Appendix A-4a
Hydrology

Fargo-Moorhead Metropolitan Area Flood Risk Management

Supplemental Draft Feasibility Report and Environmental Impact Statement

April 2011

US Army Corps of Engineers®

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Preface

Following the submittal of Hydrology Appendix A-2 it was noted that the revised hydrology significantly increased flows through Fargo, ND, yet flows further downstream, at locations such as Halstad and Grand Forks flows did not increase significantly . In order to address this discrepancy it was necessary to further analyze the Red River Reach between Fargo, ND and Halstad, MN. The Lower Sheyenne River is a major tributary that reaches its confluence with the Red River just downstream of Fargo, ND. Refinement of the hydrology associated with this reach, particularly with the flows associated with the Sheyenne River resulted in more realistic output from hydraulic modeling.

Hydrological analysis is necessary to produce balanced hydrographs associated with the 0.2-, 0.5-, 1-, 2-, 3-, 4-, and 5-% exceedance frequency events in the Red River Basin. These balanced hydrographs are utilized as inputs to hydraulic modeling. In order to develop balanced hydrographs at points of interest within the Red River Basin located between Fargo, ND and Halstad, MN the 2006 event hydrograph had to be determined at all points of interest in the basin. The 2006 event hydrograph is utilized as the pattern event for balanced hydrographs. The pattern hydrograph provides for the shape and timing of the balanced hydrographs. Because not all points of interest are gaged locations, 2006 flows had to be routed throughout the basin. Routing was determined using HEC-HMS. Routing had to be determined for the Sheyenne River and its tributaries and then routed to the Sheyenne River's confluence with the Red River of the North. Flows from Fargo, ND had to be routed along the mainstem of the Red River to Halstad, MN and combined with tributary flow from the Sheyenne River, Buffalo River, Elm River and the Wild Rice River (MN). Routing was verified by calibrating to USGS streamflow gages.

1. SHEYENNE RIVER HMS MODELING

The Sheyenne River is a major tributary of the Red River of the North. It reaches its confluence with the Red River about 20 miles north of Fargo, ND. There are two major tributaries to the Sheyenne River between Baldhill Dam and its confluence with the Red River of the North: the Maple River and the Rush River. The Sheyenne River is regulated by Baldhill Dam. Baldhill Dam forms the impoundment of Lake Ashtabula and provides flood control to the downstream communities of Valley City, Lisbon and Kindred. Additional flood control measures constructed in the Lower Sheyenne River Basin include the West Fargo Diversion, the Horace Diversion and the Maple River Dam. A diagram detailing the study reach can be found in **Figure 1. Figure 5** displays available gaged data in the Lower Sheyenne River Basin.

1.1 Baldhill Dam Modeling

In a previous study that was completed in Fall 2010, Ford Consulting Engineering developed a HEC-ResSim model for Baldhill Dam and a portion of the Sheyenne River. The modeling conducted by Ford Consulting was part of a Corps Water Management System (CWMS) implementation. This ResSIM model includes the 5' pool raise at Baldhill Dam, which was implemented in 2004 and is thus representative of current regulatory conditions.

The ResSim model has control points representative of the inflows and outflows from Baldhill Dam, as well as a series of junctions located near Valley City, Lisbon, Gol Bridge and Kindred, North Dakota. The ResSIM reservoir network is displayed in **Figure 2**. Ford used Muskingum-Cunge, 8-point cross section routing throughout their model. They chose to use Muskingum-Cunge routing instead of Modified Puls routing because of the relatively flat energy gradient that exists in the Sheyenne River Basin.

The ResSIM model doesn't include the effects of the breakout flows known to occur near Kindred, ND. Because the model doesn't include the effects of breakouts, ResSim will only be used for the reach of the Sheyenne River between Baldhill Dam and Lisbon.

1.1.1 Changes made to the Ford HEC-ResSim Model

The ResSim model developed by Ford Consulting was designed to model specific events. It was not designed to be used as a continuous simulation model. The following changes to the model are necessary for continuous simulation:

1. Pool evaporation must be removed from the model. The inflow record available for modeling includes evaporation.
2. In order to more closely simulate actual operation of the reservoir the maximum outflow from the reservoir is adjusted to 6, 590 cfs. This is the maximum outflow that has historically (Spring 2009) been released from the reservoir.
3. The minimum release rule is changed to reflect the minimum release rule prescribed by the Normal Pool Drawdown Schedule which can be found in Table 7-9 of the Baldhill

Dam Water Control Manual. The minimum release rule is altered to reflect a gradual drawdown by using seasonal variation as displayed in **Table 1** :

Table 1. Minimum Release Rule

	Minimum release (cfs)			
Flow (cfs)	Jan	Feb-Mar	Apr-Sep	Oct-Dec
0	60	55	10	65
100	160	155	10	165
1, 000	1060	1055	10	1065

4. Because the Ford model was setup in order to be a regulatory aid different rule sets governing the top elevation of the conservation pool were developed that could be used given four different Snow Water Equivalent (SWE) scenarios in the basin. Different rule sets were developed for SWE <1, 1-1.5, 1.5-2 and > 2 inches.

   If a complete SWE record was available for the period of record (1942-2009) near Baldhill Dam these different scenarios could have been incorporated into the continuous simulation. Unfortunately, a complete record of SWE in the basin is not available. SWE data at Baldhill Dam is only available from the U.S Army Corps of Engineers-St. Paul District Water Control Website for the years between 1985- 2009.

   As can be seen from **Figure 3**, the majority of years for the period of record have snow water equivalent values above 2 inches (20 out of 25 years). Based on the observed SWE values and because we are most interested in capturing the larger events we selected the conservation pool elevation based on a SWE of greater than 2 inches for our continuous simulation.

1.1.2 Reservoir Inflow

One required input into the ResSim Model is Baldhill Dam inflow. This record was acquired from the USACE St. Paul District Water Control Website (WCWS). Inflow values presented on the WCWS are back calculated using measured outflows and pool elevation. These calculations do not account for wind-wave effects on the pool or evaporation. As can be seen from the inflow record displayed in **Figure 4**, there are negative inflow values. This is representative of when pool evaporation exceeds inflow into the reservoir.

1.1.3 Local Flow

Ford Consulting computed their local flow values using an HMS model. Because a continuous HMS model is not available for the basin it is necessary to use an alternative means of estimating these local flows. Local flow records must be developed between Baldhill Dam and Valley City, as well as between Valley City and Lisbon.

These local flow records can be generated by acquiring gaged flow measurements at the upstream locations and routing them to the downstream gaged location. The routed flows at the downstream location are then subtracted from the gaged record at the downstream location to determine the local flow record.

Valley City does not have a complete flow record for the period of record (1942-2009). Stage data is available at Valley City for the majority of the missing portion of the flow record. A rating curve relating discharge and stage can be developed for Valley City. The rating curve, displayed in **Figure 6**, was created using NWS and USGS data. For the dates when neither discharge nor stage data was recorded a linear relationship can be used between the discharge record at Baldhill Dam and the discharge record at Valley City. This relationship can be found in **Figure 7**.

1.1.4 ResSim Model Calibration

After making the necessary changes to the ResSim Model calibration runs were carried out for 2005-2009 (POR reflecting the 5 foot rise in storage capacity). **Figure 8** through **Figure 11** display a comparison between modeled flows and actual flows released from Baldhill Dam for 2005-2009.

Figure 12 displays simulated flows at Lisbon compared to gaged flows at the USGS gage at Lisbon for the period of record form 2005-2009. As can be seen from the figures the model does a relatively good job of simulating flow through the reservoir and routing that flow to Lisbon.

1.2 Model Reach: Lisbon to West Fargo

A HEC-HMS model was used to route flows generated by the ResSim model at Lisbon, ND to West Fargo, ND.

1.2.1 Breakout Flows

Pacific International Engineering developed a study entitled *Hydraulic Study of Sheyenne and Maple Rivers and Overflow* areas for FEMA. Although this study was never officially adopted, it describes breakout flows in this part of the basin. Breakout flows occur downstream of the Gol Bridge and just upstream of Kindred. Breakout flows from the right bank of the Sheyenne River discharge southeast and east beyond the Sheyenne River watershed and drain into the Wild Rice River. A portion of the breakout flows on the left bank reach I-94 and discharge through Cass County Drain 34. Drain 34 flows into Cass County, ND Drain 14, which drains into the Maple River near its confluence with the Sheyenne River.

Information is available regarding the Sheyenne breakouts based on the Pacific International Engineering (PIE) unsteady HEC-RAS model and the 2009 flood. This information is displayed in **Table 2** and **Table 3. Figure 13** and **Figure 14** display relationship describing breakout flows just upstream and just downstream of Kindred, ND. The PIE model was used during the 2009 flood to assist with National Weather Service (NWS) forecasts. The PIE model based breakout forecasts are displayed in **Table 2** and **Table 3** (highlighted in yellow)**.** In 2009, Southeast Cass County Water Resource District contracted with the USGS to gage flows at the breakout locations. The measured flows are also displayed in **Table 2** and **Table 3** (highlighted in green). As can be seen by comparing the modeled versus gaged values, the PIE model does a relatively good job of predicting the magnitude of breakouts from the Sheyenne River upstream and downstream of Kindred.

Table 2. Upstream Breakout Flow Relationship

Upstream Breakouts - Gol Bridge to Kindred							
Unsteady PIE Model HEC-RAS Model Results							
	Gol Bridge	Left Breakouts	Right Breakouts	Kindred	Total	Left	Right
10-Year	3,456	0	0		0	0%	0%
50-Year	5,768	207	13		220	94%	6%
100-Year	7,342	788	788		1576	50%	50%
March-April 2009 modeled based on NWS forecast hydrographs	8,950	1,179	1,924	5,847	3103	38%	62%
500-Year	11,929	1,963	4,030		5993	33%	67%
Actual 2009 based on Gage Records and Measurements							
2009 based Gage records and Measurements	8,700			5,770	2,930		
	Measurement 4/23/09			Mean Daily 4/23/09			

Table 3. Downstream Breakout Flow Relationship

Downstream Breakouts - Kindred to Horace							
Unsteady HEC-RAS Model Results							
	Kindred Bridge	Left Breakouts	Right Breakouts		Total	Left	Right
10-Year	3,418	0	0		0	0%	0%
50-Year	5,528	237	804		1,041	23%	77%
100-Year	5,746	327	880		1,207	27%	73%
March-April 2009 modeled based on NWS forecast hydrographs	5,845	383	907	4,555	1,290	30%	70%
500-Year	5,933	486	944		1,430	34%	66%
Actual 2009 based on Gage Records and Measurements							
2009 based Gage record and Measurements	5,770			4,550	1,220		
	Mean Daily 4/23/09			Mean Daily 4/25/09			

Breakout flows were modeled in HEC-HMS as diversion structures. Flows are routed from Lisbon to Gol Bridge. At Gol Bridge a diversion structure applies a breakout flow relationship based on the values in **Table 2**. Flows breaking out of the left bank are routed into Drain 14. Flows breaking out of the right bank are assumed to leave the study area. Residual flows are routed to Kindred. At Kindred local flow is added to the run-of-the-river flow and routed through a second breakout relationship based on the values in **Table 3**. Flows breaking out of the left bank are routed back into the Sheyenne River just upstream of the confluence of the Maple River. Flows breaking out of the right bank are assumed to leave study area. Residual flows are routed to West Fargo.

1.2.3 Routing

1.2.3.1 Lisbon to Gol Bridge/ Kindred

Ford Consulting's HEC- ResSIM model contains Muskingum-Cunge routing for the Sheyenne River from Lisbon up to Gol Bridge. Because the model was already calibrated, the routing parameters from the Ford HEC-ResSIM model were adopted for this reach in the HEC-HMS model. Because Gol Bridge and Kindred are located in close proximity of each other it is not necessary to route flows between these two locations. Instead, a direct transfer can be utilized.

1.2.3.2 Kindred to West Fargo

Modified Puls routing is used to route flows between Kindred and West Fargo. The storage discharge relationship necessary to utilize Modified Puls comes from a steady state HEC-RAS modeled developed by the USACE St. Paul District. The storage discharge relationship associated with the diversion is adopted for the reach between Kindred and West Fargo.

1.2.3.3 Kindred to Horace

The HEC-HMS model routes flow from Kindred to West Fargo without accounting for any change in routing at the location of the USGS gage at Horace, ND. If necessary, routing can be broken up at Horace using Muskingum-Cunge Routing to route flow from Kindred to Horace. The eight point cross section required to apply Muskingum Cunge routing comes from the *Sheyenne River Geomorphology Study*. Modified Puls routing can then be applied to route the flows from Horace to West Fargo. The storage discharge relationship necessary to utilize Modified Puls comes from a steady state HEC-RAS modeled developed by the USACE St. Paul District.

1.2.4 Available Discharge Data

A chart of all USGS gages located in the Lower Sheyenne River Basin along with their respective period of record is displayed in **Figure 5.**

USGS gage 05059500 Sheyenne River at West Fargo, ND includes combined flows from the Sheyenne River at West Fargo (USGS gage 05059500) and the Sheyenne River Diversion at West Fargo (USGS gage 05059480). The USGS gage at West Fargo Diversion also includes the diverted flows from the Horace diversion. The West Fargo Diversion and the Horace to West Fargo Diversion are interconnected. The West Fargo Diversion diverts flow from the Sheyenne River around West Fargo. The Horace to West Fargo Diversion diverts water from the Sheyenne River around Horace to the West Fargo Diversion.

USGS gage 05059300 Sheyenne River above Sheyenne River Diversion near Horace, ND represents the total Sheyenne River flow immediately upstream from the Horace flood Diversion. USGS gage 05059310 Sheyenne River Diversion near Horace, ND records the flow that is diverted from the Sheyenne River at this location. When flows are greater than about 1,000 cfs at Sheyenne River above Sheyenne River Diversion near Horace (station 05059300), water is diverted in order to control discharges downstream. The diverted flow returns to the Sheyenne River main channel at a location about 13 mi downstream, below the city of West Fargo.

USGS gage 05059500 Sheyenne River at West Fargo, ND is therefore representative of natural channel flow + diverted flows at West Fargo, ND + diverted flows at Horace.

1.2.5 Local Flows

There is a significant local drainage area associated with the Sheyenne River reaches between Lisbon and Kindred and between Kindred and West Fargo. The local flow records associated with these drainage areas are generated by routing gaged flow at the upstream locations to the downstream gaged locations. The flows routed to the downstream locations are subtracted from the gaged record at the downstream locations to determine the local flow records.

For the 1997, 2001, 2006 and 2009 spring flood events Ford Consulting develop HEC-HMS based local flow records for the reaches between Baldhill Dam and Gol Bridge. This data was utilized to generate flow hydrographs at Gol Bridge for these events.

1.3 West Fargo to the Confluence of the Red River of North

The following Straddle Stagger routing parameters are used to route flows from West Fargo to the mouth of the Sheyenne River in accordance with the 1988 USACE *Timing Analysis*.

Straddle: 5, 760 min

Stagger: 1, 440 min

Table 4 contains the local area related to each of the reaches on the Sheyenne River between West Fargo and the confluence of the Sheyenne River with the Red River of the North. Because the local area is only approximately 4 square miles, it was determined that the amount of local runoff can be considered negligible for each of these reaches.

Table 4. Sheyenne River below West Fargo

Sheyenne River	
Reach	**Local Area (Sq Mi)**
W. Fargo to Mouth of Maple River	2
Maple R to the Rush R	1
Rush R to Conf w/ Red River	1
Total Local Area	**4**

1.4 Drain 14

Cass County Drain 14 flows north from near Kindred, ND to the confluence of the Maple River with the Sheyenne River. The drain picks up approximately 126 square miles of local area flow, as well as breakout flows from the Sheyenne River near Kindred, ND and the Maple River near Durbin, ND.

At the request of the Southeast Cass County Water District the USGS has installed a gaging station at Drain 14 near Mapleton, ND (USGS 465213097003901). This gage recorded flow data during the 2010 flood event. As can be seen from **Figure 15** a significant amount of flow is carried through the drain during large flood events. During the 2010 spring flood event a peak of 1,670 cfs of flow was recorded at the Drain 14 gage. A map that includes Drain 14 can be found in **Figure 16**.

1. 5 Maple River

The Maple River is a tributary of the Sheyenne River. Maple River flows are regulated by the Maple River Dam. The Maple River Dam is located near Sheldon, ND.

