the Red River at Hickson and the Red River just downstream of the Wild Rice, ND when peak flows are occurring at upstream locations. The coincidental annual flow values at Abercrombie and Hickson are determined by identifying on what date the annual instantaneous peak flows occur at the upstream locations and then determining the corresponding flow for that date at Abercrombie, Hickson and just downstream of the Wild Rice, ND. The resulting coincidental annual flows at Abercrombie, Hickson and the Wild Rice River, ND are plotted using the Weibull plotting position and a graphical curve is then drawn to fit the plotting positions. Flow Frequency Curves are displayed in **Figure 26** through **Figure 34**. The period of record used for analysis is displayed on each figure.

5.1.1 Abercrombie & Hickson

Coincidental discharge frequency values and balanced hydrographs are determined for the 500-, 100-, 50-, and 10-yr events at locations on the Wild Rice, ND at Abercrombie and the Red River at Hickson when peak flows are occurring on the Sheyenne River at the following reference points: Gol Bridge, Maple River at Mapleton and the Rush River at Amenia. The coincidental flow records are listed in **Table 20**.

Table 20. Coincidental peak flow records at Abercrombie & Hickson for corresponding Annual peak flows observed in the Sheyenne River Basin

Water Year	Coincidental Peaks at Abercombie, ND on the WRR-ND			Coincidental Peaks at Hickson, ND on the RRN-ND		
	Locations of Annual Peak			Locations of Annual Peak		
	Gol Bridge	Mapleton	Amenia	Gol Bridge	Mapleton	Amenia
1947			2,080			5,718
1948			680			1,728
1949			350			1,024
1950	766		1,550	4,416		3,014
1951	74		8	2,101		351
1952	2,450		4	1,411		748
1953	123		639	2,270		1,360
1954	41		43	1,009		816
1955	21		430	562		359
1956	32		630	943		1,280
1957	80	16	95	670		1,664
1958	25	152	135	605		434
1959	8	29	5	1,006		743
1960	206	549	620	531		1,072
1961	19	23	25	416		333
1962	2,980	2	2	5,460		576
1963	126	191	170	769		736
1964	22	339	119	509		627
1965	511	2,500	2,500	2,357		3,799
1966	880	2,320	1,140	1,626		1,805
1967	574	896	406	1,981		1,624
1968	40	29	14	866		740
1969	6,310	9,360	7,520	9,540		3,690
1970	154	59	160	932		179
1971	21	135	50	539		768
1972	2,050	1,710	395	2,355		2,330
1973	118	353	279	1,059		1,398
1974	48	556	512	789		940
1975	2,740	2,860	2,540	4,857		2,048
1976	171		800	740		1,264
1977	14		3	39		24
1978	2,100		4,400	2,862		3,518
1979	600		4,400	2,188		8,731
1980	875		1,500	3,583		2,634
1981	18		0	255		160
1982	272		1,120	1,240		4,000
1983	244		0	812		294

Table 20. Continued.

Water Year	Coincidental Peaks at Abercombie, ND on the WRR-ND			Coincidental Peaks at Hickson, ND on the RRN-ND		
	Locations of Annual Peak			Locations of Annual Peak		
	Gol Bridge	Mapleton	Amenia	Gol Bridge	Mapleton	Amenia
1984	344		2,950	1,706		3,898
1985	698		698	1,990		1,990
1986	514		26	3,236		2,060
1987	617		61	2,392		934
1988	6		33	406		684
1989	2,600		1,190	3,727		2,887
1990	2		2	617		610
1991	0		0	805		798
1992	28		149	806		451
1993	555		818	2,593		2,555
1994	1,150		30	3,340		1,373
1995	481	3,680	500	2,233	4,814	1,646
1996	432	2,000	2,000	2,123	4,378	4,378
1997	3,590	9,450	9,050	9,218	6,657	8,284
1998	350	1,500	1,300	1,628	4,540	3,320
1999	740	748	1,530	1,490	1,680	2,600
2000	106	139	130	951	1,439	1,887
2001	9,020	7,590	7,590	8,995	5,026	5,026
2002	91	15	356	1,332	668	922
2003	176	1,770	1,630	1,040	4,040	2,730
2004	28	163	270	512	1,440	785
2005	1,030	1,620	1,030	6,116	6,564	6,116
2006	8,370	8,660	8,660	13,774	8,813	8,813
2007	2,660	3,360	3,360	2,978	3,394	3,394
2008	877	938	45	3,140	3,110	446
2009	5,300	14,000	11,900	6,722	20,166	15,310

Coincidental peaks at Abercrombie are also determined for when the Red River at the North is peaking at Fargo, ND which is just downstream of the Wild Rice River's confluence with the Red River of the North. The coincidental flow record can be found in Appendix A-1. Coincidental peaks at Hickson are also determined for when the Wild Rice River, ND peaks at Abercrombie. The coincidental flow record at Hickson is displayed in **Table 21**.

Table 21. Coincidental peaks at Hickson when Annual Peaks are Occurring on the Wild Rice River-ND at Abercombie, ND

Water Year	Coincidental Flow (cfs)	Water Year	Coincidental Flow (cfs)
1942	4,045	1976	1,264
1943	4,333	1977	339
1944	2,847	1978	4,826
1945	4,795	1979	5,710
1946	3,865	1980	2,634
1947	4,670	1981	284
1948	1,728	1982	3,300
1949	1,280	1983	822
1950	4,678	1984	3,898
1951	2,945	1985	3,600
1952	7,622	1986	3,035
1953	1,047	1987	2,324
1954	662	1988	613
1955	474	1989	11,735
1956	1,114	1990	812
1957	402	1991	2,800
1958	776	1992	1,149
1959	719	1993	4,472
1960	1,072	1994	2,306
1961	301	1995	4,814
1962	5,385	1996	5,215
1963	4,916	1997	6,657
1964	1,132	1998	3,450
1965	5,255	1999	2,700
1966	5,562	2000	1,105
1967	3,169	2001	6,863
1968	711	2002	3,121
1969	7,685	2003	4,210
1970	906	2004	2,720
1971	559	2005	5,130
1972	1,440	2006	12,240
1973	1,482	2007	8,187
1974	940	2008	2,920
1975	4,446	2009	20,166

These flows are necessary to develop the design for appurtenant structures on the Sheyenne, Maple and Rush River tributaries. **Table 22** and **Table 23** show the coincidental discharges that occur at Abercrombie and Hickson respectively, to peak flows at upstream locations.

Table 22. Coincidental Peaks @ Abercrombie

Location Annual Peak	Coincident Discharge at Abercrombie (cfs) % Chance Exceedance			
	10	**2**	**1**	**.2**
GOL	3,700	9,400	10,300	13,000
Mapleton	8,000	15,500	18,000	23,000
Amenia	4,500	12,000	15,000	19,000
Red Confluence	6,185	11,655	13,780	18,342

Table 23. Coincidental Peaks @ Hickson

Location Annual Peak	Coincident Discharge at Hickson (cfs) % Chance Exceedance			
	10	**2**	**1**	**.2**
GOL	6,100	13,400	17,000	28,000
Mapleton	7,200	13,000	15,500	21,000
Amenia	8,200	12,000	15,000	24,000
Abercrombie	6,600	16,000	21,500	37,000

5.1.2 Just Downstream of the WRR-ND

Coincidental discharge frequency values and balanced hydrographs are determined for the 500-, 100-, 50, and 10-yr events at a location on the Red River of the North just downstream of its confluence with the Wild Rice River-ND with the annual peak occurring at the mouth of the Wild Rice River-ND are displayed in **Table 24.**

Table 24. Coincidental Peaks @ Red River Downstream of Mouth of Wild Rice River- ND

Location Annual Peak	Coincident Discharge at RRN DS WRR-ND (cfs) % Chance Exceedance			
	10	**2**	**1**	**.2**
Wild Rice, ND Mouth	16,000	27,000	32,000	42,000

5.2 COINCIDENT PEAK ANALYSIS- DOWNSTREAM

Coincidental discharge frequency values and balanced hydrographs are determined for the 500-, 100-, 50, and 10-yr events at a location on the Red River of the North just downstream of its confluence with the Sheyenne River when peak flows are occurring on the Sheyenne River at the following reference points: Gol Bridge, Maple River at Mapleton and the Rush River at Amenia. The coincidental flow records are displayed in **Table 25**.

Table 25. Coincidental peak flow record on the Red River DS Sheyenne River Confluence

Water Year	Coincidental Peaks on the Red River DS Sheyenne River		
	Locations of Annual Peak		
	Gol Bridge	Mapleton	Amenia
1962	9,245	5,896	4,489
1963	2,894	1,206	2,888
1964	878	4,858	804
1965	13,265	13,266	16,414
1966	11,188	17,420	14,672
1967	8,107	3,712	5,641
1968	1,568	965	1,018
1969	23,516	22,914	20,568
1970	4,683	1,956	6,901
1971	1,286	2,010	2,352
1972	10,384	10,452	625
1973	2,318	750	4,100
1974	6,023	5,521	9,781
1975	26,598	25,728	16,146
1976	1,829		4,797
1977	454		295
1978	6,030		19,161
1979	7,102		27,803
1980	6,767		4,897
1981	626		504
1982	5,829		8,777
1983	3,618		2,861
1984	4,482		14,404
1985	4,690		4,690
1986	7,705		2,539
1987	6,378		4,000
1988	1,420		2,439
1989	14,739		12,729
1990	925		1,159
1991	925		938
1992	1,876		2,626
1993	8,977		11,121
1994	7,571		2,345
1995	6,767	10,921	9,044
1996	5,608	10,184	13,399
1997	26,062	33,634	42,878
1998	4,020	4,958	11,054
1999	8,040	6,834	10,049

Table 25. Continued.

Water Year	Coincidental Peaks on the Red River DS Sheyenne River		
	Locations of Annual Peak		
	Gol Bridge	Mapleton	Amenia
2000	9,312	14,338	18,692
2001	25,191	25,125	24,521
2002	1,903	3,136	9,580
2003	2,104	2,807	7,906
2004	3,095	2,392	8,643
2005	14,136	3,203	14,136
2006	28,607	26,666	24,521
2007	10,049	6,700	16,012
2008	6,767	3,678	4,971
2009	21,975	32,964	29,143

Determination of these flows assisted design for appurtenant structures on these tributaries. The results of the flow-frequency analysis are displayed in **Table 26.**

Table 26 Coincidental Peaks @ Red DS Shey Confluence when Annual Peak Occurring @:

Location Annual Peak	Coincident Discharge at RRN DS Sheyenne River(cfs) % Chance Exceedance			
	10	2	1	.2
GOL	19,500	32,000	38,000	50,000
Mapleton	31,500	52,000	60,000	80,000
Amenia	21,000	38,000	46,000	64,000
When Mapleton Pk Arrives at Red	27,000	40,000	44,000	50,000

The Red River coincident flows just downstream of the mouth of the Sheyenne River can be estimated using the daily flow record recorded on the Red River at Halstad. The1988 Corps *Timing Study* indicates that there is a travel time of 3 days between the mouth of the Sheyenne River and Halstad. Because local area flow occurs between the mouth of the Sheyenne River and Halstad, flows recorded at Halstad are greater than what would be observed at the mouth of the Sheyenne River. A drainage area ratio can be utilized to determine the relationship between the flow magnitudes observed at the mouth of the Sheyenne River versus those observed at Halstad. Based on drainage area the flows at the Sheyenne River are 33% less than those flows recorded downstream at Halstad and need to be reduced by a ratio of 0.67.

In order to find the coincident annual flow records at the mouth of the Sheyenne River with annual peaks at Gol, Mapleton and Amenia, the dates of the annual peaks at these upstream locations are first identified. The Halstad daily flow record is then shifted back three days and reduced by a ratio of 0.67 to form an equivalent daily flow record just downstream of the mouth of the Sheyenne River. Using this equivalent flow record the flows that occur on the same day as the annual peaks at the upstream locations are determined.

In order to find the coincident annual flow record on the Red just downstream of the mouth of the Sheyenne River with when the peak at Mapleton reaches the mouth of the Sheyenne River, it is first necessary to determine the travel time between Mapleton and the mouth of the Sheyenne River. Travel time is estimated to be five days. The Mapleton annual instantaneous peak record is shifted forward in time five days to account for travel time from Mapleton to form an equivalent flow record at the confluence of the Sheyenne with the Red. The Halstad daily flow record is then shifted back three days and reduced by a ratio of 0.67 to form an equivalent daily flow record just downstream of the mouth of the Sheyenne River. Using this equivalent flow record just downstream of the Sheyenne on the Red, the annual instantaneous peak flows that occur on the same day as when the annual peaks that occurred at Mapleton reach the mouth of the Sheyenne River.

Figure 36 through **Figure 39** display the adopted, coincident discharge-frequency curves.

5.3 ANNUAL INSTANTANEOUS FLOW-FREQUENCY ANALYSIS @ ABERCROMBIE

Annual peak discharge – frequencies were determined for the Wild Rice River, ND at Abercrombie. These flows are compared with the coincident flows and provide more guidance in design of the appurtenant structures as well as an upper bound for the coincident discharge-frequencies. The period of record adopted at Abercrombie is for the WET portion of record 1942 to 2009. The frequency curve is derived analytically utilizing a weighted skew value. Skew is weighted using a regional skew of -0.230 and associated mean square error of 0.125 provided by the USGS Minnesota regional skew study. The adopted flows are listed in **Table 27**. **Figure 35** displays the analytical flow-frequency curve with corresponding statistics.

Table 27 Adopted Annual Peak for Wild Rice River, ND @ Abercrombie

Location Annual Peak	Discharge-Frequency (cfs) % Chance Exceedance			
	10	2	1	.2
Abercrombie	6,415	13,716	17,538	27,863

5.4 5-YR BALANCED HYDROGRAPHS

To refine the environmental assessment of staging water upstream 20% chance of exceedance balanced hydrographs were developed based on the 20% annual instantaneous peak flow value determined for the Red River of the North at Hickson, ND, Fargo, ND, and Halstad, MN and the Wild Rice River-ND at Abercombie, ND.

20% coincidental balanced hydrographs were determined for the coincidental peak on the Red River at Hickson when the Wild Rice River is peaking at Abercombie, ND and for the coincidental peak on the Wild Rice River-ND when the Red River is peaking at Fargo, ND.

6. REFERENCES

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14. West Consultants Inc. 2001. Sheyenne River: Geomorphology Study.

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Figures

Figure 1. Maple River Watershed- USGS Gages (source: Bengtson, M. & G. Padmanabhan)

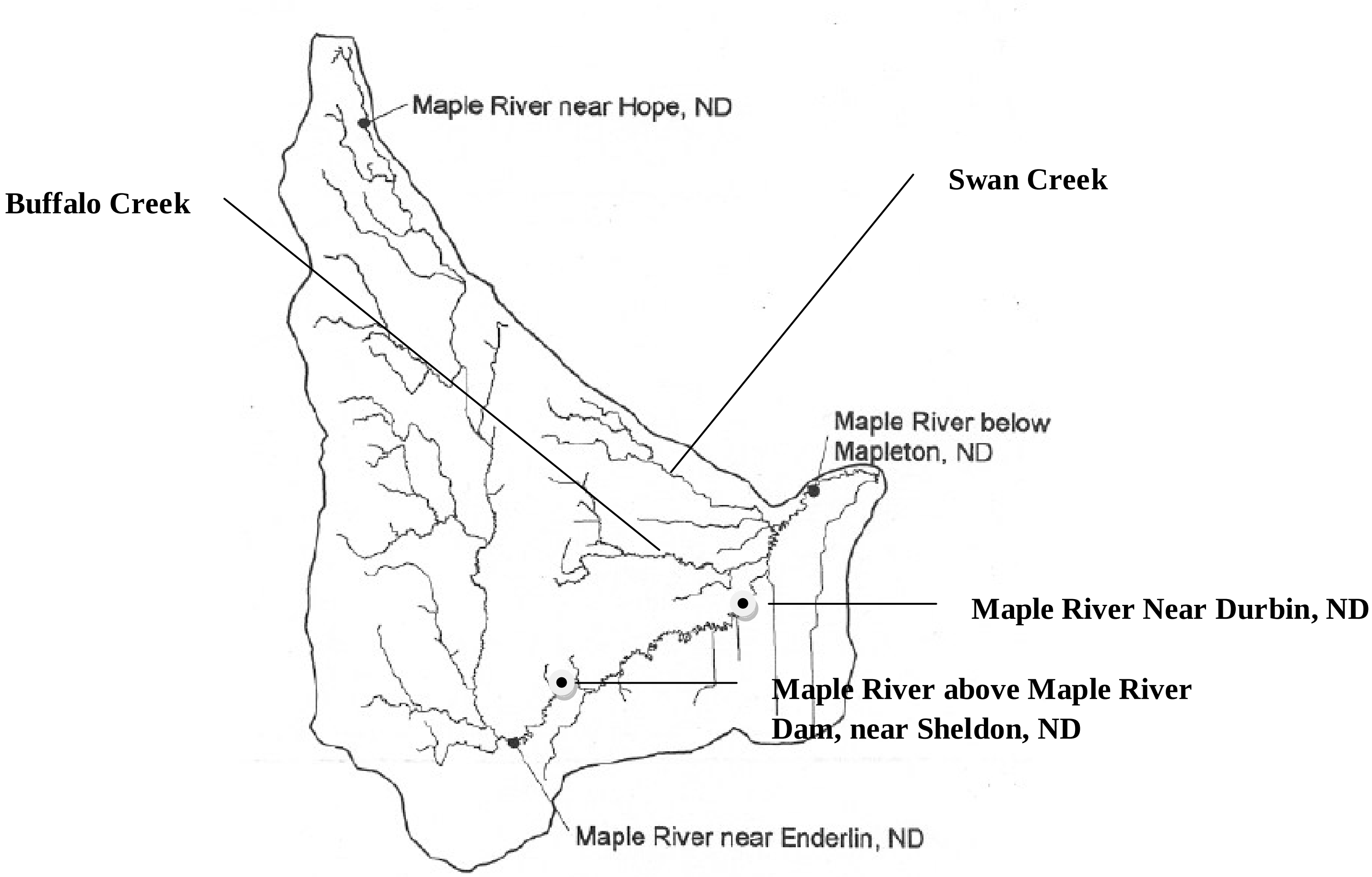


Figure 2- USGS Gage Records utilized in for Maple River Modeling

Figure 3. Justification for placing non-contributing area between the Enderlin USGS gage and the Maple River Dam

