Lower Red Basin Retention (LRBR) Study

Appendix A: HEC-HMS Model Development
Aux Marias Tributary; MB, Canada

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US Army Corps of Engineers®

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Red River of the North Basin-Wide Modeling Approach
Hydrologic Modeling – HEC-HMS Model Development
Various Tributaries below the Red River of the North at Halstad, MN

Final Submittal Aux Marias Tributary, MB- Canada

Versions:

Date	Description
August 9, 2017	Initial submittal
December 6, 2017	Incorporation of submittal comments
May 20, 2019	Final submittal

Firm Name: St. Paul Districts Army Corps of Engineers

A. SUBMITTAL OVERVIEW:

This submittal is to summarize the terrain pre-procession, HMS model setup process, basin procession, stream/subbasin characteristics, as well as provide a summary of the reach routing strategies. This submittal will also summarize the calibration results and present resultant subbasin delineations, subbasin parameters and reach routing parameters. HEC-HMS version 4.2 was used to model the Aux Marias.

B. SUBBASIN DEFINITION:

A combination of the Arc Hydro tools and HEC-GeoHMS version 10.2 tools were used to delineate the watersheds' subbasins and to calculate the subbasins' physical properties (area, slope, centroids, longest flow paths, and so forth). This information was used to setup the structure of the HEC-HMS model.

1) *TERRAIN RECONDITIONING:*

This process was started using a 5-meter bare earth DEM. This DEM was then "hydrologically corrected," as necessary. Terrain modification lines are classified into three types:

- Breach Lines: Lines cutting through an embankment (for example a roadway embankment)
- Burn Lines: Lines following a flow path (for example a defined stream or ditch)
- Wall Lines: Lines which refine a flow path between two or more competing flow paths (for example, where a cross-country ditch intersects a lower capacity roadway ditch)

The DEM Reconditioning tool modifies the terrain by lowering grid cell elevations along line features. The DEM reconditioning was completed using a stream buffer of 1 cell (5 meters). For each breach and burn line, a minimum elevation from the unconditioned DEM was determined. This minimum elevation was reduced by 1 meter and used to overwrite the elevations delineated by the terrain reconditioning line. The maximum elevation was determined under each wall line. An additional 5 meters was added to each wall line elevation. This elevation was applied to all cells delineated by each wall line. Baseline information such as the National Hydrography Drainage (NHD) stream network shapefile, aerial photography, LiDAR elevation data (one-meter resolution), stream networks from existing HMS models, and available maps of ditch networks were utilized to assist in this effort.

2) *TERRAIN PREPROCESSING:*

By using GIS algorithms, the terrain was processed to calculate fill sinks, flow direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, and watershed aggregation.

- Fill sinks – hydrodem
- Flow direction – fdr
- Flow accumulation – fac
- Stream definition– str
- Stream segmentation – strlnk
- Catchment grid delineation – cat
- Catchment polygon processing – Catchment
- Drainage line processing – DrainageLine
- Watershed aggregation – AdjointCatchment

The total area of the Aux Marais River tributary was found to be 83.520 square miles. An additional 35 squares miles was modeled that contains areas between the mouth of the Pembina and Aux Marais Rivers on the west side of the Red River of the North.

3) *NON-CONTRIBUTING AREAS:*

As part of the subbasin definition process non-contributing areas were examined. Hydrologically non-contributing areas are defined as areas that are estimated to have the storage capacity to naturally hold all runoff from the 100-yr, 10-day event. The 100-yr, 10-day runoff volumes were taken from Figure 2-1 of TR60 – Earth Dams and Reservoirs, NRCS, July 2005.

To begin this process, the Sink Prescreening function within Arc Hydro was used to prescreen the potential sinks in the Raw DEM by filling low spots encompassing a drainage area of less than two acres. Next, the Depression Evaluation function was used iteratively to identify and combine non-contributing basins. Through this process it was determined that all areas within the Aux Marais watershed contribute flow.

4) *BASIN PREPROCESSING:*

After the terrain preprocessing was completed, additional basin processing was carried out to delineate subbasin at a scale appropriate for hydrologic modeling. The process of subbasin delineation within the Aux Marais River tributary resulted in the development of 5 subbasins having areas ranging between 1.75 square miles to 33.81 square miles.

In addition to defining subbasins based on terrain, subbasins were also delineated at Environment Canada streamflow gaging sites. **Figure 1** shows the location of each resultant subbasin. **Figure 2** shows the raw DEM elevation data for the basin.

Two stream gaging sites were found within the Aux Marais watershed:

- Riviere Aux Marais near Christie, MB (EC 05OC022)
- Riviere Aux Marais near Letellier, MB (EC 05OC018)

The Aux Marais near Letellier station is discontinued. It captured a drainage area of 96 square miles. The gage was active between 1969 and 1970. Only the Christie station was available for model calibration.

The Aux Marais near Christie station has been active since 1971 and collects stage and flow daily data between March 1st and October 31st. The drainage area contributing to the station, as defined using HEC-GeoHMS is 58.89 square miles. According to Environment Canada the watershed area contributing to the gage is 75.3 square miles.

The difference between the two delineations of drainage area can be attributed to a portion of the Red River Basin located just below the international boarder on the south end of the Aux Marais Watershed. As part of this study, this area is included in the Pembina HEC-HMS model. In general, flows from this portion of the Red River Basin contribute to the Pembina River Basin because a dike constructed along the U.S-Canadian Border prevents this area from directly contributing flows to the Aux Marais Watershed. However, during high flow conditions there are culverts which connect the Pembina and Aux Marais watersheds. Runoff generated in the Pembina River Basin which contributes to the Aux Marais via this system of culverts is modeled within HEC-HMS using a breakout flow relationship (see Section 6 for more information).

5) *STREAM AND SUBBASIN CHARACTERISTICS:*

HEC-GeoHMS was used to compute a number of the topographic characteristics for the streams and subbasins in the Aux Marais watershed. Computed characteristics are listed below:

- River Length
- River Slope
- Basin Slope
- Longest Flow Path

- Basin Centroid (based on Center of Gravity Method)
- Centroid Elevation
- Centroid Flow Path