Maple River Dam became active in fall 2006. In order to generate a homogenous record at Mapleton, ND an HEC-HMS model was developed for the reach of the Maple River between the USGS gage at Enderlin to the USGS Gage located near Mapleton, ND (USGS Gage 5056000).This model can be used to generate both a regulated and unregulated continuous flow record at Mapleton, ND. A detailed description of the methodology used to develop this model can be found in **Appendix A-4b**.

1.5.1 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 events, 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.

1.5.2 Local Flow Determination

Using a calibrated HMS model, flows are first routed to the Mapleton without inputing a inflow record representing local flow between the dam and Mapleton. The resulting flow at Mapleton is subtracted from the USGS gaged record at Mapleton to determine the local inflow record between the Maple River Dam and Mapleton. This methodlogy includes breakout flows within the determined local flow record (along with any error associated with the model).

1.5.3 Model Shortcomings

Unless these breakout flows are defined and re-routed back into the Sheyenne River, the flow at the Sheyenne's confluence with the Red River will be underestimated for large events. There is no relationship representative of the breakout flows at Durbin. The magnitude of these breakouts will likely be mitigated to some degree by the Maple River Dam.

1.5.4 Mapleton to Maple River Confluence

In order to tie the Maple River modeling effort discussed in the previous section with the rest of the Sheyenne River model it is necessary to route modeled flows from Mapleton, ND to the confluence of the Maple River with the Sheyenne River.

1.5.4.1 Routing

Flows are routed from Mapleton to the confluence of the Maple River with the Sheyenne River using Muskingum-Cunge, eight point cross section routing.

1.5.4.2 Maple River Watershed Local Flows

Local flows for the drainage area between Mapleton and the Maple River's confluence with the Sheyenne River, as well as the local flows associated with Drain 14, can be estimated using a drainage area ratio and the Amenia, ND gage as a reference gage. The values in **Table 5** can be used to estimate local flow.

Table 5. Drainage Areas & Drainage Area Ratios- Sheyenne River Watershed

Location	Drainage Area (sq. miles)
Drain 14 Drainage Area – Sheyenne River Watershed	125.50
Local Drainage Area Durbin, ND (Maple River) to Conf. of Maple River with the Sheyenne River	19.70
USGS Gage Site 05060500 Rush River at Amenia	116
Drain 14 Ratio with Amenia , Rush River	1.08
Local Area Flow Ratio with Amenia, Rush River	0.17

1.6 Rush River

The Rush River is a tributary of the Sheyenne River. There is a USGS gage located on the Rush River at Amenia, ND. Recorded flows from the gaging station at Amenia are routed to the confluence of the Rush River with the Sheyenne River using Straddle Stagger Routing parameters based on the Corps of Engineers 1988 *Timing Analysis*. The Straddle Stagger parameters utilized in the HEC-HMS model are:

Straddle: 540 min

Stagger: 1, 760 min

Local Area flow between the Amenia gage and the confluence of the Rush River with the Sheyenne River are determined using Amenia as a reference gage. The drainage areas used to develop the relationship with the reference gage, along with the ratio itself can be found in **Table 6**.

Table 6. Local Area Flow- Rush River

Rush River Local Flows	
Reference Gage:	**Amenia**
Location	**Drainage Area (sq. miles)**
Amenia Gage	116
Rush River (incl. Lower Rush River D.A = 66 sq. miles)	238
Local DA Amenia to Conf. Rush River	122
Adopted Drainage Area Ratio:	1.05

1.7 Sheyenne River Breakout flows

A significant amount of flow breaks out from the Sheyenne and Maple Rivers during flood events. According to minutes recorded at the Maple River Water Resource District meeting breakout flows are known to occur along the Lynchburg Channel, Buffalo Creek, the Maple River and Drain 14. **Figure 17** through **Figure 23** display aerial photographs depicting breakouts during the 1997 flood event. These photographs give insight into the volume of water that is leaving the channel during flood events. The effects of breakouts are dispersed from near the confluence of the Maple River with the Sheyenne River to Argusville, ND.

Although the breakout flows that occur on the Sheyenne River near Kindred do add to peak flows on the Red River in 1997, the breakout flows know to occur on the Sheyenne River near Kindred, ND do not significantly add to the peak on the Red River of the North in 2009. This can be concluded because USGS gaged flows at Lisbon and Kindred do not reach bankfull magnitudes until later in April. The Red River of the North reached its flow crest in March.

2. Fargo to Halstad RRN HMS Modeling

In addition to the Sheyenne River there are three other significant tributaries that reach their confluence with the Red River of the North (RRN) between Fargo and Halstad: the Buffalo River, the Wild Rice River (Minnesota Side, WWR-MN) and the Elm River. **Figure 1** diagrams the study reach.

2.1 Tributary Flow

<u>2.1.1 The Buffalo River</u>

The Buffalo River enters the Red River of the North about 1 mile west of Georgetown, MN. It is 88 miles long and has a drainage area of about 1, 190 square miles.

2.1.1.1 Discharge Data

USGS gage 05062000 near Dilworth, MN provides tributary flow for the Buffalo River. The Dilworth gage has a drainage area of 975 square miles. The daily discharge record at Dilworth has a period of record from 1930 to present.

2.1.1.2 Routing

Because there is a significant distance between the USGS gage at Dilworth and the Buffalo River's confluence with the Red River of the North, it is necessary to use straddle stagger routing to route flows. The following Straddle Stagger routing parameters are based on the *1988 USACE Timing Analysis*, as well as model calibration:

Straddle: 4,320 min
Stagger: 2,880 min

2.1.1.3 Local Area Flow

Local Area Flow between for the Buffalo River between Dilworth and the Buffalo River's confluence with the Red River of the North is determined using a drainage area ratio. The Dilworth gage can be used as a reference gage. **Table 7** displays the drainage areas used and the ratio utilized in developing a local flow record for the Buffalo River.

Table 7. Buffalo River Local Flows

Location	Drainage Area (sq. miles)
Dilworth Gage	975
Buffalo River	1,190
Local DA Dilworth to Conf. Buffalo River	215
Adopted Drainage Area Ratio (Dilworth):	0.22

2.1.2 The Elm River

2.1.2.1 Discharge Data

There is only one USGS station located on the mainstem of the Elm River with a significant period of record: USGS Gage 05062200 located near Kelso, ND. This gaging station recorded daily streamflow measurements between 1955 and 1986. The drainage area associated with this gage is 199 sq miles.

Field measurements were taken at USGS gage site 471924097014701 on the North Branch of the Elm River at Kelso, ND and on the mainstem of the Elm River at USGS gage site 05062250 during the 2010 flood event. The locations of these gaging sites are displayed in **Figure 24**.

The long term streamflow record measured near Kelso on the mainstem can be combined with the 2010 field measurements at Grandin because these two gage sites are located close together. A regression analysis carried out between USGS gage 05066500 located on the Goose River at Hillsboro, ND and the combined observed flow record at Grandin/ Kelso yields a linear relationship. There is a relatively good correlation between the augmented streamflow record at Kelso and the streamflow record at Hillsboro for their concurrent period of record 1955-1986, 2010. This relationship, displayed in **Figure 25**, is used to develop a streamflow record representative of the Elm River near Kelso.

2.1.2.2 Routing

Using Steady State HEC-RAS Houston Engineering determined that there is a lag of approximately one day from the Elm River at I-29 to the Elm's confluence with the Red River of the North. I-29 crosses the Elm River near Grandin, ND, therefore a 1-day lag was used when routing flows from Grandin/Kelso to the mouth of the Elm River.

2.1.2.3 Local Flow Area

The local flow record for the Elm River can be estimated using a drainage area ratio. USGS gage 05066500 located on the Goose River at Hillsboro can be used as a reference gage. The drainage areas associated with the Elm River at Kelso/Grandin, the local drainage area, the Hillsboro drainage area, as well as the resulting drainage area ratio can be found in **Table 8**.

Table 8. Elm River Local Flow

Location	Drainage Area (sq. miles)
Kelso Gage (mainstem ~ Gratin Gage) source: USGS	199
Hillsboro Gage (Goose River)	1,093
D.A above Elm River	13,085
D.A Below Elm River	13,485
Elm River D.A	400
Local D.A	201
Adopted Drainage Area Ratio:	0.18

2.1.3 The Wild Rice River- Minnesota

The Wild Rice River- Minnesota flows westward until it enters the Red River of the North just south of Ada, MN. It is 160 miles long and has a drainage area of about 1, 650 square miles. USGS gage 05064000 at Hendrum, MN provides tributary flow for the Wild Rice River. The Hendrum, MN gage has a drainage area of 1, 560 square miles. The daily discharge record at Hendrum has a period of record from 1944 to present.

Based on the*1988 USACE Timing Analysis*, a 1-day lag should be applied to the flow record at the Hendrum gage in order to route flows to the confluence of the Red River of the North with the Wild Rice River .

2.2 Mainstem Routing & Local Flow

Although initially Modified Puls routing was considered, as can be seen in **Table 9,** Straddle Stagger is the adopted routing method on the mainstem of the Red River of the North. Using Straddle Stagger produces a better calibrated result. Straddle Stagger routing parameters are based on the *USACE 1988 Timing Analysis*.

Table 9. Mainstem Modeling

<table>
<tr><th rowspan="2">Reach</th><th rowspan="2">Routing Method (Straddle in days, Stagger in days)</th><th rowspan="2">Contributing Local Drainage Area (SQ MI)</th><th rowspan="2">Local Flow Determination</th><th colspan="2">Reference Gage</th><th rowspan="2">Drainage Area Ratio</th></tr>
<tr><th>Gage Location</th><th>Drainage Area (SQ MI)</th></tr>
<tr><td>Fargo to Upstream Sheyenne River</td><td>Straddle Stagger (3,1)</td><td>430</td><td>Drainage Area Ratio</td><td>Dilworth, MN</td><td>975</td><td>0.44</td></tr>
<tr><td>Downstream Sheyenne River to Upstream Buffalo River</td><td>Direct Transfer</td><td>210</td><td>Drainage Area Ratio</td><td>Dilworth, MN</td><td>975</td><td>0.22</td></tr>
<tr><td>Downstream Buffalo River to Upstream Elm River</td><td rowspan="2">Straddle Stagger (5, 2)</td><td>350</td><td>Drainage Area Ratio</td><td>Dilworth, MN</td><td>975</td><td>0.36</td></tr>
<tr><td>Downstream Elm River to Upstream Wild Rice River-MN</td><td>30</td><td>Drainage Area Ratio</td><td>Hendrum,MN</td><td>1,560</td><td>0.02</td></tr>
<tr><td>Downstream Wild Rice River-MN to Halstad</td><td>Direct Transfer</td><td>40</td><td>Drainage Area Ratio</td><td>Hendrum, MN</td><td>1,560</td><td>0.02</td></tr>
</table>

As is described in **Table 9,** drainage area ratios can be used to determine the local flow associated with reaches along the mainstem of the Red River of the North. Contributing drainage areas for mainstem locations are from the *USACE 2001 Final Hydrology Report: Hydrologic Analyses, the Red River of the North Main Stem.* Areas associated with reference gages are from the USGS.

Because local area flow in the Red River Basin runs off relatively slowly and is often attenuated by the effects of overland storage straddle stagger routing (4, 4) is applied to local runoff on the mainstem of the Red River of the North.

3. Model Calibration- Mainstem of Red River between Fargo & Halstad Incl. Sheyenne River

3.1 Discontinuities Associated with the Mapleton Gage

3.1.1 Available Data at Mapleton

There are two gages located near the city of Mapleton, ND on the Maple River. The original gage is (USGS 50561000) located downstream of Mapleton. An additional gage was installed upstream of Mapleton (USGS 50560000) in order to avoid recording breakout flows. During large flood events on the Maple River there is a significant difference between the magnitudes of flow recorded by these two gages as is apparent from the 2006 flood hydrograph found in **Figure 26**. The timing of the Maple River usually coincides with the timing of flow on the Red River of the North. A misrepresentation of flow on the Maple River can significantly affect modeled flows downstream.

3.1.2 Breakout Flows on the Maple River

There is evidence of flow being lost between Enderlin and Mapleton in 1997 and 2009 as is displayed in **Figure 27** and **Figure 28**. In 1997 there is a double peak observed at Enderlin, but not at Mapleton. In 2009 the second peak at Enderlin is approximately 1,000 cfs greater than the corresponding peak on the Maple River at Mapleton. The loss of flow between the two locations can likely be attributed to breakout flows and would presumably add to the peak in 1997 and to the receding limb of the flow hydrograph in 2009 at Halstad.

3.2 Sheyenne River Calibration to Harwood

Between 1996 and 2010 instantaneous annual peaks and National Weather Service (NWS) field measurements have been taken at USGS gage site 05060400 located on the Sheyenne River at Harwood, North Dakota. This gage is located downstream of West Fargo and downstream of the Maple River. An accurate calibration at this site implies that breakout flows near Kindred, routing and local flows are being captured adequately. The field measurements taken at the

Harwood gage are of varying quality, but do provide some insight into how well the HEC-HMS model is calibrated. As can be seen from **Figure 29**, **Figure 30** and **Figure 31**, the model calibrates relatively well to the observed measurements at Harwood.

Since the data observed at Harwood is based on field measurements and because Harwood is located at a point on the Sheyenne River that experiences a great deal of backwater effects and breakout flows, measurements taken at this location likely include a degree of error and must be considered critically. In 2009 a bimodal peak was observed on the Sheyenne River. As can be seen in **Figure 31**, the observed data at Harwood only provides insight into the timing and magnitude of the first peak on the Sheyenne River.

During 1997 it is likely that the flow measurements made at Harwood on the 22^{nd} and 23^{rd} of April are erroneous. The observed flows recorded on the 16^{th} of April and the 24^{th} of April are greater than the observed flows observed on the 22^{nd} and 23^{rd} of April. It is unlikely that the flows at Harwood decreased to the observed values recorded on the 22^{nd} and 23^{rd} of April displayed in **Figure 29**.

3.3 Calibration Events

The model was calibrated to the 1997, 2006 and 2009 events because these events are being used to develop design parameters for the Fargo Moorhead Metro Feasibility Study. As can be seen from **Figure 32**, **Figure 33**, and **Figure 34** the model calibrates relatively well to these three events.

The model captures the peak, timing and volume of the 2009 event well. The tail end of the 2009 event doesn't calibrate well to the observed USGS flows at Halstad.

The 2006 run overestimates flow by approximately 6, 000 cfs, but captures the timing and volume of the event accurately.

The 1997 event also underestimates flow by around 7,000 cfs, but captures the timing and volume of the event accurately.

4. Conclusions

For the Fargo Moorhead Metro Feasibility Study this model and the information presented in this report can be used to generate flow hydrographs at points of interest in this portion of the basin. These hydrographs can be used as input into the Unsteady RAS model being developed to assess flow through the basin.

Building the model provides insight into the basin's hydrologic properties. Based on model calibration the following conjectures can be made concerning timing and flow magnitude in the basin:

- There is a significant difference between using the two different Mapleton gages if you use USGS 50561000 you will underestimate the peak at Halstad. Because this is the only gage available in 1997 this likely contributes to the model underestimating the peak in 1997.
- Local Flow reaches the mainstem of the Red River of the North slowly and attenuates significantly.
- For the majority of years the breakout flows near Durbin, North Dakota do not appear to be significant (this could be either because of their timing or because of their magnitude) because they were not re-introduced into the Sheyenne River and the model still calibrated well. It is possible that they have a minimal effect on the model's ability to represent the 1997 and 2009 events.
- As the second peak on the Sheyenne River reached its confluence with the Red River of the North in 2009 it was attenuated significantly. The crest on the Sheyenne River is also prolonged due to backwater effects from the Red River.

For future studies this model provides for a means of adapting the Baldhill Dam ResSim model for continuous simulation and provides for a calibrated routing structure for future HMS models of the portion of the basin being considered. The model also provides for a means of creating a homogenous flow record for Lisbon and Mapleton which includes the regulatory effects of the 5' raise at Baldhill and the construction of the Maple River Dam, respectively.

References

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4. Google Earth. 2010. USDA Farm Service Agency.
5. Greg Thompson. E-mail. Houston Engineering. Oct. 7, 2010.
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8. “HEC-HMS, Hydrologic Modeling System”, U.S Army Corps of Engineers, Hydraulic Engineering Center, Oct 2008.
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11. Jeffery J. Volk. Moore Engineering Inc. Sheyenne-Maple Flood Control: Maple River Dam.Red River Basin Commission 22nd Annual Conference. January 2005.
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13. *Volume I: Timing Analysis*. Technical Resource Service Red River of the North. USACE St. Paul District. March 1988.
14. West Consultants Inc. 2001. Sheyenne River: Geomorphology Study.