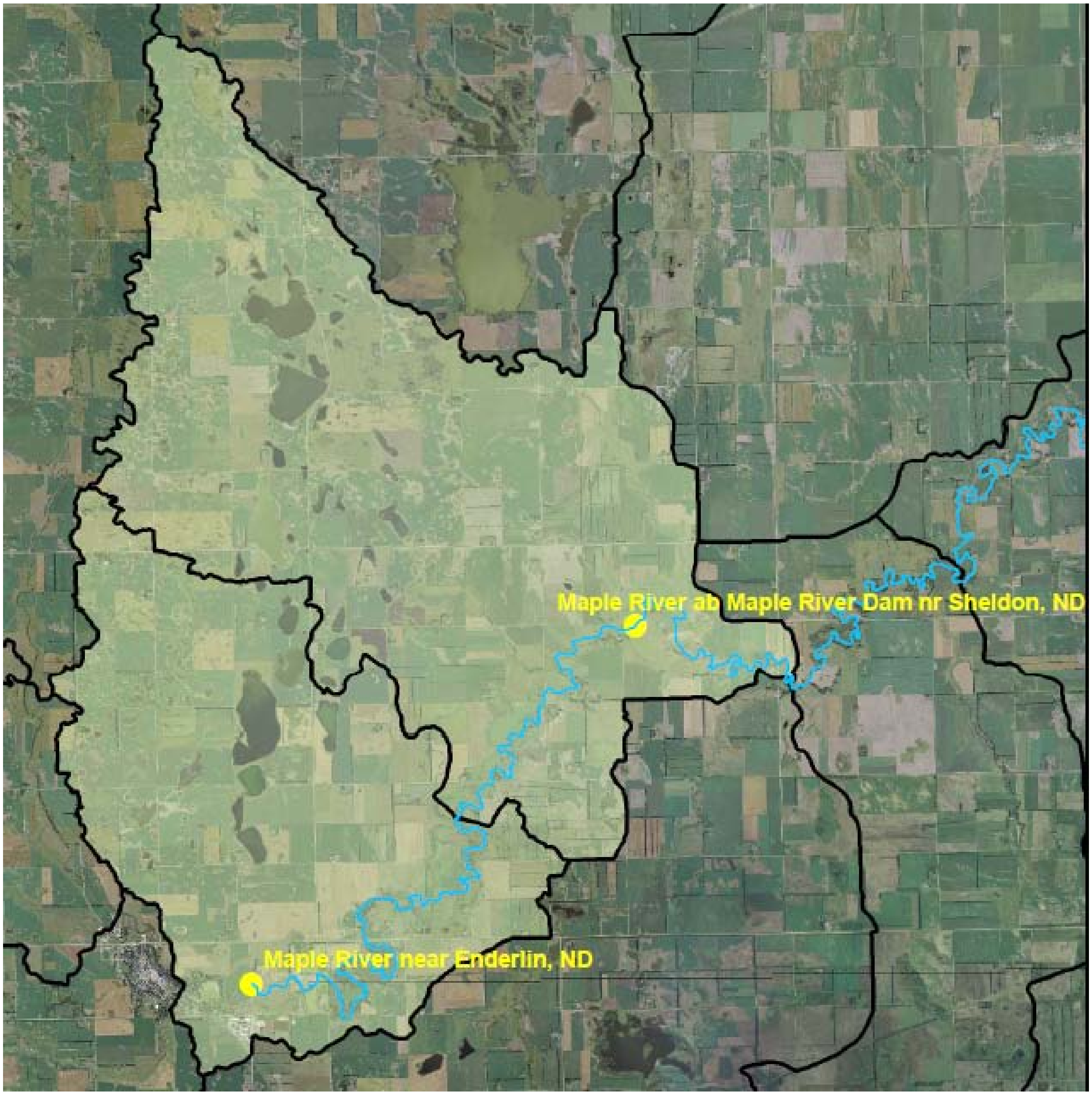


Figure 4. Channel Cross Sections

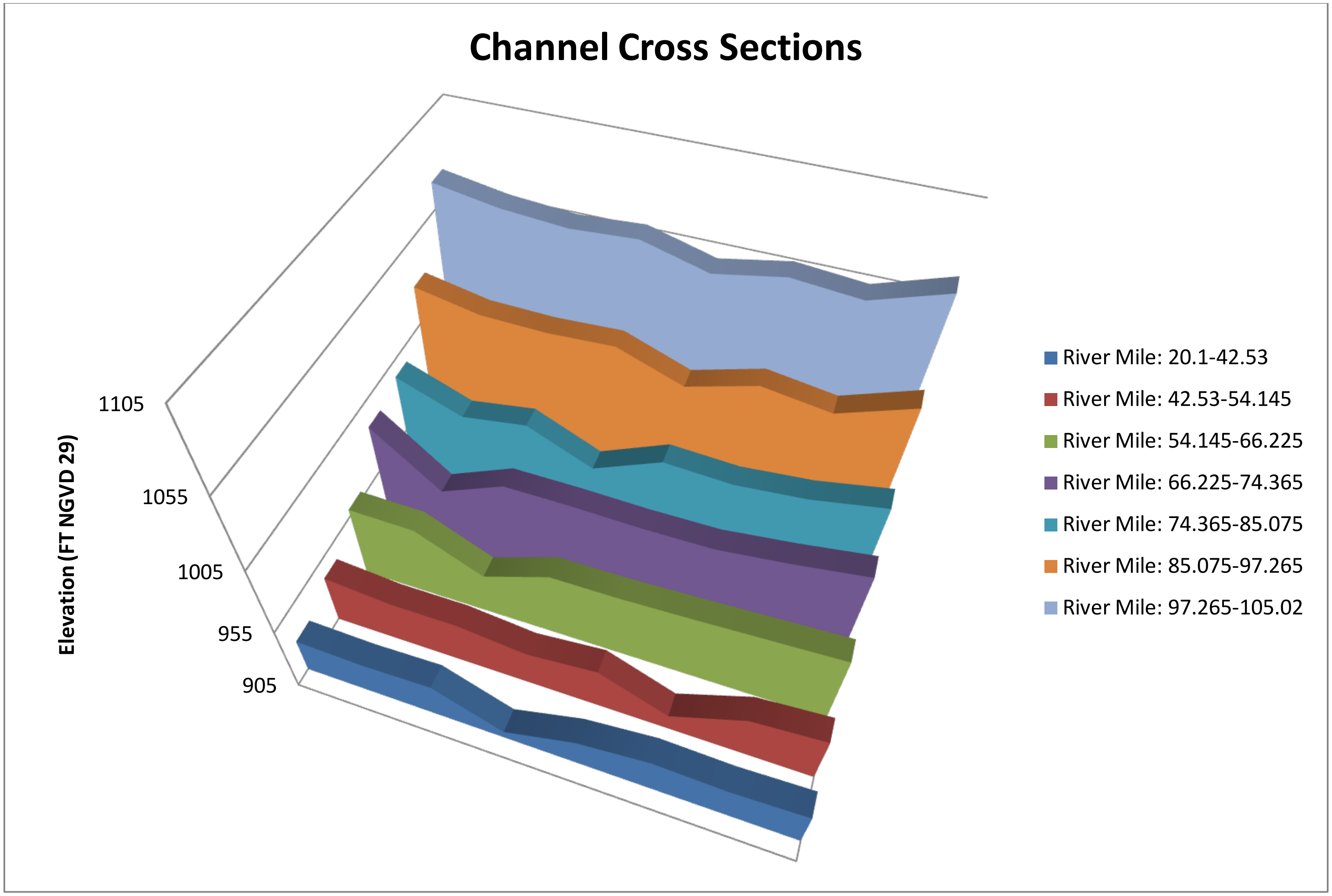


Figure 5. Aerial photograph of the Maple River near Enderlin (Source: Google Earth)

Figure 6. Aerial photograph of the Maple River near the Maple River Dam (Source: Google Earth)

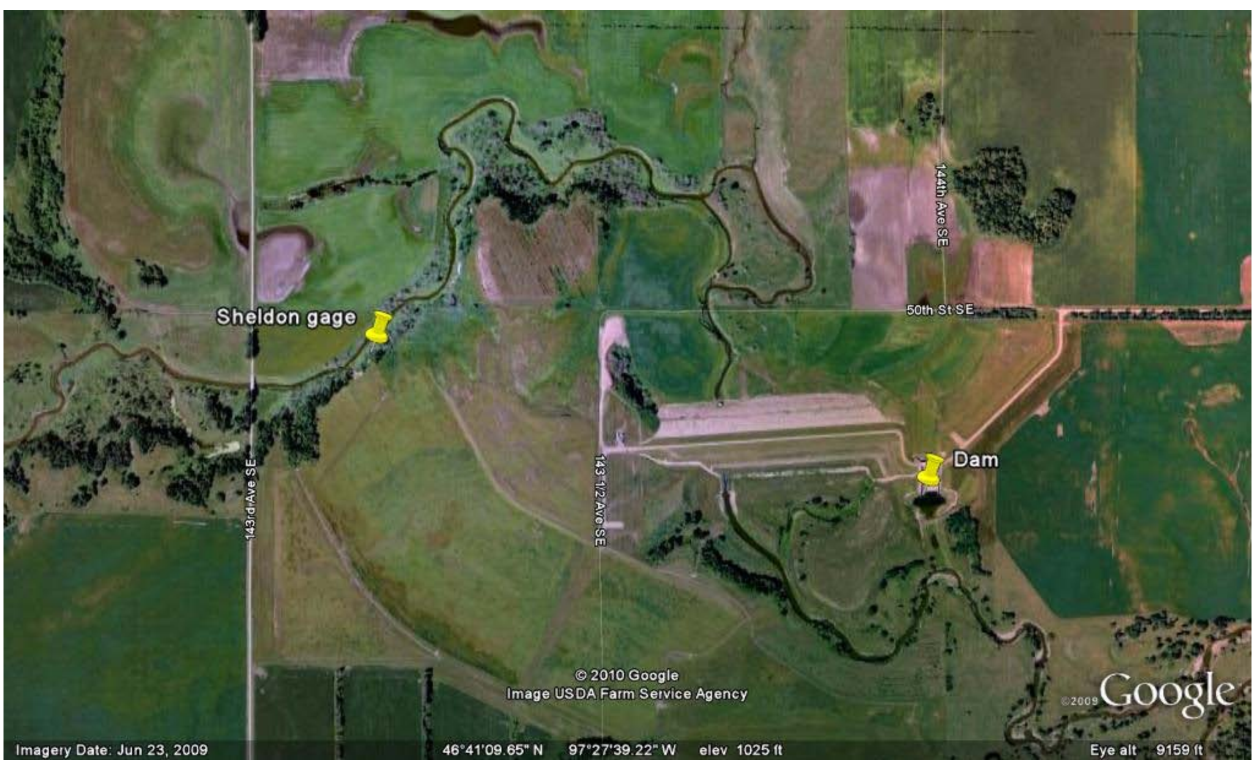


Figure 7. Aerial photograph of the Maple River near Mapleton (Source: Google Earth)

Figure 8. Maple River Dam (Source: Moore Engineering)