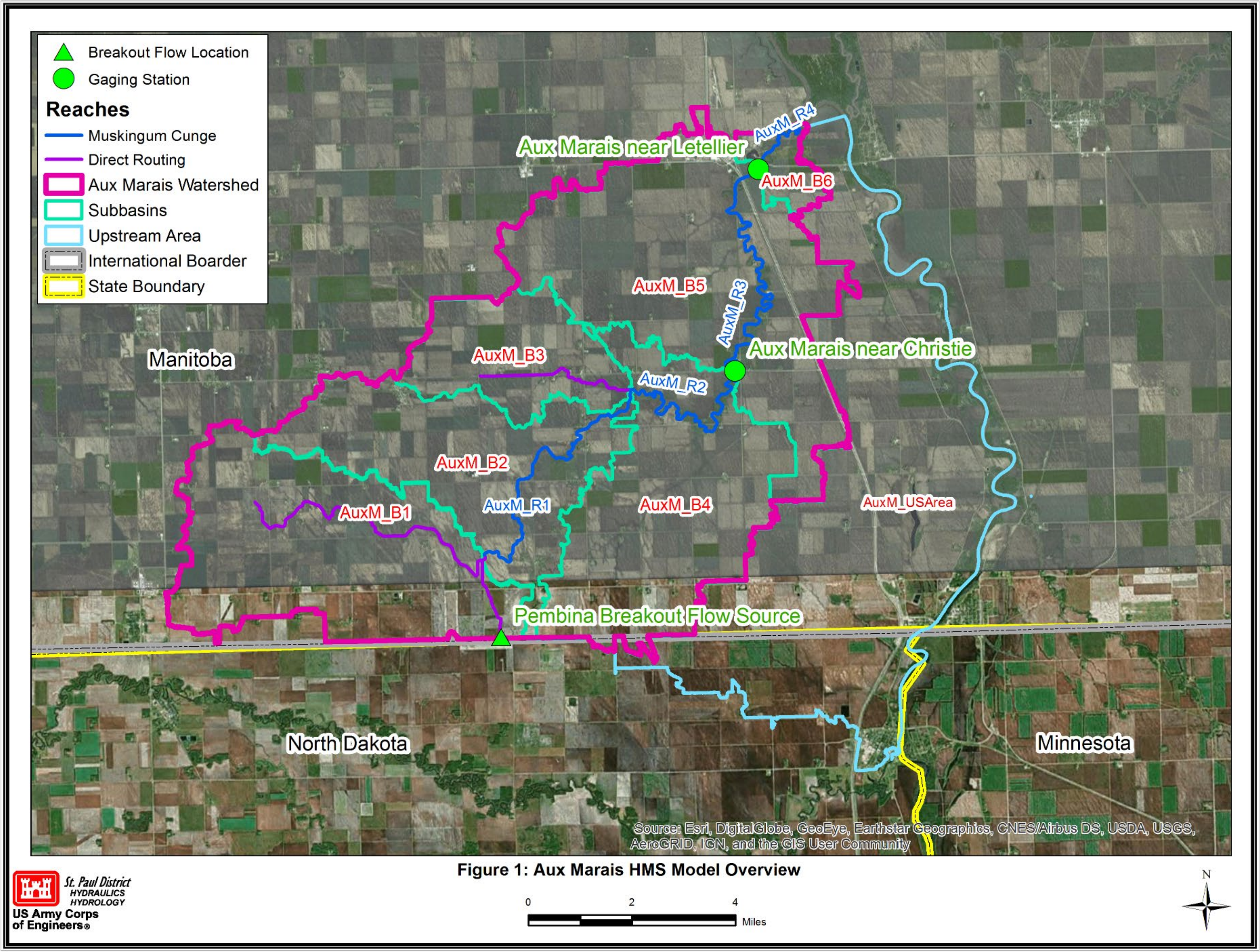

Figure 1: Aux Marais HMS Model Overview

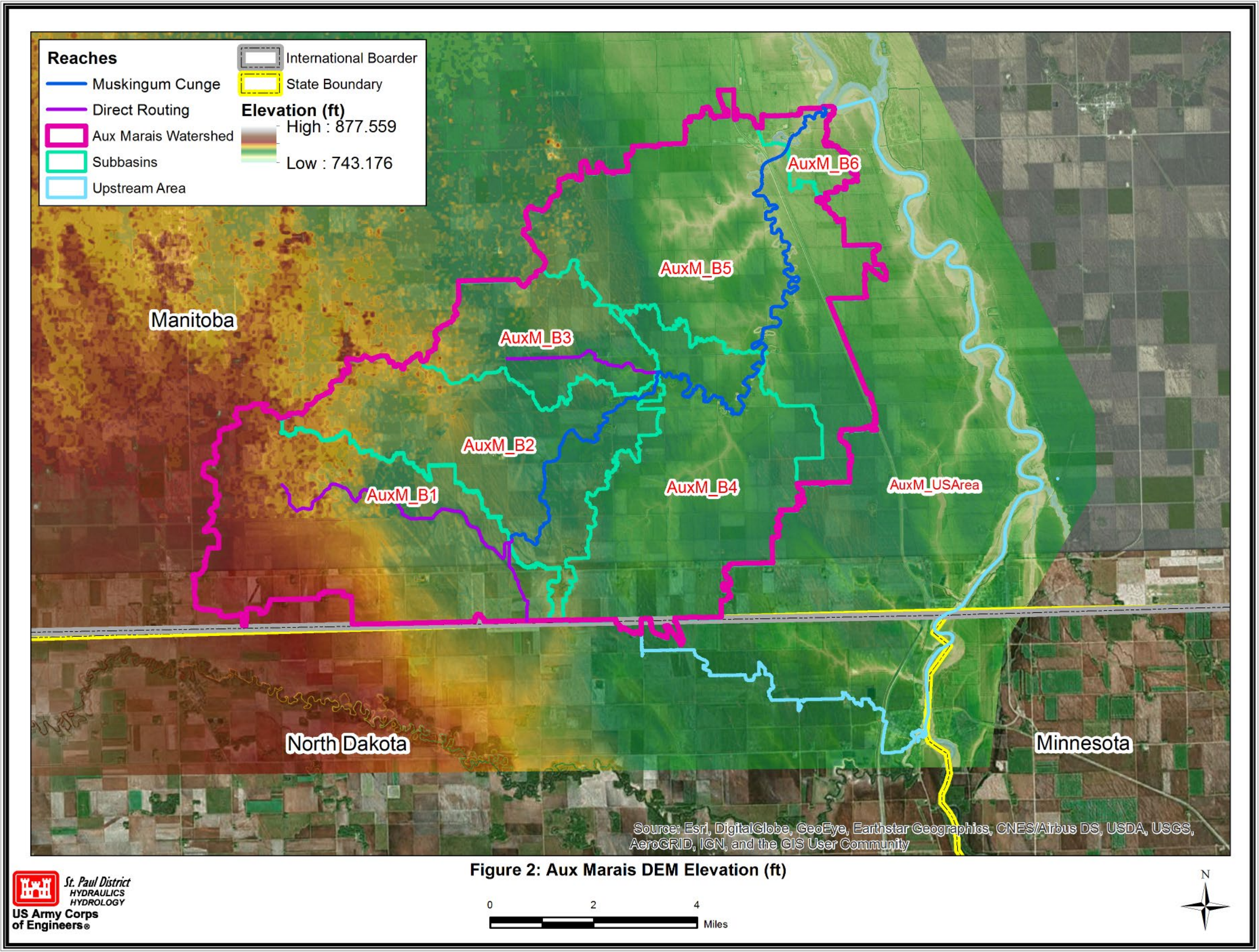

Figure 2: Aux Marais DEM Elevation (ft)

6) <u>Special Model Features: Reservoirs, Diversions and Breakout Conditions:</u>

An approximately 15 mile long road dike has been constructed along the international border between Canada and the United States. This road dike serves as a watershed boundary between the northeastern portion of the Pembina River and the southern boundary of the Aux Marais watersheds. Six drains, or crossings, exist along the international boundary from a point six miles west of Walhalla, North Dakota to the western bank of the Red River of the North.

As shown in **Figure 3**, one of these trans-boundary crossings contributes flow to the Aux Marais River. Four large culverts convey flow between the Pembina and the Aux Marais watersheds. The area south of this crossing is included in the Pembina HMS model. Breakout flows from the Pembina model into the Aux Maris were added to the model at this location. The breakout flow relationship is based on flows at the Neche node in the Pembina model and are show in **Table 1**.