Figures

Figure 1. Red River Reach Fargo to Halstad

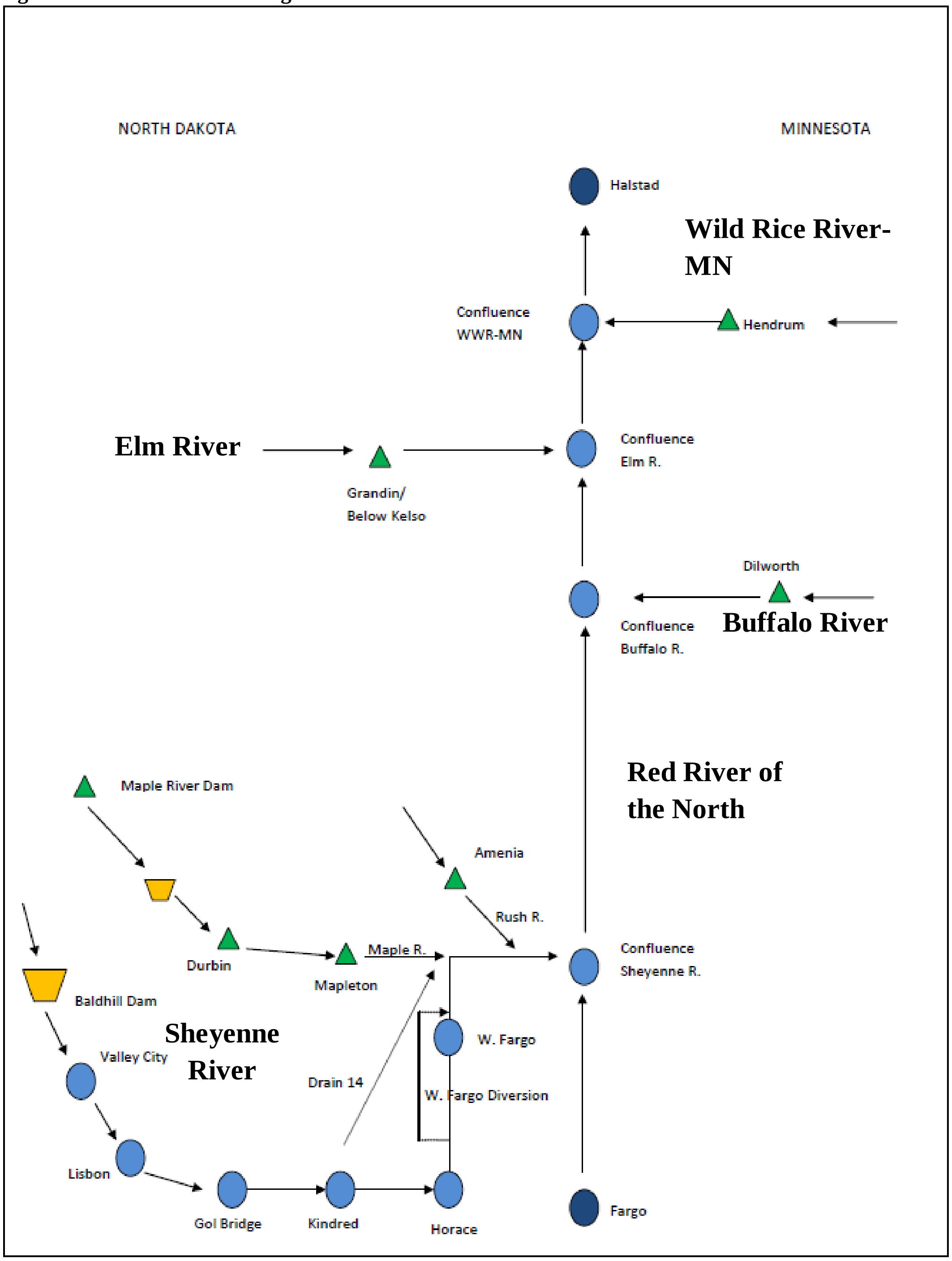


Figure 2. Ford ResSim Schematic

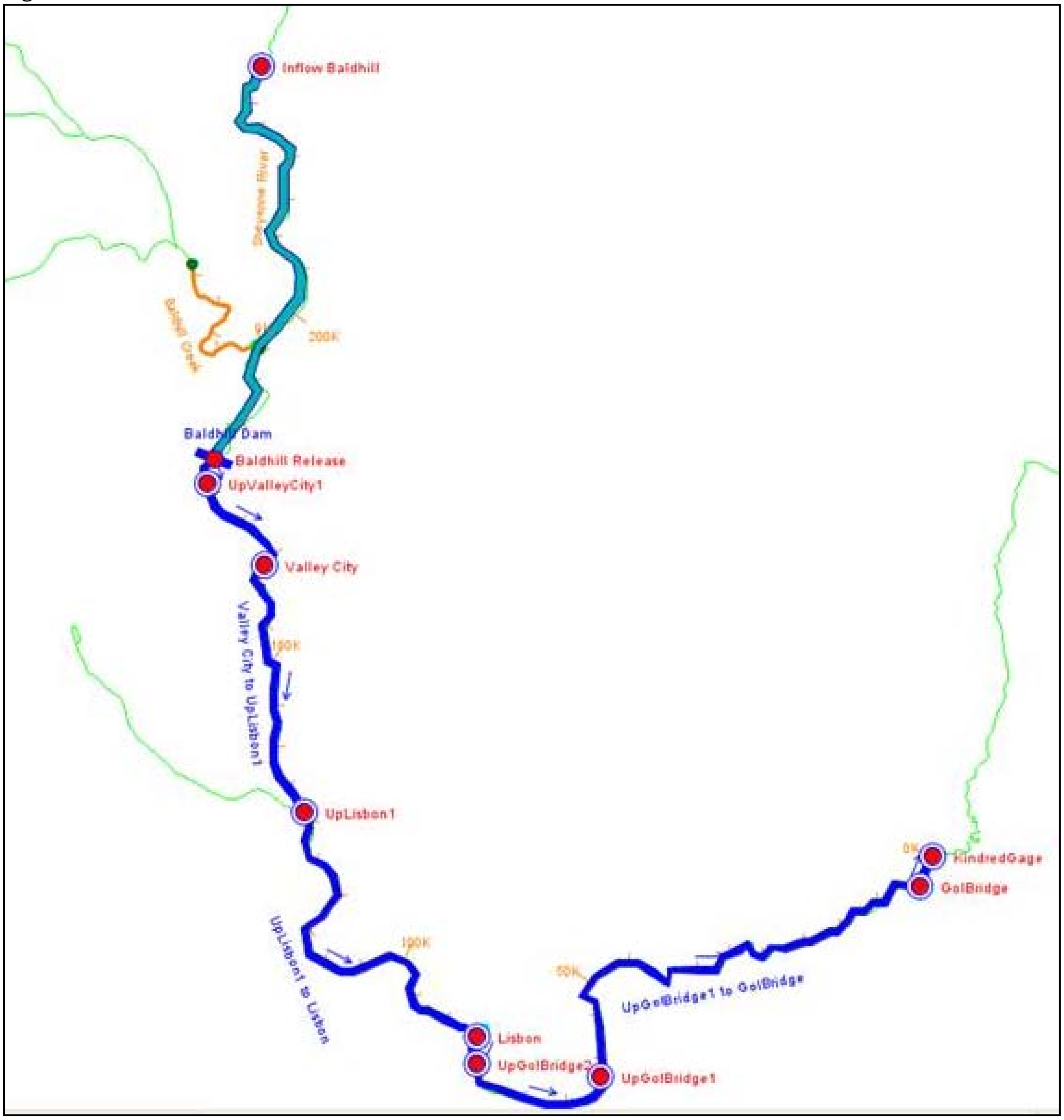


Figure 3. Snow Water Equivalent Record

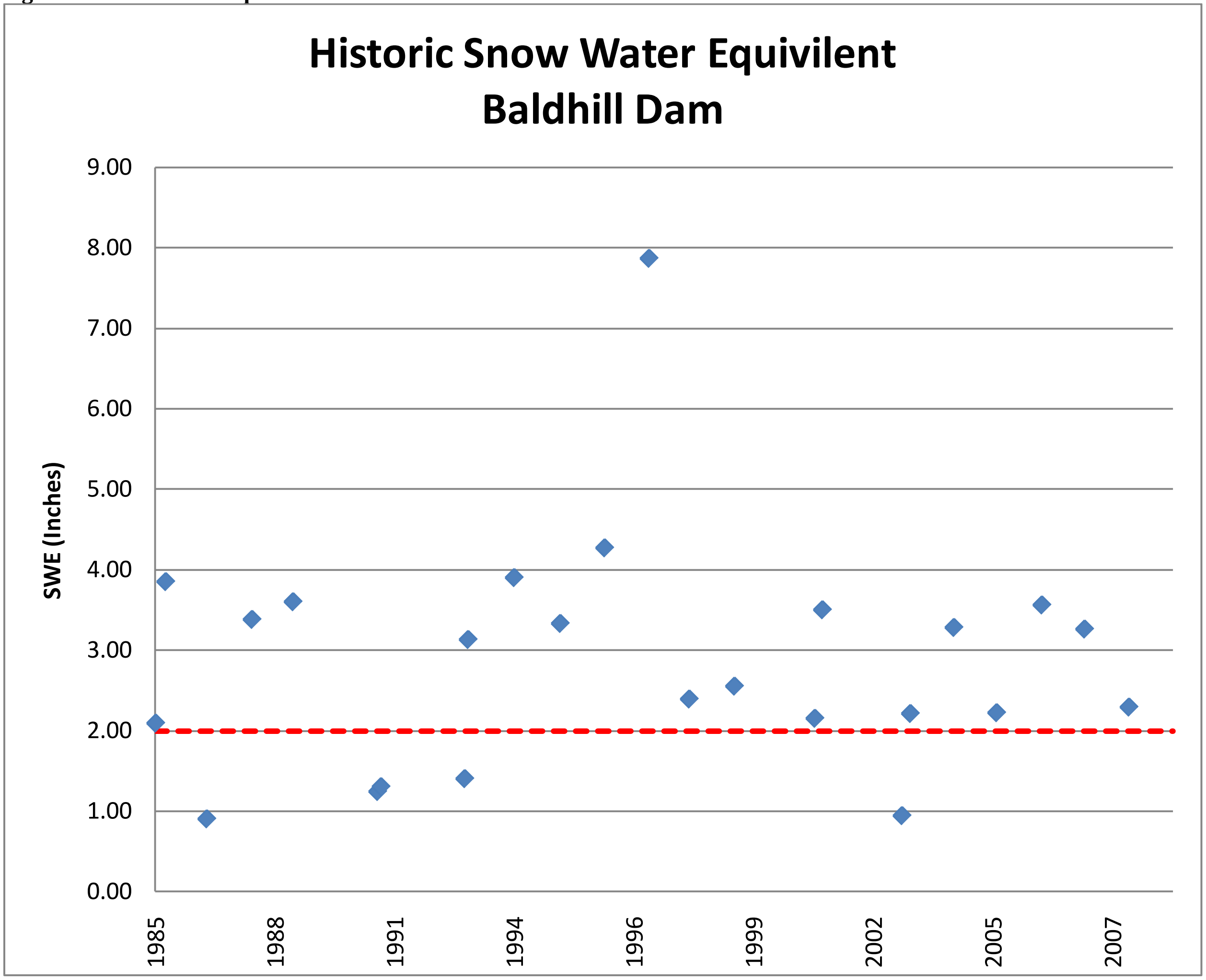


Figure 4. Inflow record into Baldhill Dam (USACE Water Control Website)