Figure 9. Maple River Dam Elevation-Storage Relationship

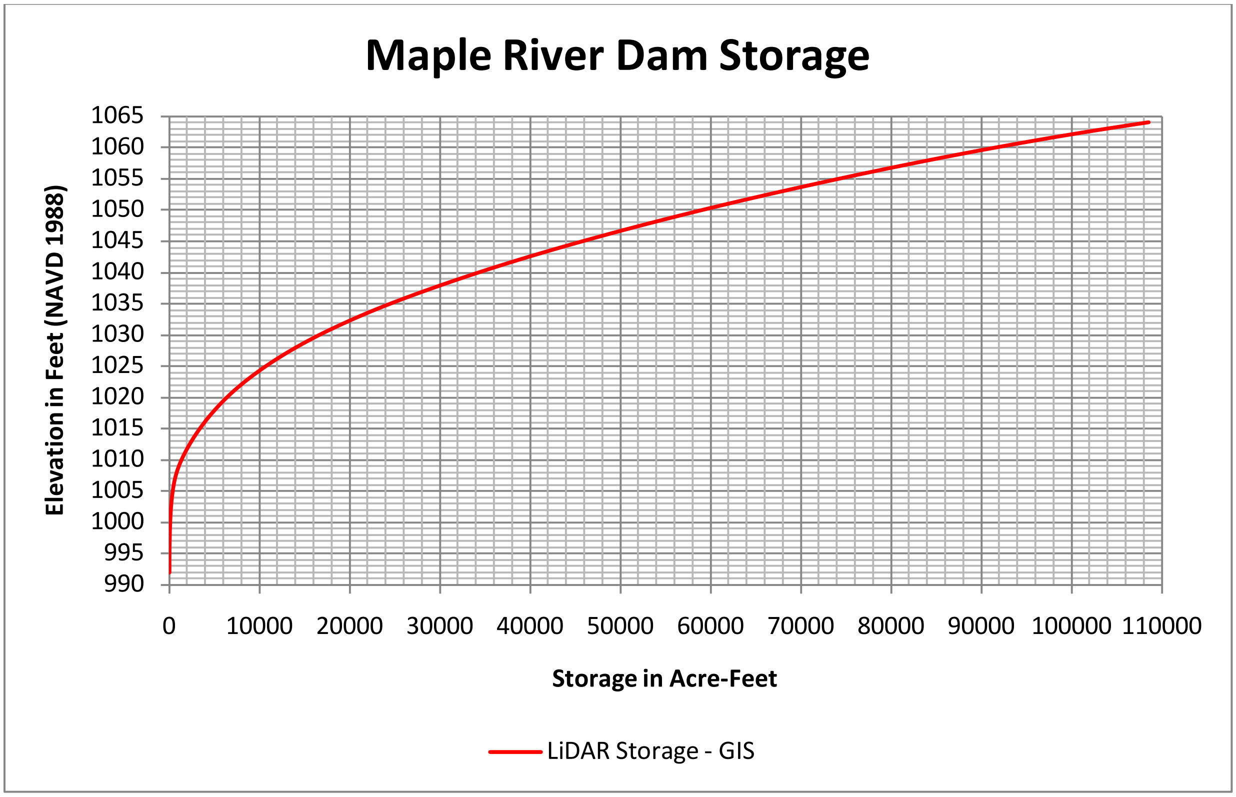


Figure 10. Maple River Dam Control Structure Rating Curve

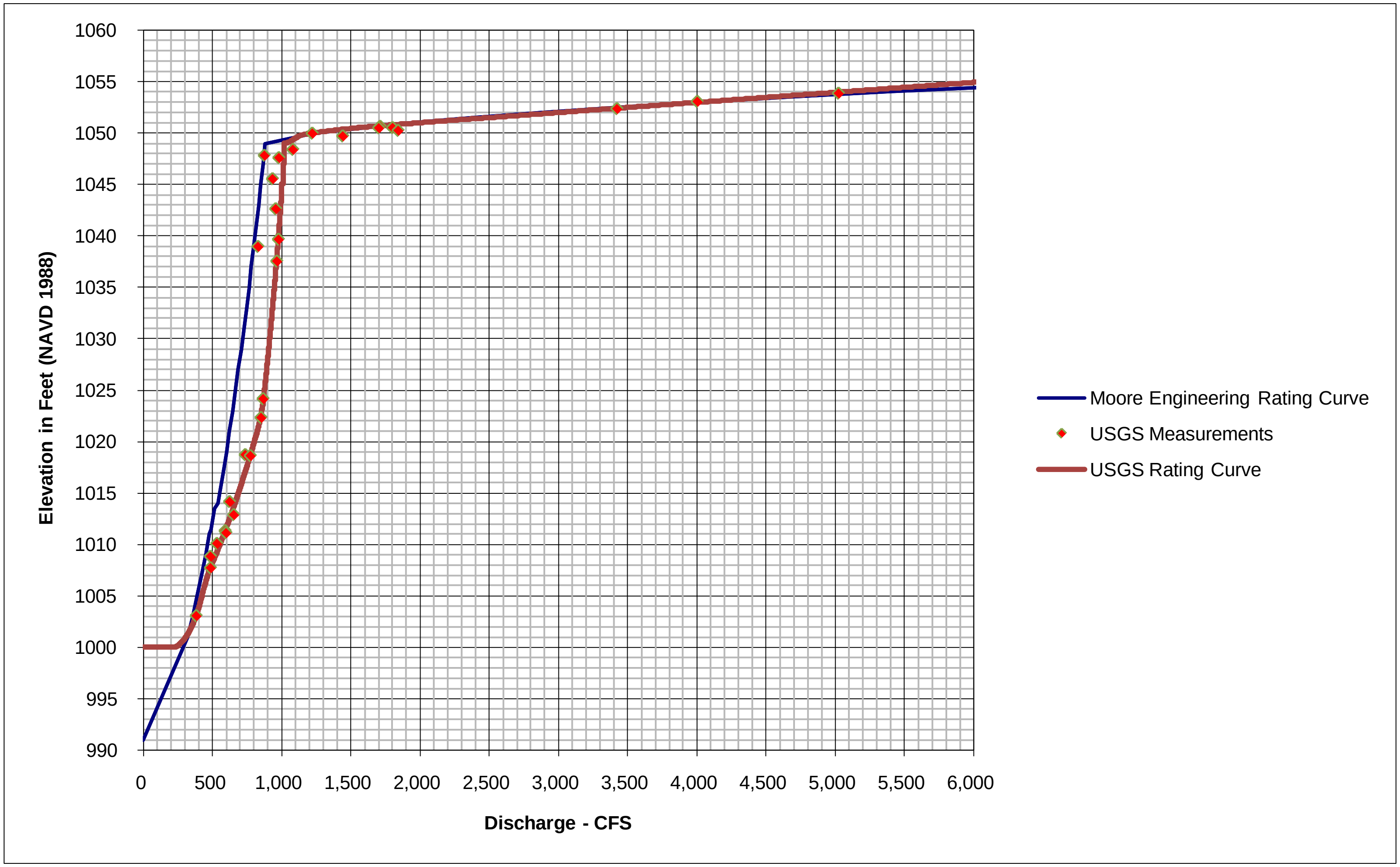


Figure 11. Breakout Flows from the Maple River to the Sheyenne River

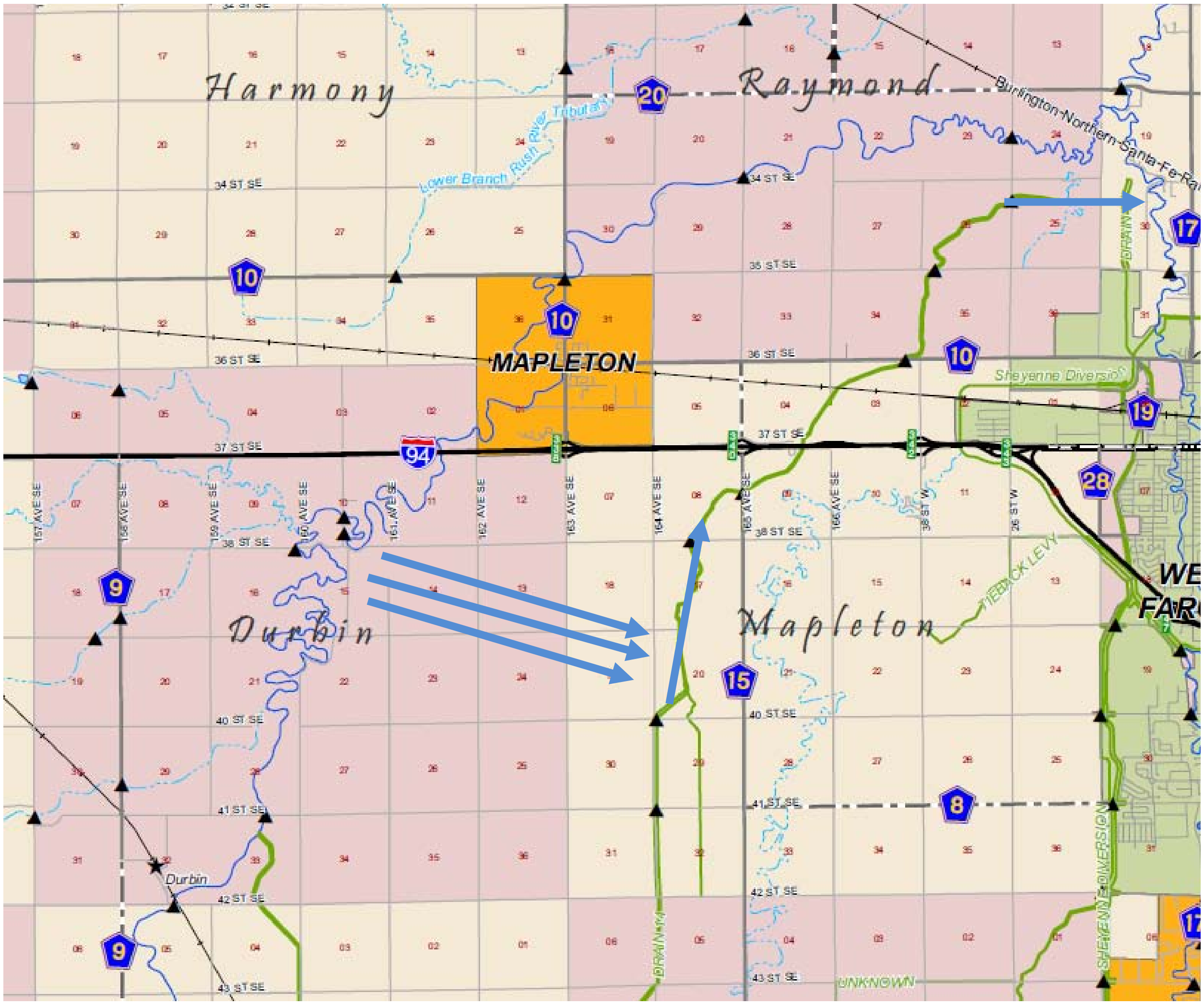


Figure 12. HMS Schematic

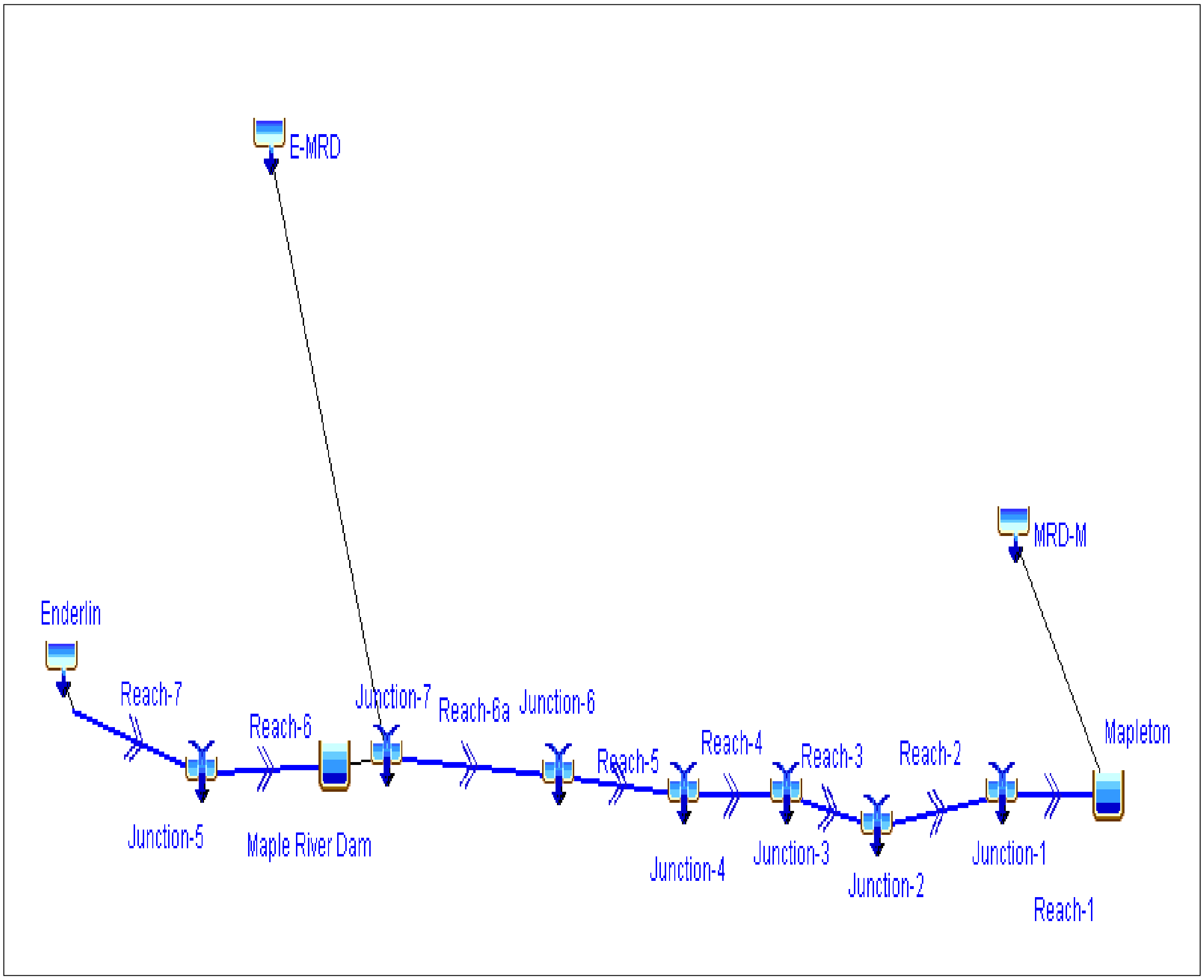


Figure 13. Dam Outflow- 2007, 2008 & 2009

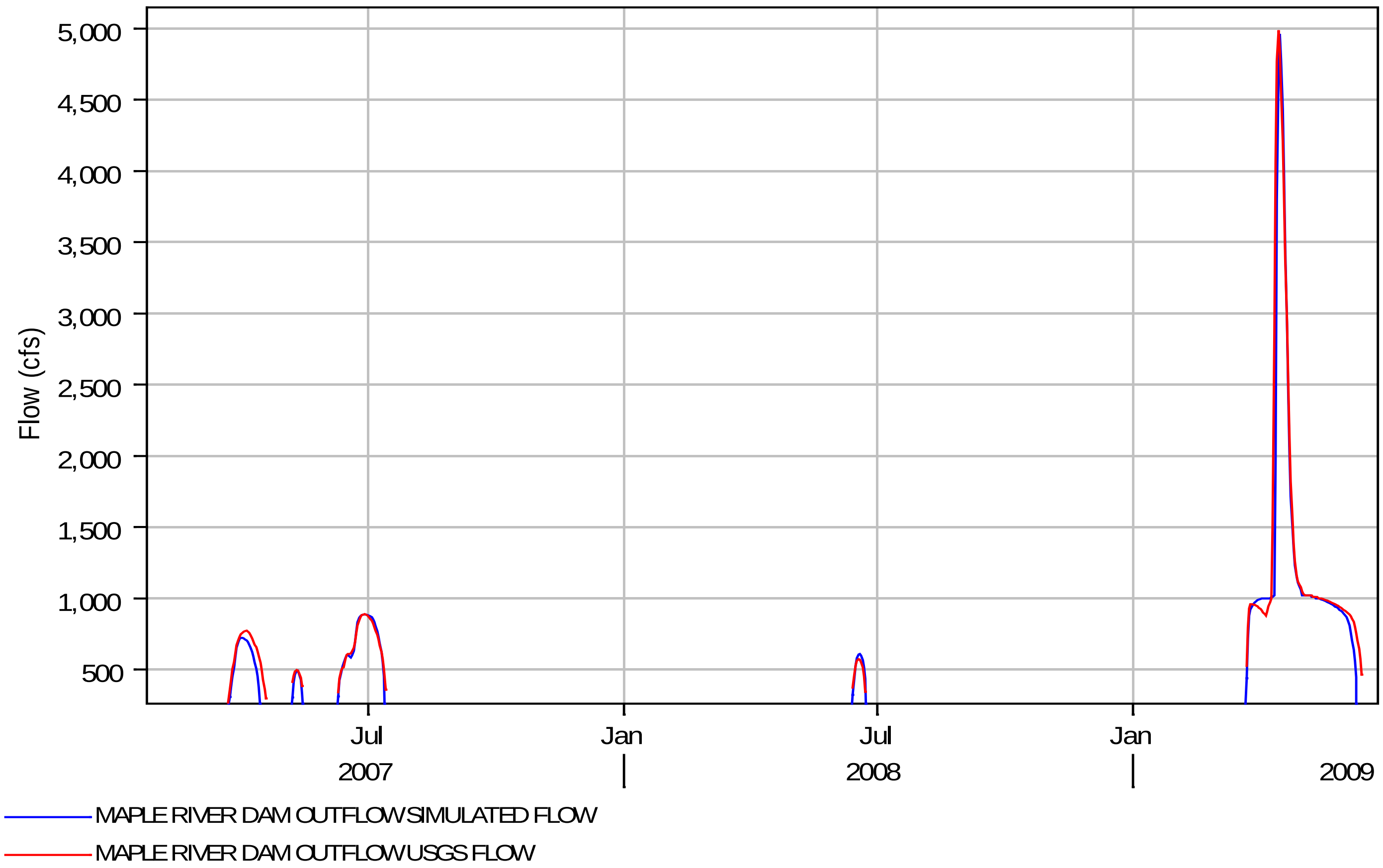


Figure 14. Elevation in Storage Pool- 2007, 2008, & 2009

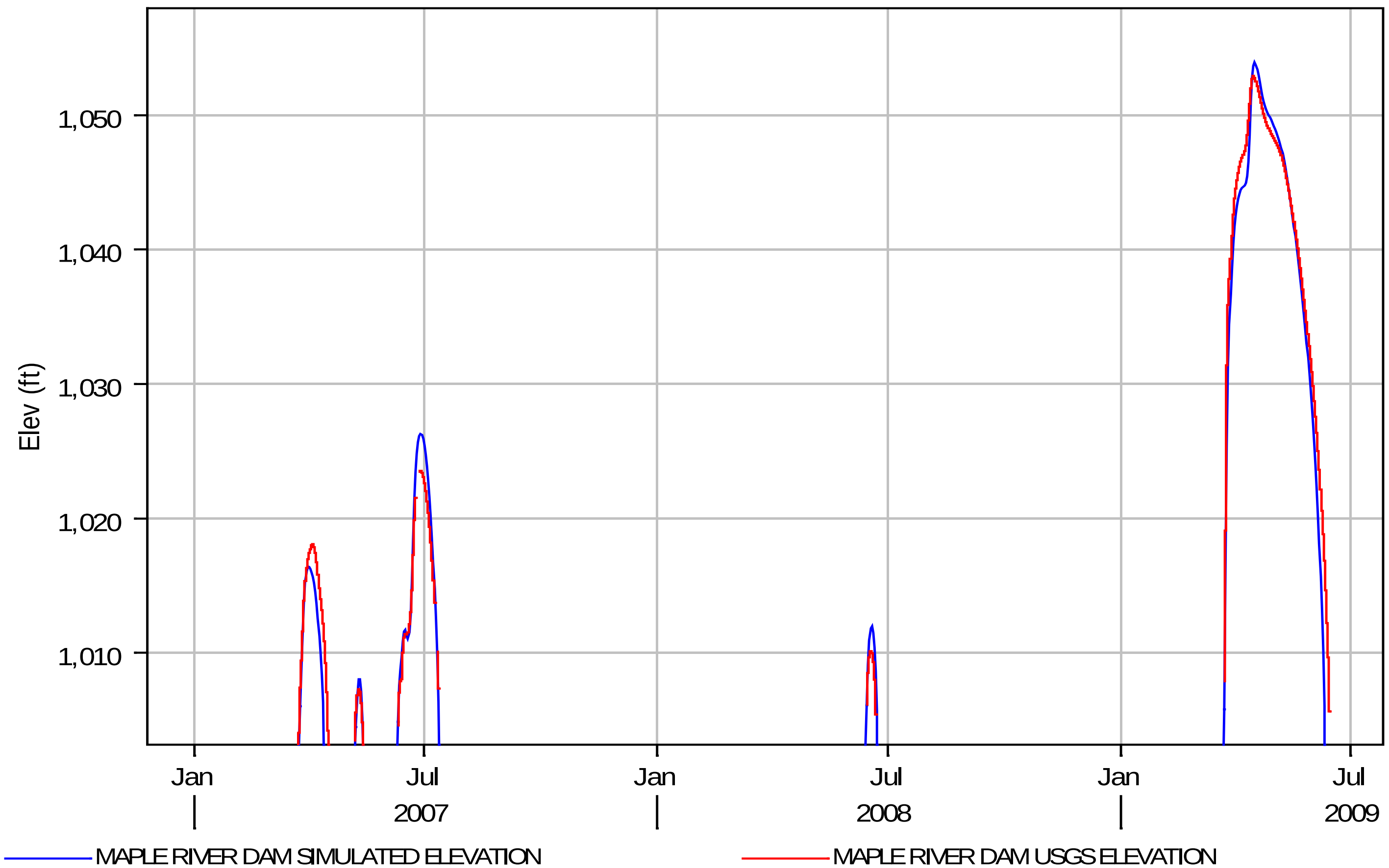


Figure 15. Homogenous Flow record at Mapleton, ND

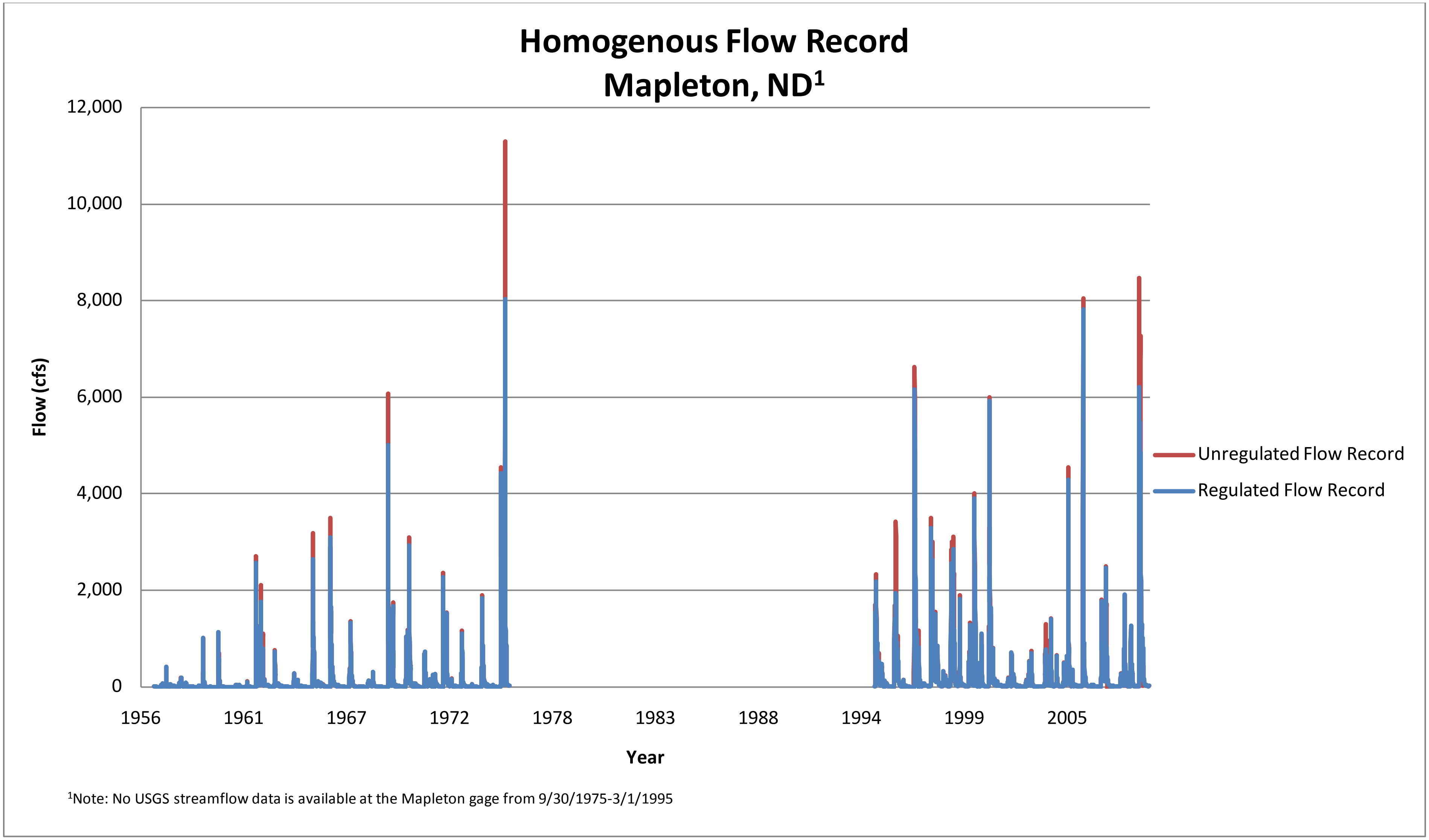


Figure 16. Flow Frequency Curve and Volume Duration Curve for Outflows from Maple River Dam (Weibull PP)