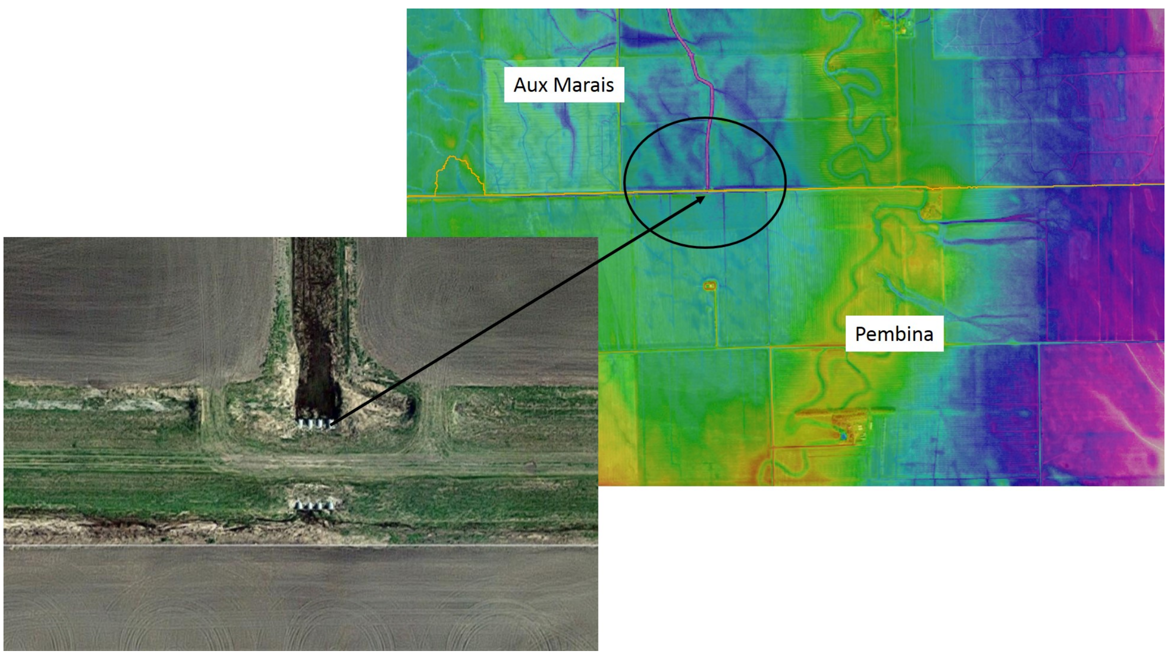

Figure 3 Border crossing culverts between the Aux Marais and Pembina watersheds

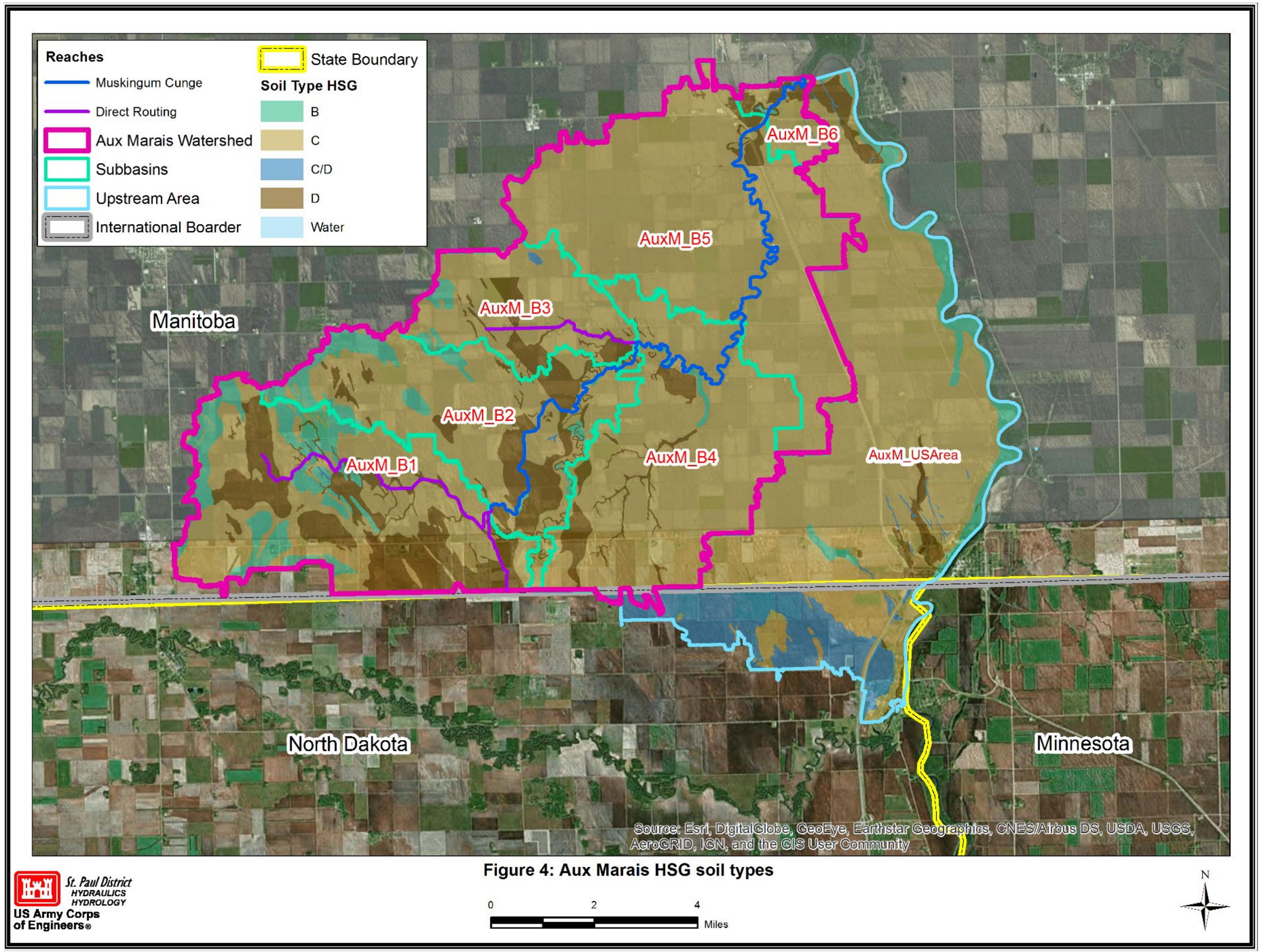

Figure 4: Aux Marais HSG soil types

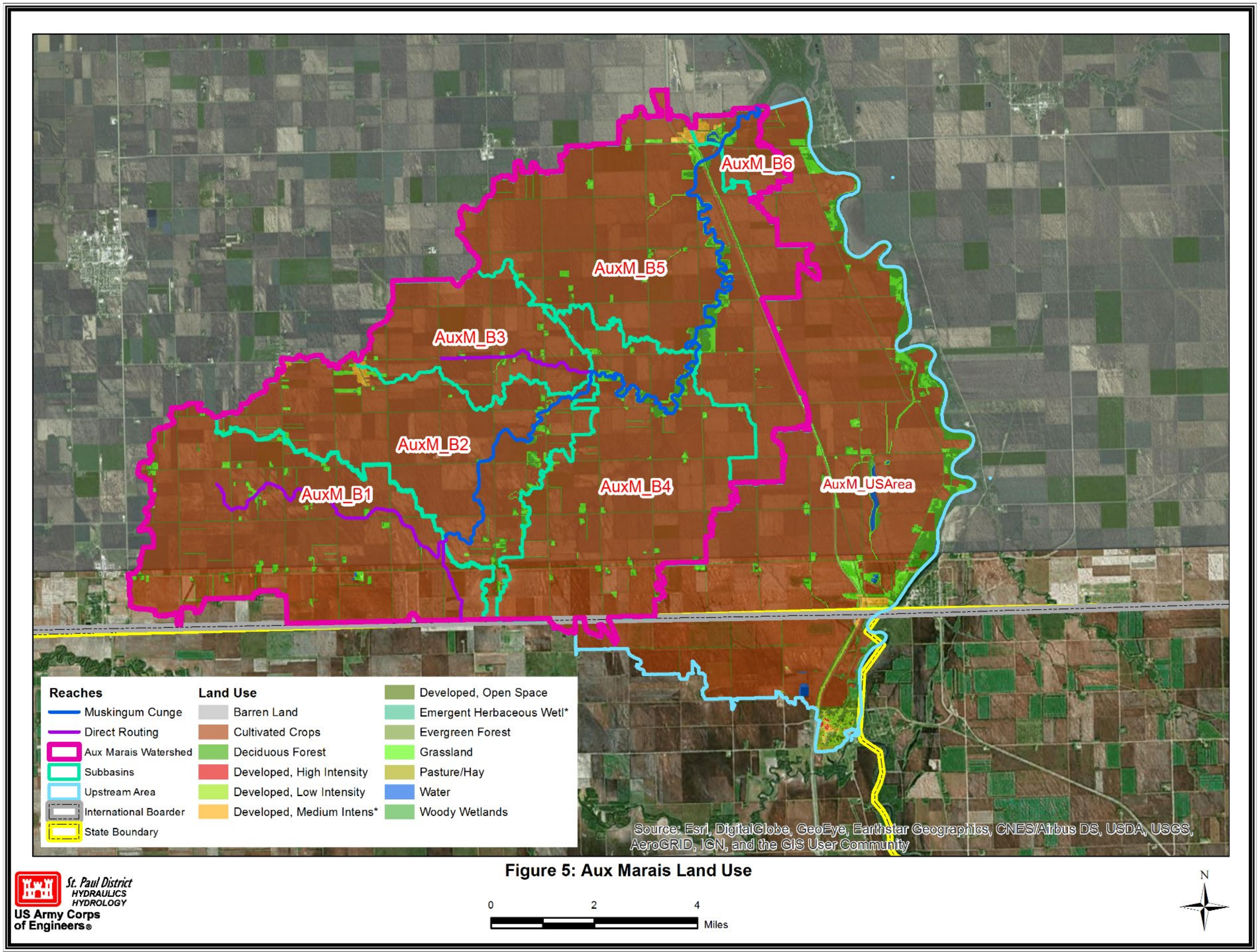

Figure 5: Aux Marais Land Use

Table 1. Breakout flow relationship between the Pembina and Aux Marais Watersheds

Neche Total Flow (cfs)	Breakout flow to Aux Marais (upper bound) (cfs)
57,500	11,450
47,140	7,480
36,070	4,544
27,430	2,990
16,300	470
8,370	0
6,750	0

C. INITIAL HYDROLOGIC SUBBASIN PARAMETER ESTIMATES:

Initial estimates of the subbasin parameters (baseflow, soil loss and transform parameters) were determined for each subbasin using the methods described below. These parameters served as a starting point for model calibration.

1) *RUNOFF CURVE NUMBER:*

The development of initial curve numbers across the entire study area was completed using methods presented in Technical Release 55 (Urban Hydrology for Small Watersheds) and the Minnesota Hydrology Guide based on a combination of the hydrologic soil type (**Figure 4**) and the land use (**Figure 5**) data obtained for Manitoba. Manitoba soils information is based on the “Agricultural Interpretation Database” provided by Manitoba Land Initiative (MLI). The Manitoba Land initiative data was converted to hydrologic soils group classification using a combination of SCS National Engineering Handbook and Manitoba soil classifications. Minnesota and North Dakota land use data and soils data were based on the Soil Survey Geographic (SSURGO) Database and the 2001 National Land Cover Data (NLCD 2001), respectively. **Table 2** provides typical 24 hour curve numbers based on land use and soil type. The National Resources Conservation Service (NRCS) TR-60 guidance was used to convert the 24-hour curve number to a 10-day equivalent. This conversion is provided in **Table 3**.

Table 2. 24-Hour Curve Numbers based on Land Use and Soil Type

Land Use Type	Code (NLCD/ MLI)	Reference	24-hour Curve Number for Soil Type						
			A	B	C	D	A/D	B/D	C/D
Barren Land	31/	TR55 Developing Urban Areas	77	86	91	94	94	94	94
Cultivated Crops	82/1	TR55 (80% row, 20% grains, good condition, contoured)	61	71	78	81	81	81	81
Deciduous Forest	41/2	TR55 Woods (Fair condition)	36	60	73	79	79	79	79
Developed, Open Space	21/16	TR55 Residential (10% impervious, good condition)	45	65	76	82	82	82	82
Developed, Low Intensity	22/	TR55 Residential (35% impervious, good condition)	60	74	82	86	86	86	86
Developed, Medium Intensity	23/13	TR55 Residential (65% impervious, good condition)	77	85	90	92	92	92	92
Developed, High Intensity	24/	TR55 Residential (90% impervious, good condition)	92	94	96	96	96	96	96
Grasslands	71/4	TR55 Meadow (Fair condition)	30	58	71	78	78	78	78

Land Use Type	Code (NLCD/ MLI)	Reference	24-hour Curve Number for Soil Type						
			A	B	C	D	A/D	B/D	C/D
Emergent Herbaceous Wetlands	95/6	MN Hydrology Guide (open water swamps)	85	85	85	85	85	85	85
Evergreen Forest	42	TR55 Woods (Good Condition)	30	55	70	77	77	77	77
Pasture/Hay	81	TR55 Pasture/grassland/range (Fair Condition)	49	69	79	84	84	84	84
Water	11/3	MN Hydrology Guide	100	100	100	100	100	100	100

Table 3. 24-hour and 10-day Initial Curve Numbers

24 hour Curve Number	10 Day Curve Number
91	82
90	81
89	79
88	77
86	74
85	72
84	71
83	69
82	68
81	66
80	65
79	64
78	62

2) *TIME OF CONCENTRATION (T_c):*
The initial value of the T_c for each subbasin was estimated using the SCS method shown in equation 1 (SCS 1975).

$$T_c(\text{min}) = 0.0526 * \left(\frac{1000}{CN} - 9\right)^{0.7} * L^{0.8} * S^{-0.5} \qquad \text{Equation 1}$$

Where, L is the longest flow path distance in feet (ft), CN is the average curve number for the watershed, and S is the average slope of the basin in ft/ft.

Slopes were calculated using elevation data and ArcMap 10.4 GIS tools to find the average slope of each subbasin.

3) *UNIT HYDROGRAPH PARAMETERS:*
In past hydrologic modeling efforts within the Red River Basin (RRB), several models have been completed using the Clark's Unit Hydrograph method. This method models the translation and attenuation of excess precipitation. In these past studies, the Clark's R parameters were used as calibration parameters for historic storm events. The initial value of R before calibration was calculated using the estimated T_C values and the initial $R/(R+T_c)$ ratio of 0.67. R values were then adjusted during the calibration of the HEC-HMS model. The initial ratio of 0.67 is consistent with the calibrated $R/(R+T_c)$ ratio adopted to model the portion of the Pembina River that boarders the Aux Marias watershed (USACE, 2014).

4) *BASEFLOW PARAMETERS:*
Baseflow parameters were initially adopted to be equivalent to values from the calibrated Pembina HEC-HMS model (USACE, 2014). Initial discharge was set to 0.1 cfs, with a recession constant of 0.7 and a ratio of 0.2 using the threshold type of Ratio to Peak. Baseflow parameters were not modified during model calibration.

Watershed parameters including Initial estimates for CN, Clark's T_C and R before calibration are shown in **Table 4**.

Table 4. Initial Watershed parameters – prior to model calibration

Watershed	Area (mi^2)	CN Base 24 hr	CN Base 10 Day	T_c (hrs)	R	R/(Tc+R)
AuxM_B1	19.182	78	62	20.5	41.7	0.67
AuxM_B2	14.628	78	62	18.3	37.2	0.67
AuxM_B3	7.458	78	62	15.1	30.7	0.67
AuxM_B4	17.623	78	62	22.4	45.6	0.67
AuxM_B5	22.877	78	62	21.4	43.4	0.67
AuxM_B6	1.749	79	64	6.5	13.2	0.67
AuxM_USArea	35.023	78	62	40.0	81.2	0.67

D. REACH PARAMETERS:
The Muskingum Cunge routing method was used for the four routing reaches in the Aux Marais model. The locations of the reaches were Muskingum Cunge routing is applied are shown in **Figure 1**. Parameters for the Muskingum Cunge method are

summarized in **Table 5**. Reach lengths were determined from the GeoHMS delineated drainage line and subbasin areas. Channel cross sections were described as eight point cross sections based on LiDAR elevation data. Only above water surface elevations were available. Cross sections do not include bathymetric survey data. Generalized Manning's N values were used to model channelized flow. For all routing reaches, a main channel Manning's N value of 0.06 was applied. Bank Manning's N values were determined based on land use. Two predominant land use categories were present along the channel banks in the Aux Marais watershed: agricultural and grassland. A Manning's N value of 0.08 was applied to agricultural areas and 0.10 applied to grassland areas. This is consistent with the Red River of the North Study modeling procedure. A weighted average value of Manning's N was determined for each reach based on the portion of the reach length associated with each land use.

Table 5. Muskingum-Cunge Routing Parameters in Aux Marais River Model

Reach	Channel Length (ft)	Channel Slope (ft/ft)	Manning's N		
			Main Channel	Left Bank	Right Bank
AuxM_R1	35,958	0.00019	0.06	0.088	0.088
AuxM_R2	29,292	0.00017	0.06	0.088	0.088
AuxM_R3	43,381	0.00023	0.06	0.086	0.086
AuxM_R4	8,899	0.00290	0.06	0.088	0.088

E. HMS MODEL CALIBRATION

The calibration procedure involved comparing the simulated HEC-HMS output to the observed flow at the only long-term gaging station within the Aux Marais Watershed. Mean annual daily flow measurements were available from Environment Canada (EC) for the Riviere Aux Marais near Christie, Manitoba gage (05OC022).The location of the gaging station is displayed in **Figure 1**.

Subbasin parameter values were adjusted to improve the agreement between the simulated and the observed data for three calibration events. Calibration parameters were primarily limited to CN, R, and Tc. Adjustments were made by scaling initial parameters up or down proportionally for all subbasins in the model. The goal of this effort was to fit the simulated hydrograph to the observed hydrographs within the following target ranges:

- 10% of runoff volume
- 10% of peak flow
- Peak within ½ day of observed

The storm events used for calibration were selected based on local knowledge of the area and a review of the observed climatic records. The time period from which to select calibration events was limited to the time period in which NEXRAD (Next

Generation Radar) gridded precipitation data was available. The following events were chosen for calibration:

- June 8, 2002 to June 21, 2002
- June 26, 2005 to July 20, 2005
- May 19, 2013 to May 30, 2013

For the calibration gage site at Christie only mean daily flow data is available. Computations being carried out by the HEC-HMS model are being conducted using an hourly time interval. Comparing coarser, daily, observed flow data to hourly modeled data may amplify differences in observed versus modeled flows.

For the 2002 event CN values were not adjusted from the CN Base 24 values given in **Table 4**. For the 2005 and 2013 events the curve numbers were adjusted from the original antecedent moisture condition (AMC) II values to AMC III values. AMC II represent average soil moisture conditions whereas AMC III represents wet soil conditions. The AMC II values are equivalent to the CN Base 24 hr values given in **Table 4**. To calibrate the 2005 and 2013 events, an adjustment factor of 1.14 is applied to the AMC II curve number of 78, resulting in a wet conditions CN of 91 (Ward et al 2004).