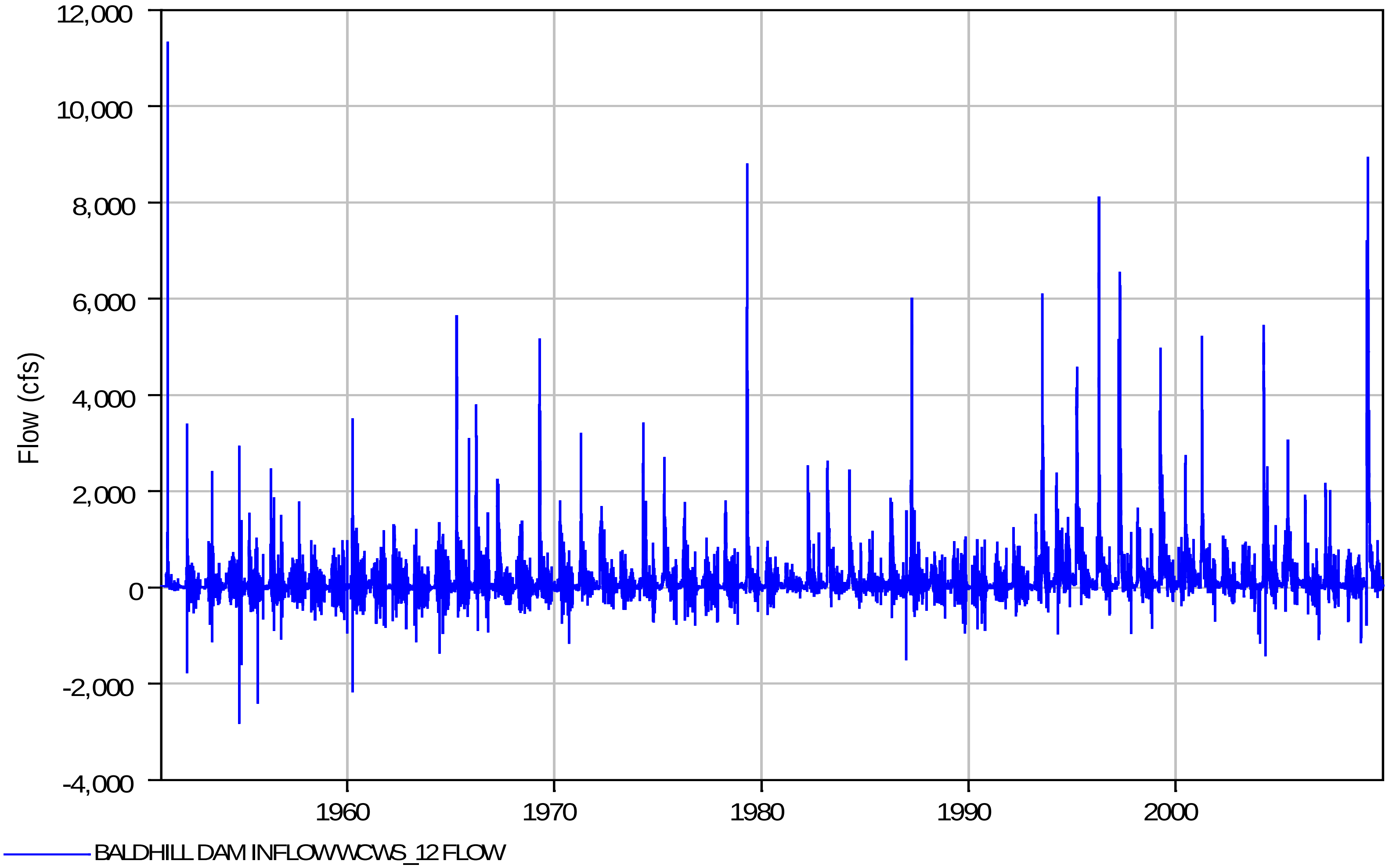
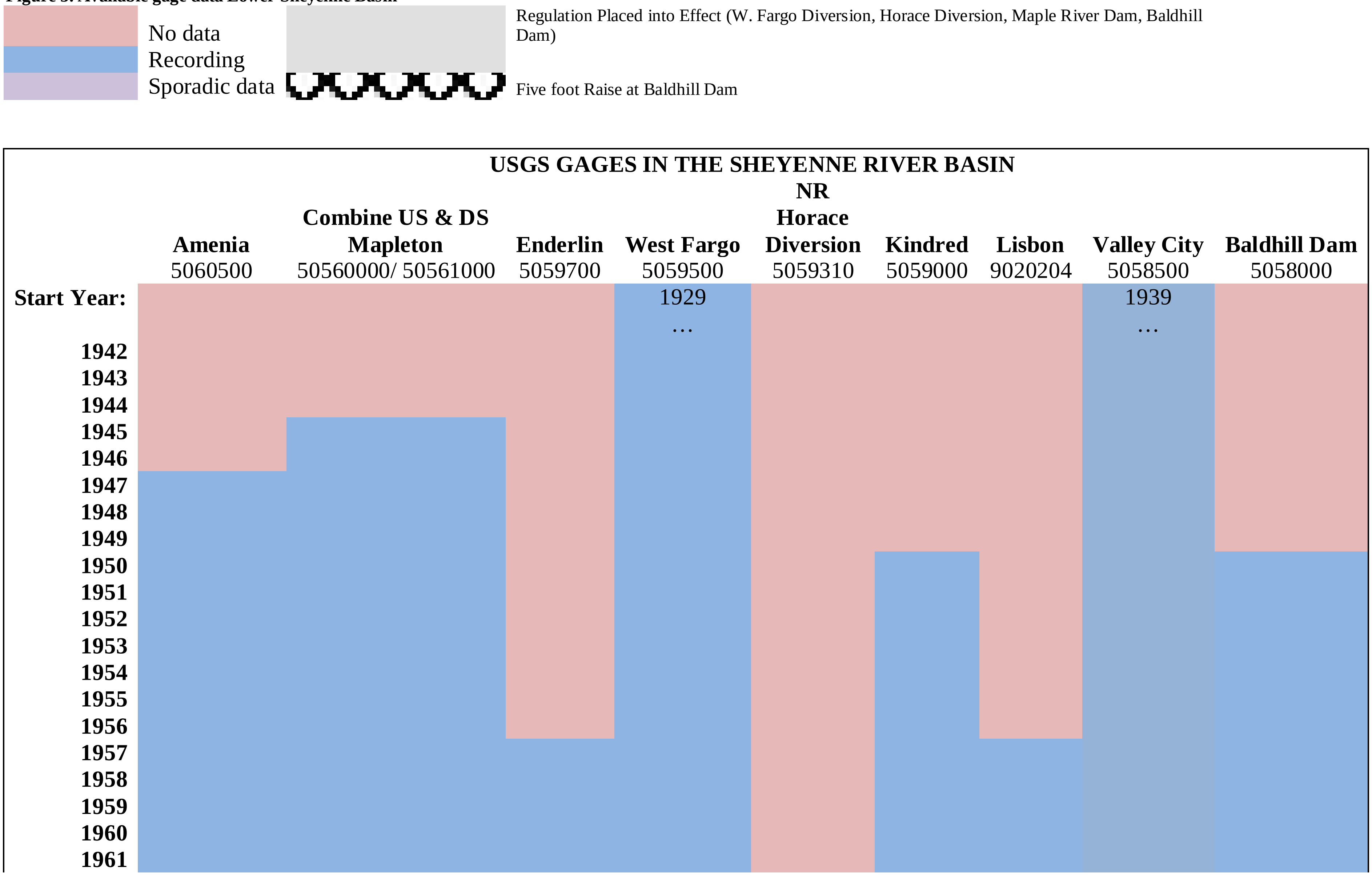
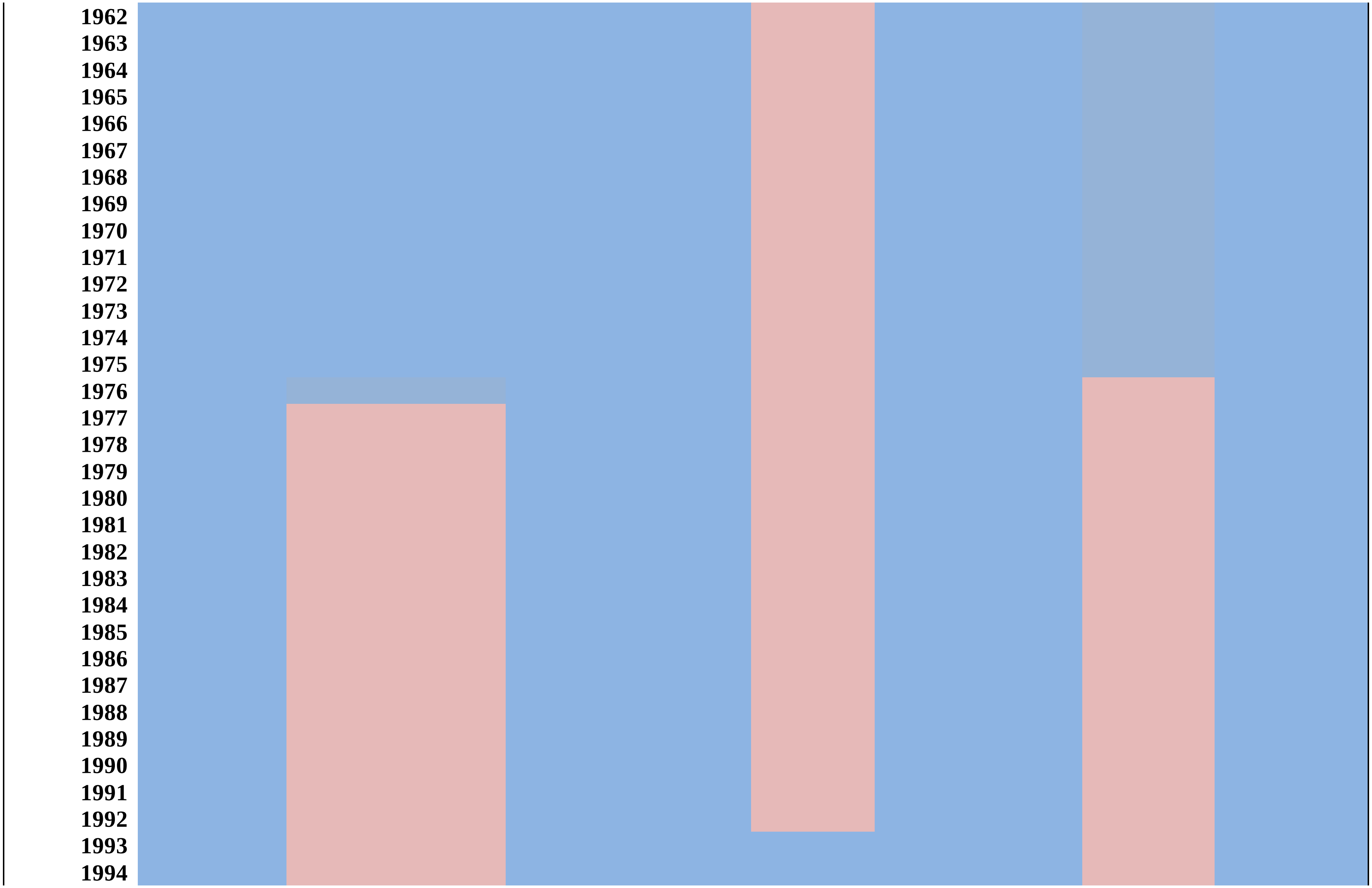


Figure 5. Available gage data Lower Sheyenne Basin

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NOTES:				
	Note: The upstream gage is the preferred gage…but only works sporadically. The gage was moved due to breakouts from the Sheyenne near Kindred	*Note: There are two gages at W. Fargo. The other gage is at the diversion. We are using the one at W. Fargo. For this project we are assuming the diversion has no effect…there is some data for 1919*	*Note: there may be mean daily data back to 1980 somewhere…b/c there is inst. Annual peak data back to 1980. There is also a gage located at the diversion. This is the gage above the diversion. We are assuming the diversion has no effect*	*Sporadic data in '38, '19, and in '95-'02*

Figure 6. Discharge-Stage Rating Curve for USGS gage at Valley City

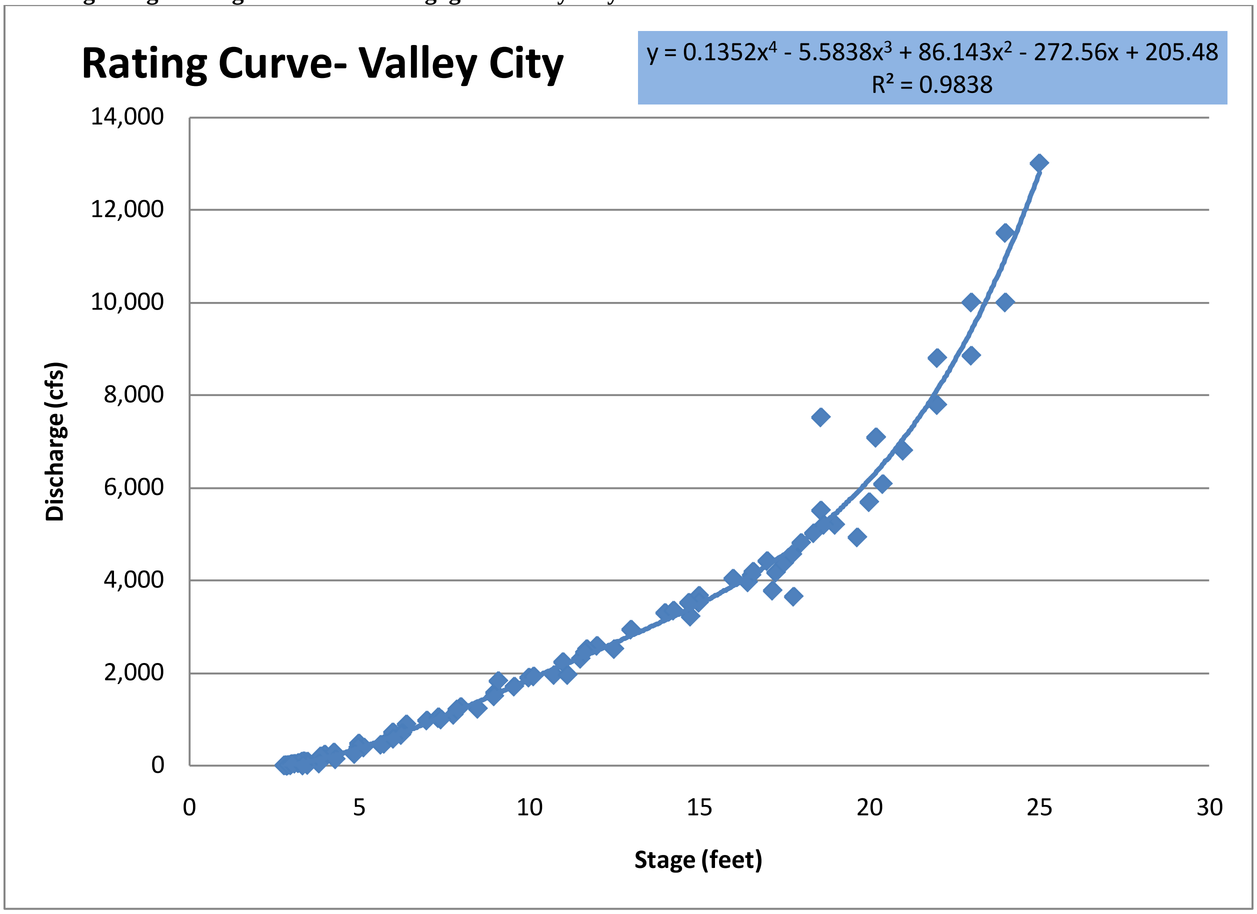


Figure 7. Linear Relationship between Baldhill Dam Discharges and Valley City Discharges

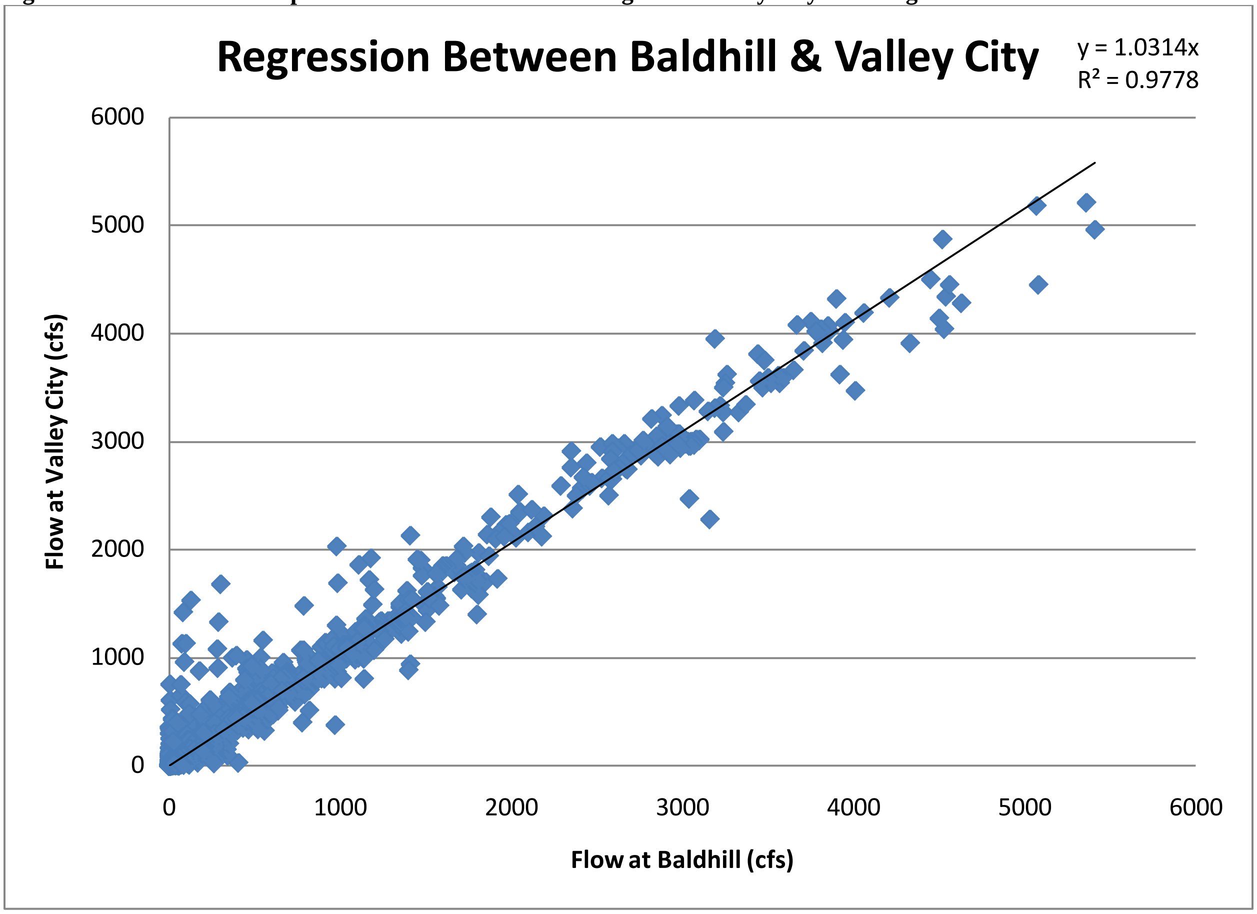


Figure 8. Calibration Outflow from Baldhill Dam for 2005: Blue = modeled flow & Red = Observed Outflows