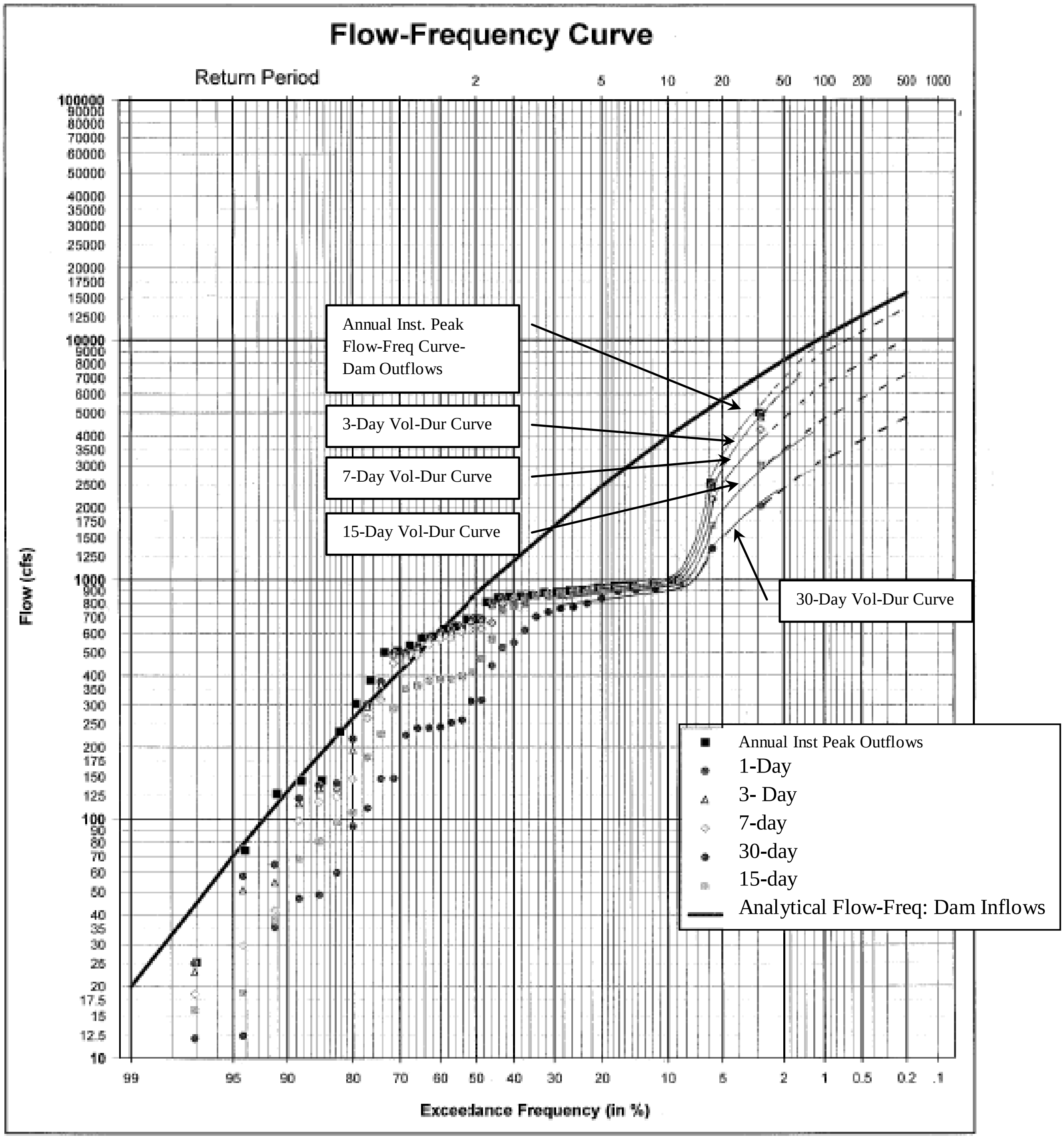


Figure 17. Relationship between Mean Daily and Annual peaks at Mapleton

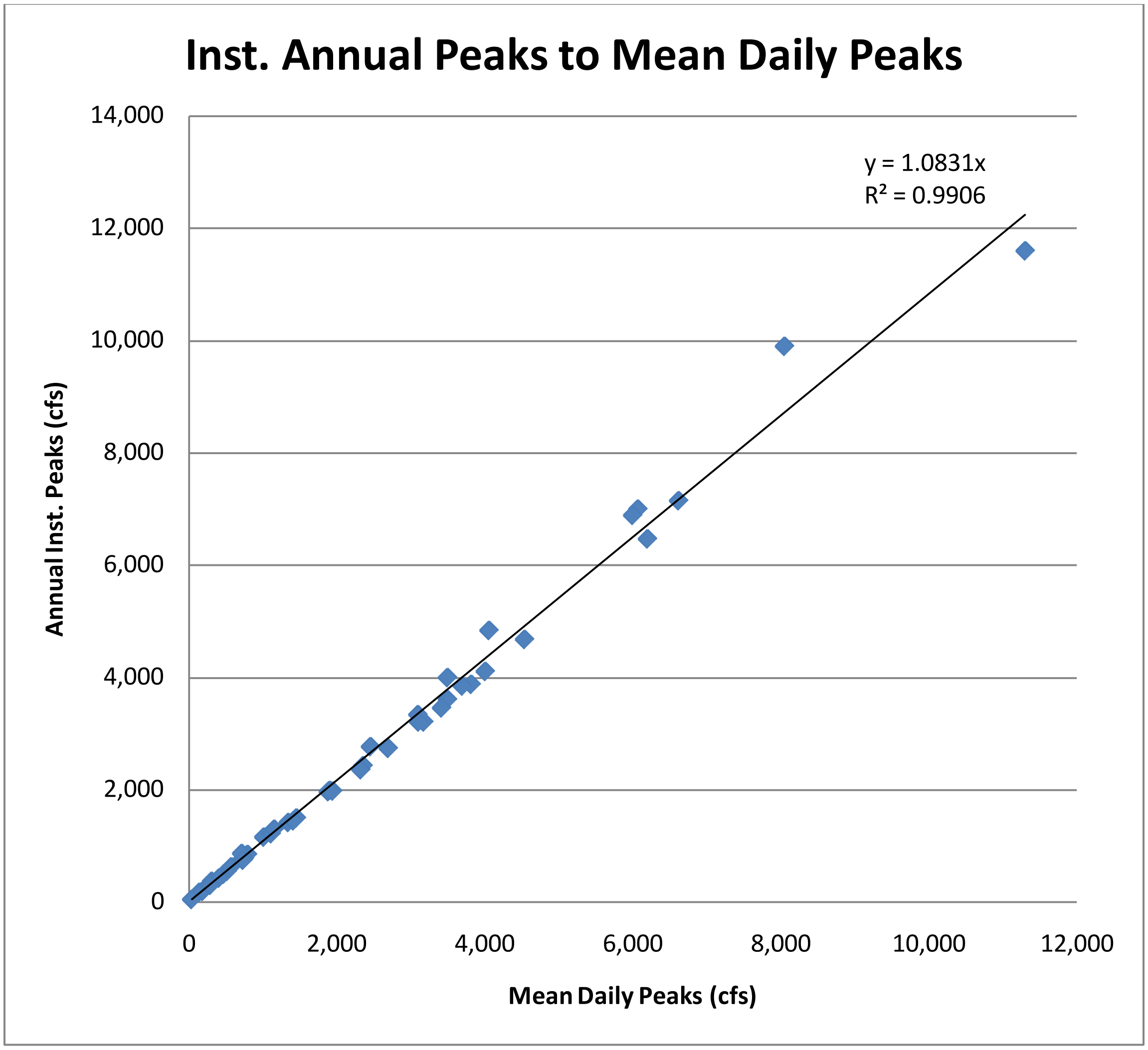


Figure 18. Instantaneous Annual Peak Flow-Frequency Curve- Mapleton (Weibull PP)

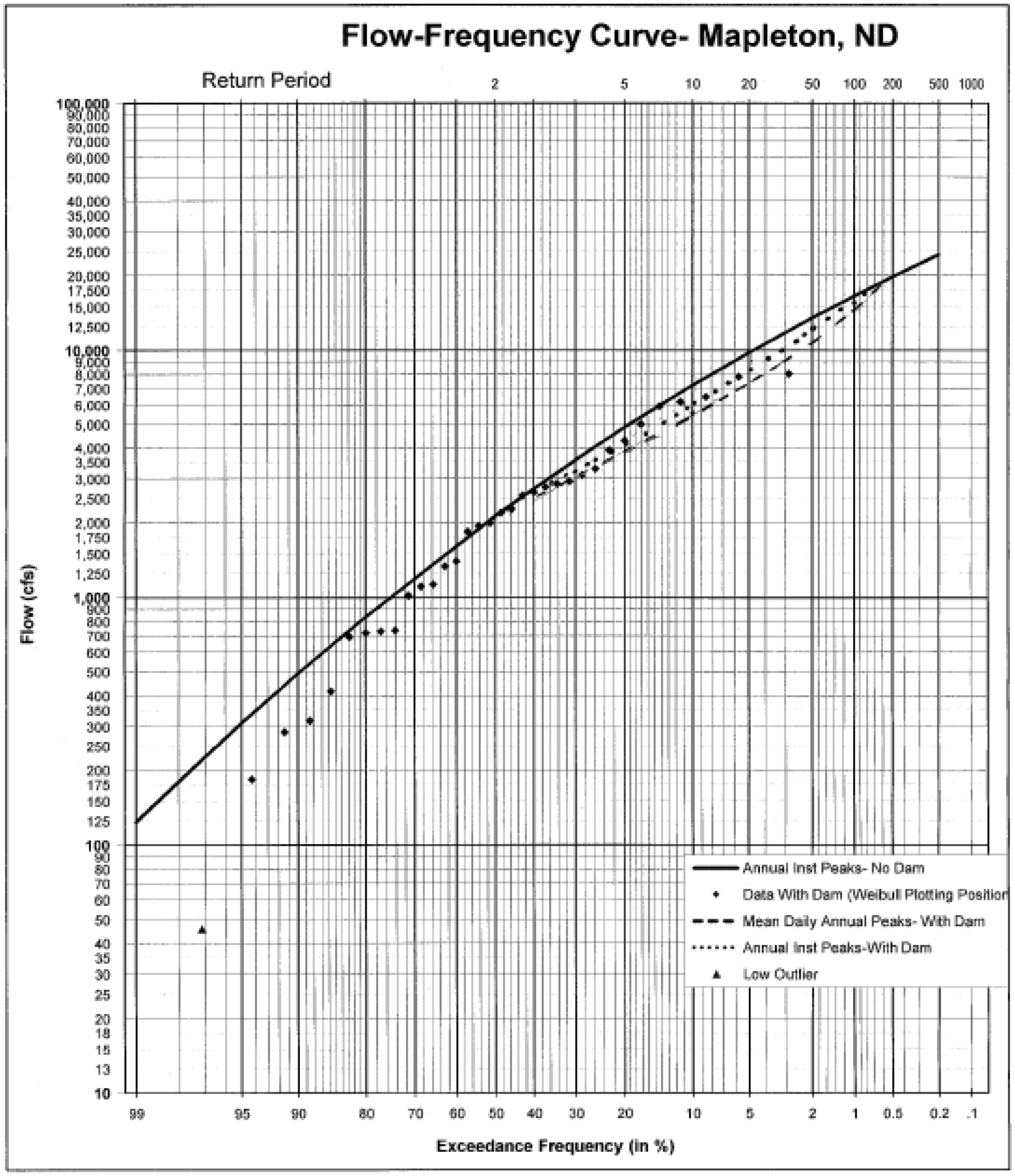


Figure 19. Volume-Duration Curves for Mapleton, ND (Dam in Place, Weibull PP)

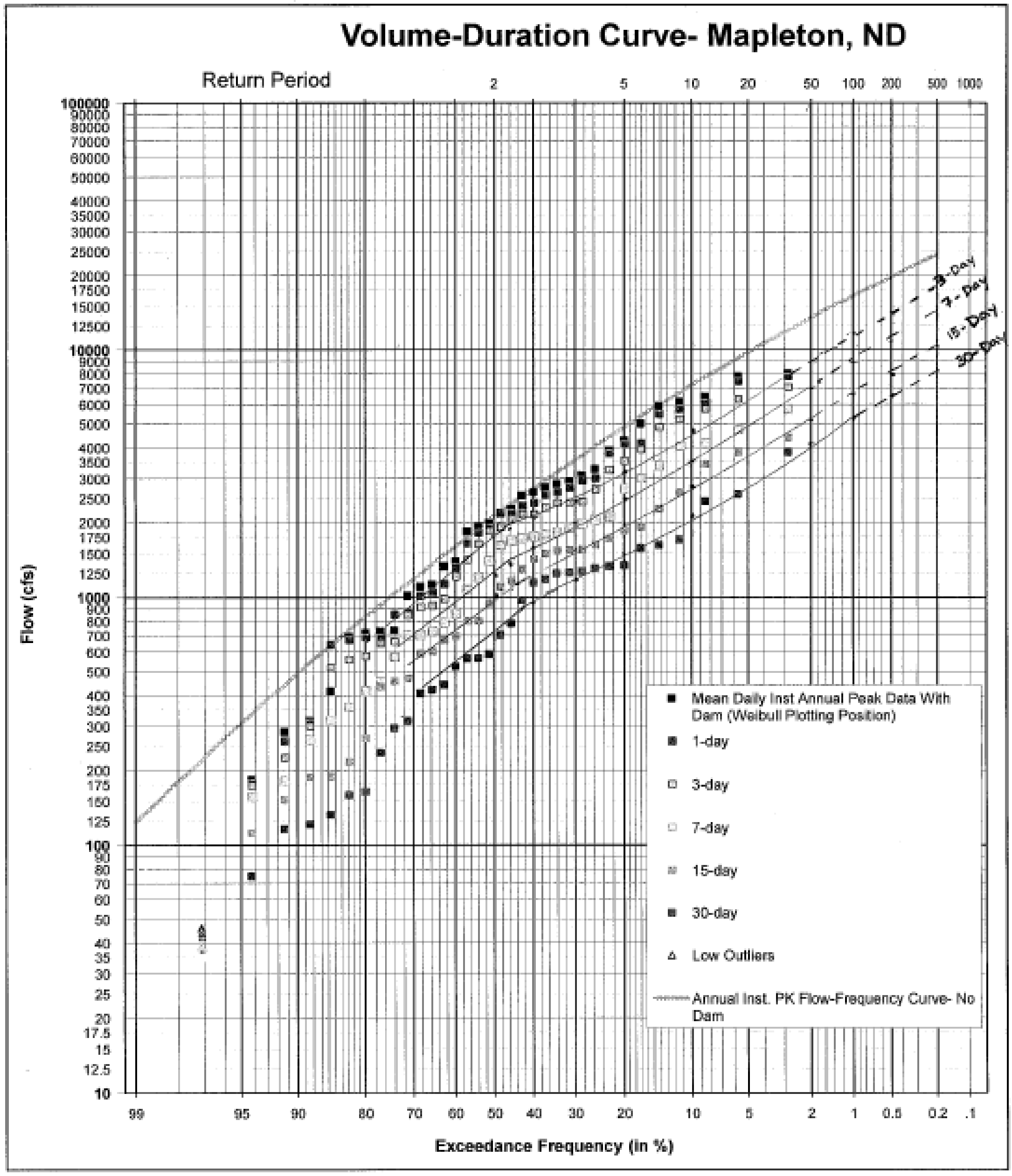


Figure 20. Rush River Watershed (*North Dakota Department of Health*)