T_C and R were also adjusted during calibration. The resulting T_C values were consistent amongst all three calibration events. Calibrated R values were 25% higher for the 2002 event than the 2013 and 2005 events. This difference is likely caused by differences in antecedent conditions. Percent impervious and initial abstractions values were not used in this model development. The final, calibrated watershed parameters used in all three calibration events are presented in **Tables 6-8**.

Table 6. 2002 Calibrated watershed parameters

Watershed	CN	Tc (hrs)	R	R/(Tc+R)
AuxM_B1	78	55.4	84.4	0.60
AuxM_B2	78	49.5	74.2	0.60
AuxM_B3	78	40.8	61.5	0.60
AuxM_B4	78	60.5	91.3	0.60
AuxM_B5	78	57.8	86.9	0.60
AuxM_B6	79	17.6	26.5	0.60

Table 7. 2005 Calibrated watershed parameters

Watershed	CN	Tc (hrs)	R	R/(Tc+R)
AuxM_B1	91	55.4	66.8	0.55
AuxM_B2	91	49.5	60.4	0.55
AuxM_B3	91	40.8	50.0	0.55
AuxM_B4	91	60.4	74.0	0.55
AuxM_B5	91	57.8	70.5	0.55
AuxM_B6	91	17.6	21.5	0.55

Table 8. 2013 Calibrated watershed parameters

Watershed	CN	Tc (hrs)	R	R/(Tc+R)
AuxM_B1	91	55.4	66.8	0.55
AuxM_B2	91	49.5	60.4	0.55
AuxM_B3	91	40.8	50.0	0.55
AuxM_B4	91	60.4	74.0	0.55
AuxM_B5	91	57.8	70.5	0.55
AuxM_B6	91	17.6	21.5	0.55

Figures 6-8 show the calibration results for the 2002, 2005 and 2013 events. Included in the figures are the observed and modeled flows, as well as the precipitation depths and the precipitation losses to infiltration. **Table 9** shows a comparison between observed and modeled results, as well as Nash Sutcliffe coefficients.