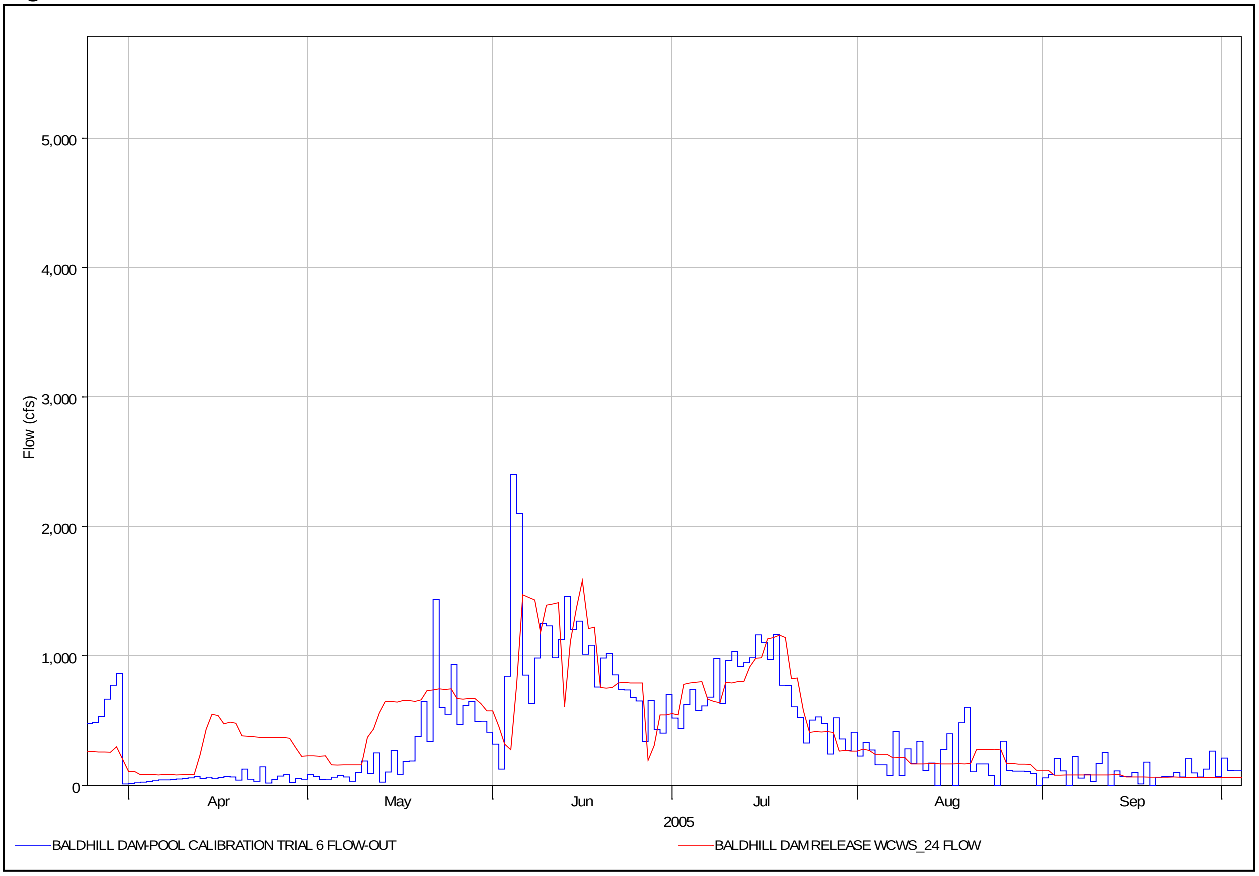
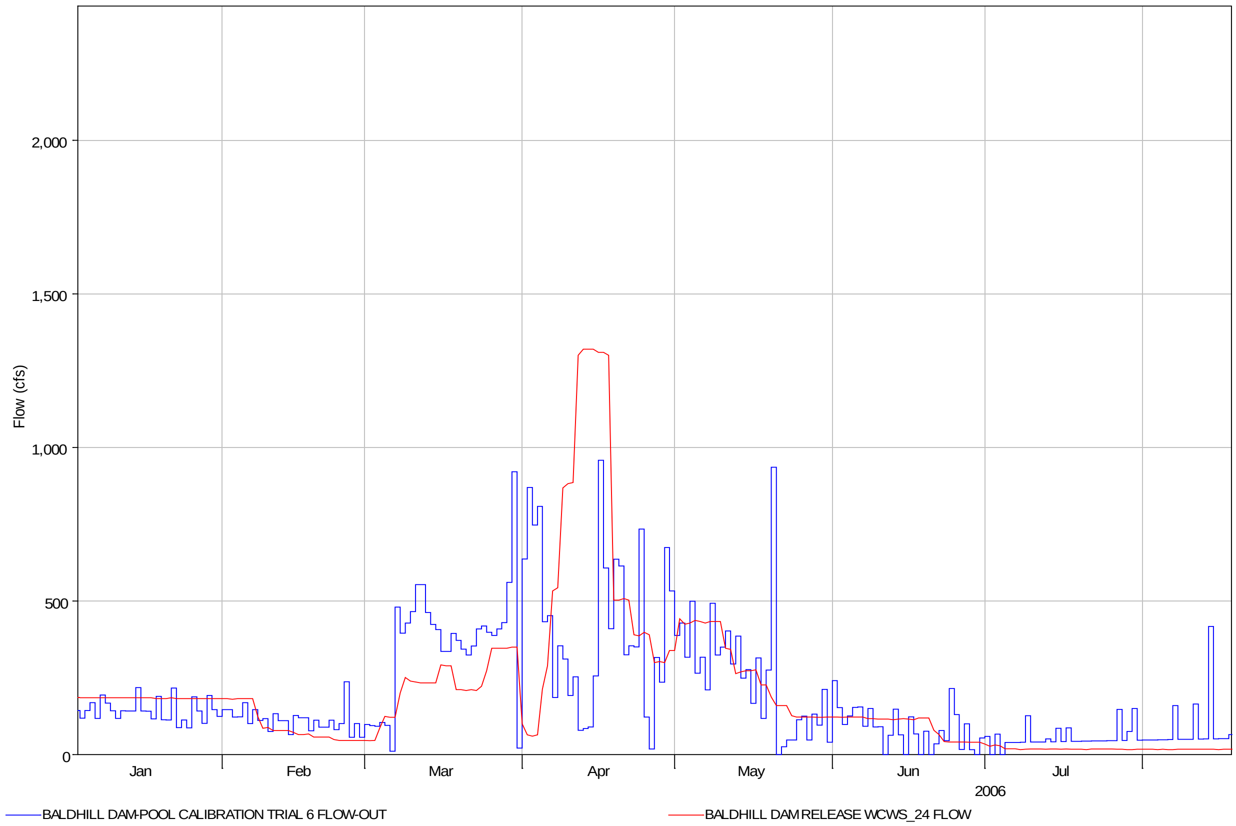


Figure 9 Calibration Outflow from Baldhill Dam for 2006: Blue = modeled flow & Red = Observed Outflows



2007

Figure 10. Calibration Outflow from Baldhill Dam for 2007: Blue = modeled flow & Red = Observed Outflows

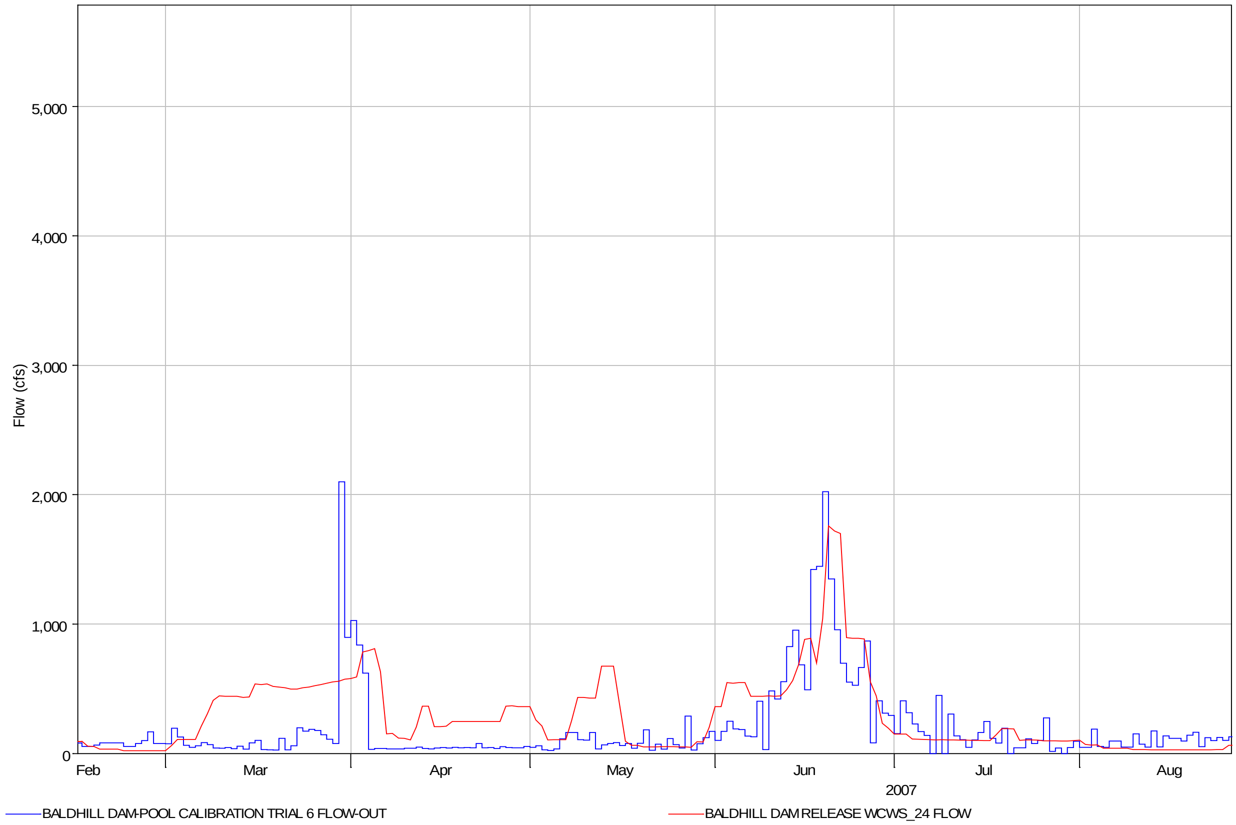


Figure 11. Calibration Outflow from Baldhill Dam for 2009: Blue = modeled flow & Red = Observed Outflows

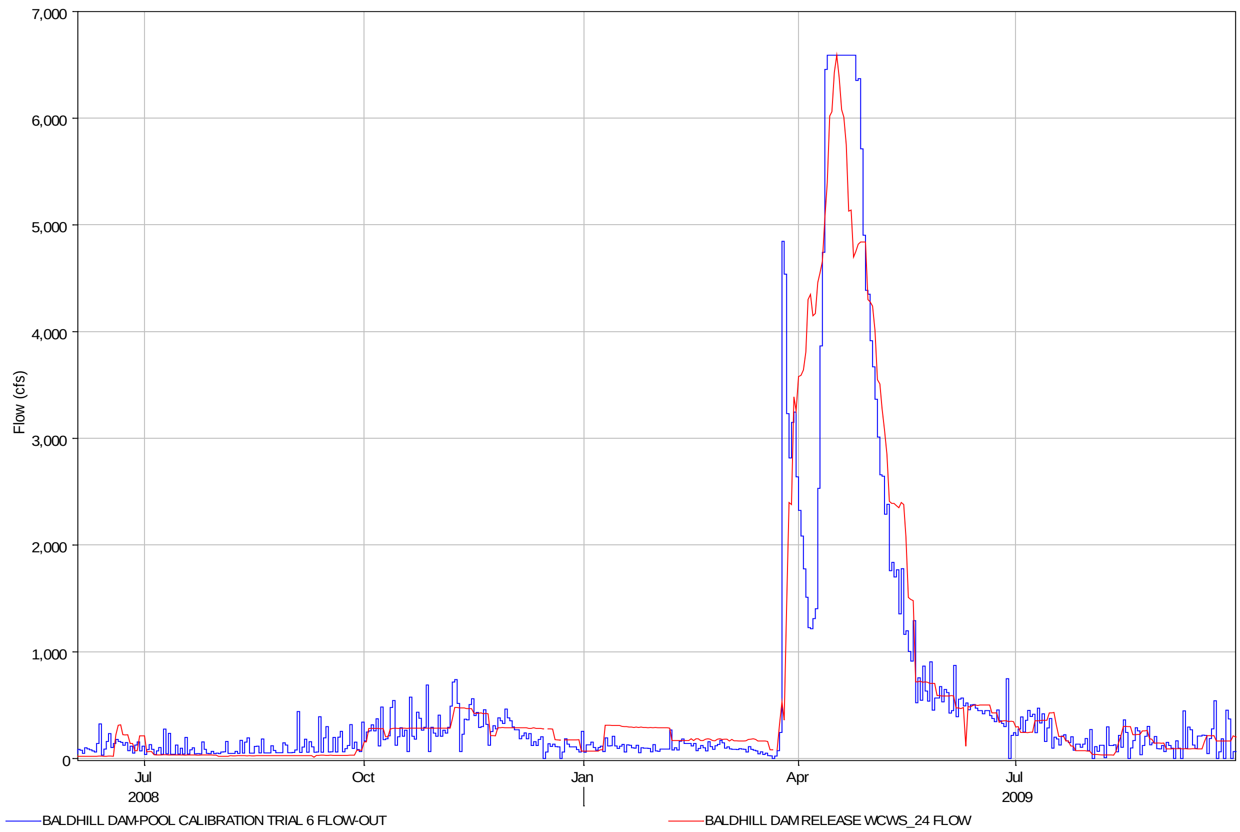


Figure 12. Calibration Run at Lisbon 2005-2009: Blue is modeled flow and red is gaged flow.