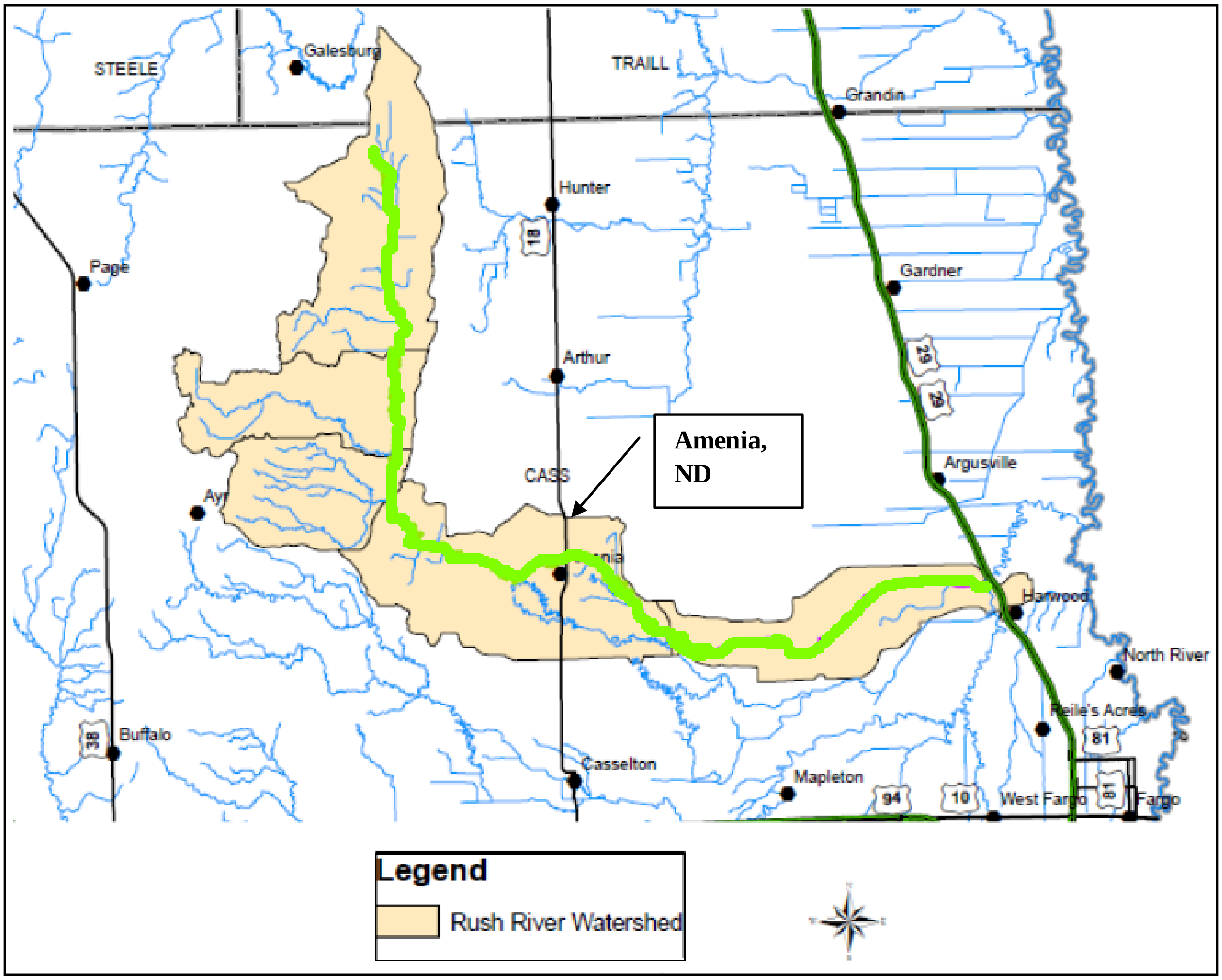


Figure 21 Annual Instantaneous Peak Discharge-Frequency; Rush River @ Amenia, ND

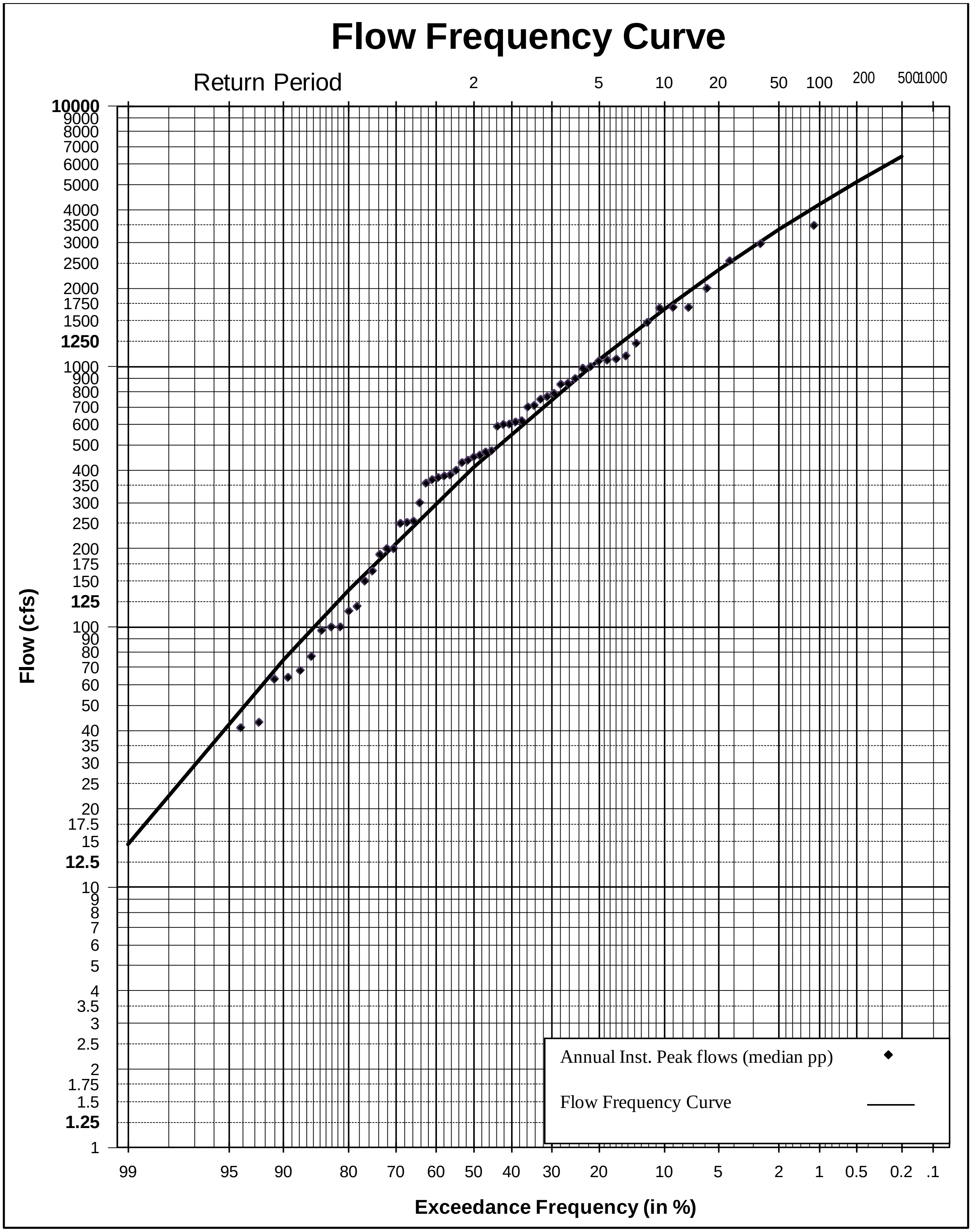


Figure 22. Gol Bridge versus Kindred Breakout Flow Relationship

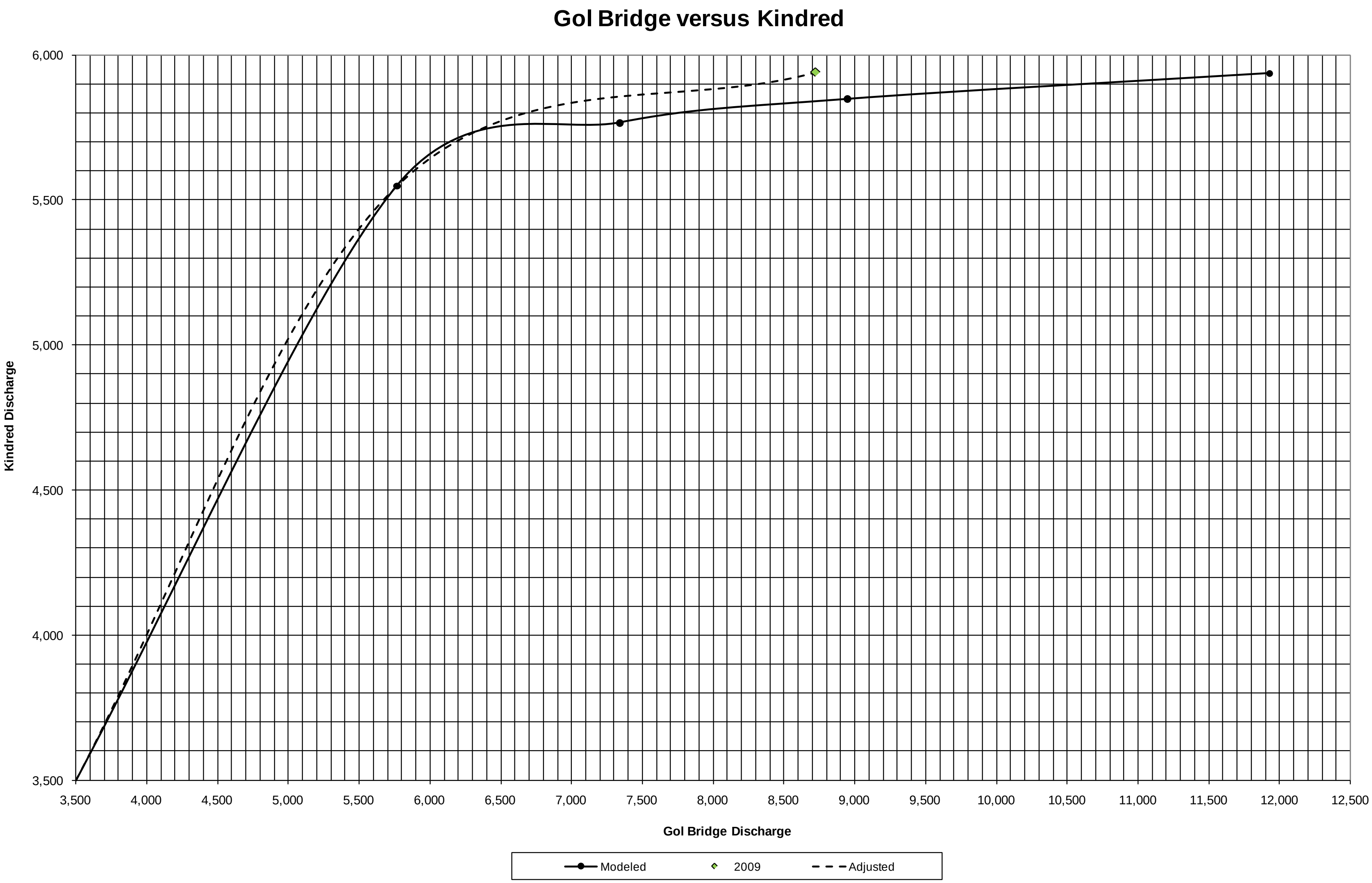


Figure 23. Flow-Frequency Curve- Gol Bridge & Kindred

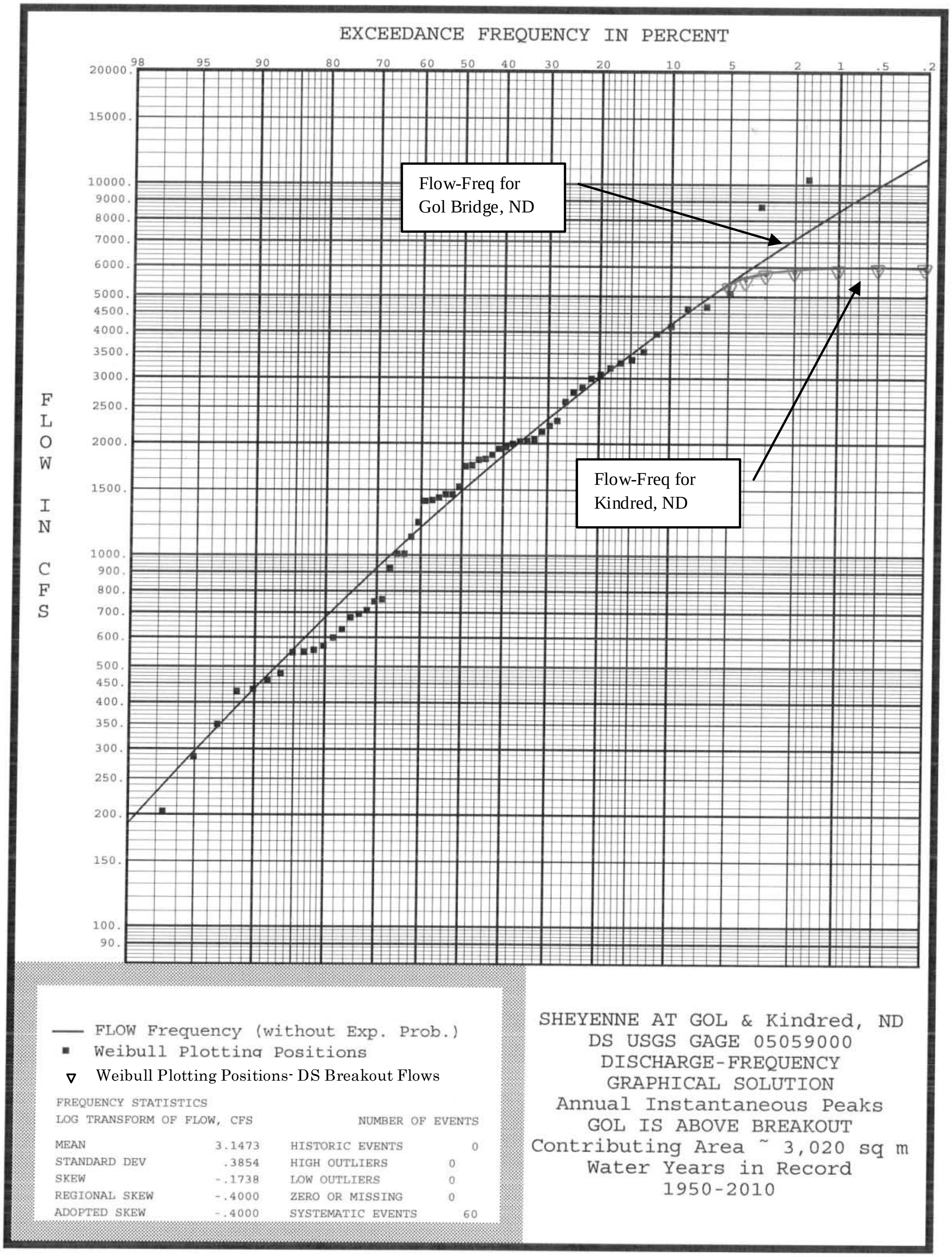


Figure 24. Annual Peak Discharge-Frequency; Sheyenne River @ West Fargo

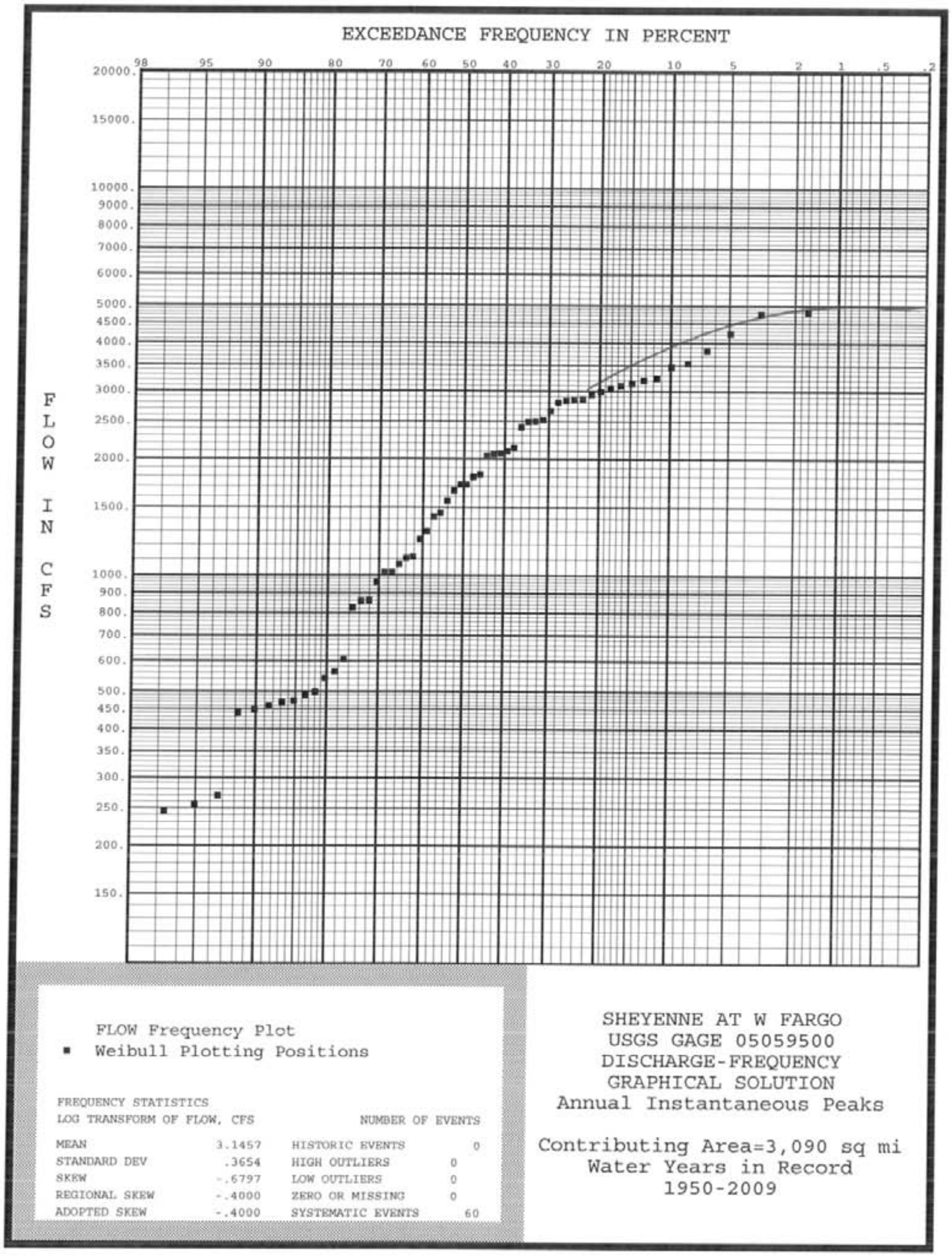


Figure 25. Estimated Discharge Volume Duration Frequencies; Sheyenne River @ West Fargo