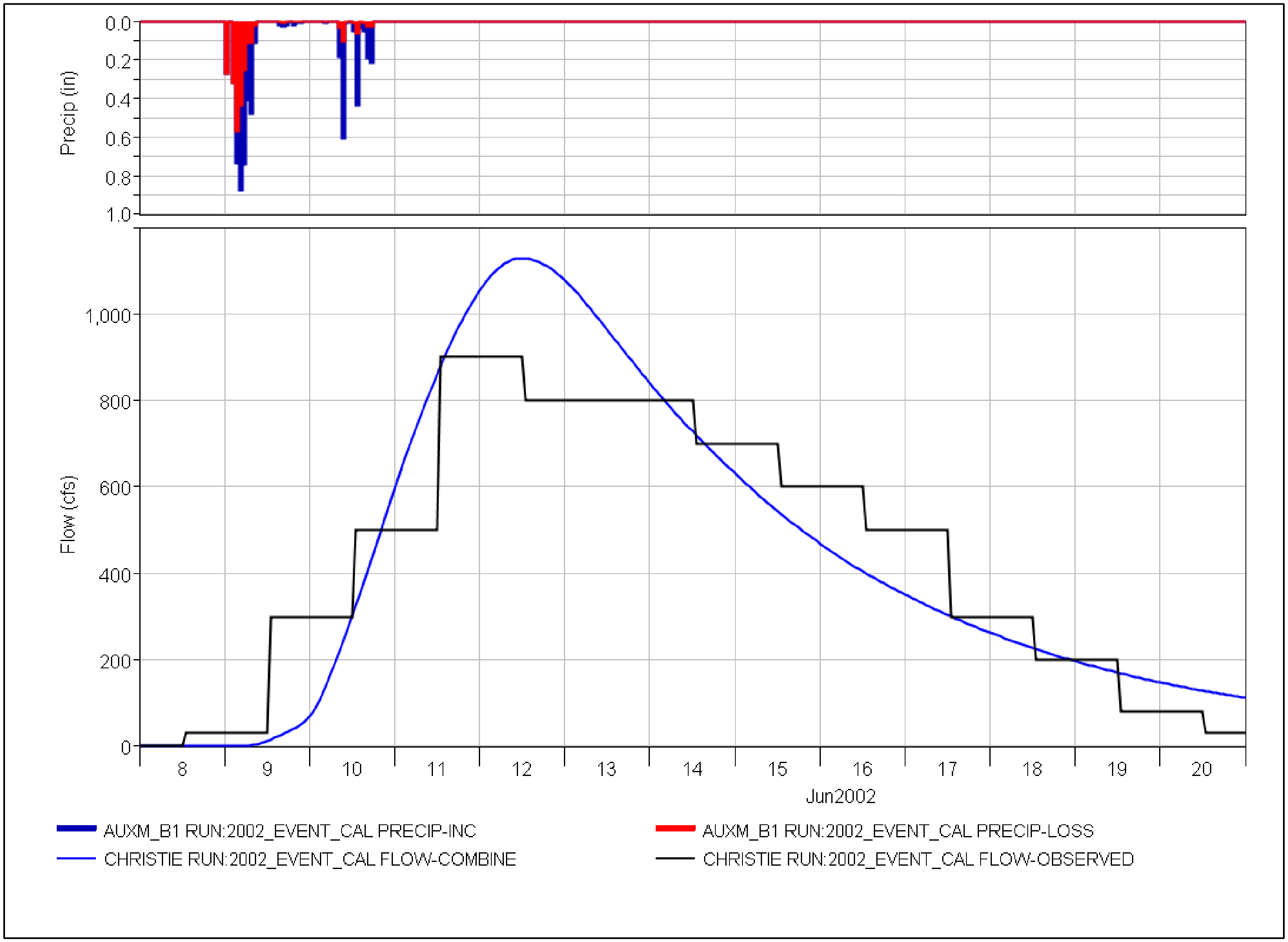

Figure 6: 2002 calibration event results at Christie gaging station

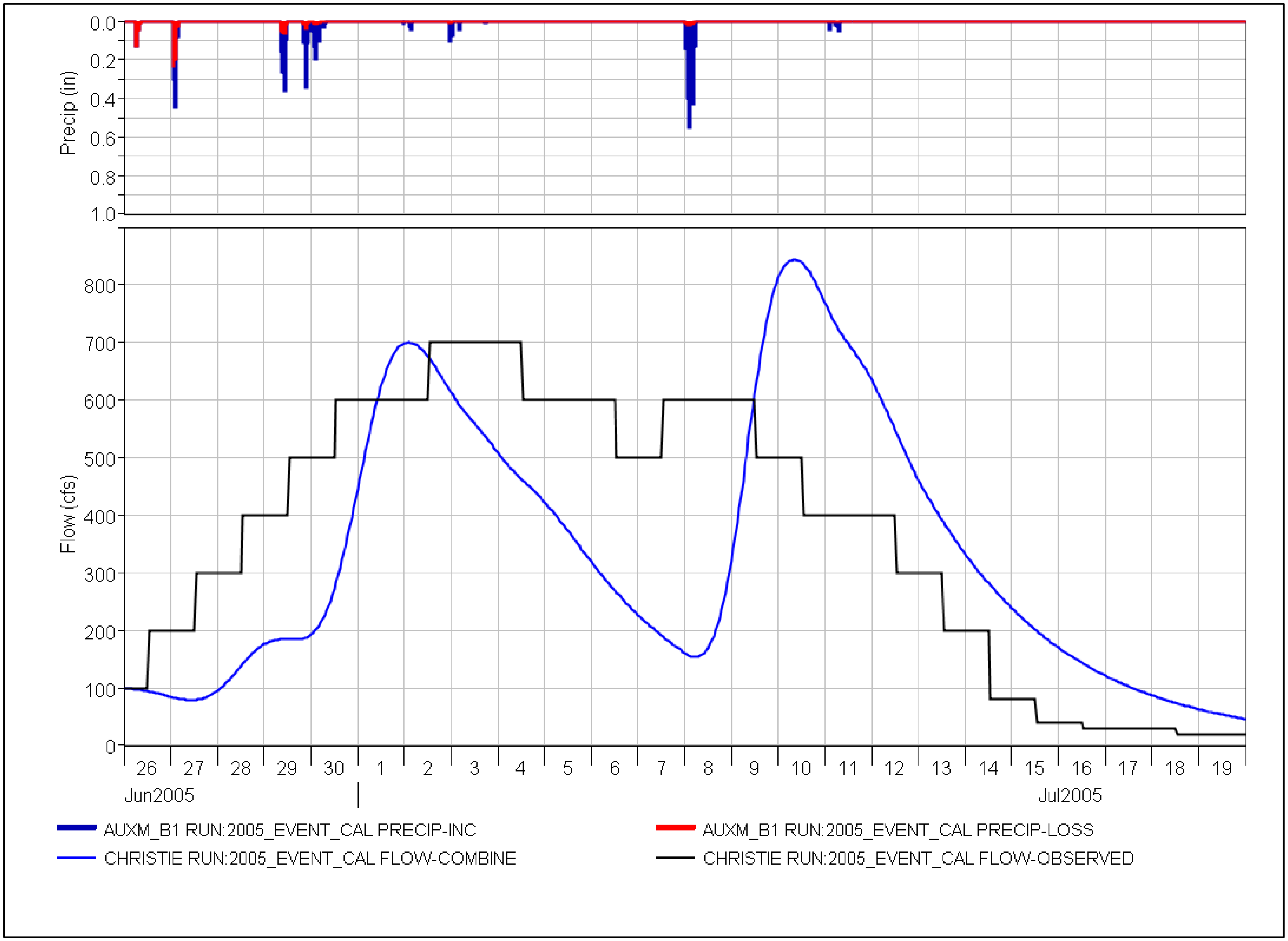

Figure 7: 2005 calibration event results at Christie gaging station

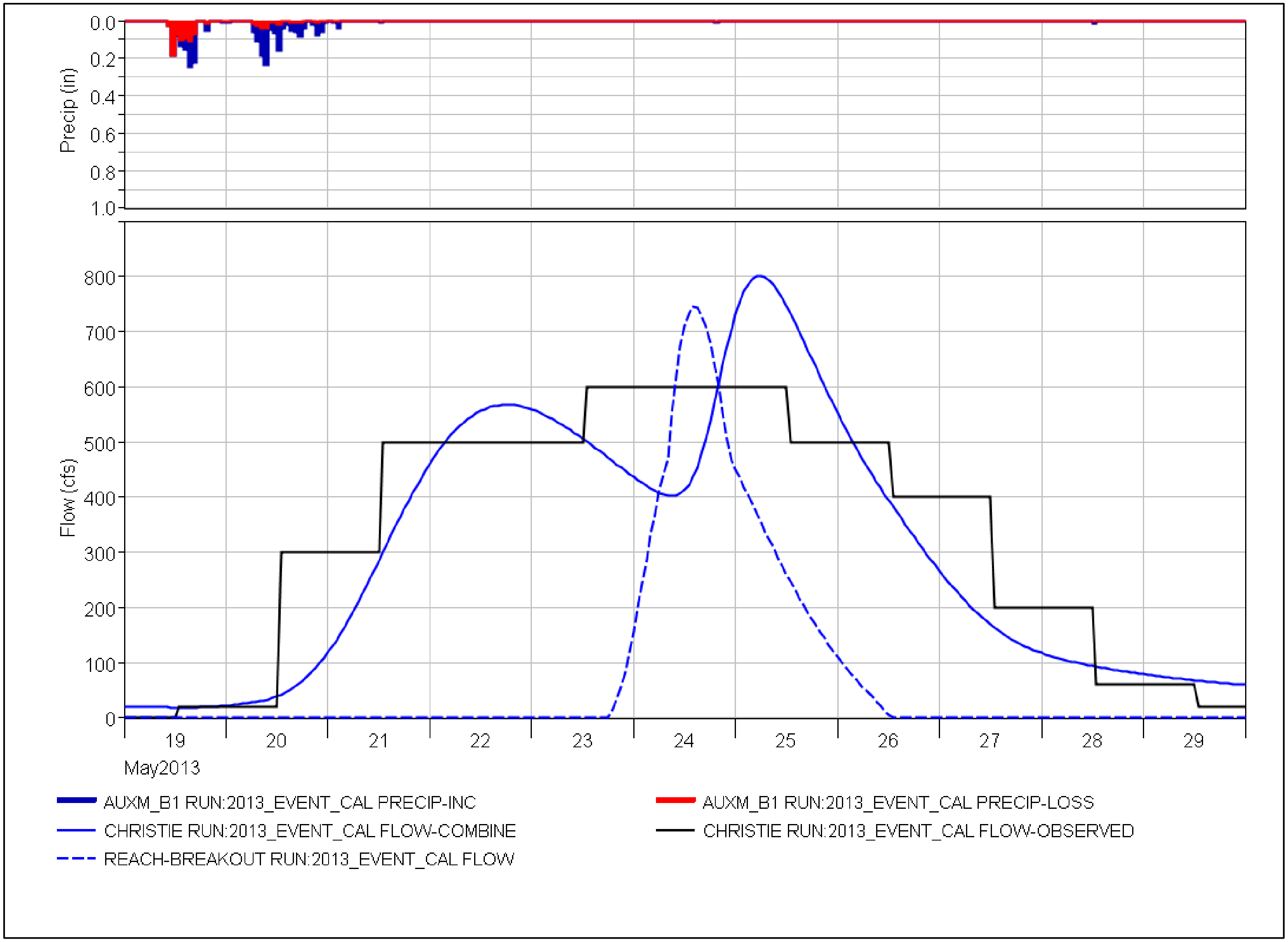

Figure 8: 2013 calibration event results at Christie gaging station

The total volume modeled meets the calibration goal of being within 10% of the observed volumes for all three calibration events. Peak flows were off by more than 10% for the 2002 and 2005 events, however, this is likely because hourly, modeled data are being compared to 24 hour average, observed data. Averaging flows over a 24 hour period would depress the observed, peak flows. Nash-Sutcliffe values show good comparison between the observed and modeled datasets for the 2002 and 2013 events. A poor comparison is present for the 2005 event. The 2005 event is a double peak event which can be hard to calibrate to due to changes in soil moisture that are not easily modeled using the SCS method. The timing of the peak flow is difficult to compare between modeled and observed results because only 24 hour average, observed values are available and an hourly time step is used to model flows. The 2002 modeled peak discharge occurred within the same 24 hour timeframe as the observed, maximum, average, daily peak. For the 2005 event, two peaks were observed. The first modeled peak was within 12 hours of when the observed, peak mean daily flow occurred. The modeled 2013 peak flow was within the same 24 hour timeframe as the observed, maximum, average, daily peak.

Table 9. Model Calibration: Observed and Modeled results comparison.

Event	Nash-Sutcliffe	Volume			Peak Flow (cfs)		
		Observed	Modeled	% diff	Observed	Modeled	% diff
2002	0.807	11,378	11,439	3%	900	1,106	25%
2005	0.150	17,775	15,853	10%	700	831	20%
2013	0.732	7,318	6,578	10%	600	800	33%

Breakout flows from the Pembina River start to contribute to the Aux Marais at flows over 8,370 cfs at the Neche gage on the Pembina River. Contributions don't become significant until Neche is over 16,300 cfs. In the 2002 event observed peak flows at Neche gage were 3,440 cfs with modeled flows of 3,700 cfs below the value that would contribute to the Aux Marais. Therefore breakout flows were 0 cfs for this case. In the 205 event peak observed flows at the Neche gage was 6,890 and modeled flows were 9,970 cfs. Based on observed flow breakout flows would be 0 cfs to the Aux Maris. Modeled flows show minimal contribution from the Pembina to the Aux Marais. In 2013 peak flows at the Neche gage were observed at 17,500 cfs with modeled flows of 17,467. Calibration of the 2013 event required the inclusion of breakout flows from the Pembina Watershed. The breakout flows form the Pembina contribute to the second peak flow on May 25th. The breakout flows from the Pembina model were routed to the Aux Marais watershed using a lag routing element. A lag of 48 hours (2,880 minutes) was applied to the breakout flow from the Pembina River model before it reached Junction 2 in the Aux Marais model and merged with the flows from subbasin AuxM_B1. This lag accounts for travel time from the Pembina model into the Aux Marais watershed. **Figure 8** shows the flow contribution from the Pembina River (Reach-Breakout) to the Aux Marais River.

F. ADOPTED HYDROLOGIC MODEL PARAMETERS

From the set of parameters generated during the calibration process a set of adopted/recommended hydrologic watershed parameters was determined. It is suggested that the CNs be reset back to the initially estimated 24-hour values or 10-day values (pre-calibration). T_C values were the same for all three calibration events, and thus calibrated Tc values are recommended for future modeling. Clark's R values were the same for both the 2005 and 2013 events, but were higher for the 2002 event. An average value between the two R values should be used for future modeling. **Table 10** shows the adopted watershed parameters.

The resulting synthetic T_c values are 2.7 times larger than the initial estimates, while the synthetic R values are 1.8 times larger than the initial estimate values. The final $R/(T_c + R)$ ratio of 0.58 is slightly higher than values in the Pembina HMS model (USACE, 2014). Pembina River subbasins adjacent to the Aux Marais have ratio values around 0.5. The CNs of 78 and 79 are within the range of proposed CNs for subbasins in the Pembina HMS model (USACE, 2014). Pembina sub-watershed CNs range between 70 and 80 in the region closest to the Aux Marais.

Table 10. Adopted HEC-HMS Model Parameters

Watershed	CN Base 24 hr	CN Base 10 Day	Tc (hrs)	R	R/(Tc+R)
AuxM_B1	78	62	55.4	75.6	0.58
AuxM_B2	78	62	49.5	67.3	0.58
AuxM_B3	78	62	40.8	55.8	0.58
AuxM_B4	78	62	60.4	82.7	0.58
AuxM_B5	78	62	57.8	78.7	0.58
AuxM_B6	79	64	17.6	24	0.58
AuxM_USArea	78	62	108.1	147.2	0.58

Due to time and budget constraints a true model validation could not be conducted. To validate the adopted model parameters each of the calibration events were re-run using the adopted hydrologic watershed parameters displayed in **Table 10**. **Figures 9 – 11** show the validation results. The 24 Hour base CNs were used for model validation. The 2013 event includes the breakout flow from the Pembina River HEC-HMS Model. Table 11 shows the model comparison values between the observed data and the validated model results.

Table 11. Model Calibration: Observed and Validated Modeled results comparison.

Event	Nash-Sutcliffe	Volume			Peak Flow (cfs)		
		Observed	Modeled	% diff	Observed	Modeled	% diff
2002	0.738	11,378	11,600	2%	900	1,180	31%
2005	-0.449	17,775	10,540	41%	700	650	7%
2013	0.086	7,318	4,060	45%	600	670	12%