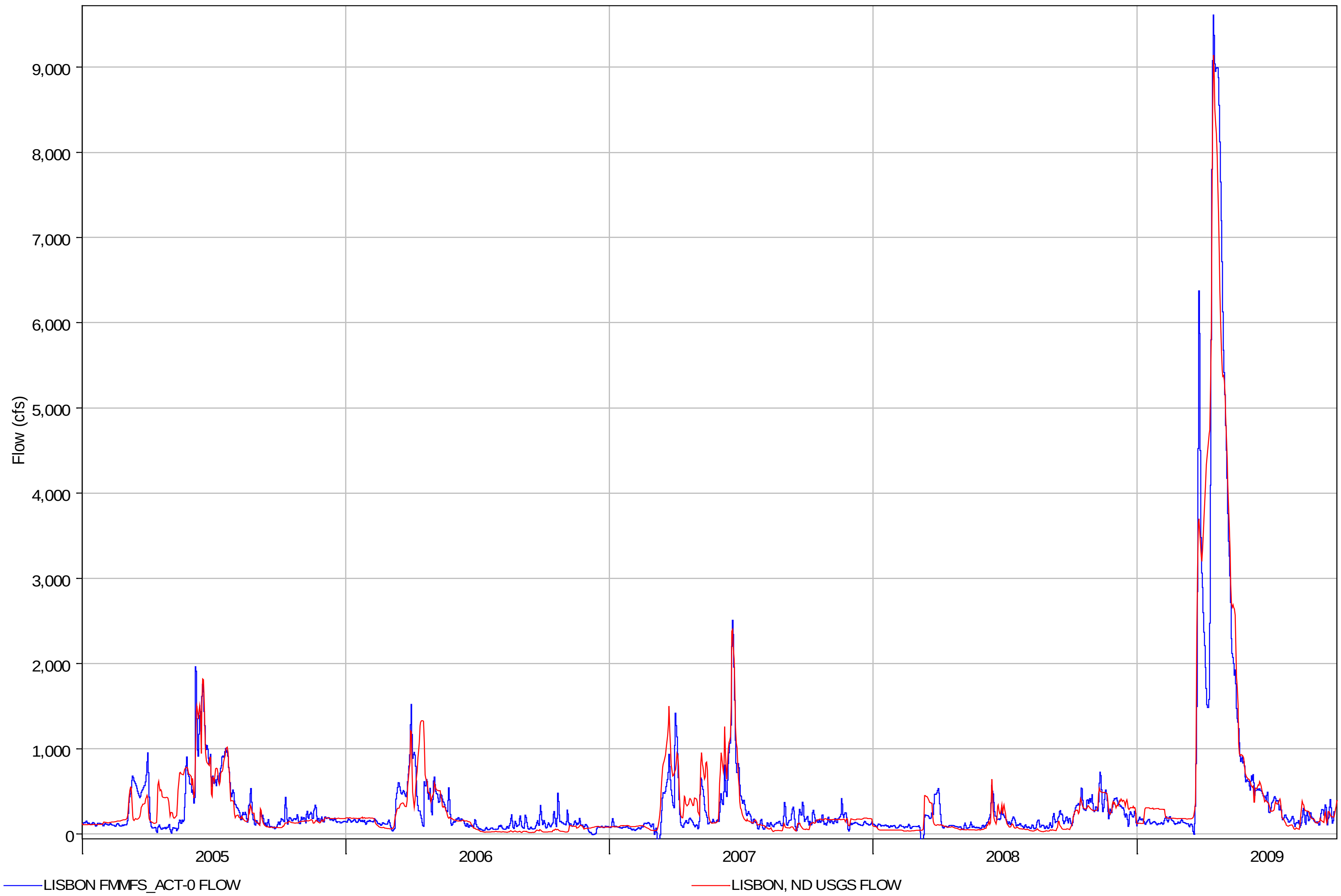


Figure 13. Upstream breakout relationship

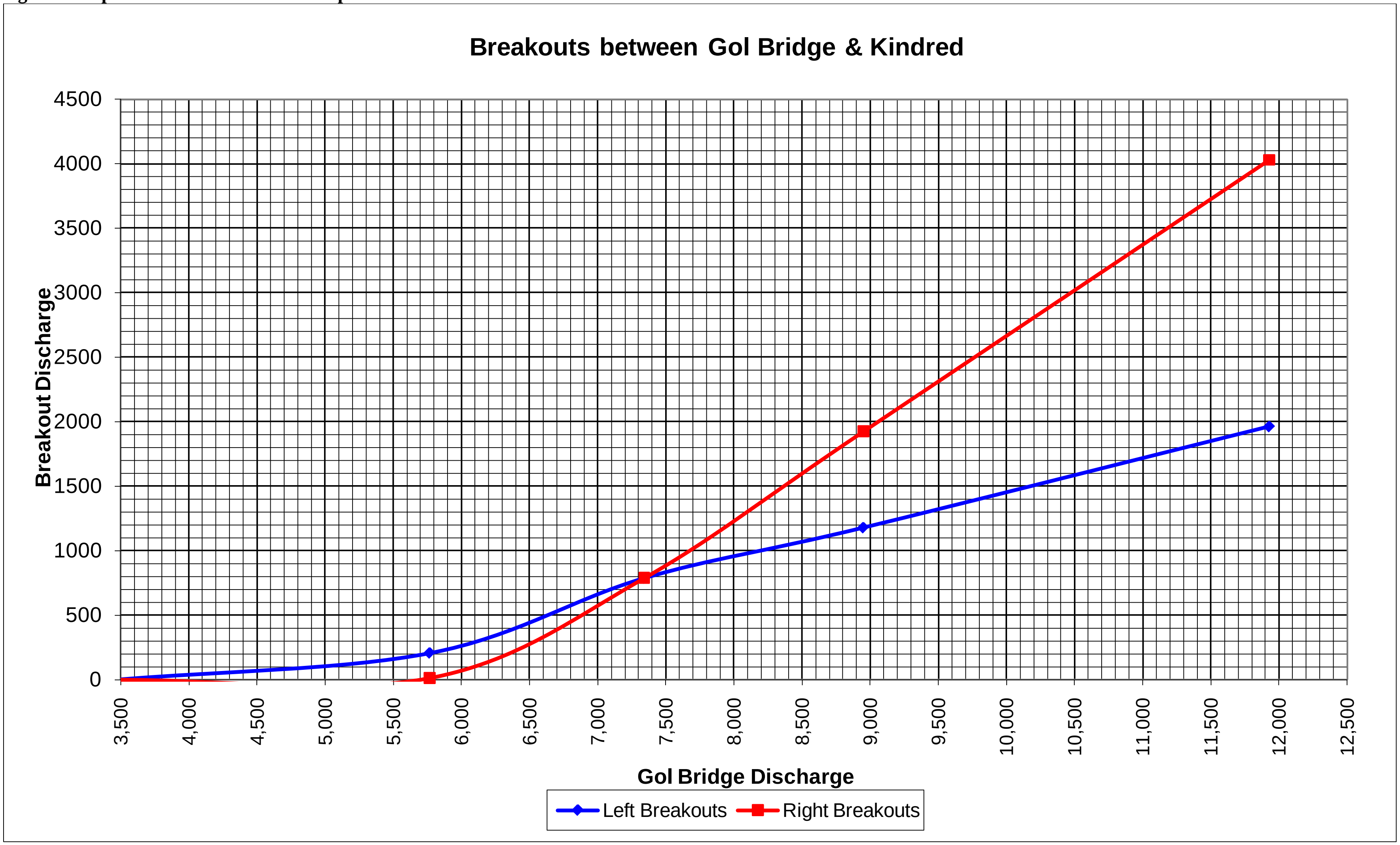


Figure 14. Downstream breakout relationship

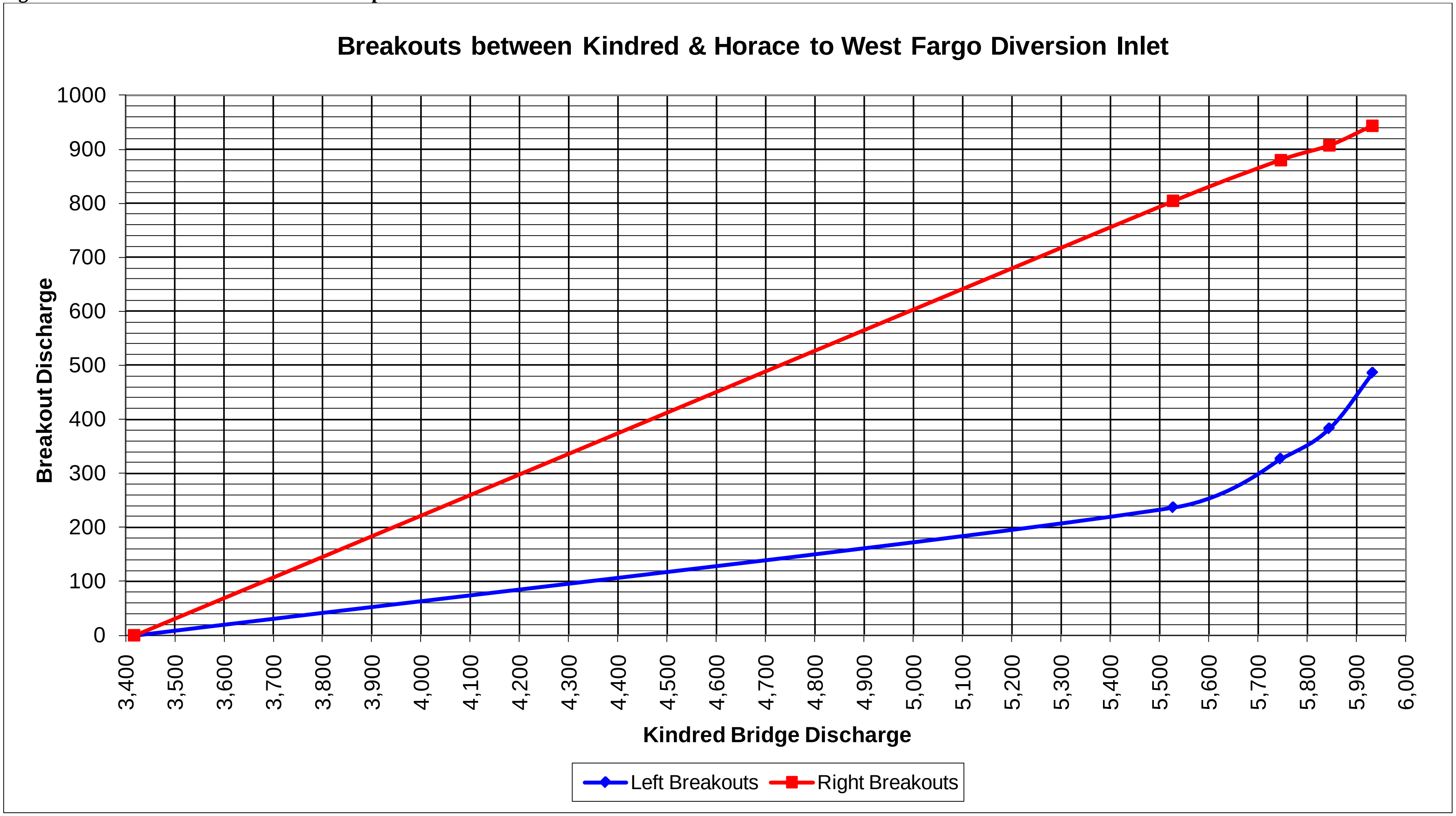


Figure 15. Drain 14 Near Mapleton looking north towards I-94.

Figure 16. Drain 14 Map (Cass County Website)

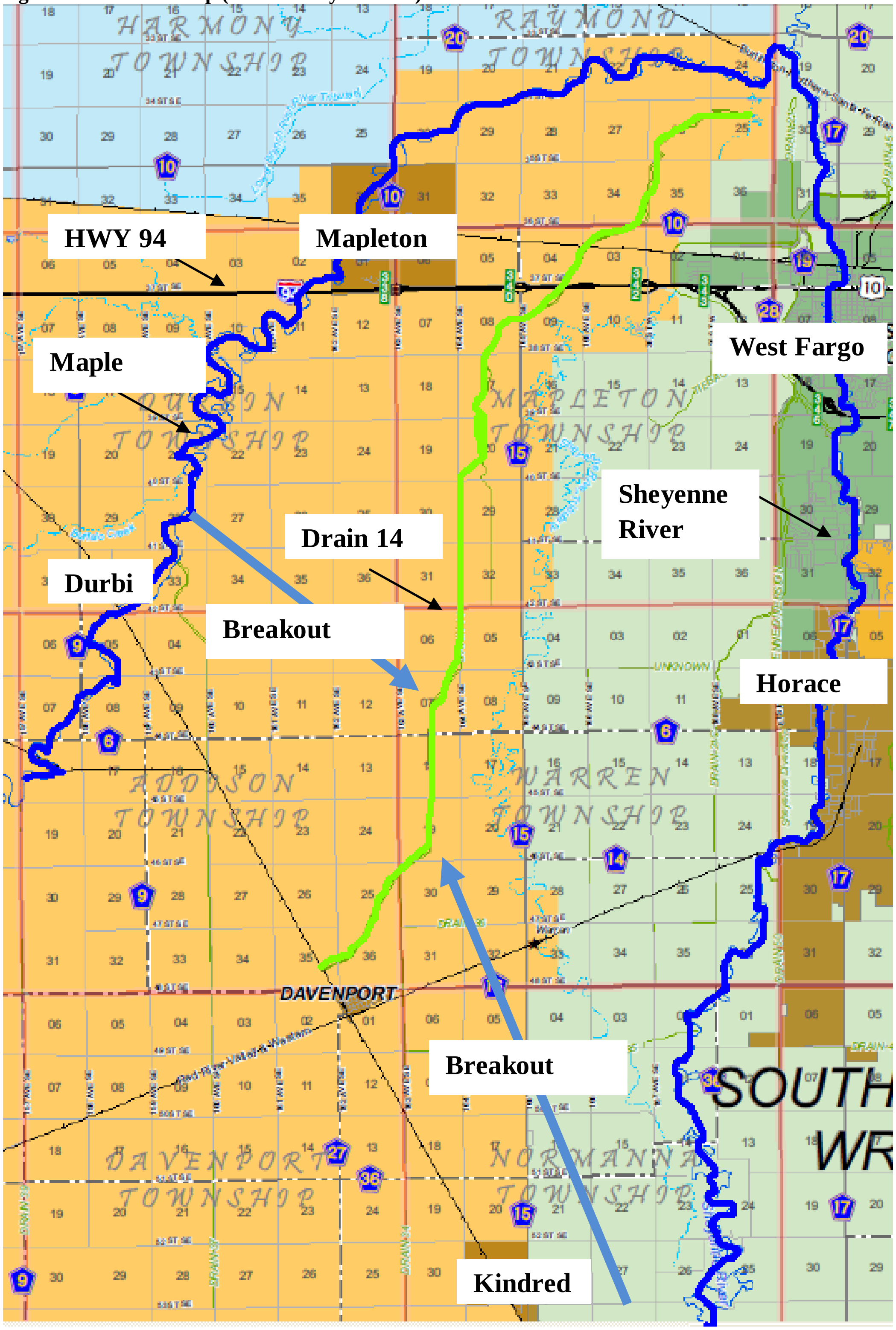


Figure 17. Breakout Flows looking Northwest, just southeast of Harwood, ND (Moore Engineering)

Figure 18. Breakout flows near the confluence of the Sheyenne River with the Maple River, Looking Northeast (Moore Engineering)

Figure 19. Breakout flows at Harwood, ND , Looking West (Moore Engineering)

Figure 20. Breakout Flows Looking Northeast near the West Fargo Diversion (Moore Engineering)

Figure 21. Looking North (Moore Engineering)

Figure 22. Looking Northeast (Moore Engineering)