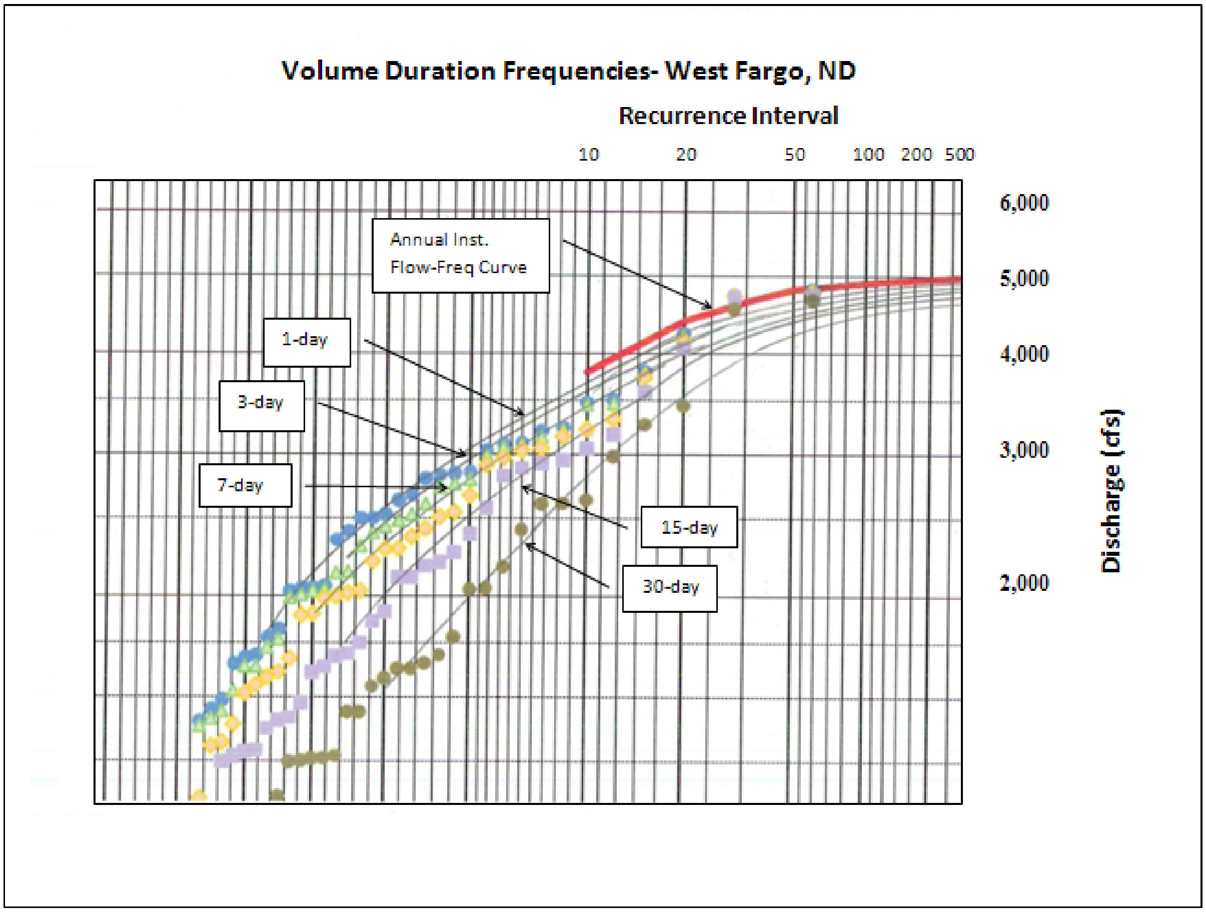


Figure 26. Coincident Discharge-Frequency; Wild Rice River @ Abercrombie when Sheyenne Peaks at Gol Bridge

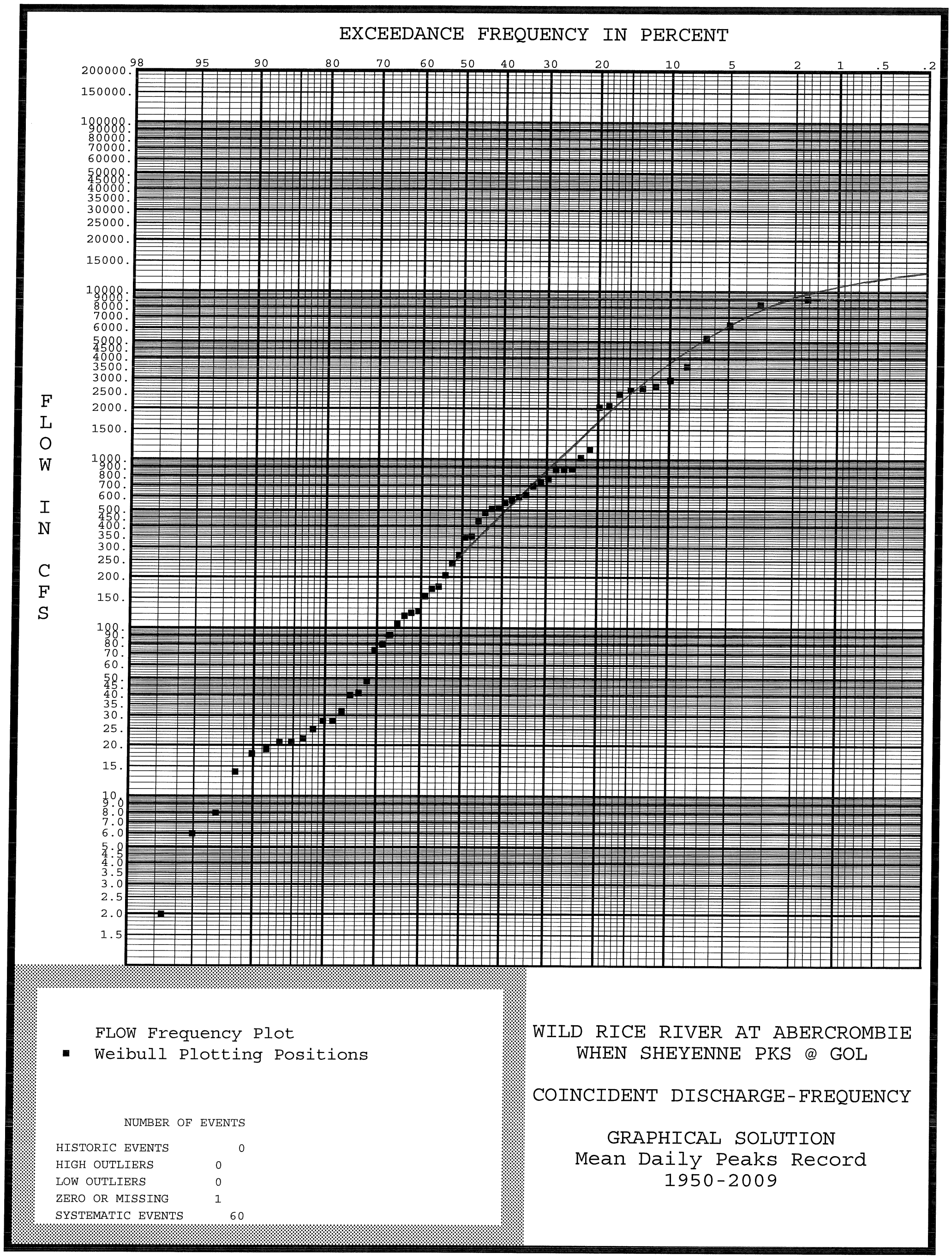


Figure 27. Coincident Discharge-Frequency; Wild Rice River @ Abercrombie when Mapleton Peaks

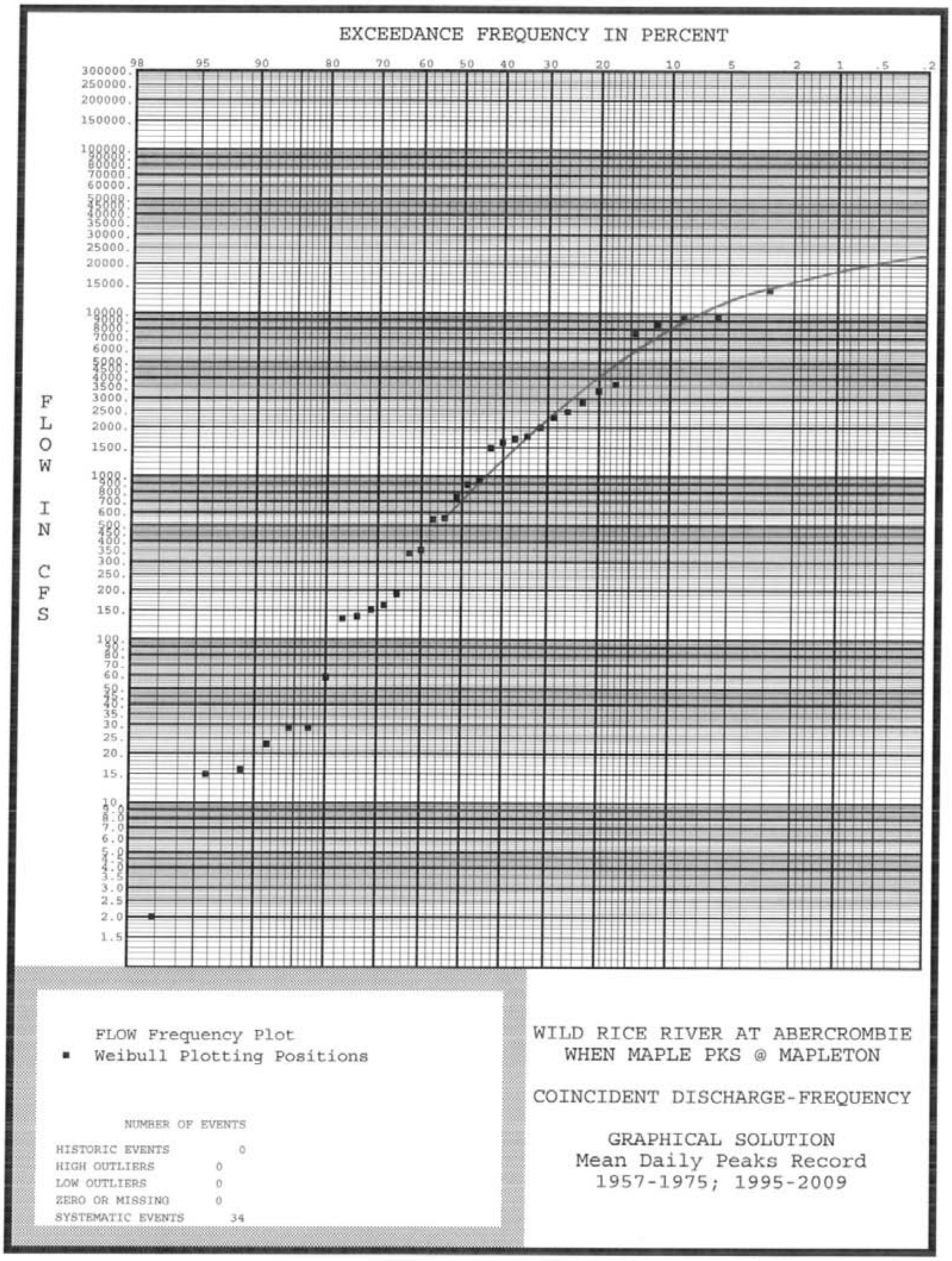


Figure 28. Coincident Discharge-Frequency; Wild Rice River @ Abercrombie when Amenia Peaks

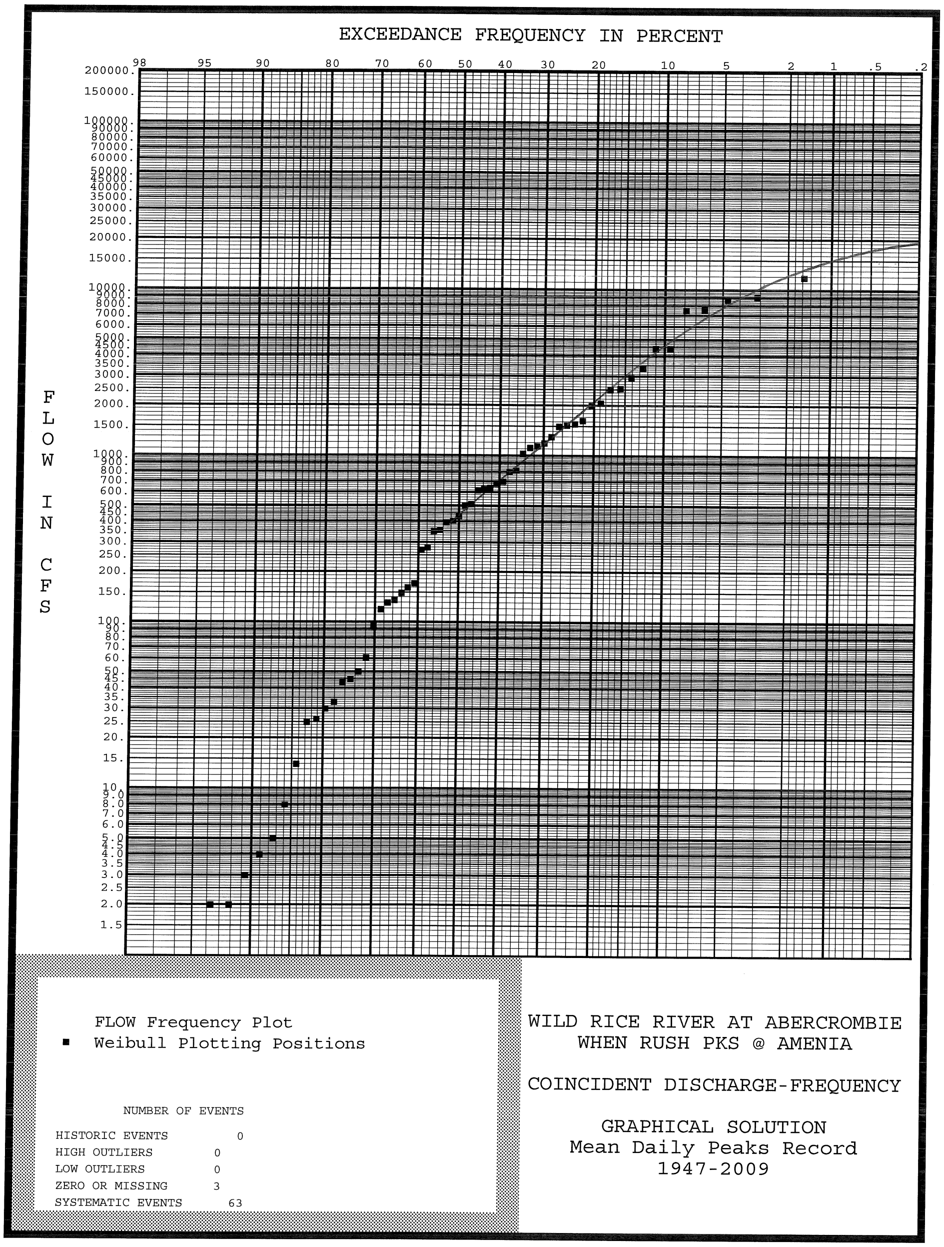


Figure 29. Coincident Discharge-Frequency; Wild Rice River @ Abercrombie when Red Peaks