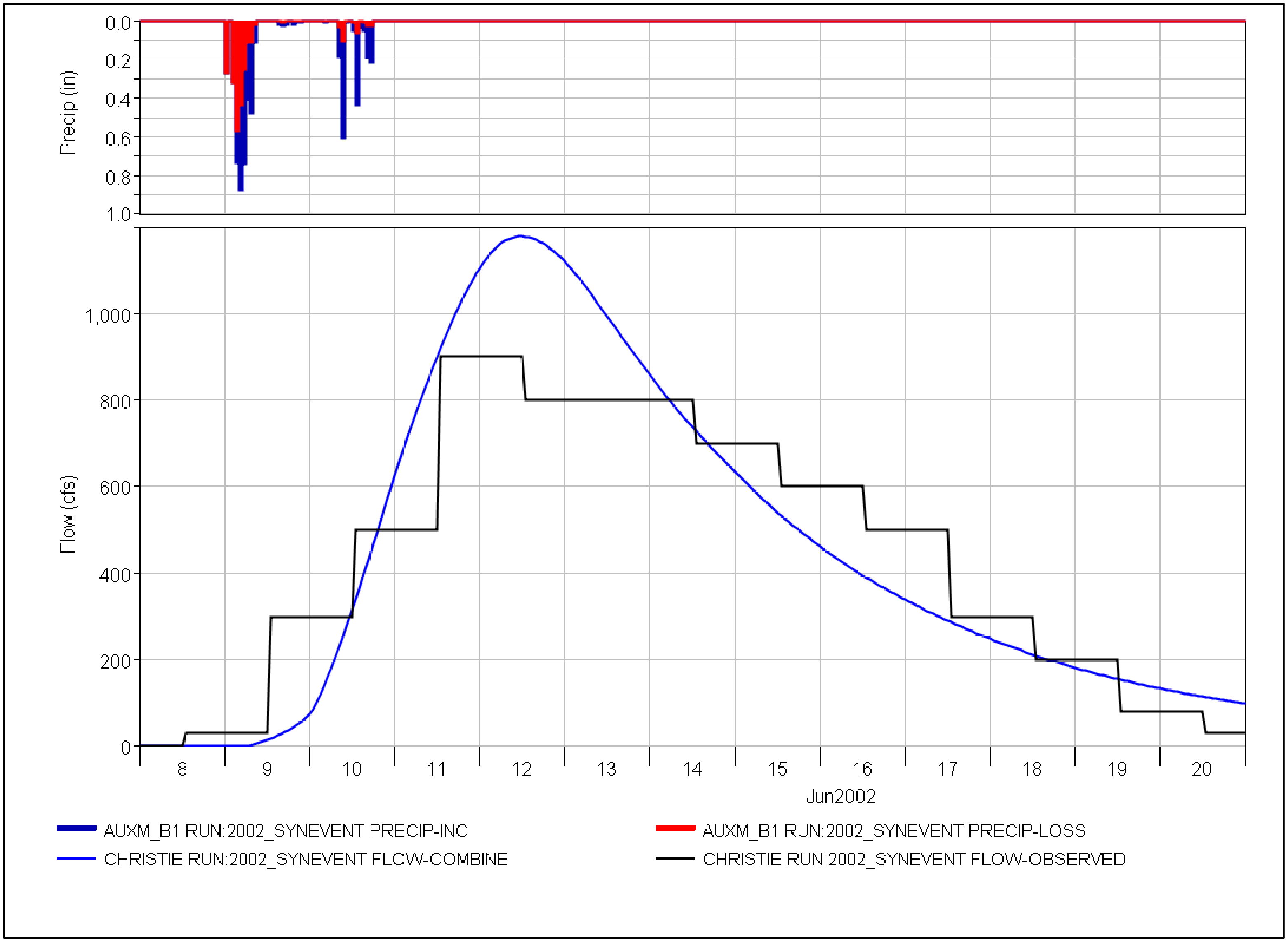

Figure 9: 2002 synthetic event results at Christie gaging station

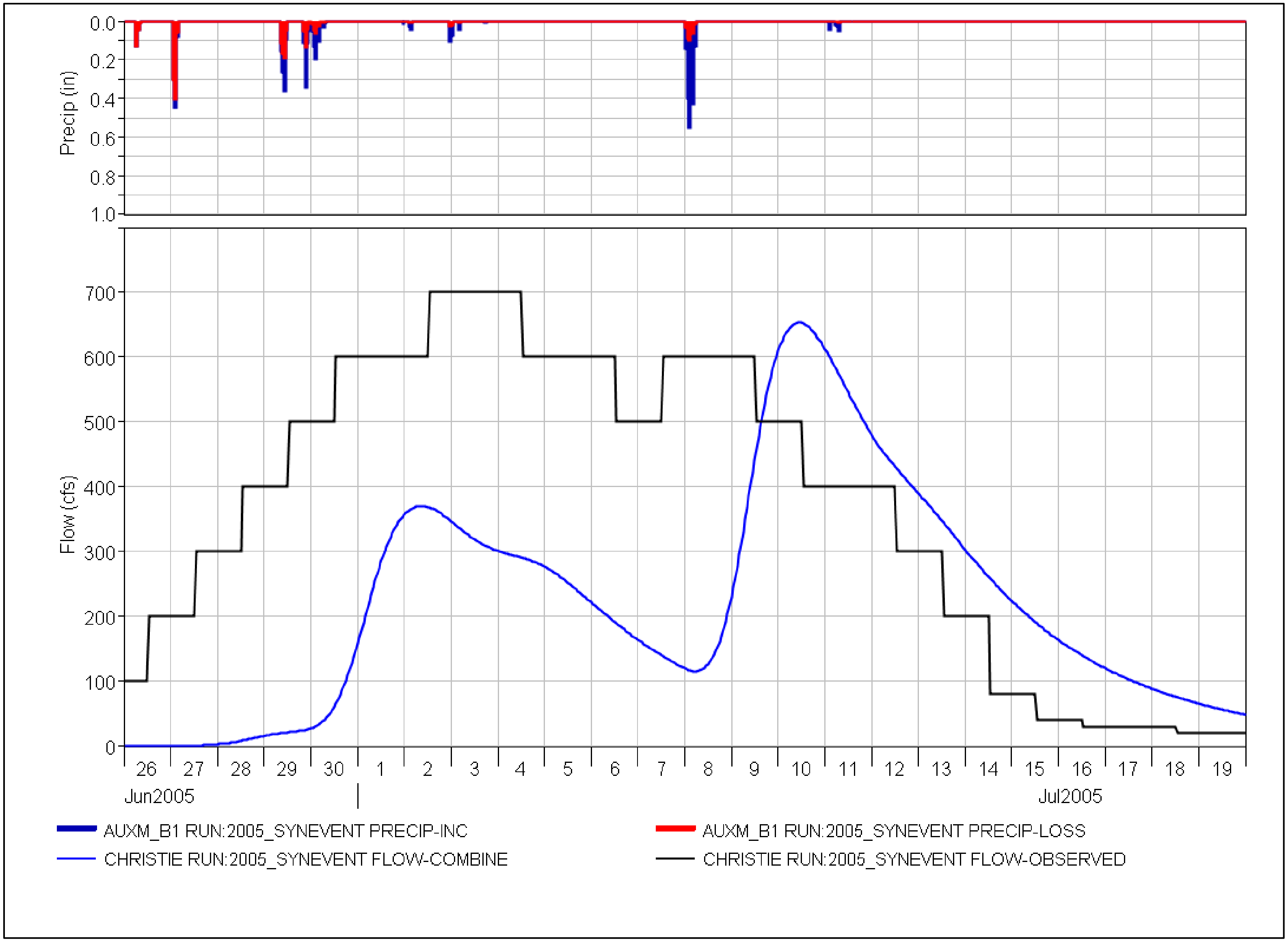

Figure 10: 2005 synthetic event results at Christie gaging station

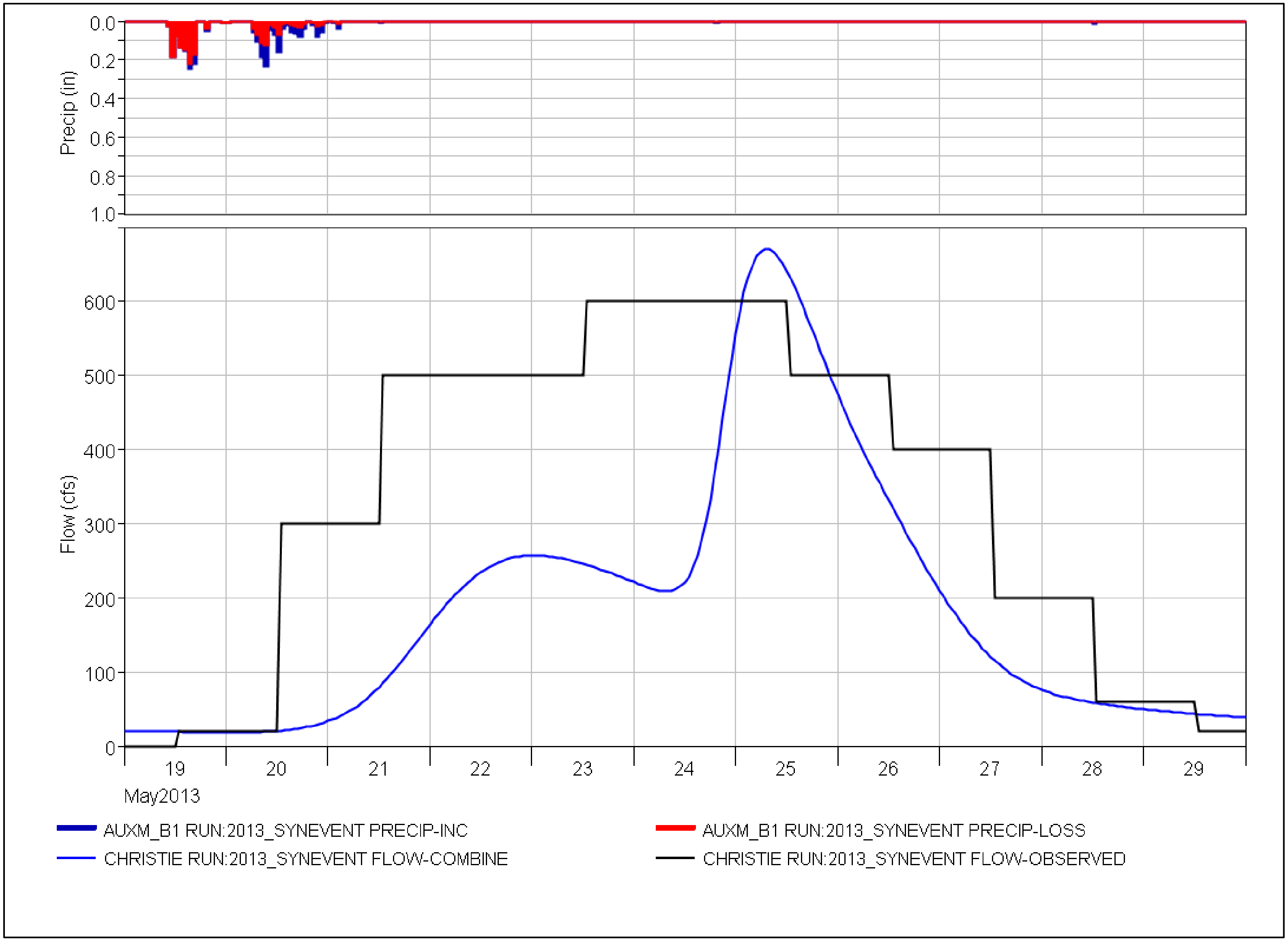

Figure 11: 2013 synthetic event results at Christie gaging station

G. ATTRIBUTED SHAPEFILES

A set of attributed shapefiles for the subbasins and reaches used to model the Aux Marais watershed is included as an attachment to this submittal. The attributes show the initial, calibrated and adopted model parameters. Common names for each attribute were chosen to allow for combining the parameters study area-wide.

H. ATTRIBUTE TABLE DEFINITIONS/GLOSSARY

- NAME: User defined name for subbasin or river in HMS
- OBJECTID: Unique identifier for feature in GIS.
- GRIDCODE: Unique identifier for feature in GIS.
- Shape_Length: Perimeter length of entity. (m)
- Shape_Area: Area of entity. (m^2)
- HydroID: Unique identifier in the geodatabase.
- DrainID: HydroID of the associated drainage area.
- BasinSlope: Average basin slope of the catchment. (%)
- Shape_Area_SM: Area of entity in sq. miles. (mi^2)
- Total_Area_SM: Total area of subbasin in sq. miles. (mi^2)
- NC_Area_SM: Non-contributing area of subbasin in sq. miles. (mi^2)
- ARCID: Unique identifier for segment in GIS
- FROM_NODE: Node at downstream end of segment.
- TO_NODE: Node at upstream end of segment.
- NextDownID: HydroID of next downstream catchment.
- Slp: Slope of the segment (i.e. river or longest flow path). (m/m)
- ElevUP: Elevation at the upstream end of the segment (i.e. river or longest flow path). (m)
- ElevDS: Elevation at the downstream end of the segment (i.e. river or longest flow path). (m)
- RivLen: Length of the river segment. (m)
- Elevation: Elevation of the feature (i.e. centroid,…). (m).
- LengthDown: Length from the beginning of the longest flow path feature to the subbasin outlet. (m)
- LongestFL: Length of the longest flow path. (m)
- CentroidalFL: Length from centroid to the subbasin outlet. (m)
- GridID - Unique identifier for feature in GIS.
- IsSink: Indicator (0/1) populated with 0 by default. Populated by function Sink Evaluation and used by function Sink Selection. Value of 1 indicates that sink is to be filled.
- Fill Depth: FillElev – BottomElev. (m)
- FillArea: Area of the sink feature in data units. (m^2)
- FillVolume: Volume of the sink. (m^3)
- BottomElev: Lowest elevation within the sink feature in data unit. (m)
- FillElev: Lowest elevation of the boundary cells located outside of the sink (e.g. lowest elevation of the outside cell along the boundary of the sink where the spill would occur first when the sink fills). (m^2)

- DrainArea: Area of the associated drainage area in data unit. (m^2)
- RunoffDA_in: Average runoff depth within local drainage area based on TR60 100yr-10day. (in)
- RunoffDA_CM: Runoff volume from local drainage area based on TR60 100yr-10day. (m^3)
- ExcessRO_I (Depression *.shp): Initial value of RunoffDA-FillVolume. Positive value indicates that Runoff Volume from local area using TR60 exceeds that local depression volume. (m^3)
- ExcessRO_I_AF: ExcessRO_I expressed in acre-feet. (AF)
- ExcessRO_I (Drainage Area *.shp): This value is the calculated ExcessRO from initial run. The excess runoff volume was spatially joined to the initial drainage area polygons to allow for spatial summation during the iterative process of combining areas with excess runoff. (m^3) This was joined based on the GridIDs of the Depression and Drainage Area *.shp.
- ExcessRO_F (Depression *.shp): Final value of the spatial summation of the initial RunoffDA-FillVolume for the combined drainage area. (m^3)
- ExcessRO_F (Drainage Area *.shp): This value is the calculated ExcessRO_F from the final run. (m^3)
- ExcessRO_F_AF: ExcessRO_F expressed in acre-feet. (AF)
- Reach: Reach identification name in HMS.
- Time Step Method: Method in HMS.
- Length: Reach length. (ft)
- Slope: Reach slope. (ft/ft)
- Shape: Shape of Channel using in Muskingum Channel Routing Method.
- I_RouteMethod: Method of channel routing used in HMS.
- I_Manning's n: Initial estimate of Manning's n for main channel.
- I_L.B. Manning's n: Initial estimate of Manning's n for left overbank.
- I_R.B. Manning's n: Initial estimate of Manning's n for right overbank.
- CAL1: Value of parameter listed for Calibration No. 1 Model.
- CAL2: Value of parameter listed for Calibration No. 2 Model.
- SYN: Value of parameter listed for proposed Synthetic Models.
- Description: Name of Reservoir in HMS Model.
- Method: Method of Reservoir Routing in HMS.
- LakesArea: Area of lakes within contributing portion of subbasin used in R/Tc calculation in sq. miles. (mi^2)
- WetlandsArea: Area of wetlands within contributing portion of subbasin used in R/Tc calculation in sq. miles. (mi^2)
- Initial: Value of parameter estimated for initial model setup.
- LossMet: Method used in HMS for estimating losses.
- TransMet: Method used in HMS for hydrograph transformation.
- BaseMet: Method used in HMS for baseflow.
- PctImp: Percent of subbasin assumed to be impervious.
- InitAbst: Initial Abstraction in inches. (in)
- Initial24H_BasinCN: Initial estimate of 24hr CN value.