Figure 23. Geographical distribution of aerial photographs

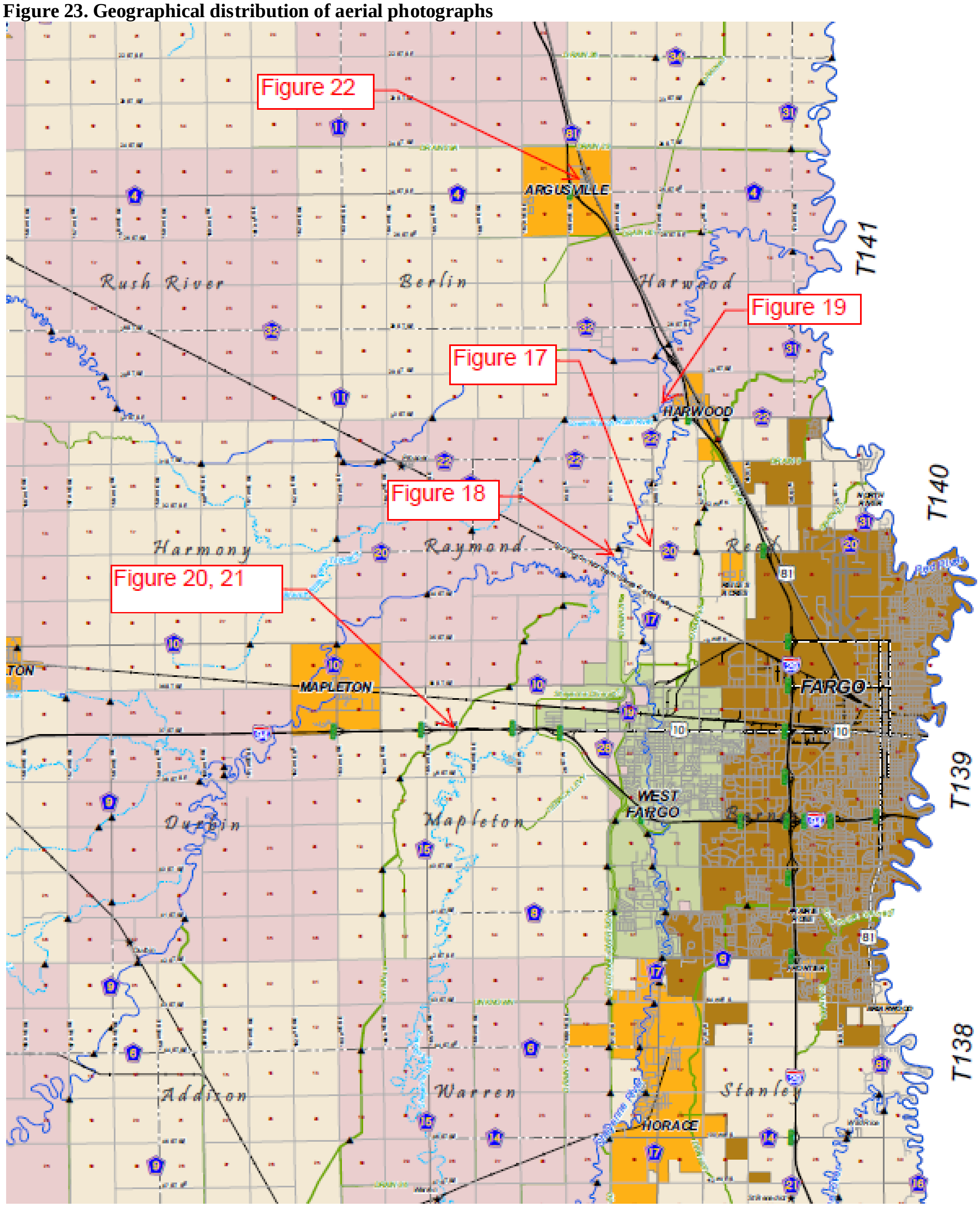


Figure 24. Elm River gages

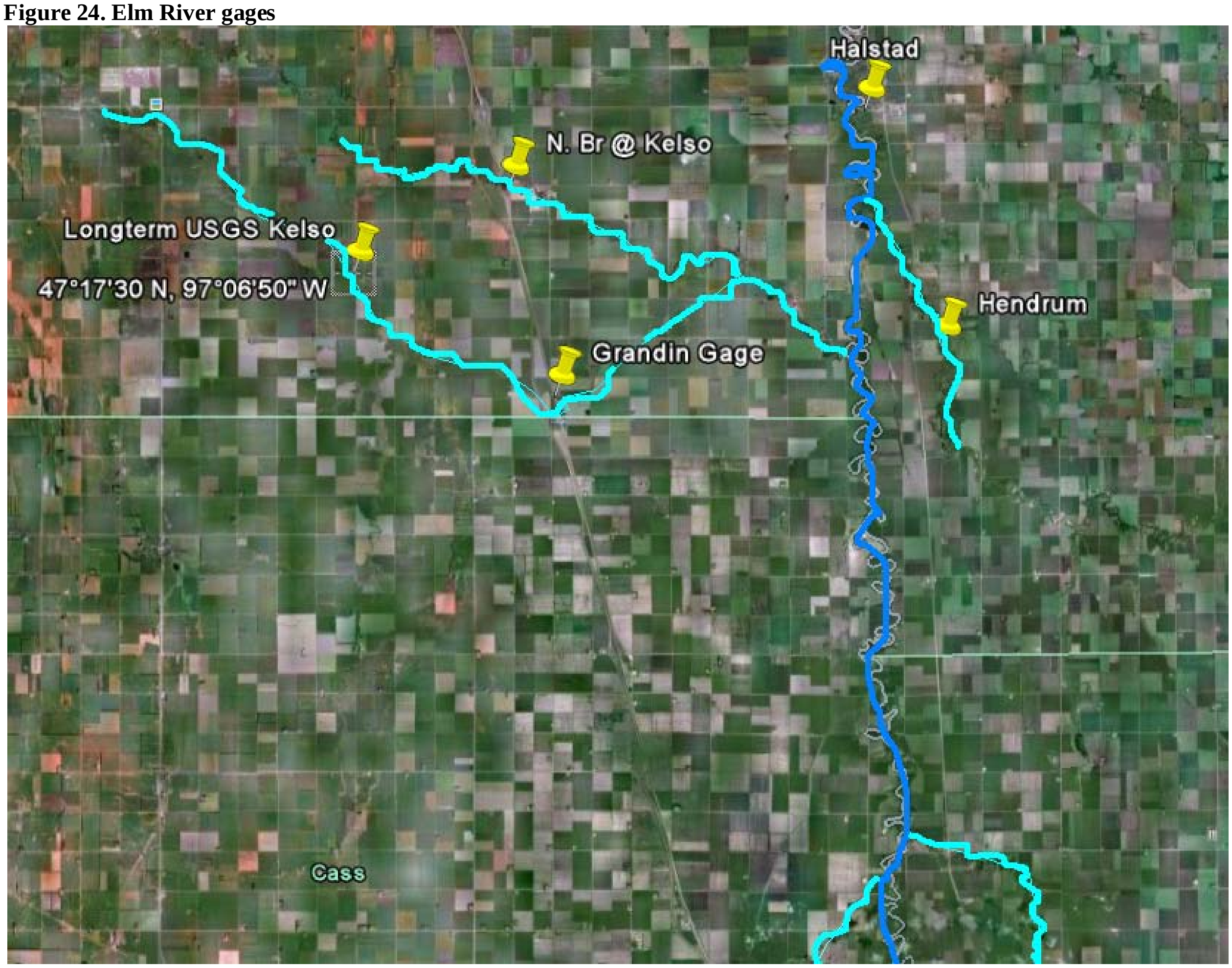


Figure 25. Flow Record Correlation for Elm River at Kelso

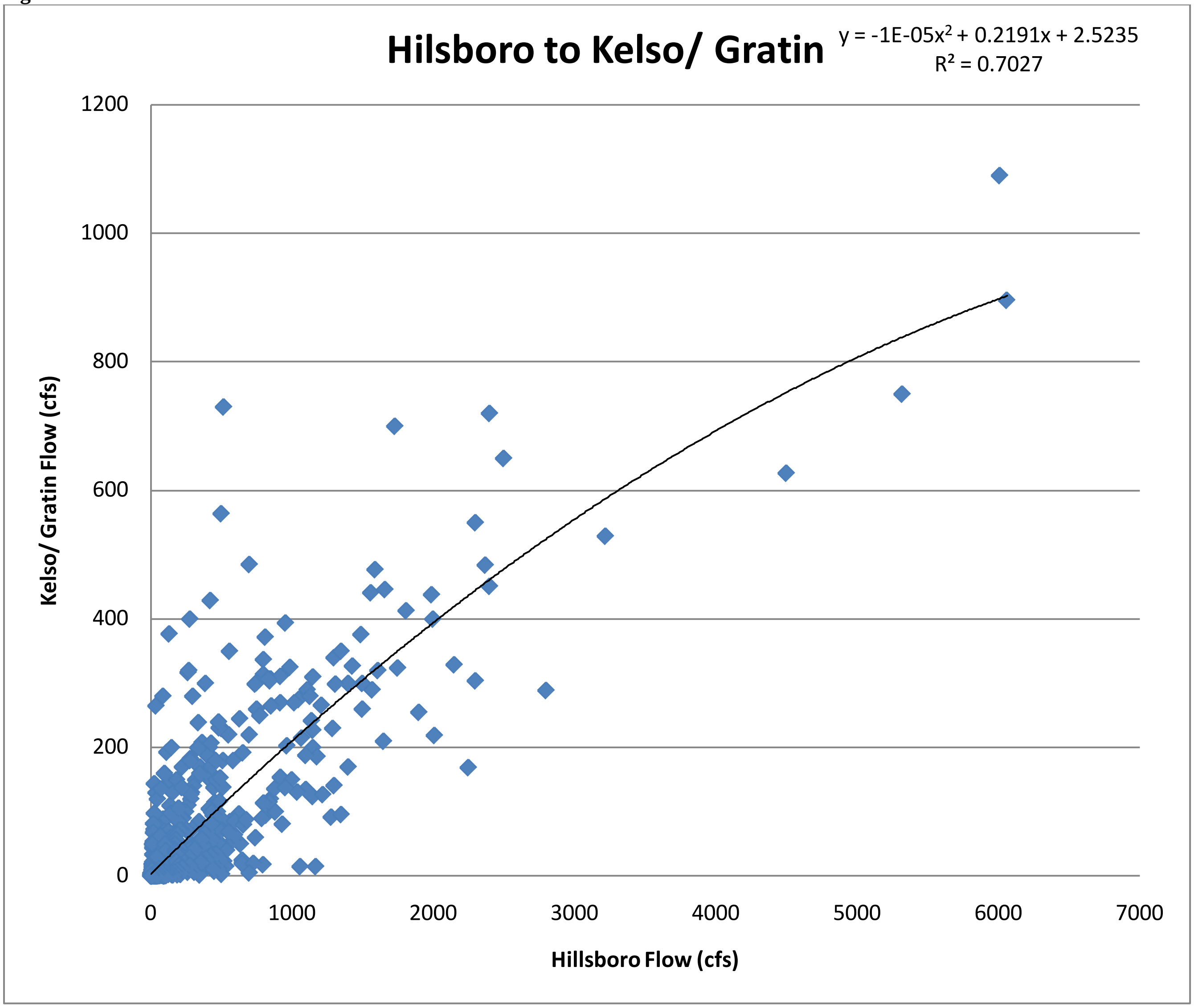


Figure 26. 2006 Event hydrograph comparing the two Mapleton Gages

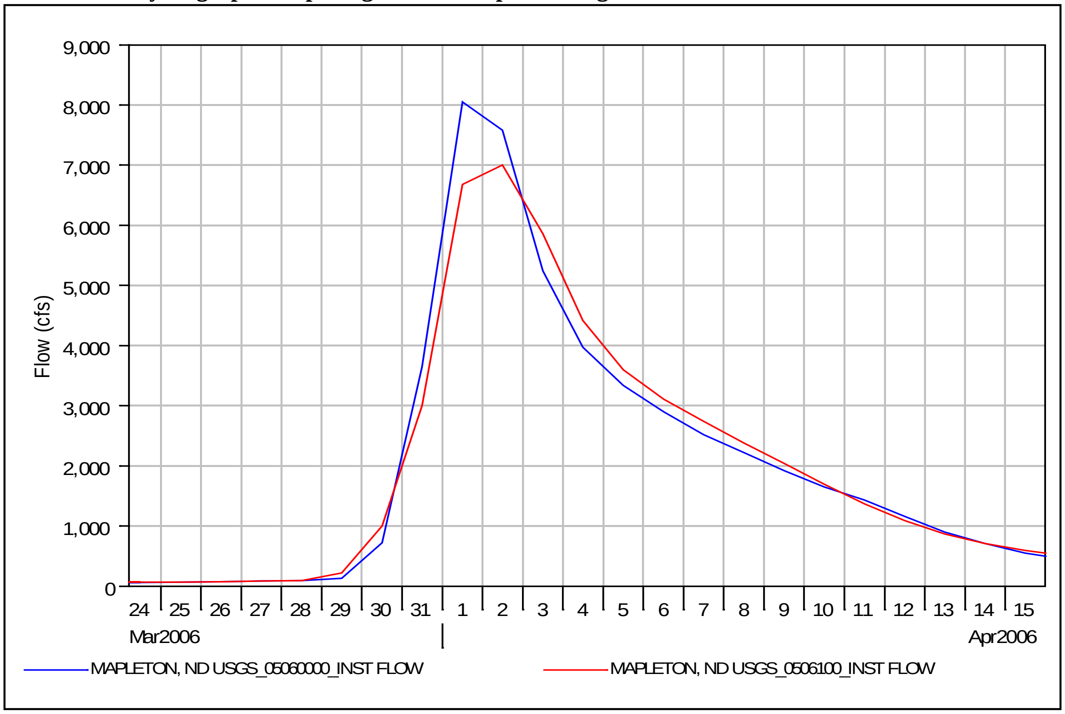


Figure 27. Comparison between Enderlin gage and Mapleton Gage: 1997

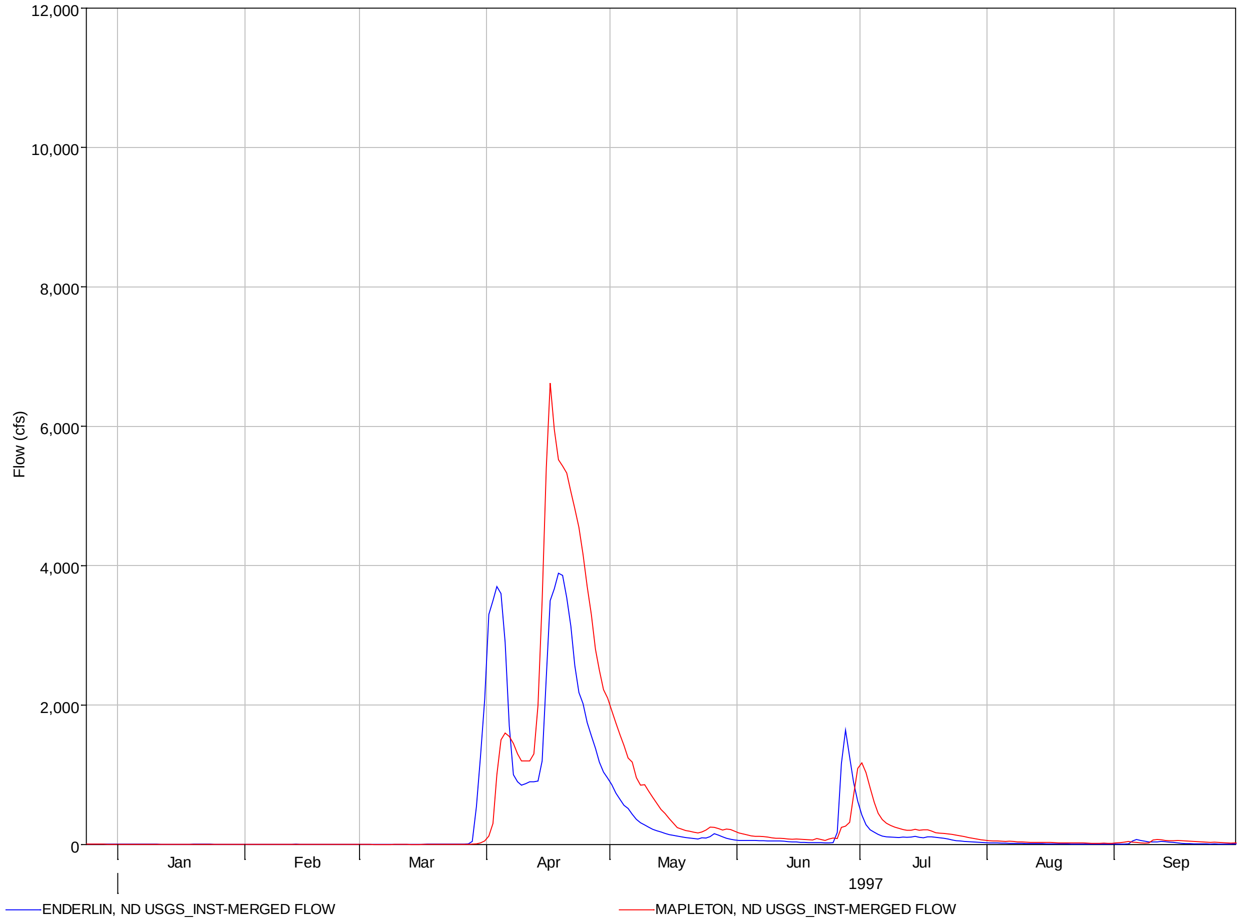


Figure 28. Comparison between Enderlin gage and Mapleton Gage: 2009