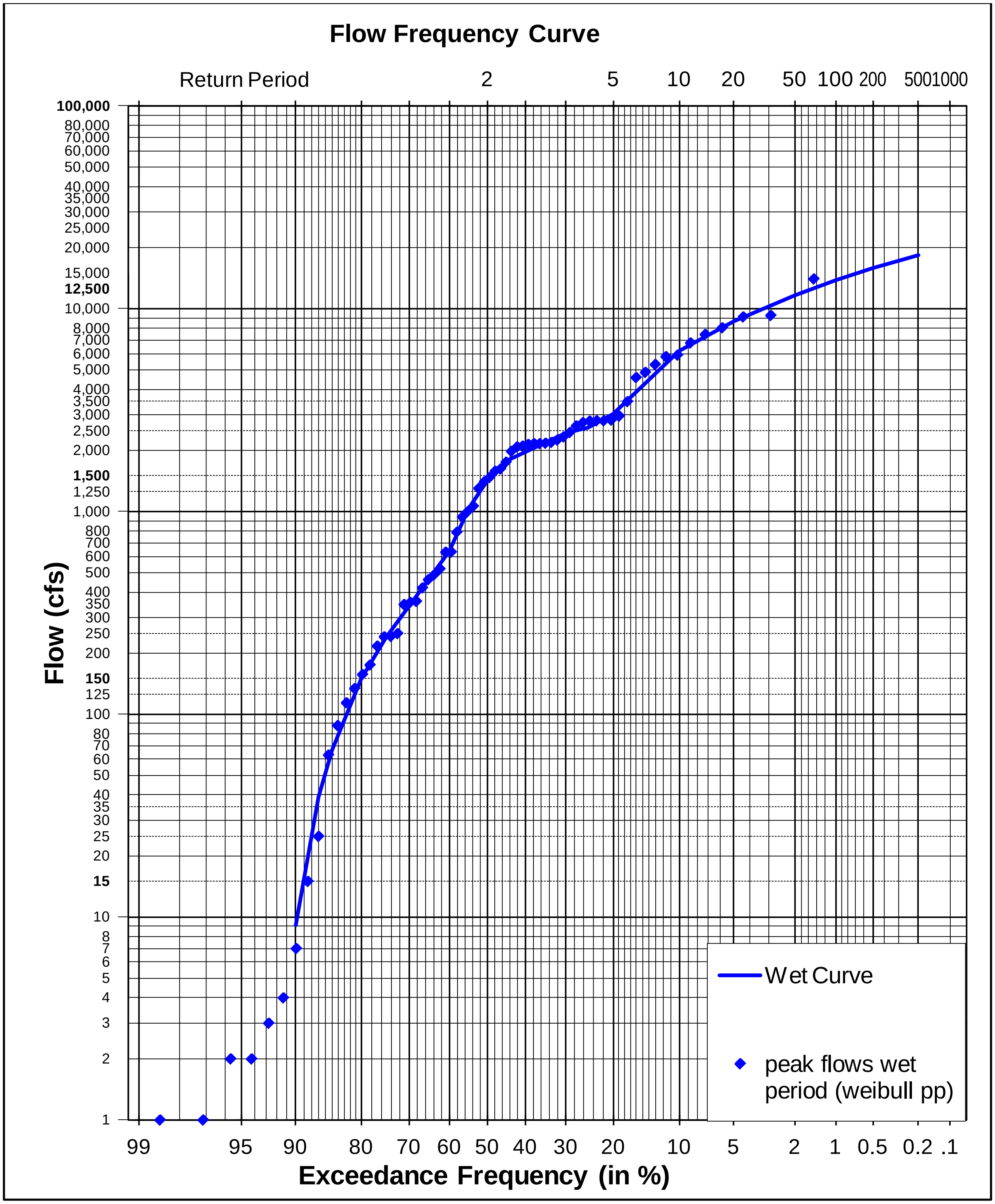


Figure 30. Coincident Discharge-Frequency; Red River @ Hickson when GOL Peaks

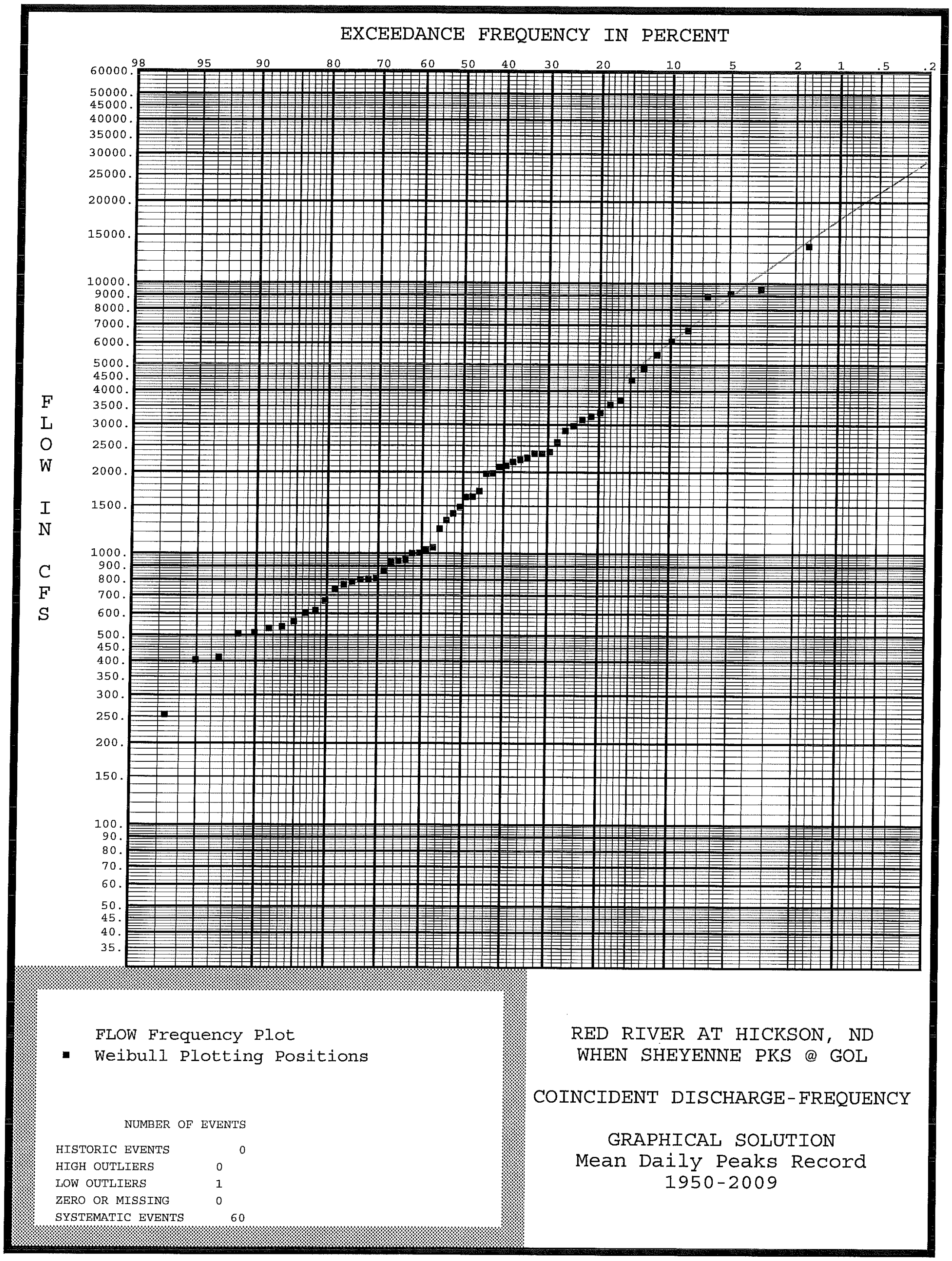


Figure 31. Coincident Discharge-Frequency; Red River @ Hickson when Mapleton Peaks

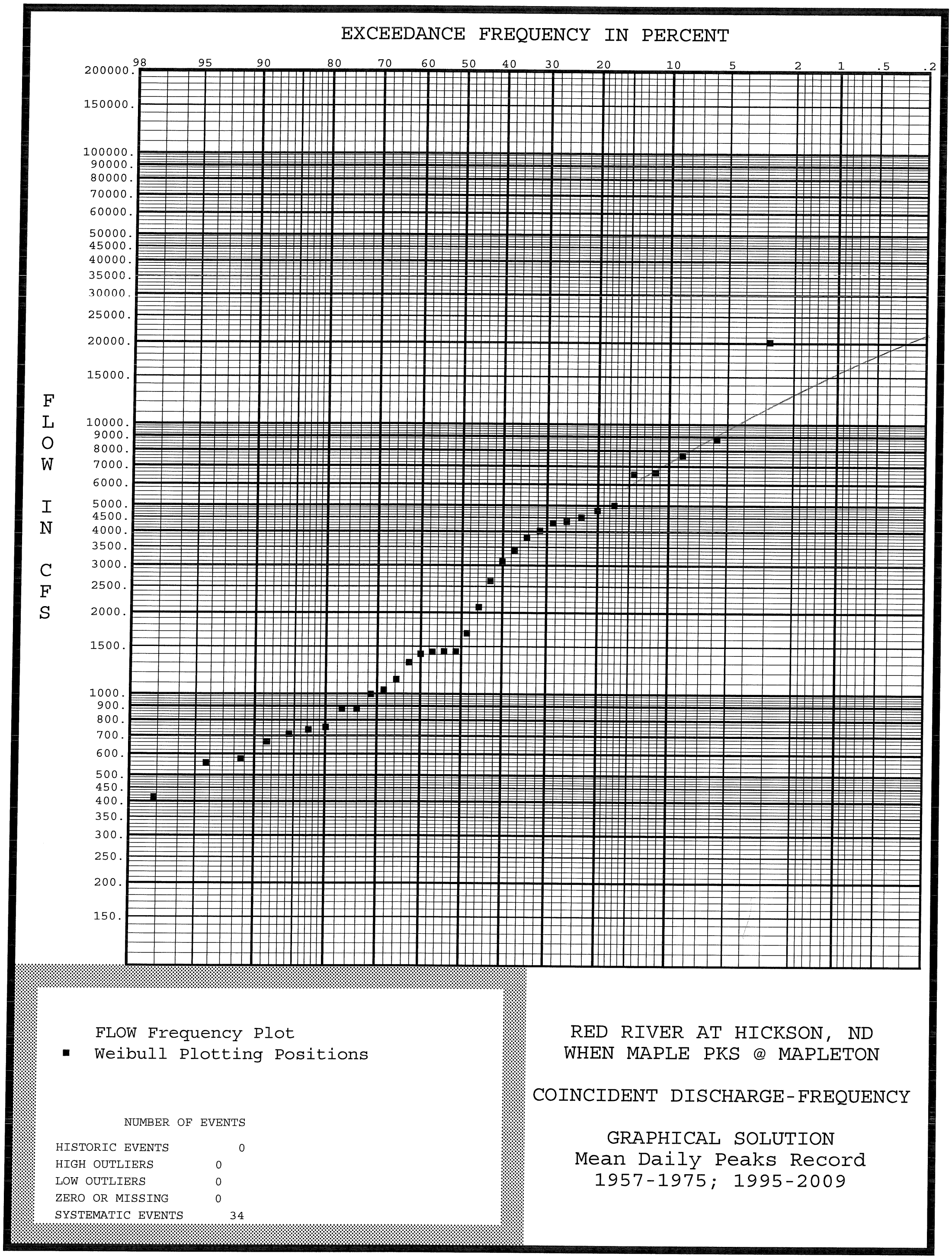


Figure 32. Coincident Discharge-Frequency; Red River @ Hickson when Amenia Peaks

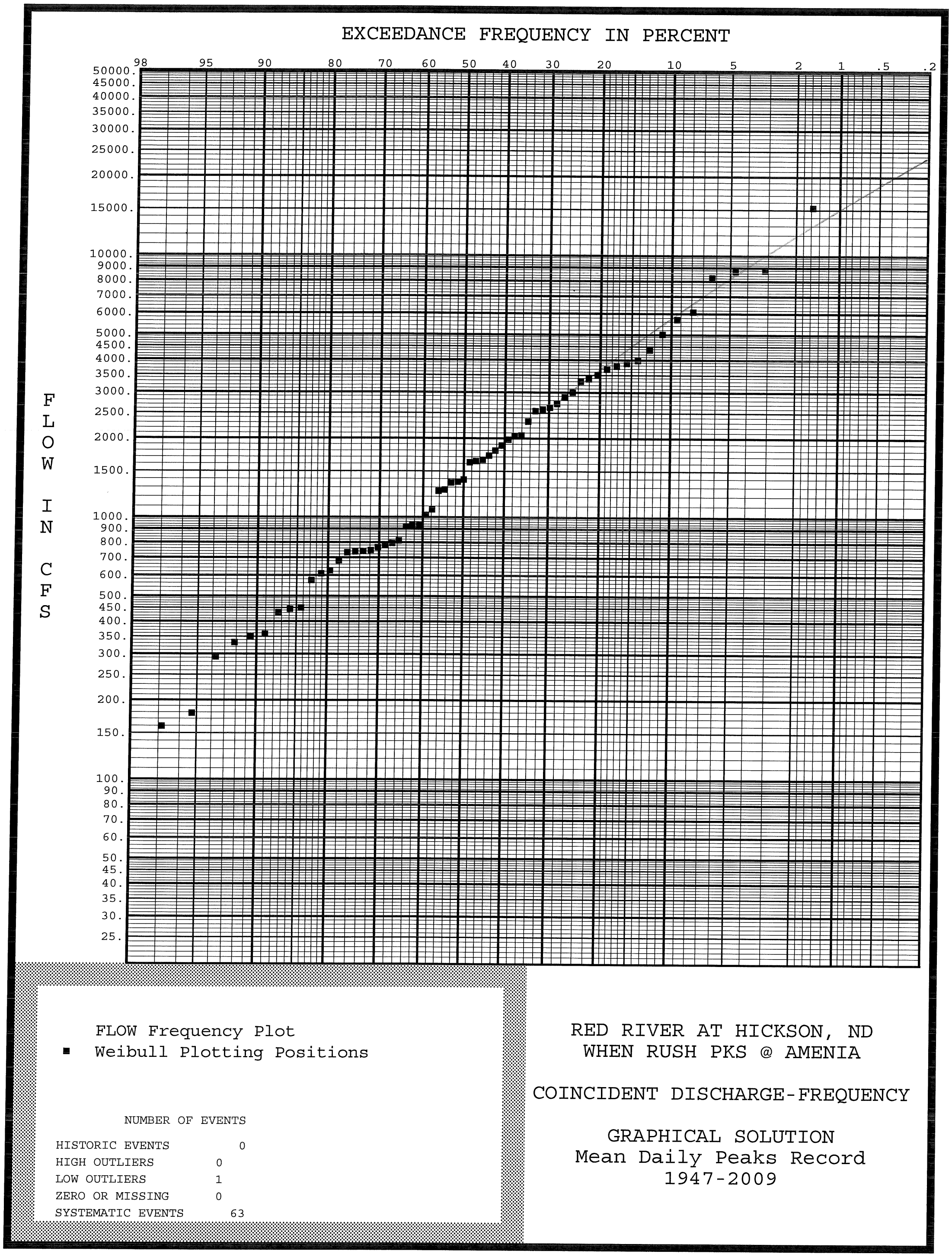


Figure 33 Coincident Discharge-Frequency; Red River @ Hickson when Abercrombie Peaks

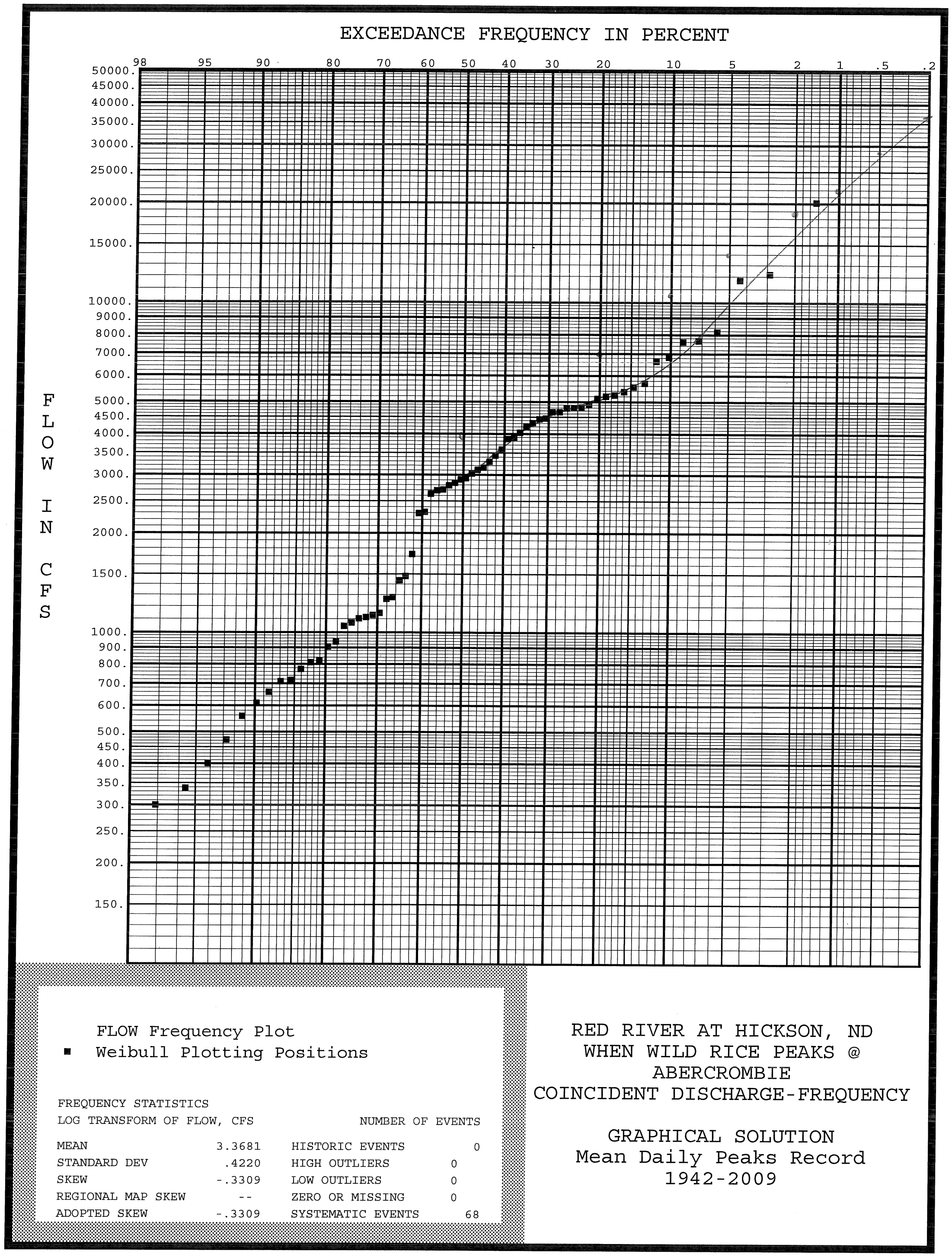


Figure 34 Coincident Discharge-Frequency; Red River @ Confluence when Wild Rice, ND Peaks