- Initial10D_BasinCN: Initial estimate of 10day CN Value.
- Tc: Time of concentration in hours. (hr)
- R: Clark’s Storage Coefficient in hours. (hr)
- Tc/R: Time of concentration divided by clark’s storage coefficient
- Prec_in: Average basin precipitation depth in inches (in).
- S24HR: Value of parameter listed for proposed 24hr Synthetic Models.
- S10D: Value of parameter listed for proposed 10day Synthetic Models.
- S10RO: Value of parameter listed for proposed 10D runoff Synthetic Models.

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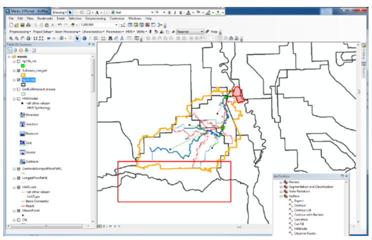
Date: 8/11/2017
Initial Review: Aux Marais Model
Reviewer: Chanel Mueller
Modeler: Eric Novotny
<u>HEC-HMS model Setup Comments</u>

Scope of Review: The GeoHMS analysis was not reviewed.

1. There is about a 30% difference between the drainage area specified by Environment Canada for the area upstream of the gage near Christie, MB versus the drainage area presented within the model. Is this due to non-contributing drainage area? Is this non-contributing drainage area indicated within the grid cell file?
   Watershed boundaries by EC were created in 1996 using 1:50,000 scale boundaries. The watershed boundary defined by EC also includes areas below the boarder dike that were_ incorporated into the Pembina HMS model. Black lines are the boundaries defined by EC. Red box is the additional area.
   
   Backcheck Response 1: This is a reasonable explanation. Please add this explanation to the text and provide additional information about the Pembina River Border Dike and the culvert connections to the Aux Marais watershed. I would recommend including a section entitled "Special Basin Features" where you discuss the Border Dike. I would discuss the drainage area issue either in Section 4 or 3.
   Add to section 4. Explanation of boarder dike and culverts added to a new section 6.
   Backcheck Response 2: CLOSED. Additional text clarifies the source of this 30% difference in drainage area and includes a description of the border dike and the interconnectivity between the Pembina and Aux Marais watersheds.

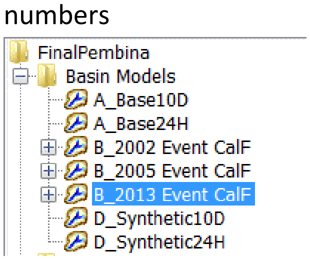
2. Consider combining AuxM_B5 and AuxMB2 because B5 is so small. Is there a reason why they are currently separated? If so please explain in write-up.
   AuxM_B5 was added because a gaging station used to be present at that location. Was only operational between 1969 and 1970.
   Backcheck Response: CLOSED. It is reasonable to break a subbasin at a gage site and the Tc is more than three hours (both original and calibrated), however, if this gage only has two years of data and there is no indication that it might be reactivated I would not break the subbasin boundary at this site. This is a judgement call for the study engineer.
   Original watershed boundaries were kept as is.

3. The adopted R/R+Tc ratios appear slightly on the high side (compared to the Lower Pembina River Model) – consider refining via calibration
   Done

Backcheck Response 1: Include a discussion of how the adopted R/R+Tc values compare to those adopted within the Lower Pembina River Basin and how they compare to the originally defined Tc and R generated based on the basin's physical properties.
This has been added to section C.3. Comparison between physically based and synthetic event Tc and Ra vales was added to section F.
Backcheck Response 2: Additional text has been added to Sections C.3 and F describing the differences between adopted R/R+Tc values in the Aux Marais Basin and the neighboring Pembina River Basin. The adopted R/R+Tc values are reasonable given the ratios adopted for other Red River of the North subbasin models developed as part of the Red River of the North Study Phase II. The write-up indicates that the ratios for the Pembina are higher than the ratios adopted for the Aux Marais for the subbasins in the Pembina adjacent to the Aux Marais. Can you please confirm this is correct? I am finding very similar or lower ratios when I review the adopted Pembina values in adjacent subbasins.
Backcheck Response 3: CLOSED. The text now states the following, "while the synthetic R values are 1.8 times larger than the initial estimate values. The final R/(Tc +R) ratio of 0.58 is slightly higher than values in the Pembina HMS model (USACE, 2014). Pembina River subbasins adjacent to the Aux Marais have ratio values around 0.5."

4. The adopted curve numbers seem on the high side (compared to the Lower Pembina River Model) – consider refining via calibration. Consider varying the curve number between subbasins.
   Done
   Backcheck Response 1: Discuss how adopted curve numbers compare to those adopted within the Lower Pembina River Basin and how they compare to the originally defined curve numbers generated based on the basin's physical properties. Curve numbers have been refined via calibration.
   Comparison has been added to Section F
   Backcheck Response 2: CLOSED. There is not a lot of variation between curve numbers for the subbasins within the Aux Marais when they are generated based on Land Use and Soil Type, so I would expect that Curve Numbers would not vary considerably between subbasins. Using the same curve number for all subbasins is reasonable. A discussion of how the curve numbers defined for the Aux Marais Watershed compare to the curve numbers defined for the Lower Pembina River Watershed has been added to Section F.

5. Please setup baseline basin models with initial parameters and initial 10 Day and 24 Hour Curve numbers



   Done
   Backcheck Response: CLOSED. Additional basin model files have been generated.

6. For the gridded precipitation, should a time shift be applied? For the Pembina River the time shift was five hours. This might be different for the Aux Marais if it is on a different time zone.
   Added the time shift
   Backcheck Response: CLOSED. A five hour time shift has been applied to all precipitation grids in the model.

7. Please add simulation runs and basin models for required synthetic event runs.
   Done
   Backcheck Response 1: Additional basin model files have been generated, but synthetic even runs will still need to be configured. It is my understanding that synthetic event analysis will be carried out as part of the 100% submittal.
   Note: Carrying out synthetic event analysis will not be carried out as part of this assessment due to funding and schedule restraints.
   Backcheck Response 2: CLOSED. Synthetic event analysis will not be conducted as part of this effort.

8. The goal of this effort was to fit the simulated hydrograph to the observed hydrographs within the following target ranges:
   a. 10% of runoff volume
   b. 10% of peak flow
   c. Peak within ½ day of observed

The 2002 event falls within this range. The 2002 event also has a decent Nash Sutcliffe (N-S) coefficient. For the 2005 event I would start the simulation later and use an initial baseflow. I would also modify calibration parameters to facilitate a better match. This event is difficult to calibrate to because of the double peak and the train of precipitation events. A multiple precipitation events causes a problem if there is any time for infiltration or drying because the SCS curve number method does not do soil moisture accounting. The 2013 event's timing is good, but I would add an initial baseflow and change R and CN. Note that parameters don't have to be exactly the same for all three events
Changes made
Backcheck Response 1: The calibration runs look reasonable. Please add explanation related to how you are matching observed flows in terms of timing. Consider adding a column to Table 8.
Add discussion to last paragraph in section E about timing.
Backcheck Response 2: CLOSED. A discussion of how the timing compared between modeled and observed streamflow data has been added to the write-up.

9. An "adopted" set of parameters for synthetic event simulation should be suggested. Verification model runs should be carried out for all three calibration events using suggested model parameters. For synthetic event runs the median calibrated unit hydrograph parameters should be used and the CNs should be reset to the initial values determined based on soil and land use type. Currently the synthetic events are not included.
   Done

Backcheck Response: CLOSED. The report now details adopted parameters suggested for synthetic event runs.

10. Please include the following in your documentation:
    a. Subbasin Delineation on top of terrain data
    b. Subbasin Delineation on top of Land use/Land cover data
    c. Subbasin Delineation on top of soil data
    d. Subbasin Delineation and river reaches on top of published topographic map or aerial so that reach delineation can be verified
    e. Watershed characteristics (river length, basin slope etc)
    f. Initial model parameterization and how it was defined
    g. How manning's n values were determined

Done

Backcheck Response 1: CLOSED a-e. Figures 1-4 address comments a-d. Table 5 includes the river length and slope. I think you could consider splitting AuxMB4 where the elevation changes and combing AuxM_B5 and AuxM_B2 – but this is a judgement call (as long as Tc for AuxM_B5 is > 3 hours) – I think it is fine.

f & g.

- Please describe how the R/R+TC ratio of 0.67 was selected/determined as a starting point. Did you develop one large subbasin above the gage to define a ratio or did you use the values from the Pembina River Model as a reference? Please add explanation and references as needed.
  Added to section C.3
- The initial Tc and R parameters in Table 3 do not appear to be consistent with what is in the model.
  Value in model were incorrect. This has been updated.
- Please explain in more detail how Manning's n values for the overbanks were determined (weighted average, average of all the CNs present in the given subbasin which the routing reach transects etc.). Also, explain how the eight point cross sections were defined in a little bit more detail – was bathymetry used or only the above the water surface LiDAR based elevation data used?
  Discussion was added to section D.

Backcheck Response 2: AuxM_B5 and AuxM_B2 are still modeled as separate subbasins. This is fine because Tc is greater than 3 hours. Section C.3 now includes a discussion of how the initial R/R+TC ratio of 0.67 was selected. It was adopted to be consistent with the ratios adopted within the Pembina River model. The parameters in the model and the write-up are now consistent. Section D now includes a detailed discussing of how Manning's N values were derived to model river reaches.

In Table 10, Table 8 and within the HMS model basins: 2013synthetic24H, Synthetic10D, and synthetic2H Tc is incorrect for subbasin AuxM_B2. It should be 49.5, but is listed as 42.3.