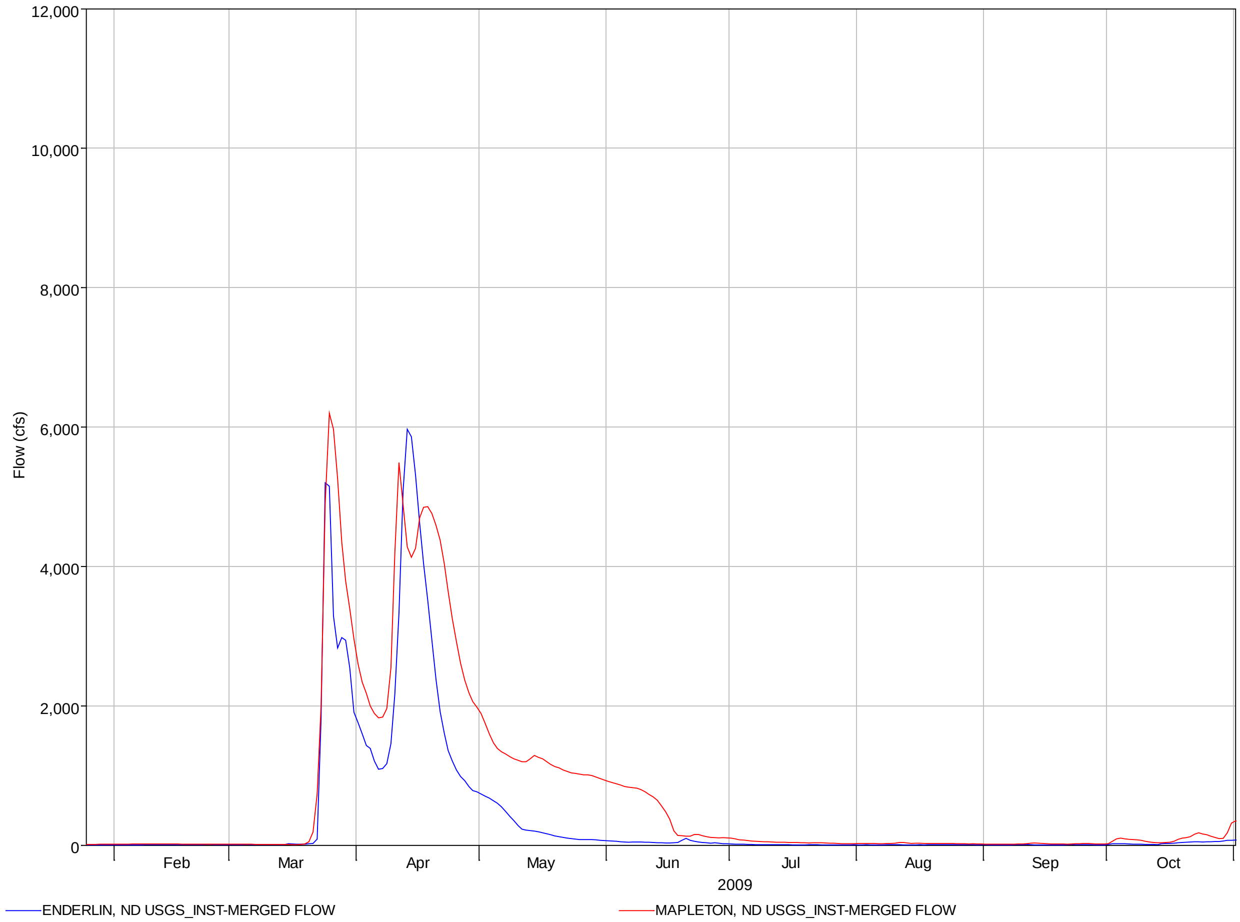


Figure 29. Sheyenne River - Model Calibration at Harwood: 1997

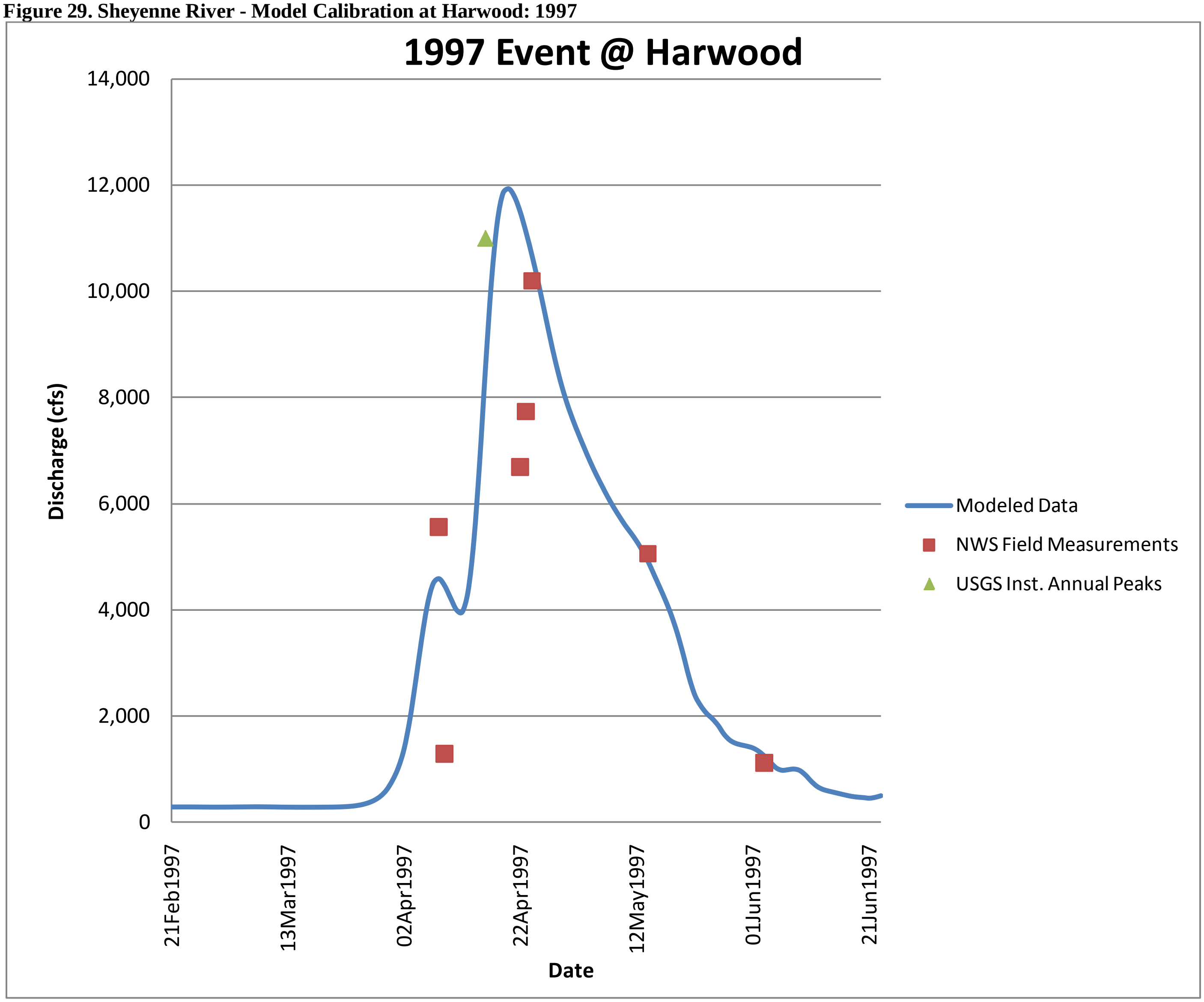


Figure 30. Sheyenne River Model Calibration at Harwood: 2006

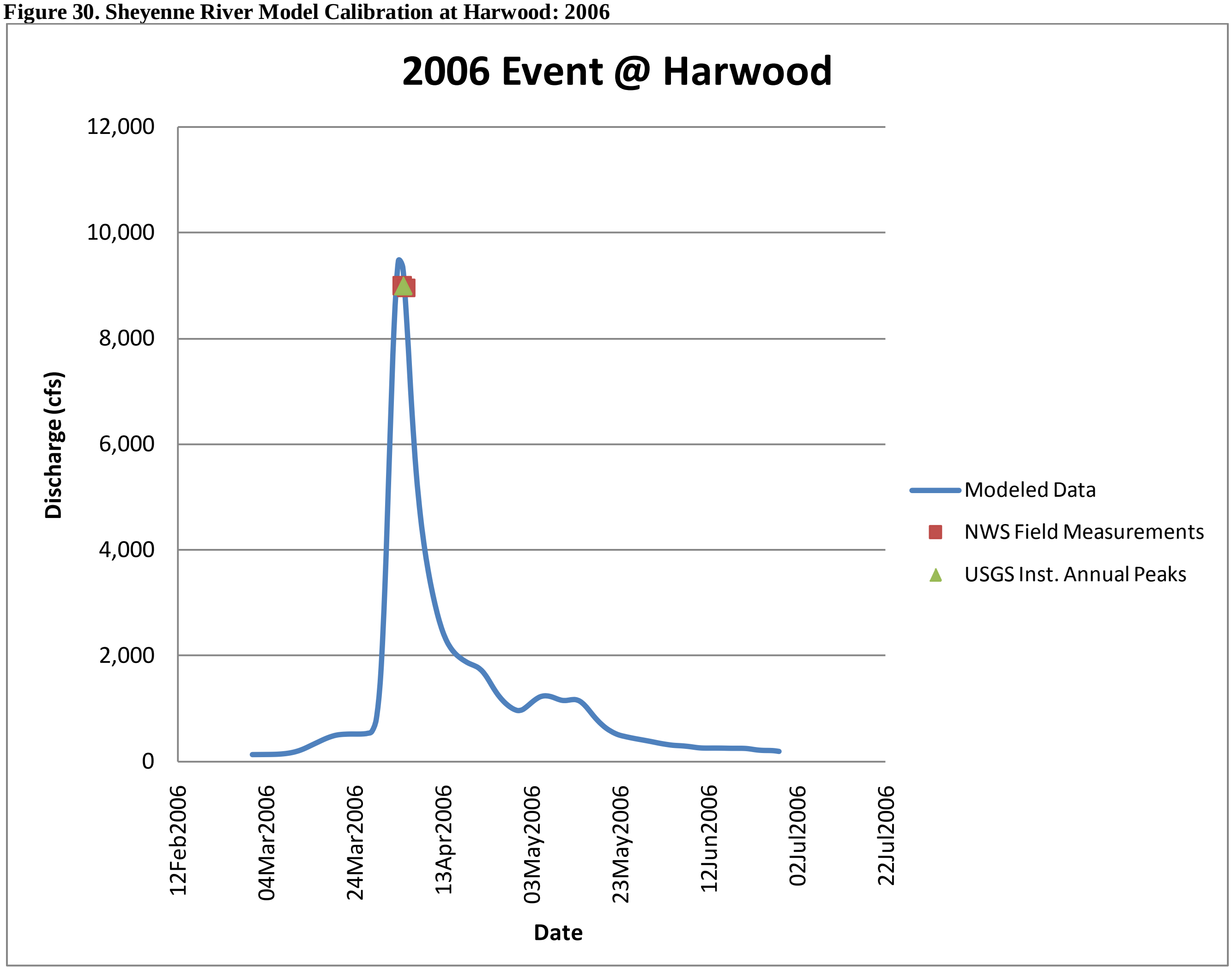


Figure 31. Sheyenne River Model Calibration at Harwood 2009

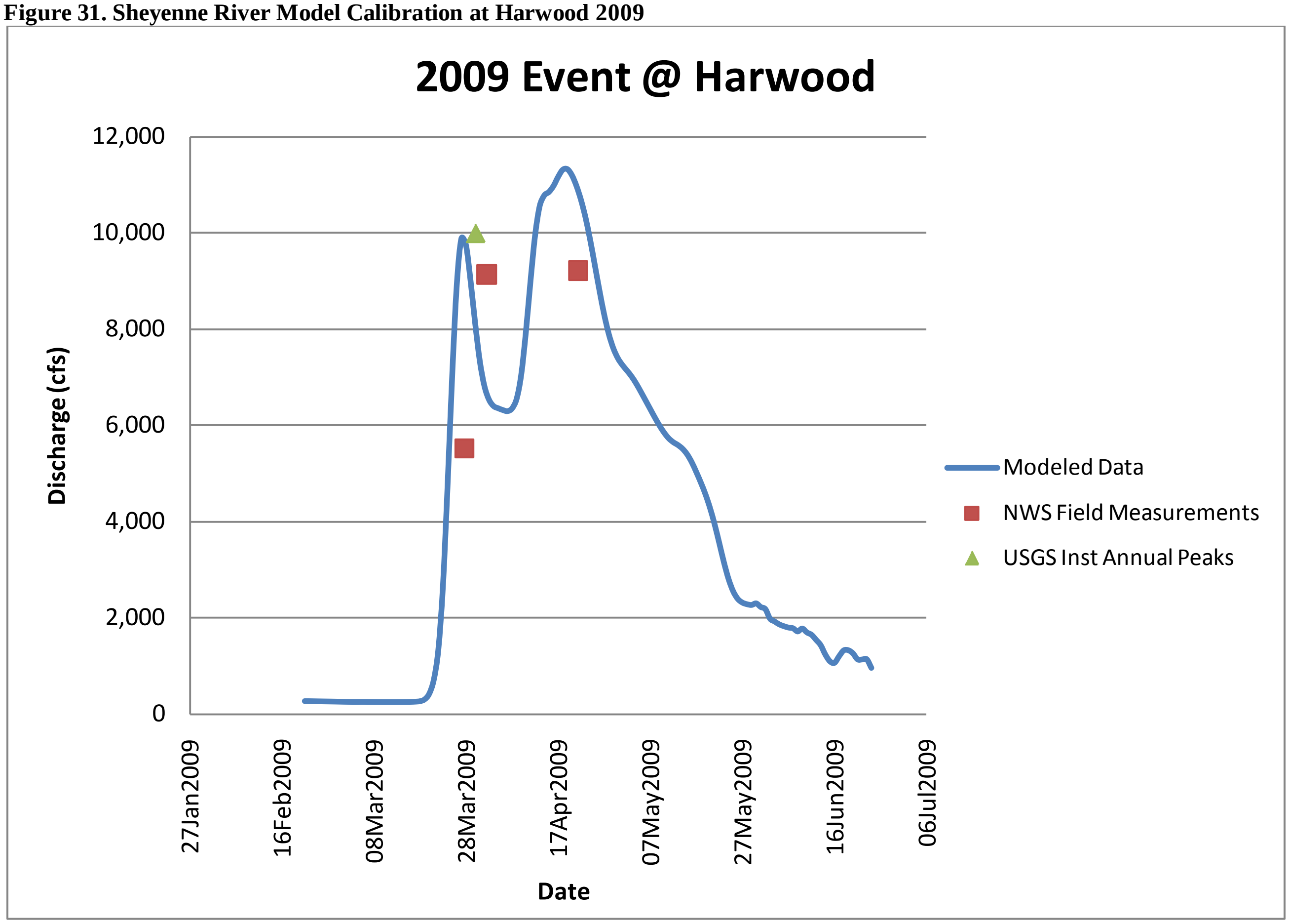


Figure 32. 1997 Event calibration

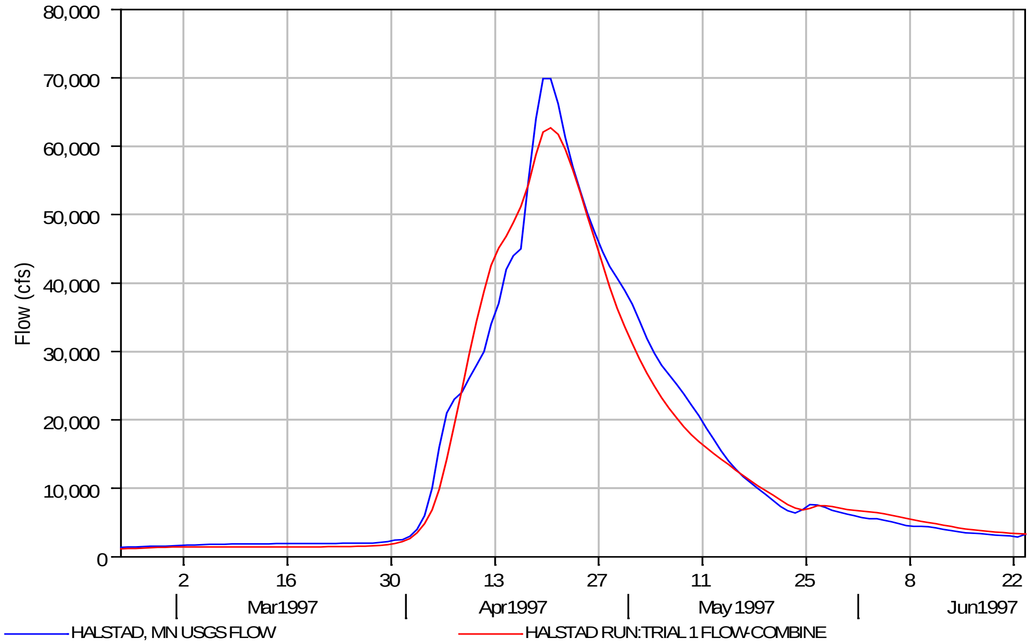


Figure 33. 2006 Event calibration

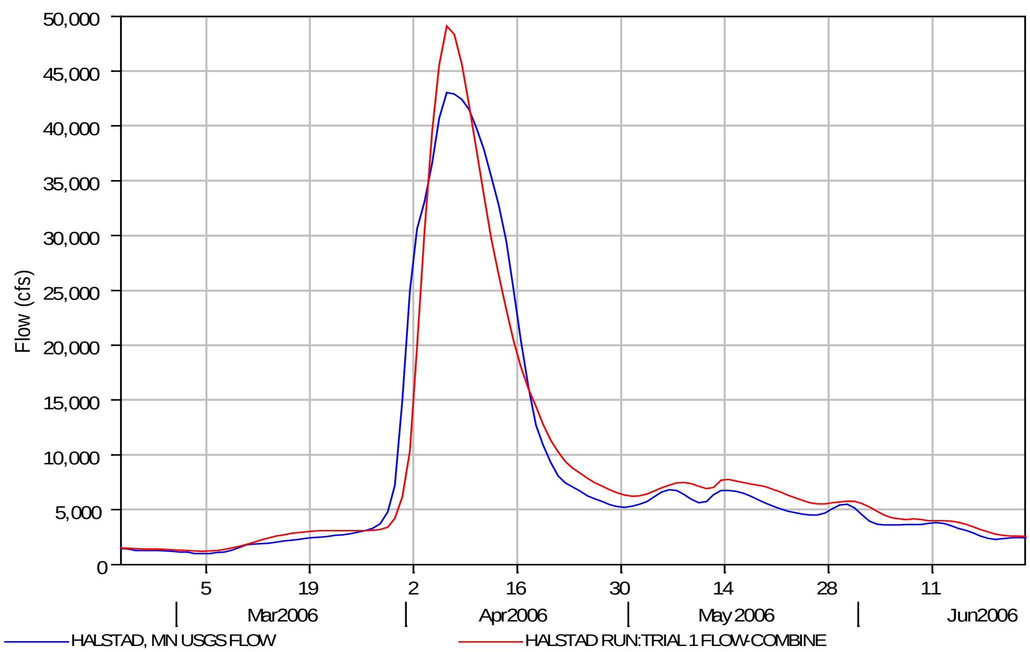


Figure 34. 2009 Event Calibration