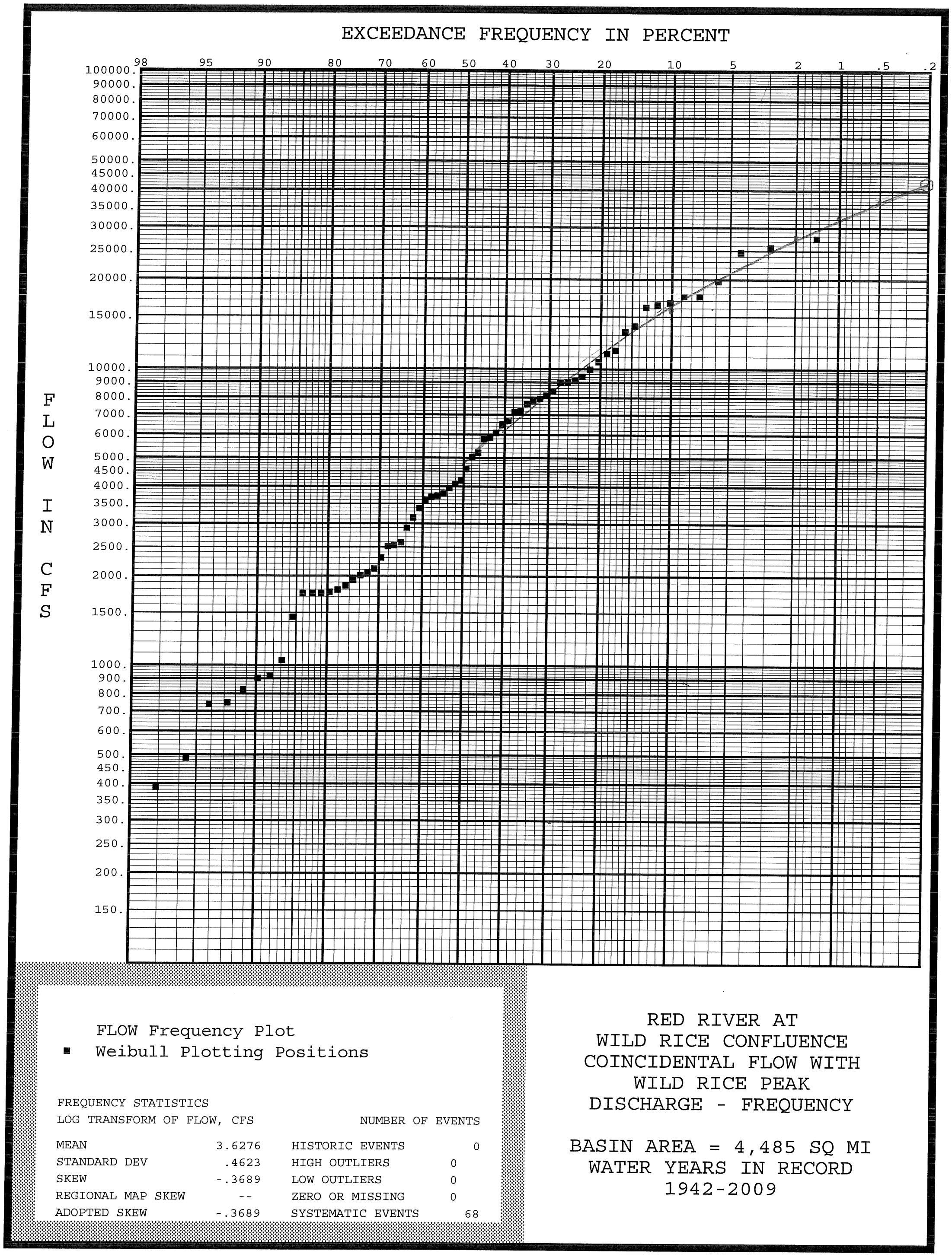
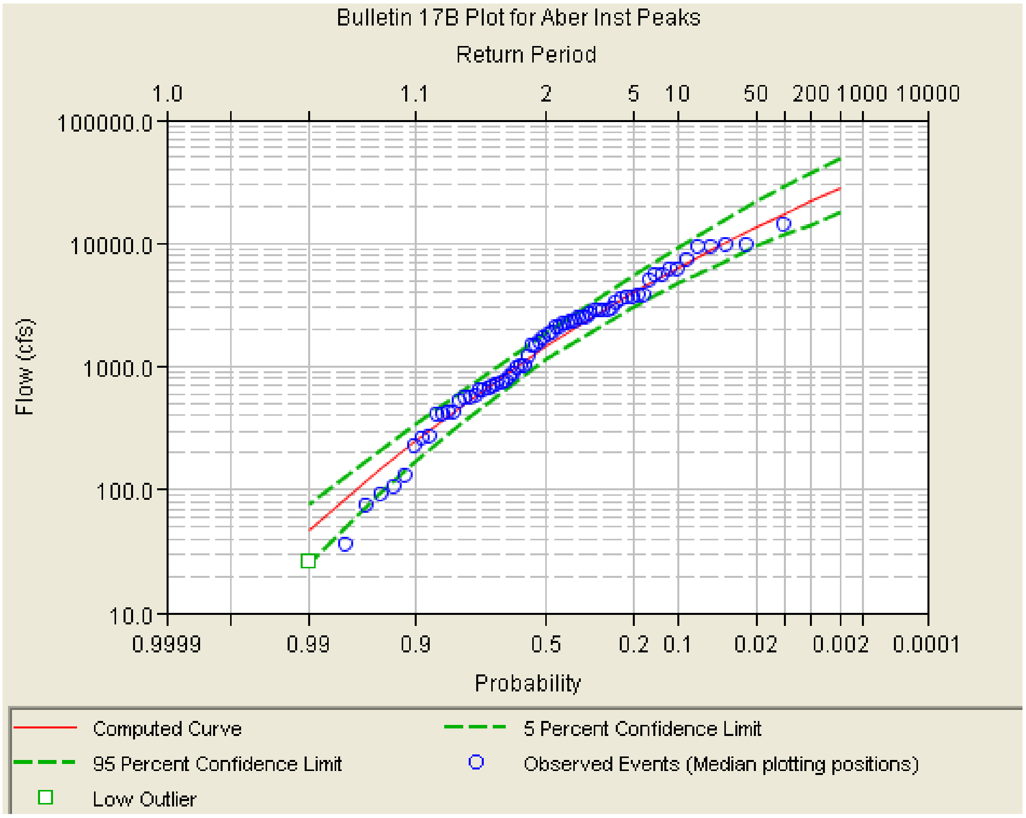


Figure 35. Annual Peak Discharge-Frequency Wild Rice River, ND @ Abercrombie



Results for Aber Inst Peaks

Frequency Curve for: Inst Pks

Percent Chance Exceedance	Computed Curve Flow in cfs	Confidence Limits Flow in cfs 0.05	0.95
0.2	27863.0	49414.9	17806.6
0.5	21743.1	37204.5	14255.8
1.0	17537.7	29109.4	11749.1
2.0	13716.4	22007.5	9410.4
5.0	9282.5	14145.3	6598.2
10.0	6415.1	9343.6	4698.8
20.0	3983.0	5512.0	3010.7
50.0	1459.3	1892.0	1129.7
80.0	471.3	621.8	342.2
90.0	247.8	341.3	167.9
95.0	141.8	205.0	89.4
99.0	46.4	75.2	25.0

System Statistics

Log Transform: Flow

Statistic	Value
Mean	3.126
Standard Dev	0.555
Station Skew	-0.593
Regional Skew	-0.230
Weighted Skew	-0.419
Adopted Skew	-0.419

Number of Events

Event	Number
Historic Events	0
High Outliers	0
Low Outliers	1
Zero Or Missing	0
Systematic Events	68
Historic Period	

Figure 36. Coincident Discharge-Frequency; Red River @ Sheyenne Confluence when GOL Peaks

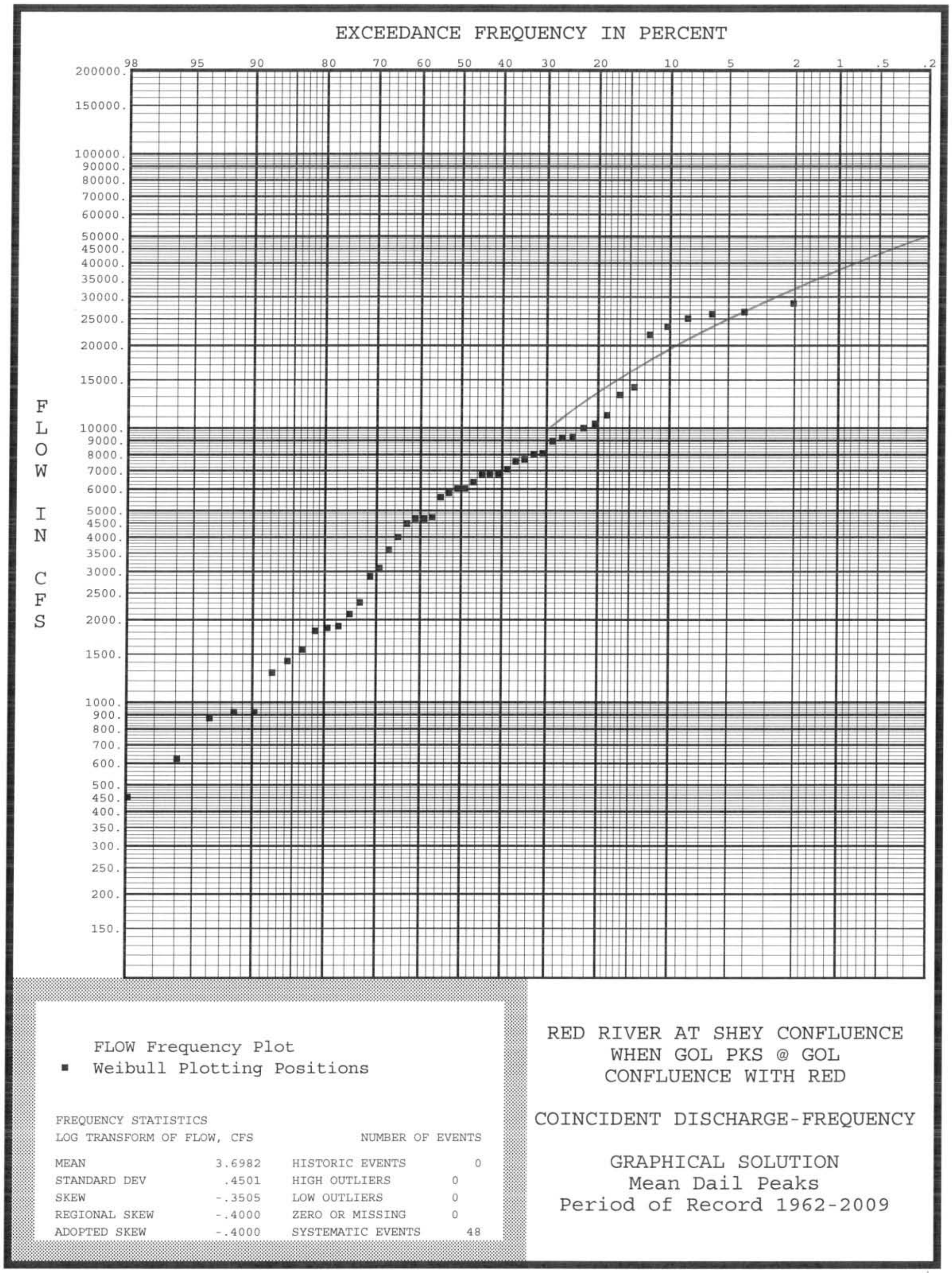


Figure 37. Coincident Discharge-Frequency; Red River @ Sheyenne Confluence when Mapleton Peaks

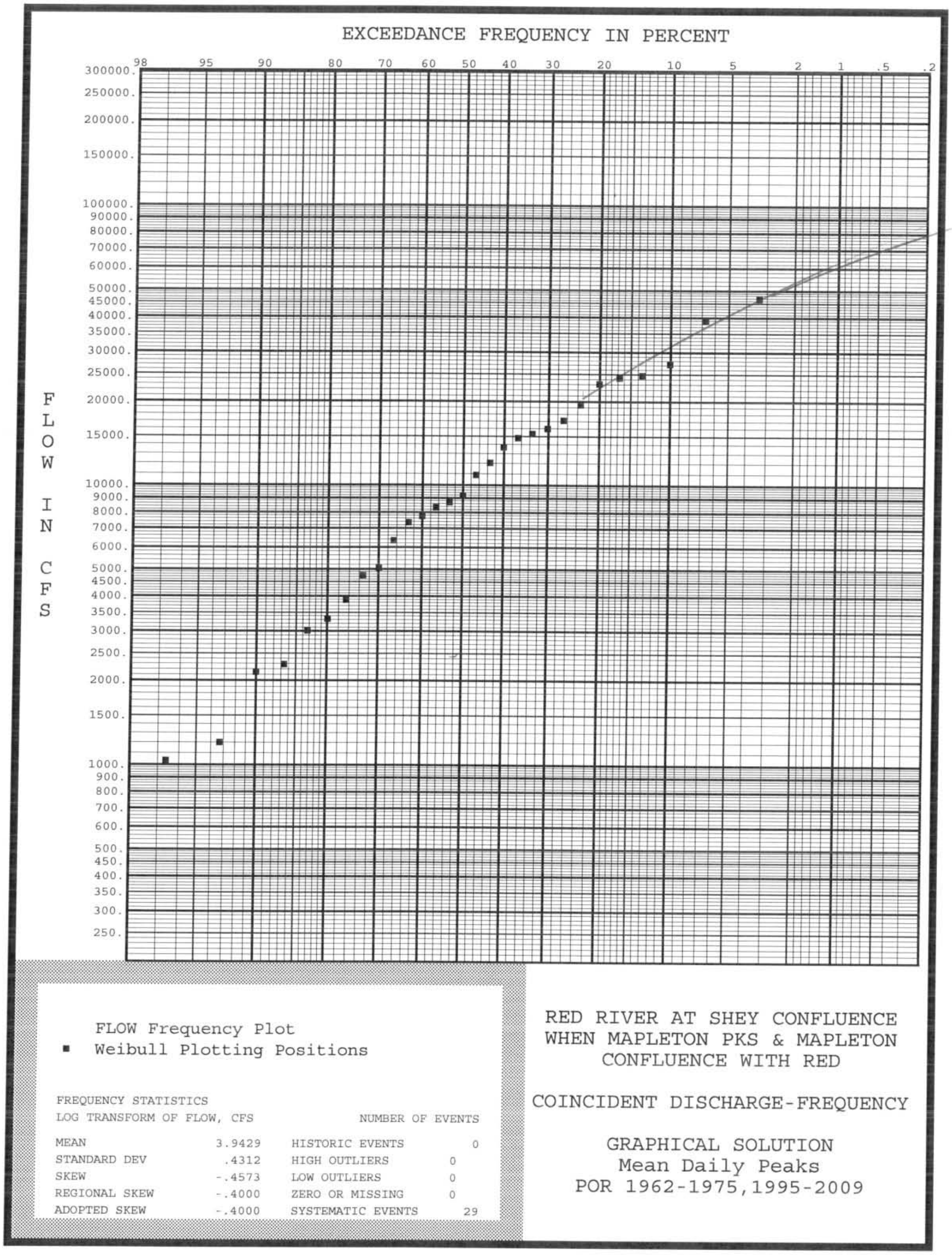


Figure 38. Coincident Discharge-Frequency; Red River @ Sheyenne Confluence when Amenia Peaks

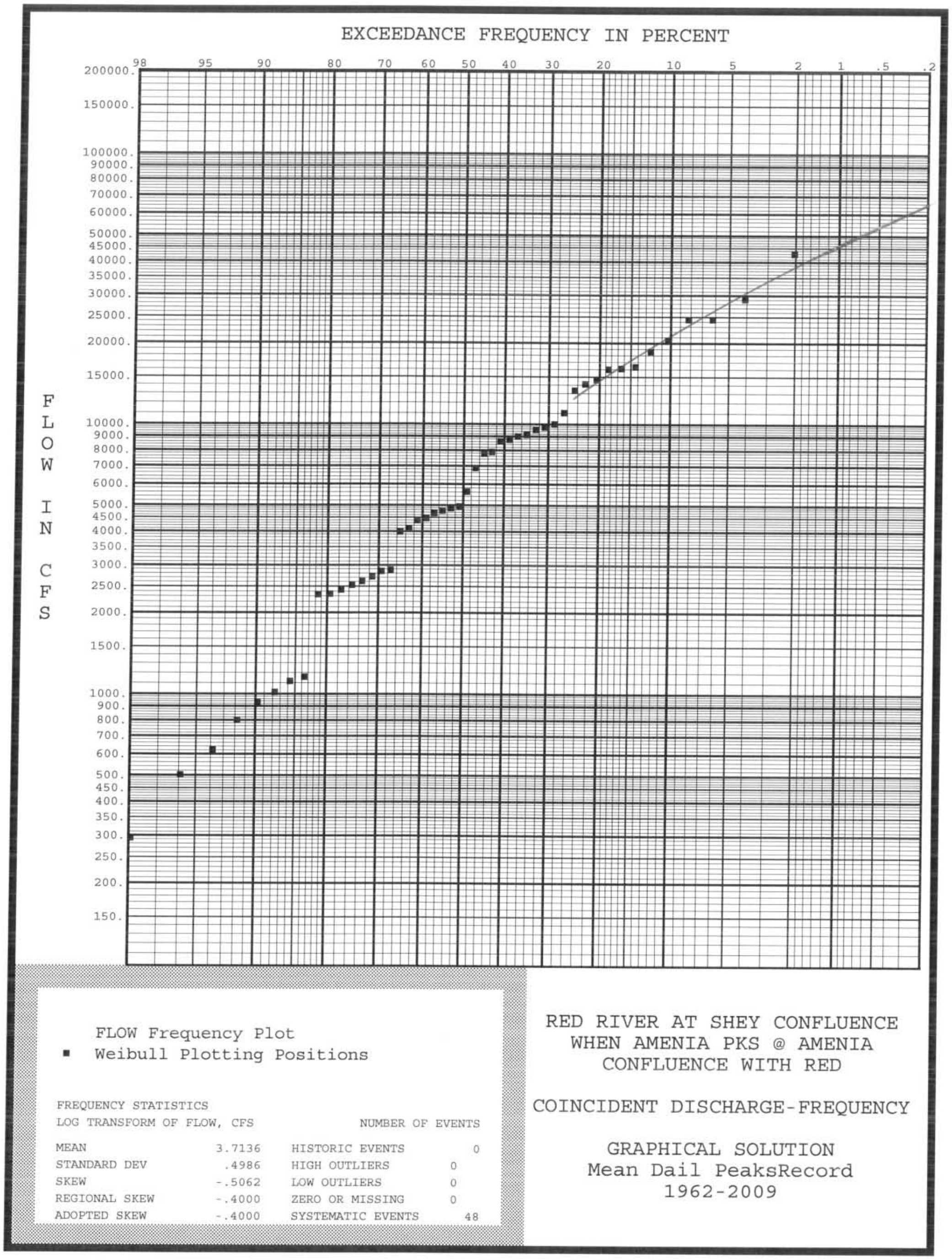


Figure 39. Coincident Discharge-Frequency; Red River @ Sheyenne Confluence when Mapleton Peaks Arrive at Sheyenne Confluence