Backcheck Response: OPEN. The value for subbasin AuxM_B2 has been corrected to 49.5 in Table 10 and Table 8. The values are still incorrect in 2013synthetic24H, Synthetic10D, and synthetic2H.

New Comments

11. Please add part E of the 30% submittal/ part H&I of the 60% submittal (attribute table and attribute table definitions). This portion of the submittal also includes a corresponding attributed shapefile and excel table.
    Added to park H and I. Park E of 30% has same attributes listed in part I of 60%.
    Backcheck Response 1: Were attributed shapefiles (G) and an attribute table (H) generated consistent with these descriptions? If they have not already been generated I would assume that generating them at this point would be beyond the scope of this assessment due to funding constraints and Sections G and H should be removed or modified accordingly.
    Backcheck Response 2: CLOSED. Additional changes to address this comment are beyond the scope of this current effort due to resource constraints.
12. Please expand your reference section to include all resources used for your analysis.
    Backcheck Response 1: Several references are still missing from your reference section.
    Backcheck Response 2: **CLOSED.** The reference section appears to be complete.
13. Add a footer with page numbers and "30% & 60% Submittal –Aux Marais Tributary (centered) – consistent with the Pembina River submittal
    Added
    Backcheck Response 1: CLOSED. A footer has been added.
14. In addition to including the names of the gages please specify the period of record and drainage area captured by each gage. Also include whether the gage is seasonal or continuous.
    Added to section B.4
    Backcheck Response 1: CLOSED. Gage period of record and drainage area has been added to the text.
15. Include a discussion of how you selected your baseflow recession parameters/methodology and adopted parameters.
    Added section C.4

    Backcheck Response 1: The report now indicates that baseflow recession parameters were adopted from a model developed for the neighboring Pembina River Basin. For your initial model parameters and the 2002 calibration event initial baseflow was set equal to zero. For the 2013 and 2005 calibration events you modified your initial baseflows. I assume this was done based on observed flows. For all your model verification runs it appears you used the initial baseflows associated with the 2013 event (these are the values in the 2013synthetic24H mode). For verification runs the initial baseflows can vary between events depending on the observed flow hydrograph and should not be the same as the 2013 event initial baseflows for all three verification events. Please add clarifying text within your write-up concerning how initial baseflow was determined and what values were adopted for each of your calibration and validation runs.

    Backcheck Response 2: OPEN. The write-up states "Initial discharge was set to 0.1 cfs, with a recession constant of 0.7 and a ratio of 0.2 using the threshold type of Ratio to Peak. Baseflow parameters were not modified during model calibration." However initial baseflow appears to have been modified for the 2013 and 2005 events, and is reflected in the 2013 Synthetic24H run. Please clarify.

16. Add the international boundary and label Manitoba and North Dakota in your figures. Also, choose a color besides orange/red/green/yellow to delineate subbasins and watershed boundary.
    Completed
    Backcheck Response 1: CLOSED. The international boundary is now included as part of all five figures. Minnesota, North Dakota and Manitoba are labeled. The line colors used to delineate subbasin boundaries now have enough contrast with the base layers to be visible.
17. Only the reaches within AuxM_B3, AuxM_B1 and AuxM_B5 are Muskingum Cunge Routing reaches, the other two river delineations are for display purposes only (direct routing/none) and are incorporated in Tc – please make this clear within the figures. Consider color coding the routing reaches and adding to the legend. Please see the Pembina River 60% submittal Figure 2 as an example.
    Completed
    Backcheck Response 1: CLOSED. The difference between reaches modeled using direct routing and Muskingum Cunge routing is now indicated by line color and clarified within the figure legend.

18. Table 3 should specify that the curve numbers displayed are 24 hour curve numbers and the table should also include the baseline 10-day curve numbers.
    Added
    Backcheck Response 1: CLOSED. Table 3 now includes both the 24 hour and 10 day curve numbers.
19. Did you use ArcHydro or GeoHMS to define subbasin delineation and drainage lines? Please clarify within the report.
    Added to section B.2
    Backcheck Response 1: CLOSED. The following explanation was added to the text: “A combination of the Arc Hydro Tools and HEC-GeoHMS tools were used to delineate the watersheds’ subbasins and to calculate the subbasins’ physical properties (area, slope, centroids, longest flow paths, and so forth). This information was used to setup the structure of the HEC-HMS model.”
20. In Section E, Please describe how II and III are defined and add a cross-reference to Table 2 within the text. Was the CN adjustment made for the 2013 event as well? – I assume so? Please clarify. Within the text include a brief explanation of why higher, antecedent water content in the soil requires a higher CN (more similar to impervious conditions because soil storage is used up etc.)
    Discussion added to section E.
    Backcheck Response 1: CLOSED. More explanation has been added to the write-up indicating how the curve numbers were modified during calibration and what the significance of AMC I and II are.
21. Offer an explanation of why R is over twice as high during the 2002 event than the 2013 and 2005 events. This is presumably because distributed storage was already filled up prior to the 2013 and 2005 events due to antecedent conditions.

Discussion added to section E.

Backcheck Response 1: The write-up states that higher R values are indicative of less storage availability (wet antecedent rainfall conditions). I think this is incorrect – it should be the reverse? Additionally a rainfall hyetographs should be included displaying rainfall prior to the start of each calibration period to justify assumptions based on antecedent conditions.

Backcheck Response 2: CLOSED. It appears a portion of the discussion has been removed from the write-up. Due to resource constraints it is not possible to determine what is causing the 2002 event to have a higher Clark's R than the 2013 and 2005 events.

22. The figures required as part of the 60% submittal are as follows:
    60% Submittal Figures
    Backcheck Response 1: CLOSED. Due to funding constraints, generating all the figures that were generated for the other HMS models produced as part of the Red River Study Phase II was deemed unnecessary. Only figures critical to conveying the modeling methodology were included.

    Figure 1: Subbasin Map – you have an analogous figure – but please confirm Included –Figure 1 (Aux Marais HMS Model Overview) includes the subbasin delineation.
    Figure 2: Routing Methods – you have similar figures, but you need to color code the routing methods adopted completed-Figure 1 (Aux Marais HMS Model Overview) indicates where a routing method was applied (Muskingum Cunge)
    Figure 3: Initial Travel Time Estimates – this figure is missing
    Figure 4: Initial 24-hour curve numbers – this figure is missing
    Figure 5: Initial 10-day curve numbers- this figure is missing
    Figure 6: Initial R/R+TC
    For figure 3-6 with so few subwatersheds and relatively consistent watershed parameters between them, these figures do not seem to be necessary. All information is given in Table 3. - I agree that these figures are not necessary to convey the information required to understand how the model was produced.
    Figure 7: Precipitation for each calibration event (three figures total) - this figure is missing Precipitation is included in the calibration figures. –Displaying the precipitation associated with each calibration event on the same figure as the calibrated streamflow response is adequate.
    Figure 8: Calibration Events Results- you have analogous figures
    Figure 9: Validation Runs Results – run events with median parameters – this figure is missing Completed- Figures 9-11 were generated to fulfil the model validation requirement.
    Figure 10: Proposed Synthetic Event TC- this figure is missing (Found in Table 10)
    Figure 11: Calibrated Curve Numbers- this figure is missing (Found in Tables 6-8)
    Figure 12: Proposed calibrated R/R+Tc- this figure is missing (Found in Table 10)
    For figure 10-12 with few watersheds and consistency between them figures do not seem to be necessary. All information is given in tables 5, 6, 7 and 9.

23. Figure 13: Calibrated initial abstraction - this figure is missing
    Backcheck Response 1: Initial abstraction and percent impervious need to be discussed within the report write-up.
    Backcheck Response 1: CLOSED. The following text has been added to the write-up: "Percent impervious and initial abstractions values were not used in this model development." Because the area is rural it makes sense for the percent impervious to be zero or assumed to be close to

zero, but not using an initial abstraction raises some questions. However, due to resource constraints it is not possible to re-evaluate whether an initial abstraction should be added to the model.

24. No model validation events have been run. This is something you should consider doing. Completed
    Backcheck Response 1: Note that this is not a true model validation. A true model validation involves running the model, using adopted parameters, for events unique from those used for model calibration. Doing this is likely not possible due to funding constraints. This should be acknowledged in the write-up. Additionally, a table analogous to Table 9 should be generated for model validation or model validation results should be discussed/reflected on in-text.
    - A separate basin file should be setup for each validation run. It is misleading to have a single basin file with 2013 in its name used for all three events.
    - Rename the basin files and compute files associated with validation runs such that the name makes it clear that these are validation runs. Synthetic event runs tied to exceedence probabilities are not being generated as part of this analysis.

    Backcheck Response 1: CLOSED. Suggested text has been added to the report and a table has been added to the write-up summarizing validation results (Table 11).

25. Please add some description to the text indicating which values you propose be adopted for the AuxM_USArea and how these values were derived (the values in Table 10). Also, add figures demonstrating the flow response for the 2005, 2002, and 2013 events to show that the hydrograph shape produced for this subbasin is realistic and analogous to what you are seeing on the Aux Marais.

26. The control specifications for the 2013 event in the model do not match up with the 2013 calibration period listed in the write-up
    Backcheck Response 1: CLOSED. The control specifications in the model now match up with what is described in the write-up.

27. Comments related to modeling breakout flows:
    a. The breakout flow source node and routing reach needs to be added to all figures that display the model schematic.
    b. The breakout flow source node and routing reach needs to be added to all basins within the HEC-HMS project. It is currently missing for the Base10D, Base24H, Synthetic10D and Synthetic24H models.
    c. More information should be added related to the location of the culverts in question. The Neche and Walhalla gage locations should be added to Figure 3.
    d. An explanation of how flows are reported at Neche should be added to the write-up. Note that if some (or all) of the culverts connecting the Pembina and the Aux Marais watersheds are located upstream of Neche, the flows reported by the USGS at Neche include the flows breaking out from the Pembina River to the Aux Marais River (they add breakout flow back into the gage record). Thus, it is appropriate to trigger the

breakout relationship off the Neche gage. Please confirm this with Garrett Blomstrand and add some description to the Aux Marais write-up (Section 6), if it is relevant.

e. The modeled 2005 event also includes some minimal breakout flows from the Pembina River. However, based on the observed flow record it is unlikely that flows on the Pembina River were large enough to contribute to the Aux Marais River. Please clarify this in the text. Consider adding information similar to the following data to your write-up (verify the following numbers if you decide to include them):
    i. The threshold for flows from the Pembina River to start to contribute to the Aux Marais River is over 8,370 cfs at Neche on the Pembina River. Contributions don't become significant until the flow at Neche is over 16,300 cfs.
    ii. Observed 2002 Peak flow at Neche: 3,440 cfs (0345 on June 12), modeled peak flow: 3,700 cfs (0300 on June 12), thus breakout flows are zero.
    iii. 2005 Peak flow at Neche: 6,890 cfs (2315 on July 2), thus based on the observed record breakout flows are zero. However, the Pembina River model indicates a flow of 9,970 cfs on 11 July, 2005. As a result of modeled flows at Neche, there would be a minimal amount of breakout to the Aux Marais Watershed
    iv. 2013 Peak flow at Neche: 17,500 cfs (1715 on May 21), thus we would expect breakout from the Pembina River to the Aux Marais during the 2013 event. The modeled maximum flow in 2013 was 17,467 cfs on 22 May, 2013 at 14:00

Backcheck Response 1: CLOSED. The suggested description has been added to the write-up.